# US Navy's Earth System Prediction Capability Effort

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International Conference on Subseasonal to Decadal Prediction, 17-21 September 2018, NCAR, Boulder, CO, USA

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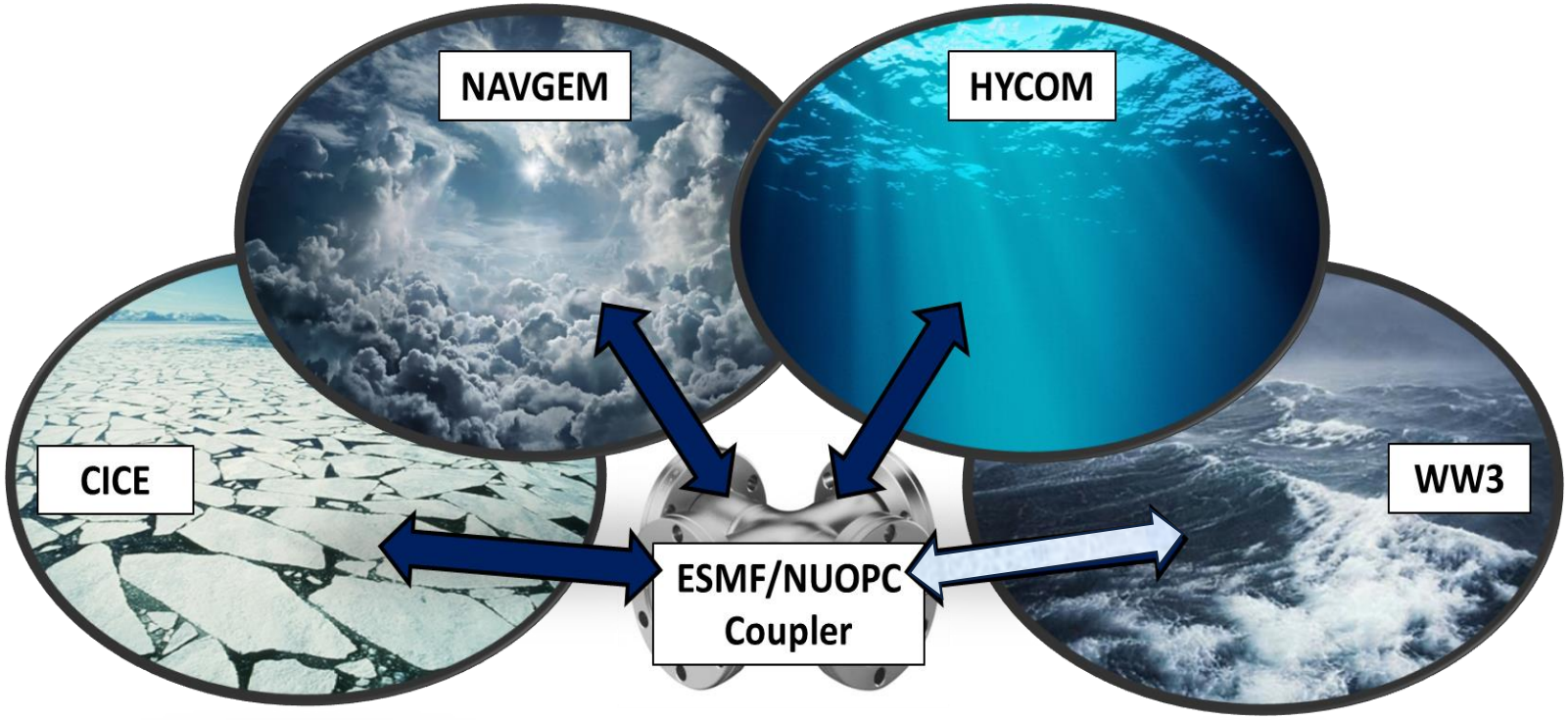
# Navy Earth System Model (NESM)




- 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
- Earth System Modeling Framework used to facilitate flexibility, upgrades
- Participated in NOAA Mapp SubX project (45-d fcsts, 4/week, 1999-present)

# NESM Operational Capability (IOC): FY19

| 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 Configuration TBD* | T359L60 (37 km) 60 levels | 1/12° (9 km) 41 layers | 1/12° (9 km) | 1/4° (28 km) |

- **IOC Data Assimilation will be weakly coupled (independent DA systems but coupled forecast for first guess). Ensembles will use perturbed observation method.**
- **Final Operational Capability: FY22**
  - **Seasonal (90-day) ensemble forecasts**
  - **Coupled data assimilation**
  - **Interactive ocean surface waves**

**Computational resources allow for about 3 members/day.*

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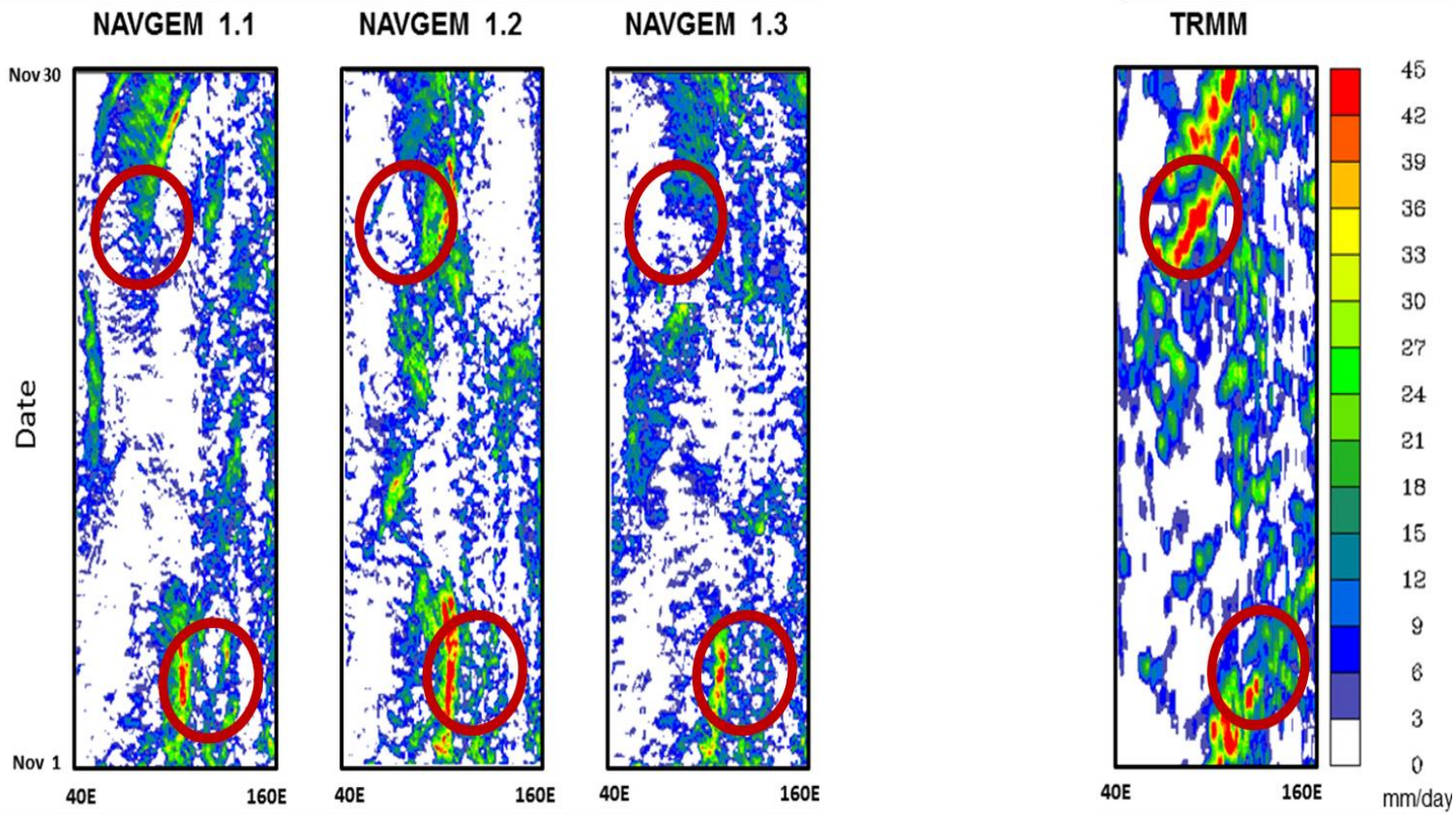
# NAVGEM Parameterization Improvements

## NESM 30-day reforecasts (5S-5N precip) from 1NOV2011




**Insertion of global NWP model into NESM not sufficient to resolve difficulties with the MJO.**
**System optimized for short-term weather forecasts will not necessarily perform well for MJO forecasts.**

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# NAVGEM Parameterization Improvements

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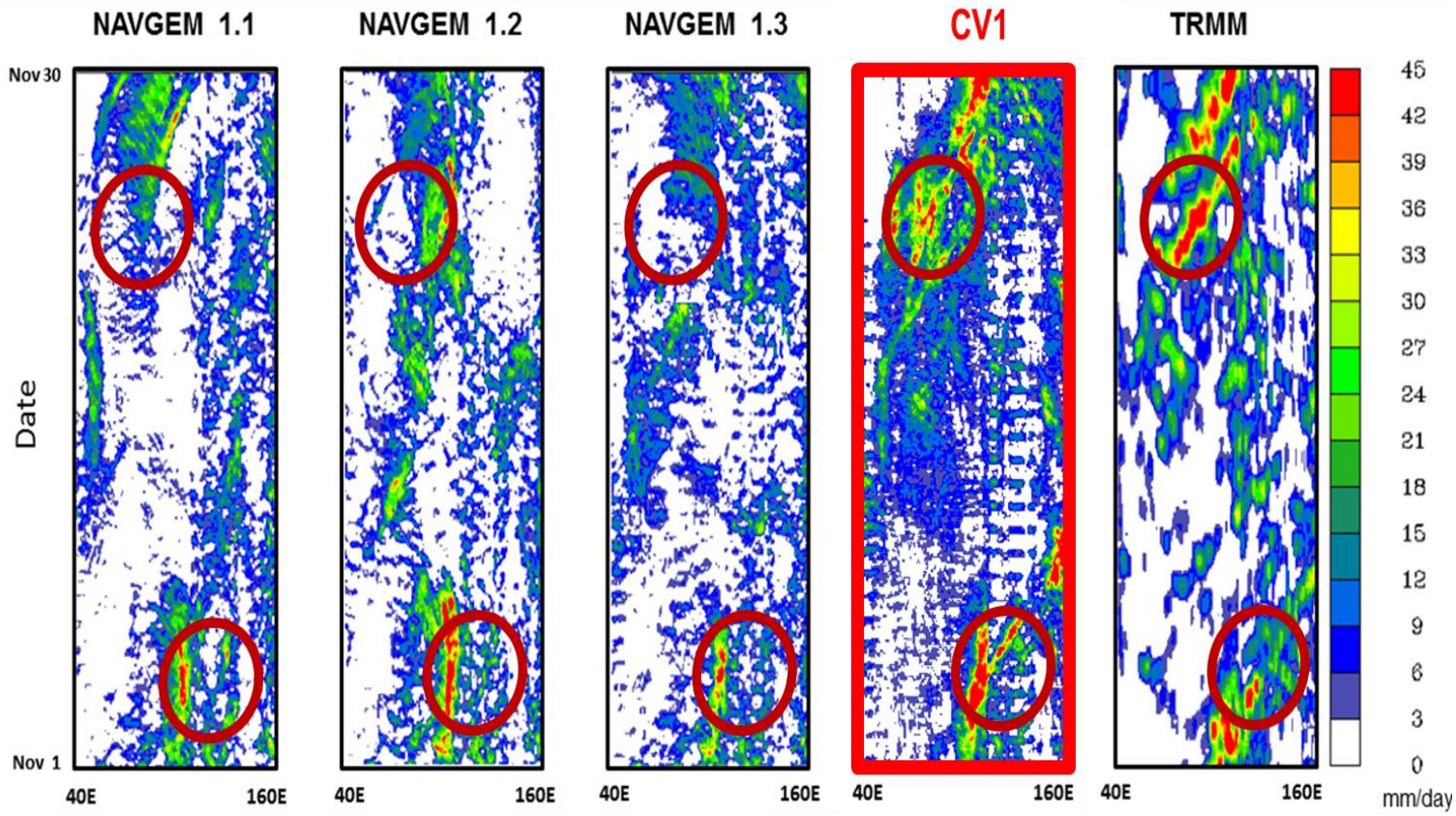


