The US Navy Earth System Prediction Capability (Navy ESPC): Overview and Future Developments



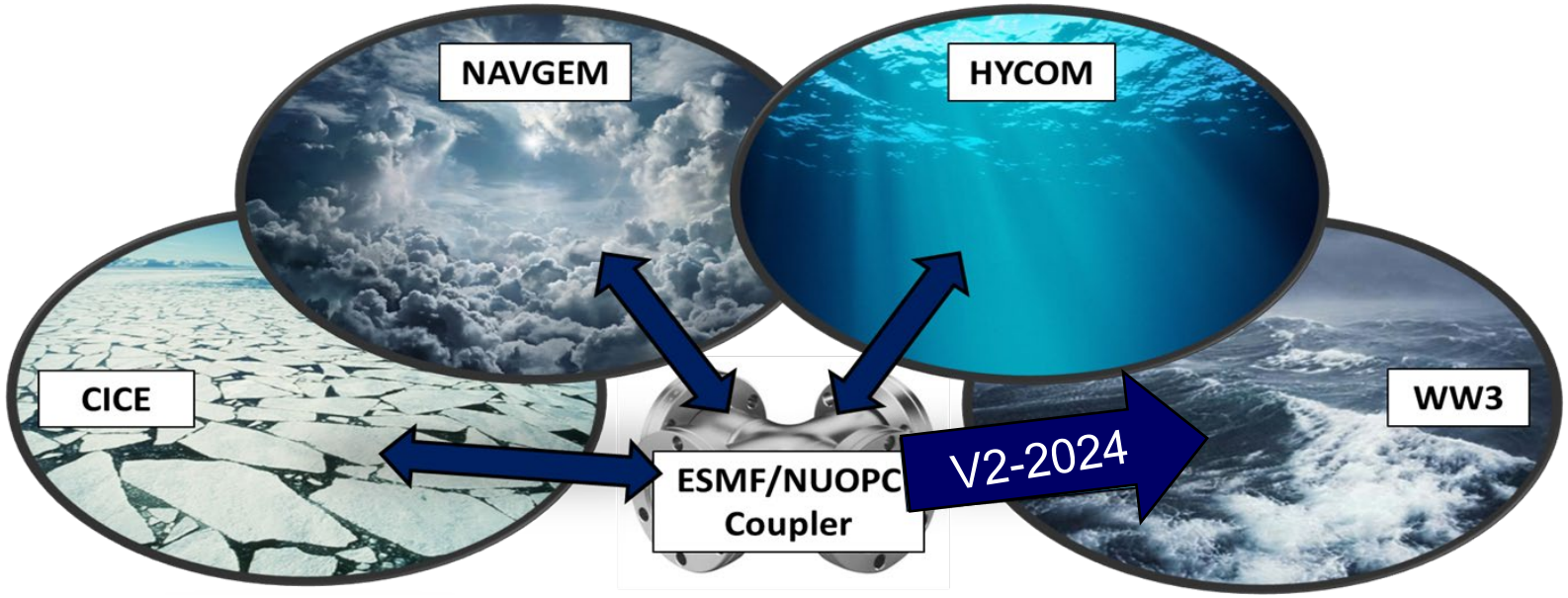
Carolyn Reynolds[1](presenter), Richard Allard[2], Charlie Barron[2], William Crawford[1], Maria Flatau[1], David Hebert[2], Gregg Jacobs[2], Matthew Janiga[1], Tommy Jensen[2], David Kuhl[3], Robert Linzell[4], Fei Liu[5], Jun Ma[3], Justin McLay[1], E. Joseph Metzger[2], Stephanie Rushley[6], James Ridout[1], Erick Rogers[2], Clark Rowley[2], Jay Shriver[2], Ole Martin Smedstad[4], Prasad Thoppil[2], Tamara Townsend[2], Timothy Whitcomb[1].

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[6]National Research Council, Monterey, CA

Funding: This work was supported under the N2N6E/ONR Navy Earth System Prediction Capability Program
Computing Support: High Performance Computing Modernization Program

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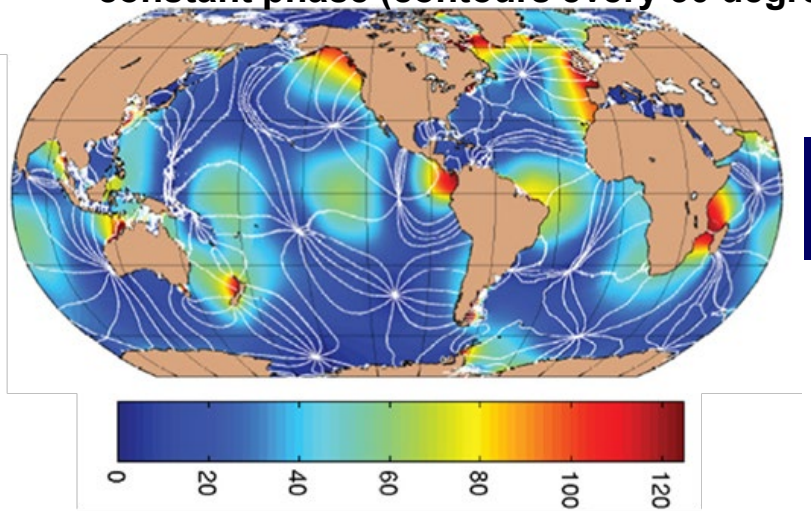
US Navy ESPC Global Coupled System



- Navy ESPC-E (Ensemble) v1 became operational at Fleet Numerical Meteorology and Oceanography Center (FNMOC) in August 2020
- Used by Joint Typhoon Warning Center for tropical cyclone genesis prediction
- Used by National Ice Center for polar exercise and resupply mission planning
- Navy ESPC-D (Deterministic) v2 became operational in August 2024
- Navy ESPC-E v2 validation test report almost finished, operational transition underway

Navy ESPC v2 Upgrades (FY24-FY25)

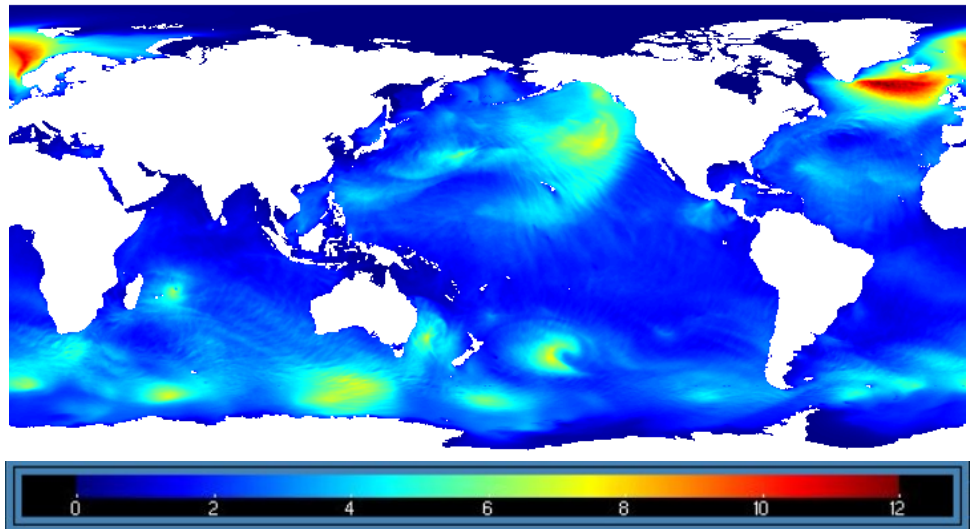
M2 barotropic tidal amplitude (cm) with lines of constant phase (contours every 30 degrees)

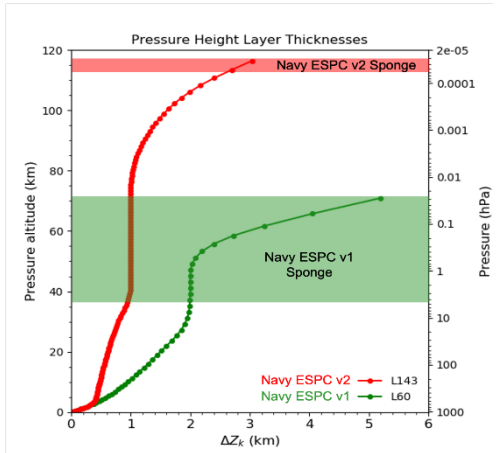


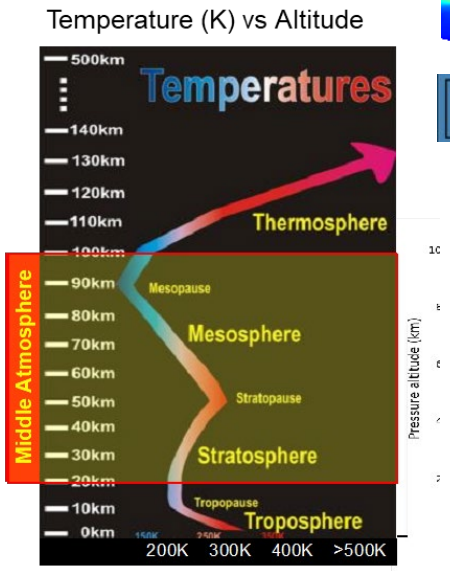
Ocean tides in the ESPC Ensemble

WW3 (one way coupling)

WW3 significant wave height (m)
15 January 2018 12Z – 20 January 2018 06Z







Extension to the middle atmosphere

U.S. NAVAL RESEARCH LABORATORY

Navy ESPC Evolution

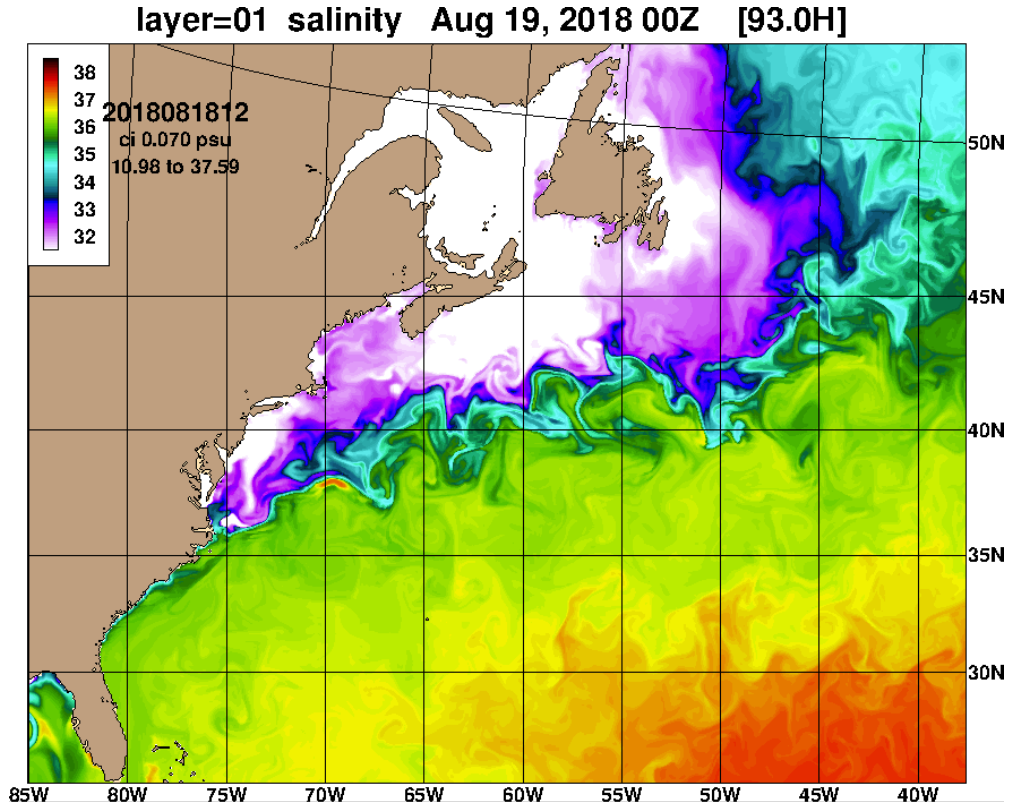
ESPC Version Number	Atmosphere NAVGEM	Ocean HYCOM	Sea Ice CICE	Waves[3] WW3	Land Surface LSM	Aerosol
ESPC-E v1 45-day ensembles	T359L60 37 km, 72-km top	1/12° (9 km)[1] 41 layers	1/12° (3.5 km)[2] CICE V4		Module within NAVGEM	
ESPC-E v2 45-day ensembles	T681L143 19 km, 110-km top	1/12° (9 km)[1] 41 layers, Tides	1/12° (3.5 km)[2] CICE V6 w/ Arctic land-fast ice	1/4° (28 km)	Module within NAVGEM	Module within NAVGEM
ESPC-D v2 8-day Forecasts	T681L143 19 km, 110-km top	1/25° (4.5 km)[1] 41 layers, Tides	1/25° (1.8 km)[2] CICE V6 w/ Arctic land-fast ice	1/8° (28 km)	Module within NAVGEM	Module within NAVGEM

