THE FIRST JOINT WCRP-WWRP SYMPOSIUM ON DATA ASSIMILATION AND REANALYSIS

Book of Abstracts

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Deutscher Wetterdienst
Wetter und Klima aus einer Hand

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DA applications

Impact of data assimilation on fog forecasting: A case study of WiFEX campaign

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Fog is a low-cloud and high-impact weather phenomenon that evolves at various Spatio-temporal scales. However, its severe impact over the IGP (Indo Gangetic Plain) region has been noticed from the last decade in terms of railroad and airline transportation. Therefore, accurate fog prediction on local to regional scales is crucial for mitigation of adverse impact on human life in the northern part of India. Nevertheless, the faithful reproduction of fog in the numerical model is a still threshold problem. One of the model-based case study from Winter Fog EXperiment (WiFEX) campaign has shown the warm bias in the initial condition and onset/dissipation error in real-time fog forecast. Using temperature and humidity profiles from the Radiosonde and Microwave Radiometer, this study investigates the data assimilation impact on fog forecasting at the Indira Gandhi International Airport (IGIA). Here, the Gridpoint Statistical Interpolation (GSI) Three-Dimensional Variational (3D-Var) based Weather Research and Forecasting (WRF) setup is utilized to improve the initial condition and minimize fog onset and dissipation error in the model. In addition, this study is further extended to explore the horizontal as well as vertical fog structure and their evolution.

Data assimilation for landscape-scale wildland fire behavior

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The recent occurrence of extreme wildfire events highlights the urgent need of designing accurate modeling systems to provide insights into the wildland fire dynamics and its driving factors at the scale of an event. Predicting landscape-scale wildfire behavior remains a challenge due to the strong atmosphere/fire interactions and to the uncertainties associated with environmental factors (e.g. biomass fuel properties and moisture content). In this context, data assimilation offers a promising mathematical framework to take advantage of the recent advances in infrared remote sensing technology to improve model predictions of the landscape-scale wildfire behavior [1]. We will discuss how to reconstruct a complete time history of a given wildland fire event using joint state-parameter estimation combined with infrared sensor observations of active burning areas [2]. A front shape similarity measure derived from image processing and based on the Chan-Vese contour fitting functional was introduced to handle position and topological errors in the propagating fire front [3]. We will also discuss the challenges to extend the data assimilation approach from controlled burns to actual wildfires, with the ultimate objective to produce reanalysis of extreme wildfire events. One cornerstone lies in its extension to a coupled atmosphere-fire model to have a better representation of the fire-induced flows near the wildland fire. [1] Rochoux et al. (2022) Book Chapter in Inversion and Data Assimilation, SCIENCES, in press. [2] Zhang et al. (2019) Fire Saf. J., https://doi.org/10.1016/j.firesaf.2019.03.009 [3] Rochoux et al. (2018) ESAIM Proc. Surv. https://doi.org/10.1051/proc/201863258

Data Assimilation on the Sub-Kilometer Scale for the Urban Environment

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The ongoing urbanization makes urban areas increasingly crucial for NWP especially in relation to extreme events or climate monitoring in the context of regional reanalysis. In this regard, the increase in computational power allows for ever-higher horizontal resolutions in NWP models towards the kilometer scale which is important to tackle the representation of urban environments. This study investigates high-resolution DA below the kilometer-scale for urban areas in order to assess the potential for future regional reanalyses at the German Meteorological Service (DWD). Therefore, we employ the Icosahedral Nonhydrostatic (ICON) Model in the Limited Area Mode (ICON-LAM), together with DWD's LETKF. We perform experiments at horizontal resolutions of 2.1km (operational) and 500m. We use a modified ICON-LAM surface module compared to the operational mode by employing the Corine land-use dataset (100-meter resolution) instead of the default Globcover 2009 (300 meters) and three urban land use categories instead of one to better capture surface heterogeneity. With respect to DA, we investigate the impact of assimilating various observing systems such as conventional upper air and surface observations as well as satellite-based land surface temperature (LST) data. We aim to assess their value for enhancing the representation of near-surface temperatures, especially in urban areas. A focus is therefore given to the tuning of relevant parameters such as the localization length to be able to better represent small-scale spatial features such as the UHI. In this regard, the LST measurements can provide valuable information on the spatial structure of surface temperatures and thus help to correct the UHI representation in ICON-LAM.

Monday, 13 Sep 2021 at 11UTC - room GREEN

Reanalysis evaluation I

Overview of the SPARC Reanalysis Intercomparison Project (S-RIP) during 2013-2021

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rological Agency, [26]National Aeronautics and Space Administration, USA; and Science Systems and Applications, Inc., [27]National Oceanic and Atmospheric Administration

The Stratosphere-troposphere Processes And their Role in Climate (SPARC) project is one of the four core projects of the World Climate Research Programme (WCRP). Researchers interested in SPARC use global atmospheric reanalysis products to understand a wide range of processes and variability in the atmosphere, to validate chemistry climate models, and to investigate and identify climate change. The SPARC Reanalysis Intercomparison Project (S-RIP) was initiated in 2011 and officially started in 2013 to conduct a coordinated intercomparison of all major global atmospheric reanalysis data sets. The S-RIP has been aiming at writing up an assessment report in the SPARC report series (to be published by September 2021) (1) on overall quality of temperature, winds, ozone, and water vapor data, (2) on more process- and region-oriented evaluation of the Brewer-Dobson circulation, extratropical stratosphere-troposphere coupling, extratropical upper troposphere and lower stratosphere, the tropical tropopause layer, the quasi-biennial oscillation, polar processes, and the upper stratosphere and lower mesosphere, and (3) with a coordinated description of the reanalysis systems. We also have an inter-journal special issue on "The SPARC Reanalysis Intercomparison Project (S-RIP)" in Atmospheric Chemistry and Physics (ACP) and Earth System Science Data (ESSD). In the presentation, we will discuss key findings and recommendations as well as the evaluation of this first phase of the S-RIP activity.

The 20th century global warming signature on the ocean at global and basin scales as depicted from historical reanalyses

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More than 90% of excess energy trapped by greenhouse gases is accumulated in the oceans. Ocean heat content (OHC) and its changes are therefore fundamental metrics to monitor climate change. However, due to sparse observation sampling before the 1950s, accurate observation-based estimations only exist for the second half of the 20 th century. A 16-member ensemble of historical ocean reanalyses is used for the first time to compile a unique estimate of 20 th century oceanic warming rates. The reanalyses combine dynamical ocean general circulation models with historical observations and observation-based atmospheric forcing. Ocean heat content tendencies (OHCT) from the multi-reanalysis ensemble agree well with independent estimates of ocean heat content, and show a coherent evolution with records of Earth's energy imbalance from atmospheric reanalyses and atmospheric CO 2 concentration at a range of timescales. OHCT from reanalyses proves to be a more effective climate change proxy than observed surface warming tendencies that contain high-frequency variability not related to the climate change signature, or historical coupled model simulations, which neglect interannual fluctuations. The ensemble mean estimate of the century-long ocean warming rate is 0.26 ± 0.08 W m −2 . The warming rate of 0.84 ± 0.21 W m −2 estimated from 1993 onwards is unprecedented. The global decadal warming rate is persistently positive from about 1925 onwards, except for two neutral periods. The Indian Ocean exhibits the highest relative contribution to centennial heat accumulation, while the Atlantic Ocean plays an increasingly prominent role, especially during the 1995-2004 decade. These findings are in agreement with previous studies.

Representation of the past weather prior to the International Geophysical Year (1957-1958) in JRA-3Q

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The Japan Meteorological Agency (JMA) is currently producing the third reanalysis, called the Japanese Reanalysis for Three Quarters of a Century (JRA-3Q). JRA-3Q is based on the TL479 version of JMA's operational NWP system as of December 2018, which was extensively improved since the Japanese 55-year Reanalysis (JRA-55). The JRA-3Q reanalysis provides improved products using rescued historical observation data as well as reprocessed satellite data in the data assimilation system. JRA-3Q covers the period starting in the late 1940's. The reanalysis is divided into three streams, stream A (a period from the 1990's onward), stream B (a period from the 1960's to 1980's) and stream C (a period from the late 1940's to 1950's). The stream C corresponds to the period for which JMA has never produced reanalysis products. This period is important because several meteorological disasters happened in Japan at that time. For example, Typhoon Kathleen in September 1947 brought severe flood damage to eastern Japan and since then criteria of flood disaster prevention in Japan has been based on the record-breaking daily precipitation due to that typhoon. However, it is difficult to produce a high-quality reanalysis for this period because there was no network of regular radiosonde observations on a global basis. In this presentation, we show the past weather reconstructed in JRA-3Q during stream C and then examine the accuracy of the reanalysis compared to other reanalyses (e.g., 20CR and CERA-20C).

Monday, 13 Sep 2021 at 11UTC - room BLUE

Ground-based remote sensing I

Ground-based atmospheric boundary layer profiling and data assimilation experiments within the EU COST Action PROBE

Löhnert, Ulrich[1]; **Haeffelin, Martial**[2]; **Cimini, Domenico**[3]; **Nemuc, Anca**[4]; **Kotthaus, Simone**[2]; **Diemoz, Henri**[5]; **Martinet, Pauline**[6]; **O'connor, Ewan**[7]; **Hirsikko, Anne**[7]; **Knist, Christine**[8]; **Walden, Chris**[9]; **Acquistapace, Claudia**[1]; **Jurcakova, Klara**[10]; **Stachlewska, Iwona**[11]; **Batchvarova, Ekaterina**[12]
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The atmospheric boundary layer (ABL) remains the most relevant under-sampled part of the atmosphere. Surface sensor networks, radiosonde soundings as well as satellite observations do not provide sufficient information on the high temporal variability and strong vertical gradients occurring in the ABL. This observational gap currently hampers our ability to improve weather forecasts, air quality prediction, and climate model parameterizations. Measurement systems which have the potential to close this gap are enhanced commercial aircraft observations, operational UAS (Uncrewed Aircraft Systems) as well as ground-based remote sensing. On the one hand, already existing state-of-the-art ground-based remote sensing instruments with the ability to provide ABL profiles (such as those of temperature, humidity, wind, aerosol, cloud) are currently deployed at numerous sites in Europe, but the harmonization of data and procedures is still under development, limiting their effective use and societal benefits. On the other hand, the use of automated UAS for profiling the ABL is currently experiencing significant advancements. This presentation describes PROBE (2019-2023), a European cooperation initiative funded by COST (www.cost.eu) aiming at filling the ABL observational gap, discussing the challenges, objectives, and the implementation plan. Preliminary results are presented includ-

ing new technology, quality control and assurance measures, studies on NWP data assimilation, regional impact, and the role of the network configuration.

Towards operational assimilation of surface based microwave radiometer and Raman lidar data at MeteoSwiss

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The current atmospheric observing systems fail to provide observations in the planetary boundary layer (PBL) with satisfactory spatial and temporal resolutions despite their potential positive impact on numerical weather prediction. This is particularly critical for humidity, which exhibits a very high variability in space and time, and for the vertical profile of temperature, which determines the atmospheric stability. Hence, the analyzed thermodynamic structure of the PBL can be prone to errors, leading to poor forecasts for relevant phenomena, such as severe storms or winter fog and low stratus. One approach to improve the model's representation of the PBL is to include novel, ground-based remote sensing profiler observations in the data assimilation system to improve the forecast initial conditions. This also improves the quality of downstream applications relying on a good representation of the PBL. In this contribution, we present our efforts to include observations from microwave radiometers and a Raman lidar into the 1km mesh-size ensemble data assimilation system KENDA-1. Brightness temperatures from the microwave radiometers are assimilated using the RTTOV-gb forward operator. The Raman lidar data is assimilated using a forward operator for water vapor mixing ratio and temperature. We show the evaluation of extensive observation-minus-background statistics and results from data assimilation cycling experiments during summer-time convective situations.

Doppler radial wind assimilation in the GFS with an observing system simulation experiment

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An observing system simulation experiment using the GFS was performed to test the impacts of assimilating Doppler radial wind observations in an idealized framework. The goal of this study is to lay the groundwork for assimilating radial wind observations within the GFS by (1) first assess the impact of assimilating radial winds from a network that is accessible to the US today (i.e., the NEXRAD network), (2) explore a scenario where all worldwide radial winds are available for assimilation, and (3) a hypothetical scenario where the worldwide network was designed with highly uniform spatial coverage. The final experiment is intended to provide an upper limit on the impact, useful for assessing the relative values of the real networks. In each of these experiments, only radial wind observations are assimilated to simplify and isolate the impact of such observations. The NEXRAD network alone improves the forecast skill over the US but is not able to constrain the forecast in up/downstream data void regions. The realistic worldwide radar network shows improved results over both continental as well as oceanic data void regions and demonstrates quantitatively comparable performance to the purely hypothetical network. This work suggests that the assimilation of global Doppler radial wind data could be beneficial to the GFS, and likely other global NWP applications; however, such potential can only be realized if Doppler radial wind data are accessible.

Monday, 13 Sep 2021 at 12UTC - room RED

Coupled DA I

Development of Coupled Data Assimilation for the Bureau of Meteorology's Operational Climate Forecast System ACCESS-S

Yin, Yonghong[(1)]; Alves, Oscar[(1)]; Sakov, Pavel[(1)]; Hudson, Debra[(1)]; Gray-Weale, Angus[(1)]; Zhao, Mei[(1)]; Zhou, Xiaobing[(1)]
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The Bureau of Meteorology's climate forecast system for weekly to seasonal and longer-range climate outlooks is called the Australian Community Climate Earth-System Simulator – Seasonal (ACCESS-S). The first version ACCESS-S1 operational in August 2018 is based on the UK Met Office GloSea5-GC2 seasonal prediction system, but has enhancements to the ensemble generation strategy to make it appropriate for multi-week forecasting. The ocean and sea ice are initialised using the FOAM (Forecast Ocean Assimilation Model) analyses as per GloSea5. A weakly-coupled data assimilation system for the new version ACCESS-S2 has been developed and implementing in operations. First guess fields are generated from 1-day coupled model integration but cross error covariances between different components are not considered in the data assimilation. Sea surface temperature is strongly relaxed to the daily observations. Ocean in-situ temperature and salinity profiles are assimilated using the ensemble optimal interpolation (EnOI) method with seasonally varying background error covariance estimated from historical intra-seasonal anomalies. The atmospheric component is nudged towards a pre-exiting atmospheric analysis and land surface responds to the atmospheric forcing. Results from experiments and their validation for multi-year reanalysis with both assimilated and independent observations will be presented. Comparisons are made with both the previous ACCESS-S1 and a non-assimilating control system. Assessments reveal considerable improvement in the ACCESS-S2 to the subsurface ocean current fields. Further experiment with sea level assimilation that show further improvements to the surface currents will also be presented.

The impact of incorporating flow-dependent oceanic background-error covariance information into air-sea coupled data assimilation on the evolution of a tropical cyclone

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Tropical cyclones tend to result in distinctive spatial and temporal characteristics in the upper ocean, which means that traditional, parametrisation-based background-error covariances in oceanic data assimilation (DA) may not be suitable. Using the case study of Cyclone Titli, which affected the Bay of Bengal in 2018, we explore hybrid methods that combine the traditional covariance modelling strategy with flow-dependent estimates of the ocean's error covariance structures based on a short-range ensemble forecast. This hybrid approach is investigated in the UK Met Office's state-of-the-art system. Single-observation experiments in the ocean reveal that the hybrid approach is capable of producing more anisotropic and vertically less uniform analysis increments. When the hybrid oceanic covariances are included in cycled, weakly coupled atmosphere-ocean DA, the resulting temperature differences beneath the ocean mixed layer are brought to the surface as the cyclone passes through the region, due to vertical mixing induced by the strong surface winds. Through air-sea coupling, such differences in the sea-surface temperature can then change the analysed structure of atmospheric fields associated with the cyclone.

Weakly and strongly coupled data assimilation with the coupled ocean-atmosphere model AWI-CM

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[1]Alfred-Wegener-Institut, Helmholtz-Zentrum für Polar- und Meeresforschung, [2]Institute of Geographic Sciences and Natural Resources Research, [3]Qingdao National Laboratory for Marine Science and Technology

We compare the results of strongly coupled data assimilation and weakly coupled data assimilation by analyzing the assimilation effect on the prediction of the ocean as well as the atmosphere variables. The AWI climate model (AWI-CM), which couples the ocean model FESOM and the atmospheric model ECHAM, is coupled with the parallel data assimilation framework (PDAF, http://pdaf.awi.de). The satellite sea surface temperature is assimilated. For the weakly coupled data assimilation, only the ocean variables are directly updated by the assimilation while the atmospheric variables are influenced through the model. For the strongly coupled data assimilation, both the ocean and the atmospheric variables are directly updated by the assimilation algorithm. The results are evaluated by comparing the estimated ocean variables with the dependent/independent observational data, and the estimated atmospheric variables with the ERA-interim data. In the ocean, both the WCDA and the SCDA improve the prediction of the temperature and SCDA and WCDA give the same RMS error of SST. In the atmosphere, WCDA gives slightly better results for the 2m temperature and 10m wind velocity than the SCDA. In the free atmosphere, SCDA yields smaller errors for the temperature, wind velocity and specific humidity than the WCDA in the Arctic region, while in the tropical region, the error are larger in general.

Incorporating flow dependent ocean information into weakly coupled atmosphere-ocean 4D-Var data assimilation: experiments with an idealised system

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Strongly coupled data assimilation (DA) is scientifically and technically challenging; as a first step operational centres are implementing weakly coupled DA systems in which the model-observation misfits for the separate atmosphere and ocean domains are measured against the coupled model forecast state, but the analysis is computed independently for each model component. One of the challenges with this approach is representation of the flow dependent interaction between the atmosphere and ocean at the air-sea interface within the DA scheme. This is especially important in the prediction of phenomena where strong air-sea interaction is important. We explore this problem in an idealised single-column coupled atmosphere-ocean system. In particular, we consider methods for incorporating flow dependent forecast error covariance information derived from ocean ensembles into variational weakly coupled DA. A key aspect of this is to investigate different methods for generating the ocean ensemble, with the goal of producing a limited sized ensemble that best represents the uncertainty in the ocean fields. We examine how the structure of the ocean ensemble forecast error correlation matrices change when different ensemble generation methods are used, and how the inclusion of this information alters the coupled analysis compared to using static forecast error covariances.

Monday, 13 Sep 2021 at 14UTC - room RED

DA platforms

PDAF - features and recent developments

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PDAF, the Parallel Data Assimilation Framework (http://pdaf.awi.de), is an open-source framework for ensemble data assimilation (DA). PDAF is designed to be particularly easy to use and a DA system can be quickly build, while PDAF ensures the computational efficiency. PDAF's ensemble-component provides online-coupled DA functionality, thus data transfers in memory and by using the MPI parallelization standard, by inserting 3 function calls into the model code. These additions convert a numerical model into a data-assimilative model, which can be run like the original model, but with additional options. Alternatively, one can use separate programs to compute the forecasts and the DA analysis update. PDAF further provides DA methods (solvers), in particular ensemble Kalman filters and particle filters. Tools for diagnostics, ensemble generation, and for generating synthetic observations for OSSEs or twin experiments, provide additional functionality for DA. PDAF is used for research purposes, teaching, but also operationally. In the operational context, PDAF is e.g. used at the CMEMS marine forecasting center for the Baltic Sea and in the Chinese Global Ocean Forecasting System (CGOFS). A recent addition to PDAF is OMI, the Observation Module Infrastructure, a library extension for observation handling. OMI is inspired by object-oriented programming, but for ease of use, it is not coded using classes. Recent developments further include support for strongly-coupled DA across components of Earth system models, model bindings for NEMO, SCHISM, and the climate model AWI-CM and ensemble-variational solvers. This presentation discusses the PDAF's features and recent infrastructure developments in PDAF.

JCSDA's vision of a community data assimilation for research and operations

Auligne, Tom[(1,2)]
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The Joint Center for Satellite Data Assimilation (JCSDA) is spearheading a revolutionary approach to developing next-generation data assimilation capabilities in support of scientific research and operations. Our major objectives are to reduce duplication of effort without imposing a single approach, to improve our agility to use observations, and to enable innovative solutions for coupled analysis of the Earth system. This presentation provides JCSDA's overarching vision, which is supported by the following three pillars: 1. Collaborative Infrastructure: we are committed to developing, maintaining, and distributing open-source software via modern working practices such as agile/SCRUM methodology, automated and multi-tier testing, continuous integration and continuous delivery. Additional focus is devoted to training and facilitating rapid community contributions. 2. Generic software components: leveraging the separation of concerns and generic programming, the data assimilation combines generic components (e.g., forward operators, error covariance modeling, data assimilation algorithms), which get instantiated for each specific model, set of observations and configuration. This approach allows the use of a common data assimilation framework for a variety of applications. 3. Joint testbed applications: we are now deploying end-to-end systems to continuously test all components in several pseudo-operational environments and inform on future design updates. A shared ecosystem to manage research experiments will ensure that results are transparent and easily reproduceable throughout the community, thus maximizing the benefits of "jointness".

A CESM+DART Atmospheric Reanalysis for Forcing Ocean, Land, and Other Surface Models.

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Ensemble reanalyses of the ocean, sea ice and land are crucially dependent on both the mean and variability of atmospheric forcing. An ensemble atmospheric reanalysis using the Community Earth System Model with the Data Assimilation Research Testbed generated a unique dataset of ensembles of surface fluxes and other variables required by non-atmosphere component models. These data can force reanalyses and hindcasts with CESM component models; CLM5 (land), CICE5 (sea ice), POP2 and MOM6 (ocean), MOSART (atmospheric chemistry), and CISM (land ice). They can also force non-CESM Earth system models. This presentation describes the generation and quality of the reanalysis and how to access and use the dataset for reanalyses with other models. This reanalysis used a 1 degree CAM6-FV configuration of CESM to assimilate millions of observations per day for 2011-2019. Data saved include 80-member ensembles of: 1) High-frequency atmospheric forcing for non-atmospheric models of CESM, 2) Weekly CAM6, CLM and CICE restart files, 3) 6 hourly prior estimates of the assimilated observations, 4) 6 hourly land model plant growth variables, 5) 6 hourly ensemble mean atmospheric analyses. The reanalysis' ensemble spread and agreement with observations vary with atmospheric field, location, and time. These can be evaluated in great detail using 3), above. This 120 Tb dataset has a combination of a large ensemble, high frequency, and multiyear time span providing opportunities for statistical analysis and use as a training dataset for machine learning. It is freely available from the Research Data Archive at NCAR.

Monday, 13 Sep 2021 at 15UTC - room RED

Coupled DA II

Skillful Coupled Atmosphere-Ocean Data Assimilation - on a Laptop

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A wide range of problems in weather and climate science depend upon dynamically consistent coupled states. For example, in climate science, direct ocean observations become increasingly sparse back in time prior to the 21st century, increasing the importance of effectively using atmospheric observations to inform on the state of the ocean. For weather, the S2S forecast problem depends upon consistent initialization of the coupled state, and operational assimilation systems typically employ weakly coupled assimilation (coupled model and uncoupled assimilation). Perhaps the main challenges to progress involve the computational burden of both the forecast and analysis steps, and the technical difficulty of developing and testing assimilation techniques in large, complex coupled modeling systems Here we use a low-dimensional linear emulator, trained on source datasets. This emulator has demonstrable skill on S2S timescales and allows fully coupled data assimilation using the unapproximated Kalman filter. Specifically, we use a linear inverse model (LIM), trained on data from the Climate Forecast System Reanalysis (CFSR), and observations also drawn from that dataset. We conduct a hierarchy of assimilation experiments, including uncoupled, weakly coupled, and strongly coupled cases. Results show a reduction in analysis error for the weakly and strongly coupled cases over the uncoupled case. Improvement is particularly large for midlatitude sea-surface temperature, where strongly coupled data assimilation reduces errors by over

10% compared to the weakly coupled case. The LIM framework facilitates decomposition of the dynamics into coupled and uncoupled subspaces, which are used to diagnose the sources of improvement.

Skin temperature analysis used for the assimilation of clear-sky radiances

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[(1)]European Centre for Medium-Range Weather Forecasts

We recently proposed a new approach to the skin temperature analysis used for the assimilation of clear-sky radiances, as part of ECMWF atmospheric 4D-Var system. For that purpose, we added hourly skin temperature fields in the 4D-Var control vector. Some of these fields are associated with the infrared (IR) instruments and others with the microwave (MW) instruments. We will first present the impact of the new approach on the ECMWF Integrated Forecasting System forecast skill. This new approach is the first stepping stone toward a seamless coupling between atmosphere and surface (land and ocean). We will show for example how the IR skin temperature fields could be used to derive a sea surface temperature that could be used to force the ocean model. We will also show that, with this approach, we change the surface emissivity used for the assimilation of MW radiances. This emissivity change could be used to provide information on the emissivity models.

Modernising the Land Data Assimilation and Land Model Uncertainty Estimation in NOAA's Global NWP Systems

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In contrast to other national NWP centers, the soil moisture and temperature in NOAA's global NWP models is not directly constrained with observations, and our operational snow analysis is also outdated. This presentation then provides an overview of research efforts to modernise the land data assimilation used in our global atmospheric systems, together with relevant experimental and scientific results. For snow, we have developed an Optimal Interpolation (OI) snow depth analysis to assimilate station snow depth and remotely sensed snow cover observations, based on the schemes used elsewhere. The OI corrects our current analysis' bias against adding snow, while improving the snow depth and low-level atmospheric temperatures over land. It is now being implemented in NOAA's global prediction systems within the JEDI software framework. For the soil states, a coupled land/atmosphere Ensemble Kalman Filter (EnKF) has been developed to constrain the soil temperature and soil moisture with observations of 2m temperature and humidity. The EnKF is in early testing, and results from initial experiments will be presented. Additionally, since NWP ensembles are consistently under-dispersed at and near the land surface, prior to developing the EnKF we introduced a scheme to account for land model uncertainty in the generation of our NWP ensembles. This scheme perturbs key parameters controlling the land/atmosphere fluxes,thus generating ensemble-based land/atmosphere error covariance estimates that represent uncertainty in these fluxes, while also showing agreement with independent estimates of the model uncertainty. This scheme is intended to be introduced operationally together with the land/atmosphere EnKF described above.

Improved Understanding of Land-Atmosphere Interactions Using Profiling and Surface Flux Observations

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Land-atmosphere interactions play a critical role in both the atmospheric water and energy cycles. Mixing diagrams provide insight into the evolution of the heat and moisture budget within the convective boundary layer (CBL). Mixing diagrams enable us to quantify the contributions from surface fluxes, advection, radiative heating, encroachment, and entrainment to the evolution of the CBL moisture and energy budgets as a function of the time-of-day. We demonstrate that observations from the ARM Southern Great Plains (SGP) site provide all of the inputs needed for the mixing diagram framework. In particular, the high temporal resolution profiles of temperature and humidity retrieved from the Atmospheric Emitted Radiance Interferometer (AERI) are a critical component in this analysis, as they provide a unique opportunity to quantify encroachment, advection, and mixed-layer quantities from observations. We demonstrate that the mixed-layer mean values of temperature and humidity are optimal for understanding the evolution of the CBL; past work using 2 m above ground in-situ observations in mixing diagrams results in biases. We also demonstrate that encroachment is a critical term for understanding the CBL evolution; past work had convolved this term with entrainment. We use this framework to evaluate both large-eddy simulation (LES) and the High-Resolution Rapid Refresh (HRRR) models using this approach.

Monday, 13 Sep 2021 at 15UTC - room GREEN

Reanalysis evaluation II

Overview of MERRA-2 for Applications, Decision-making, and Climate Assessment

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The Modern Era Retrospective-analysis for Research and Applications (MERRA) began development in the early 2000s with intention to provide informed regional climate assessment for decision support. Retrospective-analyses include an abundance of observations so that synoptic-scale weather is faithfully depicted. However, key features in high time resolution (1 hourly), long duration (starting in the late 70s early 80s) and timely near real time data production are particularly useful for decision-making. In addition, attention to useful output diagnostics can also increase the usefulness of the reanalyses (e.g. boundary layer winds for wind energy production). Here, we review some recent efforts that employ reanalyses output in applied uses, including heatwaves, drought, extreme rainfall, renewable energy, sustainable building systems and health (air quality). We also consider lessons learned and potential directions in the future.

Mechanisms Associated with Daytime and Nighttime Heat Waves over the Contiguous United States

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Heat waves are extreme climate events that have the potential to cause immense stress on human health, agriculture and energy systems. Previous studies have found heat wave frequency to have increased over recent decades in many regions. There is no single accepted definition

of a heat wave, but it is generally defined as temperature exceeding a threshold for a sustained amount of time. However, multiple different temperature variables can be used – daily mean, maximum and minimum temperature are potentially relevant, as are variables which account for humidity, such as apparent temperature, equivalent temperature and heat index. In this study, heat waves are examined over the United States using the NASA Modern-Era Retrospective Analysis for Research and Applications 2 (MERRA-2). We focus explicitly on the difference between heatwaves manifest during daytime versus nighttime hours. Both can be detrimental for human health, so it is important to understand the conditions leading to their onset. A daytime (nighttime) heat wave is defined as average daytime (nighttime) temperature exceeding its calendar day 90th percentile for at least 3 days, where daytime and nighttime hours are differentiated locally using hourly downward shortwave radiation at the top of the atmosphere. We characterize the large-scale circulation and identify local and remote processes associated with these two heatwave types over different regions of the United States.

Homogenetity of time series and trends from ERA5

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The stratosphere and its dynamics are a very important part of atmospheric circulation. We need to analyze its climatology, as well as long-term trends. A long-term trend study needs homogenous datasets without significant artificial discontinuities. The analysis is based on the newest released reanalyses, European Center for Medium-Range Weather Forecast Reanalysis (ERA5). The aim of this study is to detect discontinuities and homogeneity in the temperature and wind time series from the above reanalysis with the various homogeneity tests for pressure layers above 500 hPa up to 1 hPa and show a comparison of temperature trends from the studied reanalyses and GPS radio occultation (GPS RO). We search for individual grid points where these discontinuities occur, and also for the years when they occur (geographical and temporal distribution). As expected, the study confirms better results for the Northern Hemisphere due to the denser data coverage. A high number of grid points with jumps on the Southern Hemisphere is found, especially at higher pressure levels (from 50 hPa). The spatial and vertical distribution of discontinuities is also presented. The vertical distribution reveals the reduction of the number of jumps around 10 hPa for ERA5 reanalysis. We also study temperature trends from reanalyses and GPS RO and our analysis shows that the agreement between the reanalyses and observations are very good for the period 2006–2018. We will add also comparison with AEOLUS measurements.

Tropical wave analyses: variability, trends and uncertainties in ERA-Interim, JRA-55, MERRA and ERA5 reanalyses

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We discuss uncertainties in tropical wave circulation using ERA-Interim, JRA-55, MERRA and ERA5 reanalyses. The equatorial Rossby and inertia-gravity waves are filtered using the three-dimensional linear wave theory. The results quantify amplitudes and trends in the equatorial wave activity across scales. We show that the four reanalyses agree regarding recently increased subseasonal variability in the large-scale Kelvin waves, mixed Rossby-gravity waves and westward-propagating inertio-gravity waves with the lowest meridional mode. The amplitude and sign of trends at smaller zonal scales with greater meridional modes differ between the ERA-Interim and JRA-55 datasets on one hand, and the ERA5 and MERRA data on the other. Increased variability in the ERA-Interim and JRA-55 accounts for positive trends in their global subseasonal variability.

Monday, 13 Sep 2021 at 15UTC - room BLUE

Hybrid DA

4D-hybrid formulation of 4DEnVar for global data assimilation at Météo-France

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There is growing interest for using ensemble information in the formulation of data assimilation, which can be combined with advantages of variational approaches. The 4DEnVar formulation is a variational method based on the use of 4D ensemble non linear trajectories, at relatively high resolution, in order to represent 4D background error covariances, which are localized spatially. A usual approach in 4DEnVar is also to employ an hybridation with error covariances which are spatially averaged, for representing long-distance correlations. Moreover, these spatially averaged covariances are usually static within the assimilation window. This can be seen as a 3D-hybrid approach, partly relying on 3D static error covariances, which are employed repeatedly for the different time slots of the 4D data assimilation window. A new (4D) formulation of the hybridation is proposed at Météo-France for 4DEnVar, in order to combine respective advantages of 4DEnVar and of more conventional variational approaches. Its properties will be discussed both in the perfect model framework and also in the case where model errors are taken into account. Preconditioning aspects will be considered too. A preliminary implementation of this 4D-hybrid formulation of 4DEnVar has been made possible thanks to the flexibility offered by the OOPS (Object-Oriented Prediction System) software, and experimental results with the Météo-France global ARPEGE system will be presented.

Ensemble-variational assimilation with constrained non-stationary spatial convolutions

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We propose a new approach to hybrid ensemble-variational assimilation based on direct estimation of a square root, W, of the prior covariance matrix. The W matrix is a spatial convolution filter constrained to model slowly varying in space covariances. It is estimated online by (1) applying a spatial multi-scale bandpass filter to ensemble perturbations, (2) estimating a local spectrum from the ensemble band variances, and (3) converting the local spectra to the rows of W. The estimation of the local spectra is regularized with climatological statistics and can be done in a scale-dependent manner. The estimation scheme can be efficiently parallelized. The estimated online W matrix is used in a variational analysis scheme. The scheme is fast because a square root of the prior covariance matrix is known to be an efficient preconditioner. The scheme does not require localization. The technique was tested in static simulation experiments with synthetic data on circular and spherical spatial domains. With a reasonable degree of spatial non-stationarity, the new analysis outperforms the classical covariance-localized analysis for ensemble sizes up to 100. With the ensemble size of 10, the RMSE of the new analysis is 3-4 times closer to the RMSE of the best possible analysis (which has access to the true spatially non-stationary covariance matrix) than the RMSE of the covariance-localized analysis. The performance of the new technique in cycled data assimilation experiments on a 1D domain will be presented at the symposium.

Integrated Hybrid Data Assimilation for an Ensemble Kalman Filter

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Hybrid ensemble-variational assimilation methods have been widely applied for numerical weather predictions. The commonly used hybrid assimilation methods compute the hybrid analysis increment using a variational framework and update the ensemble perturbations by an EnKF. To avoid the inconsistence resulted from separated hybrid assimilation and EnKF systems, two integrated hybrid ensemble Kalman filters (EnKFs) that update both the ensemble mean and ensemble perturbations by a hybrid background error covariance in the framework of EnKF are proposed here. The integrated hybrid EnKFs approximate the static background error covariance by use of climatological perturbations through augmentation or additive approaches. The integrated hybrid EnKFs are investigated in the Lorenz (2005) models II and III with different magnitudes of model error. Results show that the static background error covariance can be sufficiently estimated by climatological perturbations withan order of hundreds. The integrated hybrid EnKFs are superior to the traditional hybrid assimilation methods, which demonstrates the benefit to update ensemble perturbations by the hybrid background error covariance. Sensitivity results reveal that the advantages of the integrated hybrid EnKFs over traditional hybrid assimilation methods maintained with varying ensemble sizes, inflation values and localization length scales.

Tests of hybrid EnKF-Variational Data Assimilation capabilities using JEDI with NOAA's Next Generation Regional High Resolution NWP System

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The JEDI (Joint Effort for Data assimilation Integration) system is the next generation data assimilation framework planned to underpin the NCEP production suite and is developed following the principles of object-oriented design. At NCEP's Environmental Modeling Center, the hybrid EnKF and Variational Applications of JEDI on regional domains has been tested and evaluated using various configurations in comparison with the current operational data assimilation framework (Gridpoint Statistical Interpolation; GSI) to prepare for its future role in NOAA's Next Generation Regional High Resolution NWP System - the Rapid Refresh Forecast System. The evaluation of JEDI in comparison to GSI will focus on the performance and analysis characteristics of the hybrid EnVar algorithms of both systems and provide helpful insight toward the ongoing JEDIagile development process.

Tuesday, 14 Sep 2021 at 11UTC - room RED

Operational DA I

National Analysis System

Krysta, Monika[(1)]; Rennie, Susan[(1)]; Steinle, Peter[(1)]; Lee, Jin[(1)]; Le, Tan[(1)]; Lu, Wenming[(1)]; Dharssi, Imtiaz[(1)]; Bermous, Ilia[(1)]; Smith, Andy[(1)]; Cooper, Shaun[(1)]; Tingwell, Chris[(1)]; Smith, Fiona[(1)]; Franklin, Charmaine[(1)]
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National Analysis System, NAS, is essentially a response to internal customers' requirements to provide a rapid and frequent update on the current state of the atmosphere in order to increase situational awareness, particularly in an advent of extreme meteorological conditions. For this purpose, Australian Bureau of Meteorology is developing a high-resolution limited area cycling suite, for a domain covering entire Australia at 2.2 km of horizontal grid spacing and 80 vertical levels. This suite is to a large extent based on existing implementations of an hourly cycling 4D-Var suite for limited area applications. This latter concept constitutes a backbone of the new system, while essential additions consist in supplementary 3D-Var analyses performed using low-latency observations. The 3D-Var processing comes in two steps, a standard step which adjusts large scales and an additional step for which errors of conventional observations are tuned. This second step limits smoothing and provides 3D-Var overfitting objective analyses with a closer match to those observations which are considered reliable and representative, rather than achieving a balanced analysis created for the purpose of initialising a weather forecast. In this presentation we propose to illustrate the new system and its applications. We will start with a brief description of NAS and its components. The observations taking part in various analyses will be listed as well as their numbers and timeliness. In the context of case studies three types of analysis increments shall be illustrated. The added value of the overfitting 3D-Var will be discussed alongside modifications to the observation error. Cross-validation verification results will be presented.

New Variational Data Assimilation System for Regional Model at JMA

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The four-dimensional variational method needs to keep up with the updates of the forecast models used as strong constraints. In JMA, with the development of non-hydrostatic model “ASUCA”, we have developed the variational data assimilation system based on ASUCA (ASUCA-Var). In the ASUCA-Var, the control variables include the underground temperature and the soil moisture in addition to atmospheric variables, and the climatological background error covariances are classified by sea/land and local time. The cost function is designed to be in fully quadratic form, is minimized by three times the line search as inner loop with the basic field update twice in between the inner loops. For advanced observation processing within the variational system, variational quality control and variational bias correction have also been introduced. In addition, we developed an optimization method for the model's topography based on the variational method. Since the various validation indicators showed that the forecast accuracy of the NWP system using ASUCA-Var has been significantly improved compared to the former system, ASUCA-Var has been operated as the Meso-scale Analysis since March 2020. Currently, we have been developing the introduction of hybrid 4D-Var with ensemble of data assimilation and the extension of control variables to hydrometeors. In this presentation, the overview of ASUCA-Var, the impact of the observations using the degree of freedom signal and the verification results of the ASUCA-Var's performance will be shown.

Building a JEDI- and FV3-based Rapid Refresh Forecast System (RRFS) upon Decade of Development and

Implementation of the High Resolution Rapid Refresh (HRRR)

Hu, Ming[(1)]; Kenyon, Jaymes[(2,1)]; Holt, Christina[(2,1)]; Trahan, Samuel[(2,1)]; Li, Ruifang[(2,1)]; Ge, Guoqing[(2,1)]; Beck, Jeff[(3,1)]; Weygandt, Stephen[(1)]; Curtis, Alexander[(1)]; Ladwig, Terra[(1)]; Rogers, Eric[(4)]; Carley, Jacob[(4)]; Lei, Ting[(4)]; Liu, Shun[(4)]; Zhang, Xiaoyan[(4)]
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The Rapid Refresh Forecast System (RRFS) is NOAA's next generation rapidly-updating regional/storm scale operational NWP system under development collaboratively by many partners. It will replace current regional and storm scale operational NWP systems, including RAP/HRRR, HREF, and NAM. In the past ten years, NOAA has worked with the research community to develop HRRR for operational storm forecasts. Many data assimilation and physical schemes used in HRRR are still valuable for RRFS development. The RRFS uses a limited area model version of the FV3 (FV3LAM), but retains the majority of the HRRR physics, hourly cycling, and data assimilation capabilities. The data analysis engine is transitioning from the Gridpoint Statistical Interpolation (GSI) to the Joint Effort for Data assimilation Integration (JEDI). We are currently evaluating various data assimilation capabilities using the GSI coupled with the FV3LAM inside the UFS Short-Range Weather Application. These include 3D hybrid EnVar, non-variational cloud analysis, soil adjustment, and the use of radar reflectivity via a derived temperature tendency. We are also conducting tests of these analysis capabilities using JEDI coupled with the FV3LAM, benchmarking them against similar GSI-FV3LAM capabilities. To effectively couple the RRFS with the FV3-based Global Forecast System (GFS), we are running a single large 3-km RRFS domain covering North America and adjacent oceanic regions to assess the need for a 13-km resolution intermediate RAP-like domain between GFS and 3-km CONUS domain as was done with RAP/HRRR. In this talk, we will summarize the latest RRFS retrospective and real-time tests results with comparisons against the HRRR and other systems.

Tuesday, 14 Sep 2021 at 11UTC - room GREEN

Reanalysis evaluation III

Brewer-Dobson circulation represented in JRA-3Q

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The Brewer-Dobson circulation (BD circulation) represented in the reanalysis data is known to have differences in structure and strength, although seasonality and asymmetry in the northern and southern hemispheres are common among the reanalyses (Iwasaki et al., 2009). The BD circulation, represented in JRA-55, shows similar characteristics to that in ERA-Interim climatologically, but it has been pointed out that the long-term trend of the circulation strength, indexed by the upward mass flux near the tropopause, shows an increasing trend and is opposite to that of ERA-Interim (Abalos et al. 2015, Kobayashi and Iwasaki, 2016). The Japan Meteorological Agency (JMA) has been conducting the third Japanese global atmospheric reanalysis for Three Quarters of a Century (JRA-3Q). The characteristics of the mean meridional circulation represented in JRA-3Q in recent 30 years, especially the BD circulation, were compared with those in other reanalyses such as JRA-55 and ERA5

(5.1). The results show that the BD circulation represented in JRA-3Q is weaker than that of JRA-55 throughout the year, and the associated tropospheric and stratospheric mass exchange rates are smaller throughout the year. The exchange rates in JRA-3Q are less than ERA5 (5.1) in DJF season and similar in JJA season, indicating a difference in the representation of the Northern Hemisphere cell of BD circulation.

Comparison of land surface data assimilation results driven by MERRA-2 and ERA5 meteorological forcings

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In this study, the sensitivity of a land surface data assimilation system to the choice of meteorological forcing is explored. We assimilate microwave-based satellite retrievals of surface soil moisture into the Noah-MP land surface model using NASA's Land Information System (LIS). Two forcing data sets are tested: the Modern-Era Retrospective analysis for Research and Applications, version 2 (MERRA-2) from NASA, and the European Centre for Medium-Range Weather Forecasts (ECMWF) Reanalysis Version 5 (ERA5). We explore the impact of this choice of meteorological forcing on the performance of the data assimilation system. More specifically, surface and root-zone soil moisture estimates of both data assimilation runs are compared with each other and evaluated against in situ observations as well as existing root-zone soil moisture products, such as the SMAP Level 4 Surface and Root-zone soil moisture product. Our data assimilation approach uses a one-dimensional Ensemble Kalman Filter (EnKF) and allows to obtain consistent surface and root-zone soil moisture estimates over the European continent for the period 2002-2020. Satellite data are acquired from the combined active-passive ESA CCI Soil Moisture product, which harmonizes and merges soil moisture retrievals from multiple satellites. Acknowledgments: this work is part of the ESA CCN1 CCI+ Soil Moisture Scientific Evolution project and the FWO-FWF CONSOLIDATION project.

Data assimilation impact studies with the AROME-WMED reanalysis during HyMeX SOP1

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The Hydrological cycle in the Mediterranean Experiment (HyMeX) aimed to study the heavy precipitation that regularly affects the Mediterranean area. A reanalysis with a convective-scale model AROME-WMED (Application of Research to Operations at MEsoscale western Mediterranean) was performed, which assimilated most of the available data for a 2-month period corresponding to the first special observation period of the field campaign in September-November 2012 (Fourrié et al., 2019). Among them, observations related to the low-level humidity flow were assimilated : a dense reprocessed network of high-quality Global Navigation Satellite System (GNSS) zenithal total delay (ZTD) observations, reprocessed data from wind profilers and Spanish radar data. The aim of this study is to assess the impact of the assimilation of these observation types on the analyses and the forecasts through several observing system experiments by removing one single data set from the observation data set assimilated in the reanalysis. Ground-based GNSS ZTD data set provides the largest impact on the analyses and the forecasts, as it represents an evenly spread and frequent data set providing information at each analysis time over the AROME-WMED domain. The impact of the reprocessing of GNSS ZTD data also improves the forecast quality, but significantly. The assimilation of the Spanish radar data improves the 3 h precipitation forecast quality as well as the short-term (30 h) precipitation forecasts, but this impact remains located over Spain. In addition, marginal impact from wind profilers was observed on wind background quality.

Tuesday, 14 Sep 2021 at 11UTC - room BLUE

Theoretical Developments in DA

An optimal linear transformation for data assimilation

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Estimation of extremely large covariance matrices and their use computationally to update prior state estimates (whether through minimization or solution of linear systems) are key difficulties in data assimilation for geophysical systems. It is often helpful to apply linear transformations of the state or observations, for example to facilitate the implementation of multivariate spatial covariances or improve the conditioning of the numerical problem. In particular, recent literature on multiscale ensemble Kalman filters can be cast as a search for transformations to coordinates in which localization of sample covariances is especially straightforward and effective. This leads to two questions: What linear transformation yields the simplest form of the update equations for the Kalman filter or best linear unbiased estimator? And what linear transformation is optimal to precede localization in ensemble Kalman filters? Answers to these questions appear to be the same. The resulting transformation diagonalizes the update, in the sense that all covariances become the identity and each coordinate in the observation space depends on a single, unique coordinate in the state space. The number and signal-to-noise ratio of the observations in the transformed space then characterize the update, including measures of information content for the observations, the condition number of the minimization problem, and the effects of sampling error from ensemble techniques.

