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Coupling in the Navy Earth System Prediction Capability (Navy-ESPC) global coupled model

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Acknowledgements: This work was supported under the N2N6E/ONR Navy Earth System Prediction Capability Program, and the NOAA MAPP Subx Project. Computing support was provided by the Navy DoD Supercomputing Resource Center.
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Acknowledgements

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Navy-ESPC Configuration

Weakly Coupled Data Assimilation

Model Modifications For S2S Forecasting and Results

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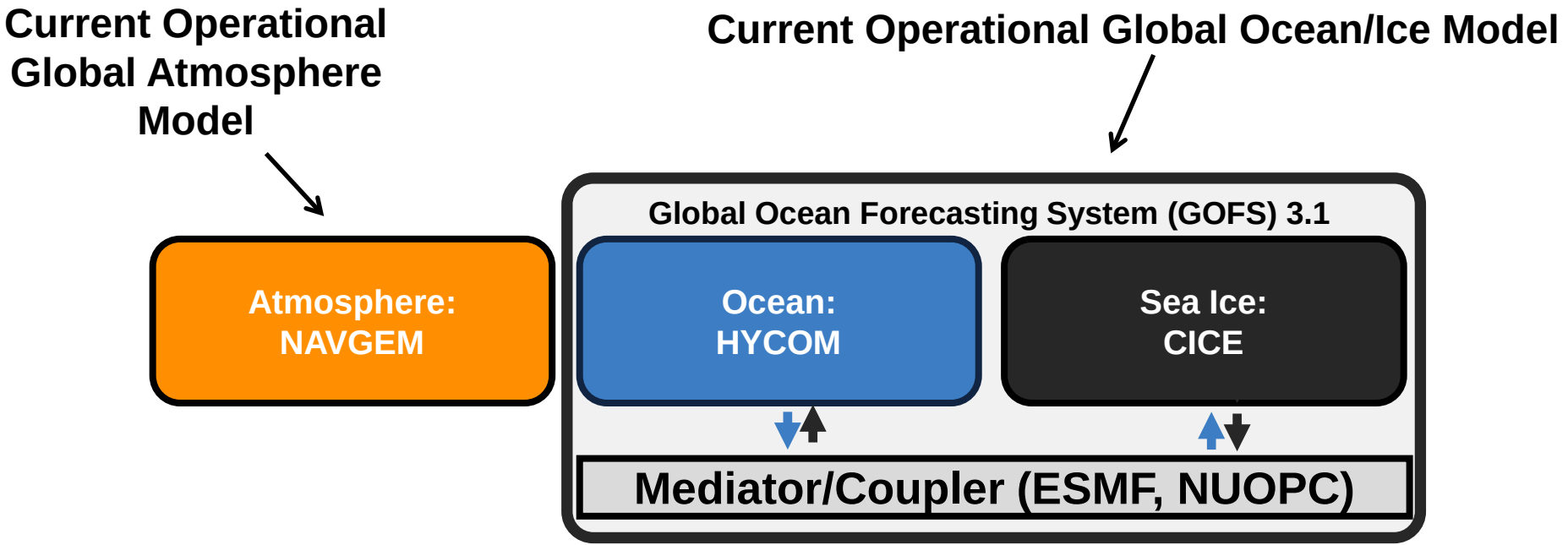
Model Modifications For S2S Forecasting and Results

Navy-ESPC Built Upon Stand-Alone Operational Systems



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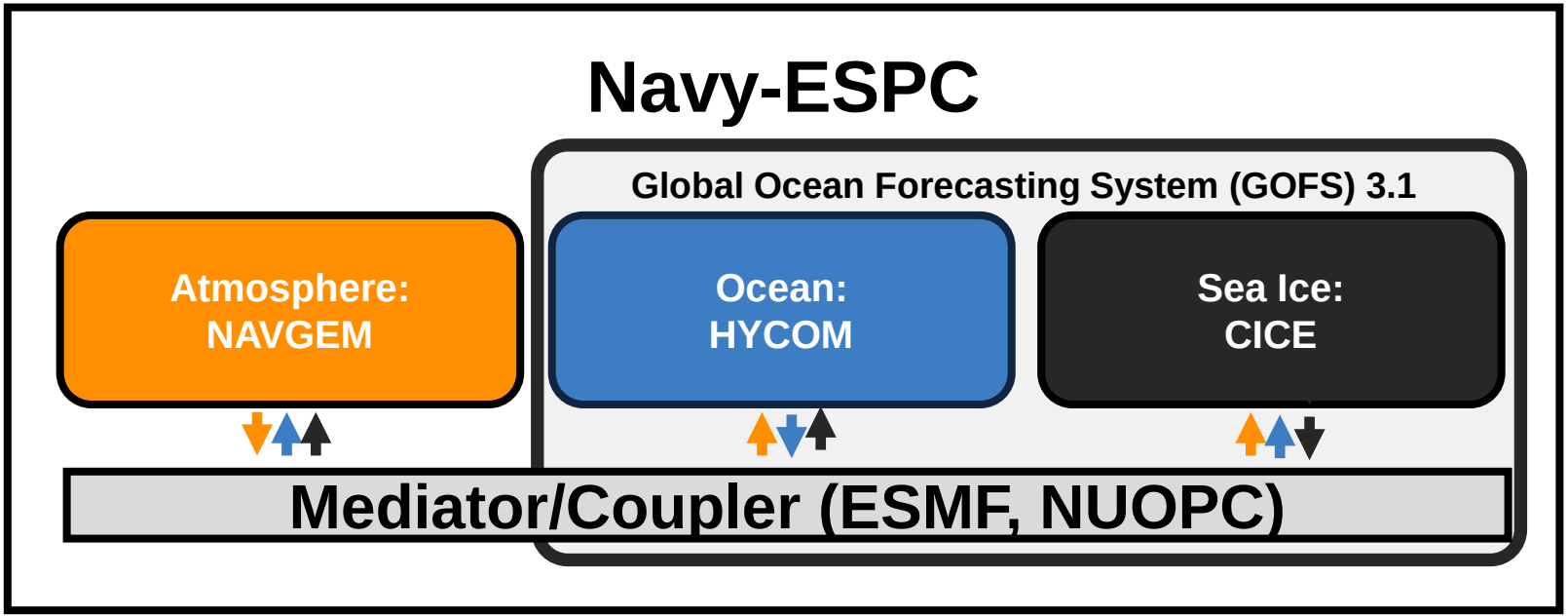
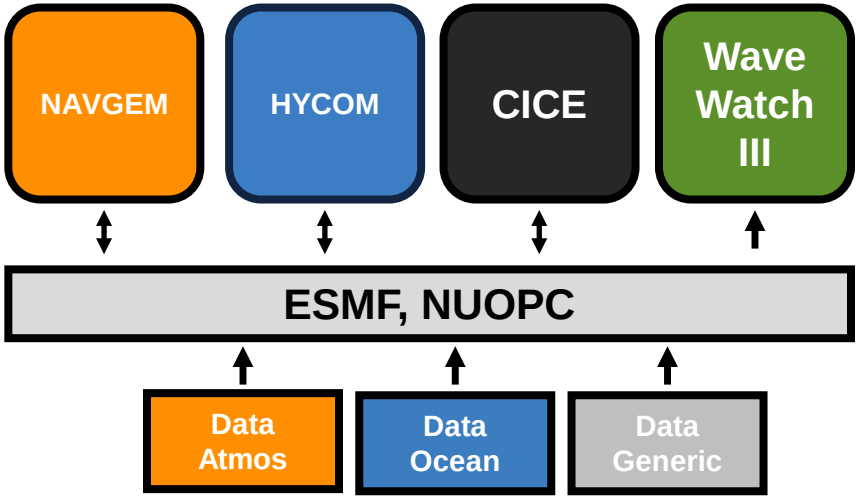


