The Navy Earth System Prediction Capability Global Coupled Ensemble

27 August 2019

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Acknowledgements: This work was supported under the ONR DRIs Predictability of Seasonal and Intraseasonal Oscillations and Propagation of Intraseasonal Tropical Oscillations, the ONR Navy Earth System Prediction Capability Program, and the NOAA MAPP Subx Project. Computing support was provided by the Navy DoD Supercomputing Resource Center.

U.S. NAVAL RESEARCH LABORATORY

Navy ESPC Global Coupled System

Outline

- The Navy need
- System design recap
  - General specifications
  - DA and ensemble specifics
  - NAVGEM physics changes
- Validation results
  - Atmosphere
  - Ocean
  - Sea-ice
- Ongoing design work
- Summary

Highlights

First Navy system to provide atmospheric forecasts beyond 16 days, ocean and ice forecasts beyond 7 days, and ocean and ice ensemble forecasts.

- Madden Julian Oscillation anomaly correlation forecasts above 0.6 out to 20-30 days.
- NAO, AO, AAO, and PNA forecast anomaly correlation above 0.6 for ~10d.
- SST forecast RMSE verified against ship obs is more skillful than climatology for the entire 60 day forecast period.
- Global ocean temperature / salinity forecast RMSE averaged from 8 to 500 meters is more skillful than climatology out to 30 days and salinity out to 20 days.
- Arctic and Antarctic sea-ice extent forecasts better than climatology in some cases out to 45 days.

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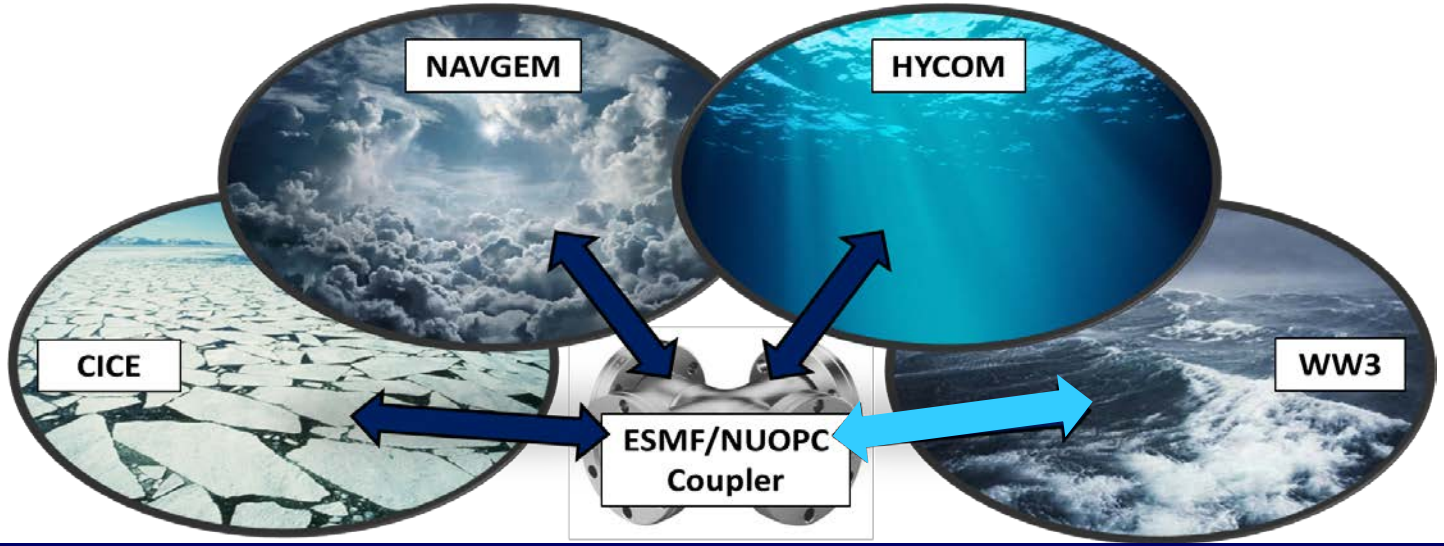
Navy ESPC Global Coupled System



- Developed to meet Navy needs for global earth system forecasts on timescales from days to months:
- Navy ESPC team: NRL Monterey CA, NRL Stennis MS, NRL DC, NOAA ESMF
- Participating in the NOAA SubX (subseasonal experiment): 45-day forecasts produced 4xweek, 1999-present, provides archive for research and system evaluation, and is being used in real time by National Ice Center for resupply mission and field campaign planning.

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Navy ESPC Initial Operational Capability 2020
General specifications

Forecast	Time Range, Frequency	Atmosphere NAVGEM	Ocean HYCOM	Ice CICE	Waves WW3[3]
Deterministic short term	0-16 days, Daily	T681L60 (19 km) 60 levels	**1/25° (4.5 km)** 41 layers	**1/25° (4.5 km)**	1/8° (14 km)
Probabilistic long term	0-45 days 16 members once per week	T359L60 (37 km) 60 levels	**1/12° (9 km)** 41 layers	**1/12° (9 km)**	1/4° (28 km)

- **Very high resolution ocean and ice components compared to other systems**
- **Final Operational Capability: FY22 (seasonal forecasts, coupled data assimilation, interactive ocean surface waves).**
- **Will not immediately replace the stand-alone atmospheric system (NAVGEM ET) due to resource constraints.**

Navy ESPC Initial Operational Capability 2020
DA and ensemble configuration

Weakly-Coupled Data Assimilation

Background (prior) forecasts taken from fully-coupled simulation but DA solve is uncoupled

NAVDAS-AR (hybrid-4DVAR) system used for atmosphere

NCODA (3DVAR) system used for ocean and ice

Ensemble

Models: NAVGEM CV3, HYCOM, CICE v4

Generation: 16 independent DA cycles with randomly perturbed observations
(not to be confused with an ensemble Kalman filter [EnKF])
No dynamical conditioning
No prior/posterior inflation, no stochastic forcing

With current resources, member production must be staggered in time across different machines.

This is a short-term situation.