A Numerical Approximation Method for Fast Computations of Matrix-Vector Products with Spatially Correlated Observation Error Statistics

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Recent studies have shown that observations such as geostationary satellite observations and Doppler radar radial winds can exhibit strong spatial error correlations. The estimated error correlation lengthscales are found to be significantly longer than the observation-thinning distances used by many operational centres. Therefore, there is a need to include the correlated error statistics in the data assimilation procedures. However, this can potentially increase the computation costs for the matrix-vector multiplications arising in the solution of the variational minimization problem. The calculation of these matrix-vector products is perfectly parallel when observations are distributed across different processing elements (PEs) according to their geophysical locations and if their errors are assumed to be uncorrelated. However, if correlated error statistics are used, the PEs cannot complete their own tasks without excessive communications between each other. Previous studies have proposed many methods or strategies that can be used to reduce the computational cost. These include allocating observations with correlated errors into one PE and using the Cholesky decomposition, assimilating spatial difference observations, using truncated eigen-decomposition to approximate the error covariance matrix, using data compression technique to reduce the number of observations and using diffusion operators to model correlated errors. In this presentation, we will present a new numerical approximation method developed based on the fast multipole method. This method works with the domain decomposition of the observations and can compute the matrix-vector products with reduced communication costs.

Randomised preconditioning in variational data assimilation

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In variational data assimilation, the analysis can be obtained by minimising a series of linear least-squares cost functions. Each minimisation (called an inner loop) can be performed by using the conjugate gradient (CG) method, which needs preconditioning for fast convergence. In previous work, limited memory preconditioners (LMPs) have been constructed using approximations of the eigenvalues and eigenvectors of the Hessian of the cost function from the previous inner loop. If the Hessian changes significantly between consecutive inner loops, the LMP may perform poorly. To circumvent this, we propose using randomised methods for low rank eigenvalue decomposition to construct LMPs using information from the current inner loop. These methods can be easily parallelised and the cost can be comparable to just a few CG iterations if there are enough computational resources available. We compare three randomised methods when minimising the quadratic cost function arising in incremental weak constraint 4D-Var. Numerical experiments in idealized systems show that the resulting randomised LMPs perform better than the existing deterministic LMPs: a randomised LMP gives faster minimisation than a deterministic LMP, even when the former is constructed with fewer eigenvectors than the latter. Using these methods may allow more efficient and robust implementations of variational data assimilation methods.

Tuesday, 14 Sep 2021 at 12UTC - room RED

Operational DA II

NCEP Operational Global Data Assimilation System (GDAS): Recent Upgrades and Future Plans

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The Global Forecast System (GFS) and GDAS were recently updated to version 16. This included a doubling of the number of vertical layers in the model and raising the model top to ~80km. The data assimilation system continues to utilize hybrid 4DEnVar within the Gridpoint Statistical Interpolation (GSI). Additional changes included replacing the Ensemble Serial Filter with the Local Ensemble Transform Kalman Filter (LETKF) for the ensemble perturbation update, 4D incremental analysis update (IAU), improvements to the inline sea surface temperature analysis, and semi-coupled land analysis as forced by observed precipitation. Additional changes included calibration to account for the new model layer specification, changes to stratospheric humidity increments, satellite channel selection to include higher peaking channels from ATMS and AMSU-A, bias correction, the use of inter-channel correlated observation errors for IASI and CrIS, and incorporation of additional clear-sky radiance data from geostationary satellites. Work is underway on future upgrades to include improved use of observations such as the utilization of commercial GPS radio occultation, additional atmospheric motion vectors, new sensors for constraining sea surface temperature, antenna corrected radiances, and updates to the use of scatterometer winds. This presentation will provide details regarding the upgrades included in version 16 as well as preliminary results from the upcoming changes related to improved use of observations. Progress and plans on

the transition from GSI to the Joint Effort for Data assimilation Integration will be discussed. Finally, plans for coupled assimilation as part of the Unified Forecast System and GFSv17 will be presented.

The Global-to-Regional Data Assimilation System for the ICON Model

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The Icosahedral Non-Hydrostatic (ICON) Model and its Ensemble Data Assimilation Systems EnVAR+LETKF are developed by an international consortium with Deutscher Wetterdienst (DWD), the Max-Planck-Institute for Meteorology (MPI), the German Climate Computing Center (DKRZ), the Karlsruhe Institute of Technology (KIT), the COSMO Consortium (Germany, Russia, Switzerland, Italy, Romania, Poland, Greece and Israel) and the Center for Climate Systems Modeling (C2SM). Globally, an ensemble data assimilation system based on an ensemble-variational system (EnVAR) in combination with a Localized Ensemble Transform Kalman Filter (LETKF) is used for the 13 km global deterministic ICON and the 40 km ensemble prediction system (ICON-EPS) with 40 members. The models are run with a two-way nested 6.5 km resolution area ICON-EU over Europe, where the ICON-EU-EPS has 20 km resolution. The analysis is carried out every 3 hours. Operationally, the full LETKF ensemble analysis is coupled to the high-resolution EnVAR analysis by relaxation of the ensemble mean to the deterministic analysis. The convective-scale ICON-D2-EPS is run on 2 km resolution with 40 members. The operational system employs the LETKF with an additional deterministic analysis for the deterministic run, where the Kalman matrix of the LETKF is employed. Regional analysis is carried out every hour. Rapid Update Cycle analyses and forecasts hourly are under preparation within the SINFONY project in combination with Nowcasting. For ICON-D2 we also develop an EnVAR, which can use any of the available ICON-EPS (global, mesoscale and convective-scale) as input for its covariance estimator. The system is portable and can be employed for regional data assimilation anywhere on the globe.

Advancing Data Assimilation in Global NWP and Climate: the ECMWF Perspective

Bonavita, Massimo[1]
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Data assimilation (DA) is traditionally used to combine observations and models in a statistically optimal fashion in order to provide the best estimates of the initial state of the Earth system, given the assumed uncertainties of their inputs. This is a crucial activity in alloperational NWP and Climate Centre, as the accuracy and reliability of the analysis pdf is one of the main drivers of forecast skill from hour to seasonal predictions. Standard DA systems need to evolve to respond to the opportunities and challenges presented by emerging trends in e.g. the ever increasing availability, density and temporal frequency of new observations; the increasing importance of nonlinearities in both observations and model; the rapidly increasing resolution of the prognostic models; the demands of a seamless and physically consistent initialisation across the Earth system components. In the first part of the talk we review the recent evolution of the ECMWF DA system and its planned future developments aimed at tackling the methodological challenges connected to these trends in observations and model. More recently, there has been a growing realisation that limitations and imperfections of the current generation of prognostic models are arguably the biggest hurdle in order to overcome historical predictability barriers in both NWP and Climate prediction. This has led to renewed efforts to extend data assimilation methodologies and employ new hybrid DA-Machine Learning techniques to enhance, improve and correct forecast models. In the second part of the talk we describe the ECMWF experience and plans in this area and discuss some of the opportunities and challenges ahead in light of the ambitious goals set out in the ECMWF 2021-2030 Strategy.

Status and Plans of Data Assimilation at KIAPS

Kwon, In-Hyuk[(1)]; Clayton, Adam[(1)]; Kang, Jeon-Ho[(1)]; Lee, Sihye[(1)]
[(1)]Korea Institute of Atmospheric Prediction Systems

The renewed Korea Institute of Atmospheric Prediction Systems (KIAPS) aims at developing a unified framework for seamless prediction from very short range (~6 hours) to extended medium range (~30 days), including coupling to various earth system components, such as the land surface, oceans, and sea ice. The first phase of the KIAPS project delivered the global atmosphere-only NWP system that was made operational at the Korea Meteorological Administration (KMA) in April 2020. The NWP model - named the Korean Integrated Model (KIM) - is a non-hydrostatic model based on a cubed-sphere grid, utilizing the spectral element method within the dynamics. The global data assimilation (DA) system is based on a hybrid-4DEnVar system for the deterministic analysis, and an LETKF for ensemble perturbation updates, and is already giving good performance. Many types of observations, including conventional data, GPS-RO, AMSR2, AMSU-A, MHS, ATMS, MWHS2, IASI, CrIS, and clear sky radiances from GK-2A, are quality controlled by the KIM Package for Observation Processing (KPOP). Trials to test assimilation of ALADIN wind data and Ground GNSS observations are also due to begin shortly. As well as continuing to strengthen the existing atmospheric DA system, we are planning new developments which include convection-permitting scale DA for areas of interest, coupled atmosphere-ocean DA, machine learning techniques for observation quality control, and an extended observation processing system for newly available observations.

Tuesday, 14 Sep 2021 at 14UTC - room RED

Observation Impact I

Aircraft data and Covid-19: impact and mitigation measures at ECMWF

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Meteorological reports from aircraft are an important source of data for global weather forecasting. Their largest impact is in the upper troposphere at short-range as determined from observing system experiments. Due to the pandemic the number of aircraft reports reduced by about 75% between mid-March and mid-April 2020, recovering somewhat to almost 50% of normal by July 2020. However it is difficult to see any evidence of degradation in forecast skill - partly because forecast skill varies on daily, monthly and anual time-scales. New satellite data became available during 2020 and ECMWF started using European Mode-S aircraft winds to mitigate the loss of standard aircraft reports. So, despite the downturn in aviation we are now using more aircraft reports over Europe than before the pandemic.

Estimation of the benefits of remote-sensing profilers for sustainable energy applications

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Over the last years, climate monitoring and operational weather forecasts have become an important topic for renewable energy management. One of the ways for a substantial improvement of numerical weather prediction (NWP) is the assimilation of new observational data. Data assimilation (DA) combines observations with short-term weather forecasts to achieve an optimal estimate of the atmospheric state required for NWP. One of the sources of information potentially valuable for DA are ground-based remote-sensing instruments. Our study focuses on the potential impact of ground-based remote sensors for energy applications. The potential impact is analyzed using ensemble sensitivity analysis which allows us to investigate how the assimilation of hypothetical ground-based profilers can reduce the forecast variance. We analyze relative changes in the variance associated with the assimilation of synthetic observations from a wind Doppler lidar. The variance reduction is investigated for domain-averaged sensitivities of 80 m wind (typical hub-height of wind turbines). For our analysis, we apply the first convective-scale 1000-member ensemble simulation over Germany. The simulation uses a full-physics non-hydrostatic regional model, consists of 16 ensemble forecasts and covers a high impact weather period in May/June 2016. Our study focuses on the urban and highly populated Rhein-Ruhr area and surrounding regions that feature wind parks.

EFSO at different geographical locations verified with observing system experiments

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An ensemble-based forecast sensitivity to observations (EFSO) diagnosis has been implemented in an AGCM-LETKF data assimilation system to estimate the impacts of specific observations from the quasi-operational global observing system on weekly short-range forecasts. It was examined whether EFSO reasonably approximates the impacts of a subset of observations from specific geographical locations for 6-h forecasts, and how long the 6-h observation impacts can be retained during the 7-day forecast period. The reference for these forecasts was obtained from 12 data-denial experiments in each of which a subset of three radiosonde observations launched from a geographical location was excluded. The 12 locations were selected from three latitudinal bands comprising (i) four Arctic regions, (ii) four midlatitude regions in the Northern Hemisphere, and (iii) four tropical regions during the Northern Hemisphere winter of 2015/16. The estimated winter-averaged EFSO-derived observation impacts well corresponded to the 6-h observation impacts obtained by the data denials and EFSO could reasonably estimate the observation impacts by the data denials on short-range (from 6 h to 2 day) forecasts. Furthermore, during the medium-range (4-7 day) forecasts, it was found that the Arctic observations tend to seed the broadest impacts and their short-range observation impacts could be projected to beneficial impacts in Arctic and midlatitude North American areas. The midlatitude area was located just downstream of dynamical propagation from the Arctic toward the midlatitudes. Results obtained by repeated Arctic data- denial experiments were found to be generally common to those from the non-repeated experiments.

Tuesday, 14 Sep 2021 at 15UTC - room RED

Operational DA III

The JEDI-GEOS application: NASA's development pathway for coupled Earth system data assimilation

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NASA's Global Modeling and Assimilation Office is developing a unified coupled data assimilation system based on the GEOS model and the JCSDA's Joint Effort for Data assimilation Integration (JEDI) infrastructure, to achieve its objectives in weather analysis and prediction, reanalysis, composition forecasting, and S2S prediction. The unified system does not mean a single configuration for all GEOS applications, but rather a configurable GEOS system within the JEDI framework. The focusing vehicle for building this capability is the recently initiated JEDI-GEOS application – a continuously evolving, continuously functional testbed encompassing the configuration files, workflows, and data access for instantiating end-to-end tests of new developments and establishing trusted baselines. An important objective of JEDI-GEOS is to produce the first JEDI-based candidates for replacing current-generation GEOS production systems. This talk summarizes the plans and progress in developing the JEDI-GEOS application. Work is progressing on three separate but convergent subprojects: (i) development of the GEOS-configured unified forward operator (UFO), to produce the JEDI-based observing system configurations for GEOS systems; (ii) development of a prototype weakly coupled atmosphere-ocean data assimilation system based on the coupled GEOS-MOM6 model currently operating within JCSDA's Sea-Ice Ocean and Coupled Assimilation (SOCA) framework; and (iii) development of the GEOS-JEDI applications workflow environment based on JCSDA's Experiments and Workflows Orchestration Kit (EWOK) and Research Repository for Data and Diagnostics (R2D2) into which (i) and (ii), and their extensions, will be incorporated.

Data Assimilation for NOAA's Next Generation Regional High Resolution NWP System

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The Rapid Refresh Forecast System (RRFS) is NOAA's next generation rapidly-updating regional/storm scale operational Numerical Weather Prediction (NWP) system. Development is a highly collaborative process involving many partners. The RRFS is targeted to replace many current regional and storm scale operational NWP systems, including the Rapid Refresh (RAP), High Resolution Rapid refresh (HRRR), High Resolution Ensemble Forecast System (HREF), and North American Mesoscale Forecast System (NAM). The RRFS is based upon a hybrid EnVar framework having rapid analysis updates of at least an hourly cadence, ensemble forecasts initialized every hour, and covers North America on a 3 km grid - over 9 million grid cells in the horizontal dimension. This presentation will cover a broad, programmatic description of the RRFS data assimilation system, current progress, and scientific as well as computational design considerations.

Initial Evaluation of JEDI Unified Forward Operator For Use in NCEP's Global Data Assimilation System

Martin, Cory[1]; Dougherty, Kevin[2]; Kleist, Daryl[3]; Liu, Emily[3]; Liu, Shun[2]; Mahajan, Rahul[3]; Treadon, Russ[3]; Auligne, Thomas[4]; Diniz, Fabio[4]; Han, Wei[4]; Shao, Hui[4]; Thompson, Greg[4]; Tremolet, Yannick[4]; Vandenberghe, Francois[4]
[1]RedLine @ NOAA NWS NCEP EMC, [2]IMSG @ NOAA NWS NCEP EMC, [3]NOAA National Centers for Environmental Prediction, [4]Joint Center for Satellite Data Assimilation

The Joint Effort for Data assimilation Integration (JEDI) project aims to create a modern, advanced, and configurable data assimilation system to be used by numerous operational forecast centers and researchers alike. Led by the Joint Center for Satellite Data Assimilation (JCSDA), groups from NOAA, NASA, the US Navy and Air Force, and the UK MetOffice all contribute to development and testing of this system. One component of JEDI, the Unified Forward Operator (UFO) is a collection of model-agnostic, generic forward operators and quality control procedures that can be used with a variety of observation types to compute the first-guess departures needed for assimilation. Currently, the National Centers for Environmental Prediction (NCEP) uses the Gridpoint Statistical Interpolation (GSI) software in the operational Global Data Assimilation System (GDAS). Here we present a comprehensive evaluation of the UFO in comparison to the operational GSI system for the same set of observations and model backgrounds. This evaluation includes comparing first-guess departures and final observation counts after quality control produced using UFO to that from GSI for a variety of observation types (conventional and satellite) over a period of one month. Overall results and statistics will be shown as well as a deeper investigation into specific cases/scenarios where the two systems differ. The results presented here represent the first milestone in the process of NCEP's acceptance of JEDI and its path towards a transition to operations.

Progress towards a global hourly-updating data assimilation system

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Currently, the US global forecast system (GFS) uses a 6-hour data assimilation window within a hybrid 4DEnVar framework, providing analyses from which to initialize forecasts every 6 hours. This “long” window provides less accurate information on rapidly-evolving systems such as hurricanes and continental convective storms. In order to improve forecasts of these fast systems, more frequent analysis updates, and possibly shorter assimilation windows, will be necessary. To this end, we are testing different approaches to updating the GFS every hour. A challenge for hourly updating is data latency: many observations are not available for assimilation until 1-2 hours after the valid observation time. One method to overcome this challenge is the “catch-up cycle”, in which an hourly cycling system is re-initialized 2-4 times per day and catches back up to real-time through a succession of rapid-update cycles. This procedure allows late-arriving observations, that would have otherwise been missed, to be included into the hourly system. Another possible solution is to implement overlapping assimilation windows, in which the system is updated every hour with observations that have arrived within the last hour, but that are valid in a longer window (3-6 hours), removing the need for a separate 6-hourly global system. Preliminary results suggest that the overlapping windows technique can improve upon short-term fit-to-observations in the GFS, relative to the current operational method. Comparisons with catch-up cycles are underway.

Tuesday, 14 Sep 2021 at 15UTC - room GREEN

Reanalysis evaluation IV

Daily extreme temperatures in ERA5-LAND versus in-situ measurements in Poland 1991-2020

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Monitoring and analysing extreme events in high spatial and temporal resolution is one of the most critical tasks facing national hydrometeorological services in the context of present climate change. It is also crucial in contemporary mitigation measures and necessary adaptation actions awaiting in the future. Reanalyses may serve as a tool that allows the monitoring and analysis of meteorological variables' long-term features, thus allowing a proper estimation of probabilistic characteristics of extreme events. The research aimed to assess the concordance of ERA5-LAND reanalysis data (air temperature) with the resolution of 0.1x0.1 degree (~9km) with in-situ measurements acquired from the network of synoptic stations in Poland (56 stations). The temporal scope of analysis comprises the last normal period 1991-2020. Analysed variables comprised daily maximum and minimum temperatures. Those originated, where possible, from 1h temporal resolution datasets for both ERA5-LAND and in-situ measurements. The analysis covered the biases and the comparison of statistical distributions and characteristics of analysed variables. Additionally, GEV distribution characteristics at selected stations and the resulting differences of return levels for selected return periods were compared. The results show reasonably good concordance of ERA5-LAND reanalysis data with in-situ measurements, making it a suitable tool in long-term climate characteristics analysis.

Evaluation of a high-resolution dust regional reanalysis using in-situ and remote sensing observations

Mytilinaios, Michail[(1)]; Mona, Lucia[(1)]; Trippetta, Serena[(1)]; Barnaba, Francesca[(2)]; Basart, Sara[(3)]; Di, Tomaso Enza[(3)]; Jorba, Oriol[(3)]; Pérez, García-Pando Carlos[(4,3)]; Proestakis, Emmanouil[(5)]; Marinou, Eleni[(6,5)]; Gkikas, Antonis[(5)]; Amiridis, Vassilis[(5)]; Formenti, Paola[(7)]; Cuesta, Juan[(7)]; Di, Biagio Claudia[(7)]; Laurent, Benoît[(7)]; Marticorena, Beatrice[(7)]

[(1)]National Research Council of Italy, [(2)]National Research Council of Italy, [(3)]Barcelona Supercomputing Center, [(4)]Catalan Institution for Research and Advanced Studies, [(5)]National Observatory of Athens, [(6)]German Aerospace Center, [(7)]Laboratoire Interuniversitaire des Systèmes Atmosphériques

An advanced dust regional reanalysis has been recently released in the framework of the ERA4CS DustClim project at the high spatial resolution of 0.1°. The reanalysis has been produced by ingesting an innovative dust optical depth data set, derived from the MODIS Deep Blue products, in the dust module of the MONARCH atmospheric model. The reanalysis products cover a wide range of dust-related properties, both optical and physical, such as dust optical depth (DOD), dust PM10 mass concentration and dust extinction profiles. One of the DustClim's main tasks is to provide a thorough evaluation of the reanalysis performance through the synergy of various measurement techniques. A wide variety of dust-filtered products, retrieved from independent data sets of in-situ and remote sensing aerosol observations was compared to collocated reanalysis fields. In particular, we have considered the following reference data sets: LIVAS and EARLINET dust extinction profiles; AEROIASI set of dust-related products; AERONET, MISR and MODIS DOD; INDAAF and EIONET-derived dust PM10 concentrations. Here we present the results of our extensive validation of the dust reanalysis in terms of common metrics that are used to quantify the mean departure between modeled and observed quantities. By assessing its quality, we provide a useful reference to potential users of this novel reanalysis data set which is suitable for studies as well as services of air quality and climate. Acknowledgment Project DustClim is part of ERA4CS, an ERA-NET initiated by JPI Climate, and funded by FORMAS (SE), DLR (DE), BMWFW (AT), IFD (DK), MINECO (ES), ANR (FR) with co-funding by the European Union (Grant 690462).

Comparison of a Multidecadal Walker Circulation in European reanalyses

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We investigate tropical multidecadal variability using ERA-20C, ERA5, and ERA Interim reanalyses. One of the most prominent features of tropical wave circulation is the Kelvin wave that what can be used as a proxy of the Walker circulation over the Pacific. This is demonstrated by comparing a new Walker circulation index, based on the three-dimensional Kelvin wave energy integral, with the classical Walker circulation indices defined in terms of surface pressure differences and upper-troposphere velocity potential. We show that the new index compares well in the three reanalysis datasets during the satellite era. Multidecadal variability of the Walker circulation in 20th century in ERA-20C is subsequently discussed using the new index.

Operating in risky sand and dust storm environments in Northern Africa, the Middle East and Europe: a portfolio of climate services

Basart, Sara[1]; Votsis, Athanasios[2,3]; Rautio, Tuukka[3]; Barnaba, Francesca[4]; Lindfors, Anders[3]; Di, Tomaso Enza[1]; Mona, Lucia[5]; Mytilinaios, Michalis[5]; Formenti, Paola[6]; Werner, Ernest[7]; Pérez, García-Pando Carlos[8,1]
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Over the last few years, there has been an increasing need for Sand and Dust Storms (SDS) accurate information and predictions. SDS information is fundamental to support early warning systems, and preparedness and mitigation plans in addition to growing interest from diverse stakeholders in the aviation sector (including airlines, airports, engine manufacturers) and solar energy (plant operators and market consultants). The ongoing ERA4CS "Dust Storms Assessment for the development of user-oriented Climate services in Northern Africa, the Middle East and Europe" (DustClim) project is enhancing our knowledge on the way SDS affect society by producing and delivering an advanced dust regional reanalysis. The resulting 10-year (2007-2016) dust reanalysis covers Northern Africa, the Middle East and Europe at a horizontal resolution of around 10km. This data set has been obtained by combining satellite remote sensing observations based on MODIS Deep Blue dust-filtered retrievals with the MONARCH chemical weather system. Here, we will present our approach to developing purpose-specific products that help air quality, aviation and solar energy production industry in understanding and reducing SDS-related risks for long-term managing purposes. This process includes the identification of SDS-related ‘objective threats', the dialogue with the identified final users (that includes industry partners and public stakeholders) and the portfolio of proposed services.

Tuesday, 14 Sep 2021 at 15UTC - room BLUE

New approaches to DA I

A General Ensemble Filtering Framework Using Quantiles

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Ensemble Kalman filters are commonly used for data assimilation for numerical weather prediction and climate applications. These methods fit a normal distribution to the prior ensemble estimate and use Bayes' rule with a normal likelihood to generate a sample from a normal

posterior. A novel efficient algorithm that allows use of arbitrary continuous priors and likelihoods is presented. The key innovation is to select posterior ensemble members with the same quantiles with respect to the continuous posterior distribution as the prior ensemble had with respect to the prior continuous distribution. This is a generalization of previously documented square root ensemble Kalman filters for normal distributions. It also generalizes non-parametric ensemble filters such as the rank histogram filter. Examples using continuous priors that are gamma, inverse gamma, beta and a sum of normal kernels are presented. These examples are useful for physical variables that are bounded on one or both sides such as the concentration of a pollutant, relative humidity, or fractional sea ice coverage. They are also useful for variables that have multimodal or other non-normal distributions. The method can be extended to directly estimate the marginal distributions of state variables, mostly eliminating the linear constraints imposed by traditional ensemble methods that use a Kalman gain (regression).

A new multiscale data assimilation method: Multiscale Local Gain Form Ensemble Transform Kalman Filter (MLGETKF)

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A new multiscale, ensemble-based data assimilation (DA) method, MLGETKF (Multiscale Local Gain Form Ensemble Transform Kalman Filter), is introduced. MLGETKF allows simultaneous update of multiple scales for both the mean and ensemble perturbations through assimilating all observations at once. MLGETKF performs DA in independent local volumes, which lends the algorithm a high degree of computational scalability. The multiscale analysis is enabled through the rapid creation of many pseudo ensemble perturbations via a multiscale ensemble modulation procedure. The Kalman gain therefore intrinsically includes multi-scale model space localization. Experiments with a statistical model show that the full background covariance estimated by MLGETKF more accurately resembles the shape of the true covariance than a scale-unaware localization. The mean analysis from the best-performing MLGETKF is statistically significantly more accurate than the best performing scale unaware LGETKF. MLGETKF is further examined in a cycling DA context with a Surface Quasi-Geostrophic model. The root-mean-square potential temperature analysis error of the best performing MLGETKF is 17.2% lower than that of the best-performing LGETKF. MLGETKFreduces analysis errors measured in kinetic energy spectra space by 30-80% relative to LGETKF with the largest improvement at large scales. MLGETKF forecasts are more accurate than LGETKF, gaining 12-hour ~ 1-day of predictability.

Operational Data Assimilation using the Ensemble Kalman Filter with a Modified Cholesky decomposition

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[1]Universidad del Norte, Barranquilla

Numerical Weather Prediction (NWP) is of high relevance nowadays as it allows us to model the behave of the weather given physical models to produce short-term forecasts. But even the best models have uncertainty associate. To improve the quality of such, we can employ Data Assimilation techniques that allow us to manage that uncertainty, given the dynamics of the system. Since these models are computationally expensive, we require the use of High-performance computing to produce those analyses, in a reasonable amount of time (computationally speaking, as the model's parameters is in the range of O(10**8)). Given those models and meteorological information obtained by the National Oceanic and Atmospheric Administration (NOAA), we can give a better estimate using the Ensemble Kalman Filter (EnKF). We believe we can take advantage of those observations provided by the NOAA in their Reanalysis II dataset and making use of the atmospheric general circulation

model SPEEDY with the Ensemble Kalman Filter formulation based on a Modified Cholesky decomposition (EnKF - MC) for inverse covariance matrix estimation. We interpolate the data from the NOAA dataset to the SPEEDY grid resolution to perform the forecasts. Results show how the use of the EnKF-MC reduces the impact of spurious correlations during the assimilation cycle.

Adaptive Tuning of Innovation Weight Parameters: Formulation and Results with NAVDAS-AR/NAVGEM

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This work investigates new applications of the observation sensitivity tools for improving the performance of the Naval Research Laboratory Atmospheric Variational Data Assimilation System-Accelerated Representer (NAVDAS-AR) and the U.S. Navy's Global Environmental Model (NAVGEM). Adaptive tuning of innovation-weight parameters is used for adjusting a suboptimal analysis increment and alleviate issues related with radiance bias correction. Our work relies on a validation state produced by ECMWF to evaluate the observation sensitivity of an initial-condition (analysis) error aspect, here measured in a dry total energy norm, and avoids the increased uncertainty associated with a nonlinear model forecast. A training stage is set for April 1-14 of 2018 when information derived from adjoint-based observation sensitivity and innovations is used to adaptively tune the weight parameters. Validation is performed for April 15 – May 31 of 2018 when the performance of the tuned NAVDAS-AR/NAVGEM system is investigated in terms of the reduction in the analysis errors and the 24-hour forecast errors. The validation results show that in average, as compared with the control run and verified against the ECMWF analyses, the tuning procedure provides 10%-20% reduction of the analysis errors and 2%-5% reduction of the 24-hour forecast errors. A comparative assessment of the observation impact on reducing the initial-condition and forecast errors is provided. The analysis of the time series of the errors in the temperature fields shows a significantly improved performance in the first half of the validation period, indicating that systematic updates of the innovation weights are necessary to maintain the performance of the tuned system.

Wednesday, 15 Sep 2021 at 11UTC - room RED

DA for atmospheric composition I

A novel regional reanalysis of dust aerosols

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We present a regional reanalysis of dust aerosols which has been recently released by the Barcelona Supercomputing Center for a 10-year period and at the high spatial resolution of 0.1°. The reanalysis has been obtained by ingesting an innovative dust optical depth data set, derived from the MODIS Deep Blue products, in the dust module of the MONARCH atmospheric model by means of a LETKF with a four-dimensional extension. We outline the different modelling, observational and assimilation aspects related with the production of the reanalysis, whose unprecedented high resolution has required the use of advanced computing and workflow strategies, which are also described. By providing an accurate and complete reconstruction of dust for a recent decade, this novel reanalysis yields useful information to support operational early warning systems, as well as the development and refinement of environmental monitoring and mitigation strategies, in line with the mission of the WMO Sand and Dust Storm Warning Advisory and Assessment System. Acknowledgment The authors acknowledge co-funding from the H2020 ERA-net ERA4CS (GA 690462) as part of the project DustClim; HPC access from PRACE (eDUST/eFRAGMENT1/eFRAGMENT2) and RES (AECT-2020-3-0013/AECT-2019-3-0001/AECT-2020-1-0007). Carlos Pérez García-Pando acknowledges support from the ERC (GA 773051) and the AXA Research Fund.

Radiance intercalibration of INSAT-3D ozone channel with MSG-SEVIRI and successive improvements in ozone optimal/ML retrieval and validations

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Among various trace gases, ozone has a very unique vertical distribution and plays different roles at different altitudes. The useful stratosphere ozone absorbs harmful UV radiations, while tropospheric ozone, a powerful greenhouse gas adversely affects living beings and vegetations. In Asian countries, the increasing anthropogenic emissions, higher solar radiation, and water vapor further intensifying ozone photochemistry. Thus the continuous monitoring of the ozone is necessary. Nowadays ozone monitoring via satellite-based remote sensing has gained wide importance. The Indian geostationary satellite INSAT-3D/3DR is accomplishing this need for India. Apart from the meteorological sounding, it is also incorporated with a 9.6 um strong ozone absorption channel, for ozone observations. We have assessed the INSAT-3D retrieved total ozone with respect to our ozonesonde observations. The total ozone column from INSAT-3D showed a maximum difference upto 10% with the ozone-derived total ozone column that also varies in seasons. To mitigate these deviations or errors we have checked the radiance biases in INSAT-3D/3DR observations by inter-calibration with MSG-SEVIRI for collocated pixels, and observed biases in INSAT by more than 4K. Further, in the new retrieval algorithm based on a feed-forward neural network and the optimal estimation (1D Variational assimilation) method, we have inculcated these biases and observed very significant improvements in the INSAT-3D/3DR ozone retrievals.

Development of an Ensemble-Variational Data Assimilation System for Global Aerosol Forecasting at NOAA

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A hybrid ensemble-variational (EnVar) aerosol data assimilation (DA) system is being developed within the Joint Effort for Data assimilation Integration (JEDI) to improve global aerosol forecasting in the NOAA's operational Global Ensemble Forecast System - Aerosols (GEFS-Aerosols) model. The GEFS-Aerosols model adopts the Finite-Volume Cubed-Sphere (FV3) dynamical core and the aerosol parameterization is based on the Goddard Chemistry Aerosol Radiance and Transport (GOCART) model. In the variational solver, the ensemble background covariances updated by the Local Ensemble Transform Kalman Filter (LETKF) are blended with static background covariances. Aerosol optical depth (AOD) retrievals at 550 nm derived from the Visible/Infrared Imager Radiometer Suite (VIIRS) instruments are assimilated. AOD forward operator is calculated using NASA lookup tables. Stochastically-perturbed emissions are developed and implemented in the GEFS-Aerosols model to reduce model bias and alleviate ensemble spread deficiency. Cycled experiments show that assimilation of AOD retrievals reduces bias and root-mean-square error of simulated AOD, and improves agreement of global aerosol analyses and forecasts with aerosol reanalyses from NASA and ECMWF. Experimentation of leveraging ensemble forecasts at varying valid times to populate background ensemble suggests enhanced background ensemble error-spread consistency and further improves global aerosol analyses and forecasts.

Wednesday, 15 Sep 2021 at 11UTC - room GREEN

New approaches to DA II

The Effective Use of Anchor Observations in VarBC in the Presence of Model Bias

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Satellite data have a significant impact on forecast skill, but the data must be bias corrected prior to use. At many operational centres, the bias correction is performed using Variational Bias Correction (VarBC), however, VarBC relies on unbiased observations that are not bias corrected (anchor observations) in order to constrain any model bias that is present within the system. As the number of satellite observations increases, the proportion of unbiased observations to biased observations decreases, so it is important to use these anchor observations effectively. In order to understand how anchor observations impact the bias correction, we derive analytical expressions to show the sensitivity of the bias correction to the anchor observations. We find that the ability of the anchor observations to correct the observation bias is dependent on the information shared between the biased observations and the unbiased observations via the background error covariance matrix. We show that it is necessary for the anchor observations to observe the regions of significant model bias, in order to reduce the effect of model bias on the estimate of the observation bias. We demonstrate these results in a series of idealised numerical experiments to show the implications on the current network of anchor observations in the use of VarBC for operational NWP.

Newly developed impact diagnostics for cross-validating the consistent use of different observation types

Stiller, Olaf[(1)]
[(1)]Deutscher Wetterdienst [Offenbach]

New cross-validation diagnostics have been derived by partitioning the established impact diagnostic originally introduced by Langland and Baker (2004). They give rise to consistency relations, the most prominent of which indicates whether the first guess departures of a given

observation type pull the model state into the direction of the verifying data (when processed with the employed model error covariances). This is a fundamental condition for getting a beneficial impact from these observations. As verifying data we use well established observations as, e.g., radiosonde measurements, and the new diagnostic relationship is exploited to quantify the consistency of other observation types with these data in different locations (e.g., at different latitudes or altitudes) or under some otherwise specified conditions. To obtain a sensitive statistical tool, a normalization is provided which renders results largely independent from the total number of observations and the closeness of their collocation and, also, an indicator of statistical significance. While the model error covariances employed in this work are estimated from the DWD's localized transform ensemble Kalman filter, we expect results to be highly relevant also for our hybrid EnVar system which also makes use of the ensemble estimated covariances. As the quality of the assessment strongly depends on the suitability of the ensemble covariances, in a first step the method is applied to the cross-validation of two well established types of in situ observations whose results give some indication of the quality (and some limitations) of these covariances and can be taken as a benchmark when applying the method to more complex observations (like, e.g., satellite radiances).

State, global and local parameter estimation using ensemble Kalman filters for model error correction

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[(1)]École des Ponts ParisTech

We investigate data-driven techniques based on an ensemble Kalman filters (EnKF) in order to either learn the dynamics or a model error parametrisation thererof. The (local) EnKF can be used to gradually learn both the state and the dynamics as observations are collected. The surrogate model, which represents the dynamics learned in the process, is parametrised (typically as a neural network) and the update is a two-step process: a state update, possibly localised, and a parameter update consistent with the state update. In this framework, the parameters of the surrogate model are assumed to be either global, local or both. To that end, we show how to rigorously extend the classical augmented state parameter EnKF method to the case where the surrogate model admits both global and local parameters. This results in a collection of useful new algorithms, based on either covariance localisation or domain localisation, applied to the state and/or to the parameters. Finally, these algorithms are implemented and tested with success on the chaotic 40-variable Lorenz model. The method is also illustrated on a more challenging two dimensional non-homogeneous multi-layer Lorenz model with radiance-like non-local observations, where a hybrid domain and covariance localisation is implemented.

Wednesday, 15 Sep 2021 at 11UTC - room BLUE

Ground-based remote sensing II

Long-term assessment of Doppler lidars for an operational use in a future network

Kayser, Markus[(1)]; Lehmann, Volker[(2)]; Knist, Christine[(1)]; Löffler, Moritz[(3)]; Leinweber, Ronny[(1)]; Klink, Stefan[(4)]
[(1)]Deutscher Wetterdienst [Lindenberg], [(2)]Deutscher Wetterdienst [Lindenberg], [(3)]Deutscher Wetterdienst [Potsdam], [(4)]Deutscher Wetterdienst [Offenbach]

Fibre-optic based Doppler wind lidars (DL) are widely used for both meteorological research and in the wind energy sector. These compact systems are able to obtain vertical profiles of the mean horizontal wind vector from the atmospheric boundary layer as well as from optically thin cloud layers in the free troposphere with high spatio-temporal resolution. It is therefore likely that especially short-term forecasting would benefit from assimilating their data. However, their potential is currently not yet employed operationally. Here, we present results from a long-term assessment of DLs at Lindenberg, starting in 2012, in the context of the DWD's effort to evaluate ground-based remote sensing systems for their operational readiness, called “Pilotstation”. The tests focus on aspects such as technical reliability, uncertainty characterization, scanning strategies, and the verification of the retrieved mean wind speed and direction with the help of independent reference data from a 482 MHz radar wind profiler and 6-hourly radiosonde ascents. Through this assessment, we developed a standardized retrieval assuring a high quality Level-2 product, which is compatible with the EUMETNET's E-PROFILE observation program. Further, a software implementation of the retrieval is freely accessible and continuously improved to account for different scanning strategies and additional products.

Assessment of microwave radiometers for operational network deployment and its observational value for forecasting models

Knist, Christine[1]; Löffler, Moritz[2]; Vural, Jasmin[3]; Schomburg, Annika[3]; Kayser, Markus[1]; Lehmann, Volker[1]; Klink, Stefan[3]
[1]Deutscher Wetterdienst [Lindenberg], [2]Deutscher Wetterdienst [Potsdam], [3]Deutscher Wetterdienst [Offenbach]

The DWD currently runs the project “Pilotstation” to evaluate ground-based remote sensing instruments at dedicated testbed sites for their operations, readiness for network deployment, and forecast benefits. One of the maturing technologies that are tested are ground-based microwave radiometers (MWRs). This complements well the efforts of the EUMETNET's E-PROFILE observation program towards an operational MWR network by 2023. MWRs have shown their potential for a 24/7 monitoring of brightness temperature (BT) and retrievals such as temperature and water vapour under all-weather conditions except rain, which can be assimilated into numerical weather prediction systems. However, the most common challenges we identified are gaining reliable absolute calibration results, identifying hydrometeors on the hygroscopic window and the need to routinely quality-assure the observations for forecast applications. Additionally, the use of MWR-derived BTs for data assimilation requires developments for the implementation in the data assimilation system, e.g. the forward operator RTTOV-gb, in combination with the ICON limited area model (ICON-LAM). This work introduces our developments for the technical monitoring and assessing data quality and stability in near real time, using e.g. observations minus background statistics, and presents results of the first assimilation experiments. This knowledge is important to make the MWR applicable to routine network operation.

Expected Benefit of Cloud Radar and Microwave Radiometer Observations for Future Data Assimilation During Fog Conditions

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[1]Centre national de recherches météorologiques, [2]Groupe d'étude de l'atmosphère météorologique, [3]Laboratoire Atmosphères, Milieux, Observations Spatiales

Fog is still poorly represented in even the highest resolution operational NWP models. Continuous transmission, 95 GHz cloud radars (CR), sensitive to cloud droplets, open up the possibility of retrieving vertical profiles of fog microphysical properties with unprecedented capabilities. Additionally, ground-based microwave radiometers (MWR) can provide information on the thermodynamics and total liquid water path.

This work aims at combining ground-based MWR and CR measurements with a one-dimensional variational approach (1D-Var) as a first step to 1D-Var + 3D-Var data assimilation. Developments were made on an existing 1D-Var algorithm designed to retrieve temperature and humidity from MWR brightness temperatures. This algorithm, which uses the operational model AROME information as the background, was extended to make use of radar reflectivities to directly retrieve liquid water content profiles in addition to temperature and humidity profiles. The expected benefit to improvements in the AROME analysis is shown firstly by using synthetic observations. The benefit of the synergistic method will be discussed by comparing 1D-Var retrievals made with only one instrument to the dual-instrumental approach. The 1D-Var algorithm will then be applied to real measurements from the SOFOG-3D field campaign. The CR and MWR were collocated at two sites where in-situ observations of cloud microphysics and temperature/humidity profiles during intensive observation periods were made. Retrievals will thus be validated using these in-situ measurements. The improvement brought to the AROME model analysis during fog events will be discussed through case studies and a statistical evaluation throughout the campaign.

Wednesday, 15 Sep 2021 at 12UTC - room RED

New approaches to DA III

Contributions of the parametric Kalman filter in practical and theoretical data assimilation

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The parametric Kalman filter (PKF) is a novel implementation of the Kalman filter (KF) which approximates the covariance dynamics by the parametric evolution of a covariance model all along the analysis and the forecast steps. In this talk we review the ideas behind this new approach and show some applications when the covariances are parameterized from the error variance and local anisotropy tensor. We first describe the update of the covariance parameters during the assimilation step in a 2D domain. Then, for the forecast step, we explain the design of the evolution equations by using an automatic symbolic computation tool, SymPKF, which calculates the second-order Gaussian filter equations. The PKF provides a low cost computation of the covariance dynamics but often needs a closure. An example of analytical closure is introduced, then generalized by the use of IA combining the physical equations and an automatic generation of a neural network architecture (PDE-NetGen). A multivariate prediction is shown for a simplified non-linear chemical model in 1D domain. While the PKF provides a practical implementation of the KF, it also offers some new theoretical tools to tackle difficult issues, such as the characterization of the model-error covariance due to the discretization. In particular, we characterized the loss of variance due to the model error which occurs in the discretization of the advection as encountered when using an ensemble Kalman filter in air quality.

What does the spread amongst ensembles tell us about forecast errors?

Lonitz, Katrin[1]; Healy, Sean[1]

[1]European Centre for Medium-Range Weather Forecasts

In 2020 a new data source of GNSS-RO (GNSS radio occultation) observations from COSMIC-2 and Spire became available, adding about 9000 additional occultations per day to the ECMWF data assimilation system. This dataset enables us for the first time to investigate how the relationship between the Ensembles of Data Assimilations (EDA) spread values and the forecast error statistics from Observing System Experiments (OSEs) changes as a function of number of "real" assimilated GNSS-RO measurements. At 100hPa in the Tropics, the addition of COSMIC-2 and Spire shows the largest effect on reducing the EDA spread by about 13% and 7%, respectively. In this region the reduction in ensemble spread behaves linearly with the reduction in forecast error for an increase in GNSS-RO data numbers. In other geographical areas and height levels the relationship is not linear. However, it is important to highlight that it is not useful to derive a quantitative relationship between the two measures as limitations in the EDA experiments and OSEs can have a profound impact on those numbers. Nevertheless, the reduction in EDA spread can be used as a relative measure to estimate the reduction in forecast errors when adding GNSS-RO data.

"Twin-analysis" verification: a new verification approach that alleviates pitfalls of "own-analysis" verification when applied to short-range forecasts

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[(1)]Meteorological Research Institute, Japan Meteorological Agency, [(2)]Numerical Prediction Develpment Center, Japan Meteoroglogical Agency

In operational NWP, forecast verification against analysis from the same experiment is part of the standard evaluation practice. This "own-analysis" verification is beneficial in providing complete spatial coverage but is known to suffer from overly optimistic scores when applied to short-rage forecasts due to the inevitable positive correlation between the forecast and analysis errors. This issue is particularly problematic when a new development involves assimilation of new observations since the more observations we assimilate, the less correlated the background and the analysis tend to be, leading to apparent degradation in the score which makes interpretation a delicate task. To alleviate this problem, we propose "twin-analysis" verification in which we produce "twin analyses" by running an independent cycle using the same NWP system as the one used to produce the forecasts, but initializing from an independent first guess and then verify the forecasts against these twin analyses. This way the error correlation between the forecasts and analyses should be reduced while preserving the statistical properties of the analyses, hopefully enabling a clearer interpretation of verification. In this talk we will report the results of comparison between "twin-analysis" and "own-analysis" verification scores obtained for the JMA's global NWP system. The two scores disagree up to two days, suggesting that "own-analysis" verification is unreliable for such short ranges.

Local Ensemble Transform Kalman Filter with Cross-Validation

Buehner, Mark[(1)]
[(1)]Environment and Climate Change Canada

Many ensemble data assimilation (DA) approaches suffer from the so-called “inbreeding” problem. As a consequence, there is excessive reduction in ensemble spread by the DA procedure, causing the analysis ensemble spread to systematically underestimate the uncertainty of the ensemble mean analysis. The stochastic EnKF algorithm used for operational NWP in Canada largely avoids this problem by applying cross validation, that is, using an independent subset of ensemble members for updating each member. The goal of the present study is to evaluate new variations of the local ensemble transform Kalman filter (LETKF) that also incorporate cross validation. The new LETKF approaches are evaluated using both idealized experiments and in the context of real NWP systems. In idealized numerical experiments, the new LETKF approaches are shown to produce reliable analysis ensembles such that the ensemble spread closely matches the uncertainty of the ensemble

mean, without requiring any ensemble inflation. In the context of a regional numerical weather prediction system, experiments are performed with the new LETKF-based approaches with cross validation, the standard LETKF, and the stochastic EnKF. All approaches with cross validation produce similar ensemble spread, though the amplitude of the changes to the individual members is much larger with stochastic approaches. Results from pre-operational testing of the LETKF with cross validation in the global ensemble prediction system show a statistically significant improvement over the operational system when no recentering on a 4D-EnVar analysis is performed. The new LETKF approach will replace the operational stochastic EnKF during the next system upgrade.

Wednesday, 15 Sep 2021 at 14UTC - room RED

Ocean DA I

A new global ocean ensemble system at the Met Office: Assessing the impact of hybrid data assimilation and inflation settings

Lea, Daniel[(1)]; While, James[(1)]; Martin, Matthew[(1)]; Weaver, Anthony[(2)]; Storto, Andrea[(3)]; Chrust, Marcin[(4)]
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We have developed a global ocean and sea-ice ensemble forecasting system based on the operational FOAM (Forecasting Ocean Assimilation Model) system run at the Met Office. The ocean model NEMO and the CICE sea-ice model are run at 1/4 degree resolution and the system assimilates data using NEMOVAR. This is primarily a variational data assimilation (DA) system, but it can now also perform hybrid ensemble/variational assimilation. A 36 member ensemble of hybrid-3DEnVars with perturbed observations (values and locations) has been set-up, with each member forced at the surface by a separate member of the Met Office Global-Regional Ensemble Prediction System (MOGREPS-G). The system includes stochastic model perturbations and a Relaxation to Prior Spread (RTPS) inflation scheme. The system has an additional unperturbed or deterministic member with higher resolution Met Office Numerical Weather Prediction (NWP) atmospheric forcing. A control run of the system using an ensemble of 3DVars is shown to be generally reliable for sea level anomaly (SLA), temperature and salinity (the ensemble spread being a good representation of the uncertainty in the ensemble mean), although the ensemble is under spread in eddying regions. In this system the optimal results, in terms of short-range forecast error and ensemble reliability statistics, are obtained with hybrid-3DEnVar - pure 3DVar and pure 3DEnVar do not perform as well. The inflation scheme is beneficial in producing an appropriate ensemble spread in response to hybrid DA. Work has started to include the ocean ensemble system in a coupled NWP system.