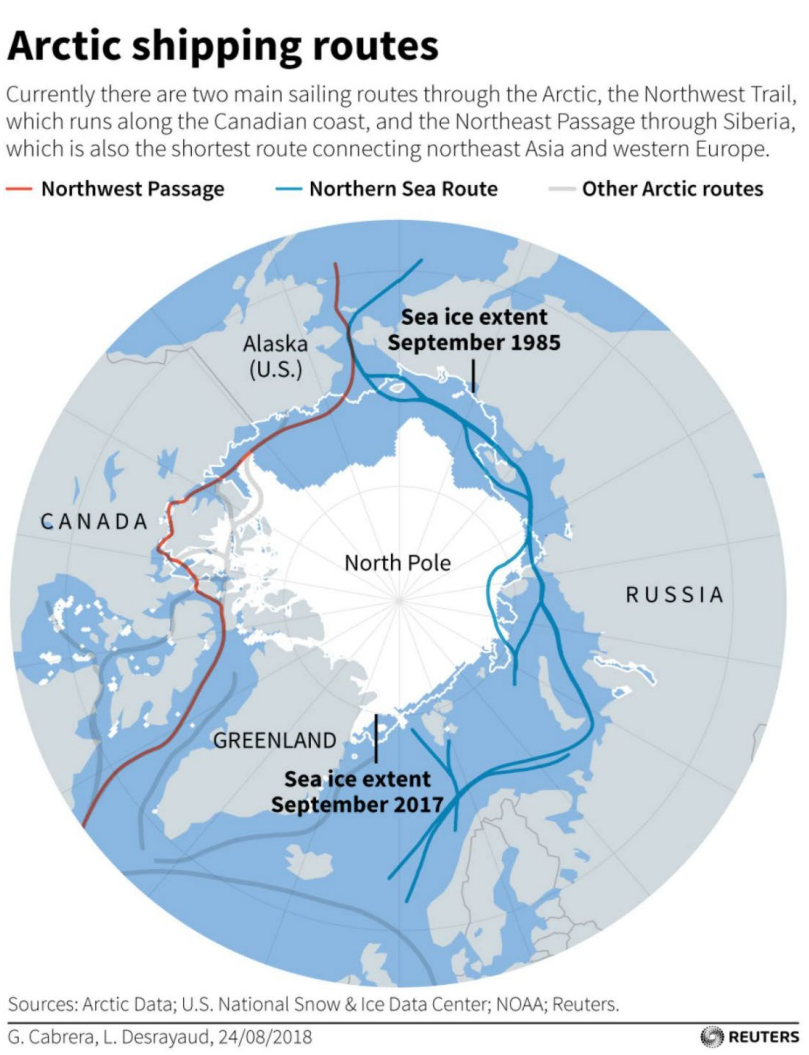
Very high-resolution ocean and sea ice reflects US Navy interests.

v2 includes higher NAVGEM resolution and model top, internal tides, land-fast Arctic sea-ice, radiative impact of climatological aerosols, and 1-way coupling to waves.

[1] Horizontal resolution at the equator, [2] Horizontal resolution at the North Pole, [3]One-way coupling to waves.

Uniqueness of US Navy ESPC: High Resolution Ocean and Sea Ice





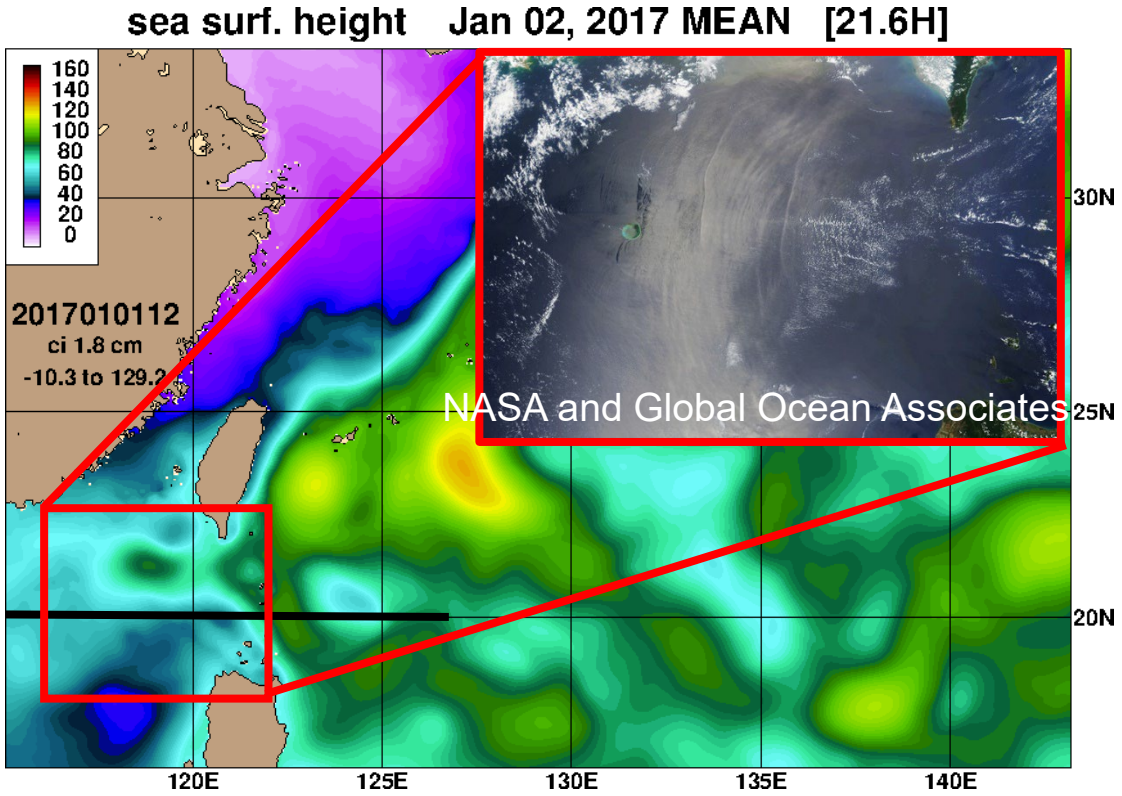


Marine Ecosystems (NOAA)

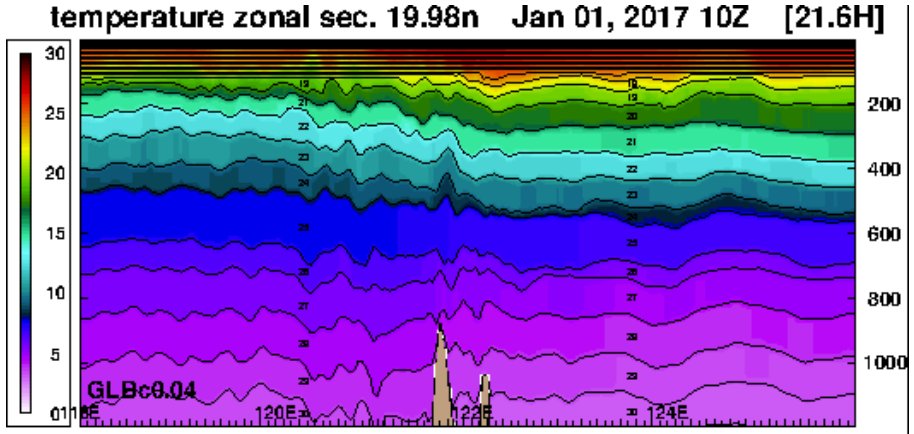


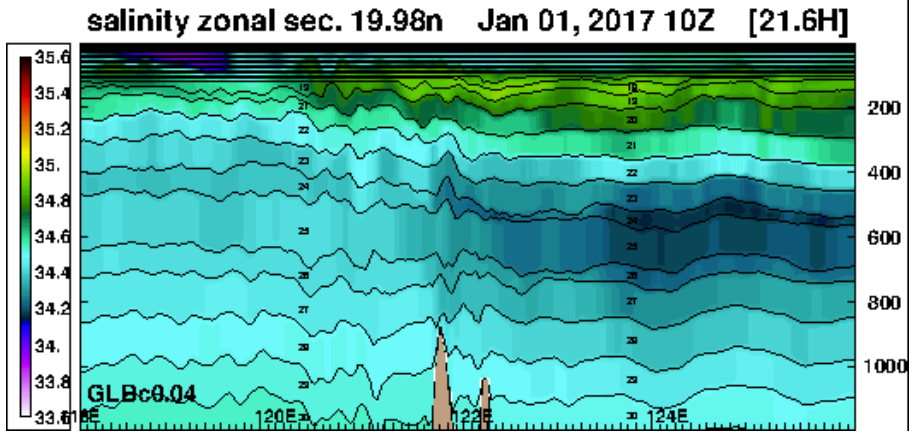
US Navy needs high-fidelity simulations in atmosphere, ocean and sea-ice

Why High Resolution? - Internal Tides



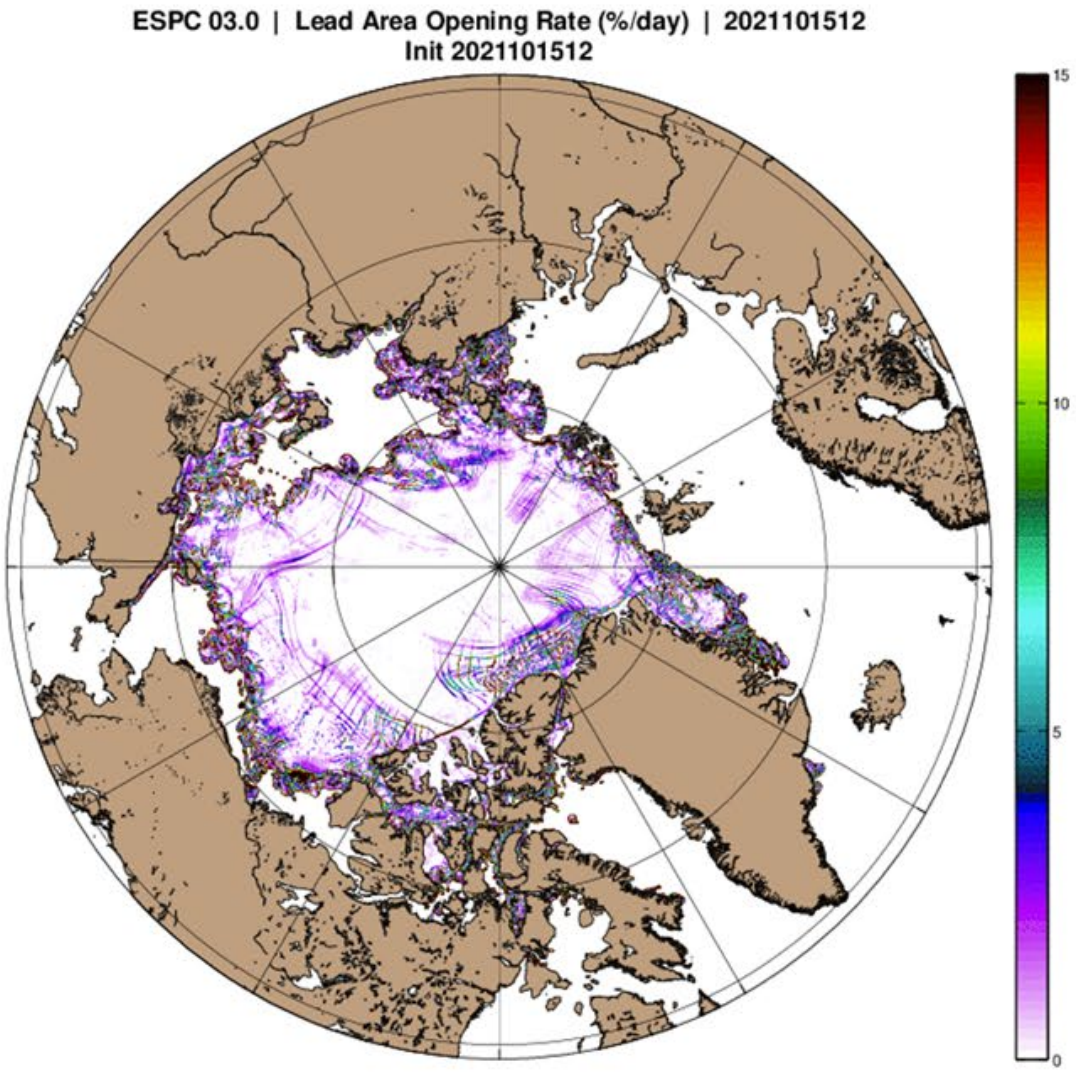
Internal Tides in Navy ESPC 1/25° HYCOM
48-h animation

