US Navy’s Earth System Prediction Capability Effort

Daniel Eleuterio, William Schulz, Ron Ferek, Josh Cossuth
*Office of Naval Research, Arlington, VA, USA*
Carolyn Reynolds, Neil Barton, Maria Flatau, Sergey Frolov, Andrew Huang, Matt Janiga, Justin McLay, James Ridout, Ben Ruston, Tim Whitcomb,
*Naval Research Laboratory, Monterey, CA, USA*
Will Crawford, *ASEE post-doc*, Philippe Papin, *NRC Post-Doc, Monterey, CA*
Craig Bishop, *University of Melbourne, Melbourne, Australia*
Pat Hogan, Gregg Jacobs, E. Joseph Metzger, Erick Rogers, Clark Rowley,
*Naval Research Laboratory, Stennis Space Center, MS, USA*
James Richman, *Florida State University, Tallahassee, FL, USA*
Extended-range Prediction Plays a Critical Role in DoD/Navy Planning and Policy

Navy Operational Planning
- Mission planning (e.g., typhoon risk assessment, ship routing)
- Long-term infrastructure installation and replacement planning

Navy Climate Change Task Force
- US Navy has a long history of Arctic Ocean operations and explorations
- Reduced summer sea ice will make Arctic Ocean viable for international shipping and resource explorations, and critical for national security concerns
- Estimates for economic potential of hydrocarbon resources exceed $1 trillion in U.S. Arctic

Navy S&T Strategic Plan
Match environmental predictive capabilities to tactical planning requirements: Fully coupled (ocean-atmosphere-wave-ice) global, regional and local modeling and prediction capabilities for operational planning at tactical, strategic, and subseasonal to seasonal scales

Typhoon Cobra, or Halsey’s Typhoon, DEC1944. Three destroyers and 790 lives lost.

NRL supports US Icebreaker Healy on Geotraces mission
Navy ESPC Model Overview

- Developed to meet Navy needs for global earth system forecasts on timescales from days to months: Initial operational implementation and transition in FY19
- Navy ESPC team: NRL Monterey CA, NRL Stennis MS, NRL DC, NOAA ESMF
- Earth System Modeling Framework (ESMF and NUOPC) used to facilitate upgrades
- Participate in NOAA Mapp SubX (45-d fcsts, 4/week, 1999-present) allows for robust evaluation
## Navy ESPC Initial Operational Capability: 2019

<table>
<thead>
<tr>
<th>Forecast</th>
<th>Time Range, Frequency</th>
<th>Atmosphere NAVGEM</th>
<th>Ocean HYCOM</th>
<th>Ice CICE</th>
<th>Waves WW3</th>
<th>Land Surface</th>
<th>Aerosols</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Deterministic short term</strong></td>
<td>0-16 days, Daily</td>
<td>T681L60 (19 km) 60 levels</td>
<td>1/25° (4.5 km) 41 layers</td>
<td>1/25° (4.5 km)</td>
<td>1/8° (14 km)</td>
<td>Module within NAVGEM</td>
<td>Module within NAVGEM</td>
</tr>
<tr>
<td><strong>Probabilistic long term</strong></td>
<td>0-45 days, 16 members, weekly</td>
<td>T359L60 (37 km) 60 levels</td>
<td>1/12° (9 km) 41 layers</td>
<td>1/12° (9 km)</td>
<td>1/4° (28 km)</td>
<td>Module within NAVGEM</td>
<td>Module within NAVGEM</td>
</tr>
</tbody>
</table>

- **IOC: Weakly-coupled DA, perturbed observation ensembles, reforecasts, DA components.**
- **Final Operational Capability: FY22**
  - Seasonal (90-day) ensemble forecasts
  - Coupled data assimilation, inline aerosols, middle atmosphere
  - Interactive ocean surface waves

*16 members once per week vs. 3 members per day.*
Uniqueness of Navy ESPC: High Resolution Ocean and Sea Ice

Navy needs high-fidelity simulations in atmosphere, ocean and sea-ice
Navy ESPC (red) competitive with other SubX models for PNA and NAO forecasts in deterministic mode

From E. Poan and H. Lin, Environnement et Changement Climatique Canada, Recherche en Prevision Numerique, March 2018: “NAO and PNA skill of analysis on the Subseasonal Experiment datasets”
Wavenumber-frequency diagram of symmetric power normalized by a red noise background for 15°S-15°N 1999-2015 JJA OLR

Navy ESPC matches observations well for MJO and Kelvin waves

Navy ESPC overactive in Tropical Depressions

ECMWF matches observations best of the three systems

CFSV2 has weak MJO and Kelvin waves

Janiga et al. (2018, Monthly Weather Review)
Navy ESPC Anomaly Correlation skill comparable to CFSv2 at beginning of forecast, and comparable to ECMWF by day 21

Navy ESPC amplitude too strong, in contrast to other models

Navy ESPC, ECMWF, CFSv2
There are periods when enhanced rainfall and storminess along the equator is predictable more than a month in advance when associated with a strong Madden Julian Oscillation (MJO).
Tropical Cyclone Prediction Using the SubX Forecasts

0-10°N OLR anomalies shaded from (a) NOAA obs. and (b) 45 d NESM forecast. MJO-filtered OLR anomalies are contoured in red every 15 W m⁻².