Quantitative Observing System Design within ECCO's 4DVar ocean data assimilation framework

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We leverage Hessian-based uncertainty quantification (UQ) within the ECCO (Estimating the Circulation and Climate of the Ocean) data assimilation framework to explore a quantitative approach for ocean climate observing systems. Here, an observing system is considered optimal if it minimizes uncertainty in a set of investigator-defined design goals or quantities of interest (QoIs), such as oceanic transports or other useful climate indices. Hessian UQ unifies three design concepts: (1) An observing system reduces uncertainty in a target QoI most effectively when

it is sensitive to the same dynamical controls as the QoI. The dynamical controls are exposed by the Hessian eigenvector patterns of the model-data misfit function. (2) Orthogonality of the Hessian eigenvectors rigorously accounts for complementarity versus redundancy between distinct members of the observing system. (3) The Hessian eigenvalues determine the overall effectiveness of the observing system, and are controlled by the sensitivity-to-noise ratio of the observational assets (analogous to the statistical signal-to-noise ratio). We illustrate Hessian UQ and its three underlying concepts in a North Atlantic case study. Sea surface temperature observations inform mainly local air-sea fluxes. In contrast, subsurface temperature observations reduce uncertainty over basin-wide scales, and may therefore inform transport QoIs over large distances. This research provides insight into the design of effective observing systems that maximally inform the target QoIs, such as ones related to the Atlantic Meridional Overturning Circulation (AMOC), while being complementary to the existing observational database.

Forecast Sensitivity to Observations in an Analysis-Forecast System of the California Current Circulation

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[(1)]Department of Ocean Sciences, [(2)]Department of Marine and Coastal Sciences, [(3)]RPS North America, [(4)]Department of Oceanography

The U.S. Integrated Ocean Observing System (IOOS) forms the backbone of real-time ocean analysis-forecast systems of U.S. territorial waters. In addition to satellite remote sensing, the IOOS is augmented with in situ observations from a variety of platforms including Argo floats, buoys and gliders. In addition, remote sensing observations of surface currents are also available from an extensive national network of coastal HF radars. Maintenance of these observing systems is obviously labor-intensive and costly. Routine monitoring of the impact of the data from each element of the observing array on ocean analysis-forecast systems is therefore recognized as an important activity, not only for maintaining the array and demonstrating its value, but also as an aid for planning future expansions of the observing network. This talk will focus on current efforts to quantify forecast sensitivity to observations (FSO) in an ocean analysis-forecast system of the California Current System (CCS) along the U.S. west coast. The real-time system is based on ROMS-4D-Var, and FSO has been applied to metrics of forecast skill that target important features of the CCS circulation along the central California coast. On average, ~50-60% of all observations assimilated into the model were found to yield improvements in the forecast skill. An adjoint-based approach for Observing System Experiments has also been used in combination with FSO to quantify the extent to which different components of the observing network support each other.

Wednesday, 15 Sep 2021 at 15UTC - room RED

Ocean DA II

The Estimating the Circulation and Climate of the Ocean (ECCO) "Central Estimate": a Multi-decadal, Coupled Ocean Reanalysis

Fenty, Ian[(1)]; Fukumori, Ichiro[(1)]; Heimbach, Patrick[(2)]
[(1)]Jet Propulsion Laboratory, [(2)]University of Texas at Austin

The Consortium for Estimating the Circulation and Climate of the Ocean (ECCO) has been producing dynamically- and kinematically-consistent global ocean state estimates for nearly two decades. Our current focus is Version 4 of the "Central Estimate", a data-constrained global, 1-degree, coupled ocean, sea-ice, and thermodynamic ice-sheet model that spans the period 1992-present. Our coupled model is made consistent with a diverse in-situ and remotely-sensed ocean, sea-ice, and ice-sheet data in a least-squares sense by iteratively adjusting a set of control parameters using the gradient of an uncertainty-weighted model-data misfit cost function. The cost function gradient is provided by the adjoint of the model (MITgcm). By construction, ECCO state estimates satisfy the laws of physics and thermodynamics encoded in the numerical model and therefore conserve heat, salt, mass, and momentum. Our philosophy of strict adherence to conservation principles ensures that ECCO reanalyses are useful for investigating the causal origins of observed ocean climate variability. However, because of the enormous scale of the nonlinear optimization problem, strictly obeying conservation laws involves a trade-off with goodness-of-fit; on the whole, ECCO reanalyses are unlikely to reproduce observations as well as ocean reanalyses that allow incremental adjustments to their state vectors through time. Here we summarize our recent efforts and challenges associated with (i) coupling to the sea-ice and thermodynamic ice-sheet models, (ii) adding novel data constraints such as ocean bottom pressure from GRACE and GRACE-FO, and (iii) increasing the spatial resolution of the state estimation system to achieve eddy-resolving scales.

Assimilation of satellite total surface current velocities in global ocean forecasting systems

Jennifer, Waters[(1)]; Martin, Matthew[(1)]; King, Robert[(1)]; Elisabeth, Remy[(2)]; Mirouze, Isabelle[(3)]; Gaultier, Lucille[(4)]; Ubelmann, Clement[(5)]
[(1)]Met Office, [(2)]Mercator Ocean International, [(3)]Cap Gemini, [(4)]OceanDataLab, [(5)]OceanNext

Accurate prediction of ocean surface velocity is important for various applications such as search and rescue, marine plastic tracking and coupled forecasting. Observations of ocean velocities are currently limited and are not routinely assimilated in global operational ocean forecasting systems. This may change with proposed new satellite missions designed to observe ocean surface velocities. The ESA Assimilation of Total Surface Current Velocities (A-TSCV) project aims to investigate the design, implementation and impact of assimilating synthetic TSCV data in global ocean forecasting systems. The project will use observing system simulation experiments (OSSEs) to test the assimilation methodology and provide feedback on the observation requirements for future satellite missions. Synthetic observations of the standard observing network along with synthetic observations of new satellite total surface current velocities are being generated from a high-resolution nature run. The assimilation of these observations will be tested in the Met Office FOAM and the Mercator Ocean forecasting systems. The OSSEs are not yet complete, but we will present an overview of the project, the design of the experiments and the data assimilation developments being made to effectively assimilate the surface velocity data into these systems.

Impact of superobbing high resolution marine glider and HF radar data in regional marine JEDI data assimilation system

Liu, Ling[(1);] Kim, Jong[(1);] Kleist, Daryl[(2)]; Mehra, Avichal[(2)]; Book, Cameron[(1)]; Li, Yongzuo[(1)]; Sluka, Travis[(3)]; Bhargava, Kriti[(3)]; Vernieres, Guillaume[(3)]; Kim, Hyun-Sook[(4)]; Kang, HeeSook[(4)]; Kalina, Evan[(5)]; Turuncoglu5, Ufuk[(5)]
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Ocean data assimilation is important to improve coupled numerical weather and climate prediction. Joint Effort for Data Assimilation Integration (JEDI) infrastructure has been developed and is being testing for coupled (ocean and atmospheric) forecast systems by NOAA. Use of ocean observations for initialization is critical for coupled Hurricane forecasts using Marine JEDI. High-resolution ocean glider data are useful for

providing details of vertical mixing process during Hurricanes at sub-surface levels due to their continuous high vertical resolution; High-frequency radar surface radial velocity data provide broader spatial coverage over Hurricane passage comparing to ocean glider data. The assimilation of both will help us advance our understanding of data assimilation systems especially during Hurricane season. Experiments set up during Hurricane Isaias show that when glider data were superobbed to a similar vertical resolution to that of regional model background, data assimilation produces optimal analysis and forecast skill. Our results also indicate superobbing oceanglider data provides fuller details of vertical mixing than thinning because of rapid hydraulic changes in the surface mixed layer, whereas thinning might skip or miss these details. HF Radar radial velocity obtained over deployment at US Virgin Island with 6 km resolution are also assimilated into 10 km resolution regional marine JEDI during Hurricane Isaias. The forward operator H(x) and observation minus background, observation minus analysis are analyzed for HF radar data. Details on superobbing and observation error correction is also discussed to compensate for the observation errors caused by optimal interpolation of the radar data.

Wednesday, 15 Sep 2021 at 15UTC - room GREEN

Satellites

All-sky microwave humidity sounder assimilation in the Korean Integrated Model forecast system

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[(1)]Korea Institute of Atmospheric Prediction Systems, [(2)]Myongji University, [(3)]Korea Meteorological Administration

The Korean Integrated Model (KIM) and hybrid data assimilation system were extended to assimilate all-sky radiance from microwave satellite sensors. Initially, RTTOV-SCATT (version 11.3) was implemented to assimilate the Microwave Humidity Sounder (MHS) 183 GHz channels over the ocean. While there is no cloud/precipitation control variables in our system, temperature and humidity profiles are improved in the all-sky assimilation. In the cycled analysis and forecast experiments, an assimilation of the MHS in a cloudy region shows globally substantial benefits; a 1.11% reduction in the humidity root-mean-square-error occurred in the background field compared to clear-sky radiance assimilation as verification against the ECMWF IFS analysis. Even though the MHS all-sky assimilation's impact on the Northern Hemisphere mid-latitudes is not remarkable, it nonetheless produces a highly realistic humidity analysis increment for heavy rainfall events over East Asia. This improvement is consistent from the analysis initial time to 120 h forecasts.

Evaluation and Assimilation of Geostationary Hyperspectral InfraRed Sounders (GeoHIS) : Progress and Challenges

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[(1)]Joint Center for Satellite Data Assimilation, [(2)]Space Science and Engineering Center [Madison], [(3)]National Meteorological Center of CMA

High temporal geostationary (Geo) hyperspectral IR sounder (GeoHIS) radiance measurements enable continuous sounding of the atmospheric temperature and moisture, and thus capture the temporal and spatial variability for high impact weather or rapid changing weather events. On 10 December 2016, the successful launch of China's Fengyung FY-4A satellite into geostationary orbit initiated a new era in Earth observation by providing the first time-continuous observations of the upwelling thermal infrared at high spectral resolution with the Geostationary Interferometric Infrared Sounder (GIIRS). A subset of GIIRS longwave temperature sounding channels has been assimilated in China's global NWP

system GRAPES (Global/Regional Assimilation and PrEdiction System) since December 2018 and improve the forecast over East Asia , especially for high impact weather forecasting, such as Typhoons and cold air outbreaks. The European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) is developing an operational advanced GEO hyperspectral IR sounder (IRS) as a part of Meteosat Third Generation (MTG-3) in the mid 2020's. Based on the evaluation and assimilation of the real GeoHIS data from GIIRS, this talk will discuss the recent progress , current major challenges of GeoHIS assimilation. The opportunities include targeted observing for high impact weather, and improvement in convective storm forecasts, including tornadoes and hurricanes. The challenges include accurate spectral and radiometric calibration, considering the possible diurnal variation, fast radiative transfer model for large satellite zenith angles, and continuous data assimilation for application to high temporal observations.

Improving cloud and radiation forecasts by assimilating visible satellite images

Scheck, Leonhard[1,2]; Geiss, Stefan[2]; Bach, Liselotte[1]; De, Lozar Alberto[1]; Weissmann, Martin[3]
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As the share of renewables in electricity generation is increasing, there is also a rising interest in improved radiation forecasts that allow for a better prediction of the uncontrollable and intermittent generation of photovoltaic power. Convective scale radiation forecasts can be improved by assimilating cloud-related observations. A promising type of observation for this purpose are satellite images in the visible spectral range, which contain high-resolution information on the location, water content and microphysical properties of clouds. Here we report on assimilation experiments using the ICON-D2 regional model and the local ensemble transformation Kalman filter implemented in the data assimilation system of the German Weather Service. A forward operator based on the Method for FAst Satellite Image Synthesis (MFASIS) and accounting for slant rays and 3D radative transfer effects is used to generate model equivalents for 0.6 micron Meteosat SEVIRI satellite images. Systematic difference between observed and systematic images and the benefits of using visible channels for model evaluation are discussed. Assimilation results for test periods of several weeks indicate that errors in the cloud distribution and the surface radiation can be significantly reduced by assimilating visible satellite images. Some beneficial impact is still present after 24 hours and also the agreement with most conventional observations is improved.

An observation operator for geostationary lightning imager data assimilation in storm-scale numerical weather prediction systems

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The Lightning Imager (LI) onboard the Meteosat Third Generation (MTG) satellite will provide total lightning observations. The assimilation of such data could improve the thunderstorm prediction accuracy. To prepare the assimilation of the flash extent accumulation (FEA) measured by LI in the French storm-scale regional AROME NWP system, a lightning observation operator is required to convert the model variables into a product comparable to the observations. Since LI FEA observations are not available yet (launch planned in the forthcoming years), pseudo-LI FEA observations were generated from a ground-based lightning detection system (Erdmann et al., in revision for JTECH). This study focuses on the evaluation of different FEA observation operators from various proxies encountered in the literature and calculated from the outputs of 1 h AROME-France forecasts for 27 storm days in 2018. The data are processed as distributions over the whole domain and time period since

a pixel-to-pixel comparison exhibits a rather poor correlation. Different regression techniques, linear regression as well as machine learning models, are used to relate the synthetic FEAs and the modeled proxies. The training of observation operator is performed on 25 days of the dataset and 2 days are used for validation. The observation operator is finally evaluated by computing Fraction Skill Scores for simulated FEAs. The performance of a principal component analysis is also examined.

Wednesday, 15 Sep 2021 at 15UTC - room BLUE

Non-Gaussian DA

4D-Localized Particle Filter Method in KENDA for ICON-LAM

Schenk, Nora[1,2]; Walter, Anne[3,2]; Potthast, Roland[3,2]
[1]Institute of Mathematics [Goethe University Frankfurt], [2]Deutscher Wetterdienst [Offenbach], [3]Department of Mathematics and Statistics [University of Reading]

Nonlinear data assimilation methods like particle filters aim to improve the numerical weather prediction in a non-Gaussian setting. The localized adaptive particle filter (LAPF), introduced by R. Potthast, A. Walter and A. Rhodin in 2019, overcomes filter collapse in a high-dimensional framework. This particle filter was further developed by Walter et al. (2021) to the local mixture coefficients particle filter (LMCPF) which was tested within the global ICON model. In the LMCPF method the background distribution is approximated by Gaussian mixtures. After a classical resampling step, Bayes' formula is carried out explicitly under the assumption of a Gaussian distributed observation error. Furthermore, the particle uncertainty can be adjusted which affects the strength of the shift of the particles toward the observation. Lastly, Gaussian resampling is employed. As for the LETKF, all steps are carried out in ensemble space. We explore the potential of the LMCPF in the kilometre-scale ensemble data assimilation (KENDA) system with the limited area mode of the ICON model (ICON-LAM) and compare the particle filter method to the localized ensemble transform Kalman filter which is operationally used at the German Weather Service (DWD). Both methods describe four-dimensional data assimilation schemes if the observation operators are applied during the model forward integration at the exact observation times and not only at analysis time. This leads to four-dimensional background error covariance matrices at times and locations of the observations which are employed to derive the analysis ensemble. We present experimental results for the LMCPF in comparison with the LETKF method in KENDA used at DWD for the ICON-LAM model.

Improving the stability of the Local Particle Filter and Its Gaussian Mixture Extension: Experiments with an Intermediate AGCM

Kotsuki, Shunji[1]; Oishi, Ken[2]; Miyoshi, Takemasa[3]
[1]CEReS, Chiba University, [2]Chiba University, [3]RIKEN Center for Computational Science

Penny and Miyoshi (2015) developed the local particle filter (LPF) in a form as the ensemble transform matrix of the Local Ensemble Transform Kalman Filter (LETKF). Potthast et al. (2018) applied the LPF in the German weather service's operational LETKF system and reported a stable performance. Walter and Potthast (2021) improved their LPF as a Gaussian mixture filter (LPFGM), what they call the LMCPF (Local Mixture Coefficients Particle Filter). Kotsuki et al. (2021) implemented the LPF and LPFGM with an intermediate global circulation model known as the

Simplified Parameterizations, Primitive Equation Dynamics (SPEEDY), and reported that the LPFGM outperformed the LETKF in sparsely observed regions. However, performances of the LPF and LPFGM were sensitive to tunable parameters such as inflation and resampling frequency. This study aims to explore methods for improving the stability of the LPF and LPFGM. First, we revised the way to compute the posterior weights for the LPFGM. Walter and Potthast (2018) approximated the posterior weights of the LPFGM by those of the LPF. We introduced the exact posterior weights without approximation for the LPFGM, and showed that the exact weights improved the stability of the LPFGM in terms of the inflation parameter. Second, we implemented the optimal transport (OT) for constructing the resampling matrix from the posterior weights. Farchi and Bocquet (2018) reported that the OT was optimal for constructing the resampling matrix in the LPF through a series of experiments with the 40-variable Lorenz-96 model. However, our experiments revealed that the use of the OT in SPEEDY generally results in underdispersive posterior particles.

A new way to infer non-Gaussian observation errors based on ensemble innovations

Hu, Chih-Chi[(1)]; Van, Leeuwen Peter Jan[(1,2)]
[(1)]Department of Atmospheric Sciences, Colorado State University [Fort Collins], [(2)]University of Reading

The proper specification of the observation error is critical to a well-performing data assimilation system. The observation error can be divided into the measurement error, which is an inherent part of the results of the measurement, and the representation error, which is the uncertainty in the forward operator. The measurement error is usually well-known based on the design of the instrument, while the representation error is often less understood and often dominant. Previous studies have infered the observation error from the innovation statistics, often assuming that the background error in observation space and the observation error are Gaussian. However, this Gaussian assumption can be problematic, especially for nonlinear forward operators. This study infers a non-parametric observation error pdf based on a background ensemble without any assumption on the shape of the background error or observation error pdfs. The only assumption is that each ensemble member is statistically indistinguishable from the truth. Since the innovation pdf is the convolution of observation error and background error pdfs, the observation error pdf can be found by expressing the pdfs as histograms and solving a linear system. Experiments with toy systems and real cloudy observations show that this new method is able to retrieve non-Gaussian observation pdfs, even multimodal pdfs, demonstrating the potential of this method for complex representation errors in real atmospheric observations.

Non-Gaussian Hybrid Variational Data Assimilation

Fletcher, Steven[(1)]; Goodliff, Michael[(2)]; Hossen, Md Jakir[(1)]; Kliewer, Anton[(3)]; Zupanski, Milija[(1)]; Wu, Ting-Chi[(4)]
[(1)]Cooperative Institute for Research in the Atmosphere, [(2)]Cooperative Institute for Research in Environmental Sciences, [(3)]Cooperative Institute for Research in the Atmosphere, [(4)]RIKEN Center for Computational Science [Kobe]

With the advancement of non-Gaussian based variational techniques the need to extend this to hybrid ensemble-variational techniques is the next step towards operational viability. However, the problem lies in the Gaussian assumptions that are made in the derivation of the Kalman filter. In this presentation we shall show a lognormal, and Gaussian-lognormal based Kalman filter which is then approximated with the Maximum Likelihood Ensemble Filter (MLEF) approach. The MLEF is a hybrid scheme that utilizes Kalman filter equations for the analysis and forecast error covariance matrices but solves a variational-based cost-function projected in the ensemble space. The hybrid nature makes MLEF a suitable system for our non-Gaussian applications. As a theoretical study, we shall present results of these new formulations with the Lorenz 1963 model.

DA for atmospheric composition II

Aerosol data assimilation as a tool to detect model errors

Tsikerdekis, Athanasios[1]; Schutgens, Nick A. J.[2]; Hasekamp, Otto[1]
[1]SRON Netherlands Institute for Space Research, [2]Vrije Universiteit Department of Earth Science

An ensemble Kalman-filter smoother (LETKS) is used to estimate aerosol emission in the global climate/aerosol model ECHAM-HAM by assimilating retrievals from the multi-angle polarimeter POLDER. The assimilated observations (aerosol optical depth, angstrom exponent and single scattering albedo) provide a wealth of information in order to correct the aerosol amount, size and composition simultaneously. The emissions are estimated per species (dust, sea salt, organic carbon, black carbon, sulfates and sulfate precursor gases), per sector (biomass burning and fossil fuel) and by size (Aitken, Accumulation and Coarse). An evaluation of the data assimilation experiment reveals that the model errors are reduced for all the assimilated observables in most areas over the globe. Surprisingly, in the biomass burning outflow area of South Atlantic the aerosol optical depth error increases. This increase cannot be attributed to emission errors, since the model error (for all observables) over the biomass burning African sources is very low after the assimilation. Hence, we use the new corrected emissions and tune various model processes (e.g. emitted particle size, wet growth, emission height, removal processes) in order to improve the aerosol optical depth in the outflow and not affect it negatively in the sources. This application shows how data assimilation results can be used to highlight “hidden” model errors and promote future model development.

Assimilation of Aerosol Optical Depth (AOD) retrievals and PM2.5 in NCEP's Next-Generation Regional Air Quality Forecasting System

Wang, Hongli[1,2]; Weygandt, Stephen[2]; Pagowski, Mariusz[1,2]; Li, Ruifang[1,2]; Montuoro, Raffaele[1,2]; Liu, Quanhua[3]; Dang, Cheng[4]; Ma, Yingtao[5,3]; Kumar, Rajesh[6]; Kondragunta, Shobha[3]; Martin, Cory[7]; Huang, Jianping[8]; Mcqueen, Jeffery[9]; Stajner, Ivanka[9]; Hughes, Brian[8]
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Wildfires provide a major source of emissions contributing to poor air quality in the United States. Current operational models at the National Centers for Environmental Prediction (NCEP) show large uncertainties in the analysis and prediction of wildfire emissions with respect to emission strength, composition, duration, diurnal evolution, as well as to what altitude smoke plumes rise. This presentation describes efforts to improve wildfire smoke forecasting capabilities for air quality applications by assimilating satellite retrievals of Aerosol Optical Depth (AOD) and PM2.5 in-situ measurements into NCEP's Next-Generation Regional Air Quality Forecasting System, which consists of a Limited Area Model version of FV3 (FV3LAM) coupled with the Community Multi-scale Air Quality Model (CMAQ) to provide inline atmospheric chemistry. The ability to assimilate AOD and PM2.5 has been developed for FV3LAM-CMAQ within the Gridpoint Statistical Interpretation (GSI) 3-dimensional variational data assimilation system (3DVar). The Community Radiative Transfer Model (CRTM) AOD module is used as an observation operator for AOD assimilation. The control variables are individual aerosol species, with associated background error statistics derived via the NMC

method. The diurnal variations of background error statistics are examined and discussed. The VIIRS smoke and dust mask products are used to help produce physically reasonable aerosol analysis increments in smoke and dust areas. The performance of the developed GSI 3DVar data assimilation system will be presented and limitations will be discussed.

Thursday, 16 Sep 2021 at 11UTC - room GREEN

Regional reanalysis I

A high resolution reanalysis for the Mediterranean Sea

Escudier, Romain[1,2]; Clementi, Emanuela[2]; Omar, Mohamed[2]; Cipollone, Andrea[2]; Pistoia, Jenny[2]; Drudi, Massimiliano[2]; Grandi, Alessandro[2]; Lecci, Rita[3]; Aydogdu, Ali[2]; Masina, Simona[2]; Coppini, Giovanni[3]; Pinardi, Nadia[4]
[1]Mercator Océan International, [2]Centro Euro-Mediterraneo per i Cambiamenti Climatici [Bologna], [3]Euro-Mediterranean Center on Climate Change, [4]Alma Mater Studiorum University of Bologna

Here we present a new physical reanalysis of the Mediterranean Sea at high resolution, developed in the Copernicus Marine Environment Monitoring Service (CMEMS) framework. The hydrodynamic model is based on NEMO combined with a variational data assimilation scheme (OceanVar). The model has a horizontal resolution of 1/24° and 141 vertical z* levels and provides daily and monthly 3D values of temperature, salinity, sea level and currents. Hourly ECMWF ERA-5 atmospheric fields force the model and daily boundary conditions in the Atlantic are taken from the global CMCC C-GLORS reanalysis. 39 rivers model the freshwater input to the basin plus the Dardanelles. The reanalysis covers 33-years, initialized from SeaDataNet climatology in January 1985, getting to a nominal state after a two-years spin-up and ending in 2019. In-situ data from CTD, ARGO floats and XBT are assimilated into the model in combination with satellite altimetry data. This reanalysis has been validated and assessed through comparison to in-situ and satellite observations as well as literature climatologies. The results show an overall improvement of the skill and a better representation of the main dynamics of the region compared to the previous, lower resolution (1/16°) reanalysis. Temperature and salinity RMSE is decreased by respectively 12% and 20%. The deeper biases in salinity of the previous version are corrected and the new reanalysis present a better representation of the deep convection in the Gulf of Lion. Climate signals show continuous increase of the temperature due to climate change but also in salinity. The new reanalysis will allow the study of physical processes at multi-scales, from the large scale to the transient small mesoscale structures.

IMDAA regional reanalysis over the Indian monsoon region

Rani, S Indira[1]; George, John P[1]; Rajagopal, E N[1]; Arulalan, T[2]; Renshaw, Richard[3]; Maycock, Adam[3]; Barker, Dale[4]
[1]NCMRWF, MoES, [2]IMD, MoES, [3]Met Office, [4]Centre for Climate Research Singapore

Indian Monsoon Data Assimilation and Analysis (IMDAA) is the high resolution (~ 12 km), long-term (40 years, 1979-2018, extended to 2020), satellite-era regional reanalysis over the Indian monsoon region, covering the area 30ºE to 120ºE, and 15ºS to 45ºN. IMDAA reanalysis is a result of the collaboration between the National Centre for Medium Range Weather Forecasting (NCMRWF), India and the U. K. Met Office, funded by the National Monsoon Mission (NMM) project of the Indian Ministry of Earth Sciences. The reanalysis was prepared using the 4D-Var data assimilation method and the UKMet Unified Model. This is presently the highest resolution atmospheric reanalysis available for the Indian

monsoon region. Conventional and satellite observations from different sources are used, including Indian surface and upper air observations, of which some were not used in any previous global or regional reanalyses. IMDAA used the meteorological observations collated by the European Centre for Medium range Weather Forecasts (ECMWF) for reanalysis as the main dataset. Lateral boundary conditions for the IMDAA runs are provided by ECMWF global reanalysis of ERA-Interim. The hourly and three hourly IMDAA variables are released to the international researchers through the NCMRWF reanalysis portal (https://rds.ncmrwf.gov.in/). This presentation is intended to provide the details of the IMDAA reanalysis, including the observations used and their quality control procedures, data assimilation system, the forecast model, post-processing, and the comparison of various IMDAA estimates during different seasons over India with IMD gridded observations and ERA5 global reanalysis.

Performance of a 5-km regional reanalysis over Japan with respect to summer precipitation

Fukui, Shin[(1)]; Soga, Daiki[(1)]; Ohara, Ryota[(1)]; Usui, Ken[(1)]; Takiguchi, Kaito[(1)]; Ito, Junshi[(1)]; Iwasaki, Toshiki[(1)]; Yamazaki, Takeshi[(1)]; Saito, Kazuo[(2,3,4)]; Seko, Hiromu[(3)]
[(1)]Tohoku University, [(2)]Japan Meteorological Business Support Center, [(3)]Meteorological Research Institute, [(4)]The University of Tokyo

We are conducting a regional reanalysis with 5 km grid spacing over Japan for investigating regional climate change. The reanalysis is produced using a system developed by Fukui et al. (2018). The reanalysis system is a one-way double nesting system consisting of regional model (Japan Meteorological Agency Nonhydrostatic Model) and local ensemble transform Kalman filter. The inner reanalysis covers Japan with a grid spacing of 5 km (RRA-5km). The outer reanalysis covers East Asia with a grid spacing of 25 km (RRA-25km), nested in the Japanese 55-year reanalysis (JRA-55), whose resolution is approximately 55 km. The assimilated data are limited to conventional observations, such as in-situ surface pressure observations and aerological sonde observations, and tropical cyclone center position data, in order to keep the long-term consistency in the analysis quality through the total reanalysis period. Focusing on precipitation in summer seasons, we checked the performance of RRA-5km comparing with JRA-55 and RRA-25km. Higher resolution reanalysis improves representation of precipitations. RRA-5km fits to the rain-gauge data the best, and followed in order by RRA-25km and JRA-55, in terms of frequencies of heavy precipitation and spatial distribution of total precipitation. However, some problems still remain that it underestimates the frequencies of precipitations over 10 mm h-1 and overestimates precipitations in the mountainous area in central Japan.

Thursday, 16 Sep 2021 at 11UTC - room BLUE

Aeolus

Validation and Impact assessment of Aeolus Doppler Wind Lidar Observations at the German Weather Service

Cress, Alexander[(1)]
[(1)]Deutscher Wetterdienst [Offenbach]

Validation and Impact assessment of Aeolus Doppler Wind Lidar Observations at the German Weather Service Alexander Cress; Alexander .Cress@dwd.de Deutscher Wetterdienst, Frankfurter Strasse 135, 63067 Offenbach am Main ABSTRACT The first European Space Agency (ESA) Earth Explorer satellite mission Aeolus was launched successfully in August 2018, providing globally distributed profiles of horizontal line-of-

side (HLOS) wind information. From the beginning, the Deutscher Wetterdienst (DWD), as part of the German project team EVVA (Experimental Validation and Assimilaton of Aeolus data), investigated statistics of differences of the Aeolus winds relative to the global ICON model system of DWD, the observation error characteristic and bias behaviour of the HLOS winds, for both Laser A and Laser B, on a routinely basis and giving contributions to the CAL/VAL activities of ESA and for internal use. Several impact studies were conducted for both, Laser A and Laser B, showing a significant positive impact of the Aeolus HLOS winds in our data assimilation system for both hemispheres and the Tropics. The impact is largest in the tropical upper troposphere and lower stratosphere and over polar areas. All the activities accumulated in the operational use of the Aeolus HLOS winds in May 2020, only 1 and a half year after the first arrival of the winds in our observational data base system. This was only possible by an excellent collaboration between a variety of partners, including ESA, ECMWF, the DISC team and the national EVVA team. In my talk, I will give an overview of the activities and impact assessments, mainly for Laser B, leading to the successfully operational usage of the Aeolus HLOS winds in the data assimilation and foresting system of DWD.

Impact Assessment of Aeolus Wind on NOAA Global NWP Analyses and Forecasts

Ide, Kayo[(1)]; Liu, Hui[(2)]; Garrett, Kevin[(3)]; Lukens, Katherine[(2)]; Hoffman, Ross[(2)]
[(1)]University of Maryland, [(2)]NOAA and University of Maryland, [(3)]NOAA

The Aeolus mission, launched by the European Space Agency in August 2018, provides the first observations of vertical wind profiles from a space-borne Doppler wind lidar (DWL). The Aeolus Atmospheric LAser Doppler Instrument (ALADIN) measures both molecular and Mie (e.g., aerosol, hydrometeor) backscatter to derive Horizontal Line of Sight (HLOS) winds throughout the troposphere and lower stratosphere. Since the data have been made available to the Aeolus cal/val teams in December 2018, NOAA has been evaluating the quality of the HLOS winds, characterizing random and systematic errors, integrating the observations into the NOAA Finite-Volume Cubed-Sphere Global Forecast System (FV3GFS) numerical weather prediction (NWP) model, and iterating on refinements to maximize the impact on medium-range forecasts. Several Observing System Experiments (OSEs) have been performed for different periods of the Aeolus record, and with various optimizations including the reprocessing of the Aeolus Level 2B data using the FV3GFS background and refinement of the observation operator components. In each case, the assimilation of Aeolus HLOS winds has shown positive impact on FV3GFS forecasts. In this study, we will provide a summary of the optimized data assimilation configuration for the FV3GFS including approaches to quality control, bias correction, and observation error specification, and draw some preliminary conclusions on the overall impact of Aeolus on NOAA global forecasts.

Validation of Aeolus L2B Wind Product with ECCC Short-Range Forecasts and ERA5 over the Arctic

Chou, Chih Chun[(1)]; Kushner, Paul[(1)]; Laroche, Stéphane[(2)]; Mariani, Zen[(3)]; Rodriguez, Peter[(3)]
[(1)]University of Toronto, Department of Physics, [(2)]Environment and Climate Change Canada, [(3)]Environment and Climate Change Canada

In August 2018, the European Space Agency launched the Aeolus satellite, the first spaceborne Doppler Wind Lidar, that measures global horizontal line-of-sight (HLOS) wind profiles by analyzing the Doppler frequency shift of backscattered signal from air molecules (Rayleigh) and aerosol and cloud (Mie). This mission has the potential to improve numerical weather prediction over the Arctic where wind observations are sparse. In this study, the Aeolus Level-2B wind product is compared to the ECCC's short-range forecast (ECCC-B) and the reanalysis product, ERA5, from the ECMWF in the Arctic during the early FM-A (2018-09 to 2018-10), early FM-B (2019-08 to 2019-09), and mid-FM-B periods (2019-12 to 2020-01). Notably, consistency is found in the Rayleigh channel from the troposphere to the stratosphere and in the Mie channel from the PBL to the lower stratosphere. The correlations between the analyses and observations are greater than 0.7 and their RMSD

are within one normalized standard deviation in the higher atmosphere for Rayleigh winds and lower atmosphere for Mie winds. The reprocessed product, 2B10, has no significant improvement compared to the near-real time product, 2B06. Nevertheless, this reprocessed product does not need further model-based bias correction which could ease the inter-comparison of experiments across different weather centers. ECMWF's estimated error product for Aeolus is found to be coherent with the differences between Aeolus and the other datasets, and thus can be used as a guide for expected consistency. Thus, the new Aeolus product provides a valuable addition to current wind products in regions such as the Arctic Ocean sector where few direct wind observations have been available to date.

Thursday, 16 Sep 2021 at 12UTC - room RED

Global reanalysis I

JRA-3Q: Japanese Reanalysis for Three Quarters of a Century

Kobayashi, Shinya[(1)]; Kosaka, Yuki[(1)]; Chiba, Jotaro[(1)]; Tokuhiro, Takayuki[(1)]; Harada, Yayoi[(2)]; Kobayashi, Chiaki[(2)]; Naoe, Hiroaki[(2)]
[(1)]Office of Earth System Modeling / Numerical Prediction Division / Japan Meteorological Agency, [(2)]Meteorological Research Institute / Japan Meteorological Agency

Reanalysis has been playing a crucial role in JMA's climate services and related activities, such as climate monitoring, seasonal forecast modelling and climate research underpinning them, by providing long-term, high-quality climate data. To further improve the quality of reanalysis data, thereby contribute to advancing climate services and applications, JMA is currently conducting the third Japanese global atmospheric reanalysis, called the Japanese Reanalysis for Three Quarters of a Century (JRA-3Q). It covers the period from the late 1940s to present and the initial release of the data for the 1990s onwards is planned around the end of 2021. JRA-3Q is being produced with the TL479 resolution version of JMA's operational data assimilation system as of December 2018, which was extensively improved since the JRA-55 reanalysis was conducted. In JMA's Global Spectral Model, for example, biases of radiation budget, surface sensible/latent heat fluxes and precipitation have been significantly reduced due to extensive improvements of parameterisations for physical processes. A boundary condition over the ocean for the mid-1980s onwards is also replaced with satellite-based high-resolution (0.25-deg) SST data to improve the representation of atmospheric processes around the western boundary currents and associated SST fronts. This presentation provides an overview of JRA-3Q and an initial evaluation of its characteristics and performance.

The ERA5 reanalysis: a detailed record of the climate and weather for the past 70 years.

Hersbach, Hans[(1)]; Bell, Bill[(1)]; Berrisford, Paul[(1)]; Horanyi, Andras[(1)]; Nicolas, Julien[(1)]; Radu, Raluca[(1)]; Munoz, Sabater Joaquin[(1)]; Soci, Cornel[(1)]; Schepers, Dinand[(1)]; Simmons, Adrian[(1)]
[(1)]European Centre for Medium-Range Weather Forecasts

At the European Centre for Medium-Range Weather Forecasts (ECMWF), reanalysis is a key contribution to the Copernicus Climate Change Service (C3S) that is implemented at ECMWF on behalf of the European Commission. The most recent ECMWF global reanalysis, ERA5, provides hourly snapshots of the Earth's atmosphere, land surface and ocean waves from 1950 with updates with a latency of 5 days. It is highly popular

and used for a wide range of applications. The focus will be on the ERA5 back extension from 1950 to 1978 that supplements the previously published segment from 1979 onwards. It features the assimilation of many conventional observations and improved use of early satellite data. The fidelity of the extension is illustrated by the accurate depiction of the North Sea Storm of 1953, and the events leading to the first discovery of Sudden Stratospheric Warmings in 1952. Time series of ERA5 global surface temperature anomalies show temperatures to be relatively stable from 1950 until the late 1970s, in agreement with the other contemporary full-input reanalyses and independent datasets. The evolution of upper air temperatures, humidities and winds show smoothly varying behaviour, including tropospheric warming and stratospheric cooling, modulated by volcanic eruptions. The Quasi Biennial Oscillation is well represented throughout. Despite these good characteristics, the ERA5 back extension did use historical observations for tropical cyclones in a sub-optimal way, which, given their sparsity is a challenging subject in itself. The back extension was published as a separate, preliminary data set and the production of an improved version is currently in progress. The presentation will end with an outlook on future ECMWF reanalysis plans.

A synoptic to decadal evaluation of the 20th Century Reanalysis Version 3

Slivinski, Laura[1,2]; Compo, Gilbert[1,2]; Sardeshmukh, Prashant[1,2]; Whitaker, Jeffrey[2]
[1]Cooperative Institute for Research in Environmental Sciences, [2]NOAA Physical Sciences Laboratory

The performance of a new historical reanalysis, the NOAA-CIRES-DOE Twentieth Century Reanalysis version 3 (20CRv3), is evaluated via comparisons with other reanalyses and independent observations. This dataset provides global, 3-hourly estimates of the atmosphere from 1806 to 2015 by assimilating only surface pressure observations and prescribing sea surface temperature, sea ice concentration, and radiative forcings. Comparisons with independent observations, other reanalyses, and satellite products suggest that 20CRv3 can reliably produce atmospheric estimates on scales ranging from weather events to long-term climatic trends. Not only does 20CRv3 recreate a ‘‘best estimate" of the weather, including extreme events, it also provides an estimate of its confidence through the use of an ensemble. Surface pressure statistics suggest that these confidence estimates are reliable. Comparisons with independent upper-air observations in the Northern Hemisphere demonstrate that 20CRv3 has skill throughout the twentieth century. The skill of analyzed 500-hPa geopotential heights from 20CRv3 for 1979– 2015 is comparable to that of modern operational 3–4-day forecasts.

Thursday, 16 Sep 2021 at 14UTC – room RED

Regional reanalysis II

Regional reanalysis activities at DWD: review and outlook

Kaspar, Frank[1]; Borsche, Michael[1]; Niermann, Deborah[1]; Ostermoeller, Jennifer[1]; Roesch, Thomas[1]; Spangehl, Thomas[1]; Keller, Jan[1]; Potthast, Roland[1]
[1]Deutscher Wetterdienst [Offenbach]

In 2011, the development of a regional reanalysis based on the COSMO model began within the Hans-Ertel-Centre for Weather Research. The Meteorological Institute of the University of Bonn and the Institute of Geophysics and Meteorology of the University of Cologne focused on the question of whether it is possible to produce a long-term regional reanalysis for applications in the field of climate analysis and climate services

by using DWD's weather forecast model. A regional reanalysis for Europe (COSMO-REA6, 6 km spatial resolution, available from 1995) and Central Europe with Germany in the center (COSMO-REA2, 2 km spatial resolution, currently available for 2007-2013) was produced with the COSMO model and the quality has been evaluated with various methods. The data product is widely used by a large and diverse community of researchers, companies, and governmental institutions alike. In this presentation, we summarize the background and current status of DWD's reanalysis activities and present quality estimates and evaluation results. We provide an overview over recent studies as performed at DWD and at the Hans-Ertel-Centre in combination with REA6. Examples are shown addressing renewable energy applications with a focus on offshore wind speeds as well as for the analysis of weather and climate extremes. Finally, we provide an outlook on our near future plans, which include the preparation of an ICON based reanalysis.

Copernicus European regional reanalysis

Schimanke, Semjon[(1)]; Isaksson, Ludvig[(1)]; Edvinsson, Lisette[(1)]; Ridal, Martin[(1)]; Berggren, Lars[(1)]; Hopsch, Susanna[(1)]; Le, Moigne Patrick[(2)]
[(1)]Swedish Meteorological and Hydrological Institute, [(2)]Météo-France

The Copernicus European regional reanalysis (https://climate.copernicus.eu/regional-reanalysis-europe) is produced as part of the Copernicus Climate Change Service (C3S). We will give an overview on the service main objectives as well as we will present produced data. In the first phase of the service, systems inherited from the FP7 project UERRA (Uncertainties in Ensembles of Regional ReAnalyses, http://www.uerra.eu) were applied extending the UERRA-HARMONIE as well as the MESCAN-SURFEX datasets. These datasets contain analyses of the atmosphere, the surface and the soil. Data are available for the period 1961 – July 2019 through Copernicus Climate Data Store (CDS). The next generation of the regional reanalysis for Europe comprises three components: - CERRA (5.5 km horizontal resolution) - CERRA-EDA (10-member ensemble at 11 km resolution) - CERRA-Land (5.5 km horizontal resolution) In addition to the higher resolution, CERRA is more sophisticated than UERRA. For instance, more observations are assimilated into CERRA, in particular remote sensing data. The production of CERRA, CERRA-EDA and CERRA-Land will complete in September/October 2021 and data will become available in the CDS shortly thereafter. The quality of the regional reanalysis in comparison to ERA5 will be shown with results of the standard HARMONIE-verification package as well as based on certain case studies. For instance, the winter storm Gudrun (January 2005, southern Sweden) will be investigated.

The Copernicus Arctic Regional Reanalysis

Schyberg, Harald[(1)]
[(1)]Norwegian Meteorological Institute

The Copernicus Climate Change Service (C3S) is now implementing an Arctic climate reanalysis. ECMWF organizes this service on behalf of the European Commission, and the work is led by MET Norway with the other Nordic and the French national meteorological services as partners. Due to Arctic climate warming on average faster than the rest of the globe, there is enhanced user focus on change processes in this area. The Copernicus Arctic Regional Reanalysis service (where the data set is abbreviated as CARRA) produces its regional reanalysis on two Arctic subdomains of interest for change processes and economic activities. The production is ongoing and the reanalysis covers the period 1991 - 2021 with a horizontal resolution of 2,5 km. Recently the first batch of the data covering the period 1998-2019 was made publicly available. Additionally a proof-of-concept for a next generation pan-Arctic reanalysis system will be provided for the period September 2017 - September 2018, to cover part of the Year of Polar Prediction. In this presentation we will focus on how the data set verifies and compares to other data sets. We demonstrate how the Arctic reanalysis adds value versus the global reanalysis ERA5 both statistically and for special weather

events. This value adding is obtained both by using a higher-resolution model and by using fine scale regional input data not used in the global system. (A companion presentation by Xiaohua Yang provides more detail on the development and the performance of the assimilation system.)

Thursday, 16 Sep 2021 at 15UTC - room RED

Innovative observations

Usage of crowd-sourced meteorological car data for new real time road weather forecast

Acevedo, Walter[1]; Paschalidi, Zoi[1]; Riede, Hella[1]; Steinbach, Maximilian[1]; Heyer, Lisa[1]; Hellweg, Meike[2,3]; Nachtigall, Jens[3]; Kratzsch, Thomas[1]; Potthast, Roland[4,1]

[1]German Weather Service, [2]The Institut für Mess- und Regelungstechnik / The Department of Measurement and Control, [3]AUDI AG, [4]University of Reading

New mobility approaches like autonomous driving require high precision weather solutions, such as real time weather maps and warnings. The development of such demanding products is becoming possible due to different emerging technologies like Internet of Things, 5G mobile networks and the growing availability of high resolved meteorological data from automobiles. So, the Flotten-Wetter-Karte (FloWKar) project, a joint work of the German Meteorological Service (DWD) and the car manufacturer AUDI AG, explores how environmental data from car sensors, can be used within DWD's forecast system, respecting data protection regulations. As the standard assimilation systems cannot achieve the needed exceptionally fast assimilation cycles, an ultra-rapid data assimilation (URDA) method is developed. URDA achieves an update rate of the order of minutes, using only a reduced version of the state variables in an existing model forecast and different kind of observation data available. However, the meteorological data collected by moving vehicles suffer from errors and an almost real time improvement is needed. Thus, a series of quality control and bias correction algorithms has been built for the correction of the raw observations, employing among others artificial intelligence techniques. The corrected measured variables of the mass-produced vehicle-based sensors match well with the ‘ground truth' and real time maps can be produced after the assimilation of the high resolved project data.

The potential of assimilating wind power data for future reanalysis

Kelbch, Alexander[1]; Keller, Jan[1]

[1]Deutscher Wetterdienst [Offenbach]

Reanalyses are continuously developed towards smaller grid spacing. Thus, the representation of processes influenced by surface heterogeneity is expected to improve but accompanied by a growing impact of model errors. This affects downstream applications, e.g. renewable energy, where boundary layer (PBL) data are crucial. Recent studies also suggest to further improve near-surface winds in NWP products. While DA can help to attenuate errors, it relies on the availability of long time series of relevant observations. The FAIR project, in which the German Meteorological Service (DWD) participates, aims at better utilizing weather and climate data. Specifically, DWD benefits from using third party data for product improvement. In this context, our goal is to investigate the potential of wind power output DA for improving future reanalysis

products. Wind power output data are provided by BayWa re GmbH with record lengths of up to 20 years. These data may provide the necessary retrospective information on wind speeds in the lower PBL. The data is assimilated into DWD's operational NWP framework (ICON-LAM, LETKF) for Central Europe. To successfully assimilate wind power data the construction of a forward operator is crucial. We can rely on specific power curves also provided by BayWa. We present comparisons and evaluations of identical twin experiments stretching over several weeks long periods in different seasons to assess the benefit for reanalysis.