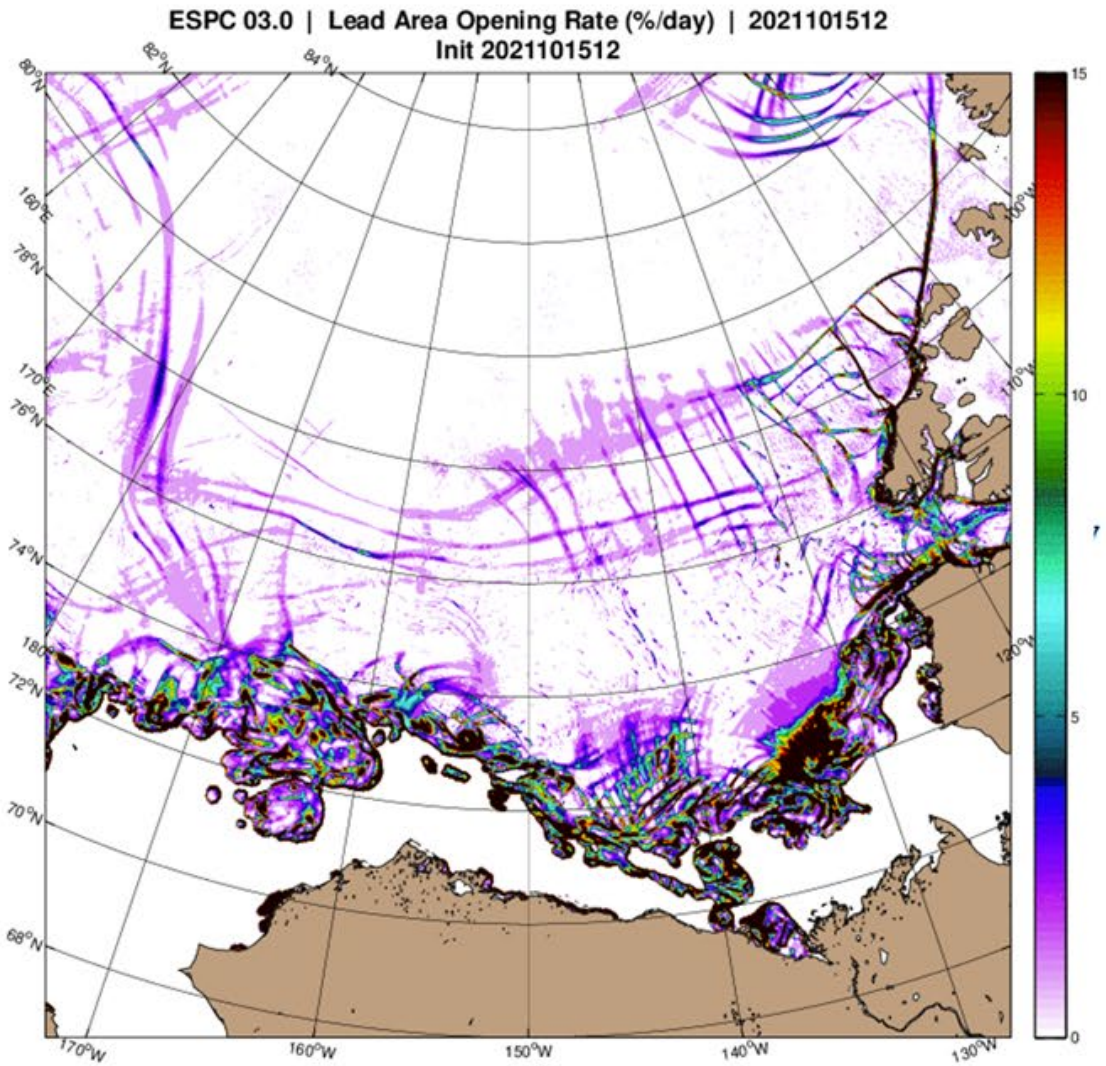




The addition of astronomical tidal forcing generates internal gravity waves at tidal frequencies. These internal tides are generated by large-scale barotropic flow over bathymetric features.

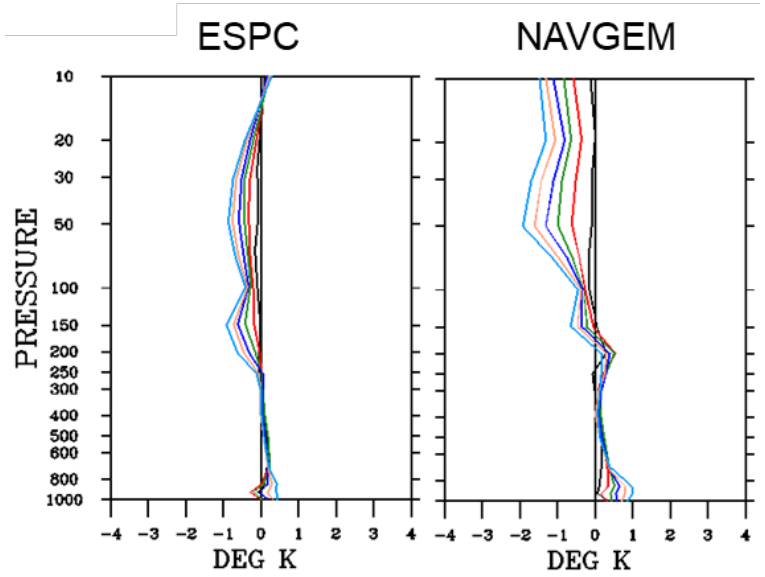
Example of Ice Fractures in CICE Component 1.75 km Resolution at the Pole (ESPC-D)





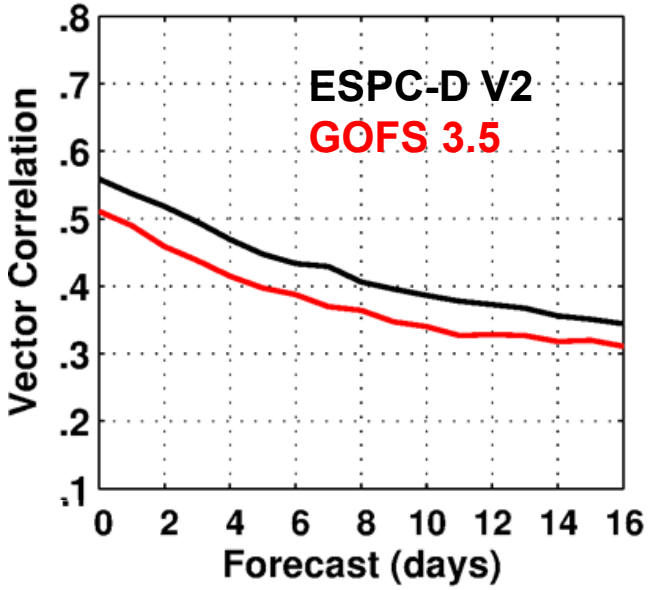
Navy ESPC-D v2 vs. Stand-alone Systems

Temperature bias (k) as compared to radiosondes at tau=0 h (black) through tau= 120 h (cyan)



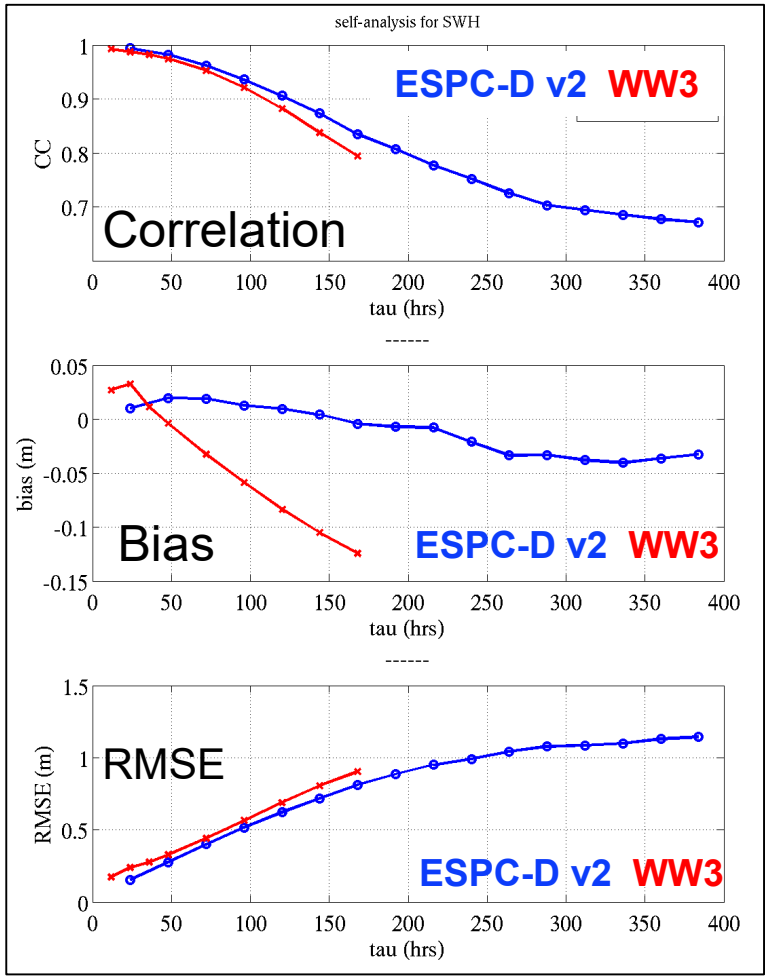
Smaller biases in middle atmosphere and in troposphere (higher top, better physics)

Upper Ocean Currents



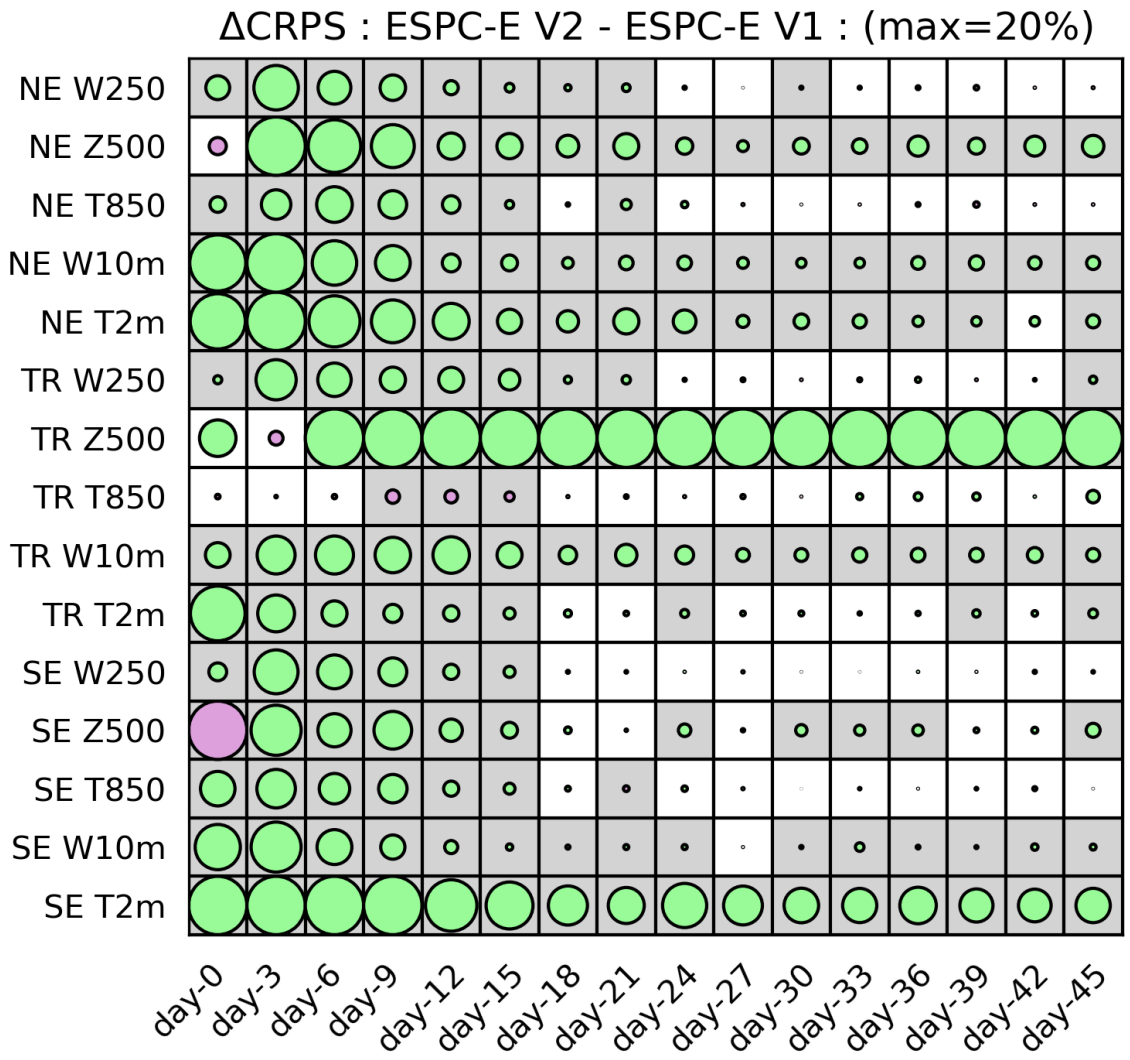
ESPC-D v2 outperforms stand-alone GOFS 3.5 for most (not all) metrics.

WW3 in ESPC-D v2 vs Stand-alone WW3 Significant Wave Height Self Analysis



WW3 forecasts in ESPC better than stand-alone WW3 in terms of correlation, RMSE, and bias.