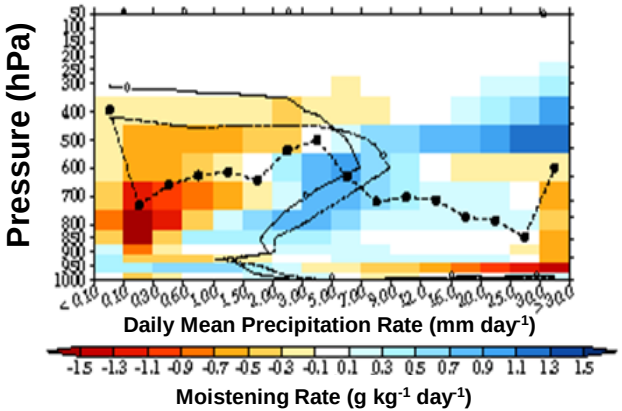
NAVGEM model updates for Navy ESPC

	NAVGEM v1.4	Navy ESPC NAVGEM CV3
Convection Parameterization:	SAS	Modified Kain-Fritsch
Boundary Layer Scheme:	Luis	COARE 3

Kain-Fritsch modifications:

1. Modified cloud top constraint to better represent feedbacks between convection and environmental moisture (Klingaman et al. 2015, JGR)
2. Mixed-layer Richardson number constraint on the turbulence-forced convective component (Ridout and Reynolds, 1998).

Observed moistening rate



NAVGEM CV3 moistening rate

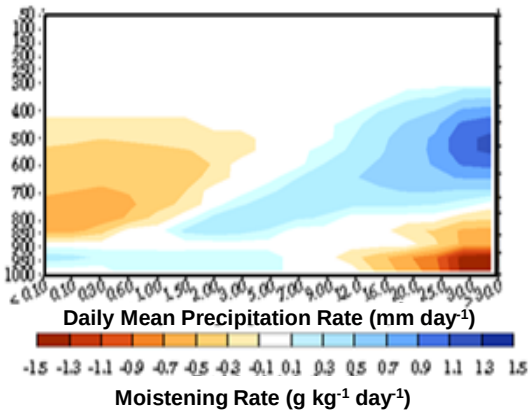
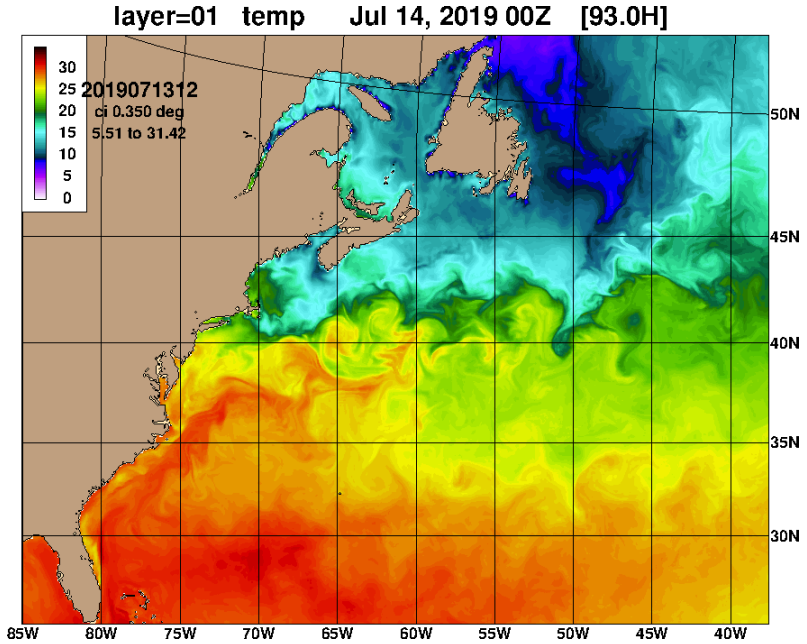


Illustration: High Resolution Ocean

GOFS 3.1 1/12° Global HYCOM+CICE

NCODA 3dvar (daily mean as background), NAVGEM forcing, ISOP

SST



Salinity

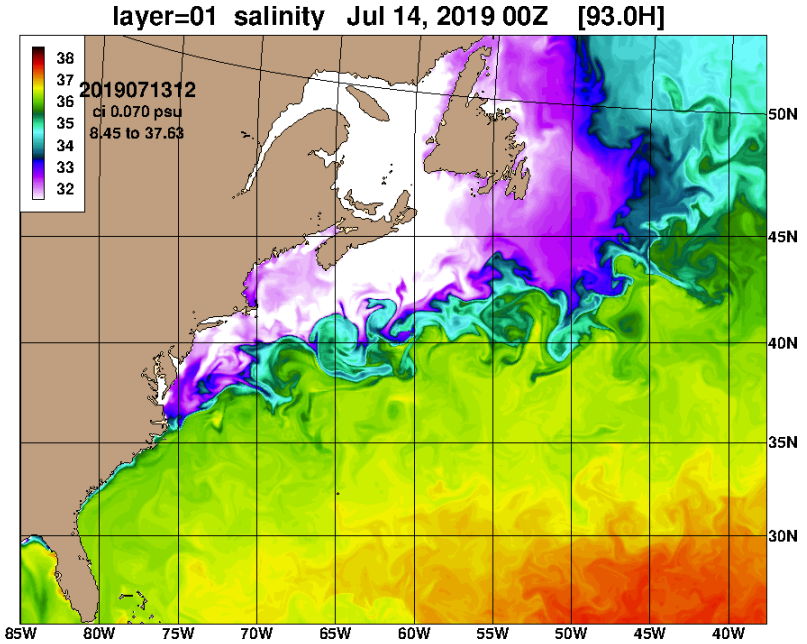
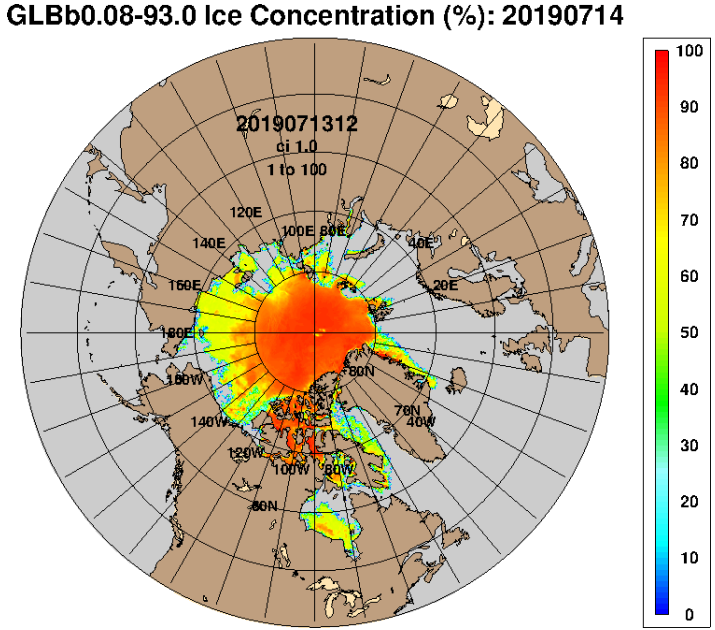