Assimilation of surface observations from citizen weather stations into a regional weather prediction system

Paschalidi, Zoi[(1)]; Acevedo, Walter[(1)]; Sgoff, Christine[(1)]; Ulbrich, Sven[(1)]; Kratzsch, Thomas[(1)]; Potthast, Roland[(1,2)]
[(1)]German Weather Service, [(2)]University of Reading

The new unprecedented massive amount of near-surface meteorological measurements from crowd sourced observation networks offers various new possibilities for improved weather forecast on regional and local scale, as well as for the development of real time weather products. That is why in the German Meteorological Service (DWD) we study the impact of assimilating observations from the private weather station's network NETATMO, within the regional weather model ICON-LAM. A comparative study takes place, where temperature and humidity observations from NETATMO over Germany are assimilated in addition to their synoptic analogues and a full set of available measurements, such as 2m temperature, surface pressure, 10m winds, observations from airplanes, wind profilers and radiosondes. As the crowd-sourced measurements suffer from strong biases and high noise, a bias correction approach is applied, based on the diurnal cycle of temperature and humidity variables. The preliminary results show that the assimilation of NETATMO observations profits always from the bias corrections and it can keep up with the positive effect of assimilating temperature and humidity synoptic observations. The model's cold bias in the lower atmosphere can be reduced by the assimilation of NETATMO surface temperature observations, while the corresponding humidity observations give a neutral error reduction.

Exploring the characteristics of a vehicle-based temperature dataset for convection-permitting numerical weather prediction

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[(1)]University of Reading, [(2)]Met Office@Reading

Crowdsourced vehicle-based observations have the potential to improve forecast skill in convection-permitting numerical weather prediction (NWP). Our aim is to explore the characteristics of vehicle-based observations of air temperature. We describe a novel low precision vehicle-based observation dataset obtained from a Met Office (UK) proof-of-concept trial. In this trial, observations of air temperature were obtained from built-in vehicle air-temperature sensors, broadcast to an application on the participant's smartphone and uploaded, with relevant metadata, to the Met Office servers. We discuss the instrument and representation uncertainties associated with vehicle-based observations and present a new quality-control procedure. It is shown that, for some observations, location metadata may be inaccurate due to unsuitable smartphone application settings. The characteristics of the data that passed quality-control are examined through comparison with km-scale NWP data and nearby independent observations of air temperature. Our results show that the uncertainty associated with vehicle-based observation minus-model comparisons is likely to be weather-dependent and possibly vehicle-dependent. Despite the low precision of the data, vehicle-based observations of air temperature could be a useful source of spatially-dense and temporally-frequent observations for NWP.

Thursday, 16 Sep 2021 at 15UTC - room GREEN

New approaches to DA IV

Assimilation of microwave radiances over the rainbands of tropical cyclones

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Microwave satellite observations are one of the largest datasets assimilated into Numerical Weather Prediction (NWP) models. However, the potential of microwave observations in improving the weather forecasts is limited by the accuracy of all-sky radiative transfer calculations. We introduce a novel Bayesian Monte Carlo technique to improve the assimilation of microwave observations over the rainbands of tropical cyclones. The BMCI technique eliminates the need for a forward model in the data assimilation system. The technique includes three steps, (i) generating a comprehensive dataset using in-situ cloud measurements and atmospheric profiles, (ii) generating synthetic ATMS observations from the training dataset, and (iii) using real observations to estimate the geophysical variables over the rainbands of tropical cyclones. The retrieved profiles of temperature, relative humidity, and cloud water content as well as surface information such as SST were then assimilated into the model. The results show that assimilating the BMCI retrievals can influence the dynamical features of the cyclone, including a stronger warm core, a symmetric eye, and vertically aligned wind columns.

Hilbert curves for data thinning and application to aircraft data

Su, Xiujuan[1]; Purser, R. James[1]
[1]IMSG at NOAA/NCEP/EMC

The space-filling Hilbert curve associates points on a parameterized interval (the Hilbert parameter) with points in a spatial domain of higher dimensions in a continuous way. Point observations scattered in space can be mapped, and serially sorted, onto the Hilbert parameter efficiently. When the data density is high on the Hilbert curve, it is necessarily high in space. This suggests that when there is a need to thin data, such as aircraft observations, which are very dense in compact locations (airports) distributed sporadically, we can perform this thinning relatively easily on the Hilbert curve with the assurance that the effects of this thinning will be reflected in physical space. We shall discuss our experience using this method, and will discuss the impacts with application of hilbert curve method to aircraft data.

Evaluation of background error models for JEDI-based data assimilation with GFS and GEOS.

Holdaway, Daniel[1]; Ménétrier, Benjamin[1,2]; Thomas, Catherine[3]
[1]Joint Center for Satellite Data Assimilation, [2]Institut de recherche en informatique de Toulouse, [3]NOAA National Centers for Environmental Prediction

The Joint Center for Satellite Data Assimilation's (JCSDA's) Joint Effort for Data assimilation Integration (JEDI) will be used to initialize future versions of NOAA's Global Forecast System (GFS) and NASA's Goddard Earth Observing System (GEOS). FV3-JEDI will form the interface between the atmospheric component of these models and the JEDI system, performing data assimilation with JEDI algorithms directly on the cubed-

sphere grid. One of the difficulties when developing any data assimilation system is in constructing a suitable background error model, and using the native grid introduces a number of novel challenges. In this presentation we will discuss the work that is being done at the JCSDA to construct the background error model for GFS and GEOS. The work utilizes the infrastructure that the JCSDA has put in place for enabling use of a range of background error models with any grid. We will show some scientific evaluation for the various flavors of static background error model, including different balance operators and covariance models. We will also demonstrate the use of the models for producing a stand-alone analysis. Localization of ensemble covariance in JEDI can be done with fixed length scales or dynamic length scales diagnosed from an ensemble. We will show some comparison of these approaches for GFS and GEOS and discuss the tuning of both localization and static background errors.

Are we minimizing the appropriate errors in data assimilation for weather forecasting?

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[(1)]Department of Atmospheric and Oceanic Sciences, McGill University

Data assimilation approaches and algorithms used for weather forecasting generally seek to minimize errors on model fields at analysis time and at the resolution of the model to help reduce forecast errors. While this may be the best assimilation strategy to improve analyses, does it lead to the best forecasts? If not, what error minimization criteria should be used for smaller initial condition errors to result in improved forecast skill? Four error-minimization criteria were considered, together with their combination: lower errors at analysis time, at two times, on smoothed fields, and on time tendencies. Four months of existing forecasts from the Canadian Global Ensemble Prediction System were analyzed in a simulation context. We determined the extent with which pairs of members with smaller differences considering different types of initial condition errors led to smaller differences in forecasts. At short forecast times, minimizing errors on initial values still provides the best forecasts; for medium-range forecasts, also minimizing errors on initial tendencies provide additional value as both types of errors are not 100% correlated. This suggests that, for best forecast results, we may want to adjust assimilation approaches to also minimize errors on tendencies.

Thursday, 16 Sep 2021 at 15UTC - room BLUE

Global reanalysis II

The ERA5-Land Global land surface reanalysis

Munoz, Sabater Joaquin[(1)]; Dutra, Emanuel[(2)]; Agusti-Panareda, Anna[(1)]; Albergel, Clément[(3,4)]; Arduini, Gabriele[(1)]; Balsamo, Gianpaolo[(1)]; Boussetta, Souhail[(1)]; Choulga, Margarita[(1)]; Harrigan, Shaun[(1)]; Hersbach, Hans[(1)]; Martens, Brecht[(5)]; Piles, Maria[(6)]; Gonzales, Miralles Diego[(5)]; Rodriguez-Fernandez, Nemesio[(7)]; Zsoter, Ervin[(1)]; Buontempo, Carlo[(1)]; Thepaut, Jean-Noel[(1)]
[(1)]European Centre for Medium-Range Weather Forecasts, [(2)]Instituto Português de Investigação do Mar e da Atmosfera, [(3)]European Centre for Space Applications and Telecommunications, [(4)]Centre National de Recherches Météorologiques, [(5)]Hydro-Climate Extremes Laboratory, [(6)]Department of Thermodynamics, Faculty of Physics, [(7)]CESBIO

ECMWF has produced the ERA5-Land dataset, a dynamical downscaled version of the land component of the ERA5 global reanalysis. The production of this dataset has been motivated, primarily, to serve the land surface community, and other communities focused on land applications, requiring a multi-decadal consistent dataset at resolutions higher than those currently offered by atmospheric reanalysis. ERA5-Land is a unique dataset of its kind that provides a global scale description of the most important land variables through a single simulation driven by near-surface atmospheric fields from ERA5, with thermodynamical orographic adjustment of temperature. The global projected horizontal resolution is 9 km (around 4 times finer resolution than ERA5), matching the ECMWF TCo1279 operational grid, and therefore providing consistent input for Numerical Weather Prediction and climate studies involving land water resources, but also for accurate hydrological and agricultural modeling. Owing to its relatively low computational cost, forefront model developments can also be quickly tested before the production phase. ERA5-Land is currently available in the Copernicus Climate Data Store from 1981 to present, with 2-3 months delay with respect to the real time. However, the synchronization with ERA5T mode will also make it possible to provide close to NRT updates. The production of the back-extension from 1950 to 1980 is completed and is currently under verification before made it available. This presentation will provide an overview of the ERA5-Land dataset and the main findings of a substantial evaluation exercise against in-situ data from different networks around the world and global satellite-based reference datasets.

Preparations for assimilating rescued and reprocessed satellite sounding observations in the next generation global atmospheric reanalysis at ECMWF - ERA6

Bell, William[(1)]; Hersbach, Hans[(1)]; Berrisford, Paul[(1)]; Horanyi, Andras[(1)]; Munoz, Sabater Joaquin[(1)]; Nicolas, Julien[(1)]; Radu, Raluca[(1)]; Schepers, Dinand[(1)]; Simmons, Adrian[(1)]; Soci, Cornel[(1)]; Schulz, Joerg[(2)]; John, Viju[(2)]; Hanschmann, Timo[(2)]; Poli, Paul[(2)]; Prunet, Pascal[(3)]; Klonecki, Andrzej[(3)]; Standfuss, Carsten[(3)]; Mittaz, Jon[(4)]; Hall, Tom[(4)]; Six, Bruno[(5)]; Vidot, Jerome[(6)]; Barbossa, Silveira Bruna[(6)]; Roquet, Pascale[(6)]; Turner, Emma[(7)]; Saunders, Roger[(7)]

[(1)]European Centre for Medium-Range Weather Forecasts, [(2)]European Organisation for the Exploitation of Meteorological Satellites, [(3)]Sté SPASCIA, [(4)]University of Reading, [(5)]University of Lille, [(6)]Météo France, [(7)]Met Office

An extension of the fifth generation atmospheric reanalysis at ECMWF, ERA5, back to 1950 has recently been completed. ERA5 makes use of early infrared sounding data from VTPR, carried on NOAA-2 through-5 from 1973-1979. Preparations are now underway for the next generation of reanalysis, ERA6, due to start in early 2024. These preparations aim to address some aspects, reviewed here, in the assimilation of sounding data evident in ERA5, including: drifting biases for the advanced IR sounding data due to the handling of evolving CO2 concentrations; large inter-satellite biases in MSU data; and discontinuities in analysed stratospheric temperatures as a result of discontinuities and inter-satellite biases in SSU data. In addition, ERA6 will make use of several reprocessed radiance datasets produced by EUMETSAT as part of the first (2015-2021) and second (2021-2027) phases of the EU's Copernicus Climate Change (C3S) programme. Plans currently include the assimilation of FCDRs for ATMS, MHS, MWHS-2, HIRS, SSM/T, SSMIS and Japanese geostationary satellite radiances. This element of C3S also, under current plans, aims to produce FIDUCEO-type uncertainty analyses for MSU, AMSU-A and ATMS. ERA6 will also make use of several recently rescued early (1970s) satellite datasets, including radiances from SI-1, SMMR, SSH, IRIS, SIRS, PMR, MRIR, NEMS, SCAMS, ESMR and SCR. Preparations to date have included the generation of new RTTOV coefficients and evaluation of the quality of these radiances relative to ERA5 using analysis departures computed off-line. These evaluations have uncovered several biases in these datasets which are under investigation.

The NASA GMAO retrospective analysis for the 21st Century GEOS-R21C

El, Akkraoui Amal[1,2]; Takacs, Lawrence[1,2]; Wargan, Krzysztof[1,2]; Sienkiewicz, Meta[1,2]; Chattopadhyay, Mohar[1,2]; Jin, Jianjun[1,2]; Bloecker, Christine[1,2]; Mccarty, Will[2]; Gelaro, Ron[2]; Pawson, Steven[2]
[1]Science Systems and Applications, Inc. [Lanham], [2]NASA Global Modeling and Assimilation Office

Building on the success of MERRA, and its successor MERRA-2 (released in 2009 and 2015 respectively), the GMAO continues its incremental effort towards a decadal goal of an Integrated Earth System retrospective analysis, MERRA-3 (~2025), coupling atmosphere, ocean, chemistry, land, and ice. With aspects of the coupled Goddard Earth Observing System (GEOS) still under development, an intermediate reanalysis featuring recent advances in the GEOS atmospheric component is planned as a stepping-stone towards MERRA-3. The GEOS-5 Retrospective analysis for the 21st Century, GEOS-R21C, will be a hybrid 4D-EnVar atmospheric reanalysis at 25km, covering the period 2000-onwards, and featuring the NASA's EOS and post-EOS satellite observations. MERRA-2 by contrast covers 1980-present and uses 3DVar at 50km. Other planned features in GEOS-R21C include All-sky radiances, new/re-processed data, and new radiance and aircraft bias correction strategies. Efforts to reduce field discontinuities involve alternative treatment of ozone data and an adjustment to the frequency of the Incremental Analysis Update (IAU) in the initialization process. The output fields from GEOS-R21C are planned to drive an off-line chemistry reanalysis (GEOS-R21C-Chem) and a high-resolution downscaling for the polar regions (PolarMERRA). GEOS-R21C is currently in the pre-production stages. This talk presents the GMAO strategy for upcoming reanalyses and focuses on GEOS-R21C configuration details and preliminary results from prototype-R21C with comparisons with MERRA-2 and ERA5. Along with an overall review of the new features, a reassessment of MERRA-2 strategy for dry-mass conservation is presented as well as a new diagnostic tool for GEOS-R21C.

The CMCC Global Ocean Reanalysis System (C-GLORS): a series of consolidated eddy-permitting ocean reanalyses

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In the last decade, CMCC has been dedicating a constant effort in the production of up-to-date global ocean reanalyses that can be suited for diverse purposes, from climate studies to initialization of forecasting systems and downscaling applications. The robustness of the C-GLORS series on key oceanic variables has been confirmed by the participation to several reanalysis inter-comparison projects through these years and is continuously monitored being part of the GREP ensemble product in the CMEMS catalogue. The last consolidated version is the C-GLORSv8 and covers the altimetry era 1993-present. While the spatial resolution is similar to the previous v7, the new version employs the latest hourly atmospheric Reanalysis ERA5 as boundary forcing. The optimization of the sea-ice ocean parametrizations and an improved version of SST and SSS surface nudging scheme largely reduced the underestimation of sea ice extension and volume that affected the v7. A cold temperature bias affecting the water column at mid-latitude (-0.1°C) is also removed. The assimilation of SLA data has been revised with the inclusion of a new unbiased scheme, thus reducing the error with respect to SLA observations. The new configuration shows a slight increase in the heat and volume transport at mid-latitudes. An in-depth evaluation of skills of the new Reanalysis is currently underway.

Friday, 17 Sep 2021 at 11UTC - room RED

Convective scale DA I

Representation of model error in convective scale data assimilation

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The convection-permitting numerical weather prediction models are able resolve highly nonlinear dynamics and physics. However, they often fail to capture processes that trigger convection or miss intensity and location of convective storms. Due to the very short-scale and stochastic properties of convection, as well as boundary condition errors, it is extremely difficult to parameterize the model error for convection permitting models. We investigated a variety of methods for treating the model error in ensemble based convective scale data assimilation. The experiments are done using the convection-permitting models and data assimilation system KENDA of German weather service. Conventional and radar observations are assimilated hourly by the LETKF. The model error due to unresolved scales and processes, is represented with samples coming from the difference between high-resolution model run and low-resolution experiment, through warm bubble initialization, stochastic boundary layer perturbations, perturbation in microphysics variables as well as through parameter estimation. It is shown that the additive noise approach, contributes greatly to ensemble spread, and considerably improves the skill of precipitation forecasts up to six hours. Combining the additive noise with time evolving estimates of model error, for example, either the stochastic boundary layer perturbations, parameter estimation or the warm bubble technique even further improves the skill of the precipitation forecasts.

Assimilation of Nowcast Objects in the Regional Forecast Model ICON-LAM

Neef, Lisa[(1)]; Potthast, Roland[(2,3)]; Welzbacher, Christian[(2)]; Blahak, Ulrich[(2)]
[(1)]Deutscher Wetterdienst [Offenbach], [(2)]Deutscher Wetterdienst [Offenbach], [(3)]University of Reading

Data assimilation methods are designed to update gridded model variables based on their statistical correlation to observations at other locations. This framework, while reliable and well-established, does not entirely take into account the coherent nature of convective systems but rather relies on modeled correlations to account for the fact that observations at neighboring gridpoints may be part of a coherent system. As assimilation updates are becoming more frequent (from several hours to hourly or less), data assimilation is starting to enter the world of nowcasts, i.e. rapidly updated short-term forecasts based on recent radar composites. On these time scales is makes sense to assimiliate not just gridded fields of observed precipitation, but also information about convective systems as a whole, e.g. the area of a convective cell or the cell-based Vertically Integrated Liquid Water. At the German Weather Service, cell attributes are computed from radar composites using the KONRAD3D cell detection and gridding system. We have implemented a method for assimilating these cell attributes into to the ICON-LAM regional forecast model, by generating model-equivalent radar fields that are then fed into the cell-detection and subsequently counted up on a model grid. This talk will explain the approach and show some first experiments that illustrate the extra information that can be obtained by considering objects.

Comparison of 4D-EnVAR and 4D-LETKF when running with 1000 ensemble members

Duc, Le[(1,2)]; Kawabata, Takuya[(1)]; Saito, Kazuo[(2,1)]; Oizumi, Tsutao[(2,1)]
[(1)]Meteorological Research Institute, [(2)]Japan Meteorological Business Support Center

The typical number of ensemble members in ensemble data assimilation is of the order of 100 in almost all forecast centers. The increase of the number of ensemble members in one order from 100 to 1000 is expected to better produce ensemble analyses, since uncertainties are much better represented with 1000 members. In this study, three 1000-member ensemble data assimilation schemes are compared using the same observation dataset as the operational meso-scale data assimilation system of the Japan Meteorological Agency: (1) the hybrid four-dimensional variational-ensemble assimilation 4D-EnVAR, (2) the four-dimensional local ensemble transform Kalman filter 4D-LETKF, and the four-dimensional local diagonal ensemble transform Kalman filter 4D-LDETKF. Vertical localization is turned off in all schemes to retain significantly vertical correlations, which also helps to reduce computational costs considerably. It is found that 4D-EnVAR produces better analyses and therefore better forecasts than the two ETKF variants, which can be attributed to the use of climatological error covariances beside ensemble error covariances in 4D-EnVAR.

Friday, 17 Sep 2021 at 11UTC - room GREEN

Deep learning in DA I

Model error correction with data assimilation and machine learning

Farchi, Alban[(1)]; Bocquet, Marc[(2)]; Bonavita, Massimo[(3)]; Laloyaux, Patrick[(3)]
[(1)]CEREA, [(2)]CEREA, [(3)]ECMWF

The idea of using machine learning (ML) methods to reconstruct the dynamics of a system is the topic of recent studies in the geosciences, in which the key output is a surrogate model meant to emulate the dynamical model. In order to treat sparse and noisy observations in a rigorous way, ML can be combined to data assimilation (DA). This yields a class of iterative methods in which, at each iteration a DA step assimilates the observations, and alternates with a ML step to learn the underlying dynamics of the DA analysis. This framework can be used to correct the error of an existent, physical model. The resulting surrogate model is hybrid, with a physical and a statistical part. In practice, the correction can be added as an integrated term (i.e. in the model resolvent) or directly inside the tendencies of the physical model. The resolvent correction is easy to implement but is not suited for short-term predictions. The tendency correction is more technical, in particular it requires the adjoint of the physical model, but also more flexible and can be used for any prediction. In this presentation, we start by a proof of concept for the use of joint DA and ML tools to correct model error. We use the resolvent correction with simple neural networks to correct the error of a two-dimensional, two layer quasi-geostrophic model. We then illustrate the difference between the resolvent and the tendency correction with the two-scale Lorenz system. Finally, we show that the tendency correction opens the possibility to make online model error correction, i.e. improving the model progressively as new observations become available. We compare online and offline learning using the same twin experiment with the two-scale Lorenz system.

high-resolution Ensemble Kalman Filter with a low-resolution model using a machine learning super-resolution approach

Barthélémy, Sébastien[(1)]; Brajard, Julien[(2)]; Bertino, Laurent[(2)]; Counillon, Francois[(2)]
[(1)]University of Bergen, [(2)]Nansen Environmental and Remote Sensing Center

Going from low- to high-resolution models is an efficient way to improve the data assimilation (DA) process in three ways: it makes better use of high-resolution observations, it represents more accurately the small scale features of the dynamics and it provides a high-resolution field that can further be used as an initial condition of a forecast. Of course, the pitfall of such an approach is the cost of computing a forecast with a high-resolution numerical model. This drawback is even more acute when using an ensemble DA approach, such as the ensemble Kalman filter (EnKF), for which an ensemble of forecasts is to be issued by the numerical model. In our approach, we propose to use a cheap low-resolution model to provide the forecast while still performing the assimilation step in a high-resolution space. The algorithm is based on a machine learning approach: from a low-resolution forecast, a neural network (NN) emulates a high-resolution field that can then be used to assimilate high-resolution observations. This NN super-resolution operator is trained on one high-resolution simulation. This new DA approach denoted "Super-resolution data assimilation" (SRDA), is built on an EnKF algorithm. We applied SRDA to a quasi-geostrophic model representing simplified ocean dynamics of the surface layer, with a low-resolution up to four times smaller than the reference high-resolution. We show that this approach outperforms the standard low-resolution DA approach and the SRDA method using standard interpolation instead of a neural network as a super-resolution operator. For the reduced cost of a low-resolution model, SRDA provides a high-resolution field with an error close to that of the field that would be obtained using a high-resolution model.

Deep-Learning Augmented Data Assimilation: Reconstructing Missing Information With Convolutional Autoencoders

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Remote sensing data play a critical role in improving numerical weather prediction (NWP), especially for regions with no in situ observations available. However, Data voids often exist in physical space (e.g., no-precipitation region for radar reflectivity) which undermines the accuracy of initial conditions from data assimilation, negatively impacting NWP. Here, we use the barotropic vorticity equation (BVE) to demonstrate the great potential of deep learning (DL) in augmenting data assimilation, by reconstructing spatially complete observation fields from incomplete observations. The training data set for deep learning is a long-term BVE simulation on a coarse resolution (T63). By training a convolutional autoencoder (CAE), we obtained a deep-learning approximation of a 'reconstruction operator,' which maps spatially incomplete observation to reconstruction with full spatial coverage. The reconstruction operator was tested with the streamfunction generated from a high-resolution (T85) simulation and exhibited satisfactory performance. We further evaluated the impact of DL reconstruction on assimilation and forecast with four groups of observations from the T85 benchmark simulation, including ones with complete coverage (FullObs), incomplete observation (PartObs), DL reconstruction (RecObs), and a combination of PartObs and RecObs (MixObs). The data assimilation using RecObs and MixObs generates significantly more accurate initial conditions than those using PartObs, close to the accuracy when using FullObs. Predictions based on the initial conditions from the DL-augmented data assimilation are also considerably better than the predictions relying on digesting spatially incomplete observations only.

Friday, 17 Sep 2021 at 11UTC - room BLUE

Regional reanalysis III

A new temporally flow-dependent EDA to estimate B-matrix in Copernicus European Regional Reanalysis

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[(1)]Meteo-France, [(2)]Swedish Meteorological and Hydrological Institute, [(3)]Norwegian Meteorological Institute

A new Ensemble of Data Assimilations (EDA) framework to estimate the background error covariances (B-matrix) has been developed and tailored to the new Copernicus European Regional Re-Analysis (CERRA). CERRA is produced by the HARMONIE NWP system with ALADIN physics, 3DVAR to analyse upper-air fields and Optimal Interpolation (MESCAN) to analyse surface fields, cycling every 3 hours. CERRA spans 40 years and has 5.5km resolution. Background errors are assumed isotropic, homogeneous and non-separable, meaning isometric horizontal breadth and vertical depth in 3D space. Linearised geostrophic and hydrostatic balances are incorporated as multivariate relationships, coupling vorticity and geopotential extended to wind, mass and specific humidity fields via f-plane approximation. We augment the estimation of background errors to be temporally dynamic, accounting for `errors of the day', seasonal and weather regime variation (CERRA-EDA). CERRA-EDA has 10 members cycled 6-hourly. CERRA-EDA comprises 2 components. The first component is 'seasonal' (5.5km), with respective summer and winter periods. A new augmentation governs the uptake of summer and winter differences at a given time of year. The second component is 'daily' (11km). B-matrix computation occurs every 2 days, with a fixed split of 80-20% seasonal-daily. Temporal flow dependence enables a degree of real-time tethering to meteorological situations as they arise. We show how the EDA accounts for weather regime change by case study. We also show the impact of varying EDA-component weighting on the statistics, and analysis and forecast quality, with improvements worth considering.

A 20-year High resolution Red Sea Reanalysis using a Hybrid ensemble data assimilation

Sanikommu, Siva Reddy[(1)]; Langodan, Sabique[(1)]; Zhan, Peng[(1)]; Hoteit, Ibrahim[(1)]
[(1)]King Abdullah University of Science and Technology

A 20-year (2001-2020) eddy resolving reanalysis is generated for the Red Sea by assimilating satellite and in situ observations of sea surface temperature, sea surface height, ocean temperature and salinity profiles into a 4 km Massachusetts Institute of Technology general circulation model (MITgcm). The assimilation is performed using a Hybrid system combining a monthly varying quasi-static ensemble and a flow-dependent ensemble from the ensemble adjustment Kalman filter (EAKF) of the Data Assimilation Research Testbed (DART). The flow-dependent ensemble integrates 50 different MITgcms to account for uncertainties in initial conditions, model physics, and atmospheric forcing. The system is forced with 50-member atmospheric ensemble from the European Center for Medium Range Weather Forecast (ECMWF) available at 50 km every 6 hours, and open boundary conditions from the Mercator ocean reanalysis. The generated reanalysis is compared against available global ocean reanalyses products to show its relevance. This high resolution long-term reanalysis of the Red Sea is important not only for exploring the circulation of this historically sparsely observed basin, but to also deepen our understanding of its biological processes.

Evaluation of European anthropogenic trace gas and aerosol emissions using 4D-var: First results of a full-year re-analysis for 2016

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In densely populated areas as in many parts of Central Europe, anthropogenic emissions are the key driver of air pollution. Emission inventories use yearly, reported emission data to provide estimates of spatially distributed emission maps, which include large uncertainties for several reasons: statistical data as proxy for spatial emission distribution, fixed time profiles for temporal distribution, lack of resilience to regional societal or meteorological effects (e. g. change of road transport in dependence on weather conditions). In order to analyze the emission inventory for Europe and for Germany in particular, the four dimensional variational data assimilation system of the EURopean Air pollution Dispersion – Inverse Model (EURAD-IM) is used to validate the emission data of CO, SOx, NOx, NMVOC, NH3, PM10, and PM2.5 against ground-based and space-borne observations. The analysis has been performed for the year 2016 on 15 km (Europe) and 5 km (Central Europe) horizontal resolution. The results provide insights into the spatial and temporal distribution of anthropogenic emission corrections across Europe. Areas of large deviations between emission-driven model data and observations are identified and reasons for the large emission correction factors are discussed. Further, the results will be discussed in view of implications for emission inventories.

Friday, 17 Sep 2021 at 12UTC - room RED

Deep learning in DA II

Combining Data Assimilation and Machine Learning to Estimate Parameters of a Convective-Scale Model

Legler, Stefanie[(1)]; Janjic, Pfander Tijana[(1)]
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Parametrization of microphysics, as well as parametrization of processes in the surface and boundary layers, typically contain several tunable parameters that are only crudely known, leading to model errors in the representation of clouds in convection-permitting numerical weather prediction models. Traditionally, the numerical values of these model parameters are chosen by manual model tuning. More objectively, they can be estimated from observations by the augmented state approach during the data assimilation. Alternatively, in this work, we look at the problem of parameter estimation through an AI lens by training two types of artificial neural networks to estimate several parameters of the one-dimensional modified shallow-water model as a function of the observations or analysis of the atmospheric state. We show that Bayesian neural networks and Bayesian approximations of point estimate neural networks are able to estimate model parameters and their relevant statistics. The estimation of parameters combined with data assimilation for the state decrease the initial state errors even when assimilating sparse and noisy observations. The sensitivity to the number of ensemble members, observation coverage, and neural network size is shown. Additionally, we use layer-wise relevance propagation to gain insight into how the neural networks are learning and discover that they naturally select only a few grid points that are subject to strong winds and rain to make their predictions.

Surrogate Tree and Model Forest Extensions to the Multifidelity Ensemble Kalman Filter

Popov, Andrey A[(1)]; Sandu, Adrian[(1)]
[(1)]Department of Computer Science at Virginia Tech

Recently, the idea of using a hierarchy of models for sequential data assimilation has been gaining traction. We present an extension of this idea to surrogate trees (and model forests thereof). We present a formal theory of such methods, through a rigorous extension of the theory

of linear control variates, and present a hypothetical framework for non-linear coupling.We showcase this methodology on the multifidelity ensemble Kalman filter with surrogate derived from data-driven methods such as POD-Galerkin, and neural-network based autoencoders. We thus aim to provide a convincing argument that such methods can be applied not only on toy models but for operational data assimilation as well.

Data-Driven Methods for Weather Forecast

Acevedo, García Felipe José[(1)]; Niño, Ruiz Elias David[(1)]
[(1)]Universidad del Norte, Barranquilla

Numerical weather forecasts are of extreme importance in different aspects of life, particularly in scenarios wherein human lives can be compromised (i.e., forecasts of storms, floods, hurricanes, and tsunamis). Numerical models are commonly employed to mimic the behavior of actual system dynamics, for instance, the ocean and the atmosphere. Since numerical models are computationally demanding, high-performance computing is necessary to produce forecasts within reasonable computational times, especially for high-resolution grids. We propose efficient and practical data-driven methods for weather forecasts. We exploit the information brought by historical weather datasets to build machine-learning-based models. For instance, the National-Centers-for-Environmental-Prediction Department-of-Energy (NCEP-DOE) Reanalysis II is a data set that holds meteorological information since 1979 onto global grids at varying resolutions. These models are employed to produce numerical forecasts, which can be improved by injecting additional data via data assimilation. Our approaches' general idea is as follows: given a set of time snapshots of some dynamical system, we group the data by time across multiple days. These groups are employed to build first-order Markovian models that reproduce dynamics from time to time. Our numerical models' precision can be improved via sequential data assimilation. Experimental tests are performed by using the NCEP-DOE Reanalysis II dataset. The results reveal that numerical forecasts can be obtained within reasonable error magnitudes in the L_2 norm sense. Even more, observations can improve forecasts by order of magnitudes, in some cases.

Learning UFS State-Dependent Systematic Errors from the Analysis Increments

Chen, Tse-Chun[(1,2)]; Penny, Stephen G.[(1,2)]; Whitaker, Jeffrey[(1)]; Frolov, Sergey[(1,2)]; Pincus, Robert[(1,2)]; Tulich, Stefan[(1,2)]
[(1)]Physical Sciences Laboratory, NOAA ESRL, [(2)]Cooperative Institute for Research in Environmental Sciences

Systematic errors in the state-of-the-art NWP models degrade the accuracy of forecasts made with these models. Past studies showed that a running average of analysis increments from data assimilation can reveal part of these systematic errors in seasonal and diurnal time scales. Applying corrections based on these simple estimates improves the model forecast skill. However, in addition to stationary seasonal and diurnal time scales, the analysis increments also contain information about state-dependent errors. Using the GFSv16b parallel runs, a variety of Neural Networks (NN) are trained to predict the corresponding increment from a forecast, with the goal to capture the underlying state-dependent systematic model errors. We will show that in addition to the obvious diurnal and seasonal signals in the analysis increments (accounting for 30% of the total variation) the NNs can predict on average more than 50% of the signal in the increments at any given point, using only the model forecast as an input. Adding both neighboring points from the forecast and background fields from the previous DA cycles further improves the skill of the NNs in predicting the analysis increments. We will also demonstrate a sensitivity measure of the NN prediction to the input information.

Friday, 17 Sep 2021 at 14UTC - room RED

Convective scale DA II

Big Data Assimilation: Real-time Demonstration Experiments of 30-second-update Forecasting in Tokyo in 2020 and 2021

Miyoshi, Takemasa[1,2,3,4]; Honda, Takumi[1]; Amemiya, Arata[1]; Otsuka, Shigenori[1]; Maejima, Yasumitsu[1]; Taylor, James[1]; Tomita, Hirofumi[1]; Nishizawa, Seiya[1]; Sueki, Kenta[1]; Yamaura, Tsuyoshi[1]; Ishikawa, Yutaka[5]; Satoh, Shinsuke[6]; Ushio, Tomoo[7]; Koike, Kana[8]; Hoshi, Erika[8]; Nakajima, Kengo[9]

[1]RIKEN Center for Computational Science [Kobe], [2]RIKEN Cluster for Pioneering Research, [3]RIKEN Interdisciplinary Theoretical and Mathematical Sciences Program, [4]Japan Agency for Marine-Earth Science and Technology, [5]National Institute of Informatics, [6]National Institute of Information and Communications Technology [Tokyo, Japan], [7]Osaka University, [8]MTI, Ltd., [9]Information Technology Center, The University of Tokyo

The Japan's Big Data Assimilation (BDA) project started in October 2013 and ended its 5.5-year period in March 2019. Here, we developed a novel numerical weather prediction (NWP) system at 100-m resolution updated every 30 seconds for precise prediction of individual convective clouds. This system was designed to fully take advantage of the phased array weather radar (PAWR) which observes reflectivity and Doppler velocity at 30-second frequency for 100 elevation angles at 100-m range resolution. By the end of the 5.5-year project period, we achieved less than 30-second computational time using the Japan's flagship K computer for past cases with all input data such as boundary conditions and observation data being ready to use. The direct follow-on project started in April 2019. We continued the development to achieve real-time operations of this novel 30-second-update NWP system for demonstration at the time of the Tokyo 2020 Olympic and Paralympic games. The games were postponed, but the project achieved successful real-time demonstration of the 30-second-update NWP system at 500-m resolution during July 31 and August 7, 2020 using a powerful supercomputer called Oakforest-PACS operated jointly by the Tsukuba University and the University of Tokyo. This presentation will summarize the real-time demonstration in 2020 and early results from the planned 2021 experiment during the Tokyo 2021 games using the world's leading supercomputer Fugaku.

Evaluating errors due to unresolved scales in convection permitting numerical weather prediction

Waller, Joanne[1]; Dance, Sarah[2]; Lean, Humphrey[1]

[1]Met Office, [2]University of Reading

In numerical weather prediction (NWP), observations and models are quantitatively compared for the purposes of data assimilation and forecast verification. The spatial and temporal scales represented by the observation and model may differ and this results in a scale mis-match error which may be biased and correlated. Here we investigate the structure of representation error in convection-permitting NWP models for four meteorological variables: temperature, specific humidity, zonal and meridional wind. We use high resolution data from the experimental Met Office London Model (approximately 300 m grid-length) to simulate perfect observations and lower resolution model data. The scale mis-match error and its bias, variance and correlation are calculated from the perfect observation and low-resolution model equivalents. Our new

results show that the scale mis-match bias is significant in the boundary layer for temperature and specific humidity, whereas the variance is significant in the boundary layer for all analysed variables. Furthermore, they are shown to be related to the mismatch in the high- and low-resolution orography. Contrary to previous studies using low-resolution, (km-scale) data, horizontal correlations are shown to be insignificant. However, all variables exhibit considerable vertical representation error correlation throughout the boundary layer; for temperature a significant positive vertical correlation persists for all model levels in the troposphere. Our results suggest that significant biases and vertical correlations exist that should be accounted for to give maximum observation impact in data assimilation and for fairness in model verification and validation.

Localization on convective scales: What can we learn from a 1000-member ensemble?

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Finding a proper localization is crucial for the success of ensemble data assimilation systems. Localization mitigates sampling errors and damps spurious correlations, which arise when modeling ensemble-based background error covariances using small ensembles. However, choosing an optimal localization is very challenging, especially for non-local satellite observations. Our goal is to improve localization techniques on convective scales by applying a novel convective-scale 1000-member ensemble simulation. The data set covers several forecasts in a high-impact weather period in summer 2016 (Necker et al. 2020a & 2020b). Our latest study analyzes correlations and optimal localization in the vertical. We focus on 40-member subsamples and assume the 1000-member ensemble as truth. We present estimated optimal localization length scales based on the often-applied Gaspari-Cohn tapering function. Besides, we discuss optimal localization functions for different variables and observations in model and observation space. That includes the open question on how to optimally localize visible and infrared satellite observations. A distance-based localization can be suboptimal for non-local satellite observations considering domain localization. A possible solution offer statistical sampling error correction approaches.

Friday, 17 Sep 2021 at 15UTC - room RED

Convective scale DA III

Further development of simultaneous multiscale data assimilation in EnVar to improve convective scale weather prediction

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Accurate prediction of convective scale weather requires accurate analysis of the storm as well as its larger-scale environment. In this study, a simultaneous multiscale data assimilation (MDA) approach is further developed and implemented in the EnVar. This approach allows all resolved scales including both the storm and its embedded environment to be updated simultaneously with all available observations. This approach enables both model space scale-dependent localization and variable-dependent localization. Three experiments are designed to evaluate the impact of simultaneous MDA on radar observation assimilation. Experiments are performed on the 8 May 2003 OKC tornadic

supercell storm with assimilation of both radar reflectivity and radial velocity. The simultaneous MDA outperforms the experiment with scale unaware uniform localization (UNI) in increasing the coverage of low-level reflectivity forecast, better capturing of the hook-echo structure, and enhancing the midlevel updraft. It is found that the improved forecasts in simultaneous MDA result from the enhanced storm ambient convergence. This result states that although only the radar observations are assimilated, the simultaneous MDA is capable of updating not only the storm but also the storm environment. Additionally applying the state variable-dependent localization favors to reduce the spurious reflectivity and further enhance the midlevel updraft.

Experiments with a continuously cycling 3-km ensemble Kalman filter over the entire conterminous United States for convection-allowing ensemble initialization

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[1]National Center for Atmospheric Research [Boulder], [2]NOAA Earth System Research Laboratory

Using the Weather Research and Forecasting model, 80-member ensemble Kalman filter (EnKF) analyses with 3-km horizontal grid spacing were produced over the entire conterminous United States (CONUS) for 4 weeks using 1-h continuous cycling. For comparison, similarly-configured 15-km EnKF analyses were also produced. The EnKF analyses initialized 36-h, 3-km, 10-member convection-allowing ensemble forecasts. Additionally, forecasts were initialized from operational Global Ensemble Forecast System (GEFS) initial conditions (ICs) and experimental "blended" ICs produced by combining large scales from GEFS ICs with small scales from EnKF analyses using a low-pass filter. Precipitation forecasts initialized from 3-km EnKF analyses were better than those initialized from downscaled GEFS and 15-km EnKF ICs through 12–18 and 6–12 h, respectively. Conversely, after 18 h, GEFS-initialized precipitation forecasts were better than EnKF-initialized precipitation forecasts. Blended 3-km ICs reflected the respective strengths of both GEFS and high-resolution EnKF ICs and yielded the best overall performance: blended 3-km ICs led to short-term forecasts with similar or better skill and reliability than those initialized from unblended 3-km EnKF analyses and 18–36-h forecasts possessing comparable quality as GEFS-initialized forecasts. In addition to describing these results, this presentation will discuss challenges that were overcome to produce the 3-km EnKF analyses; this work likely represents the first time a convection-allowing EnKF has been continuously cycled over a region as large as the entire CONUS. Furthermore, sensitivity studies regarding assimilation of radar observations will be briefly described.

Reduced non-Gaussianity by 30-second rapid update in convective-scale numerical weather prediction

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[1]Consejo Nacional de Investigaciones Científicas y Técnicas, [2]University of Buenos Aires [Argentina], [3]Central Weather Bureau, [4]Meteorological Research Institute, [5]RIKEN Center for Computational Science [Kobe], [6]RIKEN Center for Computational Science [Kobe], [7]RIKEN Cluster for Pioneering Research, [8]RIKEN Interdisciplinary Theoretical and Mathematical Sciences Program, [9]University of Maryland, College Park, [10]Japan Agency for Marine-Earth Science and Technology

Non-Gaussian forecast error is a challenge for ensemble-based data assimilation (DA), particularly for more nonlinear convective dynamics. This study investigates the degree of non-Gaussianity of forecast error distributions at 1-km resolution using a 1000-member ensemble Kalman filter, and how it is affected by the DA update frequency and observation number. Regional numerical weather prediction experiments are performed with the SCALE (Scalable Computing for Advanced Library and Environment) model and the LETKF (Local Ensemble Transform Kalman Filter) assimilating every-30-second phased array radar observations. The results show that non-Gaussianity develops rapidly within

convective clouds and is sensitive to the DA frequency and the number of assimilated observations. The non-Gaussianity is reduced by up to 40% when the assimilation window is shortened from 5 minutes to 30 seconds, particularly for vertical velocity and radar reflectivity. Also, short-range forecasts confirm the beneficial impact of reducing the length of the assimilation window to assimilate phased-array radar observations.

Large error correction in storms at convective scales by "grafting" look-alike modelled storms from other ensemble backgrounds

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Traditional assimilation approaches assume the existence of a linear relationship between field errors, a condition typically found where errors are small. This, however, makes it difficult to correct large errors that grow highly non-linearly, such as in storms at convective scales. Here a method we call "grafting" is proposed. In areas where observation errors are high, the ensemble members are searched for a storm that looks like the observations (such as radar reflectivity). Upon a successful match, that near-twin storm, with its adjacent environment is transplanted in other members with high observation errors, hence the name grafting. The hypothesis is that a storm that looks similar to the observed storm is likely to have similar dynamics. The hope is that large errors are reduced at the location of the storm. The grafting method shares some similarity with bogus DA that has been historically used to improve larger-scale hurricane forecasts. We experimented with grafting in an identical-twin setup using WRF at convective scales. Early results show that the storm placed in a member with this method lasts longer and evolves more closely to the real storm than one where the analysis is generated via EnKF. This method is only applied in the region (i.e., storm) where the errors are large, while in the rest of the domain the observations are assimilated with EnKF. The proposed method is complimentary to other traditional assimilation methods and benefits from the use of information from the available members. Current and future work includes minimizing model shock after grafting and generating perturbations for the grafted storm to increase ensemble spread.

Friday, 17 Sep 2021 at 15UTC - room GREEN

Observation Impact II

Implementation of Ensemble Forecast Sensitivity to Observations (EFSO) on a operational-like CFSv2 model and modifications for reanalysis

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[(1)]Department of Atmospheric and Oceanic Science, University of Maryland, College Park, [(2)]Physical Sciences Laboratory, NOAA ESRL

The EFSO (Kalnay et al., 2012) is a powerful tool to identify the beneficial or detrimental impact of every observation used in ensemble-based data assimilation (DA). Encouraged by the exciting success in the EFSO/PQC application on the operational GFS (Ota et al., 2013, Chen and Kalnay, 2020), we implemented the EFSO, for the first time, on the operational-like coupled system CFSv2-LETKF (Sluka et al., 2018). With the implementation of EFSO on the ocean components, the scientific questions we investigate are: (1) Does the EFSO work for the coupled DA system with real observations? (2) Ocean has a significantly longer timescale which is associated with depth. How long should the lead time be

to capture meaningful signals? (3) How do the different characteristics of ocean observations (i.e., distribution, density, and platforms) affect the observation impacts? This study aims to provide more insights into how to optimize the use of observations and improve the forecasts and analysis within a coupled system. A series of experiments are conducted with the weakly coupled assimilation of the preBUFR data for atmosphere and the ocean profiles and the NOAA Level 4 SST for the ocean. Preliminary result shows that the EFSO can estimate the cross-components (i.e., atmosphere-ocean) observation impacts. We found that assimilating the sea temperature and the salinity observations provides significant beneficial effects on the ocean analysis, especially for the regions with large SST variability. Moreover, EFSO captures the significant beneficial impacts of SST, which is associated with tropical cyclones. This result gives a piece of clear evidence on how the SST WCDA can improve the ocean components perturbed by air-sea interactions.

Impact of Losing Aqua and Legacy POES and of Gaining Radio-Occultation Observations

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[1]NASA Goddard Space Flight Center, [2]Global Modeling and Assimilation Office

This work summarizes the findings of a GMAO Observing System Simulation (OSE) study to evaluate the impact of Aqua leaving the A-Train and the termination of access to the Legacy Polar Operational Environmental Satellites (POES) for NWP applications. The summary also provides a brief assessment on the potential for new data sources to compensate for the loss of Aqua-POES; a case study is developed here that looks at the impact of adding COSMIC-2 to the main observation denial experiment. Overall, the impact of losing the observations from Aqua-POES is found to be large and particularly detrimental to forecasts, especially in the range of a few hours to about three days. Introduction of COSMIC-2 is seen to largely compensate for the loss of Aqua-POES in the Tropics, but the Extratropics are found not to recover to the level of performance of the control experiment. Ultimately, results from the GMAO OSEs suggest that loss of Aqua-POES would come to considerable detriment to the quality of its NWP system. In the hopes of trying to regain lost skills in the Extratropics, this work looks further into studying the impact of commercial RO being added to the mix. This presentation will show the highlights of this investigation.

Assessment of observation impact on the low troposphere in the GMAO GEOS system

Zhu, Yanqiu[1]; Todling, Ricardo[1]; Arnold, Nathan[1]; Errico, Ronald[2]; Chattopadhyay, Mohar[3]; Conaty, Austin[3]; Holdaway, Dan[4]; Mccarty, Will[1]
[1]Global Modeling and Assimilation Office, NASA Goddard Space Flight Center, [2]USRA/GMAO, [3]SSAI/GMAO, [4]UCAR/GMAO

The planetary boundary layer (PBL) is an important interface between the earth and its atmosphere, core to understanding the flux balances across the earth system components. However, due to various limitations in the existing observations and their usages, no single observing system is able to provide adequate information to characterize the PBL structure, therefore advanced data assimilation systems play a critical role by combining a wide range of observations with model physics in a consistent and coherent manner. The GMAO GEOS hybrid Ensemble-Variational (EnVar) data assimilation system assimilates about 4.5 million observations at each analysis cycle. The purpose of this study is to assess the impacts from various observation types on the low troposphere and constraining the PBL in terms of analysis and short-term and medium-range forecasts. A set of Observing System Experiments (OSE) is performed, where different observation types including microwave and infrared radiances and conventional observations are removed respectively, to evaluate the roles of different observation types. To complement the OSE assessment, Forecast Sensitivity to Observation diagnostics are performed. In this study, the dissipative aspect of the model PBL schemes is also discussed.

