Assimilation of Local and Global Datasets with Regional and Basic-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 30ºS to 70ºN). Extensive use and experimentation has been carried out in the North Atlantic Ocean.

RESULTS

Research highlights

(i) Malanotte-Rizzoli, Young, Hedstrom, Arango and Haidvogel (1998)

Together with the group of Rutgers University, we have used a free surface, terrain—following primitive equation model to study the mean water pathways in the North Atlantic subtropical and tropical ocean. A numerical calculation, carried out with realistic basin geometry, 3/4° by 3/4° resolution, under climatological wind stress forcing, is analyzed on isopycnal surfaces outcropping at the boundary with the subpolar gyre as well as in the subtropics. The latter ones define the pathways of the thermocline waters that subduct at the southeastern border of the subtropical gyre and feed the equatorial current system. To our knowledge, this is the first such investigation carried out in the North Atlantic ocean.

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Circulation properties are diagnosed on isopycnal surfaces through the evaluation of the Bernoulli function and of particle trajectories. As B contours are geostrophic streamlines, the comparison with the particle trajectories reconstructed from the current velocities on the considered isopycnal allows us to assess whether the subducted water columns move along geostrophic contours, consistent with the theoretical expectations of the ventilated thermocline theory and of its tropical extensions.
The analysis of the three isopycnal surfaces σ_o=25.50-25.70-26.00 kg/m^3 that outcrop at the southern border of the subtropical gyre allows us to determine the subtropical to tropical pathways.
Examination of the Bernoulli function shows the presence of three classes of subduction regions, and related particle streamlines, in the northern hemisphere. The first region has open Bernoulli contours in the subtropics west of ~45°W. Here subducted water particles proceed westward to the western boundary, where they turn northward and are entrained in the subtropical gyre circulation. The second region lies roughly between 30° and 40°W. Here Bernoulli contours and associated particle streamlines also proceed westward but turn equatorward when hitting the western boundary. At the equator, this western boundary current merges with the analogous one moving northward from the southern Atlantic to form the Equatorial Under Current (EUC) that flows eastward along the equator. The third region of open Bernoulli contours is located in the easternmost Atlantic, east of ~30°W. Particles here subducted proceed first westward but then turn southeastward in the Atlantic interior, moving towards the equator in a zig-zag pattern and finally joining the EUC.
In the southern ocean this interior pathway is not present. Rather Bernoulli contours and particle streamlines all move westward as a broad South Equatorial Counter Current. Upon hitting the western boundary, they form a tight Brazil current that flows equatorward to join the EUC.
The above results are analogous to the subtropical to tropical water pathways found in the Northern Pacific Ocean in a variety of investigations, both in idealized and in realistic model calculations. They confirm the theoretical expectations than the subducted flow indeed follows geostrophic contours in most of the model domain.
This effort is part of the DAMÉE-NAB project. Understanding of basic dynamical mechanisms is infact the necessary basis for any successive development of nowcasting/forecasting capabilites which rely greatly upon this understanding for success. A paper has been submitted to the *Deep-Sea Research* special issue devoted to DAMÉE-NAB.

(ii) Malanotte-Rizzoli and Levin (1998)
Together with 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. As an example, we show the results of an assimilation of TOPEX altimetry at every other grid point of the sea surface, one-year long, in the context of a twin experiment approach. The model is run for 10 years under surface forcings to allow for complete spin-up of the wind driven circulation. Year 11 of the calculation constitutes the "true" ocean from which altimetry data are taken. The model is successively initialized with the 10th year average fields for velocity, temperature salinity and sea surface and one year calculation is carried out, thus obtaining the "false" ocean. The surface heights from the "true" ocean are then assimilated for one year and the Kalman filter effectiveness is assessed by comparing the time-evolution of the root-mean-square (RMS) errors between the assimilation run and the "true" ocean versus the analogous evolution of the RMS-errors between the "false" and "true" ocean.
Fig. 1 shows the error between assimilation and "true" ocean for the temperature field at 200 m depth at a specific day of the assimilation. The randomness of the error field with no systematic patterns present shows that the two experiments are totally uncorrelated. Fig. 2 shows the time-evolution of the global RMS-error of sea surface height respectively for the test-run, i.e. ("true" ocean-"false" ocean), solid line, and the assimilation run, ("assimilation"-"true" ocean), dotted line. As expected, after an initial adjustment time, the assimilated sea-surface height has a small, basically constant RMS-error with respect to the "true" height.
Fig. 3 shows the global RMS-error in the temperature field, i.e., summed over the entire three-dimensional grid, again for the test run, solid line, and the assimilation run, dotted line. This result is important because only sea surface height is assimilated, and any improvement in the estimate of other properties, such as temperature, is due to the K-filter effectiveness.
After an initial time in which the test-run error is smaller than the assimilation run error, the global RMS in the assimilation remains consistently and significantly lower for the remainder of the calculation.

