The Global ECCO 1992-2002 and the Global ECCO 1952-2001 Ocean Synthesis

Armin Köhl
Institut für Meereskunde, Universität Hamburg ,armin.koehl@zmaw.de

1 Configuration of ECCO-SIO

The ECCO model is based on the Massachusetts Institute of Technology (MIT) general circulation model (Marshall et al., 1997b,a), which consists of conservation equations for horizontal and vertical momentum, volume, heat, and salt, and an equation of state which are solved on a staggered "C"-grid. Spatial coordinates are longitude, latitude, and height. A detailed description of the model is provided by Adcroft et al. (2002). For our application, the ECCO model was configured on a 1° horizontal grid over $\pm$ 80° in latitude and on a vertical grid with 23 levels (same as in Stammer et al. (2002) with one additional 500m thick level).

For present purposes, we use a hydrostatic version with an implicit free-surface. A GM eddy-parameterization scheme (Gent and McWilliams, 1990) was implemented and a full "KPP" surface mixed layer model (Large et al., 1994) is used.

The optimization is initialized with the Levitus and Boyer (1994); Levitus et al. (1994) January potential temperature and salinity fields after the baroclinic flow field was spun up during a one-month forward integration. Daily surface heat and freshwater forcing fields, obtained from the National Center for Environmental Prediction (NCEP)/National Center for Atmospheric Research (NCAR) first re-analysis project (Kalnay et al., 1996), and twice-daily wind stress fields are used to force the model at its surface. The meridional boundaries are closed, i.e., no volume flux occurs normal to them. In addition, no relaxation of the model fields toward the climatological T, S fields was applied at the poleward lateral boundaries to avoid artificial sinks and sources of heat and freshwater. Moreover, no relaxation was applied in the Strait of Gibraltar since the Mediterranean is part of the model domain. As a result, in our runs all sources for heat and freshwater reside in the surface boundary only.

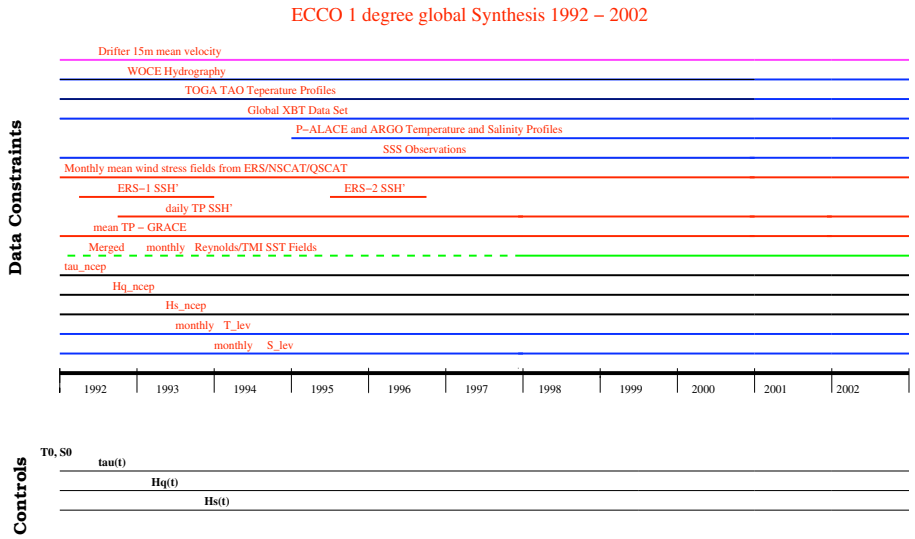

Figure 1: Schematic of the optimization. The upper part shows the data constraints imposed on the model. The lines indicate times when data is available, mean or climatological data is shown as available throughout the whole period. The lower part summarizes the control parameters that were changed during the optimization. These include the adjustments to the initial potential temperature (θ) and salinity (S) fields, as well as two-day averages of surface forcing fields over the full 11 years.

