Coupled Modeling and Benchmark Testing

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CWB-EMC Meeting
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NOAA
National Weather Service

Motivation

- The NWS issues global forecasts at two time scales – weather (e.g. GFS, GEFS etc) and seasonal (CFSv2)
- The weather act from Congress instructs NWS to provide forecast guidance from weather to *sub seasonal* and seasonal scales
- NWS is in the process of upgrading its operational modeling suite using a new atmospheric dycore (FV3)
- NWS is using this opportunity to upgrade and unify its modeling capability across different scales

Contributors

- NCEP
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  - *Shan Sun, Rainer Bleck, Benjamin W. Green, Ning Wang*
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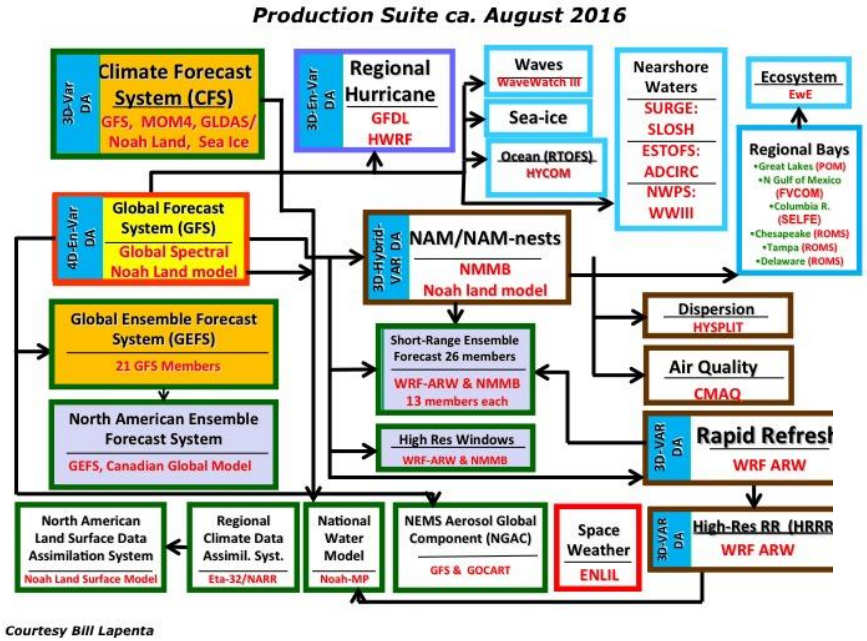
- GFDL
  - *Rusty Benson, Brandon Reichl, Stephen M. Griffies, Robert Hallberg, Alistair Adcroft*
- UCAR/NCAR
  - *Mariana Vertenstein, Rocky Dunlap, Dave Bailey*

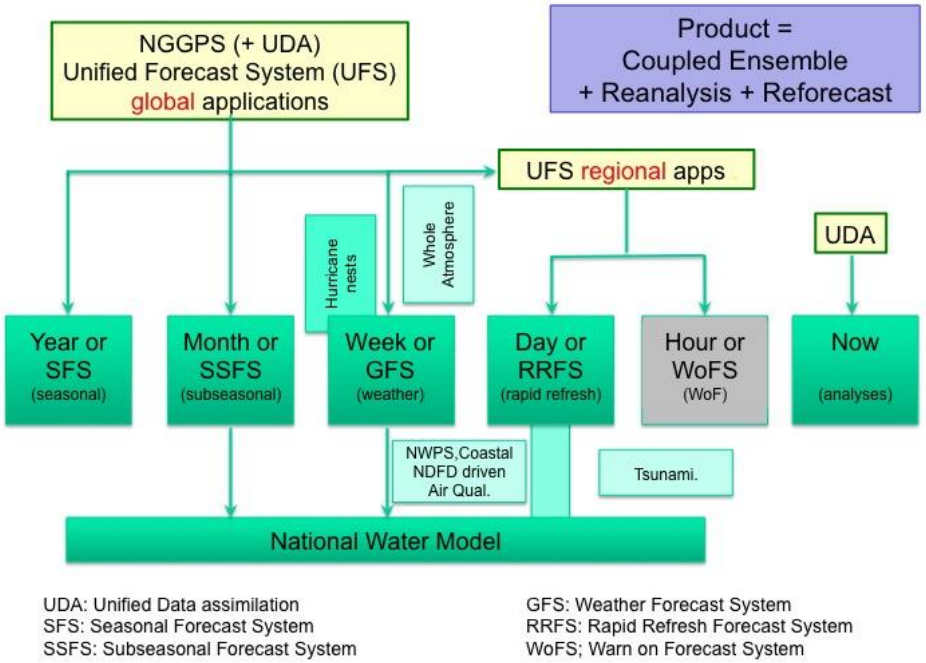
Strategic Vision
Simplify Modeling Suite



