New Features of HYCOM

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HYCOM 2.2 (I)

- Maintain all features of HYCOM 2.1
  - Orthogonal curvilinear grids
  - Can emulate Z or Sigma or Sigma-Z models
    - It is “Arbitrary Lagrangian-Eulerian”, see: Adcroft and Hallberg, O. Modelling 11 224-233.
  - Explicit support for 1-D and 2-D domains
  - KPP or Kraus-Turner or Mellor-Yamada 2.5 or Price-Weller-Pinkel
  - Rivers as bogused surface precipitation
  - Multiple tracers
  - Off-line one-way nesting
  - Scalability via OpenMP or MPI or both
    - Bit-for-bit multi-cpu reproducibility

HYCOM 2.2 (IIa)

- **Alternative LeapFrog barotropic time splitting**
  - Provided by SHOM
  - Twice as expensive as standard scheme
    - Still a small fraction of total run time
  - Significantly more stable
  - May allow 2x longer baroclinic time step
- Alternative scalar advection techniques
  - Provided by Mohamed Iskandarani
  - Donor Cell, FCT (2nd and 4th order), MPDATA
  - FCT2 replaces MPDATA as standard scheme
- Vertical coordinate changes
  - Vertical remapping uses PLM for fixed coordinate layers
  - Thin deep iso-pycnal layers
  - Stability from locally referenced potential density
  - Spatially varying layer target densities
    - Different isopycnal layers in semi-enclosed seas

HYCOM 2.2 (IIb)

- **Equation of state that is quadratic in salinity**
  - HYCOM must "invert" the equation of state
    - tofsig(r,s) and sofsig(r,t)
  - Traditional version is cubic in T and linear in S
    - Finding the root of a cubic is expensive, but exact
    - Linear in S is not accurate at low salinity
  - Optional version is cubic in T and quadratic in S
    - Coefficients provided by Shan Sun
    - More accurate at low salinity
      - Rivers, Black Sea, Caspian Sea
    - Not much more expensive
- **Pade equation of state**
  - Optional Pade version: P_{22}/Q_{11}
    - P_{22} is quadratic in T and S
    - Q_{11} is linear in T and S
  - Developed at NCEP
    - Only Sigma0 at present
  - More accurate at low salinity

HYCOM 2.2 (IIc)

- Special halo exchange for tripole global grid
  - Arctic dipole patch on standard Mercator globe
  - Logically rectangular domain
    - Two halves of top edge “fold” together
    - V-velocity changes sign across the fold
- Improved thermobaricity
  - No single reference state is appropriate for the global ocean
    - Hallberg, Ocean Modelling, 8, 279-300
  - Use a linear combination of pressure gradients from two out of three reference states
    - Atlantic (3°C, 35.0 psu)
    - Arctic/Antarctic (0°C, 34.5 psu)
    - Mediterranean (13°C, 38.5 psu)
  - Most locations use just one reference state
    - Linear combinations allow smooth transition between states
      - Do this in shallow water if possible
  - **In deep water, constrain the T&S used for thermobaricity to be close to the reference state**

HYCOM 2.2 (IIIa)

- Mixed layer changes
  - GISS mixed layer model
    - Provided by Armando Howard
  - KPP bottom boundary layer
    - Provided by George Halliwell
  - KPP tuning
- Atmospheric forcing changes
  - Option to input ustar fields
    - Best option for monthly forcing
    - Otherwise calculated from wind stress or speed
  - Can relax to observed SST fields
  - Improved COARE 3.0 bulk exchange coefficients
  - Black-body correction to longwave flux
  - Climatological heat flux offset, $\overline{Q}_c$

    $$Q = (Q_{sw} - Q_{lw}) + (Q_l + Q_s) + \overline{Q}_c$$
    - $\overline{Q}_c$ is constant in time
      - Typically based on the model's climatological SST error, times (say) -45 $Wm^{-2}/^{\circ}C$

HYCOM 2.2 (IIIb)

- Improved support for rivers
  - Still bogused surface precipitation
  - High frequency inter-annual river flow allowed
    - Add it to atmospheric precip, off-line
    - Instead of monthly climatology,
      or in-addition to it (flow anomalies)
  - Better control of low salinity profiles
  - Option for mass (vs salinity) flux
  - Equation of state that is quadratic in salinity
- **Tidal forcing**
  - Provided by NCEP
  - Body forcing and open boundary forcing
  - Boundary forcing currently for “Flather” ports
    - Extend it to Browning-Kreiss ports and nesting
  - Tidal drag based on bottom roughness
    - Presently applied to total near-bottom velocity
      - Can we apply this to tidal signal only?