Navy ESPC-E v1 vs. v2 - Atmospheric CRPS



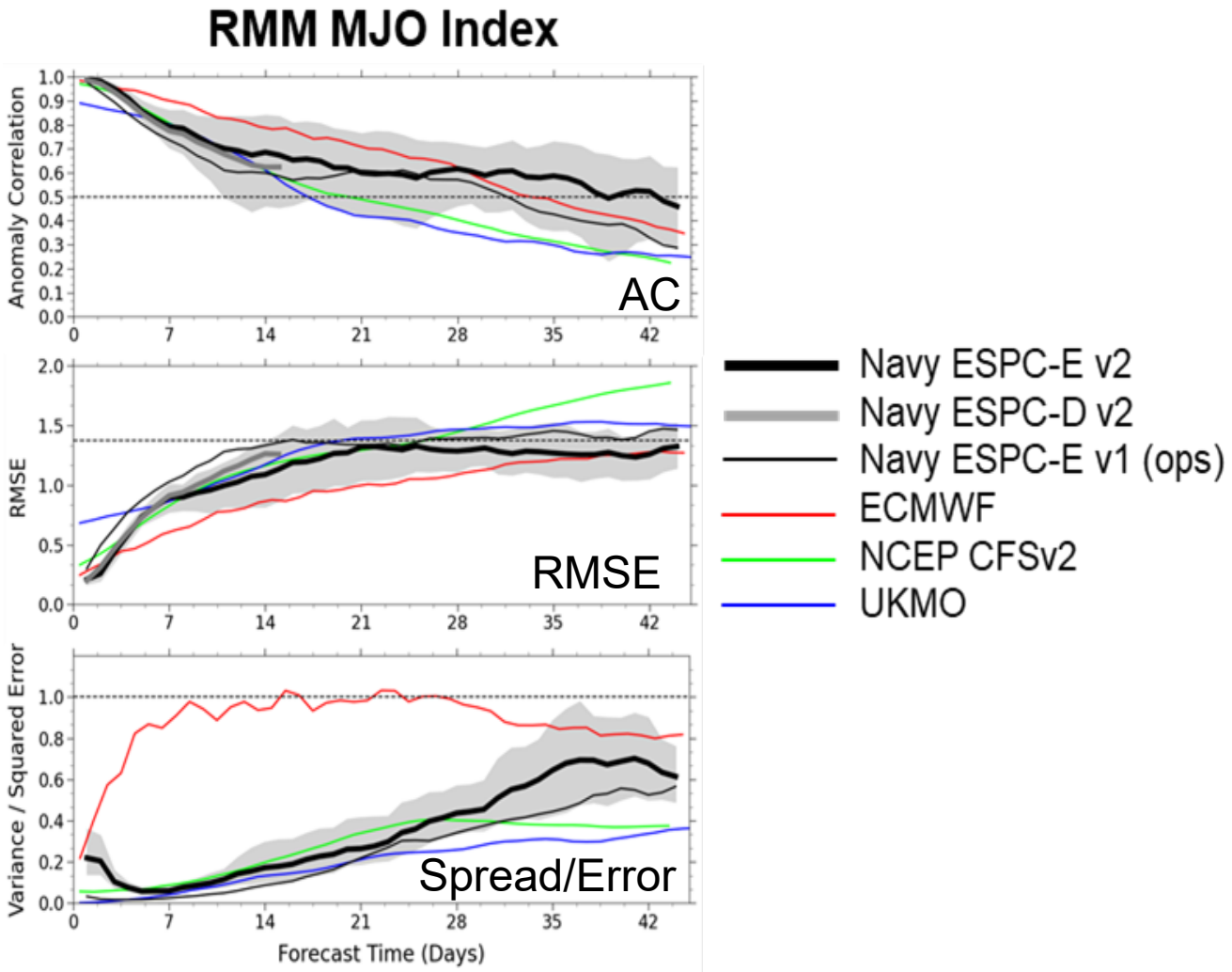
v2 shows improvements in CRPS for almost all variables within the first two weeks. Relative improvements largest for tropical 500-hPa height and southern extratropical 2m temp

Extra slides:

- Ensemble mean RMSE results very similar to CRPS results
- Impact on bias mixed, but bias trends with forecast time are smaller in v2
- Spread-skill ratio also improved (closer to 1) for almost all variables within the first two weeks

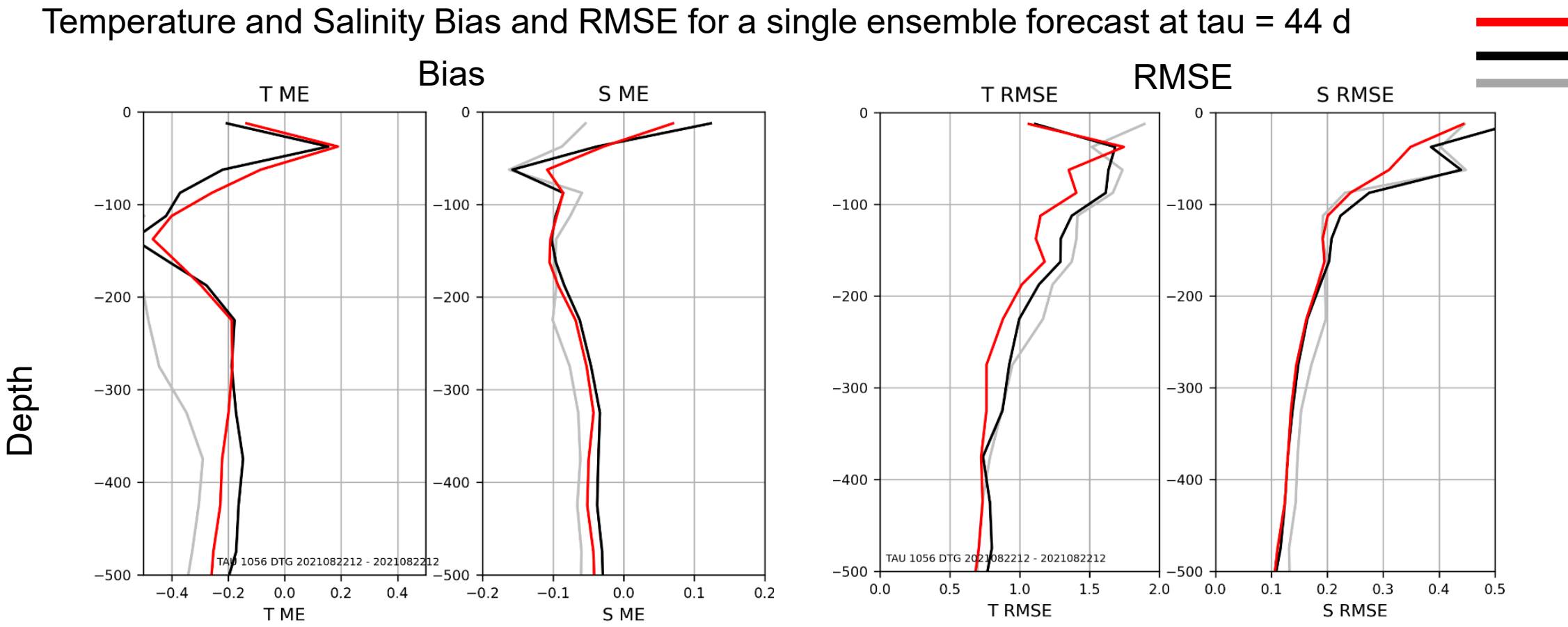
Navy ESPC-E v1 vs. v2 Madden-Julian Oscillation

- ESPC-E v1 outperforms ESPC-E v2 for MJO AC, RMSE, and spread-error relationship
- Comparable to NCEP and UKMO, not as good as ECMWF
- All models other than ECMWF are substantially under-dispersive – currently examining stochastic atmospheric forcing to enhance ensemble spread



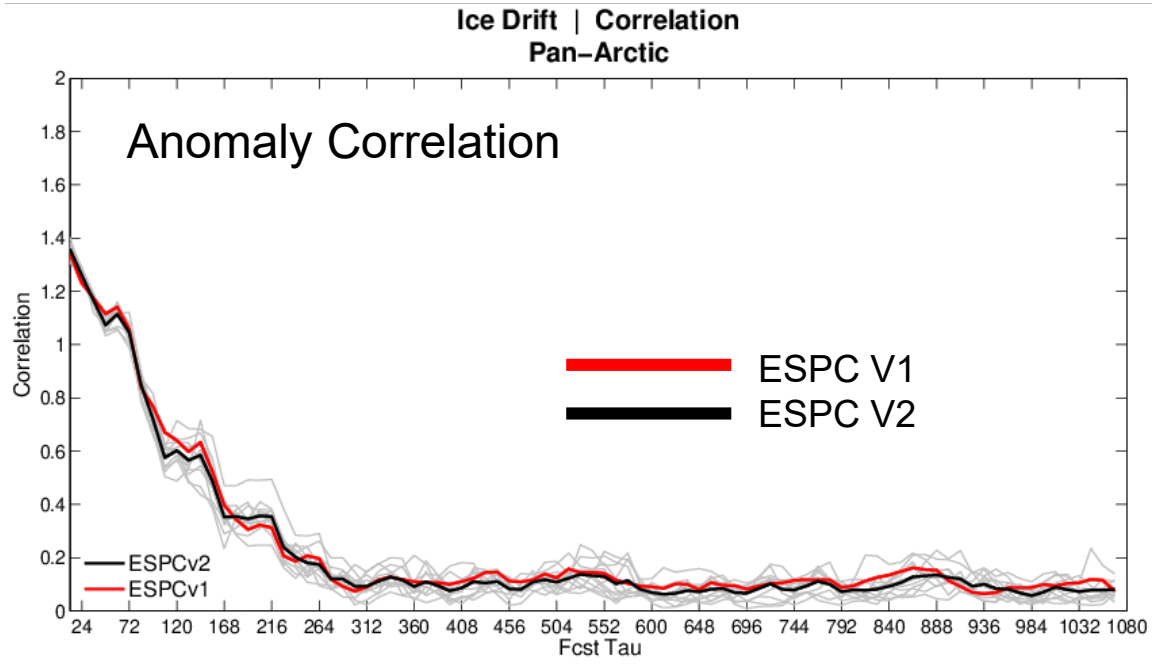
Navy ESPC-E v1 vs. v2 – Preliminary Results

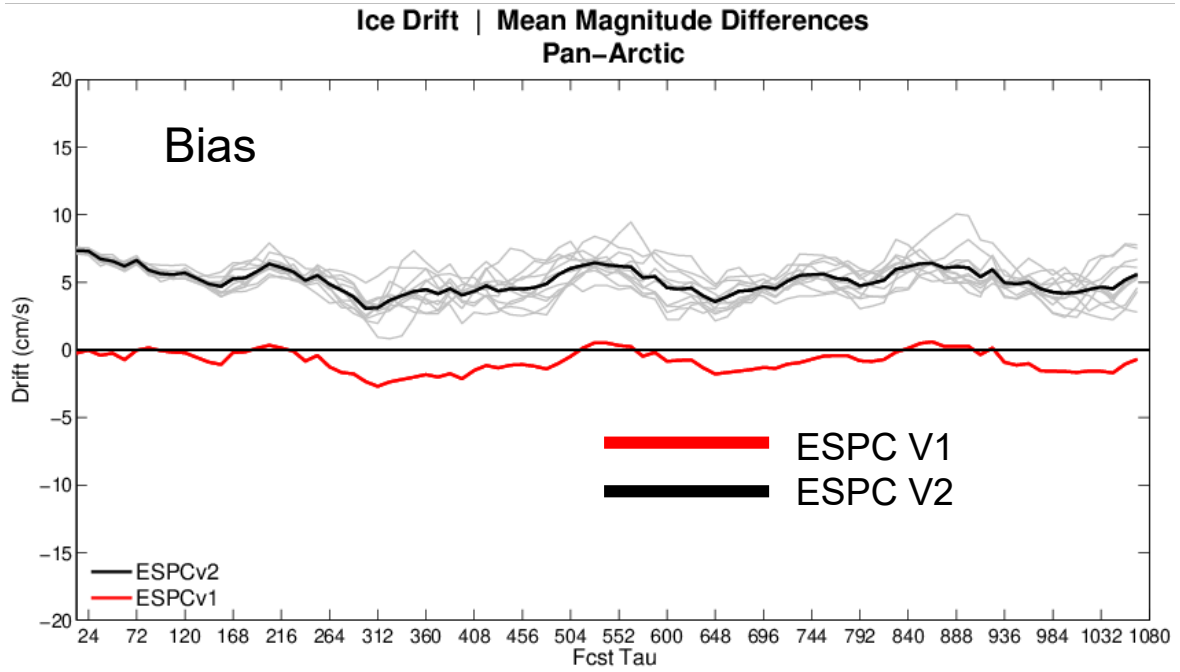
Temperature and Salinity Bias and RMSE for a single ensemble forecast at tau = 44 d



- Biases improved at depths less than 150 m, but worse at depths greater than 300 m
- Temperature RMSE comparable near surface, but improved at all levels deeper than 50 m
- Salinity RMSE improved for depths less than 200 m, comparable below that

