Toward the Next Generation of Altimeter Data Assimilation for Physical Ocean and Marine Ecosystem Monitoring and Prediction

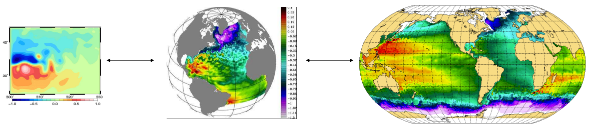
P. Brasseur(1) , J. Ballabrera(2) , A. Barth(3) , L. Bertino(4) , P.A. Bouttier(1) , N. Ferry(5) and the project team

(1) MEOM, OSUG, Grenoble (France)
(2) CSIC, ICM, Barcelona (Spain)
(3) GHER, University of Liège, Liège (Belgium)
(4) NERSC, Bergen, (Norway)
(5) Mercator-Océan, Ramonville-St-Agne (France)

The overarching objective of this project is to further develop, implement and assess advanced methods for the assimilation of altimeter data, in combination with other data sources, into the next generation of ocean circulation and ecosystem models. The project will uniquely contribute to the development of operational oceanography, and will enable better understanding of th role of the ocean on climate variability through the production of improved ocean reanalyses based on altimetry and other observational components. In this poster we present the status and perspectives of a collaborative research project, gathering initial contributions from the ongoing FP7 SANGOMA GMES project (http://www.data-assimilation.net/) to be expanded in the near future to new contributions in the framework of the OSTST. The methods that are being explored and further developed to assimilate altimeter data are multiple, taking advantage of the most recent advances in the field of stochastic modelling, statistical estimation and optimal control. On the one hand, well established methodologies such as Kalman-type filters and smoothers and variational methods are expanded and complexified to take into account non-Gaussian error statistics or non-linear model dynamics. On the other hand, more generic methods such as particle filters will be adapted to cope with the huge dimension of realistic ocean models.

This project will stimulate the application of assimilation methods for improved ocean real-time analyses as well as multi-year reanalyses, providing a unique source of information to (i) improve our understanding of the role of the mesoscale variability on the general circulation, (ii) develop our capability to monitor and forecast the mesoscale/submesoscale variability, (iii) contribute to the scientific understanding, monitoring and forecasting of seasonal to interannual climate anomalies and climate variability, (iv) demonstrate the capability of coupled physico-biological systems with data assimilation to provide a rationale basis for the future management of living resources, especially in coastal regions and for the understanding of the ocean carbon dioxyde storage and fluxes.

Strategy: implementing assimilation testbeds of increasing complexity



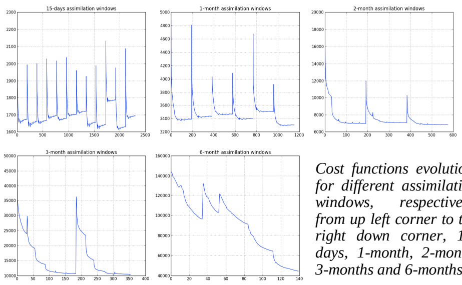
Altimetry from the JASON suite, and from forthcoming missions (HY-2A, Sentinel-3, SARAL/Altika), are the primary source of data for this project, in conjunction with ENVISAT, Cryosat-2 and other historical altimetry data sets, GRACE and GOCE for gravimetry, and SMOS for salinity. A particular effort is set on the use of multiple data sources including *in situ* observations and to their optimal complementarity to altimetry.

Testbed altimeter data assimilation configurations (instantaneous SSH is shown on both panels) that will be considered to assimilate altimetry with other data sources. The Lorenz-96 model (not shown) exhibits a wide range of different chaotic regimes as the external forcing varies, ranging from weakly chaotic to fully turbulent. This model provides a very good starting point to investigate the fundamental behaviour of advanced data assimilation schemes in the context of non-linear model dynamics, before switching to ocean models based on primitive-equations. *The SQuareBox configuration (left) will enable testing of assimilation methods and assessing performance of multi-satellite altimetry; the NATL4/LOBSTER (center) will be used as a pre-operational testbed for multi-source assimilation experiments; the Global Mercator-Ocean configuration (right, showing also sea-ice extent in white) will be hosting the most mature assimilation developments and reanalyses production. This cascade of configurations of increasing complexity will enable back-and-forth academic-to-operations revisits of assimilation approaches best suited to altimeter data assimilation.*

Recent advances: testing variational and stochastic assimilation methods with non-linear models and non-gaussian errors

A first objective is to explore the robustness of the incremental 4D-VAR assimilation method in strongly turbulent eddy-active oceanic circulations using NEMO and NEMOVAR. In a non-linear context, a well known issue with the incremental 4D-VAR algorithm, is the sensitivity of the minimization process to the length of the assimilation window. We are interested in quantifying and qualifying precisely the impact of the length of DA window on the minimization process, analysis and forecast error statistics.

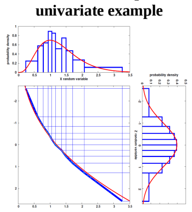
SQuareBox testbed for altimeter data assimilation



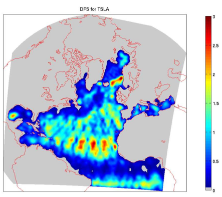
Cost functions evolution, for different assimilation windows, respectively, from up left corner to the right down corner, 15-days, 1-month, 2-month, 3-months and 6-months.

