Ocean Data Assimilation and Prediction Experiments in JMA and MRI

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Abstract

We discuss the current status of operational ocean data assimilation and prediction in a category "Ocean Weather" (mesoscale to coastal ocean states) in the international project "Global Ocean Data Assimilation Experiment (GODAE)". It is shown how ocean observing systems act as an important role for understanding ocean phenomena through data assimilation; water mass and its pathway are analyzed through data assimilation; recent operational predictions of ocean state are performed; long range variability is analyzed with ocean analysis/reanalysis. These issues are discussed with examples mainly adopted from the projects of Meteorological Research Institute (MRI) ocean data assimilation system MOVE/MRI.COM and its operation in Japan Meteorological Agency (JMA). Possible future developments are also addressed.

Key word: Ocean prediction, data assimilation, operational system. Western North Pacific

1. Introduction

Recent developments of observing system, modeling and data assimilation method enable us to estimate and predict ocean state operationally. As a result, seasonal to interannual forecasting, fisheries, marine safety, offshore industry, management of shelf/coastal areas, security applications, and improved information for related fields (marine biogeochemical process and numerical weather prediction) are among the expected beneficiaries of ocean data assimilation and prediction.

The Meteorological Research Institute multivariate ocean variational estimation (MOVE/MRI.COM) System has been developed as the operational ocean data assimilation system in Japan Meteorological Agency. A multivariate three-dimensional variational (3DVAR) analysis scheme with vertical coupled temperature–salinity empirical orthogonal function modes is adopted.

The MOVE/MRI.COM system has two varieties, the global (MOVE/MRI.COM-G) and North Pacific (MOVE/MRI.COM-NP) systems (Usui et al., 2005). The aims of MOVE/MRI.COM-G are initialization of MRI coupled GCM for seasonal-interannual forecasting and reanalysis. The period of the reanalysis product is 1948 to 2007. The aims of MOVE/MRI.COM-NP are initialization of ocean forecasting in the North pacific (esp. around Japan) and reanalysis, which period is 1993-2007.

Information about the systems and recent publications are given in the MRI homepage http://www.mri-jma.go.jp/Dep/oc/oc.html.

2. GODAE

The Global Ocean Data Assimilation Experiment (GODAE) started from 1997, and was conducting its main demonstration phase from 2003 to 2005. Operational and research institutions from Australia, Canada, China, France, Japan, Norway, United Kingdom, United States are performing global oceanic data assimilation and ocean forecasting in order to provide regular and comprehensive descriptions of ocean fields such as temperature, salinity and currents at high temporal and spatial resolution.

This demonstration phase will be followed by a consolidation and transition phase from 2005 to 2008 where synthesis and transition to operational systems will take place. 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 integrated description of the ocean that GODAE will provide will also be highly beneficial to the research community.

The rationale and scope of GODAE, its strategy and guiding principles have been presented in the GODAE Strategic Plan. It also identified the required inputs, outputs and main functional components of GODAE and defined a GODAE "Common" of materials that need to be shared during the Project. It gives a detailed description of the main components of GODAE, from the measurement networks through to the end users, as they currently exist, and identifies a number of issues and areas that need to be addressed. Figure 1 describes the main functional components of GODAE and the ways in which they are interacted. The components include:

Measurement networks
Data assembly centres
Data servers
Modelling/assimilation centres
Product servers
Application centres or service providers
End-users

The aim of the GODAE common is to instil modern scientific practice into the building of operational oceanography. It is based on the concepts of open access to data and products and open scientific investigation.

Its scope is broad and includes (see GODAE Strategic Plan):

(a) Assimilation products from existing national, pre-operational and operational, activities;
(b) Data products developed specifically for GODAE through existing facilities (e.g. from the GODAE High Resolution Sea Surface Temperature (GHRSST) pilot project);
(c) Infrastructure, such as data and product servers, assembled specifically for GODAE;
(d) The knowledge base accumulated through joint development, intercomparison experiments, and other GODAE collaborations.

