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INTERIM

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Paola Malanotte-Rizzoli, P.I.

1. Application of the adjoint method to the GFDL model.

Dr. Lisan Yu began her Postdoctoral Fellowship at MIT supported full time by the present grant on January 1, 1993. Together with her, we have adapted the GFDL model of Cox (1984) with its adjoint to the North Atlantic Ocean. This GFDL plus adjoint configuration is not the one developed by Tziperman et al, (1992) or Marotzke and Wunsch (1993). In their application, they use a simplified version of the GFDL plus adjoint codes that is steady and linearized, i.e. diagnostic, in the horizontal momentum equations so that they cannot cross the equator. The adjoint we use was developed for the fully nonlinear time-dependent version of the GFDL code in the context of NSF supported Mediterranean work. We have adapted it to the Northern Atlantic in two configurations: a) The latitudinal band from 10°N to 60°N in latitude analogous to the one used by Marotzke and Wunsch (1993); and b) The latitudinal band from 15°S to 65°N in latitude as in the CME (Community Modeling Effort).

In both cases, we use the CME medium resolution of 1.2°C in longitude by 1° in latitude and 30 levels in vertical. We also use the CME bottom topography and sponge layers at the northern and southern open boundaries. During this last year we have carried out and completed a sensitivity study to assess the dynamical importance of different hydrographic climatologies affecting circulation features such as the North Atlantic Deep Water (NADW) thermohaline cell, the meridional heat transport etc., when reconstructed by the adjoint. We have compared the two climatologies for temperature and salinity of Levitus (1982) and Fukumori and Wunsch (1991) assessing their realism and effectiveness in reconstructing the above dynamical features of the North Atlantic circulation. We use the surface heat flux climatology of Oberhuber (1988) and the surface winds of Hellerman and Rosenstein (1983). We minimize the misfit between the model (T,S) and the Levitus ones and include in the cost function a steady penalty term. The adjoint code also evaluates the surface heat and moisture flux as part of the optimization procedure. This can be done in two ways. The surface fluxes can be included as a control variable. Then the minimum of the cost must also satisfy the condition that the cost derivative with respect to any control variable must vanish. Then the surface fluxes are evaluated by direct differentiation of the augmented cost function. Alternatively, explicit terms can be included in the cost representing the misfit between the surface fluxes and an initial guess. Thus, through the adjoint calculation we obtain steady state estimates of the circulation, T and S fields and surface fluxes consistent with the observations used and the model dynamics. A paper has been submitted to *Journal of Marine Research*, Yu and Malanotte-Rizzoli, 1996 (see Publications).

2. Inverse modeling applied to open-boundary conditions.

Dr. Philip Bogden was a Post Doctoral Fellow with a UCAR-Ocean Modeling Postdoctorate. I have extended his Postdoctorate by six months under this grant.

Open-ocean boundary conditions for a dynamical model of flow in a semi-enclosed coastal basin have been estimated from data. Current-meter observations provide information about flow within the model domain. The estimation problem, a generalized inverse problem, involves fitting the dynamics to "interior" data by allowing for errors in a prescribed open-boundary condition (OBC). Linear shallow-water dynamics govern the

forced by local measured winds and by adjustments to the prescribed OBC. Optimal estimates of the OBC adjustments are obtained by solving an inverse problem that minimizes a combined measure of mean-square model error and data-model-misfit.

The methodology follows an approach used by Bennett and McIntosh (1982) and McIntosh and Bennett (1984) in a study of tides. This inverse methodology has been applied to the estimation of currents in Massachusetts Bay. Data for the study include buoy winds and current-meter measurements from six different mooring locations within Mass. Bay (Geyer et al., 1992)). At sub-tidal frequencies, optimal OBC's obtained by consistent inversion of the data brings model skill up to 70% on the offshore stations. The adjustments to the radiation OBC drive a strong geostrophic along-shore flow that accounts for most of the energy in the off-shore measurements. A paper by Bogden et al is in press in *Journal of Geophysical Research* (see Publications).

Publications supported by the grant in the present period.

1). Capotondi, A., P. Malanotte-Rizzoli and W.R. Holland, "Assimilation of altimeter data into a quasi-geostrophic model of the Gulf Stream System. Part I: Dynamical Considerations," *J. Phys. Oceanogr.*.

2). Capotondi, A., R. Holland and P. Malanotte-Rizzoli, "Assimilation of altimeter data into a quasi-geostrophic model of the Gulf Stream System. Part II: Assimilation Results," *J. Phys. Oceanogr.*, 1994.

3). Bogden, P.S., P. Malanotte-Rizzoli and R.P. Signell, "Open-ocean boundary conditions from interior data: local and remote forcing of Massachusetts Bay", in press in *J . Geophys Res.*, 1996.

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Geyer, W.R., G.B. Gardner, W.S. Brown, J. Irish, B. Butman, T. Loder, and R.P. Signell, "Physical oceanographic investigations of Massachusetts and Cape Cod Bays", TR MBP-92-03, Massachusetts Bays Program, Boston, Massachusetts, 497 pp., 1992.

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Tziperman, E., W.C. Thacker, R.B. Long, S. Huang and S.R. Rintoul, "Oceanic data analysis using a general circulation model. Part II. A North Atlantic model", *J. Phys. Oceanogr.*, 22, 1458-1585, 1992.