Full Schematic of Navy-ESPC



* Multiple Versions of NAVGEM, HYCOM, and CICE

- Model can be compiled with combinations of colors. (NAVGEM and data atmosphere cannot be compiled together)
- CICE resolution is compiled dependent
- Script selects components and writes compile namelists, including CICE resolution, before compile
- Ensemble and deterministic configurations are compiled separately
- Script also selects if non ESMF tools need to be compiled
  - Data assimilation (atmosphere and ocean)
  - Post and pre processing tools

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Navy-ESPC v1 Operational Capability

Forecast	Time Range, Frequency	Atmosphere NAVGEM	Ocean HYCOM	Ice CICE
Ensemble long term (S2S)	0-45 days 16 members, Sundays at 12Z	T359L60 (37 km) 60 levels	1/12° (9 km) 41 layers	1/12° (9 km)
Deterministic short term	0-16 days, Daily	T681L60 (19 km) 60 levels	1/25° (4.5 km) 41 layers	1/25° (4.5 km)

- **Very high resolution ocean and ice components compared to other systems**

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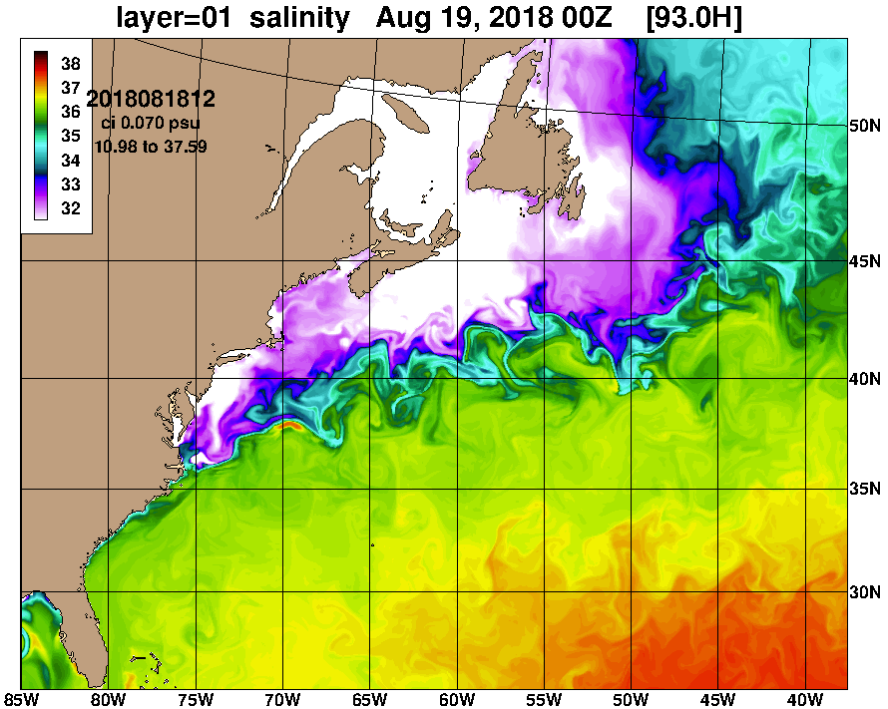
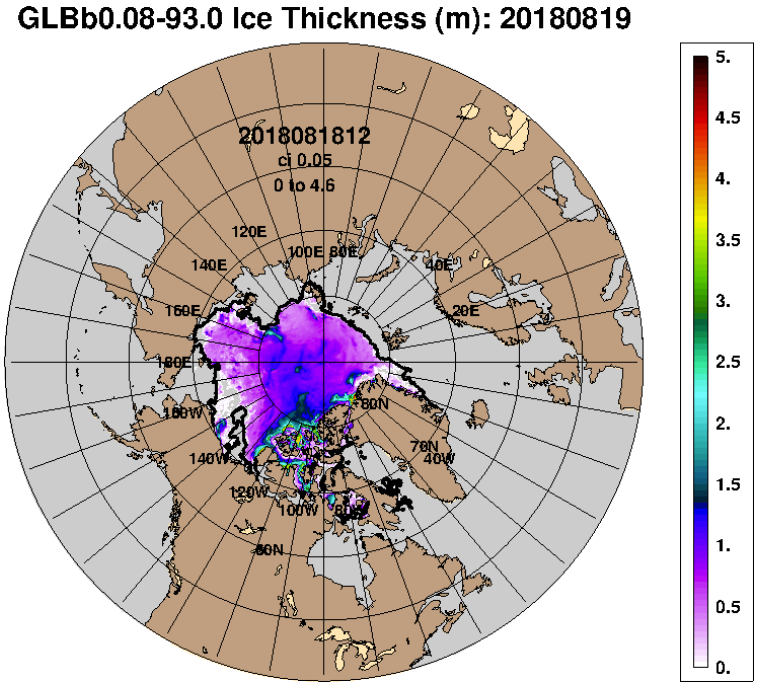
Navy-ESPC Ensemble is currently operational at Fleet Numerical Meteorology and Oceanography Center (FNMOC)

- **Very high resolution ocean and ice components compared to other systems**

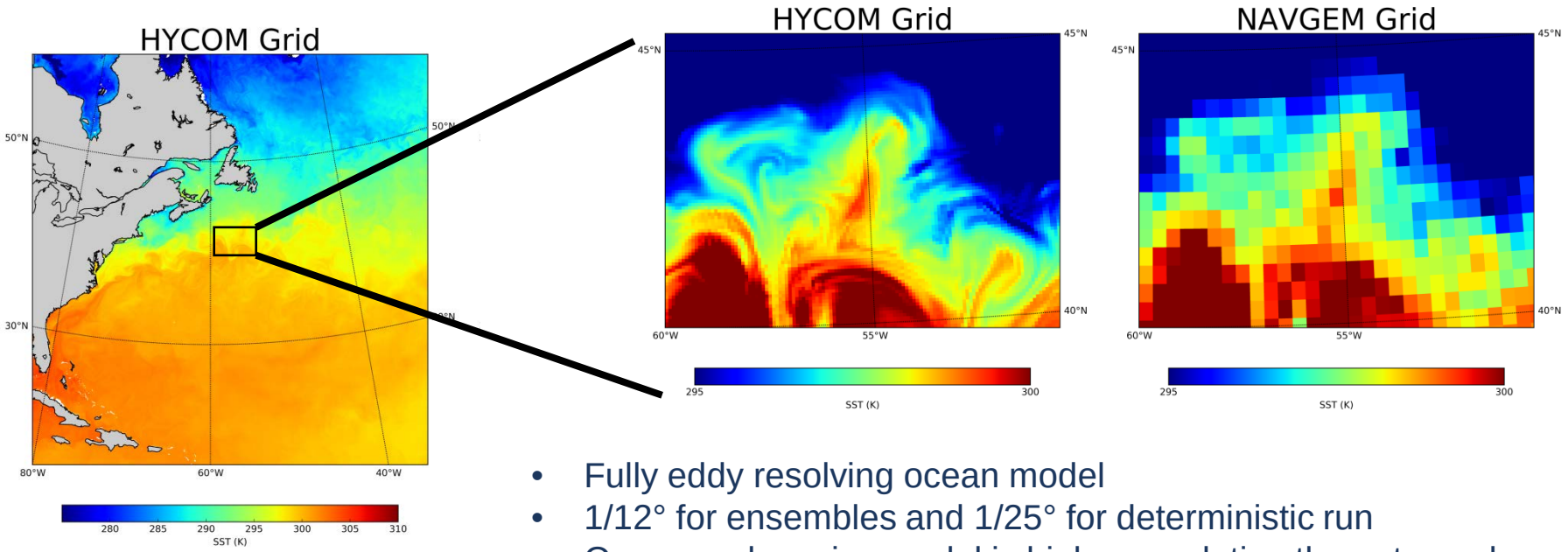
Uniqueness of Navy-ESPC: Global High Ocean Resolution





- High fidelity forecasts needed for Atmosphere, Ocean, and Sea Ice

Uniqueness of Navy-ESPC: Global High Ocean Resolution



- Fully eddy resolving ocean model
- 1/12° for ensembles and 1/25° for deterministic run
- Ocean and sea ice model is higher resolution than atmosphere
- Metrics diagnosed for each component including sea ice

Creep and Fill Extrapolation

Issue: definition of coastlines is different between the atmosphere and ocean grids.

