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The TOPAZ Arctic monitoring and prediction system

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SYNOPSIS

Ocean data assimilation systems allow combining remote-sensing and in-situ ocean observations with primitive equations ocean general circulation models (OGCM). They thus provide initial conditions for short-term ocean currents forecasts (ten days to one month) and boundary conditions to nested high-resolution models of coastal seas and can be operated in hindcast to reproduce past events over long periods. At the time when the offshore activities are moving toward deeper waters and ice-covered seas, accurate monitoring and forecasting of the environment (particularly ocean currents and sea-ice) cannot be neglected. This paper presents the TOPAZ system, being the Arctic component of the MERSEA integrated system and one of the contributors to the GODAE international initiative. The system is based on the latest scientific developments in terms of ocean modelling with the Hybrid Coordinate Ocean Model (HYCOM), coupled with different biogeochemical modules and data assimilation with the Ensemble Kalman Filter (EnKF). The paper presents validation results of the system and applications in nested regional models.

INTRODUCTION

The need for high quality predictions of marine parameters has been well identified. E.g., during recent years, offshore oil-exploration activities have expanded off the continental shelves to deeper waters. Drilling and production of oil and gas at depths of 2000 meters or more are ongoing at several locations, and the Arctic Shelf contains considerable gas resources in ice-covered areas. This has introduced a need for real time forecasts of oceanic currents and sea-ice, which in some cases may have severe impact on the safety related to drilling, production and critical operations. Besides sustainable exploitation of marine resources are becoming increasingly important, e.g. commercial fisheries and fish farming. In future fisheries management systems, information about marine parameters such as nutrient and plankton concentrations, and pollutants, will be increasingly important for accurate monitoring and prediction of fish stocks. Thus, there are needs for operational monitoring and prediction of both physical and biological marine parameters.

An operational ocean forecasting system relies on integrated use of both satellite and in-situ observations of physical, biological, and chemical variables and coupled physical and marine biogeochemical models. This integration is best done using data assimilation techniques. Thus, one will have to further develop and implement consistent data assimilation techniques for primitive equation models and also new suitable methods for assimilation of data into the models of the marine ecosystem that respect their statistical properties (probability distribution). Further, the real time processing and flow of observational data must be developed and maintained and the data and validation results made accessible to users, and in particular to the research community for planning their campaigns in the Arctic.

The TOPAZ system is being developed to meet the needs from future users of marine parameters. It involves both the implementation and validation of state of the art ocean circulation models and marine ecosystem models, and the development of novel data assimilation methodologies. The system development has been supported by two previous European Commission funded projects, i.e. the DIADEM (Brusdal et al., 2003) and TOPAZ projects, and current work is aimed at integration into the European MERSEA system within the MERSEA Integrated Project. By gathering the expertise of major European groups, the challenges of operational oceanography (e.g. fitness for purpose, accuracy and data distribution) are more likely to be met in a near future.

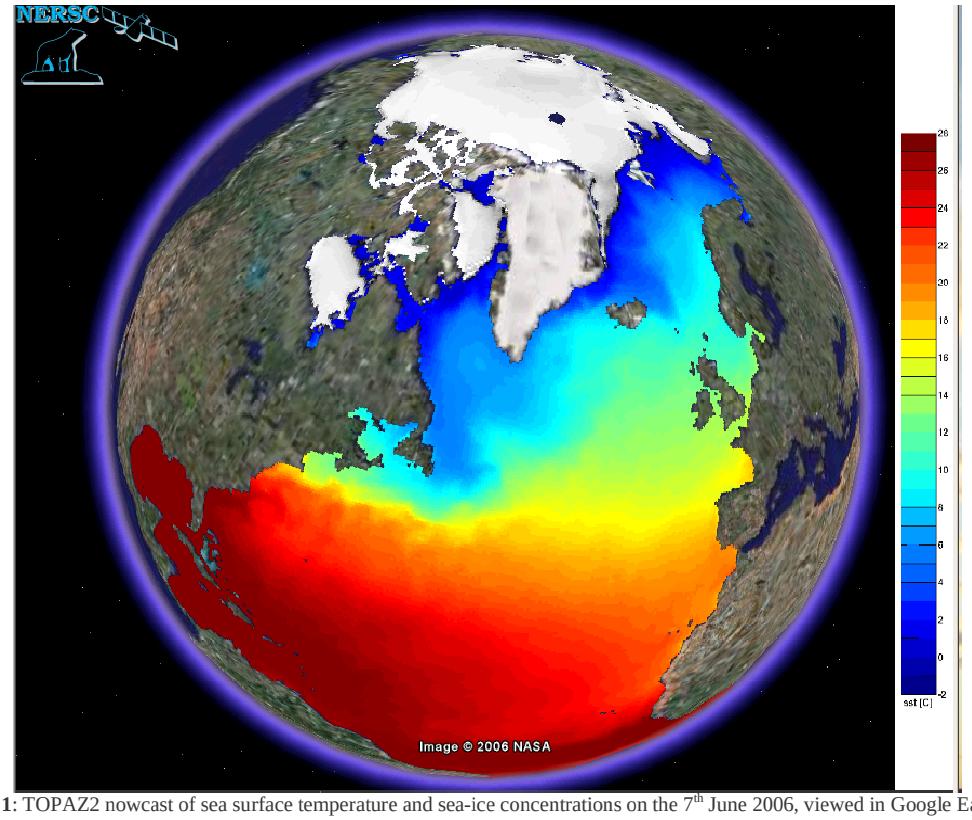

Fig 1: TOPAZ2 nowcast of sea surface temperature and sea-ice concentrations on the 7th June 2006, viewed in Google Earth.

