Uncertainty quantification and observing system design in the subpolar North Atlantic

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Abstract

We present a new approach to quantify uncertainties in oceanographic metrics of interest (referred to as Quantities of Interest – QoI) and to assess the value of ocean observing systems in the context of the adjoint-based state and parameter estimation frameworks of the global "Estimating the Circulation and Climate of the Ocean" (ECCO) and the regional "Arctic and Subpolar North Atlantic State Estimate" (ASTE) projects. We take advantage of Optimal Experimental Design tools, developed in computational science and engineering, by framing the inverse problem as one of Bayesian inference. Under suitable assumptions, the ECCO and ASTE solutions and their associated optimal time-evolving ocean states provides a Maximum a Posteriori Point (MAP) in the observation-constrained space of uncertain input variables. While sequential estimation carries an approximate posterior error covariance matrix along with the analysis, ECCO and ASTE have so far not considered formal posterior uncertainties. Nevertheless, the availability of the adjoint model permits, in principle, the calculation of posterior error covariances via Hessians, and of the reduction of the prior uncertainty afforded by the observations. More efficiently, a projection of uncertainty reduction onto climate metrics provides a direct measure of how valuable the considered observing system is for climate metrics of interest. The power of this method stems from the fact that uncertainty propagation is mediated by the (linearized) model operator and involves the full space of uncertain control variables. It is therefore an adequate tool to rigorously quantify the value of observations–as well as their redundancy or complementarity–, and has a more systematic underlying mathematical framework than conventional observing system [simulation] experiments (OS[S]Es).

We demonstrate the approach through assimilation experiments in the North Atlantic subpolar gyre, using both the global ECCO and regional ASTE framework. For demonstration purposes we consider the following existing arrays: RAPID, OSNAP-West, OSNAP-East, Denmark Strait, Fram Strait, and Davis Strait. Assuming that both volume and heat transport may be estimated with these arrays, we seek to quantify to which extent these observations constrain subsurface heat content changes at the western and southeastern margins of the Greenland ice sheet (our chosen quantities of interest). Overall uncertainty reduction is determined by the extent to which observation sensitivities from each of the arrays project onto subsurface heat content sensitivities, and the signal-to-noise ratio which incorporates magnitudes of prior and observation uncertainties.