- Atmosphere defines coastline where water begins
- Ocean defines coastline where water reaches certain depth

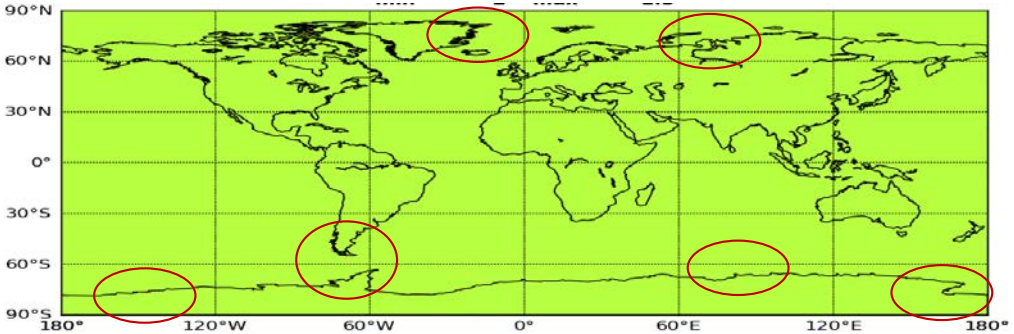
Results: Many prepackaged interpolation routines results in not interpolating many grid points near coastlines

Solution: Extrapolation being using creep/fill method. Initial implementation in ESMFv8

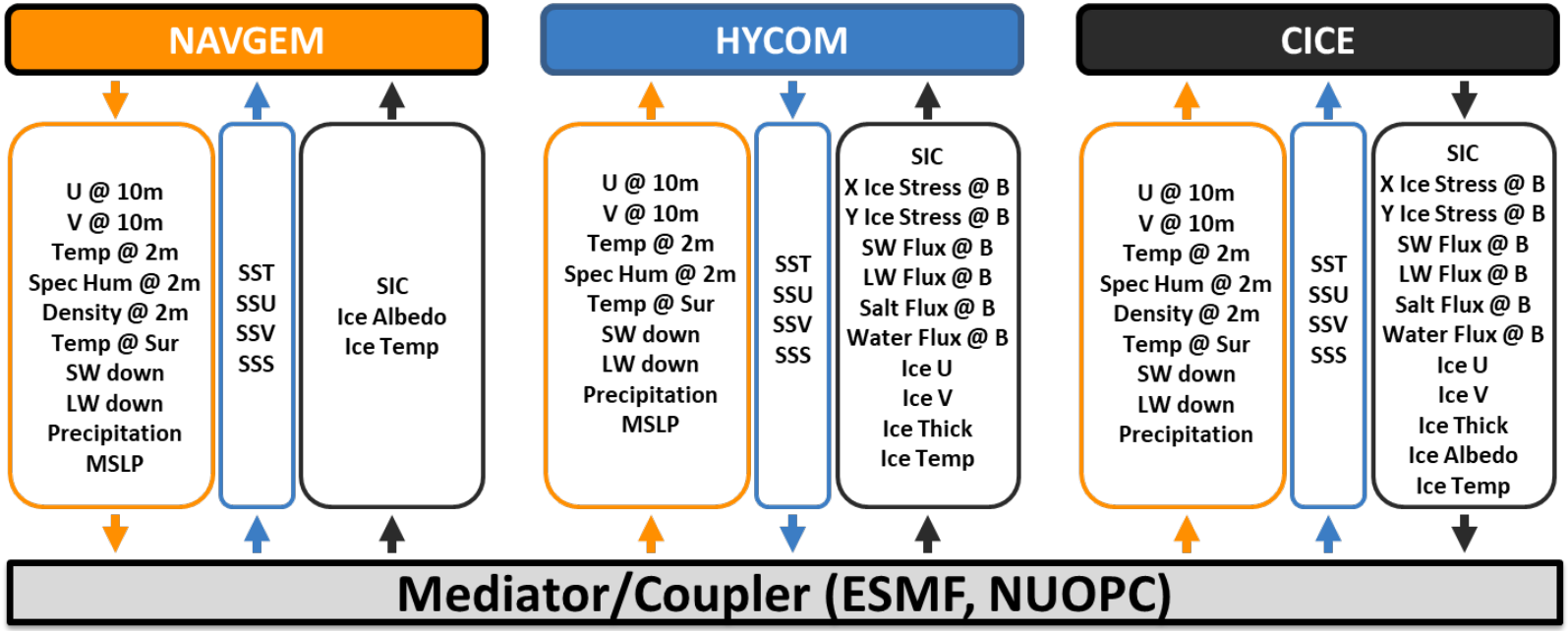
Creep – Fill Solution:

- define a stencil size of source grid. i.e., enlarge source domain.
- use stencil size on source and destination grid to fill (creep) values at missing destination grid

Holes (undefined interpolation) on Atmosphere Grid



Variables Exchanged in Navy-ESPC



Each Component Computes Its Own Fluxes

Computational Considerations with High Resolution Ocean

Example of Timings: Multiple Core Configurations Tested

Configuration	NAVGEM		HYCOM		CICE		Total Cores	Time to Completion (10 Day Forecast)
	Cores	%	Cores	%	Cores	%		
Ensemble	111	25%	1005	44%	180	29%	1296	2.38 hours
Deterministic	96	16%	2314	45%	360	38%	2770	10.3 hours

Currently Running a 16 member ensemble: 1296 * 16 = 20,720 cores
~ 70% of machine currently in use

Navy-ESPC Configuration

Weakly Coupled Data Assimilation

Model Modifications For S2S Forecasting and Results

Weakly Coupled DA System Based on Current Systems (NAVDAS-AR/NCODA)

Atmosphere and Ocean Stand-Alone DA Systems

	NAVGEM/ NAVDAS-AR	GOFS 3.1/ NCODA
Method:	4DVar Hybrid	3DVar FGAT
Assimilation Window:	6 hours	24 hours
Insertion:	direct Insertion	6 hour incremental analysis update

