New Features of HYCOM

Alan J. Wallcraft

Naval Research Laboratory

2015 Layered Ocean Model Workshop

June 3, 2015

DYNAMIC MEMORY ALLOCATION

- HYCOM had all arrays in common blocks
  - Re-compile for every region, every number of layers, and for a selected range of processors
    - Static memory allocation, typically more memory than necessary
    - Compile-time dimensions provide more opportunities for compiler optimization
  - ESMF has a single executable, with multiple coupled components each potentially running on separate cpus
    - HYCOM arrays on all cpus
- HYCOM now fully region-independent
  - Compile once (with macro RELO), run on any region and any number of processors (still select equation of state at compile time)
    - Run-time memory allocation, less memory used but still allocates for the largest tile
    - Changes performance
      - Compilers make different optimizations
      - Arrays not over-sized (better cache behavior)
    - Retains the option to specify dimensions at compile time and use common blocks
  - For ESMF, HYCOM arrays allocated only on HYCOM cpus

SKIPPING LAND

- **HYCOM used loop indexes to skip land, margin is for the halo**

```
      do j=1-margin,jj+margin
        do l=1,isp(j)
          do i=max(1-margin,ifp(j,l)),min(ii+margin,ilp(j,l))
            ...
          enddo !i
        enddo !l
      enddo !j
```

- **This isn't optimal for GPGPUs - so HYCOM now uses a mask**

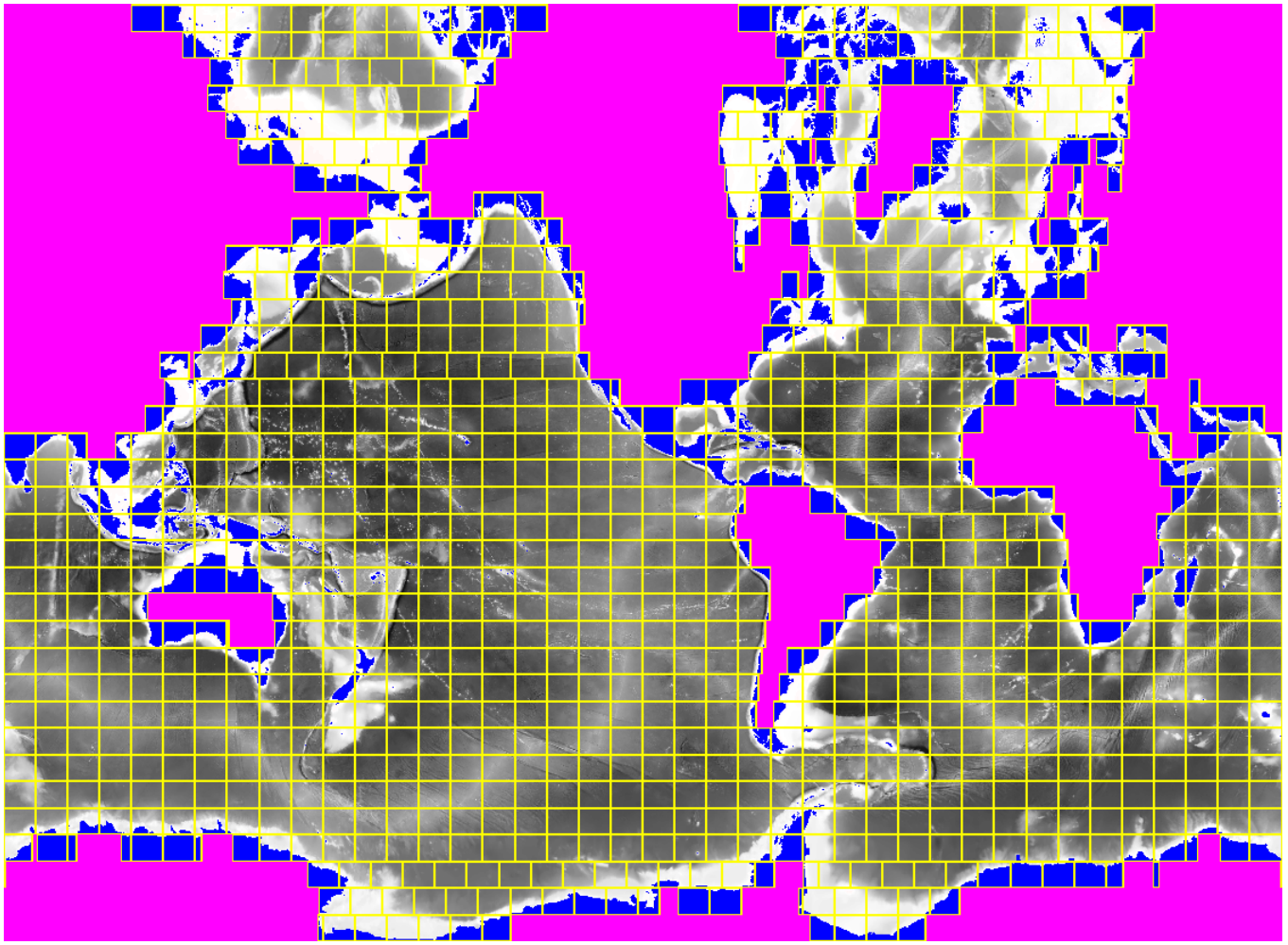
```
#define SEA_P ip(i,j).ne.0
      do j=1-margin,jj+margin
        do i=1-margin,ii+margin
          if (SEA_P) then
            ...
          endif !ip
        enddo !i
      enddo !j
```

