The TOPAZ monitoring and prediction system for the Atlantic and Arctic Oceans

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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 a 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) and data assimilation with the Ensemble Kalman Filter (EnKF). The paper [1] 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 during recent years, when 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. In addition, sustainable exploitation of marine resources is 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 will have to rely 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 can best be 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.

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[1] **Authors' Biography**

Dr. Laurent Bertino is presently co-director of the Mohn-Sverdrup Centre for Globlal Ocean Studies and Operational Oceanography / Nansen Environmental and Remote Sensing Centre, a position he has held since 2004. Prior to joining the Nansen Centre, he has obtained a PhD in geostatistics applied to data assimilation from the Ecole des Mines de Paris.

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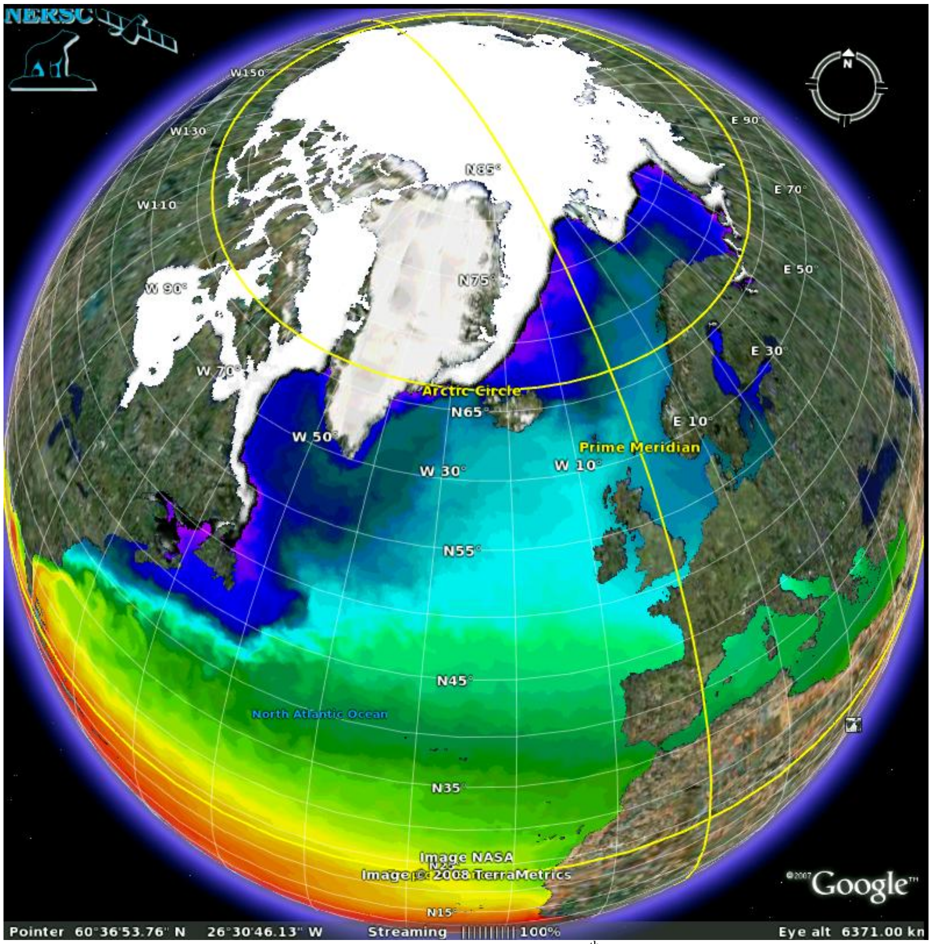

Fig 1: Nowcast of sea surface temperature and sea-ice concentrations on the 14th of April 2008. Ensemble average, 100 members.

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 coupled ice-ocean circulation models, 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. Recent work has been carried out within the MERSEA Integrated Project leading to the TOPAZ2 and TOPAZ3 systems, soon transitioning towards Marine Core Services in the MyOcean project.

