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D1.3 Advanced ocean data assimilations systems, based on improved optimal interpolation, Ensemble Kalman Filter, and variational methods, developed in the ENACT project, adapted to the OGCMs to be used in the ENSEMBLES system

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CERFACS

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Dissemination Level		
PU	Public	PU
PP	Restricted to other programme participants (including the Commission Services)	
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D1.3: Advanced ocean data assimilations systems, based on improved optimal interpolation, Ensemble Kalman Filter, and variational methods, developed in the ENACT project, adapted to the OGCMs to be used in the ENSEMBLES system

Ocean Data Assimilation systems are designed to combine in some optimal sense information from general circulation models and from observations of ocean parameters (temperature, salinity, sea level…). The resulting estimations of the ocean state (called ocean analyses or reanalyses) over several decades can help understand ocean variability and processes, and can be used as a reference to which coupled models can be compared, and coupled models hindcast capability can be estimated. Since there is no long term high resolution ocean reanalysis equivalent to ERA40 available, the approach used here is to consider several low resolution (of the order of one degree) ocean reanalyses, and to consider their differences as an estimate of the uncertainty on the ocean state.

Based on the outputs of former projects, and especially of the EC-FP5 ENACT project (contract EVK2-CT2001-00117), the WP1.3 partners [CERFACS, KNMI, ECMWF, METO-HC, INGV, IfM, and CNRS-IPSL] have made further developments in order to improve, upgrade or adapt different ocean data assimilation systems in the perspective of their use for production of ocean analyses, particularly for Stream 2 of seasonal-to-decadal hindcast experiments. The developments achieved during the first 18 month of ENSEMBLES are twofold:

- Improvement of the input needed by any assimilation system (observation databases, model forcing, perturbations,…), which is carried out essentially by two partners (ECMWF and METO-HC) for the benefit of all others;
- Improvement of the assimilation systems *per se* carried out individually by each partner.

In the following, we will review the improvements brought by partners on those two fields.

A) Improvement of some elements needed by assimilation systems

METO-HC

A central element is the provision of a comprehensive, extensive and quality controlled data base of ocean observations over the period of interest (1960s to 2000s). Following the ENACT project, for which a data base of ocean subsurface temperature and salinity observations covering 1957-2001 (Ingleby and Huddleston, 2006) has been produced, a new data base has been produced for ENSEMBLES. This data set has the following new features:

- A significant upgrade and reduction of errors since the ENACT version by applying an improved quality control;
- It has been extended to the 1957-2004 period;
- More data are included especially in the deep waters and in the polar seas.

A first version of this improved data set has been made available to all partners, as well as the EU FP6 MERSEA partners, since April 2005, and the final version will be available in 2006[1]. This data base is an important product of ENSEMBLES because it will be used in the community outside and after the project. All partners have interfaced their system with this new data set.

ECMWF

Besides the availability to all partners of wind stress and heat and water fluxes derived from the ERA40 reanalysis, including a correction for precipitations as diagnosed by Trocolli and Kallberg (2004), ECMWF has worked on the production of a new set of forcing perturbations. As shown in EC-FP5 DEMETER project, those perturbations are used to produce ensembles of ocean initial conditions for seasonal to decadal hindcasts. The production of such perturbations for wind stress and SST is documented in a separate note (Weisheimer, 2005, available at http://www.ecmwf.int/research/EU_projects/ENSEMBLES/documents/docu_perturbations.pdf). It discusses how the choice of different SST and Wind Stress products (different Reynolds SSTs, and ERA40 and CORE Wind Stress) impacts the statistics of the perturbations, discriminating before and after 1980 because of the availability of satellite derived estimates.