The IGST (International GODAE Science steering Team) has played the leading role in building the GODAE common (Fig. 2). The vision of GODAE has always been to build on existing resources and programs, and to extract the greatest value from them by improved collaboration.

The other issue is links to various intergovernmental initiatives (e.g. the Global Ocean Observing System (GOOS), the Joint WMO/IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM) and the World Climate Research Program (WCRP)), international bodies like the Committee for Earth Observing Satellites (CEOS) and the Partnership for Observations of the Global Ocean (POGO), and related research Programs such as CLIVAR and IMBER.

In summary the GODAE provides encouragements, promotion and framework for the development of operational oceanography (the GODAE partners). A clear appreciation and commitment to the rationale for the GODAE common has been needed to fuel the energy and enthusiasm that will be needed to build it. The comprehensive 12 years results of GODAE project will be reported in the Final GODAE Symposium (http://www.godae.org/Final-GODAE-symposium.html).

3. MOVE/MRI.COM

MOVE/MRI.COM systems are composed of OGCMs and a variational analysis scheme which synthesizes the observed information (i.e., temperature, salinity and SSH) together with the OGCMs.

3.1 Model

The numerical code for the OGCMs used in the MOVE/MRI.COM system is the MRI community ocean model (MRI.COM). MRI.COM has been developed in JMA/MRI and is independent of any other popular OGCM code (Ishikawa et al. (2005)). It is a multilevel model code that solves the primitive equations under the hydrostatic and Boussinesq approximations. The vertical coordinate is a terrain following-depth (σ–z) hybrid, i.e., the levels near the surface follow the surface topography. It enables us to adopt a fine vertical resolution near the surface because it prevents the uppermost layer from vanishing during integration when the free surface variation is explicitly solved. For momentum advection, MRI.COM uses the generalized enstrophy-preserving scheme (Arakawa, 1966) along with the Takano–Oonishi scheme, which contains the concept of diagonally upward/downward mass momentum fluxes along a sloping bottom (Takano, 1978, Oonishi, 1978 and Ishizaki and Motoi, 1999). The no-slip condition is adopted for lateral boundaries. Bottom friction is parameterized according to Weatherly (1972).

The OGCM used in MOVE/MRI.COM-G is a model with a global domain (model G). On the other hand, MOVE/MRI.COM-NP employs two models, namely the North Pacific and western North Pacific models (models NP and WNP). Model WNP is nested into model NP, i.e., the boundary conditions for the western, eastern, and southern boundaries in model WNP are passed from model NP (one-way nesting). Daily outputs from model NP are linearly interpolated both in time and space to replace boundary data of model WNP at every time step.

The model domain of model G extends from 75°S to 75°N globally. The grid spacing in the zonal direction is 1° and that in the meridional direction is 0.3° within 5°S–5°N, and 1° poleward of 15°S and 15°N. There are 50 levels in vertical. The bottom topography is based on ETOPO5 (NOAA, 1992). The northern boundary is closed, i.e., an artificial wall is set. The isopycnal diffusion (Redi, 1982) and the isopycnal thickness diffusion (Gent and McWilliams, 1990) (GM), the background coefficients for vertical diffusion by Tsujino et al. (2000) (Tsujino00), the harmonic viscosity with the parameterization of Smagorinsky (1963) (SMA63), and the level-2.5 turbulent closure scheme of Mellor and Yamada (1982) (MY2.5) are all used in model G.

The model is driven by daily wind stress, heat flux, and fresh water flux fields calculated from NCEP–NCAR reanalysis (NCEP R-1; Kalnay et al., 1996). Latent and sensible heat flux fields are calculated with the bulk formula of Kara et al. (2000) (Kara00). The solar heat flux penetrates surface layers according to Paulson and Simpson (1977). The fresh water flux of NCEP R-1 is adjusted by adding time-independent (space-dependent) flux correction terms (Vialard et al. (2002)).