HYCOM 2.2 (IIIc)

- **I/O optimizations**
  - I/O can be a bottleneck when running on many processors
    - MPI-2 I/O option
    - Faster code for “endian” conversion
  - Remove density from restart and archive files
    - Less I/O, smaller files
    - Must track which equation of state is used
- **New diagnostics within HYCOM**
  - Time-averaged fields (in archive files)
    - Identical to off-line mean archives
    - No on-line capability to capture variability
    - Instantaneous archives still available
  - Synthetic instrumentation
    - Provided by George Halliwell
    - 3-D particle tracking
    - surface and constant depth drifters
    - isopycnic drifters
    - fixed instruments and moorings

HYCOM 2.2 (IIId)

- Finer control over energy loan ice model
  - Melting point can be linear in salinity
  - Set ice minimum and maximum thickness
  - Set ice vertical temperature gradient
    - Or get ice surface temperature from T_a
  - Made compatible with coupled sea-ice approach
- **Two-way coupling to LANL's CICE sea ice model**
  - 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

HYCOM AND ESMF

- Earth System Modeling Framework
  http://www.esmf.ucar.edu/
  - Superstructure couples components
    - Air/Ocean/Ice/Land
    - Asynchronous I/O component
      - Run “concurrent” with model components
  - Infrastructure provides data structures and utilities for building scalable models
- **Added a superstructure “cap” to HYCOM**
  - Simplifies coupled systems
    - HYCOM coupled to LANL CICE sea-ice
  - Future uses
    - Use ESMF for (user-level asynchronous) I/O
    - Convert atmospheric field processing and the energy-loan ice model into ESMF components
    - Inter-operate with other ESMF compliant ocean models (e.g. Poseidon, MITgcm, MOM4)
- This initial ESMF support is optional
  - TYPE=esmf instead of TYPE=mpi
- ESMF may eventually be required to run HYCOM

HYCOM AND CCSM

- Community Climate System Model
  http://www.ccsm.ucar.edu/
  - Fully-coupled, global climate model
  - Sea-Ice: CICE
  - Ocean: POP
- **HYCOM can be used in place of POP in CCSM3**
  - Only tested at NCAR on an IBM p575+ (blueice), for the gx1v3 domain with ocean as the only active component
- Uses the standard HYCOM source code
- Subdirectory CCSM3 used to hold and build the CCSM3 version
  - Some source code files are specific to CCSM3
  - HYCOM ".f" files are renamed ".F" to simplify CCMS3 integration
  - Macro USE_CCSM3 for CCSM3-specific code

HYCOM 2.2 (IV)

- Climatological nesting now allowed
  - Start from monthly mean outer model archive files
  - Allows nested runs longer than the outer run
    - But with less accurate boundary state
  - Probably only suitable for regional nests
- Nesting no longer requires co-located grids
  - General archive to archive horizontal interpolation (curvilinear)
- Hybrid to fixed vertical grid remapper
  - Allows fixed-coordinate nests inside hybrid coordinate outer domains
    - HYCOM to (fixed-grid) HYCOM
    - HYCOM to NCOM

HYCOM 2.2 (V)

- Enhanced hycomproc and fieldproc
  - NCAR-graphics based
  - Many more color palette options
    - Can read in an arbitrary palette
  - Mark locations, and draw tracks, on plot
  - Plot diffusion coefficients and tracers (hycomproc)
  - Overlay vector and line-contours (fieldproc)
- Added fieldcell
  - Like fieldproc, but for cell-array (vs contouring)
    - Mark locations and draw tracks
    - Overlay line-contours
  - Uses NCAR's map projections
  - Typically much faster than fieldproc, but can leave unfilled cells
  - Option to increase resolution of input (bi-linear interpolation)

HYCOM 2.2 (VI)

- Diagnostic fields to netCDF and other file formats
  - Archive fields in layer space
    - On p-grid (interpolated velocity)
  - 3-D archive fields interpolated to z-space
    - On p-grid, or
    - Sampled at stations or along arbitrary tracks
  - 3-D archive fields sampled on iso-therms
  - Meridional stream-function from (mean) 3-D archive
    - In logical array space (rectilinear grids)
    - Binned to latitude bands (curvilinear grids)
  - Atmospheric forcing input fields
    - Time axis depends on ".b" file format
    - Any ".a" file with the right ".b" file structure can be converted to netCDF
  - Fields binned into lon-lat cells

WETTING AND DRYING

- Current free surface formulation
  - Assumes the free surface is a small fraction of the total depth
    - Includes steric effects, but does not exactly conserve either mass or volume
    - Not satisfactory for coastal domains
  - Replaces dp with dp’ nearly everywhere
    - Simplifies split-explicit time step
- Mass conserving formulation
  - Remove the dp’ “equals” dp approximation
  - Could still archive dp’ (for compatibility)
  - Allows wetting and drying
    - Almost for “free”, given HYCOM’s existing numerics
  - Already implemented in SHOM variant of HYCOM
  - Will be in HYCOM 2.3
- Mass conservation also allows:
  - E-P and rivers as a mass flux
    - Already approximately available via ”epmass” option

OTHER CANDIDATE FEATURES FOR HYCOM 2.3

- Fully region-independent
  - Compile once, run on any region and any number of processors
    - Run-time memory allocation
    - Might reduce performance (fewer compiler optimizations available)
  - Needed for full ESMF compliance
- Enhanced support for ESMF
- More hybgen options
  - Add PQM remaping
  - Use PLM or PQM for “isopycnal” layers
- Diurnal heat flux cycle
  - Already in CCSM3 version
- Wind drag coefficient based on model SST