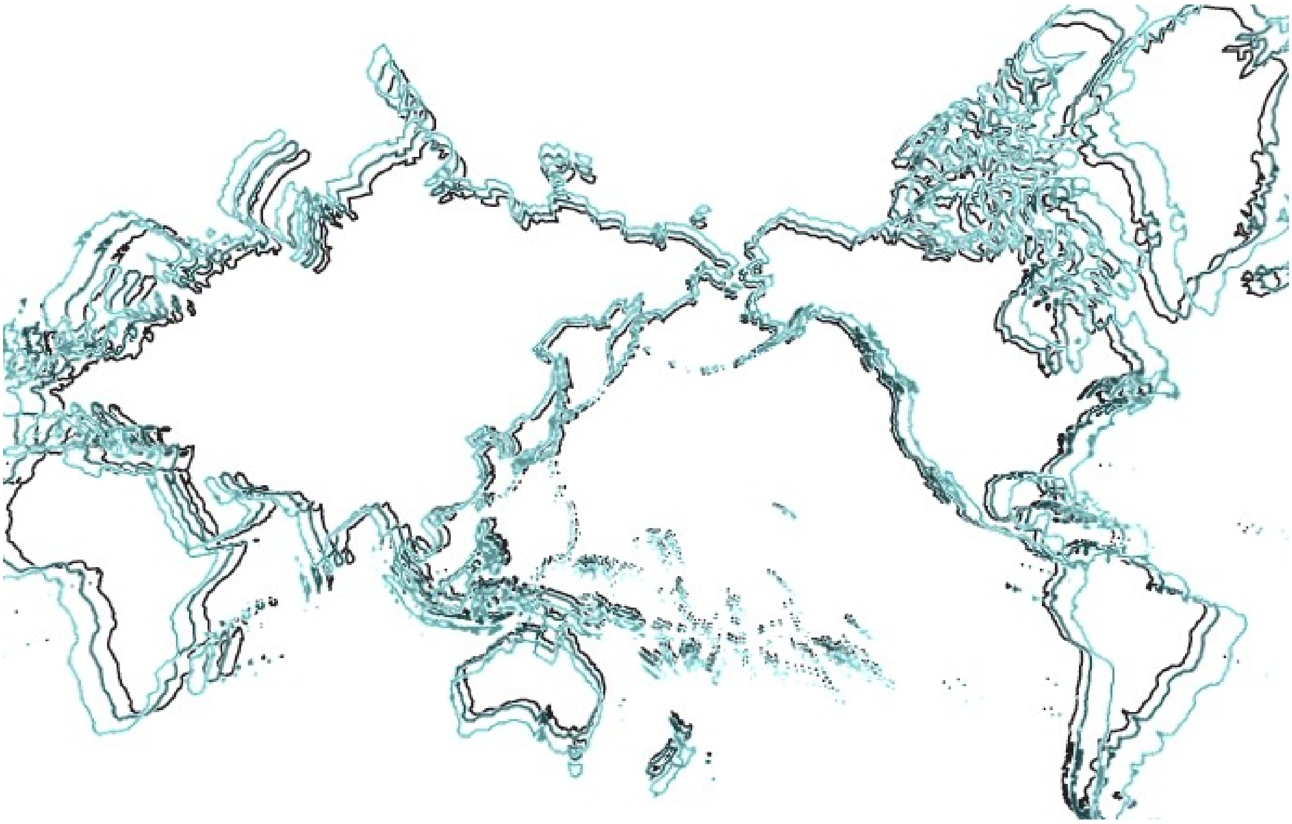
Towards the assessment and demonstration of the value of GODAE results for coastal and shelf seas models and forecasting systems

The GODAE Coastal and Shelf seas Working Group:
Pierre De Mey[1], Peter Craig[2], John Kindle[3], Yoichi Ishikawa[4], Roger Proctor[5], Keith Thompson[6], Jiang Zhu[7], and contributors[8]



[1] LEGOS/POC, France, pierre.de-mey@legos.obs-mip.fr
[2] CSIRO, Australia
[3] NRL, USA
[4] U. Kyoto, Japan
[5] POL, United Kingdom
[6] DAL, Canada
[7] IAP, China
[8] listed in Appendix 1

First Edition / December 14, 2006

Table of Contents

1.Rationale

The Global Ocean Data Assimilation Experiment (GODAE) is a practical demonstration of near-real-time, global ocean data assimilation that provides, regular, complete descriptions of the temperature, salinity and velocity structure of the ocean in support of operational oceanography, seasonal-to-decadal climate forecasts and analyses, and oceanographic research.

According to the GODAE Strategic Plan (IGST, 2000), the first objective of the project is to "apply state-of-the-art ocean models and assimilation methods to produce short-range open-ocean forecasts, boundary conditions to extend predictability of coastal and regional subsystems, and initial conditions for climate forecast models." The 2002 GODAE Development and Implementation Plan states: "Climate and seasonal forecasting, navy applications, marine safety, fisheries, the offshore industry and management of shelf/coastal areas are among the expected beneficiaries of GODAE." The usefulness of GODAE systems to coastal and shelf seas forecasting will therefore be one of the measures of the success of the project.

The consensus within the GODAE project is that it is too early to develop the large-scale coordination effort required to comprehensively meet the needs of, and get feedback from, a very wide range of coastal modellers and users, but that exploring the application of GODAE models to a relatively small number of regional and coastal models in the countries involved in GODAE is within reach. It is particularly important for GODAE to examine how the suitability of the existing large-scale estimates to coastal downscaling can be improved.

With that purpose in mind, it is felt that an important part of the work will be to share experience gained from using the different existing Coastal and Shelf Seas (CSS) systems during the life of the GODAE project (typically up to 2008). An *ad hoc* working group, the GODAE Coastal and Shelf Seas Working Group (CSSWG), was created at the beginning of 2006 with the mission to **define, monitor, and promote actions, within GODAE, aimed at the assessment and demonstration of the value of GODAE results for regional, coastal and shelf seas models and forecasting systems, within the 2006-2008 time frame**.

This Position Paper is a first step towards that goal. It has been prepared by the GODAE Coastal and Shelf Seas working group, and has been reviewed by the International GODAE Steering Team at the Beijing meeting in October 2006. Its primary purpose is to make a first set of achievable actions emerge, and to identify the groups and models who are willing to participate. Our focus here will be on regional seas, marginal seas, coastal seas, and on processes linked to the exchanges between the shelf and the open ocean and atmosphere-ocean interactions at the coastal scale.

2.Coastal and shelf seas downscaling within GODAE

2.1 Uses of coastal models

Coastal ecosystems have been subject to unprecedented stresses in recent decades. The main stressors are the increasing number of people moving into the coastal zone (e.g. Nicholls and Small, 2002) and climate variability and change. The resulting issues are diverse. They include changes in shorelines and nearshore bathymetry, increased coastal flooding, habitat modification, loss of biodiversity, eutrophication, increased probability of harmful algal blooms and chemical contamination, reductions in the abundance of exploitable living marine resources, and public health problems associated with water quality, beach and storm-water pollution, and increased seafood contamination.

In parallel, there are increasing requirements for forecasts of currents and marine parameters in shelf seas, over the shelf slope and beyond, in support of offshore oil industry operations, fish stock management, and water quality modelling (e.g. Holt, 2002).

Coastal modelling and forecasting is a major challenge for the scientific community because of the specific and rich dynamics of coastal regions, and because of the various couplings with the lower atmosphere and exchanges with the near-shore and offshore regions.

These issues, needs and challenges have led to the development of a wide range of models of various types. The most advanced models are based on physical principles and are used to mitigate the effect of coastal hazards and facilitate marine management. Phenomena of interest include tides and storm surges, tsunamis, shoreline change, coastal currents and hydrography, coastal upwelling, river plumes and regions of freshwater influence, atmosphere-driven processes, surface waves, and sea ice. The specific models used to manage living marine resources, and also help maintain ecosystem and public health, are often based on empirical relationships and statistical constructs (e.g. sequential population analysis, multi-species production and ecosystem models, dose-response relationships for ecotoxicology applications).

Coastal models cover variability on time-scales of minutes (e.g. tsunamis) to centuries (e.g. global sea level rise, vertical crustal movement and their combined effect on coastal flooding). The space-scales of interest range from tens of meters (e.g. water quality predictions in a specific harbor) to global (e.g. storm surge predictions by NCOM).

The models are used to help understand how coastal systems work (often in conjunction with specifically designed field programs), to reproduce specific situations and scenarios, to forecast marine parameters, and to design observing systems. The most important practical applications include reconstructing changes over recent decades (hindcasts), generating climatologies and spatial maps of the occurrence of extreme events, nowcasting of the present state of the coastal ocean in support of adaptive biological sampling and safe navigation, and finally short-term forecasting (e.g. sea level, currents and sea-state).

The models are sometimes used to provide “what-if” scenarios, looking at the implications, mostly, of climate change and variability, and coastal development. For instance a dynamical model can be run in conjunction with biogeochemical models to explore potential changes in nearshore primary productivity (e.g. Craig, pers. comm., 2006) and assess the effect of increased water temperature associated with climate change on the probability of occurrence of harmful algal blooms.

Although the coastal models are quite diverse in terms of their structure and application, the quality of their results is almost always critically dependent on the quality of the physical/dynamical component that is used to model the thermohaline and hydrodynamic variability. To illustrate, transport and dispersion are critical physical processes in determining the spatial distribution of harmful algal blooms and faecal pollution indicators. Similarly interannual changes in water temperature and depth are critical determinants of the health of coral reefs. This point of view is consistent with the conclusions of the Coastal Ocean Observations Panel of the Global Ocean Observing System. After objectively assessing the importance of a large number of physical, chemical and biological variables in terms of predicting and detecting change in coastal ecosystems, the panel concluded that the top 5 variables were sea level, water temperature, currents, changes in bathymetry and salinity (see Table 4.2 of The Integrated Strategic Design Plan for the Coastal Ocean Observations Module of the Global Ocean Observing System, 2003).

Clearly any improvement in the predictive skill of coastal models of physical conditions has the potential to increase the usefulness of a much wider range of models of nonphysical coastal processes and phenomena. As a consequence, **our main target in this document will be the assessment and demonstration of the value of GODAE results for physical coastal modelling (thermohaline/hydrodynamical), with time scales from hours to interannual, and space scales typical of coastal and regional seas processes (including the scales of exchanges between the open ocean and the shelf, excluding littoral processes).**

2.2 Links between large-scale and coastal models

Apart from the applications linked to global climate change monitoring, **most of the practical applications to which ocean forecasting, and GODAE in particular, can contribute are in the coastal zone**. Some of these applications are described in the previous section; other important applications are related to the **regional impact and sources of global change**. The GODAE systems are targeted at estimating the global ocean, but they also provide solutions in coastal and shelf seas. However, even though the coastal and deep ocean are components of the same coupled system, and the fundamental equations governing their physical evolution are identical, **models of the coastal ocean have specific requirements which are almost never met by the global open-ocean systems in their present state**. One important reason is that the spatial and temporal resolution required to make realistic predictions of coastal conditions are generally much higher than the resolution required for the adjacent deep ocean. For example tides, and the barotropic response to high-frequency atmospheric forcing, often dominate sea level and current variability on shelves and can control mixing and transport; these processes have time scales of hours and horizontal scales that can be of order 100 m or less. Also most large-scale ocean models have poor representation of shelves in addition to poor cross-shelf exchange. Another reason is that some of the phenomena important on shelves may require special numerical treatment (e.g. non-hydrostatic motion on small spatial scales, tidally generated solitons, upwelling and downwelling coastal fronts, jets, strong buoyancy input and regions of freshwater influence).

On the other hand, we are witnessing a slow **convergence between global and coastal models**. This can take the form of unique models for both classes of scales, or on-line integration of both types of models. The NCOM model, as a "global coastal model", is an example of a unique code, although it does not address all coastal processes. Also, depending on availability of appropriate resources, some GODAE groups plan to further increase the horizontal (and vertical) resolution of their models while adapting the mixing parameterizations. Two-way coupling (**Section 3.3.2**), mesh refinement techniques (e.g. AGRIF; Blayo and Debreu, 2005b) as well as unstructured-grid models (finite-element, finite-volume models; **Section 3.3.3**), are also being developed by several groups worldwide, but are not yet part of a GODAE core system. Two-way coupling may lead to a better scientific understanding of the scale interactions and possibly better parameterizations of coastal processes in open-ocean models. It may also lead to more effective ways of assimilating coastal data (such as coastal sea level) into ocean models by allowing for more accurate model representations of the observations. A specific advantage of the feedback onto the large-scale model is that many large-scale models have a poor representation of shelf seas even though coastal buoyancy fluxes and cross shelf exchange can have a significant effect on conditions over the slope and adjacent deep ocean (in particular its thermohaline structure). Although these new approaches are potentially ground-breaking, in the time frame considered in this Position Paper, **the separate modelling of the large scales and the coastal areas will remain the dominant practice**.

Although coastal and open-ocean models may continue to evolve separately in the near future, there are several **reasons for adopting a "downscaling" approach and coupling the models in a systematic way**. It is becoming increasingly clear that specifying the offshore boundary conditions of coastal models by using forecasts from a hydrodynamical large-scale ocean model has the potential (1) to provide better local estimates by **adding value to GODAE products**, (2) to **extend predictability on shelves**, and (3) to **enhance the representativeness of local observations**. This has been shown for instance in the Mediterranean Forecasting System (described in **Appendix 3**) in both 1-way and 2-way coupling situations. Given the central importance of the physical variables in coastal prediction, this has the potential to extend the predictability of many of the other types of multidisciplinary coastal models mentioned above. **In the short term, one-way coupling is a realistic starting point for this type of activity and will provide GODAE with a very direct way of demonstrating the value of its ocean products.**

One-way coupling has its own advantages in an operational context: flexibility in the selection of the most appropriate model physics and of the best locally available atmospheric products; *ad hoc* validation by teams knowledgeable about the local physical oceanography; functional links to end users permitting more effective feedback; experience with specific locally-validated numerical schemes which can then be ported to larger-scale systems. However in order to demonstrate the value of large-scale GODAE products, **their downscaling will have to address several critical issues and meet some specific requirements** (**Section 3.2**).

2.3 Ongoing/planned CSS downscaling projects linked to GODAE

This section lists (pre)operational coastal and shelf seas forecasting systems and academic projects with the declared intention of downscaling one or several of the produces from GODAE systems within the time frame considered in this Position Paper (2006-2008). A summary of those CSS systems, including their downscaling strategy and time frame, is contained in **Table 1** presented in the next pages. The approximate geographic locations of the systems are illustrated by **Figure 1**. The detailed system descriptions can be found in **Appendix 2**.

Table 1: An overview of some ongoing/planned CSS downscaling projects linked to GODAE

Project name	Contact	Domain	Objectives	Downscaling strategy	Project status
P1 Regional Ocean around Southern Africa (TOMOROSA)	Bjorn Backeberg bjorn.backeberg@nersc.no	Regional ocean around Southern Africa	Advance the understanding of mesoscale dynamics and eddy evolving processes in the Agulhas Current system.	TOMOROSA is forced at the boundaries by a basin scale HYCOM model of the Indian and Southern Ocean developed and operated by the MohnSverdrup Center at NERSC	In development
P2a ROAM	Peter Craig Peter.Craig@csiro.au	Australasian shelf regions	To provide to the Australian Navy an automated, relocatable, high-resolution model for several-day forecasts of ocean conditions	Australia's global GODAE model is OFAM, to be run operationally, providing 10-day forecasts at 10-km resolution. ROAM nests down to 2 km. Tides are incorporated from a global tidal model	Projected completion Jan 2007
P2b ROAM II	Peter Craig Peter.Craig@csiro.au	Australasian shelf regions	To incorporate data-assimilation, surface waves, and possibly two-way ocean-atmosphere coupling into ROAM	As above	4-year project commenced in July 2006
P3 CLAM-TC	Peter Craig Peter.Craig@csiro.au	Northern Australian shelf	To improve tropical cyclone forecasts by incorporating active coupling with an ocean model	The ocean model is presently nested into OFAM at the same (10-km) resolution, but the limited area model is rerun to allow ocean-atmosphere-coupling	Ongoing, due for completion in June 2010
P4 Ocean Data Assimilation and nowcasting system for China Marginal Seas	Jiang Zhu jzhu@mail.iap.ac.cn	China Seas (including the Yellow Sea, East China Sea and South China Sea)	To provide various operational agencies a prototype ocean data assimilation and nowcasting (0-3 days) system for China Seas	A 2-step one-way nesting HYCOM model system is used. The larger domain covers the Western Pacific and the Indian Ocean. The open boundary conditions of the larger domain are relaxed to climatology.	Approved and sponsored by the Chinese Academy of Sciences. This 3-year project will start January 2007
P5 Mohn-Sverdrup Center South China Sea HYCOM (MSC-SCS)	Laurent Bertino Laurent.Bertino@nersc.no	South China Sea	Real-time monitoring and prediction system, hindcast studies, research. To forecast the currents in the South China Sea.	One-way and off-line nesting. The interactions with the Pacific Ocean need to be correctly represented. HYCOM-to-HYCOM downscaling, the outer model is a Pacific Ocean HYCOM.	A 20-year hindcast study has been completed

Table 1 (page 2)

Project name	**Contact**	**Domain**	**Objectives**	**Downscaling strategy**	**Project status**
P6 Comprehensive nowcast/forecast system for the Japanese coast (MOVE /MRI.COM-JC)	Hiroyuki Tsujino htsujino@mri-jma.go.jp	Coastal region around Japan	Real-time monitoring and prediction, reanalysis of coastal sea-level (tides and storm surges), currents, water temperature.	Open BC from MOVE/MRI.COM-WNP (JMA operational nowcast/forecast system for the western North Pacific region). Surface atmospheric BC from JMA operational nowcast/forecast system.	In planning. Funded by MRI.
P7 Monitoring and forecasting system of the ocean circulation off Rokkasho	Yoichi Ishikawa ishikawa@kugi.kyoto-u.ac.jp	Northwestern Part of North Pacific	Real time monitoring of the circulation to provide current field, which is used for tracking radionuclides released from a spent nuclear fuel reprocessing plant in Aomori Pref.	2 step one-way nesting. Northwestern part of the North Pacific Data assimilation system (1/6x1/8°) → Japan regional model (1/18x1/24°) → Off Rokkasho Coastal model (1/54*1/72°)	In testing
P8 Japan Coastal Ocean Predictability Experiment (JCOPE)	Yasumasa Miyazawa miyazawa@jamstec.go.jp	12-62°N, 117-180°E	Forecasting large-scale variations and coastal impacts of the Kuroshio path south of Japan	One- or two-way nesting	Constructing higher resolution (1/108°) tidal model including the Tokyo Bay, Sagami Bay, and Suruga Bay
P9 National Ocean Partnership Program (NOPP) GODAE HYCOM	John Kindle kindle@nrlssc.navy.mil	US West Coast; Monterey Bay	To evaluate the influence of HYCOM GODAE boundary conditions on the circulation of the US west coast as represented by a suite of nested models	Use Global HYCOM to provide boundary values to a suite of nested models ranging from regional(entire US west coast) to local(Monterey Bay)	Boundary conditions between NCOM and HYCOM developed and tested. Presently awaiting global HYCOM with data assimilation for evaluation relative to global NCOM.
P10 Coupled Bio-optical and Physical Processes (CoBIOPP); Coastal Ocean Nesting Studies (CoNESTS)	John Kindle Naval Research Laboratory kindle@nrlssc.navy.mil	US West Coast; Monterey Bay	To evaluate the relative influence of HYCOM and NCOM GODAE boundary conditions on the circulation of the US west coast as represented by a suite of nested models, including coupled bio-physical models; to evaluate HYCOM as a coastal model; to evaluate HYCOM as a host for coastal ecosystem models	Use Global HYCOM and Global NCOM to provide boundary values to a suite of nested models ranging from regional(entire US west coast) to local(Monterey Bay) Modeling strategy: Regional HYCOM at 9km and 4km resolution and Multi-nested NCOM, ranging from 9km to .5km for finest Monterey Bay model	Ongoing

Table 1 (page 3)

Project name	**Contact**	**Domain**	**Objectives**	**Downscaling strategy**	**Project status**
P11 Assessing the Impact of GODAE Boundary Conditions on the Estimate and Prediction of the Monterey Bay and California Central Coast Circulation (CODAE California)	Christopher Edwards University of California—Santa Cruz cedwards@ucsc.edu	Monterey Bay, CA	To evaluate the relative influence of ECCO GODAE boundary conditions on circulation metrics of the Central California Coast.	To move from West Coast, 10 km model-scale to 3 and then to 1 km scale. Inner model nest extends from Big Sur to Pt. Arena. Modeling strategy: Triply nested ROMS configuration. Nesting presently carried out offline. 3 Km COAMPS forcing	Forward model successfully implemented with GODAE boundary conditions and COAMPS surface forcing. 4D-variational assimilation of SST and SSH and sensitivity studies are underway.
P12 "Oregon Coast": Boundary conditions, data assimilation, and predictability in coastal ocean models (OSU-NRL-NCAR NOPP-CODAE)	Roger Samelson Oregon State University rsamelson@coas.oregonstate.edu	Oregon Coast	Assess impact of GODAE boundary conditions using data assimilation, and address closely related issues of uncertainty and predictability in coastal ocean circulation models.	High-resolution three-dimensional terrain-following primitive equation coastal ocean model (ROMS code) with generalized inverse or ensemble-based data assimilation; NCEP and COAMPS meteorological forcing and observed river inflow; all standard physical oceanographic fields estimated; hindcast model simulations of months to years.	First year
P13 HYPO Coastal Ocean Hindcasts and Predictions: Impact of Nesting in HYCOM GODAE Assimilative Hindcasts (NOPP-CODAE)	George Halliwell University of Miami ghalliwell@rsmas.miami.edu	Gulf of Mexico: various sites	Determine the impact of initial and boundary conditions provided by HYCOM GODAE ocean nowcasts and forecasts on the capability of nested models to hindcast and predict the coastal ocean environment	Each of the three coastal modeling efforts will conduct nested ocean hindcasts, and then use all available in-situ observations to evaluate model performance. Sensitivity to initial and boundary conditions will be assessed by nesting the models within different outer model products. For this project, these products will be provided by the evolving HYCOM nowcast-forecast system.	The first sets of outer model archives within which the coastal models will be nested either have been, or are being generated, for the initial study interval (2004-2005). The NCODA and ROIF nowcast products are being developed within a HYCOM domain spanning the Gulf of Mexico.

Table 1 (page 4)

Project name	Contact	Domain	Objectives	Downscaling strategy	Project status
P14 Enabling and Initiating Observing System Simulation Experiments of a Coastal High Resolution Oceanographic Model in the Northern Gulf of Mexico (NOPP GODAE HYCOM)	Villy Kourafalou University of Miami vkourafalou@rsmas.miami.edu	Northern Gulf of Mexico	Develop an Observing System Simulation Experiment (OSSE) system applicable to the Northern Gulf of Mexico (NGoM), and begin to conduct OSSEs to define the optimal observing systems for this region.	Use a high resolution HYCOM assimilative model covering the Gulf of Mexico through the Florida Straits (GoM-HYCOM), itself nested within the larger-scale HYCOM GODAE product, to obtain initial and boundary conditions for a higher resolution coastal model (NGoM-HYCOM).	The project just started and will finish summer of 2009.
P15 Mohn-Sverdrup Center Gulf of Mexico HYCOM (MSC-GOM)	Laurent Bertino Laurent.Bertino@nersc.no	Gulf of Mexico	Real-time monitoring and prediction system, hindcast studies, research. The objective is to forecast the Loop Current and Eddies as they approach the Northern Shelf of the GOM.	One-way and off-line nesting. The inflow through the Yucatan Strait needs to be correctly represented. HYCOM-to-HYCOM downscaling, the outer models are TOPAZ and HYCOM 1/12°.	Forecasts are running weekly since 2004
P16 Canada-Newfoundland Operational Ocean Forecasting System (C-NOOFS)	Fraser Davidson davidsonf@dfo-mpo.gc.ca	35N-80N, 77W-35W	Develop end-to-end operational ocean prediction system for the Northwest Atlantic with particular emphasis (grid refinement) on Canadian Waters.	One-way nesting within global /basin model for Northwest Atlantic. Two-way coupling using the AGRIF grid refinement scheme within the domain on area of interest.	Pilot project, underway
P17 "US Northeast coast (WHOI)": Evaluation of GODAE Hindcasts in Providing Open Boundary Conditions for High Resolution Coastal Circulation Modeling	Ruoying He Woods Hole Oceanographic Institution ruoying@whoi.edu	The coastal region from Nova Scotia to Cape Hatteras, including the Gulf of Maine (GOM) and the middle Atlantic Bight (MAB).	To resolve open ocean impact on coastal circulation; remote forcing through coastal wave guide; well-posedness on open boundaries.	High-resolution three-dimensional terrain-following primitive equation Regional Ocean Modeling System; NCEP meteorological forcing and observed river flow; hindcast model simulations of months to years.	In progress

Table 1 (page 5)

P18 Mohn-Sverdrup Center Barents Sea HYCOM (MSC-Barents)	Laurent Bertino Laurent.Bertino@nersc.no	Barents and Kara Seas	Real-time monitoring and prediction system, hindcast studies, research. The objective is to forecast the currents and sea-ice conditions in the Barents and Kara Seas and to provide input data to an iceberg forecasting system.	One-way and off-line nesting. The Barents Sea is very sensitive to the variability of the North Atlantic Water inflow, the exchanges of Arctic Water and of sea-ice with the Central Arctic. TOPAZ boundary conditions for 3D ocean parameters and sea-ice.	Forecasts are running daily since 1st September 2006.
P19 DAMOCLES (Developing Arctic Modelling and Observing Capabilities for Long-term Studies)	Laurent Bertino Laurent.Bertino@nersc.no	The Fram Strait	Forecast the complex mesoscale currents and sea-ice conditions in the Fram Strait and to provide input data to an acoustic tomography inversion system.	One-way and off-line nesting. The Fram Strait is the main connection between the Nordic Seas and the Actic and the fluxes are mainly controlled by the West Spitzberg and East Greeland currents. High quality lateral boundary conditions of ocean and sea-ice parameters are absolutely vital. TOPAZ boundary conditions for 3D ocean parameters and sea-ice.	In development
P20 Eddy resolving HYCOM model of the Nordic Seas (NORDIC)	Laurent Bertino Laurent.Bertino@nersc.no	Nordic Seas	To study the mesoscale currents in the Nordic Seas.	One-way and off-line nesting. The inflow of North Atlantic Water and Arctic Waters needs to be correctly represented. TOPAZ boundary conditions for 3D ocean parameters.	In development
P21 Mohn-Sverdrup Center Norwegian Sea Ecosystem MSC-NWS-ECO	Laurent Bertino Laurent.Bertino@nersc.no	Norwegian Sea and Coastal Current	To study the influence of mesoscale fronts and eddies on the ecosystem in the Norwegian Sea	One-way and off-line nesting. A three level HYCOM-to-HYCOM downscaling is used.	A hindcast study for the years 1995-1996 is ongoing.