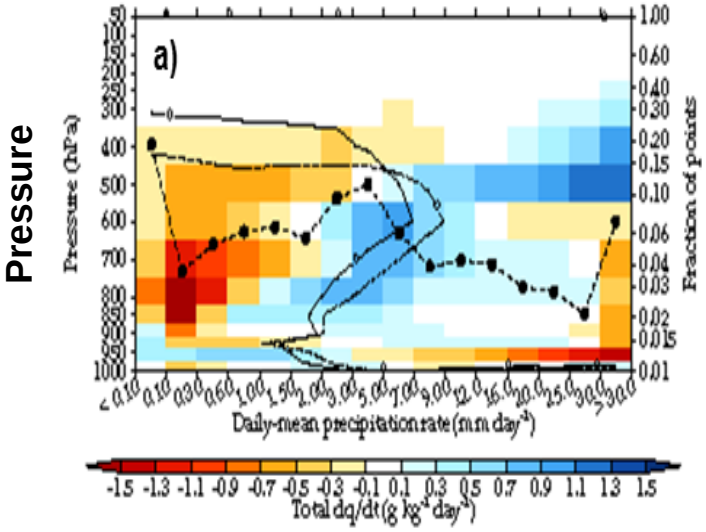

**MJO much improved– main factor is change in convection scheme. Also includes implementation of COARE 3.0 air-sea flux scheme in NAVGEM, following the treatment in the ocean model component (HYCOM).**

# NAVGEM Parameterization Improvements

## Improving Moistening/Rain Rate Relationship (*J. Ridout, M. Janiga*)

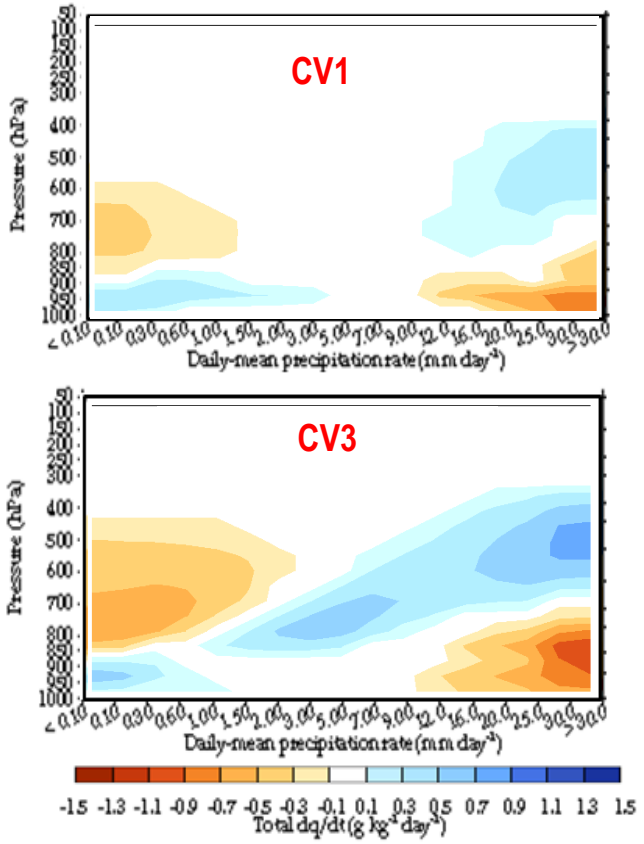
1. **Modify cloud top constraint to enhances the ability of the scheme to represent feedbacks between convection and environmental moisture, considered to be a key process in the development of the MJO (Klingaman et al. 2015, JGR)**
2. **Constrain the turbulence-forced convective component based on a mixed layer Richardson number constraint (*Ridout and Reynolds, 1998*).**

**Net Moistening Vs. Rain Rate**




**Daily Mean Precipitation Rate**

**Pressure**



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# NAVGEM Parameterization Improvements

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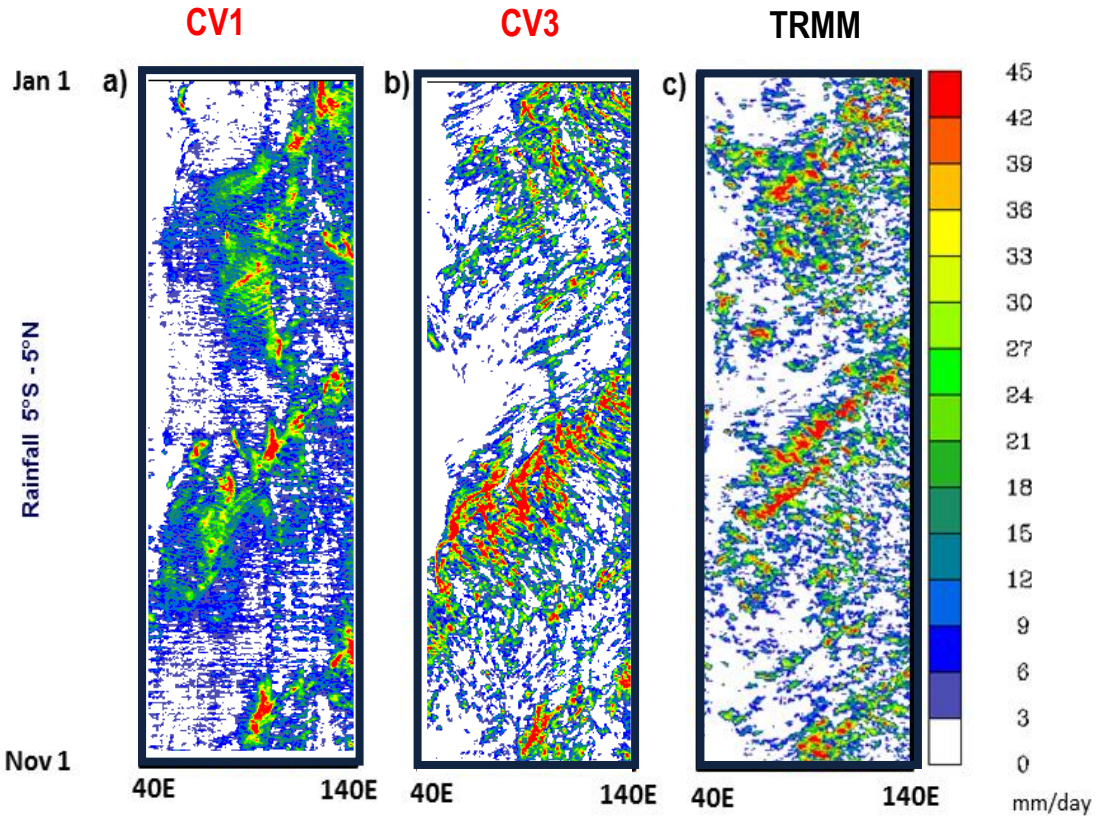
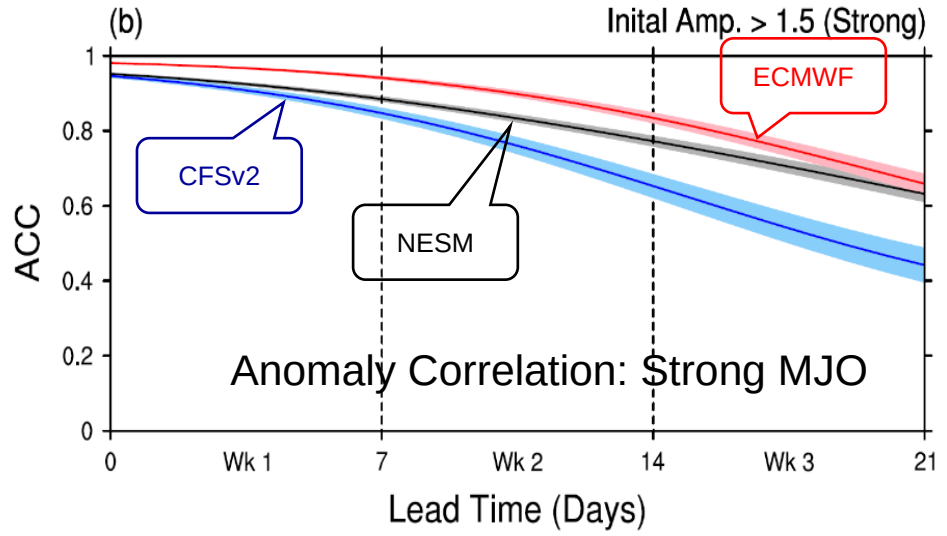
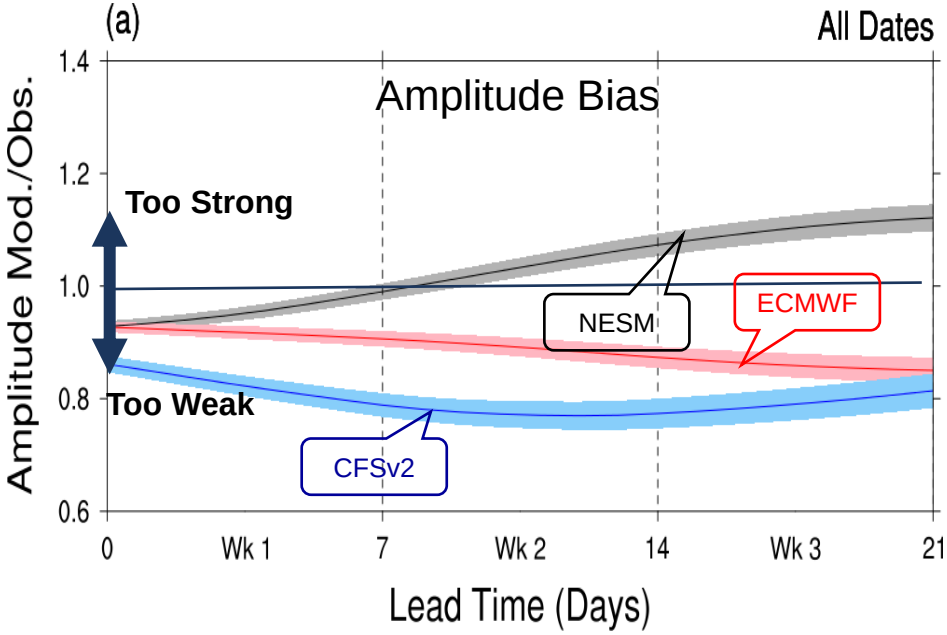



**Several improvements with CV2, including a reduction in too much light rain, and a more realistic (faster) MJO propagation speed.**

# SubX JJA 1999-2015: MJO Forecast Skill




**NESM Anomaly Correlation skill comparable to CFSv2 at beginning of forecast, and comparable to ECMWF by day 21 for JJA. Performance not quite as good in DJF.**



