

ASSIMILATION OF LOCAL AND GLOBAL DATASETS WITH REGIONAL AND BASIN-SCALE MODELS OF OCEAN CIRCULATION

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LONG-TERM GOALS

The overall objective of the research is to construct through data assimilation a “synthetic” ocean simultaneously consistent with the model dynamics and the observations, having both realistic global behavior and local fine-scale evolutions.

OBJECTIVES

Two major objectives will be achieved:

- a) to improve and extend the model(s) predictive skill beyond its intrinsic predictability timescale and forecast the evolution of mesoscale features both in regional and basin-wide configurations;
- b) to carry out long-duration hindcast assimilations aimed to process studies that will enhance our understanding of complex jet-like currents, frontal systems, and the tropical/subtropical/ subpolar interactions of the North Atlantic circulation.

APPROACH

- a) Application of simple schemes (“nudging”) to assess and improve the models’ predictive skill through the assimilation of both global and local datasets with particular emphasis on TOPEX altimetry.
- b) Construction of a suboptimal Kalman filter which is affordable and efficient by following a procedure that makes its construction “standard” for any primitive equation model in any domain configuration.

WORK COMPLETED

The suboptimal, affordable and efficient Kalman filter has been constructed following a standardized procedure and has been implemented for two primitive equation models, SPEM (in the regional Gulf Stream System configuration); and SCRUM (in the Northern Atlantic configuration from 30°S to 70°N).

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RESULTS

Research highlights

Malanotte-Rizzoli, Fukumori and Young (1996)

In this study we present a methodology for the construction of a hierarchy of Kalman filters for primitive equation models. We eliminate the time-invariant linearization of the dynamic model used for the time-integration of the state-error covariance matrix by using two different procedures. In the first one we allow for full time evolution of the error covariance but preserve the time-invariant linearization of model dynamics around a unique mean state. The second procedure allows for the covariance time—evolution by time evolving the linearization of the model dynamics around successive time intervals.

The most important conclusion is that nonlinearities in the model may be more important than the covariance time evolution per se when based on a time-invariant linearization. Allowing time evolution of the covariance through the second procedure produces better assimilation estimates. Thus a procedure similar to, but simpler than, extended Kalman filtering would be affordable and efficient.

Gunson and Malanotte-Rizzoli (1996a,b)

The problem of estimating boundary and initial conditions for a regional open-ocean model from sparse data is addressed using the adjoint method. The estimation of error covariances for the estimated boundary and initial conditions and interior fields, in the presence of strongly nonlinear dynamics, is investigated. The evaluation of the full error covariance matrix for the estimated control variables from the inverse Hessian matrix is presented along with its dependence upon the degree of nonlinearity in the dynamics. Major new results here obtained are the availability of off-diagonal covariances, the successful calculation of error covariances for all boundary and initial conditions, and the estimation of errors for interior fields. The role of the Hessian matrix is assessed in gauging the sensitivity of the estimated boundary and initial conditions to the data.

Malanotte-Rizzoli, Young and Levin (1997)

Together with my collaborators, Research Scientist Dr. Roberta E. Young and Postdoctoral Associate Julia Levin, we have constructed a suboptimal Kalman filter that overcomes the formidable storage requirements and computational expense required by the full filter for oceanographic applications. This effort is part of the DAMÉE-NAB project.

By making careful assumptions, it is possible to obtain a suboptimal Kalman gain matrix which is an affordable approximation, i.e., doable and efficient. Such a suboptimal K-filter has been designed by following a procedure that makes its construction “standard” for any primitive equation ocean model in any domain configuration. The three approximations made are:

- a) The reduction of the model’s effective state dimension. This is achieved by evaluating the basis set of EOF’s (Empirical Orthogonal Functions) that describe the model’s intrinsic evolution. The amplitudes of the fields projected onto the EOF space constitute the reduced state dimension of the model.

- b) The numerical linearization (time-invariant) of the model dynamics for the calculation of the state transition matrix. The assumption underlying this approximation is that the model

evolution can effectively be linearized (but only for the evaluation of the Kalman gain) over the time interval of interest.

c) Asymptotic, steady-state limit approximation of the model error covariance which eliminates the need for storage and continuous integration of the error covariance matrix.

Such a filter has been constructed for a primitive equation general circulation model (SCRUM) in a fully realistic configuration of the North Atlantic Ocean. The 10-day maps of surface TOPEX altimetry constitute the basic dataset assimilated into the model over different durations in time. The K-filter assimilations are then assessed against nudging assimilations.

As a preliminary example, we show results from a 3-month long assimilation of the same map of sea surface height obtained from TOPEX altimetry, i.e., the 10-day average surface height for the end of March 1993. Fig. 1 shows the sea surface height (SCRUM allows for the free surface as prognostic variable) at the end of March (90 days) after a 10-year spin-up of the model under surface forcings provided by climatological wind stress and heat/moisture fluxes according to the guidelines established in the DAMÉE-NAB effort. Fig. 2 shows the sea surface height of TOPEX altimetry for the last 10 days of March 1993. Fig. 3 shows the model sea surface height obtained after a 3-month long assimilation of the TOPEX map of Fig. 2. The modifications in Fig. 3 induced by the assimilation in the smooth height field of Fig. 1 are evident. A paper on these results is in preparation.