Courtesy Bill Lapenta

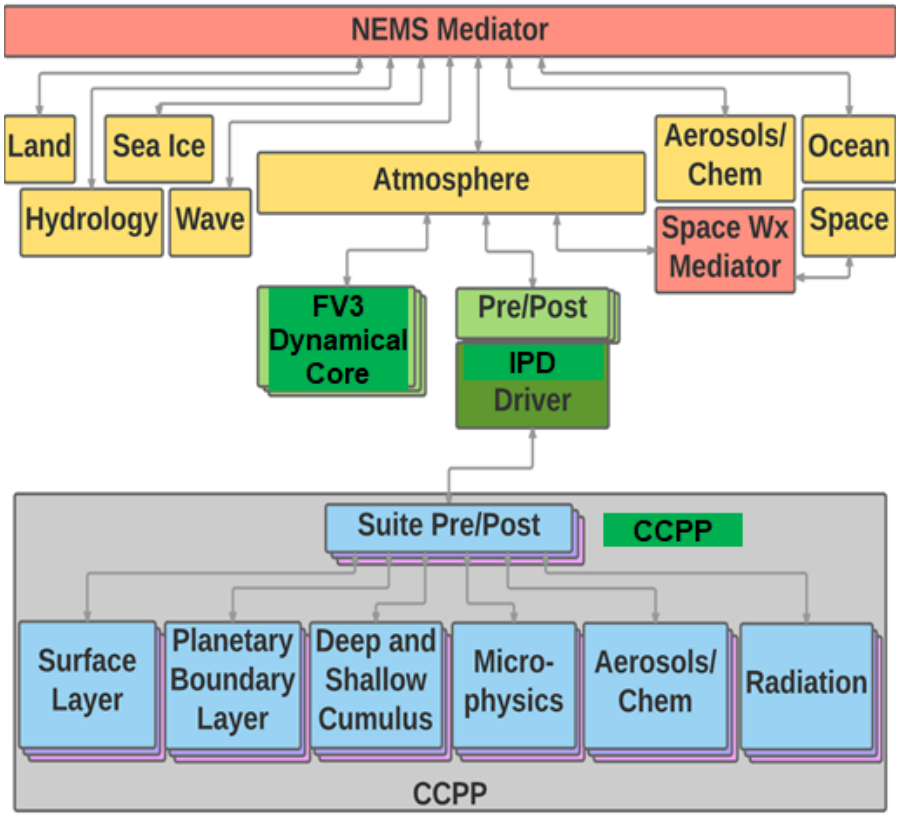
… we will move to a product based system that covers all present elements of the production suite in a more systematic and efficient way

Starting from the quilt of models and products created by implementing solutions rather than addressing requirements ….



Unified Forecast System

- NWS UFS system consists of the following components (at the moment)
  - NEMS for infrastructure
  - FV3 dycore with Physics driver (IPD)
  - MOM6 ocean model (S2S scales)
  - HYCOM ocean model (weather scales)
  - WW3 wave model
  - CICE5 ice model
  - GOCART aerosol model
  - Noah MP land model
- Each component has its own authoritative repository. NEMS infrastructure allows flexibility to connect instantiations of the repositories together to create a coupled model.



Current Developments

- Each of these is a working coupled application which is actively being tested

FV3 – WW3
Effects of waves on atmospheric stress at ocean surface

FV3 – CHEM
Atmosphere, aerosols interaction

ADCIRC – WW3
Wave and surge coupling (COASTAL ACT)

MOM6 – CICE5
Ocean ice coupled model to look at polar dynamics and for developing a marine DA system

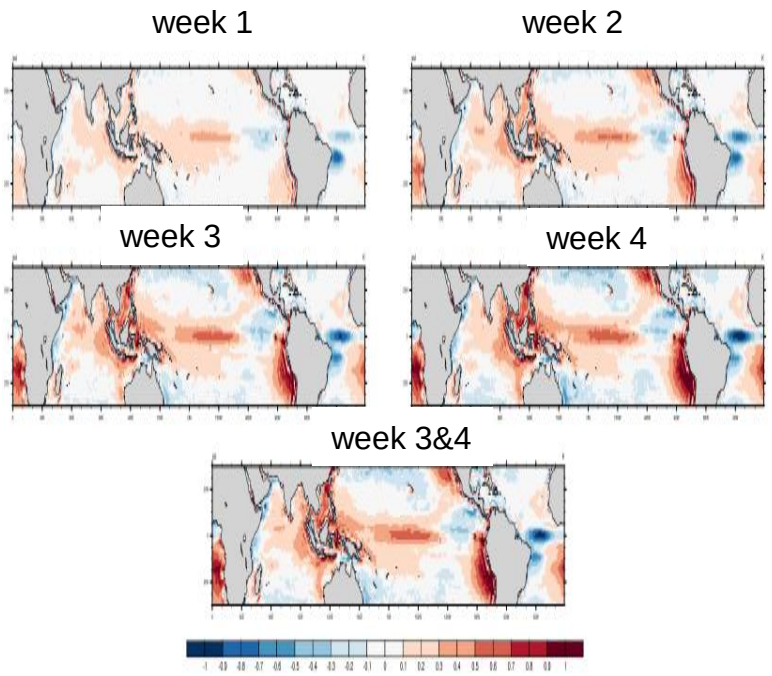
FV3 – MOM6 – CICE5
Coupled system for S2S scales (25 km atm, ¼ deg ocean and ice)