Illustration: High Resolution Sea-Ice

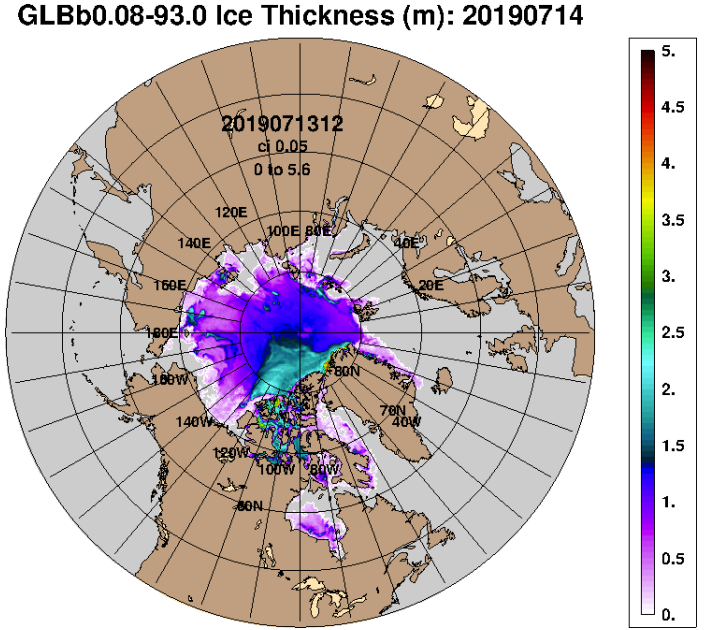
GOFS 3.1 1/12° Global HYCOM+CICE

NCODA 3dvar (daily mean as background), NAVGEM forcing, ISOP

Sea-ice concentration



Sea-ice thickness



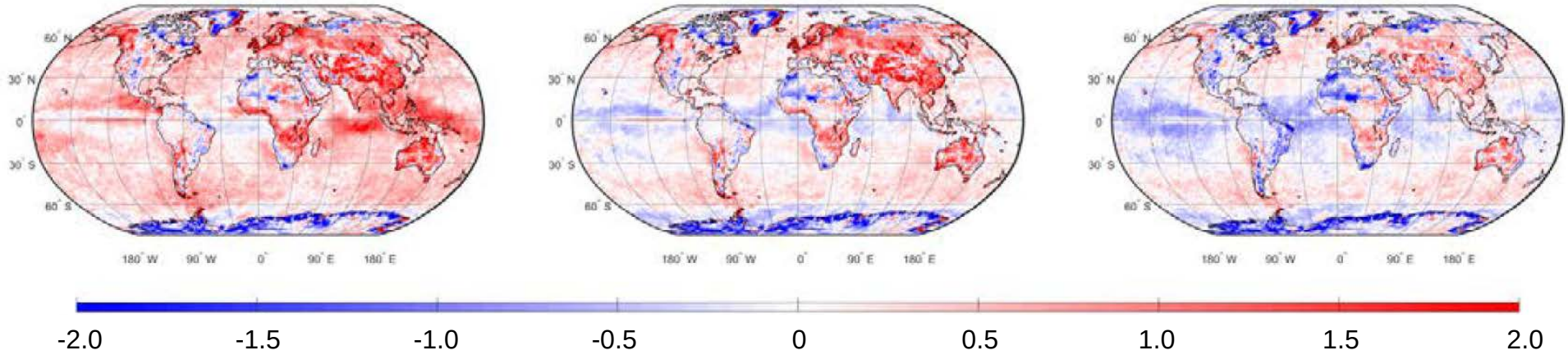
Navy ESPC Validation: Atmospheric Diagnostics

Analysis bias (ms^{-1}) for 10-m wind speed relative to ECMWF

NAVGEM ET ensemble
Uncoupled low-resolution

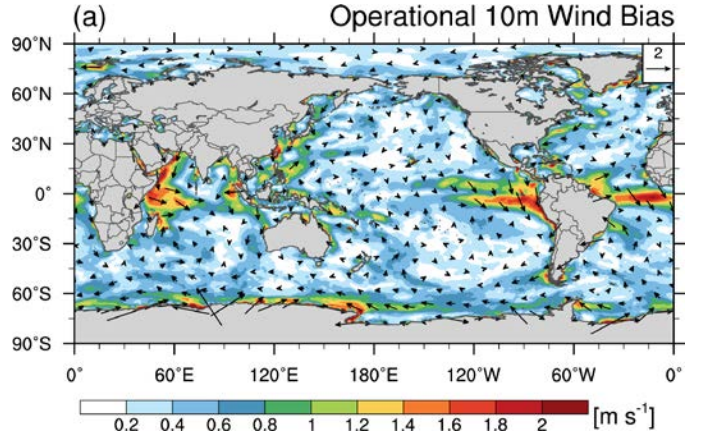
Navy ESPC ensemble
Coupled low-resolution

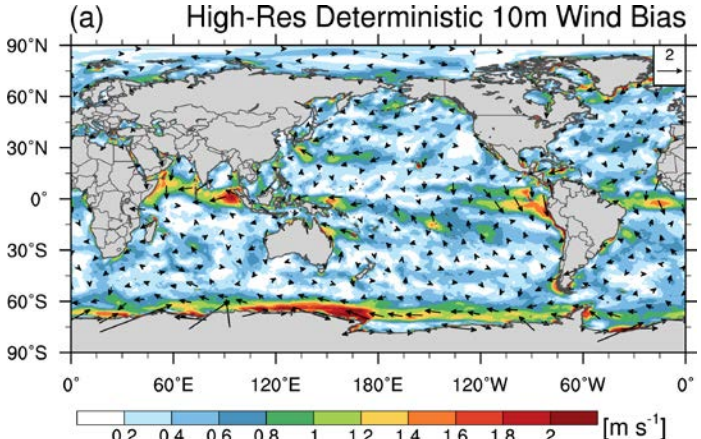
Navy ESPC deterministic
Coupled high-resolution



The Navy ESPC coupled analysis shows reduced bias for 10m wind speed over the oceans. In some regions this improvement is on the order of 1.5 to 2 ms-1.

