US Navy's Earth System Prediction Capability Effort

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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

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

US Navy Arctic Roadmap: 2014-2030
Navy Climate Change Task Force

NRL supports US Icebreaker Healy on Geotraces mission

- 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

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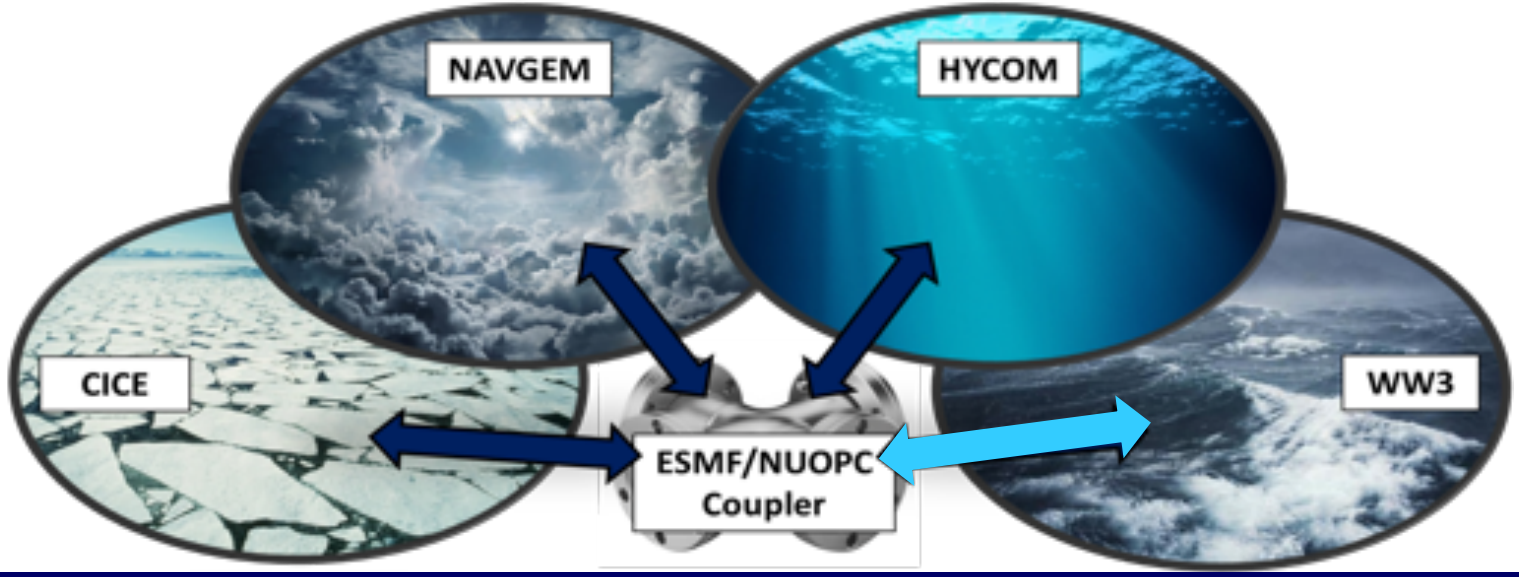
Navy ESPC Model Overview



- 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

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Navy ESPC Initial Operational Capability: 2019

Forecast	Time Range, Frequency	Atmosphere NAVGEM	Ocean HYCOM	Ice CICE	Waves WW3	Land Surface	Aerosols
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)	Module within NAVGEM	Module within NAVGEM
Probabilistic long term	**0-45 days, 16 members, weekly**	T359L60 (37 km) 60 levels	**1/12° (9 km) 41 layers**	**1/12° (9 km)**	1/4° (28 km)	Module within NAVGEM	Module within NAVGEM

- **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.*

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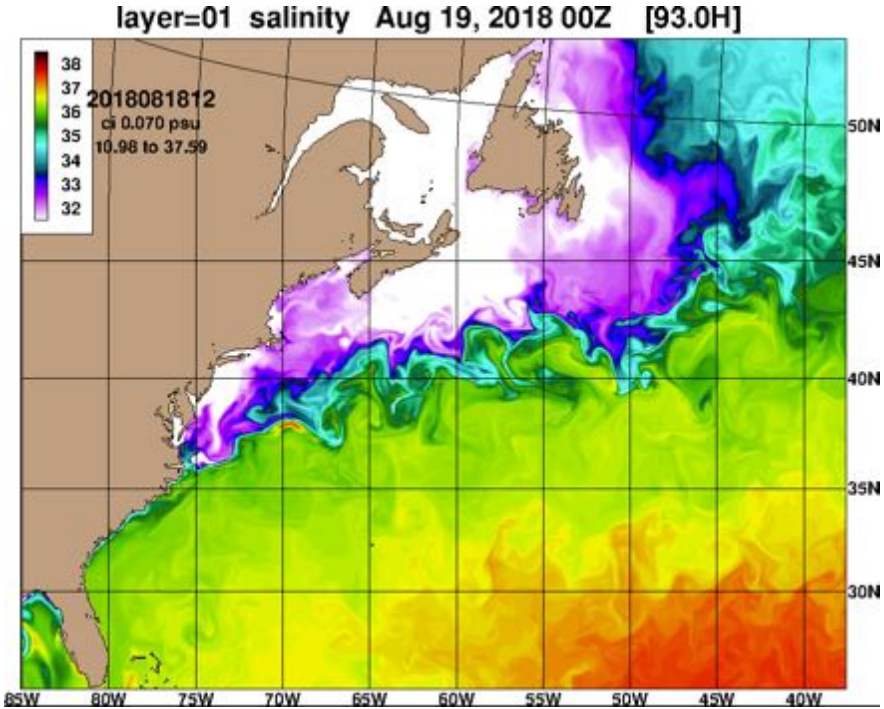
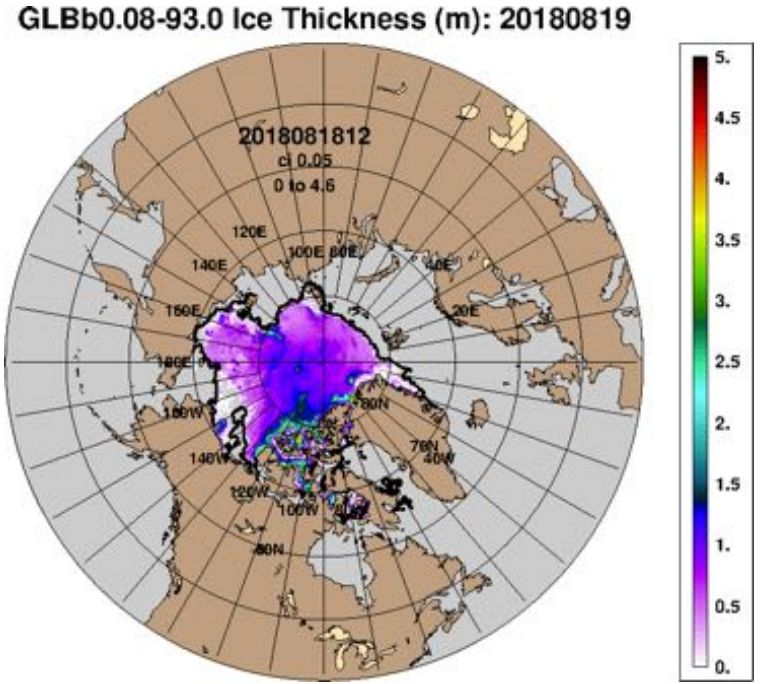
Uniqueness of Navy ESPC: High Resolution Ocean and Sea Ice