Table 1 (page 6)

P22 Mohn-Sverdrup Center CONMAN HYCOM (MSC-CONMAN)	Laurent Bertino Laurent.Bertino@nersc.no	Norwegian Sea and North Sea	Real-time monitoring and prediction system, hindcast studies, research. To forecast the currents in the North Sea and Norwegian Sea, in particular at the Ormen Lange field, and to compare HYCOM to POM and ROMS models operated at met.no .	One-way and off-line nesting offer sufficient flexibility for operating the nested model. The North Atlantic Water inflow needs to be correctly represented. High quality lateral boundary conditions of ocean parameter are absolutely vital.	Forecasts are running daily since 15th December 2005
P23 ECOOP BalEco	Tapani Stipa Tapani.Stipa@fimr.fi	Baltic Sea (8.9E-30.1E, 54N-67N)	Real-time monitoring and prediction, reanalysis, scenario-testing. Operational modelling with 72 hour forecasts (ECMWF).	Downscaling to improve representation near model boundaries, boundary conditions between Baltic Sea and North Sea. Several estimates are used pre-operationally from MERCATOR and Topaz	Operational
P24 ECOOP Modeling the Baltic Sea with coupled POP and CICE model (IOPAS-POPCICE)	Robert Osinski roberto@water.iopan.gda.pl	Baltic Sea	Reanalysis, scenario-testing, research	From 9-km to 2-km.	9km version working
P25 MERSEA-ECOOP Baltic-North Sea system (DMI)	Jun She js@dmi.dk	Baltic Sea and North Sea	Real-time prediction	Use large scale predictions from MERSEA (EU GODAE Component) as boundary conditions of DMI operational 3D ocean forecasting system. The impact of this downscaling will be assessed by using model validation in MERSEA and ECOOP projects. The GODAE products will be provided by NCOF in UK.	Ongoing

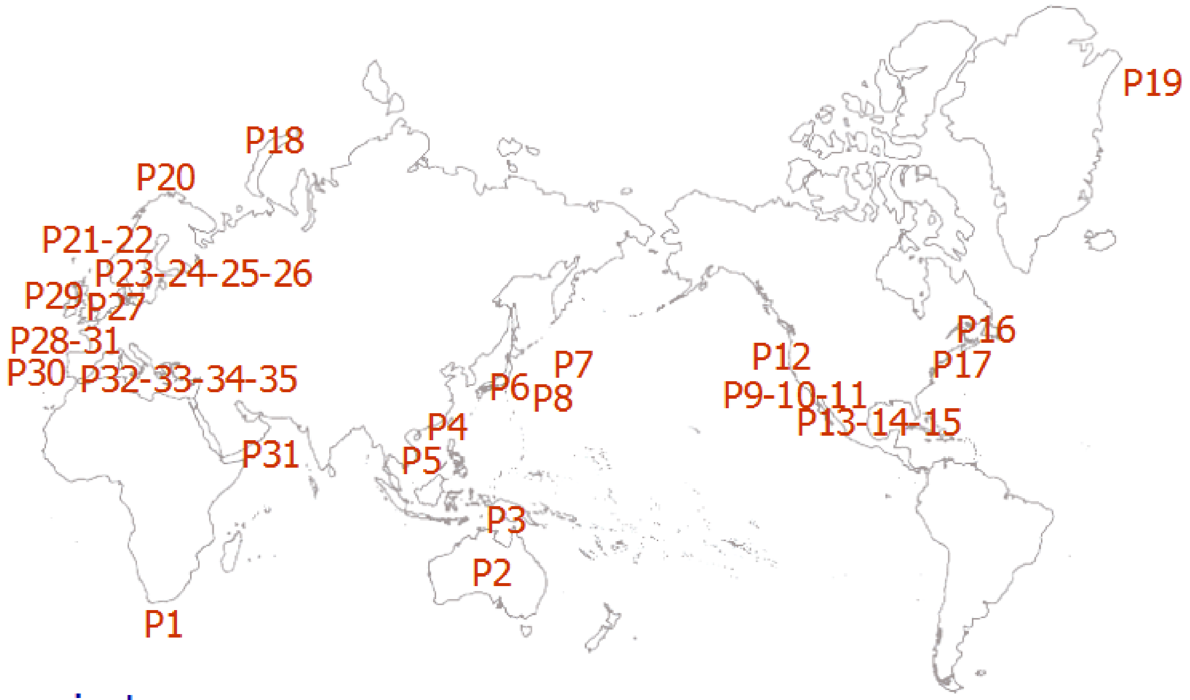
Table 1 (page 7)

P26 ECOOP BSHcmod	Stephan Dick stephan.dick@bsh.de	Baltic Sea and North Sea	Operational forecasting Support of water level prediction and storm surge warning service Drift- and dispersion predictions in case of marine pollution (e.g. oil) Support of SAR and various customers (navy, fisheries, tourism ...)	Nested models driven by tidal predictions and meteorological forecasts of German Weather Service (DWD)	Operational activity, ongoing
P27 MONCOZE	Laurent Bertino Laurent.Bertino@nersc.no	North Sea	To forecast the currents and ecosystem in the North Sea.	One-way and off-line nesting. The North Atlantic Water inflow needs to be correctly represented. TOPAZ boundary conditions for 3D ocean parameters.	The project is completed, its domain is now covered be the larger CONMAN system
P28 MERCATOR-ECOOP FAÇADE system	Dominique Obaton (MERCATOR) dobaton@mercator-ocean.fr	Atlantic arc (SW Europe) from North of Ireland to Canaries islands	Improve the global MERCATOR system along the SW European shelf slope and in adjacent coastal regions	Off-line nesting: open boundary conditions from the GODAE/MERSEA global system used for the regional system	Under development
P29 ECOOP POL Coastal Observatory	Roger Proctor rp@pol.ac.uk	Liverpool Bay in the eastern Irish Sea	Real-time monitoring and prediction, reanalysis, scenario-testing, research. Real-time monitoring and nowcasting / prediction system for understanding a shelf sea's response to anthropogenic and climate change. To provide scientific underpinning for coastal zone management.	One-way nested models (hydrodynamic and coupled ecosystem) from the Atlantic into Liverpool Bay. To provide the oceanic influence on the NW European Shelf we use FOAM (MERSEA) data for boundary conditions.	Started in 2002, ongoing.
P30 ECOOP Establecimiento de un Sistema Español de Oceanografía Operacional (ESEOO)	Enrique Alvarez Fanjul enrique@puertos.es	Spanish waters of the Atlantic	Real-time monitoring and prediction, reanalysis, scenario-testing, assessment of observational networks, research. To build up the capabilities required in Spain related to Operational Oceanography with special focus in fight against marine pollution.	3 D models are employed nested into global solutions. System is run once per day. We need downscaling from global to regional application due to the nature of the problem to be solved.	Project will be completed in 3 months. Activities will continue with new project or probably a permanent institution such as MERCATOR or NCOF.

Table 1 (page 8)

P31 MOUTON (Regional to Local Operational Oceanography)	Yves Morel Yves.morel@shom.fr	North-Eastern Atlantic & Arabian Sea	Extend the operational capabilities of the French Navy nowcast/forecast systems to regional and local areas including coastal zones. One first aim is to build a demonstrator on the English Channel/Bay of Biscay/Portugal/Cadiz area and to evaluate its operational performance.	The regional and local models are forced by MERCATOR (GODAE/MERSEA global system) for the low frequency oceanic fields, and by MOG2D for the tides. Several atmospheric forcings are also tested (ARPEGE, ALADIN, AROME).	Ongoing. Started in September 2001, end in December 2009.
P32 ECOOP-MOON-COOL (IMEDEA GODAE)	Joaquín Tintoré jtintore@uib.es	Western Mediterranean: South of Mallorca, Balearic Islands, Algerian and Alboran sub-basins	Real-time monitoring and prediction to address scientific questions associated with the high resolution modelling in the near coastal area. Coupling hydro-dynamical processes (waves and currents) in the coastal zone.	A high resolution PE ocean circulation model is used following a downscaling approach from a basin-scale model of the Mediterranean Sea.	Starting October 2006
P33 MOON Adriatic core system (ADRICOSM)	Paolo Oddo oddo@bo.ingv.it	Adriatic Sea	Integrated management of Adriatic Sea coastal areas and river basin water resources	AREG: Variational Balanced Initialization (VIFOP) from MFS OGCM	In progress
P34 MOON Levantine core system (ALERMO)	Sarantis Sofianos sofianos@oc.phys.uoa.gr	Levantine basin and Aegean Sea	Estimates of marine parameters, forecasting, provide i.c.s/b.c.s to downscaled systems (e.g., Cyprus)	Variational Balanced Initialization (VIFOP) from MFS OGCM	In progress
P35 MOON North-Western Mediterranean system (NWMED)	Eric Jeansou jeansou@noveltis.fr	Northwestern Mediterranean: Ligurian Sea, Gulf of Lions, Catalan Sea	Estimates of marine parameters, forecasting, provide i.c.s/b.c.s to downscaled systems	Variational Balanced Initialization (VIFOP) from MFS OGCM	In progress

Figure 1: Coastal & Shelf Seas downscaling projects linked to GODAE



- 35 projects
- Varied in objectives and methods
- Geographically clustered
  - Africa: 1
  - Australia: 2
  - China Seas: 2
  - Japan Seas: 3
  - Indian Ocean: 1
  - North America West Coast: 4
  - Gulf of Mexico: 3
  - North America East Coast: 2
  - Arctic and Nordic Seas: 3
  - Norwegian, Baltic, and North Seas: 7
  - Northeast Atlantic: 4
  - Mediterranean: 4

3.Issues and requirements related to downscaling

3.1 Overview

As mentioned above, for the coastal demonstration exercise to be successful, the downscaling of large-scale GODAE estimates will have to address some critical issues and meet some specific requirements. This Section provides a preliminary list of important topics to consider when downscaling. (This list, and the categorization between "critical" and "open", will be updated as experience is shared among modelling groups in the later stages of the exercise.)

Examples of questions dealt with in this Section are the following: What are the main current issues regarding the usability/quality/suitability of large-scale estimates for downscaling? Can we define minimal/optimal requirements for downscaling? What should be looked at on the large-scale (data producer) side? What should be examined on the CSS (intermediate user) side? What questions are solved, and which ones are research topics?

This section contains (1) a list of critical issues and requirements for downscaling, (2) open issues which are felt to be important for the performance of coastal and shelf seas models, and (3) a discussion on how the benefit of using GODAE estimates should be objectively measured in CSS model configurations.

3.2 Downscaling : Some critical issues and requirements

3.2.1 Access to adequate large-scale GODAE simulations

The first critical requirement when downscaling is ready access to adequate large-scale simulations. The GODAE systems provide such estimates. **Appendix 3** lists the large-scale GODAE models which are currently running and which are set up to provide estimates to regional/coastal modelling groups for downscaling, as well as the corresponding data servers and links.

The information in **Appendix 3** is frustratingly incomplete and uneven at this time in terms of representing the actual international GODAE efforts. On the one side, some GODAE groups do not communicate information readily; on the other side, the preparation of this document has shown how much effort still has to be done, at the GODAE project level, to simply communicate what is available, and to promote homogenized procedures to access model outputs. It would be particularly useful to be provided with up-to-date information on the existing models, data servers, and types of products: hindcasts, forecasts, reanalyses, and existence of error estimates. This request will be included in the recommendations.

It is striking to see that except for some marginal seas and polar regions, almost every oceanic location on earth is covered by one or several available GODAE estimates. However there is a great deal of variety among the available solutions in terms of goals, timeliness (real time or offline), modes of distribution, formats, assimilated data, level of validation, horizontal resolution (from 2° to eddy resolving), vertical resolution, parameters and physics. As a consequence, many of the models in **Table 1/Appendix 2** are downscaled from a GODAE model with similar physics and handled by the same group of people or a closely related group (e.g. HYCOM within HYCOM, ADRICOSM within MFS, etc.). This is not a problem for a demonstration exercise, but promoting standards and interchangeability of the large-scale estimates is an option GODAE might want to consider on the medium term.

An important question which will need to be addressed is the question of usability, i.e. **are the existing GODAE products good enough for coastal modellers**. It is often seen for instance that the offshore location, strength, continuity, and vertical structure of coastal/slope currents as presently represented in OGCMs are not realistic in an absolute sense, although they are in equilibrium with the thermohaline structure and wind patterns given the OGCM's resolution and viscosity. In such a case, extracting those particular pieces of information which will be useable by the coastal model will not be straightforward. This in our view calls for two comments:

- Our perception of how good the available solutions are in a coastal region (from CSS models as well as large-scale models) is connected to the issue of the **definition and use of metrics** at the regional scale. **Section 3.2.5** gives an overview of how "goodness" is measured in forecasting systems, with an emphasis on coastal models. However it is felt that this is one of the areas where experience-sharing between CSS modellers is the most critical.

- It might help when setting up a downscaling problem to consider the OGCM fields not as forcing, but as data with its own error characteristics. The presence of random and systematic errors in the OGCM fields would advocate for an estimation-based approach when downscaling. We will come back to this below in the **Initialization (3.2.3)** and **Data assimilation (3.3.1)** sections.

3.2.2 Jump in ocean physics and in forcing functions

An important issue arises with the rapid change in dominant physical processes moving between the coastal areas and the open ocean, and the corresponding requirements concerning the required model forcing functions. Continental shelf and slope seas differ from the open ocean in the presence of the coast, strong bathymetry gradients, inputs from rivers, and shallower water. Coastal-trapped waves propagate cyclonically around the ocean basin, on the gradient of potential vorticity caused by this depth change (Huthnance, Mysak and Wang, 1986). Shelf-scale responses to forcing are transmitted along the shelf in this sense. Flows in these shallower seas are forced by (*inter alia*):

- Pressure and current fields from ocean-scale mass balances, circulation, tides and eddies;

- Winds and air pressure variations;

- Non-uniform density (due to solar heating, river inputs, precipitation-evaporation, latent and sensible heat fluxes).

For all these, responses differ between the deep ocean and shallower shelf as follows.

Along-slope currents can be forced by an along-shelf pressure gradient from the oceanic density field. The barotropic pressure gradient can be larger in shallower shelf and slope waters, with only part of the steric gradient, than in the deep ocean where steric and surface-elevation contributions nearly cancel. (This is ? an aspect of the constraints applied to ocean circulation by the shelf as distinct from a “wall”). Other agents of along-slope flow are: steady wind stress; a response to fluctuating winds that is biased because coastal-trapped waves only cause form drag on flow that is anti-cyclonic around the ocean basin; rectified tides and other waves; geostrophic balance in a front along the shelf-break (Gawarkiewicz and Chapman, 1992), e.g. significant fresh-water input on a narrow shelf.

Tides in the open ocean often have amplitudes O(0.2 m) that scale with the equilibrium tide. (The near-resonant Atlantic has larger tides). However, wave dynamics and energy convergence often amplify the response in shelf seas, by a factor as large as 10 or more. Shelf-sea currents filling the volume between high and low tide are shallow and correspondingly strong. Tides carry momentum-flux and sharp spatial gradients (e.g. headlands and the shelf edge) give rise to tidal *residual currents*, along depth contours if friction is weak (e.g. Huthnance, 1981). *Tsunamis* also amplify on the shelf for similar reasons; their shorter period favors a progressive form and continued run-up at the coast.

Internal waves are ubiquitous in the ocean. The continental shelf edge in particular generates internal tides where vertical (possibly non-hydrostatic) displacements are induced by tidal flow across the steep slope. Then non-linear interactions distribute the energy over a spectrum between the Coriolis and buoyancy frequencies. Internal tides often propagate onto (and off) the shelf, and may be generated at banks on the shelf.

Storm surges are driven by winds and air pressure of large spatial scale 100 – 1000 km to which shallow shelf seas respond quickly (hours) with the coast acting as a barrier and setting up pressure gradients. A layer below stratification may be 180° out of phase with the surface layer (Rippeth et al., 2002).

Upwelling and downwelling are induced by (respectively) offshore or onshore transport of surface water, forced by the wind and diverging or converging towards the coast. Spatial gradients of wind stress in the land-sea transition (effects of vegetation versus waves, topography, sea breezes) also cause surface transport gradients and sheltering in various configurations (e.g. Huthnance, 2002). Divergent transport requires surface-water replacement by upwelling; downwelling is the reverse. Capes tend to favor upwelling, through topographic effects and because a wider range of wind directions causes offshore transport somewhere. Upwelling may raise a seasonal thermocline to the surface as a front, which may further develop instabilities and filaments.

Surface-wave currents reach the bottom in shallow shelf seas, causing sediment suspension, mixing and increased wave breaking, a source of near-surface turbulence.

(Seasonal) heating and cooling are affected by mixing: by bottom turbulence from tidal currents and from the surface by winds and waves. Dense water, formed by heat removal from shallow shelf seas in winter, may *cascade* down the continental slope (Shapiro et al., 2003). Seasonal *fronts* occur between summer-stratified areas and (usually shallow) areas where the water column is well-mixed (Simpson and Hunter, 1974). Fronts may also occur between oceanic

waters and coastal waters freshened by river inputs. Frontal density fields imply pressure gradients, typically in near-geostrophic balance with along-front or coastal currents (which may be baroclinically unstable).

A close relationship with the *topography* is common to all these features. Hence good predictions require bathymetry on the predominant scales of a few kilometers at the shelf break and coast. Near-coast predictions also require *winds, air pressure and waves* resolved on similar scales, and well-resolved in time; Warrach (1998) found that monthly-, daily-averaged and hourly winds gave successive improvements in shelf-sea seasonal thermocline prediction, and that local winds were needed. Other *meteorological* variables needed are temperature and relative humidity, precipitation, cloud cover and radiation (long-wave and short-wave, downwards and upwards). Temperature in shallow seas is sensitive to the heating; cloud-cover especially can be a problematic input. Obtaining local meteorology which resolves the effects of coastal features, such as exposed sandbanks/mudflats or cliffs/steep coastal topography is usually not possible. An example of its impact was demonstrated in the German *Kustos* experiment, where a local high resolution atmospheric model was coupled to coastal ocean model of the German Bight thereby better resolving the processes at the sea/land interface (see Ocean Dynamics, 51 (2/3), 1999 for a selection of papers on *Kustos*); also see results from the MEAD experiment in the Kattegat (Spokes et al, 2005). River inputs are important to near-coast salinity and dynamics, but are often not readily available as time series; un-gauged inputs are often significant.

3.2.3 Initialization

Care must be exercised when controlling the initial and boundary values of an embedded free-surface 3D model from a large-scale solution or an assimilated solution in order to avoid that unphysical gravity transients be triggered. This is because the large-scale solution is unbalanced with respect to the local physics, due to the different resolution and bathymetry, numerical boundary conditions, etc. Therefore simple interpolation may lead to problems, and a specific initialization procedure must be applied. One mistake would be to apply a similar procedure as for large-scale initialization. Let us look at the differences between the initialization of both types of models.

Based on the spectral gap between surface gravity waves and basin scale circulation, the very popular, low cost, rigid lid assumption used in most GODAE OGCMs filters out the most rapidly propagating waves. In the coastal areas, surface waves (associated for instance with barotropic tides or storm surges) have a strong impact on the shelf hydrodynamics, mixing, etc., and free-surface models must be used to propagate these waves. A drawback of such modelling is that any initialization mismatch leads to spurious unphysical transients.

At the basin scale, the impact of bathymetry gradients can most often be neglected, and over the flat-bottom ocean, the geostrophic currents are parallel to the isobars. This is not true in the coastal areas where we are close to a solid boundary condition, and where strong bathymetry gradients (shelf break etc.) are often found. Any canyon cutting through the shelf break, and which cannot be resolved by the large-scale model, will lead to violation of dynamical balances in the nested model when the large-scale fields are interpolated onto the nested model's high-resolution grid. Any surface elevation or density structure leads to an equilibrium state within the corresponding geostrophic adjustment time scale. Due to bathymetry constraints, geostrophic currents in the coastal area are often observed to flow along lines of constant ratio f/h, where h is the depth and f the Coriolis parameter, which in many cases is equivalent to isobath flow. The density stratification partly relaxes this constraint based on the Joint Effect of Baroclinicity and Relief term (JEBAR).

Problems may also arise when downscaling from an OGCM with a different vertical coordinate system, in particular when the open boundary is located in steep bottom topography regions; this situation should be avoided.

To optimally solve for such difficulties, a variational balanced analysis code named VIFOP (Auclair et al., 2006) is used by the operational Mediterranean Forecasting System (MFSTEP) and of several other downscaling projects. It is based on the minimisation of a cost function involving data constraints (including the GCM solution used as "data" with its error characteristics, if available) as well as a dynamical penalty involving the tangent linear model. This approach leads to several improvements of the free-surface coastal model solution such as a drastic decrease of the spurious numerically generated external gravity waves and a decrease of the amplitude some of the model biases such as the horizontal pressure gradient truncation errors. The variational method has been set up for several free-surface models including SYMPHONIE and POM in the Gulf of Lions, in the Northern Adriatic, in the Bay of Biscay and in many other areas.

3.2.4 Tides and barotropic dynamics

The tides are the dynamical process with the largest amplitude in shelf/coastal seas. During severe meteorological events, storm surges can match the tidal elevation and currents, especially close to shore. In contrast to the open ocean, high frequency dynamics (HFD) can impact the lower frequency coastal processes (LFD) for several reasons e.g.

vertical mixing (bottom layer, internal waves along the shelf break), horizontal exchange across the shelf break, residual transport along shelf edges and shorelines. Two choices can be made when modeling the effect of tides in coastal circulation models:

1. The tides and storm surges are not taken into account in the external forcing (open boundary conditions), body forcing (astronomical and loading/self-attraction potential) and surface forcing (HF wind and pressure). In addition any assimilated data must be carefully detided and lowpass-filtered. When such a choice is made, all the possible interactions between HFD and LFD must be parameterized. The parameterizations would preferably be fed with dedicated HF models (such as the 2D barotropic models developed at POC, Toulouse and in other groups). The advantage of this choice is to keep the time step and archive dump at reasonable levels. However, nothing can guarantee today that such parameterizations will be accurate enough to meet the requirements of realism of the applications.

2. The full HFD is taken into account. Providing that proper numerical schemes are used for the external mode, the advantages of this choice are obvious: improved state vector representativity (when assimilating or comparing to data), less parameterization hassles. In the other hand, such an approach will require time splitting capabilities in the numerical schemes to limit the computational cost of the fast barotropic modes. More annoyingly, the vertical current generated by the tides at the shelf edges might limit the internal time step (Courant-Friedrichs-Levy condition on the vertical, although there are numerical treatments to overcome this, e.g. James 2000[1]). Also the periodic variation of the ocean surface layers due to the internal waves can interact with some turbulence closure schemes. Last but not least, the model archive will need a built-in post processing module to filter out the HF signal, especially tides. This can be performed by the means of harmonic analysis.

Both options are compatible with the approaches mentioned in the **Initialization (3.2.3)** section. In particular for option 2, one can penalize departures from a known large-scale barotropic field containing the tidal solution and large-scale response to high-frequency atmospheric forcing.

Plans have been made at POC, Toulouse to build a state-of-the-art Tidal Library that includes all functional aspects needed to force and remove tides in a numerical model. A preliminary version was successfully implemented in the MOG3D finite volume model at POC. Such a library would benefit a large number of hydrodynamical models used in GODAE downscaling activities since most of them have none or very limited tidal capabilities (such as NEMO, ROMS, HYCOM etc..).

In our opinion, the parameterization approach should remain a last option choice as it adds some conceptual noise in the model. The full dynamics option is more natural, but will require a significant initial effort which may not fit within the time frame considered in this Position Paper.

3.2.5 How do we measure goodness and benefit in CSS models?

Previous sections list critical issues and requirements which must be taken in consideration when designing or maintaining a Coastal/Shelf Seas forecasting system. When implementing new features, two basic questions will be asked by CSS modelling groups: How good is my (new) system B? How good is B compared to my old system A?

In the framework of this Position Paper, these two questions translate as: How good is my CSS system when properly downscaled from a GODAE solution? And how good is it in comparison to a system that ignores the existence of GODAE products and procedures, or a system downscaled from another GODAE solution?

Absolute and relative measures of "goodness" of hindcasts and forecasts have been the subject of many papers, in particular in the meteorological literature. The MERSEA, GODAE and CLIVAR communities have put a lot of effort into defining and applying "metrics" for basin-scale and global models (Le Provost, 2002; Stammer, 2006). The aim of that approach was to propose a strategy to be shared between the GODAE Assimilation Centers for model and data assimilation validation and performance evaluation. Agreed products in four "classes", such as interpolated 3D and 2D fields, time series, transports, and innovation statistics, were to be output by the assimilation centers and fed to a central facility where intercomparison material would be prepared. The exercise has been carried out during the European MERSEA Strand-1 project, but the metrics have only been implemented in part of the GODAE systems.

Pinardi and Tonani (2005) are among the few who have attempted to adapt those metrics to the specific requirements of coastal and shelf forecasting models. Their version of the diagnostics is specific to Mediterranean models (e.g., choice

[1] James, D., 2000. A high-performance explicit vertical advection scheme for ocean models: how PPM can beat the CFL condition. Applied Mathematical Modelling, 24(1): 1-9.

of standard levels, choice of mixed-layer depth criterion) although some adaptations would have to be done in any coastal region (e.g., addition of sea level time series, instantaneous fields instead of daily averages, sections along open boundaries, etc.). This illustrates the fact that the local metrics, and therefore our measures of goodness, will be partly but strongly problem-dependent. Therefore, estimates of value of GODAE products for regional/coastal systems will be also problem-dependent. In our future discussions, we will attempt to divide the issues into the general issues and specific issues.

Two categories of problems are involved for the sake of the present analysis:

1. Hindcast and forecast quality assessment ("validation") of CSS systems using GODAE products; assessment procedures are included in every forecasting system and are usually very specific to the problem studied; following Murphy (1993), the authors cited above, and many others, there are three to four types of "goodness":

   - *Consistency*: verify that the system outputs are consistent with current understanding of the ocean circulation. This type is for instance about comparing mean, statistically steady-state marine parameters with climatological products (e.g. World Ocean Atlas, position of major fronts and currents). The approach is complicated in the coastal areas by the difficulty in defining the "statistical mean" in an open system, subject to low- and high-frequency variations of its forcing functions. However one can in general characterize the transports of coastal currents, "mean" stratification (Rossby radii), θ-S census, characteristics of winter water formed over the shelf, etc.

   - *Analysis quality*: quantify the differences between the system's "best results" (analyses) and non-assimilated observations. The corresponding MERSEA/GODAE metrics are Class 1 (fields), Class 2 (sections/moorings) and Class 3 (integrated quantities such as transports), but one really only needs to look at statistics at observation locations. It is recommended that systems which assimilate data be evaluated first without assimilation, but with GODAE-derived boundary conditions; a realistic model is a prerequisite to the success of assimilation anyway. One of the approaches is to calculate *rms* error normalized by the standard deviation of the data (which should be small), and the ratio of the standard deviation of the model to the standard deviation of the data (which should be close to 1). Another attractive approach is the "Brier skill score" (BSS), given by $BSS = 1 - \Sigma\,(\text{model} - \text{obs})^2 / \Sigma\,(\text{baseline} - \text{obs})^2$ where the baseline can be climatology or, in this case, the prediction by the "mother" global simulation. BSS of 1 means that the model is predicting the observations perfectly, 0 means that it is the same as the baseline, < 1 that it is worse.

   - *Forecast quality*: quantify the forecasting capabilities of each system with respect to back-up products (typically persistence, "mother" GODAE solution, and climatology), as a function of forecast range and across variables of interest for the problem at hand. This will be done with the assimilating system, when available. One example from the European NW shelf is the slope current intrusion into the northern North Sea (Proctor, pers. comm.). The corresponding MERSEA/GODAE metrics are Class 4 (innovation & residual statistics). Forecasting skill analysis, if not overly dependent on the quality of forcing forecasts (atmosphere, boundaries), is a good synthetic test of the overall system performance (model + assimilation). It is also able to detect the spurious effects of unbalanced assimilation (e.g. spurious tracer fluxes).

