The Forecasting Ocean Assimilation Model (Foam) System

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THE FORECASTING OCEAN ASSIMILATION MODEL (FOAM) SYSTEM

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Abstract
The FOAM system produces daily 5-day forecasts of three-dimensional ocean temperatures, salinities, currents and sea-ice properties on a routine basis. It assimilates temperature profile, satellite surface height and satellite and in situ surface temperature data and is driven by 6-hourly surface fluxes from the Met Office numerical weather prediction (NWP) system. High resolution model configurations are nested inside a global configuration. Statistics on the difference between the model forecasts and observations are routinely produced and re-analyses can be generated from 1997 onwards.

Keywords: operational oceanography, ocean forecasting, ocean data assimilation, ocean modelling.

1 Introduction
The aim of the FOAM system is to provide real-time, operational analyses and forecasts of the three-dimensional structure of the deep ocean and of sea-ice. The ocean fields that are forecast are the temperature, salinity, currents and mixed layer depth. The velocity, concentration and depth of sea-ice are also forecast. The main long-term objectives are to forecast the surface mixed layer to 3-5 days ahead and the mesoscale structure to 10-20 days ahead.

A global version of the FOAM system has run each day in the Met Office's operational suite since it was introduced in 1997 on a grid with 1^o spacing in the horizontal and 20 levels in the vertical. It is based on the z co-ordinate primitive equation ocean and sea-ice model developed by the Hadley Centre for coupled ocean-atmosphere climate change experiments. The model is forced by 6-hourly surface fluxes from the Met Office's NWP system and assimilates thermal profile and surface temperature data. The system is described in detail in Bell et al. (2000b).

This paper outlines the developments that have been made to the FOAM system since that coarse resolution global model was introduced and indicates the directions in which further development is planned.

2 Developments to the Suite and Model Configurations

In order to perform integrations for geographically limited areas using models with horizontal grid spacings of 10 km or finer, the facility has been developed to nest higher resolution, limited area, models inside larger area, lower resolution, models. The nesting is one-way and based on the flow relaxation scheme (FRS, Davies 1983).

All prognostic variables (including the barotropic streamfunction) of the inner model are relaxed towards those from the coarser grid model over regions (4 to 8 model grid points wide) adjoining the boundary of the inner model. The bathymetries in the two models in this nesting region are prescribed to be as similar as possible. Typically the grid spacing of the inner model is about three times smaller than that of the coarser resolution model. The limited area models use a "rotated" latitude-longitude grid in which the pole need not coincide with the North-South geographical pole and is chosen to achieve a nearly uniform grid within the model domain.

Accessible archives of 6-hourly surface fluxes from the Met Office's NWP system have now been established dating back to 1997. Also a new suite control system (SCS) has become available. This is used for the operational forecasts, for pre-operational forecasts (which can also be run on a daily cycle), and for long period (e.g. 3 year-long) hindcasts using 6-hourly fluxes. A system has also been introduced to calculate the statistics of differences between observations and forecasts.

A series of integrations has been performed using 6-hourly fluxes for the 3 year period 1997-1999. Each of the integrations was performed using three nested models: an "**Atlantic**" model covering the Atlantic and Arctic with a grid spacing of $1/3^{o}$ nested in the standard global model; and a "**Gulf of Mexico**" model covering the Gulf of Mexico and Caribbean with a grid spacing of 12 km nested inside the Atlantic model. Some of the integrations assimilated observations, others a subset of observations, and some no observations. The Atlantic model was implemented in the operational suite on 23 January 2001.

Figure 1 illustrates a model covering most of the North Atlantic and the Mediterranean sea, with a grid spacing of 12 km, that has also been nested within the Atlantic model.This model has been run on a daily pre-operational basis since May 2002 and the output made available on http://www.nerc-essc.ac.uk/las as a contribution to the GODAE project. Additional model configurations for the Indian Ocean and Mediterranean Sea and a global model with a grid spacing of $1/2^{o}$ and 40 levels have also been established.