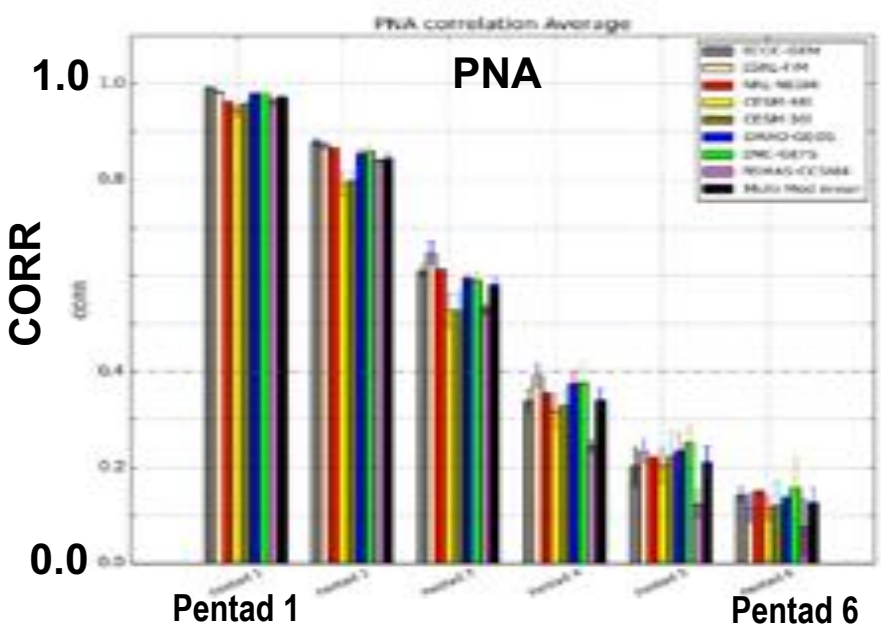


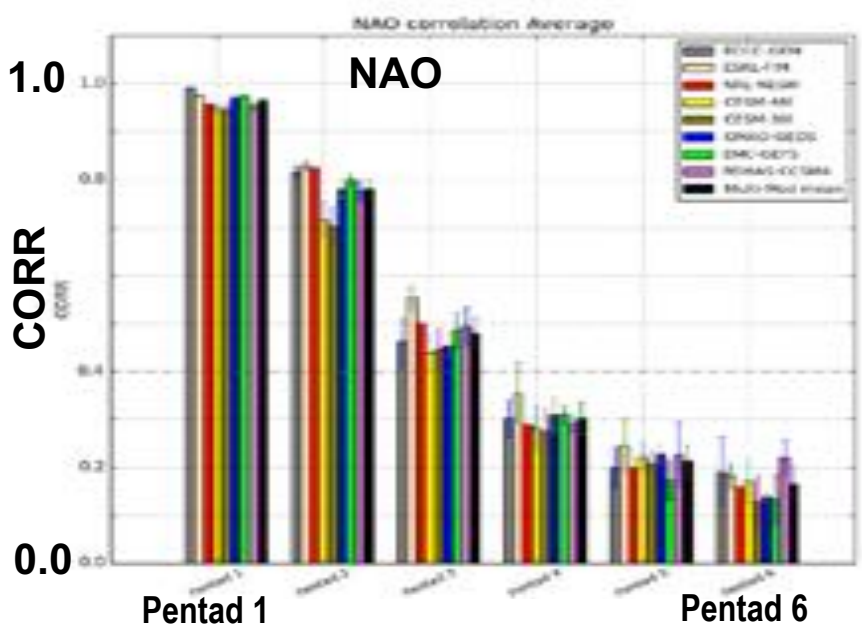


Navy needs high-fidelity simulations in atmosphere, ocean and sea-ice

SubX Pacific North American Oscillation and North Atlantic Oscillation

Navy ESPC (red) competitive with other SubX models for PNA and NAO forecasts in deterministic mode

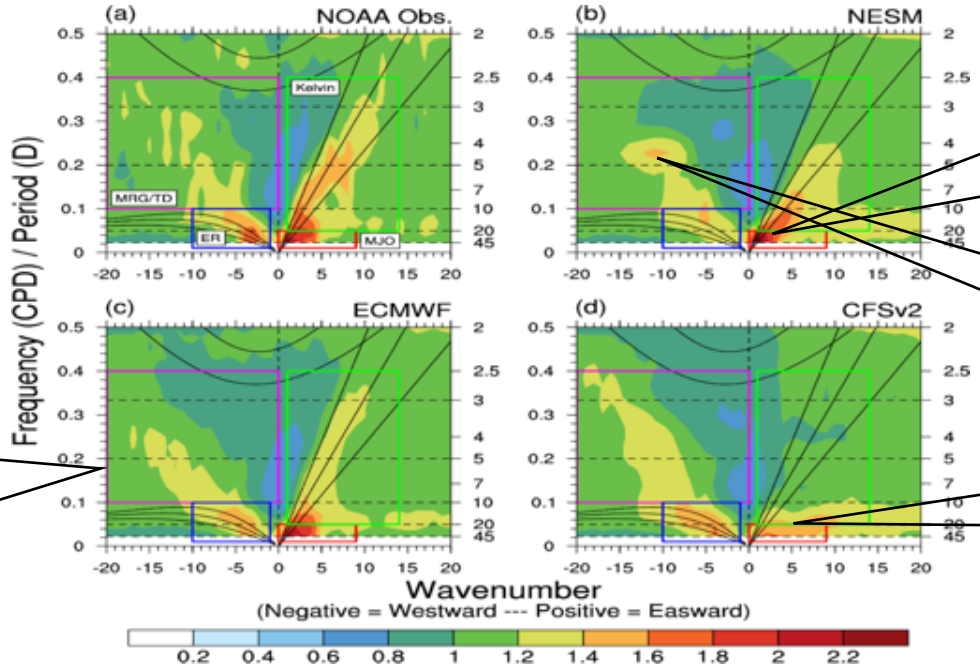




From E. Poan and H. Lin, Environnement et Changement Climatique Canada, Recherche en Prevision Numerique, March 2018: "NAO and PNA skill of analysis on the Subseasonal Experiment datasets"

