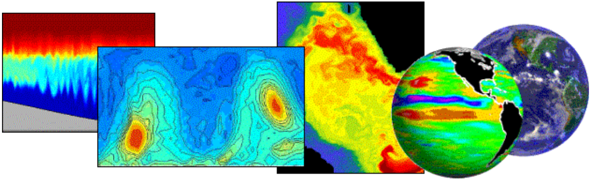
ECCO Projects Meeting

MITgcm formulation improvement



Pasadena, CA Jan 25-26, 2023

MITgcm

1. Formulation improvement
   - TEOS-10
   - Anelastic and non-Boussinesq
   - Latent heat
   - Quasi-Hydrostatic
2. Fluid exchange and Energy Reference Level
   - heat budget
   - Run-Off scheme

MITgcm formulation

1. TEOS-10
   - more accurate
   - incorporate variation of C_p into "Conservative Temperature" (CT).
     Since we have never considered variation of C_p, using TEOS-10 and CT is the only way to be consistent with constant C_p.
     Same regarding absolute salinity (since salinity has always been considered as total amount of salt and not directly related to conductivity).
   - Issue: In Boussinesq model, the Heat budget is computed using the constant (Boussinesq) density ρ_0. And variation of density are larger than variation of C_p, and in opposite direction.
     $\rightarrow$ the product $\rho \times C_p$ varies less than ρ alone (true for pressure effect and salinity effect). So, in Boussinesq model, using TEOS-10 is not making the heat-content more consistent.

MITgcm formulation

2. EOS p-dependence in Boussinesq formulation
   - using directly $\rho(T, S, p)$ to integrate hydrostatic pressure is not recommended (in MITgcm, *selectP_in EOS_Zc* $= 2$ or *eosType='JMD95P'*)
   - the case of external gravity wave in homogeneous ocean: compressibility leads to artificial mass source and sink that amplified surface pressure anomaly at depth leading to an increase of the pressure gradient term at depth ($\rightarrow$ no longer barotropic).
   - should use instead: $\rho(T, S, p(z))$
   - current default: $p(z) = -\rho_0 \, g \, z$ is a crude approximation
   - better to use: $p(z) = \int g\rho(T_{ref}, S_{ref}, p(z))dz$ with *selectP_in EOS_Zc* $= 1$

MITgcm formulation

3. Anelastic formulation
   - account for the large part (all deep-water) of density variations $\rightarrow$ more precise heat-budget with TEOS-10
   - but still ignore significant density changes in coastal water (e.g., near river mouth)
4. Non-Boussinesq formulation using pressure or mass vertical-coordinate
   - would make heat-budget fully consistent when using TEOS-10
   - tried a long time-ago (Losch etal, 2004) but without r^* nor GM
   - recently made to work with few important pkgs (gmredi, ggl90) (use "reasonable" assumption for conversion factor in parameterization)
   - issue with direct comparison of diagnostic η field with SSH observation and with slope term (i.e., $\nabla\eta$) in seaice dynamics

MITgcm formulation

5. Latent heat
   should account for temperature variation of latent-heat:
   - linear relation would be consistent with constant C_p for seawater and water vapor $L_v(T) = L_v^o + (C_p^v - C_p^{sw}) * T$
   - constant L_v assumes seawater and water vapor have identical C_p (however C_p^v is less than half of C_p^{sw})
6. Quasi-Hydrostatic formulation to account for $f' = 2\Omega \cos(\phi)$
   - negligible effects reported in Marshall *etal* 97a paper. However, this was before CVS repository; and a bug was found in early CVS repos versions.
   - llc90 has better resolution near equator and near the surface
   - QH AB time-stepping is now fixed (PR #433, was missing for staggered time-step)

Using ERL in MITgcm

Fluid exchange and Energy Reference Level (ERL):
How to account for temperature (heat) forcing and any tracer forcing anytime fluid is added or remove at the surface — primarily run-off, precipitation and evaporation but also freezing and melting — or at depth using *addMass* field.

1. From experience gained with coupled model, it's easier to define an ERL (e.g., liquid water at 0^oC) and any departure from the ERL is accounted for in the net heat-flux (sort of "advective" heat flux or a modified latent heat flux).
2. In MITgcm, setting *temp_EvPrRn* (e.g., $= 0^oC$) defined the ERL.
   Note: this is the default for any other tracer but not for Temp. with "unset" default, i.e., assuming exchange at the local temperature.
3. The ERL is needed to do a heat-budget when fluid is exchanged (with useRealFreshWaterFlux and Non-Lin Free-Surf); but using it in the model formulation greatly simplify the heat budget estimation: everything is in the net heat flux.

Using ERL in MITgcm

4. This is a small component of the heat-flux (few W/m^2, more Evap over warmer SST and precip over colder SST) but comparable to GHG perturbation and larger than, in the atmosphere, the conversion term PE $\rightarrow$ KE and heating due to dissipation.
5. Useful also with other components. Otherwise, to close the budget, needs to track the local temperature precisely when fluid is added/removed (many additional terms added in *seaice_growth.F* just for this reason).
6. Easier for run-off routing: if 2 rivers merge or flow in same grid-cell, just add the rivers flow, the advective heat-flux and any tracer flux all the same way (no need to compute a "flow weighted" temp).
7. Implementation detail: with (default) synchronous time-stepping, the fluid addition/removal is delayed by 1 time-step vs heat and salt forcing, for consistency between model thickness factor (hFac) update and divergence of advective velocity field. In MITgcm, we choose to preserve the exact tracer conservation and tolerate a one time-step mis-match in fresh-water "advective" heat flux addition when using synchronous time-stepping.

Summary

Model formulation improvements

1. TEOS-10 : caution in Boussinesq model
2. EOS p-dependence in Boussinesq formulation
3. Anelastic formulation: account for most Boussinesq inaccuracy
4. Non-Boussinesq formulation using pressure or mass vertical-coordinate
5. Latent heat: fct of SST
6. Quasi-Hydrostatic : minor improvement ?
7. Use Energy Reference Level (ERL): simpler