- **These two approaches are interchangeable, and not all do-loops have been converted to masks**

DOMAIN DECOMPOSITION

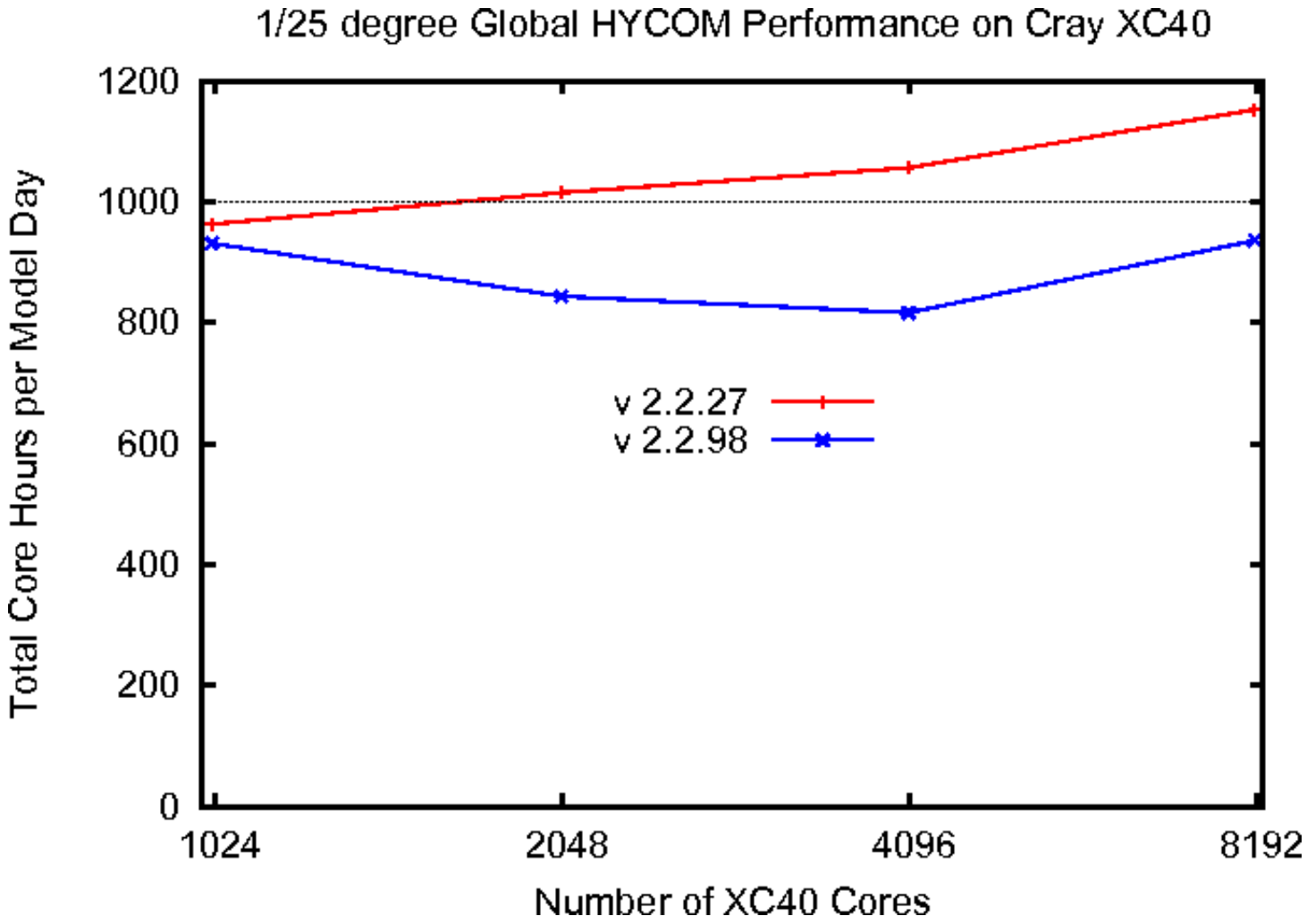
- Simplest domain decomposition is equal-sized rectangular tiles
  - Each tile has four neighbors
    - Eight neighbors including halo corners
- HYCOM decomposes each axis separately
  - Still have rectangular tiling
  - All tiles in same row are equal height
  - Two East-West neighbors
  - Potentially many North-South neighbors
- Heuristic: we skip land, so only ocean points matter
  - variable size “equal-ocean” tiles, or
  - double-up equal-sized tiles if less than half ocean
  - Does not work well with optimizing compilers on recent cpus
    - Still available, might be best in some cases
- Now best for global: optimized equal-sized rectangular tiles
  - Shift tiles to fit coastline
  - Discard all-land tiles

