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MARINE ENVIRONMENTAL MONITORING AND PREDICTION

Abstracts

Local Organizer: Modelenvironment, University of Liège, B5 Sart-Tilman, B-4000 Liège, Belgium, e-mail:gher@ulg.ac.be

Gappy data in oceanographic data sets. Reconstruction of SST AVHRR cloudy images of the Adriatic Sea

A. ALVERA-AZCÁRATE[1], A. BARTH[1], M. RIXEN[2], AND J.-M. BECKERS[1]

[1]*GHER, University of Liège, Belgium*

[2]*SACLANT Undersea Research Centre, Italy*

Satellite data are very useful for many applications in oceanography and other environmental sciences. They offer a great coverage both in time and space, not attained by *in situ* measures. Cloud coverage presents a limitation when dealing with visible range receptors, and in some seasons it can attain an important percentage. Other problems, such as technical misfunctions or noise, may also affect the total coverage. Many data analysis techniques do not need a total coverage, although it is always desirable. Some applications, such as Empirical Orthogonal Function (EOF) analysis, or wavelet decomposition need a complete set of data, and a technique for recovering these missing data would be desirable.

In this work a method for the reconstruction of missing data in oceanographic data sets is presented. The method, called DINEOF (Data INterpolating Empirical Orthogonal Functions) is based on EOF decomposition [*Beckers and Rixen* 2003]. The method needs no *a priori* information about the error statistics of the data, which is an advantage in comparison with other reconstruction methods, such as optimal interpolation [*Bennett* 2002].

DINEOF has been applied to a large data set in the Adriatic Sea, 105 AVHRR satellite images ranging from May to October 1995 [*Alvera-Azcárate et al.* 2003]. The error of the reconstruction in relation with the original data is of about 0.6°C, as depicted for a cross validation analysis. The method has been tested with different amounts of cloud coverage. A no-cloud set of 15 images has been selected, and artificial clouds have been added, ranging from 40% to 80% of coverage. The RMS error between the reconstruction of these sets and the original fields varies between 0.78°C and 1.25°C. A comparison with MEDAR/Medatlas database [*MEDAR Group* 2002] has also been made, and the RMS error is of 0.95°C. The reconstruction of the missing data shows accurate results, even when the percentage of lost data is very high. The temperature distribution is reliable, and realistic physical features are obtained. For example, cold filaments detaching from the east coast of the Adriatic Sea [*Borzelli* 1999], the Po plume [*Cushman* 2001], and the Ionian water entering the domain can be observed.

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GeoHydrodynamics and Environment Research Lab., University of Liège, Sart Tilman, B5, B-4000 Liège.

Forecast Verification of a 3D model of the Ligurian Sea. The use of Discrete Wavelet Transforms in the skill assessment of spatial forecasts.

A. ALVERA-AZCÁRATE[1], A. BARTH[1], Z. BEN BOUALLÈGUE[1], L. VANDENBULCKE[1], M. RIXEN[2], AND J.-M. BECKERS[1]

[1]*GHER, University of Liège, Belgium*
[2]*SACLANT Undersea Research Centre, Italy*

The results obtained by the GHER 3D primitive equation model are analysed. A reduced order, optimal interpolation data assimilation scheme has been used for an assimilation experiment. Different data are assimilated separately and jointly to the model (Sea Surface Temperature (SST), Sea Surface Height (SSH) and CTD profiles) (see [*Barth et al.*, 2003]). The skill of these different experiments is assessed, to establish the impact of the assimilation in the model results and predictability.

The verification of spatial forecasts is a difficult task. Although the use of traditional error measures is a simple way to obtain information about the skill of the model results, they usually reduce the comparison of two fields (in this case, the 3D model and the observations) to a single number. The spatial distribution of the error is not considered. Also, the skill assessment in the spatial domain must be made carefully, because the correlation between adjacent points may be important and interfere in the results [*Wilks, D.S.* 1995]. New techniques have been used when dealing with spatial forecasts, in an attempt to preserve the spatial complexity of the data. 2D Discrete Wavelet Transforms reveal to be very useful, as they allow to compare forecast and observations at different scales. The analysis performed in this way is thus more exhaustive, and the identification of the errors is more complete.

For the skill assessment of the results, two steps are realized: first, a general study is made, applying classical statistical tools to the results, such as Root Mean Square (RMS) error, Anomaly Correlation Coefficient (ACC) and Mean Square Error Skill Score (MSESS). For the MSESS different reference systems are used, such as climatology and a free run of the model (model without assimilation). The time evolution of the error is analysed, as well as its spatial distribution. In a second step, the spatial distribution of the data is taken into account. A 2D wavelet analysis is made to decompose the results into different spatial scales, ranging from $\sim$1 km (the spatial scale of the model) to 128 km. A Haar wavelet is used [*Daubechies* 1992]. The error measures already used in the first step are now applied to each of the scales, to establish which are the scales that mainly contribute to the global error. Special attention is paid to the land-sea boundaries, as they affect the wavelet analysis.

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GeoHydrodynamics and Environment Research Lab., University of Liège, Sart Tilman, B5, B-4000 Liège.

Sensitivity study of the DMI-HIRLAM forecast model to SST observational networks

B. AMSTRUP, J. SHE, AND J.L. HØYER
Danish Meteorological Institute, Denmark

The DMI-HIRLAM (HIgh Resolution Limited Area Model) numerical weather prediction forecast model relies on updates of sea surface temperatures (SST). Former impact studies with use of the operational DMI-HIRLAM analysis and forecasting system have shown that use of climatological values for SST give worse forecasts than forecast made with updated SST's. In particular 2 metre temperature biases are improved.

For this study one year (2001) of OI (Optimum Interpolated) ($0.167\,^\circ \times 0.100^\circ$) gridded SST fields is made using all available observations, in-situ and satellite observations. These fields are used to force the DMI-HIRLAM forecast model with a resolution of $0.075\,^\circ \times 0.075^\circ$ covering the North Sea and the Baltic to produce met-forcing data for forcing an ocean model.

Within this 1 year period some extreme or SST-sensitive cases are selected. For these cases sensitivity studies with the DMI-HIRLAM forecast model are made it investigate the impact from different SST monitoring networks and sampling strategies. Among these sensitivity studies will be runs with forcing by the gridded SST fields in different resolutions and from different SST observing networks.

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Danish Meteorological Institute, Lyngbyvej 100, DK-2100 Copenhagen Ø, Denmark

Sea Surface Temperature assimilation in the POL Coastal Ocean Modelling System

I. ANDREU-BURILLO, J. ANNAN, R. PROCTOR, J. HOLT AND D. PRANDLE

Proudman Oceanographic Laboratory, U. K.

A simplified Kalman Filter (KF) has been used to assimilate Sea Surface Temperature (SST) data into the POL Coastal Ocean Modelling System (POLCOMS). The objective is to improve the model representation of surface features, as for example fronts, as well as of vertical thermal structure.

The POLCOMS model has run over year 1995 in free (*i. e.* without assimilation) and SST-constrained simulations of the Irish Sea, at 12 km and 1.8 km horizontal resolutions respectively. AVHRR data on a 9 km mesh provide the SST data used in the constrained simulations.

Comparison of model output with respect to independent data shows an improvement of upper temperature estimation through assimilation. Nevertheless, some weaknesses of the assimilation method are revealed in the higher resolution (1.8 km) model runs. The approximations leading to the simplified KF are then reviewed and an alternative assimilation scheme, based on the Ensemble Kalman Filter, is implemented.

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Proudman Oceanographic Laboratory, Joseph Proudman Building, 6 Brownlow Street, Liverpool, L3 5DA; iabu@pol.ac.uk .

Mercator Ocean Monitoring and Forecasting System, near-real-time assimilation of satellite and in situ data in different operational ocean models

BAHUREL P.[1], DOMBROWSKY E. [2], LELLOUCHE J.-M.[3] AND THE MERCATOR PROJECT TEAM

[1] *MERCATOR OCEAN, France*
[2] *CLS, France*
[3] *CERFACS, France*

The Mercator Ocean Monitoring and Forecasting System is routinely operated in near-real-time in Toulouse by the Mercator project since early 2001, and has been regularly upgraded, expanding the geographical coverage, improving models and assimilation schemes, adding new data and building new products.

The aim of this service is to provide estimates of the ocean circulation and thermodynamics at high resolution at the global scale. These ocean state estimates are to be distributed to the scientific community, to public bodies such as met services and agencies dealing with the ocean and its environment, and also to private bodies that are directly linked with the customers operating in the marine environment. This ocean monitoring and forecasting service is implemented using high resolution ocean general circulation models (OGCM), real-time processing of remotely sensed and in situ observations, and the merging of the two with data assimilation techniques. Three prototypes of the MERCATOR system are currently running: one global low resolution (2°) configuration, one in the north and equatorial Atlantic at medium resolution (1/3°) and one with high resolution (1/15°) in the north Atlantic and Mediterranean. The 1/3° system is a test bed for more sophisticated assimilation techniques. The 1/15° configuration provides a very advanced depiction of the mesoscale situation due to the high resolution, and the system behaviour has been carefully scrutinized in 2003. An upgrade in the resolution will soon be achieved for the global configuration from 2 to 1/4°. The goal is to build a high resolution O(1/12°) global unique system by the end of 2008. This service is one component of GoDAE in Europe, and is one of the key components of the GMES/MERSEA European integrated project.

After a brief presentation of the structure of Mercator Ocean monitoring and forecasting service, we will present some recent results obtained with the system, in particular the quantitative comparison with in situ data, including the ARGO profiles, and recent validation issues of the high resolution system. Then we will present some of the applications already performed with Mercator Ocean outputs.

[1] MERCATOR OCEAN ; 8-10 rue Hermès ; .31 520 Ramonville Saint Agne – France ; http://www.mercator-ocean.fr ; Phone : +33 5 61 39 38 02 ; Fax : +33 5 61 39 38 99

Towards a biogeochemical model of the ocean for monitoring air-sea fluxes of CO_2 in near-real-time using earth observation data

ROSA M. BARCIELA[1], MIKE BELL[1], JOHN HEMMINGS[2], STEVE SPALL[1] AND IAN TOTTERDELL[2]

[1]*Met Office, United Kingdom*
[2]*Southampton Oceanography Centre, United Kingdom*

A coupled physical-biogeochemical model is being developed by the UK Centre for Observation of Air-sea Interactions and Fluxes (CASIX) with the aim of producing accurate high resolution estimates of the air-sea flux of CO_2 over the North Atlantic region, in near real-time, using earth observation data. The deep ocean component of this model is based on the UK Met. Office's Forecasting Ocean Assimilation Model (FOAM) which has been coupled with the Hadley Centre Ocean Carbon Cycle Model (HadOCC).

FOAM consists of a series of operational and pre-operational ocean models that use data assimilation to produce daily analyses and forecasts of temperature, salinity, ocean currents and mixed layer depth up to five days ahead. The data assimilation component in FOAM is based on *in situ* as well as satellite observations. FOAM is driven by six-hourly surface fluxes from the Met. Office's operational Numerical Weather Prediction (NWP) system. The global version of FOAM consists of a 1° x 1° horizontal resolution model and 20 unequally spaced vertical levels. Regional (North Atlantic) versions of FOAM with 1/3° (operational) and 1/9° (pre-operational) horizontal grid resolution, nested within the global model, are also part of the FOAM suite.

HadOCC is a simple Nutrient-Phytoplankton-Zooplankton-Detritus ecosystem model with a variable carbon:chlorophyll ratio. The model uses nitrogen as its currency but also calculates carbon flows through the ecosystem.

The coupled model will be modified to assimilate biogeochemical observations to improve the accuracy of its surface pCO_2 estimates. Initially, the derived ocean colour product chlorophyll *a* will be assimilated and *in situ* observations will be reserved for validation. Preliminary results from the coupled model at 1° and 1/3° resolution, without chlorophyll assimilation, show some differences in biogeochemistry between the two model runs. Results from both versions of the model are compared with satellite and *in situ* data, focusing on mid-latitude areas where the model performs well against chlorophyll time series during the spring bloom and on lower latitude oligotrophic area where the model's performance can be poor.

Assimilation of surface chlorophyll data presents particular problems because of seasonal and spatial variations in both the structure of the vertical chlorophyll profile and the correlations between chlorophyll and other model fields requiring adjustment during the analysis. The feasibility of extending the existing Analysis Correction scheme in FOAM to the assimilation of chlorophyll, without the computational overhead of evolving the error statistics, is assessed. The results of a preliminary investigation are presented, based on statistical analyses of ensemble integrations of the biogeochemical model and twin experiments, in which simulated observations are assimilated into a degraded model to estimate a known true state. The physical environment for these experiments is prescribed, based on FOAM output at locations in the North Atlantic.

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[1] Met Office, Fitzroy Road, Exeter, Devon, EX1 3PB
[2] Southampton Oceanography Centre, European Way, Southampton, SO14 3ZH

Multigrid state vector for data assimilation in a two-way nested model of the Ligurian Sea.

A. BARTH[1], A. ALVERA-AZCÁRATE[1], J.-M. BECKERS[1], M. RIXEN[2], L. VANDENBULKE[1] AND Z. BEN BOUALLEGUE[1]

[1]*GHER, University of Liege, Belgium*

[2]*SACLANT Undersea Research Centre, Italy*

A system of nested models described in [*Barth et al.,* 2003] is coupled with a data assimilation module. The system is composed by a low resolution model (1/4°) covering the whole Mediterranean Sea, an intermediate resolution model (1/20°) of the Liguro-Provenal basin and a high resolution model (1/60°) simulating the fine mesoscale structures in the Ligurian Sea. Boundary conditions and the averaged fields (feedback) are exchanged between two successive nesting levels.

A reduced order, optimal interpolation data assimilation scheme was implemented. The state vector is composed by temperature, salinity and sea surface elevation. Novel in the present approach is that these variables from the three nested model grids are assembled to one multigrid state vector. This implementation allows to take into account the correlation of the variables across the nested model grids in order to avoid for example artificial gradients after an assimilation cycle.

The eigenvectors of the covariance matrix are constructed by an EOF analysis of the free model run. Cross-grid correlations especially in the overlapping domains are thus consistently represented. Horizontal correlations over long distances are suppressed by multiplying each error mode with a set of radial Gaussian functions. This procedure increases considerably the rank of the covariance matrix but ensures the local impact of each observation.

Sea surface temperature (SST, from the DLR EOWEB), sea surface height (SSH, from the CLS) and CTD profiles (SIRENA cruise from SACLANT Center and cruises from the MEDAR/Medatlas database [*MEDAR Group,* 2002]) are assimilated into the model. In overlapping model grids the measurements are related to the highest resolution grid. Since the SSH has a resolution of 1/8°, the surface elevation of the Ligurian Sea and the Liguro-Provencal model are filtered in order to be coherent with the space scales present in the observations.

Starting from the 1st January 1998 the low and intermediate resolution models are spun up for 18 months. The initial conditions for the Ligurian Sea are interpolated from the intermediate resolution model. The three models are then integrated until August 1999. During this period SST, SSH and the CTD profiles are assimilated. The results are compared with a free model run. In particular the model forecast just before the assimilation step are compared with the observations. The model forecast and the measurements are then independent and the difference is a measure of the model forecast skill and the impact of the previous assimilation cycles. The validation procedure is detailed in [*Alvera-Azcrate et al.,* 2003].

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GeoHydrodynamics and Environment Research Lab., University of Liege, Sart Tilman B5, B-4000 Liege.

Spatio-temporal dynamics of the Pyrenees Front during fall (NW Mediterranean)

BASTERRETXEA G[1], JORDI A[1], ORFILA A[1, 2], VIZOSO G[1], TINTORE J[1]

[1]IMEDEA (CSIC-UIB), Spain
[2]Cornell University, USA

During summer and early fall, the Pyrenees Front (PF) turns out as a strong signal reflecting the differentiated meteorology at both sides of the Pyrenees. The origin of this front is speculated to be the shadowing effect of the Pyrenees over the Mistral jet which cools the sea surface and induces mixing counteracting in this way the seasonal stratification. The intersection of the PF with the circulation patterns in the area generates intense mesoscale dynamics. In this work we analyse detailed field and satellite observations of the hydrographic of the front during September-October 2002. Repeated sampling over the area revealed a strong near surface thermal front (>4ºC) located at 41.5ºN. The vertical and horizontal structure and its short-time (weeks) temporal evolution are analyzed. The observed spatio-temporal evolution is compared with modelling predictions based on satellite data. The feasibility of this type of predictions for operational purposes is discussed.

[1] Grupo de Oceanografía Interdisciplinar, IMEDEA (UIB-CSIC), Miquel Marqués 21, 07190 Esporles, Baleares, Spain.

[2] School of Civil and Environmental Engineering. Cornell University, Hollister Hall. Ithaca (NY, USA).

The Forecasting Ocean Assimilation (FOAM) system

MIKE BELL, ROSA BARCIELA, ADRIAN HINES, MATT MARTIN, ALISTAIR SELLAR AND DAVE STORKEY
Met Office, UK

The Forecasting Ocean Assimilation Model (FOAM) is a deep ocean forecasting system which is run daily in the operational suite at the Met Office to produce 5-day forecasts of ocean temperatures, salinities, currents and sea-ice. The system is driven by 6-hourly average surface fluxes of heat, momentum and moisture and assimilates in situ temperature and salinity profile data, in situ and satellite surface temperature data, and surface height data from satellite altimeters. The system includes a coarse resolution global model and higher resolution nested models for the Atlantic, north Atlantic and Mediterranean Seas. Major improvements have been made within the last year to the quality control of profile observations, the specifications of the forecast error covariances and the timeliness of the assimilation of observations.

Results will be presented from a set of integrations investigating the accuracy of forecasts of the ocean mesoscale in the Intra Americas Seas using a nested model with 7 km grid spacing and 40 levels. Investigations of the impact of altimeter data and data from the Argo system on the system will also be summarised.

Work is in progress to extend the range of variables assimilated by FOAM. An ecosystem component developed for climate simulations is being incorporated into FOAM and a project is underway to improve the assimilation of sea-ice concentration and velocity data into the system. The FOAM group are also participating in the Mersea project, particularly in the development of a shared European Ocean Model Framework applicable to both the shelf seas and the deep ocean.

Finally we will present the main conclusions from a consultation exercise with government agenices and commercial companies in the UK on the services we should aim to provide.

Met Office, FitzRoy Road, Exeter, Devon, UK, EX1 3PB.

A system evolution decomposition method : Application to the assessment of an operational forecasting system.

Z. BEN BOUALLEGUE[1], A. ALVERA-AZCÁRATE[1], L. VANDENBULCKE[1], A. BARTH[1], M. RIXEN[2], AND J.-M. BECKERS[1],

[1] *GHER, University of Liege, Belgium*

[2] *SACLANT Undersea Research Centre, Italy*

The MFSTEP[1] project is an international scientific collaboration program which aims to create an operational forecasting system for the Mediterranean sea. The simulations provided at the basin scale are 10 days forecasting fields in a 3-D ocean. The primitive equations hydrodynamic model is combined with the data assimilation scheme SOFA[2]. The data collection is done in a near real time process and the set of XBT and SLA observations are used in one week assimilation cycle.

The forecast assessment is traditionnally realised using classical statistic tools like RMSE or the bias and the assimilation benefit is estimated by skill scores using as reference the free model, persistence or also climatology [*Pinardi et al.,* 2002]. The process is essentially based on the comparison of two fields at a fixed time, one corresponding to the simulations and the other one to the observations. The interest of such statistical methods comes in the quick and sensitive appreciation they provides about the quality, accuracy and consistency of the simulation [*Demirov et al.,* 2002]. However this kind of assessment procedure brings in it self a conceptual contradiction: performances of a dynamical process are measured using a snap shot view of the ocean state.

A system evolution assessment procedure inspired of the object-oriented verification procedure introduced in the meteorological forecast assessment [*Ebert and Mc Bride,* 2002] is carried out within the framework of the MFSTEP hindcast. The hindcast system is intrinsically analysed (without independant informations) comparing the background forecast evolution with the abrupt variation which occurs at the observations assimilation time steps. The system evolution between two consecutive days is analysed using a decomposition method. The temperature and salinity fields evolution in a sub-region of the Western Mediterranean basin is seen in a structural point of view and decomposed in three elements : a global spatial (2D) displacement which conserve the internal features, a global intensity variation which expresses the system energy changes, and an internal pattern changes ensemble.

The index of evolution used is a mean squared difference between the two consecutive simulations. The displacement contribution is estimated after the determination of the shift (field translation) which minimises the local mean squared difference between the translated field and the next simulation. The intensity variation contribution is calculated as the difference of the squared mean fields. The remaining difference after manipulations is considered as the internal pattern changes contribution to the system evolution.

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(2) *System for Ocean Forecast and Analysis.*

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GeoHydrodynamics and Environment Research Lab., University of Liege, Sart Tilman B5, B-4000 Liege.

Impact of SSH, SST and SSS data assimilation in a coupled physical-biogeochemical model of the North Atlantic

LEO BERLINE, PIERRE BRASSEUR AND JACQUES VERRON

LEGI, B.P.53, 38041 Grenoble Cedex 9, France

The general objective of this work is to examine how the assimilation of data in a circulation model can improve the biological response simulated by a coupled ecosystem model. In this work, the focus will be on the impact of altimetric, SST and SSS data assimilation in an eddy-permitting coupled model of the North Atlantic. The physical model is a z-coordinate, rigid lid, primitive-equation model based on the OPA code [Madec et al, 1998]. The horizontal resolution is 1/3° and there are 43 vertical levels with refinement near the surface. The biogeochemical model is the P3ZD biogeochemical model [Aumont et al., 1998] that describes the cycling of carbon, silica and calcium. The simulations are performed using realistic forcings during 1998. The assimilation method is a sequential scheme based on a Kalman filter with reduced order error covariance matrix, known as the SEEK filter [Pham et al., 1998].

In order to evaluate how the assimilation can improve the representation of the biological fields, comparisons are made between free runs and simulations with assimilation. A first comparison with the assimilation scheme developed by Testut et al. [2003] reveals the spurious vertical mixing of biological tracers induced by the sequential corrections of the physical model. This can be partly attributed to the statistical method which is unable to maintain the model constraint of hydrostatic stability. Due to the hydrostatic instability of the water column after analysis, unrealistic vertical diffusion and advection enhances the input of nutrients in the euphotic zone and further, the biological production.

Several strategies are examined to improve the representation of the sub-surface properties, based on a a post-correction after analysis, or modifying the analysis stage to preserve the stratification.

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The TOPAZ monitoring and prediction system

L. Bertino[1], J. Verron[2], E. Dombrowsky[3],
J. Schröther[4]
[1]Nansen Environmental and Remote Sensing Center, Norway
[2]Université Joseph Fourier, Laboratoire des Ecoulements Géophysiques et Industriels, France
[3]Collecte Localisation Satellites, France
[4]Alfred Wegener Institute, Germany

Within the EC funded TOPAZ project and its predecessor DIADEM, a pre-operational monitoring and prediction system has been run in real-time since January 2003. The system uses the Hybrid Coordinate Ocean Model (HYCOM) and covers the Arctic and Atlantic domains with a horizontal resolution between 20 and 40km, and nested models with fine resolution covering the North Sea and the Gulf of Mexico are run jointly in real-time. HYCOM is coupled to a sea-ice model and a Carbon:Nitrogen Regulated Ecosystem Model (REcoM) with carbon and nitrogen being decoupled. The system is currently assimilating satellite observation of sea level anomaly, sea surface temperature and ice concentrations as well as in-situ observations of temperature and salinity from the ARGO floats and XBTs. Assimilation of future satellite observations of temperature brightness and ice thickness has been evaluated. The assimilation method is the Ensemble Kalman Filter (EnKF). After 16 months of real-time operation of TOPAZ, a synthetic assessment of the system capabilities with respect to the observational network is presented. The links towards end-users and the perspectives for TOPAZ in MERSEA and GODAE are also presented.

NERSC, Edv. Griegsv. 3A, N-5059 Bergen, Norway.
laurent.bertino@nersc.no/Fax: +47 55 20 58 01

Revisiting open boundary conditions

E. BLAYO
Laboratoire Modélisation et Calcul, Grenoble, France

Artificial boundaries are a necessity in any non-global ocean circulation model. The choice of relevant boundary conditions for such artificial interfaces is an old and difficult problem, which has motivated numerous studies for more than 30 years. We present here a critical review of classical open boundary conditions (OBCs), revisited in particular in the light of the notion of "characteristic variables", defined for hyperbolic partial differential equations.

In our opinion, clamped boundary conditions should be avoided, even in the case of high resolution boundary values coming from a large scale numerical model, since the outflowing information does not depend on the internal solution. Similarly, despite their frequent use in actual numerical simulations, radiation methods should also be avoided. They are only designed for single waves, and cannot manage correctly a complex flow. Their apparent effectiveness in some cases is a mere artefact of the addition of a nudging term towards external data. Although quite crude, relaxation methods, which pull the model solution towards external data in a dissipative sponge layer, seem preferable and often lead to reasonable results in actual applications. They cannot however be extended to two-way nesting applications.

Better conditions can in fact be obtained when noting that a key point for the effectiveness of an OBC is the peculiar role of characteristic variables. These variables are defined using the hyperbolic part of the model equations, and separate the flow into incoming and outgoing quantities. We show that efficient OBCs must satisfy two criteria: they must involve incoming characteristic variables, and must satisfy a particular consistency relationship connecting the model variables with external data.

Several such conditions are already existing for the shallow water equations. The extension of this approach to the case of primitive equations will be discussed.

Laboratoire Modélisation et Calcul, Université Joseph Fourier, BP 53X, 38041 Grenoble cedex, France.

Evaluation of two atmospheric models applied to wave forecasting in the NW-Mediterranean

BOLAÑOS-SANCHEZ, R., CATEURA, J., SANCHEZ-ARCILLA, A.

Laboratory of Maritime Engineering. Catalonia University of Technology, Barcelona. Spain. Jordi Girona 1-3,Campus Nord, D1. CP 08034 rodolfo.bolanos@upc.es

The NW – Mediterranean has experienced, within the last years, strong storms with high waves and winds. This has motivated the continuous validation of models and has increased the efforts to improve wave and wind prediction. In this paper we use two atmospherics models: MASS (from SMC-Meteorological Office of Cataluña) and ARPEGE (from Météo-France) to force two third generation wave models WAM and SWAN during two severe storms registered during November 2001 and March-April 2002.

The MASS model data available consist of two spatial resolutions: a coarse grid with a resolution of 0.16° and a nested grid with 0.08°. The time resolution is 6 hours for the coarse grid and 3 hours for the medium grid. The ARPEGE model consists of one grid with a spatial resolution of 0.25° and time resolution of 3 hours. An atmospheric model validation was carried out using 5 meteorological stations located along the catalan coast. Wind records consist of a mean of wind velocity and direction every half hour. To validate the models, different methods were applied in order to analyze the sensitivity to averaging and interpolation.

Results show for most of the cases a better agreement with the coarser grids and ARPEGE was the one with better performance. For all the positions the models predicted higher wind speeds than measured, a fact attributed to land influences on the meteorological station. Regarding the wind direction, models do not present large differences, although considerable differences with recorded data are found during some dates. The spatial distribution show different patterns for both storms. For the November storm, ARPEGE predicts higher wind velocities than MASS (except for the peak of the storm) over the Mediterranean Sea. Very close to the coast, the opposite occurs, being the wind from ARPEGE lower than those of MASS. For the March-April storm, the winds from MASS are larger all above the Mediterranean sea.

The wind field from both models were used to force the wave models and analyze the sensitivities and the effect of different wind fields when predicting severe wave storms. The wave models were used with the spatial resolution of the coarse MASS model. The ARPEGE winds, thus, were interpolated to be re-scaled. The wave model runs show interesting results; during the November storm the spatial distribution using ARPEGE shows a higher maximum, although the values of Hs at the buoy are lower than the ones forced by MASS (with both WAM and SWAN). The SWAN runs show a better agreement in predicting the growing and waning of the storm peaks. The prediction of mean period was improved by the ARPEGE wind field. The situation is different during the march-april storm, when winds from MASS are higher and the waves forced by ARPEGE winds produce a considerable underestimation of significant wave height. Within this storm differences on Tz with both wind fields are not significant.

AKNOWLEDGMENT

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A database for the Optimum Design of Observational Networks (ODON)

BORENÄS K[1], AMSTRUP B[2], AXE P[1], FUNKQUIST L[1], HØYER JL[2], LARSEN J[2], LOEWE P[3], LUYTEN P[4], OLESEN SM[2], PROCTOR R[5], SHE J[2]

[1]*Swedish Meteorological and Hydrological Institute (SMHI), Sweden*
[2]*Danish Meteorological Institute (DMI), Denmark*
[3]*Bundesamt für Seeschiffahrt und Hydrographie (BSH), Germany*
[4]*Management Unit of the North Sea Mathematical Models (MUMM), Belgium*
[5]*Proudman Oceanographic Laboratory (POL), UK*

A fundamental part of ODON (Optimum Design of Observational Networks) is the construction of a 'proxy' ocean, which will be regarded as a representation of the actual conditions in the Baltic and the North Sea. This 'proxy' ocean will be obtained by running the ocean models (HIROMB and COHERENS) for a one-year period using met-forcing data, boundary conditions and initial fields of the highest possible resolution and quality. To enable this, a large dataset consisting of data collected in 2001 has been assembled for the model initialisation, forcing, assimilation and validation. The database contains SST data, T/S profiles, river runoff, boundary conditions, wave data, sea level data, and high-resolution (1 nm) bathymetry.

The presentation will describe the various stations, sections and platforms from which data have been obtained, together with information on temporal and spatial properties of the data.