   - *Value*: the incremental economic and/or other benefits realized by end users and decision makers through the use of products. This is very useful whenever available, although in the case of GODAE it is still about "potential" benefits. Two interesting approaches would be: (1) elements of cost-benefit analyses of using GODAE products; (2) illustrations of goodness of derived parameters (e.g. surface currents, etc.) for quantitative purposes (oil slick or objects drift, etc.).

2. Assessment of the impact of using GODAE products. This is performed as above in each case, and is clearly only possible for systems which have another choice than using those products, or which have a choice among the available GODAE products. As an example, the Kuroshio intrusion and its variations have important impacts on circulation patterns and coastal processes in the China Sea and Yellow Sea; You et al. (2001) performed simulation experiments in the South China Sea (SCS) with closed and open boundary conditions; the results show that the Kuroshio inflow has significant impact on the circulation pattern of the north SCS and the intensity and path of the SCS Warm Current. Such studies can be extended to use various GODAE large scale inputs; comparing results using the diagnostics defined above could help discriminate between the GODAE estimates.

Finally, it would be extremely useful to compare the consistency and analysis quality diagnostics for the downscaled systems with the same diagnostics for the "mother" GODAE solutions, in order to evaluate the impact of downscaling on those diagnostics.

3.3 Some open issues

We include here issues which are not necessarily critical for the success of downscaling *per se*, but which can be critical for other purposes (e.g. forecasting), and which can enhance the quality and performance of the coastal systems.

3.3.1 Data assimilation in CSS models

Data assimilation is not necessary *per se* for downscaling. However it can play an important role in the initialization of coastal models (see **Section 3.2.3**) and it may increase the predictability time scale of coastal models. . In this subsection we summarize the main uses of coastal data assimilation and review some current approaches. This is followed by a discussion on some of the main issues in coastal data assimilation and suggestions for future work.

Uses of Data Assimilation in the Coastal Zone: The most important practical use of coastal data assimilation is in the estimation of past, present and future conditions on continental shelves and also providing associated measures of uncertainty. It is typically used to sequentially update initial conditions and sometimes the open boundary conditions. Estimation of past changes (sometimes called historical reconstructions or hindcasts) gives climatologies of the seasonal mean state of the coastal ocean and its variability. The reconstructions can also be used to generate maps of the return period of extreme events (e.g. Bernier and Thompson, 2006). Such statistics are essential when designing coastal infrastructure or assessing, for example, the risk of coastal flooding. Maps of the present state (i.e. nowcasts) are used in adaptive sampling of the coastal ocean (e.g. Robinson and Lermusiaux, 2006). Forecasts of future states are needed for a wide range of applications including marine search and rescue, pollution control, and mitigating the effect of coastal flooding and harmful algal blooms.

Data assimilation methods are also used to downscale predictions from open ocean models to the coastal zone. More specifically data assimilation can be used to (i) suppress the unrealistic transients that can be generated by the change in model physics, forcing and resolution at the coastal model's open boundary, (ii) blend information from the larger-scale ocean model field with local observations.

The design of sustained coastal ocean observing systems, and adaptive/targeted field programs, are topics of considerable interest. The design of future satellite missions is of critical importance to oceanography at the present time (e.g. ESA and NASA are currently trying to jointly support WatER[2] as an offspring to Wide Swath Ocean Altimeter in order to make altimetric measurements). Data assimilation can help with Observing System Simulation Experiments (OSSEs; e.g. Lamouroux et al., 2006), and can provide useful design tools and concepts such as adjoint models, representers, ensemble spread in EnKF (Mourre et al., 2004, 2006), and singular value decomposition of representer matrices approximated using ensembles. After an observing system is operational, data assimilation can help with near real-time quality control of observations and the ongoing assessment of the observing system's performance.

Data assimilation is also used to test dynamical hypotheses and make inferences about ocean processes. This is particularly important when developing biogeochemical models because the parameterizations of many biogeochemical processes is highly uncertain (e.g. Robinson and Lermusiaux, 2002 and references therein).

Existing Approaches: A wide range of methods are presently used to assimilate data into coastal models. The sequential methods include simple nudging, optimal interpolation, reduced order optimal interpolation (as in ADRICOSM, see **Section 7**), ensemble-based optimal interpolation (e.g. Lamouroux et al., 2006) and various forms of Kalman filter including the extended, singular evolutive, and ensemble Kalman filters (e.g. Mourre et al., 2004, 2006). Adjoint-based methods continue to be used extensively to identify parameters, initial or boundary conditions (Taillandier et al., 2006) based on the minimization of cost functions. Variational balanced analyses are used to suppress transients, and to adjust solutions when projecting a coarser solution onto a finer model grid. (This is described in more detail in **Section 3.2.3** on **Initialization.)** Ensemble-based methods are also being used to explore the model error subspace and help specify assimilation statistics e.g. forecast error covariances (e.g.. Echevin et al., 2000; Auclair et al., 2003; Lamouroux et al., 2006).

The diversity of assimilation methods mentioned above reflects the complexity of coastal processes and the large number of coastal modeling applications. Although some relatively simple assimilation schemes have proved remarkably useful in open ocean modeling (e.g. the widely-used method of Cooper and Haines for assimilating altimeter data), such schemes are based on relatively simple and robust dynamical balances that hold over wide regions of the ocean, and do not work in the more complex coastal zone. It is likely that coastal data assimilation schemes and the way the forecast error is modelled in such schemes will continue to exhibit much more diversity than their deep

[2] The Water Elevation Recovery (WatER) mission is designed to measure water surface elevations with an accuracy (after processing) of about 3cm.

ocean counterparts for the foreseeable future and that convergence toward a single scheme is highly unlikely. A coordinated and sustained effort by the scientific community will be required to improve coastal assimilation schemes particularly for operational use. Assimilation of data into unstructured grid models will be a potentially important issue. One way forward is the development of community assimilation software, standardization of observational datasets for testing of assimilation schemes and models, and finally diagnostics and metrics for assessing performance of the coastal assimilation models.

Issues: Several important issues related to coastal data assimilation are discussed below, with suggestions for further work.

Large number of variables to be predicted and the models to predict them: Within GODAE the focus is on the physical properties of the upper ocean on time scales of days to seasons. The variables of interest for coastal applications include physical properties throughout the water column (e.g. near surface currents for marine search and rescue, near bottom currents for sediment transport) with time scales that range from minutes and hours (e.g. tsunamis, tides) to decades (effect of sea level rise). Recently there has been increased interest in predicting biogeochemical properties (e.g. harmful algal blooms) and this greatly increases the number of variables and the complexity of the assimilation schemes (Lermusiaux and Robinson, 2002). Given the large number of variables to be predicted, and the scales of interest, it is not surprising that many types of shelf models have been developed over the years e.g. nested finite difference and unstructured grid, sigma coordinate and spectral in the vertical, barotropic and baroclinic, hydrostatic and non-hydrostatic, advection-diffusion and individual based (Lagrangian) models for biological variables.

Many data types available for assimilation: Data assimilation in coastal models offers the possibility to incorporate information not or improperly incorporated in the large-scale estimates such as GODAE simulations. A wide range of data is available for assimilation into coastal models, e.g. sea level from coastal tide gauges and bottom pressure gauges, currents from land-based radars and acoustic Doppler current profilers mounted on moorings and moving vessels, water properties from fixed moorings and ferries, multi-frequency acoustics and multi-spectral optics for biological state estimation, satellite observations of sea surface roughness, height, temperature and color, measurements from Lagrangian profilers (ARGO), gliders and AUVs. The assimilation of sea-level and satellite data from coastal regions hold particular promise but both present major challenges. The assimilation of thermal satellite imagery is complicated by the fact that a composite of several hours of satellite data can introduce distortions because of tidal (and other forms of) advection. This can complicate the specification of the model error (see below). The assimilation of tide gauge data must take into account the fact that sea-level is a spatial integrator of ocean dynamics and is thus influenced by shelf and deep ocean conditions. The assimilation of altimetry must also correct for the aliasing of the strong tidal signals evident in many coastal regions as well as for inertial oscillations. In addition the sampling configuration of nadir altimetry is not well adapted to constraining the high spatial and temporal frequencies characterizing the coastal processes. Projects using wide-swath altimeters such as WATER, or constellations of nadir altimeters, are of great interest to coastal forecasters. The economic implications of coastal forecasting could provide a strong argument for pushing global coastal observing systems such as these.

Complex physics and range of scales of variability: In the coastal zone one has to deal with many factors that can complicate the assimilation of data compared to the open-ocean, e.g. free-surface variations (tides, storm surges), anisotropy (offshore scales are generally shorter than alongshore scales), non-homogeneity, non-separable covariance functions in space, non-hydrostatic motion, friction and mixing effects throughout the water column (driven in part by tides), shallow water and strong variations of bathymetry, baroclinicity and significant freshwater input from terrestrial sources. To further complicate the situation, the time scales of these factors range from hours (tides) to decades (e.g. river runoff) and complex nonlinear processes can couple the variability at different frequencies. This means that it is often not possible to model the error subspace in one frequency band in isolation (e.g. a realistic estimate of the seasonal mean state must include the effect of the tides and rapidly evolving storms).

Characterization and specification of model error: This is critical in any assimilation scheme but extremely challenging in the coastal zone. The model errors are strongly dependent on time scale (and thus application) but any attempt at separation is confounded by strong nonlinearity in the dynamics that can couple variability at different frequencies. (For example, model error at tidal frequencies can influence the predicted tides and this, in turn, can influence the lower-frequency baroclinic motion through the effect of tidal mixing on the vertical structure of temperature and salinity.) This argues in favor of "advanced" assimilation methods (including dynamically-consistent error prediction schemes, as in Mourre et al., 2004, 2006). As a first step, one must characterize the forecast errors under various error regimes by methods which include realistic error dynamics such as stochastic modelling (e.g., Echevin et al., 2000; Auclair et al., 2003; Lamouroux et al., 2006).

Non-Gaussian errors and biases: Most existing assimilation schemes are based on the Kalman Filter which is optimal for linear systems and unbiased Gaussian observation and model errors. For many physical processes the Gaussian assumption is open to question (e.g. penetration of slope currents onto the shelf) and the situation is even less clear for biogeochemical processes (e.g. eutrophication). Similarly, biases can be a major problem in limited-area coastal models that are strongly influenced by imperfectly known fluxes across the air-sea interface and lateral boundaries. Eventually it will be necessary to allow for non-Gaussian observation and model errors and use bias-aware approaches as in Drécourt and Haines (2006).

Assimilation into coupled coastal-deep ocean models and unstructured-grid models: Downscaling allows the changes on the coarser deep-ocean model grid to influence the higher resolution shelf model through its open boundary condition. Ideally one would like the shelf model, into which has been assimilated all available coastal data on the finer shelf model grid, including inputs from terrestrial sources, to similarly influence the deep-ocean model (upscaling). The most effective way to achieve this is by assimilating in a coupled shelf-deep ocean model (see also **Section 3.3.2**) or in an unstructured-grid model (**Section 3.3.3**) representing both types of scales. This will allow shelf data to correct the deep ocean state and the deep ocean data to simultaneously correct the shelf state. A good example of a measurement that would benefit from such an approach is coastal sea level which, as mentioned above, is influenced by both shelf and open-ocean processes.

Limits to predictability and skill assessment of assimilation models: An important topic for immediate study is the limit to predictability of coastal models, and how it is influenced (hopefully, improved) by data assimilation (e.g. Andreu-Burillo et al, 2006) and the downscaling from GODAE-type models. A related issue is skill assessment i.e. how we assess the effectiveness of data assimilation schemes in the coastal zone. Two categories of indicators can be considered to that end: skill assessment metrics (**Section 3.2.5**) and internal consistency (cross-validation, minimum value of the cost function). Finally let us mention the perspective of probabilistic prediction, i.e. methods which do not provide a single estimate but a posterior distribution of the ocean state given the prior distribution the state and the observations. On the "elementary" end of the spectrum, multi-model ensembles could be very useful for practical applications. On the "advanced" (and expensive) end, one could consider Particle Filters and Markov Chain/Monte-Carlo (MCMC). Such methods have the potential to significantly advance data assimilation in coupled physical-biogeochemical models.

3.3.2 Two-way coupling

The quality of the results from a one-way downscaling mainly depends on two aspects :

- The quality of the “external data”, i.e. the data from the coarse model used to force the local model at its open boundaries. This quality is directly linked to the quality of the coarse model, its resolution, the frequency of the sampling used to force the local model as well as the interpolation methods used to downscale the fields.

- The open boundary condition, i.e. the mathematical operator used at the open boundary of the local model to radiate the outgoing information and to take into account the incoming information. For atmospheric and oceanic flows, the best results are given by conditions based on characteristic variables (Blayo and Debreu, 2005a,b).

The two-way interaction differs from the one-way method by the addition of an update procedure. The goal of this additional step is to improve the external solution u_{ext} by modifying it locally using the local solution u_{loc}. This retroaction from the local model onto the external model is performed every external model time step, or less frequently. The update operator generally replaces the values of u_{ext} at grid points located in the local region by the corresponding values of u_{loc}, possibly after some time and space averaging. A flux correction step must then be added to ensure the balance of mass and tracers fluxes through the interface between both models unless the interpolation methods are designed to conserve the fluxes.

Thus the two-way method allows the coarse model to "see" the high-resolution local solution, and allows some partial propagation in the coarse model of the outgoing information generated in the local one. Globally, this better coupling? between both models generally decreases the difficulties that can be encountered by the one-way method (e.g. instabilities in the vicinity of the interface), and improves the model solutions (Cailleau et al., 2006). The improvement can even be significant in remote parts of the coarse-resolution model because of better representation of crucial dynamic features (e.g. a shelf break front resolved in the local model) that may control dynamics elsewhere (Barth et al., 2005).

Data assimilation also benefits from the bi-directional nesting, but the coupling frequency can be decreased in some cases (e.g. when data assimilation is performed over a state vector regrouping all models variables, the assimilation step updates fields everywhere, not only at the interface, hence relaxing the need for perfectly matched interface values, see Barth et al., 2006).

The WG will attempt to identify groups who could undertake sensitivity studies which would assess the benefits of two-way coupling on the predictability of the coupled system.

3.3.3 Unstructured grid modelling

The recent progress in ocean modelling has highlighted the need to solve for the short scales of the ocean dynamics. Among others, the most demanding processes in terms of space resolution are the ocean fronts, deep convection and internal waves. The unstructured grid modelling is a powerful approach to extend the model resolution range at a reasonable computational cost, while eliminating the need for nesting. The inherent geometric flexibility of unstructured mesh numerical models offers distinct advantages for oceanic simulations at various spatial and temporal scales. Chief among these are a faithful and efficient representation of the complex coastlines and topography, and a variable resolution grid that can be adapted to capture critical evolving dynamical features. Vertical coordinate specifications are also much more flexible when using the unstructured discretization.

The unstructured mesh approach can easily accommodate a vast variety of numerical schemes, such as the finite elements with Continuous Galerkin or Discontinuous Galerkin schemes, finite volumes schemes, as well as an unlimited range of higher order schemes. Moreover, it allows the flexibility of mixing different numerical schemes and their orders in the same model, hence offering to the modellers an unprecedented flexibility in picking the optimal scheme for a given dynamical problem to solve. The geometric and numerical flexibility of the unstructured mesh approach is illustrated by the present developments, such as the mesh adaptivity and the temporal sub-cycling. A wide range of new techniques are being assessed and used, both with respect to hydrodynamic modelling as well as for data assimilation. At the price of a higher preliminary complexity, the unstructured mesh approach offers the modellers a nearly unlimited flexibility and the ability to select numerical solutions appropriate for different classes of problems, and reduces the need for multi-level nesting in mixed open ocean and shelf applications.

Building on the recent progress in finite-element and finite-volume flow solvers, a number of research groups have embarked on a journey to develop unstructured mesh ocean models aimed at simulating basin, coastal and estuarine flows. The UGO initiative (Unstructured Grid Ocean) has been initiated in 2002. It aims to federate the international efforts toward a new generation of hydrodynamic ocean models based on the unstructured grid discretization. A series of annual workshops serves as a forum for developers and users to discuss common issues, share ideas and collaborate on model development and applications. The fifth workshop on unstructured grid numerical modelling has been held on November 13-15 2006 in Miami (http://www.rsmas.miami.edu/personal/ugom06).

4.Proposed approach

4.1 General approach

The mission of the CSSWG is to define, monitor and promote actions, within GODAE, aimed at the assessment and demonstration of the value of GODAE results for regional, coastal and shelf seas models and forecasting systems, within the 2006-2008 time frame.

The rules to move ahead must be rather simple to be effective, because of the short time left before 2008. Our priorities will be the following:

- **Prepare some examples of the impact of GODAE products on the downscaled/nested CSS models**
  - Identify a small group of systems with active validation procedures, observations and metrics, and already using GODAE data
  - Assess the performance of said systems with (and if possible, without) GODAE initial/boundary conditions
  - Make the local metrics available to the *ad hoc* GODAE validation facility or web page

- **Promote procedures and share experience**
  - Promote the use of GODAE products (more than 1 if possible)
  - Share experience on the critical scientific issues in **Section 3** (downscaling/initialization, tides/HF, benefit evaluation/metrics, data assimilation) and on the actual impact of using GODAE products
  - Share toolboxes (initialization, tides, data assimilation)
  - Exchange with GODAE core systems
  - Issues related to the standardization of procedures, formats, etc. will come only as a second priority.

As a first step, the GODAE Coastal and Shelf Seas working group will be extended to include representatives of the 35 CSS systems listed in this document. Most of the results sharing, discussions and feedback will happen in **two annual workshops in the last parts of 2007 and 2008**. A **CSSWG mailing list** and a **Coastal GODAE web page** on the main GODAE web site will be maintained to disseminate information about the working group activities and to show results demonstrating the impact of GODAE at the regional/coastal scale. A summary of these activities and the most significant examples will be shown at the GODAE final Symposium in 2008.

Although the Working Group mailing list, and even more effectively the Workshops, will provide a forum to facilitate interactions between large-scale and coastal groups, the working group will not play the role of middleman. In other terms, the GODAE project must ensure that reasonable requests from CSS systems will be honored by GODAE core systems.

4.2 GODAE Coastal Workshops

4.2.1 *Objectives*

In order to foster interactions between coastal modelers and assimilators, and between them and the large-scale GODAE systems, it is proposed to have two Coastal Workshops in 2007 and 2008. The general objectives of the workshops are the same as the priorities listed in **Section 4.1** above. More specifically the objectives would include:

- Discussions on the – positive or negative – *impact* of initial/boundary conditions from large-scale GODAE products on the performance of regional/coastal/shelf seas systems; methods of impact assessment

- Examples *demonstrating the potential* of GODAE products to improve the local solutions, and the potential of local models to *add value* to GODAE products

- Discussions of the *usability* issue: are GODAE large-scale estimates good enough for coastal modellers?

- Interactions between coastal modellers and large-scale modellers on the downscaling issues and requirements

- Discussions on *regional datasets*, the definition of *regional metrics* and their use to measure consistency, accuracy/quality, value and benefit; share the regional metrics for other systems to use

- Experience-sharing on the other critical *scientific issues* in **Section 3**: downscaling/initialization, tides/HF, data assimilation

- Examine the impact of satellite altimetry on CSS systems (direct through data assimilation, indirect through GODAE initial/boundary conditions); in particular consider assessing the impact of degraded altimetry coverage if the corresponding GODAE products are available

- Discussion of *code and data sharing* opportunities:
  - Code: numerical models, data assimilation, initialization, tidal toolboxes, couplers
  - Data: surface fluxes, bathymetry solutions
  - Identification of areas where additional R&D would be required, which could lead to proposals for additional funding

- Discussion of opportunities for *intercomparison*:
  - Comparison of CSS model results to GODAE core system results at the coastal scale
  - Intercomparison between CSS systems: some opportunities for geographic overlap exist (**Section 1**)
  - Comparison of CSS systems using the same large-scale product in different areas
  - Comparison of the impact of several GODAE products on a single CSS model

- Discussion and preparation of follow-up actions at the coastal scale *beyond GODAE*.

4.2.2 Themes

The 2007 workshop will address almost equally both of the **Section 4.1** main priorities. The proposed title is *"Assessing the value of GODAE products in coastal and shelf seas".*

The 2008 workshop will be more devoted to priority 1. The proposed title is *"Demonstrating the value of GODAE products in coastal and shelf seas".*

4.2.3 Format and attendance

Typically the workshops will span over two days and be held each year after summer. They will gather regional/coastal modellers from the CSSWG as well as interested large-scale GODAE modellers, one or two experts of the GODAE strategy of validation and metrics, and a few invited colleagues in order to provide critical mass for interesting scientific discussions.

4.3 Proposed actions for the CSSWG

The CSSWG will be extended in 2007-2008 to include the CSS modelling groups listed in **Section 1**.

The participating groups will provide their own funds and resources for their attendance to the workshops and for possible additional work which may arise from their participation in the GODAE CSSWG activities.

Actions to be conducted by the extended CSSWG include:

- Use and promote the procedures recommended in this Position Paper:
  - Use GODAE products for downscaling (more than one is possible)
  - Critically consider the recommended procedures in **Section 3**
  - Assess the objective benefit of using GODAE products

- Prepare together, and actively participate in, the 2007-2008 GODAE Coastal Workshops

- On request, prepare short write-ups and figures of ongoing scientific activities in the working group, to be included in reports and on the Coastal GODAE web page

- Maintain links with other international activities (see below).

4.4 Relations with other international activities

Clearly the promotion of the use of GODAE products for regional and coastal downscaling is an international activity, and it would be worth identifying relevant connections within the existing international networks. Two instances of particular interest are:

- **Global Ocean Observing System (GOOS)**

  The importance of coupling coastal and large-scale ocean models, and the important contributions that could be made by GODAE, have been clearly recognized by the Coastal Module of GOOS and, more recently, the Integrated Global Observing Strategy (IGOS). For example, The Integrated, Strategic Design Plan for the Coastal Ocean Observations Module of GOOS (2003) highlights the GODAE High-Resolution Sea Surface Temperature Pilot Project (GHRSST) and the contributions that could be made by GODAE in the evaluation of coastal models (by rigorous definition and use of metrics). The Implementation Strategy for the Coastal Module of the Global Ocean Observing System (2005) calls for pilot projects that can *"…quantify the increase in predictability of physical and biogeochemical conditions on the shelf that result from using open boundary conditions generated by deep ocean forecast systems such as those being developed by GODAE."* More recently the Coastal Theme of IGOS (2006) notes the potential advantages of a Coastal Ocean Data Assimilation Experiment (CODAE) and the development of a Coastal Ocean Data Assimilation System.

  The Integrated, Strategic Design Plan for the Coastal Ocean Observations Module of the Global Ocean Observing System GOOS Report No.125; IOC Information Documents Series N°1183; UNESCO 2003

  An Implementation Strategy for the Coastal Module of the Global Ocean Observing System. GOOS Report No. 148; IOC Information Documents Series N°1217; UNESCO 2005

  IGOS. A Coastal Theme for the IGOS Partnership - For the Monitoring of our Environment from Space and from Earth. Paris, UNESCO 2006. 60 pp. (IOC Information document No. 1220)

- **MERSEA/ECOOP**

  The EU Framework 6 integrated project European COastal-shelf sea OPerational observing and forecasting system (ECOOP, a 3-year project with 72 partners) has the overall goal to consolidate, integrate and further develop existing European coastal and regional seas operational observing and forecasting systems into an integrated pan-European system targeted at detecting environmental and climate changes, predicting their evolution, producing timely and quality assured forecasts, providing marine information service's (including data, information products, knowledge and scientific advices) and facilitate decision support needs. Since the major part of the consortium is from regional alliances in operational oceanography, i.e. Baltic Sea (BOOS), North West shelf (NOOS), Iberia-Biscay-Ireland region (IBIROOS), Mediterranean Sea (MFS-MOON) and Black Sea (Black Sea GOOS), the pan-European ECOOP system will have the maximum sustainability in making long-term observations, forecasts and services. The ECOOP system, a system of 15 coastal systems, is designed clearly for addressing end- user needs, e.g., detecting environment and climate change signals, forecast, decision making, technology transfer and international cooperation, and fits well with GEO/GMES initiatives and the GEOSS implementation plan. There is a clear connection between ECOOP and MERSEA in that MERSEA has the capability to provide the global and regional downscaling products for ECOOP in the NW European Shelf seas and the Mediterranean; ECOOP conversely can provide regional products to MERSEA for the Black Sea.

  MERSEA and ECOOP are described in more detail in **Appendix 4**.

4.5 Proposed actions for the GODAE Project

Here are recommended actions for the GODAE Project Office and IGST:

- Improve information on, and access to, available GODAE large-scale products
  - Maintain, on the web site or in a downloadable document, an up-to-date list of GODAE systems and products, along with system details, domains and resolutions, data server and downloading procedures.
  - Publicize the GODAE strategy with respect to products delivery and standards. Will GODAE have a central server facility for data delivery? Promote the use of standards (e.g. NetCDF with agreed formats) to facilitate interchangeability of the large-scale estimates.

- Facilitate practical organization of working group
    - Define CSSWG mandate and chairpersons
    - Add a Coastal GODAE web page to the GODAE homepage, which could be directly updated by the WG
    - Contribute to the financial support of workshops.

- Wrap up and draw conclusions, in particular towards an evolution of the GODAE Terms of Reference beyond 2008.

5.References

Andreu-Burillo, I., J.T. Holt, R. Proctor, J.D. Annan, I.D James, and D. Prandle, 2006: Assimilation of Sea Surface Temperature in the POL Coastal Ocean Modelling System. *J. Mar. Sys.*, in press.

Auclair, F., P. Marsaleix and P. De Mey, 2003: Space-time structure and dynamics of the forecast error in a coastal circulation model of the Gulf of Lions. *Dyn. Atmos. Oceans,* **36,** 309-346.

Auclair F., C. Estournel, P. Marsaleix and I. Pairaud, 2006: on coastal ocean embedded modeling. *Geophysical Research Letters*, Vol. 33, L14602.

Barth A, A. Alvera-Azcarate, M. Rixen and J.-M. Beckers, 2005: Two-way nested model of mesoscale circulation features in the Ligurian Sea, Progress In Oceanography, 66, 171—189.

Barth, A., A. Alvera-Azcarate, J.-M. Beckers, M. Rixen and L. Vandenbulcke, 2006: Multigrid state vector for data assimilation in a two-way nested model of the Ligurian Sea, Journal of Marine Systems, accepted.

Bernier, N. and K. R. Thompson, 2006: Predicting the Frequency of Storm Surges and Extreme Sea Levels in the Northwest Atlantic. Journal of Geophysical Research, 111, C10009, doi:10.1029/2005JC003168.

Blayo E. and L. Debreu, 2005a: Revisiting open boundary conditions from the point of view of characteristic variables. Ocean Modelling, 9, 231-252.

Blayo E. and L. Debreu, 2005b: Nesting ocean models. In An Integrated View of Oceanography: Ocean Weather Forecasting in the 21st Century, ed. by E. Chassignet and J. Verron, Kluwer.

Cailleau S., V. Fedorenko, B. Barnier, E. Blayo and L. Debreu, 2006: A comparison of different methods of coupling between a north Atlantic ocean model and a model of the bay of Biscay. To be submitted to Ocean Modelling, 2006.

Drécourt, J.-P. and K. Haines, 2006: Use of bias aware data assimilation to improve the GOCINA mean dynamic topography. Submitted to *J. Geophys. Res. Oceans*.

Echevin, V., P. De Mey, and G. Evensen, 2000 : Horizontal and vertical structure of the representer functions for sea surface measurements in a coastal circulation model. *J. Phys. Oceanogr.,* Vol. **30**, No. 10, 2627–2635.

Gawarkiewicz, G and D.C. Chapman, 1992: The role of stratification in the formation and maintenance of shelf-break fronts. *Journal of Physical Oceanography* 22, 753-772.