FV3 – MOM6 – CICE5 – WW3
S2S scales including Langmuir mixing (25 km atm, ¼ deg ocean and ice, ½ deg waves)

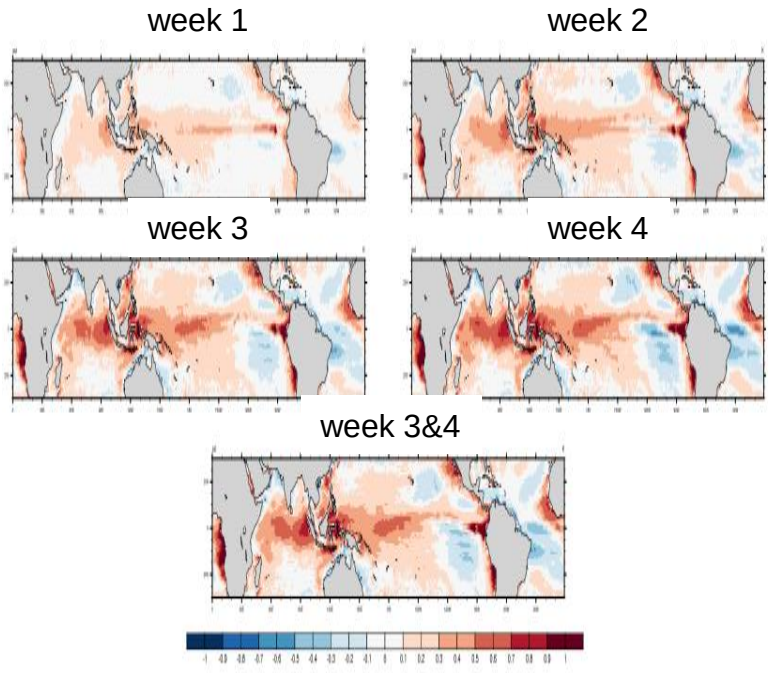
Benchmark Runs

- A good test plan needs the following
  - Include multiple important cases
  - Short enough to be run multiple times
- To test the Sub seasonal modeling system
  - Initialize the model on the 1st and 15th of each month for 35 day runs
  - Model initialized with CFS analysis
  - Repeat for all months over a 7 year period (2011/2012 – 2017/2018)
  - Covers important El Nino / La Nina years as well as years of very low ice
  - Provides a large enough sample for statistically relevant metrics

