U.S. Navy Earth System Prediction System (ESPC) Development from R&D to Operations

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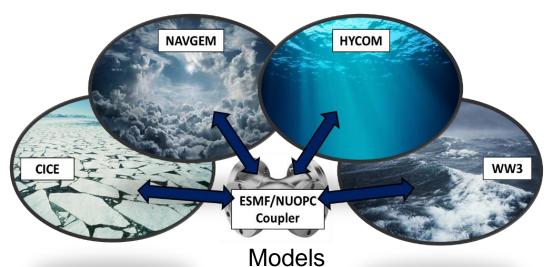


A historical perspective on US Navy environmental prediction

- The Navy DoD Supercomputing Resource Center (DSRC) dedicates a portion of the total cpu cycles (15%) to operational meteorology/ oceanography applications run by FNMOC
- All operational forecast systems must fit with this 15%
 - Atmosphere, ocean, sea ice and wave models stand-alone and coupled
 - Global, regional and coastal domains
- This controls what can be accepted into operations
 - Governs the horizontal and vertical resolution of the prediction systems
 - Governs the complexity of the physics within the models and the associated data assimilation

Move toward a whole Earth prediction via coupling

- Earth System Prediction Capability (ESPC) is the development of a whole Earth prediction system with coupling between the atmosphere, ocean, cryosphere and waves via the Earth System Modeling Framework
- Prediction from the top of the atmosphere to the bottom of the ocean
- Extending the forecast lead times from weekly to subseasonal (45 days)



NAVGEM: NAVy Global Environmental Model HYCOM: HYbrid Coordinate Ocean Model CICE: Community Ice CodE WW3: WAVEWATCH III[®]

Data Assimilation

NAVDAS: NRL Atmospheric Variational Data Assimilation

NCODA: Navy Coupled Ocean Data Assimilation

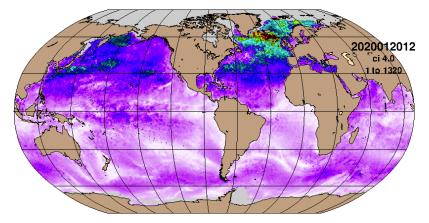
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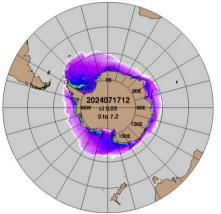
ESPC development - version 1

- Two-way coupled NAVGEM, HYCOM and CICE
- ESPC-D: Deterministic system
 - T359L60 NAVGEM 1/25° HYCOM 1/25° CICE
 - A single daily 16-day forecast
 - Did not outperform the corresponding stand-alone uncoupled forecast systems
- ESPC-E: Ensemble system
 - 16-member ensemble, perturbed observations
 - T359L60 NAVGEM 1/12.5° HYCOM 1/12.5° CICE
 - Every Sunday, 45-day subseasonal forecasts
 - Declared operational in August 2020
 - First eddy-resolving ensemble ocean/sea ice forecasts for US Navy use

HYCOM Mixed Layer Depth



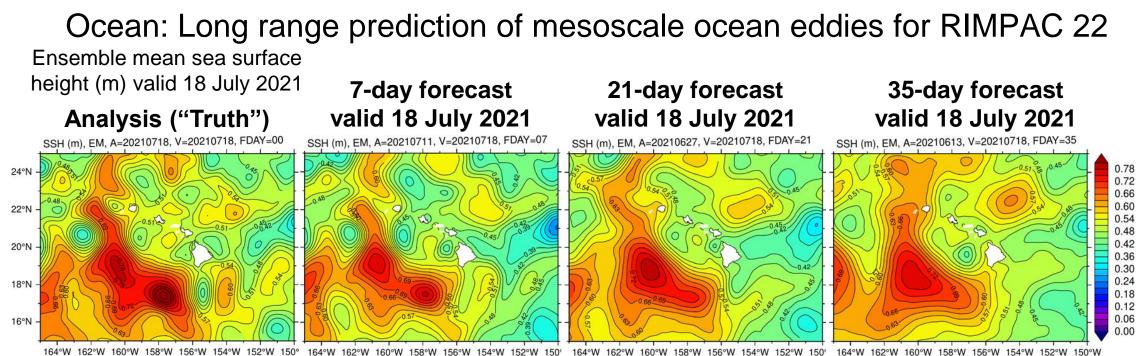
CICE Sea Ice Thickness



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US Navy use of ESPC-E v1 ocean products

