Aspects of an adjoint-based ECCO MARK-2 configuration

Report of the 2 December 2005 Meeting
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Contents

1 Forward model

1.1 Introduction

The purpose of the meeting was to discuss aspects of a new-generation configuration of an adjoint-based state estimation system which incorporates both improved "physics" and numerics, taking advantage of many improvements of the MITgcm that have taken place over the last few years. In doing so, we should attempt to stay close to the high-resolution configuration of ECCO-2 to the extent that this is possible.

1.2 Basic features

1.2.1 Mass vs. volume conserving (Boussinesq) configuration

We will explore MITgcm's feature of fully relaxing the Boussinesq approximation through the height (z) vs. pressure (p) vertical coordinate isomorphism [*Marshall et al.* 2004, *Adcroft and Campin* 2004]. A preliminary assessment of the significance of the Boussinesq approximation exists [*Losch et al.* 2004], but a more detailed assessment will be difficult to carry out (R.F.). From a conceptual point of view, using a mass-conserving model will settle many arguments with e.g. geodesists (mass, angular momentum balances, etc.). Gridding/re-gridding routines will be needed at an early stage to complement and facilitate this transition (E.H.). Preliminary experience exists for the adjoint via an atmospheric Held-Suarez-type setup, and no fundamental obstacles are perceived (P.H.). Further adjoint tests will be done with a pressure-coordinate global 4x4 degree setup.

1.2.2 Treatment of free surface and tracer conservation

We will extend the adjoint to enable the use of the nonlinear free surface (NLFS) code [*Campin et al.* 2004]), which will improve tracer conservation properties, in particular for salinity (see also [*Roullet and Madec* 2000], [*Griffies et al.* 2001]). Modifications here will be slighly non-trivial. They require (i) clearer separation between the `nonlinFreeSurf` and the `select_rStar` code (i.e. distinguishing code necessary for NLFS, and code necessary for a z^* implementation), (ii) activity of partial cells `hFacC/S/W`, similar to bottom topography control [*Losch and Heimbach* 2005], and activity of `ini_masks_etc`, etc., (iii) care, to preserve self-adjointness of pressure solver.

Special care must be taken for ocean salt conservation and treatment of sea surface salinity (e.g. *Huang* [1993]). This affects treatment of freshwater flux into the ocean [*Roullet and Madec* 2000], and formulation of the free surface [*Campin et al.* 2004]. We'll use `realFreshwaterFlux`, but need to understand, why it gives rise to significantly increased cost when used/replaced in current production config.

Implementation of atmospheric loading in p coordinates does not currently exist.

1.2.3 The horizontal polar cap grid

Horizontal grid is the newly developed polar cap grid (EH3,CNH). It consists of 3 components: (1): a longitude-latitude grid between the Equator and xxx°N/S, (2): a transition/terassing area between xxx°N/S and roughly yyy°N/S, (3): a regularly spaced polar cap poleward of yyy°N/S.

The parallelization of the polar cap grid is based on the `EXCH2` or the newly developed `EXCH3` package (EH3,CNH). For `EXCH2` package prototype adjoint routines exist for a single-processor advection-diffusion adjoint problem (P.H.,CNH). These need to to be extended (exchanges for velocity, vorticity, etc. fields, and pressure solver). This could be outsourced (R.Giering).

1.2.4 Resolution

It might be useful to separate horizontal from vertical resolution: The idea is that for the vertical resolution we would choose a fairly high value right from the start (Nr=42 or 50), and leave it untouched. As for horizontal resolution, it is likely that we may go in several steps, i.e. initially a Mark-2.1 setup which incorporates many new numerics aspects, but still similar (or only slightly/regionally higher) to 1x1 degree, and Mark-2.2 significantly higher resolution.

Nominal horizontal resolution for Mark-2.1 is telescoping from 0.25° in the Tropics to 1° at mid-latitude, and approx. xxx° in the polar cap.

Increasing horizontal resolution in the Western boundary currents is very difficult to realize currently. It won't be attempted initially, but should be kept in mind.

The resolution in the vertical will consist of Nr vertical layers (for high-res. cubed-sphere runs Nr=50, for Southern Ocean setup Nr=42).

1.2.5 Time-stepping and advection schemes

Time-stepping is currently Adams-Bashforth. C-D scheme for Coriolis terms is still required to stabilize momentum terms (depends on resolution; [*Adcroft et al.* 1999]), but won't work with EXCH2. Need to explore alternative (stability of staggered time-stepping).