Navy ESPC Validation: Atmospheric Diagnostics

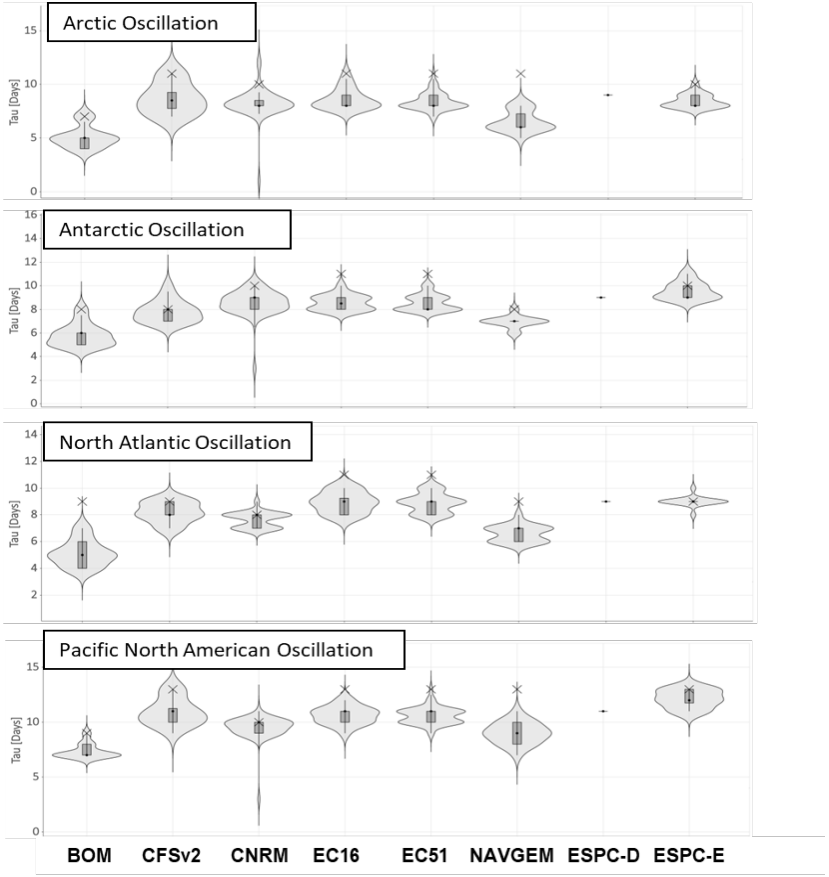




Deterministic 10-m wind speed biases (shading) and wind vector errors (vectors) for operational NAVGEM (top) and Navy ESPC (bottom) averaged for the first 7 days as verified against ECMWF analysis.

Navy ESPC shows improved performance over most of the tropics, western boundary current regions. Degradation in skill off the coast of Antarctica and eastern Indian Ocean.

Navy ESPC Validation: Atmospheric Teleconnection Indices

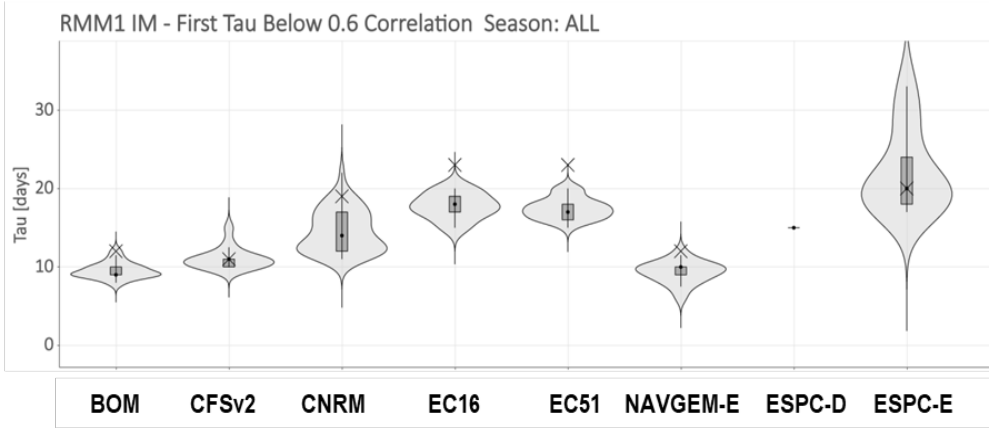


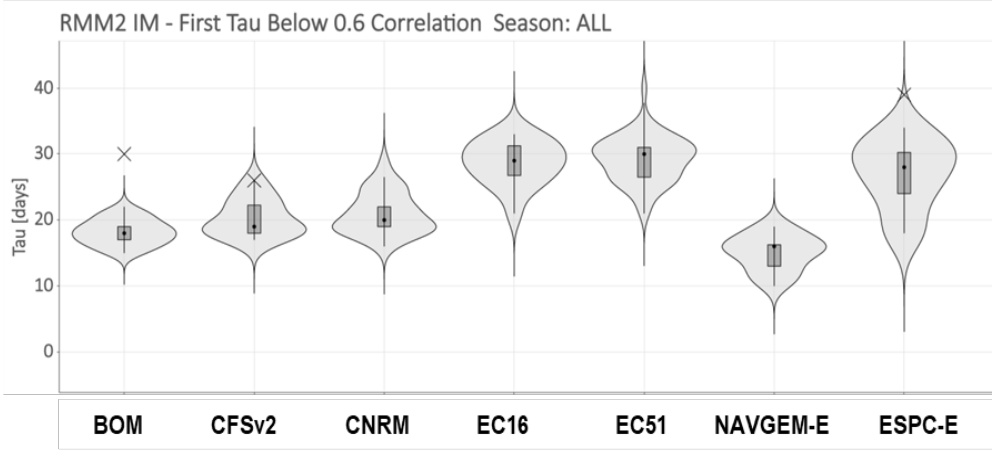
Distribution of days where individual forecast teleconnection index correlation drops below 0.6 (ensemble mean denoted by "x")

Navy competitive for teleconnection forecasts, very good for AAO and PNA (higher is better).