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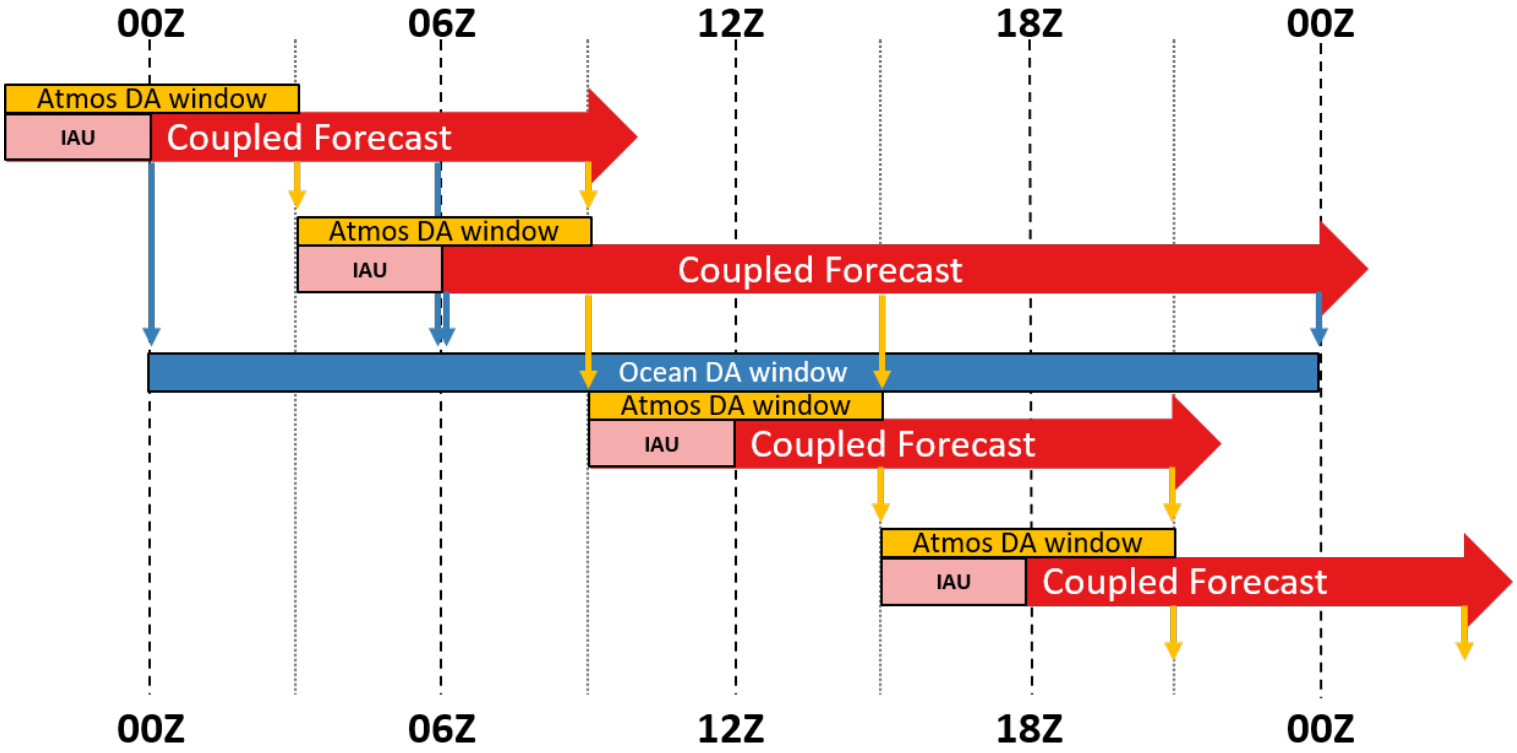
Method:	4DVar Hybrid	3DVar FGAT
Assimilation Window:	6 hours	24 hours
Insertion:	direct Insertion	6 hour incremental analysis update

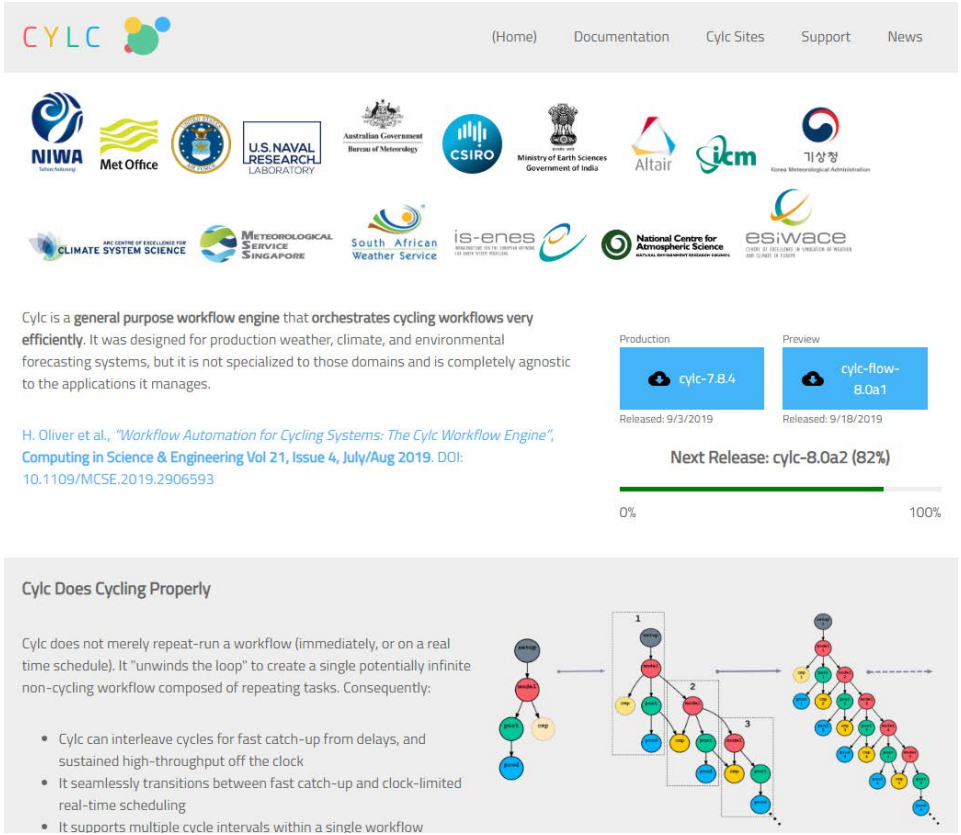
Weakly Coupled Configuration:

- Keep Method and Update Windows for Each System
- Use 3 hour insertion of incremental analysis update (IAU)

Weakly Coupled DA Schematic



Weakly Coupled DA: Task Management with cylc



cylc
- Task manager to handle dependencies
- Designed with cycling in mind

Navy-ESPC Use
- Data Assimilation
  - Task dependencies/ cycling in (previous plot)
- Long forecasting (> 45 Days)
  - Separate suite for task dependencies for long forecasts
  - Post processing is performed while the model is running
- Ensembles
  - Each member has its own suite and there is currently no interdependencies between members/suites

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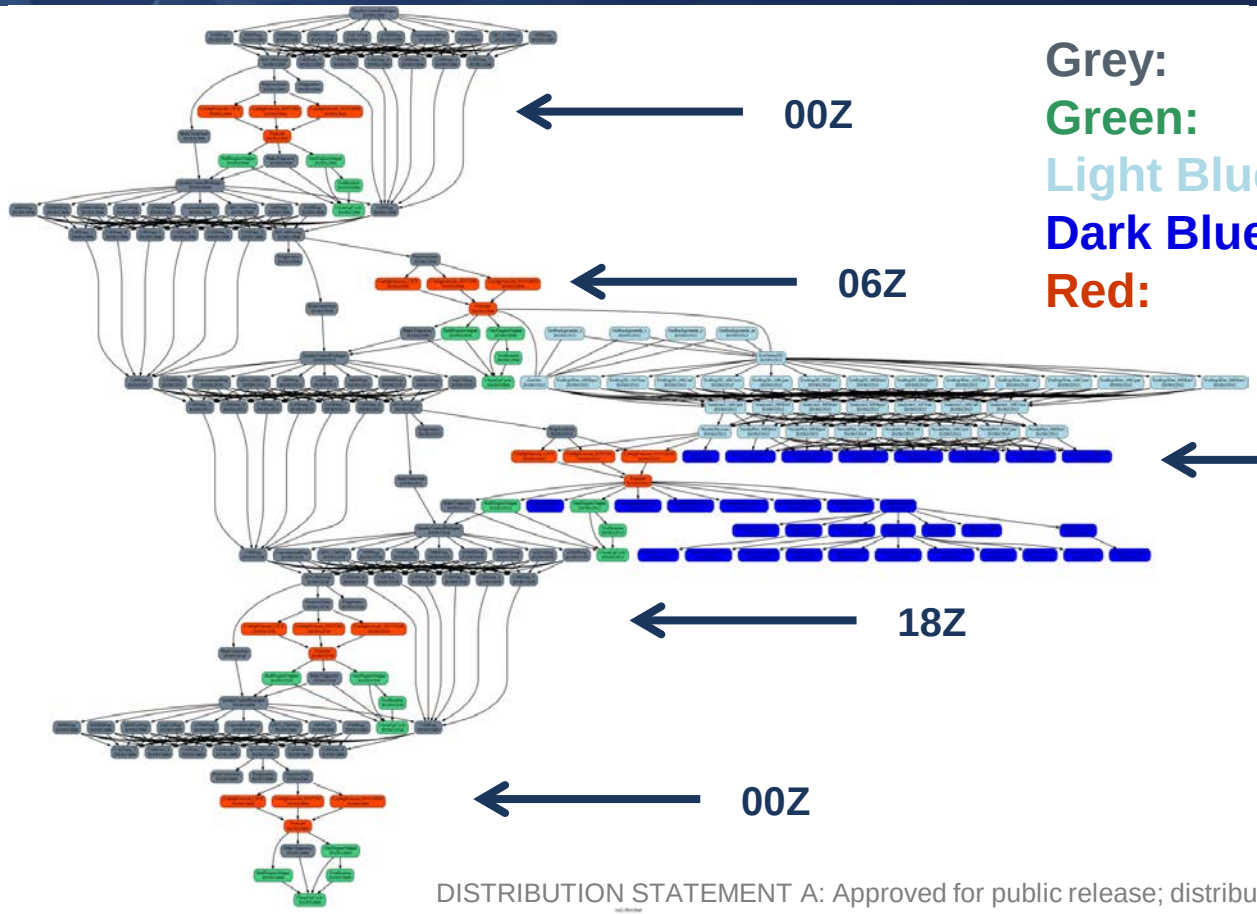
Weakly Coupled DA System Tasks