HYCOM 1/25° GLOBAL TILE MAP



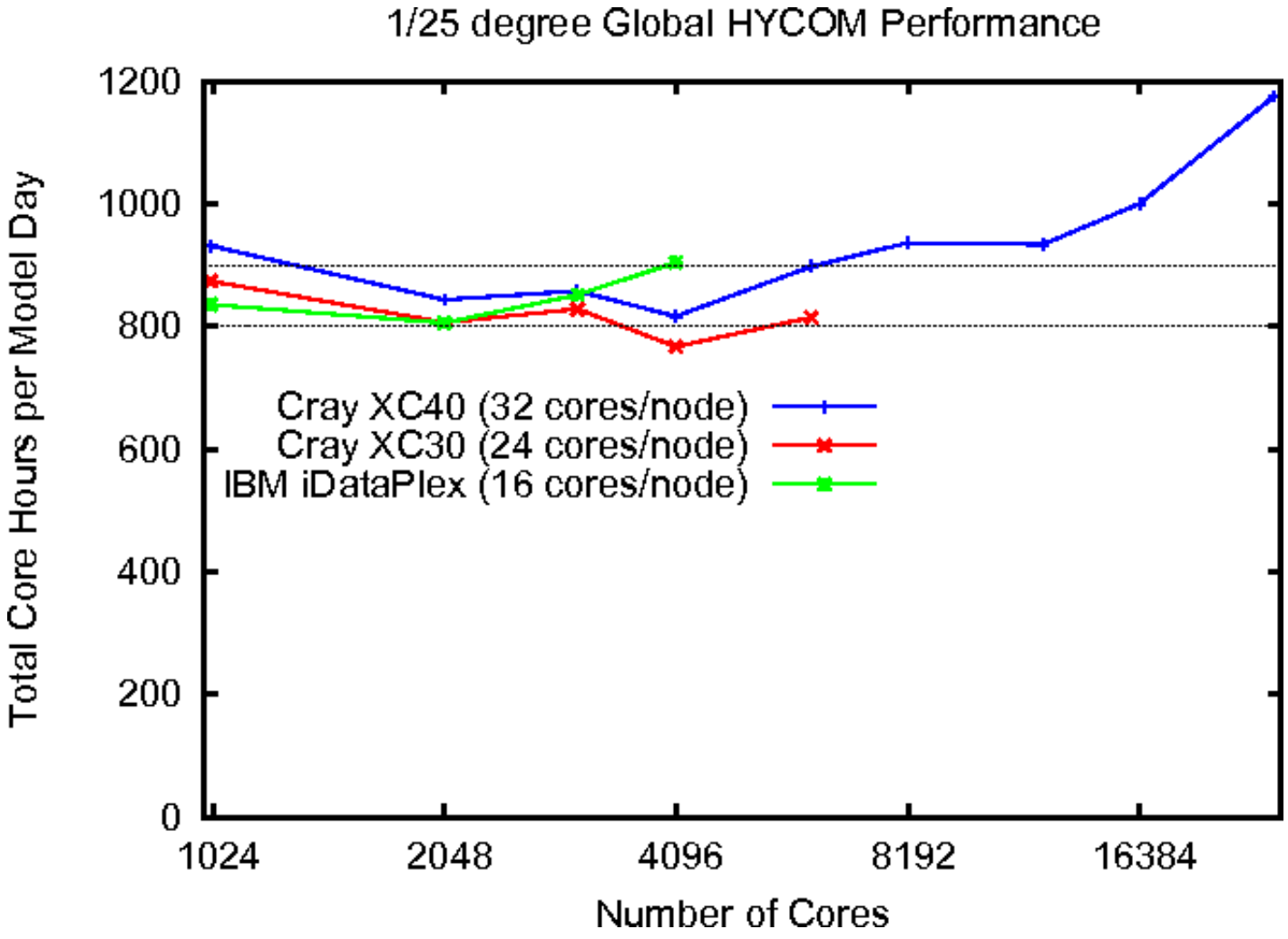
- 40 by 35 tiling, 1018 tiles used out of 1400 (73%)
- 200 by 126 tiling, 16342 tiles used out of 25200 (65%)

