Overview of the GOFS, the U.S. Navy ocean prediction system

Presented by Patrick Hogan, Naval Research Laboratory

Many contributors, the HYCOM consortium, etc.

www.godae-oceanview.org
Global Ocean Forecast System (GOFS)

HYCOM, NCODA, CICE, MODAS/ISOP, NAVGEM

**GOFS 2.6** – 1/8° Navy Coastal Ocean Model (NCOM (Global configuration))
- Decommissioned 31 Aug. 2013

**GOFS 3.0** – 1/12° Hybrid Coordinate Ocean Model (HYCOM/MODAS)
- 3DVar implemented on 12 Dec. 2012 (3.01)
- GOFS 3.01 officially declared operational (20 Mar. 2013)
- NOGAPS to NAVGEM on 20 Aug. 2013 (3.02)

**GOFS 3.1** – GOFS 3.0 with 41 layers, CICE and ISOP (2QFY14)

**GOFS 3.5** – 1/25° GOFS 3.1 with tides (2QFY16)

**GOFS 4.0** – Coupled GOFS 3.5 ocean-WWIII (waves) (part of ESPC, IOC in 2018?)

1993-2012 Reanalysis, Earth System Prediction Capability, Global ocean ensembles
3DVar - analysis of 5 ocean variables: temperature, salinity, geopotential, velocity (u,v)


Adaptive Sampling Guidance

Forecast Fields Prediction Errors

First Guess

Navy Coupled Ocean Data Assimilation: operational at Navy production centers (NAVOCEANO, FNMOC)

HYCOM Assimilation: NCODA

Raw Obs

Ocean Data QC

HYCOM

QC Data Cut

Incremental Update Cycle
GOFS 3.0 Temperature Evaluation
HYCOM-32L, NCODA 3DVar, MODAS, NAVGEM, E-P)
Bias and RMS Error between unassimilated profiles and GOFS 3.0
NAVGEM 1.1 replaced NOGAPS

- NAVGEM 1.1 was declared operational on 13 Mar 2013 becoming the Navy’s new atmospheric forecast system
  - Calibrate NAVGEM winds to scatterometer winds
  - Calibrate heat flux relative to forecast SST error
- Two year-long HYCOM hindcasts and two series of 5-day forecasts were used for heat flux calibration
- NAVGEM has an aggressive transition schedule (T575 L60 in FY14, T639 L70 in FY15), calibrations will be necessary for each transition
- **NAVGEM 1.2 will be operational 6 Nov 12Z (tomorrow!)**
NAVGEM 1.1 vs. NOGAPS

Monthly 2 m air temperature difference (°C)

NAVGEM0.5a-sea minus NOGAPS0.5a-sea airmpl Jun 2012

NAVGEM0.5a-sea minus NOGAPS0.5a-sea airmpl Dec 2012

Monthly net surface shortwave radiation difference (W/m²)

NAVGEM0.5a-sea minus NOGAPS0.5a-sea shwflx Jun 2012

NAVGEM0.5a-sea minus NOGAPS0.5a-sea shwflx Dec 2012

(NAVGEM colder)

(less shortwave)
The switchover from NOGAPS to NAVGEM 1.1 atmospheric forcing in GOFS

5-day SST forecast error: Jun 2012

Wind and heat flux calibration

- NAVGEM wind speeds were scaled to scatterometer via regression analysis.

- From a year-long hindcast 5-day SST forecasts were compared to the verifying analysis to produce a monthly SST forecast error estimate.

- Each 1°C error corresponds to a 45 w/m² heat flux offset.

- Covers June 2012 – May 2013.

- Had to process NAVGEM, run HYCOM, calculate corrections in < 8 months...

smoothed heat flux offset: Jun 2012
Impact of Heat Flux Bias Correction

Not unique to NAVGEM, also done with NOGAPS, CFRS, etc.