SubX JJA 1999-2015: Equatorial Waves

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

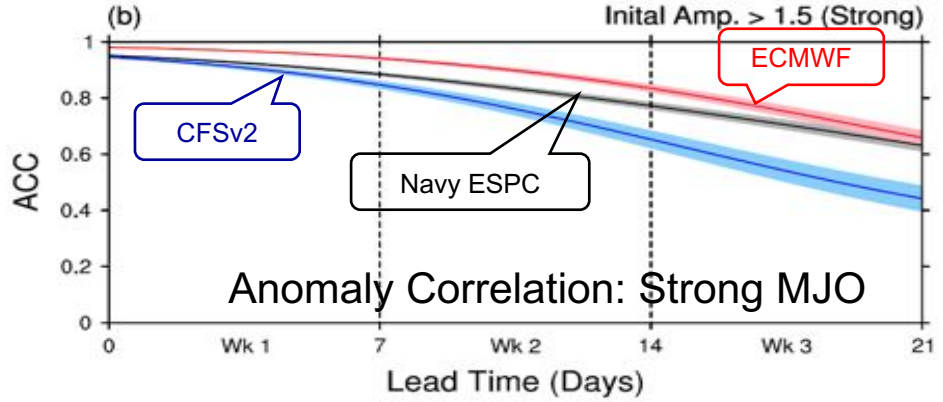
Navy ESPC overactive in Tropical Depressions

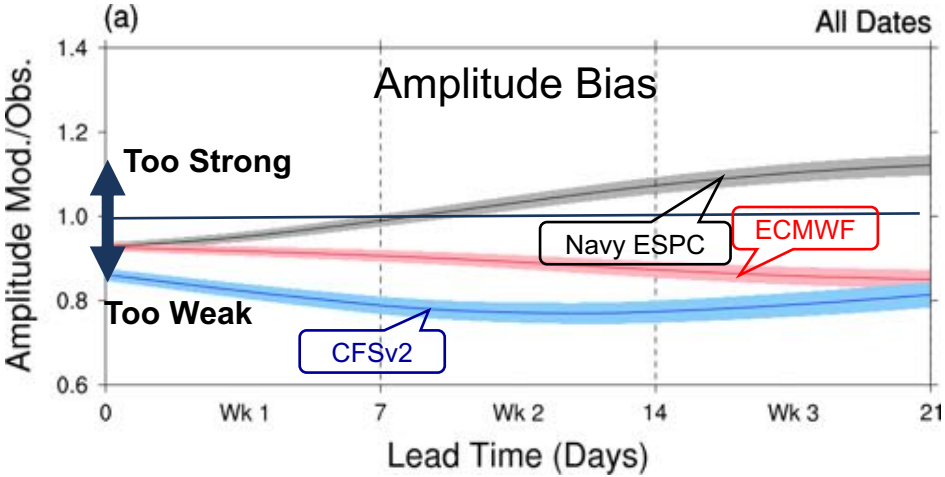
ECMWF matches observations best of the three systems

CFSV2 has weak MJO and Kelvin waves

Janiga et al. (2018, Monthly Weather Review)

NMME-SubX JJA 1999-2015: MJO Forecast Skill



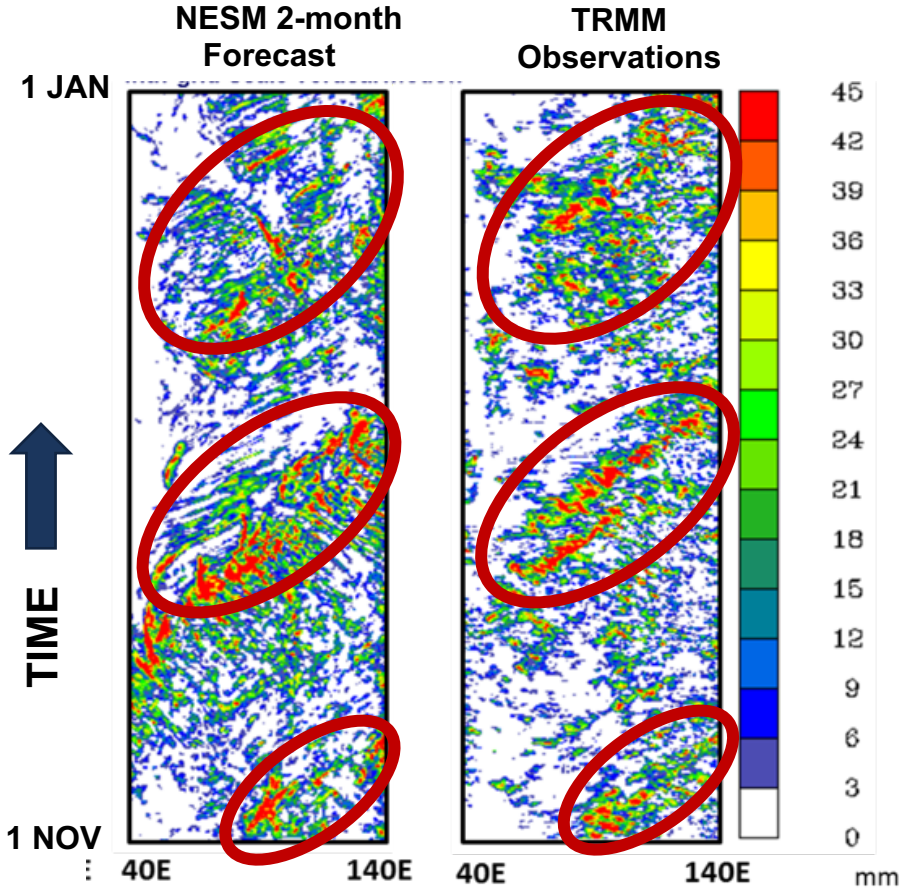


Navy ESPC Anomaly Correlation skill comparable to CFSv2 at beginning of forecast, and comparable to ECMWF by day 21