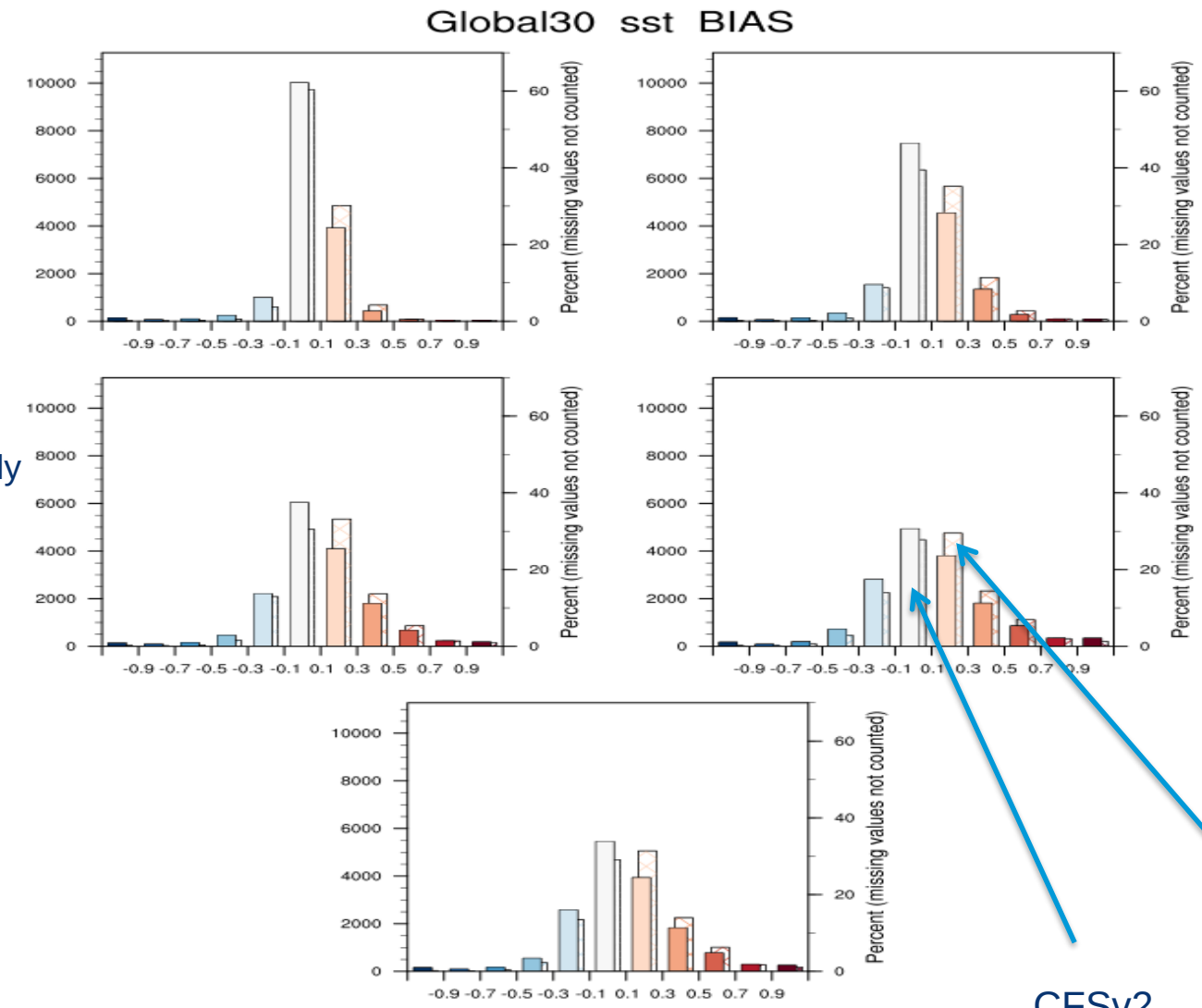
SST Bias comparison



CFSv2



UFS

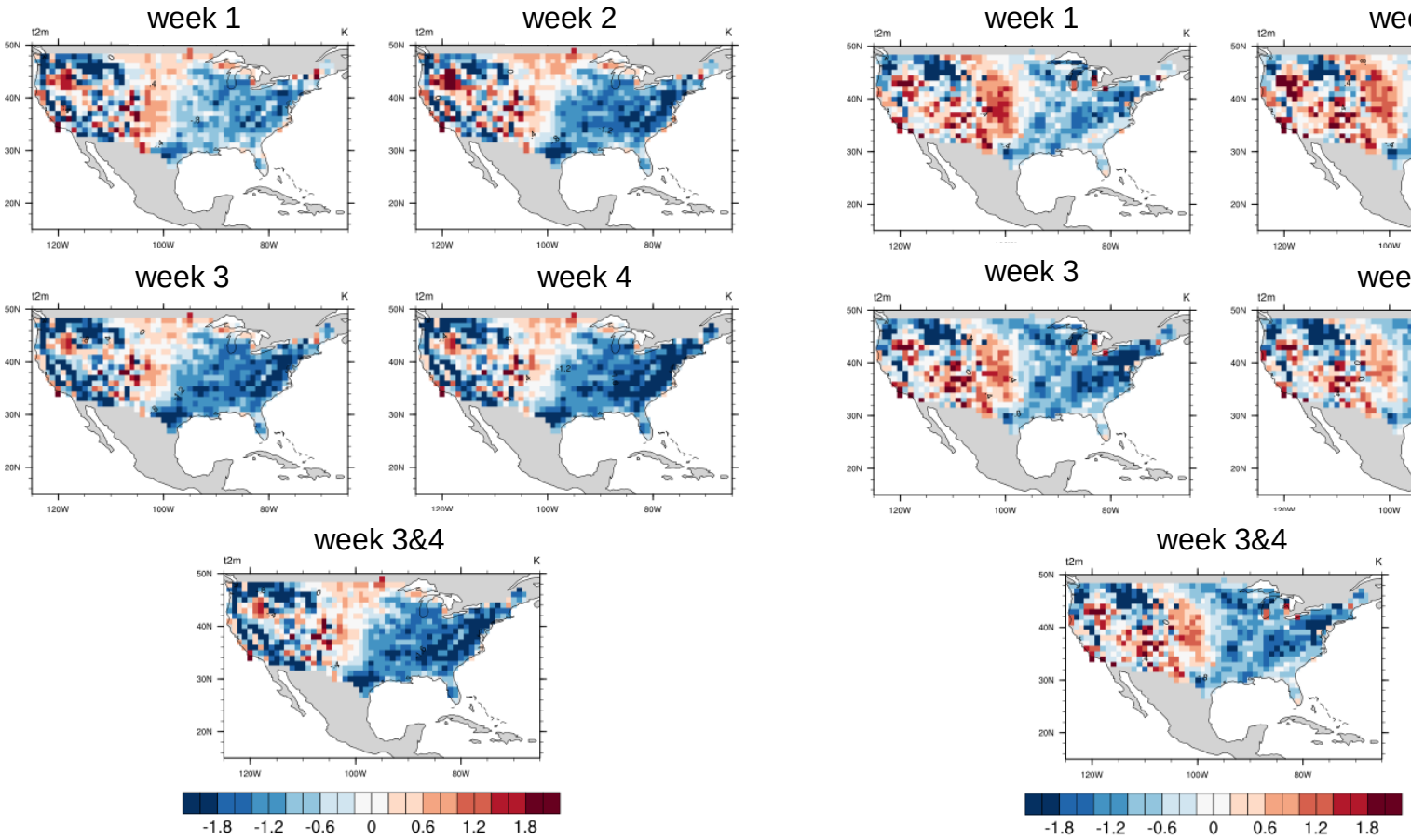