Grey: Atmos DA
Green: Atmos Post Process
Light Blue: Ocean DA
Dark Blue: Ocean Post Process
Red: Coupled Model Tasks

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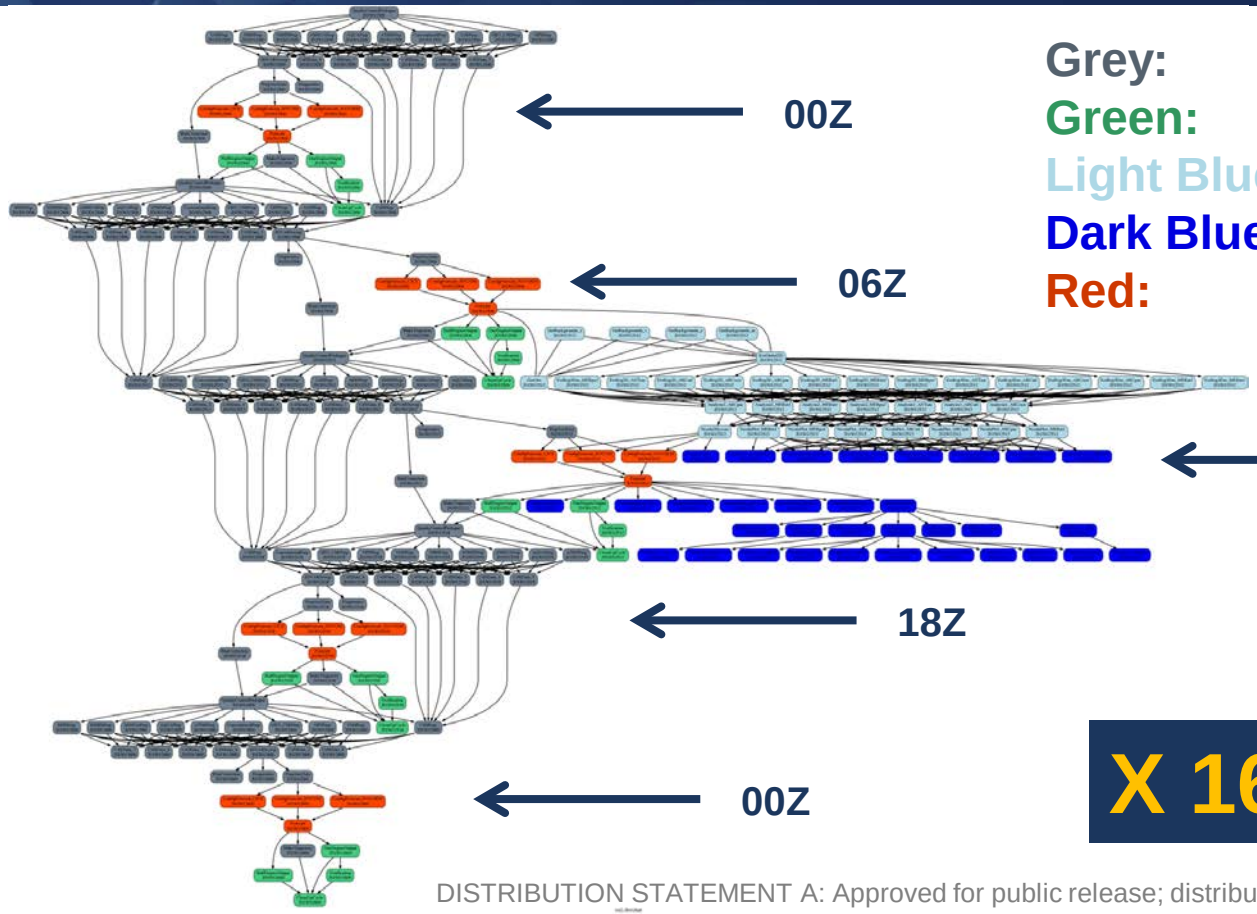
Weakly Coupled DA System Tasks



Grey: Atmos DA
Green: Atmos Post Process
Light Blue: Ocean DA
Dark Blue: Ocean Post Process
Red: Coupled Model Tasks

X 16 for ensembles

Navy-ESPC Configuration

Weakly Coupled Data Assimilation

Model Modifications For S2S Forecasting and Results

NAVGEM model updates in Navy-ESPC

	NAVGEM v1.4	Navy-ESPC
Convection Parameterization:	SAS (Moorthi et al. 2001)	Modified Kain-Fritz (Ridout et al. 2005)
Boundary Layer Scheme:	Louis et al. (1982)	COARE 3 (Kara et al. 2005)

NAVGEM model updates in Navy-ESPC

MJO Subseasonal Forecasting

	NAVGEM v1.4	Navy-ESPC
Convection Parameterization:	SAS (Moorthi et al. 2001)	Modified Kain-Fritz (Ridout et al. 2005)
Boundary Layer Scheme:	Louis et al. (1982)	COARE 3 (Kara et al. 2005)

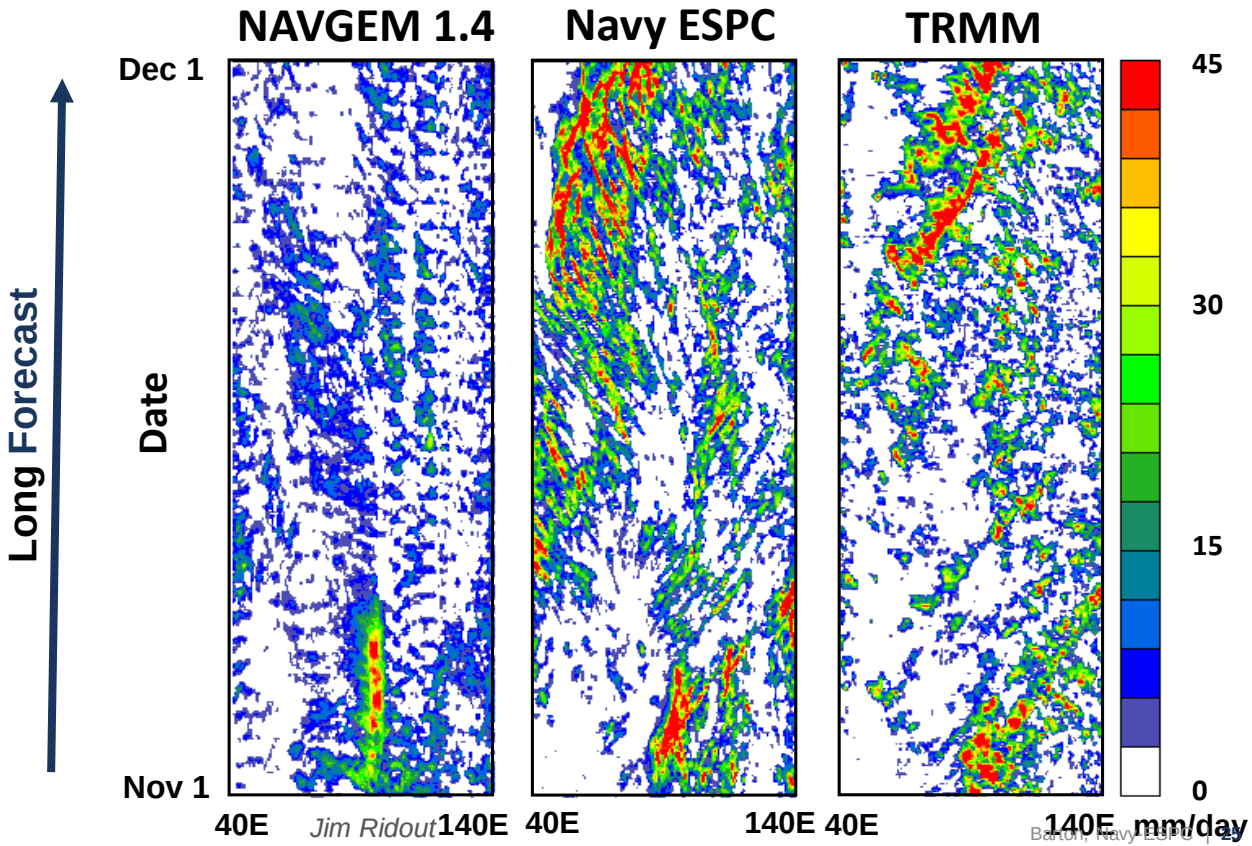
(greater) flux consistency between atmosphere and ocean