3 Improvements to the observations supplied to the system

Since 1997 the in situ measurement system has of course been greatly strengthened by the Argo project. Although the FOAM group had experimented with the assimilation of altimeter data for several years (Forbes 1996, Hines 2001), routine delivery to the Met Office of altimeter data (with suitable corrections) for operational use was only established in August 2001. Data are now supplied by CLS (Centre Localisation Spatiale) twice a week. They have been assimilated in the operational Atlantic model since 25th September 2001.

Fields of sea-ice concentration data have been assimilated into the FOAM operational models since 6 July 1999 (Bell et al. 2000a). These data, provided by the Canadian Meteorological Center, are based on Special Sensor Microwave Imager data interpreted using the York/AES algorithm. On the same date the Met Office NWP system started to calculate surface fluxes using sea-ice fractions based on analyses provided by NCEP.

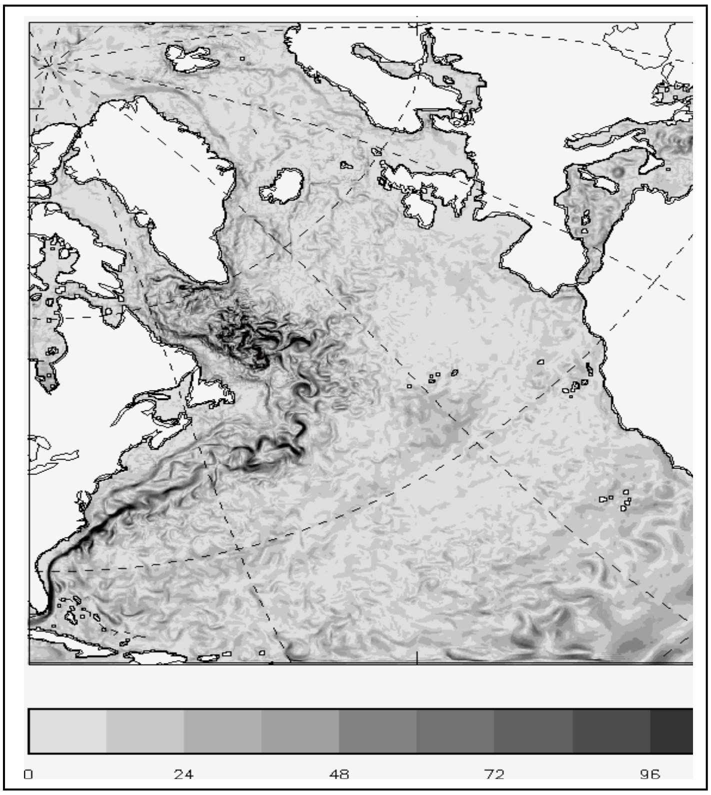

Figure 1: Surface currents (cm/s) in the North Atlantic model on 11 April 2003.

The AVHRR satellite surface temperature data available from NOAA/NESDIS via the Global Telecommunications System (GTS) has until this year been rather coarse resolution (2.5^o). Global data at 1^o and 0.5^o resolution are now being distributed on a daily and weekly basis respectively. We intend to assimilate these data and the Merged Atlantic Product (MAP) produced by the EuMetSat Ocean and Sea-Ice Satellite Application Facility (OSI-SAF) at Lannion.

4 Improvements to the ocean and sea-ice models

A system has been developed for intepolating bathymetries and initial temperature and salinity fields for new model configurations. The bathymetry is slightly smoothed and important channels inspected and re-excavated if necessary. The tracer fields are taken from the Levitus et al. (1998) climatology. Grid points where climate values are missing are filled in by limited horizontal and vertical "extrapolation". The models are typically spun-up to real-time over a period of 6-18 months, assimilating data over the last 6 months of the spin-up.

A semi-implicit free surface formulation is available for use but our main integrations still use a barotropic streamfunction in a formulation which avoids the Killworth instability (Bell 2000, appendix A). The Brown & Campana (1978) pressure averaging technique is used in some configurations to increase the model timestep. Several experiments similar to Chassignet & Garraffo (2001) have been made exploring the choice of viscosity (and thermal diffusivities) for models of widely differing horizontal resolution. A third order accurate upwind interpolation scheme is used for advection of tracers (Holland et al. 1998).