The domain of model WNP extends from 15°N to 65°N, and 117 °E to 160°W, with a grid spacing of 1/10° × 1/10° around Japan. This model is nested into model NP, whose model region is from 15°S to 65°N, and 100°E to 75°W with a grid spacing of 1/2° × 1/2°. All lateral boundaries of model NP are closed although they are planned to be nested in model G. Models NP and WNP have the same vertical grid spacing (54 levels). Bottom topographies in models NP and WNP are based on Smith and Sandwell (1997) (Smith–Sandwell). The configurations of models NP and WNP are the same as model G, except for a few differences. The biharmonic viscosity with a parameterization based on SMA63 (Griffies and Hallberg, 2000), instead of harmonic viscosity, and the turbulent closure scheme of Noh and Kim (1999) (Noh–Kim), instead of MY2.5, are used in models NP and WNP. Biharmonic diffusion, instead of isopycnal diffusion and GM, is used in model WNP. The models are driven by the daily wind stress and flux fields calculated from the NCEP–DOE AMIP-II reanalysis (NCEP R-2; Kanamitsu et al., 2002). Models NP and WNP adopted the bulk formula of Kondo (1975) (Kondo75), instead of Kara00, for latent and sensible heat fluxes. The water flux is corrected by restoring SSS to the climatology with a restoring time of 1 day (the time-independent correction term is not applied). A sea ice model with the elastic-viscous-plastic dynamics of Hunke and Dukowicz (1997) and the thermodynamics of Mellor and Kantha (1989) (EVP sea ice model) is also applied in models NP and WNP.

3.2 Assimilation system

The analysis fields for models G, NP, and WNP are calculated separately. The analysis scheme adopted in the MOVE/MRI.COM system is a multivariate 3DVAR analysis scheme with vertical coupled T–S EOF modal decomposition of a background error covariance matrix. The scheme is based on Fujii and Kamachi, 2003c and Fujii et al., 2005. The amplitudes of the coupled EOF modes are employed as control variables and the analyzed temperature and salinity fields are represented by the linear combination of the EOF modes in the scheme.

The preconditioned optimizing utility for large-dimension analysis (POpULar; Fujii and Kamachi, 2003b and Fujii, 2005) is applied for minimizing the nonlinear cost function. This scheme can minimize a cost function including a constraint of the background without inversion of a background error covariance matrix, even if the function is nonlinear. It is useful for handling the correlation among background errors.

The regions of the models G, NP, and WNP are divided into 22, 7, and 10 subregions, respectively. EOF modes are calculated in each subregion for each model from world ocean database 2001 (WOD2001; Conkright et al., 2002), as well as the representativeness error covariance matrix, according to Fujii and Kamachi (2003b). We retained 12 dominant modes in each subregion. In fact, more than 85% of the total variance can be explained by the dominant 12 modes although this estimate will differ from one in a different subregion. The Gaussian function is adopted as the horizontal correlation model applied in the background covariance matrix B. The e-folding scales along latitude and longitude lines are also different in different subregions and are decided from Kuragano and Kamachi (2000).

The model temperature and salinity fields are corrected by the analysis result through the incremental analysis updates (IAU) technique (Bloom et al., 1996). The assimilation period is 1/3 month.

Temperature, salinity and along-track SSH observations are employed in the analysis. The temperature and salinity observations were collected from WOD2001 and the global temperature–salinity profile program (GTSPP) database (Hamilton, 1994). We also adopted the along track SSH anomaly data of TOPEX/Poseidon (T/P), Jason, ERS, ENVISAT (Kuragano and Shibata, 1997) after adding it to the mean SDH calculated from a preliminary analysis using temperature and salinity observations alone.

3.3 experimental conditions

The assimilation experiment (analysis/reanalysis) was conducted from January 1948 to December 2007 for global and North Pacific systems, and from January 1985 to September 2007 for western North Pacific system.