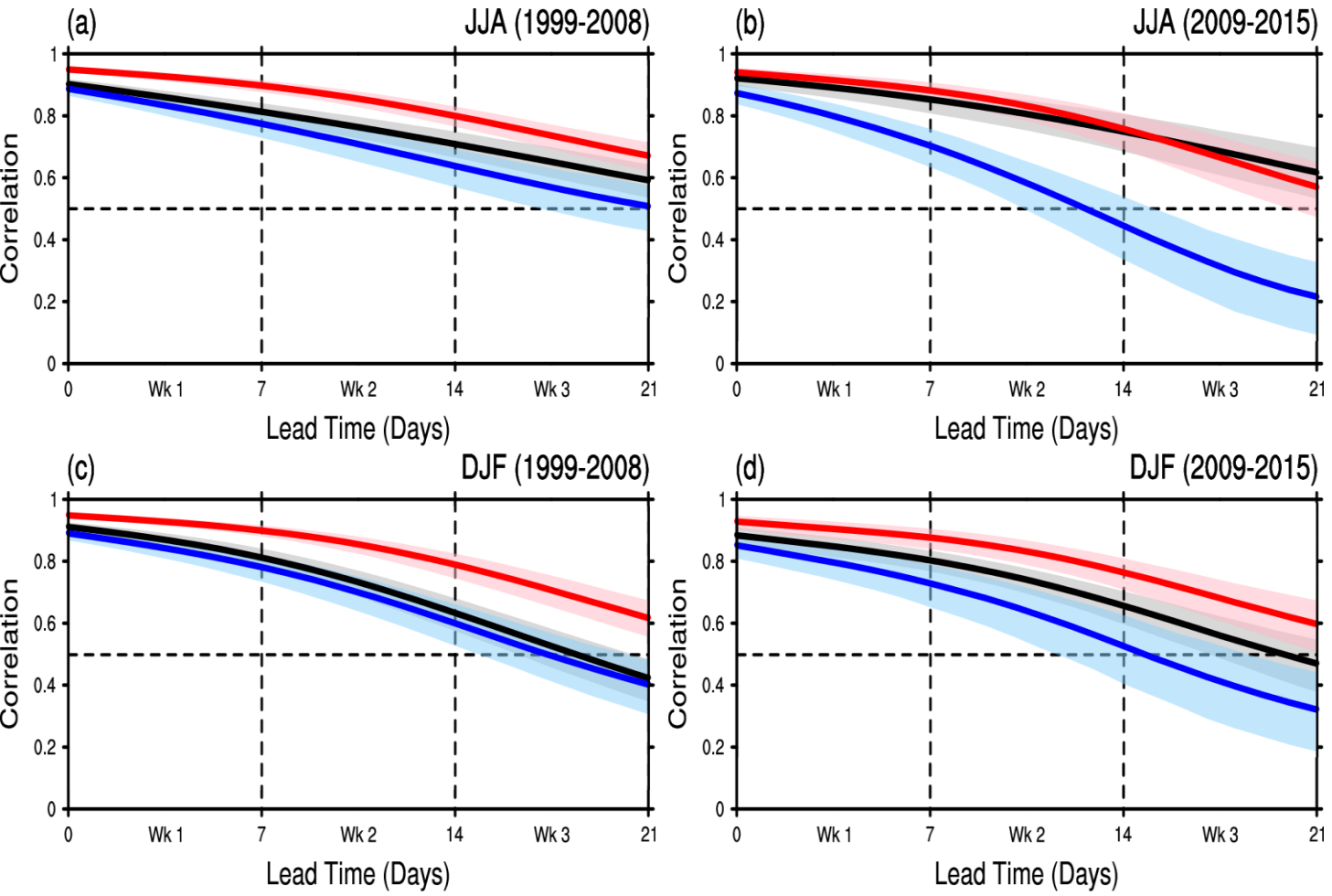

**NESM amplitude too strong, in contrast to other models**

**NESM, ECMWF, CFSv2**

# SubX 1999-2015: MJO Forecast Skill

**Inconsistent ICs for NAVGEM**

**Consistent Reanalysis for NAVGEM**



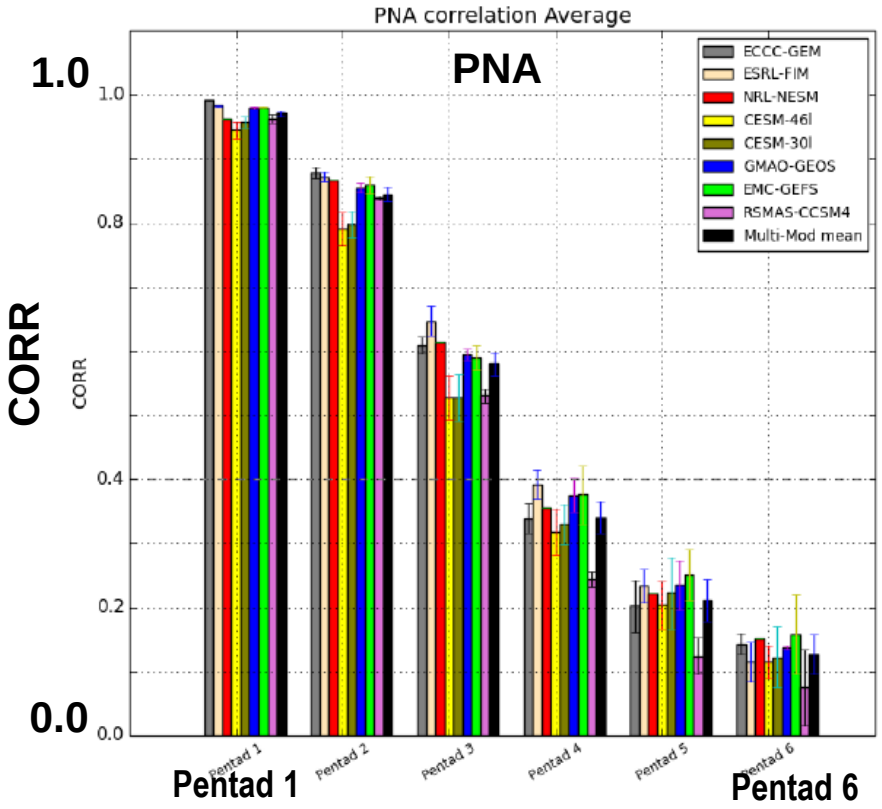

**Better-quality ICs for NAVGEM result in better forecasts relative to other systems.**

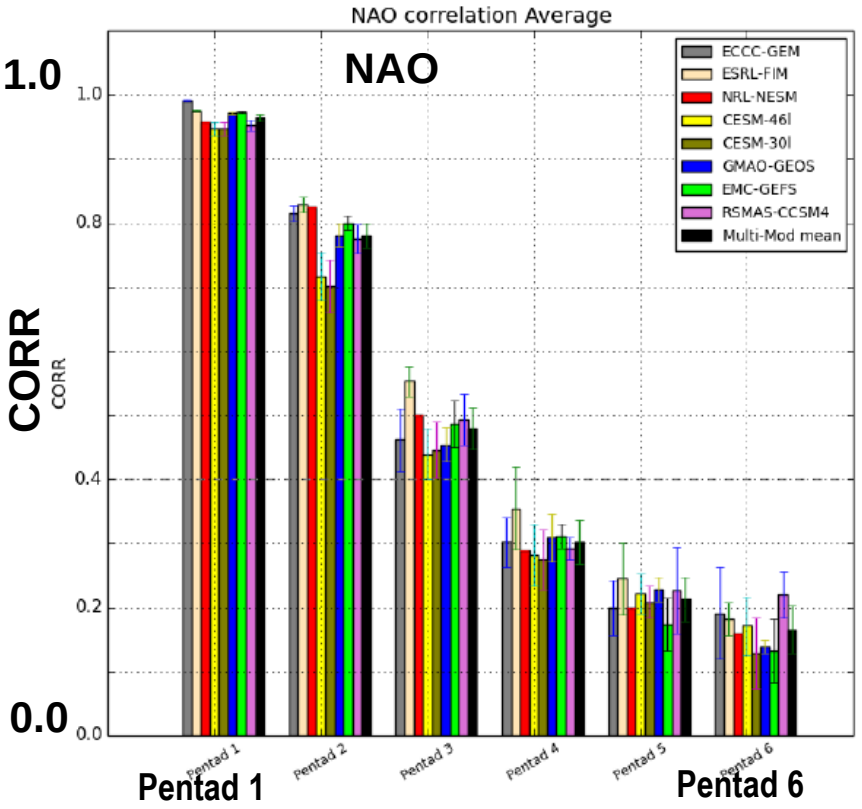
**"Experiment of Opportunity" to examine initial condition accuracy impact.**

**NESM, ECMWF, CFSv2**

# SubX Pacific North American Oscillation and North Atlantic Oscillation

**NESM (red) competitive with other SubX models for PNA and NAO forecasts in deterministic mode. We lag in ensemble mode (extra slide) as we have 1 member 4 days per week.**




*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"*

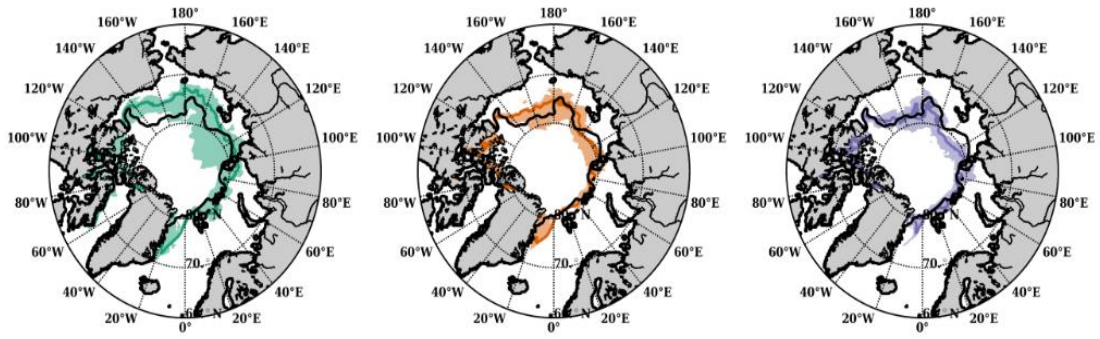
# Sea Ice Prediction Network Sea Ice Outlooks