Holt, M., 2002: Real-time forecast modelling for the NW European Shelf Seas. In: *Operational Oceanography: Implementation at the European and regional Scales*. N.C. Flemming, Ed., Elsevier Science, 69-76.

Huthnance, J.M., 1981: On mass transports generated by tides and long waves. *Journal of Fluid Mechanics 102*, 367-387.

Huthnance, J.M., 2002: Wind-driven circulation in coastal and marginal seas. *Canadian Journal of Remote Sensing* 28, 329-339.

International GODAE Steering Team, 2000: GODAE Strategic Plan. GODAE report no. 6, 36pp.

The Integrated, Strategic Design Plan for the Coastal Ocean Observations Module of the Global Ocean Observing System GOOS Report No.125; IOC Information Documents Series N°1183; UNESCO 2003

Lamouroux, J., P. De Mey, F. Lyard and E. Jeansou, 2006: Control of a barotropic model of the Bay of Biscay in presence of atmospheric forcing errors. *J. Geophys. Res.*, under revision.

Le Provost C., 2002: *GODAE Internal Metrics for model performance evaluation and inter-comparison – The GODAE metrics over the Atlantic Ocean.* GODAE internal report.

Mourre, B., P. De Mey, C. le Provost, and F. Lyard, 2004: An Ensemble-based method for the study of errors due to uncertainties on bathymetry in a free-surface regional model. Outlook for the assimilation of sea-level data over continental shelves.. Implications on requirements for future altimeter observing systems. *Dyn. Atmos. Oceans,* **38**, 93-121. doi:10.1016/j.dynatmoce.2004.09.001.

Mourre, B., P. De Mey, Y. Ménard, F. Lyard and C. Le Provost, 2006 : Relative performances of future altimeter systems and tide gauges in controlling a model of the North Sea high-frequency barotropic dynamics. *Ocean Dynamics*, doi: 10.1007/s10236-006-0081-2.

Murphy, A.H., 1993: What is a good forecast? An essay on the nature of goodness in weather forecasting. Weather and Forecasting, 8, 281-293.

Pinardi, N., and M. Tonani, 2005: The quality assessment of basin-scale and shelf forecasting models in the Mediterranean Sea. MFSTEP Internal report, Unpublished ms.

Rippeth, T.P., J.H. Simpson, R.J. Player and M. Garcia, 2002: Current oscillations in the diurnal-inertial band on the Catalonian shelf in spring. *Continental Shelf Research* 22, 247-265.

Robinson, A. R. and P. Lermusiaux, 2002: Data assimilation for modeling and predicting coupled physical–biological interactions in the sea. Chapter 12 in The Sea, Volume 12, edited by Allan R. Robinson, James J. McCarthy, and Brian J. Rothschild ISBN0-471-18901-4, John Wiley and Sons, Inc., New York.

Shapiro, G.I., J.M. Huthnance and V.V. Ivanov, 2003: Dense water cascading off the continental shelf. *Journal of Geophysical Research* 108 C123390, doi:10.1029/2002JC001610.

Simpson, J.H. and J. Hunter, 1974: Fronts in the Irish Sea. *Nature* 250, 404-406.

Spokes, L. et al. 2005: MEAD: An interdisciplinary study of the marine effects of atmospheric deposition in the Kattegat. Environmental Pollution, 140:453–462.

Stammer, D., 2006: How do we measure goodness in the synthesis evaluation? CLIVAR/GODAE metrics. Presentation at the CLIVAR/GODAE meeting on ocean synthesis evaluation, ECMWF, Reading, UK, 31 August-1 September 2006. (available on www.clivar.org)

Taillandier V., V. Echevin, L. Mortier, and J.-L. Devenon, 2006: A 4DVAR assimilation approach to estimate the regional forcing from observations of the coastal circulation. *J. Mar. Sys.*, in press.

Warrach, K., 1998: Modelling the thermal stratification in the North Sea. *Journal of Marine Systems* 14, 151-165.

6.Appendix 1: CSSWG and contributors

6.1 Working Group

Pierre De Mey is a physical oceanographer, CNRS Research Director at LEGOS (Laboratoire d'Etudes en Géophysique et Océanographie Spatiales), Toulouse, France. He is Habilité à Diriger des Recherches at Paul Sabatier University, Toulouse, and leads the Ocean Dynamics team at LEGOS. With his team, he is conducting research in deep-ocean and coastal data assimilation, on theoretical aspects (Ensemble filters), physical aspects (reduced-order schemes, isopycnal schemes, downscaling) and applications. He has been Project Scientist for assimilation in MERCATOR in 1996-2003, where he has developed the SAM-1 multivariate assimilation system currently used by MERCATOR for real-time forecasting and reanalyses, former member of the EuroGOOS Mediterranean and Atlantic Task Teams, and Principal Investigator for TOPEX/POSEIDON, JASON-1, ENVISAT and OST. Along with colleagues of the Laboratoire d'Aérologie and LEGOS, he has founded in 2001 the Pôle d'Océanographie Côtière (Coastal Oceanography Group) in Toulouse. He is a member of the International GODAE Steering Team and of the MERCATOR Science Committee.

Peter Craig is a physical oceanographer, whose research focus has been mainly internal tides and wave-affected surface dynamics, and on application of ocean models to coastal environmental and engineering issues. More recently, his main role has been in leadership of interdisciplinary coastal studies. He currently leads the development of an relocatable nested ocean and atmospheric modelling package as part of Australia's operational oceanographic initiative BLUElink, and a second project, aimed at coastal management, that involves downscaling from global models, through a set of ecological models, to assess the dynamics of benthic habitat on fringing reefs along Australia's temperate coastline.

John C. Kindle, an Oceanographer at the Naval Research Laboratory-Stennis Space Center for the past 24 years, is head of the Coupled Processes Section within the Ocean Sciences Branch. He received the Ph. D. in Physical Oceanography from the Florida State University in 1979, the M.S. in Oceanography from New York University in 1971, and the B.S. in Physics from the University of Dayton in 1969. His research focuses primarily on the use of numerical models to examine such topics as the equatorial dynamics of the Pacific and Indian Oceans, the dynamics of the Arabian Sea circulation, coupled biological-physical processes of the Arabian Sea and along the west coast of the US, and coupled air-ocean processes in coastal zones. Recent efforts have also focused on research issues in the development real-time coupled physical-biological models, including such topics as the importance of high resolution atmospheric forcing, coupling models across scales that range from global to regional to local, and the utilization of recent advances in remotely sensed ocean color products. He is a member of the International JGOFS Indian Ocean Modeling and Synthesis Committee and has served on the Science Working Teams for TOPEX-Poseidon and ERS-1.

Yoichi Ishikawa, Ph. D., is physical oceanographer, assistant professor at Department of Geophysics, Graduate school of Science, Kyoto University. He has built the monitoring/forecasting system for the Japan coastal region. This system consists of two parts, the 4D-VAR assimilation system for the Northwestern part of North Pacific, and the downscaling to a coastal model with 1-2km resolution. His scientific interests are data assimilation, especially 4D-VAR (adjoint method) and its applications, as well as numerical modeling including downscaling approaches.

Roger Proctor is a Principal Scientific Officer (Band 4 scientist) at POL with over 20 years experience of modelling coastal seas. Leader of the POL Science programme 'Modelling and Observation Systems for shelf Seas'. Research interests include: operational oceanography, operational forecast systems (work package leader in recent EU FP5 projects ODON (Optimal Design of Observing Networks) and FerryBox, and in ECOOP); particle tracking studies of the fate of oil spills and fish larvae dispersion; coupled hydrodynamic-ecosystem models to explore physical-biological interactions; data assimilation in coastal seas using sequential methods. Executive Committee Member of the National Centre for Ocean Forecasting (NCOF). Represents POL in NOOS (Northwest Shelf Operational Oceanography Services).

Keith R. Thompson holds a Canada Research Chair in Marine Prediction and Environmental Statistics at Dalhousie University. He is jointly appointed in the Department of Oceanography and the Department of Mathematics and Statistics. His research interests include shelf and deep ocean modelling, data assimilation, global and regional sea level variability and the analysis of extremes. He was involved in the development of the first operational storm surge model for the east coast of Canada and is working with colleagues at the Bedford Institute of Oceanography on eddy resolving models of the North Atlantic that can forecast with lead times of tens of days. Ongoing research interests include particle filters, the assimilation of Lagrangian data into ocean models, and assimilation into coupled atmosphere ocean models. He is a member of the Science Advisory Committee for the Global Sea Level Observing System (GLOSS) and, to 2005, a member of the Coastal Ocean Observations Panel of the Global Ocean Observing System (GOOS).

Jiang Zhu is deputy director, Institute of Atmospheric Physics (IAP), Chinese Academy of Sciences. He currently leads a group of ocean data assimilation. He is currently PI of two ocean data assimilation projects. One, sponsored by Chinese Academy of Sciences, is to build an ocean data assimilation and nowcasting system for China Seas. Another, sponsored by the Ministry of Science and Technology of China, is to construct an ocean reanalysis for the Western Pacific-South China Sea-Indian Ocean for climate study that focus on impacts of Western Pacific-South China Sea-Indian Ocean on China's climate. His group has developed a three-dimensional variational ocean data assimilation system (OVALS). This system is now testing for IAP's ENSO prediction CGCM. The OVALS assimilation system has been applied to South China Sea and East China Sea by several outside research groups. Several operational agencies of China also installed OVALS for potential forecast and reanalysis applications. His group has a strong tie with the Nansen Center, Norway, and collaborates on using HYCOM and the ensemble Kalman filter in order to develop a high-resolution ocean modeling and assimilation system for China adjacent seas.

6.2 Contributors

We gratefully acknowledge the participation of the following colleagues to the material and discussions contained in this document:

Dr. **Francis Auclair**, Laboratoire d'Aérologie, Université Paul Sabatier, Toulouse, France

Prof. **Jean-Marie Beckers**, GeoHydrodynamics and Environment Research (GHER), University of Liège, Liège, Belgium

Dr. **Eric Blayo**, Institut d'Informatique et de mathématiques Appliquées de Grenoble (IMAG), Laboratoire de Modélisation et Calcul (LMC), Grenoble, France

Dr. **Eric Chassignet**, Florida State University, Tallahassee, FL, USA

Dr. **Fraser Davidson**, Department of Fisheries and Oceans Canada, St John's, Canada

Dr. **Christopher Edwards**, University of California—Santa Cruz, Santa Cruz, USA

Dr. **Ichiro Fukumori**, NASA Jet Propulsion Laboratory, Pasadena, USA

Dr. **George Halliwell**, University of Miami, Miami, USA

Dr. **Ruoying He**, Woods Hole Oceanographic Institution, Woods Hole, USA

Prof. **Naoki Hirose**, Kyushu University, Kyushu, Japan

Dr. **Harley Hurlburt**, Naval Research Laboratory, Stennis Space Center, MS, USA

Dr. **John Huthnance**, Proudman Oceanographic Laboratory, Liverpool, United Kingdom

Dr. **Villy Kourafalou**, University of Miami, Miami , USA

Dr. **Tong Lee**, NASA Jet Propulsion Laboratory, Pasadena, USA

Dr. **Florent Lyard**, Laboratoire d'Etudes en Géophysique et Océanographie Spatiales (LEGOS), Toulouse, France

Dr. **Shuhei Masuda**, JAMSTEC Frontier Research Center for Global Change, Yokohama, Japan

Dr. **Yasumasa Miyazawa**, JAMSTEC Frontier Research Center for Global Change, Yokohama, Japan

Dr. **Dominique Obaton**, MERCATOR OCEAN, Toulouse, France

Prof. **Nadia Pinardi**, University of Bologna, Bologna, Italy

Dr. **Roger Samelson**, Oregon State University, Corvalis, OR, USA

Dr. **Hiroyuki Tsujino**, Meteorological Research Institute, Japan Meteorological Agency, Japan

7.Appendix 2: the CSS projects

In addition to the summary in **Table 1**, this section gives details on (pre)operational forecasting systems and academic projects with a declared intention to follow a downscaling procedure from one or several of the GODAE systems within the time frame considered in this Position Paper (2006-2008).

For most entries, topics are organized as follows:

a. Project name, acronym

b. Domain

c. Objectives
   Type: Real-time monitoring and prediction, reanalysis, scenario-testing, assessment of observational networks, research
   Operational objectives, customers, funding aspects

d. Downscaling strategy
   Modelling strategy, forcings, variables estimated, prediction range
   Why does this project need large-scale estimates?
   What for? Boundary conditions, more sophisticated downscaling schemes, etc., on/off-line?
   What particular GODAE estimates does this project use, how often, etc.?
   Through which Modelling/Assimilation Center?
   Does project have a verification/validation strategy which can help assess the impact of large-scale estimates?

e. Project status

7.1 Africa

P1 – Regional Ocean around Southern Africa (TOMOROSA)

Domain
The focus of the nested model domain is the regional ocean around Southern Africa, approximately 060°E and 1050°S.

Objectives
Advance the understanding of mesoscale dynamics and eddy evolving processes in the Agulhas Current system, the retroflection through integrated use of the ocean model HYCOM, satellite observations and in-situ measurements. Investigate the importance and impacts of applying advanced numerical schemes, improved model parameterization and data assimilation techniques.
Real time monitoring and prediction system, research.
Implementing HYCOM as one component of in a operational monitoring and forecasting system for the Southern African Ocean.

Customers
Research, fisheries, oil industry, shipping (commercial and leisure)

Funding aspect
This project is supported by the MohnSverdrup Center for Global Ocean Studies and Operational
Oceanography, through a private donation from Trond Mohn C/O Frank Mohn AS, Bergen, and by the Department of Oceanography, University of Cape Town.

Downscaling strategy
TOMOROSA is forced at the boundaries by a basin scale HYCOM model of the Indian and Southern Ocean developed and operated by the Mohn Sverdrup Center at NERSC. The time resolution of the lateral boundary conditions is 6 hours, anticipating for ulterior addition of astronomical tides. The downscaling method is that of Browning and Kreiss (1982, 1986) with bilinear interpolation to the nested horizontal grid.
The monitoring and prediction system is driven by external inputs, i.e. atmospheric forcing fields. Further observational external information, such as sea level anomaly, sea surface temperature and in-situ measurements of temperature and salinity profiles, is merged with a coupled model system including an ocean general circulation model using

sophisticated data assimilation techniques. The products include short range (weekly) predictions of physical and biological variables as functions of space and time.

Why does this project need large scale estimates?

The mesoscale variability in the Agulhas Current is forced by interactions with the basin scale

Circulation in the Indian and Southern Ocean. Large scale estimates are applied as boundary conditions in a two model system, i.e. a parent basin scale model and a nested regional model.

Strategy for validation of boundary conditions

The incoming fluxes, kinetic energy and water mass properties are monitored in the nested model and compared to available observations.

Project status

Project is in development phase, preliminary results have been presented at the "15 years of progress in radar altimetry" symposium in Venice (March 2006) [Backeberg et al., 2006].

References

Backeberg, B. C., J. A. Johannessen, L. Bertino, N. G. Winther, and K. A. Lisæter, The uses of satellite altimetry in model validation and variability studies for the Agulhas Current, in ESAs Publications Division (EPD), Special Publication SP614 on CD, European Space Agency (ESA), 2006, Proceedings paper for the 15 years of progress in Radar Altimetry symposium, available online: http://earth.esa.int/workshops/venice06/participants/900/ .

7.2 Australia

P2 – ROAM / ROAM-II

Project name: Relocatable Ocean and Atmosphere Model (ROAM)

Domain: Nominally 90ºE-180ºE, 60ºS-10ºN, but focussed on the coastal regions of Australasia and Indonesia

Objectives: To provide an automated, relocatable, high-resolution, model-based forecasting system for the ocean and atmosphere with the following characteristics:

- The system to be driven from a graphical interface, requiring input only of the spatial domain, the spatial resolution and the forecast period

- The models to be nested inside global forecasting models. For the ocean, the global model is the GODAE model OFAM (Ocean Forecasting Australia Model), with 10-km resolution in the Australian region. ROAM provides resolution down to 2 km, and forecasts up to 7 days.

Operational objective: To provide the Royal Australian Navy with a forecast system for ocean thermal structure, for planning acoustic strategies.

Downscaling strategy: The global OFAM system (see section 8.1) is to be run operationally by the Australian Bureau of Meteorology, with updates every 3 days, and forecasts out to 7 days. The ocean forecasts will complement their existing atmospheric forecasting. The ROAM system will reside on user computers, in particular those of the Royal Australian Navy. Once the user has initiated a run for a specified domain (typically a region of order 100 km x 100 km), ROAM will automatically download the global data and execute the nested atmospheric and ocean model runs. The nested models are the Colorado State University atmospheric code RAMS, and an in-house coastal-ocean model (called SHOC). Coupling between the two models is one-way, from the atmosphere to the ocean. The models have been configured for robustness, so that they run stably every time. In particular, the ocean model uses only sponge conditions at the open boundaries, but includes the addition of tide height (derived from an independent global tidal model) along these boundaries. Model robustness has been verified by many test runs within the working region. Model accuracy has been tested against data for 3 specific, and well-studied regions on the Australian shelf. However, the accuracy tests were done before the availabilty of the OFAM data stream. The nested ocean model has proved to be very sensitive to the conditions specified at the open boundary.

Project status: The ROAM system is in its final stages of development, and due to become operational on 1 January 2007. This date coincides with the scheduled initialisation of the OFAM operational data stream by the Bureau of Meteorolgy. ROAM has been in development since July 2003.

In July 2006, ROAM II, a second phase of the ROAM development was initiated. ROAM II will incorporate the following enhancements:

- Local data assimilation, in particular of CTD profiles collected on-site by Naval vessels;
- Coastal freshwater runoff, which is also to be incorporated into OFAM;
- Surface waves;
- More complex atmosphere-ocean coupling, depending on the outcome of sensitivity tests.

ROAM II is due for completion in July 2010.

P3 – CLAM-TC

Project name: Coupled Limited-Area Modelling for Tropical Cyclones (CLAM-TC)

Domain: A 27°x 27° domain incorporating tropical Australia

Objectives: To improve tropical cyclone forecasting by incorporating active coupling of the atmospheric model with an ocean model.

Operational objective: To provide the Australian Bureau of Meteorology with improved operational forecasting capability for tropical cyclones.

Downscaling strategy: The atmospheric model is downscaled, but the ocean model is run at the same scale as the global model. The atmospheric model is presently the Australian Bureau of Meteorology's tropical forecasting model TCLAPS, nested inside their Local Area Prediction System. The global ocean model is the Ocean Forecasting Australia Model (see section 8.1), which is based on MOM. The local-area model is also MOM. The present operational version of TCLAPS uses only satellite-derived sea-surface temperature. Within CLAM-TC, TCLAPS and MOM will be run with active coupling. Over the period of the study, various levels of coupling will be tested for their sensitivity, including the incorporation of surface wave dynamics. In spin-up mode, before real-time, the ocean model will use data assimilation (optimal ensemble interpolation) of SST and salinity-temperature profiles. The model will be validated against an extensive set of tropical cyclone observations, incorporating satellite and ground-station data.

Project status: The project is in its early stages, with implementation and initial testing of the models. It is due for completion by July 2010. By that time, a production version of CLAM-TC will be available for operational forecast trials at the Bureau of Meteorology.

7.3 China Seas

P4 – Ocean Data Assimilation and Nowcasting System for the China Marginal Seas

Configuration

At the Institute of Atmospheric Physics (IAP), Chinese Academy of Sciences, a project supported by the Natural Science Foundation of China is undergoing to develop a coastal ocean nesting modeling/assimilation system that aims to potential operational coastal ocean forecast for Chinese Waters. Currently there are two candidate modeling/assimilation systems are under developing. One is based on an IAP eta-coordinate, 3-D, baroclinic regional ocean model. The model can be multi-nested at various resolutions. Accompanying data assimilation system (OVALS) is based on 3DVAR (Yan et al., 2004; Zhou et al., 2004; You et al., 2003; and Zhu et al., 2006). Currently, a 1/4 degree version is running the OVALS assimilation and a 1/12 degree version is running in the simulation mode. Another candidate uses HYCOM as the model and an ensemble Kalman filter as data assimilation scheme. The both systems are going to use GODAE products to provide the open boundary conditions. Currently they are using a large domain model to provide open boundary conditions. The target processes mainly focus on the variations of the shelf fronts in the East China Sea (ECS) and the Yellow Sea (YS), upwelling along Chinese coast in the time scales from few hours to several days. The mesoscale eddies in South Chnia Sea (SCS) are also studied. Other important processes such as Korushio intrusions into ECS, YS and the SCS and mesoscale eddies in ECS and YS that maybe harder to attack due to more complicated mechanisms and the lack of routine, high temporal-spatial resolution observations resolving these processes will be focused in future.

Another system we used is the HYCOM that uses 2-step one-way nesting. The larger domain covers the Western-Pacific and the Indian Ocean at the resolution of about 1/4 degree. The smaller domain covers the Yellow Sea, the East China Sea and the South China Sea, with the resolution of 1/10 degree. The data assimilation system used is based on EnKF in which some static ensembles are "dressed" to few dynamical ensembles in order to reduce the computational cost.

Objectives of systems

For the Chinese CSS modeling/assimilation system developed, the main objectives are providing temperature, salinity and velocity reanalysis fields based on high resolution, nested models and GHRSST, GTSPP, coastal station and altimeter observations. The main applications of the reanalysis products include processes studies and ecosystem modeling. The customers are mainly scientific community.

A new project that will start in 2007 with the objective to develop a nowcasting system for Chinese CSS.

Use of GODAE solutions

The large-scale GODAE outputs are needed for providing open boundary conditions of the nested models of Chinese Waters. Currently we do not consider more sophisticated downscaling schemes. However there is a potential interest to implement such downscaling schemes using GODAE outputs. The temperature, salinity and velocity fields from GODAE products are planed to be used as open boundary conditions in the China coastal model system. The GODAE sea surface height (SSH) fields are also have the potential to constrain the SSH field of coastal models at deep part of coastal model domains near open boundaries. The tidal sea level boundary conditions from large scale GODAE estimates are also important to CSS models. For Chinese CSS, the Kuroshio plays important role in the circulation patterns, thermal fronts, upwelling in the north of SCS and ECS. The Kuroshio also contributes to the Yellow Sea Warm Current. The tidal mixing is very important in the shelf fronts formation. Therefore the outputs from the GODAE large scale estimates are required to provide reliable Kuroshio axis/transport and tidal open boundary conditions.

References

C. X. Yan, J. Zhu and G. Q. Zhou, 2004: The roles of vertical correlation of the background covariance and T-S relation in estimation temperature and salinity profiles from surface dynamic height. J. Geophys. Res. 109. doi:10.1029/2003JC002224

You X. B., G. Zhou, J. Zhu, R. Li and Q. Zeng, 2003: Sea Temperature Data Assimilation System for the China Sea and Adjacent Areas, Chinese Science Bulletin , 48 Supp.II.70-76.

You X. B., Li R., Zhang M, Zeng Q., Numerical Calculation of the Wintertime Circulation in the South China Sea by using a Baroclinic Model, Acta Oceanologia Sinica, Vol. 23, No. 6, Nov. 2001 (In Chinese with English Abstact)

G. Zhou, W.Fu, and J. Zhu, 2004: The impact of location dependent correlation length scales of background covariance on an ocean data assimilation system. Geophy. Res. Letters. 31, L21306, doi: 10.1029/2004GL020579.

Zhu J., G.. Q. Zhou, C. X. Yan and X. B. You, 2006, A three-dimensional variational ocean data assimilation system: Scheme and preliminary results. Science in China (D), in press.

P5 – Mohn-Sverdrup Center South China Sea HYCOM (MSC-SCS)

Domain
The model covers the South China Sea with 12 km resolution (conformal mapping grid)
Approximately from 8S to 24N and from 100E to 130E.

Objectives
Real-time monitoring and prediction system, hindcast studies, research.
The objective is to forecast the currents in the South China Sea.

Customers
Research, oil &gas industry (Exxon Mobil). society at large.

Funding aspect

This project has been set up by an Ocean Numerics industry project funded by Exxon Mobil. It is being transferred to the Nansen-Zhu Center in Beijing.

Downscaling strategy
One-way and off-line nesting offer sufficient flexibility for operating the nested model.
HYCOM-to-HYCOM downscaling, the outer model is a Pacific Ocean HYCOM model of half a degree. The downscaling method is from that of Browning and Kreiss (1982, 1986) with bilinear interpolation to the nested rotated horizontal grid. The frequency of nesting conditions is 6-hourly. Astronomical tides are added.
The system is driven by external inputs, atmospheric forcing fields from ECMWF.
Why does this project need large-scale estimates?
The interactions with the Pacific Ocean need to be correctly represented. High quality lateral boundary conditions of ocean parameter are absolutely vital.
Strategy for validation of boundary conditions
The incoming fluxes, kinetic energy and water mass properties are monitored in the nested model and compared to available observations and to the outer model.
What particular GODAE estimates does this project use, how often, etc.?
The project has produced its own boundary conditions for 3D ocean parameters. The frequency of nesting files is 6-hours. Tides are included.
Through which Modelling/Assimilation Center?
BCs are provided by the Mohn-Sverdrup Center at the Nansen Center, Bergen.

Project status
A 20 years hindcast study has been completed and validated and is owned by Exxon Mobil.
The system will be used by the Nansen-Zhu Center in Beijing.

7.4 Japan Seas

P6 – Comprehensive nowcast/forecast system for the Japan coast (MOVE/MRI.COM-JC)

Configuration

The Meteorological Research Institute (MRI) of Japan Meteorological Agency (JMA) is planning to develop a coastal ocean modeling/assimilation system that is intended for a possible operational use in JMA's forecasting and warning system for the coastal region of Japan.

a. **Project name, acronym:** Comprehensive nowcast/forecast system for Japan coast (MOVE/MRI.COM-JC)

b. **Domain:** Coastal region around Japan

c. **Objectives**
type: Real-time monitoring and prediction, reanalysis
operational objectives: coastal sea-level (tides and storm surges), surface waves, currents, water temperature
customers: JMA, prefectural offices, ship navigation, marine leisure
funding aspects: MRI

d. **Downscaling strategy**
Modelling strategy: horizontal resolution: a few km; ocean model: MRI.COM (Ishikawa et al. 2005)
Forcings: nested within 10km resolution nowcast/forecast system operationally run by JMA (MOVE/MRI.COM-WNP) surface atmospheric forcings from JMA operational nowcast/forecast system
variables estimated: sea-level, wave height, currents, water temperature, salinity
prediction range: about one week
Why does this project need large-scale estimates?
Because the state of the strong currents such as the Kuroshio, the Oyashio, the Tsushima current, the Tsugaru current, the Soya current are important for the prediction of the oceanic environments around Japan. These currents have large-scale features.
What for?
mainly for the JMA's warning system around the coastal region (abnormal tides, wind waves, storm surges), possibly for fisheries, ship navigation, marine leisure…
Boundary conditions, more sophisticated downscaling schemes, etc., on/off-line?
medium resolution model between 10km and 1km models, two-way nesting, coupled with atmospheric forecast models (especially with the typhoon model for storm surges)

What particular GODAE estimates does this project use, how often, etc.?
JMA's Japan GODAE product (temperature, salinity, velocity and SSH from JMA operational ocean data assimilation system MOVE/MRI.COM-WNP). The detail of this products is introduced in section 8.3.
GHRSST (JMA/Tohoku-Univ.)
Jason and ENVISAT altimetry data
Through which Modelling/Assimilation Center?
JMA (Japan GODAE-server)
Does project have a verification/validation strategy which can help assess the impact of large-scale estimates?
Monitoring sea-level change in an interannual time scale is one of our main objectives
Verification/validation will be done according to GODAE North Pacific Metrics (Kamachi and Minato, 2001) which will be revised for coastal regions.

e. **Project status:** planning

References

Ishikawa, I., H. Tsujino, M. Hirabara, H. Nakano, T. Yasuda & H. Ishizaki (2005): Meteorological Research Institute Community Ocean Model (MRI.COM) Manual.