HYCOM PERFORMANCE: 2.2.27 VS 2.2.98



- **DoD HPCMP benchmark case, 1 model day with standard I/O**
  - **2.2.27: static memory allocation, land via do-loops**
  - **2.2.98: dynamic memory allocation, land via masks**

HYCOM SCALABILITY (2.2.98)



- **Three generations of Intel Xeon with little difference in performance**
  - **Dual socket nodes: Sandybridge, Ivybridge, Haswell**
  - **Moore's Law giving us more cores per socket**

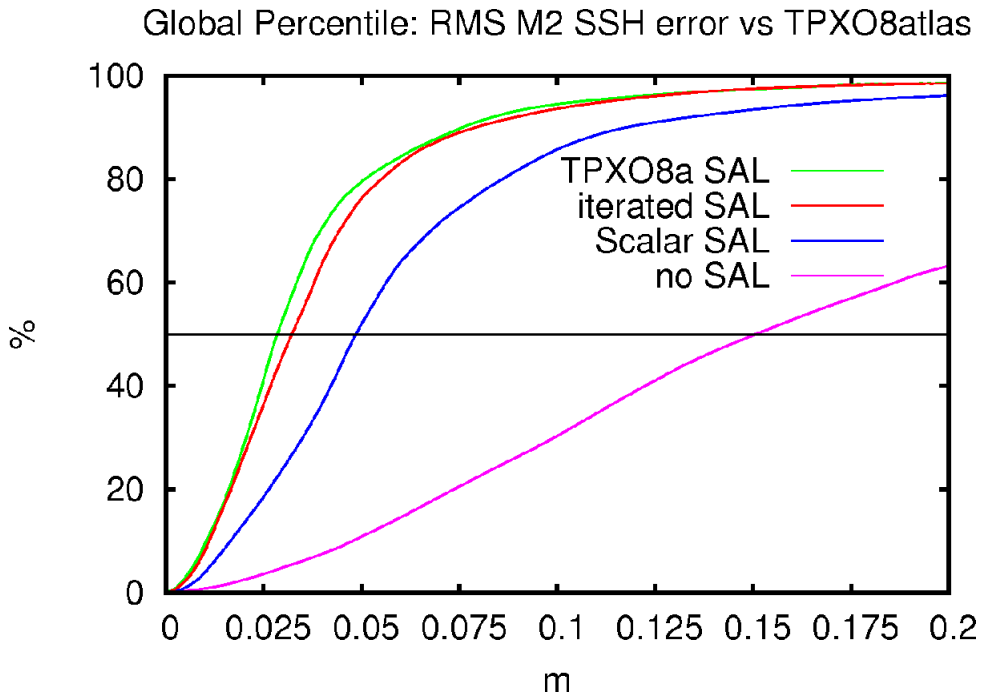
TIDES IN HYCOM - I

- **Astronomical tidal potential forcing for 8 largest components**
  - **M_2, S_2, K_1, O_1, N_2, P_1, K_2, Q_1**
  - **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 now implemented by using the under-ice water extent as the depth and applying only tidal forcing there**
- **Suite of post-processing programs for tides in HYCOM file format**
  - **Foreman tidal analysis**
  - **Script to calculate SAL (on uniform lat-lon grid)**

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 spatially varying, fraction**
  - **Input SAL complex amplitude fields from a file**
    - **With or without a "scalar" SAL**
    - **Iterate SAL to convergence, or**
    - **Use the "observed" SAL, e.g. from TPXO8atlas**
      - **Recommended approach for regional models**

