ROMS/TOMS Tangent Linear and Adjoint Models: Testing and Applications

Andrew M. Moore
Program of Atmospheric and Oceanic Sciences
University of Colorado
Boulder, CO 80309-0311
phone: (303) 492-3290 fax: (303) 492-3524 email: andy@australis.colorado.edu

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LONG-TERM GOALS

Our long-term technical goal is to produce a tested tangent linear and adjoint model for ROMS/TOMS (Regional Ocean Modeling System/Terrain-Following Ocean Modeling System) that is suitable for general use by ROMS/TOMS modelers. This is complementary to the Kalman Filter, ESSE, and Green's Functions techniques being developed in other contexts. Our long-term scientific goal is to model and predict the mesoscale circulation and the ecosystem response to physical forcing in the various regions of the world ocean through ROMS/TOMS primitive equation modeling/assimilation.

OBJECTIVES

We seek to develop an adjoint model for the Rutgers/UCLA ROMS/TOMS, a parallel/improved physics descendent of the serial SCRUM (Song and Haidvogel, 1994). We also seek to complete the assimilation system by including the adjoint in an estimation procedure for fitting the model to data. The resulting codes will be suitable for general use in any geometry of ROMS/TOMS, which presently lacks an adjoint.

APPROACH

This is fundamentally a collaborative effort involving University of Colorado (A. Moore), Rutgers (H. Arango) and Scripps (B. Cornuelle, Ph. D. student E. Di Lorenzo, A. Miller, and D. Neilson). Our approach is to write the tangent linear and adjoint models for ROMS/TOMS by hand. With each participant in the project contributing expertise in coding and model testing, the approach is feasible. As the development is accomplished, the assimilation scheme is tested in various scenarios involving observations. The Scripps contingent will test the adjoint for ROMS/TOMS in the California Current CalCOFI region where they are presently applying ROMS (under NASA funding) to a physical-biological data synthesis and a model forecast scenario. Arango and Moore will test the adjoint in the Mid-Atlantic Bight (under NSF funding) for coupled atmosphere-ocean hindcast experiments using data collected at the observational network centered at the Long-Term Ecosystem Observatory (LEO-15).

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WORK COMPLETED

The ROMS/TOMS adjoint team met many times over the past two years in intensive tangent linear and adjoint model writing/testing sessions. A working 2D and 3D tangent linear and adjoint model is now running and being used in various 2D and 3D applications. A large percentage of ROMS/TOMS 3D routines are now completed and tested, but some of the less frequently used routines still need to be coded in for the adjoint.

Finite-time normal modes have been tested in the 2D and 3D. The optimal perturbations scheme as been developed and tested in 2D and 3D. The stochastic optimals scheme has the driver completed but still needs testing. The 4D variational assimilation (4DVAR) is being constructed. So far, the driver for the inner and outer loops has been designed along with the modules needed to sample the model at observational locations and times. The cost function, pre-conditioning and descent algorithms are being built for 4DVAR. The ensemble prediction scheme needs the driver and module to compute random linear combinations of singular vectors.

The 4DVAR and optimal perturbation schemes are now being set up to be tested in the Southern California Bight domain where CalCOFI hydrography and TOPEX altimetry observations are available.

RESULTS

The building of the adjoint is largely a technical task. Many scientific technical results will follow once the codes are ready. We here present an interesting application of the tangent linear and adjoint codes for a classic theoretical problem in physical oceanography.

A 3D test case for computing optimal perturbations (Moore and Farrell, 1994) to study model error growth was set up in a simple stratified double gyre basin. The optimal perturbations are computed by an iterative application of forward and backward integrations of the tangent linear and adjoint equations in conjunction with the ARPACK library. Figure 1 shows an example from this case. The basic state surface circulation is shown in Figure 1a,b for a 10-day interval. This was generated by forcing the model for three years with steady sinusoidal winds and a relaxation to a hyperbolic tangent vertical temperature profile with linear latitudinal dependence. The circulation takes the form of two unsteady counter-rotating gyres that are often used as an analog of the subpolar/subtropical gyre systems. The surface structure of the fastest growing optimal perturbation for this 10-day period is shown in Figure 1c,d. Of all possible perturbations, this is the one that maximizes growth of perturbation energy over the 10-day period. At initial time, the sea level structure shows a pronounced upstream tilt against the basic state flow that is indicative of barotropic growth. As the perturbation evolves, it is advected downstream by the basic state circulation and grows in amplitude by a factor of 40.