In contrast to other state-of-the-art forecasting systems, among which FOAM, MERCATOR, HYCOM-NRL, and MFSTEP, the TOPAZ team has chosen to use an advanced data assimilation technique (the Ensemble Kalman Filter, distributed as a freeware on http://enkf.nersc.no). The other systems use optimal interpolation type of data assimilation, this choice on the other hand enables them to afford higher horizontal resolution than TOPAZ has.

The model domain used for the TOPAZ prediction system is shown in Figure 1. The grid is created using a conformal mapping of the poles to two new locations using the algorithm outlined in Bentsen et al. (1999). The figure shows sea surface temperature. The resolution of the model varies from 18 km in the Arctic Ocean to 36 km near the Equator. As new computer resources are made available to us, the model resolution is being increased to 11-16 km in the next version of the forecasting system (referred as TOPAZ3). Preliminary results show that the circulation in the Nordic Seas is considerably improved in the higher-resolution TOPAZ3 (see Figure 2).

To meet the end users needs it is necessary to introduce nested regional models with very high resolution in the target areas where mesoscale processes must be properly resolved. The nested models depend on the basin-scale model but not the contrary so that each nested system can be tuned on purpose to satisfy one application without disturbing the rest of the system. HYCOM (Bleck, 2002) has been coupled to a sea-ice model and three ecosystem models of increasing complexity, including Fasham et al. (1990) and NORWECOM (Søiland and Skogen, 2000). A multi-category sea-ice model has recently been coupled to HYCOM (Lisæter, 2006).

With the inclusion of a nesting capability and the assimilation of both in situ data and data from a variety of satellite sensors, the TOPAZ system constitutes a state of the art and flexible operational ocean prediction system. The model system has been designed to be easily extendible to other geographical areas including the global domain and it allows for nesting of an arbitrary number of regional high resolution models with arbitrary orientation and horizontal resolution. Regions currently nested into TOPAZ are

1. The Gulf of Mexico, with 5km horizontal resolution, updated weekly and assimilating altimetry data. The model is served commercially by Ocean Numerics Ltd to the oil and gas industry.

2. The North Sea and Norwegian Sea, with 4km horizontal resolution, run daily without data assimilation. The model has been originally developed by the CONMAN project, funded by the Norwegian Drilling Programme (NDP).
3. The Barents and Kara Seas, with 4 km resolution, also run daily. Is developed at the Mohn-Sverdrup Center and has received partial funding from Statoil.
4. A model of the whole Nordic Seas is under development within the Norwegian NFR project "Ocean Weather and Ecosystems", with 4km horizontal resolution.
5. A model of the Fram Strait is under development within the European Damocles IP.

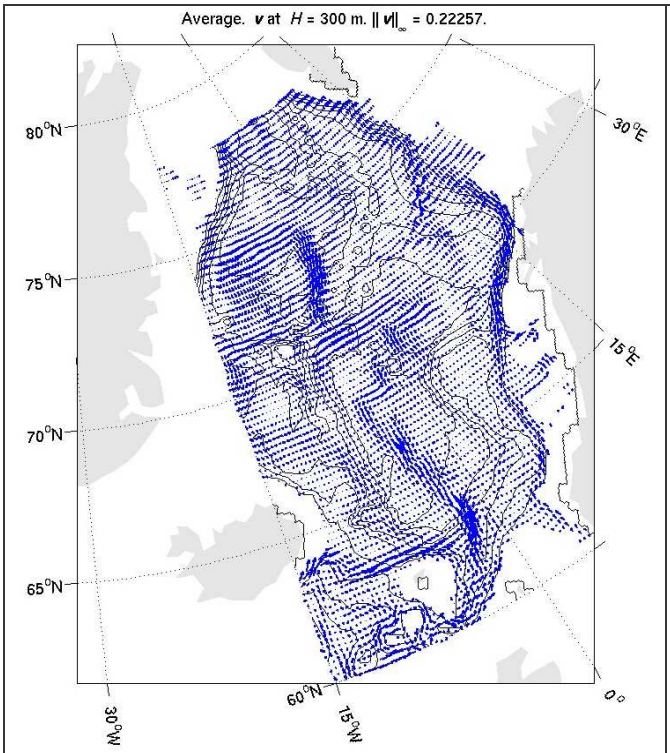

Figure 2a*(TOPAZ2 velocities at 300m depths, extract in the Nordic Seas, average for January 2006*