NAVGEM model updates in Navy-ESPC

DYNAMO Period

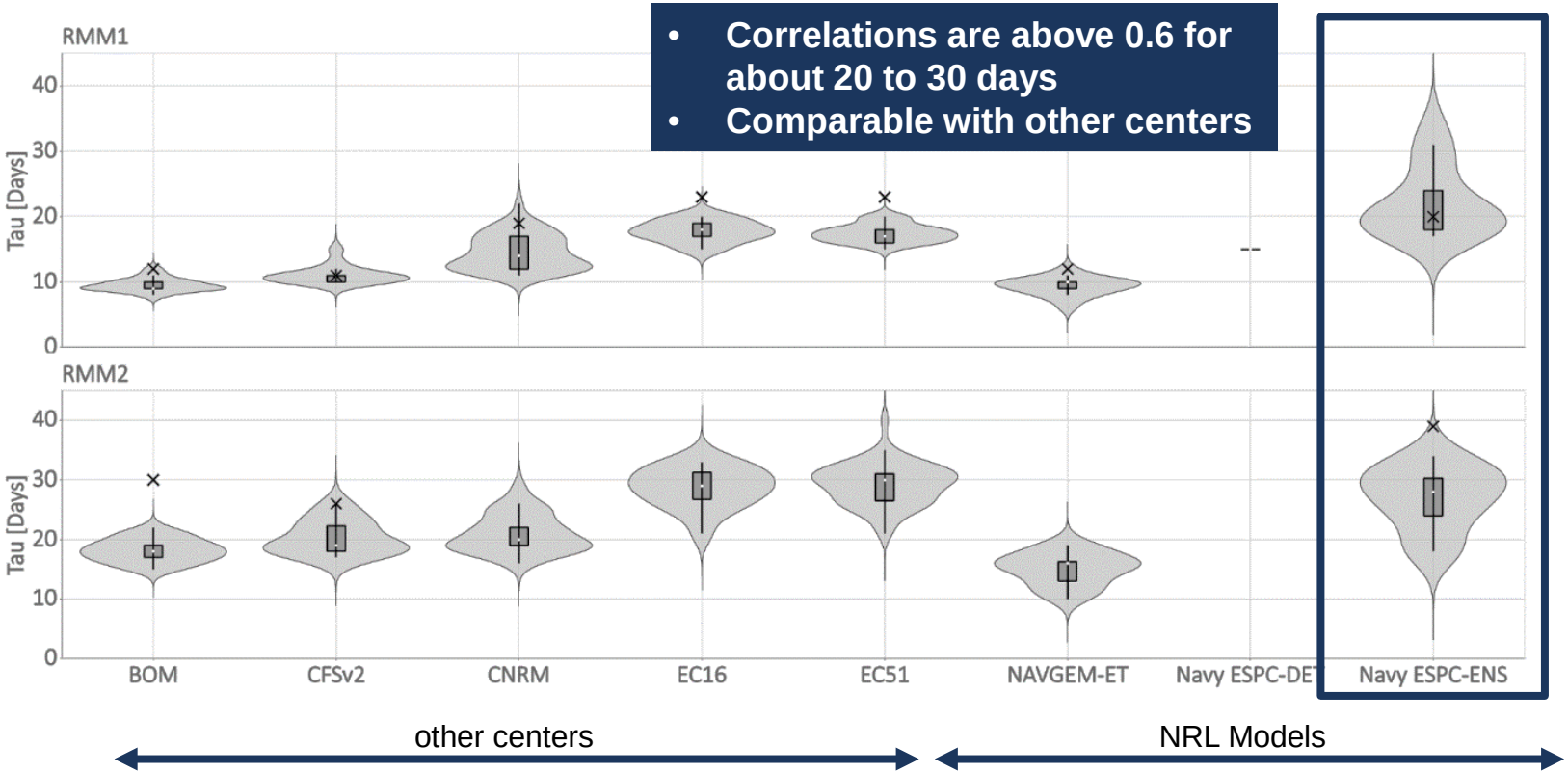
Forecast starting on 2011-11-01

Update convection parameterization aids in capturing first and second MJO



Results: MJO

Forecast Day MJO correlation drops below 0.6



- Correlations are above 0.6 for about 20 to 30 days
- Comparable with other centers

Conclusions: Navy ESPC

Navy's Earth System Model (Navy ESPC)

- Configuration
  - Atmosphere and Ocean Centric Model
  - High resolution ocean and sea ice model, eddy resolving
    - Miss-match in atmosphere and ocean grid/coastline
    - Development of Creep-Fill Method (implemented in ESMF8)
    - Ocean is more computationally expensive than atmosphere
- Weakly Couple DA
  - 4DVar atmosphere with 3Dvar ocean
  - Use of cylc in task management
    - Data Assimilation, ensembles, long forecasting
- Forecast Modifications
  - Convection Modifications for MJO forecasting
  - Initial results (MJO, PNA, NAO, Sea Ice) are encouraging, SSTs out to 60 days, Sea ice extent until 45 days
- Future work for Version 2:
  - ESMF8, NAVGEM2 (meshgrid, inline aerosols, middle atmosphere), tides in HYCOM, Wave Watch 3, CICE6, Ensembles

Barton et al. (in press): *The Navy's Earth System Prediction Capability: a new global coupled-atmosphere-ocean-sea ice prediction system designed for daily to subseasonal forecasting*. Earth and Space Sciences

Questions?