Navy ESPC amplitude too strong, in contrast to other models

Navy ESPC, ECMWF, CFSv2

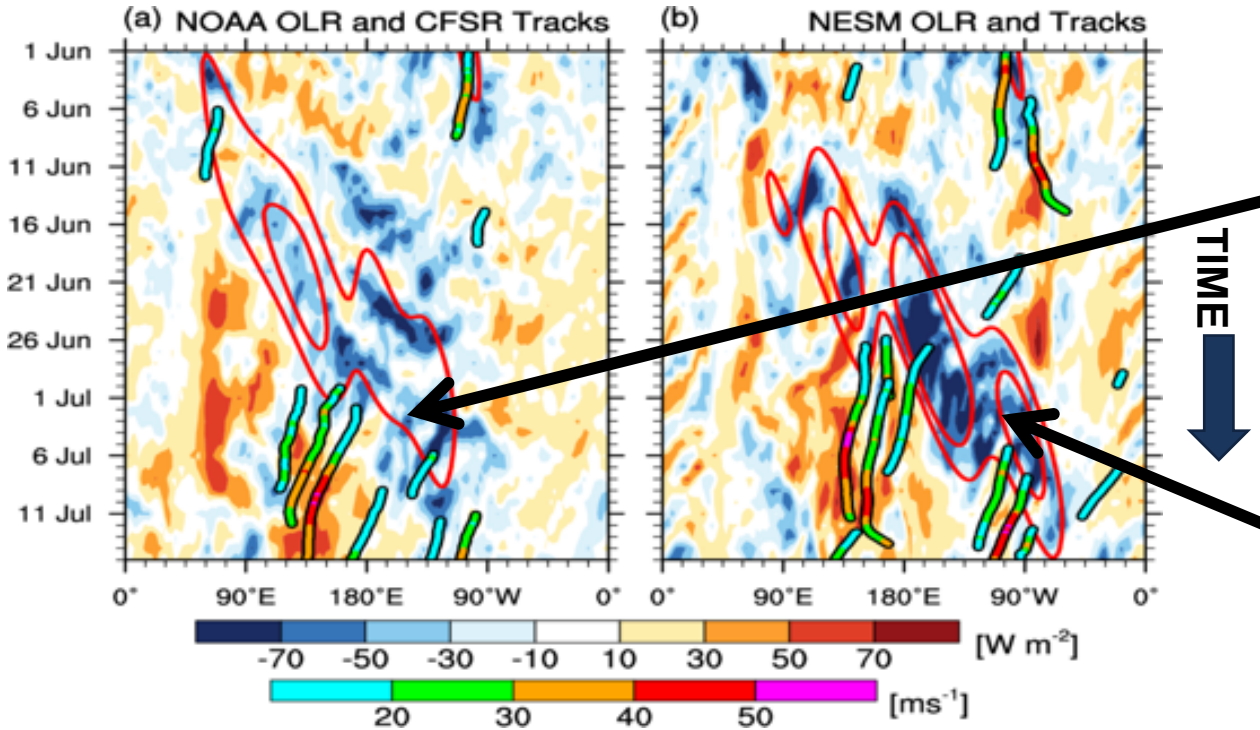
Example of Long-range Forecast Skill: Tropics



Rainfall (5S-5N) for NESM 60-day forecasts as compared to TRMM observations for the DYNAMO period (NOV-DEC 2011)

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



TIME

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

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).

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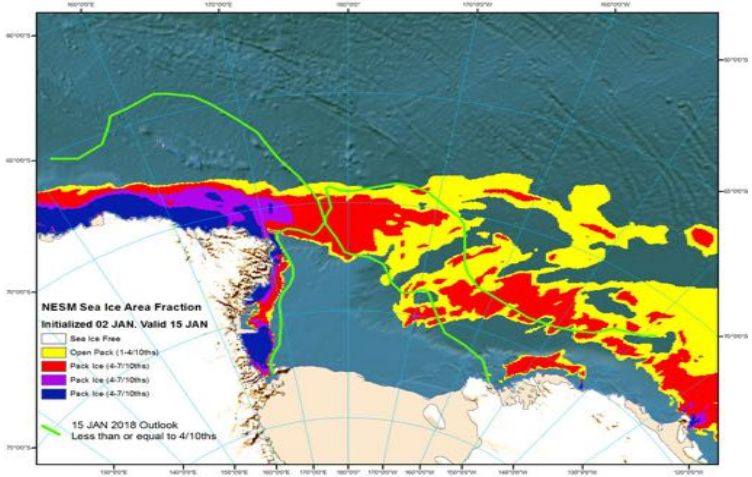
SubX Real-time Forecasts used by National Ice Center

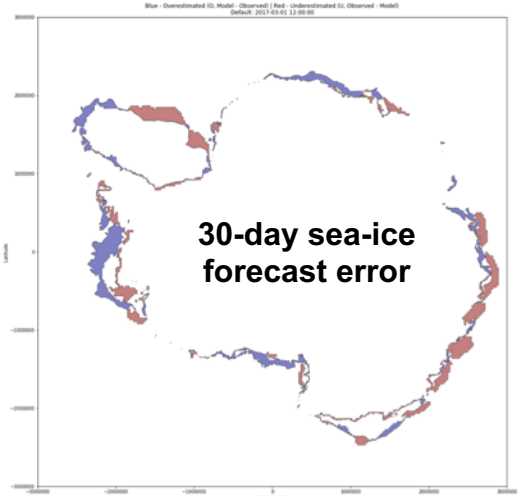
Navy ESPC real time forecasts were leveraged to provide the National Ice Center with 45-day forecasts of sea ice concentration, thickness and drift for long-range planning guidance for 2018 Operation Deep Freeze (McMurdo resupply mission) and ICEX (Beaufort Sea) field campaign support