PUBLICATIONS SUPPORTED BY ONR DURING THE LAST YEAR OF THE GRANT

P. Malanotte-Rizzoli and R.E. Young, "Gulf Stream system assimilation experiments: a sensitivity study," *J. Atmos. Ocean. Technol., 14*, 1392-1408, 1997.

D.B. Haidvogel, H. Arango, K. Hedstrom, A. Beckmann, P. Malanotte-Rizzoli, and S. Shchepetkin, "Model evaluation experiments in the North Atlantic basin: simulations in non-linear terrain following coordinates," submitted to special issue of *Deep-Sea Research* devoted to DAMÉE-NAB, 1998.

P. Malanotte-Rizzoli, R.E. Young, K. Hedstrom, H. Arango and D.B. Haidvogel, "Water mass pathways between the subtropical and tropical ocean in a climatological simulation of the North Atlantic ocean circulation," submitted to special issue of *Deep-Sea Research* devoted to DAMÉE-NAB, 1998.

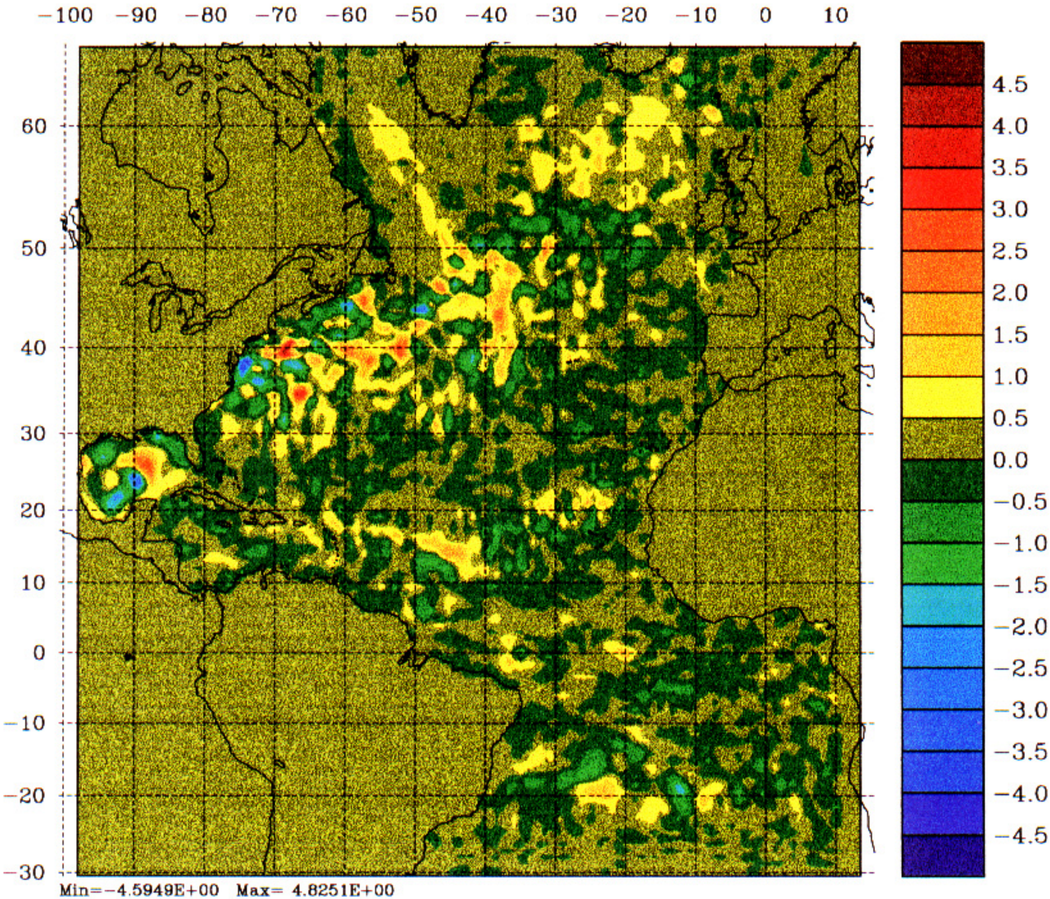
P. Malanotte-Rizzoli and J. Levin, "TOPEX altimetry assimilation in the Northern Atlantic Ocean with a suboptimal Kalman filter", in preparation.