A parametrisation of exchange flow through unresolved straits and river inflow based on monthly-mean climatological values from the Global Rivers Data Centre (GRDC) database have been tested and will be implemented shortly.

The Hadley Centre Ocean Carbon Cycle (HadOCC) "ecosystem" model (Palmer & Totterdell 2001) has been coupled to the global and Atlantic FOAM configurations and will be developed further through collaboration in the Centre for Air-Sea Interface fluXes (CASIX). Some tests of the elastic-viscous-plastic (EVP) sea-ice dynamics formulation of Hunke & Dukowicz (1997) have also been performed in the Atlantic FOAM configuration. Tests using 1D mixed layer models and Argo profile data suggest that a modified version of the Large et al. (1994) scheme will provide better mixed layer analyses than our present scheme. We intend also to trial the impact of various versions of the Gent-McWilliams scheme

5 Improvements to assimilation of observations

A number of useful sensitivity and tuning experiments have explored the assimilation of altimeter data (Hines 2001) and surface temperature data. Assimilation of both types of data can be improved by attention to the horizontal correlation scales used. It has also been found that the Cooper & Haines (1996) scheme can be improved by limiting the displacement of isopycnals near the sea surface.

Spurious circulations near the equator arising from the assimilation of thermal data into models with systematic errors have been explored in some detail. Martin et al. (2002a) proposed and implemented a scheme to improve the assimilation in these circumstances.

The FOAM assimilation scheme has been re-organised in order to achieve two objectives. Firstly the assimilation scheme has been reformulated to enable observational data to be fully utilised on the day they are received and thereafter given appropriate weight relative to newly arriving observations. Analyses are calculated once a day by a process of iteration towards the statistically "optimal" solution. Secondly the model's error covariance is specified as the sum of "mesoscale" and "synoptic" scale components estimated using statistics of observation minus model values from three-year hindcasts (Martin et al. 2002b). The synoptic scale component has a relatively large horizontal scale (~300 km) and small vertical scale (~50 m). The mesoscale component has a relatively small horizontal scale (~50 km) and larger vertical scale (~200 m). The variance of these components is calculated as a function of depth and geographical location. The variance of the synoptic scale component depends relatively little on geographical location whereas the variance of the mesoscale component varies markedly and is largest in the western boundary current regions.

Other developments to the assimilation system are also being tested. B. Ingleby and M. Huddleston have implemented improvements to the quality control of profile data as part of the ENACT project. Code is also in place to assimilate salinity data (from Argo profiles) and to estimate the bias in satellite surface temperature data.

The new methods are being tested by six-month integrations of the new and old systems for the 1/3^{o} Atlantic model using observation minus analysis statistics for objective assessment. At present the results for the new system are better than the old near the surface, particularly in the north-west Atlantic, but are slightly worse than the old system in mid-thermocline. Figure 2 illustrates the improvement in the north-west Atlantic.

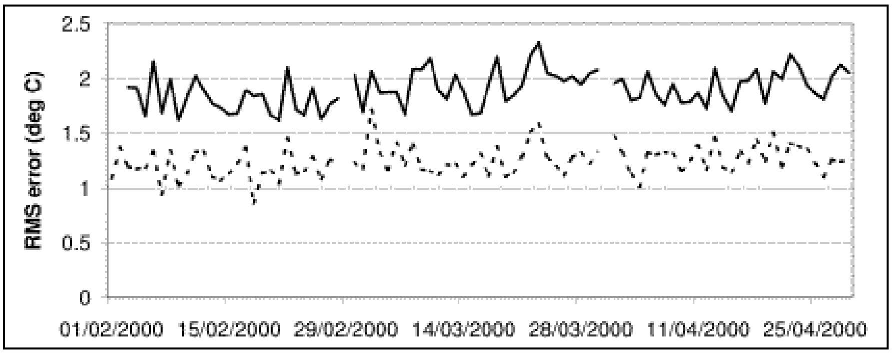

Figure 2: Timeseries of RMS differences between analyses and surface temperature observations before they are assimilated for the original scheme (solid line) and the new scheme (dashed line) from a six-month integration