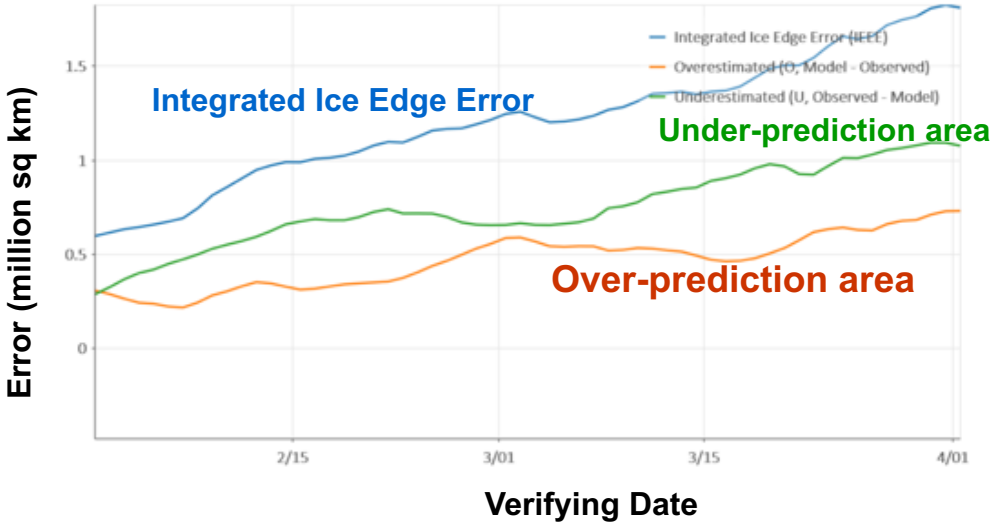
15 Jan 2018 NRL Navy ESPC 15-day sea ice fraction forecast (color shading) compared to 15 Jan 2018 NIC Outlook (green line) for the Ross Sea, Antarctica

Ice Forecast Evaluation

Navy ESPC 60-day forecast of Antarctic Sea Ice Extent from 1 February 2017



Blue: Predicted ice where none observed
Brown: Ice observed where not predicted



- 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

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Navy ESPC

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 (“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

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Extra Slides

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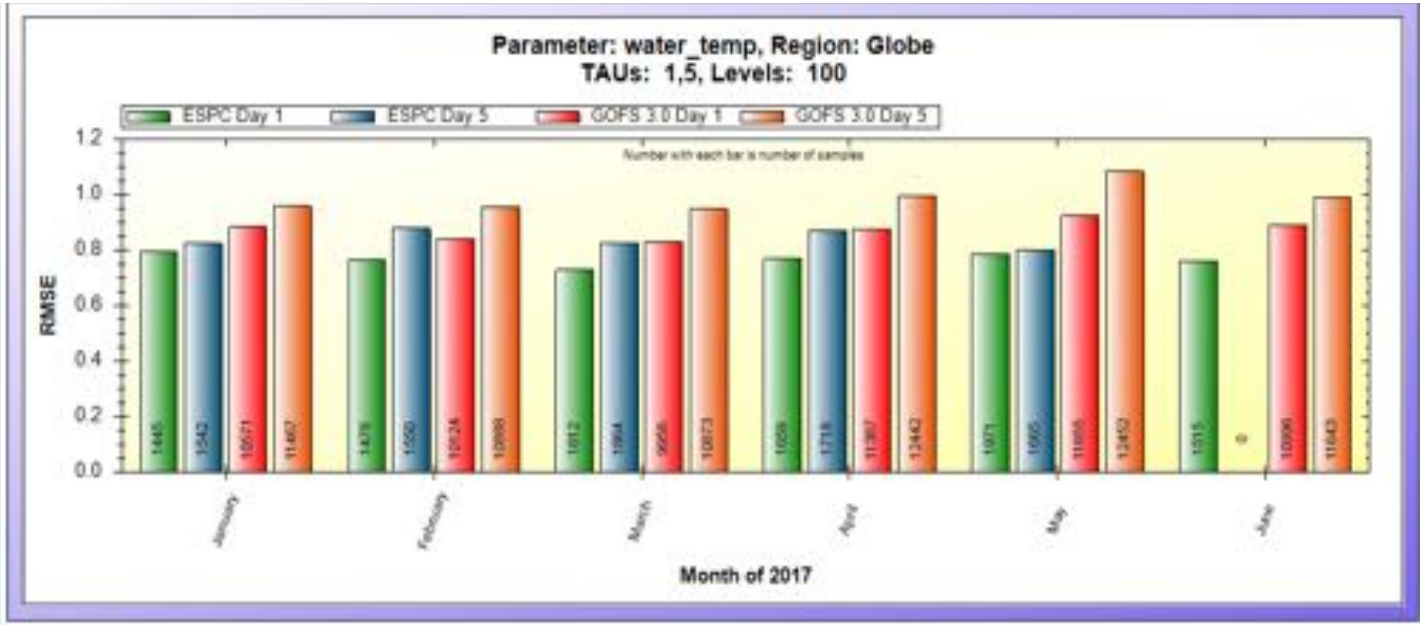
Comparison to Operational Systems



Navy ESPC Day 1
Navy ESPC Day 5
GOFS 3.0 Day 1
GOFS 3.0 Day 5

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

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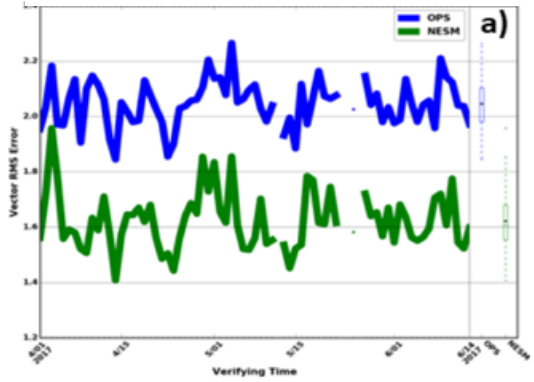
Comparison to Operational Systems

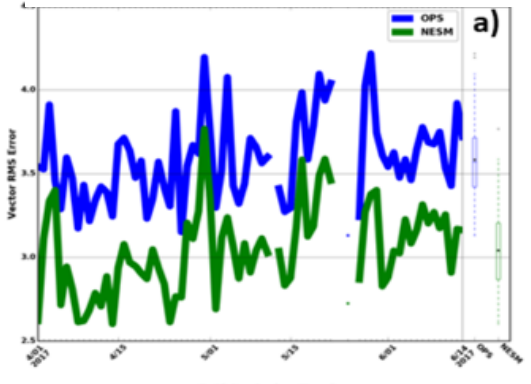
850-hPa Wind 24-h RMSE

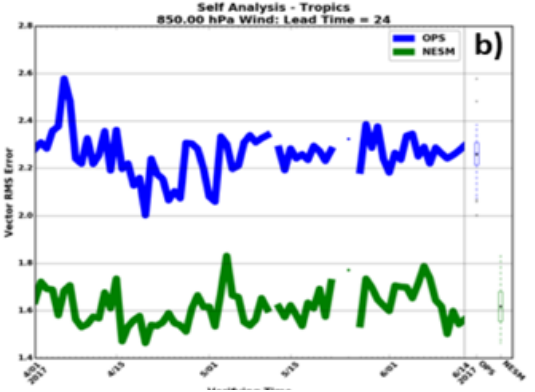
200-hPa Wind 24-h RMSE

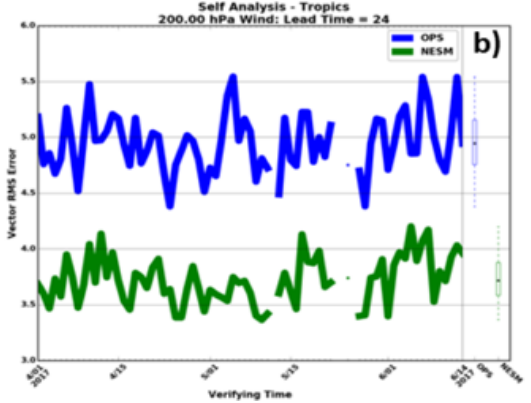
Northern Hem.

