



Advanced Altimeter Data Assimilation for the Development of Operational Oceanography.

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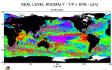
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Ocean observation system

Sea-level anomalies



time, accurately, at the global scale, and with high resolution.

satellite observations provide a unique opportunity to monitor the ocean evolution in real

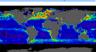
As the properties of the sea-surface only can be observed from space, data assimilation ms are useful to improve the consistency between data sets and model simulations. to dynamically extrapolate and interpolate data scattered in space/time, to better exploit the results of observation programs, and to make comprehensive interpretation of

The data considered in the various assimilation activities of the MEOM team are mainly: -altimetric data from the Topex-Poseidon and ERS missions (fig. 1.1); -sea-surface temperature products from the NASANOAA Pathfinder project (fig. 1.2); -ocean colour data from the SeaWiFS project (fig. 1.3).

temperature 1/4° gridded SST October 21st 1992 from the NASA



Ocean colour



Sea-surface



SeaWiFS data - May 1998

Assimilation methodology

Schematic representation of

the sequential SFFK algorithm

ABSTRACT: Various developments of advanced data assimilation systems have been made to assimilate satellite tobservations such as altimetry, see-surface temperature and ocean colour into high-resolution models of the ocean have been carried out, contributing to improve the understanding of assimilation methods with ocean models, and to help in the optimisation of ocean observing systems, in the perspective of developing realistic monitoring and prediction capabilities in an operational context.

motheds are variants of the reduced order Assimilation methods are variants of the reduced-order Kalman filter (SEKE: Singular Footivitive Extended Kalman) for 4DVAR schemes, in which forecast error statistics are defined within a three-dimensional, multivariate sub-space. The most recent developments of the algorithms include (i) a non-linear to the model dynamics, (ii) an improved definition of the reduced error space using EOFs, singular or breeding vectors, (ii) a "local" formulation designed to improve the analysis of high-resolution signals, and (iv) an adaptive mechanism used to extract perintent information from the innovation vector.

Experiments have been conducted in a variety of ideal Experiments have been conducted in a variety of idealized models, in order to validate the methodologies, investigate the models, in order to validate the methodologies, investigate the and participate to the design of future satellite missions like and participate to the design of future satellite missions like altimetric scenarios have been simulated in twin assimilation statistic control of the satellite consistation have been simulated in twin assimilation satellite constitution of the measurement of the satellite constitution in the beautiful control of the satellite constitution in the beautiful control of the satellite constitution of the measurement of the satellite constitution were carried out to diagnose the impact of assimilating sea surface salinity observations in the Tropical Pacific.

The SEEK filter has been further implemented with two different realistic models of the Atlantic ocean: a coupled isopycnic ocean circulation nonpente ocean circulation and marine ecosystem model of the North Atlantic and Nordic Seas (European DIADEM and TOPAZ projects), and a z-coordinate primitive equation model of the Atlantic ocean circulation (French Mercator project), into which NASA
pathinder SST, and combined
Topex-PosaidonERS altimeter
Topex-PosaidonERS altimeter
Topex-PosaidonERS altimeter
Hindcast experiments have
been conducted from 1992 to
1999 in order to reconstruct the
variability in the Atlantic Ocean
variability in the Atlantic Ocean
variability in the Atlantic Ocean
scales and to examine the error
statistics associated with the
solutions. A real-time
solutions of the Atlantic Ocean
(started in October 2000)
weekly deliver an ocean
forecast builtelin for the North
Atlantic. The SESAM software is a flexible system of assimilation modules, that has been developed by the MEOM group to implement the SEEK filter. It consists of a library of numerical tools gathered in a single computer program which performs all tasks usually needed to solve a data assimilation problems.

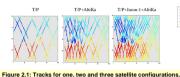
The poster provides an overview of recent results obtained in the various

Optimisation of observation systems

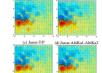
The general objective of this study is to assess a variety of multi-satellite altimetric scenario from the perspective of the future space missions (Jason-2, AltiKa, etc.) that will be launched to monitor the mesoscale ocean circulation. The approach taken for this work is based on the use of numerical models and assimilation methods using twin experiments. The numerical model is used to generate synthetic data sets following the muti-satellite sampling schemes that are academic configuration. The model is eddy-resolving (20 Km) and 11 layers on the vertical.

The Singular Evolution Extended Kalman (SEEV) filter is implemented (using the SESAM system) to assimilate the altimetric data, using an EOF basis to reduce the error sub-space.

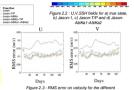
The sea-surface height data are sampled from the model output, along the ground track following the missions parameter of Topex/Poseidon (T/P) and Jason-1(Ja) and one scenaric which is under consideration for the foresee Atlika (AtK) satellite mission (with 35 days orbita period). Different satellite sampling strategies are explored.



Examples of track patterns for 5 days of observation







From WOCE to CLIVAR: the South Atlantic

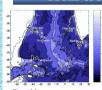


Figure 3.4 WHOLE BASIN 1993 1998

laboratories, data assimilation experiments have been performed in the South Atlantic to reconstruct the ocean variability during the WOCE The model configuration is extracted from the 1/3° Atlantic model

developed by the Clipper project (OPA model), limited at 20°N with an open-sea boundary (figure 3.1).

As a joint research effort between the LEGI (Grenoble) and LPO (Brest)

Hindcast experiments have been performed using a simplified SEEK filter, assimilating SST and SSH data between January 1993 and January 1997 in a similar way as in the North Atlantic experiments (see next frame).

The behaviour of the error statistics on SST and SSH is illustrated by figure 3.2, showing a stable reduction of the RMS model/data misfit of about 1°C for temperature, and 12 cm for sea-level.