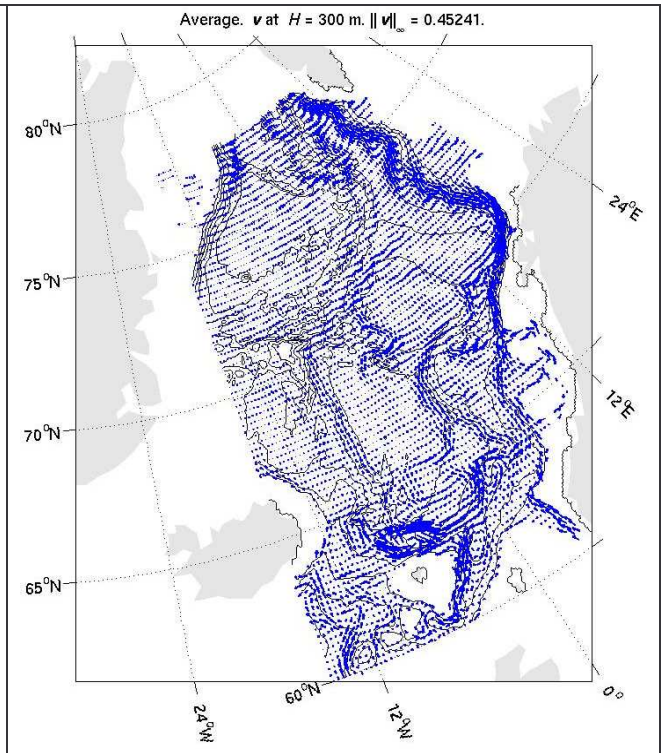

Figure 2b: *Preliminary TOPAZ3 velocities at 300m depths during the model spin up phase, the North Atlantic and the West Spitzberg Currents are much more realistic*

REAL TIME OPERATION

Within the TOPAZ project we have now replaced the original MICOM ocean model with the new advanced Hybrid Coordinate Ocean Model (http://hycom.rsmas.miami.edu/). From January 2003, the real-time experiment has resumed with assimilation of sea level anomalies merged from three satellites (SSALTO/DUACS product from CLS) and SST (Reynolds data). Since September 2003, remotely sensed ice concentrations observations from SSM/I are assimilated too. The Ensemble Kalman Filter is used for assimilation of all three data types. Further, we have developed an implementation for assimilation of real-time in situ observations of temperature and salinity. These will be integrated into the real time system in 2007. Two regional high-resolution models covering the Gulf of Mexico and the North Sea / Norwegian Sea are currently receiving boundary conditions from TOPAZ and run in real-time. A regional system covering the Barents Sea is under development and will also be run in real time. On the first of January 2005, HYCOM has been upgraded by its latest version (v2.1) which has improved physics (better representation of the Montgomery potential) this upgrade has in particular significantly improved the transport of North Atlantic Waters into the Nordic Seas and the Arctic.

One critical issue is the forecast reliability in case of incident (e.g. computer failure, missing input data). Due to the very nature of the Ensemble Kalman Filter, the computational burden is split between an ensemble of independent computer jobs. This has strong advantages in term of optimal use of computing

facilities; it makes the system easy to restart in case of incident and makes innovative use of machine idle time.
Results are displayed on the project web-page http://topaz.nersc.no as well as validation statistics against in-situ data provided by the Coriolis center (since these are not assimilated yet). Since the beginning of the MERSEA TOP1 demonstration period in October 2005, TOPAZ2 results (both graphics and numerical files in standard CF1.0 format) are updated weekly on the Live Access Server (LAS). In the next MERSEA demonstration period (TOP2, April to October 2007), TOPAZ will be upgraded to the TOPAZ3 version and provide higher quality operational forecasts and their validation statistics to the scientific community, in particular to support the IPY research cruises.

SUMMARY

This paper has discussed the implementation and operations of an operational monitoring and prediction system for the Atlantic and the Arctic Basins. The system is based on sophisticated coupled physical-biogeochemical modelling and data assimilation tools and operates in near real-time.
The real time operation of the system has proved to be feasible and relies on the availability of remote sensing products in near real time, and atmospheric forcing fields from meteorological forecasting centres. TOPAZ will supply operational ice-ocean forecasts and their validation statistics to the research activities of the IPY. The forecasts of eddies in the Gulf of Mexico have been presented to potential users in the offshore oil industry by Ocean Numerics Ltd. revealing their strong interest in the way the problem is tackled and providing useful feedback for the future product developments. Oil companies have also invested into the Barents Sea high-resolution system nested into the TOPAZ system in the perspective of offshore exploration and production in the ice-covered Shtokman field. The latter system provides information on ice-ocean conditions and will be the basis for iceberg forecasting systems.
Finally it should be stated that the TOPAZ system complies with and contributes to the plans of international programs such as GODAE and GMES. The system developed has similarities with the other major initiatives in GODAE and will in many respects be complementary to these. Further, the system is one of the major initiatives contributing to the EuroGOOS task teams, in particular the Atlantic Task Team by developing an assimilation system for predicting the ocean circulation in the Atlantic, and the Arctic Task Team by the focus on ice modelling and assimilation of ice variables in the Arctic.

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