Impact of Dropsondes from the Atmospheric River (AR) Reconnaissance Program on Forecast Skill of ARs and the Satellite Radiance Assimilation

Zheng, Minghua[(1)]; Delle, Monache Luca[(1)]; Ralph, F. Martin[(1)]; Tallapragada, Vijay[(2)]; Cornuelle, Bruce[(3)]; Haase, Jennifer[(3)]; Wu, Xingren[(4)]; Subramanian, Aneesh[(5)]
[(1)]Center for Western Weather and Water Extremes, [(2)]NOAA National Centers for Environmental Prediction, [(3)]Scripps Institution of Oceanography, [(4)]I. M. Systems Group Inc., [(5)]University of Colorado

Atmospheric rivers (ARs) over the western US are responsible for ~30–50% of the annual precipitation, and their accurate forecasts are essential for aiding water management decisions and reducing flood risks. Sparse coverage of conventional observations over the Pacific Ocean can limit the improvement of forecast skill for these events. A targeted field program called AR Reconnaissance (Recon) was initiated in 2016 to better understand and reduce forecast errors of landfalling ARs at 1–5-day lead times. During the winter seasons of 2016, 2018–2020, 32 Intensive Observation Periods (IOPs) sampled the upstream conditions for landfalling ARs. This study assesses the impact on forecast accuracy of assimilating these dropsonde data. Data denial experiments with and without dropsonde data were conducted using the WRF model with the GSI hybrid 4DEnVar system. Comparisons between the paired experiments demonstrate that dropsondes reduced the root-mean-square error in integrated vapor transport (IVT) and inland precipitation for more than 70% of the IOPs, averaged over all forecast lead times from 1 to 6 days. Dropsondes have improved the spatial pattern of forecasts of IVT and precipitation in all 15 IOPs in 2016, 2018–2019. IOP sequences (i.e., back-to-back IOPs every other day) show the most improvement of inland precipitation forecast skill. Additional data denial experiments from January 23 to March 13 in 2020 were performed to investigate the anchoring impact of dropsondes with the NCEP GFS model. Radiance counts and total bias corrections show significant differences between the GFS paired experiments. The anchoring impact of dropsondes for radiance data are found to be far beyond the North Pacific and the western US.

Friday, 17 Sep 2021 at 15UTC – room BLUE

Reanalysis development

Towards an enhanced regional atmospheric reanalysis for Australia

Su, Chun-Hsu[(1)]; Rennie, Susan[(1)]; Dharssi, Imtiaz[(1)]; Smith, Andy[(1)]; Black, Mitchell[(1)]; Stassen, Christian[(1)]; Steinle, Peter[(1)]; Jakob, Doerte[(1)]; Jones, David[(1)]
[(1)]Australian Bureau of Meteorology [Melbourne]

The Bureau of Meteorology is now embarking on developing the next regional ensemble-based atmospheric reanalysis, to improve upon its first deterministic reanalysis – Bureau of Meteorology Atmospheric Regional high-resolution Reanalysis for Australia (BARRA) – completed in 2019. This will lead to a foundational dataset to provide a consistent, detailed characterisation of historical hazards and continuous intelligence. It is a part of a strategic initiative to establish a single authoritative source of information, analysis and expertise on climate and natural disaster risks that is focused on relief, recovery and resilience. The enhanced reanalysis is expected to span the era of modern meteorological satellites from 1979 and will be kept up to date as an operationally supported system. The reanalysis will use the same modelling components as those in other modelling systems in the Bureau including nowcasting, weather forecasting, seasonal forecasting and regional climate pro-

jections, reflecting the Bureau's strategy for a common modelling approach across all time scales from historical analysis to multi-decadal outlooks to support seamlessness in services. Here we report on the quality of BARRA and the development of the enhanced reanalysis, and benchmarking results against the Bureau's global numerical weather prediction system and the global reanalyses. We also describe how BARRA is disseminated to users and used to inform climate risk.

Developing Aerosol Reanalysis at NOAA Version 1.0: Methodology and Results

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In collaboration with the Global Modeling and Assimilation Office at NASA and State University of New York at Albany, NOAA is developing capability to assimilate observations to create the first ever aerosol reanalysis at this institution. The observations include Aerosol Optical Depth (AOD) derived from Moderate Resolution Imaging Spectroradiometer (MODIS) and AErosol RObotic NETwork (AERONET) direct sun measurements. The model relies on Finite-Volume Cubed-Sphere (FV3) dynamical core, Global Forecast System (GFS) physics and the aerosol parameterization based on the Goddard Chemistry Aerosol Radiance and Transport (GOCART). The assimilation tools are from the Joint Effort for Data assimilation Integration (JEDI): the forward operator uses aerosol scattering tables from NASA/GMAO and the assimilation approach combines the variational solver and the Local Ensemble Transform Kalman Filter (LETKF). Reanalysis for year 2016 is compared to NASA's Modern-Era Retrospective analysis for Research and Applications Two (MERRA-2) and ECMWF's Copernicus Atmosphere Monitoring Service interim Reanalysis (CAMSiRA) and evaluated against multiwavelength observations from AERONET, attenuated backscatter from Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO), and other independent satellite AOD retrievals.

Development of kilometer scale regional data assimilation for Copernicus Arctic Regional Reanalysis

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[1]Danish Meteorological Institute, [2]Swedish Meteorological and Hydrological Institute, [3]Norwegian Meteorological Institute [Oslo], [4]Icelandic Meteorological Office

Copernicus Arctic Regional Reanalysis covers the recent three decades for the European arctic at 2.5 km grid. The region is characterised by extensive areas with complex orography, cold surfaces and weather with strong local variability. It has a sparse conventional observation network. The reanalysis system is adapted from the HARMONIE-AROME NWP system, focusing on improved treatment of cold surfaces and enhancement on data input for physiographic databases, ocean and sea ice, snow and use of remote sensing data. A large amount of surface observations, including those over icecap, has been collected with quality control, resulting in significantly more use of surface data than in ERA5. High resolution, gap free albedo data over permafrost regions in the region have been used to improve physical realism. Efforts have been spent to enhance representation of the background error covariance model, and for optimal use of large scale information from the lateral boundary model in the analysis. From verification intercomparison, it appears that high resolution and the above mentioned enhancement in enhancement on data input, assimilation algorithm and treatment for cold surface have all contributed to the added values in the reanalysis. In this talk, we also discuss about weakness of assimilation system as found in some of the analysis bust cases. The work is part of the Copernicus Climate Change Service. ECMWF implements this Service on behalf of the European Commission.

A novel approach to surface reanalysis

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An alternative to running an NWP model and data assimilation scheme for generating reanalysis is a so-called surface reanalysis. Here, an existing reanalysis is used as prior information (for the near-surface state). This first guess is then corrected in a DA step, often performed only for a single parameter at at time and employing simple DA methods, e.g., optimal interpolation. In such a scheme, an additional downscaling is often performed to enhance the spatial representation. The aim of a surface reanalysis is to provide enhanced climate data of surface parameters relevant to a large number of users and downstream applications. Here, we show results from a more complex approach to surface reanalysis. As background data, we use COSMO-REA6, the operational regional reanalysis at the German Meteorological Service (DWD) with a horizontal resolution of about 6km. The target resolution is 1km with the DA step being performed using DWD's LETKF scheme. As COSMO-REA6 is a deterministic reanalysis, we generate a synthetic ensemble as input by employing the analog ensemble technique. The aim of this approach is that the generated data set is still consistent among its parameters as in a full reanalysis. Thus, the approach requires a multivariate DA step in contrast to previous surface reanalysis efforts. We start with temperature and humidity and successively extent the set of parameters. In addition, the approach is not restricted to the surface but allows the estimation of multiple layers. Therefore, it provides a reanalysis for the lower boundary layer which is of potential interest to application such as renewable energy. Further, the approach provides uncertainty information which can also benefit downstream applications.

Improving Met Office predictions of Artic sea ice through assimilation of CryoSat-2 and SMOS thickness data

Carneiro, Davi[(1)]; Martin, Matthew[(1)]; Fiedler, Emma[(1)]; Blockley, Ed[(1)]
[(1)]Met Office

Arctic sea ice is one of the most rapidly and visibly changing components of the global climate system. Although global analysis and forecasting systems have been used successfully for mid-latitude ocean prediction for some time, their application to Arctic sea ice is less mature, since observations are much less abundant and data assimilation techniques less advanced in the polar regions than at lower latitudes. In this work, we aim at implementing sea-ice thickness data assimilation from satellite measurements within the Met Office Forecast Ocean Assimilation Model (FOAM), specifically: CryoSat-2 and Soil Moisture and Ocean Salinity (SMOS). The FOAM data assimilation scheme is NEMOVAR, a three-dimensional variational data assimilation (3D-Var) with the first guess at appropriate time (FGAT). We derive sea-ice thickness from along-track sea-ice freeboard measurements in CryoSat-2, focusing on the assimilation of thicker ice, whereas SMOS assimilation is particularly focused on the thinner ice. Therefore, we will show results of FOAM runs with additional assimilations of CryoSat-2 and SMOS individually, as well as combined.

Partial analysis increments as diagnostic for LETKF data assimilation systems

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For convective-scale data assimilation there is potentially a vast amount of information available from ground-based remote-sensing instruments, various satellites and also human and economic activities e.g. smartphones, weather cameras, renewable energy production. However, the assimilation of such complex observations is non-trivial and requires better understanding of the processes and effects of the data assimilation system. For this purpose we developed an efficient method for the quantification and visualization of the analysis influence of observations in the convective-scale data assimilation system of the German Weather Service, which is based on a Local Ensemble Transform Kalman Filter (LETKF). Previous studies analysed the integrated influence of observations as a scalar quantity. A key aspect of our work is to investigate the influence in 3-dimensional space, which seems to be crucial for better understanding the effects of observations. The latter include the vertical and horizontal propagation of information but also the generation of potential unphysical gradients due to spurious correlations. Our method is based on the computation of partial analysis increments from standard LETKF output variables. The method was validated by single observation experiments in which spatio-temporally close radiosonde - and satellite observations were assimilated. Further we discuss potential applications of our method and its potential to optimize LETKF data assimilation systems.

Investigation of the potential factors that caused the July 2020 Kyushu heavy rain using a 1000-member ensemble simulation

Duc, Le[1,2]; Kawabata, Takuya[1]; Saito, Kazuo[1,2]; Oizumi, Tsutao[1,2]
[1]Meteorological Research Institute, [2]Japan Meteorological Business Support Center

The potential factors that caused the July 2020 Kyushu heavy rain have been investigated with the help from a 1000-member ensemble simulation. The 1000 ensemble simulations are produced from the ensemble analyses of a 1000-member ensemble Kalman filter. The data assimilation method is the four-dimensional local diagonal ensemble transform Kalman filter 4D-LDETKF, which is chosen to ensure relatively independence between ensemble members. Three multivariate statistical techniques are used to identify the critical factors: (1) ensemble sensitivity analysis, (2) canonical correlation analysis, and (3) clustering with the generative topographic mapping algorithm. The heavy rain is shown to be strongly associated with mesoscale frontal depressions along the Baiu front.

Evaluating block methods for Ensemble Data Assimilation in JEDI

Gas, Clementine[1]
[1]University Corporation for Atmospheric Research

In the context of Ensemble Data Assimilation, many similar identical optimization problems are solved. So far, these problems have been solved independently of each other, using for example a Lanczos algorithm. However, it is possible to use information from all the members to construct a better approximation of the eigen-structure of the matrix at the heart of the optimization problem and accelerate the convergence. The block Lanczos algorithm is one of the block methods that exist to solve an Ensemble of Data Assimilation. This presentation describes the block Lanczos algorithm implementation in the JEDI data assimilation framework, and presents results of the EDA experiments with GFS model, focusing on comparisons of eigenvectors produced by both the regular and the block Lanczos algorithms.

Test and evaluation of data assimilation algorithms and configurations to improve the Rapid Refresh Forecast System for convection forecasts

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The regional/convective application of the United Forecast System, or Rapid Refresh Forecast System (RRFS), is under development and aims to replace the NOAA operational suite of regional models in 2023. In order to achieve skillful convection forecasts comparable to operational models, each component needs to be exhaustively tested and the best configuration determined. RRFS currently includes the FV3 Limited Area Model with the Common Community Physics Package, the Unified Post-Processing system, and data assimilation capability using the Gridpoint Statistical Interpolation (GSI) analysis system. In this work, the RRFS capability to simulate convection was investigated through a case study on a squall line that occurred over Oklahoma during the afternoon of 4 May 2020. Various analysis algorithms in GSI were evaluated along with

different analysis grid ratios, supersaturation removal, planetary boundary layer pseudo-observations, vertical localization length scales, and various ensemble background error covariance weights in hybrid analysis. Observation impact experiments were conducted and cold start runs from HRRR and GFS were also evaluated. Hourly cycled experiments ran from 00Z on 4 May 2020 to 06Z on 5 May 2020 with 18-h forecasts launched at each cycle. Forecast verification was performed using MET. Results obtained in this research may inform RRFS developers on the performance of the system and will be presented during the symposium.

Ensemble Data Assimilation and Probabilistic Forecast with 1000 Members Coupled with a Hydrological Model Using the Supercomputer “Fugaku” Aiming to the Impact-Based Forecast

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[1]Meteorological Research Institute [Tsukuba], [2]Japan Meteorological Business Support Center

We started the supercomputer Fugaku project "Large Ensemble Atmospheric and Environmental Prediction for Disaster Prevention and Mitigation" in April 2020, in Japan. The Theme 1 "Short-range regional prediction" of the project aims “the impact-based forecast” for convective scale disasters and their predictions. To realize this concept, we developed a probabilistic forecast system coupled with a hydrological model based on a 1000-member ensemble. The objective is to show the probability of disaster itself such as flooding and landslide. This large ensemble simulation is conducted on the supercomputer Fugaku, which is the Japanese flagship supercomputer ranked in the top seat of TOP500, HPCG, HPL-AI, and Graph500. As the first attempt, we ran NHM-LETKF with 1000 members at a 5-km resolution and downscaled-into a 2-km resolution. The target event is a quasi-stationary line-shaped rainband case in July 2020, whose scales in space and time were about 200 km in east-west and 12 hours, respectively. In this event, over 80 lives were claimed by a flood of the Kuma river in Kyushu. By assimilating ordinary observations, the deterministic and ensemble forecasts of NHM-LETKF outperformed the JMA operational mesoscale forecasts 12-h before the flooding. By applying the ensemble forecast results to a hydrological model, we obtained amazing 60% of probability of the occurrence of flooding hazard. In this presentation, as well as this case study for the impact-based forecast, we will show the objective of the project, and other applications.

WRF- 3DVAR application for Georgia

Kutaladze, Nato[1]
[1]National Environmental Agency

Accurate weather forecast is very valuable, but also a very challenging for Georgia. Territory of country lies between of the Major Caucasian Ridge and the Lesser Caucasus mountains. About 85 percent of the total land area occupies complex mountain ranges divided with river's valleys and ravines of different exposition. Peculiarities of locally developed weather phenomena at any time a year are often characterized with diversity and extremality. Two lams run at the NHMS of Georgia (WRF and COSMO), mother domain centered on South Caucasus territory and covers black and Caspian seas, the territory, which is less overlapped by other regional and local domains from neighboring NHMSs and consortia. Convective scale forecast (deterministic and ensembles) very demanding. We run WRF taking boundaries from GFS assimilating surface parameters and radar's reflectivity with 3DVAR in the pre-operational mode. At the current moment, we are working to utilize ground base GPS data for the assessment of the amount of water vapor and perceptible water in the atmosphere profile. These are very important meteorological parameters determining such essential processes as precipitation and latent heat release. The forecasting of these fields by NWPs are still problematic as well as their proper verification. These data together with the satellite data are very important for the Caucasus region, because

of the shortage of the sounding observations. Similar synthetic analysis of observation data at a region scale from the conditions of atmospheric processes and the mechanisms of interaction allow the atmospheric physics specialists to carry out its absolutely deep understanding.

The enhancement of usage of the aircraft based observations in the KIAPS data assimilation system

Kwon, Hui-Nae[1]; Kang, Jeon-Ho[1]; Kwon, In-Hyuk[1]
[1]Korea Institute of Atmospheric Prediction Systems

The aircraft based observations such as AMDAR and AIREP are one of the key observations that are used as an anchor observation, being assimilated without any bias correction, in the Korea Meteorological Administration (KMA) operational Numerical Weather Prediction (NWP) system. Our sensitivity tests showed that increasing the number of well-qualified observations to be assimilated enhances the positive impacts. In this study, we compared the quality control methods of the KIM (Korean Integrated Model) Package for Observation Processing (KPOP) to that of the Meteorological Assimilation Data Ingest System Aircraft-Based Observation (MADIS ABO) data-producing process. We didn't find something specifically different in categorical methods of Quality Control (QC) through this comparison study. But it was clear that the QC methods should be more sophisticated for the KPOP such as putting vertically separated more tightened tolerance to the gross-error QC for temperature or winds. Our efforts to put a more sophisticated QC process for the KPOP and to enhance the usage of those qualified observations to the Korea Institute of Atmospheric Prediction Systems (KIAPS) Data Assimilation (DA) system by controlling the observation errors will be presented.

Comparison of JEDI Unified Forward Operator and GSI Observer Using Rapid Refresh Forecast System Background

Liu, Shun[1]; Martin, Cory[2]; Lei, Ting[3]; Carley, Jacob[4]; Zhang, Xiaoyan[1]; Liu, Emily[5]; Mahajan, Rahul[5]; Kevin, Dougherty[6]; Kleist, Daryl[4]; Ming, Hu[7]; Thompson, Greg[8]
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The Joint Effort for Data assimilation Integration (JEDI) is the next generation data assimilation system for research and operational use. JEDI may be potentially implemented to improve data assimilation in the Rapid Refresh Forecast System (RRFS), which is the next generation regional convection-allowing model forecast system under development for the National Weather Service. One of the key components in RRFS's data assimilation system is to simulate observations with RRFS's background using Gridpoint Statistical Interpolation (GSI) observer. The Unified Forward Operator (UFO) is being developed under the JEDI project and plays the same role as the GSI observer. The initial effort is to compare GSI observer and UFO to identify if they are equivalent in science using backgrounds from RRFS. The comparison includes the simulated observations from both systems, the forward operators, observation data pre-processing and quality control methods. The comparison will focus on the observations used in RRFS. The computational resource usage for GSI and JEDI will be compared as well, based on the project's progress. The result will be reported at the conference.

Whole Atmosphere-Ionosphere Data Assimilation and Ensemble Forecasting System

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Accurate forecasting of the ionosphere-thermosphere conditions is critical to radio communication, navigation, positioning, and satellite tracking. Located at the intersection between geospace and the Earth's atmosphere, the ionosphere-thermosphere is exposed to drivers from both space and terrestrial weather that operate over a wide range of spatial and temporal scales. Recent observational and modeling studies have revealed clear signatures of the effects of terrestrial weather far beyond the mesosphere into the topside ionosphere, motivating the extension of an operational forecasting system to the ionosphere-thermosphere. With an increased availability of geospace data from recent NASA Heliophysics missions such as GOLD and ICON as well as COSMIC-II, the use of a single seamless system, extending from the ground to geospace, to assimilate observations from both Earth and geospace observing systems is becoming a real possibility. This presentation will report on recent progress with ongoing research efforts to develop a capability to assimilate geospace satellite data into a coupled whole atmosphere-ionosphere-plasmasphere model as an integral part of the NOAA National Weather Service's operational ensemble forecasting and data assimilation systems.

The WMO Global Air Quality Forecast and Information System (GAFIS) project

Ménard, Richard[1]
[1]Environnement et Changement climatique Canada

GAFIS in a new WMO-GAW initiative to support the transition of science and prototype applications of air quality information system to operational and user driven services. The overall objective is to provide harmonized and standardize air quality forecasting and services worldwide, and promote chemical data assimilation. The activities of this effort ranges from building capacity development, good practices of air quality forecasting information systems, the observations for air quality information systems and the operational and scientific synergies between air quality forecasting and numerical weather prediction. Examples of such synergies will be shown from the experience at ECCC on other nodes will be presented.

ACTRIS/EARLINET pilot for NRT provision of aerosol remote sensing profiles to CAMS

Mona, Lucia[1]; D'amico, Giuseppe[1]; Gagliardi, Simone[1]; Amato, Francesco[1]; Amodeo, Aldo[1]; Sergio, Ciamprone[1]; De, Rosa Benedetto[1]; Ripepi, Ermann[1]; Summa, Donato[1]; Alados-Arboledas, Lucas[2]; Amiridis, Vassilis[3]; Baars, Holger[4]; Komppula, Mika[5]; Mattis, Ina[6]; Nicolae, Doina[7]; Pietras, Christopher[8]; Stachlewska, Iwona[9]; Letertre-Danczak, Julie[10]; Peuch, Vincent Henri[10]
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A pilot NRT provision of ACTRIS/EARLINET lidar-derived aerosol optical properties profiles to CAMS will be introduced. Setting up this service required implementation of new solutions for automation of data processing, transfer and quality control with an aim at improving the retrievability of data products in NRT. Starting from very heterogeneous lidar stations in terms of system set-up and data processing, large efforts were done in ACTRIS/EARLINET over the years for gaining in harmonization of the data processing and provision. Nowadays, ACTRIS/EARLINET has reached a degree of maturity that makes it suitable for near real time data provision. New modules and submodules of the ACTRIS/EARLINET Single Calculus Chain (SCC) have been designed for the provision. In particular, optimized algorithms for cloud screening have been implemented. Moreover, additional procedures for improving the quality of NRT Level 2 data products (delivered after 6-months) were realized. The pilot data provision started in October 2020 at the test site in Potenza. In January 2021, the provision started for a group of 9 stations located over Europe, which are seen as representative for the whole network in terms of instrumental capability, but also ensuring a good geographical coverage of the European continent.

An Overview of Atmospheric Data Assimilation at the Naval Research Laboratory

Satterfield, Elizabeth[(1)]; King, Sarah[(1)]; Baker, Nancy[(1)]; Ruston, Benjamin[(1)]; Campbell, William[(1)]; Christopherson, Hui[(1)]; Crawford, William[(1)]; Langland, Rolf[(1)]; Pauley, Patricia[(1)]; Stevens, Bailey[(1)]; Swadley, Steve[(1)]; Tsu, Justin[(1)]; Tyndall, Dan[(1)]; Zhao, Allen[(1)]
[(1)]Naval Research Laboratory

This talk will overview current work in data assimilation (DA) being conducted at the Naval Research Laboratory Marine Meteorology Division. In this presentation, we will highlight four major areas of research and development. These include: • Developing a new hybrid 4DVar global data assimilation system for the Navy's next generation unified model NEPTUNE using the JCSDA/JEDI DA infrastructure. This new NEPTUNE-JEDI infrastructure will efficiently utilize tens of thousands of cores, facilitate rapid integration of new observations and community-developed software, and be adaptable to support both basic DA research as well as future coupled and limited area applications. • Maintaining NRL's utilization of atmospheric sounding observations though the addition of the sensors onboard NOAA-20, MetOp-C and through the observations of COSMIC-2. • Integrating new observations by assimilating GNSS-RO sensors of opportunity (KOMPAT-5, PAZ and commercial weather data), GNSS Zenith Total Delay and Aeolus winds, and evaluating small satellite microwave observations. • Continuing to enhance our model verification through community partnerships with MET/METplus.

Developing Unified Forward Operator (UFO) for JEDI at the Joint Center for Satellite Data Assimilation (JCSDA)

Shao, Hui[(1,2)]; Thompson, Greg[(1,2)]; Han, Wei[(1,2)]; Liu, Emily[(3)]; Zhangz, Hailing[(1,2)]; Diniz, Fabio[(1,2)]; Honeyager, Ryan[(1,2)]; Vandenberghe, Francois[(1,2)]; Schweiker, Rachel[(1,2)]; Johnson, Benjamin[(1,2)]; Tremolet, Yannick[(1,2)]; Auligne, Thomas[(1,2)]
[(1)]Joint Center for Satellite Data Assimilation, [(2)]University Corporation for Atmospheric Research, [(3)]Environmental Modeling Center, NOAA National Centers for Environmental Prediction

The Joint Effort for Data assimilation Integration (JEDI) is a unified and versatile data assimilation system for Earth System Prediction. It is a joint project by the Joint Center for Satellite Data Assimilation (JCSDA) and its main stakeholders (NOAA, NASA, DoD, UKMO). The goal is to enable collaborative development, sharing of resources and faster transfer of research to operations. The JCSDA stakeholders are committed to using JEDI to develop their next-generation prediction systems. The use of observations in JEDI is generally handled by the Unified Forward Operator (UFO) software component. The function of the UFO is to represent, as well as possible, the precise relationship between what is observed and what is modeled, so that the information provided by the observations can be used to improve the model forecasts. For the past couple of years, the UFO has rapidly evolved and now includes observation operators for most of the operational observation types (radiance, conven-

tional, GNSS-RO, satellite retrievals, etc.). Some of the observation types even have multiple operators to choose from based on the existing operational capabilities (e.g., NOAA, UKMO, NRL, etc.). This paper will introduce the joint development efforts at JCSDA and its stakeholders and current status of UFO. This paper will also present the working efforts to evolve UFO as an integral part of applications supported by JCSDA. UFO validation through such a JEDI application testbed (e.g., GDAS) will be demonstrated.

Coupled data assimilation development with Joint Effort for Data assimilation Integration

Shlyaeva, Anna[1]; Tremolet, Yannick[2]
[1]Joint Center for Satellite Data Assimilation, [2]Joint Center for Satellite Data Assimilation

Joint Effort for Data assimilation Integration (JEDI) is a unified data assimilation software framework developed for research and operational use. Data assimilation algorithms in JEDI (including a wide range of variational algorithms and Local Ensemble Kalman Filter-type algorithms) are written in a generic way, allowing their use with any model implementing a JEDI interface. This generic approach simplifies development of coupled data assimilation algorithms. In this presentation we will describe the coupled data assimilation software approach in JEDI.

New Variational Quality Control scheme and application in GSI

Su, Xiujuan[1]; Purser, R. James[1]
[1]IMSG at NOAA/NCEP/EMC

The original implementation of variational quality control in NOAA's Grid-point Statistical Interpolation (GSI) assumed the effective measurement error distribution to be a mixture of a dominant Gaussian plus a minor uniform contaminant. But the effective distribution of errors appears to conform more to a distribution such as the Logistic distribution, or variants of it, whose log-probability densities, being convex or only very weakly concave, have the advantage of avoiding, or substantially mitigating, the problem of multiple minima in the cost function minimization. The shape of the assumed error distribution is controlled by two main parameters: one determines the broadness of the tails, and the other determines the convexity of the logarithm of those tails. We discuss the application in GSI and forecast impacts with new variational QC.

Developments Towards a Unified Naming Convention for Observations Used in a Data Assimilation System

Thompson, Gregory[1]; Honeyager, Ryan[1,2]; Herbener, Stephen[1]; Shao, Hui[1]
[1]University Corporation for Atmospheric Research, [2]Joint Center for Satellite Data Assimilation

The Joint Center for Satellite Data Assimilation (JCSDA) has a framework for storing and reading observations used in the JEDI (Joint Effort for Data assimilation Integration) software for data assimilation. JEDI's Interface for Observation Data Access (IODA) bridges the external observational data to the components that utilize the data during assimilation. The various agencies that comprise JCSDA typically have a variety of variable names and store their own data individually in numerous formats, many of which diverge from their true origins. Typical steps of DA systems are conversion from raw format type such as BUFR, derivation of new variables, bias correction, diagnostics like model departures, and quality control. While IODA handles data ingest, the Unified Forward Operators (UFO) handle most of the remaining steps. To facilitate these linked steps, the JCSDA has organized a common set of conventions for variable and dimension names as well as storage of I/O files that lend themselves to rapid diagnostic tools for post-processing and DA-related investigations. While NetCDF Climate and Forecast (CF) conven-

tion has had great success establishing a standard for numerical model data dissemination, the conventions do not adequately describe the breadth of observational variables. The JCSDA has created a draft version of naming conventions for most existing DA-related observational variables and metadata that can assist in the quality control and forward operator steps.

The Joint Effort for Data assimilation Integration

Tremolet, Yannick[1]
[1]Joint Center for Satellite Data Assimilation

The long term objective of the Joint Effort for Data assimilation Integration (JEDI) is to provide a unified data assimilation framework for research and operational use, for different components of the Earth system, including coupled systems, and for different applications. The project also aims at reducing or avoiding redundant work within the community and increasing efficiency of research and of the transition from development teams to operations. The key concept in modern software development for complex systems is the separation of concerns. In this project, the concept of models is clearly separated from the observation handling with clear interfaces. The data assimilation algorithms are themselves separated from the model space and observation space components. Generic code is used wherever possible to further reduce duplication of effort. The JEDI project is based on modern programming technology, it is also a joint effort between the JCSDA partner agencies. Very rapid progress has been possible through the use of a new approach to development. However, these tools imply changes in working habits and practices, affecting individual and collaborative work. In this talk, the new development practices will be described. An overview of the system and the current status of the implementation of the various data assimilation components for use in atmospheric, marine, land, atmospheric composition and coupled systems will be presented.

Satellite radiance data assimilation within NOAA's prototype Rapid Refresh Forecast System

Zhang, Xiaoyan[1]**; Carley, Jacob**[2]**; Liu, Emily**[2]**; Liu, Haixia**[1]**; Rogers, Eric**[3]**; Lei, Ting**[1]**; Liu, Shun**[1]**; Martin, Cory**[4]**; Weygandt, Steve**[5]**; Lin, Haidao**[6]
[1]IMSG at NOAA/NWS/NCEP/EMC, [2]NOAA/NWS/NCEP/EMC, [3]NOAA/NWS/NCEP/EMC, [4]Redline at NOAA/NWS/NCEP/EMC, [5]NOAA/OAR/GSL, [6]CIRA/CSU and NOAA/OAR/GSL

NOAA's next-generation Rapid Refresh Forecast System (RRFS), a unified hourly-updated, convective-scale ensemble data assimilation and forecasting system, is currently under development and testing. Satellite radiance data from both polar orbit and geostationary satellites have been assimilated in this system at an hourly cadence. New satellite instruments and new methods of assimilating radiance data are also continuously tested and updated within the RRFS. This presentation will provide a general overview of the assimilation of satellite radiances in the RRFS and address recent progress in evaluating the ABI radiance data, DBNet radiance data, and higher peaking channels from microwave radiance data.

Poster session P1 - Reanalysis

SPI-based drought forecasting data assimilation by using ARIMA models

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Drought always has more severe impacts on the agriculture sector and adversely affects many people's livelihood than any other natural hazard. Pakistans' economy mainly revolves around the agriculture sector, and nearly 62 percent of the country's population depends on this sector that primarily depends on rainfall water. Therefore, an effective monitoring system is indispensable in developing countries like Pakistan to mitigate the negative impacts of drought. This study aimed to create the seasonal stochastic (SARIMA) models to investigate and forecast the meteorological drought in Pakistan. Meteorological data from 20 rain gauge stations over 1951 – 2017 were used to calculate the SPI at the 12-months timescale. The Box-Jenkins approach was employed to build SARIMA models for SPI of various stations and was then utilized to predict Pakistan's drought conditions over the next three years, from 2018 to 2020. SPI-12 month time scale results indicate that all the four provincial capitals experienced frequent severe droughts (SPI) for different months of the year during the period 1951-2017.Furthermore, the SARIMA model used for modeling and predicting SPI-12 time series for each rain gauge station was reasonably found. Moderately dry periods are expected for Karachi and Lahore stations, whereas the Quetta station is expected to have an arid period by 2020-2060. This study's findings can be important for Pakistan as a comprehensive valuation of drought features at the national level is indispensable for frequent droughts management.

Examining the model parameters of COSMO-CLM in 11 selected extreme events over West Bengal (WB), India

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The performance of the regional climate model COSMO-CLM driven by Era-Interim over West Bengal domain (81.25° E – 94.64 ° E and 15.87° N – 27.76° N) on 11 extreme events have been obtained by performing 3-hourly simulations for 11 days (5 days before and after central date) with different model parameter values (25 tunning parameters). The purpose of this study was to ascertain model performances with respect to changes in tuning parameters which are mainly related to turbulence, surface convection, cloud parameterization. The model performances are evaluated on the ability of reproducing temperature, precipitation and cloud cover for all the 11 extreme events. The metric used for investigating the COSMO-CLM parameters uncertainty is Performance Score computed from Performance Index. Additionally, model parameters for different areas of the domain are also investigated using Skill Score and expressed with respect to the area of the reference simulation (setting all the tuning parameters as default value). The model is particularly sensitive to a subset of all the tested parameters. The model with the largest effect on model performance is qi0, the cloud ice threshold for automatic convection.

Assessment of past and present human biometeorological environment over WB, India based on observations and Era-Interim

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Research works are scanty on the validation of long-term trend of human thermal stress over West Bengal (WB), India. Therefore, this study focuses on the past and present human bio-meteorological environment in WB reproduced from Era-Interim and observed station data respectively. To account for the prolonged thermal stress periods, the duration of three UTCI stress categories such as strong heat stress, very strong heat stress, and extreme heat stress are counted as an event. An event is classified as a strong or very strong event if the corresponding stress category turns up in consecutive days for more than or equal to five days and less than twelve days. Extreme events are numbered when the extreme stress class renews for more than or equal to 2 days and less than five days. No extreme heat stress events/year are identified for any of the study stations in WB for past (Era-Interim) and present (IMD) bio-climate conditions. For strong heat stress, number of events/year ranges from (41-48) past 40 years (Era-Interim) at 12 hr for all the stations except Darjeeling. In the same stress category, for the last two years, observed station data (IMD), at 11:30 am, computes (23-53 events/year) for all the stations except Darjeeling. At 12 hr, the highest number for very strong heat stress class occurs in Alipore and Dum Dum for last four decades ranging from 2-3 events/year whereas observed station data identifies Diamond Harbour (11.5 events/year) for the last two years and no other observed station identifies such events/year at 11:30 am.

Evaluation of multiple reanalyses in reproducing temperature and precipitation indices over southern South America

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Several temperature and precipitation indices, with special focus on extremes, were analysed in different sub-regions of southern South America (SSA) during 1979-2017 using multiple reanalyses, the CPC gridded dataset and the most extended network of meteorological stations employed in regional climate studies up to date. Reanalyses generally well represented the spatial patterns of the indices, although they showed some differences in extreme indices over large portions of SSA and tended to overestimate precipitation maximums, especially in southern Chile. Furthermore, ERA-Interim presented clear difficulties in reproducing precipitation near the Andes mountains, exhibiting the largest overestimations. This seemed to be improved in ERA5. When evaluating the long-term changes, most of the datasets agreed in general warming conditions, stronger and more homogeneous for the maximum temperature. NCEP1 and NCEP2 showed contrary temporal changes in almost all the temperature indices. Precipitation indices exhibited less consistent changes among reanalyses, notwithstanding, most of the datasets agreed in drier conditions in the arid region of Argentina as reflected by significant positive trends for dry spells and negative trends for the total annual precipitation. In terms of the inter-annual correspondence, reanalyses presented good correlations to the stations reference in the regional series. The use of reanalyses data to perform regional climate studies should consider the existent differences among them. Using multiple sources of information is strongly recommended to account for observational uncertainty, especially in regions like SSA, where data availability and its resolution are often limited.

Assimilation strategies of sea-ice remotely-sensed observations for ocean Reanalysis

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Despite the first sea-ice thickness observations from satellite date back to 2000s, multivariate assimilation strategies for sea-ice are still in an early stage, due to the highly non-gaussian distributions of related uncertainties and the low accuracy of such measurements especially during summer season. In literature, several sea-ice comparison studies, starting from ORA-IP, has shown large variability in crucial sea-ice parameters among diverse state-of-the-art ocean/sea-ice reanalyses, despite a general agreement in the sea-ice extension. To better constrain the sea-ice, the CMCC ocean 3dvar scheme (called OceanVar), employed in the routinely production of global/regional ocean reanalysis and forecasts, has been recently extended to ingest sea-ice concentration and thickness via gaussian anamorphosis operator. This operator is used to covary thickness and concentration by transforming the probability density function of sea-ice variables into Gaussian ones. The investigation of different sea-ice assimilation strategies (univariate/multivariate) is underway and will be presented together with the impact on the sea-ice variability and on several integrated climatic indexes that are of crucial importance in reanalysis applications. The sea-ice DA scheme is meant to be coupled with the ocean DA in the future.

Using reanalysis to assess ‘design-level' wind events with the potential for infrastructure damage in the built environment

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Extreme surface wind speeds in urban regions can cause significant damage to the built environment. Understanding how extreme winds, which are used in infrastructure design, may change under climate change may be an important consideration for climate change adaptation. Climate model projections of future extreme winds are highly uncertain, in part because models do not adequately capture turbulent boundary-layer processes at small scales. Still, large-scale dynamics in the free troposphere could provide reliable constraints on local extreme winds. To investigate, we produce composites of ERA5 reanalysis fields during observed extreme wind events in selected Canadian cities. We include only the strongest 100 events in each season, robust across multiple weather stations in the city, to isolate “design-level” winds with potential for causing damage. In the winter and shoulder seasons, when most extreme wind events occur in these cities, composites show synoptic wave patterns and mesoscale frontal systems centred near the city. Typically, extremes at the stations occur in ERA5 10 m wind speeds within a two-day window of the observed event. Compositing separately across events that appear in both datasets and those not captured by ERA5 within this window reveals weaker wave amplitude and smaller frontal zones during the extremes found in the station data only. This suggests that these events may be driven by processes at smaller scales, challenging to capture within reanalysis.

Evaluating extreme wind speed in regional and global reanalysis products

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Due to continuous higher spatial and temporal resolutions, reanalyses are used by a steadily growing group of users. The development of new applications requires a comprehensive quality assessment focusing on different temporal scales, parameters and geographical areas. Within

the framework of the joint project ClimXtreme (https://www.climxtreme.net/), which is funded by the German Federal Ministry of Education and Research (BMBF), Deutscher Wetterdienst (DWD) evaluates the quality of its current reanalysis product COSMO-REA6 concerning the representation of extreme events like heat waves, windstorms and heavy precipitation. Therefore, COSMO-REA6 is evaluated and compared to known global reanalysis products such as ERA5 and several measurements (e.g. station based and gridded products). Reanalyses enable a comprehensive assessment of extreme events and relevant processes. Here we are aiming at an objective and systematic evaluation approach of extreme wind events in order to document related uncertainties and guide potential users.

Exploring Information Exchange in Climate System Applications.

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Quantifying Information exchange (IE) between sub-components in climate systems often assists in understanding the underlying system dynamics. We present various information theory estimators (linear and non-linear) and their application to idealized systems and climate applications. As expected the linear estimators work for linear systems but fail for strong non-linear systems. Among the non-linear estimators, TE-kraskov proved to be reliable than kernel and discrete binning estimators. However, all the non-linear estimators are sensitive to the free tuning parameters which are to be tuned and tested while applied. We apply these estimators to real-world climate system applications such as the interaction between the Indian and Pacific Oceans. An expected bi-directional IE is observed between these two sub-components. However, while these estimators are applied to the interaction between NAO and European Surface air temperatures, an unexpected bi-directional IE is observed. This hints of a possible hidden driver. We also applied these estimators to the Vb-events precipitation and its possible moisture sources. We observe that the northwest Mediterranean sea supplies moisture to the extreme Vb events. In a three climate system component interaction example, we observed a synergistic information exchange between IOD and ENSO to the monsoon precipitation during the summer season over central India. Furthermore, we also evaluated various global and regional climate simulations. We conclude that the information theory framework provides insights into the system dynamics in observations and also can be useful in model verification provided their limitations and sufficient time series length are taken into account.

Use of remote sensing retrievals of evapotranspiration based on reanalysis data for assessment of forested landscape drying

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A multi-sensor satellite data fusion approach to study the response of conifer forest evapotranspiration (ET) to drought and disease is applied. The work concerns a real forestry problem with health disturbance and patch wilting of conifers in the lower forest belt in Bulgaria (Eastern Mediterranean). It is accent on a specific case of progressive mass wilting after injuries by a snow storm in 2015 when broken trees become affected by a disease and subsequent desiccation. Ten years period (2011-2020) of reanalysis ET data from MSG reprocessing chain are used for diagnoses of forest cover health after the storm. For diagnosis, the Evapotranspiration Stress Index (ESI) is used to designate the intensity of water stress and correspondingly of disturbed ecosystems functionality. This is calculated on the bases of EUMETSAT LSA-SAF products of reference ET and actual ET. Using monthly means values, evaluation is based on the comparison of ESI on a site scale for a selected health and ill forest, and then this ESI difference is used as a reference for the whole target region. Georeferenced ESI information is used for constructing time series maps indicating the severity of conifer landscape injuries, and their spatial allocation, which appears to be maximal for July, August

2016 and 2017. The results are analysed to capture signals of drought, disease disturbance and subsequent recovery after restored water cycle at stand scale, and consequently are confirmed by using higher spatiotemporal resolution remotely sensed data of NDVI obtained by PROBA V environmental satellite. Analyses demonstrate differential response to water stress of conifers in health and infected areas, and the utility of Meteosat based information for water use change monitoring.

Regionalization of MERRA-2 50-m wind speed over the United States for Energy Applications

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[1]NASA GSFC GMAO, [2]USRA, [3]Science Systems and Applications, Inc. [Lanham]

Climate regionalization is a tool for dividing a large region into smaller regions that are coherent with respect to a chosen climate variable. Here we use climate regionalization on 50-meter wind speed over the United States from NASA's Modern-Era Retrospective Analysis for Research and Applications 2 (MERRA-2) to determine appropriate regions for studying wind resources. Identified regions are then examined further to assess drivers of inter-annual variability, including modes of climate variability. We will then explore how these results may be useful for predictability of wind resources over the United States.

Usage of reanalysis data for wind energy expansion in the North Sea and Baltic Sea

Spangehl, Thomas[1]; Borsche, Michael[1]; Niermann, Deborah[1]; Kaspar, Frank[1]; Tinz, Birger[1]
[1]Deutscher Wetterdienst

The exploitation of offshore wind energy is an essential part of the German energy transition (Energiewende). The regional reanalysis COSMO-REA6, operated by the German Meteorological Service (Deutscher Wetterdienst, DWD), and the global reanalysis ERA5, produced by the European Centre for Medium Range Weather Forecasts (ECMWF), are suited to support offshore wind farm planning in the German Exclusive Economic Zone of the North- and Baltic Seas. DWD delivers reanalysis data and statistical evaluation results to Federal Maritime and Hydrographic Agency (Bundesamt für Seeschifffahrt und Hydrographie, BSH) to facilitate offshore site tenders. Data and a report have been published in February 2021 as part of the tenders for 2021 (https://pinta.bsh.de/). The presentation gives an overview on the data and evaluation results. Examples are shown for two offshore sites in the North Sea and one in the Baltic Sea. The sites are located nearby FINO1 and FINO2 (Research platforms in the North Sea and Baltic Sea, https://www.fino-offshore.de/en/index.html) which enables a comprehensive evaluation of the wind speed and direction near turbine hub heights.

Tuesday, 14 Sep 2021

Poster session P2 - Observations

Assimilating atmospheric infrasound data to constrain atmospheric winds in a two-dimensional grid

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Infrasound waves travelling through atmospheric channels are affected by the conditions the encounter in their path. The shift in the backazymuth angle of a wave front detected a reception site depends on the cross-wind it encountered. Estimating the original field from this integrated measurement is an (ill-posed) inverse problem. By using a prior, this can be converted into a Bayesian estimation problem. In this work we use the (ensemble) Kalman filter to tackle this problem. In particular, we provide an illustration of the setup and solution of the problem in a two-dimensional grid, depending on both across-track distance and height, which has not been done in previous works. We use a synthetic setup to discuss the details of the method. We show that one of the effects of along-track averaging (something done in previous studies to simplify the problem) is to overestimate the magnitudes of the analysed values, and propose that this should a source of model error. We also illustrate the process with real data corresponding to nine controlled ammunition explosions that took place in the summer of 2018.

Assimilation of Web Camera Derived Estimates of Horizontal Visibility

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Conditions associated with limited horizontal visibility account for a disproportionate number of aviation related accidents in Alaska. This is in part due to the relatively sparse observing network in the region. In order to supplement traditional visibility observations the U.S. Federal Aviation Administration (FAA) maintains a network of high quality web cameras throughout the state. This work explores the potential for deriving automated estimates of horizontal visibility via image processing and assimilating the resulting estimates in NOAA's Real Time Mesoscale Analysis System. Results suggest that the web camera-derived estimates of visibility are effective for capturing visibilities associated with the most restrictive flight categories. The assimilation of these estimates can improve the resulting analysis. Implications for future studies and operations are discussed.

Ensemble Forecast Sensitivity to Observations applied to a regional data assimilation system over Argentina

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[1]Departamento de Ciencias de la Atmosfera y los Oceanos, [2]National Meteorological Service, [3]Consejo Nacional de Investigaciones Científicas y Técnicas [Buenos Aires], [4]Consejo Nacional de Investigaciones Científicas y Técnicas, [5]Central Weather Bureau

Observations that are assimilated into numerical weather prediction systems are conformed by numerous data sets and the impact of the observations must be objectively evaluated. The Forecast Sensitivity to Observation (FSO) provides an efficient impact evaluation of each observation on forecasts. This study proposes applying the simpler ensemble formulation of FSO (EFSO, Kalnay et al 2012) to the Weather Re-

search and Forecasting model coupled with the Local Ensemble Transform Kalman Filter in Argentina (Dillon et al 2019). The experiment is carried out during 25 days of the intensive observing period of the RELAMPAGO-CACTI field campaign that was conducted during the 2018-2019 austral warm season in the center of Argentina (Nesbitt et al 2021). Analyses were obtained every 6-h with a 20-km resolution, assimilating data from soundings, aircrafts, satelite, AIRS and surface and automatic stations. 6-hour forecast sensitivity is computed for each observation type. The results evidence that wind, temperature and humidity from automatic stations have nearly neutral impact on the forecast skill. Sounding, aircrafts and atmospheric infrared sounder observations present a larger positive impact. Also the spatial distribution of the sensitivity documents the beneficial impact of observations in the forecasts for the central area of Argentina. It is shown that the EFSO method can efficiently suggest data selection criteria.