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Examining air-sea interfacing in environmental monitoring/forecasting systems

CARLO BRANDINI[1], GRAZIANO GIULIANI[1], BERNARDO GOZZINI[1], SIMONA GUERRIZIO[2], ANDREA ORLANDI[1] AND ALBERTO ORTOLANI[1]

[1] *CNR-Ibimet LaMMA, Italy*
[2] *Dipartimento di Sistemi e Informatica Università di Firenze, Italy*

A number of marine environmental problems such as pollutant dispersion and diffusion find a significant improvement through the coupling, at a high level of resolution, of the atmosphere, ocean and wave part of the marine environmental system, with the aim of a better description of the atmosphere-sea surface boundary layer, that would then furnish a better estimation of the driving forces for surface pollutants (such as, but not only, oil slicks).

While at larger scales the most important fact is the radiative energy and momentum balance, at smaller scales interfacing problem is mainly due to waves, since all the fluxes of interest are sea state dependent. Most of atmosphere models usually run taking the SST not as a system variable, but as a more or less fixed boundary conditions, that is from climatological data (roughest approach), or from satellite measurements (in any case from some days averaging/filtering to cope with the declouding problem), or rarely taken from an Ocean model run (but generally not in a dynamic way) that may include assimilation of ocean data. However air-sea energy fluxes are strictly dependent on actual air-sea temperature gradients, and also SST (as used in the atmospheric models) influences, through the long wave up-radiation, the net long wave flux (and hence the total energy budget) from sea to air. At smaller scales the momentum flux between air and sea is affected by sea surface roughness, hence surface winds calculated by using local functions for sea state evaluation may be different from actual winds. Ocean waves play an important role in the evolution of different fluxes: ocean waves receive momentum and energy from the atmosphere trough wind input while through wave breaking the ocean transfer energy and momentum to the ocean generating a continuum feed-back process. Also surface currents are affected by the type of wave motion (whether swell or active sea state conditions). Finally even local energy fluxes (heat transfer) and mass fluxes (due to a local evaporation/precipitation balance affecting salinity) are influenced by sea state conditions.

Models connection are considered through the specified boundary conditions used. In fact hydrodynamic and wave data at sea are strictly dependent on the quality of the atmospheric fields used as boundary condition for oceanographic models. We will first discuss a number of model linking strategies where the SST are taken as much dynamic as possible (so that air-sea energy fluxes will vary accordingly). In addition we will then study the problem of satellite measurement assimilation in a SST-linked models. The second level of the study will be oriented to couple currents, waves and wind, studying local effects on forecasted (interface) parameters. In particular the sensible and latent fluxes are sensible to the roughness evolution and this effect is comparable to the sensitivity to parameterize the sea spray. The definition of a superficial roughness depending on the sea state generates not only effects on the fluxes dimension but even on the wind profile near the sea surface and the same correctness of the wave model forecasting.

The numerical models, mostly implemented at an operational level, used in the work are the atmospheric models RAMS [*Walko et al.,* 1995], the ocean model ROMS [*Exer et al.,* 2002] and the wave propagation model WAVEWATCH [*Tolman,* 1991]. A discussion about the model linking strategy and preliminary results will be discussed at the meeting.

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[1] Laboratorio per la Meteorologia e la Modellistica Ambientale, via Madonna del Prato Edificio D, 50019 Sesto Fiorentino, Italy.

[2] Università di Firenze, Dipartimento di Sistemi e Informatica, Via di Santa Marta 4, Firenze (Italy)

A Singular Evolutive Extended Kalman filter for data assimilation in marine environment monitoring and prediction systems

PIERRE BRASSEUR AND JACQUES VERRON

LEGI, B.P.53, 38041 Grenoble Cedex 9, France

An implementation of the extended Kalman filter has been developed for the purpose of assimilating observations into high-resolution non-linear numerical models of the ocean circulation and marine ecosystems. It is based on three major customizations of the filter:
(i) approximation of the error covariance matrix by a singular low-rank matrix which leads to making corrections only in those directions for which the error is not naturally attenuated by the system ;
(ii) modification of these directions over time according to the model dynamics and forecast misfits, reflecting the evolutive nature of the filter,
(iii) generation of new error directions according to the statistics of the innovation sequence (which measures the misfit between the estimation and the observations), reflecting the adaptive nature of the filter.

The reduction of the error covariance matrix avoids the overwhelming burden of computing the temporal evolution of the forecast error with all the degrees of freedom of the full state vector. Several strategies can be adopted to initialize the error sub-space. A method based on the computation of empirical orthogonal functions obtained from prior model simulations (without assimilation) has been applied in the majority of case studies, but other possibilities have also been tested recently, by considering singular or breeding modes of the model propagator. This scheme has been extensively published in the scientific literature, using SEEK (Singular Evolutive Extended Kalman filter) as a generic acronym [*Pham et al., 1998 ; Verron et al., 1999 ; Brasseur et al., 1999*].

The assimilation scheme has been implemented and evaluated in a wide variety of numerical ocean codes (OPA, MICOM, HYCOM) and configurations (global, basin-scale, laboratory experiments, 1D vertical models), using different data sets (satellite altimetry, sea-surface temperature, ocean colour, in situ measurements of physical and biogeochemical properties). It can be used in hindcast mode to reconstruct the variability of marine properties, or in conjunction with forecasting systems to initialize marine predictions.

In this paper, the progress made during the past ten years using the SEEK filter will be reviewed and evaluated. The essence of the assimilation methodology will be illustrated through idealized and real-case experiments. Finally, a number of recent innovations of the filter undertaken in collaboration with operational prediction groups will be presented.

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Operational forecasting in the southeastern Levantine Basin: Model implementation, evaluation, and the selection of atmospheric forcing.

STEVE BRENNER[1,2], ISAAC GERTMAN[1], AND ALEXEY MURASHOVSKY[1]

[1]*National Institute of Oceanography, Israel Oceanographic and Limnological Research, Israel*
[2]*Department of Geography, Bar Ilan University, Israel*

Within the framework of several local and international programs we have set up a quasi-operational forecasting system based on the Princeton Ocean Model (POM) for the hydrodynamics [*Blumberg and Mellor,* 1987], and the Wave Model (WAM) for surface waves [*Hasselmann et al.,* 1988]. A common requirement for both types of models is the need for meteorological forcing. In addition, the hydrodynamic model requires initial conditions and time dependent lateral boundary conditions at the open boundaries. In this presentation we will focus on the POM related system.

As part of our participation in the Mediterranean Forecasting System Pilot Project (MFSPP), [*Pinardi et al.,* 2003] and its follow on project MFSTEP we developed a high-resolution model for the southeastern corner of the Levatine Basin [*Brenner,* 2003]. For operational purposes, once per week MFSPP/MFSTEP provides basinwide 10-day forecasts for the entire Mediterranean as well as hindcasts (i.e., synoptic analyses) for the previous seven days. These forecasts are used to drive an intermediate model which in turn provides the one way nesting information (initial and lateral boundary conditions) for our shelf model. We have subsequently developed a flexible interface to the MFSPP/MFSTEP data which now allows our model to be easily relocatable to anywhere within the Mediterranean Sea. Some of the other applications of the model have included short range hindcasts and forecasts (up to 5 days) for various subregions of the Levantine Basin and the region around the Straits of Sicily [*Brenner,* 2002]. Evaluation or validation of the model consists primarily of a comparison with the MFSPP/MFSTEP hindcasts. We have also done some comparisons with direct current measurements which has helped us to identify some systematic biases in the model.

For atmospheric forcing we have several options available. These include the ECMWF based wind stress and heat fluxes provided as part of the MFSPP/MFSTEP forecasts, operational forecasts from the UK Met Office global model, and forecasts from a regional atmospheric model run in house. Selected results of the POM forecasts as forced by each of the above will be presented.

Finally it is important to note that all of the simulations and forecasts, including the in house atmospheric model, are run on Pentium IV based workstations and are available within a reasonable amount of time.

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[1] Complete adress for the first institution using the « Adresses » style.
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Reconstructing vertical profiles from surface data

B.BUONGIORNO NARDELLI, O.CAVALIERI, R.SANTOLERI AND M.-H. RIO
Istituto di Scienze dell'Atmosfera e del Clima, C.N.R.

Different methods for the extrapolation of vertical profiles from sea surface measurements have been developed and tested. These methodologies, called Coupled Pattern Reconstruction (CPR, Buongiorno Nardelli and Santoleri, 2003a) and multivariate EOF Reconstruction (mEOF-R, Buongiorno Nardelli and Santoleri, 2003b) base on the multivariate analysis of the variability of vertical profiles from hydrographic data and on the hypothesis that only few modes are needed to explain most of the variance/covariance of the fields. The CPR and mEOF-R methods have been first applied and tested on several years of Conductivity-Temperature-Depth (CTD) measurements collected in the northern Mediterranean sea during the DYFAMED (DYnamique des Flux de mAtière en MEDiterranée) program, and in the northern Pacific during the HOT (Hawaii Ocean Time-series) program. The results have been compared with ad hoc climatologies and with results of previous similar techniques as those adopted by MODAS (Fox et al., 2002), indicating the potential of these techniques in relation to the surface measurement accuracy. Successively, some tests have been performed using directly Topex/Poseidon altimeter data as input for the sea surface elevation in a selected area inside the Mediterranean sea (Cavalieri et al., 2003). At this step, a synthetic mean dynamic topography computed from drifters and altimeter data (Rio and Hernadez, 2003) was added to standard altimeter sea level anomalies to improve the estimate.

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Simulation of tidally-induced currents in the Strait of Gibraltar

MANUEL J. CASTRO[1], JOSÉ M. GONZÁLEZ-VIDA[2], JORGE MACÍAS[1], CARLOS PARÉS[1]

[1] *Departamento de Análisis Matemático, Universidad de Málaga, 29080, Málaga*

[2] *Departamento de Matemática Aplicada, Universidad de Málaga, 29080, Málaga*

Abstract

The numerical simulation of the interface and exchange flow through the Strait of Gibraltar is performed by means of a finite volume numerical model. The model is suited for flows of stratified fluids through channels with irregular geometry where channel cross-sections are supposed to be symmetric but not necessarily rectangular. The fluid is supposed to be composed of two shallow layers of immiscible fluids of constant densities, and the flow is assumed to be one-dimensional. Therefore, the equations to be solved are a coupled system composed of two Shallow Water models with source terms involving depth and breadth functions. To apply the numerical model to the simulation of the flow through the Strait of Gibraltar real bathymetric and coast-line data were considered in order to include in the model the main features of the abrupt geometry of this natural strait connecting the Atlantic Ocean and the Mediterranean Sea. A steady state solution is obtained from *lock-exchange* initial conditions. This solution is then used as initial condition to simulate the main semidiurnal and diurnal tidal waves in the Strait of Gibraltar through the imposition of suitable boundary conditions obtained from observed tidal data. Comparisons between numerical results and observed data will be presented.

Introduction

This work is a stage of a more general project whose final goal is to obtain a numerical model well suited to study geophysical flows of stratified fluids. This kind of flows frequently appears in applications, such as in estuarine systems, marine density flows, etc. This is the situation, for instance, occurring in the Strait of Gibraltar, where surface water from the Atlantic inflows over saltier westward-flowing Mediterranean water. In this general project, we consider a range of models in increasing order of complexity. It is clear that, in oder to obtain realistic simulations of flow exchanges through natural narrows, the final model has to include Coriolis effects, friction, mixing between layer, atmospheric forcing, etc. Moreover, possibly a multi-layer formulation would eventually be required to obtain a more accurate representation of water stratification in some particular cases. Nevertheless, two-layer models can capture some of the most relevant features of this kind of flows and they have frequently been used to study exchange flows through channels connecting two basins with different hydrological characteristics, as it is the case of Gibraltar Narrows. At the present stage of our project, we consider this kind of models for channels with irregular geometry.

Equations and numerical scheme

The model solves a coupled system of one-dimensional shallow water equations for two-layer fluids of inmiscible layers through channels with symmetrical sections of arbitrary geometry. See [*Castro et al.,* 2001b] or [*Castro et al.,* 2003] for model deduction and equations. The resulting system of equations writes under the form of two systems of conservation laws with source terms. The numerical scheme is based on Approximate Riemann Solvers for general coupled systems of conservation laws with source terms (see [*Castro et al.,* 2001a] and [*Castro et al.,* 2003] for further details).

Tidal simulation

The goal pursued is to study the effects of tidal forcing on the exchange flow through the Strait of Gibraltar and over the behaviour and location of the interface separating Mediterranean waters flowing at depth and surface Atlantic waters. To perform this experiment a steady state solution, representing the secular exchange through the Strait, is firstly computed. This solution is obtained by means of a *lock-exchange* experiment where no other forcing is imposed and then used as initial condition in the tidal simulation. At the internet web site `http://www.damflow.org` some animations of these experiments can be visualized.

In order to study the essential elements of the time dependent response in the Strait of Gibraltar to tidal forcing, a numerical experiment consisting in a simulation of the main semidiurnal (M2 and S2) and diurnal (O1 and K1) tidal waves in this narrows is performed. The numerical experiment has been designed as follows: Using the steady state solution reached at the previous lock-exchange experiment as initial condition, the model is integrated over 30 semidiurnal tidal cycles to achieve a stable quasi-time-periodic solution. The model is forced at the open boundaries with boundary conditions that simulate the four main tidal components to be considered (M2, S2, O1 and K1). The values for phases and amplitudes for these tidal components were obtained by interpolating the measured data at the coastal stations of Trafalgar and Spartel (on the western end) and the coastal stations of Punta Carnero and Ceuta (on the eastern end) obtained by [*Garc ía LaFuente et al.*, 1990]. Once the quasi-time-periodic regime is established, the model is integrated for another 29-day period. Thereafter an harmonic analysis is performed on the tidal elevation over this 29-day period in order to compare the results with the measured data provided by [*Garc ía LaFuente et al.*, 1990] at some relevant points. The comparison between observed and numerical data are presented in table 1 and 2, where phases are related to the M2 tide.

Table 1: Tarifa – Punta Cires section

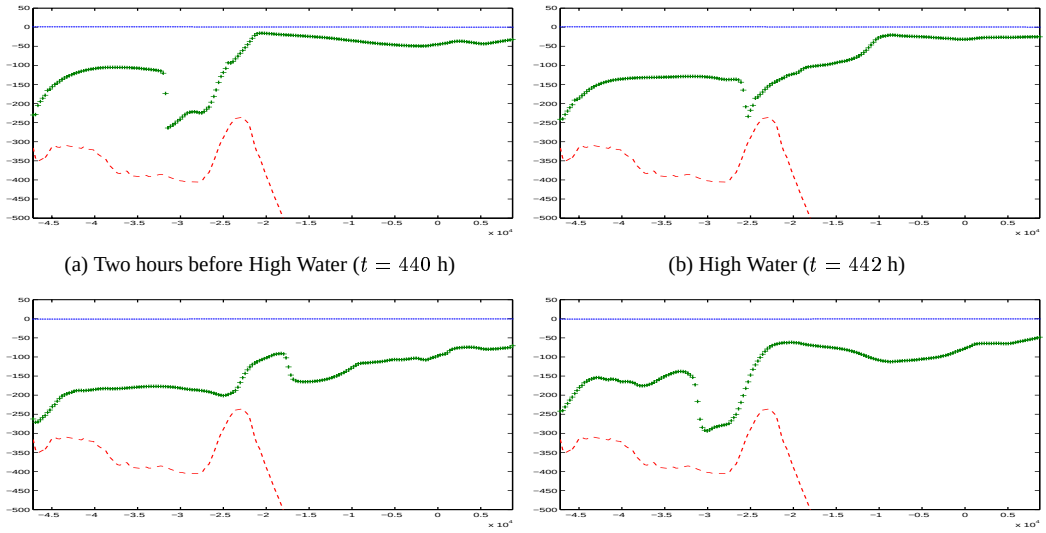
	M2		S2		K1		O1	
	Obs	Pred	Obs	Pred	Obs	Pred	Obs	Pred
Amplitude (cm)	38.94	39.88	14.13	14.85	2.73	2.16	0.84	0.87
Phase	0°	0°	27.75°	26.07°	80.25°	77.21°	ND	ND

Table 2: Punta Gracia – Punta Kankoush section

	M2		S2		K1		O1	
	Obs	Pred	Obs	Pred	Obs	Pred	Obs	Pred
Amplitude cm	57.7	55.15	21.5	20.08	3.8	1.22	2.25	3.11
Phase	0°	0°	22.37°	24.33°	22.75°	-16.01°	262.91°	198.58°

In Figure 1 the free surface and the interface at four stages (High Water, Low Water and two hours before each of them) of a semidiurnal tidal cycle corresponding to a spring tide are depicted. We are also interested in analysing the nature of the flow along the Strait. This is done looking at the Froude numbers associated to the simulated flow.

The numerical results are compared with the synopsis of the essential elements of the time-dependent response of the flow in the Strait of Gibraltar made by [*Armi et al.,* 1988] from observed data collected in April 1986.



(a) Two hours before High Water ($t = 440$ h)

(b) High Water ($t = 442$ h)

(c) Two hours before Low Water ($t = 446$ h)

(d) Low Water ($t = 448$ h)

Figure 1: Simulated free surface and interface during a semidiurnal tidal cycle at the Strait of Gibraltar.

Through the simulation it can be observed that Tangier Basin acts as a reservoir that fills and drains on each tidal cycle. A brief description of the process is as follows: At spring tides about one hour after High Water, when Tangier Basin has been filling and the interface there has raised, the moving control close to Camarinal Sill is lost. This happens for about one hour. For neap tides this occurs closer or at High Water conditions and the lose control situation lasts longer, for about three hours. Then, the Tangier Basin starts draining, first due to the reversal of the Mediterranean flow at Camarinal Sill and later on for a larger Mediterranean outflowing flow through Spartel Sill than the incoming flow though Camarinal Sill this makes the interface to drop below the interface level east of Camarinal Sill. The large amount of Mediterranean water incoming through Spartel Sill makes that the moving control close to Camarinal Sill is re-established. Meanwhile, the interface behaves in a complex manner (in our presentation we will show this behaviour plotting more intermediate snapshots of the simulated interface and presenting an animation of the numerical results). About one hour before Low Water, the increasingly larger and progressively more supercritical flow of Mediterranean water entering through Camarinal Sill into the Tangier Basin initiates the formation of a bore west of Camarinal Sill. The bore initially grows up to occupy half of the Tangier Basin, remaining there for about half of the tidal cycle when a new refilling of the basin makes the bore move eastwards and latter, when the control is again lost in a new tidal cycle, makes it dissappear propagating east of the sill.

East of Camarinal Sill, between the sill and the contraction, there is another fluctuating reservoir of water. In this case it is the Atlantic water that fills or drains from this reservoir of the Strait. Just as Tangier Basin can drain from both ends on a falling tide, so does the pool of Atlantic water east of Camarinal drain from both ends, west over Camarinal Sill and east through Tarifa

Narrows, on a rising tide.

Over the 29 days of tidal simulation presented here the mean fluxes for the surfacial Atlantic water was of 1.0923 Sv and of -1.0327 Sv for the Mediterranean water. The supercritical nature of the flow at both ends of the Strait is preserved along all the tidal simulation. However, the nature of the flux connecting these two supercritical sections is highly time-dependent and interface behaviour complex: bores are formed that move and dissappear, the moving control at Camarinal is periodically lost, etc. From a qualitative point of view model solutions are in good agreement with the observed data and analysis performed by [*Armi et al.*, 1988].

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Global Ocean Prediction with the HYbrid Coordinate Ocean Model (HYCOM)

E. P. CHASSIGNET[1], H. E. HURLBURT[2], G. R. H. HALLIWELL[1], A. WALLCRAFT[2], J. METZGER[2], O. M. SMEDSTAD[3], C. LOZANO[4], R. BLECK[5], C. THACKER[6]. A. MARIANO[1], T. M. CHIN[1], P. BRASSEUR[7], L. PARENT[8], H. NGODOCK[9]

[1]*RSMAS/MPO, U. of Miami, Miami, FL, USA;* [2]*Naval Research Laboratory, Stennis Space Center, MS, USA;* [3]*Planning Systems Inc., Stennis Space Center, MS, USA;*[4]*NOAA/NCEP, Camp Springs, MD, USA;* [5]*Los Alamos National Laboratory, Los Alamos, NM, USA;* [6]*NOAA/AOML, Miami, FL, USA;* [7]*LEGI, Grenoble, France;* [8]*Sverdurp Technology Inc., Stennis Space Center, MS, USA;*[9]*University of Southern Mississipi, Stennis Space Center, MS, USA.*

A broad partnership of institutions is collaborating in developing and demonstrating the performance and application of eddy-resolving, real-time global and Atlantic ocean prediction systems using the the HYbrid Coordinate Ocean Model (HYCOM). These systems will be transitioned for operational use by both the U.S. Navy at the Naval Oceanographic Office (NAVOCEANO), Stennis Space Center, MS, and the Fleet Numerical Meteorology and Oceanography Centre (FNMOC), Monterey, CA, and by NOAA at the National Centers for Environmental Prediction (NCEP), Washington, D.C. These systems will run efficiently on a variety of massively parallel computers and will include sophisticated data assimilation techniques for assimilation of satellite altimeter sea surface height and sea surface temperature as well as in situ temperature, salinity, and float displacement. The Partnership addresses the Global Ocean Data Assimilation Experiment (GODAE) goals of three-dimensional (3D) depiction of the ocean state at fine resolution in real-time and provision of boundary conditions for coastal and regional models. An overview of the effort will be presented.

GeoHydrodynamics and Environment Research Lab., University of Liege, Sart Tilman B5, B-4000 Liege.

Adaptation of Global Volume Transport for Coastal Ocean Models

PETER C CHU AND CHENWU FAN

Naval Ocean Analysis and Prediction Laboratory, Department of Oceanography
Naval Postgraduate School, Monterey, CA 93940, USA

One difficulty in coastal modeling is uncertain volume transport at lateral open boundaries. A simple model for determining global volume transport from winds and hydrographic data is developed on the basis of the ocean circulation theories by Ekman and Munk. The volume transport stream function Ψ satisfies the Poisson equation with the depth-integrated vorticity Π as the forcing term. This model contains four major components: (1) development of an objective method to determine Ψ-values at individual islands, (2) use of the P-vector method (Chu, 1995; Chu et al., 1998; Chu and Li, 2000; Chu et al., 2001) to obtain the interim velocity field (U*,V*) and then the forcing function, (3) use of the interim velocity field to determine the Ψ-values at boundaries and islands, and (4) integration of the Poisson Ψ-equation to obtain the volume transport stream function and the depth-integrated velocity (U,V). The calculated global Ψ-field agrees well with earlier studies and provides realistic open boundary conditions for regional/coastal models.

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PREDICTABILITY OF JAPAN/EAST SEA (JES) SYSTEM TO UNCERTAIN INITIAL/ LATERAL BOUNDARY CONDITIONS AND SURFACE WINDS

PETER C CHU AND CHIN-LUNG FANG

Naval Ocean Analysis and Prediction Laboratory, Department of Oceanography
Naval Postgraduate School, Monterey, CA 93940, USA

Numerical ocean modeling usually composes various initial- and boundary-value problems. It integrates hydrodynamic and thermodynamic equations numerically with atmospheric forcing and boundary conditions (lateral and vertical) from initial states of temperature, salinity and velocity. Past observations, historical datasets and climatological datasets of the ocean have contributed greatly to the knowledge of the data fields of initial condition, atmospheric forcing and boundary conditions. Change in either initial or boundary condition leads to a variety of model solutions. It is necessary to specify realistic initial and boundary conditions to achieve better understanding and prediction of the ocean behavior. However, uncertainty often exists in both initial and boundary conditions. Up to now, most studies on ocean predictability have usually been for one particular type of model input uncertainty within the three types of uncertainty (initial conditions, open boundary conditions, atmospheric forcing function). This study investigates the response of ocean model to the three types of model input uncertainty simultaneously using Princeton Ocean Model (POM) implemented for the Japan/East Sea (JES).

For uncertain velocity initial conditions with and without diagnostic initialization, the model errors are quite comparable and significant, but they decrease with time. For uncertain wind forcing with the Gaussian random noise, the model error increases with time and noise intensity. The vertically averaged RRMSE of the horizontal velocity fluctuates with time. For the noise intensity of 0.5 m/s, it increases slowly from 11% on the 5^{th} day to 12% on the 45^{th} day and then decreases to 8% (the minimum value) on the 75^{th} day and then increases again to 19% (the maximum value) on the 180^{th} day. For the noise intensity of 1.0 m/s, it increases slowly from 18% on the 5^{th} day to 20% on the 45^{th} day and then decreases rapidly to 11% (the minimum value) on the 75^{th} day and then increases again to 28% (the maximum value) on the 180^{th} day. The maximum RRMSE of horizontal velocity, occurring near the surface, increases from 35% on the 5^{th} day to 50% on the 180^{th} day for noise intensity of 0.5 m/s, and increases from 60% on the 5^{th} day to 80% on the 180^{th} day for noise intensity of 1.0 m/s. The model errors generally decrease with depth and become small below sigma level-8. For uncertain lateral boundary transport with the Gaussian random noise, the model error increases with time and noise intensity. The vertically averaged RRMSE of the horizontal velocity fluctuates with time between 9% and 20% (17% and 34%) for the noise intensity to be 5% (10%) of the transport of the control run. It generally increases with time from the 5^{th} day to the 150^{th} day with a peak value of 20% for 5% noise and 34% for 10% noise and then decreases with time to 15% for 5% noise and to 22% for 10% noise on the 180^{th} day. The maximum RRMSE of horizontal velocity, occurring near the bottom, increases from 14% on the 5^{th} day to 18% on the 180^{th} day for 5% noise, and increases from 24% on the 5^{th} day to 28% on the 180^{th} day for 10% noise. The model errors generally increase with depth.

Finite Volume Coastal Ocean Model

PETER C CHU AND CHENWU FAN

Naval Ocean Analysis and Prediction Laboratory, Department of Oceanography
Naval Postgraduate School, Monterey, CA 93940, USA

A three dimensional finite volume ocean circulation model with a free surface is presented. The basic equations are transformed from differential into integral forms using the hydrostatic and anelastic approximations. The integral equations are solved for finite volumes (rather than grid points) with the flux conservation easily enforced even on arbitrarily meshes. Moreover, this model can easily incorporate the upwind scheme to increase the computational stability and the high-order combine compact schemes to enhance the accuracy. For abrupt topography, a crystal grid discretization is designed to reduce computational errors such that the four lateral boundaries of each finite volume are perpendicular to x and y axes, and the two vertical boundaries are not purely horizontal. This grid system reveals a superior feature than z- and sigma coordinate systems. The accuracy of this model was tested by the standard seamount test case.

Use of the finite volume discretization leads to a conserved scheme for pressure gradient computation that has better truncation properties with high accuracy. The analytical coastal topography and seamount test cases are used to evaluate the new scheme. The accuracy of the new scheme is comparable to the sixth-order combined compact scheme (with an error reduction by a factor of 70 comparing to the second-order scheme) with mild topography and much better than the sixth-order combined compact scheme with steep topography. The computational efficiency of the new scheme is comparable to the second-order difference scheme. The two characteristics, high-accuracy and computational efficiency, make this scheme useful for the sigma coordinate ocean models (Chu and Fan, 2003).

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How long can an ocean model predict?

Chu, Peter C., and Leonid, M. Ivanov, Naval Postgraduate School, Monterey, California, USA
(chu@nps.navy.mil, tel: 1-831-656-3688)

"How long can an ocean model predict?" is a fundamental question for ocean modeling and prediction. To answer this question, full knowledge of the prediction error statistics of each model is needed. Due to high structural complexity and high dimensionality of the error phase space, establishment of such statistics is difficult. Usually the Gaussian distribution is assumed for the error statistics for simplicity. However, it might not be true for ocean models.

A new scalar with the dimension of time, the irreversible-skill time (IT), is defined as the time period when the prediction error first exceeds a pre-determined criterion (i.e., the tolerance level) [originally defined as valid prediction period by Chu et al. (2002a, b, c)], is introduced to estimate the model predictability for linear and nonlinear stages in the prediction error evolution. The probability density function (PDF) of IT satisfies the backward Fokker-Planck equation (or called Pontryagin-Kolmogorov equation in the Russian literature).

Great advantages of IT for model evaluation are: (1) establishing the analytical framework for estimating the local prediction-skill of regional ocean models, (2) understanding the temporal intermittency of prediction-skill, and (3) searching physical mechanisms causing extremely successful prediction (ESP). Application to ocean (atmospheric) model evaluation is demonstrated (Chu et al. 2003).

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Bio-optical Monitoring in the Black Sea

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T.CHURILOVA[1], V.SUSLIN[2], G.BERSENEVA[1], L.GEORGIEVA[1]

[1]Institute of Biology of the Southern Seas, National Academy of Science, Sevastopol, Ukraine,

[2]Marine Hydrophysical Institute, National Academy of Science, Sevastopol, Ukraine

A modeling requires in situ measured data for both a) assimilation into the model and b) validation of model results. At present time for the analysis and prediction of marine ecosystem state Chlorophyll and Primary production models based on optical satellite data are widely used. However, the SeaWiFS algorithms providing the transformation of color images to chlorophyll maps give inaccurate estimation of chlorophyll *a* concentration in deep-water part of the Black Sea – an overestimation in summer and an underestimation – in peak of winter-spring blooming of phytoplankton. A development of the regional chlorophyll *a* algorithm requires an estimation of spectral characteristics of all light absorbing components and their relationships with chlorophyll *a* concentration.

With this aim bio-optical monitoring was organized in two fixed stations: in the central western part of the Black sea (~ 2000 m depth) and in slope zone near the Crimea (> 200 m depth). These regular measurements were conducted out using a ship opportunity. This monitoring showed U-type of pigment (Chl *a* + Phaeo) concentration dynamics with a minimum of value in summer (0.21 mg/m^3) and a maximum - in cold period (autumn-winter-spring, up to 2.44 mg/m^3). The weekly monitoring allowed to determine phytoplankton community succession: seasonal dynamics of size and taxonomic structure, development of large diatoms blooming in March and coccolithophores – in June. The significant variability in pigment concentration and species content of phytoplankton is accompanied by high variability in shape of the phytoplankton absorption spectra and in values of chl *a*-specific absorption coefficients. The relationships between phytoplankton specific absorption coefficients (at 412, 443, 490, 510, 555, 678 nm) and Chl *a* + Phaeo concentration were described by power functions. The contribution of detritus to total particulate absorption significantly varied and correlated with Chl *a* + Phaeo concentration. The main light-absorbing component in the Black Sea is colored dissolved organic matter (CDOM), its absorption at 443 nm is 50-70 % to total particulate and CDOM absorption.