Figure 3.3 illustrates the impact of the assimilation on the eddy kinetic energy. A better positioning of the turbulent structures is obtained. Figures 3.4 illustrates the impact of the assimilation on the RMS difference with respect to independent XBT profiles.



9001/10 9601/05 9501/10 9601/05 97/01/11 Figure 3.2

The MERCATOR project: the North Atlantic MERCATOR is a French initiative which aims at the



Figuera 4.1

As a contribution to the research activities conducted around the MERCATOR Project, a prototype assimilation system has been developed at LEGI based on the SEEK filter, the SESAM software, and a 1/3* resolution OPA model of the North Atlantic between 20°S and 70°N (Testut et al., 2002). A series of hindcast experiments have been performed. assimilating SST and SSH data between October 1992
and November 1999 using ECMWF atmospheric

implementation of an operational capacity of global ocean monitoring and prediction within the time frame of the GODAE experiment (2003-2005).

Figure 4.1 illustrates the impact of the assimilation on the mean currents during the nineties at 50 m depth. The Gulf Stream separation at Cape Hatteras, its northward extension and the associated meso-scale activity are significantly improved in the run with

simulation (top). The behaviour of the error statistics on SST and SSH is illustrated (fig 4.2), showing a stable reduction of the model/data misfit of $\sim0.8^{\circ}\text{C}$ for temperature, and ~8 cm for sea-level. In addition, the adaptive mechanism of SEEK is useful to improve the consistence between the error standard deviation predicted by the filter and the

RMS mistirs for SST on NATI 3 adial have the another state of the RMS misfits for SSH on NATL3 Figure 4.2

/alidation of the system:

The hindcast experiment has beer validated using a set of independen XBT data during 1994. A positive impact of the assimilation on temperature is obtained in the top 700m.



The DIADEM and TOPAZ projects

DIADEM: Development of operational data assimilation systems for the North Atlantic and the Nordic Seas

TOPAZ : Towards an Operational Prediction system for the North Atlantic and European coastal Zones The main objective of these european projects is to develop advanced data

assimilation systems for coupled primitive equation ocean circulation and marine ecosystem models of the North Atlantic and the Nordic Seas. The SEEK filter has been interfaced with the isopycnic MICOM model to sasimilate Nasa Pathfinder SST, Topex-Poseidon/ERS altimetric and SeaWIFS ocean color data sequentially, every 3 or 10 days. In TOPAZ, deep temperature and salinity data are also assimilated in the model.

In figure 5.1, a zoom on the Gulf Stream region from the 10-day forecast of and SST (in °C) is on the right. Figure 5.2 illustrates the phytoplankto concentration (in mmol-N/m3) on April 5th, 1998. The SeaWIFS observation is on the left and the DIADEM system analysis is on the right



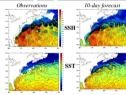


Figure 5.1



Figure 5.3

The Tropical Pacific Ocean

The assimilation of satellite altimetry data (T/P+ERS) has been performed, using the SEEK filter in a primitive equation model (OPA) of the whole Tropical Pacific ocean between 30°S and 30°N to reconstruct the ocean variability during the 1994-1998 period. The reduced basis of the SEEK filter is evaluated from a threedimensional multivariate EOF analysis of a reference model simulation (fig. 6.1), which is forced at the surface with ERS/TAO wind stress fields and heat fluxes from the NCEP reanalysis The SESAM sofware allows an easy interface between the SEEK

First EOF OF SSH FROM THE REDUCED BASE 130E140E150E160E170E180W170W160W150W140W130W120W110W100W90W-80W-70W

-8.00 -6.00 -4.00 -2.00 -2.00 -1.00 .00 1.00 2.00 2.00 4.00 6.00 1.00 0.00

Figure 6.3

A variety of diagnostics with independent data have been computed to validate the assimilation scheme. On figure 6.2, the reduction of the RMS error between the model and thermal profiles from the TAO array becomes significant after , years or assimilation. The zonal velocity field in the assimilation is also better than in the free model run. It allows to produce a more realistic circulation with a more intense Equatorial Under Current along the the atorial Under Current along the thermocline and as South Equatorial Current at the surface (fig. 6.3).

Conclusions

 Advanced data assimilation methods, have been developed to assimilate a variety of ocean circulation and ecosystem data in various ocean models. Thes studies are carried out in the perspective of operational oceanography, with a special focus on satellite observations of altimetry, sea-surface temperature and ocean colour.

In particular, a reduced-rank Kalman filter (SEEK) has been implemented in a variety of ocean models. The assimilation method has been first validated in a series of twin experiments conducted in idealized situations, and then implemented into real ocean simulation and prediction systems.

 Observation system simulations have been conducted in twin assimilation experiments in order to assess the ability of different multisatellite scenarios to observe the ocean mesoscale activity. This study is carried out to help in the planification of future spatial mission to observe ocean altimetry.

New methodological developments, such as local error covariance, local gain, and adaptive mechanisms have been undertaken to address specific issues raised by real assimilation problems. The capacity of the assimilation scheme to predict realistic and statistically consistent error bars on the field estimates has been examined and improved by "recycling" the residual innovation information.

· A special effort is currently dedicated to the validation of the assimilation system with independent in situ measurements: so far, the residual msifits with TAO array data in the Tropical Pacific, and XBT profiles in the Atlantic Ocean, objectively demonstrate the benefit gained from the assimilation

In addition to the hindcast experiments realized in a scientific perspective, a real-time demonstration of the DIADEM/TOPAZ system is currently underway in a technical perspective to deliver ocean circulation predictions on the North Atlantic within the european DIADEM/TOPAZ projects.

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