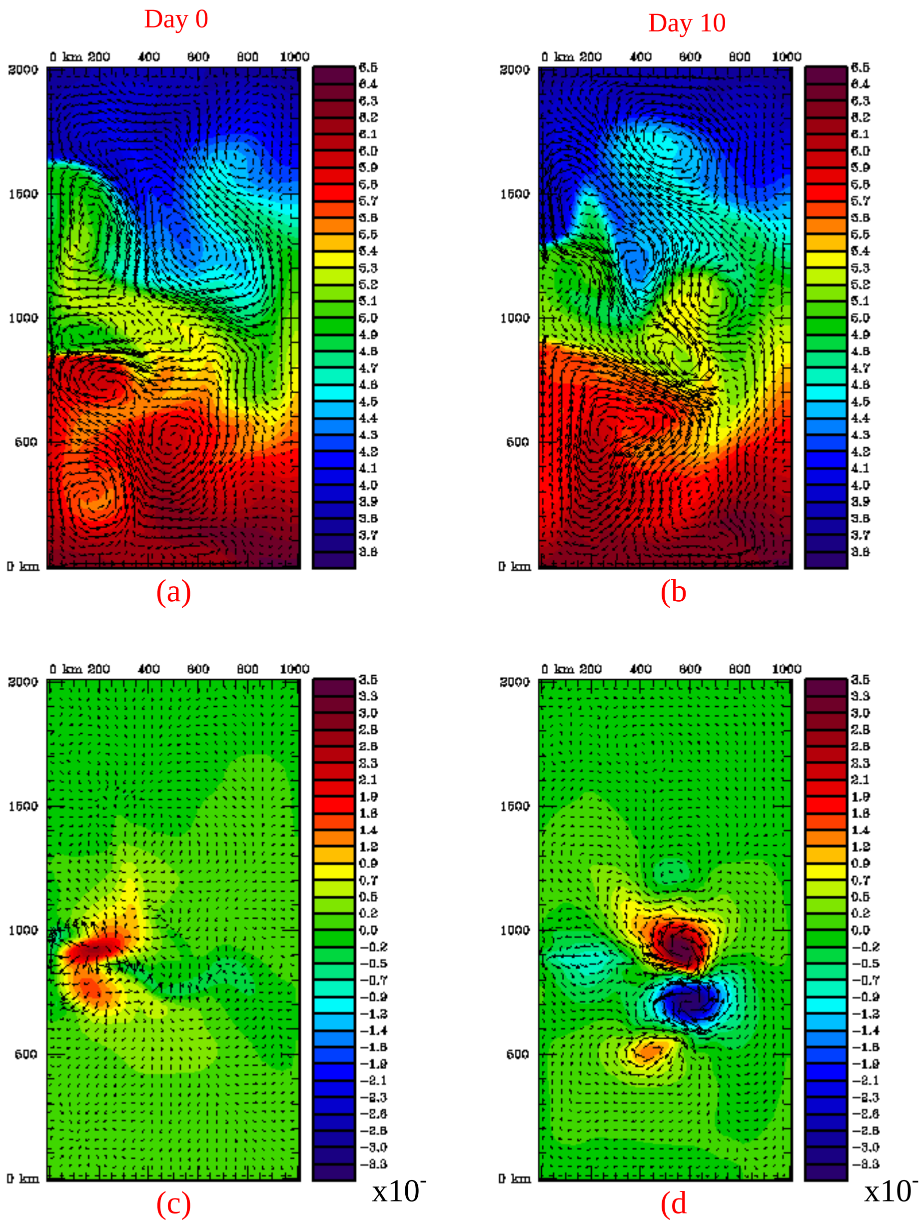

Figure 1: Idealized Double-Gyre Optimal Perturbations
[Panels a and b show the surface temperature and velocity vectors of the double gyre basic state flow 10 days apart. Panels c and d show the surface velocity and sea level at initial and final times for the optimal perturbation that maximizes the growth of perturbation energy over the 10 day period.]

IMPACT/APPLICATIONS

Users of the tangent linear and adjoint model for ROMS/TOMS will have a powerful tool for exploring data assimilation issues that include sensitivity to initial conditions and surface forcing, predictability and ocean dynamics.

TRANSITIONS

The work completed here will be part of the ROMS/TOMS utilities that will be freely available to all interested users.

RELATED PROJECTS

Moore, Arango, Miller and Cornuelle have a project funded by NSF (lead PI: A. Bennett, OSU) entitled "Modular Ocean Data Assimilation". The goal is to use the infrastructure of the Inverse Ocean Modeling System of Chua and Bennett (2001) in conjunction with the ROMS/TOMS tangent linear and adjoint models for ocean data assimilation. The IOMS requires a somewhat different tangent linear model (but fortunately the same adjoint) that is based on the full fields rather than the perturbations fields. Both versions are now available for the 2D ROMS/TOMS kernel. Miller and Cornuelle are funded by NASA to explore Green's Functions model fitting techniques (Miller and Cornuelle, 1999) with ROMS in the Southern California Bight of the California Current System http://osep.ucsd.edu/index.cgi?rsadjoint. Those results will prove useful in comparing with results from applying the adjoin t to these same data.

REFERENCES

Chua, B. S., and A. F. Bennett, 2001: An inverse ocean modeling system. *Ocean Modelling*, in press.

Miller, A. J., and B. D. Cornuelle, 1999: Forecasts from fits of frontal fluctuations. *Dynamics of Atmospheres and Oceans*, **29**, 305-333.

Moore, A. M., and B. F. Farrell, 1994: Using adjoint models for stability and predictability analysis. In: *Data Assimilation*, P. P. Brasseur and J. C. Nihoul, eds., NATO ASI Series, **119**, Springer-Verlag, Berlin, 217-239.

Song, Y. H., and D. B. Haidvogel, 1994: A semi-implicit ocean circulation model using a generalized topography-following coordinate system. *Journal of Computational Physics*, **115**, 228-244.

PUBLICATIONS

Di Lorenzo, E., 2002: Seasonal dynamics of the surface circulation in the Southern California Current System. *Deep-Sea Research, sub judice*.

Di Lorenzo, E., A. J. Miller, D. J. Neilson, B.D. Cornuelle, and J. R. Moisan, 2001: Modeling observed California Current mesoscale eddies and the ecosystem response. *International Journal of Remote Sensing*, in press.

Miller, A. J., E. Di Lorenzo, D. J. Neilson, B. D. Cornuelle, and J. R. Moisan, 2000: Modeling CalCOFI observations during El Nino: Fitting physics and biology. *California Cooperative Oceanic Fisheries Investigations Reports*, **41**, 87-97.