5 Plans

We will collaborate in the intercomparison between the FOAM, Mercator, MFS and TOPAZ systems within the Mersea Strand-1 project. We will also implement a model for the Intra-Americas Seas (IAS) with a 6 km grid and 40 levels and assess the forecast skill of this and lower resolution models and the impact on the model skill of the altimeter and Argo profile data.

References

Bell, M. J. 2000 An assessment of the value of semi-implicit schemes, semi-Lagrangian schemes and various grids for ocean dynamics. Ocean Applications Technical Note No. 25. Available from Ocean Applications, Met Office, Bracknell, UK.

Bell, M. J., T. Allen, J. O. S. Alves, and A. Hines 2000a The FOAM system and the use of satellite information. Proceedings of SAF Training Workshop, Ocean and Sea Ice. EUMETSAT Hosted by Meteo-France, Perros-Guirec, France 30 November - 2 December 1999.

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

Brown J. A., and K. A. Campana 1978 An economical time-differencing system for numerical weather prediction. *Mon. Weath. Rev*., **106**, 1125-1135.

Chassignet, E.P. and Garraffo, Z.D., 2001 Viscosity parameterization and the Gulf Stream separation". Pp 37-41 In "From Stirring to Mixing in a Stratified Ocean". Proceedings 'Aha Huliko'a Hawaiian Winter Workshop. U. of Hawaii. January 15-19, Eds. P. Muller and D. Henderson.

Cooper M., and K. Haines 1996 Data assimilation with water property conservation. *J. Phys. Oceanogr*., **101**, 1059-1077.

Davies, H. C. 1983 Limitations of some common lateral boundary schemes used in regional NWP models. *Mon. Weath. Rev*., **111**, 1002-1012.

Forbes, R.M., 1996: Initial results from experiments assimilating satellite altimeter sea surface height data into a tropical Pacific ocean model. Ocean Applications Technical Note 12. Available from Ocean Applications, Met Office, Bracknell, UK.

Hines, A. 2001 Implementation and tuning of an altimeter data assimilation scheme for high resolution FOAM models. Ocean Applications Technical Note No. 26. Available from Ocean Applications, Met Office, Bracknell, UK.

Holland, W. R., J.C. Chow and F.O. Bryan 1998 Application of a third-order upwind scheme in the NCAR ocean model. **J. Climate,** *11*, 1487-1493.

Hunke, E. C., and J. K. Dukowicz 1997 An elastic-viscous-plastic model for sea ice dynamics. *J. Phys. Oceanogr*., **27**, 1849-1867.

Large, W.G., J. C. McWilliams, and S. C. Doney 1994 Oceanic vertical mixing: a review and a model with a nonlocal boundary layer parameterization. *Rev. Geophys.* **32**, 4, pp 363-403.

Levitus, S., T. P. Boyer, M. E. Conkright, T. O'Brien, J. Antonov, C. Stephens, L. Stathoplos, D. Johnson, and R. Gelfeld 1998 World Ocean Database 1998. Volume 1: Introduction. NOAA Atlas NESDIS 18, 346 pp.

Martin, M. J., M. J. Bell and N. K. Nichols 2002a Estimation of systematic error in an equatorial ocean model using data assimilation. *Int. J. Num. Meth. Fluids*, 20, 435-444.

Martin, M. J., M. J. Bell, and A. Hines 2002b Estimation of three-dimensional error covariance statistics for an ocean assimilation system. Met Office Ocean Applications Technical Note 30.

Palmer, J. R. and I. J.Totterdell 2001 Production and export in a global ocean ecosystem model. *Deep-Sea Research Part I*, **48**, 5, 1169-1198.