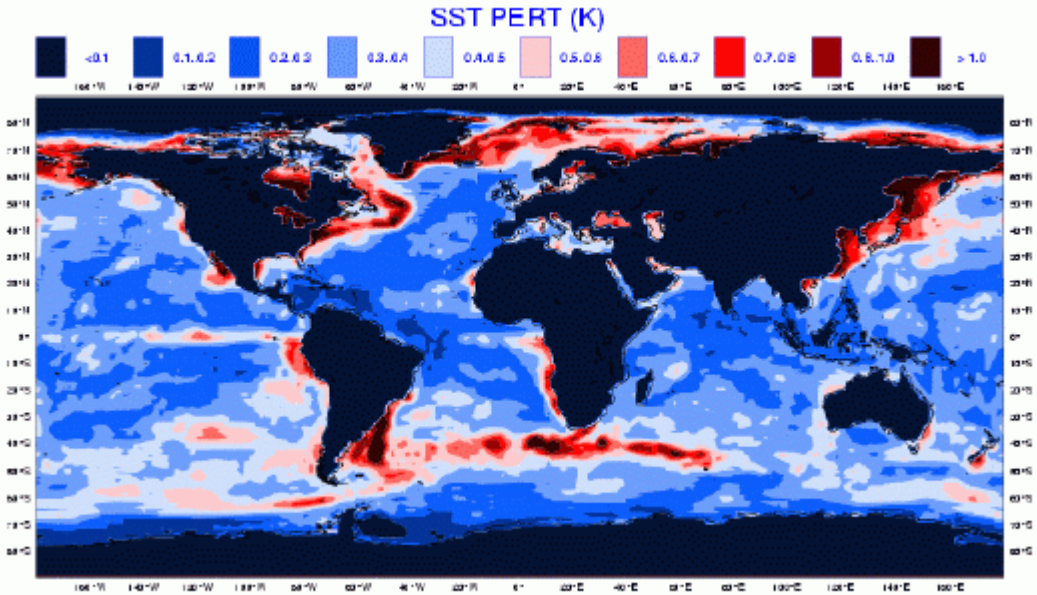

Figure 1 :
Standard deviation of the SST perturbations based on uncertainties in the ocean analysis (NCEP ERSSTv2 and Hadley SST) before 1980.

B) Improved ocean data assimilation systems

[1] A delay is anticipated because the unavailability of the World Ocean Atlas 2005, published by NODC. A two month period is expected after the release of WOD05 for the processing of the ENSEMBLES quality controlled data set.

METO-HC

The system developed by METO-HC is based on an OI-type data assimilation scheme (Bell et al., 2003) for the GloSea ocean model, which runs operationally for the Metoffice operational seasonal prediction system. Upgrades of this system have been made along two directions:

- The ocean analysis scheme has been calibrated following on from ENACT using new in situ data and wind stress perturbations;
- The scheme used to produce ensembles of ocean analyses has been calibrated using a new strategy, and by tuning the magnitude of the forcing perturbations after a comparison of their impact on ocean state ensembles against observed ocean variance.

ECMWF

The assimilation system is OI-based and was originally designed to assimilate in-situ temperature observations only, and has been adapted to assimilate salinity as well as altimetry. The model the Hamburg Ocean Primitive Equation model, HOPE. The version used in the ENSEMBLES project is close to the system running operationally in the ECMWF seasonal prediction system 3.

ECMWF has interfaced the assimilation system with the new ENSEMBLES data set. Assessment of the impact of wind stress and SST perturbations on ocean analyses has been carefully examined and is part of deliverable D2A.1.

INGV

The data assimilation system used at INGV was developed during the ENACT project and is based on the System for Ocean Forecasting and Analysis scheme (SOFA; De Mey and Benkiran,2002) implemented on the global ocean general circulation model OPA 8.2 model. It consists of a reduced order multivariate optimal interpolator (OI) where the order reduction is based on the state vector projection onto vertical empirical orthogonal functions (EOFs).

At the beginning of ENSEMBLES a quantitative assessment of the ENACT system performances has been started through validation against observations and evaluation of assimilation statistics in order to detect the main deficiencies of the system and set up a strategy to improve it. Some of the ENACT results suggested that the corrections on salinity implied by the model T/S EOF statistics did not always generate an improved salinity mean state. Among the factors which contribute to create this lack of accuracy, the resolution is likely to play a relevant role. For the ENACT system the bivariate EOFs have been computed by splitting the model domain into a number of macro regions, which may not capture in the most appropriate way the dominant dynamical regimes in a given area of the world ocean. An additional source of inaccuracy may be associated with the temporal resolution of the EOFs. The computation of the EOF set adopted during ENACT was indeed based on the full length of the control experiment (40 years), and no time evolution was introduced. This was equivalent to assume that the T/S properties (hence, the background error statistics) are stationary.

Alternative assimilation strategies aimed to improve the salinity representation have been undertaken. Test experiments using a finer horizontal resolution and EOFs derived from different time periods have been performed and the analysis is under way.
A further improvement is represented by the implementation of seasonally dependent (versus stationary) bivariate EOFs computed at each model gridpoint and not in selected sub-regions as previously done (high resolution versus coarse resolution). Further efforts on the optimization of the assimilation scheme code was needed in order to make this new version as efficient as the previous one. With the new system both temperature and salinity observations have been assimilated and the impact of space and time resolution of the background error covariance parameterization on salinity has been investigated.
Finally, work on the optimization of the code has been carried out with the aim of producing an MPI (Message Passing Interface) version of the assimilation system.

