THE SATCHMO PROJECT: ASSIMILATION OF SATELLITE ALTIMETER DATA IN OCEAN MODELS

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The SATCHMO Project was selected by CNES in 1987 as a response to the joint NASA/CNES TOPEX/POSEIDON Announcement of Opportunity, and in 1995 with new objectives for the T/P Extended Mission. The purpose is to examine how data assimilation (in particular T/P altimetry) can help to better understand ocean dynamics at the coastal, regional, basin and global scales, and improve nowcasting and forecasting capabilities in ocean models. This goal has been pursued for the last 11 years through methodological research, regional and global data assimilation studies, and pre-operational studies and forecasting exercises.

Past and ongoing research

Methodological research

Realistic, eddy-resolving ocean assimilation problems are characterized by their very large size ($O(10^6\text{-}10^9)$ variables) and by poor knowledge of model errors. Ocean data assimilation technologies must therefore be both efficient and tolerant with respect to model error misspecification. First, the order of the problem can be decreased by order-reduction approaches. The Singular Evolutive Extended Kalman Filter [Pham et al., 1997] and Reduced-Order Optimal Interpolation [SOFA; De Mey, 1998] are two reduced-order approaches devised by the SATCHMO group. Second, the group has put forward so-called adaptive methods which in particular do not need specification of model errors: the gain, or forecast error variances, is adaptively estimated using a variational adjoint method [e.g. Hoang et al., 1997]. Other methodological advances by SATCHMO investigators include the comparison of representer and adaptive methods, extensive study of adjoint variational methods [e.g. Luong et al. 1995; Morrow and De Mey, 1995] including descent approaches using simulated annealing, genetic algorithms and neural networks [e.g. Wenzel, 1993], and approximation of representers using the ensemble Kalman filter [Echevin and De Mey, pers. comm., 1998].

A second kind of methodological research includes studies linked to assimilation physics (e.g. the specification of the reduced-order space) and numerical model interface. The isopycnal EOF method [Gavart and De Mey, 1997] seems an efficient method for separating physical processes and providing order reduction. A lot of work has also been devoted to the study of the contents of the altimeter signal, to multivariate formulations of the assimilation problem, and to assimilation in primitive-equationmodels [e.g. Pinardi et al., 1995]. The problem of open boundary specification has been greatly advanced by a new formulation of the adjoint variational problem [Seiler, 1993].

Regional and global data assimilation

A number of regional and global data assimilation projects by the SATCHMO partners are ongoing, mostly within European Union projects. In the Mediterranean, an 1/8° GCM is being run by two of the investigators [Pinardi and De Mey; see Figure 1] with the SOFA scheme; in addition, a coastal data assimilation effort using a mix of ensemble Kalman Filtering and SOFA is being conducted in Toulouse. In the Atlantic, a basin-scale eddy-resolving quasi-geostrophic model has been run in Grenoble in the last few years [e.g. Blayo et al., 1994]; other Data assimilation studies, both basin-scale and open-boundary, are ongoing. In the Tropics, Data assimilation is used to improve the heat flux estimates in the Pacific [Greiner, pers. comm., 1996], and to analyze the propagation of Rossby waves in the Indian Ocean [Morrow, pers. comm., 1998]. Finally, altimetric data assimilation with a global medium-resolution model is being conducted in Toulouse and Bologna as a participation to the EU AGORA project.

