MERCATOR global ocean analysis systems

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Mercator has developed two global ocean systems to produce ocean analyses. These systems share the same ocean model but differ on the assimilation component. The first system called MERCATOR-2 (MCT2) is based on a reduced order Kalman filter assimilation scheme, while the second one called MERCATOR-3 (MCT3) uses 3D-variational data assimilation.

For this CLIVAR-GODAE GSOP model inter comparison we provide a set of two 9 year long reanalyses from 1993 to 2001. The two reanalyses are based on different assimilation scheme but are using the same ocean model configuration, forcing fields and assimilated observations.

Ocean Model

Both systems (MCT2 & MCT3) are based on ORCA2 global ocean general circulation model (OGCM) developed by LOCEAN (Madec et al., 1998). It has been widely used in climatic (e.g., Delecluse and Madec, 1999; Guilyardi, 2001) and tropical ocean circulation studies (e.g., Blanke and Delecluse, 1993; Vialard et al. 2002) as well as in operational mode at Mercator to produce global ocean analyses (Ferry et al., 2006). This model is based on the OPA8 code which solves the incompressible Navier-Stokes equations with the Boussinesq approximation. The ORCA2 configuration of OPA used in Mercator-Océan has an implicit free surface formulation. The ocean model includes a 1.5 turbulent kinetic energy closure scheme to describe the vertical physics (Blanke and Delecluse, 1993). The downward solar flux is able to penetrate the top few metres of the ocean according to the Paulson and Simpson (1977) formulation and the Jerlov (1968) clear open ocean water is used for the whole ocean. Laterally, there is free slip condition near the coast while friction at the sea bottom is quadratic. Horizontal diffusion is harmonic for velocity, temperature and salinity (the horizontal eddy viscosity for the dynamics is set to 4×10^4 m.s^{-2} and the horizontal eddy diffusivity for tracers is set to 2×10^3 m.s^{-2}). In addition, diffusion is isopycnal for tracers and horizontal for velocity. Density is calculated from temperature, salinity and depth (Jackett and McDougall, 1995). The model integration time step is 1 hour 36 minutes (i.e. 15 time steps per day). The ORCA2 ocean model is characterised by its stretched horizontal grid with two poles located in the northern hemisphere on the North American and Asian continents. The grid is isotropic (Mercator grid, about 2°×2°cos(latitude) in longitude × latitude) at mid and high latitudes with a refinement in latitude between 5°N / 5°S and a meridional resolution of 0.5°. The model uses a vertical z-coordinate with 31 levels whose first 21 levels are in the top 1,000 metres of the ocean. The thickness of the levels varies from 10 m at the surface (within the first 100 m) to 500 m below the 3,000 m level. The maximum depth is set to 5,000 m and a realistic topography based on the ETOPO5' global atlas is used.

The model is forced by the daily surface fluxes coming from ERA-40, namely (i) surface wind stress, (ii) solar and (iii) non-solar surface heat fluxes and (iv) the evaporation minus precipitation budget. The simulated sea surface temperature (SST) – i.e., the first layer of the model – is restored towards the Reynolds real-time analysed SST product (Reynolds and Smith, 1994) which is available on a weekly basis with a restoring constant of 40 W.m^{-2}.K^{-1}. The surface salinity is restored towards the monthly mean climatology of Levitus et al. (1998). In addition, the model is forced in an explicit way by the flow rate of rivers, based on the climatology reported by Baumgartner and Reichel (1975).The model also includes a weak relaxation towards Levitus et al. (1998) monthly climatology for temperature and salinity below the mixed layer, with a time scale of 3 years. Initialisation of the model for temperature and salinity is based on the Levitus et al. (1998) climatology with a null initial velocity field. Presently, there is no ice model: the presence of ice is simply diagnosed at the surface.

MERCATOR-2 assimilation scheme

The Mercator-2 assimilation scheme is an algorithm based on the SEEK filter (Pham et al., 1998). It consists in a Reduced Order Kalman Filter where the error statistics are represented in a sub-space spanned by a small number of dominant directions. The analysis step is reformulated to take advantage of the low-rank approximation, leading to more efficient inversions of the data in the reduced space than in observation space

(Testut et al, 2003). A local approach for the analysis has also been implemented by setting to zero the error covariances between distant variables which are believed to be uncorrelated in the real ocean. Moreover, MCT2 includes new features from the original SEEK filter such as 3D multivariate modes from prior model simulations and an adaptativity scheme. The use of 3D model representation for the error statistics is intended to overcome some the limitations of optimal interpolation algorithm in highly inhomogeneous, anisotropic, and non separable regions of the world ocean such as shallows areas, as well as in the surface layer. The adaptativity algorithm corresponds to an adjustment of the background error variance to the observed misfits.