**Note: Underdispersion will increase average of individual forecast skill.*

Navy ESPC Validation: MJO





Distribution of days where individual forecast MJO correlation drops below 0.6 (ensemble mean denoted by "x")

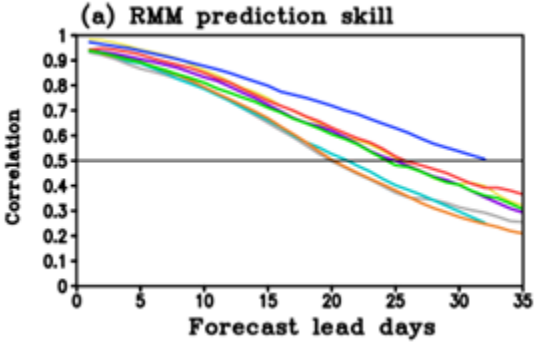
Individual forecasts very skillful for RMM1, however, ensemble skill does not match some other centers due to ensembles being under-dispersive.

**Note: Underdispersion will increase average of individual forecast skill.*

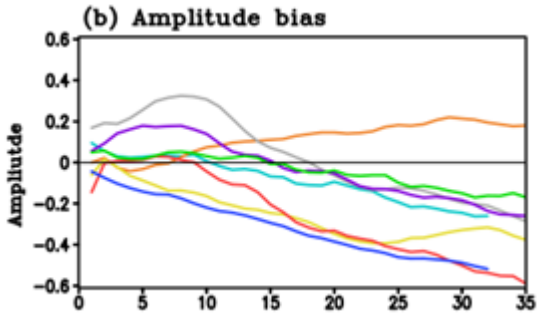
Navy ESPC Validation: MJO

RMM from the forecast ensemble mean compared against observations, for initially strong MJOs.

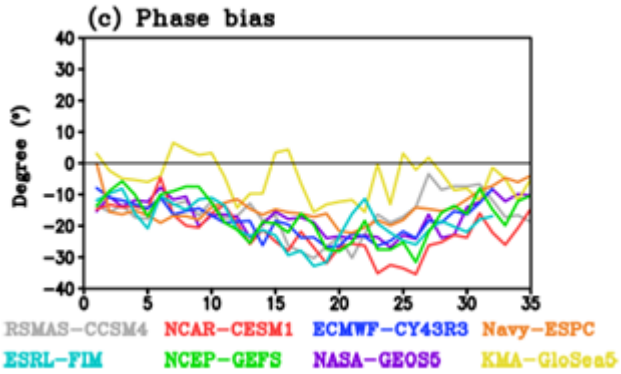
Bivariate correlation coefficient



Amplitude bias



phase bias

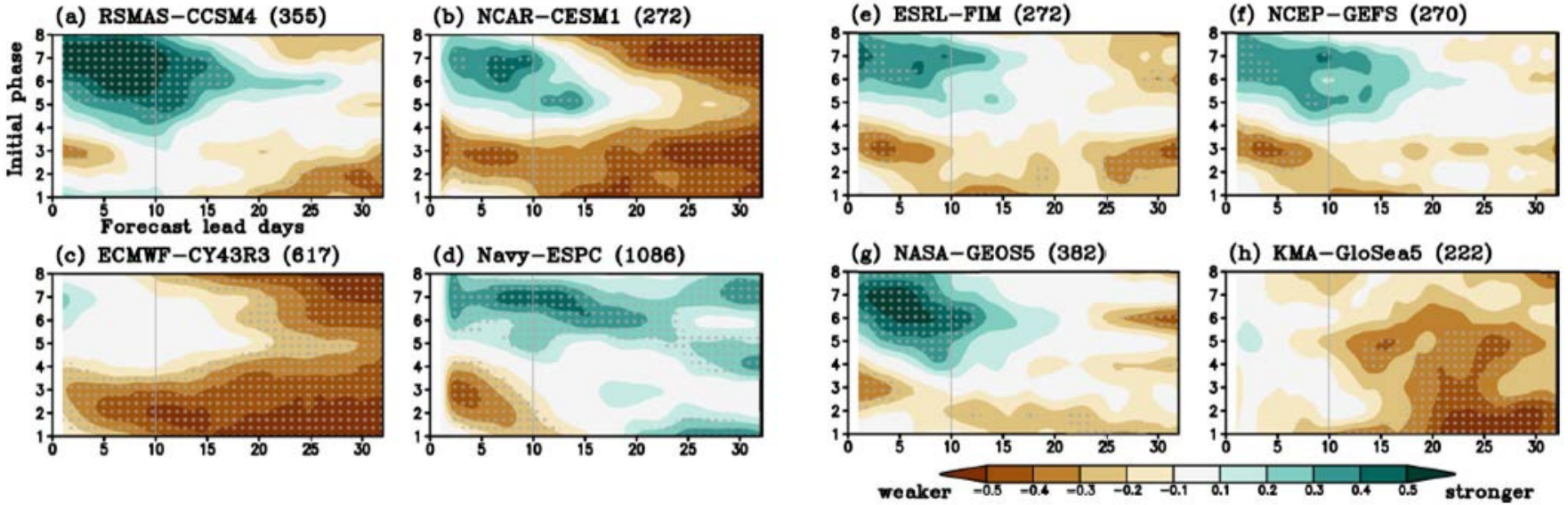


Negative value indicates weaker and slower MJO than in observations, respectively.