Advection scheme will be 3rd order Direct Space-Time (DST3; `advScheme=30`). Non-flux-limited variant has been successfully tested and used with adjoint (P.H., M.M.). Need to explore whether flux-limited scheme (DST3fl; advscheme=33) can be used in a modified, adjointable form ([*Adcroft et al.* 2002]).

1.3 Parameterization schemes

1.3.1 Variable horizontal viscosity

Variable horizontal viscosity a la Smagorinsky or Leith (B.F.-K.); currently not adjointable; need to explore whether simplified version of existing scheme(s), or simpler formulation such as *Bryan and Lewis* [1979] can yield stable adjoint (P.H.).

1.3.2 Diapycnal mixing, K-Profile Parameterization (KPP)

Proper working of KPP in p-coordinates is unclear.

As currently, on in forward, off in adjoint. But might take a fresh look at adjointability issues.

1.3.3 Gent-McWilliams / Redi (GM/Redi) isopycnal diffusion

Can be discussed in the context of controlling GM coefficient or controlling eddy stress.

1.3.4 Seaice

Differentiability; focus on coupling/growth term (D.M., P.H., I.F.).

It seems we'll have to switch to a different seaice model, very likely CICE, which is well maintained; some AD experience exists for this one using ADIFOR's forward mode (Kim, Hunke, ...). T.B.D.: proper implementation of dynamic solver on C-grid to work with EXCH2; rather deferred to CISE code.

Alternatively, explore code of *Winton* [2000] (package `thsice`).

1.3.5 Topographic mixing, overflows, bottom boundary layer

Parameterization of topographic mixing is discussed in e.g. *Jayne and St. Laurent* [2001], *Simmons et al.* [2004].

An overflow parameterization has been developed by R. Käse, IfM Hamburg (e.g. [*Kösters et al.* 2004]?).

A bottom boundary layer scheme ... (C.Edwards?)

1.3.6 Gravity

Effects of gravitational self-attraction and seafloor loading are described e.g. in *Condi and Wunsch* [2004]. Such corrections are usually included in ocean tide models so presumably the numerics are known. In the barotropic model context, see e.g. *Hendershott* [1972], *Ray* [1998], *Stepanov and Hughes* [2004].

1.4 Forcing

1.4.1 Boundary layer scheme (bulk formulae)

Controlling atmospheric state via bulk formulae seems to work fine (see ongoing 1x1 degree bulk/seaice optimization at NASA/ARC).

CNH suggest extending existing bulk formulae according to *Kara et al.* [2006].

1.4.2 Improved runoff

Are there improved time-evolving runoff estimates for Greenland and Antarctica?

1.4.3 Atmospheric loading?

Dynamical response of the ocean to atmospheric loading, and its deviation from an inverted barometer (IB) are reviewed in *Wunsch and Stammer* [1997] (see also *Ponte* [1999]) (R.P.) No implementation currently exists in pressure coordinates.

1.5 Other aspects

1.5.1 Carrying passive tracers

M.F., S.D.

1.5.2 Inclusion of biogeochemistry?

M.F., S.D.

1.5.3 Parallelizing line search

2 Adjoint model, control, cost

2.1 Control vector

2.1.1 “Standard” variables

“Standard” variables by now would refer to initial temperature, salinity, time-dependent fields for atmospheric state, i.e. atmospheric temperature, specific humidity, wind speed vector, precipitation, shortwave flux, atmospheric loading.

2.1.2 Beyond the standard

- isopycnal and diapycnal mixing coefficients (see e.g. *Bugnion* [2001],*Stammer* [2005]) G.F.
- eddy stress (see e.g. *Ferreira et al.* [2005]) D.F.
- bottom topography or lateral boundary conditions [*Losch and Heimbach* 2005] M.L.
- ...

2.2 Cost function

There are issues and specific data sets/cost terms that need revisiting.

- Spatial averaging:
  May become more important for comparison of low-resolution observational sets with high-resolution model results. C.E., P.H.
- Treatment of in-situ data:
  Change data format to enable work on daily profile-by-profile. This will considerably reduce these data sets and better collocation in space and time. Affected data sets are ARGO, CTD, XBT. G.F.
- Surface drifter data:
  need to obtain new, ubdated, higher-resolution drifter data. Latest references I have are those of *Niiler et al.* [2003], *Pazan and Niiler* [2004] (also: N. Maximenko, private communication).
- TOGA/TAO buoy array:
- Tomography:
  B.Cornuelle
- Tide gauge data:
  S.V.
- geoid error covariance:
  finish code C.E., P.H.

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