The model topography was derived from the Smith and Sandwell (1997) topography provided on a

1/30° horizontal resolution and ETOPO5 poleward of 72.006° latitude. The synthesis is obtained by forcing the ocean model to near consistency (within specified error margins) with most of the WOCE observations by using the model's adjoint to modify the initial temperature and salinity conditions over the full water column and to adjust the time-varying meteorological forcing fields over the full estimation period on a daily basis. The adjoint model was obtained from the forward code by using the TAF Model Compiler (Giering and Kaminski, 1998). The nonlinearity of the KPP and GM scheme causes the adjoint related to these parameterizations develop unstable modes that grow rapidly in time. The respective code was excluded from the adjoint model. The data constraints are shown in the upper panel of Fig 1. The lower panel summarizes the control variables that are being adjusted during the optimization. The weights are diagonal error measures which were also used in the pre-conditioning. For the optimization a quasi-Newton descent algorithm (Gilbert and Lemaréchal, 1989) was used; it was stopped after 46 iterations when the cost function changes of two successive iterations became small.

More details are available in Köhl et al. (2006b) or can be downloaded as a report (Köhl et al., 2002).

2 Configuration of ECCO-50y

The setup and assimilation approach are essentially identical to the above described 11 year ECCO global data synthesis

Before the optimization was started initial corrections were calculated from the climatology of the correction fields from the the 11 year ECCO global data synthesis and altered by diagnosing the additional fluxes from restoring the model toward Reynolds and Smith (1994) SST and climatological Levitus and Boyer (1994); Levitus et al. (1994) salinity with a time scale of 30 days. In contrast to the previous optimization experiment over the 11 year period 1992 through 2001, the reduced adjoint of the longer run shows exponentially growing adjoint variables when integrated over the full 50 years period. In order to suppress this instability we followed the approach of Köhl and Willebrand (2002) and used a larger diffusivity value in the original adjoint model.

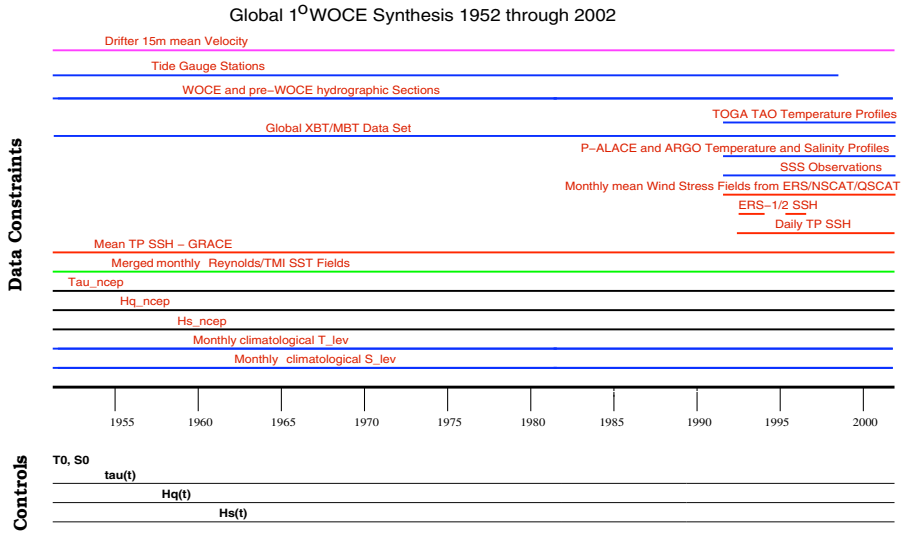

Figure 2: Schematic of the ECCO-50y optimization analogous to the scheme in Fig. 1

Additionally to the data that was also assimilated in the ECCO-SIO product, tide gauge data and XBT/MDT data as well as CTD data from the pre-WOCE period before 1992 were assimilated. Fig 2 shows an overview of the data constraints and estimated parameter.