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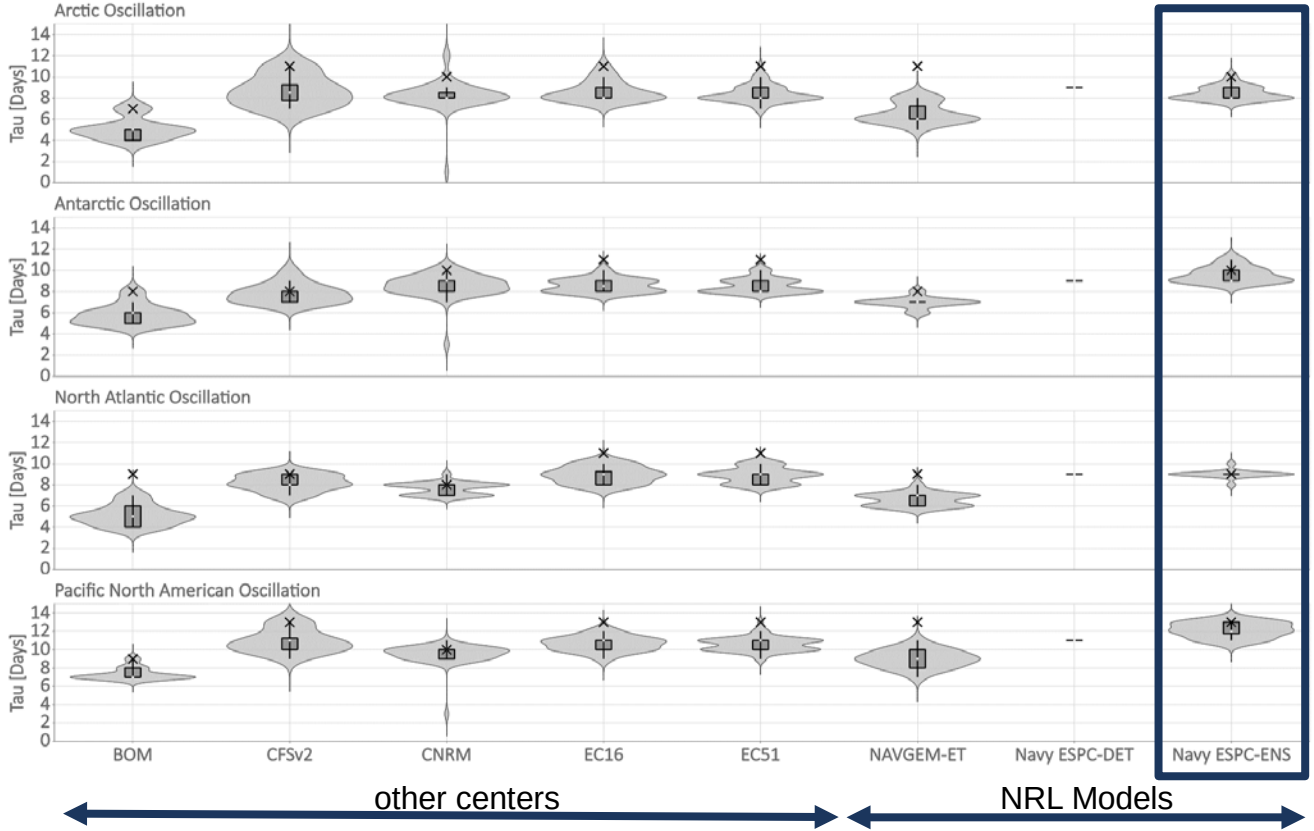
Ensemble Results Design

Ensemble Configuration :

- T359 (37km) NAVGEM, 1/12^{o} HYCOM, CICV v4
- Data assimilative ensemble from Feb. 2017 to Jan. 2018
- Forecast Frequency: every Wednesday at 12Z
- Forecast Length: 60 Days
- Members: 16
  - 15 perturbed runs
  - 1 control run
- Model Comparisons:
  - Compared to other S2S and SubX systems
  - GOFS 3.1 (1/12^{o} HYCOM/CICE)
  - Observations
  - Generalized Digital Environmental Model (GDEM4) climatology
  - Persistence

Results: AO, AAO, NAO, PNA

Forecast Day correlation drops below 0.6



- Correlation above 0.6 for 8 to 10 days depending on metric
- Navy ESPC is Comparable with other centers

