An Overview of the U.S. Navy’s Global Ocean Forecast System (GOFS) and Earth System Prediction Capability (ESPC)

GOVST 2017 Annual Meeting
Bergen, Norway
05 November 2017
1- Concise (“i.e. Nutshell”) overview and goals of your task team or national system

Real-Time Operational Global ocean forecasting via GOFS and ESPC

2- Summary of achievements/progress over the last 8 years

1/32° NLOM (1990s) to 1/8° G-NCOM (2000s) to 1/12° G-HYCOM (2010s)

3- Short-term future and experienced/foreseen challenges in near term (next 2 years)

GOFS 3.5 (1/25°), ESPC (IOC), both 4QFY18, ESPC FOC FY22

4- Your group/TT vision and strategic outlook for the next 10 years

Global coupled ensembles, LETKF, SWOT….
GOFS Descriptions

GOFS 3.0: 1/12° 32 layer HYCOM/NCODA-3DVAR/MODAS synthetics/e-loan ice
- Operational system running on Navy DSRC IBM iDataPlex computers (unclassified – Kilrain; classified – Cernan)
- Switch from NOGAPS to NAVGEM 1.1 forcing in August 2013
- Switch from NAVGEM 1.1 to NAVGEM 1.2 forcing in April 2014
- Switch from NAVGEM 1.2 to NAVGEM 1.3 forcing in March 2016

GOFS 3.1: 1/12° 41 layer HYCOM/NCODA-3DVAR/ISOP synthetics/CICE
- Add nine near surface layers
- Two-way coupled HYCOM with Los Alamos CICE model
- Replace MODAS synthetics w/ Improved Synthetic Ocean Profiles (ISOP)
- Needs new VTR using new hindcast with revised ISOP

GOFS 3.5: 1/25° 41 layer HYCOM/NCODA-3DVAR/ISOP synthetics/CICE/tides
- Increase equatorial horizontal resolution to ~3.5 km
- Tidal forcing

GOFS 4.0: 1/25° 41 layer HYCOM/NCODA-3DVAR/ISOP synthetics/CICE/tides
- Higher order operators for HYCOM momentum equations
- Full CICE 5.0 physics implemented
- Explore MOM6–HYCOM compatibility

Items in red are different from the preceding system
Global Ocean Forecast System (GOFS) 3.1 Validation

• A year-long GOFS 3.1 reanalysis was integrated for validation against operational GOFS 3.0 (ocean) and the Arctic Cap Nowcast Forecast System (ice)

• Reanalysis period: 1 July 2014 – 30 June 2015
  – Examine skill at the analysis time

• A series of 5-day GOFS 3.1 forecasts were also integrated
  – Examine skill as a function of forecast length

• Use only unassimilated observations

• Ocean error analyses
  – Temperature and salinity vs depth
  – Acoustical proxies (sonic layer depth, mixed layer depth, below layer sound speed gradient)
  – Acoustical trapping as a function of frequency
  – Upper ocean velocity (bias, RMSE and vector correlation)

• Ice error analyses
  – Ice edge, thickness and drift
Global Ocean Forecast System (GOFS) 3.1 Validation

Analysis regions defined by NAVOCEANO

Analysis regions defined by NIC
GOFS 3.1 Validation: T vs. depth error at the analysis time

For the global domain, ME is similar but GOFS 3.1 has lower RMSE than 3.0. Regionally the results vary.

Mean over this depth range
Number of observations
GOFS 3.1 Validation: T vs depth error as a function of forecast length

1-day forecast
3-day forecast
5-day forecast
FY17 HPC Review
Eddy-Resolving Global/Basin-SOM

GOFS 3.1 Validation: Ocean scorecard

Global (50°S-50°N) scorecard: Composite and 7 metrics

Perfect

No skill

\[
\text{GOFS 3.1 GOFS 3.0 Number of observations}
\]
GOFS 3.1 Validation: Ocean scorecard

Composite scorecard: 8 regions

Perfect

No skill

a) Globe: +/- 50°
b) West Pacific
c) Kuroshio Extension
d) S. California
e) Arabian Sea
f) Gulf Stream
g) GIN Sea
h) GoM/IAS

GOFS 3.1  GOFS 3.0
FY17 HPC Review
Eddy-Resolving Global/ Basin-SOM

GOFS 3.5 to replace GOFS 3.1 in FY19

- Increase horizontal resolution from 0.08° to 0.04°
- Addition of tides

The reanalysis year needed for the VTR is currently being integrated

Sea surface height (cm) on 25 January 2017 with IR frontal overlay

GOFS 3.1

GOFS 3.5
Existing un-coupled systems generally have one-way exchange from the atmosphere to the other model components.

Ocean DA is 3DVar.