Co-editor, with E. Chassignet and R. Williams, of the *Deep-Sea Research* special issue devoted to DAMÉE-NAB.

Temperature at 200 m

Assimilation run − True run

Day 3825



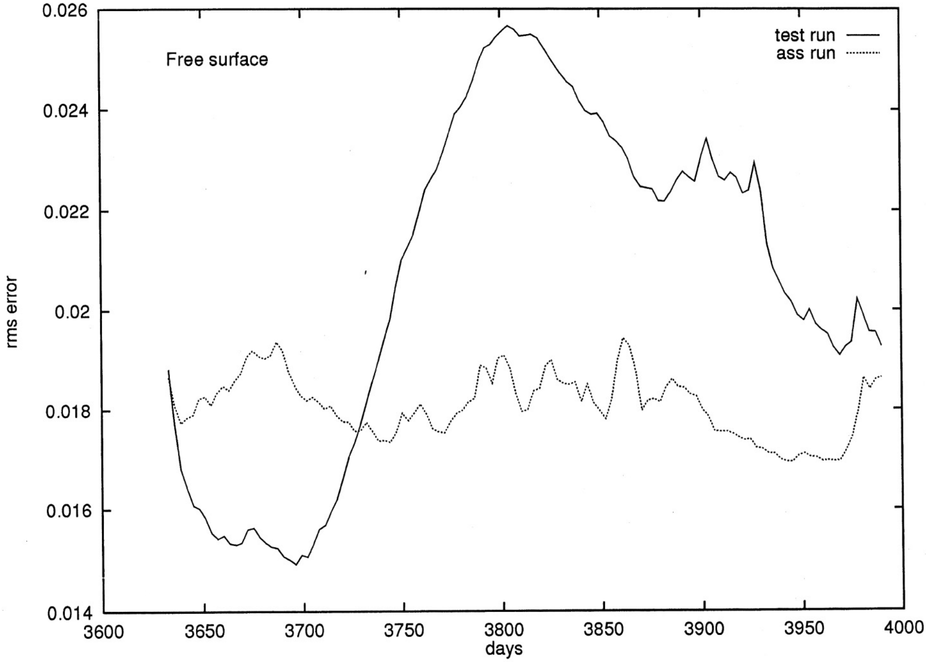


Figure 2

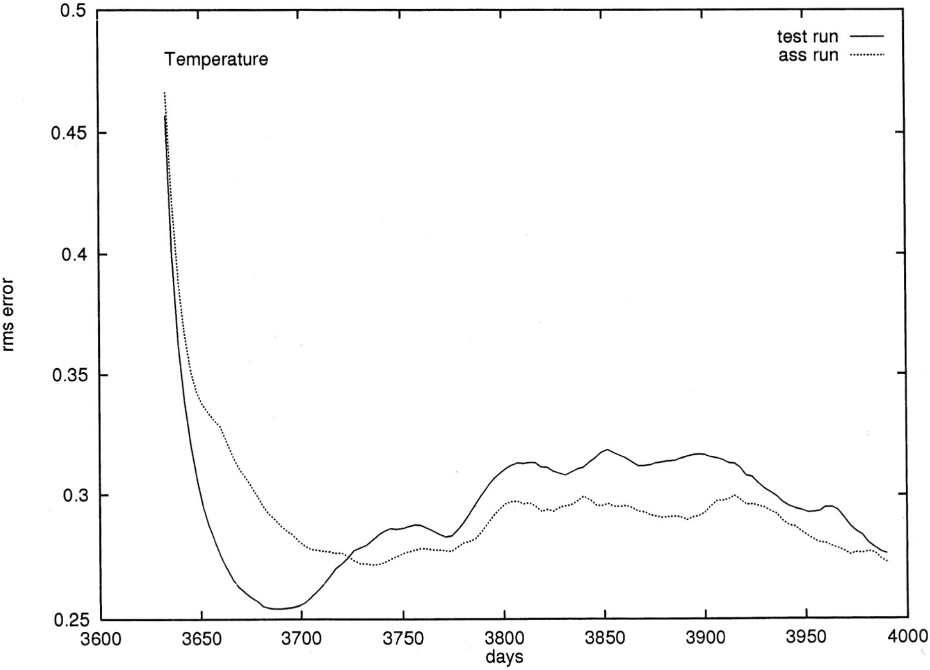


Figure 3