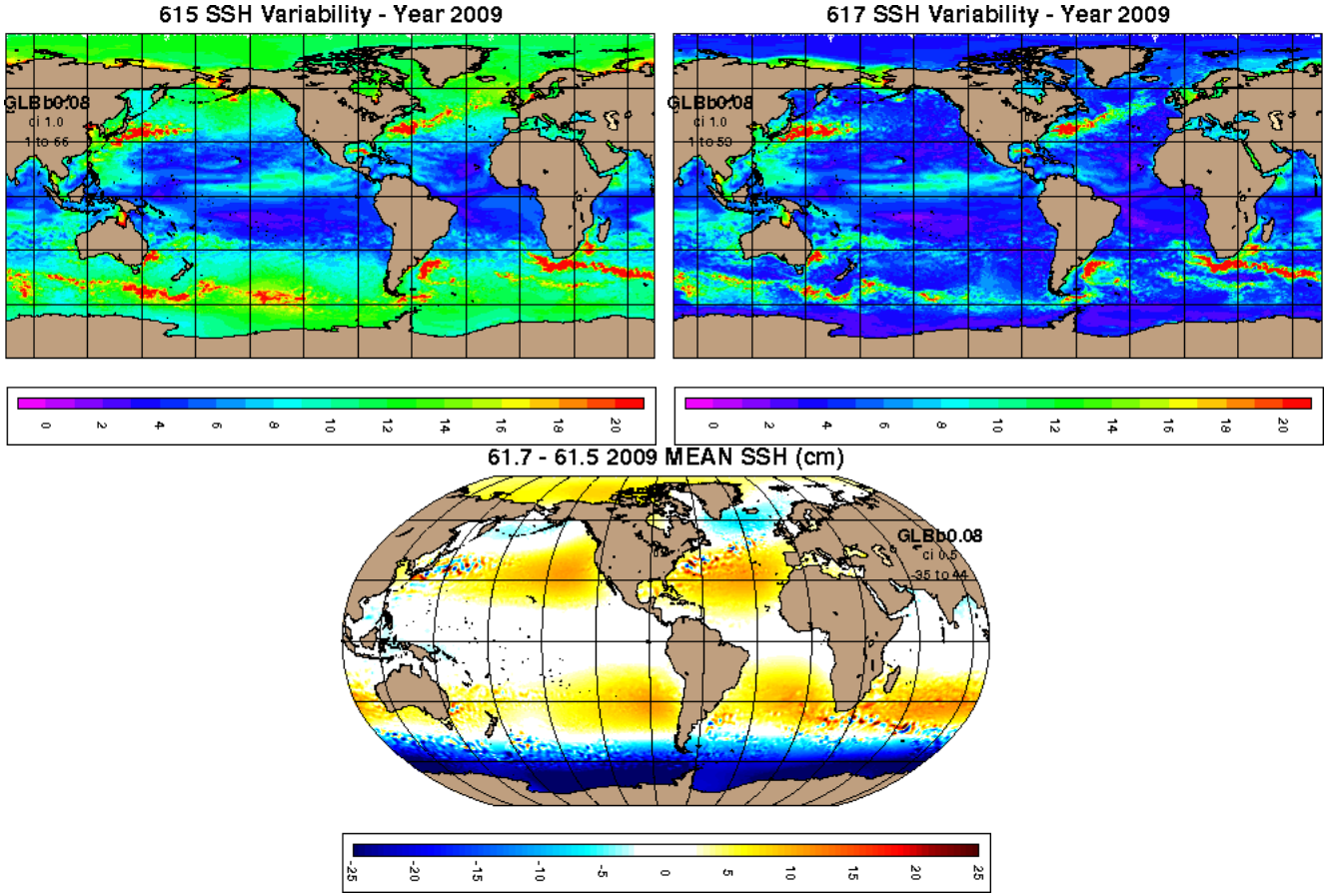
SELF ATTRACTION AND LOADING COMPARISON



- **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) M2 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**

ATMOSPHERIC PRESSURE FORCING

- HYCOM can now read in atmospheric surface pressure
  - Used for air density in accurate in-line bulk parameterizations
  - Can be used as direct surface forcing
    - S2 atmospheric “tides” effect S2 ocean tides
    - Significantly increases SSH variability
    - Some effect on the mean SSH zonal distribution



In-Line Wind Stress

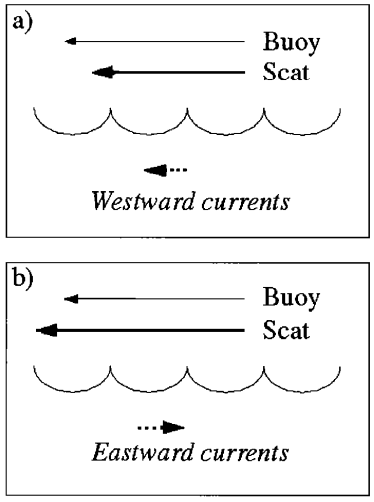
- The bulk parameterization for wind stress includes (T_{air}-SST) and 10m winds (U_{10})