Kamachi, M. & S. Minato (2001): Pacific Inter-Comparison (Internal Metrics), Handout in the International Workshop on GODAE with Focus on the Pacific, IPRC, University of Hawaii, 18pp.

P7 – Monitoring and forecasting system of the ocean circulation off Rokkasho

The aim of the project is real-time monitoring and forecasting the current structure off the northeastern coast of Japan. The product of the system will be used for the tracking radionuclides released from a spent nuclear fuel reprocessing plant in Rokkasho village, Aomori Pref.

a. **Project name, acronym**: Monitoring and forecasting system of the ocean circulation off Rokkasho

b. **Domain:** Northwestern part of North Pacific (around Japan), northeastern coastal region of Japan

c. **Objectives**
Type: Real-time monitoring and prediction
Operational objectives: tracking radionuclides released from a spent nuclear fuel reprocessing plant in Rokkasho village, Aomori Pref.

d. **Downscaling strategy:** 2-level one-way nesting using data assimilation result of Northwestern part of North Pacific developed in Kyoto university (see detail in section 8.3) as the open-boundary condition. The middle model covers the region around Japan coast including Kuroshio-Oyashio system and Japan Sea, (128E-155E, 30N-50N) with 1/18 and 1/24 deg resolution. The region of the inner model is around the northern part of the Japan (141E-146E, 39N-44N). The resolution of the model is 1/54 and 1/72 deg. which corresponds about 2km.
Modeling strategy: The numerical model commonly used in this project is the ocean general circulation model with sigma-z hybrid vertical coordinate developed in Kyoto University (Toyoda et al., 2004).). The vertical levels are same for 3 models for convenience and stability for nesting technique, so those are determined as 78 levels in (4 m resolution in surface, 67 levels above 100m), which are enough to resolve the detailed topography for the coastal high-resolution model
Forcing: NCEP reanalysis data for middle model. JMA meso-scale analysis data (MANAL) for inner model.

e. **Project status:** Testing.

References

Toyoda, T., T. Awaji, Y. Ishikawa, and T. Nakamura, "Preconditioning of winter mixed layer in the formation of North Pacific eastern subtropical mode water", *Geophy. Res. Lett.*, L17206, 2004.

P8 – Japan Coastal Ocean Predictability Experiment (JCOPE)

A high-resolution forecast system of the Northwest Pacific Ocean has been developed to investigate predictability of the Kuroshio path variation south of Japan (Miyazawa and Yamagata, 2003). This project has begun October 1997 under the initiative of the Frontier Research Center for Global Change (FRCGC), which is supported Japan Agency for Marine-Earth Science and Technology (JAMSTEC).

Our ocean model is based on the Princeton Ocean Model with generalized coordinate of sigma (POMgcs). A high-resolution regional model with spatial grid of 1/12° and 45 vertical levels is embedded in a low-resolution model covering the North Pacific region (30°S-62°N, 100°E-90°W) with a spatial grid of about ¼° and 21 sigma levels. The inner model domain covers the northwest Pacific (12°-62°N, 117°-180°E) and its lateral boundary conditions are determined from the basin-wide model using the one-way nesting method (Guo et al., 2003). The model is driven by wind stresses, and heat and salt fluxes. The wind stress and heat flux field are calculated from the 6-hourly NCEP/NCAR reanalysis data and the QuikSCAT Near-Realtime (NRT) data product using the bulk formula. The salinity at the surface is restored to the monthly mean climatology with a time scale of 30 days. Synoptic variations in the Northwest Pacific Ocean are well simulated using the high-resolution model (Miyazawa et al., 2004). Using an optimum interpolation (OI) method, weekly mean various data are created from sea surface height anomaly (Jason-1 and Geosat Follow On), sea surface temperature (NOAA/AVHRR), and subsurface temperature/salinity profiles including the ARGO data (GTSPP). To consistently assimilate those data into the model, the multivariate optimum interpolation method is adopted to estimate the analysis data of temperature/salinity in vertical column. The analysis data are smoothly introduced into the model using the Incremental Analysis Update (IAU). Since our preliminary study suggests the model has a forecasting skill of two months for the Kuroshio path variation south of Japan (Miyazawa et al., 2005), two months forecast run driven by the monthly mean climatological surface forcing is weekly updated. Visualized forecast results are weekly uploaded to the JCOPE web site (http://www.jamstec.go.jp/frcgc/jcope/). Since the beginning of the forecast operation in December 2001, the JCOPE system has shown passable forecast skill of the Kuroshio path south of Japan. In particular, both the formation in summer 2004 and decline in summer 2005 of the Kuroshio large meander have been successfully predicted two months before the events. Detail of the JCOPE forecast system is described in Kagimoto et al. (2006).

The present JCOPE forecast system with the horizontal resolution of approximately 10 km has potential to predict path variations of the Kuroshio. Hence by releasing the output to the public we may contribute to people who are engaged particularly in open-ocean fishery and shippings as well as scientists who study on the Kuroshio. The resolution is, however, still too coarse for public people to utilize the output (e.g. for coastal fishery and coastal leisure). Now we have been developing a further fine resolution (1/108°) forecast model for the coastal region including the Tokyo-bay, Sagami-Bays and Suruga-Bay. Since in such areas tidal currents are as important as the geostrophic currents, we are now developing a tidal simulation model (Kagimoto et al., 2006).

Outputs of the current JCOPE ocean forecast system can be utilized as pseudo-data for many purposes. We have distributed the JCOPE data products to many users including scientists, governmental organizations, and private companies since November 2003. Because of the fineness of the horizontal resolution, the JCOPE data have been used for the lateral boundary condition of a regional ocean model and for the bottom boundary condition of a regional atmospheric model. Recently JAMSTEC and the Fisheries Research Agency of Japan (FRA) have started a collaboration study, FRA-JCOPE, to establish the ocean fishery forecast in Japan coastal ocean through inclusion of additional observations obtained by the FRA into the modified JCOPE system.

References

Guo, X., H. Hukuda, Y. Miyazawa, and T. Yamagata, 2003: A triply nested ocean model for simulating the Kuroshio -Roles of horizontal resolution on JEBAR-. J. Phys. Oceanogr., 33, 146-169.

Kagimoto, T., Y. Miyazawa, X. Guo, and H. Kawajiri, 2006: High resolution Kuroshio forecast system -Description and its applications-, in High Resolution Numerical Modeling of the Atmosphere and Ocean, W. Ohfuchi and K. Hamilton (eds), Springer, New York,, submitted.

Miyazawa, Y. and T. Yamagata, 2003: The JCOPE ocean forecast system: First ARGO Science Workshop, November 12-14, 2003, Tokyo, Japan. ftp://kakapo.ucsd.edu/pub/www-argo/workshop/Miyazawa.pdf

Miyazawa, Y., X. Guo, and T. Yamagata, 2004: Roles of meso-scale eddies in the Kuroshio paths , J. Phys. Oceanogr., 34, 2203-2222.

Miyazawa, Y., S. Yamane, X. Guo, and T. Yamagata, 2005: Ensemble forecast of the Kuroshio meandering, J. Geophys. Res., 110, C10026, doi:10.1029/2004JC002426.

7.5 Indian Ocean

P31 – MOUTON

See full description of P31 in the "Northeast Atlantic" subsection below.

7.6 North America West Coast

P9 – National Ocean Partnership Program (NOPP) GODAE HYCOM

a. **Project name**, acronym: NOPP GODAE HYCOM

b. **Domain**: US West coast from 30N to 50N

c. **Objectives**: To evaluate the influence of HYCOM GODAE boundary conditions on the circulation of the US west coast as represented by a suite of nested models.
Type: Reanalysis, research
Operational objectives: potential real-time modeling system

d. Downscaling strategy: Use Global HYCOM to provide boundary values to a suite of nested models ranging from regional (entire US west coast) to local(Monterey Bay)
Modeling strategy: Multi-nested NCOM
Forcings: COAMPS fields provided by J. Doyle (NRL Monterey), ranging in resolution from 27km to 3 km
Variables estimated: 3-dimensional T,S,u,v,ssh
Prediction range: 2003-present

Why does this project need large-scale estimates? Initial and boundary conditions .

What particular GODAE estimates does this project use, how often, etc?
Daily Global NCOM fields

Through which Modelling/Assimilation Center? NRL-Stennis

Does project have a verification/validation strategy which can help assess the impact of large-scale estimates?
A variety of model-data comparisons and metrics. Comparisons relative to use of Global NCOM for boundary and initial values

e. Project status: Boundary conditions between NCOM and HYCOM developed and tested. Presently awaiting global HYCOM with data assimilation for evaluation relative to global NCOM.

P10 – CoBIOPP / CoNESTS

a **Project name**, acronym: NRL Core projects CoBIOPP and CoNESTS

b. **Domain**: US West coast from 30N to 50N; High resolution Monterey bay Models

c. **Objectives**: To evaluate the realtive influence of HYCOM and NCOM GODAE boundary conditions on the circulation of the US west coast as represented by a suite of nested models, including coupled bio-physical models; to evaluate HYCOM as a coastal model; to evaluate HYCOM as a host for coastal ecosystem models
Type: Reanalysis, research
Operational objectives: potential real-time modeling system

d. **Downscaling strategy**: Use Global HYCOM and Global NCOM to provide boundary values to a suite of nested models ranging from regional(entire US west coast) to local(Monterey Bay)
Modeling strategy: Regional HYCOM at 9km and 4km resolution and Multi-nested NCOM, ranging from 9km to .5km for finest Monterey Bay model
Forcings: COAMPS fields provided by J. Doyle (NRL Monterey), ranging in resolution from 27km to 3 km

Variables estimated: 3-dimensional T,S,u,v,ssh
Prediction range: 2003-present for use of Global HYCOM; 1999-present for use of Global NCOM
Why does this project need large-scale estimates? Initial and boundary conditions .

What particular GODAE estimates does this project use, how often, etc? Daily Global HYCOM and NCOM fields
Through which Modelling/Assimilation Center? NRL-Stennis
Does project have a verification/validation strategy which can help assess the impact of large-scale estimates? A variety of model-data comparisons and metrics.

e. Project status: Boundary conditions for HYCOM to HYCOM and HYCOM to NCOM developed and tested. Presently awaiting global HYCOM with data assimilation for appropriate boundary values. Multi-nested NCOM developed and tested; running in real-time using NCOM boundary conditions. Development of regional HYCOM model that is consistent with Global HYCOM is under development.

P11 – CODAE California / Monterey Bay

a. **Project name**, acronym: CODAE California

b. **Domain**: Central California Coast

c. **Objectives**: To evaluate the relative influence of ECCO GODAE boundary conditions on circulation metrics of the Central California Coast.
Type: Reanalysis, scenario-testing, assessment of observational networks, research
Operational objectives, customers, funding aspects

d. **Downscaling strategy**: To move from West Coast, 10 km model-scale to 3 and then to 1 km scale. Inner model nest extends from Big Sur to Pt. Arena.
Modeling strategy: Triply nested ROMS configuration. Nesting presently carried out offline.
Forcings: COAMPS 3km fields provided by J. Doyle (NRL Monterey).
Variables estimated: 3-dimensional T,S,u,v,ssh
Prediction range: 2002-2004
Why does this project need large-scale estimates? Initial and boundary conditions .

What particular GODAE estimates does this project use, how often, etc.? ECCO GODAE, monthly. In the future, we will most likely need daily output.
Through which Modelling/Assimilation Center? MIT
Does project have a verification/validation strategy which can help assess the impact of large-scale estimates? (1) Adjoint Sensitivity, (2) Ensemble Predictions, (3) Analysis of Representer functions.

e. **Project status:** Forward model successfully implemented with GODAE bcs and COAMPS surface forcing. 4D-variational assimilation of SST and SSH and sensitivity studies are underway.

P12 – Oregon Coast (OSU-NRL-NCAR NOPP-CODAE)

a. **Project name, acronym**: "Boundary conditions, data assimilation and predictability in coastal ocean models." OSU-NRL-NCAR NOPP-CODAE.

b. **Domain:** Oregon coastal ocean, roughly 40-47 °N, 124-130 °W.

c. Objectives
Type: Research
Operational objectives: Assess impact of GODAE boundary conditions using data assimilation, and address closely related issues of uncertainty and predictability in coastal ocean circulation models.
Customers: NOPP/ONR, research community
Funding aspects: NOPP CODAE program (ONR Grant N00014-05-1-0891)

d. Downscaling strategy:
Modelling strategy, forcings, variables estimated, prediction range:
High-resolution three-dimensional terrain-following primitive equation coastal ocean model (ROMS code) with generalized inverse or ensemble-based data assimilation; NCEP and COAMPS meteorological forcing

and observed riverflow; all standard physical oceanographic fields estimated; hindcast model simulations of months to years.
Why does this project need large-scale estimates?
Influence of open ocean on shelf-slope circulation; remote forcing through coastal wave guide; well-posedness on open boundaries.
What for? Boundary conditions, more sophisticated downscaling schemes, etc., on/off-line?
Optimal methods of combining large-scale data-assimilating model state information with nested models are the object of the project research.
What particular GODAE estimates does this project use, how often, etc.?
NRL NCOM CCS initially, 1/12th-degree Pacific HYCOM when available; multi-year daily output records.
Through which Modelling/Assimilation Center?
NRL Stennis
Does project have a verification/validation strategy which can help assess the impact of large-scale estimates?
Yes. (Comparison of model results with existing data from extensive regional coastal ocean field experiments during 2000-2003 that formed part of the NSF CoOP-COAST and NSF/NOAA GLOBEC-NEP programs.)

e. **Project status**: In progress. (Three-year project with start date 1 August 2005.)

7.7 Gulf of Mexico

P13 – HYPO (NOPP-CODAE) / Gulf of Mexico

a. **Project name, acronym:** HYCOM Coastal Ocean Hindcasts and Predictions: Impact of Nesting in HYCOM GODAE Assimilative Hindcasts (our shorthand name for this project is NOPP-CODAE). The participants are RSMAS, University of Miami, Naval Research Laboratory, Stennis Space Center, Naval Research Laboratory, Monterey, Planning Systems, Inc., and the University of South Florida.

b. **Domain:** Coastal United States from the northern Gulf of Mexico to east-central Florida. We are focusing on three nested domains: Northern GOM, West Florida Shelf, and the South Florida domain. The latter domain including the Straits of Florida, Florida Keys, and Florida Bay and is part of the environmental monitoring effort being conducted as part of the Everglades restoration effort.

c. **Objectives:** Determine the impact of initial and boundary conditions provided by HYCOM GODAE ocean nowcasts and forecasts on the capability of nested models to hindcast and predict the coastal ocean environment

Evaluate the quality of coastal ocean hindcasts and predictions against observations that include existing elements of the Coastal Ocean Observing System.

Identify the most useful observations for evaluating and improving coastal ocean models that should be maintained as part of a coastal observation network.

Provide feedback and recommendations designed to improve the HYCOM GODAE product. This information will also help improve other ocean nowcast products produced as part of GODAE.

Evaluate HYCOM performance as a nested coastal model against other model types (POM, ROMS). This comparison will be performed in the West Florida Shelf domain and involves collaboration between RSMAS and the University of South Florida.

Perform scientific studies in all three nested domains. Topics will include, but are not limited to, (1) impact of offshore currents (Loop Current and eddies, Florida Current) on coastal circulation (all domains), (2) shelf-slope exchanges (all domains), (3) impact of the Mississippi river plume (locally in the northern GOM, remotely in the other two domains), and (4) the coastal ocean response to hurricanes (all domains). Results will also support other funded projects such as the SEED program in the northern GOM, the coastal oceanography projects being conducted along the West Florida Shelf at the University of South Florida, and the Everglades restoration project that is substantially supporting the modeling effort in the South Florida domain. We are providing physical fields from the West Florida Shelf and the South Florida domains to other RSMAS researchers interested in biochemical processes such as larval recruitment, red tide, etc.

d. **Approach**: Each of the three coastal modeling efforts will conduct nested ocean hindcasts, and then use all available in-situ observations to evaluate model performance. Sensitivity to initial and boundary conditions will be assessed by nesting the models within different outer model products. For this project, these products will be provided by the evolving HYCOM nowcast-forecast system. Three initial products will be evaluated: (1) the original product that assimilated satellite altimetry and SST using optimum interpolation with vertical projection of SSH anomalies; (2) nowcasts produced by the NCODA assimilation system based on objective analysis; the operational NCEP HYCOM nowcast-forecast system based on objective analysis; and (4) nowcasts produced by the ROIF assimilation system. For evaluation, these runs will be compared to each other, to the hindcast fields that provided initial and boundary conditions, and to in-situ observations. Evaluation will be performed not only on coastal hindcasts, but also on forecast runs initialized by different products. Two sets of forecast runs will be performed, one where the boundary conditions are held constant and one where they are provided by HYCOM GODAE assimilation system forecasts. Outer model nowcasts will be generated using different subsets of all available observations. Evaluation of coastal models nested within these different products will help identify those observations that lead to the most improvement and thus have priority in being maintained as part of the Coastal Ocean Observing System. Evaluation of coastal models will also be performed to determine (1) how often should boundary condition fields be provided (daily, weekly, …); (2) determining where the boundaries of the nested domains should be situated and how wide they should be; and (3) identifying and using the best available atmospheric forcing (e.g., COAMPS, ETA, …) .

e. **Project status:** At present, the first sets of outer model archives within which the coastal models will be nested either have been, or are being generated, for the initial study interval (2004-2005). The NCODA and ROIF nowcast products are being developed within a HYCOM domain spanning the Gulf of Mexico. Model files have been set up for two of the nested coastal domains (West Florida Shelf and South Florida) and test nested simulations have been run. During the remainder of 2006, multiple nested nowcasts will be conducted for years 2004 and 2005.

P14 – Northern Gulf of Mexico (NOPP GODAE HYCOM)

a. **Project name, acronym**: Enabling and Initiating Observing System Simulation Experiments of a Coastal High Resolution Oceanographic Model in the Northern Gulf of Mexico.

Collaborators: RSMAS, University of Miami; NOAA/AOML

b. **Domain:** Northern Gulf of Mexico

c. **Objectives:** Develop an Observing System Simulation Experiment (OSSE) system applicable to the Northern Gulf of Mexico (NGoM), and begin to conduct OSSEs to define the optimal observing systems for this region.

Determine the impact of initial and boundary conditions provided by HYCOM GODAE ocean nowcasts and forecasts on the capability of the nested model to hindcast and predict the coastal ocean environment. The NGoM model will be nested both directly to the GODAE North Atlantic HYCOM and to a nested Gulf of Mexico HYCOM to evaluate the optimal downscaling approach for coastal models. Boundary conditions from free-running and data assimilative outer models will also be avaluated.

Perform process oriented studies to determine the best parameterization for the Mississippi River plume and understand the interaction of the plume with the Loop Current.

Examine the influence of nested boundary conditions on the improvement of coastal to open sea interactions (such as the Mississippi River plume and the Loop Current).

Evaluate the quality of coastal ocean hindcasts and predictions against observations that include existing elements of the Coastal Ocean Observing System.

Identify the most useful observations for evaluating and improving coastal ocean models that should be maintained as part of a coastal observation network.

Provide feedback and recommendations designed to improve the HYCOM GODAE product. This information will also help improve other ocean nowcast products produced as part of GODAE.|

d. **Approach**: We use a high resolution HYCOM assimilative model covering the Gulf of Mexico through the Florida Straits (GoM-HYCOM), itself nested within the larger-scale HYCOM GODAE product, to obtain initial and boundary conditions for a higher resolution coastal model (NGoM-HYCOM). The GoM-HYCOM model has already successfully incorporated a state-of-the-art assimilation scheme (NCODA) so coastal hindcasts and predictions nested within it will enable us to demonstrate the impact of high resolution initial and boundary conditions on coastal forecasts, to conduct Observing System Simulation Experiments (OSSEs) with available CODE drifter, SVP drifter and satellite data and help guide the design for the Gulf Coastal Oceanographic Observing System (GCOOS).

e. **Project status;** The project just started and will finish summer of 2009.

P15 – Mohn-Sverdrup Center Gulf of Mexico HYCOM (MSC-GOM)

Domain
The model covers the Gulf of Mexico with 5 km resolution (conformal mapping grid)

Objectives
Real-time monitoring and prediction system, hindcast studies, research.
The objective is to forecast the Loop Current and Eddies as they approach the Northern Shelf of the GOM.

Customers
Research, oil&gas industry (via the joint venture Ocean Numerics Ltd.). The model is part of the Ocean FOCUS forecast service by Ocean Numerics Ltd. Hurricane simulations have been performed and funded by Ocean Weather Inc.

Funding aspect
This project has been initially set up during the TOPAZ project funded by the EC. It is further supported by Ocean Numerics and Shell E&P.

Downscaling strategy
One-way and off-line nesting offer sufficient flexibility for operating the nested model.
HYCOM-to-HYCOM downscaling, the outer models are TOPAZ and HYCOM 1/12th. The downscaling method is from that of Browning and Kreiss (1982, 1986) with bilinear interpolation to the nested rotated horizontal grid. The frequency of nesting conditions are 6-hourly and daily respectively from TOPAZ and HYCOM 1/12th. Astronomical tides are not included.
The GOM model uses local data assimilation of altimetry data provided by CLS. An Ensemble Optimal Interpolation (EnOI) has been set up based on an OI version of the Ensemble Kalman Filter (EnKF).
The monitoring and prediction system is driven by external inputs, atmospheric forcing fields from ECMWF. The predictions are run weekly on a forecast horizon of 2 weeks.
Why does this project need large-scale estimates?
The inflow through the Yucatan Strait needs to be correctly represented. High quality lateral boundary conditions of ocean parameter are absolutely vital.
Strategy for validation of boundary conditions
The incoming volume fluxes, kinetic energy and water mass properties are monitored in the nested model and compared to available observations and to the outer model.
What particular GODAE estimates does this project use, how often, etc.?
The project uses TOPAZ boundary conditions for 3D ocean parameters. The frequency of nesting files is 6-hours.
The project also uses NRL HYCOM 1/12th boundary conditions for 3D ocean parameters. The frequency of nesting is daily.
Through which Modelling/Assimilation Center?
TOPAZ is provided by the Mohn-Sverdrup Center at the Nansen Center, Bergen.
HYCOM 1/12th is provided by the NRL, Stennis, via the NOPP-HYCOM project.

Project status
The forecasts are running weekly since 2004, HYCOM has been upgraded in April 2006. The model forecasts are served to the oil and gas industry operating in the Gulf of Mexico by Ocean Numerics Ltd. Hurricane hindcasts have been run for hurricanes Andrew (1992), Lili (2002) have been delivered to the Mineral Management Service (MMS) and Ivan (2004) is licensed by Oceanweather Inc.
The NRL-GOM nesting has been successfully integrated on a test period of one year.

Web: http://msc.nersc.no/gulf_mexico.php

7.8 North America East Coast

P16 – Canada-Newfoundland Operational Ocean Forecasting System (C-NOOFS)

The Canada-Newfoundland Operational Ocean Forecasting System (C-NOOFS) is currently the most advanced initiative within Canada in terms of downscaling GODAE products. The goal is to foster an end-to-end operational ocean prediction system for the North West Atlantic with particular emphasis on Canadian Waters. This project includes (i) Automated collection of *in situ* and remotely sensed data e.g. temperature, salinity, oxygen, nutrients and chlorophyll profiles, (ii) Development of new, near real-time data streams from marine mammals (seals) and Fisheries and Oceans research and monitoring cruises (iii) Sharing of these new data sets with data service centres, (iv) Assimilation of data in ocean models and (v) Transmission of model forecast output to defined government end-users (e.g. the Canadian Coast Guard) and generation of publicly available ocean model output via a web page.

The planned system will feature two coupled grids:

(i) a ¼ degree grid covering the Northwest Atlantic. It is a subset of the ORCA025 (1/4 deg) global model domain which has poles situated over Canada, Russia and Antarctica. The C-NOOFS initiative is restricted to the north-west Atlantic (35N-80N, 77W-35W) and has a horizontal resolution of roughly 20 km in the south of the domain and 6 km at the northern extremities in the Canadian Arctic Archipelago. The open boundary conditions are presently supplied by the Mercator ocean product PSY1v2 for the North Atlantic.

(ii) A refined grid nested within the Northwest Atlantic model that covers the shelf regions around Newfoundland. The grids will be two-way coupled using the AGRIF nesting protocol with a grid refinement factor of 3.

Anticipated outcomes from C-NOOFS for this upcoming year include daily updates for the Northwest Atlantic domain with wind forecasts provided by Environment Canada. No data assimilation is planned in the first set of model products which will include (i) data extracted along transects of regular DFO monitoring cruises (3 times a year), (ii) vertical profiles coinciding with available observed in-situ profiles (e.g. from Argo floats, seals) (iii) standard MERSEA metrics. In the future, an increase in resolution from ¼ degree North West Atlantic will be considered once the system is operational.

P17 – US Northeast Coast (WHOI)

a. **Project name,** acronym: Evaluation of Global Ocean Data Assimilation Experiment (GODAE) Hindcast IN Providing Open Boundary Conditions for High Resolution Coastal Circulation Modeling

b. **Domain**; the coastal region from Nova Scotia to Cape Hatteras, including the Gulf of Maine (GOM) and the middle Atlantic Bight (MAB).

c. **Objectives**
Type: Research
Customers: scientific community
Funding aspects: Woods Hole Oceanographic Institution

d. **Downscaling strategy**
Modeling strategy, forcings, variables estimated, prediction range
High-resolution three-dimensional terrain-following primitive equation Regional Ocean Modeling System; NCEP meteorological forcing and observed riverflow; hindcast model simulations of months to years.

Why does this project need large-scale estimates?
To resolve open ocean impact on coastal circulation; remote forcing through coastal wave guide; well-posedness on open boundaries.

What for? Boundary conditions, more sophisticated downscaling schemes, etc., on/off-line?
To better understand coastal circulation in GOM and MAB, and it seasonal and inter-annual variability

What particular GODAE estimates does this project use, how often, etc.?
$1/12^{th}$-degree Atlantic HYCOM; multi-year daily output records.

Through which Modeling/Assimilation Center?
NRL Stennis Center

Does project have a verification/validation strategy which can help assess the impact of large-scale estimates? Yes. Comparison of model results with existing data from regional coastal ocean observing systems.

e. **Project status:** In progress.

7.9 Arctic and Nordic Seas

P18 – Mohn-Sverdrup Center Barents Sea HYCOM (MSC-Barents)

Domain
The model covers the Barents and Kara Seas with 4 to 5 km resolution (conformal mapping grid)
Approximately from 65N to 82N and from 5E to 100E.

Objectives
Real-time monitoring and prediction system, hindcast studies, research.
The objective is to forecast the currents and sea-ice conditions in the Barents and Kara Seas and to provide input data to an iceberg forecasting system.

Customers
Research, oil&gas industry (Statoil, KARBIAC JIP), shipping, society at large.

Funding aspect
This project is supported by a private donation from Trond Mohn C/O Frank Mohn AS, Bergen, by the European MERSEA Integrated project and industry projects with Statoil and the KARBIAC JIP.