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

**Forecasts from late May**

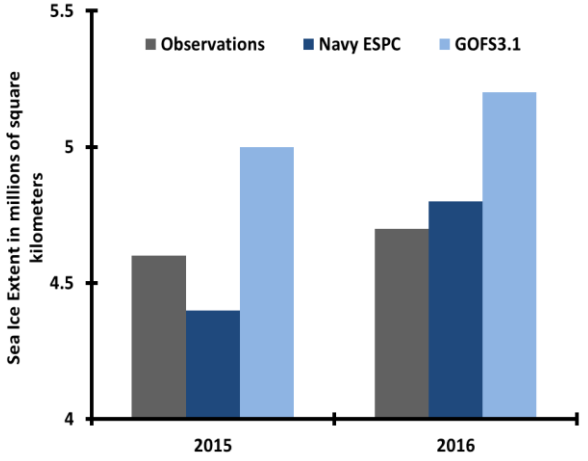
**Forecasts from late June**

**Forecasts from late July**



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

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



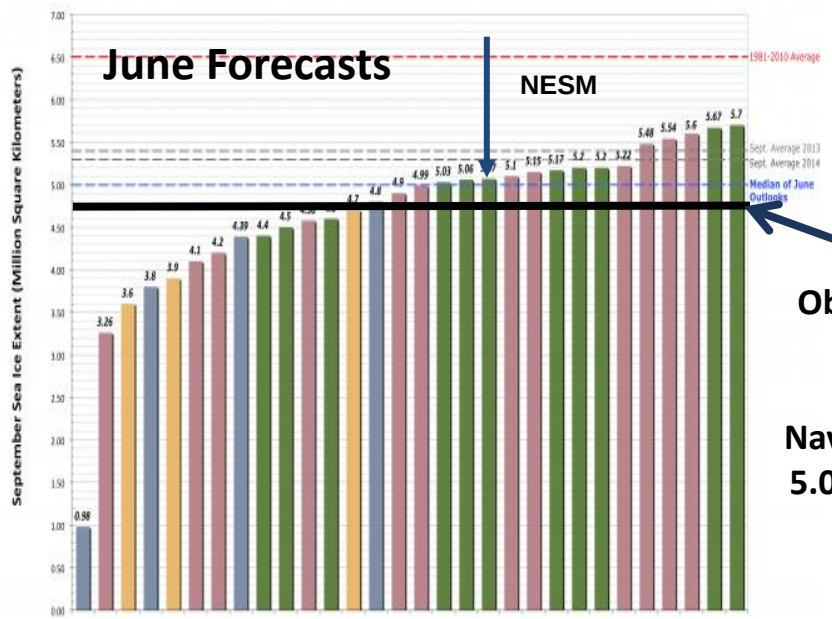

**Ensemble spread decreases as lead time increases. Observed ice edge (black) mostly contained within ensemble spread.**

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

# Sea Ice Prediction Network Forecasts: September Mean Sea Ice Extent

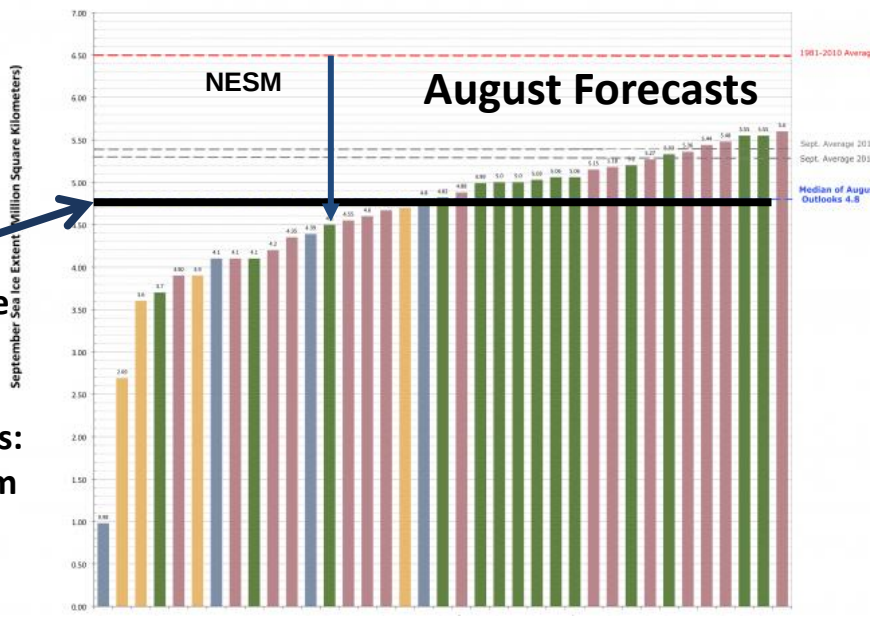
Figures from www.arcus.org/sipn/sea-ice-outlook

## September 2015 Sea Ice Outlooks




**Observed Value 4.68m km²**

**Navy Predictions: 5.07m and 4.5 m km²**

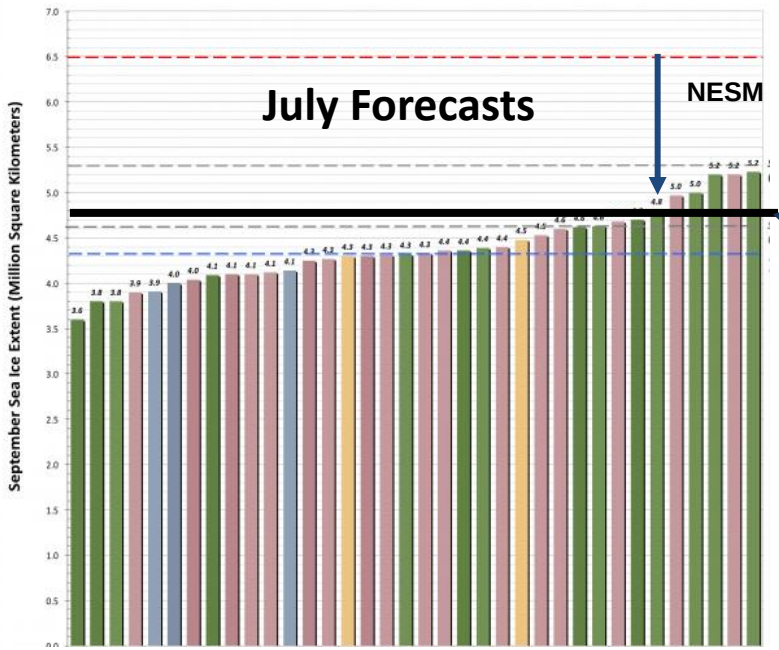



**NESM is in the middle of the distribution, close to observed value *(good!)***

# Sea Ice Prediction Network Forecasts: September Mean Sea Ice Extent

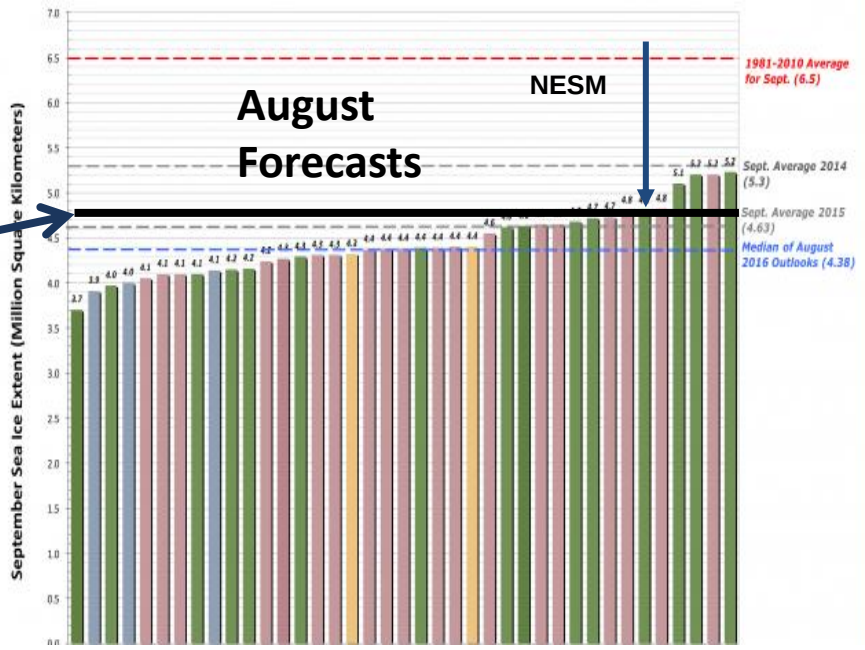
Figures from www.arcus.org/sipn/sea-ice-outlook

## September 2016 Sea Ice Outlooks




**Observed Value 4.72m km²**

**Navy Prediction: 4.8m km²**




**NESM is very close to observed value *(great!)***

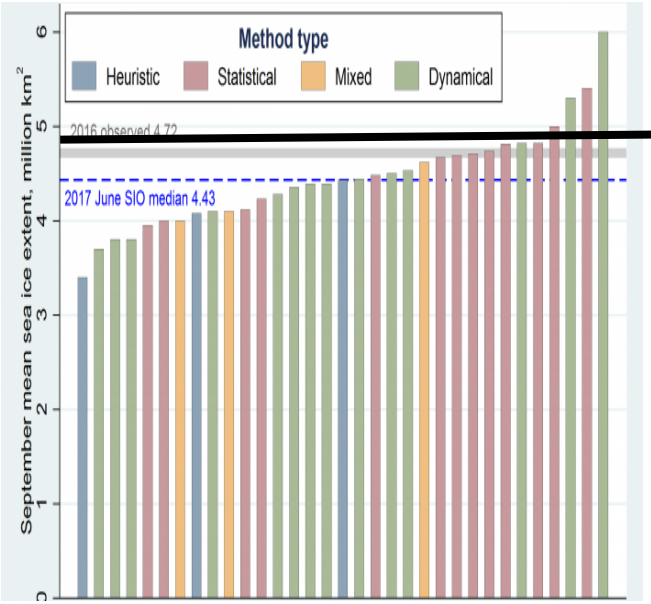
# Sea Ice Prediction Network Forecasts: September Mean Sea Ice Extent

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

## September 2017 Sea Ice Outlooks

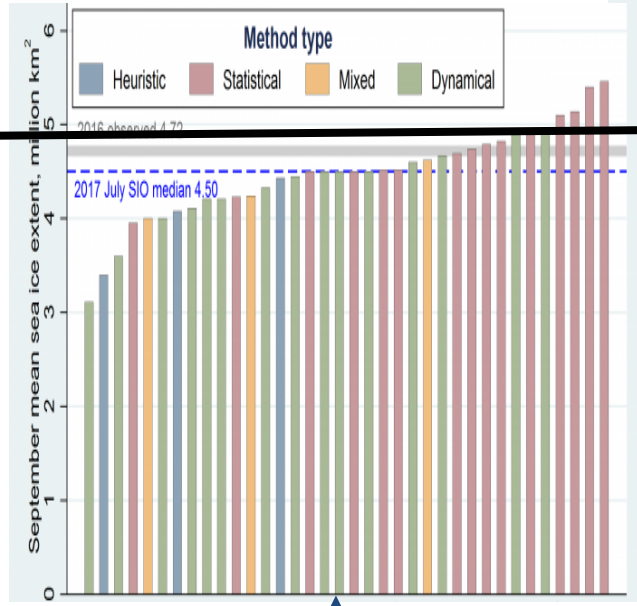
**Observed Value 4.80m km²**

### June Forecasts



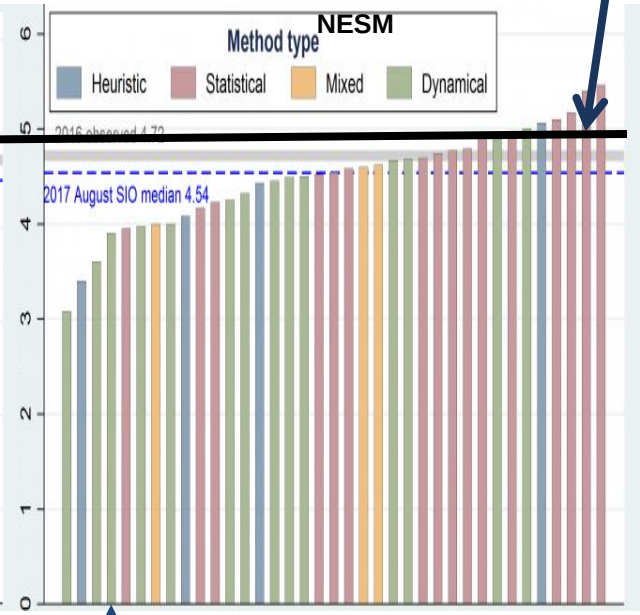

**NESM 6.0m km²**

### July Forecasts




**NESM 4.5m km²**

### August Forecasts




**NESM 3.9m km²**

**NESM forecasts vary widely *(interesting!)***

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# Navy Earth System Model

## Summary

- Operational transition scheduled for FY19
- Relatively high resolution for ocean and ice models (1/12$^{o}$ for ensembles, 1/25$^{o}$ for deterministic)
- Initial results promising (“in the mix”)
- Latency issue preclude replacement of stand-alone NAVGEM forecasts
- SubX runs being used by National Ice Center for resupply missions and field campaigns