UFS: generally warmer bias

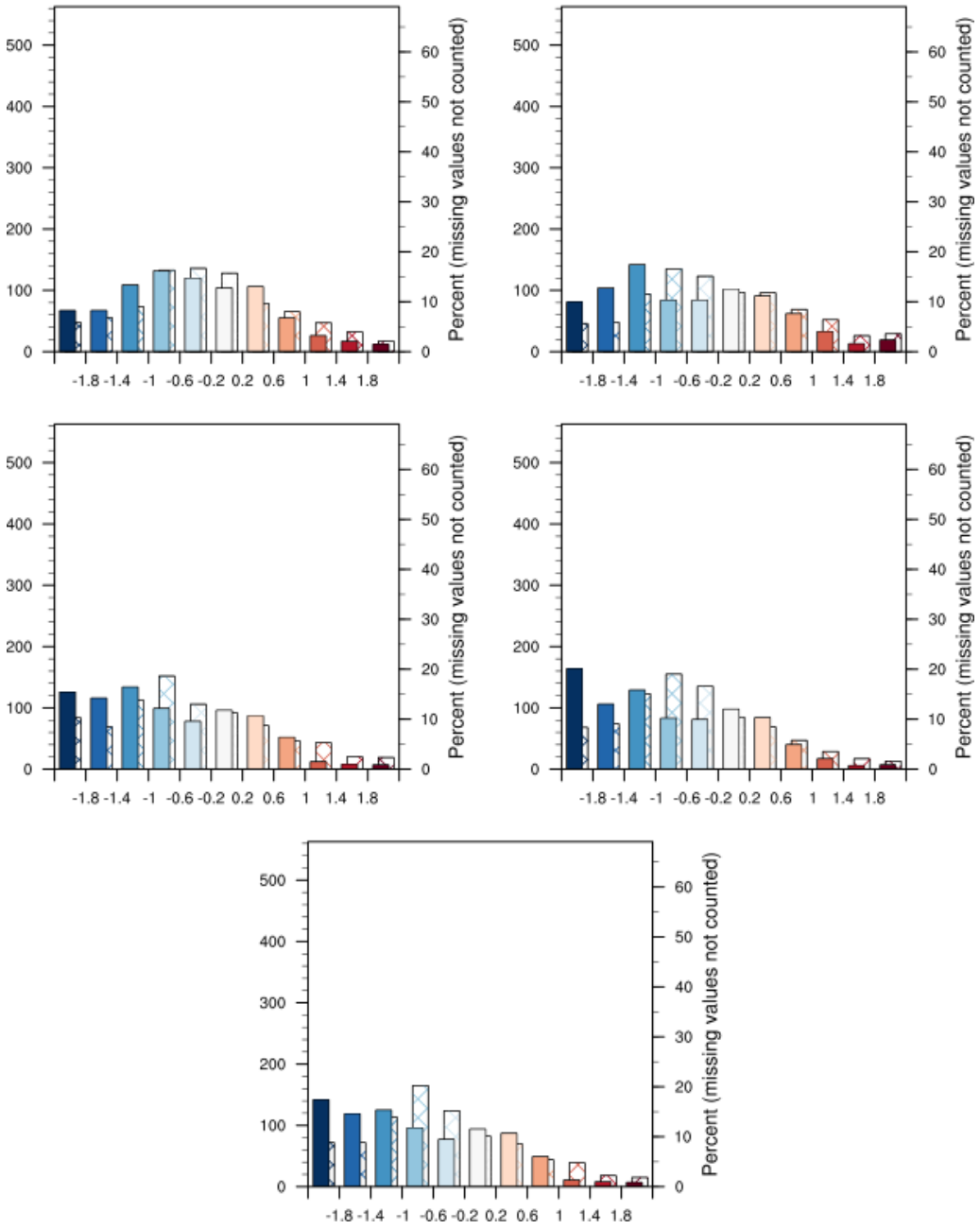
CFSv2

UFS

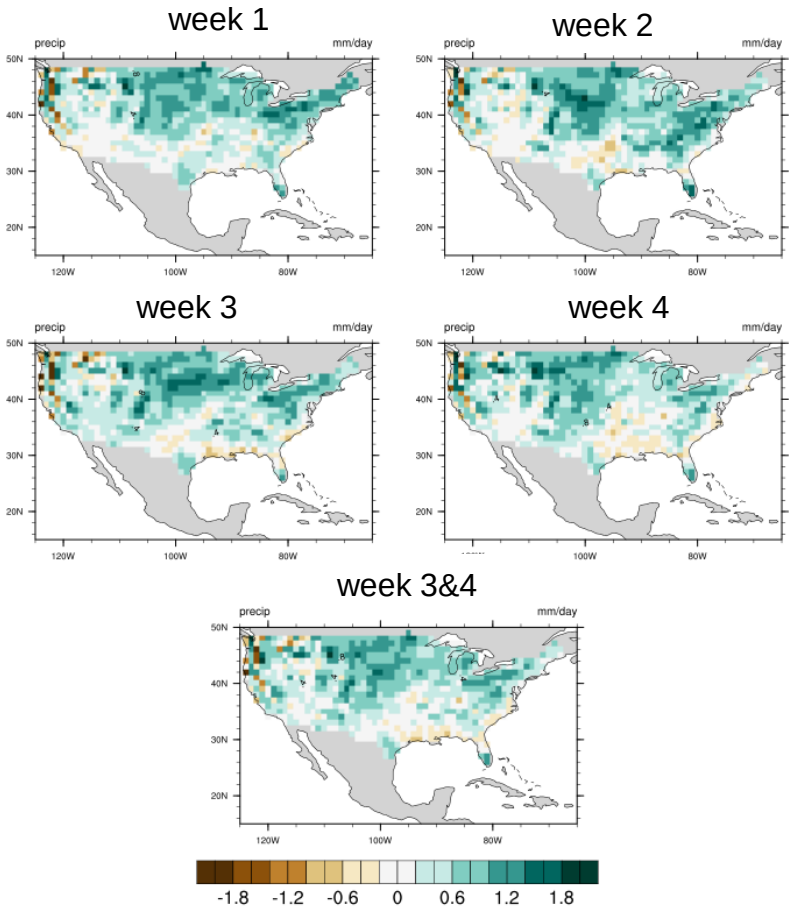
