New Features of HYCOM

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**New Features of HYCOM**

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Mass Conservation - I

• Mass conservation is important for climate studies
  ○ It is a powerful debugging tool even for shorter time scales
• Many ocean models are Bousinessq
  ○ Density differences are neglected except in terms multiplied by $g$
  ○ Implies conservation of volume, not mass
    ◦ Still want, and can get, tracer conservation
• HYCOM is not Bousinessq, so it should conserve mass
  ○ Except that it assumes the non-steric SSH is a small fraction of the total depth
    ◦ Includes steric effects, such as mean SSH rise due to thermal expansion, but does not exactly conserve either mass or volume
    ◦ Not satisfactory for coastal domains
  ○ Replaces $dp$ with $dp'$ nearly everywhere
Mass Conservation - II

• HYCOM’s reputation for non-conservation is partially due to using dp’ in mean calculations
  ◦ Much better conservation properties when correctly using dp in region-wide means
  ◦ HYCOM source code uses dp’ for means, i.e. this is a long standing “bug”

• New option, btrmas=1, for exact mass conservation
  ◦ From Remy Baraille at SHOM
  ◦ Removes the dp’ “equals” dp approximation
  ◦ Note that dp’ is still the prognostic variable
    ◦ Still dp’ in restart and archive files
  ◦ Currently, btrmas=1 is less stable than btrmas=0
    ◦ Still working on making it more stable

• As a test, 0.72° Global HYCOM was spun-up for 5 years with typical atmospheric forcing and then all forcing was removed
  ◦ During “spin down” there should be no change to the total heat and salt, i.e. to the mean T and S
Spin Down Test of Conservation - I

GLBT0.72, spin-down, Potential Temperature

GLBT0.72, spin-down, Salinity
Spin Down Test of Conservation - II

GLBT0.72, spin-down, Potential Temperature

GLBT0.72, spin-down, Salinity
Spin Down Test of Conservation - III

GLBT0.72, spin-down, Potential Temperature

GLBT0.72, spin-down, Salinity
Robert-Asselin Time Filter

• One potential source of non-conservation is the RA filter used to stabilize the leapfrog time step scheme
  ◦ Williams (2009) proposed a modified filter that is more conservative and more accurate
    ◦ However, it is not applicable to models with time varying layers than must filter \( h \) and \( hC \) consistently while maintaining non-negative fields
• Leclair and Madec (2009) showed that RA is:
  ◦ Conservative without surface forcing
    ◦ As demonstrated numerically by spin-down case
  ◦ Can be made conservative if surface forcing terms are calculated at half time steps
    ◦ Implies no time splitting from forcing
    ◦ Explicitly remove forcing from RA filter
• HYCOM is not currently conservative with surface forcing
  ◦ Started testing Leclair’s approach
Bit-for-Bit Multi-CPU Reproducability

- Repeating a single processor run:
  - Produces identical results
- Repeating a multi-processor run:
  - Produces different results
    - Using either OpenMP or MPI
    - e.g. fastest global sum is non-reproducible
    - Unless programmer explicitly avoids non-reproducible operations
    - May need to avoid some compiler options
- Two levels of reproducability
  - On the same number of processors
    - Some scalable libraries provide this
  - On any number of processors
    - Only “safe” option for code maintenance
      - Always requires careful programming
      - Can be slower
    - Should be required for operational ocean prediction models
      - Is implemented by HYCOM
Are Two HYCOM Runs Identical? - I

- The only way to confirm bit-for-bit identity is to compare binary fields
- Could compare binary archive and/or restart files
  - But these don’t tell you where any differences came from
- P-MICOM used “named pipes” to compare arrays between MASTER and SLAVE model runs while they were in progress
  - A named pipe is a special Unix file providing a FIFO capability via a shared memory buffer
  - Can read and write to it just like a normal file
- SLAVE writes an array to the pipe, MASTER reads the array and compares it to its own version
  - Usually MASTER runs on one processor and SLAVE on multiple processors
  - Only limitation is that MASTER and SLAVE must be running under the same Unix image
    - May be difficult to arrange for MPI on a cluster
Are Two HYCOM Runs Identical? - II

- HYCOM includes a named pipe based comparitor
  - Similar to P-MICOM, but easier to use
  - Calls to compare or compareall in source code:
    - Can trigger a comparison of arrays at run time, between two HYCOMs via the named pipe
    - Can invoke other run-time debugging options
- A new option is to compile with the OCEANS2 macro
  - Runs two instances of HYCOM in the same executable
    - Each on a different number of MPI tasks
  - Calls to compare or compareall in source code:
    - Will trigger a comparison of arrays at run time via MPI send/recv
  - Easier to use than named pipes and only requires MPI
    - Works for OpenMP with MPI, but same number of threads used by both HYCOMs
    - Does not currently work in coupled models
Tides in HYCOM - I