In contrast to other state-of-the-art forecasting systems, among which FOAM (Bell *et al*., 2000), MERCATOR (Brasseur *et al*., 2005), HYCOM-NRL (Chassignet *et al*. 2007), and MFS (Dobricic *et al*., 2005), the TOPAZ team has chosen to use an advanced data assimilation technique (the Ensemble Kalman Filter, EnKF) that propagates flow-dependent error statistics with an ensemble of 100 members (Evensen, 2006). The other systems use non-evolutive data assimilation methods. This choice on the other hand enables them to afford higher horizontal resolution than TOPAZ has.

The model domain used for the TOPAZ3 prediction system is shown in Figure 1. The grid is created using the conformal mapping tools outlined in Bentsen et al. (1999). The figure shows sea surface temperature and sea ice concentration. The resolution of the model varies from 11 km in the Arctic to 16 km in the North Atlantic. 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. The HYbrid Coordinate Ocean Model HYCOM (Bleck, 2002) has been coupled to a sea-ice model and four ecosystem models of increasing complexity.

The model system has been extended to other geographical areas and it allows for nesting of an arbitrary number of regional high resolution models with arbitrary orientation and horizontal resolution.

REAL TIME OPERATION

The first TOPAZ system stated its operations in January 2003 with assimilation of sea level anomalies merged from different satellites (DUACS products from CLS) and SST (Reynolds data). From September 2003, remotely sensed ice concentrations observations from SSM/I are assimilated too, following Lisæter et al. (2003). The assimilation of sea-ice drift products from CERSAT, Ifremer has been included in October 2007. The assimilation of real-time in situ observations of temperature and salinity profiles from Argo floats available from the Coriolis center is presently underway. The EnKF is used for assimilation of all data types. Regional high-resolution HYCOM models covering the Gulf of Mexico, the Norwegian Sea, the Barents Sea and the Fram Strait are receiving boundary conditions from TOPAZ either in real-time or hindcast mode. In January 2005 the TOPAZ2 version of the system was launched, HYCOM was upgraded to its latest version (v2.1). The model horizontal resolution was doubled in the summer of 2007, when the TOPAZ3 version of the system started. Both upgrades have significantly improved the transport of North Atlantic Waters into the Nordic Seas and the Arctic.
The EnKF is an advanced data assimilation method using flow-dependent forecast error covariances. However, it remains relatively simple in its practical implementation. The computational burden is mainly taken by the forward integration of the ensemble, a naturally parallel operation. This has strong advantages in term of optimal use of computing facilities making innovative use of machine idle time. The forecast results and numerical data are regularly updated on the web-page http://topaz.nersc.no as well as validation statistics and forecast skills against sea-ice concentrations. Since March 2008, The TOPAZ3 real-time system is exploited in met.no's operational suite, while the modelling and data assimilation developments are continuing at NERSC.