## Future work

- Optimize ensemble design and configuration (testing analysis correction-based additive inflation method)
- Continue model development to address biases
- Develop new extended-range forecast products
- Final operational implementation (2022) will include coupled data assimilation and coupled ocean surface waves

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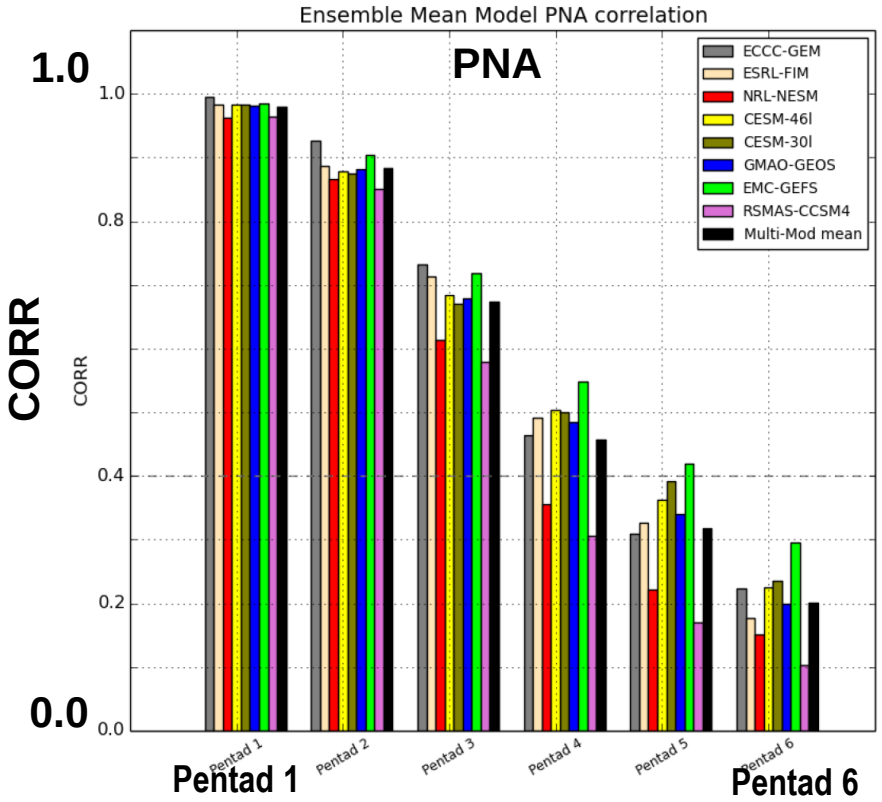
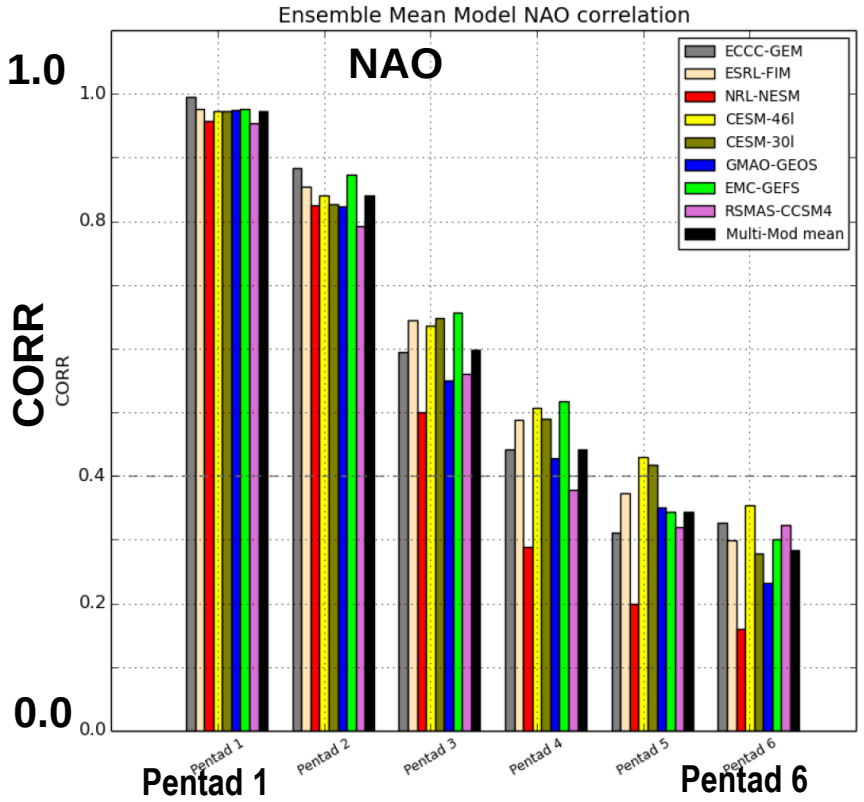
# Extra Slides

# SubX Pacific North American Oscillation and North Atlantic Oscillation

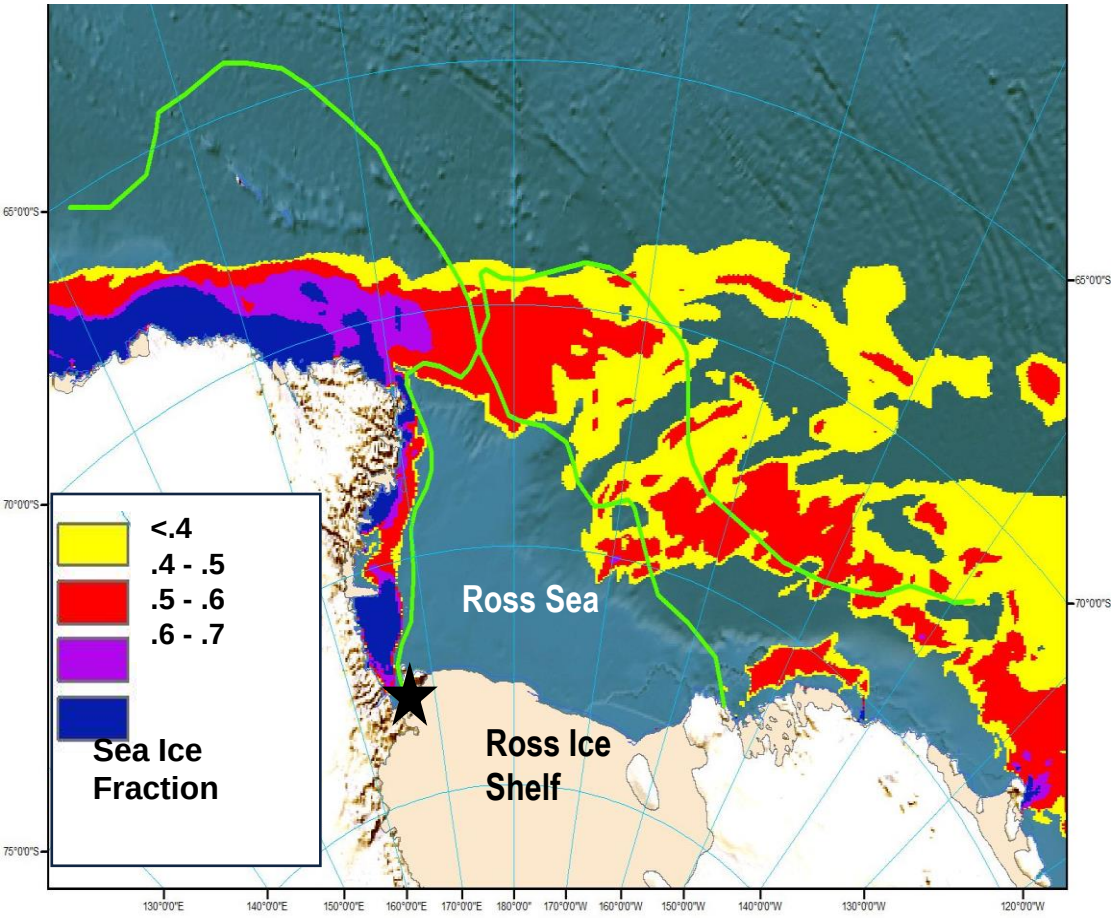
**When compared against ensembles, NESM is not competitive. There are open questions about how best to design the ensemble.**




*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 Real-time Forecasts used by National Ice Center



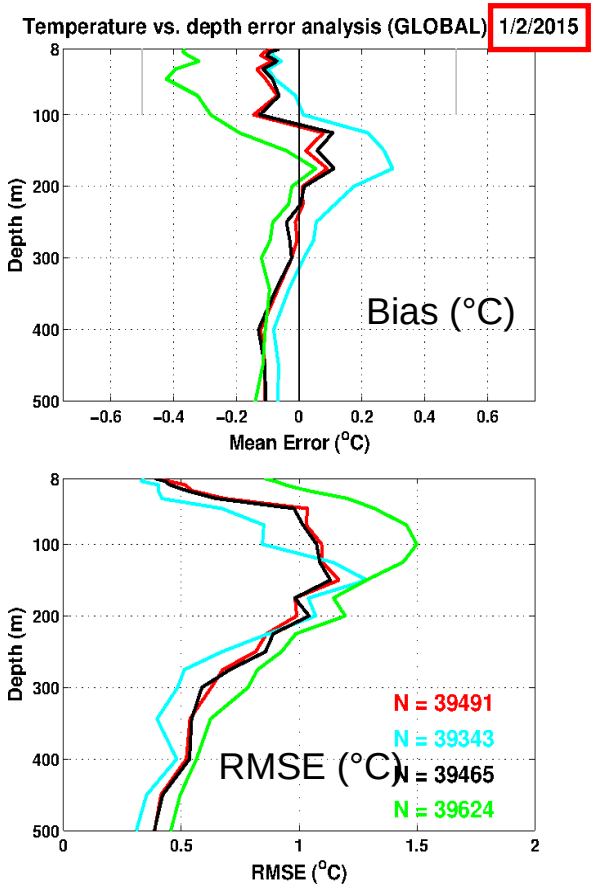

*15 Jan 2018 NESM 15-d sea ice fraction forecast (shading) and NIC outlook (green line .4 pack ice) for Ross Sea*

National Ice Center used NESM real-time sea ice forecasts for long-range planning guidance for 2018 Operation Deep Freeze (McMurdo resupply mission) and ICEX (Beaufort Sea) field campaign support.

Quantitative validation planned within the next year.