Tropics









1APR 1MAY 1JUN 2017

1APR 1MAY 1JUN 2017

- 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

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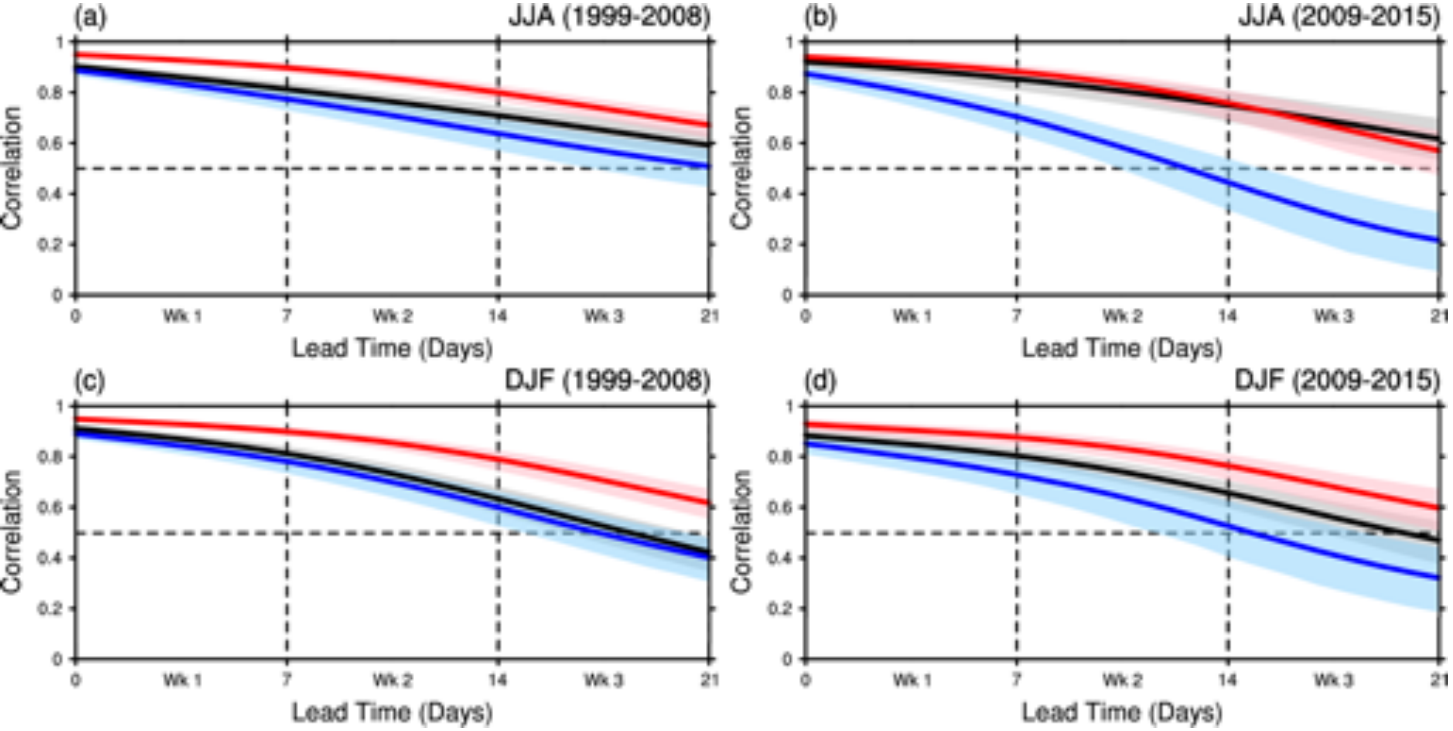
SubX 1999-2015: MJO Forecast Skill

Inconsistent ICs for NAVGEM

Consistent Reanalysis for NAVGEM



Navy ESPC, ECMWF, CFSv2

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

"Experiment of Opportunity" to examine initial condition accuracy impact.

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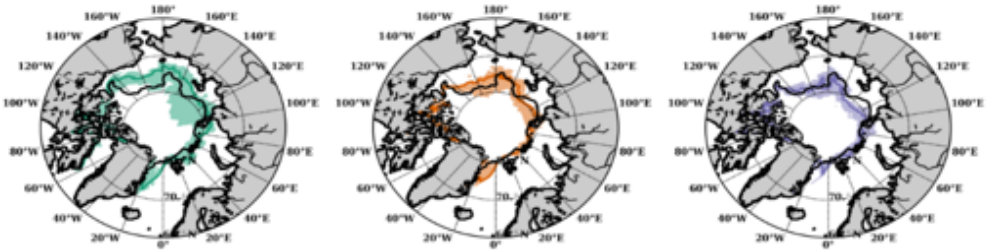
Sea Ice Prediction Network Sea Ice Outlooks

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

Forecasts from late May

Forecasts from late June

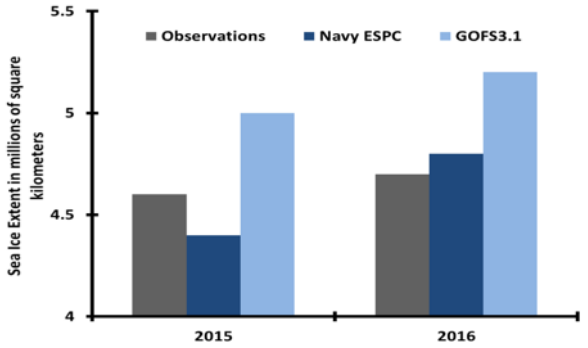
Forecasts from late July



(black) observations from NASA; (light color) NESM ensemble; (bold color) NESM mean