CONUS 2m Temp bias



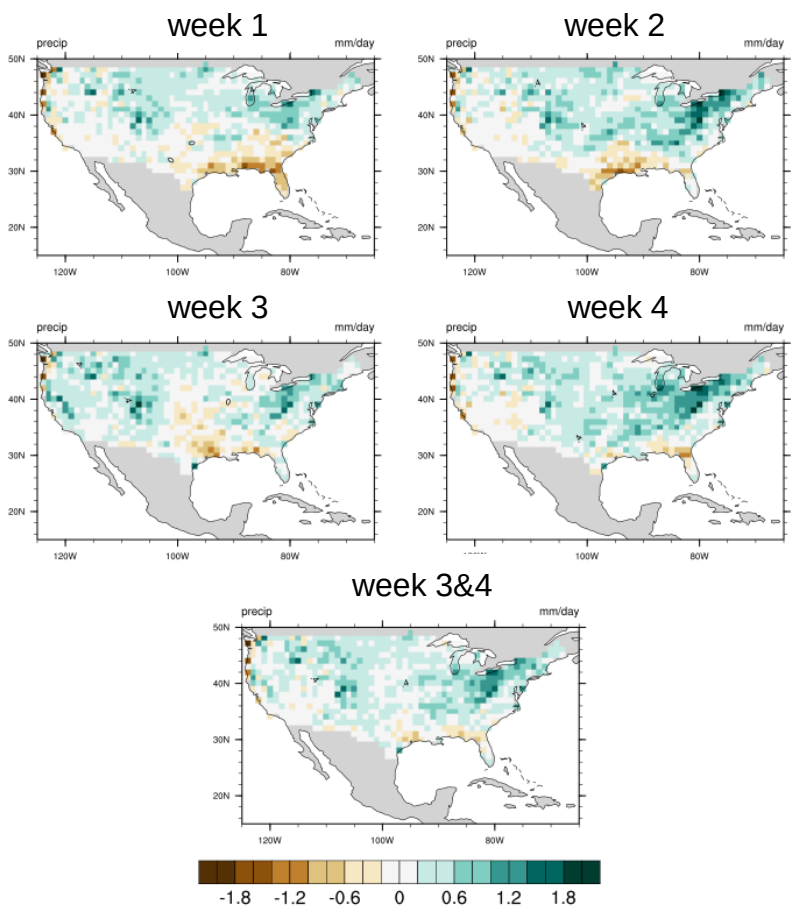
UFS: generally reduced cold bias; more instances of warm bias