Navy ESPC-E v1 vs. v2 Arctic Sea Ice Drift





- Ice drift correlations are very similar between v1 and v2 (and above 0.5 at least out to 5 days)
- However, the bias (mean magnitude differences) is about 5 cm/s (too fast) for v2 and near zero for v1
- Bias exists during the first day and doesn't grow with time
- Investigations continue as to what may be causing this bias (not consistent with wind speed biases)
- Ice edge errors also larger in v2 than in v1

Summary and Future Plans

Navy ESPC-E v1 - Operational at FNMOC in August 2020; weekly 16-member 45-day ensembles

- Used by Joint Typhoon Warning Center for tropical cyclone genesis forecasts
- Used by National Ice Center for resupply mission and field experiment planning

Navy ESPC v2 - Upgrades include ocean waves; middle atmosphere; internal tides; land-fast ice

- ESPC-D v2 operational in August 2024 - comparable or better than stand-alone systems for most (not all) metrics
- ESPC-E v2 validation nearly complete, transition to operations underway - comparable or better than v1 for most metrics (worse for some sea ice metrics)

Navy ESPC v2.1 (2025-2026)

- Improved ensemble design, minor component upgrades

Navy ESPC v3 (2028)

- NEPTUNE[1] will allow km-scale atmosphere-ocean coupled forecasts

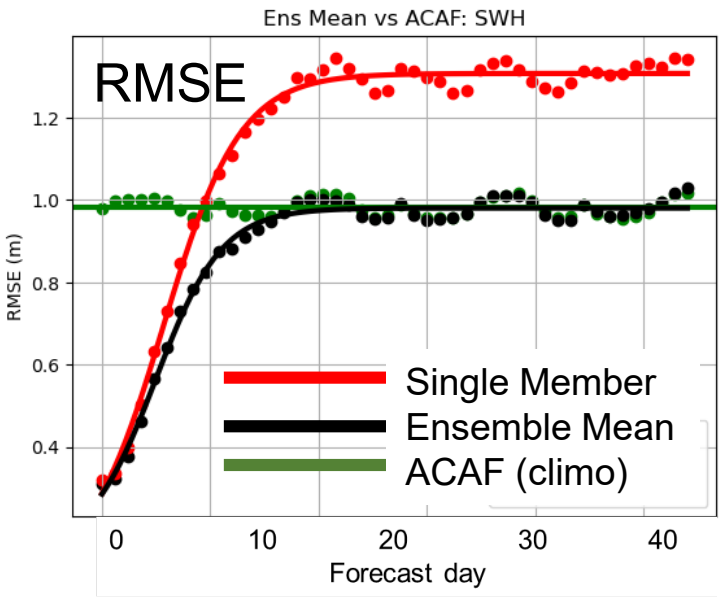
[1]Navy Environmental Prediction sysTem Using a Nonhydrostatic Engine

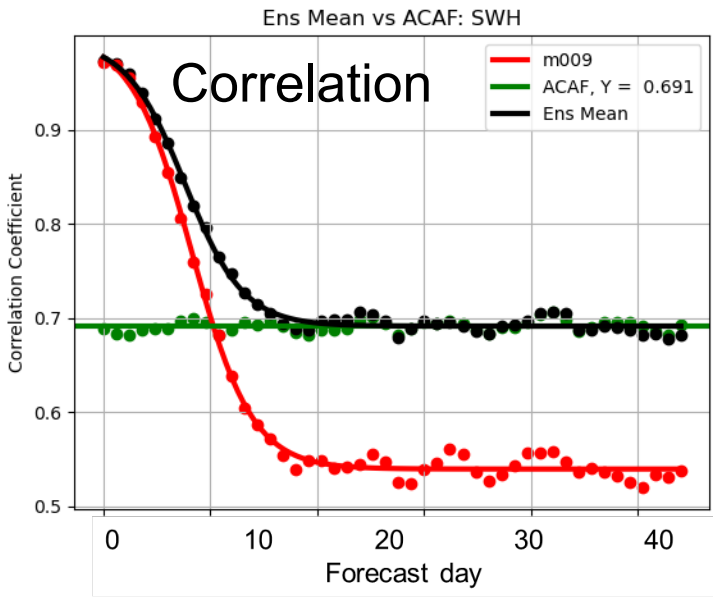
Extra Slides

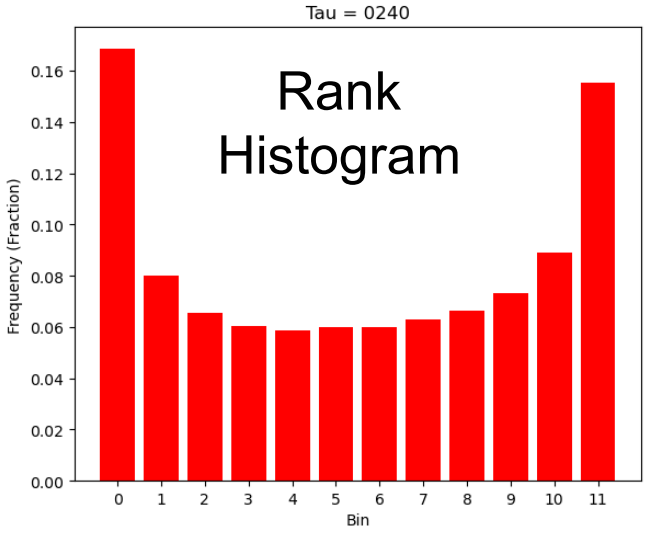
[1]Navy Environmental Prediction sysTem Using a Nonhydrostatic Engine

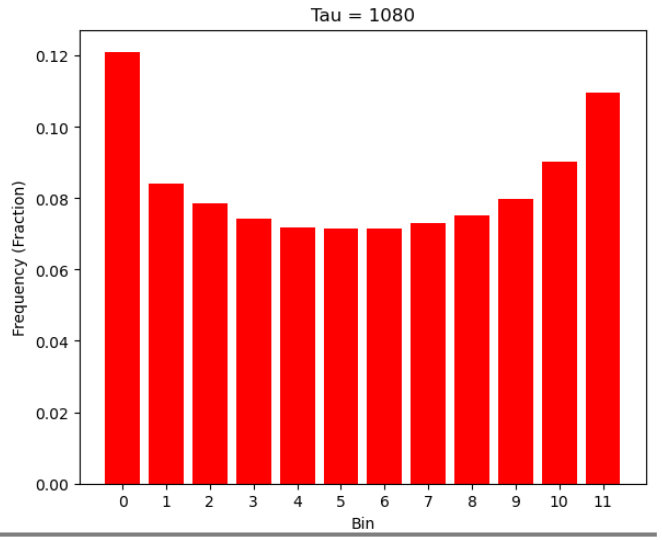
Navy ESPC-E v2 vs Climo Significant Wave Height

Significant Wave Height verification against observations (buoys and altimetry)





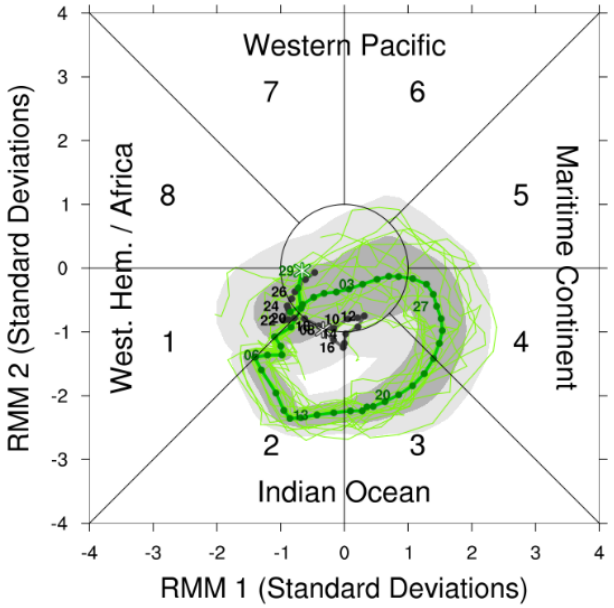




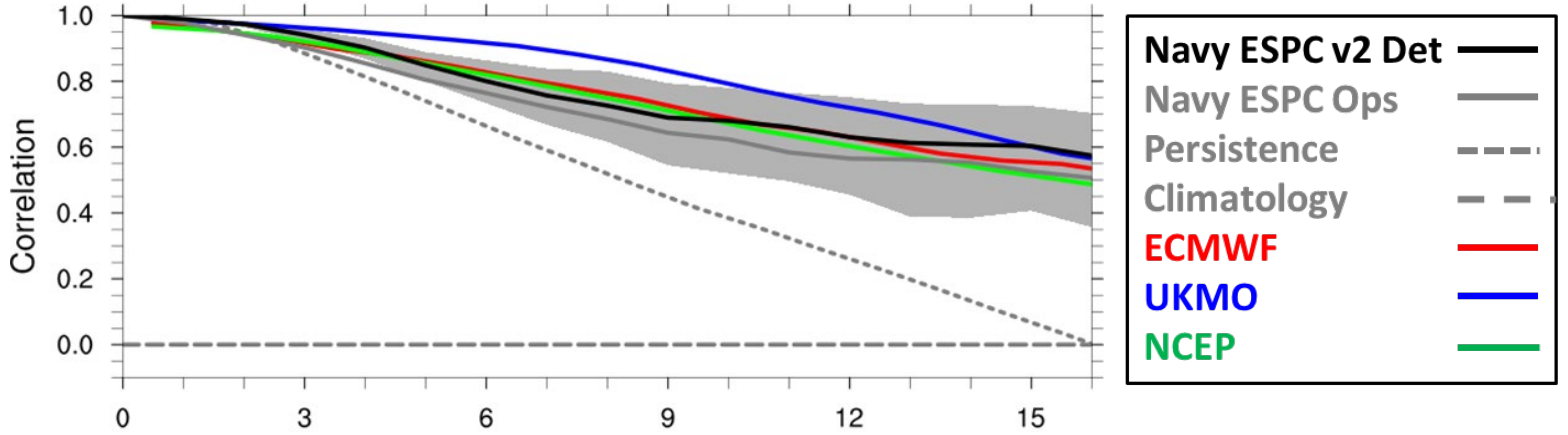
- Single forecast becomes less skillful than climo in about 8 days
- Ensemble forecast becomes comparable to climo around 11-12 days
- Ensemble is under-dispersive (u-shaped rank histogram)
- Tropical predictability a bit longer than extratropical predictability (not shown)

Large-Scale Tropical Environment Products

RMM MJO Forecast Product

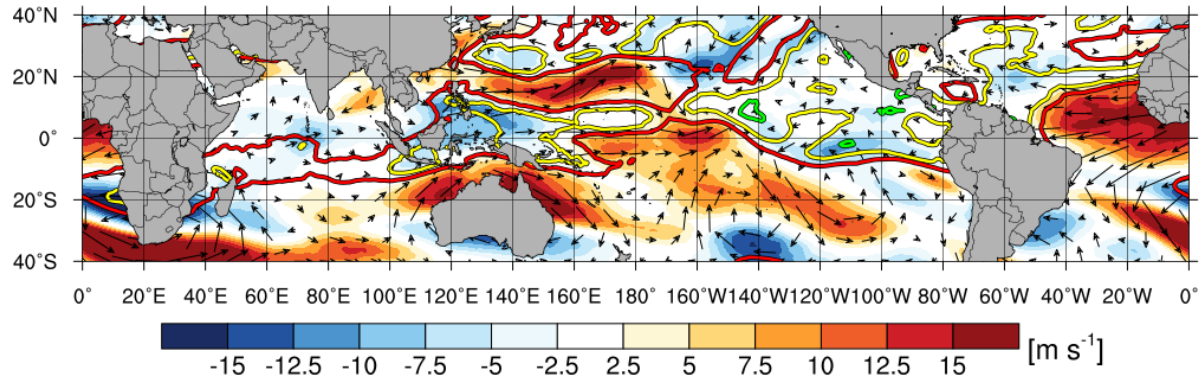


ESPC v2 Deterministic vs ESPC v1 Control and S2S (09/2020 – 08/2021)