IfM

The system developed at IfM is based on the MPI HOPE-C ocean model, and implements a 3D-Var and an Ensemble Kalman Filter, in collaboration with KNMI.

In the ENSEMBLES early phase, work has continued on the adaptation and testing of the 3Dvar scheme after diagnosing some deficiencies in the quality of the ocean analysis in early tests. To mitigate these problems efforts have been to adapt the current uni-variate assimilation scheme to a multi-variate scheme. However, this development has not yet been completed. In parallel, the development of the Ensemble Kalman Filter is ongoing.

KNMI

The system developed at KNMI is based on as Ensemble Kalman Filter (EnKF) systems which had been implemented in the MPI-OM1 ocean model. Progress has been made in the ENSEMBLES project to implement it in the OPA ocean model.

The first step towards setting up the OPA-EnKF system was the merger of the analysis codes for MPI-OM-1 and OPA, and preparing it for use on the ECMWF supercomputer. Additional work on the code was done in cooperation with ECMWF computing staff. The result of this has been a code with improved serial efficiency. At the same time it had to be concluded that parallelisation of the analysis code is currently not feasible.

The second step was the construction of data constraint error models for OPA, following the same method as was used for MPI-OM-1 (described in detail in Leeuwenburgh, 2005).

The third and final step is the testing of the system on the IBM supercomuter. The first steps have now been completed successfully and show that the system is now ready for assimilation of sea level, temperature and salinity. A comparison of such schemes with the standard method was reported in a paper submitted to the QJ special issue on the 4th WMO Data Assimilation Symposium.