Special attention should be given to shelf regions. The comparison of bio-optical data for the open part with those for the shelf region showed pronounced differences:

a) the relationships between phytoplankton specific absorption coefficients and Chl *a* + Phaeo concentrations (at 412, 443, 490, 510, 555 nm) are different;

b) in the shelf waters relative absorption by detritus was higher and weakly correlated with Chl *a* compared with deep-water part of the Sea.

The comparison of spectral characteristics of light absorbing components and their relationships with chlorophyll *a* concentration in deep-water region with those in shelf region showed that regional approach to modeling is required. The complex of bio-optical parameters collected during monitoring can be used for ecosystem models as well.

Implementation of a Regional Forecasting Pollutant Drift System in the Catalan Shelf zone

COMERMA, E., ESPINO, M., AND S.-ARCILLA, A.

Laboratory of Maritime Engineering, Polytechnic University of Catalonia, Barcelona, Spain
C/Jordi Girona 1-3, Campus Nord UPC, 08034 Barcelona. eric.comerma@upc.es

On November 2002, a tanker named *Prestige* spilled more than 40.000 tons of heavy fuel oil. Once more, the Atlantic European coast was affected by a catastrophic pollutant accident (Aegean Sea, Erika and many others in the last 30 years…); the marine environment was damaged through thousands of kilometres also affecting many economic activities (tourism, fisheries, etc.).

The consequences of this accident carried out a social reaction, forcing the Spanish national and regional administrations to improve management skills in this kind of environmental crisis. According to this, some lines of scientific and technical research were launched due to this accident. As national improvements, some management tools are needed in the form of legal and technical procedures. In particular, the issues are contingency planning and prevention against marine pollution and prediction for a proper response. In this work, we will present the activities of the Maritime Eng. Lab. related with the set-up of an operational forecasting system implemented in the Catalan coastal area, taking forcing inputs from the pre-operational Mediterranean Forecasting System [*MFSTEP Kick-off Report*, 2003].

Catalonia, located in the northeast of Spain, is a relevant hub for maritime transport, exchanging oil and other petrochemical products. Tarragona, situated south of Catalonia, is an important refinery centre in the Western Mediterranean Sea. Therefore, due to the vicinity of these maritime corridors, the regional government, the *Generalitat de Catalunya*, approved recently the Contingency Plan for Marine Pollution [CAMCAT, 2003]. This Plan includes two main activities: the organisation of the management and response of an hypothetical environmental crisis and the set-up of an operational system of monitoring and forecast.

In collaboration with the Public Works and Civil Protection departments of the *Generalitat*, and the Catalan Met Office (MeteoCat), this system will be achieved within the next year as an operational system, using the oceanographic and meteorological monitoring data as forcing for the forecasting module part. The main activities for this system are:

· Update of the existing measurement network, XIOM [S.-Arcilla, 2002], that will include surface currentmeters, 6 meteorological stations, tide and wave buoys. At the moment, the XIOM net is already distributing near real time data results through the internet (http://lim050.upc.es/projects/xiom/).

· Implementation of hydrodynamics modelling, transport and fate pollutant in a the large domain of study (including the Catalan and the Balearic shelf, Fig.1). These models are being feed through atmospherics forcing (by MeteoCat and MFSTEP) and with initial hydrodynamics conditions (nesting to MFSTEP currents forecast results).

· In case of an emergency, deployment of surveillance techniques of the pollutant by means of, i.e., satellite images and tracking of drifting buoys (Argos)

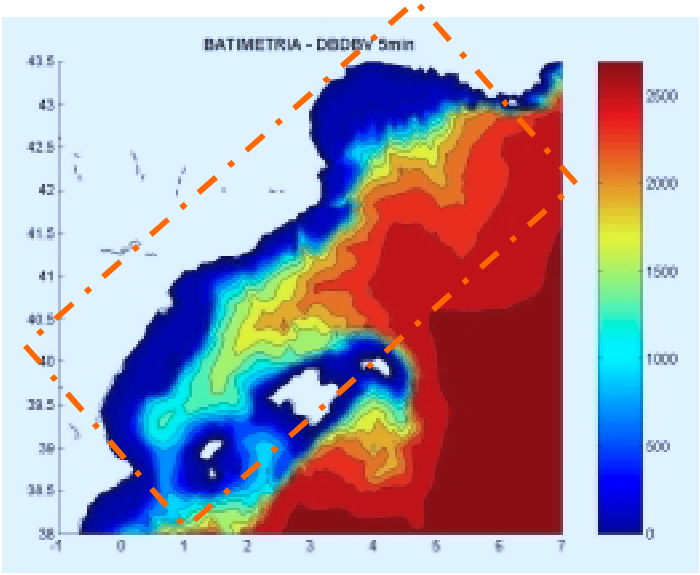

Fig.1.- Area of implementation of the Operational Forecasting system: Catalan Shelf area

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Using Data Assimilation for investigating the spatial and temporal variability of the trophic state in the Venice Lagoon.

COSSARINI, G. [1], LERMUSIAUX P. [2], SOLIDORO, C. [1]

[1] *Istituto Nazionale di Oceanografia e di Geofisica Sperimenta, Italy*

[2] *Harvard University, Massachusetts USA.*

Data Assimilation techniques were applied to an ecosystem model of the Venice lagoon to obtain reliable and coherent estimations of the nutrients and chlorophyll fields, improving the knowledge on spatial and temporal evolution of the trophic state. The model, already released, parameterizes the transport processes in term of pure turbulent diffusion, and describes the evolution and interaction of 12 biological compartments. Rivers and urban nutrient loads, the exchanges with the Adriatic Sea, the energy and matter exchanges at the interface air-water, are the input factors which drive the model.
Assimilation procedures utilize monthly observations collected in a monitoring network well-distributed in space during year 2001. Data were interpolated to the regular grid of the model using an objective analysis technique specifically developed for the lagoon. Such a technique is based on the definition the correlation between points as function of a "characteristic distance", that accounted for the hydrodynamic condition of the system.
Different estimates of the state of the system provided by different DA techniques were compared to the reference solution, in order to judge the capability of the methods of reproducing reliable seasonal evolution of nutrient and chlorophyll spatial gradients in the lagoon.
Finally an application of the Error Subspace Statistical Estimation scheme on a simplified domain of the model was used to evaluate the error distribution of the forecast of the model and the assimilated fields in relation to the uncertainty of input factors, driving forcing and model parameters.

Cossarini Gianpiero
Istituto Nazionale di Oceanografia e di Geofisica Sperimentale
Borgo Grotta Gigante 42/C, 34010 Sgonico, Trieste
e-mail: gcossarini@ogs.trieste.it

BIOMONITORING WITH SEAWWED AND DIRECT ASSAY OF HEAVY METALS IN SEAWATER AND SEDIMENT OF THE KISH ISLAND COAST (NORTHEASTERN OF THE PERSIAN GULF)

A. Dadolahi-Sohrab[1], A. Savari[2], H. Omar [3], A. Ismail[3] and M. Kusnan[3]

[1]Department of Marine Science, University of Kish, Amir Kabir Square 79417, Kish Island, I.R. Iran
[2]University of Marine Science and Oceanography, Khoramshahr 669, I. R. Iran
[3]Department of Biology, Faculty of Science and Environmental Studies, 43400, University Putra Malaysia, Malaysia

The study was carried out to evaluate the use of seaweed as biomonitoring in Kish Island, Iran. Seaweed, sediment and seawater samples were collected bimonthly from June 1999 to April 2000 at 5 different sites. The status of selected heavy metals (Cd, Cu, Ni, Pb, V and Zn) were determined in seawater (V level was not measured in seawater), sediment and 10 dominant seaweed species. Metals level in seawater ranged from 0.02-0.10, 0.09-1.22, 0.11-0.18, 0.27-2.04 and 0.17-0.27 μg l^{-1} for Cd, Cu, Ni, Pb and Zn, respectively, the metals concentrations were higher during cold seasons compared to the warm seasons. Metal concentrations in sediments ranged from 0.18-0.39, 2.39-4.55, 2.30-11.92, 2.92-5.92, 1.69-4.76, 4.04-9.51 μ g g^{-1} dry weight for Cd, Cu, Ni, Pb, V and Zn, respectively. Higher variations in metal concentrations were observed at sites 1 and 5 compared to other sites. Metal levels in seaweeds showed considerable variations ranging from 0.44-1.74, 0.76-3.42, 0.37-2.23, 0.96-4.47, 0.53-2.16 and 3.44-10.23 μg g^{-1} dry weight for Cd, Cu, Ni, Pb, V and Zn, respectively. Cadmium was lower in Chlorophyta compared to the Phaeophyta and Rhodophyta. Chlorophyta accumulated more Zn, V, Pb, Ni and Cu than other groups. In addition, variations in metals contents between species were obvious from the same habitat and in several cases within the same taxonomic groups. Generally, heavy metals level in this study were relatively lower than the other parts of the world and in some cases lower than the other parts of the Persian Gulf. The MPI (Metal Pollution Index) values of sediment and seawater during different periods showed a maximum and minimum values to the cold and warm seasons, respectively. Maximum MPI values in different classes of seaweeds were observed during cold seasons. In the present study, periodic concentration factor were significant ($p < 0.05$) for Cd, Cu, Ni, Pb and Zn in Chlorophyta and Pb and Zn in Phaeophyta. Whereas, Rhodophyta species did not show any significant variations to the metals concentration factors. However, concentration factor for each metal studied was found significant in one or two classes of seaweeds (e.g. Pb, Zn). Under the present conditions, Chlorophyta could be used to estimate the mean seawater contents in Cd, Cu, Ni, Pb and even Zn, but Phaeophyta probably good for Pb and Zn, whereas, Rhodophyta was not reliable for any metals.

A Finite Element Ocean Model: application to data assimilation in the North Atlantic

S. DANILOV, G. KIVMAN, J. SCHRÖTER

Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany

We present results of assimilation of altimetry data obtained with an eddy-permitting version of the Finite Element Ocean Model (FEOM) configured for the North Atlantic. The FEOM uses the primitive equations discretized on a tetrahedral mesh that is unstructured horizontally. Its horizontal resolution is refined in coastal and dynamically important regions, and along the shelf break. The latter feature allows the sloping bathymetry to be accurately represented within the z-coordinate vertical discretization (similar to cut cells), so that pressure gradient errors are avoided. The model is equipped with a finite-element ice model that uses unstructured triangular grid and could provide enhanced spatial resolution in areas of interest.

The FEOM runs for the North Atlantic were performed on the mesh with the horizontal resolution varying from 0.15^0 to 2.2^0. Assimilation of altimetry data into the model increases the SSH variability in the Gulf Stream region and corrects the model behaviour in the vicinity of open boundaries. Intercomparison of the Kalman-filter-based assimilation algorithms implemented with FEOM is given in the companion presentation.

Monitoring the mesoscale ocean circulation with multi-satellite altimetric missions: a data-assimilation study.

F.DEBOST, J-M BRANKART, P.BRASSEUR AND J.VERRON
LEGI,Grenoble, France

The general objective of this work is to assess a variety of multi-satellite altimetric scenarios aimed at monitoring the mesoscale ocean circulation in connection with numerical models and assimilation methods. The approach taken for this work is based on Observing-Systems Simulation Experiments (OSSE). We performed twin assimilation experiments, using a numerical model to generate synthetic data according to the sampling schemes achieved by the satellite constellations under study.

An academic model of the Gulf Stream system has been developed, using the OPA primitive-equation model at eddy-resolving resolution with a simplified ocean configuration forced by zonal winds. The sea-surface height data are sampled from the model output, along the ground tracks figuring out the Jason-1 (and Topex/Poseidon), GFO and AltiKa satellites flying with 10, 17 and 35 days orbital periods respectively.

The SEEK (Singular Evolutive Extended Kalman) filter is implemented to assimilate the altimetric data, using an EOF basis to reduce the error sub-space and a local approximation to improve the impact of along-track measurements. The evolution of the reduced order error covariance matrix is performed dynamically using the OPA model, in order to propagate in time the error statistics produced by the filter. The dynamical and local evolution of the error modes manage to represent a forecasted state that is statistically more coherent with the system state.

Results of several assimilation experiments will be discussed by considering a variety of analyses, forecasts diagnostics from a statistical point of view, such as temporal evolution of the rms error for various variables of the state vector (U,V,T,SSH and SST), and from a physical point of view, such as eddy induced heat transport or time series of running mean eddy kinetic energy.

Two-satellite missions seem to be the minimum configuration required for the reconstruction of the oceanic mesoscale activity. The combination of three satellites brings significant benefits regarding the evaluation of the non-observed (and non assimilated) variables (i.e. essentially subsurface variable).

Laboratoire des Ecoulements Géophysiques et Industriels,BP 53 38041 Grenoble Cedex 09, France.

Local mesh refinement with the **AGRIF** software
Applications to ocean modelling

L. DEBREU, C. VOULAND AND E. BLAYO
INRIA and Laboratoire de Modélisation et Calcul, Grenoble, France

http://www-lmc.imag.fr/IDOPT/AGRIF/

AGRIF (Adaptive Grid Refinement In Fortran) is a software designed to simplify the integration of mesh refinement features in complex models written in the Fortran language and discretized on structured grids. AGRIF deals with 1, 2 or 3D fixed or adaptive mesh refinement, staggered grids, masked fields and MPI parallelization of the grid's interactions. During this talk, several aspects of the software are illustrated by presenting its application to three different ocean models: MARS (IFREMER, France), OPA (LODYC, France) and ROMS (UCLA, USA).

The usual nesting problems appearing in realistic simulations are first reminded: conservation properties, elliptic solvers, masked fields extrapolation, issues related to time refinement, ...

Then the current status of the nesting capabilities of the previously cited ocean models is outlined. These ocean models noticeably differ by their treatment of gravity waves (implicit or explicit with time splitting) and their vertical coordinates system (z or σ). A review of specific numerical treatment of the grid's interaction is presented. Effectiveness of the approach is illustrated with realistic applications.

In a last part, a step by step example of the use of AGRIF in a simplified ocean model is given and a critical comparison with other computing way to implement mesh refinement is made.

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Address: Laurent Debreu, LMC/IMAG, 51 rue des Mathématiques, 38400 Saint Martin d'Hères, France.

Data assimilation in regional and shelf seas

PIERRE DE MEY[1], FRANCIS AUCLAIR[2], GABRIEL JORDA[1,3], JULIEN LAMOUROUX[1], FLORENT LYARD[1], SYLVAIN MANGIAROTTI[1], PATRICK MARSALEIX[2], BAPTISTE MOURRE[1], IVANE PAIRAUD[2], CLAUDE ESTOURNEL[2], CHRISTIAN LE PROVOST[1]

[1]Pôle d'Océanographie Côtière (POC), Laboratoire d'Etudes en Géophysique et en Océanographie Spatiales (LEGOS), 18 av. Edouard Belin, F-31401 Toulouse Cedex 4, France
[2]Pôle d'Océanographie Côtière (POC), Laboratoire d'Aérologie (LA), 14 av. Edouard Belin, F-31400 Toulouse, France
[3]Laboratori d'Enginyeria Marítima (LIM), Universitat Politècnica de Catalunya, Jordi Girona, 1-3, Campus Nord-UPC, Edif. D-1, E-08034 Barcelona, Spain

The Pôle d'Océanographie Côtière in Toulouse is in the process of setting up specific advanced data assimilation tools to make use of both globally and locally available data in regional, open-boundary, free-surface numerical models at space scales intermediate between the global and coastal scales, and at time scales from hours to months. Our working domains include several different regions of the Mediterranean and Northeast Atlantic. This effort is conducted in the framework of the MFSTEP, GAMBLE and MERSEA European projects, ALBICOCCA project, JASON Science Team, as well as within national projects such as the MERCATOR Mission Group.

We run both finite-element 2-D ocean models and finite-difference 3-D ocean models. Our objective is to assimilate nadir altimetry as well as the "open ocean" data types in addition to locally available data such as tide gauges, ADCP, coastal radars and AXBT. Several categories of advanced multivariate estimation techniques are being developed and used: (1) Ensemble methods will play a central role in the preliminary exploration of the model error subspace and in the specification of assimilation statistics; (2) variational balanced analysis will be used in the downscaling of the larger-scale solution in the regional free-surface model and in the projection onto a suitable dynamical attractor akin to the well known "slow manifold"; (3) reduced-optimal interpolation using Ensemble statistics will drive the costlier models (e.g. high-resolution 3-D); (4) Ensemble Kalman filter and similar schemes will be used in studies involving highly non-stationary statistics and in the objective testing of observational networks.

Some specific objectives include the following:

- Study of the sensitivity of sea level, currents and other variables in 2D and 3D models to wind, atmospheric pressure and bathymetry errors, as well as the sensitivity to larger-scale errors through the open boundaries; test of different atmospheric products
- Study of the variability and dynamical balance of coastal currents and their interaction with shelves and plumes (Ebre, Rhône)
- Assimilation of available in situ and satellite data during regional observation campaigns; cross-validation of observations and models
- Test of the performance of future altimeter instruments configurations (such as OSTM); added value of tide gauges in the assimilation problem.

Beyond the central objective of a better knowledge of the coastal ocean, the tools developed here are expected to be useful for the design of future campaigns, permanent observational networks and satellite missions, and for the design of future Regional/Coastal Ocean Forecasting Systems (R/COFS) nested in systems such as MERCATOR, which are needed to address major environmental and societal issues in regional and coastal seas.

Hindcasts of North Atlantic circulation, 1991 to 2000: Preliminary results from a prototype Canadian operational ocean forecast system

ENTCHO DEMIROV[1], YOUYU LU[1,2], KEITH THOMPSON[1], DAN WRIGHT[1,2]

[1] *Department of Oceanography, Dalhousie University, Canada*

[2] *Ocean Sciences Division, Fisheries and Oceans Canada, Bedford Institute of Oceanography, Canada*

A group of government and university researchers has recently started work on an operational ocean forecast system for the North Atlantic with the capability of assimilating remotely sensed and in situ data. The dynamical circulation model is presently based on the Parallel Ocean Program (POP) with a horizontal resolution of $\frac{1}{3}^o$ in longitude/latitude and 23 levels in the vertical. The model domain includes the North and Tropical Atlantic Ocean (30^o S to 70^o N).

Following a 10 year spin up, during which time the model is forced by monthly mean winds and restored at the surface to observed monthly mean temperature and salinity, the surface forcing is computed from (i) daily mean NCEP momentum and heat fluxes, and (ii) the monthly mean precipitation data of [*Xie and Arkin*, 1996]. In addition, altimeter measurements of sea level are assimilated using the approach of [*Cooper and Haines*, 1996] which ensures conservation of local water properties. To overcome the common problem of model drift, and to provide a realistic background state that can act as an energy source for the growth of instabilities, "frequency dependent nudging" is used to ensure the model's climatology (as opposed to its instantaneous state) does not drift too far from an observed temperature and salinity climatology. One advantage of this form of nudging is that eddy variability with periods far from 1 year are not affected by the nudging and can evolve freely.

The system is run in hindcast mode for the period 1991-2000 and the results are evaluated through comparison with observed climatologies, maps of observed variability, and time series of coastal sea level and volume transport measured with submarine cable. The hindcast is also compared with results from similar studies carried out by other groups. The sensitivity of the hindcasts to the strength of the seasonal nudging, and the frequency bands over which it occurs, is evaluated. The presentation concludes with a demonstration of the performance of the system in forecast mode and a discussion of some of the new assimilation techniques that are being developed and tested.

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Department of Oceanography, Dalhousie University, Halifax, Nova Scotia Canada B3H 4J1

Sciences Division, Fisheries and Oceans Canada, Bedford Institute of Oceanography, 1 Challenger Drive, Dartmouth, Nova Scotia, Canada B2Y 4A2

Seasonal variability of tidal, non-tidal sea levels and atmospheric forcing along the west coast of India.

P.K. DINESH KUMAR

National Institute of Oceanography, India.

Analysis of long-term sea level data collected at adjacent ports along the west coast of India has been made to understand tidal and non-tidal variations. Amplitudes of the tidal harmonic constituents showed that M2 is maximum, followed by K1. A dominant spring neap variation and monthly variation in the semi-diurnal forcing was also seen. The Form Numbers indicated that the tides are of a mixed and predominantly semi-diurnal type. Though the amplitudes of most of the tidal constituents are slightly differ at each location, the sea level variation is dominated by the tidal signals. Seasonal variation of the amplitudes of the most important harmonic constituents namely O1, K1, M2 and S2 are presented. The mean spring and neap tidal ranges exhibited a higher degree of variability. The annual cycles of non-tidal sea levels were observed to be similar in characteristics. With most conspicuous changes during June and July caused by summer monsoon river discharge. The annual cycles of atmospheric forcing were also similar which showed that atmospheric pressure is not an important controlling factor on sea level. Analysis of sea level series pertaining to the premonsoon season indicated that the southern zones marginally lead the northern, suggesting the propagation of coastal-trapped waves from south to north. The cross-correlograms of the atmospheric pressure time series for the premonsoon and summer monsoon seasons suggest the mesoscale nature of the atmospheric pressure system.

Regional Centre, P.B. NO: 1616, Dr. Salim Ali Road, Cochin. 68 2014. India.

The GODAE High Resolution Sea Surface Temperature Pilot Project (GHRSST-PP)

C J DONLON[1]

[1]*The GHRSST-PP International Project Office, Met Office, Fitzroy road, Exeter, EX1 3PB, UK.*

The measurement of sea surface temperature (SST) in situ and using satellite sensors is arguably one of the most basic yet important oceanographic parameters and the production of near real time SST data products represents a fine example of operational oceanography. But, satellite-derived SST products are of varied heritage, assembled using many different approaches and algorithms having characteristic errors. Furthermore, sampling at different times of the day introduces regional and temporal biases associated with diurnal stratification of the upper ocean that are often ignored. A considerable duplication of effort is also evident as many groups in different countries derive their own SST data products. Fundamental challenges remain as the accuracy, sensitivity, and sampling resolution of global SST products are far from optimal.

The Global Ocean Data Assimilation Experiment (GODAE) high-resolution sea surface temperature pilot project (GHRSST-PP) has been established to give international focus and coordination to the development of a new generation of global, multi-sensor, high-resolution (~6 hours and 10 km), SST products that can address many of these issues. The aim of the pilot project is to:

"Ensure the provision of rapidly and regularly diffused, high-quality sea surface temperature products at a fine spatial and temporal resolution that meet the diverse needs of GODAE, the scientific community, operational users and climate applications at a global scale."

The GHRSST-PP is now fully established having a project office and five GHRSST-PP regional data assembly centres located in the EU, Autralia, USA, Japan and Frnace. Rather than improving individual satellite data streams, a fresh approach based on the fusion and combined analysis of complementary satellite and in situ measurements has been adopted by the GHRSST-PP. The combination of satellite and in situ SST data is one of great significance. Only by careful reference to in situ observations can satellite measurements attain the quality and accuracy required to confidently reveal the small signals associated with climate change and variability. GHRSST-PP SST data products will be derived by harnessing the unique strengths of separate data streams to alleviate the weakness of others. Quality controlled high-resolution products and analyises will be generated in real time for the benefit of data assimilation systems and will be freely and widely available.

This presentation reviews the current status of the GHRSST-PP which brings together international Space Agencies, Research Institutes, Universities, operational ocean forecasting agencies (civil and military) and Government agencies to collectively solve the scientific, logistical and managerial challenges posed by creating the SST data products and services within the GHRSST-PP.

REMARKS ON THE COASTAL VULNERABILITY INDEX

Efstratios Doukakis
Associate Professor
National Technical University of Athens

The natural environment is unequivocally the life support for all human systems. Far for being a luxury available only to those who can afford it, successful environmental management will increasingly become the basis for the success or failure of the economics and social systems of entire countries.
It has been estimated that around 60% of the world's population live near the coast and not surprisingly it is here that many problems are being experienced due to unrestricted development and unsustainable use of coastal resources. In addition to these problems, concern has recently been expressed about possible effects of climate change in coastal areas. By the year 2100 the rate of global sea level rise may increase to over 10mm/year (pessimistic scenario), which would represent a sevenfold increase over present rates. Local increases could be still greater, depending on local subsidence factors. The ability to identify areas vulnerable to future changes in local sea level as a result of local subsidence, erosion and sea level rise is necessary if a timely response is to be made to the rising sea.
The Coastal Vulnerability Index (CVI) may be used to identify areas that are at risk to erosion, permanent or temporary inundation by using six risk variables. Six different algorithms to calculate the CVI have been internationally proposed using the same classification of the six risk variables.
Twenty five coastal areas in the same Greek island have been incorporated to calculate all CVIs and their sensitivity to incorrect or doubtful risk parameters used. The coastal areas are with different orientation, length and inclination. It is proved that the promotion of the CVI has only very local and relative sense, the promoted algorithms are in fact highly correlated and the sensitivity to the incorrect data very high. It is concluded that it is necessary to alter and enlarge the classification of the risk parameters and to include more than the six ones adopted today.

Tidal assimilation in the Canadian Arctic Archipelago

FREDERIC DUPONT[T] AND DAVID GREENBERG

Coastal Oceanography,
Bedford Institute of Oceanography,
PO Box 1006,
Dartmouth, NS, B2Y-4A2, Canada.
E-mail: dupontf@mar.dfo-mpo.gc.ca
fax: (902) 426-6927

We assimilated coastal tidal observations into a finite element model of the Canadian Arctic Archipelago. The modelling system consists of a forward time-stepping nonlinear model and a linear harmonic inverse model that provides an incremental tidal correction to apply at the open boundaries in order to minimize the deviation between the predicted and observed elevation tidal constituents. The difficulties in this region are the small number of high quality observations, the seasonal presence of ice and the highly complex geometry of the archipelago. Errors for the main constituent M2 are therefore about 10 cm.

Forecast error study for the MERCATOR assimilation system: Estimation of the Fully Multivariate Multi-data Assimilation parameters.

H.Etienne, M. Benkiran

helene.etienne@mercator-ocean.fr

MERCATOR Project - CLS Space Oceanography Division
8-10 Rue Hermes 31526 Ramonville St Agne Cedex
fax: +33 5 61 393 782

MERCATOR is an operational ocean forecasting system. It is currently implemented in the North Atlantic based on a primitive equation OGCM (OPA) with 43 levels on the vertical and a 1/3° horizontal resolution, and the second version of a sequential data assimilation system based on Optimal Interpolation. Assimilation occurs every week on Wednesday, the model forecast being updated to reflect the newly collected near-real-time observations. The new assimilation system implemented in the operational system uses fully multivariate Empirical Orthogonal Functions (EOFs of T(z), S(z) and the barotropic stream function) to perform a Reduced Order Optimal Interpolation (ROOI). This system allows to assimilate simultaneously altimeter SLA, *in situ* temperature and salinity profiles and surface observation such as the Sea Surface Temperature (SST) and Salinity (SSS).

The ROOI is based on some simplification of the Extended Kalman filter formulation. The major simplification concerns the estimation of the forecast error covariance matrix **B** in the reduced space which is computed from forecast error variance and an empirical correlation function which takes into account spatial and temporal length scales, as well as anisotropy and phase speeds. Error variance in reduced space is kept as ratio of the variance explained by each the mode. Correlation radii are computed from the system output and the correlation function. The purpose of this work is to better estimate the **B** matrix parameterisation. Ensemble methods are known to significantly improve the estimation of error statistics. Ensembles of 50 members have been created with statistics corresponding to those of the correction bring by the first ROOI scheme implemented in the system (using only SLA altimetric data.) Ensemble forecasts over 28 days have been computed. We can show the strong difference in error growth depending both of the considered period and the physical field studied. But final spatial repartition of the error variance seems to be correlated to the signal spatial variation, as expected by the assumption made to compute the error variance in reduced space. Ensemble results are also used to study the spatial and temporal part of the correlation function. Error correlation radii are compared with those computed using model output.

A Observing and Forecast System of Hydrodynamic Properties and Water Quality for the Tagus Estuary

RODRIGO FERNANDES[1], PAULO LEITÃO[2], ÂNGELA CANAS[1], RAMIRO NEVES[3] , FRANK BRAUNCHWEIG[1], PEDRO PINA[1], J.J. DELGADO DOMINGOS[3]

[1]*MARETEC – Instituto Superior Técnico, Portugal*
[2]*Hidromod, Portugal*
[3]*Instituto Superior Técnico, Portugal*

For the management of estuaries is needed to have access to online data and also to organised records of historical data for analysing water quality events. Additionally, it is important the use of an adequate modelling tool to interpolate and assess the processes responsible for water quality. Following this context, in this paper is presented a observing and forecast system of hydrodynamic properties and water quality built for the Tagus Estuary, in Portugal, providing historical and real-time observations and daily predictions of several atmospheric and water conditions, including hydrodynamic and biogeochemical properties (e. g.: water level, currents, salinity, oxygen, phytoplankton), to users through an Internet interface (http://www.mohid.com/tejo-op).

The observing system comprises data from two automatic acquisition stations and field campaigns. One of the automatic data acquisition stations collects meteorological data, while the other station measures current meter data and several water properties (e.g.: turbidity, temperature, salinity, chlorophyll) in the Tagus mouth.

The forecast system is based in 3D hydrodynamic/water quality model MOHID (http://www.mohid.com). Because the model requires the online specification of boundary conditions (namely referring to the atmosphere, open sea, and river) this model is coupled with a meteorological model and a large scale hydrodynamic model. The meteorological model is based on the MM5 model and provides in the interface also daily results for final users (http://meteo.ist.utl.pt). The forecast system is aimed at satisfying several local users, permitting different detail levels in analysis, and thus a nested model approach is used, allowing the inclusion in the open boundary of large scale processes (e.g.: upwelling jet) and at the same time high resolution predictions. These small scale predictions are used in the outfall and beaches water quality monitoring along Costa do Estoril, helping to explain microbial field data results. In the case of the outfall, the fate of a plume of treated wastewater is done, predicting the near field (plume initial dilution and location) with a jet integral model and the far field with a Lagrangian 3D transport model forced by jet model conditions. Model predictions have also been helpful planning efficient measurement field campaigns. All results are validated with the observed data included in the system but also with tidal gauges, ADV data, synoptic CTD campaigns and data measured in Tagus in several research projects.