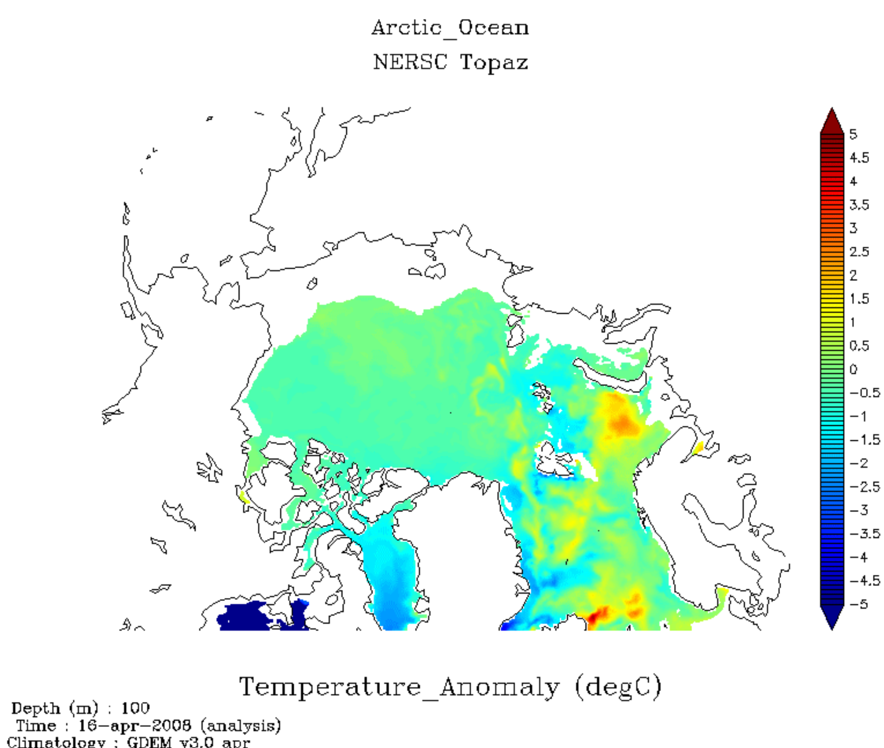

Fig 2: A comparison of TOPAZ3 100m depths temperature against climatology on 16th April 2008. The orange and red areas in the Barents Sea and Nordic Seas indicate the model is warmer than normal. Illustration extracted from the MERSEA viewing V2 system http://www.mersea.eu.org.

3 EUROPEAN INTEGRATION

Data collection, model validation and upgrades of system components necessary to satisfy the user needs are heavy time demanding activities. Fortunately some of these tasks can be shared between groups. Some level of integration has already been achieved by the use of common sources of data (Coriolis for in-situ profiles, Aviso for altimetry and ECMWF weather forecasts), by the definition of metrics and file formats for assessing the quality of the model output (as initiated during the Mersea Strand-1 EC project) and by data distribution on a THREDDS server via the OPeNDAP protocol (http://www.opendap.org) allowing interoperable presentation of forecast and analysis fields by different web clients, for example a Live Access Server (LAS). Such joint efforts will be further pursued within the MyOcean projects and other follow on GODAE projects. One contribution of this work is the definition of metrics in the Arctic Ocean for assessing model consistency, accuracy and forecast skills. The comparison of the Arctic systems against climatology and their intercomparison can be undertaken using the above framework, as in Crosnier *et al*. (2006). The LAS capability is illustrated in Figure 2. It presents the difference between TOPAZ3 temperatures at 100m depths and the corresponding climatology in the Arctic (the Generalized Digital Environmental Model, Teague *et al.*, 1990). The warm anomaly in the Nordic Seas and Barents Sea (up to 3 degrees C) indicates an excess of North Atlantic Waters compared to climatology and is consistent with recent observations (Hátun *et al.*, 2005).

The above tools for system validation and intercomparison are especially useful in the perspective of coupling different systems since they make the outer system fields visible to potential users. The TOPAZ fields are provided freely without registration. In addition to real-time forecasts, a 20-years reanalysis of TOPAZ3 is planned for the next 3 years, consistently with the plans of other systems in the MyOcean project.

SUMMARY

This paper has discussed the implementation and operations of a monitoring and prediction system for the Atlantic and the Arctic Basins. The system is based on sophisticated 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. 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. The TOPAZ system is also presented to oil and gas companies preparing to undertake operations in the harsh Arctic environment and in interaction with scientific projects of the International Polar Year (IPY, 2007 - 2009).

The TOPAZ system contributes to GMES. The system developed has similarities and differences with the other major initiatives in GODAE and will in many respects be complementary to these. Further, the system is contributing to EuroGOOS and the Arctic ROOS, providing sea-ice modelling and assimilation of ocean and sea-ice variables in the Arctic.

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