The control variables are temperature, salinity and horizontal velocity. The assimilated data are temperature and salinity profiles (from XBTs, CTDs and Argo float measurements) from the ENSEMBLE EN2 data base, weekly Reynolds sea surface temperature (Reynolds and Smith, 1994) and along track sea level anomaly data from the available altimetric satellites over this period (i.e., ERS1/2, TOPEX/Poseidon and GFO). The model SLA is computed using a model mean sea surface height estimated from a free simulation. In practise, the misfit is computed using the 3D FGAT approximation over the 7-day time window.

The model error covariance is calculated from a ten year long free run (1993-2002). Model state deviations from the model low frequency trajectory are used to compute the forecast error covariance used for assimilation. The observation error (including the model representation error) is spatially dependant and has been estimated for all data sets using Fu et al. (1993) approach.

MERCATOR-3 assimilation scheme

The MERCATOR-3 assimilation system is based on the ORCA configuration and a variational assimilation scheme, ORCAVAR, developed at CERFACS (Weaver et al., 2003). The 1993-2001 reanalysis is performed with the 3DVar approach and assimilate not only in situ observations (T, S profiles) but also sea level anomalies.

The control variables are the initial conditions on temperature, salt, horizontal velocities and sea surface height, and the assimilation window is 10 days. The assimilated observations come from the in situ observations of the ENSEMBLE data base and the Topex-Poseidon along track sea level anomalies. They are referred to a forced ORCA2 model run Mean Dynamical Topography. The model also uses a strong nudging towards the observed Reynolds SST (-200 $W/m^2/K$).

The model error covariance is multivariate and the diagonal observation error matrix includes a spatially dependent model representativity error.

References:

Blanke, B., Delecluse, P., 1993. Variability of the tropical Atlantic ocean simulated by a general circulation model with two different mixed layer physics. J. Phys. Oceanogr., 23, 1363-1388.

Delecluse, P., Madec, G., 1999. Ocean modelling and the role of the ocean in the climate system. In Modeling the Earth's Climate and its Variability, Les Houches, Session LXVII 1997, W. R. Holland, S. Joussaume and F. David, eds., Elsevier Science, 237-313.

Ferry, N., E. Remy, P. Brasseur, C. Maes: The Mercator global ocean operational analysis / forecast system: assessment and validation of an 11-year reanalysis. J. of Marine Systems, 2006, in press.

Fu, L.-L., I. Fukumori and R. N. Miller, 1993. Fitting dynamic models to the Geosat sea level observations in the Tropical Pacific Ocean. Part II: A linear, wind-driven model, **JPO**, **23**, 2162-2181.

Guilyardi, E., Madec, G., Terray, L., 2001. The role of lateral ocean physics in the upper ocean thermal balance of a coupled ocean-atmosphere GCM. Clim. Dyn., 17, 589-599.

Madec G., Delecluse, P., Imbard, M., Lévy, C., 1998. OPA 8.1 ocean general circulation model reference manual, Notes du pôle de modélisation IPSL, 91 pp. WWW Page http://www.lodyc.jussieu.fr/opa/

Pham, D., Verron, J., and Roubaud, M., 1998. A Singular Evolutive Extended Kalman filter for data assimilation in oceanography. J. Mar. Syst., 16(3-4), 323-340.

Reynolds, R. W., Smith, T. M., 1994. Improved global sea surface temperature analyses using optimum interpolation. J. Climate, 7, 929-948.

Testut C.E., Brasseur P., Brankart J.M. and Verron J., 2003. Assimilation of sea surface temperature and altimetric observations during 1992-1993 into an eddy-permitting primitive equation model of the North Atlantic Ocean, *J. Mar. Syst.,* 40-41, pp 291-316.

Vialard, J., Delecluse, P., Menkes, C., 2002. A model study of salinity variability and its effects in the tropical Pacific Ocean during the 1993-1999 period. J. Geophys. Res., 107, C12, 8005, doi:10.1029/2000JC000758.

Weaver, A. T., J. Vialard and D. L. T. Anderson, July 2003: Three- and Four-Dimensional Variational Assimilation with a General Circulation Model of the Tropical Pacific Ocean. Part I: Formulation, Internal Diagnostics, and Consistency Checks, Monthly Weather Review, vol. 131 n° 7, 1360,1378.