A policy for increasing the observation network is underway to improve the system's response ability to meet its users' needs.

[1] Taguspark, Núcleo Central, 363, 2780 – 920 Oeiras; rfernandes.maretec@taguspark.pt
[2] Taguspark, Núcleo Central, 349, 2780 – 920 Oeiras; paulo.chambel.maretec@taguspark.pt
[3] Av. Rovisco Pais, 1, 1096 - 001 Lisboa Codex; ramiro.neves@ist.utl.pt

Evolution of an ocean front in the north Balearic sub-basin

V. FERNANDEZ[1], R. ONKEN[2], A. JORDI[1], J. TINTORE[1]

[1] *IMEDEA(CSIC-UIB), Spain*
[2] *Institute for Coastal Research(GKSS), Germany*

Two consecutive oceanographic cruises (SOFTI and SOFTII) have been carried out in the north Balearic subbasin during September and October 2002. During those cruises, a sharp surface thermal front, which is the most prominent feature in the area (the so-called North Balearic Front), has been sampled in the hydrography and has also been observed by satellite imagery. The location and shape of this front and associated eddy like structures were found to evolve from the first to the second cruise within about two weeks. There is a net southward migration partly due to internal ocean dynamics and wind forcing.

In order to hindcast the frontal displacement, we have implemented the DieCAST diagnostic ocean model for a region including the SOFT cruise. The model is initialized from the hydrographic conditions of the SOFTI cruise using the Digital Filter Initialization technique, and then the model is driven with realistic wind forcing. A comparison of the evolution of oceanographic structures in the model with the 'reality' given by the observations of the second cruise is performed. To demonstrate the usefulness of data assimilation techniques for ocean predictions, we have in addition set up a primitive equations model (the Harvard Ocean Prediction System) for the same area and driven by the same atmospheric forcing. Comparisons of the results of both models will be presented.

[1]Max-Planck-Str, 1. 21502 Geesthacht (Germany) . Phone: +49-4152-87-1546

[2]C/Miquel Marqués, 21. 07004. Esporles, Baleares (Spain). Phone: +34-971-611732

The MERCATOR global ocean operational forecasting systems: first evaluation.

N. FERRY[1], E. RÉMY[1] , P. BRASSEUR[1] AND P. DE MEY[1]

[1] *MERCATOR-OCEAN, Toulouse, France*

In the framework of the MERCATOR project for operational oceanography, a global ocean forecasting system is being developed. It is composed of a 1/4° resolution model assimilating satellite and in situ observations, using an optimal interpolation scheme. This global forecasting system, Prototype d'Océan Global (POG) should be running in a pre-operational mode in mid 2004 during the GODAE period. In order to assess the feasibility, a lower resolution (~2°) configuration of the system, mini-POG, is also developed and is operated in near real time since November 2003.

Both configurations (POG and mini-POG) are based on the OPA8.2 ocean model [*Madec et al.*, 1998]. The 2° configuration (the mini-POG model) is the standard global configuration (ORCA2) developed at LODYC (Paris). The assimilation method used is the reduced-order optimal interpolation (OI) scheme SOFA [*De Mey and Benkiran*, 2002] which is able to incorporate both altimeter and in situ observations. Up to now only the sea level anomaly (sla) from altimetry (Topex-Poseidon, ERS2, GFO, Jason & ENVISAT) measurements along tracks is assimilated with an univariate mode. The 2D increments of sla are converted into 3D increments of T, S, U, V and TKE coefficients using an algorithm based on the lifting-lowering method of *Cooper and Haines* [1996].

Here we present the results obtained with mini-POG. Using this light configuration of the Mercator global assimilation system we have performed a 10 year long simulation (1993-2002) with weekly oceanic analyses. This oceanic reanalysis is instructive in so far as it exhibits the large scale performance that is expected from the higher resolution system. The mini-POG system is rather efficient in capturing the extra tropical large scale signals whereas the simple assimilation scheme used is unable to analyze the complex horizontal and vertical baroclinic structures near the equator. Evaluation of the system is done through comparisons with independent *in situ* observations.

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[1] MERCATOR-OCEAN, 8/10 rue Hermès, Parc technologique du canal, 31526 Ramonville St Agne, France. E-mail : pog@mercator-ocean.fr .

"The ECCO Routine Global Ocean Data Assimilation System: Budget Closure and an Effective Approximate Kalman Filter and Smoother"

Ichiro Fukumori

Jet Propulsion Laboratory, California Institute of Technology

The Consortium for "Estimating the Circulation and Climate of the Ocean" (ECCO; http://www.ecco-group.org) has established a global ocean data assimilation system. The ECCO system produces regular analyses so as to monitor global ocean circulation and to better understand processes underlying the ocean's seasonal-to-interannual changes. The assimilation system is based on a near-global primitive equation model of high resolution (1-deg telescoping to 0.3-deg with 10m near surface layers) and assimilates measurements from satellite altimetry (TOPEX/POSEIDON, Jason-1) and in situ hydrography (XBTs, moorings, floats, and climatology) using a Kalman filter and smoother.

The ECCO assimilation system is noteworthy in its products' physically consistent temporal evolution and its novel approximations of assimilation. Because of data corrections, the temporal evolution described by many data assimilation systems is often physically inconsistent. For instance, heat and other property budgets cannot be closed, limiting the utility of the analyses. A solution to these deficiencies is smoothing that not only optimizes the model state but also provides direct estimates of sources of model errors that give rise to the inconsistencies.

The ECCO system employs a hierarchy of approximations that permit application of Kalman filtering and smoothing to arbitrarily large models. These approximations include partitioning the estimation problem into smaller manageable pieces and combining the results together. These and other approximations and the issue of consistency and budget closures will be discussed, drawing examples from applications of the ECCO assimilation system.

Data assimilation used in numerical simulations of laboratory experiments in a rotating stratified fluid

M. GALMICHE, J. SOMMERIA, E. THIVOLLE-CAZAT AND J. VERRON
LEGI, Grenoble, France

Data assimilation is used to couple numerical simulations and laboratory experiments of fluid flows in a stratified, rotating fluid. The experiments are performed on the large Coriolis turntable (Grenoble) and the simulations are performed with a multi-layer shallow water model. Assimilation of velocity measurements drives the numerical model close to the experimental flow and provides an estimation of all the flow variables at each time and each point. The large dimensions of the turntable (13m diameter) enable oceanic processes to be reproduced with a good level of similarity.

The use of data assimilation for experimental purposes is a novel technique and has many applications. First, the combined experimental and numerical data provide a complete and realistic description of the flow. In particular, potential vorticity can be computed, a quantity that is generally impossible to measure but which is crucial to a better understanding of rotationg layered flows. The obtained flow field can also be used as an initial condition to test the numerical model. This makes it possible to quantify the systematic forecast errors. Lastly, the properties of the assimilation scheme can be analysed in details, in particular when only a reduced set of data is assimilated. For instance, it is possible to test the accuracy of the assimilation scheme when only surface data are available. This is clearly of practical interest because vertical extrapolation of the measured surface quantities is a great challenge in oceanography.

To illustrate this, some results on the baroclinic instability of a two-layer vortex are presented. To generate the vortex, a cylinder is introduced across the interface of the two-layer fluid in a rotating frame, the interface is displaced inside the cylinder and the cylinder is removed at t=0. After a short adjustment period, a vortex is formed which, when unstable, undergoes baroclinic instability and splits into two or more new vortices. The velocity field is measured with high precision and resolution in both layers using Particle Image Velocimetry. Numerical simulations are performed using a two-layer, shallow-water model (Miami Isopycnic Coordinate Ocean Model [*Bleck & Boudra*, 1986]) and data assimilation of the experimental velocity data is used to drive the model close to reality. The assimilation scheme is a Kalman filter similar to the sequential SEEK filter (Singular Evolutive Extended Kalman filter [*Pham et al.*, 1998]) used in real-scale simulations of the ocean. In this example, it is possible to identify model errors as weak as those due to the hydrostatic approximation of the shallow-water model.

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Laboratoire des Ecoulements Gophysiques et Industriels, BP53 ,38041 Grenoble CEDEX 9, France.

Monitoring of the Coastal Circulation in the Northern Part of the Western Mediterranean Sea using nested models.

Valérie GARNIER*, Gael ANDRE and Pierre GARREAU
IFREMER, DEL/AO, BP70, 29280 Plouzané, France

Valerie.Garnier@ifremer.fr

Gael.Andre@ifremer.fr

Pierre.Garreau@ifremer.fr

The coastal circulation in the North Western Mediterranean Sea results both from the global basin circulation and from the local forcings as wind, buoyancy fluxes, river discharges and bathymetry. Monitoring such a coastal circulation needs to manage a very large range of temporal and spatial scales. Operational results can be performed using a chain of nested models.

The finest grid model (about 1km) covers an area extending from the Balearic Front to the Gulf of Lions and the Ligurian Sea. At open boundaries, the large scale forcing results from an Ocean Global Circulation Model. These embedded models are operational and supply boundaries conditions for local studies (as a bay). Inside the finest model, smaller scale processes can be simulated using a « two way » zoom.

The modeled coastal circulation is evaluated by comparisons with available data - sea surface temperature, ocean color, current velocity, altimetry… - and by diagnostic analyses - transports through the Corsica Channel, computed geostrophic flows...-. Attention has been paid to the behaviour of the North Current, the plume of the Rhône and the local intermittent upwellings. Such processes have very short time and spacial scales and they are very usefull for the model assesment. In coastal area, a precise knowledge of the wind is necessary. Then, the sensitivity to the atmospherical forcing has been investigated.

The evaluation of such a hindcast experiment is a first step towards an operationnal coastal modelling system in an area widely opened to a large scale crculation and to local meteorological forcings. This offers a valuable test case for the devellopement of two way zooms, open boundary conditions and coupling techniques.

* current affiliation : Rosenstiel School of Marine and Atmospheric Science (RSMAS), 4600 Rickenbaker Causeway, Miami, FL 33149-1098 USA. vgarnier@rsmas.miami.edu

Regional Modelling for the POMME Experiment : an Openboundary Implementation of HYCOM with Data Assimilation for Process Studies and Operational Ocean Forecasting

M. GAVART, M. ASSENBAUM AND R. BARAILLE
SHOM/CMO/BRESM, France

The regional version of the primitive equation model HYCOM has been implemented in an open ocean zone overlaying the POMME experiment area in the north east Atlantic. The goal is to provide a dynamic modelling tool with data assimilation for high resolution realistic simulations of physical oceanic processes. The simulations can be either of short duration (one or two months) for fine process studies like eddies interactions, or on a routine basis with nesting into an operational basin model like MERCATOR. The latter case allows to study the annual cycle of mode water mass formation in the POMME area, as well as to perform operational high resolution ocean forecasts useful for the management of scientific cruises. A similar work has been done in near real-time during the POMME experiment in 2000 and 2001 using a regional configuration of the OPA model nested into the operational MERCATOR model, and provided forecasts to the on-ship scientific team. The forecasts were taken into account for design of the sampling strategy. The present work benefits from the experience gathered during this real-time exercise.

Thanks to a proper openboundary treatment, the model can be nested either in hydrological analyses from observation arrays or in time varying fields from a basin model for longer integrations. Since the extend of the modelling area is relatively small (from 500 to 1500 km), the initial dynamical state can be conveniently provided by geostrophy.

Daily atmospheric fluxes are used to force the model. The fluxes include latent and sensible heat, solar and non solar fluxes, and the hydric balance. These fields are provided by the ECMWF Center. Either analyses or forecasts are used, depending on availability.

Multi-data assimilation (altimetry, SST and in situ hydrological profiles) is performed in order to improve the realism of the simulations. The different data sets are assimilated using optimal interpolation technique into separate reduced order subspaces orthogonal to each others. We discuss the different arbitrary choices done for the subspaces and show how the present work is an introduction to implement more optimal assimilation techniques.

The results of the POMME simulations are used to validate the nested regional model approach in a realistic case. The coherence between the regional and large scale fields is investigated, and special attention is given to the behaviour of the model in the vicinity of the model boundaries.

The properties of the model eddy field are studied using eulerian and lagrangian diagnostics and compared to the numerous high quality observations made by the ships during the POMME cruises as well as by drifting and moored instruments. The vertical structure of the velocity field in the model is compared to observations including several current meter moorings, not only in a statistical way, but also with repect to some specific well-identified mesoscale structures such as eddies and frontal areas. The evolution of these structures in the model and how they are affected by data assimilation give hints on apparent shortcomings of sequential assimilation. The expected impact of improved data assimilation techniques, and some diagnostic methods useful to quantify the benefits of assimilation are described.

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LEGOS/BRESM, 14 avenue E. Belin, 31400 Toulouse, France.

AN INTERCOMPARISON STUDY BETWEEN SOAP P2 AND MERCATOR FOR NAVY END-USERS APPLICATIONS

SYLVIE GIRAUD SAINT-ALBIN [1] AND DIDIER JOURDAN [2]

[1] *CLS, Space Oceanography Direction, France*
[2] *Centre Militaire d'Océanographie, France*

For the last 10 years, the CMO/BRESM has been conducting the operational R&D System for Ocean Analysis and Prediction Program (SOAP). SOAP's goal is in supporting sea activities, Navy Operations in particular, with high resolution mesoscale ocean nowcast and forecast products. This program's incremental development strategy has generated successive prototypes of increasing complexity. These prototypes were operated and improved upon in tandem with a continuous re-evaluation of Navy needs. The experience feedback has been collected by conducting real-time demonstration experiments in collaboration with both military and civilian oceanographic research campaigns. This strategy has played a key role in defining the concept of "real-time integrated oceanography" which relies on remote and in situ ocean observations, (a hierarchy of) ocean models and data assimilation.

The military motivation for developping new prototypes is to extend the application domain of SOAP operational products from the **operative** (~ a description of the synoptic scale) to the **tactical** (~ a tailored product to strategic needs) relevance. In order to fulfill this user's requirement, a new strategy has been defined for the next SOAP P3 prototype, which would be definitely "multi-model" (taking advantage of the emergence of an increasing offer external operational ocean model outputs), "multi-scale" (developing a cascade of nested high resolution ocean models for regional/coastal/littoral purposes) and "interdisciplinary". But the computation of Navy-end users' products (operational conditions for anti-submarine warfare and amphibious warfare) would be based on a unique reference hydrographic situation.

Current SOAP P2 system is as a transition system pulled by end-user's requirements and designed by research oceanographers from existing tools and models. It has the goal to demonstrate the feasibility and the relevance of Navy end-users' products (ambient noise, acoustical impact, tactical aid indicators (surface duct conditions, surface to bottom conditions)) that constitute in practical the core of the Oceanographic Forecast Bulletin.

This paper focuses on the comparison between the products derived respectively from SOAP P2 System and from MERCATOR Prototypes. The acoustical modelling will be performed on the hydrological situation provided by internal SOAP ocean assimilating model, but also by MERCATOR high resolution ocean model in real-time conditions on a weekly basis.

The analysis of the preliminary results would help us to define how to complete the production by critical diagnostic quantities (in SOAP P2 and in MERCATOR) as well as by error bars on the estimated variables for validation purposes in the metrics of the products for military applications. This inter-comparison is a first attempt to assess the end-users' products reliability.

Recovery of North-East Atlantic temperature fields from profiling floats: determination of the optimal float number from sampling and instrumental error analysis

D. GOMIS[1], S. RUIZ[1] AND J. FONT[2]

[1]*Cross-Disciplinary Oceanography Group, IMEDEA (CSIC-UIB), Mallorca, Spain*
[2]*Physical Oceanography Group, Institut de Ciencies del Mar - CMIMA (CSIC), Barcelona, Spain*

Argo is an international project that is deploying an array of temperature and salinity profiling floats over the global ocean. The design of the Argo array is a balance between scientific requirements and the practical limitations imposed by present technology and resources. This study intends to provide some guidance on the number of floats that would be required for an optimal recovery of the temperature field (at scales larger than 500 km) in the North-East Atlantic Ocean.

We use the error formulation derived from Optimal Statistical Interpolation to obtain statistical errors, i.e., those that would be obtained by averaging errors over a very large number of different temperature fields having in common a set of prescribed statistical properties. In addition to producing total error values, we split them into the contribution attributed to instrumental errors (hereafter 'observational errors') and that derived from the station distribution (hereafter 'sampling errors'). The comparison between the two contributions will help to decide, for instance, between putting the efforts in increasing the number of floats or in improving their accuracy (provided both initiatives were equally possible).

Results indicate that with the present distribution of floats (119 in the considered domain), scales larger than 500 km can be recovered with a relative uncertainty (rms error relative to the standard deviation of the field) of about 7% at 50 m, 8% at 200 m and 10% at 1000 m. This corresponds to mean absolute errors of $0.111°C$, $0.104°C$ and $0.073°C$ respectively.

The splitting of total errors into instrumental and sampling contributions reveals that, in the present scenario, errors are more due to the small number of floats than to observational errors, specially at upper levels. For scales larger than 500 km this will hold true until 200-250 floats are deployed (less than 200 for deep levels). In such simulated scenario, the number of observations and the technology would become approximately equally limiting factors for the accuracy of the temperature field mapping, with total relative errors of less than 2% at upper levels and of about 3% at 1000 m. Beyond this point, a very large number of floats would be required to (slightly) decrease the errors associated with these scales (so that it would only make sense in case of focusing the recovery on smaller scales).

Cross-Disciplinary Oceanography Group, IMEDEA (CSIC-UIB), c/ Miquel Marqués 21, 07190, Esporles, Balearic Islands, Spain

Operational systems and research improvement for monitoring Mediterranean Pollution: from RAMSES to CLEOPATRA.

BERNARDO GOZZINI[1], ALBERTO ORTOLANI[1], CARLO BRANDINI[1], GRAZIANO GIULIANI[1], ANDREA ORLANDI[1], BERTRAND DE HAUTECLOQUE[2], ANTON MICALLEF[3], MATTHEW RYMMEL[4].

[1] CNR-Ibimet LaMMA, Italy
[2] EADS S&DE - [3] IcOD, Malta
[4] BMT, UK

Harmonisation of sea pollution monitoring activities in the Mediterranean Sea, designed from the beginning for an international utilisation, has been recently recognised as a fundamental problem, because of the crucial position of this area from a socio-economic point of view, and for its remarkable biodiversity features. The emerging use of remote sensing data for the surveillance of wide geographic areas has been successfully demonstrated in a number of previous EC funded projects such as RAMSES and VASCO. An operational system has been implemented and tested during these projects, where the satellite images are captured, then processed with help of an operator (in order to find oil spills in them) and finally, in case of detection, products containing information about the spill are merged with meteorological and ocean status forecasts to be sent to the users. CLEOPATRA (ChemicaL Effluent & Oil Pollution Alert and TRAcking) is a R&D project funded by the EC DG Research, addressing the problem of reliable detection, classification and displacement forecasting of Sea Pollution, in order to support sustainable monitoring activities, risk mitigation actions and a more effective enforcement of the international conventions in the area of marine environmental protection. The innovative features of CLEOPATRA comes from both methodology and technology: CLEOPATRA wants to achieve a fully integrated approach of state-of-art models and pollution detection methods, focusing on an optimised coupling of atmospheric, wave and hydrodynamic models in order to understand which physical quantities exchanged among the different environment described by models are critical for the final model chain performances, and to resolve scales that can be relevant to drive spilling models. Moreover the possibility to exploit EO multi-sensor data from the new satellite platforms, fused with other sources of data, is investigated inside the project. Through the integrated use of Space Technologies, Meteo/Ocean Scientific algorithms and slicks forecast modelling, CLEOPATRA will improve and update the capability of the RAMSES system to detect spills (oil and other pollutants), forecast slicks propagation, and to assess coastal and marine environmental impact. A state-of-the-art of the RAMSES-CLEOPATRA system and relative results will be shown at the meeting.

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[1] Laboratorio per la Meteorologia e la Modellistica Ambientale, via Madonna del Prato Edificio D, 50019 Sesto Fiorentino, Italy. gozzini@lamma.rete.toscana.it

[2] EADS S&DE, 6 rue Dewoitine, BP 14, 78142 VELIZY-VILLACOUBLAY cedex, France.

[3] Euro-Mediterranean Centre on Insular Coastal Dynamics(ICoD) University of Malta, St. Paul Street, Valletta, Malta

[4] British British Maritime Technology Cordah Ltd. Grove House, 7 Ocean Way, Ocean Village, Southampton, Hampshire, SO14 3TJ, UK.

Data Assimilation and Ocean Forecasting in the Adriatic Sea.

ANITA GREZIO[1],NADIA PINARDI[2],PAOLO ODDO[2],ALESSANDRO COLUCCELLI[1],MARCO ZAVATARELLI[2]

[1]*INGV-Istituto Nazionale Geofisica e Vulcanologia, Italy*
[2]*Università di Bologna, Italy*

The circulation in the Adriatic Sea is characterized by 3 gyres and two coastal currents one on the eastern coast from the Otranto Strait to the North Adriatic and the other on the western coast from the North Adriatic to the South Adriatic, which is particularly affected by the Po river run off. Moreover, dens water formation occurs a) in the Northern Adriatic due to an intense surface cooling and subsequent sinking along the continental shelf and b) in the Southern Adriatic due to the open sea-like vertical convection. Pure modeling simulations do not allow a complete understanding of the complex air-sea interactions. Data assimilation can improve the representation of the ocean processes by optimally combining a dynamic model and in situ data and provides better initial conditions for weekly coastal ocean forecasting.

The ADRICOSM project (ADRIatic sea integrated COastal areaS and river basin Management system pilot project) is the innovative application of data assimilation to a forecasting system in the coastal areas. Both large scale and coastal data sets are utilized efficiently in a data assimilation scheme that uses sequential estimations to prepare initial fields for subsequent forecasts.

The large scale observing system is based on the Sea Surface Temperature (SST) which is available daily and it is used for the surface heat fluxes corrections. The coastal observing network is localized in 4 regions: the Emilia Romagna Coast, the Golf of Trieste, the Slovenia Coast and the Croatian Coast. In addition, XBT temperature profiles up to 900 m depths are collected along two VOS tracks (Voluntary Observation Ships track between Ploce-Malta and Split-Bari) which are complementary to the coastal monitoring network.

The Adriatic Model is POM (Princeton Ocean Model) [Blumberg and Mellor, 1987] implemented by Zavatarelli et al (2002) for the Adriatic Sea. The model has a horizontal resolution of 5 km and 21 layers in the vertical, high frequency forcing, daily Po river run off and monthly heat fluxes. The interface between the Mediterranean Ocean model and the Adriatic fields permits the selection of the lateral boundary (T, S, u, v) during the assimilation and the forecasting.

The data assimilation is carried out using SOFA (System for Ocean Forecasting and Analysis) [De Mey and Benkiran,2000] which is a multivariate reduced-order optimal interpolation method. Salinity and Temperature coming from CTD stations and XBT tracks are assimilated. The system is improved because of the sequential assimilation of multivariate parameters (T, S profiles from CTD) and univariate parameters (T profiles from XBT). The Adriatic model is efficiently corrected during the date assimilation using a coordinate transformation from sigma to z and *vice versa*.

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[1] INGV, Via D.Creti, 12,40128 Bologna, Italy.

[2] Corso di Scienze Ambientali, Piazza J.F. Kennedy 12, 48100 Ravenna, Italy.

Predictability of Lagrangian particle trajectories: effects of uncertainty in the underlying Eulerian flow

by

Annalisa Griffa [12] , Leonid I. Piterbarg [3] , Tamay M. Ozgokmen [2]

1. RSMAS/MPO, University of Miami, Miami, Florida, USA
2. Consiglio Nazionale Delle Ricerche, ISMAR, La Spezia, Italy
3. Center for Applied Mathematical Sciences, University of Southern California, Los Angeles, California, USA

The increasing realism of ocean circulation models is leading to increasing use of these Eulerian models as basis to compute transport properties and to predict the fate of Lagrangian quantities. There exist, however, a significant gap between the spatial scales of model resolution and that of forces acting on Lagrangian particles. These scales may contain high vorticity coherent structures that are not resolved due to computational issues and/or missing dynamics but are typically suppressed by smoothing operators.

In this study, the impact of smoothing of the Eulerian fields on the predictability of Lagrangian particles is first investigated by conducting twin experiments that Involve release of clusters of synthetic Lagrangian particles into ``true'' (unmodified) and ``model'' (smoothed) Eulerian fields, which are generated by a highly nonlinear QG model. The Lagrangian errors induced by Eulerian smoothing errors are quantified by using two metrics, the difference between the centers of mass of particle clusters, D, and the difference between scattering of particles around the center of mass, S. The results from QG experiments show that changes in the flow field induce significant errors in D, whereas S errors are much lower.

The QG results are then compared to results obtained from a multi-particle Lagrangian Stochastic Model (LSM) which parameterizes turbulent flow using main flow characteristics such as mean flow, velocity variance and Lagrangian time scale. In addition to numerical results, also theoretical results based on the LSM are considered, providing asymptotics of D, S and predictability time. It is shown that both numerical and theoretical LSM results provide a good qualitative description, and a reasonable first-order quantitative estimate of results from QG experiments. Given estimates of several observable parameters, and the simplicity of implementation, the multi-particle LSM therefore appears to be a promising avenue to provide guidelines for predictability estimates in realistic ocean flows.

Combining satellite and in-situ T/S profile data to better estimate the 3D thermohaline fields

STEPHANIE GUINEHUT, GILLES LARNICOL, PIERRE-YVES LE TRAON

[1]*C.L.S., Ramonville, France.*

Our ability in describing and understanding the ocean vertical structure strongly depends upon the availability of oceanic observations. On the one hand, temperature (T) and salinity (S) profiles measurements from eXpendable BathyThermograph (XBT), Conductivity Temperature Depth (CTD) probes and profiling floats (P-ALACE, APEX, PROVOR) provide sparse in-situ data but with precise estimations of the ocean vertical structure. Apart from specific regions of interest, theses measurements are from far not sufficient to depict the three dimensional structure of the ocean variability over the world ocean. On the other hand, satellite altimetry provides synoptic observations of sea level over the world ocean. Despite sea level being a surface signal, it reflects the state of the ocean at depths and makes satellite altimetry a powerful tool for studying global ocean dynamics and thermodynamics. The objective of this study is to merge the accurate but sparse in-situ T/S profiles data with the high spatial coverage given by altimeter and SST measurements (as synthetic T/S profiles, deduced from statistic relationship between historical sea surface height, SST and T/S fields) to better estimate the 3-D thermohaline fields. The merging approach uses an optimal interpolation method that takes into account analyzed error on the observations and particularly correlated errors on the altimeter and SST measurements. Results show that the optimal combination is instrumental in reducing the aliasing due to the mesoscale variability and in adjusting the analyzed fields to the in-situ fields. The ability of the merging method to describe the 3-D thermohaline structure of the upper North Atlantic Ocean is also analyzed.

[1] *C.L.S., Space Oceanography Division, 8-10 rue Hermes, 31526 Ramonville Cedex, France.*

The impact of Argo and altimeter data on the FOAM system

ADRIAN HINES, MATT MARTIN AND MIKE BELL
Met Office, UK

The Forecasting Ocean Assimilation Model (FOAM) run at the Met Office is an operational deep ocean forecasting system that runs daily in real-time. The system assimilates both satellite and in situ data and produces forecasts of deep ocean parameters out to 5 days ahead. The system uses a hierarchy of nested models to allow high resolution model configurations to be run for various limited area domains.

The FOAM system has been used for an investigation into the impact of the altimeter sea surface height data and the Argo temperature and salinity profiles on the quality of the ocean analyses and forecasts. Year-long integrations assimilating all the data have been carried out in a 1/9° North Atlantic model and a 1/18° model of the Intra-Americas Seas, and output has been used to initialise monthly forecast runs out to 30 days ahead. The year-long integration and forecast runs have then been repeated with the Argo profiles and the altimeter data each withheld in turn. The impact of withholding the data on the quality of the analyses and the forecast skill of the system has been assessed.

This paper will describe the experiments carried out, and will discuss the impact of the Argo temperature and salinity profiles and the altimeter sea surface height data on the analyses and forecasts produced by the FOAM system.

Met Office, FitzRoy Road, Exeter, Devon, UK, EX1 3PB.

Operational Ocean modelling for the NW European shelf: NOOS - the NW Shelf Operational Oceanographic System

MARTIN HOLT[1], AND NOOS STEERING GROUP

[1]Met Office, FitzRoy Road, Exeter EX1 3BP United Kingdom

EuroGOOS initiated the NW European Shelf Seas Task Team in 1996, with members from operational agencies around the NW shelf. Through discussions during ESODAE meetings, an exchange of storm surge forecast data for selected locations around the North Sea coast was set up, from December 1999. This daily exchange of data by ftp-boxes continues.

During 2000 and 2001 the task team began to formulate a plan for a NW shelf Operational Oceanographic System "NOOS", closely modelled on the successful BOOS activity in the Baltic, and the NOOS Strategic Plan was published in November 2001. The task team continued to draft a Memorandum of Understanding for NOOS, which was finalised by summer 2002.

A NOOS kick-off meeting was held at RIKZ, Den Haag in September 2002, with nine agencies signed up, and more interested. A steering group was appointed, chaired by Martin Holt, and a NOOS website is being prepared, hosted by DMI in Copenhagen. NOOS will be implemented through self-funded projects. The first NOOS projects are data exchange for sea level observations, building on the successful storm surge forecast exchange, and NOOS-ESODAE1 which will set up an exchange of boundary data for nested modelling of the North Sea coasts. NOOS members are participating in preparing proposals for FP6, and have links with the ICES North Sea Pilot Project (NORSEPP) for nowcast ecosystem modelling.