ESPC will have two-way exchange between most model components.
Model Components

- Atmosphere: NAVy Global Environmental Model (NAVGEM)
- Ocean: HYbrid Coordinate Ocean Model (HYCOM)
- Sea ice: Community Ice CodE (CICE)
- Waves: WAVEWATCH III (WW3)
- Land: NAVGEM Land Surface Model (LSM)
- Aerosol: Navy Aerosol Analysis and Prediction System (NAAPS)
Assimilated Observations

- **Atmospheric Data:** FNMOC will collect, quality control, and deliver to operational runs in correct format and timely manner:
  - Conventional data
  - Radiosondes & Pibals
  - Dropsondes
  - Driftsonde
  - Land and Ship Surface Observations
  - Aircraft Observations
  - Synthetic Observations
  - Satellite data:
    - Surface Winds (Scatterometer, ASCAT, ERS-2, SSMI/SSMIS & WindSat)
    - Feature Tracked Winds (Geostationary (6 satellites)
    - Polar Orbiters (AVHRR and MODIS)
    - Combined polar/geo winds (CIMSS))
    - Total Water Vapor (SSMI/SSMIS TVAP, WindSat TVAP)
    - GPS Bending Angle
    - IR Sounding Radiances (IASI and AIRS)
    - MW Sounding Radiances (6 AMSU-A (Ch 4-14), 3 SSMIS (Ch 2-7, 22-24), 3 SSMIS/3 MHS 183 GHz)
**Oceanographic/ice Data:** NAVOCEANO will collect, quality control, and deliver to operational runs in correct format and timely manner:

- **Satellite Data**
  - Sea Surface Temperature (SST)
  - Sea Surface Salinity (SSS)
  - Altimeter Sea Surface Height Anomaly (SSHA)
  - Altimeter Surface Wave Height (SWH)
  - Sea surface color (optical) data
  - Ice concentration
  - Satellite-based heat flux estimates

- **In situ Data**
  - Temperature, salinity, etc. data from XBT, CTD, Argo, moored buoys, drifting buoys, gliders, marine mammals
  - Current observations from HF radar, drifters
  - Optical data from gliders, AUVs
  - Wave buoy SWH
The Initial Operational Capability (IOC) is scheduled for the end of FY18, with Final Operational Capability (FOC) at the end of FY22. Both a high resolution deterministic and lower resolution probabilistic ensemble will be run.

### Horizontal and vertical resolution at IOC

<table>
<thead>
<tr>
<th>Forecast</th>
<th>Time Scale, Frequency</th>
<th>Atmosphere NAVGEM</th>
<th>Ocean HYCOM</th>
<th>Ice CICE</th>
<th>Waves WW3(^1)</th>
<th>Land-Surface NAVGEM-LSM</th>
<th>Aerosol</th>
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</thead>
<tbody>
<tr>
<td><strong>Deterministic</strong></td>
<td>0-16 days, daily</td>
<td>T681L80 (19 km)</td>
<td>1/25(^\circ) (4.5 km)(^2) 41 layers</td>
<td>1/25(^\circ) (4.5 km)</td>
<td>1/8(^\circ) (14 km)</td>
<td>Module within NAVGEM</td>
<td>Module within NAVGEM</td>
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<tr>
<td><strong>Probabilistic</strong></td>
<td>0-30 days, daily</td>
<td>T359L60 (37 km)</td>
<td>1/12(^\circ) (9 km) (^2) 41 layers</td>
<td>1/12(^\circ) (9 km)</td>
<td>1/4(^\circ) (28 km)</td>
<td>Module within NAVGEM</td>
<td>Module within NAVGEM</td>
</tr>
<tr>
<td><strong>long term</strong></td>
<td>15 members(^3)</td>
<td></td>
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\(^1\)One-way coupling of atmosphere-ocean-ice to WW3
\(^2\)Horizontal resolution at the equator
\(^3\)The exact number of ensemble members will be determined by the resources available at IOC.

The number listed above assumes 15K processors daily.
Thanks
The spread and growth of the Initial Condition (the perturbations) is determined by the forecast error variance via the Ensemble Transform

Analysis error estimate – standard dev. of the ensemble set
Uncertainty – described through the PD of state parameters through the ensemble
Two month ensemble forecast of Loop Current eddy shedding
Two month ensemble SSH standard deviation
Schematic of the setup of Experiment 1: Initialized from 20 different 01 January states from the 20-year reanalysis; cycled for 90 days with identical observations and no other perturbation; and a 90-day forecast run from the 90-day states.
Ensemble (left) vs. Climatological (right) Variance
SST at days 002, 090 and 180

Day 2
Ensemble variance ~ climatology variance

Day 90
Ensemble variance collapses after DA cycling

Day 180
Ensemble variance grows but doesn’t reach climatological variance