Kim et al. 2019, JGR

Navy ESPC Validation: MJO

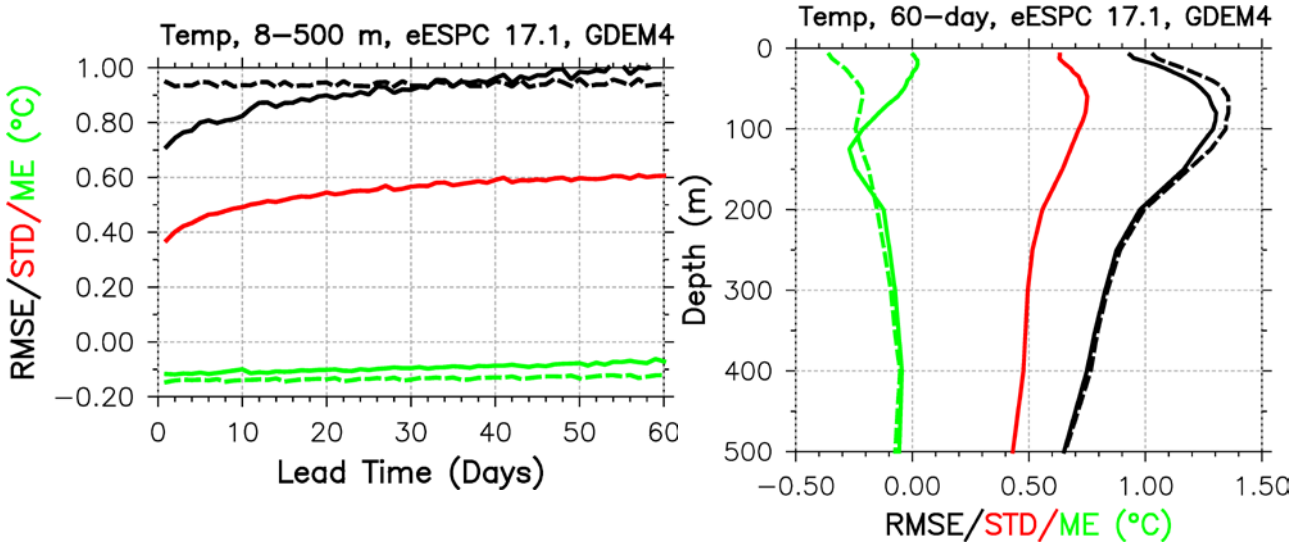
Amplitude bias as a function of initial MJO phase and forecast lead day. Numbers in parentheses indicate the number of selected initially strong MJO events. Stipples mark significant results at the 95% confidence level.



Kim et al. 2019, JGR

Navy ESPC Ensemble Ocean Diagnostics

RMSE, bias, and standard deviation of the ensemble mean ocean temperature over 8-500 m depth.

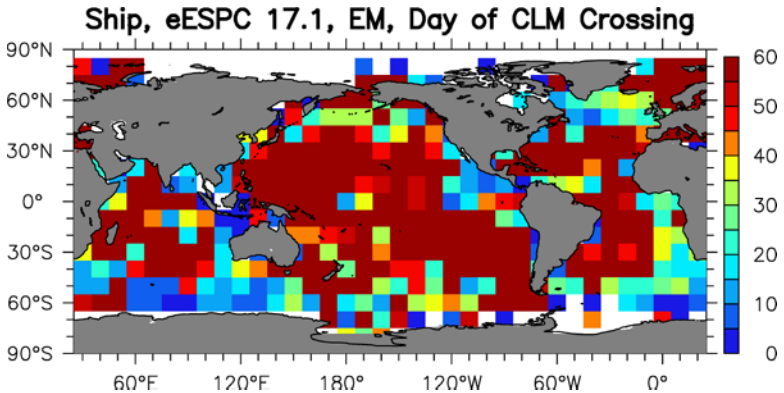


Dashed lines indicate the GDEM BIAS and RMSE.

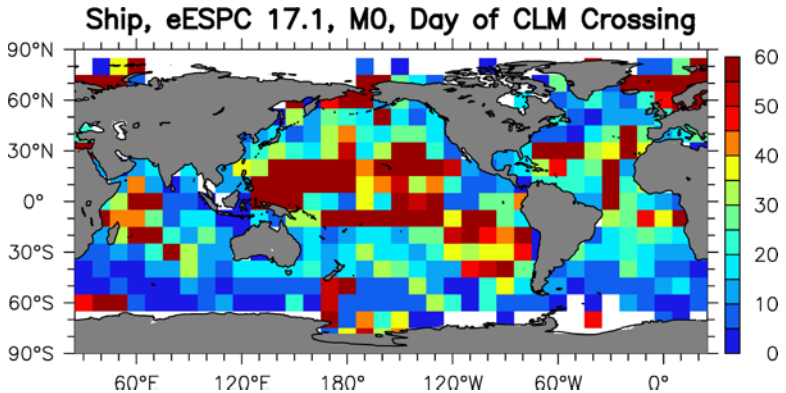
Navy ESPC Validation
Ocean Diagnostics

Spatial distribution of the forecast day when the SST forecast RMSE crosses the climatological RMSE, validated using ship SST observations.

Ensemble Mean

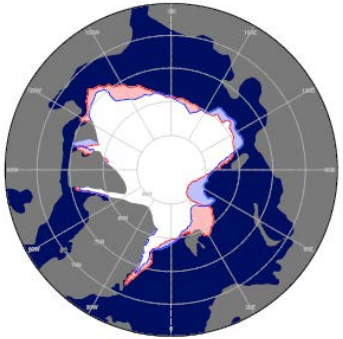


Control Member



A 60-day crossing suggests the model has value out to 60 days or longer.

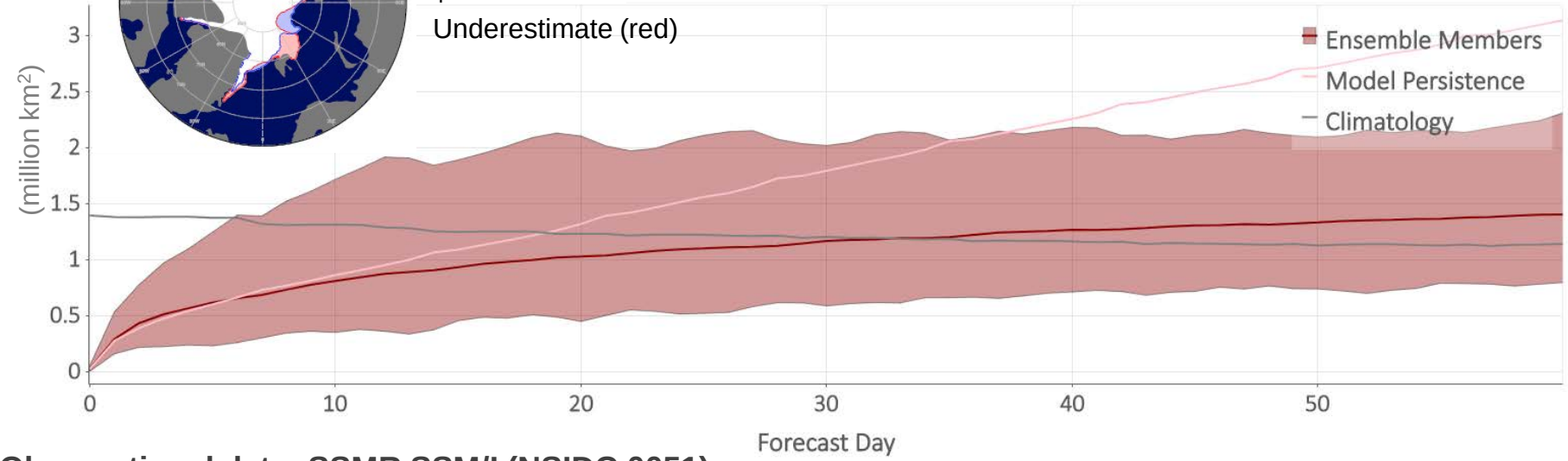
Navy ESPC Validation
Sea-Ice Diagnostics