Variational Data Assimilation with an Eddy-Resolving Model of the Tropical Pacific Ocean

I. HOTEIT, B. CORNUELLE, A. KÖHL
Scripps Institution of Oceanography, La Jolla, USA

D. STAMMER
Institut füer Meereskunde, Hamburg, Germany

A data assimilation system has been developed for the tropical Pacific Ocean. This system makes use of the method of Lagrange multipliers (adjoint method) to adjust the MIT ocean general circulation model to available observations in the tropical Pacific region.
The model used is a realistic primitive equation model of the tropical Pacific Ocean extending from $26°$S to $26°$N and from $104°$E to $68°$W with $1/3°$ degree horizontal resolution, 39 vertical layers, and includes parameterizations for the surface boundary layer (KPP). The model was forced with the NCEP atmospheric re-analysis. Open boundaries are prescribed at $26°$S and $26°$N, as well as at four straits in the Indonesian throughflow. The assimilation method is based upon the adjoint method, in which the adjustable parameters (controls) include the initial temperature and salinity conditions, temperature, salinity and horizontal velocities at the open boundaries and the time-dependent surface fluxes of momentum, heat and freshwater.
In a first experiment, the model was constrained with Levitus temperature and salinity data, Reynolds sea surface temperature data and Topex/Poseidon and ERS altimeter data. The hindcast experiments that have been performed in 1998 demonstrate that the adjoint method can be efficiently used to bring the model into consistency with data despite difficulties related to the chaotic nature of an eddy-permitting model.

Scripps Institution of Oceanography, Nierenberg Hall, 8810 Shell Back Way, La Jolla, CA, 92037 - USA.

A multi-platform OI scheme for SST based on a spatial-temporal covariance model

J. L. HØYER AND J. SHE
Danish Meteorological Institute, Denmark

An optimal interpolated sea surface temperature (SST) product has been constructed for the year 2001 for the North Sea and the Baltic Sea. Two satellite products (O&SI SAF and BSH) are used for the analysis together with a large amount of in situ observations ($\sim 10^5$). All data are quality controlled and the skin SST from the polar orbiting NOAA satellites are adjusted to bulk SST using the in situ observations. Comparisons between satellite and in situ data reveal a satellite measurement error of $\sim 0.6 - 0.7°C$ with interesting spatial variations. The temporal and spatial (x,y) covariances for 100-200 km regions show significant differences throughout the study region. Small correlation scales are found in the northern North Sea whereas longer scales are found in the Central North Sea and in the northern and eastern Baltic Sea.
The covariance models fitted to the satellite results are used in a multi-platform Optimal Interpolation (OI) scheme that accounts for the different noise characteristics on the satellite and in situ observations. A daily/weekly 10'×6' gridded bulk SST product is produced for the year 2001, based upon in situ and satellite data. The error statistics of the interpolated product will be analysed and independent in situ observations used to validate the OI product. In addition, the satellite error covariance will be estimated from comparisons with spatial covariances calculated from repeated ship of opportunity lines.
Finally, elliptical spatial SST covariances will be presented and the regions with largest influence identified.

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Danish Meteorological Institute, Lyngbyvej 100, DK-2100 Copenhagen Ø, Denmark, jlh@dmi.dk

Assessment of wind stress errors using bias corrected ocean data assimilation

M. R. HUDDLESTON[1 1], M. J. BELL[1], M. J. MARTIN[1], N. K. NICHOLS[2]
Met Office, Exeter, UK

Current seasonal forecasting methods make extensive use of wind stress products to produce ocean analyses for retrospective forecasts. The combination of inaccurate wind stress forcing and relatively accurate ocean thermal profile observations can have significant detrimental impacts on the analysis in equatorial regions as it leads to an imbalance between the zonal pressure gradient and wind stress. Model integrations have been performed to assess various wind stress products using a Pacific region ocean general circulation model in three assimilation modes. The assimilation of thermal profile data has been shown to negatively impact the zonal and vertical current structure. A bias correction scheme has been used to both illustrate how these errors can be mitigated. The method used to correct for these systematic errors, as presented in Bell et al. (2003), allows for the errors to evolve in time and space. Although the strength of the equatorial undercurrent is brought to a realistic level, the scheme does reduce its variability. The ERS scatterometer wind products have been used to illustrate the methodology and comparisons have been drawn with several other wind stress products.

[1] Met Office, FitzRoy Road, Exeter, EX1 3PB [2] University of Reading, Dept. of Mathematics Reading, UK

Assimilation of “Ocean Color” data into a coupled 3-D hydrodynamical-ecological model of the Bay of Biscay continental shelf

M. HURET[1], F. GOHIN[1] AND V. GARÇON[2]

[1]*IFREMER, Centre de Brest, France*

[2]*LEGOS, CNRS, Toulouse, France*

The hydrodynamical MARS-3D model is coupled with an ecological model and a simple deposition-erosion formulation for particulate matter over the Bay of Biscay continental shelf. The hydrodynamical model resolves the complete set of primitive equations, and is forced with tide, river discharges, and winds from the ARPEGE model from Météo-France. The ecosystem model describes the evolution of 14 state variables corresponding to the major components of this system. We consider that three nutrients : nitrogen, phosphorus and silicon may limit primary production. Solar radiances for heat fluxes calculations and light availability are derived from hourly METEOSAT data provided by Météo-France.

Recent evolutions of “ocean color” satellite derived products over coastal areas provide us with useful information on ocean surface biological and physical states. Using an empirical algorithm developped with SeaWiFS data over the french Atlantic coast, estimation of chlorophyll *a* and non-organic Suspended Particulate Matter (SPM) concentrations become more reliable.

Our goal is to use this surface information to improve our knowledge on the light limited late winter and spring phytoplankton blooms. The occurrence of these blooms mainly depends on the mixed-layer depth and on SPM concentration, which reduce the light available to the phytoplanktonic cells. The former process is resolved by the hydrodynamics, whereas SPM concentration is a state variable of our coupled model which can potentially be constrained by SeaWiFS data.

In this context, the assimilation scheme consists in the use of a global optimization method (the Evolution Strategies), for retrieving different parameter values of the biological and sedimentological models. First, SPM satellite data are used to improve the scarce information we have on river particulate load, and to assess the sinking rate of particles. Then, given the improved SPM concentration estimation, the evolutive method is used to optimize some parameter values of the ecological model from Chlorophyll *a* satellite data. The method is tested with twin experiments to assess which parameters are the most sensitive to surface simulated data. These parameters are then optimized from true satellite data, for a better simulation of the late winter and spring blooms.

Département d’Ecologie cotière, IFREMER Centre de Brest, BP 70 29280 Plouzané, France

Quality control of ocean profiles - historical and real-time data

BRUCE INGLEBY AND MATT HUDDLESTON
Met Office, Exeter, UK

Data assimilation combines observations and a prior estimate of the ocean state to provide initial conditions for an ocean or atmosphere-ocean forecast. Quality control is an important part of the data assimilation process so that erroneous or unsuitable data are not assimilated. Gross errors can affect whole reports (eg position errors) or individual values (eg spikes). Note that even 'good' observations have small errors, usually taken to be normally distributed, and that additionally they may sample features that are too small for the model to represent.

The Met Office ocean quality control system was completely rewritten in 2002/03 and now forms a robust and effective automated system for both historical and real-time data. All types of temperature-salinity profiles - bathythermographs, CTDs, moored buoys and ARGO floats - are processed. If necessary vertical thinning is used to reduce the number of levels to 150, while still retaining good resolution near the surface. Various diagnostics and displays were developed in order to validate and tune the system. There are checks of internal consistency of both ship tracks and individual profiles (spike and stability checks), a correction for XBT fall-rates and optional super-obbing of buoy data. Then there is a comparison with prior estimates of the T-S values - known as background values and either taken from climatology or (better) from a previous ocean forecast. Bayesian probability theory is used to calculate the Probability of Gross Error in individual values, both by direct comparison with the background (the background check) and comparing differences from background with those from other nearby observations (the buddy check). This requires estimates of observation and background error covariances - also used in the main data assimilation algorithm. Typically a few percent of the data are rejected, there is also optional thinning in data dense areas.

The quality control system was developed as part of the EU-supported ENACT project and has been used to process data from 1958 to the present which were then distributed in NetCDF format to all the partners in the project. After each month's data has been processed an analysis is performed and 0.9 times the anomaly is added to the next month's climatology to give the next background - this gives fewer rejections than direct use of climatology especially during ENSO events. Work on the development and testing of data assimilation methods and their use in seasonal forecasting is still on-going within the ENACT project. The revised quality control has also been introduced in the quasi-operational GloSea seasonal forecasting system and is being tested for use in FOAM, the operational short-range ocean forecasting system at the Met Office.

Met Office, FitzRoy Road, Exeter, EX1 3PB, UK

Modelling sandhopper (*Talitrus saltator*, Montague 1808) trophic dynamics on a sandy beach: How do we measure the interactions amongst species in real ecosystem?

Marcin Filip Jędrzejczak[#] & Jan Marcin Węsławski

Department of Marine Ecology
Institute of Oceanology, Polish Academy of Sciences
ul. Powstańców Warszawy 55
PL-81-712 Sopot, POLAND
Phone: +48 58 551 72 81, Fax: +48 58 551 21 30
[#]E-mail: humbak@idea.net.pl

Abstract

Measuring the strength of interactions between species in ecosystems is extremely difficult. Theorists have overcome the problem by building models based on rather arbitrary distributions of these interaction strengths, which reduces their relevance to natural systems. The coastal line is constantly submitted to change caused by natural and human sources and *Talitrus saltator* tends to be affected by these changes. A model of *T. saltator* trophic dynamics in the sandy beach system can be used for scenario simulations *i.e.* as a tool to try to predict what would happen if the present conditions changed. Since *T. saltator* is usually present on European beaches, it may serve as an indicator of the prevailing ecological conditions. The objective of the study is to develop and explore novel measures of interaction strengths amongst species in real systems that are appropriate for ecological models, as well as to identify whether changes in species composition, either through extinction or invasion, can catalyse effects on community structure and cascade through the ecosystem as a whole. Specifically, are there kinds of beach communities that are most likely to be affected by extinctions and invasions *e.g.* more open to invasions and liable to extinctions? Also, are there certain kinds of species that are most likely to be involved as actors in these scenarios?

Starting from a calibrated trophic dynamics model, hopefully validated as well, different scenarios, corresponding to different environmental conditions, may be accounted for by changing the forcing functions and by changing the model parameters in accordance. Therefore, taking the studied species, *e.g. Talitrus saltator*, as representative of the living community (indicator), the state of the system, if a given type of change occurs, may be anticipated. The following questions might be approached:

- How will the community respond to a significant increase in the number of people frequenting the beach?
- How will the community react to removing the detritus from the beach *vs.* not doing it?

Several questions may be raised for a scenario where the sandy beach community, dominated by detritivores like the sandhoppers, declines or disappears:

- Will the sanitary quality of sand be affected since the detritus will not be processed by detritivores but simply decomposed by microorganisms?
- Will the birds' community be affected by the probable reduction of available food sources?
- Are we losing something in turning pristine coastlines into leisure industry centres? If so, what is the value of the loss?

Such questions, of obvious importance in terms of managing and planning may, in a certain extent, be approached through model simulations, which appear therefore as a powerful tool.

This work has been inspired with the research within the LITUS Project (Interaction of Biodiversity, Productivity and Tourism in European Sandy Beaches). The European Science Foundation (ESF) partially ensured financial support for this study within the LINKECOL Exchange Grant No. LCEE/2002/0245.

Coupled "Ferry-Box" Ship of Opportunity and satellite data system to study plankton succession across the European Shelf Sea and Atlantic Ocean

KELLY-GERREYN BA[1], HYDES DJ[1], QURBAN MA[1], HARTMAN SU[1], MOTTRAM G[2] AND MILLER P[2]

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[1] *Southampton Oceanography Centre, UK*
[2] *Remote Sensing Group, Plymouth Marine Laboratory, UK*

A robust minimum maintenance system to measure temperature, conductivity, and chlorophyll fluorescence has run continuously between Portsmouth UK and Bilbao Spain in 2003. Measurements are taken at 1Hz frequency. This system provides an un-aliased view of all changes in the plankton community driven by physical processes and changes in nutrient supply. It samples eutrophic harbours, open-shelf (seasonally stratified and un-stratified), an up-welling shelf break and seasonally oligotrophic ocean waters. Monthly calibrations have collected samples for chlorophyll-a HPLC pigments, plankton samples and nutrients (nitrate, phosphate and silicate). The 2 dimensional scale is provided by integration with satellite images. The Ferry-Box will be used as a platform for validating data from satellites (chlorophyll and sea surface temperature) and for validating and assimilation into ecosystem models. The variation in the ratio of the chlorophyll fluorescence and the acetone extracted chlorophyll-a concentration provides an in-sight into the progression of dominant organisms and their physiological state in response to changing concentrations of nutrients and hydrodynamics. In particular, the progress of a large summer bloom (90 µg Chl l^{-1}) of the neurotoxic dinoflagellate *Karenia mikimotoi* was captured in the western English Channel. In 2004 a Fast Repetition Rate Fluorimeter, an autonomous nutrient analyser and an in situ flow cytometer will be added to the system.

Intercomparison and validation of irregular mesh storm surge models.

NICOLAI KLIEM, VIBEKE HUESS AND JACOB WOGE NIELSEN
Danish Meteorological Institute, Denmark

A storm surge system for the North Sea – Baltic Sea is running at the Danish Meteorological Institute. Currently, the system is based on a 2D finite difference model using a regular grid and is set up in a nested version in order to comply with the different needs for resolution. In order to more easily deal with the complex area and better resolve the coastline, a test of shallow water irregular mesh models is performed. The setup is similar to the present storm surge setup with respect to resolution, forcing, and boundary condition. The model domain covers the entire North Sea, Inner Danish Waters, and Baltic, with two open boundaries; one in the North Sea between Norway and Scotland, and another in the English Channel. The resolution is about 9 n.m. ($\sim$16.7 km) in the main part of the domain, 3 n.m. in the waters around Denmark, 1 n.m. in the Wadden Sea and in the Great Belt and western part of the Baltic, and about 1/3 n.m. in the Little Belt and the Sound. The model is forced by specified tidal elevations at the open boundaries, and wind stress and atmospheric pressure at the surface.

The test consist of three simulations;

1. A simulation of the M_2 tide only
2. A complete tidal simulation
3. A storm case including both tides and atmospheric forcing

The simulations are validated against sea level data from a number of tide gauges. The elevation time series are given with a resolution of 10 min and have been harmonic analyzed. The test includes different methods for the validation, both on the analyzed results and directly on the time series. The tidal simulations show the overall behavior of the model and are used to calibrate bathymetry and bottom friction parameters. These simulations are performed for a period long enough to distinguish each tidal constituent, and the validation is done in terms of harmonic analyzed results. The last simulation is performed for a real storm case, and is validated in terms of actual elevation. The presentation will focus on the methods and test procedure exemplified by the application of the test to a number of irregular mesh shallow water models.

Danish Meteorological Institute, Lyngbyvej 100, DK-Copenhagen Ø, nk@dmi.dk.

Methane Budget for the oxic/anoxic water column of the Black Sea: data synthesis, parameterisation of biochemical transformations, numerical simulation.

KONOVALOV S[1], IVANOV M[2] , LEIN A[3], MITROPOLSKY A[4] AND WEHRLI B[5]

[1]*Marine Hydrophysical Institute, Ukraine*
[2]*Institute of Microbiology, Russia*
[3]*Institute of Oceanology, Russia*
[4]*Institute of Geological Sciences, Ukraine*
[5]*Swiss Federal Institutes for Environmental Science and Technology, Switzerland*

In this presentation, we address basic questions on cycling of methane in the oxic/anoxic environment of the Black Sea: (i) variations in the distribution, (ii) physical fluxes in the water column, (iii) external sources and sinks of methane for the water column, and (iv) biogeochemical processes of production and consumption of methane in oxic and anoxic conditions. The aim of this work is to quantify and verify the budget of methane from observations and results of diagnostic and prognostic numerical experiments, and to discuss individual processes governing the budget of methane in the Black Sea water column.

Methane is rapidly oxidised in oxic conditions. In suboxic and anoxic conditions, methane is produced in large quantities as a result of organic matter decomposition by methanogenic microorganisms. In anaerobic environments, methane exists at much higher concentrations as compared to oxic conditions. Until recently, methane has been assumed to be rather conservative in anoxic waters and sediments. A possibility of anaerobic methane oxidation in sediments or in the water column has been recently discussed, but little quantitative evidences have been suggested.

For the Black Sea, a number of studies on methane have been carried out over the last 15 years. Methane is the next macro-component of the anoxic zone of the Black Sea after sulphide and ammonia. Its concentration rapidly increases from the depth of sulphide onset to the depth of 500 - 1200 m where it reaches 11 - 15 μM. The methane concentration in the deeper part of the water column remains practically unchanged or even slightly decreases towards the bottom. This makes the behaviour of methane in the Black Sea different from other anoxic systems where the concentration of methane increases steadily along with the concentration of sulphide and ammonia. Some of the published results are rather controversial. For example, the estimated residence time of methane in the Black Sea is fairly short varying from 5 to 30 years and implying fast microbial *in situ* transformations. Since sulphide is the end-product of methane oxidation, one might expect fast turnover for the sulphide too. This however is not true.

Available and published data on the distribution of methane and the rates of its microbial production and oxidation in the oxic/anoxic water column and at the continental slope over the period of 1984-2002 have been generalized to demonstrate that (i) the vertical distribution of methane is not uniform and it varies over the Black Sea on a time scale of years and (ii) the total microbial production of methane in the anoxic zone is lower, than its total oxidation.

The revealed misbalance of microbial production and consumption of methane in the water column suggests external sources of methane, which are documented methane seeps and mud volcanoes. Benthic sources (seeps) of isotopically light ($\delta^{13}C$ up to $83.8^{\text{‰}}$) methane of microbiological origin have been confirmed. Methane production in bottom sediments is estimated on the basis of organic carbon and silicate distribution and the rates of accumulation of sediments. The rate of microbial methane production and consumption is quantified from the results of direct measurements. Basin-wide spatial variations in the intensity of microbial processes and the basis of these variations are discussed.

Physical fluxes and the rates of net production are estimated from the vertical distribution of methane in the water column and profiles of vertical velocity and diffusivity. This has allowed to make estimations of stability and temporal variations in the distribution of methane and to trace the layers of most active biogeochemical processes. This has helped to identify and parameterize these processes for purposes of numerical simulation of methane cycling.

Numerical experiments have demonstrated that the vertical profile of methane can be successfully simulated, thus the suggested sequence of processes and their parameterizations are adequate. The flux of methane at the water-sediments boundary is estimated. The sequence and the importance of individual processes of biogeochemical methane production, consumption, and physical transport in oxic and anoxic layers of the Black Sea are discussed.

Influence of submarine groundwater discharge on the parameters of coastal waters

Kontar, E.A., G.I. Shapiro, and L.I. Lobkovsky

P.P. Shirshov Institute of Oceanology Russian Academy of Sciences

36, Nakhimovsky prospect, Moscow 117851, Russia

It is important to obtain reliable quantitative estimates of both in coming and outgoing fluxes of fresh cold waters in the coastal zone. In situation that incoming groundwater is cold enough to occupy the lower part of the stratified water column on the shelf, transport processes in the bottom boundary layer dominate the removal of discharged water from the coastal zone. Physical mechanisms of such removal seem to be similar to the mechanisms of dense water cascades off the continental shelf over the shelf break. Cascading is a specific type of thermohaline circulation, in which dense water formed over the continental shelf descends down the continental slope to a greater depth. This process is a major component of ventilation of intermediate and abyssal waters, hence affecting thermohaline circulation and global climate. The resulting flows produce an irreversible exchange of oceanic and shelf waters and take an important role in bio-geochemical cycles by removal of phytoplankton, carbon and chlorophyll from productive areas. Because it can take decades or more for the subducted water to re-surface, water cascades contribute to long term climatic variability. It is common to consider formation of dense water by cooling, evaporation or freezing in the surface layer. Submarine groundwater discharge (SGD) can provide an alternative mechanism of dense water formation on the shelf of the Black Sea. In the framework of the SPICES project we plan to investigate the physical mechanisms of the removal of SGD water from the Black Sea's coastal zone and try to get a quantification of off-shore fluxes and transport pathways for SGD and chemical species from the shelf through numerical modeling of the processes in the bottom boundary layer.

Data Assimilation into a Princeton Ocean Model of the Mediterranean Sea using the SEEK Filter

G. KORRES[1], I. HOTEIT[2], AND G. TRIANTAFYLLOU[1]

[1]*Hellenic Center for Marine Research, Greece*

[2]*Scripps Institution of Oceanography, USA*

In this work the implementation of the Singular Evolutive Extended Kalman filter (SEEK) filter and its variant the Singular Fixed Extended Kalman filter (SFEK) filter into the Princeton Ocean Model [Blumberg, 1987] is presented. Their performance through climatological and hindcast experiments has been tested before running near real-time operational experiments.

The SEEK filter [Pham, 1998] is a suboptimal Extended Kalman filter based on the approximation of the error covariance matrix by a singular low rank matrix, reducing in this way the computation cost and improving the filter's stability. At the initialization, the covariance matrix is parameterized by a set of three-dimensional multivariate empirical orthogonal functions (EOFs), describing the dominant modes of the system's variability. When the SEEK filter is used, these functions evolve in time to follow the model dynamics, while they remain invariant in the SFEK filter in order to save computational time.

The filters have been efficiently validated with twin experiments using a ¼ × ¼ horizontal resolution – 25 sigma levels implementation of POM model into the Mediterranean basin. The model was forced either with monthly climatological momentum, heat and freshwater fluxes or with 6-hour ECMWF re-analysis data for the period 1979-1993. In these experiments, pseudo-observations of altimetric (SSH) data and salinity (S), temperature (T) and velocities (V) profiles were assimilated using both filters with a covariance matrix of rank 20. The assimilation system was found to be very efficient, leading to a clear improvement of the model's behavior. The SEEK filter was also shown to be significantly more efficient than the SFEK filter when SSH data were assimilated.

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[1] Hellenic Center for Marine Research, Anavissos, Athens, Greece.

[2] Scripps Institution of Oceanography, La Jolla, CA, 92037, USA.

Satellite monitoring in the southeastern Baltic Sea

KOSTIANOY AG[1], LEBEDEV SA[2, 3], LITOVCHENKO KTS[4], STANICHNY SV[5] AND PICHUZHKINA OE[6]

[1] *P.P. Shirshov Institute of Oceanology, Russian Academy of Sciences, 36 Nakhimovsky Pr., Moscow, 117997, Russia, E-mail: kostianoy@online.ru*

[2] *Geophysical Center, Russian Academy of Sciences, 3 Molodezhnaya Str., Moscow, 117236, Russia, E-mail: lebedev@wdcb.ru*

[3] *State Oceanographic Institute, 6 Kropotkinsky Per., Moscow, 119838, Russia*

[4] *Russian Research and Design Institute for Economics, Information and Automated Management Systems of Fisheries, 4/2 B.Spasoglinishchevsky Per., Moscow, 101990, Russia,* E-mail: litov@mail.vnierkh.ru

[5] *Marine Hydrophysical Institute, National Academy of Sciences of the Ukraine, 2 Kapitanskaya Str., Sevastopol, 335000, Ukraine, E-mail: stas@alpha.mhi.iuf.net*

[6] *LUKOIL-Kaliningradmorneft, 23 Kievskaya Str., Kaliningrad, 236039, Russia, E-mail: opichuzhkina@kld.lukoil.com*

In recent years a number of new oil terminals have been built in the Baltic Sea area, resulting in increased transport of oil by ships and, consequently, an increased risk of accidents. Transportation is a reason of 45% of the oil in the sea while an offshore production is a source of only 2% of the oil pollution in the World Ocean. In the Baltic Sea about 2,000 large ships and tankers are at sea every day. Thus, shipping activities, including oil transport and oil handled in harbors, have a number of negative impacts on the marine environment and coastal zone. Oil and oily residue discharges from ships represent a significant threat to marine ecosystems. These discharges may occur during normal activities or may be accidental or illegal. Oil spills cause the contamination of seawater, shores, and beaches, which may persist for several months and represent a threat to marine resources. One of the main tasks in the ecological monitoring of the Baltic Sea is an operational satellite and aerial detection of oil spillages, determination of their characteristics, establishment of the pollution sources and forecast of probable trajectories of the oil spill transport.

Since 1993 there is no more regular aerial surveillance of the oil spills in the Russian sector of the southeastern Baltic Sea. Today, the monitoring of the southeastern Baltic sea surface temperature, sea level, chlorophyll concentration, mesoscale dynamics, wind and waves, oil spills and some of the meteo parameters is organized based on the satellite IR and VIS data (AVHRR NOAA, SeaWiFS, MODIS), altimetry data (TOPEX/Poseidon, Jason-1), SAR imagery (ERS-2, ENVISAT), and re-analysis data. The results of a pilot project on the complex monitoring of the southeastern Baltic Sea in 2003-2004 will be presented.

So far as the Baltic Sea ecosystem undergo growing human-induced impacts, especially associated with an increasing oil transport and production, further research of the links between physical, chemical and biological parameters of the ecosystem, a complex monitoring of the Baltic Sea state, and especially, the oil spills monitoring are of a great importance. Oil spill behavior, modeling, prevention, effects, control and cleanup techniques require supplementary information about a large number of complex physical, chemical and biological processes and phenomena.

Monitoring of the Caspian Sea

KOSTIANOY AG[1] AND LEBEDEV SA[2, 3]

[1] *P.P. Shirshov Institute of Oceanology, Russian Academy of Sciences, 36 Nakhimovsky Pr., Moscow, 117997, Russia, E-mail: kostianoy@online.ru*

[2] *Geophysical Center, Russian Academy of Sciences, 3 Molodezhnaya Str., Moscow, 117236, Russia, E-mail: lebedev@wdcb.ru*

[3] *State Oceanographic Institute, 6 Kropotkinsky Per., Moscow, 119838, Russia*

The Caspian Sea presents the world's largest isolated water reservoir, with only an isolation being its significant dissimilarity from the open seas. The other features of the Caspian Sea including its size, depth, chemical properties, peculiarities of the thermohaline structure and water circulation enable to classify it as a deep inland sea. Currently its level is at −27 m measured against the World Sea Level. The sea occupies an area of 392,600 km^2, with mean and maximum depths being 208 m and 1025 m, respectively. The Caspian's longitudinal extent is three times larger than its latitudinal one (1000 km vs. 200-400 km), resulting in great variability of climatic conditions over the sea. The isolation of the Caspian Sea from the ocean and its inland position are responsible for a great importance of the outer thermohydrodynamic factors, specifically, the heat and water fluxes through the sea surface, and river runoff for the sea level variability, formation of its 3D thermohaline structure and water circulation.

Over the past half-century, there was a regression of the Caspian Sea until 1977 when the sea level lowered to −29 m. This drop is considered to be the deepest for the last 400 years. In 1978 the water level started to rise rapidly, and now it has stabilized near the −27 m level. There has been increasing concern over the Caspian Sea level fluctuations. Estimates provide support for the view of these fluctuations as climatically conditioned and show their intimate connection with components of the Caspian water budget, especially Volga River run-off. Since the early 1990s regular measurements of the Caspian sea level and main thermohydrodynamic parameters are practically absent. Today, the monitoring of the Caspian sea surface temperature, sea level, chlorophyll concentration, mesoscale dynamics, wind and waves, and some of the meteo parameters is organized based on the satellite IR and VIS data (AVHRR NOAA, SeaWiFS, MODIS), altimetry data (TOPEX/Poseidon, Jason-1) and re-analysis data.

The results obtained show that significant interannual changes in the Caspian thermohaline structure are inevitably reflected in the functioning of the sea ecosystem. So far as the Caspian ecosystem undergo growing human-induced impacts, especially associated with an oil and gas production, further research of the links between physical, chemical and biological parameters of the ecosystem, complex monitoring of the Caspian Sea state, and assessment of the future scenarios are of a great importance.

Ob' river hydrological regime from satellite microwave measurements.

ALEXEI V. KOURAEV[1,2], ELENA A. ZAKHAROVA[2,3], NELLY M. MOGNARD[1], ANNY CAZENAVE[3]

[1]*Centre d'Etudes Spatiales de la Biosphère (CESBIO), France*
[2] *State Oceanography Institute, St. Petersburg branch, St. Petersburg, Russia*
[3] *Laboratoire d'Etudes en Géophysique et Océanographie Spatiales (LEGOS), Toulouse, France*

The arctic regions have recently become a sharp center of interest as the global warming is supposed to be stronger at the high latitudes of the northern hemisphere, leading to potential strong modification of the water cycle. The variations of fresh water input into the Arctic Ocean may influence the stratification of the upper layers, and thus have drastic consequences on the oceanographic processes like thermohaline circulation, sea ice or deep-water formation.

At the same time *in situ* measurements of river discharge are rather sparse in these remote Arctic environments . In many instances, existing monitoring networks suffer from problems that prevent to routinely monitor river level and discharge. Many data are not accessible to the public – for example, for many arctic regions existing time series of observations at gauging stations are available only up to early 1990s. Even when data are available, there are often issues of time resolution (which is often insufficient) and delivery time (for the cases of near real-time studies). For such remote locations, information from satellite sensors (e.g., satellite altimetry systems, active and passive radiometers) can successfully complement in situ observations and in some cases fill the information gaps, serving as virtual gauging stations or providing other types of hydrological and meteorological data.

Among all the Russian rivers Ob' is the biggest one by the watershed area (2 975 000 km2) and is the third biggest river by the amount of river discharge (after Lena and Yenisey) – 402 km3/year. The Ob' River originates in the Altai mountains and flows northward across the vast West Siberian lowland towards the Arctic Ocean. The ability to monitor Ob' river discharge and other parameters of hydrological regime (such as dates of formation/break-up of ice cover on the river and dates of the beginning of spring flood) using satellite data could be very valuable for various scientific and practical purposes. We present results of river water level and ice cover fluctuations in the Ob' river basin based on satellite remote sensing observations: TOPEX/Poseidon altimetry and SSM/I radiometry.