NAVGEM-forced 5-day SST forecast error
No heat flux offset applied: Jun 2012

NAVGEM-forced 5-day SST forecast error
Monthly heat flux offset applied: Jun 2012

NAVGEM-forced 5-day SST forecast error
Monthly heat flux offset applied: Jun 2013

NOGAPS-forced 5-day SST forecast error
Annual heat flux offset applied: Jun 2013
Global Ocean Forecast System 3.1 (2QFY14)
(HYCOM-41L, NCODA 3DVar, MODAS/ISOP, NAVGEM, CICE)

• Vertical resolution increased for better representation of upper ocean processes and boundary conditions

• 2-way coupled CICE

• In-line wind stress calculation (includes ocean contribution to the interfacial stress)
GOFS 3.1: 32 Layer vs. 41 Layer

Fixed problem of excessively thick layers over some shelf regions

Northwest Australian Shelf region

Internal tidal signal over shelf represented

Better representation of warm pool/cold tongue along the equatorial Pacific
Los Alamos CICE model successfully two-way coupled with HYCOM on the global domain

Comparison of Global HYCOM and Arctic Cap Systems

GLBb0.08-18.1 Ice Thickness: 2012_001

ARCc0.08-03.5 Ice Thickness: 20120101

Ice thickness January 2012
Global HYCOM/NCODA/CICE in the southern hemisphere

Sea ice concentration (%) around Antarctica near extreme ice extents

22 July 2011 - winter

1 January 2012 - summer

Overlaid black line is the independent National Ice Center ice edge
Agulhas Eddy Penetration into South Atlantic

1/25° HYCOM Surface EKE

Agulhas eddies appear to follow a single path.

Only ~1 eddy per year escapes the Cape Basin and follows a range of paths.

Including the velocity shear across the surface improves the eddy pathway, but doesn’t reproduce the observed pathway.

Eddy-Wind Interaction

Blue: no interaction

Green: with interaction
Global Ocean Forecast System 3.5 (2QFY16)

(1/25°, HYCOM-32L, Tides, NCODA 3DVar, MODAS/ISOP, NAVGEM, CICE)

GLBb0.04-01.7: 2008 169 00 steric SSH
Internal Tidal Signature Seen in 1/25° Steric Sea Surface Height

2 model days/hour
On 4000 CPUs

GLBb0.04-01.5: 2008 168 01 steric SSH
GLBb0.04-01.7: 2008 168 01 steric SSH

No tidal forcing
With tidal forcing
How Stationary Are the $M_2$ Internal Tides in Global HYCOM?

$1/12^\circ$ 32 layer global HYCOM

Statistics computed over 18 overlapping 183-day windows

Low (high) normalized stand. dev. implies (non)stationarity

“Hot spot” regions with large internal tide amplitudes (denoted by black boxes) are found to be largely stationary

Internal tide variability in HYCOM is consistent with the altimetric-based estimates of Ray and Zaron (2011, GRL)

Shriver et al. 2013 (JGR-O, submitted)
How Stationary Are the Internal Tides in Global HYCOM?

Diurnal constituents are restricted to the latitude range where diurnal internal waves exist.

Regions where the mean amplitude is less than .5 mm are excluded.

The smallest amplitude constituents ($K_2$, $P_1$ and $Q_1$) are too small to reliably estimate the stationarity.

Shriver et al. 2013 (JGR-O, submitted)
Internal/topographic wave drag in HYCOM with tides

- A global tuning experiment to accurately model deep dissipation via testing of several internal wave drag scalar and tensor schemes in barotropic HYCOM; their strength is governed with a scale factor.

- The internal wave drag scheme needed to extract the “high-mode” energy from the barotropic tide.

- Root-mean square (RMS) errors for the various schemes are compared with altimetry derived water levels (TPXO).