# Ocean Temperature Profile Validation

Daily Temperature vs. Depth Error Analysis




- **Red = NESM analyses**
- **Black = Global Ocean Forecast System (GOFS) 3.1 analyses**
- **Green = Climatology (GDEM)**
- **Light Blue = NESM forecasts**

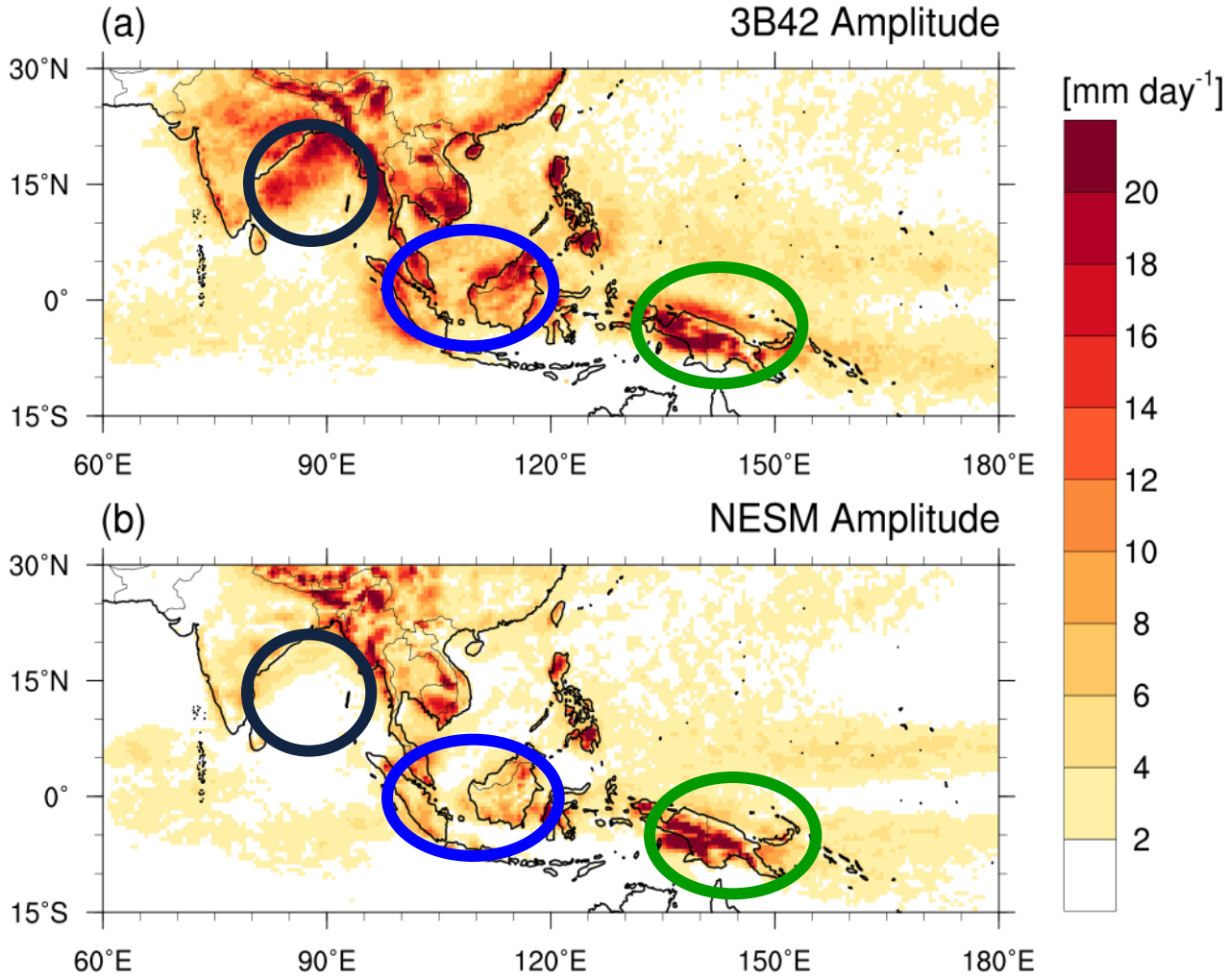
**NESM analysis (red) performs comparably to current ocean operational analysis (black)**

**NESM forecast (blue) outperforms climatology (green) with few exceptions**

**Comparisons against independent obs (50S-50N) from a 17-d forecast starting 20150101**

# SubX JJA 1999-2015: Diurnal Cycle

***The amplitude of the diurnal cycle as determined by the first harmonic in precipitation for TRMM (a) and NESM (b)***

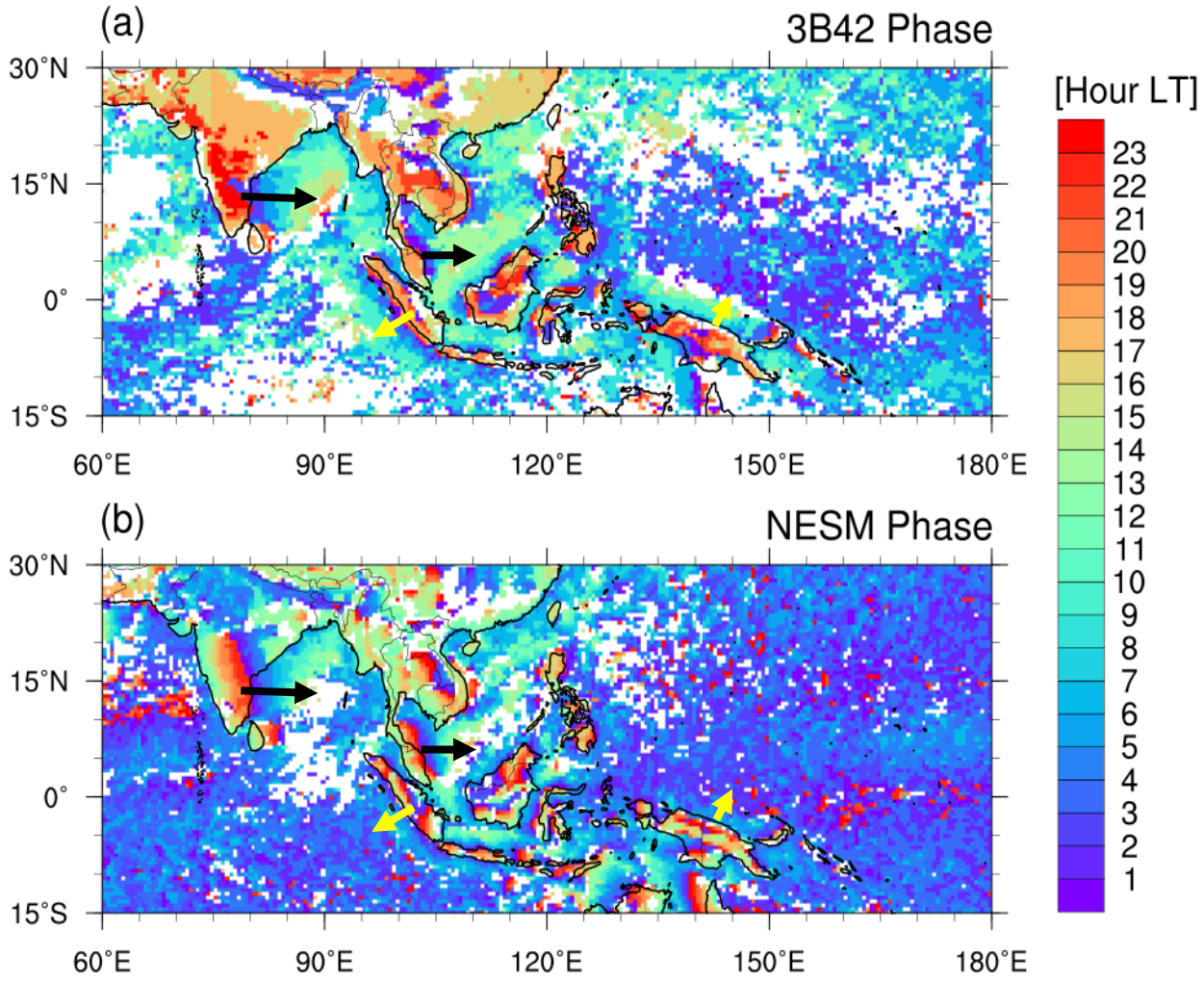



**In many regions the diurnal cycle amplitude in precipitation is too weak, particularly over/near Sumatra, Borneo and Bay of Bengal. Weak bias especially noticeable over coastal seas.**

**New Guinea is an exception.**

# SubX JJA 1999-2015: Diurnal Cycle

***Local time of day for the peak in the first harmonic of precipitation for TRMM (a) and NESM (b). Values are masked (white) where the first harmonic explains less than 70% of the total precipitation.***




**NESM captures nighttime max (purple) over ocean.**

**Errors in timing of precipitation peak in NESM are complex, generally occur too early.**

**NESM captures off-shore propagation of max precipitation (red-purple-green) in some regions (black arrows), missing/too weak in others (yellow arrows).**

**Errors are complex, island-dependent.**

# SubX 500-hPa Height Biases, NH Winter

## NESM develops substantial cold bias over much of NH during winter

| | |
|---|---|
| **6-10d** | **11-15d** |
| **16-20d** | **21-25d** |

NESM

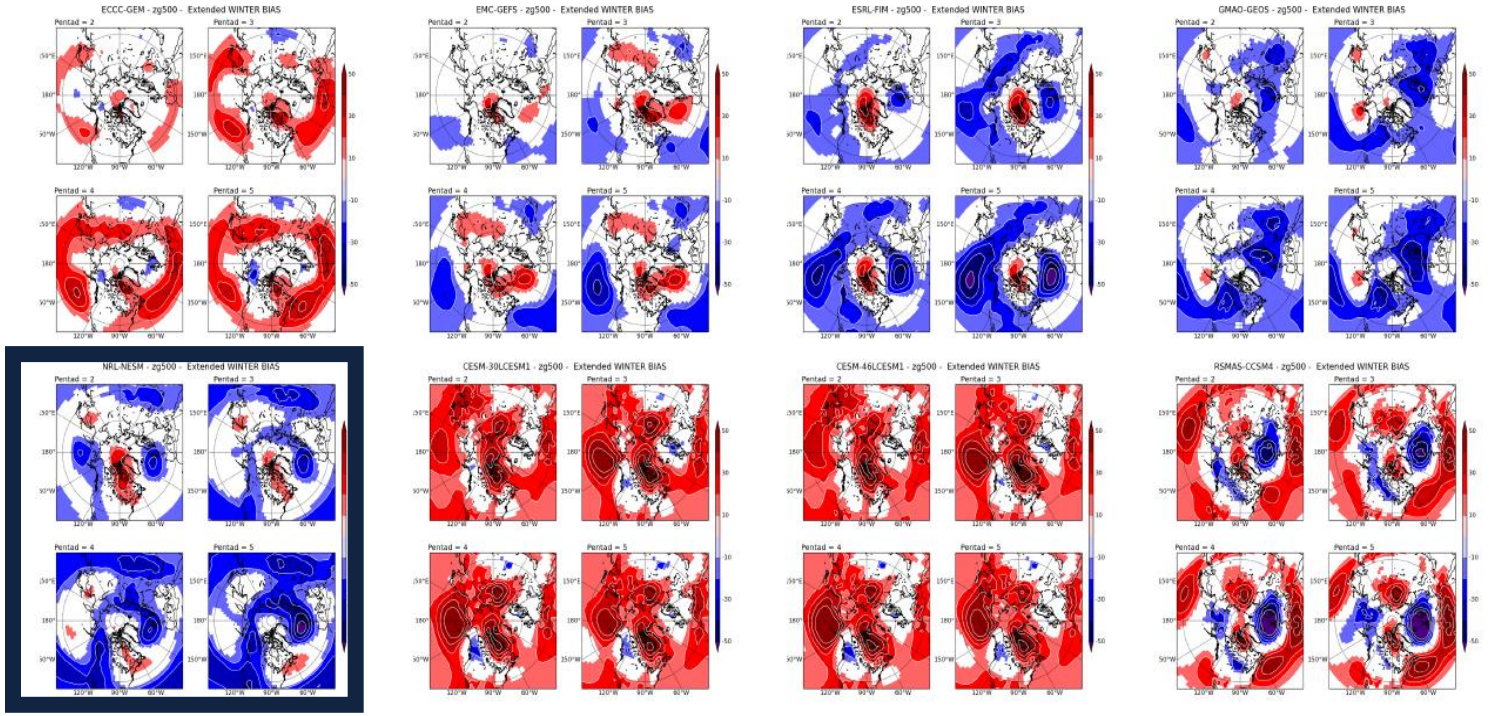



Figure 3 : 15 year extended winter [1999-2014] hindcast 500 hPa geopotential height bias (mgp) relative to NCEP2 reanalysis. Daily GZ forecast over 32 days are used to compute five day avenrage (pentads). Biases are shown starting from pentad 2 (average over days 6-11)