Downscaling strategy
One-way and off-line nesting offer sufficient flexibility for operating the nested model.
HYCOM-to-HYCOM downscaling, the outer model is TOPAZ. The downscaling method is from that of Browning and Kreiss (1982, 1986) with bilinear interpolation to the nested rotated horizontal grid. The ice parameters are also nested. The frequency of nesting conditions is 6-hourly. Astronomical tides are added
The monitoring and prediction system is driven by external inputs, atmospheric forcing fields from ECMWF.
The predictions are run daily on a forecast horizon of 2.5 days.
Why does this project need large-scale estimates?
The Barents Sea is very sensitive to the variability of the North Atlantic Water inflow, the exchanges of Arctic Water and of sea-ice with the Central Arctic. High quality lateral boundary conditions of ocean and sea-ice parameters are absolutely vital.
Strategy for validation of boundary conditions
The incoming fluxes, kinetic energy, sea ice and water mass properties are monitored in the nested model and compared to available observations and to the outer model.
What particular GODAE estimates does this project use, how often, etc.?
The project uses TOPAZ boundary conditions for 3D ocean parameters and sea-ice. The frequency of nesting files is 6-hours. Tides are included.
Through which Modelling/Assimilation Center?
The Mohn-Sverdrup Center at the Nansen Center, Bergen.

Project status
The model validation against hydrographic data has been presented at the EGU general assembly in April 2006 for a hindcast study of the year 1979 (extremely severe ice conditions). The forecasts are running daily since 1st September 2006. A 20-years hindcast is planned.

Web: http://msc.nersc.no/barents_sea.php

P19 – DAMOCLES (Developing Arctic Modelling and Observing Capabilities for Long-term Studies)

Domain
The model covers the Fram Strait with 2 km resolution (conformal mapping grid)
Approximately from 75N to 85N and from 20 W to 20E.

Objectives

Real-time monitoring and prediction system, hindcast studies, research
The objective is to forecast the complex mesoscale currents and sea-ice conditions in the Fram Strait and to provide input data to an acoustic tomography inversion system.

Customers
Research, society at large.

Funding aspect
This project is supported by the DAMOCLES IP of the European Commission (FP6), matching funds by the Research Council of Norway and additional industry projects.

Downscaling strategy
One-way and off-line nesting offer sufficient flexibility for operating the nested model.
HYCOM-to-HYCOM downscaling, the outer model is TOPAZ. The downscaling method is from that of Browning and Kreiss (1982, 1986) with bilinear interpolation to the nested rotated horizontal grid. The ice parameters are also nested. The frequency of nesting conditions is 6-hourly. Astronomical tides are added
The monitoring and prediction system is driven by external inputs, atmospheric forcing fields from ECMWF.
Why does this project need large-scale estimates?
The Fram Strait is the main connection between the Nordic Seas and the Actic and the fluxes are mainly controlled by the West Spitzberg and East Greeland currents. High quality lateral boundary conditions of ocean and sea-ice parameters are absolutely vital.
Strategy for validation of boundary conditions
The incoming fluxes, kinetic energy, sea ice and water mass properties are monitored in the nested model and compared to available observations and to the outer model.
What particular GODAE estimates does this project use, how often, etc.?
The project uses TOPAZ boundary conditions for 3D ocean parameters and sea-ice. The frequency of nesting files is 6-hours. Tides are included.
Through which Modelling/Assimilation Center?
The Mohn-Sverdrup Center at the Nansen Center, Bergen.

Project status
The model is in development phase.

Web: http://msc.nersc.no/

P20 – Eddy resolving HYCOM model of the Nordic Seas (NORDIC)

Domain
The model covers the Nordic Seas with 4 km resolution (conformal mapping grid)
Approximately from 55N to 83N and from 30W to 20E.

Objectives
Hindcast studies, research.
The objective is to study the mesoscale currents in the Nordic Seas.

Customers
Research, society at large.

Funding aspect
This project is funded by The Research Council of Norway (RCN) through the Ocean Weather and Ecosystem project of the FRINAT programme.

Downscaling strategy
One-way and off-line nesting offer sufficient flexibility for operating the nested model.
This is a HYCOM-to-HYCOM downscaling, the outer model is TOPAZ3. The downscaling method is from that of Browning and Kreiss (1982, 1986) with bilinear interpolation to the nested rotated horizontal grid. The frequency of nesting conditions is 6-hourly. Astronomical tides are added.
The system is driven by external inputs, atmospheric forcing fields from ECMWF.
Why does this project need large-scale estimates?
The inflow of North Atlantic Water and Arctic Waters needs to be correctly represented. High quality lateral boundary conditions of ocean parameter are absolutely vital.
Strategy for validation of boundary conditions

The incoming fluxes, kinetic energy and water mass properties are monitored in the nested model and compared to available observations and to the outer model.
What particular GODAE estimates does this project use, how often, etc.?
The project uses TOPAZ boundary conditions for 3D ocean parameters. The frequency of nesting files is 6-hours. Tides are included.
Through which Modelling/Assimilation Center?
TOPAZ is provided by the Mohn-Sverdrup Center at the Nansen Center, Bergen.

Project status
The project is in development phase.

7.10 Norwegian, Baltic, and North Seas

P21 – Mohn-Sverdrup Center Norwegian Sea Ecosystem MSC-NWS-ECO

Domain
The model covers the Norwegian Sea and Coastal Current with 4 km resolution (conformal mapping grid) Approximately from 62N to 68N and from 4W to 12E.

Objectives
Hindcast studies, research.
The objective is to study the influence of mesoscale fronts and eddies on the ecosystem in the Norwegian Sea. The model could easily be set up in real-time at a later stage if needed.

Customers
Research, society at large.

Funding aspect
This project is 100% funded by a private donation of Trond Mohn C/O Frank Mohn AS.

Downscaling strategy
One-way and off-line nesting offer sufficient flexibility for operating the nested model.
A three level HYCOM-to-HYCOM downscaling is used from a 40 km North Atlantic Model to a 15 km North Eastern Shelf and to the 4 km MSC-NWS-ECO model, the sequence of nested models is designed for numerical efficiency of the coupled physical-ecosystem model. The downscaling method is from that of Browning and Kreiss (1982, 1986) with bilinear interpolation to the nested rotated horizontal grid. The frequency of nesting conditions is 6-hourly. Astronomical tides are added. The ecosystem variables are also nested on all 3 levels. The same ecosystem model is used on all 3 levels, The nesting between ecosystems models with different compartments is needed for flexibility and will be implemented at a later stage.
The monitoring and prediction system is driven by external inputs, atmospheric forcing fields from ECMWF (ERA40).
Why does this project need large-scale estimates?
The North Atlantic Water inflow (including the nutrients) needs to be correctly represented. High quality lateral boundary conditions of ocean parameter are absolutely vital.
Strategy for validation of boundary conditions
The incoming volume fluxes, ecosystem variables, water mass properties are monitored in the nested model and compared to available observations and to the outer model.
What particular GODAE estimates does this project use, how often, etc.?
The project produces its own boundary conditions for 3D physical and ecosystem ocean parameters by the use of coarse resolution versions of the TOPAZ and CONMAN systems. The frequency of nesting files is 6-hours for the physical variables, daily for the ecosystem variables. Tides are included.
Through which Modelling/Assimilation Center?
BCs are provided by the Mohn-Sverdrup Center at the Nansen Center, Bergen.

Project status
A hindcast study for the years 1995-1996 is ongoing.

P22 – Mohn-Sverdrup Center CONMAN HYCOM (MSC-CONMAN)

Domain
The model covers the North Sea and Norwegian Sea with 4 km resolution (conformal mapping grid). Approximately from 50N to 68N and from 5W to 10E.

Objectives
Real-time monitoring and prediction system, hindcast studies, research.
The objective is to forecast the currents in the North Sea and Norwegian Sea, in particular at the Ormen Lange field, and to compare HYCOM to POM and ROMS models operated at met.no.

Customers
Research, oil&gas industry (Norwegian Drilling Programme, NDP), Meteorological agencies (met.no). society at large.

Funding aspect
This project has been set up by the CONMAN project funded by NDP. It is further supported by the Franco-Norwegian Foundation project PRECOC.

Downscaling strategy
One-way and off-line nesting offer sufficient flexibility for operating the nested model.
This is a HYCOM-to-HYCOM downscaling, the outer model is TOPAZ. The downscaling method is from that of Browning and Kreiss (1982, 1986) with bilinear interpolation to the nested rotated horizontal grid. The frequency of nesting conditions is 6-hourly. Astronomical tides are added.
The monitoring and prediction system is driven by external inputs, atmospheric forcing fields from ECMWF. The predictions are run daily on a forecast horizon of 2.5 days.

Why does this project need large-scale estimates?
The North Atlantic Water inflow needs to be correctly represented. High quality lateral boundary conditions of ocean parameter are absolutely vital.

Strategy for validation of boundary conditions
The incoming fluxes, kinetic energy and water mass properties are monitored in the nested model and compared to available observations and to the outer model.

What particular GODAE estimates does this project use?
The project uses TOPAZ boundary conditions for 3D ocean parameters. The frequency of nesting files is 6-hours. Tides are included.

Through which Modelling/Assimilation Center?
TOPAZ is provided by the Mohn-Sverdrup Center at the Nansen Center, Bergen.

Project status
The forecasts are running daily since 15th December 2005. A workshop has been held with 7 oil companies at met.no (1st Feb. 2006). A hindcast study for the years 2004-2006 is ongoing.

P23 – ECOOP BalEco

BalEco is a coupled hydrodynamic-ecosystem modelling system for the Baltic Seas for the prediction of (in particular) cyanobacteria algal blooms and their impact on water quality. Operated by the Finnish Institute for Marine Research.

Domain
Baltic Sea (8.9E-30.1E, 54N-67N)

Objectives
Real-time monitoring and prediction, reanalysis, scenario-testing

Downscaling strategy
Operational modelling with 72 hour forecasts (ECMWF). Variables include T,S,(u,v,w), SSH, NO3, PO4, SiO4, flagellates, diatoms, 2 cyanobacteria.

To improve representation near model boundaries between Baltic Sea and North Sea, several estimates are used pre-operationally using MERCATOR, Topaz products.

Validation anticipated in operational GODAE coupling stage.

Project status
Operational

P24 – ECOOP Modeling the Baltic Sea with coupled POP and CICE model (IOPAS-POPCICE)

Objective: Modeling the Baltic Sea with coupled POP and CICE model operated by the Institute of Oceanology Poland.

Domain
Entire Baltic Sea area.

Objectives
Type: reanalysis, scenario-testing, research

Downscaling strategy
Forcings: ERA40
variables estimated: T,S, currents, SSH

Project status
The model is now working quite well. At the moment we do some effort to increase horizontal resolution from 9-km to 2 –km.

P25 – MERSEA-ECOOP Baltic-North Sea system (DMI)

Operated by the Danish Meteorological Institute.

Domain
Baltic-North Sea

Objectives
Real-time prediction

Downscaling strategy
Use large scale predictions from MERSEA (EU GODAE Component) as boundary conditions of DMI operational 3D ocean forecasting system. The impact of this downscaling will be assessed by using model validation in MERSEA and ECOOP projects. The GODAE products will be provided by NCOF in UK.

Project status
On-going. An operational dynamic lateral boundary condition will be run in April 2007 in DMI Baltic-North Sea operational forecasting system.

P26 – ECOOP BSHcmod

Domain
North Sea and Baltic Sea

Objectives
Operational forecasting
National funding
Support of water level prediction and storm surge warning service
Drift- and dispersion predictions in case of marine pollution (e.g. oil)
Support of SAR and various customers (navy, fisheries, tourism ...)

Downscaling strategy
Nested models driven by tidal predictions and meteorological forecasts of German Weather Service (DWD), prediction range: 3 days

Why does this project need large-scale estimates?
Boundary data for water level, salinity and temperature (later: SPM, nutrients and plankton)
Real time boundary forcing

What particular GODAE estimates does this project use?
At moment: no use

Validation Strategy
Validation of water levels, currents, temperature and salinity in German waters on routine basis (annual, monthly, weekly, daily)

Project status
Operational activity, ongoing

P27 – MONCOZE

MONCOZE is MONitoring the COastal Zone Ecosystem.

Domain
The model covers the North Sea with 4 km resolution (conformal mapping grid)
Approximately from 50N to 63N and from 5W to 10E.

Objectives
Hindcast studies, research.
The objective is to forecast the currents and ecosystem in the North Sea.

Customers
Research, Meteorological agencies (met.no). society at large.

Funding aspect
This project has been set up by the MONCOZE project funded by The Research Council of Norway (RCN).

Downscaling strategy
One-way and off-line nesting offer sufficient flexibility for operating the nested model.
This is a HYCOM-to-HYCOM downscaling, the outer model is TOPAZ. The downscaling method is from that of Browning and Kreiss (1982, 1986) with bilinear interpolation to the nested rotated horizontal grid. The frequency of nesting conditions is 6-hourly. Astronomical tides are added.
The monitoring and prediction system is driven by external inputs, atmospheric forcing fields from ECMWF.
Why does this project need large-scale estimates?
The North Atlantic Water inflow needs to be correctly represented. High quality lateral boundary conditions of ocean parameter are absolutely vital.
Strategy for validation of boundary conditions
The incoming fluxes, kinetic energy and water mass properties are monitored in the nested model and compared to available observations and to the outer model.
What particular GODAE estimates does this project use, how often, etc.?
The project uses TOPAZ boundary conditions for 3D ocean parameters. The frequency of nesting files is 6-hours. Tides are included.
Through which Modelling/Assimilation Center?
TOPAZ is provided by the Mohn-Sverdrup Center at the Nansen Center, Bergen.

Project status
The project is completed. A hindcast study for the years 1997-1998 has led to 3 peer reviewed scientific publications (Winther & Evensen 2006, Winther et al. 2006, Winther & Johannessen 2006), the model has been run in real-time for a test period and its domain is now covered be the larger CONMAN system.
The model may be run with a coupled ecosystem model at a later stage.

http://www.nersc.no/Projects/MONCOZE

7.11 Northeast Atlantic

P28 – MERCATOR FAÇADE

To improve the realism of its system near the coast, Mercator Océan is currently developing a regional system of the South European Atlantic, named Façade, with a resolution of 1/36° nested in the global system.

The regional Façade model uses the European NEMO version of the OPA code, which includes free surface and partial cells on the vertical. Its open boundaries will be forced by daily average data of temperature, salinity, U and V velocities and surface elevation from global Mercator. Multivariate data assimilation will be used.

a. Project name, acronym

MERCATOR "Façade"

b. Domain

Atlantic Arc (South-western Europe): North of Ireland to Canaries Island and 24°W to the coast

c. Objectives:

To improve the Mercator global system near to the shelf and coast on SW Europe
Type: Real-time monitoring and prediction, reanalysis
Operational objectives: service of initial and boundary conditions to coastal modellers
Customers: Coastal modelling users:

- French Navy (SHOM) and research institutes: CNRS, IFREMER, IRD which are consortium members of Mercator Océan
- IBI-ROOS partners : IMI (Ireland), IST/MARETEC (Portugal), ESEOO (Spain)

Funding aspects: self funding, budget from the Navy and from European project (ECOOP, EASY if accepted).

d. Downscaling strategy:

Nest regional "Façade" on GODAE-MERSEA global system
Modelling strategy: use of NEMO European code (OPA1.9, free surface, partial cells on vertical). High resolution horizontal system, 1/36°, nested in global ¼° which will be upgraded to 1/12°.
Forcings: atmospheric forcings from ARPEGE (Météo France), open boundary conditions from GODAE/MERSEA global system.
Variables estimated: temperature, salinity, radial and zonal velocities, surface elevation, mixed layer depth
Prediction range: do not know yet, 14 days if chosen the same as global system.
Why does this project need large-scale estimates? What for? To take into account the large scale circulation which influences the circulation near to the coast especially when crossing the slope
Boundary conditions, more sophisticated downscaling schemes, etc., on/off-line? Boundary conditions, off-line.
What particular GODAE estimates does this project use, how often, etc.? temperature, salinity, U and V velocities, surface elevation will be used once a day.
Through which Modelling/Assimilation Center? Mercator Océan.
Does project have a verification/validation strategy which can help assess the impact of large-scale estimates? Yes. Comparison on the gulf of Biscay of several systems (using different codes) without and with large scale circulation from open sea system.

e. Project status

Under development.
Plans for collaboration with the future of the Spanish operational oceanographic project, following of actual ESEOO.

P29 – ECOOP POL Coastal Observatory

Domain
Focus is Liverpool Bay in the eastern Irish Sea.

Objectives
Real-time monitoring and nowcasting/prediction system. For understanding a shelf sea's response to anthropogenic and climate change. To provide scientific underpinning for coastal zone management.

Customers
NERC, NCOF, Mersey Dock Company, JNCC

Funding source
NERC, Cefas (Defra), Met Office, EU

Downscaling strategy

Modelling strategy, forcings, variables estimated, prediction range
A set of one-way nested 3-dimensional models (hydrodynamic and coupled ecosystem) from the Atlantic into Liverpool Bay. Open boundary forcing for Atlantic Margin Model from FOAM (6h); atmospheric forcing from Met Office NWP system (3h); lateral boundary river data provided by combination of daily climatology and daily real-time runoff. Nowcasting and 36h forecasting.
Why does this project need large-scale estimates?
To provide the oceanic influence on the NW European Shelf. We use FOAM N Atlantic model data for boundary conditions.
Downscaling into Liverpool Bay provided through one-way nesting utilizing radiation condition for the barotropic forcing (including specification of tides) and a relaxation condition for baroclinic forcing. 3-dimensional temperature, salinity, currents and surface elevation derived from the rigid lid pressure (6h).
Through which Modelling/Assimilation Center?
Met Office / Mersea / POL
Does project have a verification/validation strategy which can help assess the impact of large-scale estimates?
Model outputs are routinely compared to satellite SST, in-situ moorings (Coastal Observatory, Cefas Smartbuoy), Irish Sea ferry measurements.

Project status
Started in 2002, ongoing.

Website: http://cobs.pol.ac.uk

P30 – ECOOP Establecimiento de un Sistema Español de Oceanografía Operacional (ESEOO)

Domain
Spanish waters

Objectives
Real-time monitoring and prediction, reanalysis, scenario-testing, assessment of observational networks, research. To build up the capabilities required in Spain related to Operational Oceanography with special focus in fight against marine pollution. Three year national project funded with 1 million Euro. Project objectives are:

- Development of a regional scale national oil spill and current forecasting system.
- Set-up of high resolution numerical models and systems able to forecast currents and spill evolution at local scale.
- Validation and intercomparison of models in a pilot area
- Development of a data service able to quickly provide information based on analysed historical measurements.
- Set-up of a unified access point to real-time oceanographic and meteorological data at Spanish coasts.
- Basic research in the fields of data assimilation in ocean models, oceanographic and meteorological data processing...
- Design of coordination procedures in case of emergency.

Downscaling strategy
Forecast horizon is 3 days. 3 D models are employed nested into global solutions. System is run once per day.
We need downscaling from global to regional application due to the nature of the problem to be solved.
We are developing real time validation based on the Puertos del Estado deep water network. It is critical for us to have good solutions in the deep sea, so nesting makes sense. Assimilation is obviously critical for that.

Project status
The project in its present form will be finished in December 2006). Activities will continue within a new project (agreed) and later as a permanent institution.

P31 – MOUTON

a. Project name, acronym

MOUTON (Modélisation Océanique d'un Théâtre d'Opérations Navales) is about modelling of regional to local areas for the French Navy needs.

b. Domains

North Eastern Atlantic : English Channel, Bay of Biscay, West Spain and Portugal, Gulf of Cadiz at 1' (1/60°) resolution, plus zooms on several chosen areas.

Models of the North Western Indian Ocean are also developed.

c. Objectives

The main objective is to extend the operational capability of the French Navy nowcast/forecast systems to regional or local areas including coastal zones.

The sub-objectives of the MOUTON project are :

- Evaluate the possibilities of modelling the deep and shallow water areas of the ocean using a multi-model approach , in particular based on OPA, the model that has been chosen by the MERCATOR project, and a model using hybrid vertical coordinates, HYCOM.
- Improve the parameterization of mixing processes, in particular the processes influenced by the topography along continental shelves ;
- Evaluate the ability of oceanic circulation models to accurately represent the tides and internal tides ;
- Evaluate the possibilities of developing operationnal systems based on coastal models, in particular by integrating data assimilation sub-systems in the latter ;
- Evaluate or develop new sensors, or methods to exploit data from existing sensors, for assimilation in coastal areas ;
- Improve data assimilation techniques to optimize the use of data and define strategies for observations ;
- Obtain some pertinent diagnostics to validate models, in particular on the basis of in situ observations.

The latter actions aim at building a demonstrator on the EC/Biscay/Portugal/Cadiz area. Its operational capabilities will be evaluated by :

- Comparison between in situ observations and the results from realistic models ;
- Evaluation of the impact of data assimilation on these results;
- Evaluation of the limits of the demonstrator.

The results will be used to specify the future nowcast/forecast systems of the French Navy for both open and coastal areas.

d. Downscaling strategy

The regional and local models developed in MOUTON are forced by MERCATOR (GODAE/MERSEA system) for the low frequency oceanic fields, and MOG2D for the tides. Several atmospheric forcing solutions are also tested (ARPEGE, ALADIN, AROME).

e. Project status

The MOUTON project has been launched in september 2001 and will end in December 2009. The MOUTON project is a research program funded by DGA (Office of Research and Development of the French Ministry of Defence) and the French Navy.

7.12 Mediterranean Operational Oceanography Network (MOON)

Due to the large natural variability and the human induced changes, the Mediterranean Sea water resources and coastal areas sustainable development need to be continuously monitored, analyzed and predicted following the practice of operational oceanography (GOOS, 1996). Operational oceanography in the Mediterranean Sea is now a reality but it is mainly connected to physical environmental variables. However, it is clear that the practices and methodologies of operational oceanography could be of benefit to sustainable development issues related to marine coastal areas, water and marine resources management. In particular, the practice of real time monitoring and modelling together with field estimation needs to be exported to the other environmental aspects of sustainable development of marine areas. The availability of a real time, quality controlled stream of complex environmental information coming from the optimal estimation of observations and models could provide an innovative support to policy makers and managers of environmental marine emergencies. For some of the aspects of environmental monitoring and modelling in real time, basic research still needs to be carried out and new tools have to be developed. It is timely to start these developments coordinating the efforts in the various disciplines with operational oceanography in order to develop them within the concepts of operational science.

MOON – the Mediterranean Operational Oceanography Network – has been proposed in the framework of GOOS and of GMES (Global Monitoring of Environment and Security), a common initiative of EU and ESA, the European Space Agency. MOON tries to undertake the task of consolidating the present Mediterranean operational oceanography network and at the same time using the forecasting system to improve the present state of monitoring the marine environment state of health and the information to be used for the management of water and marine resources in the Mediterranean area. In other words, MOON links operational oceanography to users of environmental information in order to reach the goal of sustainable development of this critical marine area.

The MOON plan is subdivided into six areas of action that are:

1. Ocean hydrodynamics,

2. Water cycle and resources,

3. Biochemical fluxes and cycles,

4. Open ocean and coastal marine pollution,

5. Sedimentary fluxes and coastal erosion,

6. Operational Fisheries.

These key action areas are the focus of research, development and demonstration exercises to bridge the gap between operational oceanography and the final end users of the forecasts, for the practical solution of sustainable development problems. The strategy for development of the different action areas is outlined in five special focus projects that should be developed in the next five years.

Information can be found on the MOON web page: http://www.moon-oceanforecasting.eu/ where several systems downscaled from the MFS OGCM, including the two systems listed here, are listed as "Core Services" of MOON.

P32 – ECOOP-MOON-COOL (IMEDEA GODAE)

This ongoing project, coordinated by IMEDEA, Spain, aims at real-time monitoring and prediction to address scientific questions associated with the high resolution modelling in the near the coastal area of the Western Mediterranean: South of Mallorca, Balearic Islands, Algerian and Alboran sub-basins. Another objective is the coupling of hydrodynamical processes (waves and currents) in the coastal zone.

A high resolution PE ocean circulation model is used following a downscaling approach from a basin-scale model of the Mediterranean Sea. The atmospheric forcing is provided by the Spanish National Institute of Meteorology in terms of 3 hourly fields of the High Resolution Limited Area Model (HIRLAM, http://hirlam.org). However, high resolution output form MM5 will be tested in the near future.

Domain
Local (South of Mallorca, Balearic Islands, Algerian and Alboran sub-basins, Mediterranean Sea)

Objectives
Real-time monitoring and prediction to address scientific questions associated with the high resolution modelling in the near coastal area.
Coupling hydro-dynamical processes (waves and currents) in the coastal zone.

Downscaling strategy
A high resolution PE ocean circulation model is used following a downscaling approach from a basin-scale model of the Mediterranean Sea.
The atmospheric forcing is provided by the Spanish National Institute of Meteorology in terms of 3 hourly fields of the High Resolution Limited Area Model (HIRLAM, http://hirlam.org). However, high resolution output form MM5 will be tested in the near future.
The variables estimated are currents, salinity, temperature and sea surface elevation.
The prediction range is 3 days.
Large-scale estimates are needed to update the boundary conditions. We are testing different nesting approaches: off-line nesting, on-line and nesting via assimilation of large-scales estimates.
The model assimilates GODAE satellite data (SST, SSH). High-resolution satellite products with improved coastal processing are required for the model.
Large-scale estimates are provided by MFS and MERCATOR.

Project status
The project will begin in October 2006.

P33 – ADRICOSM

This ongoing demonstration project, coordinated by INGV, Italy, aims at the integrated management of Adriatic Sea coastal areas and river basin water resources. It is based upon four modules:

- Module 1 - Adriatic Coastal Areas Forecasting system (ACAF) The construction of a Near Real Time monitoring and modeling system to accurately forecast the short-term variability of the coastal areas circulation.

- Module 2 - Integrated River basin MAnagement system (IRMA) The implementation of an integrated planning and management system of urban drainage and wastewater utilities in a test site for the Croatian coasts.

- Module 3 - ACaf-IRma Interface (ACIRI) The development of an interface (of the river basin module) with the marine coastal area forecasting module.

- Module 4 – MAnagement of the Project and the CApacity Building (MAPCAB).

ACAF is needed to know and forecast the variable transport field from the open sea to the coastal areas up to 500 meters resolution. IRMA is required to monitor water quality at river mouths and connect it both to urban sources and to the marine coastal areas transport.

The ADRICOSM organizes the automatic and Near Real Time distribution of marine data sets and implements advanced modeling and data assimilation tools to be synthesized via Module 1. The models and data sets are:

- Five marine models nested in each other: 1 regional model (AREG) downscaled from the MFS OGCM (GODAE configuration), 2 shelf models (ASHELF), and 2 coastal models (ACOAST).

- Data assimilation software. A multivariate data assimilation system (the same as in MFS) assimilates satellite SST, in situ CTD stations, XBT, and satellite SLA into the AREG and ASHELF models.

- In situ VOS data. Two tracks of XBT temperatures profiles covering the Adriatic Sea at 10 nautical miles resolution.

- Atmospheric forcing. Surface atmospheric parameters from ECMWF (Reading, UK).

- Satellite data. Satellite Sea Surface Temperature (SST) data, colour data and Sea Surface Anomaly (SLA) data.

- In situ CTD data. CTD measure temperature, salinity and oxygen collected once a week at four different coastal areas.

- In situ buoy data. Three in situ multiparametric buoy stations: at the Po river, at the Tagliamento river, and at the Marjan Cape (Split), which measure temperature, salinity, oxygen, pH, light transmission, and current velocity.

- SISSI database. All technical, management, economic and financial data concerning the integrated water service (sewer network, river and coastal environments) in a relational database developed with a software SISSI.

- Integrated Catchment Simulator (ICS). A combination of 4 different models: MOUSE (the urban drainage system), MIKE11 (the river), MIKE21 (the marine and coastal water body), and STOAT (the wastewater treatment processes).