Goessling et al. (2016) *GRL*

Overestimate (blue)
+
Underestimate (red)

Integrated Ice-Edge Error for the Arctic

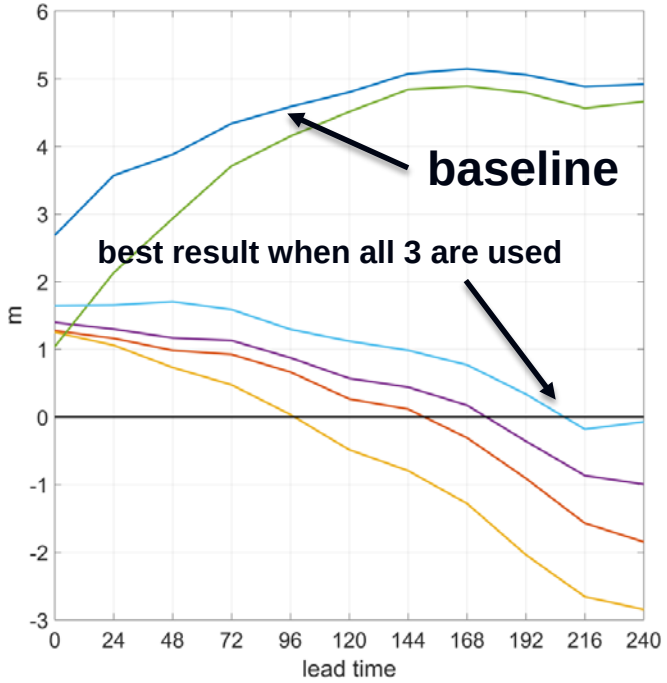


Observational data: SSMR SSM/I (NSIDC 0051)
Climatology: 2007 to 2017
Ice Edge Defined by 15%

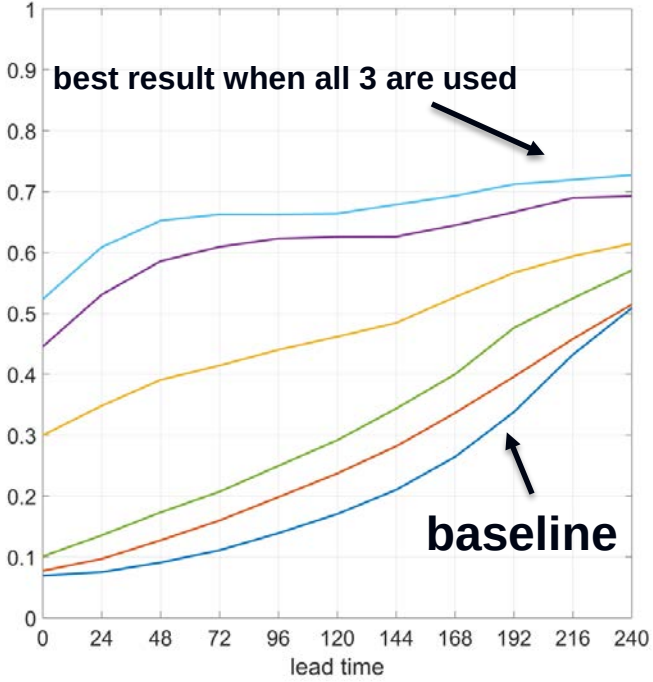
Ongoing ensemble design work: Dynamical conditioning and stochastic forcing

PO_{bl} $PO_{acai(.5)}$ $PO_{rtpp+acai(.5)}$ $PO_{rtpp+acai(1)}$ PO_{skeb} $PO_{rtpp+acai(1)+skeb}$

NE: 500hPa height bias



NE: 10m wind speed spread-skill



Methods being tested include relaxation to prior perturbation (RTPP), analysis correction-based additive inflation (ACAI), and SKEB

Navy ESPC Global Coupled Ensemble

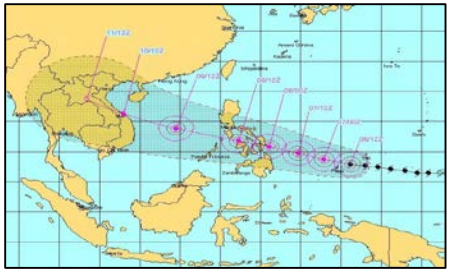
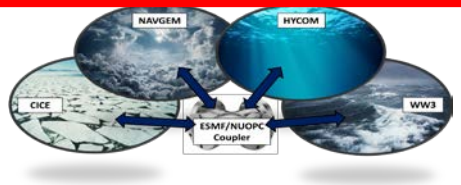
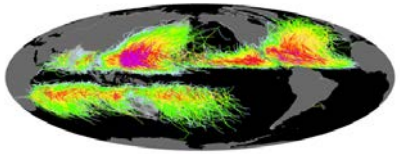
Summary

- Operational transition scheduled for FY19
- Relatively high resolution ocean ice models (1/12^{o} for ensembles, 1/25^{o} for deterministic)
- Initial results promising; There is much upside as the ensemble design is improved
- Latency issues preclude replacement of stand-alone NAVGEM forecasts
- SubX runs being used by National Ice Center for resupply missions and field campaigns