- Usually calculated off-line on the NWP (e.g. NAVGEM) grid using NWP SST
- Evidence that U_{10} should be replaced with (U_{10}-U_{ocn})
- HYCOM now has option to read in 10m winds and calculate wind stress in-line
    - Higher resolution SST
    - (U_{10}-U_{ocn})
- CICE also reads in U_{10} for ice-atm stress and gets U_{ocn} from HYCOM for ice-ocn stress.

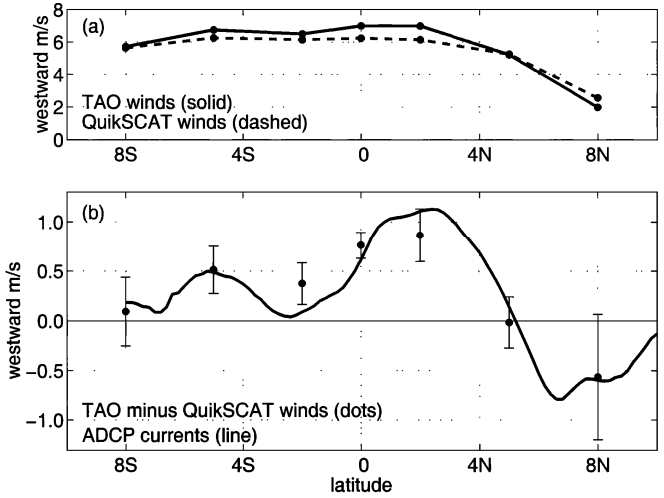
Scatterometer Wind Stress

Scatterometer responds to the wind stress (which is converted into "neutral" wind). Biases are found between scatterometer wind and observed buoy wind

Using the bias between scatterometer wind and observed wind at TAO buoys, the predicted surface current agrees well with the observed surface current