- Capital Investment Plan (CIP) and Tariff Evaluation (TE). A CIP for the optimization of the operation and management of the wastewater facilities by using the SISSI database, and a TE for the establishment of the increase of the water tariff in the long term.

P34 – ALERMO

This ongoing project, conducted by the University Athens, Greece, aims at hydrodynamical forecasting of the Levantine basin and the Aegean Sea. In the project, the ROMS model is downscaled from the MFS OGCM (GODAE configuration).

Project name
Aegean-Levantine Eddy Resolving Model (ALERMO)

This ongoing project, coordinated by the University Athens, Greece, aims at hydrodynamical forecasting of the Levantine basin and the Aegean Sea. In the project, the ROMS model is downscaled from the MFS OGCM (GODAE configuration).

Domain
The ALERMO model covers the geographical area 20ºE – 36.4ºE, 30.7ºN – 41.2ºN and has one open boundary located at 20º E. It is baed on Princeton Ocean Model (POM). The computational grid has a horizontal resolution of 1/30º × 1/30º (493×316 grid points) and 25 sigma levels.

Objectives
In the framework of MFSTEP the basic steps of implementing near real time 5 days forecasts at regional/shelf scale in the Mediterranean Sea was carried out, developing a system of fifteen (15) models, from basin to shelf scale. University of Athens (Greece) was responsible for the Aegean-Levantine domain system as well as for the whole regional and shelf scale system.

The ALERMO forecast results are used by several shelf models (seven at this moment) in the region for operational and research activities.

The ALERMO forecast system is already integrated in EU and national projects that are commencing in the next few months.

Downscaling
The ALERMO model is initialized daily from the MFSTEP Mediterranean OGCM using the Variational Initialization method (Auclair et al. 2000), producing 5-days forecast. Atmospheric conditions over the ALERMO domain are provided by the SKIRON/Eta atmospheric forecasting system (Kallos et al., 2005). The Eta atmospheric model used in the SKIRON system is an operational weather prediction model, currently running with a 1/10º × 1/10º horizontal resolution analysis for the needs of MFSTEP.

5-days forecast is available at http://www.oc.phys.uoa.gr/mfstep/bulletin (temperature, salinity, velocity at specific depths and sea surface elevation)

Details about the modeling system can be found at http://pelagos.oc.phys.uoa.gr/mfstep/ALERMO_MFSTEP_DETAILS.htm. Recently, assimilation of sea level anomaly was implemented in the system and will be expanded in other fields in the near future.

At this point GODAE estimates can be used for validation/tuning purposes. In the future, ocean parameters can be also used in assimilation procedures.

The project validation strategy is based on data of the MFSTEP operational observing system as well as University of Athens independent observational activities (ARGO floats, cruises, etc.).

Project Status
MFSTEP project was completed (31/05/2006). The ALERMO system continues to produce forecast and is integrated in EU (ECOOP) and national projects that are commencing in the next few months.

P35 – NWMED

This ongoing project, conducted by NOVELTIS, France, aims at hydrodynamical forecasting of the Northwestern Mediterranean: Ligurian Sea, Gulf of Lions, Catalan Sea. In the project, the SYMPHONIE model is downscaled from the MFS OGCM (GODAE configuration).

The downscaling from the MFSTEP OGCM to the NWMED model is carried out by using VIFOP variational balanced initialization.

The real-time bulletin can be accessed at: http://www.noveltis.net/mfstep-wp9/interface/english/NWMED_bulletin.php .

8.Appendix 3: The large-scale GODAE data producers

This section gives details on GODAE systems and modelling centers which will be able to provide estimates for initialization, boundary forcing and downscaling of regional and coastal systems.

8.1 Australia

BLUElink/OFAM/BRAN (CSIRO/BoM/RAN)

The Model

Australia's GODAE model is an implementation, called OFAM (Ocean Forecasting Australia Model), of the Princeton GFDL model MOM. It has been developed as part of the BLUElink project, a partnership between CSIRO, the Bureau of Meteorology (BoM) and the Royal Australian Navy (RAN). The model has 10-km resolution in the Australasian region, but diminishing resolution with distance from Australia. OFAM is run in two modes, operational forecasting and hindcast.

The operational forecasts will be run routinely, on a 3-day cycle, by the Bureau of Meteorology, forecasting out to seven days. Output will be in NetCDF format, with restricted availability on both OpenDAP and ftp sites. The output will be in the form of once-daily fields of currents, temperature, salinity and sea-level. The forecasts should come online in early 2007.

Data Serving

The hindcasts are called BRAN (for Bluelink ReANalysis), and will run from 1992 to the present. Again, daily files of model fields will be available on OpenDAP and via ftp. The BRAN data set is presently (Oct 2006) available in spinup (non-data-assimilating) mode. The procedure for access to the data is described on http://www.marine.csiro.au/ofam1/.

OFAM has also been used to generate a 15-year reanalysis, that is archived for broad community use.

References

The OFAM implementation and testing is described in:

Schiller, A., P. R. Oke, G. B. Brassington, M. Entel, R. Fiedler, D. A. Griffin, J. Mansbridge, G. A. Meyers, K. Ridgway and N. R. Smith 2006: Eddy-resolving ocean circulation in the Asian-Australian region inferred from an ocean reanalysis effort. *Progress in Oceanography,* submitted.

The data-assimilation approach (ensemble optimal interpolation) in:

Oke, P. R., A. Schiller, G. B. Brassington 2006: Ensemble data assimilation for an eddy-resolving ocean model. *Quarterly Journal of the Royal Meteorological Society*, in press.

8.2 China

BCC-GODAS (BCC/CMA)

The Beijing Climate Center/China Meteorological Administration provides monthly mean ocean reanalysis products based on their global ocean data assimilation operational system (BCC-GODAS). The data is written in IEEE binary of Fortran on IBM Unix workstation. It contains sea temperature, salinity and zonal, meridional velocity components from 1982 to the present, and will be updated every month. The dimensions of longitude, latitude and depth are 194, 92 and 17, respectively, while the ocean model used in the data assimilation has a dimension of 30.

A 3-dimensional variational data assimilation scheme is adopted in BCC-GODAS. Meanwhile, a time-window, about 4-weeks, is opened in order to obtain as much observation information as possible. In BCC-GODAS, both sea temperature and salinity observation data, if available, are input. The background errors covariance involves a vertical weak correlation and a loose correlation between temperature and salinity.

The Model

The dynamic model used in this system is the L30T63 OGCM Version 1.0, which is established and developed by LASG/IAP. This model has the same horizontal resolution as T63 atmosphere model, and there are 30 layers in the vertical direction, in which the first 10 layers are from 0 to 250m, the second 10 layers span from 250m to 1000m, and the last 10 layers are located deeper till 5600m. There are two vertical mixing parameterization schemes in this model. One is based on Richardson number applied in the tropic region from 30S to 30N. Another is an isopycnal mixing scheme. While using this model, we have made some improvement on the vertical mixing parameterization scheme: a transition zone to connect two areas mentioned above is designed, and the criterion of the stability depending on gradient of density in isopycnal mixing scheme is redefined as a spatial function rather than a constant.

Data Serving

The data is available from http://ingrid.ldeo.columbia.edu/SOURCES/.CMA/.BCC/.GODAS/. The contact person is: Dr. Yimin Liu, Beijing Climate Center, China Meteorological Administration, N0.46 Zhong'guan'cun South Ave., 100081 Beijing, P. R. China. E-mail: liuym@cma.gov.cn

References

Yimin Liu, Jiangxing Zhou and Qiang Ma, 2000: Study on The Pacific and The Indian Oceanic Data Assimilation System, documents for national key project-studies on short-term climate prediction system in China (1996-2000), Chinese Meteorological Press, 401-407.

Yimin Liu, 2003: Optimal estimation of the model covariance matrix of Ocean data assimilation system by neural network method, a poster in "Workshop on Advances in Marine Climatology" held in Brussels on 3/11/2003.

Yimin Liu, Renhe Zhang, Yonghong Yin and Tao Niu, 2003: The application of Argo data to optimal estimation of the model errors covariance matrix of ocean data assimilation system, a poster in the first Argo Science workshop held in Tokyo on 11/11/2003.

8.3 Japan

K7 (Frontier Research Center for Global Change, JAMSTEC)

The Models

This project produces two reanalysis datasets by using a 4D-VAR (adjoint) method. One is obtained from a coupled system, the other is from an ocean system.

1. Coupled data assimilation product

The atmosphere-ocean coupled assimilation system is investigated here by the Coupled model for the Earth Simulator (CFES), which is composed of the Atmospheric GCM for the Earth Simulator (AFES) (Ohfuchi et al. 2004) and the free-surface Ocean-sea Ice GCM for the Earth Simulator (OIFES) (Masumoto et al. 2004). The AFES component is based on the atmospheric GCM constructed by the Center for Climate System Research/National Institute for Environmental Studies (CCSR/NIES). The OIFES component is developed from version 3 of the Modular Ocean Model (MOM3) produced by the Geophysical Fluid Dynamics Laboratory and the sea ice model of the International Arctic Research Center (Hibler 1980).

The adjoint codes of the AFES and OIFES components are obtained on the basis of the Tangent linear and Adjoint Model Compiler (TAMC) (Giering and Kaminski 1998) and the Transformation of Algorithms in Fortran compiler (TAF) (Giering and Kaminski 2003).

The resolution of the AFES component is horizontally the same as the commonly--used T42 spectral model and has 24 layers in vertical s coordinates. The resolution of the OIFES component is 1degree both in latitude and longitude and has 36 vertical layers.

Adjustment factors `alpha' are introduced into each bulk formula for latent heat, sensible heat, and momentum fluxes and these are chosen as control variables together with the oceanic initial conditions of the model variables. Each value of `alpha' is optimized in each grid point for each month by the coupled assimilation. This reanalysis data is for climatological monthly state and for the period from1996 to 1998.

2. Ocean data assimilation product

The ocean reanalysis dataset was derived from the 4D-VAR assimilation system used in Masuda et al. (2003). It covers the global ocean state over the period from 1987 to 2004. The OGCM is version 3 of the GFDL Modular Ocean Model (MOM3; Pacanowski and Griffies 1999), which is equipped with several sophisticated schemes; e.g., the nonlocal K Profile Parameterization (KPP) for mixed layer physics (Large et al. 1994), and the Gent and McWilliams scheme for isopycnal mixing (Gent and McWilliams 1990). The horizontal resolution is 1degree in both latitude and longitude, with 36 vertical levels spaced from 10m (free-surface) near the sea surface to 400m at the bottom.

In 4D-VAR approach, optimized 4-dimensional datasets are sought by minimizing a cost function (Masuda et al., 2003). The assimilation covers a 19-year time window starting from 1986. We chose the initial condition of model variables and air-sea fluxes (heat, fresh water, and momentum fluxes) as the control variables with the latter modified within the assimilation period as 10-day mean values (see Masuda et al., 2003, for more detail).

Data Serving

Part of these reanalysis datasets is available from their web-site. http://www.jamstec.go.jp/frcgc/k7-dbase2/search_e/index_e.html .

MOVE/MRI.COM (Meteorological Research Institute, Japan Meteorological Agency)

The Models

The model is the Meteorological Research Institute Community Ocean Model (MRI.COM; Ishikawa et al. 2005), which is 3-D, z-s hybrid coordinate model that solves primitive equations. The model can be multi-nested at various resolutions. Accompanying data assimilation system is the Meteorological Research Institute Ocean Variational Estimation System (MOVE), which is based on 3DVAR (Fujii & Kamachi, 2003a,b,c, Usui et al., 2006). Currently, a 1/10 degree version has been developed for the western North Pacific region (MOVE/MRI.COM-WNP; Usui et al. 2006) and it will be implemented as an operational system of JMA by 2008. The surface forcing for the model is taken from the operational outputs from JMA operational nowcast/forecast system (or may be coupled to the atmospheric model in the future). For nowcast, we will make a full use of GTSPP, GHRSST (JMA/Tohoku-Univ.), Satellite Altimeter (TOPEX, Jason, Envisat …).

Data Serving

The results are not open to the public at the moment.

References

Fujii, Y. & M. Kamachi (2003a): A reconstruction of observed profiles in the sea east of Japan using vertical coupled temperature-salinity EOF modes. J. Oceanogr., vol. 59, 173-186.

Fujii Y. & M. Kamachi (2003b): Three dimensional analysis of temperature and salinity in the equatorial Pacific using a variational method with vertical coupled temperature-Salinity empirical orthogonal function modes. J. of Geophys. Res., 108(C9): 3297, doi: 10.1029/2002JC001745.

Fujii Y. & M. Kamachi (2003c): A nonlinear quasi-Newton method without inversion of a first-guess covariance matrix in variational analyses. Tellus, 55A: 450-454.

Usui,Y., Y. Fujii, S. Ishizaki, H. Tsujino, T. Yasuda, M. Kamachi (2006): Introduction of the Meteorological Research Institute Multi-Variate Ocean Variational Estimation System (MOVE-System). Advances in Space Res., 37, 806-822.

RIAM Japan Sea forecasting project (Kyushu University)

The Models

The system developed in Research Institute for Applied Mechanics (RIAM), Kyushu University produces short-term forecasts up to 5-6 days and provides nowcast and long-term forecast of basic oceanographic variables for 2-3 months in the JES.

The RIAM Ocean Model solves the primitive equations assuming the hydrostatic relation at regular latitude-longitude grid in z-coordinates. The operational version has 1/12deg grid spacing and thin top layer of 5 m thickness.

The long-term assimilation model is driven by daily-mean surface fluxes estimated by bulk formulas from the JMA high resolution (~0.1 degree) regional meteorological data. The sequential corrections have been preformed by assimilating the satellite altimeter data on a coarser 1/3° grid for the barotropic and first baroclinic modes, which is known as an approximate Kalman filter (Hirose et al., 2005). The surface relaxation is simultaneously made by the high-resolution merged satellite SST data of Tohoku University with one-day time scale. The inflow open boundary conditions at the Tsushima/Korea Straits for the volume transport are now given by long-term monthly mean data measured by ship-mounted sensors of ADCP, temperature, and conductivity.

Data Serving

The results are opened for a wide range of users through a web site at http://jes.riam.kyushu-u.ac.jp/ .

Monitoring and forecasting system of the ocean circulation off Rokkasho (Kyoto University and Japan Marine Science Foundation)

The Models

The numerical model commonly used in this project is the ocean general circulation model with sigma-z hybrid vertical coordinate developed in Kyoto University (Toyoda et al., 2004).). The vertical levels are same for 3 models for convenience and stability for nesting technique, so those are determined as 78 levels in (4 m resolution in surface, 67 levels above 100m), which are enough to resolve the detailed topography for the coastal high-resolution model.

The model for outside data assimilation system has a 1/6 and 1/8 deg. resolution for zonal and meridional, respectively, with covering the northwestern part of the North Pacific (122E-165E, 25N-55N). The OMIP climatological mean of ECMWF reanalysis data are used for the surface forcing. The observation data, SST (NGSST by Tohoku Univ.), SSH (Ssalto/Ducacus dynamic topography by AVISO), in situ XBT and CTD data (GTSPP by NOAA/NODC) are assimilate into the model using 4D-VAR (adjoint) method. The assimilation period for 4D-VAR iteration is about 1 month and the initial condition of the model is estimated as the control variables.

This system is now testing to evaluate the performance by the hindcast experiments from year 2003.

Data Serving

The results are not open to the public at the moment.

J-COPE (Frontier Research Center for Global Change, JAMSTEC)

The Models

A high-resolution forecast system of the Northwest Pacific Ocean has been developed to investigate predictability of the Kuroshio path variation South of Japan (Miyazawa and Yamagata, 2003, Miyazawa et al., 2004. Ocean model in this project is based on the Princeton Ocean Model with generalized coordinate of sigma (POMgcs). A high-resolution regional model with spatial grid of 1/12° and 45 vertical levels is embedded in a low-resolution model covering the North Pacific region (30°S-62°N, 100°E-90°W) with a spatial grid of about ¼° and 21 sigma levels. Using an optimum interpolation (OI) method, weekly mean various data are created from sea surface height anomaly (Jason-1 and Geosat Follow On), sea surface temperature (NOAA/AVHRR), and subsurface temperature/salinity profiles including the ARGO data (GTSPP). To consistently assimilate those data into the model, the multivariate optimum interpolation method is adopted to estimate the analysis data of temperature/salinity in vertical column. The analysis data are smoothly introduced into the model using the Incremental Analysis Update (IAU).

Data Serving

The assimilation and forecast results are shown in the JCOPE web site operationaly (http://www.jamstec.go.jp/frcgc/jcope/), since December 2001.

References

Miyazawa, Y. and T. Yamagata, 2003: The JCOPE ocean forecast system: First ARGO Science Workshop, November 12-14, 2003, Tokyo, Japan. ftp://kakapo.ucsd.edu/pub/www-argo/workshop/Miyazawa.pdf

Miyazawa, Y., X. Guo, and T. Yamagata, 2004: Roles of meso-scale eddies in the Kuroshio paths , J. Phys. Oceanogr., 34, 2203-2222.

8.4 Canada

COMDA/CONCEPTS, CFCAS, C-NOOFS

The Models

Although Canada has been running coastal forecast models in operational mode for almost 10 years, it has only recently started to develop the capacity to nowcast and forecast open ocean conditions.

There have been three major developments in Canadian operational oceanography over the last couple of years:

(1) COMDA and CONCEPTS: The federal department of Fisheries and Oceans Canada recently created a virtual center of excellence network entitled COMDA (Canadian Ocean Modelling and Data Assimilation). The purpose of COMDA is to accelerate the development of operational oceanographic in Canada in partnership with Canadian Universities and Environment Canada. COMDA initiatives include projects focused on the Gulf of St. Lawrence (http://www.osl.gc.ca/), the north-east Pacific, the Arctic Basin, the East Coast of Canada and contributions to global coupled ocean atmosphere modeling initiatives (see below).

The Meteorological Service of Canada, the Department of Fisheries and Oceans, and the Department of National Defence have recently entered into a partnership to develop an operational coupled atmosphere-ocean-ice modeling and assimilation system that will provide nowcasts and medium-range forecasts on global scales, with special attention paid to regions of strategic interest to Canada. Primary goals are to increase the forecast skill of the Canadian atmospheric forecast model and to start to provide, for the first time, ocean-products of interest to the partners (including open boundary conditions for nested regional and coastal models). The name of the initiative is the Canadian Operational Network of Coupled Environmental PredicTion Systems (CONCEPTS) and its implementation plan is presently being finalized. CONCEPTS will be developed in partnership with Mercator-Ocean. Currently a Memorandum of Understanding is being prepared with Mercator in order to develop an ocean–atmosphere coupled operational seasonal and short term prediction system. CONCEPTS also includes the development of regional ocean forecasting systems nested within basin and global scale models.

(2) CFCAS: It is recognized that the development of CONCEPTS will require significant research and development if it is to successfully meet Canada’s needs. With this in mind, the operational activity described above will be complemented by a parallel research activity involving atmospheric and ocean modelers and assimilators from both government and academic institutions. The Canadian Foundation of Climate and Atmospheric Sciences announced in July 2006 that it will provide \$2.8M to support the establishment of a Canada-wide research network entitled “Prediction and Predictability of the Coupled Atmosphere-Ocean System From Days to Decades”. The co-leads of the network are Keith Thompson (Dalhousie University) and Hal Ritchie (Environment Canada) and 14 additional principal investigators from across the country are involved. One of the two themes is focused on intra-seasonal time scales and many of its research projects involve the assimilation of new observations (e.g. Argo profiles, sea-level observations from altimetry and GRACE) into eddy-admitting models. It is anticipated that close collaborations will develop with the parallel operational activity and also international groups tackling similar research problems. Close interaction with GODAE researchers will be sought.

(3) C-NOOFS: The Canada-Newfoundland Operational Ocean Forecasting System (C-NOOFS) is currently the most advanced initiative within CONCEPTS in terms of both planning and implementation. It is a pilot project under the COMDA centre of excellence. The purpose of C-NOOFS is to foster an end-to-end operational ocean prediction system for the North West Atlantic with particular emphasis on Canadian Waters. This project includes (i) Automated collection of *in situ* and remotely sensed data e.g. temperature, salinity, oxygen, nutrients and chlorophyll profiles, (ii) Development of new, near real-time data streams from marine mammals (seals) and Fisheries and Oceans research and monitoring cruises (iii) Sharing of these new data sets with data service centres, (iv) Assimilation of data in ocean models and (v) Transmission of model forecast output to defined government end-users (e.g. the Canadian Coast Guard) and generation of publicly available web output. Details are given in the relevant subsection of **Appendix 2**.

The planned system will feature two coupled grids:

(iii) a ¼ degree grid covering the Northwest Atlantic. It is a subset of the ORCA025 (1/4 deg) global model domain which has poles situated over Canada, Russia and Antarctica. The C-NOOFS initiative is restricted to the north-west Atlantic (35N-80N, 77W-35W) and has a horizontal resolution of roughly 20 km in the south of the domain and 6 km at the northern extremities in the Canadian Arctic Archipelago. The open boundary conditions are presently supplied by the Mercator ocean product PSY1v2 for the North Atlantic.

(iv) A refined grid nested within the Northwest Atlantic model that covers the shelf regions around Newfoundland. The grids will be two-way coupled using the AGRIF nesting protocol with a grid refinement factor of 3.

Anticipated outcomes from C-NOOFS for this upcoming year include daily updates for the Northwest Atlantic domain with wind forecasts provided by Environment Canada. No data assimilation is planned in the first set of model products which will include (i) data extracted along transects of regular DFO monitoring cruises (3 times a year), (ii) vertical profiles coinciding with available observed in-situ profiles (e.g. from Argo floats, seals) (iii) standard MERSEA metrics.

Data Serving

Web site is under construction

8.5 USA

HYCOM

The Model

A broad partnership of institutions is collaborating in developing and demonstrating the performance and application of eddy-resolving, real-time global and basin-scale ocean prediction systems using the HYbrid Coordinate Ocean Model (HYCOM). The plan is to transition these systems for operational use by the U.S. Navy at both the Naval Oceanographic Office (NAVOCEANO) and the Fleet Numerical Meteorology and Oceanography Center (FNMOC), and by NOAA at the National Centers for Environmental Prediction (NCEP).

The present Navy near real-time 1/12° Atlantic HYCOM ocean forecasting system (http://www.hycom.org/ocean_prediction.html) is the first step toward the fully global 1/12° HYCOM prediction system. The Atlantic system spans from 28°S to 70°N, including the Mediterranean Sea (Chassignet et al., 2006a, 2006b). During 2007 it will be replaced by a real-time 1/12° global HYCOM system with a bipolar Arctic cap north of 47°N. The model has 32 hybrid layers in the vertical with z-levels (pressure coordinates) near the surface to resolve the mixed layer, isopycnal layers in the stratified interior and terrain-following (σ) coordinates in shallow water. Three-hourly wind and thermal forcing is provided by the FNMOC Navy Operational Global Atmospheric Prediction System (NOGAPS). Ocean data will be assimilated using the Coupled Ocean Data Assimilation (NCODA) system which QC's the data and performs multi-variate optimal interpolation (MVOI) analyses using a model forecast as the first guess. The global system will be run daily in real time with assimilation of satellite altimeter data (ENVISAT, GFO and JASON-1 provided via the Altimeter Data Fusion Center (ADFC) at NAVOCEANO), in situ and Multi-Channel Sea Surface Temperature (MCSST) data with 8.8 km resolution processed at NAVOCEANO, and profiles of temperature and salinity. Every Wednesday a 30-day forecast will be run with the forcing relaxed toward climatology after 5 days and with SST relaxed toward climatologically-corrected persistence on an increasing time scale. The impact of the forecast procedure is discussed by Smedstad et al. (2003) and Shriver et al. (2006).

Data serving

The Atlantic HYCOM products are freely available daily 3D fields of the ocean state served once a week at http://www.hycom.org/dataserver (hindcasts and 14-day forecasts). The same procdedure will be used for global HYCOM but with daily updates within 24 hours and 30-day forecasts once a week.

References

Chassignet, E.P., H.E. Hurlburt, O.M. Smedstad, G.R. Halliwell, P.J. Hogan, A.J. Wallcraft, and R. Bleck, 2006a. Ocean prediction with the HYbrid Coordinate Ocean Model (HYCOM). J. Mar. Sys. (in press)

Chassignet, E.P., H.E. Hurlburt, O.M. Smedstad, G.R. Halliwell, A.J. Wallcraft, E.J. Metzger, B.O. Blanton, C. Lozano, D.B. Rao, P.J. Hogan and A. Srinivasan, 2006b. Generalized vertical coordinates for eddy-resolving global and coastal ocean forecasts. Oceanography, 19 (1), 118-129.

Shriver, J.F., H.E. Hurlburt, O.M. Smedstad, A.J. Wallcraft and R.C. Rhodes, 2006. 1/32° real-time global ocean prediction and value-added over 1/16° resolution. J. Mar. Sys. (in press)

Smedstad, O.M., H.E. Hurlburt, E.J. Metzger, R.C. Rhodes, J.F. Shriver, A.J. Wallcraft, and A.B. Kara, 2003. An operational eddy-resolving 1/16° global ocean nowcast/forecast system. J. Mar. Sys., 40-41, 341-361.

The Navy Coastal Ocean Model (NCOM): the Global Implementation

The Model

The global version of the Navy Coastal Ocean Model (NCOM) encompasses the open ocean in a curvilinear global model grid with 1/8 degree grid spacing at 45N. This grid extends from 80S to a complete arctic cap. The model employs 40 levels: 19 sigma coordinate levels in the upper 137 m and 21 z-levels from 137m to 5500m. The real time system uses Navy Operational Global Atmospheric Prediction System (NOGAPS) 3-hourly wind stresses and heat fluxes. Operationally available sea-surface temperature (SST) and altimetry (SSH) data are incorporated into the Naval Oceanographic Office Modular Ocean Data Assimilation System (MODAS) and Navy Layered Ocean Model (NLOM) analyses with forecasts of SSH and SST. These surface fields are combined with the MODAS synthetic database to yield three-dimensional fields of temperature and salinity for assimilation into global NCOM.

Data Serving

The data are available online from 1 January 1998 to 30 days from the present. Data are available via the live access server at http://supply.nrlssc.navy.mil:8000/las/servlets/dataset .

References

Barron, C.N., A.B. Kara, P.J. Martin, R.C. Rhodes, and L.F. Smedstad, 2006: Formulation, implementation and examination of vertical coordinate choices in the global Navy Coastal Ocean Model (NCOM). Ocean Modelling, 11(3-4), 347-375, doi:10.1016/j.ocemod.2005.01.004.

Barron, C.N., A.B. Kara, H.E. Hurlburt, C. Rowley, and L.F. Smedstad, 2004: Sea surface height predictions from the global Navy Coastal Ocean Model (NCOM) during 1998-2001. Journal of Atmospheric and Oceanic Technology, 21(12), 1876-1894.

Kara, A.B., C.N. Barron, P.J. Martin, L.F. Smedstad, and R.C. Rhodes, 2006: Validation of interannual simulations from the 1/8° Global Navy Coastal Ocean Model (NCOM). Ocean Modelling, 11(3-4), 376-398, doi:10.1016/j.ocemod.2005.01.003.