TC tracks are colored by 10 m max windspeed. TC tracking uses TempestExtremes and settings in Zarzycki and Ullrich (2017).

NESM 45-day forecast from 2015060112
TC genesis more common during active MJO phase

NESM 45-day forecast captures both MJO and elevated TC genesis in this example.
Navy ESPC real time forecasts were leveraged to provide the National Ice Center with 45-day forecasts of sea ice concentration, thickness and drift for long-range planning guidance for 2018 Operation Deep Freeze (McMurdo resupply mission) and ICEX (Beaufort Sea) field campaign support.

15 Jan 2018 NRL Navy ESPC 15-day sea ice fraction forecast (color shading) compared to 15 Jan 2018 NIC Outlook (green line) for the Ross Sea, Antarctica.
• Quantitative verification of ice edge forecasts is underway, including comparison with persistence and climatological forecasts
• Large differences between National Ice Center and National Snow and Ice Data Center analyses
Summary

- Operational transition scheduled for FY19
- Relatively high resolution ocean ice models (1/12° for ensembles, 1/25° for deterministic)
- Initial results promising (“in the mix”)
- SubX runs being used by National Ice Center for resupply missions and field campaigns

Future work

- Optimize ensemble design and configuration (including model uncertainty)
- Continue model development to address biases
- Develop new extended-range and probabilistic forecast products
- Final operational implementation (2022) will include coupled data assimilation and coupled ocean surface waves
Comparison to Operational Systems

- Global 100-m ocean temp RMSE smaller for Navy ESPC (1/12th HYCOM) than for Global Operational Forecast System (GOFS) 3.0 (1/25th HYCOM)
- Higher-resolution GOFS has similar performance to Navy ESPC (extra slides)
Comparison to Operational Systems

- Preliminary analysis of the deterministic forecasts shows comparable performance between NAVGEM and Navy ESPC.
- Navy ESPC has lower RMSE wind errors than NAVGEM.

Navy ESPC
NAVGEM
Better-quality ICs for NAVGEM result in better forecasts relative to other systems.

“Experiment of Opportunity” to examine initial condition accuracy impact.

Navy ESPC, ECMWF, CFSv2
Multi-month 10-member Navy ESPC ensemble predictions of September 2017 mean sea ice extent provided to the Sea Ice Prediction Network.

Comparison of Navy ESPC to operational ocean-ice forecasts (GOFS 3.1) for two years of August Reports.

Ensemble spread decreases as lead time increases. Observed ice edge (black) mostly contained within ensemble spread.

Coupled atmosphere-ocean improves performance over using atmospheric forcing from previous years. Navy ESPC has replaced GOFS for SIO.
Sea Ice Prediction Network Forecasts: September Mean Sea Ice Extent

Figures from www.arcus.org/sipn/sea-ice-outlook

September 2015 Sea Ice Outlooks

June Forecasts

Navy ESPC

August Forecasts

Navy ESPC

Observed Value: 4.68m km$^2$

Navy Predictions: 5.07m and 4.5 m km$^2$

Navy ESPC is in the middle of the distribution, close to observed value (good!)
Navy ESPC is very close to observed value (great!)

July Forecasts

Navy ESPC

Observed Value
4.72m km²

Navy Prediction:
4.8m km²

August Forecasts

Navy ESPC

Figures from www.arcus.org/sipn/sea-ice-outlook

Sea Ice Prediction Network Forecasts: September Mean Sea Ice Extent

September 2016 Sea Ice Outlooks
Sea Ice Prediction Network Forecasts: September Mean Sea Ice Extent

Figures from www.arcus.org/sipn/sea-ice-outlook

September 2017 Sea Ice Outlooks

June Forecasts
- Navy ESPC: 6.0m km²

July Forecasts
- Navy ESPC: 4.5m km²

August Forecasts
- Navy ESPC: 3.9m km²

Observed Value: 4.80m km²

Navy ESPC forecasts vary widely (interesting!)
The DYNAMO period in 2011 has served as a development test case. Significant improvements have been achieved in the representation of the three MJO events.

**Coupled Physics Version 1 (CV1)**
- Modified cloud top condition and trigger for turbulence-forced convection mode.

**CV2**
- Modified coupling of dynamically-forced convection with grid-scale vertical motion.

**CV3 prototype**
- Modified cloud top condition and trigger for turbulence-forced convection mode.

**TRMM Satellite Retrieval**
- Equatorial (5°N - 5°S) Propagation of Rainfall

**Graphical Representation**
- Nov 1 vs Jan 1
- 40E to 140E
- Color scale from 0 to 45 mm