CONUS Precip bias

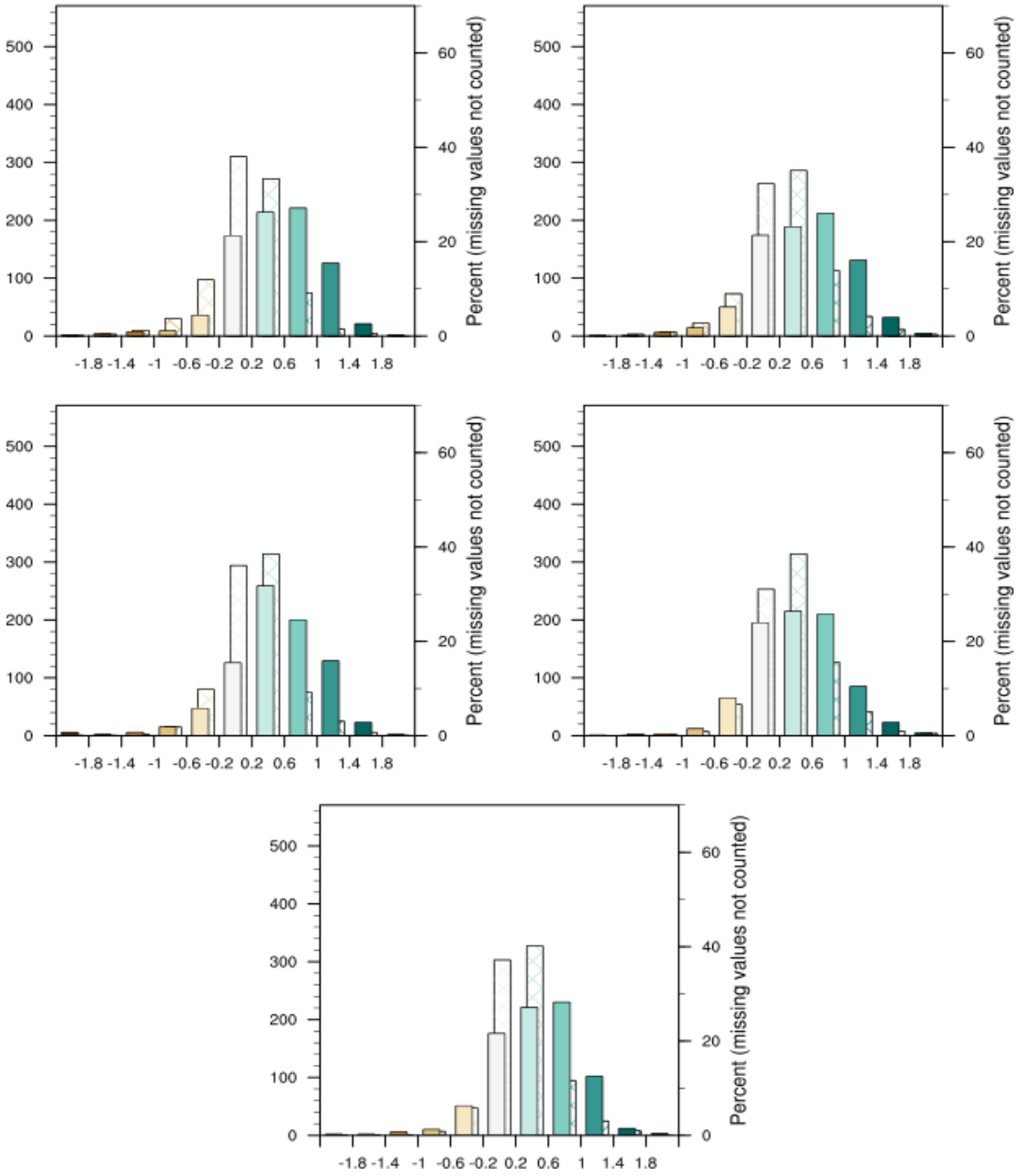


CFSv2

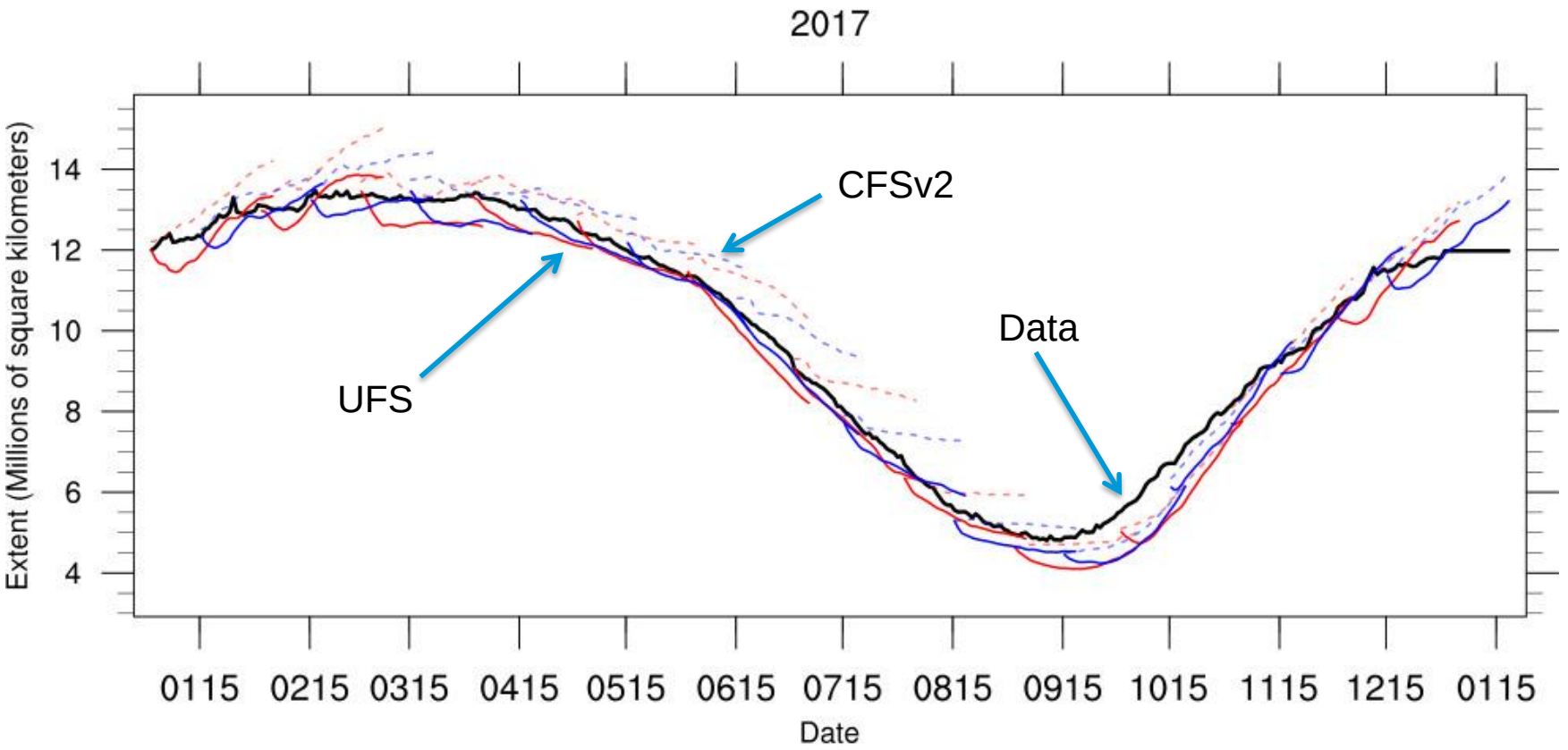