Slight improvement in MJO performance in Navy ESPC v2 Deterministic

Weekly-Averaged 850-200 hPa Wind Shear Anomaly Product

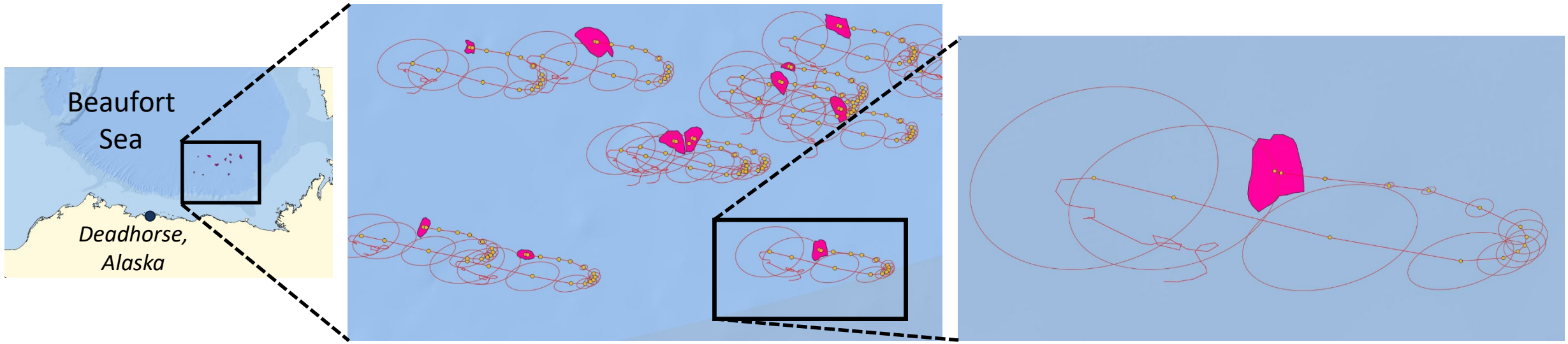


MJO, large-scale tropical environment, and wind shear products produced operationally to help inform JTWC extended-range TC genesis outlooks

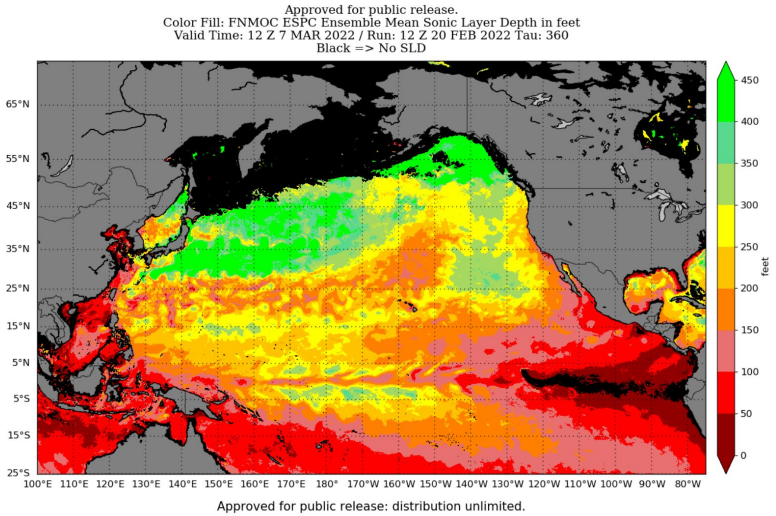
Fleet Use of ESPC-E v1 Products

Ice Exercise (ICEX) 2022 Floe Planning and Tracking

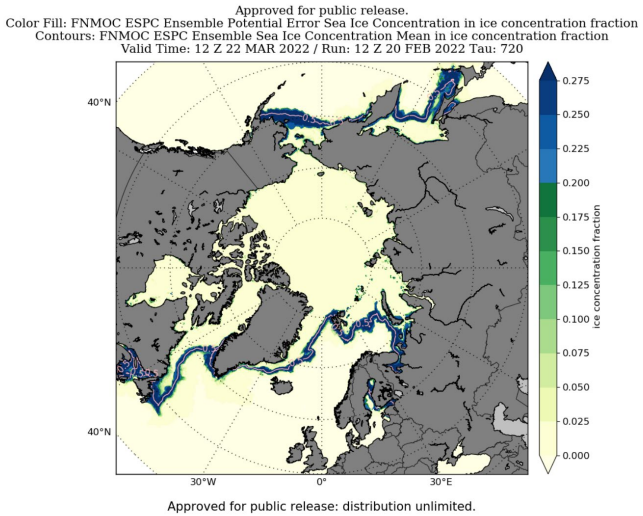
- US National Ice Center assisted in ice floe selection for ICEX 22: Navy ice camp in the Beaufort Sea
- Operational ESPC-E v1 was used to provide forecast track and uncertainty estimates
  - Both prior to floe selection and during the exercise
- Floe must remain within a flyable distance of Deadhorse, 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



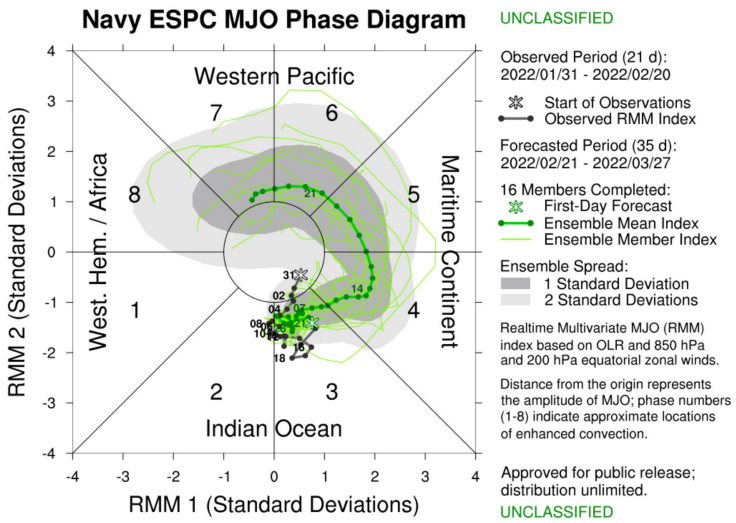
Navy ESPC Outreach and Products



Sonic Layer Depth



Sea Ice Concentration

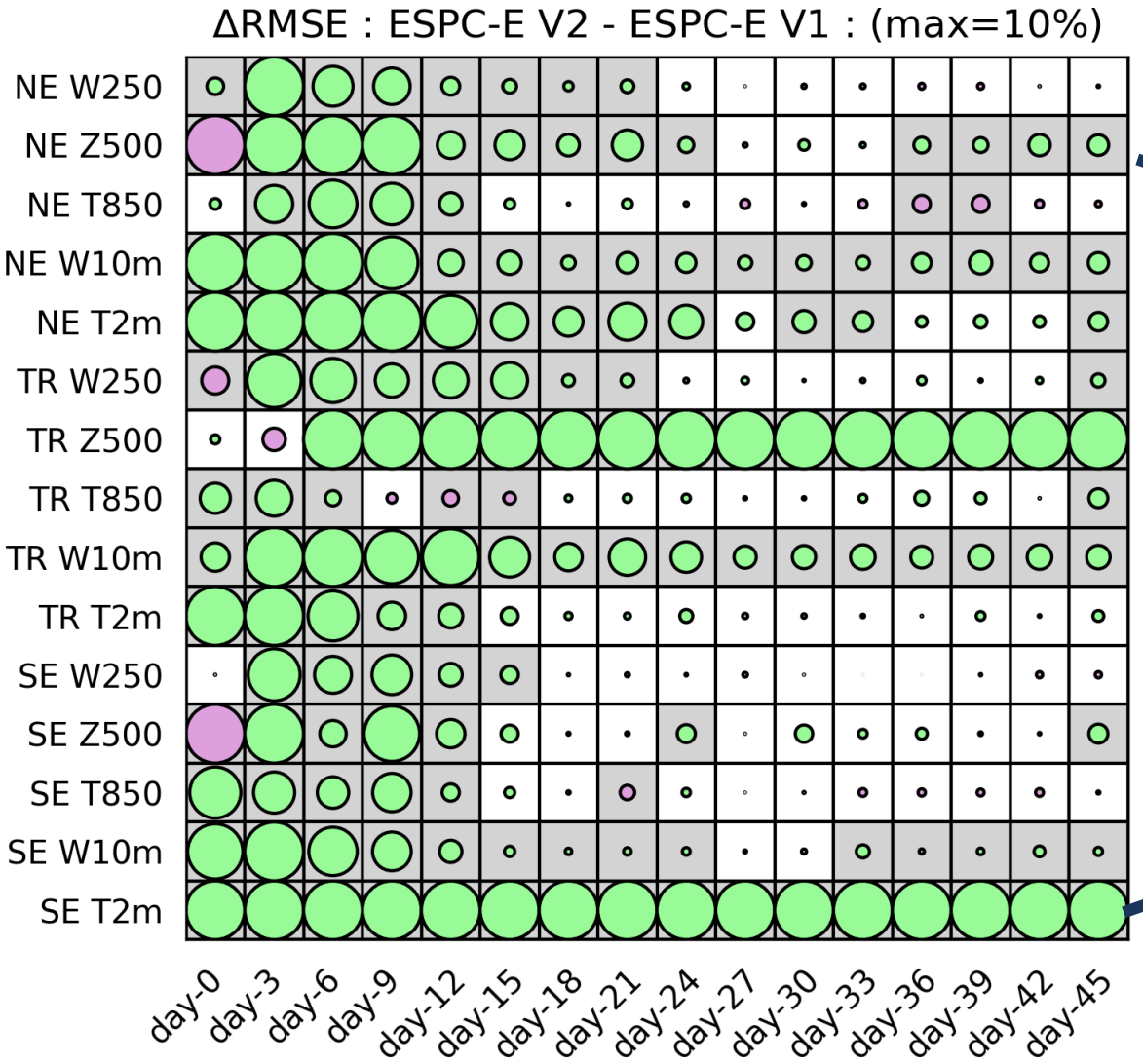


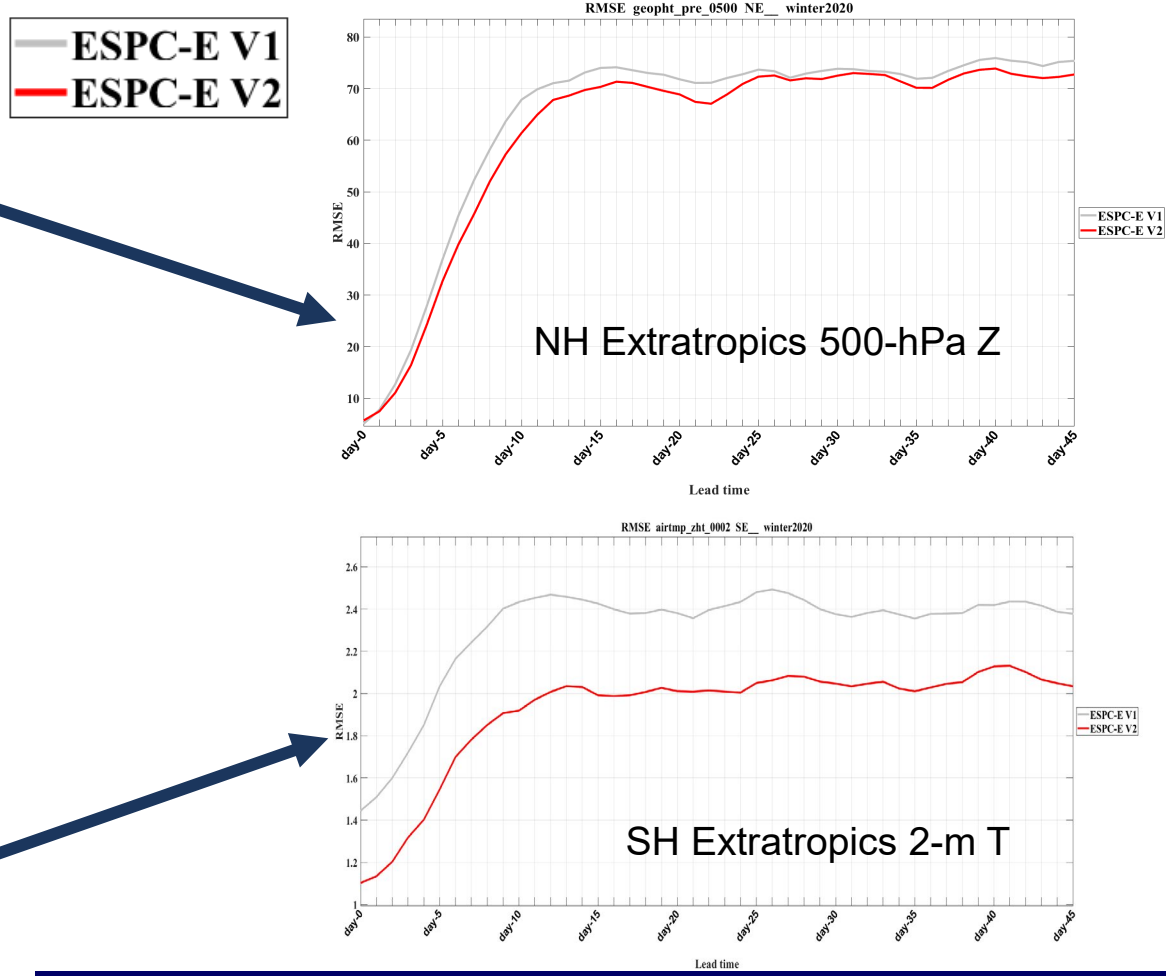
Madden-Julian Oscillation

Product dissemination to Fleet users:

- MJO and tropical anomaly graphics used by JTWC for 2-3 week TC genesis forecasts
- Naval Information Warfighting Development Center using MJO graphics to train students for warfare tactics
- Naval Air Warfare Center Aircraft Division pulling ESPC ensemble data for ASW planning
- US National Ice Center (USNIC) uses ESPC forecasts to assist biennial Ice Exercise (ICEX) and other missions.
- FNMOC Stennis produces several products related to acoustics