Study of river level (and, consequently, river discharge) was done using data from the TOPEX/Poseidon satellite, operating since 1992. The satellite altimetry measurements were compared with in situ river level and discharge at Salekhard (last observation point before Ob' enter the Ob' bay and Kara sea). We have established relations between altimeter level data and *in situ* discharge measurements for different phases of the Ob' hydrological regime. This method is applicable for estimation of daily discharge, with some exception, due to the fact that the gauging

station is located 65 km from the nearest T/P ground track and as a result the level changes are not always synchronous. However there is no doubt that the T/P water level data can be used for estimation of monthly and annual Ob' river flow with very good accuracy and thus provide sound base for continuous monitoring of the Ob' discharge

The Ob' hydrological cycle is strongly influenced by the ice cover, forming every winter over almost the whole Ob' basin. Satellite microwave data provide the mean to study temporal variations of dates of ice formation/break-up for Ob' itself and its main tributaries.

The TOPEX/Poseidon platform has two nadir-looking instruments – a dual-frequency radar altimeter and a passive microwave radiometer, designed to provide atmospheric correction for water haight measurements. A method using combination of both active (backscatter coefficient at 13 GHz) and passive (brightness temperatures at 18 and 37 GHz) microwave measurements was applied to provide information to estimate type of surface cover over the river. This information was complemented by more than twenty years-long (since 1978) passive microwave data from the SMMR and SSM/I instruments. Using combined data from these two sources of satellite data, we have provided assessment of spatial and temporal variability of the dates of ice formation/break-up for the Ob'. The ice break-up dates are closely related with the beginning of the spring flood, what gives us not only information on variability of climatic parameters, but also provides additional data on variability of this important phase of hydrological regime.

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[1] Centre d'Etudes Spatiales de la Biosphère (CESBIO), BPI 2801, 18, Ave. E. Belin, 31401 Toulouse CEDEX 4, France

Baikal lake ice cover monitoring using historical and satellite measurements.

ALEXEI V. KOURAEV[12], SERGEI V.SEMOVSKI[3], NELLY M. MOGNARD[1]

[1]*Centre d'Etudes Spatiales de la Biosphère (CESBIO), France*
[2]*State Oceanography Institute, St. Petersburg branch, St. Petersburg, Russia*
[3]*Limnological Institute, Siberian Branch of Russian Academy of Sciences, Irkutsk, Russia*

Lake Baikal, a UNESCO World Heritage site, is the World's largest non glacial source of high quality potable fresh water. Baikal's endemic ecosystem, and the region's recreational opportunities that have not yet deteriorated due to human activities argue for the intensive studies of the dynamics of Baikal's ecosystems and possible changes due to climate change and man–induced effects. Baikal's ice surveillance has been underway for more then 150 years now. This unique data base being supported by modern data on ice regime in different parts of the lake, gives an opportunity to study global and local patterns of climate variability. Present state of satellite monitoring of Baikal ice have been provided using NOAA and MODIS data in the visual band and some limited number of ERS SAR images [*Semovski et al., 2000, 2003*]. Advantage of satellite microwave measurements for ice studies is that they are not influenced on cloud cover and do not depend on daylight availability, have the benefit of being able to provide weather-independent, continuous and reliable data on various environmental parameters, including sea and lake ice cover.

We have done the study of ice cover in lake Baikal using active and passive microwave data from two sources. The first source is the data from the TOPEX/Poseidon (T/P) satellite, operating since 1992. This platform has two nadir-looking instruments – a dual-frequency radar altimeter and a passive microwave radiometer used to correct altimetric measurements for atmospheric influence. Though the primary mission of T/P is to measure sea level, we have found that the combination of active and passive microwave measurements could be successfully used for the ice cover studies [*Kouraev et al., 2003, 2004*]. A method using a combination of simultaneous active (backscatter coefficient at 13.6 GHz) and passive (brightness temperatures at 18 and 37 GHz) microwave measurements was applied to discriminate between ice and open water.

This information was complemented by more than twenty year long passive microwave data set from the side-looking radiometers - SMMR (Scanning Multichannel Microwave Radiometer, 1979-1987) instrument onboard the satellite NIMBUS-7 and from the SSM/I (Special Sensor Microwave/Imager) instrument onboard the DMSP (Defense Meteorological Satellite Program) series (since 1987). The National Snow and Ice Data Center (NSIDC) provided the SMMR and SSMI data mapped to the Equal Area (625 km^2 resolution) SSM/I Earth Grid (EASE-Grid).

Using these two sources of data we have computed time series of beginning and end dates of ice season, of ice season duration and of ice cover extent. These time series show pronounced regional, seasonal and interannual variability and for the first time provide continuous time series of modern ice cover variability in lake Baikal.

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[1] Centre d'Etudes Spatiales de la Biosphère (CESBIO), UMR 56390, 18, av. Edouard Belin, 31401 Toulouse cedex 4, France, E-mail: alexei.kouraev@cesbio.cnes.fr

[2] State Oceanography Institute, St. Petersburg branch, St. Petersburg, Russia

[3] Limnological Institute, Siberian Branch of Russian Academy of Sciences, Irkutsk, Russia

Evaluation of SST observational networks for the North Sea/Baltic Sea operational modelling

J. LARSEN, J. SHE, J. HØYER AND B. AMSTRUP

Danish Meteorological Institute, Denmark

A SST assimilation scheme has been implemented in an eddy resolving z-coordinate ocean model covering the North Sea and the Baltic Sea. The assimilation scheme is a simplified Kalman filter tailored for assimilation of satellite SST observations [*Annan and Hargreaves,* 1999]. A series of Observing System Simulation Experiments (OSSEs) have been performed for the year 2001 to investigate the impact on model forecast of assimilation of satellite SST products of different resolution and the effect of including in-situ measurements of SST in the assimilation.

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Danish Meteorological Institute, Lyngbyvej 100, DK-2100 Copenhagen Ø, jl@dmi.dk.

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Danish Meteorological Institute, Lyngbyvej 100, DK-2100 Copenhagen Ø, jl@dmi.dk.

Eddy-resolving data assimilation in the Irminger Sea: Controllability and observability

DANIEL J. LEA[1], THOMAS W. N. HAINE[2] AND RICHARD F. GASPAROVIC[1]

[1]*Johns Hopkins University Applied Physics Laboratory, U.S.A.*

[2]*Earth and Planetary Sciences, Johns Hopkins University, U.S.A.*

We examine the Irminger Sea branch of the meridional overturning circulation using variational data assimilation. Twin experiments are performed where we assimilate simulated in-situ and satellite data with realistic observing patterns into a 10-km resolution regional general circulation model (the MITgcm). These experiments address the controllability and observability of the system with the existing in-situ and satellite observing network. That is, we ask can the observations improve estimates of quantities of scientific interest? We find that over 30 days the assimilation can fit all the observations to the noise level by correcting the initial conditions. Only modest changes in the time-dependent surface forcing and open boundary values are needed. In this sense the model is controllable. For longer integration times the influence of the initial conditions relative to the boundary forcing should decline. Preliminary results suggest that for assimilation windows of a few months or longer, the assimilation is no longer controllable due to exponential divergence of the adjoint sensitivity. For a 30 day assimilation window the system is able to accurately estimate sea surface height and sea surface temperature, correcting errors in the locations of surface fronts and eddies. The existing in-situ mooring observations downstream of the Denmark Strait are inadequate to accurately track the overflow variability at the Strait. Improvement of the solution near the moorings is significant, however, and the benefit of these in-situ data propagate a few 100km upstream.

[1] Johns Hopkins University Applied Physics Laboratory, 11100 Johns Hopkins Road, Laurel, MD 20723-6099, U.S.A.

[2] Department of Earth and Planetary Sciences, Olin Building, 34th and North Charles Streets, Johns Hopkins University, Baltimore, Maryland 21218, U.S.A.

GODAE Atlantic and Mediterranean Sea Prototype Project (G-A&MPP)
An Intercomparison of Five Forecasting Systems

C. LE PROVOST[2], P. BAHUREL[2] , M. BELL[3], L. BERTINO[7], F. BLANC[4], E. CHASSIGNET[9], G. COPPINI[5], L. CROSNIER[1,2], E. DOMBROSKY[4], C. FRATIANNI[5], H. HURLURT[6], P. Y. LE TRAON[4], K. A. LISAETER[7], C.L. LIU[8], N. PINARDI[5]

[1] LEGOS / CNRS, France
[2]MERCATOR-Ocean, France
[3]Met Office,United Kingdom
[4]CLS, France
[5]INGV, Italy
[6]Naval Research Laboratory, USA
[7]NERSC, Norway
[8]NERC, United Kingdom
[9]RSMAS, USA

The aims of the GODAE prototype projects are intercomparison exercises of existing ocean forecasting systems, in order to evaluate their strengths and weaknesses. The North Atlantic and Mediterranean Sea basins have been chosen for one of these Prototype Project. Among the reasons of the choice of these basins, one is obviously that the Atlantic is one of the best instrumented (i.e. ARGO, XBT, drifters,…). The other major reason is that on these two basins, a significant number of forecasting systems are already in place. The G-A&MPP has been used as a model for establishing relevant metrics, for testing the methodology and conditions for running in parallel several forecasting systems in real-time during a given period, for sharing their outputs, and for performing an intercomparison experiment. This exercise includes testing access servers, preparing common format for inter-comparison of model products, and similar technical issues. The participants are the existing operational Atlantic and/or Mediterranean Sea models: TOPAZ, FOAM, HYCOM, MERCATOR, MFS, NLOM. This experiment has been initiated under the EC MERSEA Strand1 project: a GODAE MERSEA server has been developed, including OpenDap servers in each forecasting centre. A real time experiment has been started 1rst of June 2003: each system delivers on a weekly basis their daily best estimates of the ocean state, and their day 6 forecast. The aims of this presentation is to report on this exercise, and to point out the major conclusions after almost one year of real time experiment by the time of the colloquium.

AOSN-II in Monterey Bay: Real-time error predictions, data assimilation, adaptive sampling and dynamics

PIERRE F.J. LERMUSIAUX[1], WAYNE G. LESLIE[1], CONSTANTINOS EVANGELINOS[2], PATRICK J. HALEY[1], OLEG LOGOUTOV[1], PATRICIA MORENO[1], ALLAN R. ROBINSON[1], GIANPIERO COSSARINI[3], X. SAN LIANG[1] AND SHARAN MAJUMDAR[4]

[1]*DEAS, Harvard University, Cambridge, USA*
[2]*Ocean Engineering, MIT, USA*
[3]*Istituto Nazionale di Oceanografia, Sgonico (TS), Italy*
[4]*RSMAS, University of Miami, USA*

During the August 2003 Autonomous Ocean Sampling Network-II (AOSN-II) experiment, the Error Subspace Statistical Estimation (ESSE) system was utilized in real-time to forecast physical fields and uncertainties, assimilate various data (ships, AUVs, gliders, aircraft, satellites), provide suggestions for adaptive sampling and guide dynamical investigations. ESSE aims to capture, forecast and reduce the largest uncertainties, i.e error subspace. It is currently based on a singular value decomposition of the minimum error variance update and on an adaptive ensemble scheme to forecast the largest errors. Each ensemble member was a sample path of the HOPS primitive equation model, forced stochastically to represent model errors. Using a total of 4323 ensemble members, ESSE error forecasts, assimilation outputs, adaptive sampling recommendations and dynamical interpretations were routinely issued and posted on the web. Scientific and operational results will be presented, including: dynamical findings in Monterey Bay and California Current region, focusing on different stages of the upwelling and relaxation states; ensemble properties (convergence, mean, most probable forecast, (co)-variances and singular vectors); forecast skills; and subjective/quantitative adaptive sampling based on field, error and data forecasts.

Pierre F.J. Lermusiaux Harvard University, Division of Engineering and Applied Sciences, Pierce Hall G2A, 29 Oxford Street, Cambridge MA 02318, USA. web: www.deas.harvard.edu/ pierrel

Recent developments to the FOAM data assimilation system

MATT MARTIN, MIKE BELL AND ADRIAN HINES
Met Office, UK

The Forecasting Ocean Assimilation Model (FOAM) is a deep ocean forecasting system which is run daily in the operational suite at the Met Office to produce 5-day forecasts of deep ocean parameters. Two main improvements to the data assimilation component of the system have recently been implemented and are described here. The first is a more accurate representation of the forecast and observation error covariance matrices used in the analysis. The forecast error covariances are represented as the sum of two components due to errors in the ocean mesoscale and errors at atmospheric synoptic scales, each with its own horizontal and vertical correlation length scales and variances, which are spatially varying. These have been estimated using observation-minus-forecast statistics output from a 3 year run of the FOAM system. The second improvement to the assimilation is a restructuring of the scheme, based on a timely optimal interpolation method. This aims to make better use of observations by assimilating them in a timely manner and by taking proper account of observations which have already been assimilated. This paper will give an overview of these changes and describe their impact on the analyses.

Met Office, FitzRoy Road, Exeter, Devon, UK, EX1 3PB.

ESA and Earth Observation

PIERRE-PHILIPPE MATHIEU[1]

[1] *European Space Agency (ESRIN - EOP/SE)*

This talk will focus on the exploitation of Earth Observation (EO) in operational oceanography, with a particular focus on the ENVISAT mission and ESA EO application programmes. Real demonstration examples from ESA projects will be presented to illustrate how EO can help support business decision-making in a variety of industry sectors (e.g. ice navigation, offshore oil industry, insurance sector).

Earth Observation Science & Applications
Via Galileo Galilei - Casella Postale 64
00044 Frascati (Rm) - ITALY

DANGEROUS ICE PHENOMENA AND WINTER HYDROLOGY OF THE MARGINAL ARCTIC SEAS, RIVERS AND ESTUARIES: OPERATIONAL MONITORING WITH USING INTEGRATED SATELLITE TECHNOLOGIES

[1] Melentyev, V.V., [1] L.P. Bobylev, [2] L.H. Pettersson, [3] V.I. Chernook

[1] Nansen International Environmental and Remote Sensing Center (NIERSC)
B. Monetnaya Str. 26/28, 197101 St. Petersburg, Russia
Tel: + 7 812 234 39 24, Fax: + 7 812 234 38 65,
E-mail: vladimir.melentyev@niersc.spb.ru

[2] Nansen Environmental and Remote Sensing Center
Edvard Griegsvei 3A, N-5037 Solheimsviken, Norway
Tel: + 47 55 29 72 88, Fax: + 47 55 2000 50,
E-mail: lasse.pettersson@nrsc.no

[3] Polar Research Institute of Marine Fisheries and Oceanography (PINRO)

Knippovich Str. 18, Murmansk, 183763, Russia;

E-mail: chernook@pinro.murmansk.ru

Ice cover parameters of Dvina Bay, Pechora and Ob-Yenisey estuary as a different part of the Grand Siberian recurring polynya are studied with using regular satellite "Resourse" and "Okean" data, visual and IR airborne survey and SAR data, obtained by ERS, RADARSAT and ENVISAT. SMMR/SSMI passive microwave data are attracted for assessment of large scale processes. Dangerous ice phenomena, including flooding and "ice river" phenomenon (accelerated drift of sea ice at the different parts of the Kara and Pechora Sea), ice and water exchange between Grand Siberian rivers and estuaries, and contiguous regions of the White, Pechora and Kara Sea are investigated with using satellite data and validated by helicopter and research vessel data in sub-satellite assembly points. The modification of the processes for the different winter severity is evaluated. Sev. Dvina, Pechora and Ob Bay, as Yenisey Gulf are the vast expanded zones of saline and fresh water mixture. As the giant water intake for the most part of the Eurasia these estuaries are integrated sub-continental water flows from the Altay and Sayan Mountains at the south till the Ural Mountains and Lake Baykal at the west and east, correspondingly. Overall result that winter hydrology and ice features here has resulted from large scale sub-continental processes of humidification. Climate change which resulted modification of precipitation, degradation of seasonal frozen grounds and permafrost zones should be indicated at winter hydrology of the Arctic seas and estuaries. Our approach assumes that satellite SAR signatures of sea, freshwater and brackish-water ice (and seasonal and inter-annual modification of the salinity of ice) could be evaluated as a tracer of different natural processes of the water catchment. As was obtained from SAR data, changeability of the type of regional atmospheric processes resulted the modification of stable currents and ice dynamics at the marginal Arctic seas. As was fixed by satellite multy-spectral survey, a quasi-stable eddies in the White Sea could change their position and modify the intensity and type of rotation (it could provoke occasionally the ecological catastrophe and mass destruction of ice-associated marine mammals).

In frame of satellite monitor program, the ice regime and winter hydrology features of the inland water bodies (lakes, rivers reservoirs, artificial ponds, etc.) in Siberia has been investigated also. Different dangerous ice phenomena were revealed (debacle and ice break-up, rafting and ridging of ice, ice boom, ice jam, downstream floe and blocking of ice, "rotten" ice formation, etc.). Sub-satellite validation programs were organized on the rivers and shallow waters. Ice cores and water samples over of the Dvina, Pechora and Ob Bays, Yenisey Gulf has been accomplished and analyzed. The following ice parameters of river ice are investigated: ice development (age), color of the ice and its connection with origin of ice (formed by sea, fresh or brackish water), ice and water pollution.

ABSTRACT :

The MERSEA Project : development of a European system for operational monitoring and forecasting of the ocean physics, biogeochemistry and ecosystems, on global and regional scales.

By the MERSEA Consortium[1]

MERSEA (Marine EnviRonment and Security for the European Area) is an Integrated Project funded by the EC under the FP6, Space thematic priority for GMES[2], Ocean and Marine Applications. Forty agencies and industrial partners participate in the project whose aim is to provide an integrated service of global and regional ocean monitoring and forecasting to intermediate users and policy makers in support of safe and efficient offshore activities, environmental management, security, and sustainable use of marine resources. The system to be developed in this 4-year project (2004 –2007) will be the Ocean and Marine services element of GMES to be established in 2008.

At the core of the system is the collection, validation and assimilation of remote sensed and in situ data into ocean circulation models that allow for the self consistent merging of the data types, interpolation in time and space for uniform coverage, now-casting (i.e. data synthesis in real-time), forecasting, and hind-casting, and delivery of information products.

The project will lead to a single high-resolution global ocean forecasting system shared by European partners together with a co-ordinated network of regional systems for European waters which will provide the platform required for coastal forecasting systems. During the project the main pre-operational systems will be transitioned towards operational status and three of the centres will converge on a single ocean model framework suitable for both the deep ocean and shelf-seas.

The project will federate the resources and expertise of diverse institutes, agencies, and companies in the public and private sector, in the fields of satellite data processing, in situ ocean observing systems, data management, ocean and ecosystem modelling, ocean, marine and weather forecasting. A global high resolution model (1/12°) will be developed, as well as improved systems for the Arctic, Baltic, Mediterranean and NE Atlantic. Down scaling to regional systems will be implemented by nesting methods.

Specific applications to be developed include bio-geochemical variability in European regional and shelf seas (European Atlantic margin shelf including North and Irish Seas) and experiments on forecasting the ocean-atmosphere on daily to seasonal time scales. User products in support of offshore oil exploration and production, wave forecasts and ship routing, and oil drift fate prediction will also be developed.

The overall scope of the project will be described, including the opportunity for the delivery of ocean fields and products in support of research and application developments.

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[1] The MERSEA project is steered by an Executive Committee comprising : Y.Desaubies (Ifremer) , P.-Y. Le Traon (CLS), U.Send (IFM/Kiel), H.Roquet (Météo-France/CMS), P.Bahurel (MERCATOR – Océan), G.Manzella (ENEA), J.Verron (CNRS/LEGI), C.Le Provost (CNRS/LEGOS), M.Bell (UKMetOffice), E.Buch (DMI), N.Pinardi (INGV), R.Rayner (Ocean Numerics), J.Johannessen (NERSC).

[2] GMES : Global Monitoring for Environment and Security.

Lagrangian Data Assimilation in Multi-Layer Primitive Equation Ocean Models

By

Anne Molcard[1,2] , Tamay M. Ozgokmen [2] , Annalisa Griffa [1,2] , Leonid Piterbarg [3]

1. Consiglio Nazionale Delle Ricerche, ISMAR, La Spezia, Italy
2. RSMAS/MPO, University of Miami, Miami, Florida,
3. Mathematics Department, USC, Los Angeles, California

Because of the increase in the realism of OGCMs and in the coverage of Lagrangian data sets in most of the world's oceans, assimilation of Lagrangian data in OGCMs emerges as a natural avenue to improve ocean state forecast with many potential practical applications such as environmental pollutant transport, biological and managing related problems.

A Lagrangian data assimilation method is presented, which was introduced in prior studies in the context of single-layer quasi-geostrophic and primitive-equation models, and extended now for use in multi-layer OGCMs. Statistical correlations coefficients between velocity fields are used in order to project the information for the data-containing layer to the other model layers. The efficiency of the assimilation scheme is tested using a set of twin experiments, as a function of the layer in which the drifters are launched and of the assimilation sampling period normalized by the Lagrangian time scale of motion.

It is found that the assimilation scheme is effective provided that the correlation coefficient between the layer that contains the data and the others is high, and the data sampling period is smaller than the the Lagrangian time scale. In such cases, even the assimilation of deep layer data with low energetics are found to be very effective. The methodology remains also quite robust to large deviations from geostrophy.

Data Assimilation with the Ensemble Kalman Filter and the SEIK Filter applied to a Finite Element Model of the North Atlantic

L. NERGER, S. DANILOV, G. KIVMAN, W. HILLER, J. SCHRÖTER

Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany

Currently there are different approaches to filter algorithms based on the Kalman filter. One of the most used filter algorithms is the Ensemble Kalman Filter (EnKF). It uses a Monte Carlo approach to the filtering problem. Another approach is given by the Singular Evolutive Extended Kalman (SEEK) and Singular Evolutive Interpolated Kalman (SEIK) filters. These operate on a low-dimensional error space which is represented by the used ensemble states. The EnKF and the SEIK filter have been implemented within a parallel data assimilation framework in FEOM (Finite Element Ocean Model) which has been developed recently at the Alfred Wegener Institute and is described in the companion presentation. To assess the capabilities of the algorithms and to compare their filtering performances, several data assimilation experiments are performed. In these the filter algorithms are applied in a model configuration for the North Atlantic to assimilate the sea surface height.

Influence of lateral boundary conditions on operational forecast in semi-enclosed seas.

S.M. OLSEN AND J. SHE
Danish Meteorological Institute

A z–coordinate 3D ocean model (BSHcmod) is used at DMI for operational forecasts of the North Sea, Inner Danish Waters and Baltic. Open lateral boundaries of the model are located in the Northern North Sea and in the English Channel. Here, sea-level anomalies are obtained from a barotropic surge model covering the North East Atlantic whereas temperature and salinity are prescribed from climatology. In summer 2003 and most significantly during August, North Sea SST was significantly warmer than the climatological mean. The resulting inconsistency between the atmospheric forcing and lateral boundary fields of the model subsequently leads to erroneous model features along the boundary, propagating into the domain.

The aim of this study is to describe and quantify the improvements in model skill obtained by applying daily updated boundary values of temperature and salinity. Daily updates are based on POLCOMS operational model fields covering an extended North Sea area. The experiment mimics an operational setup and acts as a primer for real-time data exchange of boundary conditions.

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Danish Meteorological Institute, Lyngbyvej 100, Copenhagen 2100, DK-Denmark

Forecasting front displacements in the Northern Balearic Sea with a satellite based ocean forecasting (SOFT) system.

A. ORFILA[1], A. ALVAREZ[2], G. BASTERRETXEA[2], A. FORNES[2], J. TINTORE[2]

[1]*School of Civil and Environmental Engineering, Cornell University, Hollister Hall, Ithaca (NY) 14853 USA*

[2]*Instituto Mediterráneo de Estudios Avanzados-IMEDEA (UIB-CSIC),Miquel Marqués 21, 07190 Esporlas, Spain*

A sharp thermal front is usually found in the Northern Balearic Sea (Northwestern Mediterranean) during late summer and autumn. It separates warm surface waters of the Balearic Sea from colder waters coming from the Gulf of Lion and Ligurian Sea. The front is part of a larger frontal system that crosses Western Mediterranean from the east coast of Spain to the west coast of Corsica-Sardinia. Wind forcing and spreading of cold water masses from the north, force a southward displacement of the front. The marked temperature difference across the front and the relatively low cloud coverage of the area facilitate tracking the frontal motion and associated frontal instabilities from satellites.

In this work, we study the performance of a Satellite Based Ocean Forecasting (SOFT) system forecasting on real time and weekly time scales, the frontal position in the Northern Balearic Sea. The SOFT system was built using satellite observed SST data ranging from March 1993 to March 2002 and validated in the period from April 2002 to March 2003. In the validation period, real-time forecasting was emulated providing at each time, the present weekly averaged value of the satellite observed frontal position and requesting from the system a prediction from the next week. Capabilities of SOFT systems as operational tools for ocean forecasting are discusses on the basis of the results obtained.

A reduced order Kalman filter to assimilate along track altimetric observations and sea surface temperature with the HYCOM model

LAURENT PARENT[1], GREGG JACOBS[1] AND PIERRE BRASSEUR[2]

[1] *Naval Research Laboratory, USA*
[2]*LEGI-CNRS, Grenoble, France*

The main objective of this work is to implement the SEEK filter, an advanced statistical assimilation scheme (developed at LEGI Laboratory into the european Diadem and Topaz projects), and to compare results with the current ocean nowcast/forecast system running in real time at the Naval Oceanographic Office (NAVO).

At the center of the system is the HYbrid Coordinate Ocean Model (HYCOM). This model is designed to use an efficient vertical system coordinate which evolves in time and space. Isopycnal coordinates are used in the deep stratified ocean, geopotential near the surface and terrain-following in shallow coastal regions. The North Atlantic 1/3 ° configuration is used as the benchmark to estimate performances of this new assimilation scheme. This region covers 28 °S to 70°N including the Mediterranean sea. In the vertical, there are 26 levels and the mixed layer model is a K-Profile Parameterization (KPP). Simulations are produced throughout 1992-1999 with the use of ECMWF fluxes.

The method used is a reduced-order Kalman filter derived from the SEEK, in which the error covariance matrix is determinated through a three-dimensional multivariate analysis of the model variability. It allows a reduced cost of the assimilation scheme, a strong requirement of any operational ocean system. The analysis algorithm has been further developed to strenghten the local impact of the data and a physical adjustment has been incorporated to take care of the vertical coordinate of the model. The assimilated SST data come from AVHRR satellites and the altimetric data come from the Topex/Poseidon and ERS1-2 satellites.

Hindcast experiment will be presented and interpreted. Validation with independant in situ measurements (XBT) demonstrated the skill of the system to represent the Atlantic ocean circulation in surface or mid-depth, as the Gulf Stream. Later, the 1/12 ° configuration will be used to improve the control of the meso-scale activity.

Mesoscale Mapping Capabilities of Multi-Satellite Altimeter Missions: First Tests in the Western Mediterranean Using Near Real Time Data

ANANDA PASCUAL, GILLES LARNICOL, PIERRE-YVES LE TRAON

CLS- Space Oceanography Division, Toulouse, France

Satellite altimetry is considered as one of the most important input datasets for operational applications, as it provides surface dynamic topography measurements, which constitute a strong constraint to estimate and forecast the three-dimensional ocean state through data assimilation. One requirement for satellite altimetry is that at least two altimeter missions are needed to resolve the main space and timescales of the ocean. For instance, the combination of TP + ERS-1/2 has allowed a characterization of the major changes in the Mediterranean Sea level variability for the 1993-1999 period [*Larnicol et al,* 2002]. However, theoretical studies [*e.g. Le Traon et al,* 2001] have shown that three altimeters should improve the mesoscale variability mapping. Fortunately, in the present time, the data from four altimeters [TOPEX/Poseidon, ENVISAT, Geosat follow-on (GFO) and Jason-1] are available.

In this work we carry out a first test of merging near real time data from these four altimeters with the aim of obtaining high resolution maps capable to monitor the mesoscale variability. The region selected for the tests is the Western Mediterranean, but it is envisaged to be applied globally. We basically review the different processing steps involved in the mapping which generally depend on an a priori statistical characterization of errors and of the ocean signal. In particular, the selection of a suitable correlation function and associated parameters, as well as the filtering applied to data to eliminate the scales that cannot be resolved by the sampling, are examined in detail. We also compare the high resolution maps with other independent datasets such as SST and in-situ data, in order to verify the improvement with respect previous altimetric maps computed from a combination of only two altimeters.

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Eulerian and Lagrangian model studies of a marine coastal environment (Gulf of Naples, Tyrrhenian Sea)

S. PIERINI[1], R. FERRETTI[2], C. VENEZIANI[3] AND G. VISCONTI[2]

[1]*Istituto di Meteorologia e Oceanografia, Università di Napoli Parthenope (Italy)*
[2]*Dipartimento di Fisica, Università dell'Aquila (Italy)*
[3]*RSMAS, Miami (USA)*

The wind-driven dynamics of the coastal waters of the Gulf of Naples (Tyrrhenian Sea) is analyzed by means of a primitive equation multilayer oceanic circulation model. The model includes an upper layer for the Modified Atlantic Water, an intermediate layer for the Levantine Intermediate Water and a third layer for a typical deep water of the Tyrrhenian Sea. The domain of integration has a spatial resolution of 1 km in both horizontal directions and extends well outside the Gulf of Naples, embracing a portion of the Tyrrhenian deep sea and adjacent coastal areas. The forcing is provided by both ECMWF winds and high resolution (9 km) winds produced by a limited-area implementation of the MM5V3 model of PSU/NCAR. The current variability is analyzed, and typical circulation patterns are identified and compared with past observations corresponding to similar atmospheric conditions.