The optimization was stopped after iteration 23 when the cost function improvement of successive iterations became insignificant although the result can not be regarded as fully converged.

A complete report is available as Köhl et al. (2006a).

References

Adcroft, A., J.-M. Campin, P. Heimbach, C. Hill, and J. Marshall, 2002: Mitgcm Release 1, *http://mitgcm.org/sealion/*.

Gent, P. R., and J. McWilliams, 1990: Isopycnal mixing in ocean circulation models, *J. Phys. Oceanogr.*, **20**, 150–155.

Giering, R., and T. Kaminski, 1998: Recipes for Adjoint Code Construction, *ACM Trans. On Math. Software*, **24**, 437–474.

Gilbert, J. C., and C. Lemaréchal, 1989: Some numerical experiments with variable-storage Quasi-Newton algorithms, *Math. Program.*, **45**, 407–435.

Kalnay, E., M. Kanamitsu, R. Kistler, W. Collins, D. D. L. Gandin, M. Iredell, S. Saha, G. White, J. Woollen, Y. Zhu, M. Chelliah, W. Ebisuzaki, W. Higgins, J. Janowiak, K. C. Mo, C. Ropelewski, A. Leetmaa, R. Reynolds, and R. Jenne, 1996: The NCEP/NCAR 40-Year Re-analysis Project., *Bull. Amer. Meteor. Soc.*, **77**, 437–471.

Köhl, A., D. Dommenget, K. Ueyoshi, and D. Stammer, 2006a: The global ECCO 1952 to 2001 ocean synthesis, *ECCO Report No.40*, See also http://www.ecco–group.org/reports.html.

Köhl, A., Y. Lu, P. Heimbach, B. Cornuelle, D. Stammer, and C. Wunsch, 2002: The ECCO 1 degree global WOCE Synthesis, *ECCO Report No.20*, See also http://www.ecco–group.org/reports.html.

Köhl, A., D. Stammer, and B. Cornuelle, 2006b: Interannual to decadal changes in the ECCO global WOCE synthesis, *J. Phys. Oceanogr.*, in press.

Köhl, A., and J. Willebrand, 2002: An adjoint method for the assimilation of statistical characteristics into eddy-resolving ocean models, *Tellus A*, **54**, 406–425.

Large, W. G., J. C. Williams, and S. C. Doney, 1994: Ocean vertical mixing: A review and a model with a nonlocal boundary layer parametrization, *Rev. Geophys.*, **32**, 363–403.

Levitus, S., and T. P. Boyer, 1994: Temperatures. Vol. 4, World Ocean Atlas 1994, *NOAA Atlas NESDIS*, 117 pp.

Levitus, S., R. Burgett, and T. P. Boyer, 1994: Salinity. Vol. 3, World Ocean Atlas 1994, *NOAA Atlas NESDIS*, 99 pp.

Marshall, J., A. Adcroft, C. Hill, L. Perelman, and C. Heisey, 1997a: A finite-volume, incompressible Navier Stokes model for studies of the ocean on parallel computers, *J. Geophys. Res.*, **102**, 5753–5766.

Marshall, J., C. Hill, L. Perelman, and A. Adcroft, 1997b: Hydrostatic, quasi-hydrostatic, and nonhydrostatic ocean modelling, *J. Geophys. Res.*, **102**, 5733–5752.

Reynolds, R. W., and T. M. Smith, 1994: Improved global sea surface temperature analysis using optimum interpolation, *J. Climate*, **7**, 929–948.

Smith, W. H. F., and D. T. Sandwell, 1997: Global seafloor topography from satellite altimetry and ship depth soundings, *Science*, **277**, 195–196.

Stammer, D., C. Wunsch, R. Giering, C. Eckert, P. Heimbach, J. Marotzke, A. Adcroft, C. Hill, and J. Marshall, 2002: The global ocean circulation during 1992 -1997, estimated from ocean observations and a general circulation model, *J. Geophys. Res.*, **107**, 10.1029/2001JC000888.