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

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

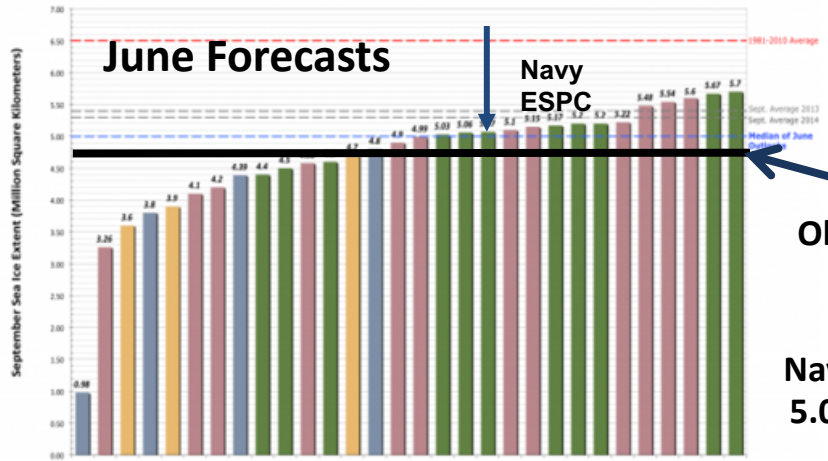


Coupled atmosphere-ocean improves performance over using atmospheric forcing from previous years. Navy ESPC has replaced GOFS for SIO.

Sea Ice Prediction Network Forecasts: September Mean Sea Ice Extent

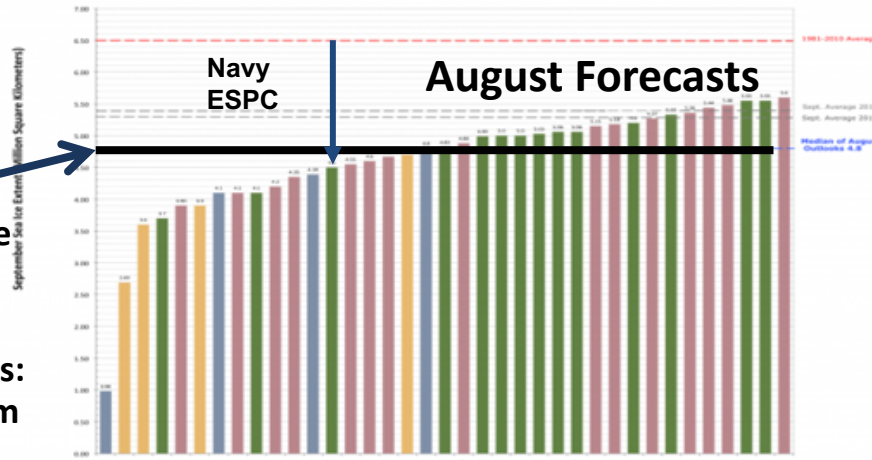
Figures from www.arcus.org/sipn/sea-ice-outlook

September 2015 Sea Ice Outlooks



Observed Value 4.68m km²

Navy Predictions: 5.07m and 4.5 m km²

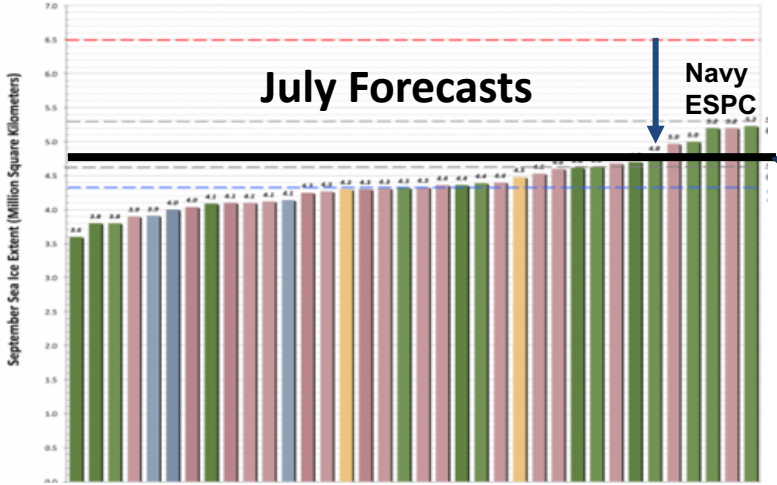


Navy ESPC is in the middle of the distribution, close to observed value *(good!)*

Sea Ice Prediction Network Forecasts: September Mean Sea Ice Extent

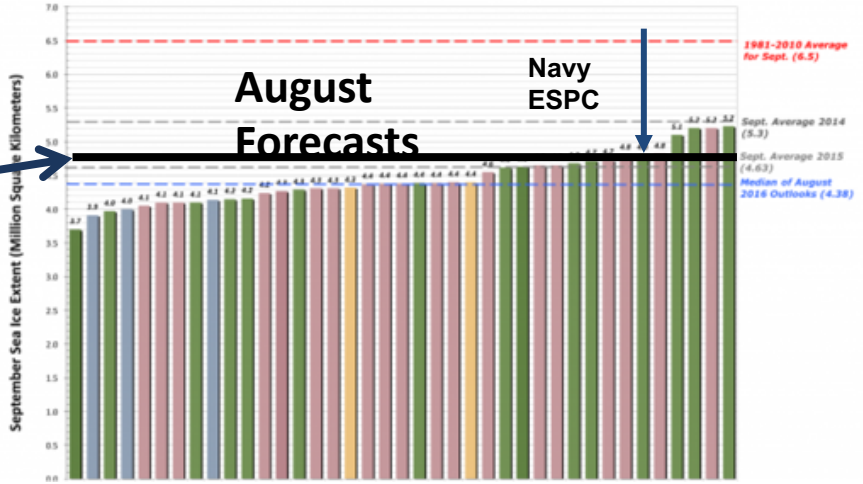
Figures from www.arcus.org/sipn/sea-ice-outlook

September 2016 Sea Ice Outlooks



Observed Value 4.72m km²

Navy Prediction: 4.8m km²



Navy ESPC is very close to observed value *(great!)*

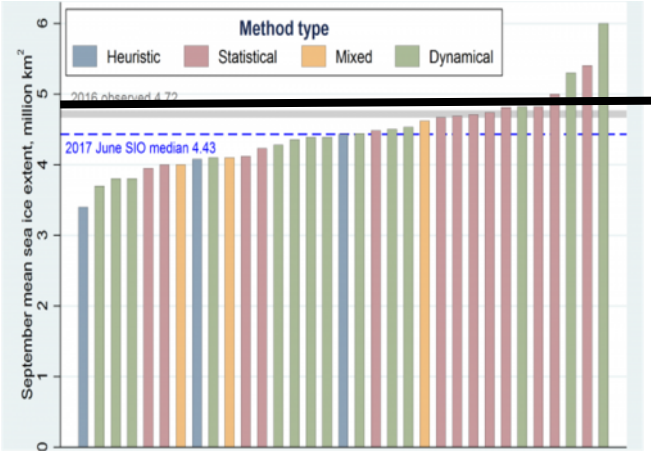
Sea Ice Prediction Network Forecasts: September Mean Sea Ice Extent