ECCO near Real-Time Ocean Analysis

The Model

The ECCO Near Real-Time Analysis provides near-global data assimilated estimates of the ocean on a regular basis. The analysis provides a means to monitor the state of the ocean and to analyze the nature of its evolution. The analysis is based on the Massachusetts Institute of Technology general circulation model (MITgcm; Marshall et al. 1997). The model is configured in a near-global domain (72.5°S~72.5°N) with a uniform zonal grid spacing of 1° longitude. The meridional grid spacing is 0.3° latitude in the tropics (within 10° of the Equator) that gradually increases to 1° in the extra-tropics (poleward of 22° latitude). There are 46 vertical levels with 10 m spacing within 150 m of the surface, gradually increasing to 400 m spacing at depth. The model is forced by 12-hourly surface wind stress and daily heat and freshwater fluxes. The fluxes are based on the reanalysis products of the National Centers for Environmental Prediction and the National Center for Atmospheric Research (NCEP-NCAR) (Kalnay et al., 1996) (approximately 2° spatial resolution), except the time-means are adjusted combining climatological products of the Comprehensive Ocean-Atmosphere Data Set (COADS) (da Silva et al., 1994) and satellite scatterometer winds (Menemenlis et al., 2005). Freshwater fluxes (evaporation, precipitation, river runoff) are implemented as a virtual salt flux in which surface salinity is modified in accordance to the freshwater forcing as opposed to changing the model's freshwater volume. Model sea surface temperature (SST) and sea surface salinity (SSS) are additionally relaxed toward NCEP's SST analysis and the climatological mean SSS of Boyer and Levitus (1998), respectively. SSS is relaxed with a time-scale of 60-days, whereas SST is relaxed using a spatially varying time-scale, typically between 1-2 months, based on the method of Barnier et al. (1995).

The near real-time assimilation employs an approximate Kalman filter and Rauch-Tung-Striebel (RTS) smoother. The approximations, consisting of a time-asymptotic approximation (Fukumori et al., 1993), state reduction (Fukumori et al., 1995), and partitioning (Fukumori, 2002), are designed to reduce the estimation's computational requirements associated with the derivation and utilization of the model's state error covariance matrix. The present analysis estimates and corrects model errors (control) associated with time-variable uncertainties in model wind forcing. The analysis assimilates sea level from satellite altimeters and vertical temperature profiles from in situ measurements. Sea level observations consist of those of TOPEX/POSEIDON and Jason along the satellites' ground tracks. Temperature profiles are from the Global Telecommunication System (GTS) and consist of measurements from XBTs, Argo, TAO moorings, and CTDs, quality controlled by NCEP (D.Behringer, personal communication). The assimilation is conducted every 6-hours, assuming available data within three hours of the assimilation instant are coincident.

The modeling and assimilation system and their estimates are being employed in studies of ocean circulation as well as in various applications beyond oceanography per se, including climate analysis and forecasting, biogeochemical studies, and geodetic analyses. Some of these examples include Lee et al. (2002), Dickey et al. (2002), Lee and Fukumori (2003), Gross et al. (2004), Fukumori et al. (2004), Wang et al. (2004), Kim et al. (2004), Fukumori et al. (2006), and Yulaeva et al. (2006). The MITgcm-based analysis is currently being transitioned to a second generation system based on the Modular Ocean Model (MOM4, Griffies et al, 2003) that is utilized in operational seasonal to interannual climate forecasting at NCEP.

Data Serving

Estimates are available at 10-day intervals (12-hour intervals for sea level and bottom pressure) from January 1993 to present and are extended in time regularly every month. All estimates are accessible for analysis and application at http://ecco.jpl.nasa.gov/external or via the Live Access Server at http://ecco.jpl.nasa.gov/las.

The model state (velocity, temperature, salinity, sea level, bottom pressure) is available for analysis and application as 10-day averages. In addition, instantaneous values of sea level and bottom pressure are saved at 12-hour intervals to better resolve their high-frequency fluctuations. Independent components of model tendencies are also saved as thirtyday integrals to diagnose temperature and salinity budgets over arbitrary regions of the model domain (Lee et al., 2004). Estimates from reference simulation, Kalman filter, and RTS smoother are separately available at http://ecco.jpl.nasa.gov/las ; in particular, the RTS smoother estimate is provided for the GSOP evaluation. The model adjoint is also available to quantify the sensitivity of the model estimate to various controls and, thereby, to deduce mechanisms of the circulation.

References

Barnier, B., L. Siefridt, and P. Marchesiello, 1995. Thermal forcing for a global ocean circulation model using a three-year climatology of ECMWF analyses, *J. Mar. Sys.,* **6**, 363-380. Boyer, T. P. and S. Levitus, 1998: Objective analysis of temperature and salinity for the world ocean on a 1/4° grid. NOAA Atlas NESDIS, Washington, D.C..

da Silva, A. M., C. C. Young and S. Levitus, 1994. Atlas of Surface Marine Data 1994, Volume 1: Algorithms and Procedures. NOAA Atlas NESDIS 6. U.S. Dept. Commerce, NOAA, NESDIS.

Dickey, J. O., S. L. Marcus, O. de Viron, and I. Fukumori, 2002. Recent Earth oblateness variations: Unraveling climate and postglacial rebound effects, *Science*, **298**, 1975-1977.

Fukumori, I., J. Benveniste, C. Wunsch, and D. B. Haidvogel, 1993. Assimilation of sea surface topography into an ocean circulation model using a steady-state smoother, *J. Phys. Oceanogr.*, **23**, 1831-1855.

Fukumori, I., and P. Malanotte-Rizzoli, 1995: An approximate Kalman filter for ocean data assimilation; an example with an idealized Gulf Stream model, *J. Geophys. Res.*, **100** (C4), 6777-6793.

Fukumori, I. , 2002: A partitioned Kalman filter and smoother, *Mon. Weather Rev.,* **130** (5), 1370-1383.

Fukumori, I., T. Lee, B. Cheng, and D. Menemenlis, 2004. The origin, pathway, and destination of Niño3 water estimated by a simulated passive tracer and its adjoint, *J. Phys. Oceanogr.*, **34**, 582-604.

Fukumori, I., D. Menemenlis, and T. Lee, 2006. A near-uniform basin-wide sea level fluctuation of the Mediterranean Sea, *J. Phys. Oceanogr.*, (in press).

Griffies, S. M., M. J. Harrison, R. C. Pacanowski, and A. Rosati, 2003: A Technical Guide to MOM4. GFDL Ocean Group Technical Report No. 5, Princeton, NJ: NOAA/Geophysical Fluid Dynamics Laboratory, 295 pp.

Gross, R. S., I. Fukumori, D. Menemenlis, P. Gegout, 2004. Atmospheric and oceanic excitation of length-of-day variations during 1980-2000, *J. Geophys. Res*., **109** (B1), art no. B01406.

Kalnay, E., and coauthors, 1996. The NCEP/NCAR 40-year reanalysis project, *Bull. Ameri. Met. Soc.*, **77**, 437-471.

Kim, S.-B., T. Lee, and I. Fukumori, 2004. The 1997-99 abrupt change of the upper ocean temperature in the Northcentral Pacific, *Geophys. Res. Lett*., **31** (22), L22304, 10.1029/2004GL021142

Lee, T., I. Fukumori, D. Menemenlis, Z. Xing, and L.-L. Fu, 2002. Effects of the Indonesian Throughflow on the Pacific and Indian Oceans, *Journal of Physical Oceanography*, **32**, 1404-1429.

Lee, T. and I. Fukumori, 2003. Interannual to decadal variation of tropical-subtropical exchange in the Pacific Ocean: boundary versus interior pycnocline transports, *J. Climate*, **16**, 4022-4042. Lee, T., I. Fukumori, and B. Tang, 2004. Temperature advection: Interior vs exterior processes. *J. Phys. Oceanogr,.* **34** (8), 1936-1944.

Marshall, J. C., A. Adcroft, C. Hill, L. Perelman, and C. Heisey, 1997. A finite-volume, incompressible Navier Stokes model for studies of the ocean on parallel computers, *J. Geophys. Res.*, **102**, 5753-- 5766.

Menemenlis, D., I. Fukumori, and T. Lee, 2005. Using Green functions to calibrate an ocean general circulation model, *Mon. Weather Rev.*, **133** (5), 1224-1240.

Wang, O., I. Fukumori, T. Lee, and B. Cheng, 2004. On the cause of eastern equatorial Pacific Ocean TS variations associated with El Niño, *Geophys. Res. Lett.*, **31**, L15309, doi:10.1029/2004GL020188.

Yulaeva, E., M. Kanamitsu, and J. Roads, 2006. The ECPC coupled prediction model, *J. Clim.*, (submitted).

8.6 Italy

Mediterranean Forecasting System

The Model

The EU-funded Mediterranean Forecasting System Project aims at the further development of an operational forecasting system for the Mediterranean Sea based upon three main components: a) the Near Real Time Observing system; b) the numerical forecasting systems at basin scale and for regional areas; c) the forecast products dissemination/exploitation system. The MFS "Towards Environmental predictions" (MFSTEP) project finished in May 2006. The Mediterranean Forecasting System is continuing its activities inside the Mediterranean Operational Oceanography Network - MOON.

The problems to be solved belong in three major categories:

1) Technology developments, connected to the new instrumentation for NRT monitoring and the provision of NRT protocols for data dissemination, comprehensive of telecommunication technology and quality control procedures;

2) Scientific development, connected to the understanding of the sampling scheme for different measuring platforms, the design and implementation of data assimilation schemes for different spatial scales, the ecosystem modelling validation/calibration experiments at the basin and the coastal areas scale and the development of data assimilation techniques for biochemical data;

3) Exploitation developments, consisting of software interfaces between forecast products and oil spill modelling, general contaminant dispersion models, relocatable emergency systems, search and rescue models, and fish stock observing systems. In addition, the study of forecast economic value and impact will be carried out.

The Modelling system component is composed of:

1) the development of optimal estimation techniques for basin scale and shelf areas forecasts;

2) the 10 days basin scale forecasting at approximately 6 km resolution with initialization from all available real time data;

3) the 3 days regional forecasting systems (3 km resolution) downscaled from the MFS OGCM in four regions: North-Western Mediterranean, Sicilian Strait, Adriatic Sea and Levantine-Aegean Sea (the Adriatic Sea forecasting activities are sponsored by an Italian national project - ADRICOSM);

4) the real time acquisition of operational weather forecasts for the basin scale (40 km resolution and 10 days forecasts), for the regional scales (10 km resolution and 3 days forecasts) and for the shelf scales (4 km resolution and 3 days hindcasts);

5) the development of three dimensional ecosystem models coupled to the forecasting hydrodynamic models and the implementation and test of data assimilation techniques for biochemical variables.

The basin-scale forecasting in the Mediterranean Sea has started in January 2000 and it is continuing since then. The system included in the MERSEA project is functioning with a weekly analysis cycle and a weekly ten days forecast cycle. It uses SLA from satellite and VOS-XBT data that were collected in near-real time as well as other data. The model code is OPA (Ocean PArallelise) version 8.1 developed by Institut Pierre Simon Laplace, Laboratoire d'Oceanographie Dynamique et de Climatologie, Paris. A detailed description of the code can be found in Madec et al. (1998) and at http://www.lodyc.jussieu.fr/opa/ . The model is a primitive equation model, the Navier-Stokes equations are used with the approximation of thin-shell, Boussinesq, hydrostatic and incompressible fluid. The resolution is 1/16° and 72 levels which is close to eddy resolving in many areas of the Mediterranean.

The data assimilation scheme is the System for Ocean Forecast and Analysis (SOFA). It is a reduced order optimal interpolation scheme (De Mey and Benkiran, 2002). The operational implementation of the scheme is described in Demirov et al. (2003). The assimilation scheme has been implemented in a multivariate smoother and filter mode. The SST is assimilated using a relaxation term which corrects the surface heat flux (Pinardi et al., 2003). The other three data sets (SLA, XBT and ARGO) are assimilated using the background error correlation matrix (correlations among temperature, salinity, sea surface elevation and barotropic stream function errors).

More information as well as the MFS bulletin can be accessed via the MOON web page: http://www.moon-oceanforecasting.eu/ .

Data Serving

Products are no longer freely available. Data and products can be downloaded via ftp from the INGV server after user has obtained an account.

- Analysis and forecasting products are offered free of charge for research and educational purposes (including most downscaling purposes in the framework of this Position Paper). Non-commercial users can obtain an account by filing a Data Access Request Form.

- Private companies and any other user who wish to access the data for commercial purposes must pay a license fee according to the amount and type of data.

A Catalogue describing the available products as well as a Data Access Request Form are available through the following link: http://www.bo.ingv.it/dataaccess/ .

References

De Mey, P., and M. Benkiran, 2002. A multivariate reduced-order optimal interpolation method and its application to the Mediterranean basin-scale circulation. Ocean Forecasting, Conceptual basis and applications, N. Pinardi and J.Woods Eds, Springer Verlag.

Demirov E., N. Pinardi, C. Fratianni, M. Tonani, L. Giacomelli, P. De Mey, 2003. Assimilation scheme of the Mediterranean Forecasting System: operational implementation. Annales Geophysicae, 21: 189-204.

Madec G., P. Delecluse, M. Imbard and C. Levy, 1998: OPA8.1 Ocean general Circulation Model reference manual. Note du Pole de modelisazion,Institut Pierre-Simon Laplace (IPSL), France, 11.

Pinardi N., I. Allen, E. Demirov, P. De Mey, G. Korres, A. Lascaratos, P.Y. Le Traon, C. Maillard, G. Manzella and C. Tziavos, 2003 : The Mediterranean ocean Forecasting System : first phase of implementation (1998-2001). Ann. Geophys., 21, 1, 3-20.

8.7 France

MERCATOR

The Model

MERCATOR OCEAN's specific mission is to provide routinely and in real time a 3 dimensional depiction of the global ocean to serve a wide range of marine applications and contribute to the development of a seasonal and climate forecasting system. The MERCATOR system has been operating for 5 years, on a pre-operational basis, and has been providing weekly ocean forecast bulletins of a 3D high resolution depiction of the North Atlantic (1/15°) and the Mediterranean Sea (1/16°) to users (system PSY2). Since October 2005, MERCATOR OCEAN has been producing global ocean forecast with a ¼° resolution, which provides one of its main contribution to GODAE within the MERSEA EU-funded project. Moreover, MERCATOR OCEAN takes part in the comparison between several global systems with a specific focus on the Atlantic Ocean and Mediterranean Sea using GODAE metrics.

The MERCATOR system uses the OPA code: a z-coordinate, primitive equation model. The global model includes an ice model. Daily wind and thermal forcing comes from the ECMWF (European Center for Medium Range Weather Forecast). The system assimilates satellite and *in situ* data using an optimal interpolation scheme: monovariate for the global system and multivariate for the North Atlantic and Mediterranean Sea. Both models assimilate daily, real time satellite altimeter data (Jason-1, ENVISAT, GFO) which are provided by the SSALTO/DUACS data centre. The basin scale model assimilates also the SST which is the Real Time Global SST analysis product (RTG_SST) from NCEP and vertical profiles of temperature and salinity measurements which are taken from the Coriolis data base.

Data Serving

For users requiring hindcast data, a free access server provides data (NetCDF format) from an on-line disk archive (openDAP) through the MERCATOR live access server (LAS), following GODAE standards. For users requiring real time data, Mercator Océan supplies selected MERCATOR data (in NetCDF format) by FTP. Hindcast and real time data are freely available to registered research users (registration: products@mercator-ocean.fr). Full resolution MERCATOR data of the North Atlantic (1/15°) and Mediterranean Sea (1/16°) configurations are also provided to some specific users, according to their requirement. This service is carried out to Mercator Océan consortium members, to partners of European projects or in the frame of bilateral collaboration.

The MERCATOR products: hindcasts and 14-day forecasts daily 3D fields of the ocean state, are freely available at http://www.mercator.eu.org.

References

The MERCATOR project:

Bahurel P. and the Mercator project team, 2006. "MERCATOR OCEAN global to regional ocean monitoring and forcasting". In Ocean Weather Forecasting, an integrated view of oceanography", ed. by E. P. Chassignet and J. Verron,381-395.

Bahurel P., Dombrowsky E., and the Mercator project team, 2006. "Mercator Ocean monitoring and forecasting system, a contribution to GMES". In European Operational Oceanography: present and future." Proceedings of the 4th international conference on EuroGOOS, Brest 6-9 June. pp 449-455.

Global MERCATOR description and results:

Drévillon M., Drillet Y., Garric G., Lellouche J-M., Rémy E., Derval C., Bourdallé-Badie R., Tranchant B., Laborie M., Ferry N., Durand E., Le Galloudec O., Bahurel P., Greiner E., Guinehut S., Benkiran M., Verbrugge N., Dombrowsky E.,Testut C.-E., Nouel L., Messal F., 2006. "The GODAE/Mercator global ocean forecasting system: results, applications and prospects." Proceedings of the World Maritime Technology Conference, London, 3-6 March.

Assimilation scheme:

Brasseur P., Bahurel P., Bertino L., Birol F., Brankart J.-M., Ferry N., Losa S., Remy E., Schrôter J., Skachko S., Testut C.-E., Tranchant B., Van Leeuwen P.J. and J.Verron, 2006, "Data assimilation for marine monitoring and prediction : the MERCATOR operational assimilation systems and the MERSEA developments", Q. J. R. Met. Soc., in press.

De Mey, P., and M. Benkiran, 2002. A multivariate reduced-order optimal interpolation method and its application to the Mediterranean basin-scale circulation. Ocean Forecasting, Conceptual basis and applications, N. Pinardi and J.Woods Eds, Springer Verlag.

8.8 UK

FOAM

The Models

The Met Office has produced operational surface wave and storm surge forecasts for over 2 decades. In the last decade, it has started to provide daily operational forecasts for the open ocean using the Forecasting Ocean Assimilation Model (FOAM) system, which provides the main UK contribution to GODAE. In addition, a high resolution (5km) global Ocean Surface Temperature and Ice Analysis (OSTIA) product is being developed to take full advantage of sea surface temperature (SST) products made available through GODAE. The FOAM ocean model is a z-coordinate, primitive equation model based on the same code as the ocean component of the Hadley Centre coupled climate models (Gordon et al., 2000). The model includes sea-ice and mixed layer models. A nested model system has been developed that allows a range of model configurations to be run from a low resolution global to high resolution regional models. Storkey (2004) provides a self-contained description of the model formulation.

FOAM is using the internal metrics agreed for the MERSEA Strand-1 project, and continues to contribute to the intercomparisons initiated in MERSEA Strand-1. In addition, an automated verification system routinely produces observation minus forecast statistics for selected areas and by station identifier for profile data.

The OCCAM model developed at NOCS and the University of East Anglia (UEA) has been developed for high resolution modelling and data assimilation hindcast studies. A ¼º global version of OCCAM with data assimilation has been run for a 5 year period. A 1/12º global version is currently under development. The OCCAM model is a z-coordinate model based on the MOM code with a free surface and with a rotated grid in the N Atlantic to permit full coverage of the arctic basin.

Data Serving

FOAM data are served in a number of ways depending upon the customer requirement. Royal Navy data feeds use secure communications links to deliver data direct to their HORACE forecaster workbench system. For customers requiring an operational data supply, the Met Office Data and Products Distribution System (DPDS, see http://www.metoffice.gov.uk/wfc/index.html) supplies selected FOAM data by FTP in GRIB format. Direct FTP feeds are provided to other customers with specific operational requirements. Finally, FOAM data and prototype OSTIA products are made freely available for research use through ESSC (http://www.nerc-essc.ac.uk/las) and GHRSST web pages respectively.

Full resolution FOAM data from the N Atlantic 1/9º configuration is being made available on the Environmental Systems Science Centre (ESSC) web site http://www.nerc-essc.ac.uk/las for the duration of GODAE in real-time. This server provides an on-line disk archive of these data with access using the live access server (LAS) software. The data is freely available to registered research users. The surface fluxes used by the FOAM system are also being delivered to ESSC and will be made accessible to GODAE partners. The ESSC LAS server also provides access to data from the ¼º global run OCCAM hindcast.

References

Bell, M. J., R. M. Forbes, and A. Hines, 2000: Assessment of the FOAM global data assimilation system for realtime operational ocean forecasting. J. Mar. Sys, 25, 1-22.

Davies, H. C. 1976 A lateral boundary formulation for multi-level prediction models. Quart. J. Roy. Meteor. Soc., 102, 405-418.

Gordon, C., C. Cooper , C. A. Senior, H. Banks, J. M. Gregory, T. C. Johns, J. F. B. Mitchell and R. A. Wood, 2000: The simulation of SST, sea ice extents and ocean heat transports in a version of the Hadley Centre coupled model without flux adjustments. Climate Dyn., 16, 147-168.

8.9 Norway

TOPAZ

The Model

TOPAZ aims at providing real-time forecasts for both the physics and ecology of the North Atlantic ocean. Since Oct. 20, 2004, the developments of the TOPAZ system are continued within the activities of the Mohn-Sverdrup Center / Nansen Center.

As its predecessor, TOPAZ develops advanced data assimilation systems for a coupled primitive equation ocean circulation and marine ecosystem model for the North Atlantic and the Nordic Seas with enhanced resolution in the European coastal zones, assimilating satellite data available for real time operational use.

TOPAZ keeps improving the results obtained in the previous DIADEM project, partly thanks to the increased computer resources recently available. The strategy is to take advantage of the newly available CPU and memory space for upgrading both the circulation and the ecological models and for increasing their resolution. Besides, the efficiency of the various data assimilation schemes is improved.

The features of the new model system, included in MERSEA, are the following :

- The Miami Isopycnic Coordinate Ocean Model (MICOM) is replaced by the Hybrid Coordinate Ocean Model (HYCOM). It adds a fixed vertical coordinate to the original isopycnic coordinate and allows for a better description of the vertical movements of water masses.

- The original ecological model by Fasham, Ducklow and Mc Kelvie (FDM model) is improved so that the phytoplankton can adapt to changes in the physical and biogeochemical environment. In particular, the new model allows variable carbon to nitrogen (C:N) and carbon to chlorophyll ratios (C:N-REcoM= C:N Regulated Ecosystem Model).

- An ice model is coupled to the physical model HYCOM, and measurements of ice concentration and ice thickness are assimilated.

- The model grid resolution is increased (18 to 35 km), and a common discretization for both the physics and biology is now possible, which simplifies their coupling.

The data assimilation schemes used in the TOPAZ project are:

- The Ensemble Kalman Filter (EnKF, used in the real-time experiment).

- The Singular Evolutive Extended Kalman Filter (SEEK).

- The Ensemble Optimal Interpolation (EnOI) scheme.

The observations used are satellite observed Sea Level Anomaly (SLA), Sea Surface Temperature (SST), Sea-ice concentrations from SSMI and - soon - Coriolis in-situ data.

Data Serving

TOPAZ data in the North Atlantic and Arctic Oceans are freely available from the OpenDAP file server. Details can be found at: http://topaz.nersc.no .

References

Bertino, L., K. Arild Lisæter, F. Counillon, G. Evensen and the TOPAZ consortium, 2004: The TOPAZ monitoring and forecasting system., Presented at AMRS Conference, London 2004.

Bertino, L., and K. Arild Lisæter, 2006: The TOPAZ monitoring and prediction system for the Atlantic and Arctic Oceans. (2006), in European Operational Oceanography: Present and Future, EuroGOOS Conf. Proc. In press.

9.Appendix 4: the MERSEA and ECOOP European projects

9.1 The MERSEA Integrated project

The MERSEA Integrated Project is Europe's main contribution to GODAE. It is funded by the EC under the FP6 program, Space / GMES priority to develop the Ocean and Marine Applications component of GMES. This project, started in April 2004 and aimed at finishing in March 2008, includes 50 contractors. The MERSEA project objective is to design, develop, and implement a global high resolution system, with biogeochemistry and sea ice; with a coordinated network of regional systems covering the European seas, based on a common modelling framework. This **system of systems** will comprise the modelling and assimilation and the data and forcing fields centers. It will provide support for coastal systems, improve and facilitate access to data, products, and services. The project stresses full validation, interoperability, the development of standards and best practices.

The strategic objective of MERSEA 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 will handle ocean physics, biogeochemistry and ecosystems, on time scales extending from days to months, including retrospective syntheses. 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 hindcasting, and delivery of information products. The project develops marine applications addressing the needs of both intermediate and end-users, whether institutional or from the private sector, with the objective to improve the safety and efficiency of maritime transport and naval operations ; enable the sustainable exploitation and management of ocean resources (offshore oil and gas industry, fisheries) ; more efficiently mitigate the effects of environmental hazards and pollution crisis (oil spills, harmful algal blooms) ; improve contribution to ocean climate variability studies and seasonal climate prediction and its effects on coastal populations ; and advance marine research with the aim to better understand the global climate, the ocean and its ecosystems.

The initial V0 version of the system, in operation since July 2004, is basically made up of the main forecasting centers: MERCATOR, MFS/MOON, FOAM/NCOP, and TOPAZ. Beyond that point, the project will lead to **a single high-resolution global ocean forecasting system** shared by European partners together with a coordinated 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 centers will converge on a single ocean model framework suitable for both the deep ocean and shelf-seas.

MERSEA has progressed on all aspects covered by the project, after an initial period of organization and ramping up. The first major milestone of the project, the upgrade to the version V1 of the system, and the associated Target Operational Period, were met in October 2005. This period showed the MERSEA integrated system in operation and gave it concrete visibility. It will build a first set of MERSEA standard products and catalogue. Assessment of the quality of these products and of the system performance will be conducted through a number of indicators.

The MERSEA project web site is http://www.mersea.eu.org .

MERSEA has undertaken actions specifically dedicated to building a central server facility to access the data catalogues and the data themselves. MERSEA data products (and access restrictions) can be seen through the MERSEA web page http://w3.mersea.eu.org/html/information/data_access.html which links users to the MERSEA Core Projects data servers (MFS, MERCATOR, FOAM, TOPAZ) described separately.

9.2 The ECOOP Integrated Project

The EU Framework 6 integrated project European COastal-shelf sea OPerational observing and forecasting system (ECOOP, a 3-year project with 72 partners) has the overall goal to *consolidate, integrate and further develop existing European coastal and regional seas operational observing and forecasting systems into an integrated pan-European system targeted at detecting environmental and climate changes, predicting their evolution, producing timely and quality assured forecasts, providing marine information service's (including data, information products, knowledge and scientific advices) and facilitate decision support needs*.

This is to be attained through the following activities:

3. Integrate existing coastal and regional sea observing (remote sensing, in-situ) networks into a pan-European observing system

4. Integrate existing coastal and regional sea forecasting systems into a pan-European forecasting system and assimilate pan-European observation database into the system

5. Assess the quality of pan-European observing and forecasting system

6. Advance key technologies for the current and next generation pan-European observing and forecasting system

7. Develop and generate value-added products for detecting environment and climate change signals

8. Integrate and implement a pan-European Marine Information System of Systems (EuroMISS) for general end user needs

9. Develop methodology and demonstrate an European Decision Support System for coastal and regional seas (EuroDeSS) that responds to the needs from targeted end users, as emphasized in the GEOSS and GMES initiatives

10. Carry out technology transfer both in Europe and at intercontinental level, establish education and training capacities to meet the need for ocean forecasters

Since the major part of the consortium is from regional alliances in operational oceanography, i.e. Baltic Sea (BOOS), North West shelf (NOOS), Iberia-Biscay-Ireland region (IBIROOS), Mediterranean Sea (MFS-MOON) and Black Sea (Black Sea GOOS) the pan-European ECOOP system will have the maximum sustainability in making long-term observations, forecasts and services. The ECOOP system, a system of 15 coastal systems, is designed clearly for addressing end- user needs, e.g., detecting environment and climate change signals, forecast, decision making, technology transfer and international cooperation, and fits well with GEO/GMES initiatives and the GEOSS implementation plan.

Some of the CSS systems listed in this paper are ECOOP systems. The ECOOP project web site is: http://ocean.dmi.dk/ECOOP/index.html .