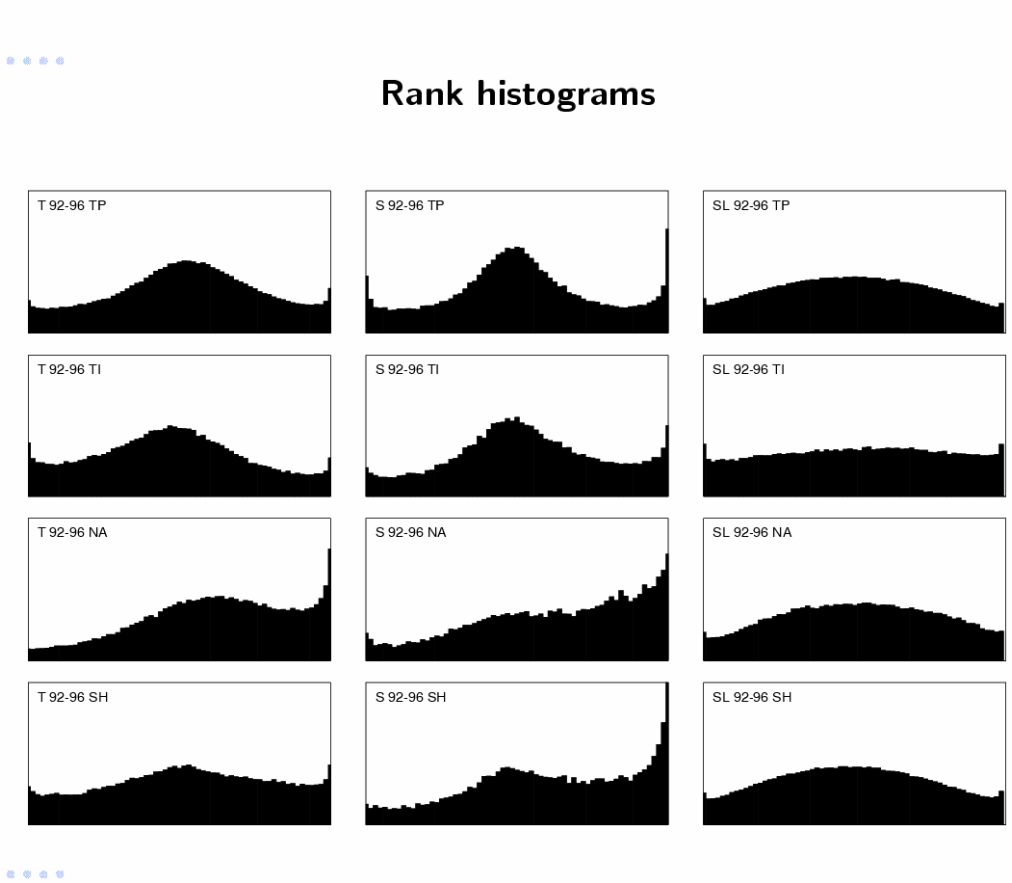

Figure 2: Rank histograms for temperature (left), salinity (middle) and sea level (right) in four regions (TP: Tropical Pacific, TI: Tropical Indian, NA: North Atlantic and SH: Southern Hemisphere. Those have been obtained from a multi-year ocean reanalysis using the KNMI Ensemble Kalman Filter with 65 members (Leeuwenburgh, 2005). Deviations from a flat histogram indicate problems in the ensemble distribution, e.g. due to model biases, as is the case for salinity.

CERFACS

The system developed at CERFACS is based on variational assimilation, and implements both 3D- and 4D-Var methods in the framework of the OPA/ORCA global OGCM (Weaver et al., 2003, Ricci et al. 2005, Weaver et al., 2006). This system has been substantially upgraded since the end of ENACT:

- improvements have been made to the balance operators in the multivariate background error covariance formulation;
- the estimates of the background- and observation-error variances have been improved;
- the new (vEN2) temperature and salinity profiles data set produced by the Met. Office has been implemented;
- nonlinear updates ("outer" iterations) have been included in the 3D-Var minimization;
- additional evaluation diagnostics have been developed;
- An ensemble strategy has been designed for two purposes: a) to calibrate the background-error covariance model; and b) to produce ocean analysis ensembles

for coupled model initialization. The ensemble is defined as a set of 3D-Var analyses produced by perturbing both the SST and wind-stress forcing fields, and the assimilated temperature and salinity profiles. The overall strategy has many similarities to an ensemble Kalman filter;

- Implementation of the above ensemble generation strategy. Daily SST perturbations, complementary to standard SST perturbations provided every three month, have been prepared by ECMWF and have been interpolated onto the model grid. A recursive filter has been used to introduce a realistic temporal correlation in the SST perturbations. Four sets of daily SST and wind-stress perturbations have been implemented. The profile perturbations are produced using the observation-error covariance model prescribed in the 3D-Var system. This approach gives us access to an unlimited number of observation perturbations. An example of the impact of these different perturbation methods on the spread of ocean ensembles is shown in figure 3.

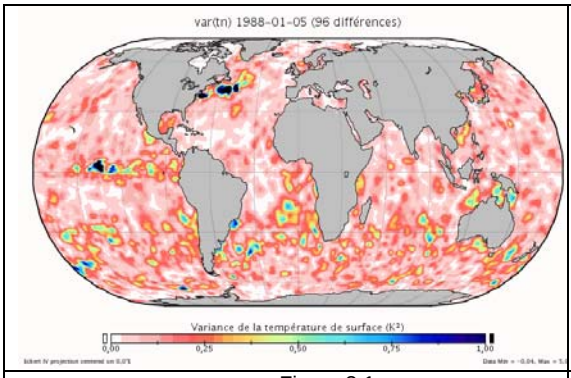

Figure 3.1 :
Impact of perturbing ocean observations on the dispersion of an ensemble of 96 ocean analyses.

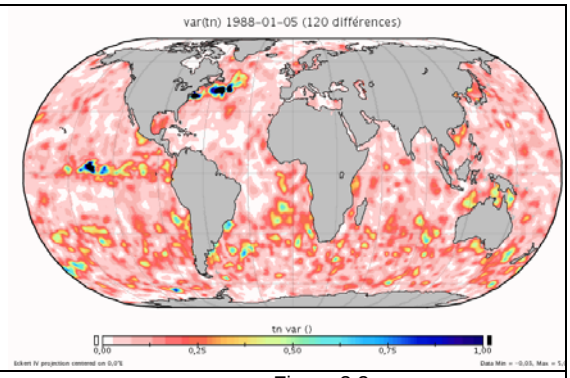

Figure 3.2 :
Impact of perturbing both ocean observations and forcing wind stress and SST on the dispersion of an ensemble of 120 ocean analyses.