- Body forcing for 8 largest components
  - With (optional) nodal corrections
  - Implemented in HYCOM by NCEP
- Boundary forcing for Flather or Browning-Kreiss ports
  - Implemented by various groups in local versions of HYCOM
  - Now in standard version
    - 8 largest components specified as complex amplitudes at each boundary point using unmodified extract_HC program from OSU’s OTPSnc or OTPS2 package
    - Allows for curvilinear grid
    - With (optional) nodal corrections
  - Tidal forcing under floating ice shelves requires 1147 ports for Global 1/12° domain
    - Port implementation updated to allocate memory at run time and to make many fewer MPI calls for better MPI performance
Tides in HYCOM - II

- Linear tidal drag based on bottom roughness
  - Applied to near-bottom tidal velocity or to depth averaged tidal velocity
    - Tensor drag for depth averaged case only
  - Use a lagged 49-hour filter as the non-tidal velocity
    - Convolution of a 21 hour Savitzky-Golay smoother and a 24.842 hour boxcar filter
    - Passes 0.02% of semi-diurnal and 3.2% of diurnal (1.2% of total) tides
      - Replaces a lagged 25-hour average
      - Better band pass and better diurnal phase
  - Limit drag’s e-folding time for stability

- Self Attraction and Loading
  - “Scalar” approximation:
    - SAL treated as a fraction of non-steric SSH
      - Constant, or spacially varying, fraction
  - Input SAL complex amplitude fields from a file
    - With or without a “scalar” SAL
    - Iterate SAL to convergence
Spacially Varying Self Attraction and Loading

TPXO8 atlas M2 Amplitude: SAL/TIDE

GLB10.08
d1 0.0025
0 to 0.278
Self Attraction and Loading Comparison

![Graph showing Global Percentile: RMS M2 SSH error vs TPXO](image)

- Barotropic Global 1/12° M2-only simulations
  - Twin cases that differ only in Self Attraction and Loading
- The percentage of the globe (Y) where model - TPXO8atlas SSH RMS is less than X m
  - Note the long tail with the median (50%), for the with-SAL cases, between 3 cm and 5 cm
  - Median is typically a more robust statistic than mean or global RMS
Tides in HYCOM - III

- Several tide-specific diagnostic programs:
  - hycom_tidal_foreman
    - Foreman tidal analysis on HYCOM .a file
    - HYCOM's 4096-word blocking allows strip-mined transpose from \((x,y,t)\) to \((t,x,y)\)
  - hycom_calcSAL
    - Calculate SAL on uniform cylindrical global grid
  - hycom_tidal_rms
    - RMS difference between two sets of tides
  - hycom_tidal_ap2ri and hycom_tidal_ri2ap
    - Amp,Phase to/from Real,Imaginary tidal components

- Tidal analysis enabling output:
  - HYCOM SSH has mass and steric anomalies
  - Steric SSH can optionally be output
    - Steric anomaly plus long term SSH mean
    - Explicitly “filters” external tides
    - Get internal tides from Foreman tidal analysis
  - Non-steric SSH from difference
    - Largely external tides
HYCOM and Sea Ice

- Two-way coupling to LANL’s CICE sea ice model, regional and global domains
  - HYCOM exports:
    - SST, SSS, SSH
    - Surface Currents
    - Available Freeze/Melt Heat Flux
  - CICE exports:
    - Ice Concentration
    - Ice-Ocean Stress
    - Actual Freeze/Melt Heat/Salt/Mass Flux
    - Solar Radiation at Ice Base
  - Coupling via the Earth System Modeling Framework
    - ESMF version 4.0.0rp2
    - Plan to migrate to NUOPC Layer on top of ESMF version 6.X.0r
- Coupled to CICE version 4.0
  - Version 4.1 was released in May, 2010
  - Plan to skip 4.1 and implement the “next release”, due later this year
Coming Soon

• Wave forcing
  ◦ Stokes Drift Current (SDC)
  ◦ Wave-to-Ocean Momentum Flux (WOMF)
  ◦ Bottom Orbital Wave Current (OWC)

• Wetting and Drying
  ◦ Made possible by mass conservation option
  ◦ Code from Remy Baraille at SHOM is already in HYCOM but needs more testing

• Fully region-independent
  ◦ Compile once, run on any region and any number of processors
    ◦ Run-time memory allocation, less memory used
    ◦ Reduces performance
      · Compilers make fewer optimizations
      · Prototype is 5% slower
  ◦ Needed for full ESMF compliance
    ◦ Single executable, multiple components each running on separate cpus
    ◦ HYCOM arrays currently on all cpus