Hereafter we introduce the western North Pacific version (MOVE/MRI.COM-WNP). The assimilation period is 1/3 month: the first and second assimilation periods in a month are 10 days and the third one varies from 8 to 11 days. Temperature and salinity profiles above 1500 m, and SSHA data are assimilated. Temperature and salinity data are collected from WOD2001 and Global Temperature-Salinity Profile Program (GTSPP) database. The SSHA data is the along track data from the TOPEX/Poseidon, Jason-1, ERS-1/2 and ENVISAT altimeters, which are extracted from the SSALTO/DUACS delayed time multimission altimeter products (CLS 2004). The model is driven by wind-stress and heat fluxes from the National Centers for Environmental Prediction (NCEP) - Department of Energy (DOE) Atmospheric Intercomparisons project (AMIP-II) reanalysis (Kanamitsu et al. 2002; hereafter NCEP2). Latent and sensible heat fluxes are re-calculated in the model using model sea surface temperature (SST) and the bulk formula of Kondo (1975). The fresh water flux is corrected by restoring sea surface salinity toward the monthly mean climatology with a restoring time of 1 day to prevent a model drift.

138 cases of prediction experiments for the Kuroshio path variability south of Japan were conducted from February 1993 to July 2004. Predictions start at the first day of every month and are integrated for 90 days. The wind-stress and heat fluxes used in the prediction experiments are NCEP2, the same as in the assimilation experiment. We should treat an external forcing as an unknown factor in the prediction. However, we treat it here as a known factor because our objective is to assess the predictive skill of the assimilation scheme and the dynamical model when a perfect external forcing is given. The predictive skill obtained from this protocol could be affected by the use of predictive forcing.

4. Analysis/Reanalysis and Prediction Results and Perspective

We conducted analysis/reanalysis experiments. Here we introduce some results of the western North pacific version.

Figure 3 shows comparison of the velocity field by the assimilation result and independent ADCP observation. Velocity field is recovered well. The correlation coefficients of the zonal (meridional) velocity between the two datasets is 0.84 (0.47). Figure 4 shows temperature and salinity distributions along two JMA's observation lines. The assimilation scheme (multivariate 3DVAR) works for representing temperature and salinity fields of the subtropical (Kuroshio) and subpolar (Oyashio) waters. The water mass property (temperature and salinity) along JMA's hydrographic observation lines around Japan are plotted in the Fig. 5. The mean water mass property, though some lines (PH line in the subtropical-subpolar boundary region, bottom layer in the Japan Sea along PM line) shows biases of the property. Using the analysis/reanalysis dataset prediction experiments are conducted. A result of the predictability is shown in Fig.6. It compares model prediction with persistency and climatological variability. It shows 40-60 days predictability (Usui et al. 2006, 2008).

GODAE will enter a new era under JCOMM with the continuation of its activity, and in addition, with coastal and biogeochemical applications. JMA's operational and MRI's research groups will also have the plans of the same direction as GODAE under JCOMM.

5. Reference

Arakawa A., (1966), J. Compt Phys., 119-143.

Bloom S C, Takacs L L, Da Silva A M, Ledvina D, (1996), Mon. Wea. Rev., 124, 1256-1271.

Collecte, Localisation, Satellites (CLS), (2004),: CLS-DOS-NT-04.103, Toulouse, France, 42pp.

Fujii Y. ,(2005), J. Oceanogr., 61, 167-181.

Fujii Y, Kamachi M., (2003a), J. Geophys Res., 108(C9), 3297, doi:10.1029/2002JC001745.

Fujii Y, Kamachi M., (2003b), J. Oceanogr., 59, 173-186.

Fujii Y, Kamachi M., (2003c), Tellus, 55A, 450-454.

Fujii Y, Ishizaki S, Kamachi M., (2005), J. Oceanogr., 61, 655-662.

Griffies SM, Hallberg RW., (2000), Mon. Wea Rev., 128, 2935-2946.

Hamilton D., (1994), Earth System Monitor.

Holland WR, Chow JC, Bryan FO, (1998), J. Climate, 11, 1487-1493.

Hunke EC, Ducowicz JK, (2002), Mon. Wea Rev., 130, 1848-1865.

Ishikawa I, Tsujino H, Hirabara M, Nakano H, Yasuda T, Ishizaki H., (2005), Technical Reports of the Meteorological Research Institute, No.47 (in Japanese)}

Ishizaki H, Motoi T., (1999), J. Atmos Oceanic Technol., 16, 1994-2010.