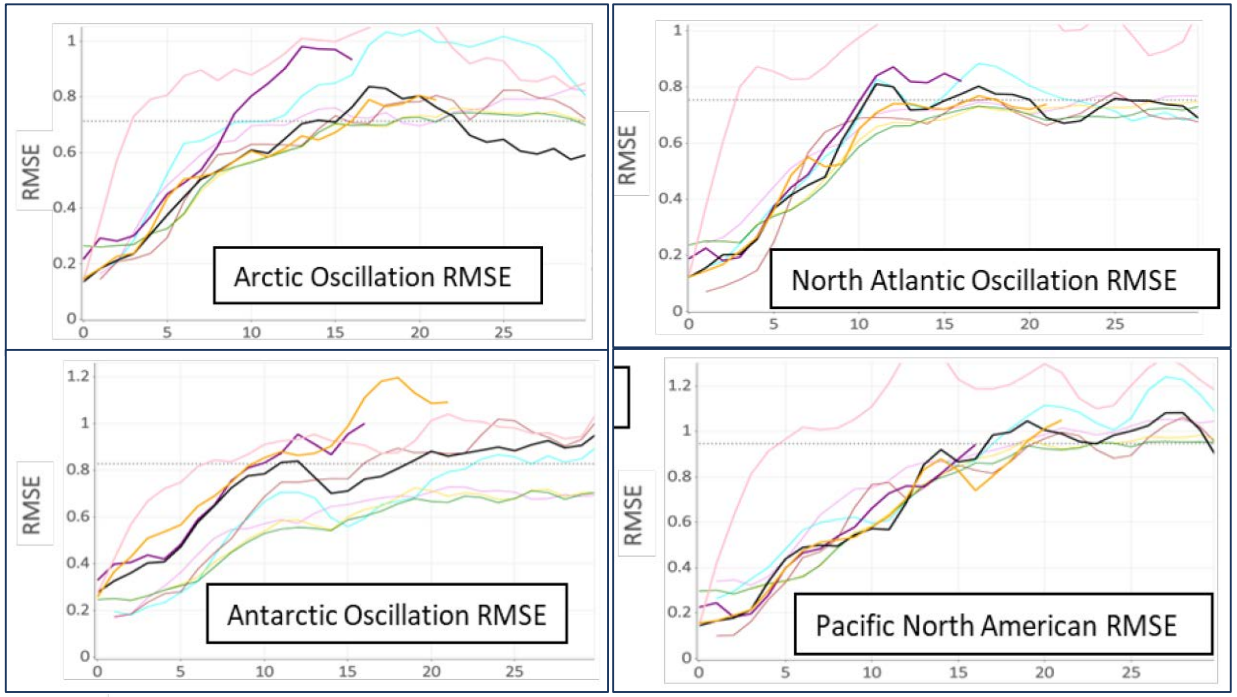
Current and Future work

- Continue to improve system (esp. ensemble design) for next system update in 2022
- ***Develop products useful on extended-range timescales with outreach to decision makers***
- ***New NRL FY20-FY22 project to develop extended-range TC prediction products***

Navy ESPC Global Coupled System Prediction Timescales

	Hours to Days	→ Weeks-Months	→ Seasons
Navy Need	**Fleet Safety and Operational Readiness**	**Ship Routing, Force Positioning, Operational Preparedness, Situational Awareness**	**Long-Range Planning for Training Exercises and Intelligence**
Navy Capability	 **Mesoscale and Global Weather Models**	 **Navy Earth System Prediction Capability** **(New Capability => New Products)**	 **Advanced Climate Analysis and Forecast (ACAF)** Climatology and Historical Analogs (Example: ENSO) Are Used

Navy ESPC Validation: Atmospheric Teleconnection Indices



RMSE of forecast ensemble mean teleconnection index

Navy ESPC competitive in terms of teleconnection index forecasts, despite rudimentary ensemble design

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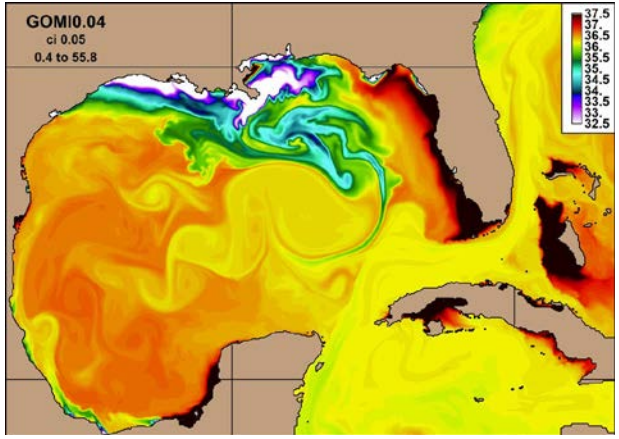
Ongoing ensemble design work: Dynamical conditioning and stochastic forcing

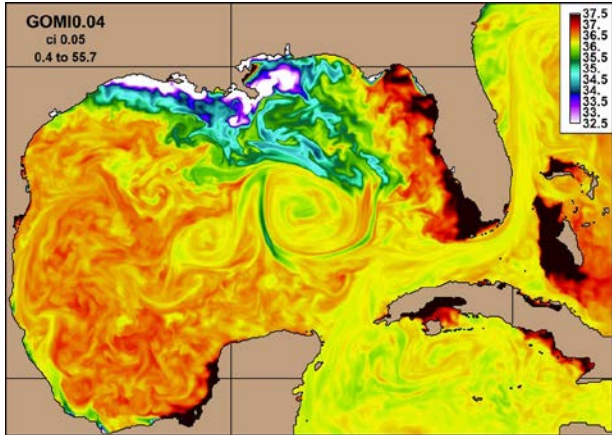
Stochastic Forcing Applied to HYCOM

Salinity on 01, Jan. 2017 after 60 days of integration

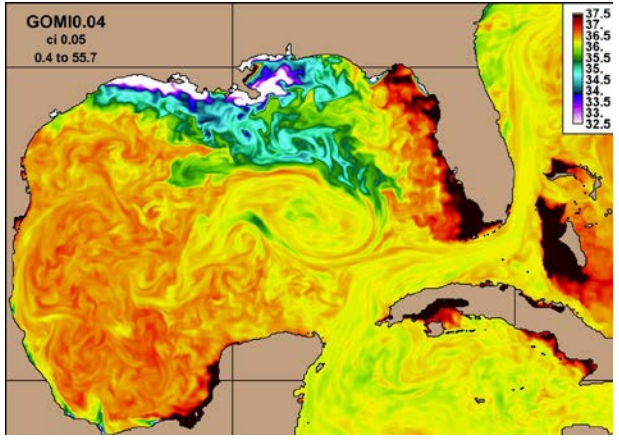
No Stochastic Forcing



Stochastic forcing on T&S



Stochastic forcing on T&S, u&v



Stochastic forcing spatial scale: 20 km (T&S, u&v)
Stochastic forcing temporal scale: 1 day (T&S, u&v)
Stochastic forcing RMS amplitude: .01/.002 (T/S)/hr
Stochastic forcing e-folding depth: 50 m (T&S, u&v)

Next step is to apply globally, coupled, across ensembles (underway)