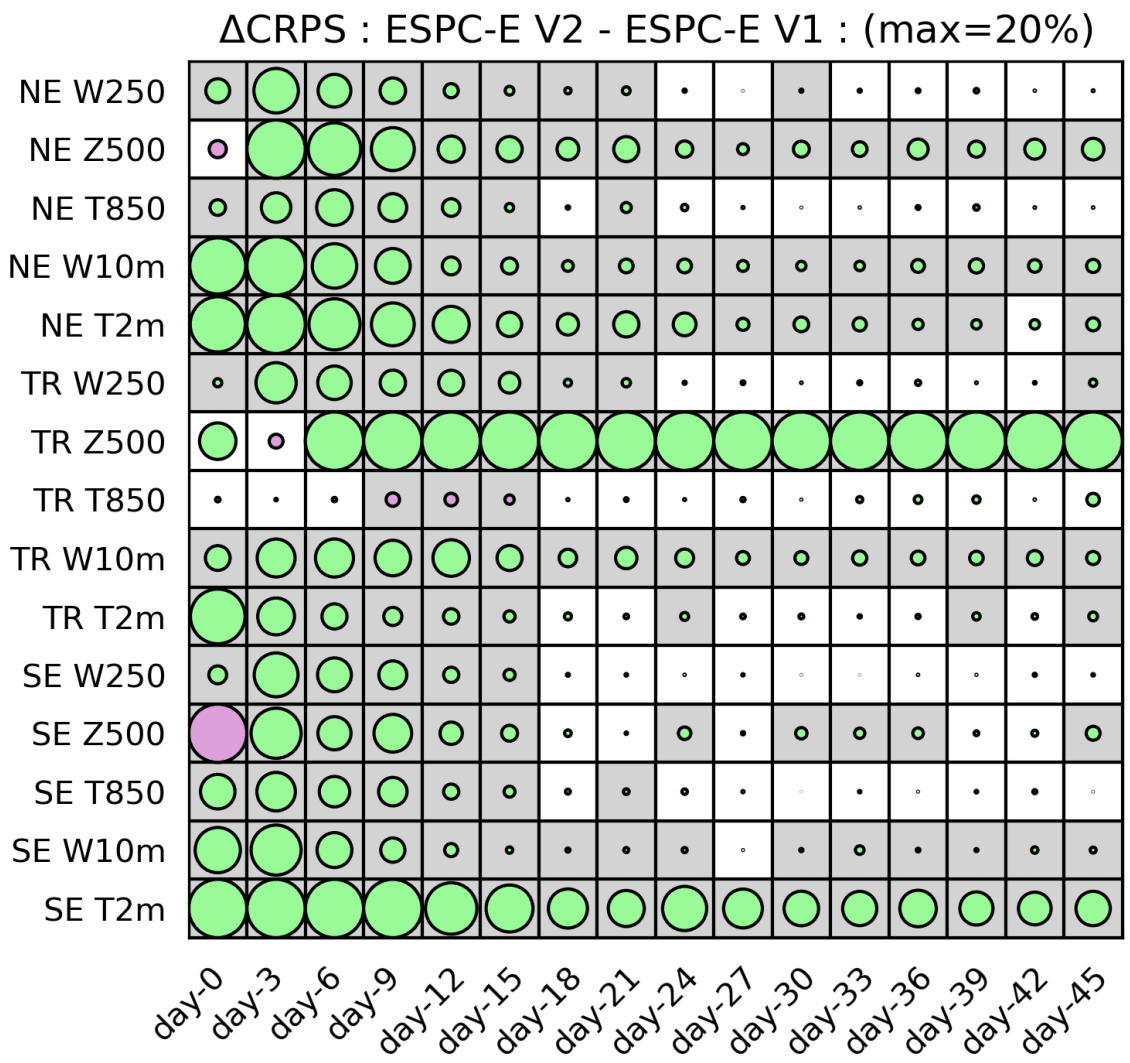
Navy ESPC-E v1 vs. v2 - Atmospheric RMSE

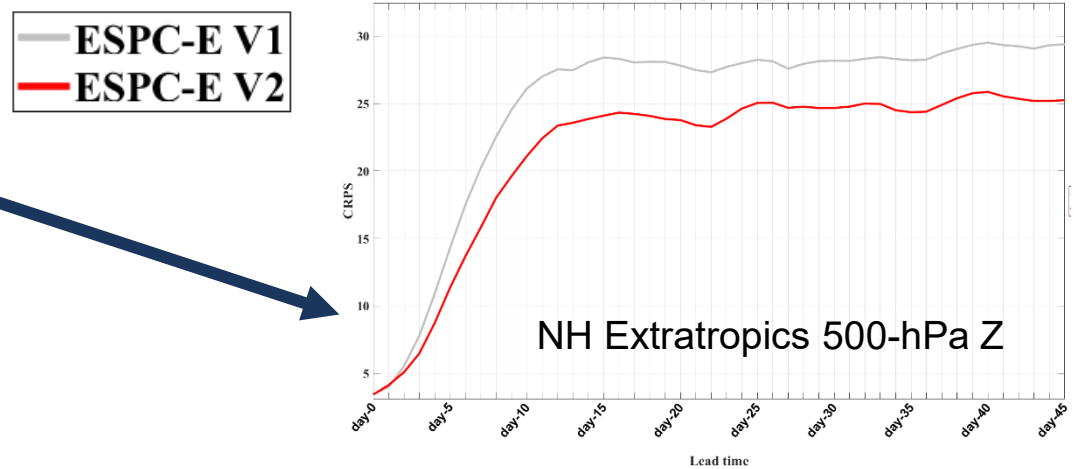


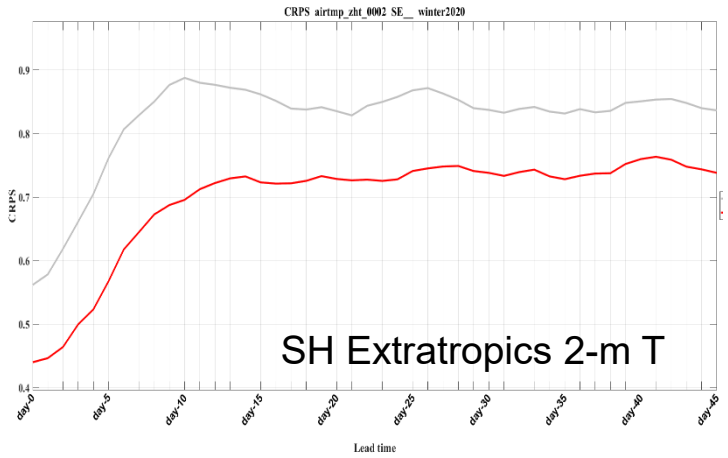


RMSE reduced for almost all fields. 500-hPa Z anomaly correlations (not shown) also improved.

Navy ESPC-E v1 vs. v2 - Atmospheric CRPS

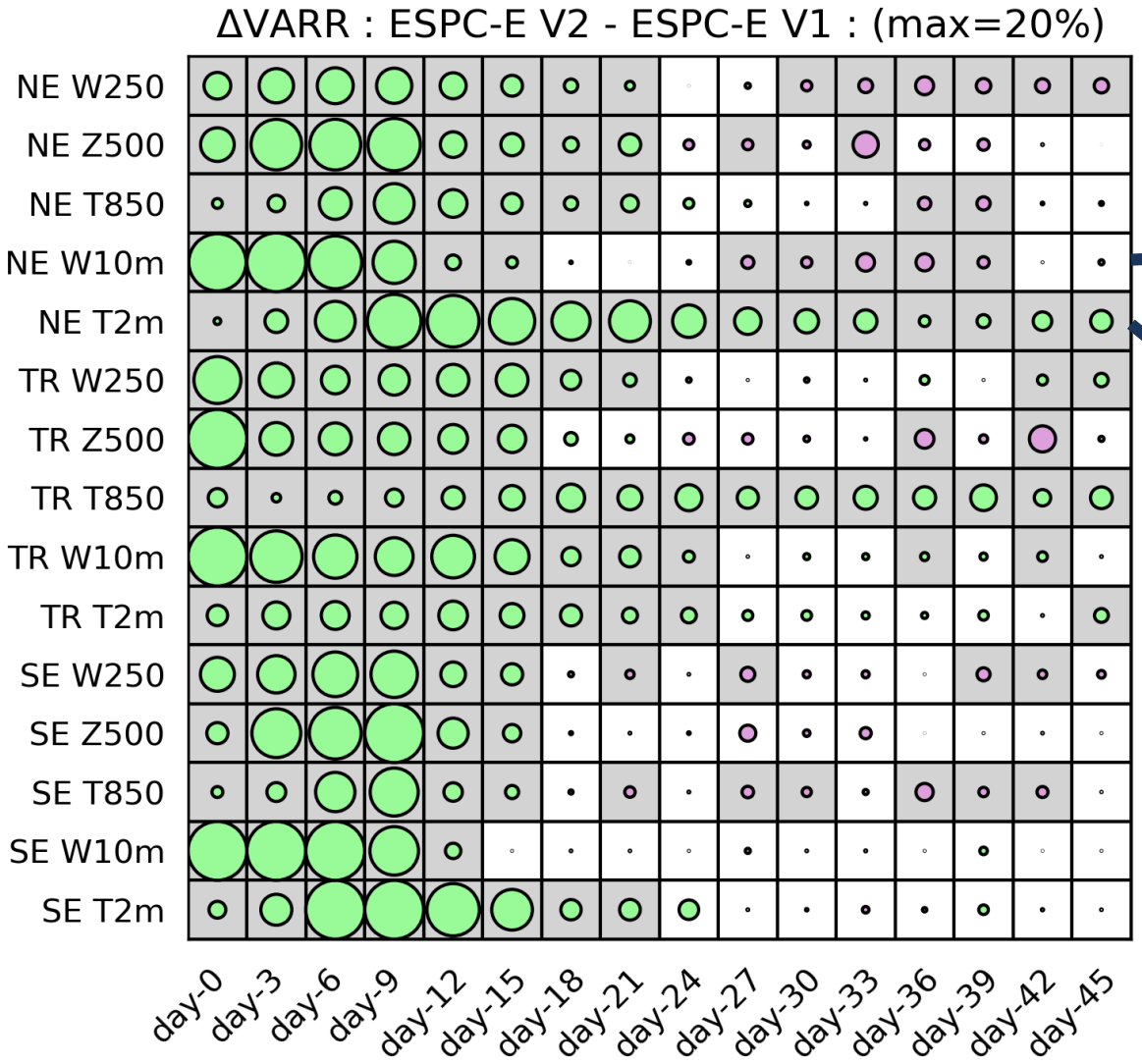




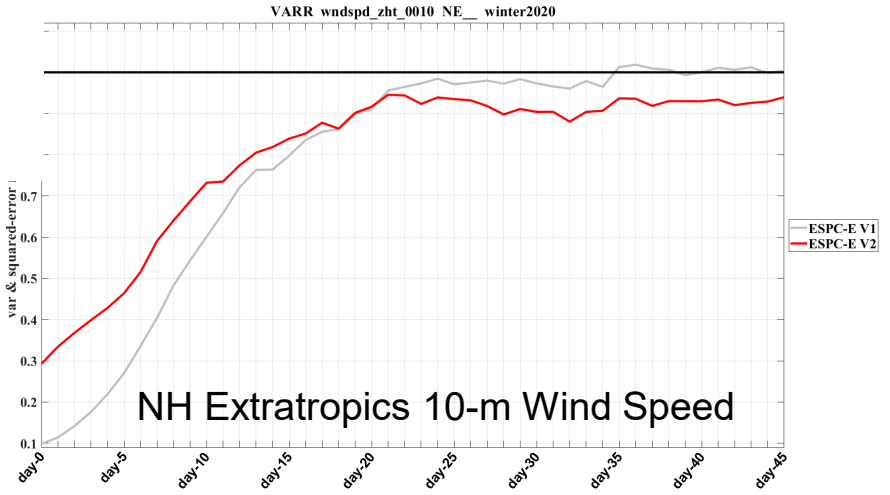


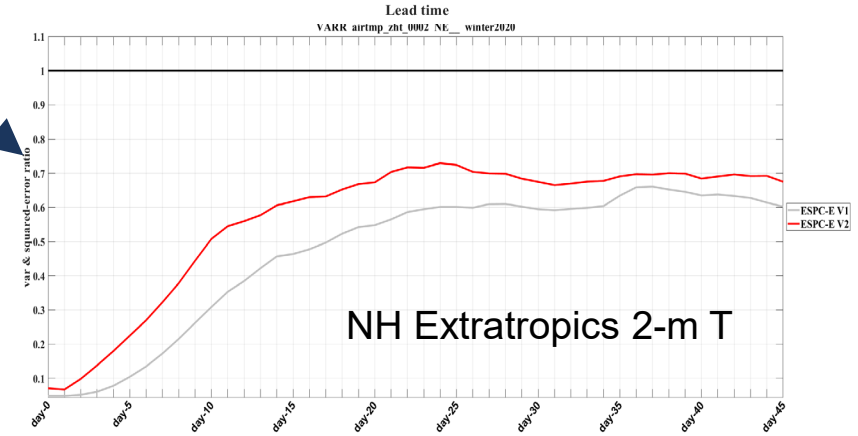
Gains in CRPS are similar to (slightly larger than) those in RMSE