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Results: Sea Ice

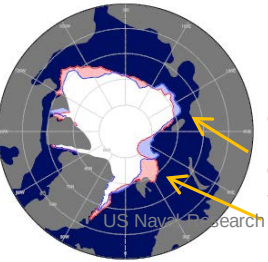
Comparison Between

- climatology (10 year) → grey
- ensemble → marron
- persistence → pink

Time Period

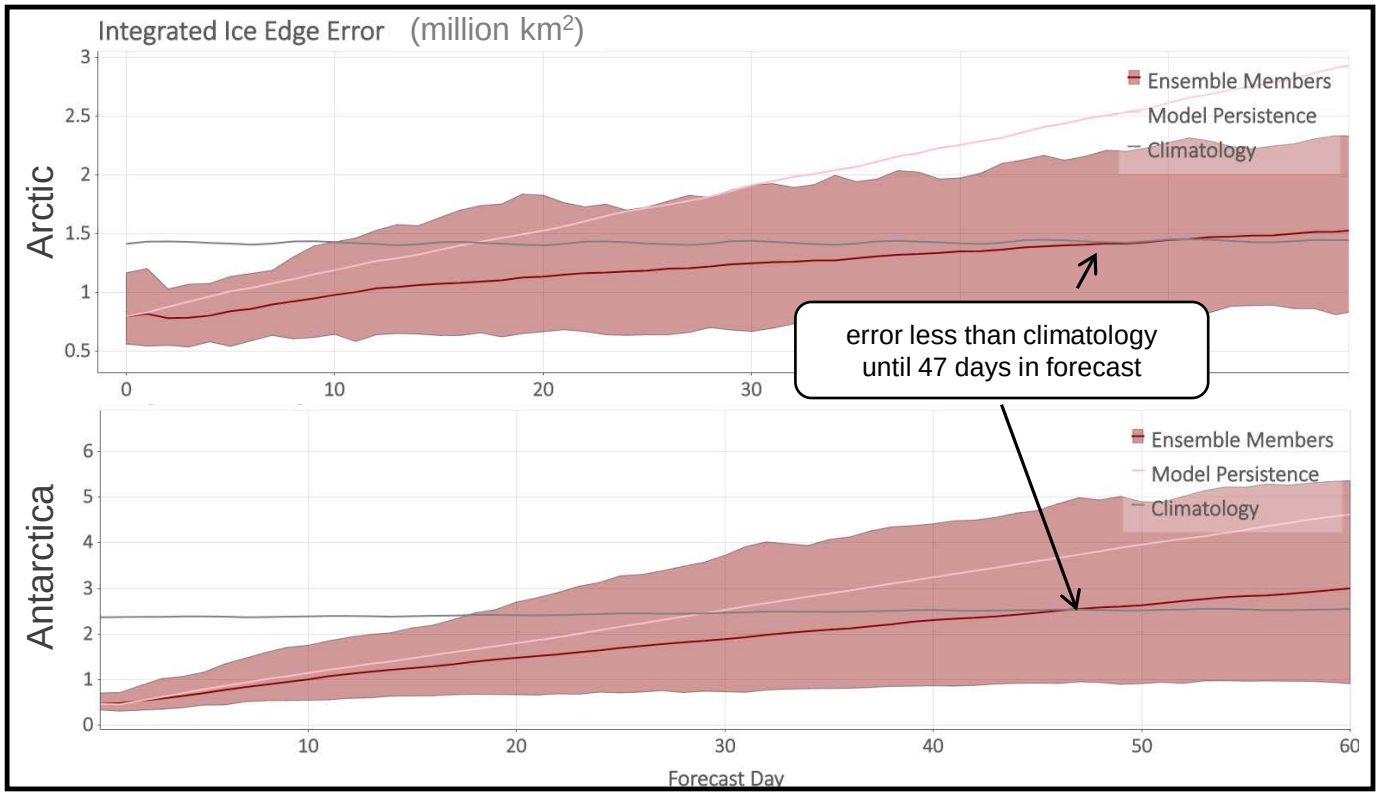
- February 2017 to August 2017

Navy-ESPC exhibits skill out to 6.5 weeks compared to climatology

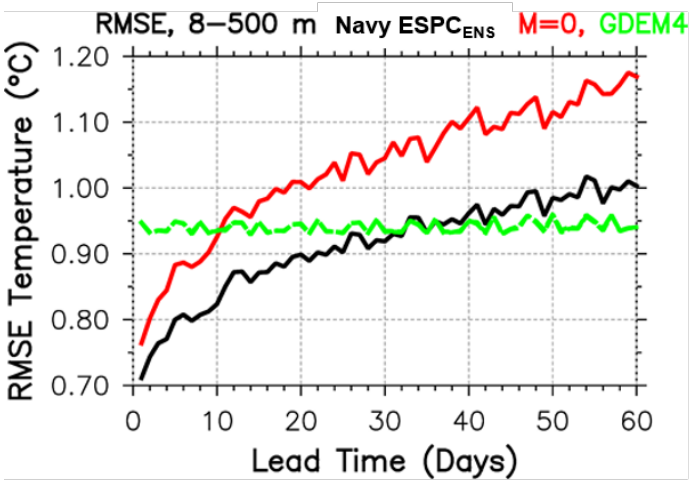


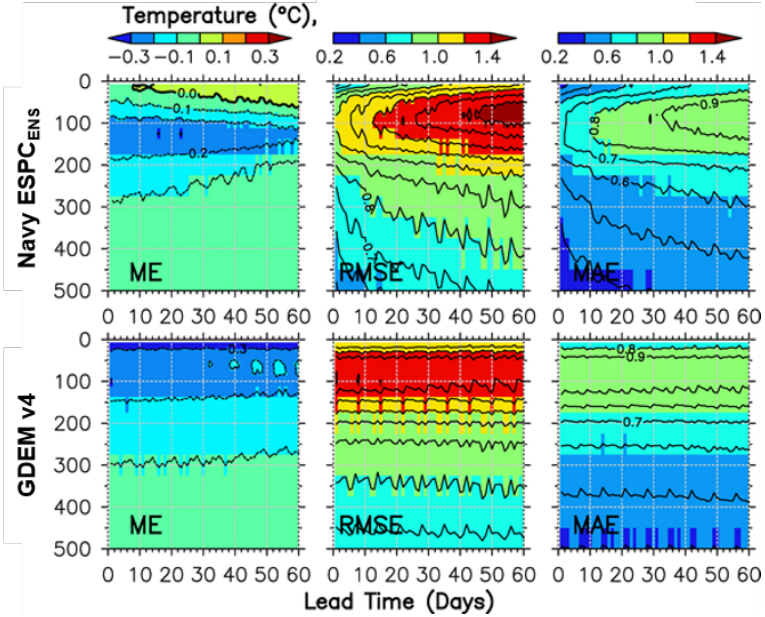
Integrated Ice Edge Error:
Goessling et al. (2016) *GRL*

Overestimate (blue)
+
Underestimate (red)



Results: Ocean Temperatures





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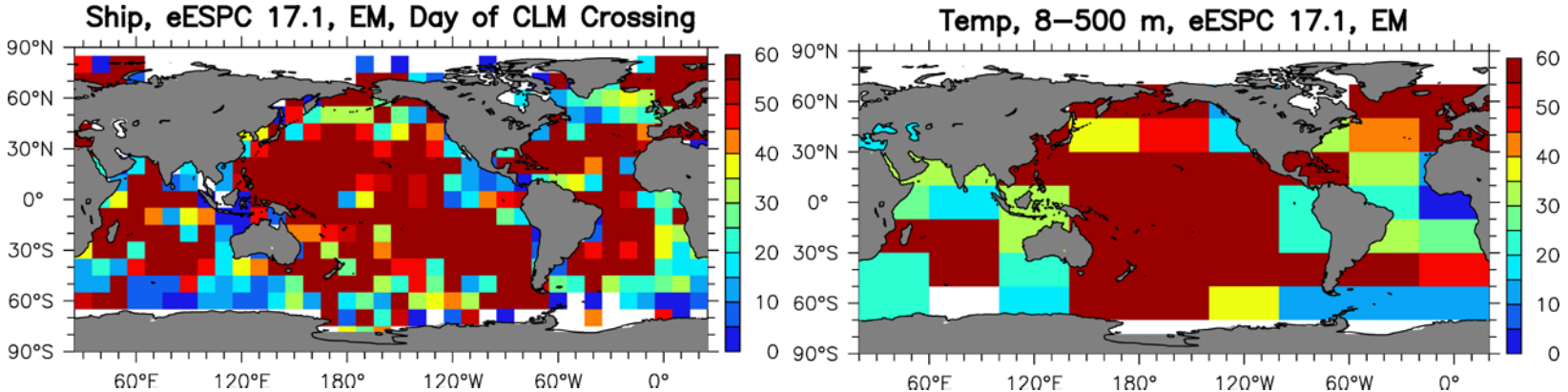

Last Day Ensemble Root Mean Square Error (RMSE) of ensemble Forecast is below RMSE of Climatology

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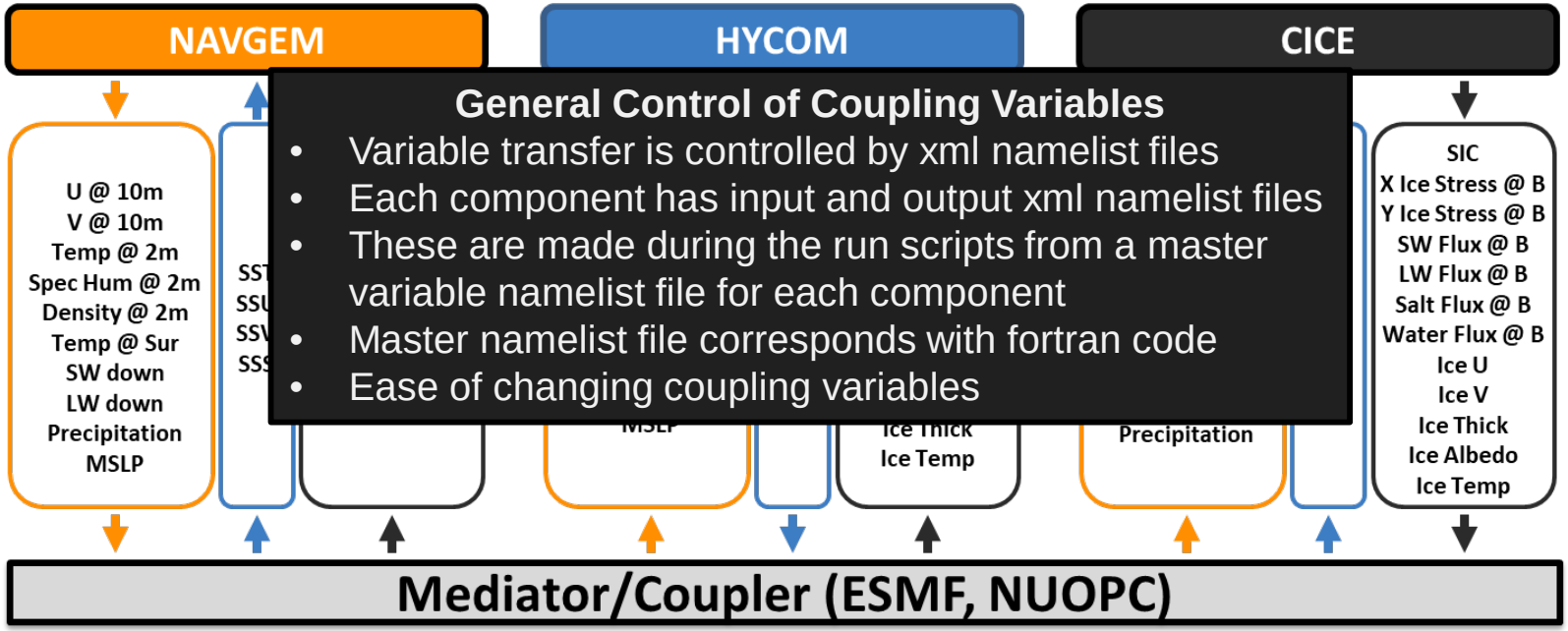
Variables Exchanged in Navy-ESPC



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