Deriving observation impact measures through the FV3-JEDI interface

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The Joint Center for Satellite Data Assimilation (JCSDA) and its partners have been interfacing a variety of models to the Joint Effort for Data assimilation Integration (JEDI). These models include the NOAA's Global Forecast System (GFS) and NASA's Goddard Earth Observing System (GEOS). Efforts are presently on the way to complete implementation and testing of a full resolution cycled data assimilation for these two models. One feature of interest to be added to the implementation is the capability to evaluate the contribution of the observations to reduce forecast errors using the Forecast Sensitivity-based Observation Impact (FSOI) technique. We have added a preliminary, model agnostic, implementation of FSOI to the Object-Oriented Prediction System (OOPS) layer of JEDI. The present work applies this OOPS capability to generate FSOI for both GEOS and GFS. The presentation will discuss practical aspects of the implementation and provide preliminary results.

Status of Atmospheric Motion Vectors use in the NCEP GFS data assimilation system

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[(1)]IMSG, [(2)]NOAA/NCEP, [(3)]NOAA/NESDIS, [(4)]NOAA/AOML, [(5)]CIMSS/UWisconsin

The Global Observing System's upper-air observations component has improved with the launch of a number of next generation weather satellites. Advanced Baseline Imager (ABI) - class imagers with surpassing spatial and spectral capabilities are now on board the Himawari and GOES satellites. In addition, the Spinning Enhanced Visible and Infrared Imager (SEVIRI) on board the Meteosat Second Generation (MSG) Meteosat-8/11 has many of the spatial and spectral features as ABI. These technological advancements have led to new algorithm development and improved Atmospheric Motion Vector's (AMVs) data products from EUMETSAT, JMA and NOAA/NESDIS. New wind products are thoroughly studied, evaluated and tested before inclusion in the NCEP's Global Data Assimilation System (GDAS) as they become available. We will present results from recent model implementations allowing the use of Meteosat-8 and 11, Himawari-8, Goes-16/17 and S-NPP/NOAA-20 VIIRS winds, preparation for Metop-B/C AVHRR winds, and evaluation of LeoGeo and Aeolus winds. We will illustrate that improved handling of the AMVs leads to the development of a more robust forecasting system.

Estimates of radiosonde impact and their implications

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[(1)]ECMWF

The impact of each assimilated data value is estimated in the ECMWF system using Forecast Sensitivity to Observation Impact (FSOI). Aggregated statistics provide useful information on the relative impact of different variables, levels and geographic locations. For radiosondes and aircraft the wind FSOI is more than twice the temperature FSOI and reports in data sparse areas have larger impact than those in data dense areas. Recent work has shown that the impact of stratospheric radiosonde data north of 45N is much stronger in winter than in summer. This has possible implications for the targets set for radiosondes (numbers of profiles reaching 30 hPa or 10 hPa etc) and should encourage the use of larger balloons in winter - on average balloons burst at lower altitude in winter unless such measures are taken.

Assimilation of GK-2A clear sky radiance products in the KIM DA system

Jeong, Han-Byeol[(1)]**; Chun, Hyoung-Wook**[(2)]**; Kang, Jeon-Ho**[(1)]
[(1)]Korea Institute of Atmospheric Prediction Systems, [(2)]Korea Meteorological Administration

The Korea Meteorological Administration (KMA)'s operational global numerical weather prediction (NWP) system, named Korea Integrated Model (KIM), was developed by the KIAPS (Korea Institute of Atmospheric Prediction Systems) and it started to run in April 2020. GEO-KOMPSAT-2A (GK-2A, located in 128.2E) Clear Sky Radiance (CSR) data assimilation (DA) system that assimilates 3 water vapor channels has been developed as a part of the KIM DA system. The Advanced Meteorological Imager (AMI) onboard the GK-2A satellite, Korea's second geostationary satellite, is composed of 16 channels. The GK-2A's CSR product is defined as the output of the area-averaged brightness temperature for a given pixel in the clear sky area observed by the satellite. To better understand the products and enhance the quality control for the GK-2A CSR in the KIM Package for Observation Processing (KPOP), we had retrieved the main features of it compare to other CSR products such as Himawari-8 CSR and investigated the impact of its data assimilation. In this study, the quality control process for GK2A CSR will be described. And, preliminary results from the GK2A CSR data assimilation will be examined around South Korea.

An Evaluation for Impacts of Ocean Observing System in the NCEP GODAS

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The current National Centers for Environmental Prediction (NCEP) Global Ocean Data Assimilation System (GODAS) assimilates in situ profile data from EXpendable BathyThermograph (XBT) and Conductivity Temperature Depth (CTD), stationary fixed moorings, autonomous Argo floats, and remotely sensed sea surface temperature using a variational method of 3D-var in a daily cycle. The ocean model of GODAS is MOM3 with one degree horizontal resolution with 40 vertical levels. With GODAS, these data from ocean observing systems are fundamental to NCEP's operational efforts not only for monitoring the ocean state but also for forecasting multi-week to seasonal variability in the NCEP Coupled Forecasting System (CFS). In order to evaluate the impact of the observation system in the NCEP operational products, a series of observing system experiments (OSE) of 5-day/10-day cycle runs have been carried out, and the observational innovations and the analysis increments associated with individual ocean observations in NCEP's GODAS are calculated from the OSE runs. The impact of individual and regional obser-

vations, based on Assimilation Impacts of Observing Systems and Forecast Impacts of Observing Systems from the OSE runs, were estimated and applied to monitor the spatio-temporal impacts of ocean observing systems in the current operational NCEP GODAS.

Sea Surface Temperature analysis within the NCEP GFS

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The Sea Surface Temperature (SST) analysis within the NCEP GFS, referred to as NSST (Near-Surface Sea Temperature), became operational in July 2017. In the NSST, the SST, with the foundation temperature as the analysis variable, is analysed together with the atmospheric analysis variables, by Grid Statistical Interpolation (GSI), the atmospheric assimilation system in the NCEP GFS. The satellite observations are used as radiances, instead of retrievals, as in other SST stand-a-lone analysis systems. The background is persistence, but modified with diurnal warming and skin-layer cooling simulated by the NSST model and with a monthly SST climatology constraint. The NSST has undergone several upgrades since becoming operational in the NCEP GFS. With the initial implementation, it was found that small-scale spatial features are not well resolved and the cloud contamination of the partly clear AVHRR radiance cannot be discriminated well with the available GSI cloud detection scheme. To address these issues, a few NSST updates have been developed and tested with GFSv15.2 and GFSv16 recently. They are: the inclusion of VIIRS radiances, new background error correlation length scales, a smaller thinning box size for AVHRR and VIIRS radiances and exclusion of AVHRR partly-cloudy radiances. Experimental results have shown the NSST analysis can be improved significantly through the aforementioned modifications. Next steps include the addition of the NSST functionality in the Joint Effort for Data Assimilation Integration (JEDI) system and the use of the NSST in coupled data assimilation in the Unified Forecast System (UFS).

Observing System Simulation Experiments in the Brazil Current using SWOT synthetic data with HYCOM+RODAS

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The assimilation of SWOT altimetry data will play a key role in the understanding of ocean energy and mesoscale processes. In the present work, Observing System Simulation Experiments (OSSEs) were performed with the Hybrid Coordinate Ocean Model + Oceanographic Modeling and Observation Network Data Assimilation System (HYCOM+RODAS) with 1/24° of horizontal resolution and 21 vertical layers. The synthetic data of SST was obtained from a free run using ROMS, the SSH to nadir and SSH type SWOT were obtained from a simulator by Gaultier et al (2017). The objective of the work is to evaluate the impact of assimilating synthetic SWOT altimetry data with HYCOM+RODAS on the Brazil Current kinetic energy (11° - 34° S). Three experiments were carried out to achieve this goal: expt 1.0, assimilating only synthetic SST data; expt 1.1, assimilating synthetic SST and nadir SLA data; and expt 1.2, assimilating synthetic SST, nadir SLA data, and SWOT SLA data. The result of the generation of synthetic SSH data showed very high SWOT errors in the regions of the outer edges of each band of the satellite ground track. However, the system managed to assimilate this data as it was evident in the analysis increment along the SWOT tracks. Mean Kinetic Energy (MKE) and Eddy Kinetic Energy (EKE) fields improved both on the surface and in depth when SWOT synthetic data were assimilated in HYCOM+RODAS. The features in the MKE and EKE fields in expt 1.2 were more similar to those in the ROMS run. The best correlations for the SSH fields, zonal and meridional velocities with respect to ROMS were found in in expt 1.2. RMSE of SST with respect to ROMS in these three experiments was reduced by more than 50% when compared to the control run.

Influence of Snow Representation in Operational Seasonal Prediction Systems

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Recent seasonal forecast systems have difficulties predicting temperature over continental regions, whereas for some regions with maritime influence their performance is better. For continental regions, the land surface can become a more important source of predictability on (sub-)seasonal time scales. Snow is a crucial component of the land surface as it stores water and modulates the earth's radiation budget each winter season. A snow-covered land surface leads to local temperature decreases in the overlying air (snow-albedo effect and high emissivity) and melting snow cools the surface air and contributes to soil moisture and river water. We compare the snow representation in seasonal forecast systems from four European weather/climate services and their performance in predicting snow, temperature and precipitation. The goal is to identify the impact of the snow initialisation and snow modelling from the four forecasts systems. The first results show that the predicted anomalies of 2m temperature over continental regions correlate with reanalyses only for the first forecasted month, whereas anomalies in snow water equivalent can be predicted up to several months. While the biases among the forecast systems differ, the correlation skills are similar for the same variable, with precipitation having the lowest correlation skills. Furthermore, we will investigate the causal relationships between snow and 2m temperature with time-lagged correlation or similar methods.

A virtual network of ground-based microwave radiometers for monitoring of atmospheric stability and its potential impact in synergy with hyperspectral satellite observations.

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In this contribution, we show the potential of a network of ground-based MWR to complement observations of the future Infrared Sounder (MTG-IRS) and to provide information on atmospheric stability. The last is described in terms of CAPE and Lifted Index. We present a neural network retrieval of CAPE and LI from simulated IRS and MWR measurements based on the COSMO-REA2 reanalysis as truth. To assess the spatial representativeness of observations of a single ground-based MWR and to estimate the required network density the retrieval is applied to a 150*150km reanalysis domain. The impact of a MWR network was investigated in two ways. First, using spatial statistical interpolation, the fields of CAPE/LI retrieved from IRS observations were merged with the CAPE/LI values from MWR. Within this method, the contribution of ground-based network consisting of a varying number of radiometers was shown to be significant under cloudy conditions. The second approach mimics the assimilation of satellite and ground-based observations in the space of retrieved CAPE/LI fields. Assuming the persistence of atmospheric fields for a period of six hours, the CAPE/LI fields calculated from reanalysis were taken as a first guess in an assimilation step. Observations, represented by CAPE/LI fields obtained from satellite and ground-based measurements with +6 hours delay, were assimilated by spatial interpolation. Within this method, the added value of MWR observations is highly dependent on the current weather situation, cloudiness, and the position of MWR. As the next step, an observing system experiment is planned and will be performed to show the possible benefit of assimilation of ground-based MWR observations into the regional high-resolution ICON model.

Estimating the impact of commercial observations with an Ensemble of Data Assimilations approach

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The assessment of the impact of individual components of the observing system on forecast quality is traditionally conducted through Observing System Experiments (OSE) or Forecast Sensitivity - Observation Impact experiments (FSOI), when the real observations are available, or Observing System Simulation Experiments (OSSE) when observations must be simulated. When an ensemble forecast is available, an alternative approach has been shown to be a good alternative, at least qualitatively. This approach estimates the analysis uncertainty from the spread between the ensemble members. The change in spread between two different ensembles, one with and one without the observing system of interest, provides useful information about the impact of that observing system on forecast accuracy. This method was demonstrated using simulated data from the AEOLUS mission, and later applied at ECMWF with simulated GNSSRO measurements. Using the JEDI's Ensemble Data Assimilation function, JCSDA has conducted similar experiments with the GNSSRO commercial data acquired during NOAA Data Order 1 period (Dec. 15 - Jan. 15) using NOAA FV3-GFS operational ensemble 6-hours forecasts. In this preliminary study, we looked at the ensemble spread reduction after analysis and no forecast was performed. The spread reduction resulting from the assimilation of commercial observations can clearly be identified and its magnitude is consistent with spread reductions that have been previously observed at ECMWF with synthetic data. Those preliminary results give confidence that the method provides useful qualitative information about observation impact on analysis accuracy, and we are planning to expand the method as more commercial weather data are available.

Impact of Aircraft High-Density Observations on GFSv16 Tropical Cyclone Forecasts

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High-density observation (HDOB) data are assimilated in the operational Hurricane Weather Research and Forecast (HWRF) model. HDOBs include flight-level wind, temperature, and moisture measurements, and SFMR-derived surface wind speeds from the NOAA P-3, NOAA G-IV and Air Force Reserve Command C-130 aircraft. The assimilation of HDOB data in HWRF showed a considerable forecast benefit for tropical cyclone forecasts. Changes to the NCEP Global Forecast System (GFS) have been driven by the successes in HWRF data assimilation. In this study the NCEP pre-operational GFS version 16 (GFSv16) was used to examine the impact of HDOB data on the GFS forecast for hurricanes. GFSv16 is based on GFS version 15, with the finite volume cubed-sphere dynamical core and microphysics from GFDL. Changes in GFSv16 include increasing the vertical resolution from 64 to 127 levels and moving the model top to 80 km height, improved physics, using a Local Ensemble Kalman Filter with model space localization and linearized observation operator, and employing the 4-Dimensional Incremental Analysis Update technique (4D-IAU) for data assimilation (DA). The experiments to assimilate HDOB data were set up and run using the same GFSv16 pre-operational version for reforecast with a 6-hourly DA cycle, over selected periods with available HDOB data. Track and intensity have been analyzed and compared to the GFSv16 reforecast. Improvements are observed with less track error and an increase in track forecast skill for the Atlantic and West Pacific when the HDOBs data are used. For the Eastern Pacific basin, the impact is neutral on the track forecast and there is slight degradation in the intensity. Based on most of the positive impacts, the HDOB was added to GFSv16 for operations.

Impact of Atmospheric River Reconnaissance Dropsonde Data on GFS Precipitation Forecasts: A Case Study

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Atmospheric rivers (ARs) are long narrow corridors of water vapor transport that serve as the primary mechanism to advect moisture into mid-latitude continental regions, including the U.S. West Coast. They are responsible for most of the horizontal water vapor flux outside of the tropics and a source of precipitation. Although the advancements in satellite data assimilation has greatly improved global model forecast skill, including the NCEP global forecast system (GFS), forecasting the AR features remains a challenge due in part to their formation and propagation over the ocean, where in-situ and ground-based observations are extremely limited. The AR Reconnaissance (AR Recon) Campaigns provides additional data by supplementing conventional data assimilation with dropsonde observations of the full atmospheric profile of water vapor, temperature, and winds within ARs. In this study we used NCEP GFS version 16 (GFSv16) to examine the impact of the AR supplemental observations dropsonde data on GFS forecast.The dropsonde data used were from the AR Recon 2021 campaigns, including 29 intensive observation periods (IOPs) from Jan 17 to Mar 18. Global denial experiment was conducted near real-time by denying the dropsonde data in the GFSv16 from January 17 to March 25 for both DA and model forecast. Preliminary analysis indicates that there is significant improvement for the precipitation prediction over California during January 27-29 for an AR landfall event when the dropsonde data were used. This is a first case AR Recon provides six consecutive IOPs from January 23 to 28.The AR supplemental observations have helped to fill the data gap that is needed for the data assimilation to provide better GFSv16 model initial condition.

Interpreting estimated Observation Error Statistics of Weather Radar Measurements using the ICON-LAM-KENDA System

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Assimilation of weather radar measurements including radar reflectivity and radial wind data has been operational at the Deutscher Wetterdienst, with a diagonal observation error (OE) covariance matrix. For an implementation of a full OE covariance matrix, the statistics of the OE have to be a priori estimated, for which the Desroziers method has been often used. However, the resulted statistics consists of contributions from different error sources and are difficult to interpret. In this work, we use an approach that is based on samples for truncation error in radar observation space to approximate the representation error due to unresolved scales and processes (RE) and compare its statistics with the OE statistics estimated by the Desroziers method. It is found that the statistics of the RE help the understanding of several important features in the variances and correlation length scales of the OE for both reflectivity and radial wind data and the other error sources from the microphysical scheme, radar observation operator and the superobbing technique may also contribute, for instance, to differences among different elevations and observation types. The statistics presented here can serve as a guideline for selecting which observations to assimilate and for assignment of the OE covariance matrix that can be diagonal or full and correlated.

Tuesday, 14 Sep 2021

Poster session P2 - Methodology

Breakdown of the equivalence between two common preconditionnings in multi-incremental variational data assimilation

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Variational Data Assimilation (DA) schemes are often used to adress high dimensional non-linear problems in operational applications in the NWP domain. Because of the high computational cost of such minimization problems, various methods can be applied to improve the convergence at a reasonable numearical cost. One of these methods currently applied in operational DA schemes is the multi-incremental approach that consists in solving a succession of linearized versions of the original non-linear problem in several outer loops, by using well known algorithms (such as Lanczos) to ensure the convergence of the linear problem at the inner loop level, and using the solution of the inner loops to update the problem at each outer loop. In order to save computational cost, the multi-incremental multi-resolution method consists in starting the minimization at a lower resolution than the original one, and increasing it at the outer loop level until the full resolution of the problem. On the other hand, the conditionning of NWP problems is often poor, and one can use preconditionning techniques in order to improve the convergence. We have applied the multi-incremental multi-resolution scheme to a simplified problem in order to study the equivalence of two well known preconditionnings ("full" or "square root") in such a scheme and also present a new alternative method to update the problem at the outer loop level. We illustrate the differences with the standard method currently used and compare those two methods to the theoretical result. Some equivalence conditions between the updating methods and the two preconditionnings are drawn according to the way the resolution change is realised at the outer loop level.

Impact of assimilating SST vs nudging in an atmosphere ocean coupled model

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In the operational CFS, the surface sea temperature (SST) and surface sea salinity(SSS) at the surface layer is constrained by nudging to the Reynolds OI SST and the annual salinity climatology, respectively. However, this nudging towards SST leads to the alleviation of the SST biases in the CFS analysis. This influences the air-sea flux estimation and leads to a biased forecast. To address this issue, we replace the SST nudging with the Weakly Coupled Data Assimilation of the level 2 (L2) and level 4 (L4) SST products (Canada Meteorological Center). We ran a series of 1-month WCDA and nudging experiments using the CFSv2-LETKF. Our results show that, unlike nudging, WCDA can efficiently correct the existing SST biases and produce a more accurate SST analysis. This also improves the SST 1 to 10 days forecasts. WCDA of SSTs also reduces the RMS error in the atmospheric forecast variables not only at the surface but also at higher model levels.

JEDI application in Assimilation and Evaluation of GTS Synoptic Snow Depth Observations into NCEP Operational FV3GFS System

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The land analysis in the NOAA's Global Forecast System with FV3 dynamical core (FV3GFS) was conducted with the Global Land Data Assimilation System (GLDAS) using the Noah LSM (Land Surface Model) to evolve land states and to compute surface fluxes. The land states are updated using a “semi-coupled” approach, where these states are generated from a parallel GLDAS driven by observed precipitation and with near-surface forcing from the parent atmospheric data analysis system. However, assimilation of in-situ and remotely-sensed estimates of land-surface states such as soil moisture and snowpack are not supported yet in the operational GLDAS. The Joint Effort for Data assimilation Integration (JEDI) is a unified and versatile data assimilation (DA) system contributing to the Numerical Weather Prediction. NOAA/NCEP working with NOAA/PSL and JCSDA will set up necessary infrastructure to replace GLDAS with JEDI based land data assimilation system for use in initializing the NCEP operational FV3GFS forecast. A set of experiments using 3DVar and JEDI-based OI were conducted to evaluate the impact of assimilating the synoptic snow depth data. The qualities of the GTS synoptic snow depth data were assessed to flag or filter out the poor observations. Optimal parameters are determined by assimilating a single point observation into FV3GFS background setup through specific parameter tuning. We will explore the impact of the snow assimilation on FV3GFS forecasts and compare to the PSL's offline OI (optimal interpolation) benchmark tests.

A Comparison of Two Local Moment-Matching Nonlinear Filters: Local Particle Filter (LPF) and Local Nonlinear Ensemble Transform Filter (LNETF)

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The local particle filter (LPF) and the local nonlinear ensemble transform filter (LNETF) are two moment-matching nonlinear filters to approximate the classical particle filter (PF). They adopt different strategies to alleviate filter degeneracy. LPF and LNETF assimilate observations in a partially sequential and a simultaneous manner, respectively. In addition, LPF applies the resampling step, whereas LNETF applies the deterministic square root transformation to update particles. Both methods preserve the posterior mean and variance of the PF. LNETF additionally preserves the posterior correlation of the PF for state variables within a local volume. These differences lead to their differing performance in filter stability and posterior moment estimation. LPF and LNETF are systematically compared and analyzed here through a set of experiments with a Lorenz model. Strategies to improve the LNETF are proposed. The original LNETF is inferior to the original LPF in filter stability and analysis accuracy, particularly for small particle numbers. This is attributed to both the localization function and particle update differences. The LNETF localization function imposes a stronger observation impact than the LPF for remote grids and thus is more susceptible to filter degeneracy. The LNETF update causes an overall narrower range of posteriors that excludes true states more frequently. After applying the same localization function as the LPF and additional posterior inflation to the LNETF, the two filters reach similar filter stability and analysis accuracy for all particle numbers. The improved LNETF shows more accurate posterior probability distribution but slightly worse spatial correlation of posteriors than the LPF.

Updating and Testing the Snow Data Assimilation in the Unified Forecast System (UFS) Land surface model Noah

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Within the NOAA National Weather Service Unified Forecast System (UFS), land processes are simulated by Noah land surface model (LSM). Currently, snow depth and snow cover observations are assimilated in to the Noah model using rule-based approaches to update the snow states on a daily time step using the Air Force Weather Agency (AFWA) gridded snow depth analysis product (SNODEP) and snow cover data from NOAA/NESDIS (National Oceanic and Atmospheric Administration's National Environmental Satellite, Data, and Information Service) Interactive Multi-sensor Snow and Ice Mapping System (IMS). While the approach used at NCEP improved the forecasts over its predecessors, it now needs updating. Other global forecast centers use more advanced data assimilation approaches, compared to the one at the NCEP UFS, to assimilate ground observations of snow depth and snow cover data. In this study, we updated the snow data assimilation in UFS by implementing the 2D Optimal Interpolation (OI) method to assimilate daily snow depth observations from the Global Hydrologic Climatology Network (GHCN) and the NESDIS IMS snow cover data. The data assimilation scheme employed here is based on ECMWF's implementation, although we have made some changes to suit our particular implementation. Evaluation of the new OI DA in UFS shows marginal improvement of snow depth and significant increase in snow cover skills. The improved snow cover leads to reduced error in near surface air temperature. Following a successful demonstration of these improvements, the OI will be transitioned into operational use at NCEP.

Continuum Covariance Propagation for Understanding Variance Loss in Advective Systems

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At the heart of modern data assimilation schemes is covariance propagation. Loss of variance experienced in large-scale applications such as numerical weather prediction is problematic, and the development of auxiliary methods to mitigate this issue is an active research area. The focus of this work is to understand the root causes of variance loss and show that for advective dynamics, the covariance propagation by itself typically causes significant, spurious loss of variance, even at full rank. To demonstrate this, we first study continuum covariance propagation by analyzing the covariance evolution equation for advective dynamics. The behavior of this evolution equation changes abruptly as the correlation length tends to zero, for example in the vicinity of sharp gradients in the advection field. This happens because the diagonal of the kernel of the covariance operator is a characteristic surface for advective dynamics. Our numerical experiments then confirm that the variance lost during numerical propagation greatly exceeds that due to numerical dissipation alone. The variance loss is driven primarily by inaccurate variance propagation resulting from standard, full-rank covariance propagation schemes, which have difficulty capturing the abrupt change in dynamics as the correlation length tends to zero. These results suggest that developing local covariance propagation methods may prove useful in ameliorating the variance loss observed in data assimilation schemes.

A new way to infer non-Gaussian observation errors based on ensemble innovations

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The proper specification of the observation error is critical to a well-performing data assimilation system. The observation error can be divided into the measurement error, which is an inherent part of the results of the measurement, and the representation error, which is the uncertainty in the forward operator. The measurement error is usually well-known based on the design of the instrument, while the representation error is often less understood and often dominant. Previous studies have infered the observation error from the innovation statistics, often assuming that the background error in observation space and the observation error are Gaussian. However, this Gaussian assumption can be problematic, especially for nonlinear forward operators. This study infers a non-parametric observation error pdf based on a background ensemble without any assumption on the shape of the background error or observation error pdfs. The only assumption is that each ensemble member is statistically indistinguishable from the truth. Since the innovation pdf is the convolution of observation error and background error pdfs, the observation error pdf can be found by expressing the pdfs as histograms and solving a linear system. Experiments with toy systems and real cloudy observations show that this new method is able to retrieve non-Gaussian observation pdfs, even multimodal pdfs, demonstrating the potential of this method for complex representation errors in real atmospheric observations.

An Adaptive R Estimator with a Storm-Scale Particle Filter

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Ueno and Nakamura (2016) proposes the adaptive R estimator (ARE) with an ensemble Kalman filter for estimating flow-dependent observational errors in sea-surface-height observations by TOPEX/POSEIDON. ARE is a Bayesian estimator with a likelihood estimated with an ensemble and a prior R with a Wishart distribution. Kawabata and Ueno (2020) have developed a storm-scale particle filter with the JMA nonhydrostatic model, and ARE has been implemented in the filter, called as NHM-RPF (NonHydrostatilce Model R-estimating Particle Filter). NHM-RPF succeeded to represent non Gaussianity of initiation and development stages of a Cb with 1000 ensemble and showed the origin of the non Gaussianity was the updraft on the top of the boundary layer in an OSSE. For this success, ARE played an essential role in stable filtering. In the case that ARE was switched off, NHM-RPF illustrated worse scores than the no data assimilation experiment. The estimated R seemed to be reasonable and to follow the stages and course of the Cb. In this presentation, we will discuss detailed impacts of ARE in the experiment and also show another case with actual observations.

Local Ensemble Transform Kalman Filter Experiments with Hybrid Background Error Covariance: A Case with an Intermediate AGCM

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Recent operational numerical weather prediction (NWP) systems have achieved significant forecast improvements by using hybrid background error covariance (HBEC) that linearly combines climatological and ensemble-based error covariance. The HBEC has been used mainly in variational data assimilation systems to use the flow-dependent error covariance in addition to static error covariance. This study explores using the HBEC within the local ensemble transform Kalman filter (LETKF). The standard LETKF approximates the error covariance matrix by sample estimates using the flow-dependent ensemble perturbations. This study followed the Kretchmer et al. (2015)'s approach and implemented the HBEC by adding a collection of climatological perturbations to the forecast ensemble mean to boost the rank of the background error covariance. For HBEC, we propose a new localization (Z-localization) that attenuates ensemble perturbation instead of inflating observation error variance (R-inflation). The Z-localization enables multi-scale localization by applying different localization scales to flow-dependent and cli-

matological perturbations. We tested the HBEC and new localization with an intermediate atmospheric model known as the SPEEDY (Simplified Parameterizations, Primitive Equation Dynamics). Our preliminary results are promising, and the HBEC successfully reduced analysis errors compared to the standard LETKF. This presentation will include the most recent progress up to the time of the symposium.

Numerical discretization causing error variance loss and the need for inflation

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The effects of model discretization errors on the propagation of error covariance are different and more complex than the effect of model discretization errors of a state variable. The analysis is carried out for the advection transport equation, where the continuous (space/time) propagation of the related error covariance function can be written, solved and compared with the discrete model applied on the covariance matrix. The numerical analysis of the problem is carried with a 1D-problem, but is also illustrated with a 3D-chemical transport model used for chemical data assimilation of satellite observations. It is shown that variance loss (compared to the continuous propagation solution) depends on the covariance function itself as well as the numerical discretization scheme. The variance loss is particularly sensitive to the correlation length and model discretization. In a simple first-order discretization an analytical expression is obtained and is used to obtain an analytical expression for inflation. Experiments shows that for example that right after an analysis using a dense network of observations (with spatially uncorrelated errors) results in a very significant variance loss, over the observed region. This effect occurs between analysis times during time propagation. With the (variance) inflation scheme, we are able to restore the variance loss at each grid point, at each time steps, during the whole time of integration. The variance inflation scheme applied to an EnKF can be formulated to change the variance spread of the ensemble or directly on the state variables.

Assimilation of Nonlinear Observations with the Maximum Likelihood Ensemble Filter

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We investigate the performance of the Maximum Likelihood Ensemble Filter (MLEF) in assimilation of nonlinear observations. MLEF is a variational-ensemble data assimilation method, and can treat differentiable or non-differentiable nonlinear observation operators. In this study, we compare MLEF with the Ensemble Transform Kalman Filter (ETKF) in assimilation experiments with a one-dimensional Burgers model. The ETKF analysis with a certain formulation of nonlinear operators diverges when the observation nonlinearity is strong and the observation error is small. This divergence is found to be associated with an extra rank of ensemble perturbation matrix. Optimization in MLEF can improve the analysis to the level comparable to or better than ETKF. In addition, the smaller observation error is, or the stronger observation nonlinearity is, MLEF with the nonlinear operators can assimilate observations more effectively than MLEF with the tangent linear operators. However, the strong nonlinearity hinders convergence. We found that re-evaluation of the Hessian preconditioning matrix can alleviate such poor convergence. These encouraging results indicate that MLEF can incorporate nonlinear effects and evaluate observations appropriately.

A hybrid nonlinear-Kalman ensemble transform filter for data assimilation in systems with different degrees of nonlinearity

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A hybrid nonlinear-Kalman ensemble transform filter (LKNETF) algorithm is build by combining the second-order exact particle filter NETF (nonlinear ensemble transform filter) with the local ensemble transform Kalman filter (LETKF). The hybrid filter combines the stability of the LETKF with the nonlinear properties of the NETF to obtain improved assimilation results for small ensemble sizes. Both filter components are localized in a consistent way so that the filter can be applied with high-dimensional models. The degree of filter nonlinearity is defined by a hybrid weight, which shifts the analysis between the LETKF and NETF. Since the NETF is more sensitive to sampling errors than the LETKF, the latter filter should be preferred in linear Gaussian cases. An adaptive hybrid weight can be defined based on the nonlinearity of the system so that the adaptivity yields a good filter performance in both linear and nonlinear situations. In particular the skewness and kurtosis of the ensemble can be applied to quantify the non-Gaussianity. The filter behavior is exemplified based on experiments with the chaotic Lorenz-63 und -96 models, in which the nonlinearity can be controlled by the length of the forecast phase. In these experiments the hybrid filter can yield an error reduction of up to 28% compared to the LETKF.

CAFE60v1: The CSIRO Climate retrospective Analysis and Forecast Ensemble system: version 1: System design, model configuration and data assimilation.

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We detail the system design, model configuration and data assimilation of the CSIRO Climate retrospective Analysis and Forecast Ensemble system: version 1. CAFE60v1 has been designed with the intention of simultaneously generating both initial conditions for multi-year climate forecasts and a large ensemble retrospective analysis of the global climate system from 1960 to present. Strongly coupled data assimilation (SCDA) is implemented via an ensemble transform Kalman filter in order to constrain a general circulation climate model to observations. Satellite (altimetry, sea surface temperature, sea ice concentration) and in-situ ocean temperature and salinity profiles are directly assimilated each month, whereas atmospheric observations are sub-sampled from the JRA-55 atmospheric reanalysis. Strong coupling is implemented via explicit cross domain covariances between ocean, atmosphere, sea ice and ocean biogeochemistry. Atmospheric and surface ocean fields are available at daily resolution and monthly resolution for the land, subsurface ocean and sea ice. The system produces 96 climate trajectories (state estimates) over the most recent six decades as well as a complete data archive of initial conditions potentially enabling individual forecasts for all members each month over the 60 year period. The size of the ensemble and application of strongly coupled data assimilation lead to new insights for future reanalyses.

Assimilation of SMAP Brightness Temperature Observations in the GEOS Land-Atmosphere Data Assimilation System

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Errors in soil moisture adversely impact the modeling of land-atmosphere water and energy fluxes and, consequently, near-surface atmospheric conditions in atmospheric data assimilation systems (ADAS). To mitigate such errors, a land surface analysis is included in many such systems, although not yet in the currently operational NASA Goddard Earth Observing System (GEOS) ADAS. This study investigates the assimilation of L-band brightness temperature (Tb) observations from the Soil Moisture Active Passive (SMAP) mission in the recently developed GEOS weakly-coupled land-atmosphere data assimilation system (LADAS) during summer 2017. The SMAP Tb analysis improves the correlation vs. in situ measurements of LADAS soil moisture by ~0.1-0.26 over that of the ADAS; the unbiased root-mean-square error (ubRMSE) of LADAS soil moisture is reduced by 0.002-0.008 m3 m-3 from that of ADAS. Furthermore, the global average RMSE vs. in situ measurements of LADAS screen-level air specific humidity (q2m) and daily maximum temperature (T2mmax) is reduced by 0.05 g kg-1 and 0.04 K, respectively, from that of ADAS. Regionally, the RMSE of LADAS q2m and T2mmax is improved by up to 0.4 g kg-1 and 0.3 K, respectively. Improvements in LADAS specific humidity extend into the lower atmosphere (below ~700 mb), with relative improvements in q2m bias and ubRMSE of 15-25% and 1-3%, respectively. LADAS air temperature bias slightly increases but ubRMSE is reduced relative to that of ADAS. Finally, the root-mean-square of the LADAS Tb observation-minus-forecast residuals is smaller by ~0.1 K than in a land-only assimilation system, which corroborates the positive impact of the Tb analysis on the modeled land-atmosphere coupling.

Towards the assimilation of microwave vegetation optical depth into global land surface models

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Only a few recent studies have considered assimilating microwave vegetation optical depth (VOD) to improve estimates of vegetation states in land surface models (LSMs) with dynamic vegetation. These studies showed that VOD assimilation can improve estimates of GPP, ET, and CO2 concentrations. We intend to assimilate VOD from merged products, as well as from multiple individual passive and active microwave sensors, using the NoahMP and SURFEX-ISBA LSMs. This poses several challenges, in particular developing observation operators for VOD for the different sensors, or characterizing model and observation error structures. We will present various linear and nonlinear approaches to map variables simulated by the models to VOD observations. These will be evaluated with respect to their performance with merged VOD products from the VOD Climate Archive (VODCA) for different bands (Ku/X/C/L), and on single-sensor VOD retrievals from LPRMv6. Additionally, we will assess the added value of including plant water status related variables compared to using only optical vegetation indices as predictor variables for VOD. Acknowledgements: This work is part of the projects CONSOLIDATION, funded by the Austrian Science Fund (FWF), and the CCN1 CCI+ Soil Moisture Scientific Evolution, funded by ESA.

A variational particle filter

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Particle filters or Sequential Monte Carlo techniques are used in data assimilation for state estimation. Unlike other Kalman-like methods, particle filters work with fewer assumptions and are generic in nature. Standard variational particle techniques involve minimizing the KL Divergence between the prior and a Bayesian posterior via kernel embeddings. However, these methods require rigorous tuning in a high-dimensional setting. In this work, we propose to perform the aforementioned minimization without kernel embeddings. We perform a sequence of transformations to push the particles towards the posterior. With this in mind, we have developed methods for both filtering and smoothing. We have run experiments on Lorenz '63, Lorenz '96 and the quasi-geostrophic equations that show promising results qualitatively(rank histogram) and quantitatively(RMSE) when compared to the Mapping Particle Filter, the Ensemble Transform Particle Filter and the Ensemble Kalman Filter.

Wednesday, 15 Sep 2021

Poster session P3 - General DA

High-Resolution Regional Ocean Data Assimilation in JEDI-SOCA framework: Hurricane Supplemental Project at NOAA-EMC

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Preliminary regional ocean data assimilation (DA) and initialization experiment results using the Modular Ocean Model Version 6 (MOM6) are presented based upon the Joint Effort for Data assimilation Integration - Sea Ice Ocean and Coupled Assimilation (JEDI-SOCA) framework. Our goal is to support the UFS-based coupled Hurricane Analysis and Forecast System (HAFS) development with improved, realistic initial ocean conditions. Along with various in-situ and satellite retrieval data sets, high-density marine observations including glider and HF-radar are assimilated using a 3DVar method. Cycled experiments have been performed for the 2020 Hurricane season with a specific focus on diagnostic evaluation of ocean conditions during Hurricane Isaias. Our analysis results are cross-validated against various independent ocean analysis products, such as the Real-Time Ocean Forecast System - Data Assimilation (RTOFS-DA), Navy Coupled Ocean Data Assimilation (NCODA), and the Operational Sea Surface Temperature and Ice Analysis System (OSTIA). Further, we conducted preliminary observation data denial experiments to investigate the impact of specific marine observation datasets on initial ocean states. In our studies, we focused on ocean dynamics in both the surface and subsurface layers along the hurricane track. As a future goal, we seek to use these MOM6 JEDI-SOCA results to better constrain ocean properties such as mixed layer temperature and salinity, as well as ocean heat content and heat fluxes for improved coupled hurricane forecasts.

Assimilation of Aerosol Observations in the NASA GEOS model

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In the GEOS near real-time system and in the latest MERRA-2 reanalysis produced at NASA's Global Modeling Assimilation Office, the assimilation of aerosol observations is performed using a so-called analysis splitting method. In this scheme, a 2D analysis of AOD is first performed, using error covariances derived from innovation data. Then, the 3D analysis increments of aerosol mass concentration are computed using an ensemble formulation for the background error covariance. The prognostic model underlying this data assimilation system is based on the GEOS earth system model radiatively coupled to GOCART aerosol module. Leveraging progress made in the JCSDA-JEDI framework, the GMAO is transitioning its aerosol data assimilation scheme to a hybrid ensemble-variational scheme. This new scheme brings the flow-dependence in the background error specification inherent in ensemble methods but retains some of the flexibility of variational methods, permitting assimilation of multi-spectral passive and active aerosol measurements. Within this new system, we continue to employ an analysis splitting strategy, this time upgrading the control variable to vertically resolved aerosol extinction. In addition, the observing system is being expanded to include observations of multi-wavelength AOD from geostationary sensors. In this talk, we will examine the impact of replacing the control variables in the analysis splitting scheme, going from single-wavelength AOD to extinction profiles at multiple wavelengths. The analysis step is also being upgraded from a 2D PSAS-based analysis to a JEDI- based hybrid approach. We will discuss the impact of including multi-wavelength AOD retrievals, and the impact of geostationary aerosol data.

Studying Causal Mechanisms of the Ocean with the ECCO Estimate: Beaufort Sea Sea-Level and Freshwater-Content Change

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The “Estimating the Circulation and Climate of the Ocean” (ECCO) consortium provides physically-consistent multi-decadal model-data syntheses of the complete, three-dimensional, time-varying, global ocean state and the underlying processes governing its dynamical evolution. In this talk we demonstrate how ECCO's strict adherence to conservation principles and the availability of its model's adjoint allow interrogation of these processes to gain novel insights into the causal mechanisms driving observed ocean climate variability — here, the rapid sea-level rise and freshwater accumulation in the Western Arctic's Beaufort Sea over the last two decades. Using the adjoint model, we calculate the sensitivity of Beaufort Sea's variation with respect to its forcings and employ it as a kernel to expand the variation in terms of those forcings, viz., surface heat, freshwater, and momentum fluxes, so as to quantify their relative contributions in space and time. After showing that wind stress and surface freshwater flux anomalies explain the observed sea-level and freshwater content rise, we then analyze the region's property budgets and quantify that wind-driven convergence and melting of sea ice dictate the freshwater flux and are as important as Ekman ocean volume transport for the observed Beaufort Sea variation. The suitability of the ECCO estimate and its adjoint model for investigating causal mechanisms of other types of ocean dynamical variation is briefly described.

Impact of COVID-19 measures on the air quality, monitored for the state of Himachal Pradesh: A Google Earth Engine Based Study

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The World Health Organization (WHO) declared the COVID-19 outbreak a pandemic on March 11, 2020, and advised countries to take immediate and concerted action. Governments of India and Himachal Pradesh carried out preventive and precautionary steps to minimize the spread of coronavirus disease. In this study, the impact of a sudden halt in human activity on air quality was investigated by looking at changes in satellite imagery using a remote sensing approach. The concentrations of the gaseous contaminants studied (CO, SO2, NO2, and C6H6) show a significant decrease during the lockdown, which is consistent with findings published in many reputed journals where studies were carried out in foreign cities and metropolitan areas. The average concentrations of particulate matter (PM10 and PM2.5) differed significantly from those of gaseous emissions, meaning that particulate matter has a greater effect occurring from anthropogenic activities.NO2 concentrations and NOx emission variations were tracked for rural/town areas around Himachal Pradesh and major urban cities of India. Daily top-down NOx emissions were measured using the TROPOspheric Monitoring Instrument (TROPOMI), which assisted in retrieving NO2 from the steady-state continuity equation. The emissions of NOx from rural, urban, and power plants were compared before and after the lockdown. The research was done in a phased manner to account for the second wave of COVID-19 for our studies. The levels of NO2, Ozone (O3), and sulfur dioxide (SO2) were monitored, using Sentinel-5P imagery using the GEE platform and photochemical processes being the cause of O3 formation concluding our study.

Evaluation of ECCO Currents in the Pacific Equatorial Undercurrent

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The representation of horizontal currents produced by the Estimating the Circulation and Climate of the Ocean (ECCO) global ocean state estimate, an inverse modeling framework constrained with nearly all available in-situ and satellite ocean observations, was evaluated with moored acoustic Doppler current profiler (ADCP) measurements recorded on the equator in the Equatorial Undercurrent (EUC) at 165E, 170W, 140W and 110W. ADCP data were not assimilated. Record lengths of 1-h data were at least 10 years. Artificial gaps in ECCO matched ADCP gaps. The average ADCP EUC core speed was nearly 100% larger than that computed with ECCO; the average ADCP standard deviation was 30% higher than ECCO. The average ADCP-ECCO correlation coefficient was higher than 0.71, indicating that more than 50% of the variance was linearly related. At each site the mean depth of the ADCP core speed was greater than with ECCO. The upward slope towards the east of mean ADCP core speeds from 165E to 170W was double that of ECCO and only slightly smaller compared to ECCO from 170W to 140W and 140W to 110W. The ADCP and ECCO EUC transports per unit width (TPUW) computed for currents greater than 0.2 m/s indicated an inflow of mass into the EUC as it flowed from 165E to 170W to 140W and then an outflow from 140W to 110W, with different magnitudes for ADCP and ECCO. As the EUC flowed eastward, the average correlation coefficient between ADCP and ECCO TPUWs was above 0.71. These and other results will be discussed.

Atmospheric radiance variation: On the basis of atmospheric aerosols in different locations Iran

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In this paper, variability of atmospheric radiance based on some fundamental atmospheric parameters was considered. Atmospheric optical indices in near infrared and visible channels including aerosol optical depth, Angstrom Exponent, albedo and visibility are studied. Subsequently, atmospheric radiance and its variability were calculated using Modtran algorithm. The incoming data are achieved from MERRA, GLDAS and space-borne observing platforms for 10 different locations including urban, continental, polluted, industrial, rural and dusty over Iran during 2000 to 2020. Results show that the maximum variability for NIR and VIS albedo is about 14% and 4.4%, respectively. Moreover, total aerosol extinction varies 22 percent in different locations. Consequently, atmospheric radiance varies 13% in visible region. Results indicate that the variation in aerosol optical indices can affect the atmospheric radiance and despite the improvements in knowledge about aerosol forcing, a great deal remains uncertain. The results also exhibited that urban locations have a significant role in variation of radiance.

Assimilating TROPOMI Nitrogen Dioxide Retrievals in NOAA's Next-Generation Regional Air Quality Forecasting System

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Current estimates of annual mortality from poor air quality are over 100,000 per year in the United States, far exceeding all other weather hazards combined, which are lower than 600 per year. At the National Centers for Environmental Prediction (NCEP), progress is being made to improve global and regional air quality and aerosol forecasting through collaborative efforts on both model improvements and enhanced data assimilation capabilities. As part of the Unified Forecast System (UFS) effort, a new regional, convection-allowing modeling system, the Rapid Refresh Forecast System (RRFS), is being developed. Within the RRFS, a new regional air quality prediction system is also being developed, using the Limited Area Model (LAM) version of FV3 coupled with the Community Multiscale Air Quality (CMAQ) model to provide inline atmospheric chemistry. Here we present results demonstrating the ability to assimilate tropospheric columns of nitrogen dioxide from TROPOMI into the LAM-CMAQ model, using a Joint Effort for Data assimilation Integration (JEDI) based 3DVar system. Sensitivity to observation thinning and quality control are shown. Limitations of the current system are also discussed, including those associated with limited observation availability, as well as the influence lateral and surface boundary conditions have on the results.

Ocean data assimilation for ICON-Seamless

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The method of the "Parallel Data Assimilation Framework" (PDAF) "Ensemble Kalman Filter" (EnKF) is used here as a test case for the assimilation of observed ocean 3-d temperature and salinity fields into the coupled climate model "Icosahedral Nonhydrostatic" (ICON) for seasonal to

decadal climate prediction. This ocean-only assimilation serves as a first step towards a weakly coupled data assimilation with ICON. An assimilation run over the period 1960-2014 is produced and analyzed in terms of the degree of realism of its climate variability. This assimilation run is used to initialize an ensemble of 10 hindcast simulations. The hindcasts are analyzed in terms of prediction skill and used to identify problems emerging from this method.