***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"***

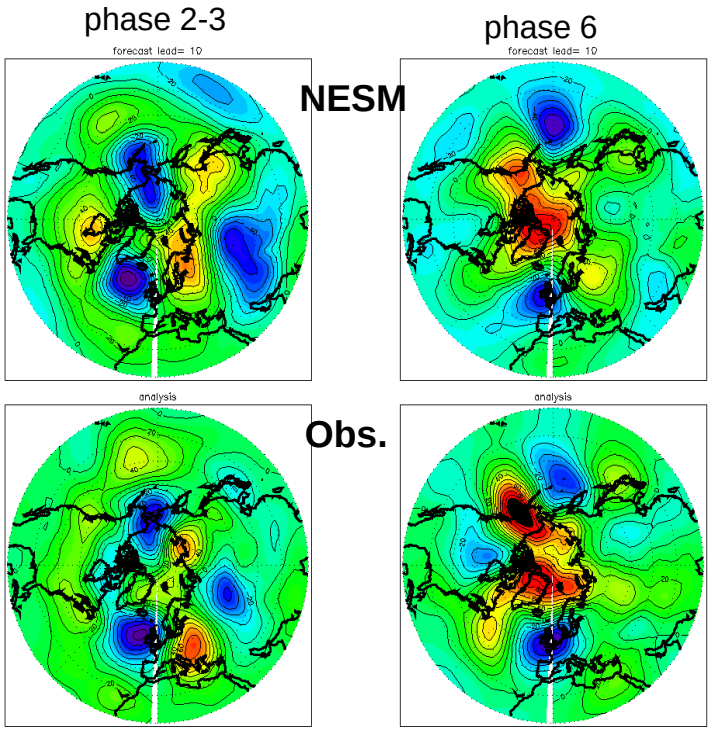
# SubX North Atlantic Oscillation

Diagnosing teleconnections and their impact on forecast skill

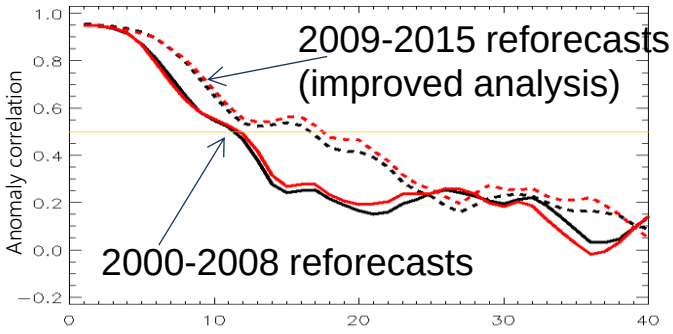
**MJO teleconnection:**

- **Good representation of MJO northern hemisphere teleconnection pattern for Indian Ocean and WP convection**
- **Slight improvement in the NAO forecast skills for strong MJO**
- **Importance of initial conditions**

500 mb height composites 10 day after strong MJO



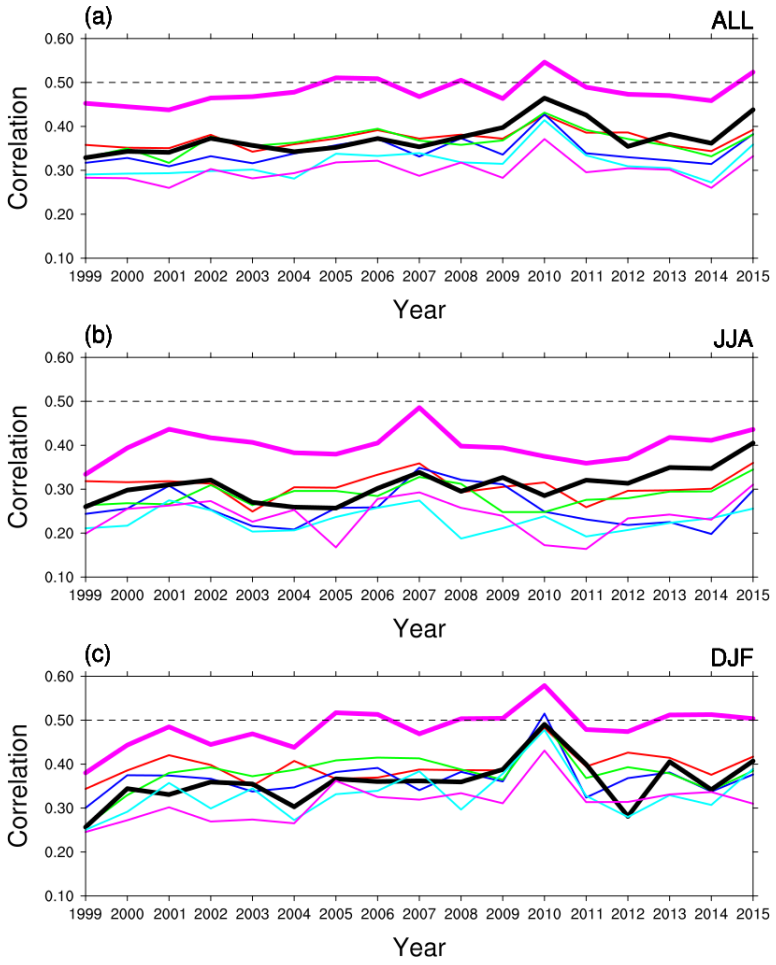

NAO Forecast Skill




__ all forecasts
__ MJO>1

# OLR Anomaly Correlation

## Week 1 20°S-20°N Average




**NRL**
**CESM**
**ESRL**
**GMAO**
**RSMAS**
EMC
**EMC_ENS**

**Improved skill with better initial conditions?**

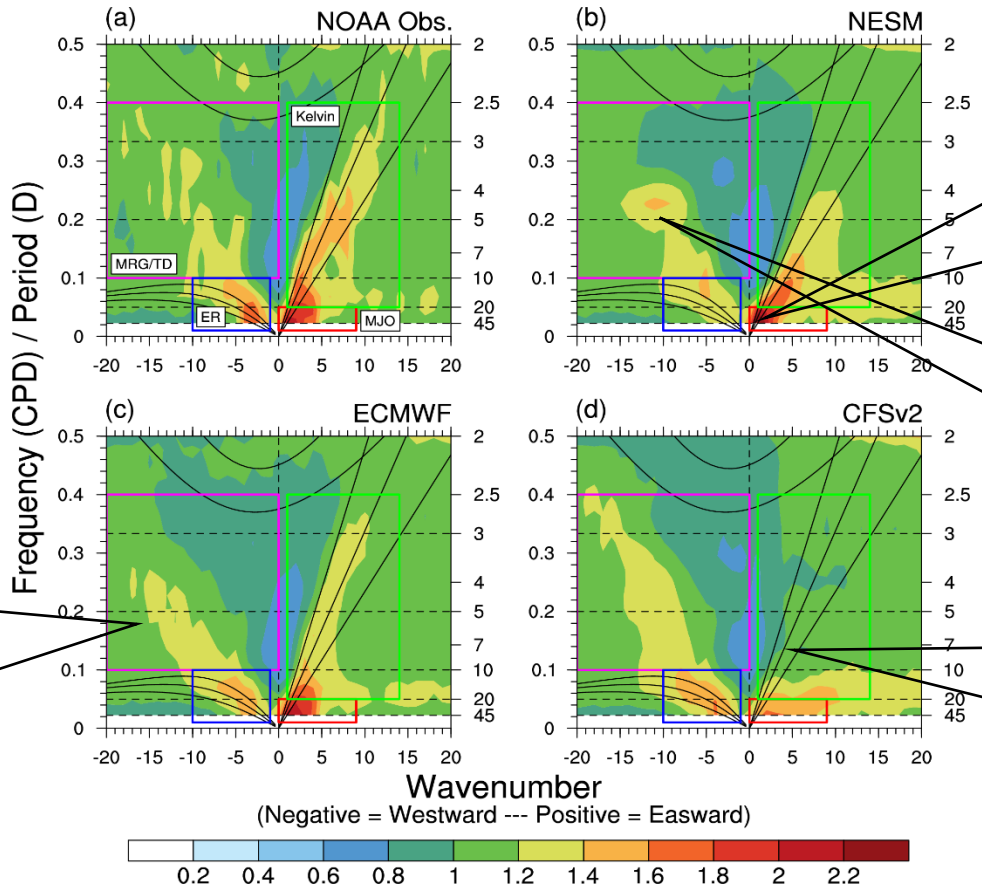
**1999-2008 initialized with operational NOGAPS.**

**2009-2015 with NAVGEM.**

Relative to NOAA CDR OLR.

# 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




**NESM matches observations well for MJO and Kelvin waves**

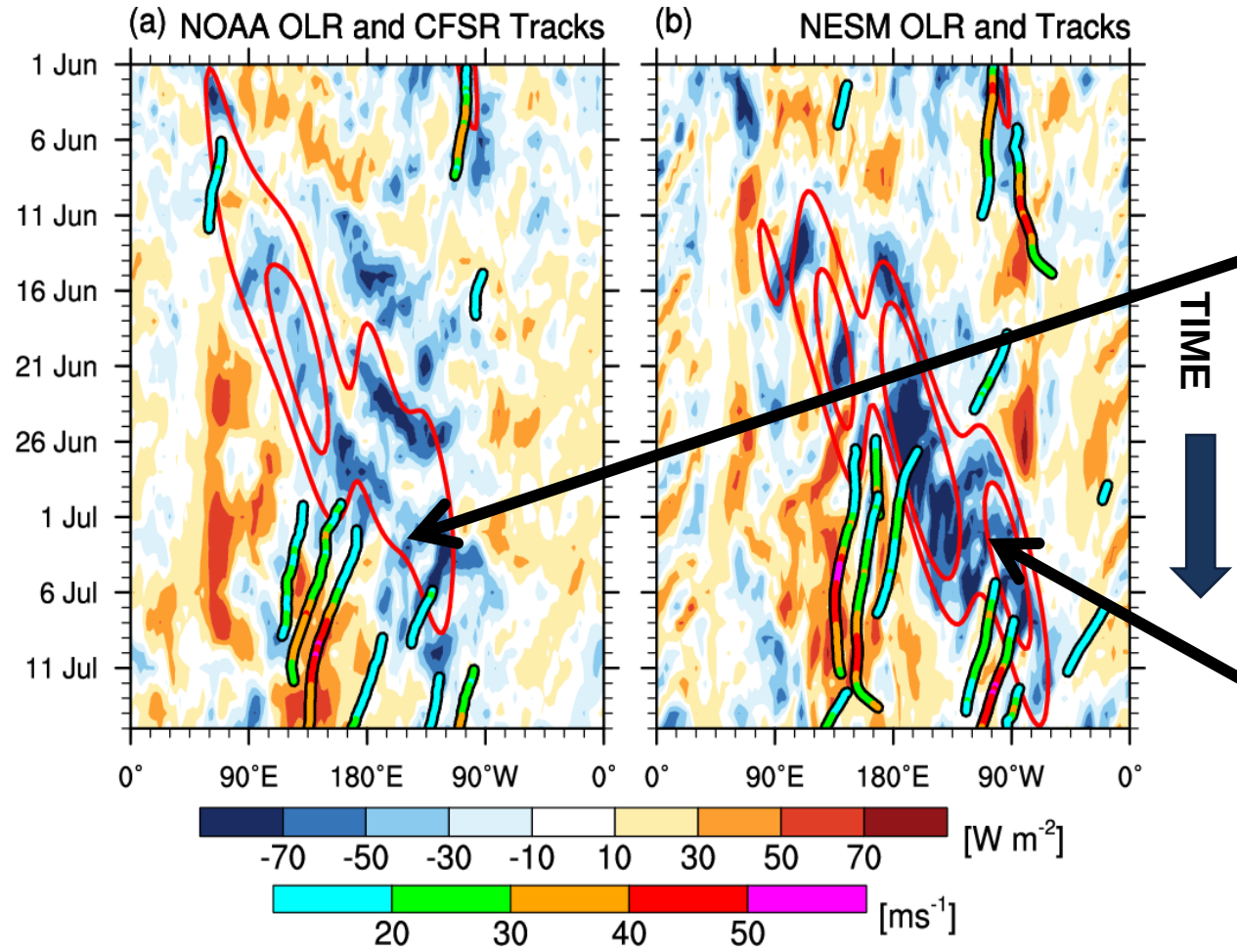
**NESM overactive in Tropical Depressions**