Navy ESPC-E v1 vs. v2 Atmospheric Spread/Skill



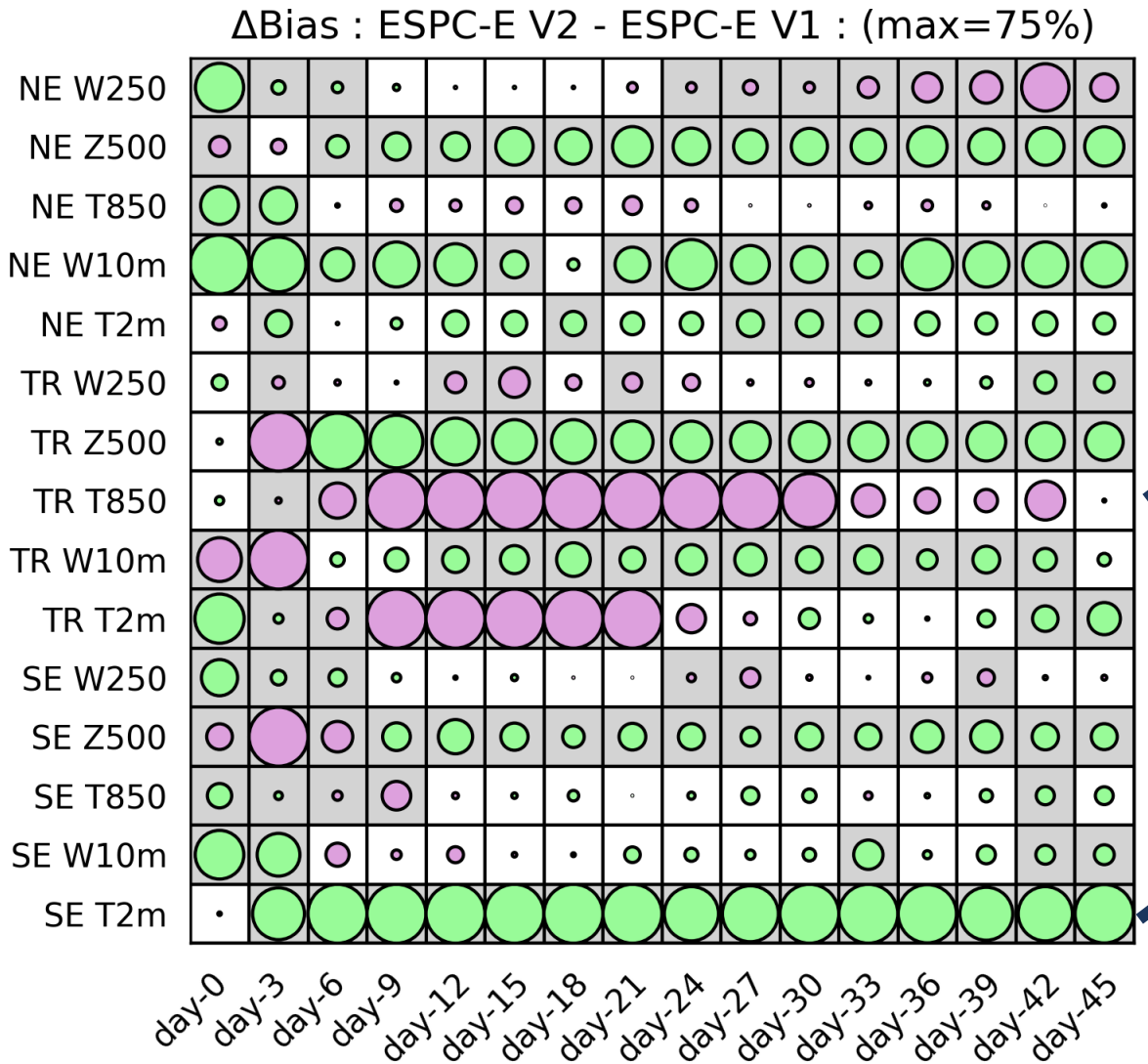


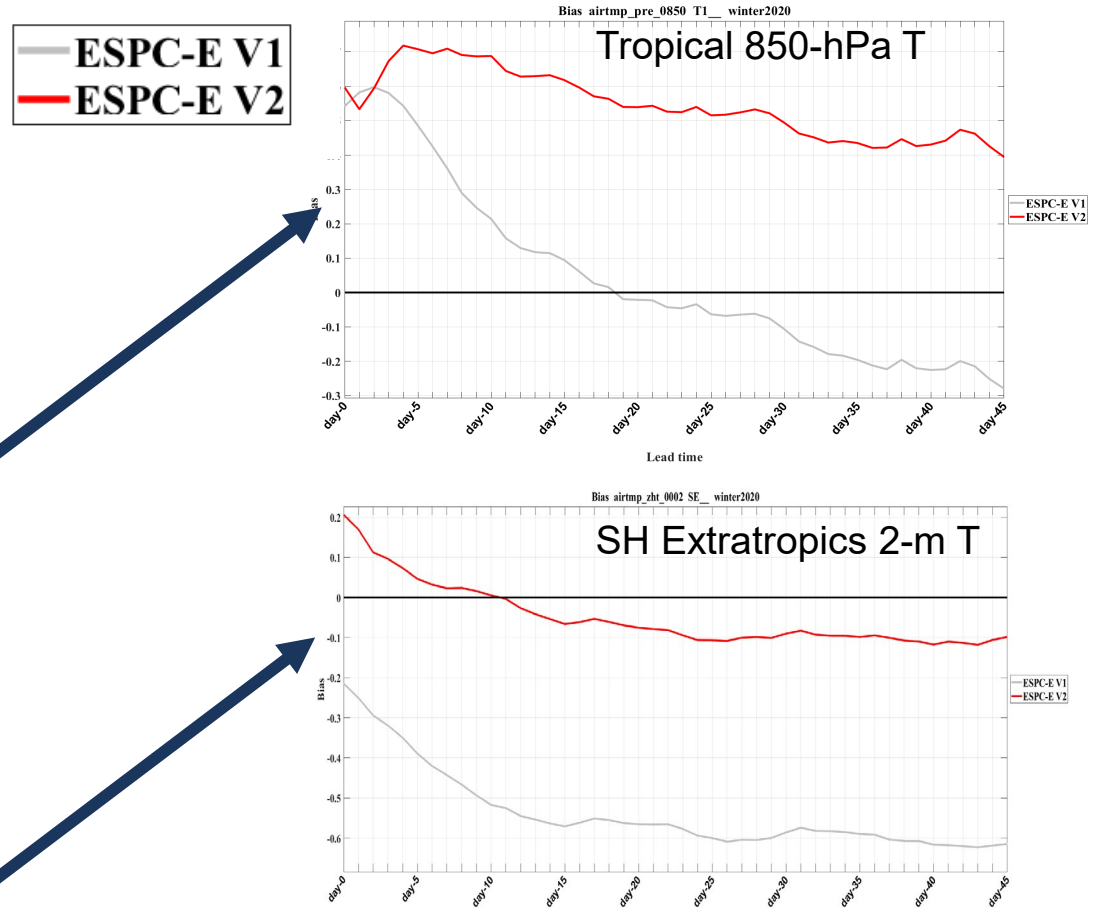




Better spread/skill ratio (VARR) for all metrics at early forecast lead times. For some metrics, VARR slightly worse for v2 at long lead times.

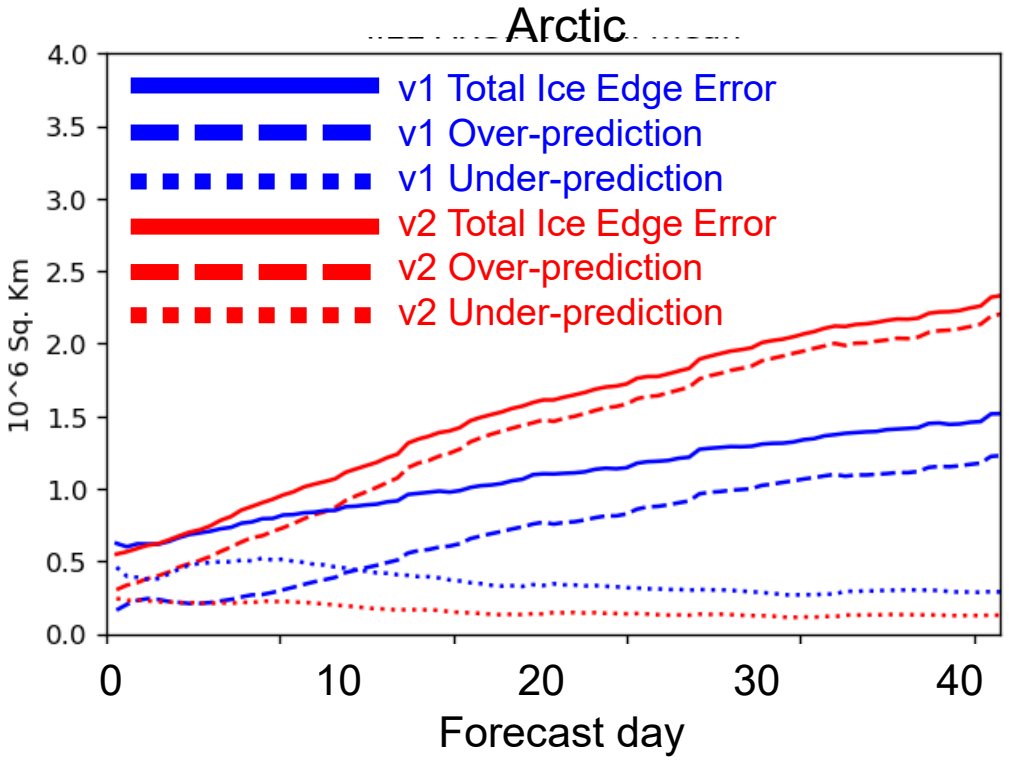
Navy ESPC-E v1 vs. v2 - Atmospheric Bias

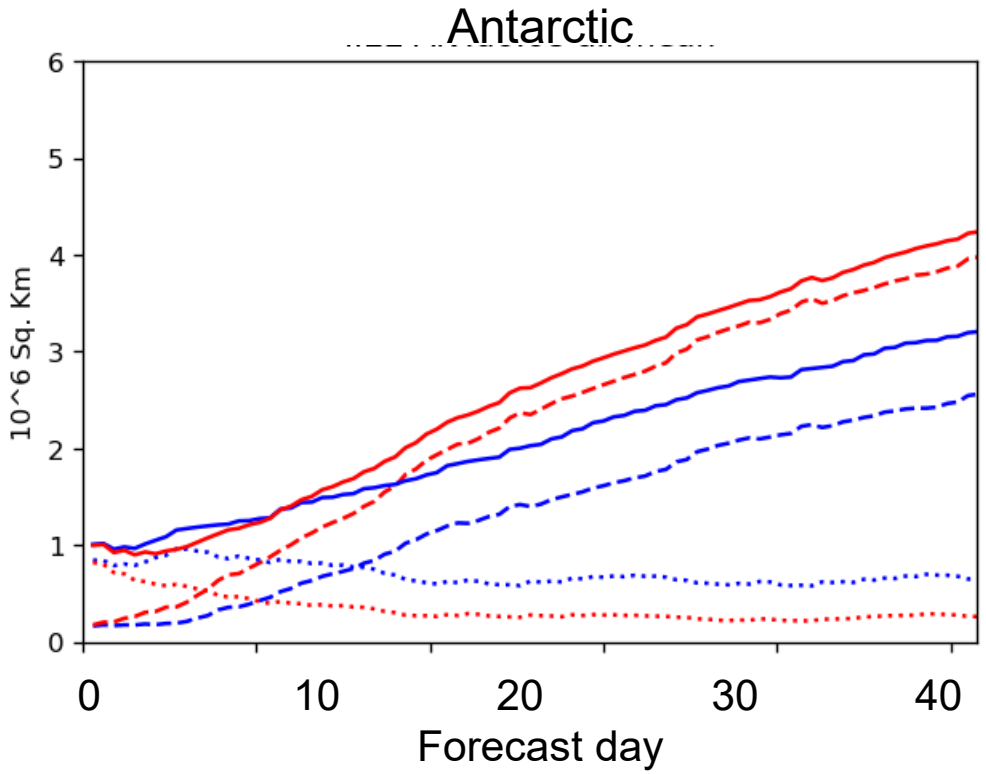




Not all biases are reduced, but more fields have reduced biases than increased biases. Cooling trend in tropical 850-hPa T much slower in v1 then in v1.

Navy ESPC-E v1 vs. v2 Integrated Ice Edge Error





Verification: USNIC Marginal Ice Zone analysis based on multi-source imagery

- Over-predicted regions larger in v2 than in v1, while underpredicted regions larger in v1 than in v2
- Total ice edge error larger in v2 than in v1
- Work continues to try to identify source of faster error growth in v2