Kamachi M, Kuragano T, Sugimoto S, Yoshita K, Sakurai T, Nakano T, Usui N, Uboldi F., (2004), J. Oceanogr., 60, 269-282.

Kanamitsu M, Ebisuzaki W, Woollen J, Yang S-K, Hnilo JJ, Fiorino M, Potter GL, (2002), Bull. Amer Meteor Soc., 83, 1631-1643.

Killworth PD, Stainforth D, Webb DJ, Paterson SM, (1991), J. Phys Oceanogr., 21, 1333-1348.

Kondo J., (1975), Bound.-Layer Meteorol., 9, 91-112.

Kuragano T, Kamachi M., (2000), J. Geophys. Res., 105, 955-974.

Kuragano T, Kamachi M, (2003), J. Oceanogr., 59, 765-781.

Mellor GL, Ezer T, (1991), J. Geophys Res., 96, 8779-8795.

Mellor GL, Kantha L, (1989), J. Geophys. Res., 94, 10937-10954.

Noh Y, Kim H-J, (1999), J. Geophys. Res., 104, 15621-15634.

Ocean Climate Laboratory, (1999), National Oceanographic Data Center.

Smith WHF, Sandwell DT, (1997), Science, 277, 1956-1962.

Spall MA, Holland WR, (1991), J. Phys Oceanogr., 21, 205-220.

Toth Z, Kalnay E., (1997), Mon. Wea. Rev., 125, 3297-3319.

Tsujino H, Usui N, Nakano H, (2006), J. Geophys Res., *Geophys. Res.*, 111 , C11001, doi:10.1029/ 2005JC003118

Usui, N., H. Tsujino, Y. Fujii, M. Kamachi, (2006), Ocean Dynamics, vol.56, 607-623, DOI 10.1007/ s10236-006-0084-z

Usui, N., H. Tsujino, H. Nakano, and Y. Fujii, (2008), J. Geophys. Res. (in press)

Weatherly GL, (1972), J. Phys Oceanogr., 2, 54-72.

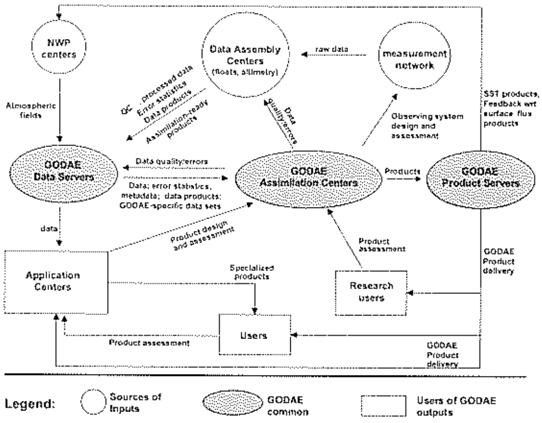
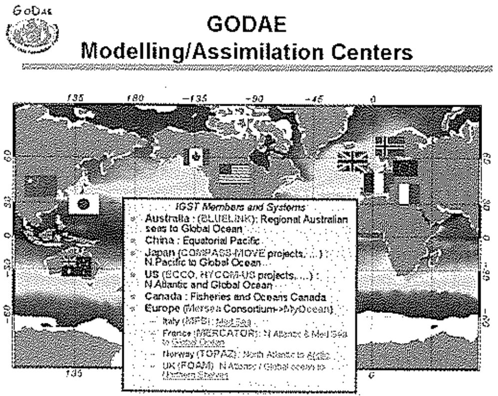


Fig.1 GODAE backbone: A schematic diagram that is illustrating the relationship between the functional components of GODAE and the transmission of data and information between them (GODAE Startegic Plan).