**ECMWF matches observations best of the three systems**

**CFSV2 has weak MJO and Kelvin waves**

Janiga et al. (2018, Monthly Weather Review)

# Tropical Cyclone Prediction Using the SubX Forecasts




**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**

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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# 1. Global System: NESM
# NAVGEM Parameterization Improvements

## Convection Scheme Development and Testing (*J. Ridout*)

**Modified Kain Fritsch Convection Scheme – Based on treatment of Ridout et al. (2005), but including recent improvements to better simulate the MJO.**

**Coupled System Physics Version 1 (CV1): Main Points**

1) **Closure relation based on an assumed quasi-balance in updraft parcel buoyancy at cloud base, similar to Emanuel and Živković-Rothman (1999). Also, constraint imposed to ensure that available buoyant energy does not entirely vanish.**

2) **Added convective momentum transport (similar to treatment in the Emanuel convection scheme).**

3) **Modified mixing rate based on the updraft mass flux and parcel buoyancy (in part, adopting an approach described by Peng et al. (2004)).**

4) **Enhanced capability to represent turbulence-forced convection, with inputs from plumes modeled in the NAVGEM EDMF scheme (Sušelj et al. 2013).**

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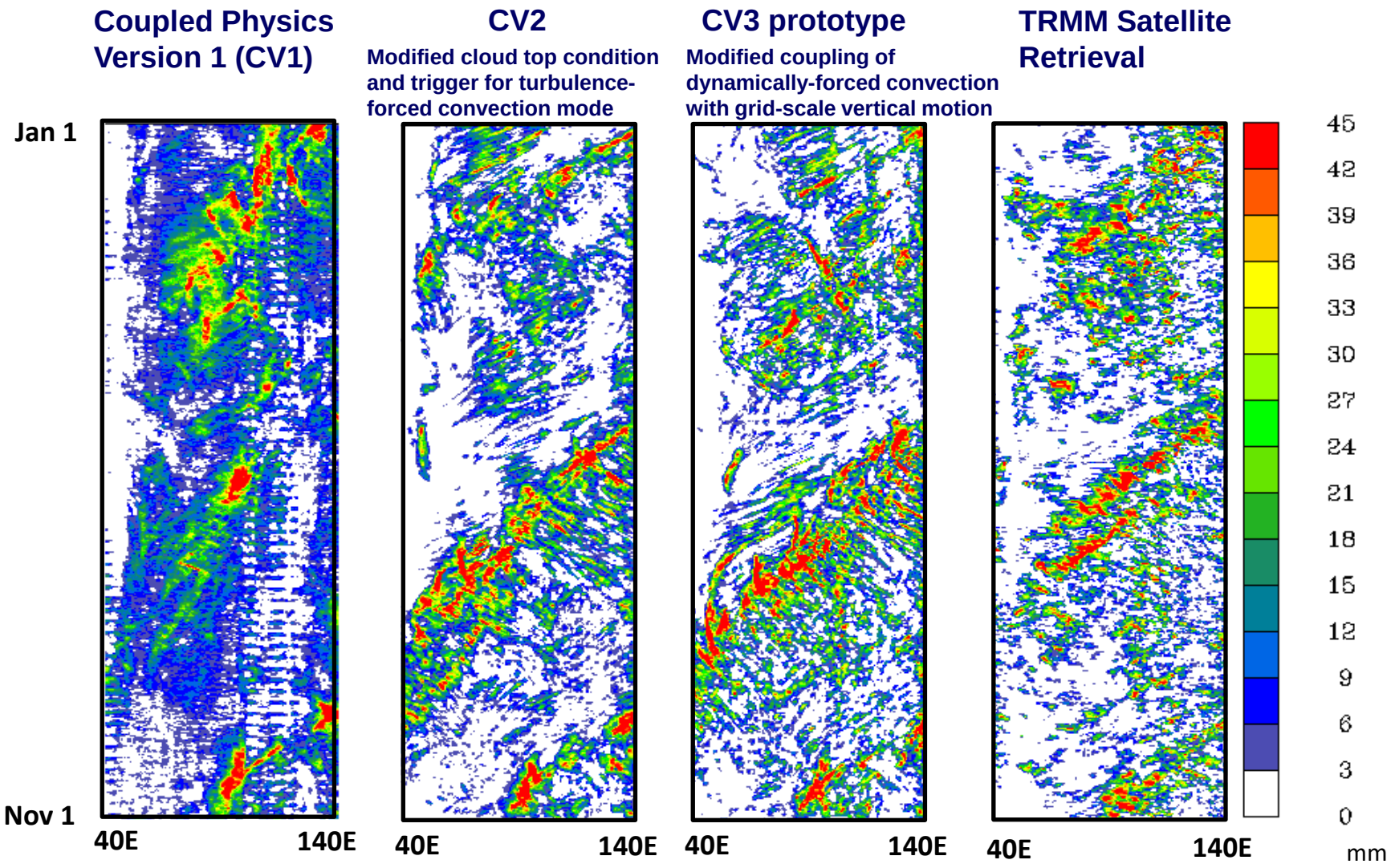
# DYNAMO Case Study 61-Day Hindcasts from 1 Nov, 2011 with ESPC Coupled System Physics

**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.**



# DYNAMO Case Study 61-Day Hindcasts from 1 Nov, 2011
# Implications of Improved Moistening/Rainfall

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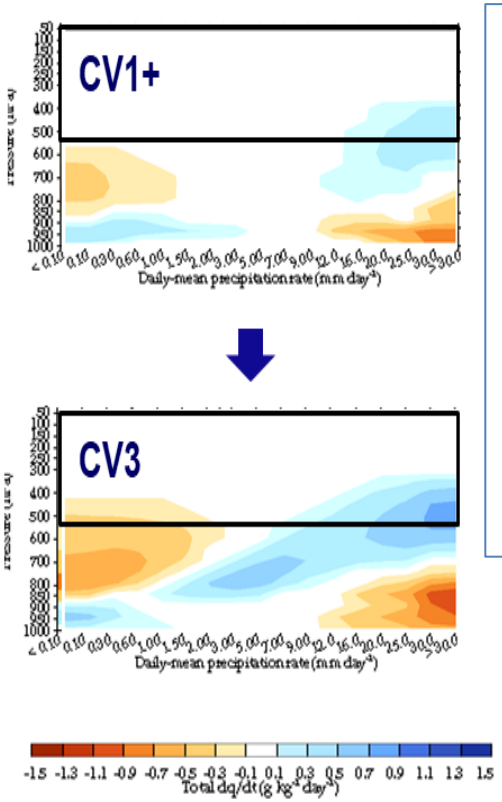
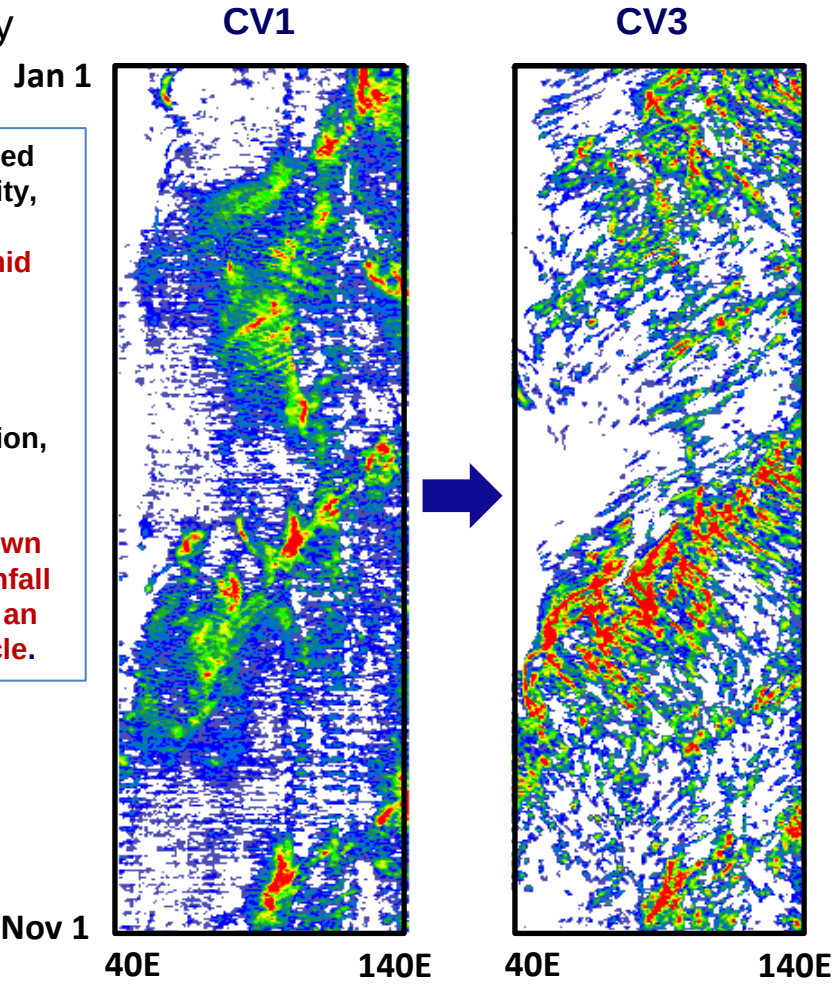
Combined improvements in moistening/rainfall relationship and rainfall rate distribution and variability




The CV1(+)* physics was characterized by a fair degree of moisture sensitivity, but did not adequately represent the observed moistening in the low-to-mid troposphere at intermediate rainfall rates.

Though CV1 succeeded in some respects with respect to MJO evolution, increased moisture sensitivity in subsequent versions brought improvements. The CV3 results shown here notably reflect an improved rainfall rate distribution and suppression of an unrealistically prominent diurnal cycle.




* *(CV1(+) includes a few changes from the original CV1 physics, most notably a modified convective trigger for the turbulence-forced mode based on Ridout and Reynolds (1998) - feature retained in CV3)*

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

# 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 to the North Pole.*

- 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**