<table>
<thead>
<tr>
<th>Model Study</th>
<th>Linear drag</th>
<th>Model (Layers)</th>
<th>Res [°]</th>
<th>Data source</th>
<th>RMS (&gt; 1km) [cm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jayne and St Laurent (2001)</td>
<td>JSL</td>
<td>JSL (1)</td>
<td>1/2</td>
<td>UT-CSR</td>
<td>6.7</td>
</tr>
<tr>
<td>Egbert et al (2004)</td>
<td>Bell</td>
<td>OTIS (1)</td>
<td>1/12</td>
<td>TPXO5</td>
<td>5.0</td>
</tr>
<tr>
<td>Green &amp; Nycander (2012)</td>
<td>Nycndr</td>
<td>OTIS (1)</td>
<td>1/8</td>
<td>TPXO7.2</td>
<td>7.0</td>
</tr>
<tr>
<td>Buijsman et al (2013)</td>
<td>JSL</td>
<td>HYCOM (1)</td>
<td>2/25</td>
<td>TPXO8</td>
<td>4.5</td>
</tr>
</tbody>
</table>

Among the lowest for a forward barotropic tide model.
Spatial distribution of amplitude and phase of “best” wave drag model

waterlevel amplitude HYCOM

waterlevel amplitude TPXO-ATLAS

RMS error between HYCOM and TPXO-ATLAS

GODAE OceanView Symposium, Hilton Baltimore, 4-6 November 2013
Dissipation in “best” HYCOM with tides vs. TPXO

Dissipation HYCOM for optimal JSL with scale=.375

Dissipation TPXO-ATLAS

Note: TPXO doesn’t assimilate tidal velocities, thus dissipation not as reliable as water level
Earth System Prediction Capability (ESPC)

A multi-agency effort to develop coupled global analysis and prediction framework at accuracies and timescales beyond traditional synoptic weather forecasts.

1/12° HYCOM/NCODA/CICE/NAVGEM/WWIII

Initial Operational Capability 2018
1993-2012 Ocean Reanalysis with CFRS Forcing

SSH mean: 1993.00-2004.00 19.1

Currently in 2005
SST: Global Ensemble Variance vs. Time Variance

Experiment 25.0 excluded

from one simulation over 2008-2011.
Thanks!

• Data assimilative 1/25° with tides in real time by FY14 Q2

http://www.hycom.org

http://www7320.nrlssc.navy.mil
Global “Ensembles of Opportunity”

- There were several global experiments with ~3 month overlap that were run as part of the normal development and improvement process such that the global simulations that differ by some parameter setting or technique.

- A very poor man’s approach; Not the proper way to develop and configure an extended range forecast capability (more on that soon).

Set 1 (2007): 5 used Cooper-Haines, 3 used MODAS synthetics. Two used 35 layers instead of 27. Some used an updated version of NCODA and one used mixed layer depth to modify the MODAS synthetic, etc.)

Set 2 (2012): All 3DVar, 32 vs. 41 layers, different ocean analysis configurations
Plans for FY14

• Spin up 41 layer non-assimilative 1/25° HYCOM/CICE as we did for 1/12° (no tides)
• Data assimilative 1/25° in real time this fall (no tides)
• Significant improvements to forward tide model
  - Changed from 32 to 41 layers with increased upper ocean resolution
  - Nycander tidal wave drag
  - Iterate self-attraction and loading (SAL) to convergence
  - Run at 1/12° and 1/25° resolution
• Develop inverse model for tides
• Data assimilative 1/25° with tides in real time by FY14 Q2
Schemes with more drag in deeper water have lower waterlevel RMS but larger TPXO dissipation errors.

Iterating the SAL reduces the RMS and dissipation error.
Old vs. New $M_2$ RMS SSH

Previous 3D HYCOM (Shriver et al, 2012); $\text{RMS}_A = 7.5 \text{ cm}$

The new model solution (bottom) is greatly improved compared to the old solution (top).
Assimilating Tides

• One-layer shallow water momentum equation

\[ \frac{\partial \vec{u}}{\partial t} + \vec{u} \cdot \nabla \vec{u} + f \hat{k} \times \vec{u} = -g \nabla (\eta - \eta_{EQ} - \eta_{SAL}) + Friction \]

• The most popular approach is to treat tides as an inverse problem with SSH as the data and with friction as the tunable model parameter
  - Coastal models vary \(c_D\) in space within a plausible range
  - Tide-only models vary linear drag in space for each tidal constituent

• We will add an additional body force term to HYCOM for each tidal constituent as the model parameters
  - Start with barotropic tide only configuration
  - Treat TPX08 atlas SSH as truth
  - May in addition vary \(c_D\) in coastal regions only