Bias changes sign with surface current direction

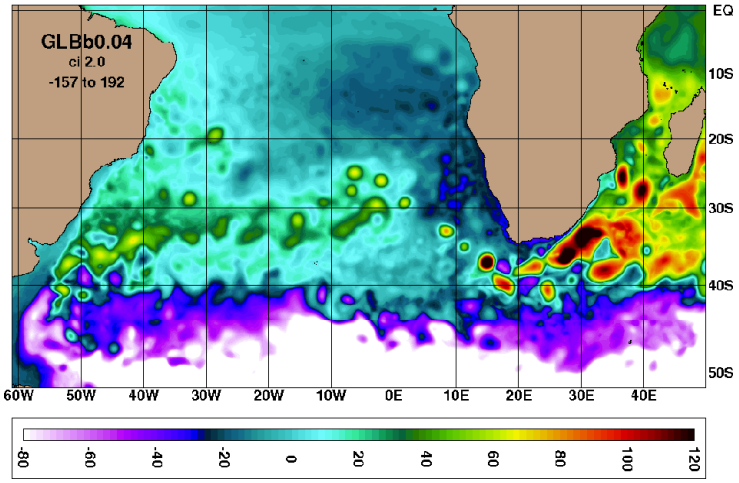




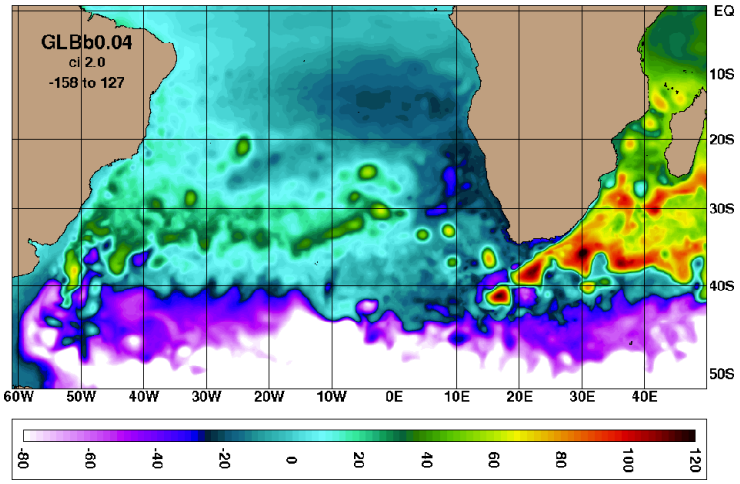
From Kelly et al. (2001) Geophys. Res. Lett.

1/25° Global HYCOM+CICE Agulhas Rings

SSH (cm) from off-line stress U_{10}



SSH (cm) from in-line stress $(U_{10}-U_{ocn})$



- No assimilation, so expect different eddy fields
- On-line has fewer rings and they follow multiple paths in the Atlantic

HYCOM AND SEA ICE

- Two-way coupling to LANL's CICE sea ice model, regional and global domains
- Co-located ocean and sea ice grids
  - HYCOM uses a C-grid
    - Velocity on cell faces
  - CICE uses a B-grid
    - Velocity at cell corners
    - Needs 2-grid point wide channels
  - All fields exchanged at cell centers
    - Tripole grid: discard HYCOM's replicated top row
- Coupling via the Earth System Modeling Framework
  - ESMF version 4.0.0rp2
    - Different domain decompositions for HYCOM and CICE
    - HYCOM has "holes" over land, but for ESMF each land point is "owned" by an active MPI task
    - Sequential execution
  - Plan to migrate to NUOPC Layer on top of ESMF version 7.X.0r
    - Sequential or concurrent execution
- Coupled to CICE version 4.0
  - Plan to update to CICE version 5.1