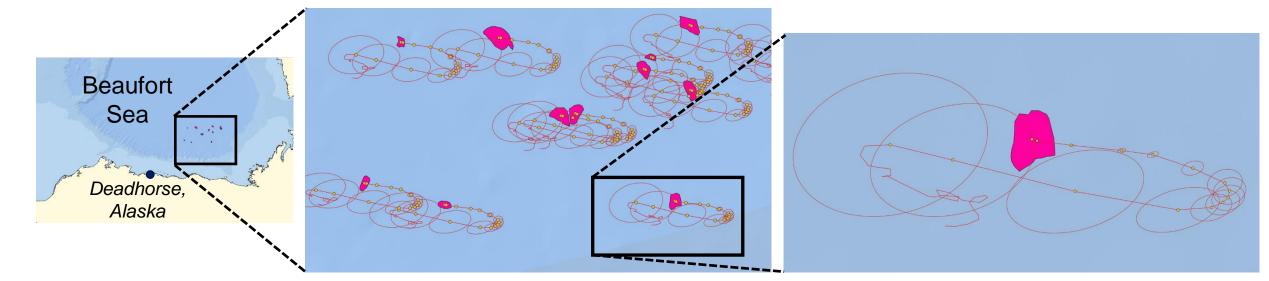


- Skill in predicting ocean mesoscale features up to six weeks in advance
- Mesoscale eddies impact ocean acoustics
- Planners can direct exercises to the most favorable regions of the RIMPAC domain



US Navy use of ESPC-E v1 sea ice products

- US National Ice Center assists in ice floe selection for ICEX: US Navy ice camp in the Beaufort Sea
- Operational ESPC-E v1 was used to provide forecast track and uncertainty estimates
 - Both prior to floe selection and during the exercise
- Floe must remain within a flyable distance of Deadhorse, AK
- Magenta shapes show various ice floes that may host the ice camp
- Yellow dots are ensemble mean forecast every 24 hours out to 14 days
- Circles represent uncertainty (standard deviation) of sea ice drift





ESPC development - version 2

- ESPC-D v2
 - T681L143 NAVGEM 1/25° HYCOM 1/25° CICE -1/8° WW3 - operational August 2024
 - Higher resolution atmosphere, ocean and sea ice models than ESPC-E v1 and the addition of wind waves
 - Deterministic daily 16-day forecast
 - Two-way coupling between NAVGEM, HYCOM and CICE; one-way coupling to WW3
 - Astronomical tidal forcing in HYCOM produces internal waves at tidal frequencies
 - Internal waves can be of order 100 m at depth and are reflected in the sea surface height _____
 - Internal waves are important for underwater operations

steric sea surface height Steric SSH: 2024 185 13 New Guinea

Internal tidal signature in

Internal tidal on model interfaces temperature zonal sec. 20.02n Jan 01, 2020 10Z salinity zonal sec. 20.02n Jan 01, 2020 10Z [2 Salinity Internal tides appear as interface deviations

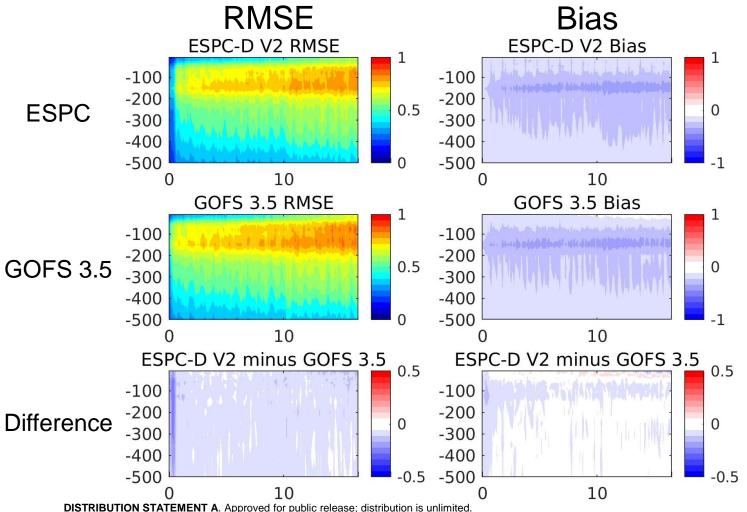


Verification and Validation (V&V)

- Before a forecast system is declared operational by FNMOC, it must undergo a thorough V&V process relative to the existing operational system
- Validation Test Panel comprised of NRL, FNMOC and independent representatives agree upon a series of validation metrics for each model component
- NRL runs a year-long reanalysis and sequence of forecasts and computes forecast system error between the two systems, then writes a Validation Test Report (VTR)



