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

Nora Loose[1] and Patrick Heimbach[*†2]

[1]University of Colorado, Boulder – Department of Applied Mathematics Boulder, CO, United States
[2]University of Texas at Austin – Oden Institute for Computational Engineering and Sciences Austin, TX, United States

Abstract

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.

Keywords: 4DVar, ECCO, ocean data assimilation, Hessian uncertainty quantification, observing system design, AMOC

*Speaker
†Corresponding author: heimbach@utexas.edu