TRANSITIONS

Transition will be made to the Navy of the Kalman filter developed in the research.

PUBLICATIONS

P. Malanotte-Rizzoli, I. Fukumori and R.E. Young, "A methodology for the construction of a hierarchy of Kalman filter/smoothers for nonlinear primitive equation models", *Modern Approaches to Data Assimilation in Ocean Modeling*, P. Malanotte-Rizzoli, ed., Elsevier Publishing Co., pp. 297-317, 1996.

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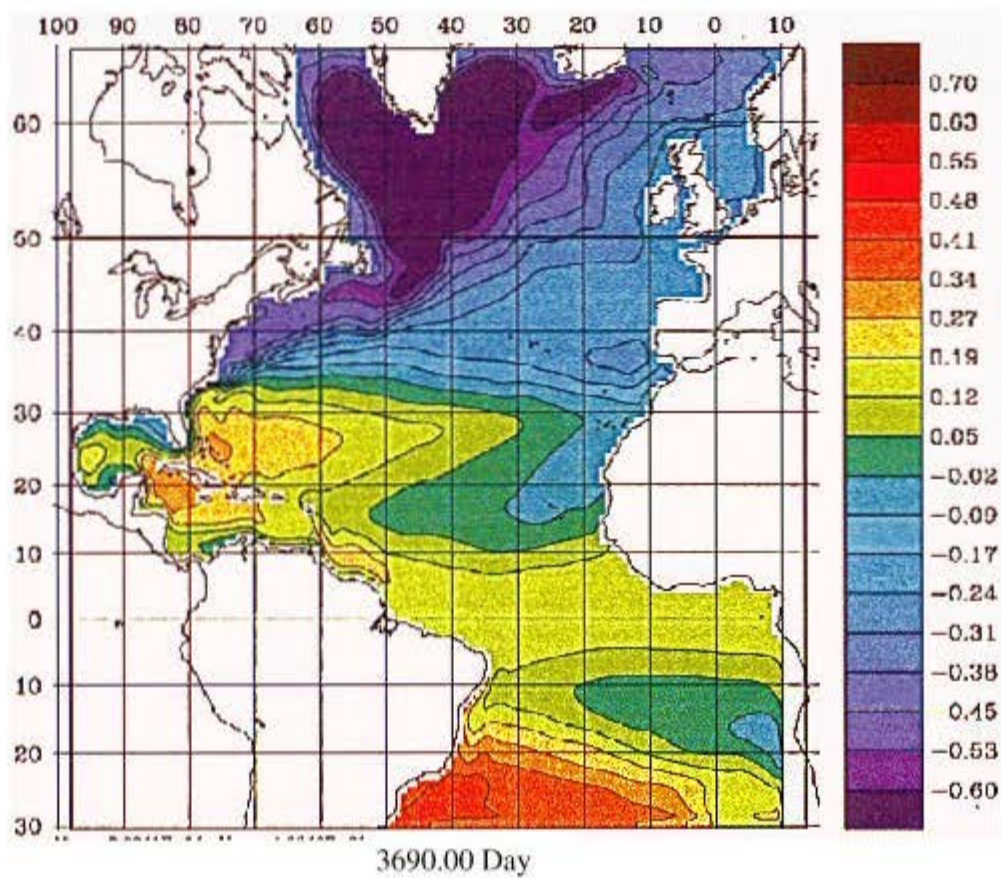


Figure 1. Sea surface elevation in the reference experiment after 10 years and 3 months evolution under surface climatological forcings.