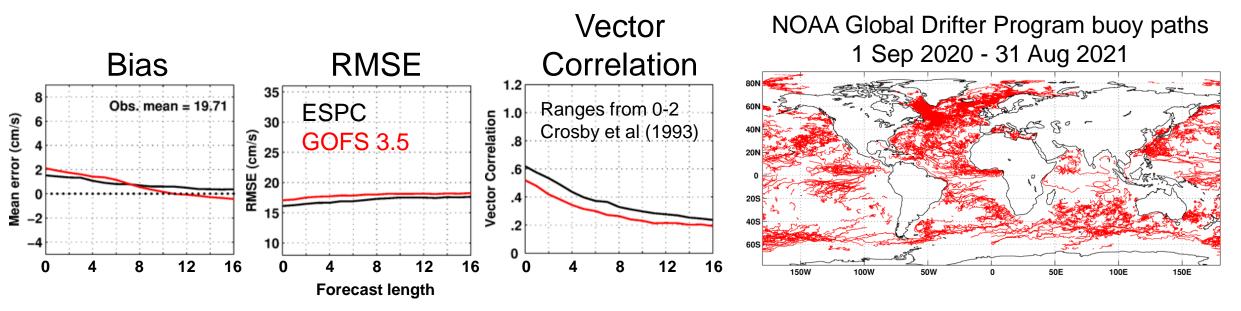
HYCOM V&V - Temperature error (°C) vs forecast length



- Slightly improved performance in ESPC-D v2 compared to the stand-alone Global Ocean Forecast System (GOFS) 3.5
- Highest error in the depth range of the thermocline
- Bottom row: blue means ESPC-D v2 has lower error than GOFS 3.5



HYCOM V&V - Near surface currents vs forecast length



- Slow error growth with increasing forecast length
- Speed bias is small, less than 10% of observed mean speed
- Slightly lower RMSE and higher directional correlation for ESPC, indicates the two-way coupling between the atmosphere and ocean improves near surface current prediction

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Dissemination of ESPC-D output

- US Navy presently allows public release of ESPC-D ocean output, but on a decimated grid - 0.08° longitude x 0.04° latitude
- 1-hourly 2D fields: sea ice fraction, thickness, velocity; sea surface salinity, temperature, velocity; surface downward stress
- 3-hourly 3D fields: T, S, U and V
- Served on hycom.org by Florida State University
- https://www.hycom.org/dataserver/espc-dv02/global-analysis

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About	ESPC-D-V02: Global 1/12° Analysis (Dataset)		 Datasets ESPC-D-V02 GLB Analysis
 HYCOM Overview Documentation Source Code Contact Info Forum README 			
	Title:	ESPC-D-V02: Global 1/12° Analysis (Aug-10-2024 to Present with 8-day forecast) output on the GLBy0.08 grid	 GOMb0.01 GOM Reanalysis GOMb0.04 GOM Reanalysis GLBy0.08 expt_93.0 CLB-0.00
	Resolution:	ESPC-D-V02 daily 1/25° (GLBz0.04) deterministic run decimated to the GLBy0.08 1/12° grid	
	Institution:	Fleet Numerical Meteorology and Oceanography Center (FNMOC)	
YouTube Videos	Date/Data Range:	2024-Aug-10 to Present with 8-day forecast [no known missing data]	 GLBv0.08 expt_93.0 expt_92.9
 Data Server espc-D-V02 	Experiment Sequence:	expt_03.1	 expt_57.7 expt 92.8
 Global Analysis GOFS 3.1 Global Analysis Global Reanalysis 	Generating Model:	ESPC-D V02: HYCOM 2.2.99, CICE 5.1.2, expt_03.1	expt_57.2expt_56.3
	Input Data Source:	FNMOC NAVGEM, Satellite SSH, SST, SMMI, in situ observations	 expt_53.X GLBa0.08
 Ice Fields GOFS 3.0 Global Analysis Global Reanalysis Gulf of Mexico GoM Analysis GoM Reanalysis NAVGEM Forcing Legacy 1.3/1.4 Legacy 1.1/1.2 NOGAPS Forcing 	2d Variables 1-hourly:	<pre>1-hourly temporal frequency: ice sic = sea_ice_area_fraction sih = sea_ice_thickness siu = eastward_sea_ice_velocity siv = northward_sea_ice_velocity sst = sea_water_salinity sst = sea_water_temperature ssu = eastward_sea_water_velocity ssv = northward_sea_water_velocity surt = surface_downward_eastward_stress surty = surface_downward_northward_stress</pre>	 expt_91.2 expt_91.1 expt_91.0 expt_90.9 expt_90.8 expt_90.6 GLBu0.08 expt_91.2 expt_91.1 expt_91.0 expt_91.0 expt_91.0 expt_91.1 expt_91.0 expt_91.0 expt_91.1
NCEP CFSR NCEP CFSv2 Access Methods		<pre>ssh surf_el = Water Surface Elevation Sssh</pre>	 expt_19.0 GOMI0.04 expt 901m000



Questions?

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