Validation of MODIS, MISR and OMI aerosol optical depth with globally distributed AERONET data over the Middle East region

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In order to ensure the reliability of satellite-based observation, this study validated the aerosol optical depth (AOD) data from three different instruments including MODIS, MISR, and OMI, against the Aerosol Robotic Network (AERONET) stations across the Middle East from 2012 to 2017. The daily level 2.0 AERONET is used for the validation of satellite retrievals at six stations across the Middle East. Errors of aerosol products were examined using the Pearson correlation coefficient, the relative mean bias (RMB), and the root-mean-square error (RMSE). Comparison between the daily averaged AOD values derived from each instrument and AERONET derived AOD values indicates that all studied platforms show the annual variation of AOD over the region. MODIS and MISR AOD show a reasonable correlation with AERONET data almost all over the Middle East, i.e. the average Pearson correlation coefficient for both of these sensors is about 0.7. The differences in the correlation coefficients in each station may be caused by different aerosol species. It should be mentioned that MODIS has the highest number of available daily data, while MISR has the least. However, the smallest average RMSE values of about 0.15 belong to the MISR data while the largest errors were found for MODIS, where the average RMSE value is about 0.3. Results also show that there is a general overestimation of all satellite-derived AOD in six sites, i.e. the RMB values are more than 1. On the other hand, two sites namely KAU and CAI, in Saudi Arabia and Egypt, respectively, show underestimation in AOD values, which is likely attributed to the inaccurate assumptions of aerosol mixtures in the aerosol algorithm and the contribution of coarse mode aerosols in these two stations.

Mesoscale and wind-driven intra-annual variability in the East Auckland Current

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Intra-annual variability in the East Auckland Current (EAuC) was studied using a year-long timeseries of in situ and remotely-sensed velocity, temperature and salinity observations. Satellite-derived velocities correlated well ($r > 0.75$) with in situ observations and well-represent the long-term (> 30 days) variability of the upper ocean circulation. Four mesoscale eddies were observed during the year (for 260 days) which generated distinct flows between the continental slope and rise. The EAuC dominated the circulation in the continental shelf break, slope and rise for 110 days and generated the most energetic events associated with wind forcing. Current variability on the continental slope was coherent with along-slope wind stress (wind stress curl) at periods between 4 and 12 days (16 and 32 days). We suggest that along-slope winds generated offshore Ekman transport, uplift on the shelf-break, and a downwind geostrophic jet on the slope. In contrast, positive wind stress curl caused convergence of water, downwelling, and increased the current speed in the region. Bottom Ekman transport, generated by the EAuC, was suggested to have caused the largest temperature anomaly ($-1.5°C$) at the continental shelf-break. Numerical simulations were

conducted to provide a 3D picture of the EAuC and its wind-driven variability. Moreover, data assimilation of satellite and in situ observations is being implemented into the model to generate more realistic simulations.

Impact of ocean observation systems on ocean analyses and subseasonal forecasts in the Indo-Pacific region

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We evaluate the relative merits of different ocean observation systems (moored buoys, Argo, satellite, XBTs, and others) by their impact on ocean analyses and subseasonal forecast skill of weather and climate phenomena in the Indo-Pacific region. Several ocean analyses were performed where different ocean observation platforms were withheld from the assimilation in addition to one ocean analysis where all observations were assimilated. We then use these ocean analyses products for initializing a set of subseasonal forecasts to evaluate the impact of different ocean analyses states on the forecast skill. We use the European Centre for Medium-Range Weather Forecasts (ECMWF) ensemble prediction system for the twenty-year sub-seasonal hindcast experiments. Results from these hindcast experiments will be presented to highlight changes in the ocean analysis states and their impact on the forecast skill in the Indo-Pacific region. Coupled air-sea interaction processes relevant to intraseasonal variability in the earth's climate system are inadequately represented in regional and global coupled models. These inaccuracies could be related to either poor parameterization of model physics or insufficient model resolution to resolve the critical processes. New efforts in observations, process understanding, and translation into weather and climate models are necessary for improvements in simulation and prediction of the intraseasonal variability and associated weather events. We will discuss the merits of different ocean observation platforms in this context and also future observation and model improvement pathways for better understanding and simulation of climate variability in the Indo-Pacific region.

Assimilation of AOD retrievals in GEFS-Aerosols using a JEDI-based 3D-EnVar Hybrid System

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We have undertaken a series of assimilation experiments using the hybrid 3d-EnVar system, which is being developed as part of the Joint Effort for Data Assimilation Integration (JEDI). It uses the Finite-Volume Cubed-Sphere Dynamical Core (FV3) combined with an aerosol parameterization from the Goddard Chemistry Aerosol Radiance and Transport (GOCART) model. This is part of the development work for the NCEP Global Ensemble Forecast System - Aerosols (GEFS-Aerosols) operational forecasting system. The assimilation uses forecast error covariance estimates weighted between a forecast ensemble and a static background (B), which is parameterized using the B matrix on an Unstructured Mesh Package (BUMP) algorithm. This system assimilates aerosol optical depth (AOD) retrievals from the Moderate Resolution Imaging Spectroradiometer (MODIS) on board the Aqua and Terra satellites, and the Visible Infrared Imaging Radiometer Suite (VIIRS), on the Suomi NPP satellite. The assimilation allows for indirect comparisons from these sensors through the observed minus forecast (O-F) resultant changes. Further comparisons are made with in situ measurements from the NASA airborne Atmospheric Tomography (ATom-1) campaign in July-August, 2016.

Biases at the base of the mixed layer induced by 3DVar assimilation of sea surface temperature observations in ocean models.

While, James[(1)]; Martin, Matthew[(1)]; King, Robert[(1)]
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Propagating sea surface temperature (SST) information to depth is a non-trivial problem in ocean data assimilation as the vertical correlations of temperature are complex. At the Met Office a parameterised function is used to specify the vertical length scales. At the surface the vertical length scale is the mixed layer depth before reducing to twice the grid scale at the base of the mixed layer. While producing accurate SST analyses/forecasts, this methodology can produce undesirable features near the base of the mixed layer. A complex interaction between the mixed layer depth and the increments often leads to positive increments being projected deeper on average than negative increments, leading to a positive temperature bias below the mixed layer. Another issue is the generation of excess mixing across the mixed layer. We have been investigating ways to reduce these issues, and we show results from experiments testing different techniques. Experiments have been conducted using both a 1-D model and a global ocean system. Assimilation was done with a 3DVar methodology. None of the methods investigated eliminated the vertical problem, but some did reduce it. In one key test It was found that applying a compensating gradient to salinity increments across the mixed layer, such that the increment to density has zero gradient, can be effective. This came at the cost of increased salinity error. Future work will look at ensemble methods to resolve the issue.

Wednesday, 15 Sep 2021

Poster session P3 - Methodology

Reconstructing the dynamics of the outer electron radiation belt by means of the standard and ensemble Kalman filter with the VERB-3D code

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Reconstruction and prediction of the state of the near-Earth space environment is important for anomaly analysis, development of empirical models and understanding of physical processes. Accurate reanalysis or predictions that account for uncertainties in the associated model and the observations, can be obtained by means of data assimilation. The ensemble Kalman filter (EnKF) is one of the most promising filtering tools for non-linear and high dimensional systems in the context of terrestrial weather prediction. In this study, we adapt traditional ensemble based filtering methods to perform data assimilation in the radiation belts. We use a one-dimensional radial diffusion model with a standard Kalman filter (KF) to assess the convergence of the EnKF. Furthermore, with the split-operator technique, we develop two new three-dimensional EnKF approaches for electron phase space density that account for radial and local processes, and allow for reconstruction of the full 3D radiation belt space. The capabilities and properties of the proposed filter approximations are verified using Van Allen Probe and GOES data. Additionally, we validate the two 3D split-operator Ensemble Kalman filters against the 3D split-operator KF. We show how the use of the split-operator technique allows us to include more physical processes in our simulations and offers computationally efficient data assimilation tools that

deliver accurate approximations to the optimal solution of the KF and are suitable for real-time forecasting. Future applications of the EnKF to direct assimilation of fluxes and non-linear estimation of electron lifetimes are discussed.

Online nonlinear bias correction in ensemble Kalman filter to assimilate GOES-R all-sky radiances for the analysis and prediction of rapidly developing supercells

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Past studies have shown the superiority of online bias correction in the context of clear-sky radiance assimilation. However, so far only the offline method is implemented to remove complex bias present in all-sky radiance observations for convective scale data assimilation. The current study is the first to explore online non-linear bias correction for GOES-R all-sky radiances in a convective scale rapid cycling EnKF data assimilation system. Experiments are designed and performed for rapidly developing supercell cases with RADAR reflectivity observations served as the anchoring observations. The online nonlinear bias correction approach is compared with an equivalent offline nonlinear approach. The results show that by using the unbiased anchoring RADAR observations, the online approach results in a less biased background and analysis compared to the offline approach. It is also found that the online nonlinear bias correction method results in physically consistent addition of humidity and hydrometeors over observed storm location compared to offline bias correction during the rapid cycling data assimilation. Subsequent forecasts of two long track supercells using the online approach are significantly improved.

Improving Tropical Cyclone Predictions by Assimilation of Satellite-Retrieved Surface Precipitation with Gaussian Transformation

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Assimilation of precipitation is challenging because: a) errors associated with precipitation are not Gaussian, and b) forcing the model to rain where observed by moistening or drying the atmosphere, does not change the main dynamical variable (potential vorticity) and thus is forgotten once the forcing of the "assimilation of moisture" ceases. Lien et al. (2013, 2016) and Kotsuki et al. (2017) developed a methodology that addressed these problems: They performed Gaussian transformation (anamorphosis) and transformed precipitation into variables with more Gaussian-like errors. Their ensemble-based assimilation approach directly adjusted the model dynamic variables, thus creating an analysis that is closer to having the right dynamics. As a result, Lien et al. (2016) showed improved forecast skill up to five days. We extend this methodology for the tropical cyclone (TC) predictions. Experiments with assimilation of GPM surface precipitation retrievals are conducted over the Western Pacific for four typhoons in 2015. The results show that assimilation of precipitation can effectively improve the sea level pressure and hydrometeor analysis of TCs. Verification against the GPS RO wet profiles reveals that precipitation assimilation reduces the root mean square errors for temperature and humidity analysis (forecast) near the TC center. Overall, the track forecasts are all improved over three days, and the minimum sea level pressure forecasts are improved beyond 36 hours due to precipitation assimilation.

Multi-layer Observation Localization for Nonlocal Observations in the LETKF

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Assimilating nonlocal observations within the Ensemble Kalman Filter is known to be a nontrivial problem. Unlike conventional observations with well-defined locations when observed, nonlocal observations (e.g., radiances, altimeter observations) are intrinsically integrated measurements in space, and thus have no single well-defined observation location. Nevertheless, a single-layer vertical localization (SLVL) approach widely used to handle these nonlocal observations, is to vertically localize them at their weighting function (WF) peaks with symmetric Gaussian-shape localization functions. While this approach can properly assimilate those observations with narrow symmetric WFs, it has difficulties handling observations with broad asymmetric WFs, or multiple WF peaks, which are typical for clear-sky radiance observations from infrared hyperspectral sounders. We developed a multi-layer vertical localization (MLVL) method for nonlocal observations in the Local Ensemble Transform Kalman Filter. The traditional SLVL can be viewed as a particular case of our newly-formulated MLVL. We compared the performance of MLVL and SLVL by assimilating simulated nonlocal observations with a multi-layer quasi-geostrophic model under three scenarios: assimilating nonlocal observations with (a) narrow WFs, (b) broad WFs, and (c) multiple WF peaks. The results show that MLVL has comparable performance as SLVL when assimilating narrow-WF observations, and superior performance than SLVL when assimilating observations with broad WFs or multiple WF peaks.

Evaluation of Observation Impact and Low-Skill Forecasts in the NCEP Global Forecast System/Global Data Assimilation System using Ensemble Forecast Sensitivity to Observation Impact

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Ensemble Forecast Sensitivity to Observation Impact (EFSOI) is a technique which derives the positive or negative impact of individual assimilated observations on the skill of a numerical weather forecast using the difference in errors against a verifying analysis between two 24-hour ensemble forecasts, one initialized with an analysis and the other initialized with the corresponding background (Kalnay et al. 2012). EFSOI has been implemented in the research version of the Global Data Assimilation System (GDAS) that produces the ensemble background component of the analysis used to initialize the newly operational v16 Global Forecast System (GFS) at NCEP, and is evaluated using an ensemble with reduced C192 (50 km) resolution and 128 vertical levels. Comparisons of sensitivities in satellite and conventional observation sources in GFS/GDAS relative to other forecasting centers, including those using adjoint-based methods, will be presented. EFSOI may also help identify assimilated observations by source, geographical location, instrument channel, or other subset that potentially contribute to low-skill forecasts through the analyses used to initialize the forecasts, and case studies of low-skill forecasts and the sensitivities and impacts of the observations assimilated for the initializing analyses of these forecasts will be examined.

Maximum Likelihood Ensemble Filter with Exact Newton Optimization

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Optimization of a cost function is a key component in variational data assimilation determining the quality of the analysis. In spite of quadratic convergence, the Newton method to operational systems is prohibitive because of difficulty in calculating the Hessian matrix explicitly. The Maximum Likelihood Ensemble Filter optimizes the cost function and enables computation of the Hessian matrix in ensemble space, providing an opportunity to use the Hessian in optimization. Thus, application of the exact Newton optimization is attempted in a single wind speed assimilation test. With the linear observation operator, where a wind vector instead of wind speed observation is assimilated, the optimization converges in a single step with little wind speed error as expected from the quadratic cost function. In the wind speed assimilation, the analysis converges to the solution and the analysis ensemble members are clustered along the circles of the wind speed with observation error. Comparison with other optimization and assimilation methods will also be given.

Local volume solver with the static covariance model: LETKF-OI

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Lack of effective ways to include static error covariance in the framework of the local volume solver (e.g. the local ensemble-transform Kalman filter (LETKF)) remains an outstanding problem in data assimilation. Here, we develop the new family of algorithms: LETKF-OI and LGETKF-OI. These algorithms are similar to the traditional optimal interpolation (OI) algorithm in that they use a static error covariance to update each of the local volume solutions. However, unlike the traditional OI that scales poorly as the number of observations increases, new algorithms achieve linear scalability by either using the observational-space localization strategy of the traditional LETKF algorithm or the modulated ensemble strategy of the gain-form LETKF. Using a simple univariate test case, we show that the new algorithms achieve close approximation to the 3DVAR and OI solutions. Extensions to the multivariate assimilation that includes physical balances is discussed.

Improvement of Accuracy of Global Numerical Weather Prediction Using Refined Error Covariance Matrices

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For accurate numerical weather prediction (NWP) and reanalysis, accurate error covariance matrices (ECMs) in data assimilation are essential. However, current ECMs used in atmospheric analysis strongly depend on empirical tunings. The objective of this study is to estimate ECMs of all observations and background variables using combining multiple sampling statistics methods, and improve global NWP accuracy and validity by using them. This study presents the first results of such entire ECM refinement (Ishibashi 2020, MWR). ECM diagnostics and numerical experiments were performed on the JMA global NWP system, where diagonal components of all ECMs and off-diagonal components of radiance observations were refined. The ECM diagnostic results show: 1) the diagnosed error standard deviations (SDs) are generally much smaller than those of the JMA operational system (CNTL) ; 2) interchannel error correlations in humidity-sensitive radiance are larger than 0.2; and 3)

horizontal correlation distances of AMSU-A are about 50 km. The numerical experiments show: 1) the diagnosed ECMs generally improve forecast accuracy over CNTL even without additional tunings; 2) one supplemental parameter, a deflation factor (0.6 in SD) for direct observations, improves forecast accuracy; 3) 10 times high-density assimilation of AMSU-A is better than CNTL; and 4) ECMs estimated using boreal summer data improve winter forecast accuracy. We will also present flow dependent nature of ECMs.

Ensemble Singular Vectors: Optimizing Convective Scale Uncertainties for Data Assimilation

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Inherent shortcomings in the representation of smaller scale features become apparent with the continuous decrease of horizontal grid spacing in NWP models. One of the phenomena affected is convective precipitation. Here, we present an approach with two major aims: (a) enhance the representations of uncertainties of convective events, and (b) use these estimates in DA to improve forecasts for convection. We employ the operational limited area model of the German Meteorological Service (DWD), i.e., ICON-LAM together with the existing LETKF implementation. Our approach is based on the ensemble singular vector technique which focuses on an optimized uncertainty representation. Here, we will use this method to (i) estimate fast growing error modes, and then (ii) apply these as initial conditions for the first guess forecast. We show, that in this way, we are able to target the uncertainty to specific scales, regions or parameters.

Including the spatial observation error correlation in data assimilation of AMSU-A radiances

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Recent developments in sensing technology increased the number of observations both in space and time. It is essential to effectively utilize the information from observations to improve numerical weather prediction (NWP). It is known to have correlated errors in observations measured with a single instrument, such as satellite radiances. The observations with the horizontal error correlation are usually thinned to compensate for neglecting the error correlation. This study explores to explicitly include the horizontal observation error correlation of Advanced Microwave Sounding Unit-A (AMSU-A) radiances using a global atmospheric data assimilation system NICAM-LETKF, which comprises the Nonhydrostatic ICosahedral Atmospheric Model (NICAM) and the Local Ensemble Transform Kalman Filter (LETKF). This study performs the data assimilation experiments at 112-km horizontal resolution and 38 vertical layers up to 40 km and with 32 ensemble members. We estimate the horizontal observation error correlation of AMSU-A radiances using innovation statistics. The computation cost of inverting the observation error covariance matrix will increase with non-zero off-diagonal terms. We assume uncorrelated observation errors between different instruments and observation variables, so that the observation error covariance matrix becomes block diagonal with only horizontal error correlations included. The computation time of the entire LETKF analysis procedure is increased only by up to 10 % compared with the case using the diagonal observation error covariance matrix. The analyses and forecasts of temperature and zonal wind in the mid- and upper-troposphere are improved by including the horizontal error correlations.

Ensemble Kalman filtering with colored observation noise

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The Kalman filter (KF) is derived under the assumption of time-independent (white) observation noise. Although this assumption can be reasonable in many ocean and atmospheric applications, the recent increase in sensors coverage and the launching of new constellations of satellites with high spatio-temporal coverage will provide high density of observations that are expected to be time-dependent (colored). In this situation, the KF update has been shown to generally provide overconfident estimates, which may degrade the filter performance. Different KF-based schemes accounting for time-correlated observation noise were proposed for small systems by modeling the colored noise as a first-order autoregressive model driven by white Gaussian noise. This work introduces new ensemble Kalman filters (EnKFs) that account for colored observational noises for efficient data assimilation into large-scale oceanic and atmospheric applications. We first consider the case where the parameters describing the observational noise time-correlations are known, and follow the standard and the one-step-ahead smoothing formulations of the Bayesian filtering problem to derive colored observational noise-aware EnKFs. We then extend these schemes to jointly estimate the time-correlations parameters along with the system state. We demonstrate the relevance of the proposed colored observational noise-aware EnKFs and analyze their performances through extensive numerical experiments conducted with the Lorenz-96 model.

Preliminary Testing of a Multigrid Beta Filter Scheme for Modeling Background Error Covariances in NCEP's GSI

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The multigrid beta filter, a new scheme for modeling of the background error covariances, is under development at the NOAA's Environmental Modeling Center (EMC). The new method is synthesizing quasi-Gaussians derived by convolution of a beta-distribution-like filter at different scales, and is intended to replace the recursive filter, which, being essentially a sequential operator, is difficult to efficiently parallelize in an environment with increasingly massive computational parallelism. This development is part of a 3D Real-Time Mesoscale Analysis (3D RTMA) project, whose goal is to provide analyses at high horizontal resolutions (~2.5 to 1.25 km) at frequent time intervals (~15 min). Our paper will briefly describe the new technique, but the main focus will be on the presentation and discussion of the first preliminary test results derived within the Grid-point Statistical Interpolation (GSI), the data assimilation system of EMC, including a comparison with the respective results derived with the recursive filter.

Effects of misspecified time-correlated model error in the (ensemble) Kalman Smoother

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We investigate what effect inaccurate model errors, in particular, an inaccurate time correlation, can have ondata assimilation results, with a KS and the EnKS. Furthermore, we use the EnKS to estimate this decorrelationtimescale encoded in the model errors. With a simple linear model, we generate the prior with a guessedtimescale ωg which differs from the real timescale ωr in the true state of the system. Both analytical

and numerical results are produced using the KS with a 1D system. Then, we extend our numerical experiments to a higher-dimensional system with the EnKS. To evaluate the performance of the data assimilation with auto-correlated model errors, we calculate the ratio of RMSE over the spread of ensemble members. The results show that the best performance of the EnKS (KS) is when the guessed decorrelation timescale matches the real timescale in the system. We find that the results are highly dependent on the observation frequency, especially the posterior variance. With a single observation, the posterior variance has a maximum at a certain ωg value. When we increase the number of observations, the posterior variance becomes a monotonic decreasing function of ωg. The results for the posterior MSE with asingle observation show that it increases with both ωr and the mismatch between ωg and ωr. It means if we don't have a fair estimate of the correlation timescale, the actual posterior error will be larger. For the estimation of the actual decorrelation timescale, we find that when the observation density is high, the state augmentation is sufficient to obtain converging results. However, with only one observation in a time window, the problem becomes too nonlinear and the estimation process is slow or does not even converge.

Effects of suppressing supersaturation in a variational data assimilation system

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The reproducibility of precipitation in the early stages of forecasts, often called a spin-down or spin-up problem, has been a significant issue in numerical weather prediction. This problem is caused by moisture imbalance in the analysis data, and in the case of the Japan Meteorological Agency (JMA) mesoscale data assimilation system JNoVA, we found that the imbalance stems from the existence of unrealistic supersaturated states in the minimal solution of the cost function in JNoVA. Based on the theory of constrained optimization problems, we implemented an exterior penalty function method for the mixing ratio within JNoVA to suppress unrealistic supersaturated states. The results of twin data assimilation cycle experiments conducted for the Heavy Rain Event of July 2018 over Japan show that—with the new method—unrealistic supersaturated states are reduced successfully, negative temperature bias to observations is alleviated, and a sharper distribution of the mixing ratio is obtained. These changes help to initiate the development of convection at the proper location and improve the fractions skill score (FSS) of precipitation in the early stages of the forecast.

Application of Data Assimilation to Reconstruct the State of the Near-Earth Space Environment and Issue Space Weather Predictions into the Future.

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The near-Earth radiation environment can be hazardous to satellites and humans in space. Understanding, predicting, and prescribing the radiation environment is complicated by the fact that a single spacecraft provides only measurements at one location in space at a given time. Data assimilation can help reconstruct the state of the environment from various measurements with observational errors. Data assimilation allows creating new empirical models, issue real-time predictions into the future that can help with anomaly resolution and can help identify missing physical processes. We present a real-time data assimilation forecast of the outer electron radiation belts. We also present the initial results of ring current data assimilation and show how data for the newly developed VERB-4D code can be used to reconstruct ring current

fluxes and now-cast, and predict surface charging. We also present the long-term reconstruction of the historical state of the radiation belts. We also show how the analysis of the innovation vector helps identify missing physical processes.

Development of the tangent linear and adjoint models of the MPAS-Atmosphere dynamic core and applications in adjoint relative sensitivity studies

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This study develops and tests a version of the Python-driven, non-hydrostatic Model for Prediction Across Scales – Atmosphere (MPAS-A) dynamic model, as well as its tangent linear and adjoint models. The non-linear, non-hydrostatic dynamic core of the MPAS-A is restructured to have a Python driver for the convenience of parsing namelists, manipulating matrices, controlling simulation time flows, reading model inputs, and writing outputs, while the heavy-duty mediation and model layers are retained in Fortran for computational efficiency. Under the same Python-driving structure, developed are the tangent linear and adjoint models for the dynamic core of the MPAS-A model with verified correctness. The case of Jablonowski and Williamson's baroclinic wave is used for demonstrating the approximation accuracy of the MPAS-A tangent linear model and the applicability of the MPAS-A adjoint model to relative sensitivity studies. Numerical experimental results show that the tangent linear model can well approximate the temporal evolutions of non-linear model perturbations for all model variables over a four-day forecast period. Employing the MPAS-A adjoint model, it is shown that the most sensitive regions of the 24-h forecast of surface pressure are weather dependent. An interesting westward vertical tilting is also found in the relative sensitivity results of a 24-h forecast of surface pressure at a point located within a trough to model initial conditions. This functionality of the MPAS-A adjoint model is highly essential in understanding dynamics and variational data assimilation.

Soil moisture assimilation system for multilayer soil model

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This research presents the future soil moisture analysis system for the global atmospheric model SL-AV. It's based on a point-wise Simplified Extended Kalman Filter (SEKF). The analysis scheme is developed within an offline version of the land surface scheme ISBA and multilayer soil scheme INM RAS for the initialization of soil water content in numerical weather prediction model. This system is compared with a fully coupled land data assimilation system. It is shown, by comparing the observation operator Jacobians of both analysis schemes, that the assumption of linearity of these operators estimated by finite differences fits offline version better. Another advantage is the reduction in computing time while running the land surface scheme outside the atmospheric model, which makes SEKF approach compatible with operational requirements. Elements of the Jacobian matrix of the observation operator for the two layers of soil and the spatial structure of the analysis increments are represented. The performance of the offline assimilation system is evaluated against the open-loop system and in-situ data. The assessing period from June till August 2014 was taken. Comprehensive estimations of analysis data against conventional screen-level temperature and relative humidity observations, non-conventional soil temperature and moisture measurements are represented. It's demonstrated that using SEKF improves medium-range forecasts of the SL-AV model.

Initializing high-resolution deterministic forecasts in hybrid-gain and hybrid-covariance ensemble DA systems

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Most operational centers calculate analysis increments at a lower resolution than that of the deterministic forecast model. In NOAA, a hybrid-covariance ensemble-variational system is used in which the analysis increment is computed at the ensemble resolution, using a high-resolution background from a single determinstic forecast. The analysis ensemble, after being updated by an EnKF, is recentered around the upscaled deterministic analysis. In this project I demonstrate an alternative strategy in which the cycling of the high-resolution deterministic forecast is de-coupled from the ensemble update. As before, the analysis increment is computed at the ensemble resolution using either hybrid-covariance or a hybrid-gain ensemble-variational approach, but using the ensemble mean as a background instead of a single high-resolution forecast. The determinstic forecast is obtained by 'replaying' (Takacs et al, https://doi.org/10.1175/MWR-D-18-0117.1) the high-resolution model to the ensemble-mean analysis using the incremental-analysis update capabilitiy of the forecast model. This approach for initializing high-resolution forecasts is more amenable to the hybrid-gain ensemble-variational framework and produces forecasts that fit observations slighlty better than the current approach. It also allows the high-resolution deterministic forecasts to be run offline, possibly with different forecast models, since the replay approach only requires the archived ensemble mean analysis states.

Including observation error correlation for ensemble radar radial wind assimilation and its impact on heavy rainfall prediction

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An assumption of uncorrelated observation errors is commonly adopted in conventional data assimilation. For this reason, high-resolution data is re-sampled with strategies like superobbing or data thinning. This also sacrifices the advantage of high temporal and spatial resolution observations that can provide essential detailed structures. However, assimilating the high-resolution data, such as radar radial wind, without considering the observation error correlation can lead to overfitting and thus degrade the performance of data assimilation and forecast. This study uses the radar ensemble data assimilation system, which combines the Weather Research and Forecasting model and Local Ensemble Transform Kalman Filter (WRF-LETKF), to assimilate the radar radial velocity and reflectivity data. We present a strategy to include the error correlation of the Doppler radar radial velocity in the WRF-LETKF radar assimilation system and examine their impact on short-term precipitation prediction based on the heavy rainfall case on 2nd June 2017 in Taiwan. Including the correlated observation error for radar radial winds leads to more small-scale features in the wind analysis corrections compared to the experiment using the independent observation assumption. Consequently, the modification on wind corrections generates stronger convergence, accompanied by higher water vapor content, and enhances local convections, resulting in more accurate simulated reflectivity and short-term rainfall prediction. In particular, such advantage is identified for the threshold of extreme heavy rainfall at small scales according to probability quantitative precipitation forecast and fractions skill score.

Data rescue of national and international meteorological observations at Deutscher Wetterdienst

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Historic observational data records are an important contribution for climate reconstructions and analysis of past weather events. Particularly in remote and data sparse regions, such as the open ocean, newly rescued data can significantly improve the knowledge about weather and climatic conditions in earlier decades and centuries. Deutscher Wetterdienst (DWD) holds several collections of original historical weather records from land stations and ships. They comprise not only observations from Germany, but also of the global oceans and land stations in many parts of the world. All German state-owned meteorological observations beginning with the Prussian Meteorological Institute in 1848 are collected in the main archive of DWD in Offenbach. DWD's branch office in Hamburg holds the marine archive starting with the collections of the German Naval Observatory, 'Deutsche Seewarte', which existed from 1874 to 1945. It includes marine data records from ships, as well as land stations in many parts of the world (e.g. from former German colonies) and signal stations situated at the coasts of the North and Baltic Sea. The documentation, digitisation and quality check of the enormous quantity of handwritten journals of all four data archives is still ongoing. The digitised data will be freely accessible to all interested scientists and are also continuously submitted to international data archives, such as ICOADS and ISPD. Through these data sets, the data are also an important input for regional and global reanalyses. The presentation will give an overview of the historical archives of Deutscher Wetterdienst and will show the recent progress of the digitization efforts and ongoing analysis of the data.

Modeling impact of climate warming on cotton growth and phenology in Pakistan from 1961 to 2010 based on provincial data

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The general circulation models (GCM) estimated an average increase in the global surface temperature of about 2.9-5.5°C by the end of this century. The increases in temperature and shift in the rainfall cycle affect cotton growth and threaten cotton production and quality in the region. The rise highly influences cotton growth and development in weather and changes in rainfall cycles. Climate data (1980-2020) were used as model input resulted that the escalating temperature increases evapotranspiration rates, sometimes causing severe water stress and fruit abscission, thus reduce the plant growth and yield. APSIM-cotton model projections of 15-agrometeorology stations showed that the growing duration during the sowing-boll opening stages and drilling-harvesting were reduced by was reduced 2.30-5.66 days decade-1 and 4.23 days decade-1. Temperature rise has advanced the planting dates, sowing-emergence, 3-5 leaves, budding-anthesis, full-bloom, cleft-boll, boll-opening, boll-opening filling by 24.42, 26.19, 24.75, 23.28, 22.62, 15.75, 14.58, 5.37, 2.85, 8.04 days. Further, our findings exhibited that climate stop-growing becomes 2.16 days premature, and the time-scale has been delayed for 8.2, 2.4, and 5.3 days in the 1970s, 1980s, and 1990s. APSIM and DSSAT quantification revealed that sowing-emergence and anthesis-maturity stages were negatively linked with

temperature -2.03, -1.93, -1.09, and -0.42 days °C1. The negative impact might be mitigated by adaptation to the climate-smart cotton production system by improving agrotechnological services.

Regional Water Cycle Consistency in Atmospheric Reanalysis

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Interannual variations of global ocean -to- land transport of water in reanalyses are generally consistent with evaporation minus precipitation (E-P) derived from observationally-constrained land data assimilation systems (LDASs) and global hydrologic models (GHMs). In the present study, we evaluate the regional water budgets consistency across several regions to determine the degree that this applies at sub-continental scales. Preliminary results for CONUS shows for MERRA-2 and ERA5 the regional atmospheric convergence of water from the atmospheric reanalysis is more consistent with the LDAS E-P, than is the reanalyses E-P. The water vapor increment (or imbalance) from the data assimilation is more related to the reanalyses E-P. This work will also extend to comparisons over regions with smaller amounts of assimilated observations (especially radiosondes). In addition, we will diagnose recycled precipitation in comparison to inflowing water vapor relative to the divergence term.

Assessment of temperature extremes based on departures from long-term reanalysis and high-resolution ensemble forecasts over Indian region

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Extreme weather prediction requires the resolution of the models to be sufficiently high in order to resolve the small-scale features of the events. Medium range ensemble prediction of extreme events helps assess the forecast uncertainty well ahead in time, enabling risk assessment and effective planning for disaster management. The global ensemble prediction system at NCMRWF (NEPS-G) features one control and 22 perturbed members with 12 km horizontal resolution and 70 vertical levels. NEPS-G is used for predicting extreme temperature events (heatwaves, coldwaves, warm nights and cold days) in the year 2019-2020 in this study. The daily gridded surface maximum (Tmax) and minimum (Tmin) temperature dataset developed by India Meteorological Department (IMD) have been used to verify the probabilistic temperature forecasts. A high-resolution regional atmospheric reanalysis data named the Indian Monsoon Data Assimilation and Analysis (IMDAA) is recently generated by NCMRWF and Met Office, UK, in collaboration with IMD under the National Monsoon Mission project. The daily climatology for Tmax and Tmin is calculated from IMDAA reanalysis data between 1988 and 2018. It has been used for calculating departures for identifying the temperature extremes over Indian regions. The probabilistic skill of the EPS medium-range forecasts of extreme day-time and night-time temperatures is examined with reference to long-term climatology from IMDAA reanalysis. The continuous ranked probability score (CRPS) shows a better correspondence between forecasted and observed cumulative distribution in the summer season than that in the winter season.

Early results of the evaluation of the JRA-3Q reanalysis

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The Japan Meteorological Agency (JMA) is conducting the third Japanese global atmospheric reanalysis named Japanese Reanalysis for Three Quarters of a Century (JRA-3Q) using the JMA operational data assimilation system that has been upgraded and improved since the Japanese 55-year Reanalysis (JRA-55) was conducted. For the evaluation of the JRA-3Q, several kinds of observational datasets based on satellite observation are used: precipitation provided by Global Precipitation Climatology Project (GPCP), radiation fluxes from the clouds and the Earth's radiant energy system project (CERES), spectral latent heating from the Global Precipitation Measurement (GPM) mission by Japan Aerospace Exploration Agency (JAXA), and water vapor retrieved from Global Navigation Satellite System Radio Occultation (GNSS-RO) and the Earth Observing System Microwave Limb Sounder (MLS). The early results show that both overestimation of precipitation in the tropics and dry bias in the middle troposphere are diminished compared with those in JRA-55, and the representation of diabatic heating rate is also improved. In addition, biases of surface heat fluxes and radiation fluxes at the top of the atmosphere are also reduced.

The Panama Bight Index: a new index for the Eastern Tropical Pacific

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This paper presents the Panama Bight Index (PBI), a new climate variability index for the Eastern Tropical Pacific, based on the Sea Surface Temperature (SST) anomaly of an area of the central Panama Bight (PB). The PB includes the waters of Costa Rica, Panama, Colombia, and Ecuador. The extent to calculate the PBI was defined as the homogeneous region between -1 and 1 standard deviation of the first Empirical Orthogonal Function (EOF) of an analysis of the regionalization of the Remote Sensing Reflectance (Rs 412 and Rs 488 Modis-Aqua, 2002-2020; Rs 412 and Rs 490 SeaWiFS, 1997-2010). The SST from the ERA5 reanalysis dataset (1950-2020), of the European Centre for Medium-Range Weather Forecasts (ECMWF), was used to generate the PBI. For calculating the SST anomalies, we used the NOAA's Climate Prediction Center for El Niño region indices (Niño 4, Niño 3.4, Niño 3, Niño 1+2 y ONI). The PBI is dominated by the interannual variations of the SST associated with El Niño and La Niña (EN/LN), which presents a high correlation with El Niño 1+2 index and the ONI Index, and allows identifying the mode of variability associated with the annual cycle. Although there are other metrics to monitor ENSO, they do not adequately fit the PB's processes in the oceanic zone. Therefore, this PBI will allow the study of the interannual climatic variability of the POT associated with EN/LN and evaluate the occurrence and intensity of the Eastern Pacific El Niño.

A kriging method for a gridded quantitative precipitation estimate over Alaska with uncertainty bounds

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In collaboration with the National Weather Service (NWS) Alaska and the Alaska-Pacific River Forecast Center, a gridded quantitative precipitation estimate (QPE) has been developed to provide a precipitation analysis for Alaska, which is a challenge because of Alaska's size, sparse population, and limited access to observations. Gridded quantitative precipitation forecasts (QPF) from high-resolution numerical weather

prediction models are merged with rain gauge data through kriging - a geostatistical interpolation technique which provides the best linear unbiased estimate at each gridpoint along with an estimated error variance. The error variance is further inflated and refined through cross-validation to produce an empirically tuned 5% and 95% confidence bounds on QPE. A 6-hour accumulated QPE was produced for the period August 01 2019 - July 31 2020, and skill scores are presented for multiple formulations of QPE to identify the value-added by a QPF first-guess compared to a climatological first-guess.

Analysis of the Wind Fields Based on Radar Network in the East Asia Reanalysis System

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The V-IVAP method (Liang et al., 2019) were proposed to retrieve wind fields based on the radial wind of weather radar. The V-IVAP method is insensitive to the alias of radial wind. Using the V-IVAP method, the wind fields were analyzed using the observations of the radar network. The weather radar network of China (CINRAD: China New Generation Weather Radar) includes 224 radars of S or C band. The wind fields have horizontal resolution of 0.12°×0.12°, vertical resolution of 0.5 km from 0.5km to 7.5 km. A dataset of wind fields from 1st Jan 2008 to 31st Dec 2018 were established based on the radar observations with time interval of 3 hours. The errors of the winds were analyzed using the radiosonde observations. The analyzed winds have a good correlation with the radiosonde observations. The RMSE of u and v are 4~15 ms-1 and 4~9 ms-1 respectively from 0.5 km to 7.5 km height. Reference Liang Xudong, Y. Xie, J. Yin, Y. Luo, D. Yao, and F. Li, 2019: An IVAP-based dealiasing method for radar velocity data quality control. J. Atmos. Oceanic Technol., 36: 2069-2085.

The 26-Year Black Sea Reanalysis

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Ocean reanalyses are becoming increasingly important to reconstruct and provide an overview of the ocean state from the past to the present-day. In the scope of the Copernicus Marine Environment Monitoring Service (CMEMS), the Black Sea reanalysis (BS-REA) is produced by using an advanced variational data assimilation method to combine the best available observations with a state-of-the-art ocean general circulation model. The hydrodynamical model is based on Nucleus for European Modeling of the Ocean (NEMO), implemented for the Black Sea (BS) domain with horizontal resolution of 1/27° x 1/36°, and 31 vertical levels. NEMO is forced by ECMWF ERA5 atmospheric reanalysis and climatological precipitation. The model SST is relaxed to daily objective analysis fields from CMEMS SST TAC. The model is online coupled to OceanVar, a 3D-Var ocean data assimilation scheme, to assimilate sea level anomaly (SLA) along-track observations from CMEMS SL TAC and available in situ vertical profiles of temperature and salinity from both SeaDataNet and CMEMS INS TAC products. Temperature fields present a continuous warming in the layer between 25-150 m, within which the BS Cold Intermediate Layer resides. SST shows a basin-wide positive bias. The root mean square difference (RMSD) can reach 0.75 °C along the Turkish coast in summer. SLA has the largest RMSD close to the shelf due to the high mesoscale activity along the Rim current. The system has produced very accurate estimates which makes it suitable for understanding the BS physical state in the last decades. Nevertheless, in order to improve the quality of the BS-REA, new developments in ocean modelling and data assimilation are still important, and sustaining the BS ocean observing system is crucial.

Evaluation of the latest Japanese Reanalysis for three quarters of a century (JRA-3Q) during a pre-satellite era

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This study evaluates the latest Japanese Reanalysis for Three Quarters of a Century (JRA-3Q) conducted by the Japan Meteorological Agency (JMA), focusing on a semi-period of pre-satellite era of 1960s and 1970s. JRA-3Q, which is based on the JMA's operational system with 6-hourly 4D-Var data assimilation as of December 2018, is the third Japanese global atmospheric reanalysis spanning late 1940s onwards, using an atmospheric model with a reduced horizontal resolution of TL479 and 100 vertical layers up to 0.01 hPa. Because only few global-covered observational datasets during the pre-satellite era are available, the JRA-3Q is mainly evaluated in reanalysis intercomparison and about temporal consistency and spatial homogeneities. Emphasis of this evaluation during the non-satellite era is placed on the representation of tropical circulation, the time consistency of reanalysed fields between the pre-satellite and satellite eras, and the quality of the stratospheric ozone and water vapor. The surface circulation over the tropical Africa is improved by reducing spurious anticyclonic circulation anomalies found in JRA-55. Stratospheric ozone is also improved by incorporating adequate ozone depletion substances, sea-surface temperature as well as the development of the ozone model. The quasi-biennial oscillation is not as good as that in JRA-55 with a shorter period of around one year in the middle stratosphere and diminished amplitude in the lower stratosphere.

Advances in the Downscaling of Extreme Hydro-Events in South America

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Reconstructions of climatological features in the tropical areas of South America may be proven challenging due to the scarcity of reliable, long-term data records. To address this problem, retrospective analyses – aka (re)analyses – are regularly used to provide spatially continuous, long-term time series of several atmospheric and land-surface variables in studies of South American climate. Overall, reanalysis comprehends forecast models and data assimilation systems. Data assimilation in a global reanalysis comprises computationally expensive techniques to generate initial conditions used in the embedded forecasting systems. Global reanalysis products also offer a wide range of opportunities to monitoring atmospheric conditions at regional scales, for instance, providing initial and boundary conditions to regional downscaling. The downscaling of a global reanalysis in the tropical-to-subtropical South America by a regional numerical model may as well be enhanced by means of empirical methods, such as spectral (dynamic) nudging and satellite-based precipitation assimilation, both employed in the present study. Examples of the combined application of the two methodologies in regional downscaling will be illustrated through the reconstruction of extreme events that occurred in the continental South America depicted by the interannual variability of South American monsoon precipitation, and the severe weather episodes near the Brazilian coastline.

Evaluation of (regional) reanalysis data using the Free Evaluation System Framework

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COSMO-REA6 is a regional reanalysis for Europe based on the COSMO model. The data set is widely used, especially in the sector of renewable energies. A new version of the regional reanalysis is currently under development with boundary conditions from ERA5. To assess the quality of the data, the output can be compared to the former version and to global reanalyses as well. Among different evaluation methods, the comparison of the regional reanalysis data with station data (of the DWD observation network) is part of the evaluation suite. To make the software and data available to a larger user group, we take advantage of the Free Evaluation System Framework (Freva) which is currently in use at DWD, FU Berlin and DKRZ. In this way, the software is available for various applications and projects. Freva was developed at FU Berlin and DKRZ to provide an infrastructure for cooperative and efficient use of standardized data and tools. REALISTIC ("Reanalysis Station Comparison") is developed as a plugin within the Freva framework. The tool compares reanalysis or other gridded data with station data by different metrics (e.g. bias, correlation, MAE). REALISTIC is based on CDO (Climate Data Operators) that are used to find the nearest neighbor of the station locations in the model grids to make pointwise comparisons. The results are plotted on a map, showing the values of the metrics at the different station locations.

The stratospheric Brewer-Dobson circulation in ERA5 and ERA-Interim reanalyses

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The stratospheric Brewer-Dobson circulation (BDC) is a key element in the climate system as it controls variations in ozone and other trace gases which impact the radiation budget. We investigate the BDC in the new ERA5 meteorological reanalysis and compare with results from its predecessor ERA-Interim, based on residual circulation dignostics and on simulations of stratospheric age of air with the transport model CLaMS. Our results show a substantial uncertainty in the representation of the BDC in reanalyses regarding both the climatology and trends. In particular, the BDC is significantly slower in ERA5 than in ERA-Interim, manifesting in weaker tropical upwelling, diabatic heating rates and larger age of air, mainly related to weaker subtropical gravity wave drag. In the tropical lower stratosphere, heating rates are 30-40% weaker in ERA5 than in ERA-Interim, likely correcting a bias in ERA-Interim. At 20km and in the NH stratosphere, ERA5 mean age values are around the upper margin of the uncertainty range from historical tracer observations, indicating a somewhat slow-biased BDC. The stratospheric age of air trend in ERA5 over 1989-2018 is negative and is related to an increase in tropical upwelling. However, the age decrease is not linear but steplike, potentially caused by multi-annual variability or changes in the observations included in the assimilation. Particularly regarding trends on decadal time scales, the different reanalyses can largely differ.

Development and Quality Evaluation of an Operational Ensemble-based Regional Reanalysis System

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In 2011 the development of a regional reanalysis began at DWD together with partners from the Universities of Bonn and Cologne within the HErZ initiative. In the meantime, the continuous processing has been transferred to DWD. The regional reanalysis system COSMO-REA6 was used to produce data sets covering the period 01/1995 – 08/2019 and Europe in a spatial resolution of 6 km. The data sets have proven high quality as shown within different activities, in particular in the project UERRA or in applications by external users especially from the sector of renewable energies. Despite the good results, COSMO-REA6 represents no longer the state of the art and will be superseded in the next years by an ensemble-based reanalysis system based on ICON and up-to-date data assimilation schemes. The new system was designed to run both a global and a regional reanalysis together in a coupled approach. In regular time intervals, the system is initialized by IFS fields from ERA5. We are going to apply reprocessed observations from ECMWF. Several production sites are taken into account. Here we present the concept of the new system and the current state of the development.

Assessment of ERA-5 wave characteristics with in-situ measurements in Southern Baltic

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Commonly used methods of obtaining wave characteristics data, such as in-situ measurements, satellite or cruise (r/v) data, are becoming insufficient in the era of contemporary climate change and the resulting need for more accurate recognition of the spatial and temporal variability of the sea state. In such a context, reanalysis data may constitute a valuable source of information.The research aimed to assess and compare the ability of ERA5 to reproduce wave characteristics for two selected points of in-situ measurements in the Baltic Sea, both of differing oceanographical characteristics (offshore and nearshore). The temporal scope of the research covered a period from June 2018 until June 2020 (nearshore) and from 2017 until 2020 (offshore) with 3 hourly temporal resolution. Two wave characteristics were taken into account: significant wave height and mean wave period. Significant wave height from ERA5 shows a high correlation (r = 0.86) for the point representing the deepwater (offshore) zone (Petrobaltic rig) where data are acquired with an AWAC device. In a nearshore location (Pomeranian Bay), the compliance is lower with a correlation coefficient of 0.67. For the mean wave period, the concordance is much lower.The analysis shows that ERA5 reanalysis, under some conditions, can be a reliable source of information in the long-term, large-scale marine analyses and may serve as a supplementary source of data on hydrodynamic parameters.

Ocean Data Impacts on the Reanalysis of Atlantic Meridional overturning circulation in the Next Generation Global Ocean Data Assimilation System (NG-GODAS)

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The Atlantic Meridional Overturning Circulation (AMOC) involves a northward movement of warm upper waters accompanied by a southward movement of cold waters at depth, and carries up to 25% of the northward global atmosphere-ocean heat transport in the northern hemisphere. The natural variations in the AMOC can affect climate over decadal timescales, so there is an obvious need for better, more quantitative, forecasts of the future behavior of the AMOC. An accurate AMOC prediction system could potentially provide a valuable early warning of imminent climate change. As part of ongoing efforts to improve forecasting, the NCEP's Environmental Modeling Center (EMC) is developing the prototype version of the Next Generation Global Ocean Data Assimilation System (NG-GODAS). The NG-GODAS uses JEDI-based SOCA (Sea-ice Ocean Coupled Assimilation) as its ocean data assimilation component, and an advanced ocean model (MOM6) is used. The following satellite and in-situ observation data are assimilated in current system: satellite sea surface temperature/sea surface salinity, in-situ temperature and salinity, absolute dynamic topography, and sea ice concentration. The AMOC at 26.5N will be investigated using the porotype NG-GODAS, and a comparison would be presented of ocean reanalyses with different observing networks, to the observations and transport estimates from the RAPID mooring array across 26.5◦ N in the Atlantic.