Particular attention is devoted to the comparison between the current fields obtained with the low and high resolution wind forcings. Relevant departures evidenced in the two wind products (due to the influence of important orographic features located along the coasts and poorly resolved by the low resolution forcing) produce analogous departures in the induced marine dynamics, which are analyzed in detail. Lagrangian simulations have been carried out as well: trajectories are computed through the Eulerian velocity field provided by the oceanic circulation model. A trajectory analysis is presented and discussed.

The Mediterranean ocean Forecasting System: operational data assimilation and predictability studies

NADIA PINARDI, SRDJAN DOBRICIC, MARINA TONANI,CLAUDIA FRATIANNI, MARIO ADANI E ALESSANDRO BONAZZI

Istituto Nazionale di Geofisica e Vulcanologia, Via Donato Creti 12, Bologna, Italy

The Mediterranean ocean Forecasting System (MFS) is an operational nowcasting/forecasting system implemented in the Mediterranean Sea in the past five years [*Pinardi et al.,* 2003].. The system provides real time 10 days forecasts of the three dimensional ocean structure for usage in pollution control and detection of ecosystem changes in the open ocean and coastal areas. The system implements a novel assimilation of temperature profiles, satellite sea surface temperature and sea level anomaly with multivariate Optimal Interpolation and a weekly assimilation cycle. In addition MFS organizes the real time data collection with in situ and satellite data, together with the transmission and quality control protocols of the collected data.

The OI uses an order reduction procedure based upon the separation of vertical and horizontal modes of the background error covariance matrix [*De Mey and Benkiran,* 2003]. The EOF are calculated from model results and historical data sets and space-time variability is included. The operational system uses the approximation that EOF are different for SLA and XBT data. The latter are used to correct only the T,S structure while SLA is used to correct T,S and the barotropic streamfunction, sequentially before or after the XBT assimilation.

The results of such an assimilation are intercompared with SLA and XBT data before insertion and ARGO profiles, which are an independent data set. The quality of the forecast is discussed in terms of skill scores and sensitivity experiments are done to show the impact of different choices of parameterizations of the error covariance matrix.

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MEDARGO: A European Profiling Float Program in the Mediterranean

PIERRE-MARIE POULAIN[1], JORDI FONT[2] AND SYLVIE LE BRAS[3]

[1]*Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (OGS), Trieste, Italy*
[2]*Institut de Ciències del Mar (CMIMA-CISC), Barcelona, Spain*
[3] *Institut Français de Recherche pour l'Exploitation de la Mer (IFREMER), Brest, France*

In the framework of MEDARGO, which is part of the EU-sponsored MFS project *[Pinardi et al*., 2003], profiling floats will be deployed throughout the Mediterranean starting in late summer 2004 to provide temperature and salinity data in near-real time to forecasting models of the Mediterranean. In order to assess the functionality of the floats and define their sampling characteristics before the operational deployments, four units were operated in the Catalan Sea in fall 2003. Two types of profiling floats were operated, the APEX and the PROVOR. All floats were equipped with Sea-Bird CTD sensors. They were programmed in the "Park and Profile" configuration with a neutral parking depth of 350 m (near the salinity maximum of the Levantine Intermediate Water - LIW) and a maximum profiling depth of 700 m, with total cycle periods of 3.5, 4 and 7 days. When at surface, the floats were located by, and transmitted data, to the Argos system onboard the NOAA satellites. The data were processed and archived in near-real time at the CORIOLIS Data Center (Brest, France) and were disseminated on the GTS following the standards of the international ARGO program. The two APEX floats were deployed in the Catalan Sea on 26 September 2003. A week later, on 2-3 October 2003, the two PROVOR floats were deployed in the vicinity of the APEX floats. CTD casts (from the ship) were made close to the float profiles. All floats were operated in "Park and Profile" mode until 7 November 2003 providing a total of 35 ascending profiles. Thereafter, the floats remained at surface until they were recovered. After showing some indication of subsurface flow towards the northeast after deployment, all the floats were trapped by the prevailing slope current (the Northern Current) and moved to the southwest. Speeds at the 350 dbar level varied between 1 and 6 cm/s. Displacements during the time spent at surface were in some cases of the same order of magnitude as the deep displacements. They showed no preferential direction due to the large variability of the surface currents at meso and inertial scales. Occasionally, the surface and intermediate displacements were in opposite directions, revealing a significant shear between the two levels. The temperature and salinity profiles obtained by the floats are typical for the region, with a marked salinity maximum in the LIW at about 400 m. The structure in the upper layer is highly variable and the depth of the seasonal thermocline varies between 30 and 70 m.

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[1]OGS, Borgo Grotta Gigante 42/c, 34010 Sgonico (Trieste), Italy.
[2]CMIMA-CISC, Passeig Marítim 37-49, 08003 Barcelona, Spain.
[3]IFREMER, BP 70, 29280 Plouzané, France.

CORIOLIS, A FRENCH PROJECT FOR IN SITU OPERATIONAL OCEANOGRAPHY.

S. POULIQUEN1, T. CARVAL1, Y. DESAUBIES1, L. PETIT DE LA VILLEON1,
G. LOAEC1, L. GOURMELEN2 ;

CONTACT SYLVIE.POULIQUEN@IFREMER.FR(1)

IFREMER, BP70, F29280 Plouzané ;
(2) EPSHOM, BP426, F29275 Brest Cedex

The seven French agencies concerned by ocean research are developing together a strong capability in operational oceanography based on a triad including satellite altimetry (JASON), numerical modelling with assimilation (MERCATOR), and in situ data (CORIOLIS).

The CORIOLIS project aims to build a pre-operational structure to collect, valid and distribute ocean data (temperature/salinity profiles and current speeds) to the scientific community and modellers.

CORIOLIS aims at four goals :

(1) To build up a data management centre, part of the ARGO network for the GODAE experiment, able to provide quality-controlled data in real time and delay modes.

(2) To contribute to ARGO floats deployment mainly in the Atlantic with about 250 floats during the 2001-2004 period.

(3) To develop and improve profiling ARGO floats. PROVOR is a self-ballasted float, able to drift at a user-defined parking depth and then to dive to 2000m before profiling up to the surface where data are transmitted using the Argos system. More than 100 cycles can be performed during its 3-year lifetime.

(4) To integrate into CORIOLIS all other data presently collected at sea by French agencies from surface drifting buoys, PIRATA anchored buoys, oceanographic research vessels (XBT, thermosalinograph and ADCP transmitted on a daily basis).

CORIOLIS data centre, already one of the two global data centres for ARGO, is an important partner in projects within GMES et 6th PRCD calls like Mersea. In 2004, recommendations will be done to transform the CORIOLIS activity into a permanent, routinely contribution to ocean measurement, in accordance with international plans which will follow the ARGO/GODAE experiment.

COMBINED USE OF ALTIMETRY , IN-SITU MEASUREMENTS AND A GEOID MODEL TO ESTIMATE A GLOBAL MEAN DYNAMIC TOPOGRAPHY. IMPACT OF GRACE AND GOCE DATA.

Rio M-H[1], Lemoine[2], J-M, Hernandez,F.[3]

[1], ISAC/ Gruppo di Oceanografia da satellite, Italy
[2], LEGOS/GRGS , France
[3], CLS/Space Oceanography Division, France

Operational forecasting systems are assimilating sea level measured by satellite altimeters. Because of the lack of an accurate geoid at small spatial scales absolute dynamic topography needed for the assimilation can not be directly inferred from the altimetric signal. Instead, along-track Sea Level Anomalies (SLA) relative to a 7 year (1993-1999) mean profile are computed**.** In order to reconstruct absolute sea level, the estimation of a realistic mean dynamic topography (MDT) consistent with altimetric SLA is a crucial issue. In that context, a method was developed to estimate globally the required MDT combining altimetric data, in-situ measurements and a geoid model.

First, the geoid model EIGEN-GRACE01 is subtracted to the Mean Sea Surface Height CLS01 at spherical harmonics degree 60. The obtained field is used to improve the Levitus climatology at wavelengths longer than 330 km (major improvements are obtained at high latitudes and in strong currents areas) providing a first guess for the computation of the MDT. On the other hand, in situ measurements and altimetric data are combined using a synthetic method. This method consists in subtracting synoptically the altimetric sea level anomaly to in-situ measurements of the full dynamical signal so as to obtain local estimates of the mean field which are then used to improve the first guess using an inverse technique. The obtained combined MDT (CMDT) is compared to other existing MDT (issued from inverse modelling or general circulation models). In particular, absolute dynamic topography values obtained referencing altimetric anomalies to the various solutions are compared to independent in situ measurements. RMS differences to the observations are significantly reduced when using the CMDT.

New and fundamental insights are expected for oceanographic applications from the launch in 2006 of the Gravity Field and Steady-State Ocean Circulation Mission (GOCE) whose objective is to determine the geoid to 1 cm accuracy for spatial scales down to 100 km. A focus is made on the Mediterranean Sea - whose mean circulation features short scales and is largely unknown- to better understand the future impact and limitation of GOCE data in areas where the mean circulation scales are expected to be inferior to GOCE resolution (i.e. ≈100 km).

Superensemble forecasting from atmospheric and ocean operational models using linear and non-linear statistics

M. RIXEN[1] AND E. COELHO[2]

SACLANT Undersea Research Centre, ITALY

Multimodel superensemble forecasts [*Krishnamurti*, 2000, 2000a], which exploit the power of an optimal local combination of individual models usually show superior forecasting skills when compared to individual models because they allow for local correction and/or bias removal. Here we apply linear and non-linear statistical methods to generate optimal superensembles from both atmospheric and ocean operational models and local observations that where available during the MREA03 field experiment in the area of the island of Elba in the Mediterranean. Optimisation methods are based on a training/forecast cycle and include simple least-square methods, neural networks and genetic algorithms. The performance and the limitations of the superensembles and the individual models are discussed for each methodology.

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[1] SACLANT Undersea Research Centre, Viale San Bartolomeo 400, 19138 La Spezia (SP), ITALY Tel: +39.0187.527-457 - Fax: +39.0187.527-331, rixen@saclantc.nato.int

[2] SACLANT Undersea Research Centre, Viale San Bartolomeo 400, 19138 La Spezia (SP), ITALY Tel: +39.0187.527-277 - Fax: +39.0187.527-331, coelho@saclantc.nato.int

A reduced-order approach for 4D-var ocean data assimilation

C. ROBERT[1], E. BLAYO[1] AND J. VERRON[2]

[1] *Laboratoire Modélisation et Calcul, Grenoble, France*

[2] *Laboratoire des Ecoulements Géophysiques et Industriels, Grenoble, France*

Actual implementations of data assimilation methods in realistic ocean applications face several difficulties common to all techniques, either variational or sequential. Among these problems, two important points are the huge size of the model state variable (typically $10^6 - 10^7$), and a poor knowledge of the error statistics of the assimilation systems.

We present here a reduced-order variational approach for drastically decreasing the dimension of the control space, and hence the cost of the minimization process. The method is based on a decomposition of the control variable on a well-chosen family of a few relevant vectors, representing in some sense an important part of the system variability. Moreover it provides a natural model-based definition of a multivariate background error covariance matrix B_r.

An illustration of the feasibility and the effectiveness of this method is given in the academic framework of twin experiments for a model of the equatorial Pacific ocean. A low-rank basis is built based on a prior EOF analysis of a model trajectory. It is shown that the multivariate aspect of B_r brings additional information which substantially improves the identification procedure. Moreover the computational cost is decreased at least by a factor of two with regard to the full-space 4D-Var method.

The extension of this approach to the assimilation of real data is addressed. In that case, the model is non longer perfect, and the reduced basis must take it into account.

Finally, we present some first comparisons of these results with those obtained with a sequential reduced-order assimilation method (SEEK filter) using a similar low-rank basis.

Laboratoire Modélisation et Calcul, Université Joseph Fourier, BP 53X, 38041 Grenoble cedex, France.

Inorganic Carbon Cycle in the Inner Scheldt Estuary

SCHIETTECATTE L.-S., BORGES A.V. & FRANKIGNOULLE M.

Unit of Chemical Oceanography, Université de Liège, Belgium

The Scheldt estuary is one of the most polluted macro-tidal European estuaries due to a high anthropogenic pressure around this catchment area. High load of suspended organic matter (with at least two third directly related to human activities) associated to a high residence time within the estuary (3monthes) [Wollast, 1988] contribute to an intense bacterial degradation. Heterotrophy has led to CO_2 production with subsequent emission to the atmosphere. High partial pressure of CO_2 (pCO_2) have been reported ranging from 4500 to 9500µatm in the maximum turbidity zone (MTZ) which represents up to 2500% of the CO_2 atmospheric pressure. CO_2 emissions to the atmosphere have been estimated to 310-790tC.day-1 (tons of carbon par day) [Frankignoulle et *al.*, 1998]. The present work deals with the cycle over one year of the partial pressure of CO_2 (pCO_2), salinity and temperature in surface brackish water measured at a station (Sainte-Anna) located in the MTZ of the inner Scheldt, closed to the city of Antwerp. Results show that, over a year, pCO_2 ranges from 2000 to more than 8000ppm with a salinity and temperature range from 0 to 11 and 4 to 24°C respectively. When we study the seasonal cycle of pCO_2 for a single water masse (*e.g.* for a salinity 1 or 5 psu for example), it appears that on a macroscale, pCO_2 is mainly dependant on the temperature and heterotrophy.

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Winter survey of Lake Baikal seal. Data reanalysis using satellite data.

SERGEI V.SEMOVSKI, EUGENY A.BARANOV

Limnological Institute SB RAS, Irkutsk, Russia

Known locally as the nerpa and referred to by scientists as *Phoca sibirica*, the Baikal seal is found only in Russia's isolated Lake Baikal, a designated World Heritage Site and the world's deepest, oldest and most voluminous mass of freshwater. The Baikal seal, one of the world's smallest pinnipeds, is in fact the only pinniped species that lives solely in freshwater.

Regular surveys of seal abundance producing during winter time (1984, 2000, 2001), demonstrate decline of seal population [*Baikal seal survey...*, 2000]. Between factors probably affecting higher seals mortality are official and unofficial hunting, contamination by several industrial sources and climatic changes. Ecology of seal during winter is highly dependent on ice and snow conditions. Seal prefer snow-covered areas and ridges and very few seals have been observed on transparent smooth ice.

The methodology of total population size estimation is based on linear interpolation between standard sections. This method of data analysis doesn't take into account type of ice. New numerical procedure is presented using information on ice conditions, derived from MODIS and NOAA AVHRR satellite images in visual band. Possible using of SAR data is discussed.

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Optimal Design of Observational Networks (ODON) for marine monitoring and prediction

J. SHE[1] AND ODON CONSORTIUM[1−5]

[1] *Danish Meteorological Institute*

[2] *Bundesamt fuer Seeschiffahrt und Hydrographie*

[3] *Management Unit of Mathematical Modelling of the North Sea*

[4] *Proudman Oceanography Laboratory*

[5] *Swedish Meteorological and Hydrological Institute*

ODON is an EU FP5 project, aiming to provide cost-effective sampling strategy and technology synergy of temperature and salinity (T/S) observing system in the Baltic and North Sea. Specifically ODON addresses following issues:

- Cost-benefit assessment of existing monitoring systems
- With affordable investment, where should we deploy instruments? what are optimal sampling distances in space and time?

To this end, a wide variety of issues in operational marine monitoring and prediction has to be dealt with, e.g., indexes for quantitatively assessing marine monitoring networks, both in their costs and quality, spatial-distribution of marine characteristic scales, Observing System Simulation Experiments (OSSEs) etc. Due to lack of high resolution 4 dimension marine observations, ODON firstly generate a proxy ocean by using state-of-art ocean models and input datasets, then perform OSSEs by sampling the proxy ocean.

ODON started from 2003. This paper presents major progress made by the consortium in the first year. During the first year ODON focuses on establishing a complete data set of T/S and forcing in the Baltic-North Sea in the proxy ocean year 2001, optimising and validating ODON 3D ocean models, assimilating SST into the 3D ocean models, and preliminary study on the observing network assessment etc.

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Danish Meteorological Institute, Lyngbyvej 100, DK-2100, Copenhagen, Denamrk, js@dmi.dk

Assessment of existing temperature and salinity monitoring network in the Baltic and North Sea

J. SHE[1], J.L. HØYER[1], E. BUCH[1], AND P. AXE[2]

[1] *Danish Meteorological Institute*

[2] *Swedish Meteorological and Hydrological Institute*

Temperature and salinity (T/S) are the most widely monitored marine parameters. A comprehensive data survey has been conducted in a EU FP5 project ODON (Optimal design of Observational networks) for existing both in-situ and satellite monitoring system, aiming to provide a complete T/S database in the Baltic-North Sea in 2001. Based on the survey, some key issues related to marine monitoring and operational forecasting are investigated: e.g., the spatial and temporal coverage, major gapped areas, synergy of monitoring technology, and the cost of the network. An assessment index is defined based on covariance models and used to assess the effective coverage of different observing networks. The possibility for running the network operationally under a more integrated umbrella is discussed and suggestions are made for rationalising the existing monitoring network.

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Danish Meteorological Institute, Lyngbyvej 100, DK-2100, Copenhagen, Denmark, js@dmi.dk.

Some key issues in operational ocean modelling in the Baltic-North Sea

J. SHE, S.M. OLSEN AND J. LARSEN

Danish Meteorological Institute

A one-year model validation is done by comparing DMI (Danish Meteorological Institute) operational 3D ocean model (BSHcmod) results with observations in 2001 on a Baltic-North Sea scale. In addition to basic error statistics, model capability for simulating key physical processes, such as stratification, circulation patterns, temperature/salinity front features in transition waters, Baltic-North sea water exchange, Baltic bottom inflow and upwelling etc, is examined. Possible error sources are discussed. Based on the validation study, priority areas for future improvements of the 3D operational ocean model for the Baltic-North Sea are proposed and discussed.

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Danish Meteorological Institute, Lyngbyvej 100, DK-2100, Copenhagen, Denmark, js@dmi.dk.

Influence of bathymetry averaging in simulating Baltic-North Sea water exchange

J. SHE AND J.B. JØRGENSEN
Danish Meteorological Institute

Ocean bathymetry is an important background parameter for ocean modelling, especially operational modelling. EuroGOOS has set up a working group to investigate model requirements to the quality of the bathymetry data. In fact this issue is closely related to optimal design of bathymetry monitoring strategy. In the ocean modelling there are some sensitive areas where accurate bathymetry data play a very important role, such as narrow sills, especially those with a water depth just below the seasonal thermohaline. This is the case in Danish Belts where narrow sills connecting the Baltic and North Sea. Maximum depth of deep trenches through the Belts area ranges from 30-50m, with a horizontal scale as narrow as a few hundreds of meters. The state-of-the-art operational models have a resolution of about 1nm in the Belts area. This means deep salinity intrusion will be largely underestimated in a model with an averaged 1nm bathymetry.

This paper describes a bathymetry parameterisation scheme which parameterises the high resolution bathymetry (200m) to a low resolution model bathymetry (1nm), The scheme results in a bathymetry being reasonable deep in the Belts while still keeping the real total water volume. The influence of this model bathymetry is tested in a five month model run, in comparison with a control run using the normal averaged 1nm model bathymetry. Results show that the salinity transport is enhanced by 10% in total during the 5months period. The bathymetry impact is extremely large in the inflow events: with the new bathymetry, salinity in Belts area are up to 4 psu higher than that in the control run.

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Danish Meteorological Institute, Lyngbyvej 100, DK-2100, Copenhagen.

A near real-time 1/32° global ocean prediction system

J. F. SHRIVER[1], H. E. HURLBURT[1], O.M. SMEDSTAD[2]

[1] *Naval Research Laboratory, USA, (shriver@nrlssc.navy.mil, hurlburt@nrlssc.navy.mil)* [2] *Planning Systems, Inc., USA, (smedstad@nrlssc.navy.mil)*

A data-assimilative 1/32° global ocean nowcast/forecast system, under development at the Naval Research Laboratory (NRL) since 1999, is currently running in near real-time. This system is scheduled for transition to the Naval Oceanographic Office (NAVO) in 2004 as an upgrade to the existing operational 1/16° NRL Layered Ocean Model (NLOM) nowcast/forecast system.

A critical issue in forecast system design is determining the resolution required. Ocean models require finer resolution and more computer time than atmospheric models in part because the space scales for variability due to flow instabilities (oceanic mesoscale eddies vs. atmospheric highs and lows) are about 20-30 times smaller than found in the atmosphere. We need to resolve the oceanic eddy space scale very well because (1) upper ocean topographic coupling via flow instabilities has a major impact on the pathways of many upper ocean currents (including mean pathways) and very fine resolution of the flow instabilities is required to get sufficient coupling, (2) very fine resolution is required to obtain (a) inertial jets and sharp oceanic fronts which span major ocean basins as observed and (b) the associated nonlinear recirculation gyres which affect the shape of large-scale ocean gyres, (3) it is necessary to resolve small islands and narrow passages which affect current pathways and current transports in many regions, (4) in data assimilative mode we do not want the ocean model to "fight" the data because the natural behavior of the ocean model is inconsistent with the observations, and (5) a very high horizontal resolution model is needed to help get an accurate mean sea surface height field to add to the deviations obtained from satellite altimetry (observations alone do not provide sufficient resolution to do this).

The need for 1/32° resolution ($\sim$3.5 km at mid-latitudes) has been demonstrated through extensive research. This research also helped establish 1/16° ($\sim$7 km at mid latitudes) as the minimum resolution needed for a fully eddy-resolving global ocean prediction system. Major improvement in model simulation skill was obtained in some regions with an increase to 1/32° resolution, but only modest additional improvement with a further increase to 1/64° resolution. Hence, our target resolution globally is 1/32°.

The 1/32° ocean model after 30 years of climatological spinup starting from a 1/16° initial state, was run interannually spanning the period 1979-present. In addition to re-equilibration, the climatological simulation was used to fix problems that arose, optimize model parameters, assess the impact of the resolution increase on model realism and dynamics and to perform climatological model-data comparisons. The interannual simulation was used for date-specific model data comparisons, generating statistics and a model sea surface height (SSH) mean used in data assimilative experiments. The model assimilates SSH from 3 satellite altimeters (currently GFO, JASON-1 and ERS-2; additonal satellites will be used as data becomes available in real-time) and sea surface temperature from satellite IR imagery. Assimilation of satellite altimeter data is critical in allowing the model to map individual current meanders and eddies. Forecast experiments were then initialized from the data assimilative experiments. Results from this 1/32° system were then compared with observed data to assess model realism and the value added of the resolution increase from 1/16° to 1/32°.

Nowcast Modelling the Hydrodynamics and Ecosystem Function of the NW European Shelf Seas

J.R. SIDDORN, M.W. HOLT AND J.P.OSBORNE

The Met Office, Bracknell, UK

The Met Office routinely run a version of POLCOMS, a 3D circulation model developed by the Proudman Oceanographic Laboratory (POL). This model covers the NW European Continental at 12km resolution, and is being run to provide short-term forecasts of physical oceanographic parameters which may be used as input to finer scale regional models.

A Medium Resolution Continental Shelf POLCOMS model of the NW European shelf has been implemented on a $1/10^o$ by $1/15^o$ grid, giving approximately 6 km resolution. This physical model is coupled with an ecosytem model (the European Regional Seas Ecosystem Model, ERSEM) provided by Plymouth Marine Laboratory (PML). EFRSEM, which has a proven pedigree in European coastal areas, uses a 'functional group' approach to describe the biota, which are classified according to trophic levels and subdivided on the basis of trophic links and/or size. Physiological processes and population dynamics are described by fluxes of carbon or nutrients between functional groups, and constrained by nutrient, oxygen and carbon biochemistry, giving a state-of-the-art description of ecosystem processes.

The model is driven at the surface by hourly winds and pressures and 3-hourly heat, light and moisture fluxes from the Met Office mesoscale weather prediction model (12km resolution). At the open ocean boundaries the model is forced with tidal elevations and velocities and temperature and salinity taken from the 12km POLCOMS model. Riverine sources of physical and biochemical parameters are also included.

The POLCOMS-ERSEM modelling system provides a detailed simulation of the physics, biochemistry and ecosystem behaviour at a regional scale which allows the prediction of, for instance, toxic algal blooms and eutrophication events. Validation of the system by comparison with measured physical, biochemical and ecosystem data is presented, and the results discussed.

The Met Office, London Road, Bracknell, Berkshire, RG12 2SZ, United Kingdom.

Past and future changes in the Mediterranean "climate" in relation to changes in the freshwater budget: a numerical modelling study.

N. SKLIRIS[1], S. SOFIANOS[1], AND A. LASCARATOS[1]

Ocean Physics And Modeling Group (OPAM), University of Athens, Greece

Important salinity increasing trends in the deep waters of both the Eastern and the Western Mediterranean Basins have been observed during the last four decades [*Lascaratos et al.,* 1999; *Bethoux and Gentili*, 1999]. These trends have been partially attributed to changes in the freshwater budget starting at the early sixties due to damming of major rivers (Nile, Ebro and Black Sea rivers) of the Mediterranean Sea region [*Rolhing and Bryden*, 1992]. In this study, the long-term changes in the thermohaline circulation and water mass characteristics of the Mediterranean Sea caused by changes of the river outflows are investigated using a 3-D primitive equation model (POM). The model is first integrated using values of the Nile and Ebro rivers runoff as well as of the Dardanelles freshwater input, typical of the late fifties. The model reaches a steady state representative of that existing in the Mediterranean prior to the damming after 80 years of integration. Then the model is integrated using the reduced river runoff values, typical of the after-damming period, to reach a new steady state after 80 years of simulation. The model results show that the dramatic reduction of the Nile freshwater input and to a lesser extend the reduction of the freshwater input from the Dardanelles Straits induced a large increase in the sea surface salinity in the Aegean and Levantine basins exceeding 0.1 psu in the early seventies, in agreement with observations. Furthermore, the Ebro runoff reduction during the same period further enhanced the salinity increase in the Levantine basin as higher salinity surface waters of the western basin reached the eastern basin via the MAW circulation. This saltier surface layer in the vicinity of the Rhodes Gyre favoured the preconditioning for the formation of the Levantine Intermediate Water, resulting in about 40% increase of its formation rate. Intermediate waters became saltier, and as they were transported westward they reduced the stability of the water column in the deep-water formation sites, namely the Southern Aegean, the Southern Adriatic, and the Gulf of Lions. Thus saltier and larger amounts of dense waters were formed filling the deep parts of the Mediterranean Sea. Model results demonstrate that river damming played a crucial role in the long-term salt preconditioning of the surface/intermediate layers of the Cretan Sea, contributing in triggering the Eastern Mediterranean climatic transient in the late eighties. According to the model, the river damming explains about 65% of the observed salinity increasing trend occurring over the last 40 years in the Western Mediterranean Deep Water while the major contributor to this trend was proved to be the Nile damming.

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A near real-time 1/12° Atlantic HYCOM prediction system

O. M. SMEDSTAD[1], H. E. HURLBURT[2], A. J. WALLCRAFT[2], E. CHASSIGNET[3] AND R. BARAILLE[4]

[1]*Planning Systems, Inc., USA, (smedstad@nrlssc.navy.mil)* [2]*Naval Research Laboratory, USA, (hurlburt@nrlssc.navy.mil, wallcraf@nrlssc.navy.mil)* [3]*University of Miami, USA, (echassignet@rsmas.miami.edu)* [4]*LEGOS/BRESM, France, (baraille@thor.cst.cnes.fr)*

A 1/12° Atlantic Ocean verison of the HYbrid Coordinate Ocean Model (HYCOM, [*Bleck*, 2002]) is used in a near real-time nowcast/forecast system. The model covers the region between 27°S and 70°N. The Modular Ocean Data Assimilation System (MODAS, [*Fox et al.*, 2002]) sea surface height analysis of available satellite altimeter data is assimilated into the model. The surface information is projected in the vertical using the [*Cooper and Haines*, 1996] technique. The model is currently run once a week to produce the nowcast. The run includes a 10 day forecast. The results from the system can be seen on the HYCOM Consortium web page at http://hycom.rsmas.miami.edu/. The results are compared to observations of frontal locations determined from independent MCSST observations. The frontal analysis is performed at the Naval Oceanographic Office. Independent observations from SeaWifs images are also used in the model-data comparisons. A series of images in the Gulf of Mexico in the summer and fall of 2003 show a very good agreement between the model sea surface height field and the pathway of the chlorophyll.

This system is the first step toward a global 1/12° nowcast/forecast system based on HYCOM that is planned for transition to the Naval Oceanographic Office in 2006. The prediction system will provide boundary conditions for higher resolution coastal models. An accurate representation of the oceanographic fields at the open boundaries of a coastal model is important for a successful coastal ocean prediction system. More advanced assimilation techniques are in the process of being implemented/tested with HYCOM, e.g. a multivariate optimal interpolation scheme (MVOI) and the Singular Evolutive Extended Kalman Filter (SEEK, [*Pham et al.*, 1998]). These techniques will be included in the system as soon as they show increased model nowcast/forecast skill and the system can run within the operational time limits.

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[1]Planning Systems Inc, MSAAP Bldg 9121, Stennis Space Center, MS 39529, USA

[2]Naval Research Laboratory, Stennis Space Center, MS 39529, USA

[3]University of Miami, RSMAS/MPO 4600 Rickenbacker Causeway, Miami, FL 33149, USA

[4]LEGOS/BRESM, 14, Av. Edouard Belin, 31400 Toulouse, France

Coastal monitoring network of the Manfredonia Gulf (Southern Adriatic Sea): new observational techniques and instrumentations as part of a monitoring system

FEDERICO SPAGNOLI, FEDERICA FIESOLETTI, ANTONIETTA SPECCHIULLI, GABRIELLA BARTHOLINI, ALESSANDRA CONVERSI

ISMAR – CNR, Sezione Ecosistemi Costieri e Lagunari, Via Pola 4, 71010 Lesina (FG), Italy

At present, news techniques and instrumentations need for real time marine environmental monitoring. This necessity arises from the need of knowing in real time the evolution of marine phenomena due to anthropic pressure or natural events. A real time observation system could permit a better management and sustainable exploitation of marine environment.