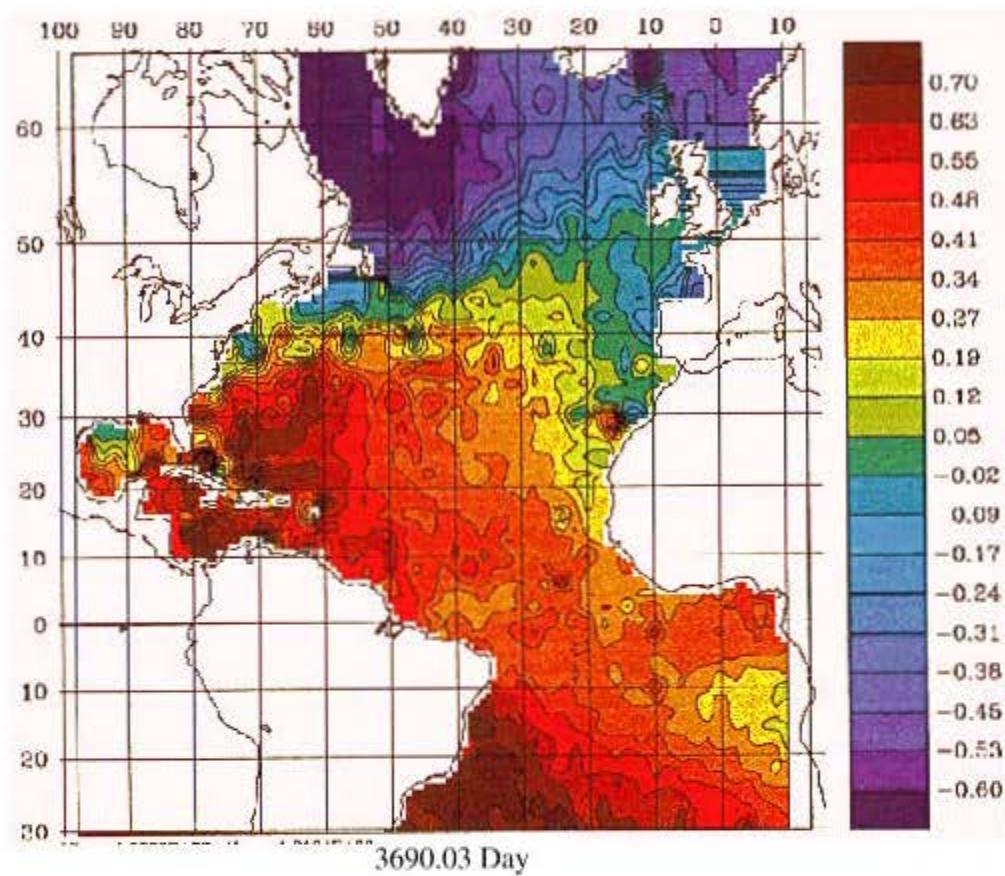


Figure 2. Sea surface elevation from TOPEX altimetry. Average of the last 10 days of March, 1993.

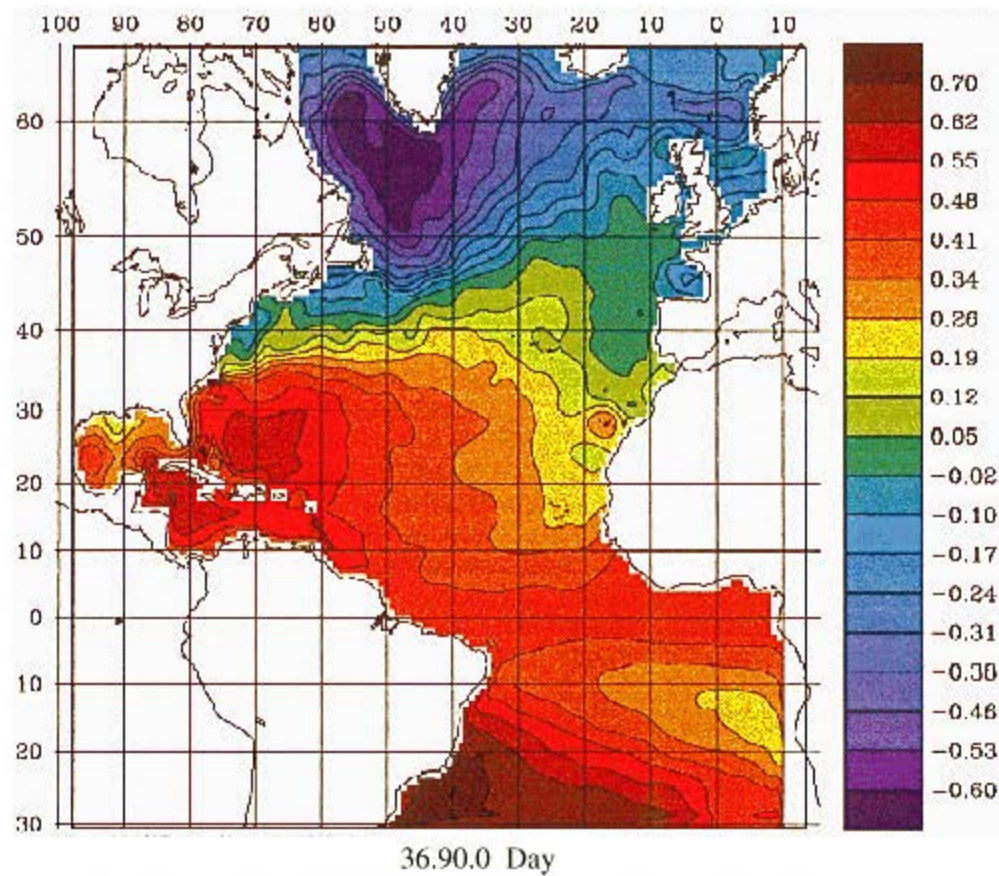


Figure 3. Sea surface elevation after 3 months assimilation of the TOPEX map of Figure 2.