Intercomparison of surface temperature estimates from IMDAA reanalysis with ERA5 and in-situ observations at selected locations over India

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Indian Monsoon Data Assimilation and Analysis (IMDAA) is the currently available highest resolution (12 km), long-term (40 years, 1978-2018, extended to 2020), satellite era regional reanalysis over south Asian monsoon region. National Centre for Medium Range Weather Forecasting (NCMRWF), Ministry of Earth Sciences, Government of India distributes the IMDAA reanalysis through reanalysis web portal, https://rds.ncmrwf.gov.in/. This study illustrates location specific verification of surface temperature estimates from IMDAA and its comparison with ERA5 global reanalysis at the selected locations over Indian landmass for 19 years during the 21st century, from 2000 to 2018. Fourteen stations selected, such that (i) they are representatives of different homogenous temperature regions of India, and (ii) continuous in-situ surface observations are available during the period of study with minimum gap. Verification of surface temperature estimates (maximum, minimum and mean) shows that, quality of IMDAA is better over the Tropics and coastal regions (south of 20°N), whereas ERA5 outperforms over extratropics (north of 20°N). This could be due to better representation of global circulation in the global reanalysis ERA5, and local effects more effectively in the regional reanalysis IMDAA. High resolution feature of IMDAA (12 km) compared to ERA5 (31 km) better captures surface temperature over the orographic region. Surface maximum and minimum temperature estimates show that IMDAA has a comparatively hot summer and cool winter over north India, whereas the reverse in the ERA5. In general, ERA5 shows better correlation with in-situ observations than IMDAA; however, the mean of the three datasets differs significantly ($p < 0.05$)

Evaluation of multi-parameter dependencies in reanalyses

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Reanalyses are an unparalleled source of data for the evaluation of climate and its variability providing 4-dimensional reconstructions of multiple meteorological parameters describing the atmopsheric's system state. Yet, the vast majority of evaluation studies focus on the evaluation of single parameters in time and space without looking at the statistical dependence between two parameters. But this is necessary especially if you are interested in specific events where two or more parameters are involved, i.e., so called compound events. Recent studies have therefore investigated the representation of natural hazards such as wildfires, heat stress, droughts by evaluating corresponding indices based on two or more parameters. We employ a more sophisticated approach by using copula theory. With this method, we aim at evaluating the multivariate statistical distribution between two parameters separately from their marginal distributions. In a second step, we can related misrepresentations of meteorological indices in model simulations to deficiencies of the model to represent either the margignal distribution or the interdependencies between the contributing variables. We will present results for a joint copula-based evaluation of temperature and humidity related to the natural hazards mentioned above.

The NCEP Reanalysis Observation Archive Contents and Formats

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Beginning in 1992, NCEP has been conducting reanalysis projects with ever evolving observation capacity and complexity. Many historical archives of weather observations have been supplied to NCEP by NCAR, NCDC, NCEI, ECMWF, JMA, among other organizations. NCEP now has BUFR archives for land surface data back to the 1930's, for marine and upper air data sets the archive reaches back to 1948. This report will detail the contents of the archive, and to document the chain of processing which prepares and integrates observations from all different sources into a common form of the NCEP BUFR dumpfile format. For conventional data types, these files are inputs to make prepbufr files for NCEP DA reanalysis processing. Ocean surface and subsurface observations are especially important for running coupled reanalysis. A focus on archive development is increasing the historical holdings for this type of data. CFSR used subsurface ocean data back to 1979, but there was much less data in the 1980's and 1990's then there is now. Combining ocean obs from several reanalysis development streams could help ocean subsurface coverage after Y2K. Finding subsurface data prior to 1980 is challenging. With the volume of the satellite datasets dominating the last twenty years of DA observations, compact and compressed datasets like the dumpbufr format are convenient for storage. The satellite datasets are by far the biggest members of the archive, starting from several NOAA-n platforms in the early 1970's, all the way to now. The NCEP satellite observation archive contains big data.

The ORAP6 ocean and sea-ice reanalysis: description and evaluation on climate and forecasts

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Ocean and sea-ice are two essential components of Earth system models. By providing initial conditions of these two system states, ocean and sea-ice analysis play a vital part in the coupled forecasting system of NWP service. Ocean and sea-ice reanalyses also provide invaluable information for climate monitoring, and for long-term prediction such as decadal or climatic projections. The Ocean ReAnalysis Pilot system-6 (ORAP6) is a new ocean and sea-ice reanalysis that has been developed based on the ECMWF operational OCEAN5 system. ORAP6 uses ERA5 Atmospheric forcing and is produced with the most up-to-date reprocessed observation datasets. The data assimilation system has been updated, including: i) assimilation of L3 sea-ice concentration data; ii) a new flow-dependent SST nudging scheme; iii) refined off-line bias correction term for both temperature and salinity. In addition, observation error covariance settings have been revised. Production of ORAP6 for the full ERA5 period (1979-2019) has been completed. Preliminary evaluation suggests that, in a general sense, ocean and sea-ice states are improved in ORAP6 w.r.t to its predecessor ORAS5, partially due to its more realistic large-scale overturning circulations in the pre-Argo period. The ORAP6 sea-ice performance is better in the sense of both climate signals and spatial distributions of sea-ice thickness and concentration. The ocean heat content tendency in ORAP6 also correlates better with variations of global net energy input derived from independently observed TOA radiation data. Initializing from ORAP6 instead of ORAS5 leads to slightly improved performance in the ECMWF seasonal forecasting system-S5.

Thursday, 16 Sep 2021
Poster session P4 - Observations

Accuracy assessment of TRMM precipitation product in different Agro-Climatic Zones of Tamil Nadu, India

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In this study, the accumulated precipitation of TRMM data over different Agro-climatic Zones of Tamil Nadu was analyzed using statistical analysis, which showed an accountable variation during the study period from 2015 to 2017. Minimum precipitation of 144.31, 34.40, and 75.01 mm was recorded with TRMM during NEM of 2015, 2016, and 2017, respectively. The corresponding maximum values were 1400, 251, and 687 mm whereas the automatic weather station (AWS) recorded a minimum of 151.65, 31.82, and 73.29 mm during the NEM of 2015, 2016, and 2017, respectively. Maximum values of 1755.31, 450.39, and 939.58 mm were recorded for the corresponding years. TRMM data was found to have higher R2 values of more than 0.8 in all the North East Monsoon (NEM) seasons of 2015, 2016, and 2017 irrespective of the Agro-climatic zones assessed. During NEM 2016, TRMM estimated maximum rainfall in High Altitude and Hilly Zone (HAHZ) and low rainfall in North Western Zone (NEZ), which revealed that the TRMM product performance was high and dependable for use. Even though RMSE values were found to be high in HAHZ and NEZ and the other Zones recorded less value, the agreement of the data with (AWS) values was found to be more than 80 percent which indicated the high correlation of the data with ground truth. It concludes TRMM product provides a lot of scope

in climate research studies. Overall, the performance of the rainfall-based satellite product TRMM – 3B42 over Tamil Nadu is promising for further application in the supplement of rain gauge station.

Variational quality control of Aeolus satellite wind LiDAR observations

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Given the positive impact by the assimilation of Aeolus horizontal line of sight wind profiles particularly in the tropics at several operational centers around the world, we want to specifically investigate how beneficial this new observation type is for the initialization of tropical cyclones (TCs) in NOAA's Finite Volume Cubed Sphere Global Forecasting System (FV3GFS).To maximize the benefits of Aeolus, several key aspects that make data assimilation in the vicinity of TCs complicated, need to be addressed. By having inaccurate a-priori estimates of the state of the atmosphere under complex flow structures combined with the use of suboptimal quality control (QC) procedures can have detrimental impacts to the analysis. Static QC and background checks, which are based on blacklisting and fist-guess rejections can make it arbitrary to take decisions, such as keeping observations with initially large departures from the model background or how much weight should be given to an observation during the analysis update stage. To address suboptimal quality controls, we implemented the assimilation of Aeolus Mie-cloudy and Rayleigh-clear observation regimes with additional Variational Quality Control (VarQC) on NOAA's FV3GFS. This VarQC algorithm can assign adaptive weights and address non-Gaussianity aspects of Aeolus observations. VarQC can also be beneficial to TC analysis and forecast as it considers information about the local TC flow, the a-priori estimates of relevant sources of error, and the analysis state in a synergistic manner. In this presentation, we describe the benefits of applying VarQC to the Aeolus observations for improving the quality of the analysis and forecast in NOAA's FV3GFS during TC activity.

Assessment and Evaluation of Commercial GPS Radio Occultations in the NCEP Global Forecast System

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The United States Weather Research and Forecasting Innovation Act of 2017 permits the National Oceanic and Atmospheric Administration (NOAA) to purchase weather data from the private sector. Through Delivery Order 1 (DO-1), NOAA obtained 30 days of commercial space-based radio occultations (RO) from Spire and GeoOptics, and through Delivery Order 2 (DO-2), NOAA obtained six months of RO observations from GeoOptics. Impact experiments were performed with data from DO-1 to test configurations for the operational assimilation of commercial RO from DO-2. Assimilation of commercial RO is planned to become operational in the Global Forecast System (GFS) in May 2021. An initial experiment was run, applying the operational GNSS-RO quality control and observation errors to the commercial RO. Two follow-up experiments tested alternate quality control and observation errors for the commercial RO observations. This presentation will detail the assessment of the quality of the commercial RO data, as well as the impacts of their assimilation in the GFS.

Extending a forward operator for visible satellite channels by near-infrared and aerosol capabilities

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Satellite images in the solar spectrum provide high resolution cloud and aerosol information and thus present a promising observation type for data assimilation and model evaluation. While visible channels contain information on the cloud distribution, cloud optical thickness and cloud structure, near-infrared channels are in addition more sensitive to cloud microphysical properties and can be used to distinguish between water and ice clouds. Moreover, solar channels are sensitive to aerosols, so their assimilation can be expected to improve forecasts of cloud and aerosol distribution, and thus also solar radiation. However, mainly due to a lack of sufficiently fast forward operators for visible and near-infrared radiances, operational data assimilation systems so far use only the thermal channels. With recent development of MFASIS, a 1D radiative transfer (RT) method that is similarly accurate but orders of magnitude faster than conventional RT solvers for the solar spectrum, it has become possible to utilize visible channels.Here we discuss MFASIS's limitations preventing it from simulating near-infrared channels accurately and present a solution increasing the accuracy significantly for near-infrared channels. Furthermore, it will be demonstrated that replacing MFASIS's look-up table by a neural network reduces computational costs significantly, thus allowing for additional input parameters. Those parameters enable us to describe the vertical aerosol distribution for multiple species. This extends the application of MFASIS towards the assimilation of aerosol-affected radiances. The new approaches presented are tested using IFS and ICON model output.

Impact of Satellite Radiance data assimilation on the prediction of extreme rain events in the haor basin area

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An attempt has been taken is to investigate the impact of satellite radiance assimilation in simulating the extreme rainfall formed over the haor basin region. In this study, the Weather Research and Forecasting (WRF) model and three-dimensional variational (3D-Var) data assimilation system is used. The Global Forecast System (GFS) model of the National Centers for Environmental Prediction (NCEP) data has used as an initial condition.WRFDA is assimilated with Advanced Microwave Sounding Unit-A (AMSU-A) radiance data and NCEP Global surface and upper-air observations (NCEP PREBUFR). Overall, the results suggest that assimilating both NCEP PREBUFR together with Radiance observations into the mesoscale model enhanced the initial condition. The results also indicate that assimilating both NCEP PREBUFR together with Radiance observations into the WRFDA system reliability is better than the control experiments.

Bayesian Inference of Oil Spill Source Parameters from Image Contours

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Oil spills at sea pose a serious threat to the coastal environment. To control and limit unreported spills, it is essential to identify pollution sources, and satellite imagery can be an effective tool for this purpose. We present in this work a Bayesian inference approach to identify the source parameters of a spill from contours of oil slicks detected by satellite images. The approach adopts an observation error model based on a non-local measure of the dissimilarity between the predicted and observed contours. A Markov chain Monte Carlo (MCMC) technique is

then employed to sample the posterior distribution of five parameters of interest: the x and y coordinates of the source of release, the time and duration of the spill, and the quantity of oil released. To make the estimation of the posterior distribution computationally feasible, a Polynomial Chaos-based surrogate of the oil spill model is used within MCMC. To that end, a feature-based object localization method based on image moments is proposed to approximate contours, or binary images, in the form of integral quantities, for which surrogate models can be built. Two synthetic experiments of a spill released from a fixed point source are investigated, where a contour is completely observed in the first case, while two contours are partially observed at different times in the second case. In both experiments, the proposed framework is able to provide good estimates of the source parameters along with a level of confidence reflected by the uncertainties within. In the case of partial observations, the estimated parameters can be used to reconstruct the missing parts of an observed slick from which an oil spill model can be initiated to better forecast the spread of oil.

Radar-measured near-surface refractivity: a rare representative constraint on the lower boundary layer

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In addition to measuring properties of hydrometeors and their motion, radars are capable of measuring the average refractive index between the radar and ground targets, or rather its temporal change. This measurement, physically similar to the GNSS refractivity, is focused on the first tens of meters of the atmosphere and on a few tens of kilometers around the radar, and are available under all weather conditions. Radar-measured refractivity data are mind-boggingly precise and are very sensitive to humidity changes, as well as being representative of conditions at meso-beta scales instead of at a point. Because refractivity measurements are difficult to interpret by people, they have not seen much use in the forecaster-centric world of operational radars. But they have the potential of being particularly useful to constrain surface properties and humidity in the lower boundary layer. In this poster, examples of measurements and applications of radar-measured refractivity will be presented.

Operational direct assimilation of radar reflectivity volumes with KENDA at Arpae-SIMC

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In convective-scale data assimilation, the high resolution of numerical weather prediction (NWP) models demands dense observations at a suitable temporal and spatial resolution. On this respect, radar reflectivity volumes are of great value since they provide a large amount of observations of a vast volume of atmosphere, typically every 5 or 10 minutes. In most operational NWP models, these observations are assimilated indirectly, employing estimated precipitation, e.g. via latent heat nudging (LHN), latent heat tendencies or relative humidity profiles. The direct assimilation of reflectivity volumes in an operational framework has been achieved just recently. This was done, first, at Deutscher Wetterdienst (DWD) and at the Hydro-Meteo-Climate Structure of the Regional Agency for Prevention, Environment and Energy of Emilia-Romagna region (Arpae-SIMC) in Italy, using the local ensemble transform Kalman filter (LETKF) as assimilation scheme. Arpae-SIMC runs the Consortium for Small-scale Modeling (COSMO) model at 2.2 km horizontal resolution, while DWD employs the icosahedral nonhydrostatic weather and climate model (ICON) at the same resolution. In both cases, reflectivities are assimilated in combination with fields of estimated precipitation via LHN. The implementation adopted at Arpae-SIMC will be described here, reporting verification results for precipitation and for upper-air and surface variables.

Evaluation of multiple GNSS radio occultation observation operators with JEDI

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Multiple observation operators for Global Navigation Satellite System (GNSS) Radio Occultation (RO) data are provided in the Unified Forward Operator (UFO) component of the Joint Effort for Data assimilation Integration (JEDI) system, JEDI-FV3 1.0.0, that was released in October 2020. JEDI is developed by the Joint Center for Satellite Data Assimilation (JCSDA) and its stakeholders ((NOAA, NASA, DoD, and UKMO). Specifically, UFO includes a refractivity operator, a one-dimensional bending angle operator replicating the NCEP Bending Angle Model (NBAM) used in operations at NOAA, as well as a one-dimensional and a two-dimensional bending angle operators incorporated through the Radio Occultation Processing Package (ROPP) adopted by ECMWF and NRL in their operations. Thanks to the unified feature of the JEDI UFO, for the first time, GNSS RO data impacts can be evaluated using multiple operational operators within the same framework. In this study, we will conduct a series of one-month numerical experiments by applying these operators for GNSS RO data assimilation to the NCEP operational FV3-GFS forecasts. We will compare the performances of the operators and evaluate RO data impact in terms of a number of metrics. The fitting of model background and analysis to RO observations in observation space, such as COSMIC2 and other RO data; as well as a series of month-long statistical results will be presented.

Ensemble-Based Data Assimilation of GPM DPR Reflectivity into the Nonhydrostatic Icosahedral Atmospheric Model NICAM

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This study aims to improve the precipitation forecasts from numerical weather prediction models through effective assimilation of satellite-observed precipitation data. We have been developing a global atmospheric data assimilation system NICAM-LETKF, which comprises the Nonhydrostatic ICosahedral Atmospheric Model (NICAM) and Local Ensemble Transform Kalman Filter (LETKF). This study pioneers to assimilate radar reflectivity measured by the Dual-frequency Precipitation Radar (DPR) onboard the Global Precipitation Measurement (GPM) core satellite into the NICAM. We conduct the NICAM-LETKF experiments at 28-km horizontal resolution with explicit cloud microphysics of a single-moment 6-class bulk microphysics scheme. To simulate GPM DPR reflectivity from NICAM model outputs, the Joint-Simulator (Hashino et al. 2013; JGR) is used. Our initial tests showed a better match with the observed reflectivity by assimilating GPM DPR reflectivity into NICAM forecasts. However, the results from a 1-month data assimilation cycle experiment showed general degradation by assimilating GPM DPR reflectivity. For better use of GPM DPR reflectivity data, we estimated a model cloud physics parameter corresponding to snowfall terminal velocity by data assimilation. Parameter estimation reduced the snowfall terminal velocity, and successfully mitigated the gap between simulated and observed Contoured Frequency by Altitude Diagram (CFAD). The estimated parameter also improved temperature and humidity fields in the mid- to lower troposphere, and precipitation forecasts.

DWD pilot station – Evaluating ground-based remote sensing systems for future observing networks

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The current surface-based observing network has an insufficient density to fully characterize atmospheric processes at scales of Meso-β (and below). It is therefore unable to capture many relevant meteorological phenomena, especially in the boundary layer. Space-based measurements are unlikely to resolve this deficiency. A new generation of ground-based remote sensing instruments, often called “profilers”, has meanwhile become commercially available. These instruments are able to provide continuous measurements of kinematic, thermodynamic and cloud/aerosol particle related variables, mostly in the form of vertical profiles. Benefits of assimilating such data were recently seen in field campaigns. It is therefore timely to ask whether such profilers can also be used successfully in an operational setting. The presentation will give an overview of the project "Pilotstation" at DWD, which is investigating various options for a qualitative extension of the surface-based observing network. A testbed approach is employed to assess data availability, quality, observation impact as well as operational sustainability for the following profilers: Doppler lidar, microwave radiometer, water vapor broadband-DIAL, cloud radar and Raman lidar.

Validation of the active microwave sensor module within the RTTOV-SCATT radiative transfer model

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Space-borne radar observations are currently emerging has an observation kind important to consider within Numerical Weather Prediction applications. Like for the forward simulation of passive microwave observations, radar data simulations require to make multiple assumptions including on the scattering properties of hydrometeors. With the objective of simulating both active and passive microwave instruments within a single framework using the same radiative transfer assumptions into a widely-used tool in the NWP community, a first version of active sensor module has recently been released within Version 13 of the RTTOV software by the EUMETSAT NWP SAF. This initial version supports the simulation of both the GPM/Dual frequency Precipitation Radar and the Cloudsat/Cloud Precipitation Radar. Simulations of the GPM/DPR, performed with RTTOV V13 and the ARPEGE global model running operationally at Météo-France will be shown. Comparisons will be performed with observations, both on a case study as well as on a large number of samples. In particular, a sensitivity of the simulations to the hydrometeor fraction profile specifications will be discussed.

3D Precipitation Nowcasting: RESNet applied to Highly Dense PAWR Data

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Sudden heavy rain may lead to disasters like flooding and loss of life and property. To reduce the risk, predicting sudden downpours is of key importance. However, predictability of such events is limited to only for a very short range within an hour or shorter because of their abruptness. In this case nowcasting is an effective approach. Detecting sudden heavy rain even 10 minutes before it occurs can reduce the damage drastically. Precipitation nowcasting is the process of short-range prediction based on observation data. In the case of sudden rainfalls, this

process is difficult due to the fast evolution of the rain and its chaotic nature. Therefore, we need innovative techniques. The novel Phased-Array Weather Radar (PAWR) offers dense 3D images of reflectivity every 30 seconds. We took advantage of this big data to perform nowcasting using neural networks. We use Residual Neural Networks (RESNet) to compress the images and extract information relevant for the prediction. Next, we use a Convolutional Neural Network (CNN) to make the prediction. Afterwards, we use the same RESNet to map the forecast to the original domain. The RESNet and the CNN are trained jointly for the compression to maximize the prediction accuracy. Our first results show that in most cases we can predict precipitations up to 30 minutes, with an error rate (false positives + false negatives) of 8%. The use of the RESNet allowed to alleviate the memory load and the computational complexity of the prediction. Moreover, training the RESNet and the CNN jointly reduced immensely the prediction noise in non-precipitation regions and improved the accuracy in precipitation regions.

Impact of ground-based water vapour and temperature lidar profiles on short-range forecast skill by means of hybrid 3DVAR-ETKF data assimilation

Thundathil, Rohith[(1)]; Schwitalla, Thomas[(1)]; Behrendt, Andreas[(1)]; Lange, Diego[(1)]; Späth, Florian[(1)]; Wulfmeyer, Volker[(1)]; Leuenberger, Daniel[(2)]; Haefele, Alexander[(2)]; Arpagaus, Marco[(2)]; Giovanni, Martucci[(2)]
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Assimilation of ground-based thermodynamic lidar observations has augmented numerical weather prediction capabilities from nowcasting to the very short-range, short-range, and medium-range. In this study, temperature and water vapour profiles obtained from the temperature Raman lidar and the water vapour differential absorption lidar, respectively, of the University of Hohenheim are assimilated into the Weather Research and Forecasting (WRF) model through a new forward operator. The operator directly incorporates the water vapour mixing ratio, avoiding undesirable cross sensitivities to temperature, enabling complete observation concerning the water vapour contents to be propagated into the model. The assimilation was performed with the three dimensional variational DA system and with the hybrid 3DVAR Ensemble Transform Kalman Filter approach at a convection-permitting resolution. The 3DVAR-ETKF experiment resulted in a 50% smaller temperature and water vapour RMSE than the 3DVAR experiment. The planetary boundary layer height (PBLH) of the analyses also showed improvement compared to available ceilometer data. A single lidar vertical profile impact spreads over a 100 km radius, promising future assimilation of water vapour and temperature data from operational lidar networks. Forecast improvement with respect to PBLH was observed for about 7 hours, while an improvement of integrated water vapour lasts for 4 hours. We also present some significant collaborative effort with the Raman lidar for meteorological observation (RALMO) from the MeteoSwiss. Also, some initial results from the assimilation Atmospheric Raman Temperature and Humidity Sounder (ARTHUS) data will be shown.

A statistical evaluation of Bayesian inversions from infrared and microwave cloudy observations for future instruments MTG-FCI, MSG-MWI and MSG-ICI

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Infrared (IR) and Microwave (MW) satellite observations are widely used in data assimilation for Numerical Weather Prediction. The so-called "1D-Bayesian + 4D-Var" assimilation method (Duruisseau et al., 2019) is used for the all-sky MW observations at Météo-France. It consists of a Bayesian inversion of the brightness temperatures, that retrieves atmospheric profiles. The resulting relative humidity is then assimilated in the 4D-Var of the global model ARPEGE. This study focuses on future instruments onboard MTG-I (Meteosat Third Generation) and MSG-B (MetOp Second Generation): the Flexible Combined Instrument (FCI), the MicroWave Imager (MWI) and the Ice Cloud Imager (ICI). Due to their

different spectral ranges, they are sensitive to various and complementary quantities within clouds and precipitation. The objective is to identify the key components of the assimilation system for reaching a synergistic use of these observations in an all-sky context. The ability of the Bayesian inversion to provide complementary information is quantified with simulations from radiative transfer model RTTOV v.13 and lagged forecasts for the observations and the background. Statistical results based on a wide sample of profiles from the ARPEGE forecast model will enable to build a global evaluation for IR and MW observations, and thus measure the degree of consistency and the differences in the retrievals from IR and MW observations. Two steps are followed: (i) considering a perfect forward model to understand the source of differences from the retrieval method and the spectral range ; (ii) introduction of errors in the radiative transfer model to understand the differences introduced by the hypotheses used. Preliminary results will be shown.

Friday, 17 Sep 2021

Poster session P5 - General DA

Exploring the potential of nested EnVAR in the global-to-regional ensemble system at DWD

Burba, Mareike[1,2]; Ulbrich, Sven[1]; Hollborn, Stefanie[1]; Anlauf, Harald[1]; Schraff, Christoph[1]; Potthast, Roland[1]; Knippertz, Peter[2]
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The German Weather Service (DWD) operationally runs ensemble predictions systems for the global and regional Numerical Weather Prediction (NWP). The global system deploys the NWP model ICON with an EnVAR+LETKF (Ensemble variational + localized Ensemble Transform Kalman Filter) data assimilation at a resolution of 40 km for the ensemble and 13 km for the deterministic run. The global setup is run with a two-way nest in central Europe (ICON-EU). This provides the lateral boundary conditions for the regional system which consists of ICON-LAM (ICON Limited Area Mode) run at a resolution of 2.1km (model configuration ICON-D2) and a 4D-LETKF scheme called KENDA (Kilometre-scale Ensemble Data Assimilation). We are investigating a number of different setups for creating a regional EnVAR analysis for the deterministic forecast. The model is ICON-LAM, but the ensemble members for the ensemble covariance matrix and the boundary conditions for the deterministic run originate from different resolutions of the ICON model, e.g. ICON-D2, ICON-EU or ICON global. We focus on a EnVAR data assimilation based on the KENDA ensemble to improve the forecasts on the convective scale.

Forecast Evaluation of a Deep Convection Case During Relampago Assimilating Conventional and Satellite Observations with the WRF-GSI-LETKF System

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We present forecast evaluation results from the first attempt to use the WRF-GSI-LETKF system in Argentina. The impact of assimilating high-resolution surface networks and satellite observations on a forecast from the analyses is evaluated. This study also represents the first steps to assimilate satellite radiances in a regional context in South America. We focus on a case study corresponding to a huge mesoscale convective system (MCS) developed over central and north-eastern Argentina during November, 22th, 2018. Analyses with 10-km horizontal grid spacing

were produced assimilating observations every hour from 11/20 18Z to 11/23 12Z. We used a 60-members ensemble which at the first assimilation cycle is initialized from the deterministic GFS run adding random perturbations with climatological covariance. A multiphysics approach is also used to represent model errors, using different physics configurations. Four assimilation experiments were conducted using increasing sets of observations: CONV assimilates conventional observations from prepBUFR, AUT uses CONV observations plus automatic stations, SATWND add satellite-derived winds and RAD also includes satellite radiances from AMSU, HIRS, MHS, ATMS, AIRS and IASI. We run two ensemble forecasts initialized from the analyses at 00Z and 06Z 11/22 to evaluate the impact of the different observing networks on forecasts. Comparing the forecasts with the observed precipitation (IMERG Final Run), the representation of precipitation is shown to improve for forecasts initialized from AUT, SATWND and RAD. Moreover, the impact continues for many hours after its initialisation. Complete results and conclusions from these experiments will be presented at the symposium.

Assimilation of solar reflectances in a pre-operational online system with a local ensemble Kalman filter

Deppisch, Thomas[(1)]; Bach, Liselotte[(1)]; Scheck, Leonhard[(2)]; Stumpf, Christina[(1)]; Geiß, Stefan[(2)]; De, Lozar Alberto[(1)]; Schraff, Christoph[(1)]; Koepken, Christina[(1)]; Faulwetter, Robin[(1)]
[(1)]Deutscher Wetterdienst [Offenbach], [(2)]Ludwig Maximilian University [Munich]

Since spring 2021, the convection-permitting ensemble data assimilation system (ICON-D2 KENDA) of Germany's National Weather Service (DWD) assimilates solar reflectances from the SEVIRI 0.6 micron channel inside the pre-operational SINFONY system for seamless prediction from nowcasting to NWP. Assimilating solar reflectances allows for deeper insight into the physical dynamics of atmospheric radiation and microphysical processes. Better tracking of clouds and convective processes may also improve the skills of short-term NWP, especially for precipitation. This work is based on the incorporation of the fast and accurate forward operator for solar reflectances MFASIS into the NWP system at DWD. Data assimilation of these reflectances further demands careful study of the underlying biases introduced by both model and forward operator. We therefore give an overview of the steps undertaken during the development of this system as observational error modelling, quality control and an adaptive bias correction. Extensive case studies and impact experiments in different seasonal conditions show that data assimilation of solar reflectances reduces the forecast error of cloud and precipitation, precipitation intensity, global radiation and screen-level variables.

Hydrometeor control variables in the AROME-France 3DEnVar assimilation scheme

Destouches, Mayeul[(1)]; Montmerle, Thibaut[(2)]; Michel, Yann[(3)]; Caron, Jean-François[(4)]
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Initialization of variables related to condensed water is a topic of active research for convective-scale weather forecasting. We present in this talk the work that has been performed at Météo-France to add hydrometeors as control variables of a three-dimensional ensemble variational scheme (3DEnVar) for the regional model AROME-France. Hydrometeor variables are added in the forecast error covariance matrix B estimated from an Ensemble of Data Assimilations. As a first approximation, no variable transform nor static hydrometeor covariance matrix are used. Common localization and Scale-Dependent Localization (SDL) are tested. Even without any direct assimilation of hydrometeor observations, hydrometeor analysis increments can be produced via covariances with observed variables in B. Cycled forecast-analysis experiments in near-operational conditions have been performed over a 3-month summer period. Three configurations were compared, (i) a control experiment without hydrometeor control variables, (ii) a test experiment with hydrometeor control variables but without cycling the resulting forecasts, and (iii) an experiment with hydrometeors and cycled forecasts. Compared to the control experiment, both hydrometeor experiments

show a positive impact in the first 7 hours of the forecast in terms of cloud cover, and in the first hour for precipitations. The forecasts display an extended short-term predictability window for precipitation, with skill scores decaying beyond a reference threshold after 1 h 14 min on average, instead of 1 h in the control experiment. The added value of hydrometeor control variables persists independently of the chosen localization method, thus confirming the robustness of the results.

1000-member ensemble forecasts for extreme events: the 2019 typhoon Hagibis and the July 2020 Kyushu heavy rain

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Forecast performances of two extreme events (the 2019 typhoon Hagibis and the July 2020 Kyushu heavy rain) have been revisited with the aim of improving the forecasts for these events. Our approach is to better quantify forecast uncertainties by running data assimilation systems with 1000 ensemble members to produce ensemble analyses. The two data assimilation methods to be used are the four-dimensional local ensemble transform Kalman filter 4D-LETKF and the hybrid variational-ensemble assimilation 4D-EnVAR. Verifications show that the resulting forecasts outperform the operational forecasts both in deterministic and probabilistic forecasts.

Enhancement of Variational Assimilation of High-Frequency and High-Resolution Radial Winds

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This study is aimed at effectively utilizing radial winds from Doppler radars densely distributed in time and space in data assimilation to initialize a forecast model. An appropriate handling of the observation error correlation is firstly important to consistently assimilate high-resolution data without applying severe thinning. Handling of detailed flow-dependency in data assimilation scheme is also essential to extract information from the high-resolution observations as a time evolution in line with the model dynamics. A hybrid 4D-Var equipped with an observation error of radial wind correlated in time and space is implemented based on the former operational Meso-scale Analysis of Japan Meteorological Agency applying the JNoVA 4D-Var (JMA 2019, Honda et al. 2005), introducing the flow-dependent background error generated by the Ensemble of Data Assimilation (EDA; Isaksen et al. 2010) with extended control variables. A case study shows the flow-dependent background error along with the correlated observation error contributes to give promising results lasting into forecast. Investigation is carried out on sensitivity of the flow-dependent background error to the EDA perturbations, including uncertainties from the random sampling of perturbations added to observations. An enhancement of the ensemble control variables also is tried to take into account the scale dependent profile of the background error.

Using a cost-effective approach to increase background ensemble size in EnVar to improve radar analyses and forecasts of convective systems

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[(1)]School of Meteorology, University of Oklahoma

The valid time shifting (VTS) method is explored for the GSI-based EnVar system extended for convective scales with direct assimilation of radar reflectivity. VTS is a cost-efficient method to increase ensemble size or reduce current cost by including subensembles before and after the central analysis time. Additionally, VTS addresses common time and phase model error uncertainties within the ensemble. VTS is examined here in a HRRRE-like continuous hourly analysis system over 1900-0000 UTC on 1-2 May 2019. The VTS application is compared against the 36-member control experiment (ENS-36) to increase ensemble size (3x36 VTS) and as a cost-savings method (3x12 VTS), with three time-shifting intervals t = 15, 30, and 45-min. The 3x36 VTS experiments increased the ensemble spread overall, with larger subjective benefits in early cycles during convective development. The 3x12 VTS experiments capture analysis with similar accuracy as ENS-36 by the third hourly analysis. Control forecasts launched from hourly EnVar analyses show skill increases in 1-h precipitation over ENS-36 out to hour 12 for 3x36 VTS experiments. Experiment VTS-3x12t45 captures similar level of skill to ENS-36 out to forecast hour 16, with at times subjectively better structure of the bowing line. The 3x36 VTS experiments add a computational cost of 35-56%, compared to the near tripling of costs when directly increasing ensemble size, while 3x12 VTS experiments save about 45-55% costs over ENS-36.

Spin-up time from switching the microphysics scheme within the assimilation cycle and impacts on the precipitation forecast quality

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[(1)]Deutscher Wetterdienst [Offenbach], [(2)]University of Reading

The SINFONY project at DWD aims to produce seamless forecast products from minutes up to 12 h focusing on convective precipitation events. While the forecasts early on are typically produced from nowcasting procedures using radar data, numerical weather prediction (NWP) aims at forecasting longer time ranges. However, the latest available forecast is usually too old to merge with nowcasting data for reliable seamless predictions. At DWD, forecasts with lead times beyond 2 h are produced by a short-range numerical weather prediction system (SRNWP) using ICON. A continuous assimilation cycle is used with relatively long cutoff times and a 1-moment microphysics. To reduce differences in predicted precipitation and nowcasting, 3 actions are taken on the NWP side. First, we reduce the latency of forecasts by using short assimilation cycles with shorter data cutoff and increasing the frequency of forecasts. This is the Rapid Update Cycle (RUC). Second, the RUC uses new observation systems, e.g. radar or all-sky satellite data, to capture and represent strong convection. Third, we introduce a 2-moment microphysics scheme into ICON, improving the simulated radar reflectivities. To keep the model state similar to that of the SRNWP, the RUC branches off from the SRNWP assimilation cycle at several pre-defined times. The introduction of the 2-moment scheme leads to a spin-up affecting both assimilation cycle and short forecasts. The resulting effects are assessed by a comparisonto the SRNWP with the 1-moment scheme.The

results are compared regarding quality of precipitation forecast and other observations. It is shown how far the resulting improvements are related to the assimilation and microphysics scheme, or to the higher forecass frequency.

The predictability of the moist convection over different mountain sizes and environmental flow conditions

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The predictability of moist convection and the accompanying rainfall is limited to a few hours since the high nonlinearity of moist convective processes could lead to rapid initial error growth. On the other hand, the topography is considered to decrease the nonlinearity of the atmosphere and increase the predictability by providing a stationary forcing. It has been shown that topography can increase the predictability of rainfall from a practical perspective. However, the impact of topography on intrinsic predictability hasn't been well investigated. By addressing the impact of topography on the initial error growth of moist convection, it is expected to be helpful in improving the weather prediction and data assimilation strategy in areas affected by topography. Here, identical twin experiments with different single Gaussian shape mountains and vertical wind shear are conducted with the Weather Research and Forecasting (WRF) model in an idealized framework. The initial error growth is evaluated by a metric referred to as moist difference total energy (MDTE), which considers the differences in horizontal wind, temperature, water vapor, and surface pressure between the two simulations. Comparing to the experiment without the mountain, the initial error growth estimated by the MDTE is smaller for the moist convection occurring over the mountain in the morning. The reduction effect of the mountain on the error growth is more distinct in the water vapor than in the horizontal wind or temperature. When the mountain slope is steeper, the effect also becomes more pronounced. It also shows a sensitivity to the stability and different flow conditions of the environment.

Improving dynamical balance and mass convervation in convective-scale data assimilation

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An idealized framework for radar data assimilation has been developed based on the COSMO-KENDA system (Zeng et al. 2021a), It is shown that the data assimilation could cause significant biased increases in divergence and vorticity as well as in total specific mass of microphysical variables. To reduce the bias, two methods have been developed: First, a new integrated mass-flux adjustment filter, which uses the analyzed integrated mass-flux divergence field to correct the analyzed wind field (Zeng et al. 2021b). It is found that the new filter considerably diminishes spurious mass-flux divergence and the high surface pressure tendency and thus results in more dynamically balanced analysis states. Second, a weakly constrained LETKF on mass conservation and nonnegativity of microphysical variables, which improves the mass conservation property of microphysical variables of analyses (Zeng and Janjic 2021). Both methods lead to better forecasts.

Poster session P5 - Methodology

Assimilating Disorganized Crowdsourced Imagery Data for Machine Learning-based Geomorphological Change Detection Research

Chen, Thomas[(1)]
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As open source data becomes more ubiquitous, the involvement of citizen scientists has increased. The collection of large quantities of relevant data and respective labels through crowdsourcing on online platforms has yielded many exciting opportunities for machine learning applications. In geomorphology, multitemporal imagery, much of which is captured through crowdsourcing, is especially useful for training deep learning models for change detection in landscapes. This is relevant in terms of natural hazards that occur, including endogenous types like volcanoes and neotectonics, exogenous ones such as floods, karst collapses, sedimentation, erosion, tsunamis, and avalanches, as well as climate change or land use-induced hazards like permafrost and desertification. However, a challenge when harnessing crowdsourced imagery is the disorganized and “unclean” fashion in which it often presents itself. Cleaning data prior to training neural network-based computer vision models is key to success in any geomorphology change detection research. We discuss approaches such as manual techniques, image restoration and denoising, and image duplication reduction. The goal is to assimilate a diverse range of data collected from many sources to successfully train machine learning algorithms. In a broader sense, this research has the potential to save lives by detecting possibly destructive and dangerous geomorphological change, and to conserve environments that have been affected severely.

Assimilating various environmental features to train machine learning algorithms for sea ice drift prediction in the Arctic as a key geophysical parameter for understanding climate change

Chen, Thomas[(1)]
[(1)]Academy for Mathematics, Science, and Engineering

The movement of sea ice is influenced by a number of factors, from winds to ocean currents. As climate change continues to occur rapidly, understanding sea ice drift in the Arctic is a key parameter to understanding the effects of rising temperatures in the region. Recent literature has shown that the Arctic and the Antarctic are most affected by global warming, which raises questions regarding climate justice, as most of the carbon emissions causing anthropogenic climate change are produced in other regions. To analyze this impact, we employ artificial intelligence to predict sea ice drift velocity based on external features. Machine learning is the process of computers gaining insights by seeing and correlating large quantities of data. Using external parameters, including wind speed, and drift velocity ground truth as the inputs of the model, we train multiple different architectures and compare the results. Particularly, we experiment with a convolutional neural network (CNN), a random forest (RF), and a support vector machine (SVM). We also experiment with various model specifications. This research leads to a greater understanding of the Arctic's response to climate change.

Timely allocation of resources after natural disasters: deep learning as a tool for damage assessment and saliency mapping

Chen, Thomas[(1)]
[(1)]Academy for Mathematics, Science, and Engineering

Natural disasters ravage the world's cities, valleys, and shores on a monthly basis. Having precise and efficient mechanisms for assessing infrastructure damage is essential to channel resources and minimize the loss of life. Using a dataset that includes labeled pre- and post-disaster satellite imagery, the xBD dataset, we train multiple convolutional neural networks to assess building damage on a per-building basis. In order to investigate how to best classify building damage, we present a highly interpretable deep-learning methodology that seeks to explicitly convey the most useful information required to train an accurate classification model. We also delve into which loss functions best optimize these models. Our findings include that ordinal-cross entropy loss is the most optimal loss function to use and that including the type of disaster that caused the damage in combination with a pre- and post-disaster image best predicts the level of damage caused. The highest accuracy percentage on the testing set that we achieve is 74.6%; the non-optimal nature of this is largely attributed to the limited discernibility between the major and minor damage categories. We also make progress in the realm of qualitative representations of which parts of the images that the model is using to predict damage levels, through gradient class-activation maps. Our research seeks to computationally contribute to aiding in this ongoing and growing humanitarian crisis, heightened by climate change. Specifically, it advances more interpretable machine learning models, which were lacking in previous literature.

Using Machine learning techniques to switch background error distributions to improve data assimilation

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With the development of non-Gaussian based data assimilation in the variational formulation, and the understanding that the underlying distribution can change dynamically, we need techniques that allow us to “switch” between the distributions to ensure a consistent background error model. To address this question, we have used different machine learning techniques with different criteria to determine if the behavior of the variable has switched between Gaussian and lognormal, but also back to Gaussian. In this presentation, we shall present results using a support vector machine technique to determine when the z component of the Lorenz 1963 model switches between Gaussian, lognormal, and back, through using skewness changing from 0 to determine this change and show that by switching between the distribution, the analysis error is improved compared to just assuming a Gaussian all the time. We shall also present results from the Lorenz 96 model as well.

A Deep Learning approach for error correction of numerical weather prediction simulation data

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Meteorological data are produced in various spatial and time sizes, depending on the application they will be used. The data are the result of Numerical Weather Prediction (NWP) simulations, e.g. the solution of mass & energy balance equations, concerning the fluids of the atmos-

phere. The uncertainty of the solution (time-series of domain) becomes higher as the prediction goes further to the future, thus, limiting the applicability of hour per hour resolution of such models, to 2 to 5 days ahead. In the current study, a deep learning approach, based on convolutional autoencoders (CAEs), is explored in order to effectively correct the error of the simulation result, hence performing a result similar to statistical downscaling methods. The global seasonal forecast (6 month ahead) Meteo France Seasonal data was used for the Greece area, alongside the reanalysis dataset NCEP FNL, that incorporates observations, satellite imaging etc and it has better spatial resolution. During the training of the model, external information is used as evidence transfer, concerning the time conditions (month, day, season) and the simulation characteristics (initialization of simulation). The study was performed for the temperature variable at 2m from the ground and it was found that the CAEs help improve the resolution of the seasonal data and successfully correct the error of NWP data for 6 month ahead forecasting. Interestingly, the season evidence yields the best results which indicates a seasonal (winter, spring, summer, autumn) dependence of the performance.

Accelerating Climate Model Computation by Neural Networks: A Comparative Study

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In the era of modern science, scientists have developed numerical models to predict and understand the weather and ocean phenomena based on fluid dynamics. While these models have shown high accuracy at kilometer scales, they are operated with massive computer resources because of their computational complexity. In recent years, new approaches to solve these models based on machine learning have been put forward. The results suggested that it be possible to reduce the computational complexity by Neural Networks (NNs) instead of classical numerical simulations. In this project, we aim to shed light upon different ways to accelerating physical models using NNs. We test two approaches: Data-Driven Statistical Model (DDSM) and Hybrid Physical-Statistical Model (HPSM) and compare their performance to the classical Process-Driven Physical Model (PDPM). DDSM emulates the physical model by a NN. The HPSM, also known as super-resolution, uses a low-resolution version of the physical model and maps its outputs to the original high-resolution domain via a NN. To evaluate these two methods, we measured their accuracy and their computation time. Our results of idealized experiments with a quasi-geostrophic model show that HPSM reduces the computation time by a factor of 3 and it is capable to predict the output of the physical model at high accuracy up to 9.25 days. The DDSM, however, reduces the computation time by a factor of 4 and can predict the physical model output with an acceptable accuracy only within 2 days. These first results are promising and imply the possibility of bringing complex physical models into real time systems with lower-cost computer resources in the future.

Using a Neural Network to choose amplitude and anisotropy parameters of an adaptive background error covariance

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As part of the development of the new 3D Real-Time Mesoscale Analysis (3D RTMA) we have developed a multigrid background covariance scheme using local superpositions of quasi-Gaussian numerical filters based on compact-support beta distributions. We plan to use a machine learning approach, specifically a neural network, to guide the optimal construction of the multigrid's amplitude scale-weights, and anisotropy-determining aspect tensor, in response to smoothed diagnostics from terrain, background and ensemble, so that the analysis can be made dynamically adaptive. Given the tensorial characterization of anisotropy, we extract from the background and ensemble fields suitable tensor

diagnostics which a neural network has only to combine additively. The quasi-Gaussian character of the covariance contributions allows some inter-observation covariances to be well approximated by direct evaluation. Thus, we construct a quadratic quality criterion measuring that covariance deviation from the corresponding sample innovation statistics that subsets of observation pairs provide, and train the neural network over multiple archived cases, to optimize the covariance parameters, and hence the analysis.

Towards Developing Radio Occultation Machine Learning Forward Operators

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Spire Global is a space-to-cloud data and analytics company that generates highly impactful earth observations and weather forecasts. Currently, Spire collects ~10,000 radio occultation soundings a day globally via the company's large nanosat constellation; these soundings, along with other data, are assimilated into a global weather model to produce the Spire operational forecast. Our main goal of developing machine learning (ML) forward operators is to improve the skill of our data assimilation analyses and subsequent weather forecasts by enhancing the impact of the radio occultation profiles. More precisely, we plan to improve over existing physics-based operators by using more accurate implicit data driven interpolation operators, and superior handling of data biases. We developed two ML operators based on the random forest and deep neural network (DNN) methods. The random forest model is used as an exploratory tool for feature importance to deal with the large number of predictors obtained from numerical weather prediction forecasts and radio occultation profiles. The first implementation of the DNN model employs a reduced number of features and takes advantage of an embedding layer to differentiate between various satellites sources characterized by categorical information. The next step is to make use of all geophysical variables as required by the data assimilation scheme and implement DNNs equipped with either a convolutional or SVD layer. Bending angles resulting from the ML forward operators will be compared against the physics-based 1D operator ROPP outcomes. The performance will be assessed based on statistics of departures from the real measurements.