The PITAGEM project (Integrated methodologies for the study of marine trophic processes and deployment and management of oceanographic platform for marine monitoring), coordinated by CNR - ISMAR of Lesina, aims to develop new oceanographic instrumentations and to set up and to manage an automatic monitoring integrated network in the Gulf of Manfredonia (Southern Adriatic Sea) and in the Gulf of Taranto (Ionian Sea).

Furthermore, in the Gulf of Manfredonia another aim is to study and understand its processes. This gulf can be considered a complex area where anthropic pressure (industrial, agricultural, urban, harbour and tourist activities) plays an important role for pollution phenomena or alteration of the marine ecosystem.

The technology and instrumentation developed during the PITAGEM project are the following:

1. An oceanographic platform, still under testing, deployed in the Gulf of Manfredonia, equipped with.
    a) a meteorological station measuring air pressure, air temperature, solar radiation, wind direction and wind speed;
    b) an automatic phosphorous and nitrogen compound analyser of water samples collected at five different depths;
    c) a multiparametric probe for temperature, salinity, dissolved oxygen, pH, *in vivo* fluorescence measurements of water samples collected at five different depths;
    d) a near real time communication system transmitting data via SMS.

The monitoring program performed by the platform has began on October 2003, but at the moment the platform is under maintenance.

2. An eight meter vessel equipped with a surface pumping system and a multiparametric probe for measuring in continuous physico – chemical parameters of surface waters of the Gulf of Manfredonia. The monitoring program performed by the vessel has began on May 2003 with bimonthly frequency, and includes:
    a) horizontal continuous tracks of surface physico–chemical parameters (temperature, salinity, dissolved oxygen, pH, *in vivo* fluorescence and turbidity) along a transect parallel to the coastline;
    b) vertical physico-chemical profiles (temperature, salinity, dissolved oxygen, pH, fluorescence) at 20 fixed stations along 4 transects (one parallel and 3 perpendicular to the coastline);
    c) sub-surface and bottom water sampling, by rosette, for suspended solid, nutrient (NO_3, NO_2, NH_3, PO_4, $Si(OH)_4$, total P and N) and chlorophyll "a" analyses at fixed stations.

An additional component of the project is the realization of two multidisciplinary cruises aiming to study optical properties, primary production and biogeochemical processes of the Gulf of Manfredonia.

The data are stored in an integrated data bank provided with a GIS system. The platform data are validated by a data quality control check (quality flags, statistical elaboration) and compared to data which are acquired in the same sampling stations by a reference instrument (field calibration). The validation and calibration protocols will be designed and modified in according to all the developing system of the platform. The final aim of this system is to set up an ecological model to obtain forecast scenarios.

The initial data obtained with the platform and the boat monitoring in the Gulf of Manfredonia show how this area is subject to high seasonal influence, that processes between coastal and central marine areas differ, and the high influence of the general winter cyclonic circulations of the Adriatic Sea in more offshore areas.

Satellite monitoring of Upwellings in the Black Sea.

STANICHNAYA R.R., STANICHNY S.V., SOLOVIEV D.M.

Marine Hydrophysical Institute of National Academy of Science of Ukraine, 2 Kapitanskaya st., 99011, Sevastopol, Crimea, Ukraine, e-mail: stas@alpha.mhi.iuf.net

DAVIDOV A.

Institute of Marine Research at the University of Kiel, Fosternbrooker Weg 20,Kiel,Germany, 24105 e-mail: adavidov@ifm.uni-kiel.de

Coastal upwelling in the Black Sea plays the significant role in horizontal and vertical mixing and redistribution of the physical, chemical and biological components in marine ecosystem.
Essential interest was focused on upwelling investigation during the period of extended summer (May15-Sept 15). This interest is due to existing of seasonal mixed upper layer prevented from exchange with deeper layers in the Black Sea. Vertical nutrient transport and related photosyntetic processes are strongly modulated by upwelling phenomena.

Satellite data for the last seven years analyzed for upwelling phenomena study on the Black Sea area. Thermal AVHRR images were used for upwellings shape and disposition investigation. Statistics of upwelling events for different regions was calculated. Two years period in total upwelling activity was detected.

It was shown that South Crimea coast, West part of the Turkish coast , Bulgarian and Romanian coast are the regions with more frequently upwelling events. Typical size and temperature difference for different regions estimated. Upwellings area coverage can reach 12% of all Black Sea. Shape of the upwelling area strongly depends from the current upper layer dynamical processes in the shelf zone. Upwelling generated jets, filaments and eddies are demonstrated, and the significance of these phenomena on cross-shelf transport processes is discussed. SeaWiFS and AVHRR data intercomparison shown that upwelling event can as increase such decrease chlorophyll concentration in the upper layer. NCEP wind data were used for joint analyses with satellite images.

Chlorophyll *a* concentration and coloured dissolved organic matter: retrieval by SeaWiFS level 2 standard products in deep part of the Black Sea

Suslin V[1]., Churilova T[2]., Korolev S[1]., Kucheryavy A[1].

[1]Marine Hydrophysical Institute, National Academy of Science, Sevastopol, Ukraine
[2]Institute of Biology of South Seas, National Academy of Science, Sevastopol, Ukraine

At present development of regional algorithms of chlorophyll *a* concentration (C_a) and coloured dissolved organic matter (*CDOM*) retrieved by satellite measurements is an actual task. Semi-analytical algorithm for deep-part of the Black Sea is considered. This one assimilates as a quality of standard SeaWiFS level 2 products as current state of optical properties of seawater. This method has three features. First consists in that the values of normalized water leaving radiance ($L_{wn}(\lambda)$) in the short wavelengths (SeaWiFS's bands 1 and 2) were not used. It can be result of large errors in standard atmospheric correction after 4th reprocessing [*Suetin et al*., 2002]. Second is in an essence of difference between the first derivatives by spectrum for sum absorption of *CDOM* and detritus (*D*) (a^{λ}_{CDOM+D}) and phytoplankton absorption (a^{λ}_{ph}) in 490-555 nm spectral domain. Third feature is in that values of a^{λ}_{CDOM+D} is weaker at respectively high values of a^{λ}_{ph} for pigment concentration and pigment composition range typical for the Black Sea. We are supposed that ratio of $L_{wn}(\lambda)$ for two bands, so-called color ratio (below "index"), $I(\lambda_1,\lambda_2)=\frac{L_{wn}(\lambda_2)}{L_{wn}(\lambda_1)}$ is a function of absorption by two variables or $I_{\lambda_1:\lambda_2}=I\left(a^{\lambda_{i=1,2}}_{CDOM+D},a^{\lambda_{i=1,2}}_{ph}\right)$. Our approach consists in separation of a^{λ}_{CDOM+D} and a^{λ}_{ph} contributions into total absorption and bases on nonlinear behavior of $I_{490:510}$ and $I_{510:555}$ indexes. If to solve the system of equations in the frame of well-known optical water model [*Burenkov et al*., 1999] for two indexes $I_{490:510}$ and $I_{510:555}$ than we will receive two decisions: $a^{490}_{ph}=a_{ph}\left(I_{490:510},I_{510:555}\right)$ and $a^{490}_{CDOM+D}=a_{CDOM+D}\left(I_{490:510},I_{510:555}\right)$, where $I_{490:510}$ and $I_{510:555}$ are calculated from SeaWiFS products variables. Our decisions include the spectral relationships $a^{\lambda}_{CDOM+D}=a^{\lambda_0}_{CDOM+D}\cdot\exp\left(-S\cdot(\lambda-\lambda_0)\right)$, for total backscattering coefficient $b_b(\lambda)$ in form $(\lambda/\lambda_0)^{n^*}=b_b(\lambda)/b_b(\lambda_0)$ and $a^{\lambda_i}_{ph}=A_{\lambda_i}C_a^{B_{\lambda_i}}$ at λ =490, 510 and 555 nm, where S is 0.018 follow by Churilova's measurements, n^*, A_{λ_i} and B_{λ_i} are model constant. We are found such the coordinate values of n^*, A_{λ_i} and B_{λ_i} for which results of a^{490}_{ph} and a^{490}_{CDOM+D} calculation by our decisions were very well correlated with independent empiric observations like *in situ* C_a during 1998-2000 and calculations of $CDOM+D$ absorption by empiric formula [*Suetin et al*., 2002] in the open deep part of the Black Sea, respectively. This method may be expand to other arias like Sea of Azov, Marmara, Kaspian and Baltic Sea, where we are also observed the analogous nonlinear effects of $I_{490:510}$ and $I_{510:555}$ behavior during annual cycle.

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[1] 2, Kapitanskaya str., Marine Hydrophysical institute, Seavastopol, 99000, Ukraine, otdp@alpha.mhi.iuf.net
[2] 2, Nahimova ave., Institute of Biology of South Seas, Seavastopol, 99000, Ukraine

Assessment of a 4DVAR approach controlling the regional circulation influence on the Gulf of Lions shelf

VINCENT TAILLANDIER AND JEAN-LUC DEVENON[1]

[1]*Laboratoire d'Océanologie et de Biogéochimie, France*

The coastal oceans are some of the most productive and active marine environments. However, their role in the global ecosystem remains relatively elusive, especially concerning mechanisms and magnitudes of lateral export to the open ocean. The Gulf of Lions, which is largely opened to the Northwestern Mediterranean basin, appears to be an appropriate case study. Quantitatively observed (routine remote sensing, periodic in situ surveys, long term measurements), the gulf circulation is influenced by the Liguro-Provençal Current which flows along the shelf break: transient cross shelf transport linked to upstream perturbations of the current has been evidenced [*Echevin et al.,* 2003]. In numerical modeling practice, optimal model parameters relevant to these regional forcing variations are determined according to information from observational systems deployed inside the gulf.

A four-dimensional variational (4DVAR) assimilation method for open boundary control is then developed and implemented on the basis of the primitive equation circulation model OPA and its adjoint [*Weaver et al.,* 2003]. The case of a barotropic lateral forcing has been already lead on a non-stratified configuration of the Gulf of Lions [*Taillandier et al.,* 2003], but the baroclinic structure of Liguro-Provençal Current needs a complete description of the model dynamics and the corresponding boundary conditions to be controlled. This is what is validated with two academic twin experiments: (i) the development of a density current inside a semi-infinite homogeneous channel is retrieved from a synthetic data set figuring density profiles distributed downstream; (ii) the observation of the spin up of a coastal circulation induced by a baroclinic Kelvin front incident to a shallow shelf topography permits to identify the upstream boundary conditions linked to the separation at the shelf break.

The assimilation method is applied in a realistic situation and evaluated in the hindcast mode for monitoring applications, especially on the data related aspect. The model configuration involves a realistic topography of the Gulf of Lions and its shelf break. In its wintertime situation, the gulf is not stratified and the model is forced along its eastern open boundary by a baroclinic Kelvin front that propagates along the shelf. This regional forcing is controlled to study the ability of the available observational networks to detect transient cross shelf intrusions according to their spatial and temporal coverage.

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[1] Centre d'Océanologie de Marseille, Campus de Luminy, Case 901, F-13288 Marseille Cedex 9.

Ecosystem prediction experiments in a cold, brackish sea
New scientific results, increased requirements for monitoring

TAPANI STIPA, ANTTI WESTERLUND, JONNI LEHTIRANTA
Finnish Institute of Marine Research

A prototype for a scientific forecasting system of the Baltic Sea has been developed. The system builds on well-established, scientifically validated models and boundary conditions where available, and combines them with observation-derived state estimates to arrive at routine short-term forecasts of the Baltic Sea state. The short-term forecasts are used for model validation purposes and ecosystem predictability studies.

The physical model is based on the MIT GCM (Marshall et al., 1997). ECMWF forecasts are used in as atmospheric boundary conditions. Nutrient and freshwater runoff from 20 largest rivers as well as atmospheric deposition are modeled with climatological values.

A new biological model for the Baltic has been developed. The prognostic components for the pelagic model are three functional groups (diatoms, flagellates and diazotrophic cyanobacteria, including two of the most common species in the Baltic Sea: Nodularia and Aphanizomenon) and three limiting nutrients (dissolved inorganic nitrogen, phosphorus and silicate). The growth rates of the brackish-water, thermophilic cyanobacteria are newly parameterised as functions of salinity and temperature (Stipa and Hense, 2003; Hense and Stipa, 2003).

The model was initialised for the northern Baltic with interpolated observations from the FIMR monitoring data of May/June, 2003, and with modeled fields (cf. Stipa (2003)) for the southern Baltic. 56–72 hour forecasts have been calculated with the model since mid-July, 2003.

The forecast experiment proved its worth already in its first months. The traditional preconditions for cyanobacterial growth in the northern Baltic for the summer 2003 were very good, with large amounts of surplus phosphate available in the Gulf of Finland in particular. However, satellite, SOOP and monitoring observations showed very little if any cyanobacterial blooms in the Gulf of Finland, but frequent surface accumulations in the northern and central Baltic Sea.

An explanation for this discrepancy is found in the forecast model results: the mean drift in the surface layer of the Gulf of Finland was directed westward, transporting the budding cyanobacteria away from the Gulf, to bloom in the northern Baltic Sea. Hence, the preconditions for the growth of cyanobacteria did not materialise as blooms in the Gulf of Finland, but rather in the northern Baltic.

An overall consistency is found between model forecasts and extensive Baltic observations from ships of opportunity (e.g. Alg@line). However, present SOOP observations do not sufficiently discriminate between functional types of phytoplankton. Novel instrumentation is urgently required for sufficient validation of present, let alone increasingly complex future ecosystem models.

Finnish Institute of Marine Research, PO Box 33, FIN-00931 Helsinki, Finland

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Recent developments of the MERCATOR Assimilation System (SAM): towards the SEEK filter

CHARLES-EMMANUEL TESTUT[1], BENOIT TRANCHANT[1], PIERRE BRASSEUR[2] AND PIERRE DE MEY[3]

[1]*Mercator-océan, 8/10 rue Hermes, 31520 Ramonville-St-Agne, France*
[2]*LEGI, B.P.53, 38041 Grenoble Cedex 9, France*
[3]*LEGOS 18 ave. Edouard Belin F-31401 Toulouse Cedex 4, France*

The French MERCATOR project is developing several operational ocean forecasting systems to take part in the Global Ocean Data Assimilation Experiment (GODAE). Prototype systems are designed to simulate (1) the Atlantic and Mediterranean Sea (from 1/3° to 1/15°), and (2) the global ocean circulation (from 2° to 1/4°). The first generation assimilation scheme referred to as SAM1 has been implemented in the operational system. It provides routine weekly analyses and forecasts. SAM1 includes an altimetry-only version (SAM1-v1), and a fully multivariate version (SAM1-v2) permitting to assimilate vertical profiles and SST in addition to altimetry (JASON, ERS-2 and GFO). The SAM1 scheme is based on the SOFA reduced order interpolation scheme (LEGOS, Toulouse). It uses vertical/horizontal separation of error statistics, and order reduction in the vertical in terms of multivariate Empirical Orthogonal Functions (EOFs) of temperature, salinity, and barotropic streamfunction. The next generation assimilation system referred as SAM2 is being developed from the SEEK (Singular Evolutive Extended Kalman) algorithm (LEGI, Grenoble). This scheme is a Reduced Order Kalman Filter using a 3D multivariate modal decomposition of the forecast error covariance as well as an adaptive scheme to specify parameters of the forecast error. The use of the SEEK filter and its 3D modal representation for the error statistic is intended to overcome some of the limitations of SAM1 in highly inhomogeneous, anisotropic, and nonseparable regions of the world ocean such as shallow areas, as well as in the surface layer. A second objective for SAM2 will be to consistently propagate error estimates between successive assimilation cycles. We also developed several methods in order to generate 3D EOF basis both from local or global EOF calculation. Comparisons between these various multivariate approaches (SAM1 and SAM2) will be presented and discussed both for single data assimilation experiments and for hindcast experiments during 2002.

Assimilating XBT profiles: How to handle salinity?

W. C. THACKER
Atlantic Oceanographic and Meteorological Laboratory, NOAA, USA

L.SINDLINGER
University of Miami, USA

When assimilating XBT data into models for simulating oceanic circulation, it is important to correct salinity along with temperature. Otherwise the model's density field can be adversely effected, leading to unrealistic pressure gradients and currents. The simplest method for incorporating salinity corrections is by assimilating salinity profiles that are estimated from the observed temperature profiles.

To estimate empirical relationships between salinity and temperature from archived CTD data, several issues must be confronted: (1) the archives contain both good and bad data; (2) the sampling is highly non-uniform, both spatially and temporally; (3) the data are non-normally distributed; and (4) TS properties can change from region to region. Fortunately, the TS plots at fixed pressure show fairly tight relationships over large regions. While both temperature and salinity vary widely in the vicinity of strong meandering fronts, this variation is confined to the neighbourhood of a curve on the TS diagram, so regression models can be easily identified. Examples are presented for a large region in the North Atlantic containing the Gulf Stream extension and for the Gulf of Mexico.

Atlantic Oceanographic and Meteorological Laboratory
4301 Rickenbacker Causeway, Miami FL 33149 USA

SYSTEMIC PARADIGM IN MARINE ENVIRONMENTAL PREDICTION

I.E.Timchenko and E.M.Igumnova
Marine Hydrophysical Institute. Sevastopol. Ukraine
e-mail:timchenko@stel.sebastopol.ua

There exist six concepts of system analysis approach [1] which have proved to be very useful in a dynamic-stochastic modeling of the ocean [2]. First one is the relativity of goals concept, demanding that environmental model must be fitted to the objectives of investigation. Second one is the integrity concept. Due to this concept a selection of the most important processes leading to the objectives could be chosen. Causality is the third concept which introduces cause-effect interactions inside a system and forms its structure. Forth concept is the subordination which defines the boundaries of the modeling system and implies external forcing. Dynamic balance of causes is the fifth concept which plays important role in a model formal presentation. And finally sixth concept is the information unity of an environmental model with the observation system feeding the model with information required. All concepts form a systemic paradigm as the ground for marine environment modeling.

We have currently applied this systemic paradigm in dynamic-stochastic models (DSM) construction for various marine environmental case studies [3,4]. One of the nontraditional consequences of such approach was the adoption of conditional upon ocean field measurements averaging of the ocean model's equations and using space-time variable turbulence exchange coefficients. That was the reason also why we have tended to exploit Kalman's filtering technique in four-dimensional data assimilation in numerical models instead of variation approach [4]. We have prepared a brief survey of these results in the paper.

Than we have focused on a new Adaptive Balance of Causes (ABC) method we have managed to develop by application of systemic concepts mentioned above [1]. We considered a problem of marine environmental prediction based on dynamic-stochastic ABC model of some n processes x_i having auto and cross correlation matrix $\{D_{ij}\}$. We explained how systemic concepts permit to ground the simple and uniform structure of the prediction model required

$$dx_i/dt + x_i = a_{i1}\,x_1 + a_{i2}\,x_2 + a_{i3}\,x_3 + \ldots + a_{in}\,x_n; \qquad (i,j = 1, 2, \ldots, n).$$

An obvious advantage of linear interactions between processes does not restrict the quality of prediction because the ABC method gives an opportunity to make the model coefficients variable. Moreover, it supplies another one dynamic-stochastic model for current prediction of the a_{ij} values

$$da_{ps}/dt + a_{ps} = D_{ps} - a_{p1}\,D_{s1} - a_{p2}\,D_{s2} - \ldots - a_{pn}\,D_{sn}; \qquad (p,s = 1, 2, \ldots, n; \quad p \neq s).$$

Our experience in using such ABC models confirmed that they are robust and very efficient. By calculation of current correlation matrix from archival data one could adjust to measurements predicted estimates of coefficients and hence of processes itself. It could be done by just the same way as in the optimal interpolation scheme. So it becomes quite evident, that the ABC approach brings together two fundamental results of multivariable processes modeling: Forrester's system dynamics and Kolmogorov's optimal filtering [1]. That opens a way to a wide implementation of ABC DSM in marine data reanalysis and operational environmental prediction. Examples of such prediction were supplied and discussed.

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Data assimilation in nested-grid models

L. VANDENBULCKE, A. BARTH, A. ALVERA-ALCAZARATE, Z. BEN BOUALLEGUE, M. RIXEN, J-M. BECKERS

GHER, University of Liege, Belgium

When using nested grids, a preliminary, simple, 1D test case showed the interest of combining all state vectors into one single vector, and using global error matrices covering all the grids at once. In this case, the assimilation procedure provides errorspace feedback from the fine grid to the coarser grid, which proves to be even more important than the statevector feedback. Assimilation of the same data in the coarse grids is not necessary anymore, as information from local stations is backpropagated in the coarse models. Large data transfers from local to basin-scale models can be avoided.

The GHER hydrodynamic model (for a full description, see e.g. [**?**]) is applied to a three times nested model covering (a) the Mediterrannean Sea, (b) the Liguro-Provencal Bassin, and (c) the Gulf of Lions. The simulation starts on Januari 1st, 1998, using NCEP atmospheric forcings and MODB4/MEDAR climatic data. As the model allows mode splitting, the simulation uses 2D timesteps of 3 seconds, and 3D timesteps of 3 minutes, on each grid.

Surface temperature and salinity are assimilated in this model every 12 hours, using optimal interpolation (see [**?**]). Different simulations are implemented, using different ways to combine grid nesting and data assimilation: with or without state vector feedback, with data assimilation only in the local (refined) grid, or in the coarser grids, or both, and with or without errorspace feedback (i.e. with 3 separated state vectors or with one global statevector). The perturbed initial condition is a delayed model state of the reference run. An initial reduced-rank model errorspace is constructed from 20 EOFs, themselves built from the reference run. The comparison of those experiments comfirms shows that using a global statevector reduces the error in the coarser grids faster than the use of 3 separated statevectors.

The effect of data assimilation, and the performances of the different methods, can be examined by calculating RMS errors between the perturbed run and the reference run. They can also be observed by following the model state trajectory in the EOF-space (for example, using the first three EOFs). In the context of the twin experiment described above, the first assimilation cycle clearly takes the model back in time. This is consistent with the choice of the disturbed initial conditions, being a delayed state of the reference run. The following assimilation cycles have little effect, as the trajectory is already almost brought back on the reference trajectory.

A new experiment performs assimilation in the Gulf of Lions in the spring of 1998 using real observations. Different variables are assimilated, using data collected during the FETCH campaign: NOAA/AVHRR SST, temperature and salinity from Atalante CTDs, and altimetric data from the ERS2 or TOPEX satellites.

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GeoHydrodynamics and Environment Research Lab., University of Liege, Sart Tilman B5, B-4000 Liege.

Modelling harmul algal events in the English Channel applied to the bloom of Karenia mikimotoï that occured during the summer 2003

A. Vanhoutte-Brunier[1], F. Gohin[2], P. Cugier[2], F. Dumas[2] and A. Ménesguen[2]

[1]IFREMER, Boulogne-sur-mer, France

[2]IFREMER, Brest, France

A spectacular bloom has been observed with SeaWIFS imagery of the surface chlorophyll in western english Channel during the summer 2003. Samplings during a cruise managed by the CEFAS show that an exceptional monospecific bloom of the dinoflagellate Karenia mikimotoï occured in the central English Channel (Fernand, pers. comm.). This ichthyotoxic species is very sensitive to turbulent conditions. Stratified areas, like north-western English Channel in summer, are favourable to its development. The aim of this study is to reproduce this event with a 3D model of the Channel ecosystem.

The model couples hydrodynamical, biological and hydrosedimental processes already described. The finite difference MARS 3D hydrodynamical model computes currents, salinity and temperature fields with a 4 km $\times$ 4 km horizontal resolution and a 12 σ-coordinate layers vertical resolution. The biological model is of NPZ type, with 4 nutrients (NH_4, NO_3, PO_4, $Si(OH)_4$) and two bulk phytoplanktonic compartments (diatoms and flagellates). Its originality lies to the adjunction of a Karenia mikimotoï specific variable, as first done in the Bay of Biscay [Loyer et al., 2001]. The transport of particles and their fate in the sediment are determined by equations implemented in the hydrosedimental model SiAM3D [Cugier and Le Hir, 2002].

The model is mainly validated by chlorophyll concentrations derived from SeaWIFS data [Gohin et al., 2003]. In situ observations from the French Phytoplancton and Monitoring Network (REPHY) complete this validation along the French coasts. The imagery shows a propagation of the bloom from the central English Channel to coasts of the northern French coasts of Brittany during july. The model enables to assess the roles of true advective transport versus spreading of propitious conditions of stratification in the apparent extension of this remarkable toxic bloom.

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IFREMER/DEL, 150 Quai Gambetta, BP 699, F-62321 Boulogne-sur-mer Cedex.

Integration of multidisciplinary observations data using OceanBase database management system.

VLADYMYROV V.[1], LYUBARTSEV V.[1] , MYROSHNYCHENKO V.[2]

[1]MARINE HYDROPHYSICAL INSTITUTE, NASU, UKRAINE

[2]INSTITUTE OF MARINE SCIENCES, METU, TURKEY

The modern systems of marine environmental monitoring and predictions need to use large sets of interdisciplinary data of the marine and coastal environment that can contain a lot of variables from different disciplines and sources and with different structure. Moreover, the most interesting scientific results can be obtained at the boundaries between different disciplines. However, it is a very complicated task to combine the interdisciplinary multivariable data sets and to provide the possibility to store and analyze them efficiently. Industry standard database management systems are not enough suitable to perform this task.

The special unique database management and processing system (OceanBase) to address this task has been developed at the Marine Hydrophysical Institute (Sevastopol, Ukraine) and Institute of Marine Sciences (Erdemli, Turkey). OceanBase can work with large sets of multivariable interdisciplinary oceanographic and environmental data. It works under Windows-9*/2000/XP in the delayed time and near-real time modes and provides quick and comfortable work with data.

The system allows to load, view, sort, select, process, combine, and export efficiently all necessary data and metadata. There are no real limitations for the number of stored variables and amount of data. The system permits to store a quality flag with each data value and to use the quality criteria in the data selection. Modeling data can be stored jointly with the data of measurements in the same database. Data can be selected on variable(s), institution, expedition, time (year, month, day, hour), region, sea depth, depth layer, etc.

OceanBase can manage not only the standard type of oceanographic data (profiles, surface or bottom measurements) but also the "layer" type of data, for example, data of the zooplankton net tows or bottom core samples. In case the necessary variables data are dispersed among different stations, user can create "virtual" stations combining variables from different stations according to defined time and space search criteria.

It includes many embedded graphical possibilities: maps, profiles, sections, histograms, etc. It is possible to calculate mean profiles, spatial distributions, and various statistics. There are special tools to analyze the interdisciplinary data jointly. For example, user can calculate the chlorophyll distribution at the predefined level of transparency or any other variable.

An example of the successful use of this system is the Black Sea interdisciplinary historical database. It has been created using OceanBase system in 1997 within the framework of the NATO TU-BLACK SEA project and updated in 2002 within the framework of the NATO SfP Black Sea Operational Database Management System project. Database includes all basic physical, chemical and biological variables (152) for the entire Black Sea (about 30,000 stations). This database is now in use in the leading Black Sea scientific institutions. It already gave the possibility to obtain some interesting scientific results in studying and modeling of the Black Sea.

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[1]Marine Hydrophysical Institute, NASU, 2 Kapitanskaya St., Sevastopol, 99000, Ukraine

[2] Institute of Marine Sciences, METU, PO Box 28, Erdemli-Icel, Turkey

New Devices for Marine Monitoring and Investigations

GIUSEPPE ZAPPALA', GABRIELLA CARUSO AND ERMANNO CRISAFI

CNR – Istituto per l'Ambiente Marino Costiero (IAMC) Section of Messina, Italy

In the last years a special effort was made in the Section of Messina of CNR-IAMC (formerly Istituto Sperimentale Talassografico CNR of Messina) to develop new instruments, devices and analytical methods for Marine Investigations.

In the framework of Cluster 10 MIUR programme, a network of seven coastal monitoring platforms was built, each equipped with a pumping system taking water samples from five depths for subsequent temperature, salinity, dissolved oxygen, turbidity, fluorescence, ammonia, nitrates, nitrites and phosphates measurements; *in situ* temperature probes are installed near the sampling inlets. A meteorological station and a computer managing all data acquisition and transmission operations complete the equipment common to all the platforms, one of which hosts also a multi-bottle water sampler, collecting and fixing with formalin up to eight 250 ml samples for in vitro laboratory determinations of faecal pollution indicators (*Escherichia coli*) and an Acoustical Doppler Current Profiler. A complete measurement cycle occurs every six hours, while every hour only *in situ* temperature probes, meteo station and ADCP are examined; measurements are then sent to the base station using GSM-GPRS modems via SMS and e-mail; mission parameters and the whole control software are remotely manageable and upgradable [*Zappalà* et al., 2002].

Since 2002, the platforms have been installed in some Sicilian (Messina, Milazzo, Palermo, Siracusa, Mazara del Vallo) and Apulian (Manfredonia and Taranto) sites; the data bank is managed in Messina and is reachable via WEB. Data collected proved to be effective to depict the environmental scenario under different, multidisciplinary (physical, chemical and biological), aspects.

As a part of the "Mediterranean Forecasting System towards Environmental Prediction" (MFSTEP) European research programme, an automatic multiple XBT launcher was designed and is now being tested. This development aims to optimize the operativity on Voluntary Observing Ships (VOS), through the automation of the XBT launch - data acquisition - data transmission operations. Basically, the system consists in a small container (about 50 x 50 x 50 cm) to be hanged outboard the ship, hosting eight XBTs, each individually released using pneumatical devices; a software running on a control computer continuously compares time and ship position with the programmed ones, issuing at the right time the launch command. The launch options (locally and remotely modifiable) include position related (near to, far from, south of, north of, east of, west of) and timed events. Data measured from the XBTs and from other optional sensors (e.g. meteorological observations) are locally stored in the computer and can be transmitted using terrestrial (GSM-GPRS) or satellite links; the real time transmission enables to use them also in nowcasting-forecasting activities.

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