A second objective will be to make stochastic assimilation methods complient with non-gaussian errors. The observational update of traditional ensemble-based or variational assimilation methods is most often calculated assuming that the prior pdfs are Gaussian. In realistic situations, this assumption is not always verified, for instance when ocean variables are linked to strongly non-linear processes (e.g. turbulent mixing, convention). Methods such as anamorphic transformations (see right) have been developed, which can cope with this issue (Bertino *et al*., 2003; Brankart *et al*., 2012).

Gaussian anamorphosis: univariate example



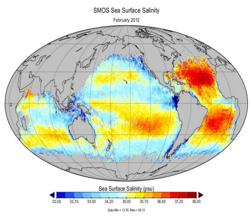
North Atlantic testbed for altimeter data impact studies



A local EnKF can provide a local assessment of the impact of observations at no costs by calculating the Degrees of Freedom for Signal (DFS = tr(KH)), for example in the case of SLA data in the TOPAZ system. Note that the effect is stronger in the vicinity of altimeter tracks and that the impact vanishes near the Equator where the geostrophic currents fade out (Sakov *et al*., 2012).

Local DFS map for assimilation of along-track altimeter data in the TOPAZ system on 12th January 2010. No units.

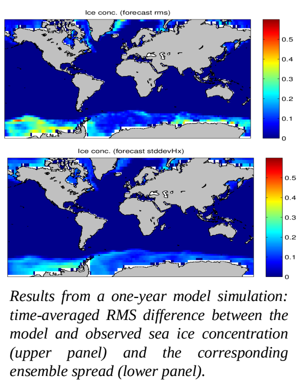
Perspective (I): looking at the complementarity between altimetry and other remotely sensed data (SSS, SST, sea-ice)



Left: SMOS SSS in ten-day, 0.25º-bin averages. The output values of the operational SMOS Level 2 processor (salinity retrievals at each satellite scene) need to be appropriately filtered to eliminate poor retrievals before spatial and temporal filtering. The accuracy of the resulting binned salinity goes from 0.2 in the open tropical ocean, and increases to more than 0.4 at high latitudes.

During the SMOS period, we plan to investigate the added value of synoptic SSS data combined with altimetry in the NATL4 testbed. As few SMOS SSS observations are available at high latitudes (due to Radio Frequency Interferences and low salinity sensitivity to the measured microwave brightness temperature), a proper balance between salinity restoring and data assimilation needs to be investigated. The ability of SMOS data to improve E-P estimates will be investigated in a tropical Atlantic simulation, where the SMOS data has the largest signal to noise ratio.

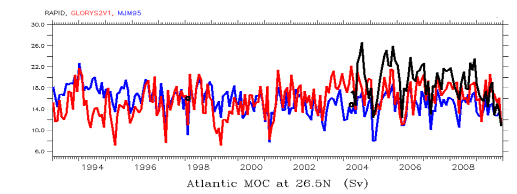
The NEMO-LIM2 global ocean model at 2° resolution is used to assimilate SST from OSTIA, ice concentration and ice drift data. As sea ice concentration is a non-Gaussian variable, an empirical Gaussian anamorphosis transform (see above) is applied. Using perturbed NCEP air temperature and wind fields, the ensemble standard deviation corresponds well to the RMS difference between the model and the observations (the area with large error in sea ice fraction). The assimilation is able to reduce the RMS error and bias of the model, as assessed with independent T/S data from the World Ocean Database.



Results from a one-year model simulation: time-averaged RMS difference between the model and observed sea ice concentration (upper panel) and the corresponding ensemble spread (lower panel).

Perspective (II): assessing the impact of new assimilation schemes in multi-year reanalyses of the global ocean

One of the objectives of this proposal is to assess the degree to which, and the regions where, the spatial and temporal structure of important climate indices (i.e. MOC, MHT) are affected by data assimilation methods. To achieve this, analyses of ocean reanalyses and simulations without data assimilations will be performed.



The figure shows the Atlantic Meridional Overturning Circulation at 26,5°N in GLORYS2V1 reanalysis (Ferry et al. 2012), MJM95 reference simulation without data assimilation and RAPID. Considering the mean value and seasonal cycle of the AMOC, GLORYS2V1 reanalysis is more realistic than the reference simulation. However and surprisingly, the reanalysis has a weaker correlation with RAPID data than MJM95.

References

Brankart J.-M., Testut C.-E., Béal D., Doron M., Fontana C., Meinvielle M., Brasseur P. and Verron J., 2012: Towards an improved description of ocean uncertainties: effect of local anamorphic transformations on spatial correlations, *Ocean Science*, 8, 121-142.

Brasseur P., Gruber N., Barciela R., Brander K., Doron M., El Moussaoui A., Hobday A., Huret M., Krémeur A.-S., Lehodey P., Matear R., Moulin C., Murtugudde R., Senina I. and Svendsen E., 2009: Integrating biogeochemistry and Ecology Into Ocean Data Assimilation Systems, *Oceanography*, 22(3), 206-215.

Cosme E., Brankart J.-M., Verron J., Brasseur P. and Krysta M., 2010: Implementation of a reduced-rank, square root smoother for high-resolution ocean data assimilation, *Ocean Modelling*, doi:10.1016/j.ocemod.2009.12.004, 33, 87-100.

Ferry N., Parent L., Garric G., Barnier B. and others: GLORYS2V1 eddy permitting ocean reanalysis over the altimetric era. (1992-2009) at meso-scale. Mercator Quarterly Newsletter 44, January 2012, 29-39

Sakov P., Counillon F., Bertino L., Lisaeter K., Oke P. and Korablev A., 2012: TOPAZ4: an ocean-sea ice data assimilation system for the North Atlantic and Arctic, *Ocean Science*, 8, 633-656.