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

September 2017 Sea Ice Outlooks

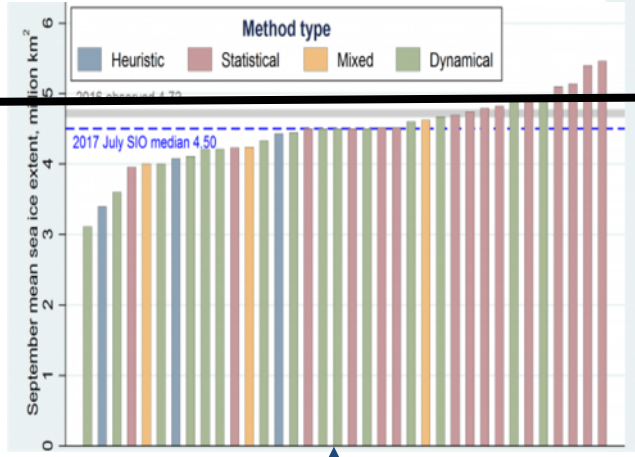
Observed Value 4.80m km²

June Forecasts



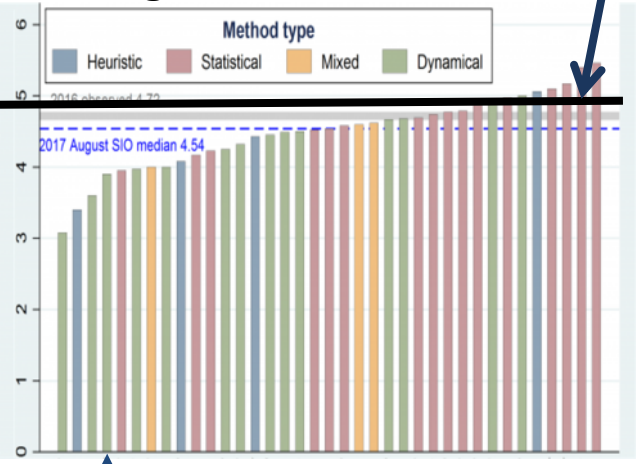
Navy ESPC 6.0m km²

July Forecasts



Navy ESPC 4.5m km²

August Forecasts



Navy ESPC 3.9m km²

Navy ESPC forecasts vary widely *(interesting!)*

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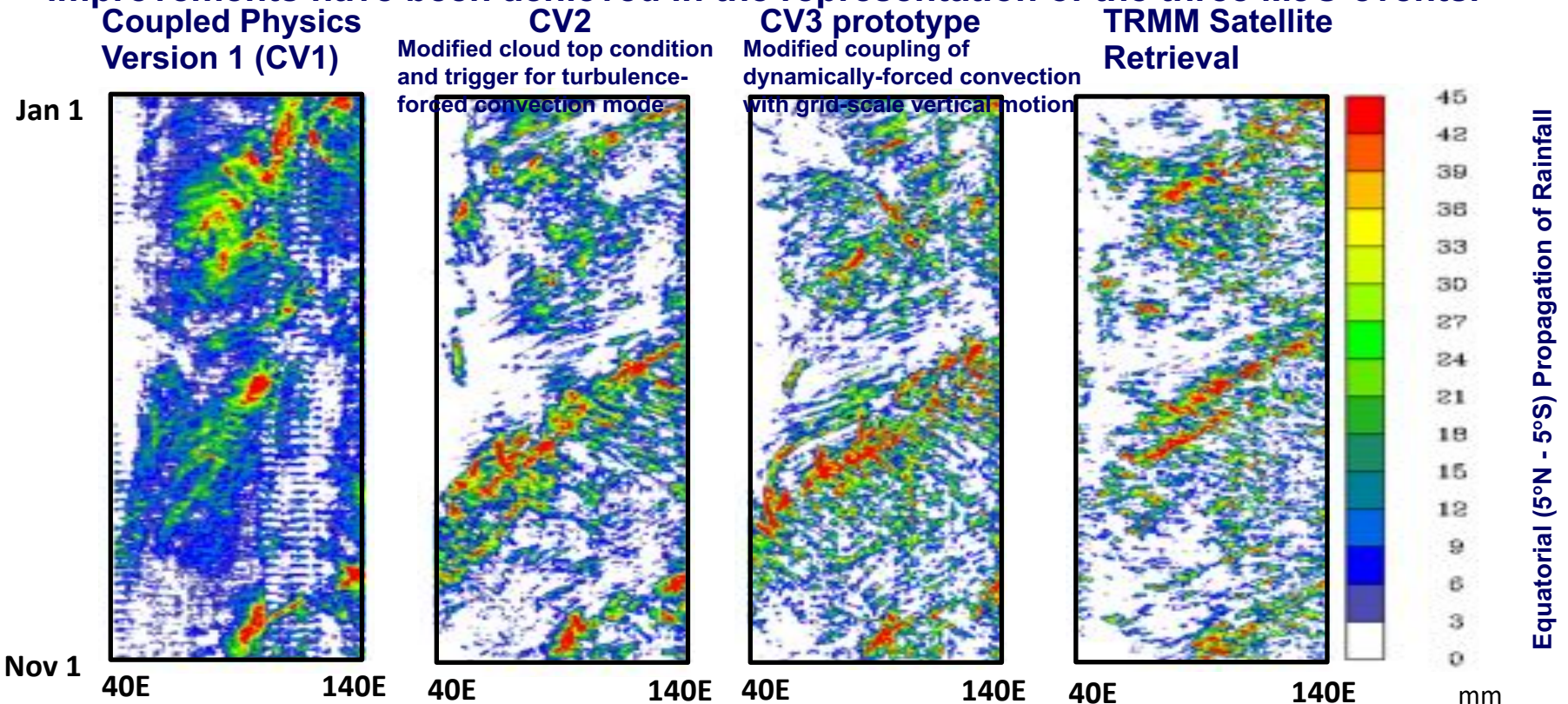
DYNAMO Case Study 61-Day Hindcasts from 1 Nov, 2011 with ESPC Coupled System Physics

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.



Extra Slides