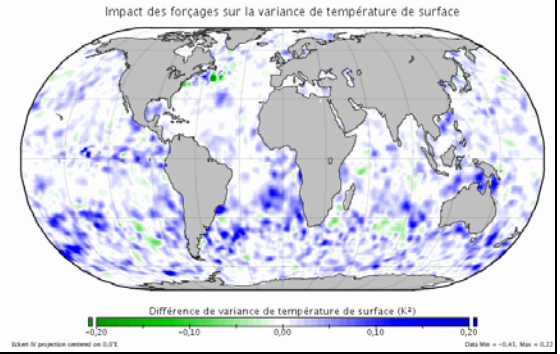

Figure 3.3 :
Difference between variances in the two figures above. The difference is mostly located in areas poorly observed.

CNRS-IPSL

CNRS-IPSL shares the same system, based on variational methods, as CERFACS but in a 4D-Var configuration and focussing on altimeter data. The work up to now has consisted in a detailed assessment of the performance of the ocean analysis system. This has shown several areas where clear improvements can be obtained (in particular in the case of altimeter data assimilation). This is in particular seen in figure 4. Assimilating sea level data allow to reproduce better the subsurface heat content variability (here with an improved restitution of the subsurface temperature anomalies associated with the 1997-98 El Niño). Assimilating sea

level data also results in improved restitution of the surface pressure gradients, and thus improved currents (see table 1).

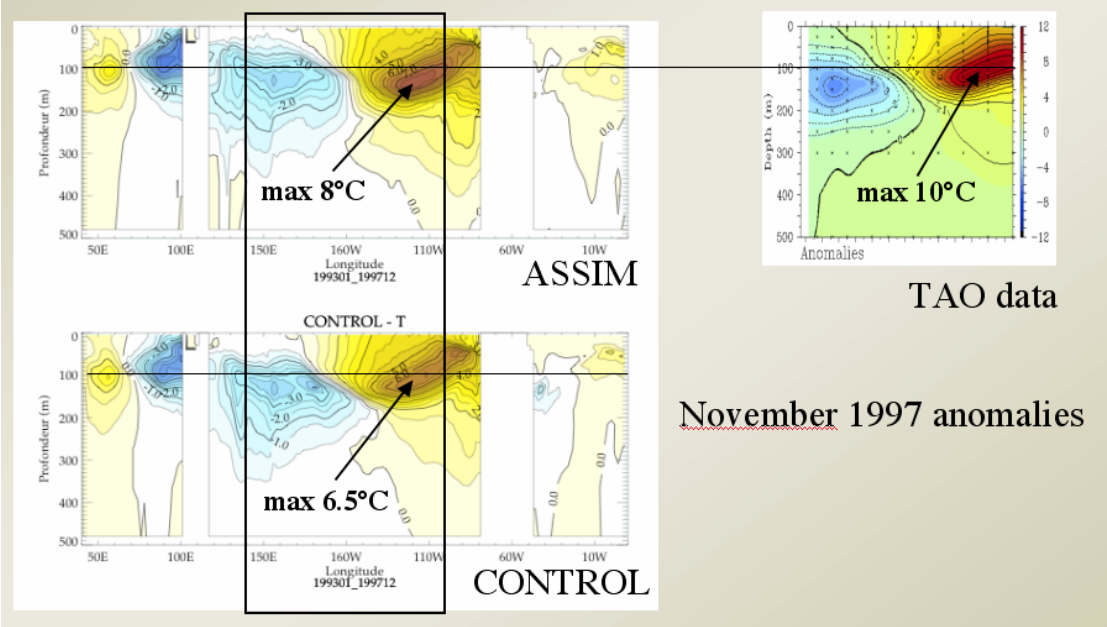

Figure 4 : *Vertical section of the interannual SST anomalies at the height of the 1997 El Niño event for the 4D-Var with Topex/Poseidon alongtrackdata assimilation, for a control experiment and fot TAO observations.*

	Nino3	Nino4	NEC	NECC
4D-VAR	c=0.97 / r=7cm.s^{-1}	c=0.98 / r=6cm.s^{-1}	c=0.9 / r=2cm.s^{-1}	c=0.98 / r=2cm.s^{-1}
Control	c=0.93 / r=10cm.s^{-1}	c=0.97 / r=7cm.s^{-1}	c=0.73 / r=3cm.s^{-1}	c=0.93 / r=4cm.s^{-1}

Table 1 : *Correlationand rms difference of Oscar montly surface current observations with for the 4D-Var with Topex/Poseidon alongtrack data assimilation, and a control experiment. The statistics are given for four regions : Nino4 (160°E-150°W, 5°N-5°S), Niño3 (150°W-90°W, 5°N-5°S), the North Equatorial Counter Current region (160°E-90°W, 5°N-7°N), the North Equatorial Current region (140°E-160°W,10°N-15°N).*

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