IGST Members and Systems

- Australia : (BLUELINK): Regional Australian seas to Global Ocean
- China : Equatorial Pacific
- Japan (COMPASS-MOVE projects, ...) : N.Pacific to Global Ocean
- US (ECCO, HYCOM-US projects, ...) : N Atlantic and Global Ocean
- Canada : Fisheries and Oceans Canada
- Europe (Mersea Consortium->MyOcean)
  - Italy (MFS) : Med Sea
  - France (MERCATOR): N Atlantic & Med Sea to Global Ocean
  - Norway (TOPAZ) : North Atlantic to Arctic
  - UK (FOAM) N Atlantic / Global ocean to Inshore Shelves

Fig.2 IGST member systems.

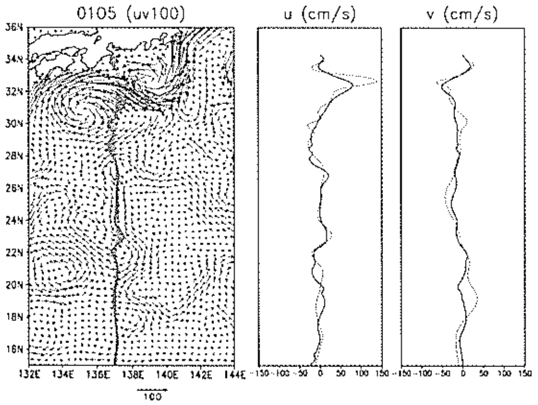


Fig. 3 Compariso of velocity fields. Black: assimilation, Red: ADCP observation.

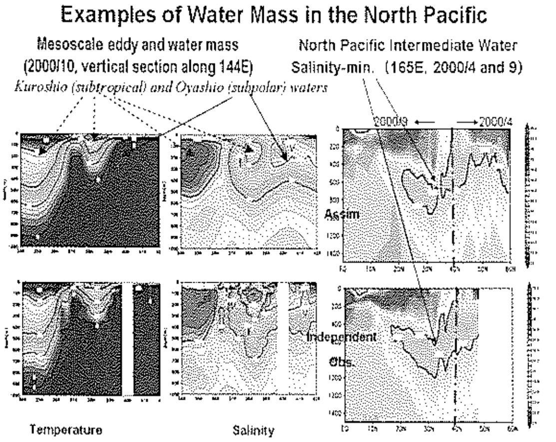


Fig.4 Comparison of temperature and salinity distribution along 144e and 165E.

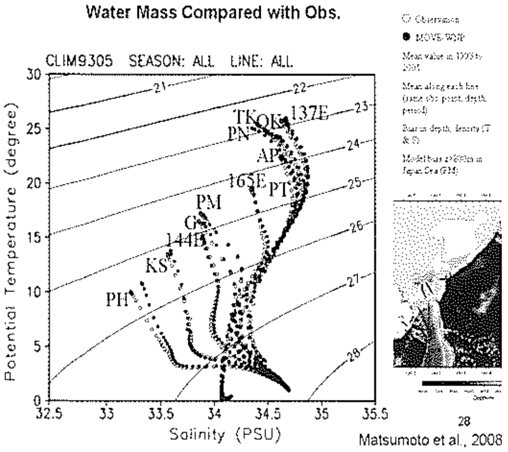


Fig.5 Comparison of water property (T-S diagram) along JMA's hydrographicsections (see right figure for the positions).

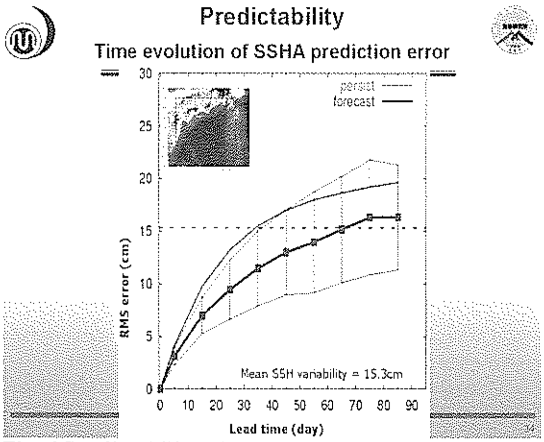


Fig. 6 Predictability diagram.