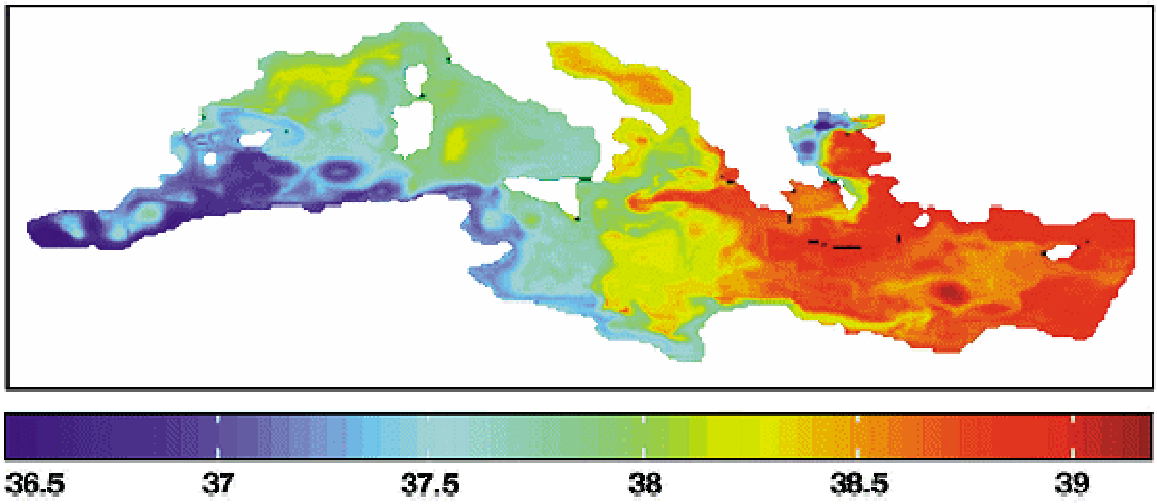

Figure 1
Salinity at 50 m depth in the Mediterranean on Nov. 4, 1993 in the 1/8° GCM (Benkiran and De Mey, pers. comm., 1998).

Pre-operational studies

SATCHMO investigators are aware of the applications of data assimilation for climate prediction, coastal monitoring, and thermal structure forecasting. We are attempting to help meet end-user requirements along three lines:

- **Observational system design**:
  With existing technology, the Grenoble group has been conducting altimeter sampling optimization studies, and the Bremerhaven group mixed scatterometer/altimeter studies. In the Mediterranean, the Toulouse and Bologna group are preparing for the optimization of XBT lines and mooring locations for a real-time exercise within the Mediterranean Forecasting System Pilot Project (MFSPP) in the year 2000.
- **Real-time forecasting exercises**:
  The Toulouse group participated in the AthenA and SEMAPHORE exercises in the past, and are contributing their technology to the SOAP Navy Forecasting system. As

mentioned above, the MFSPP basin-scale exercise is planned for the year 2000 in the Mediterranean.

- **Impact of real-time operation**:
  The SATCHMO investigators participating in MFSPP will use T/P data to help quantify the impact of near-real-time procedures on the quality of forecasts.

Prospects

Research will continue along the above lines in the next two years or so. In the longer term, we wish to undertake high-resolution multivariate forecasting problems of "global" class, within projects such as MERCATOR and GOData assimilationE. In addition, forecasting in coastal areas using altimetry and other sensors will offer new perspectives.

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References :

- Blayo, E., J. Verron, and J.M. Molines, 1994: Assimilation of TOPEX/POSEIDON altimeter data into a circulation model of the North Atlantic. *J. Geophys. Res., 99* (C12), 24691-24705.
- De Mey, P., 1998: A reduced-order multivariate optimal interpolation code for ocean data assimilation. *J. Atm. Oc. Tech.* (in preparation).
- Gavart, M., and P. De Mey, 1997: Isopycnal EOFs in the Azores Current region: a statistical tool for dynamical analysis and data assimilation. *J. Phys. Oceanogr., 27*, 2146-2157.
- Hoang, H.S., P. De Mey, O. Talagrand, and R. Baraille, 1997: A new reduced-order adaptive filter for state estimation in high-dimensional systems. *Automatica, 33*, 1475-1498.
- Luong, B., J. Blum, and J. Verron, 1995: Variational assimilation of altimeter data into a non-linear ocean model: temporal strategies. *Tellus* (submitted).
- Morrow, R.A., and P. De Mey, 1995: An adjoint assimilation of altimetric, surface drifter and hydrographic data in a QG model of the Azores current. *J. Geophys. Res., 100*(C12), 25007-25025.
- Pinardi, N., A. Rosati, and R. Pacanowski, 1995: The sea surface pressure formulation of rigid lid models. Implications for altimetric data assimilation studies. *J. Marine Sys., 6*, 109-119.
- Seiler, U., 1993: Estimation of Open Boundary Conditions with the Adjoint Method *J. Geophys. Res., 98*, 22855-22870.
- Wenzel, M., 1993: Neural Networks, a Tool for Prediction? Berichte aus dem Fachbereich Physik 36, Alfred-Wegener-Institut, Bremerhaven. 38pp.