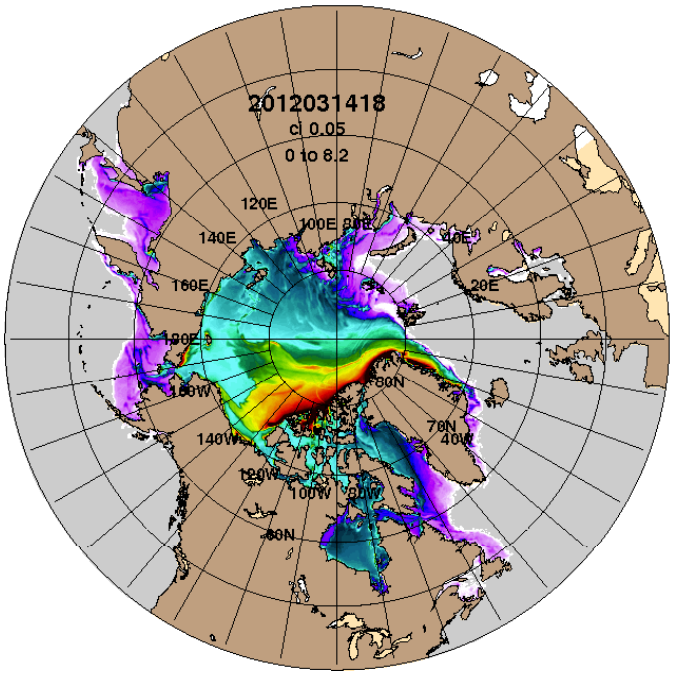
COUPLING HYCOM AND CICE

- **Uncoupled:**
  - **CICE has simple bulk ocean mixed layer**
    - **Relaxes to climatological SST and SSS**
    - **Calculates an ice-ocean stress, based on zero ocean currents**
  - **HYCOM treats sea ice as an "energy bank"**
    - **No ice advection (thermodynamic)**
    - **No ice-ocean stress (wind stress applied directly to the ocean)**
- **Traditional coupling (no data assimilation):**
  - **HYCOM's ocean and CICE's sea ice**
  - **Ice-Ocean Stress identical in HYCOM and CICE**
  - **Ice-Ocean Fluxes identical in HYCOM and CICE**
- **GOFS coupling (with 3DVAR data assimilation):**
  - **Ice-Ocean Stress identical in HYCOM and CICE**
  - **Similar, but not identical, Ice-Ocean Fluxes**
    - **CICE's SST strongly relaxed to HYCOM SST**
    - **HYCOM's sea ice concentration strongly relaxed to CICE sea ice concentration**

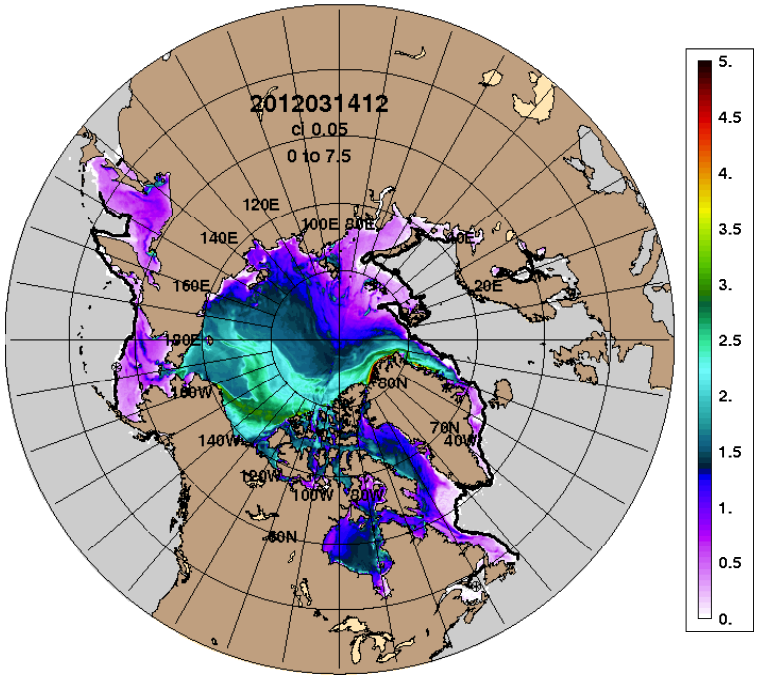
HYCOM/CICE in GOFS

Ice thickness (m) – 15 Mar 2012

ACNFS



New GOFS hindcast



Black line is the independent NIC ice edge analysis

Overall improvement in Arctic ice thicknesses

HYCOM VERSION 3.0

- All the features of 2.2.98
- Standardize on NUOPC Layer and ESMF version 7.X.0r for coupling
  - Remove ESMF version 4.0.0rp2 CICE coupling
- Distributed with capability to:
  - Run HYCOM stand-alone without ESMF
  - Run HYCOM+CICEv4 via NUOPC
  - Compatible with Navy ESPC via NUOPC
    - Example of coupling to atmosphere component and sea ice component
- Provide a mechanism to add HYCOM to other NUOPC-based coupled systems
  - NCAR CESM, NOAA ESPC, etcetera
- Make HYCOM v3 available via GitHub
  - Groups can contribute NUOPC-based couplers, etcetera
  - Everyone can track latest HYCOM updates