UFS

UFS: generally reduced wet bias

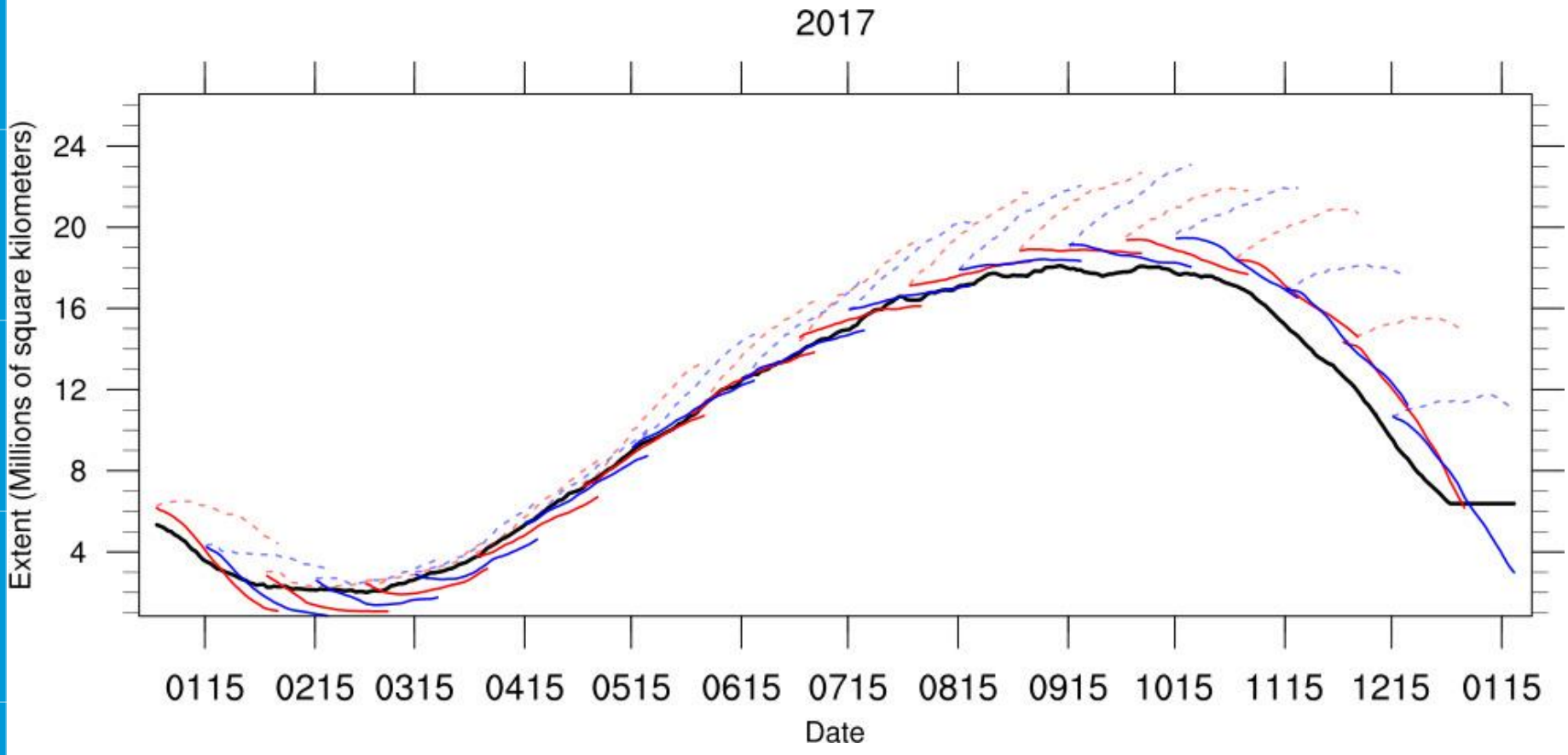


Sea Ice Extent (Arctic)

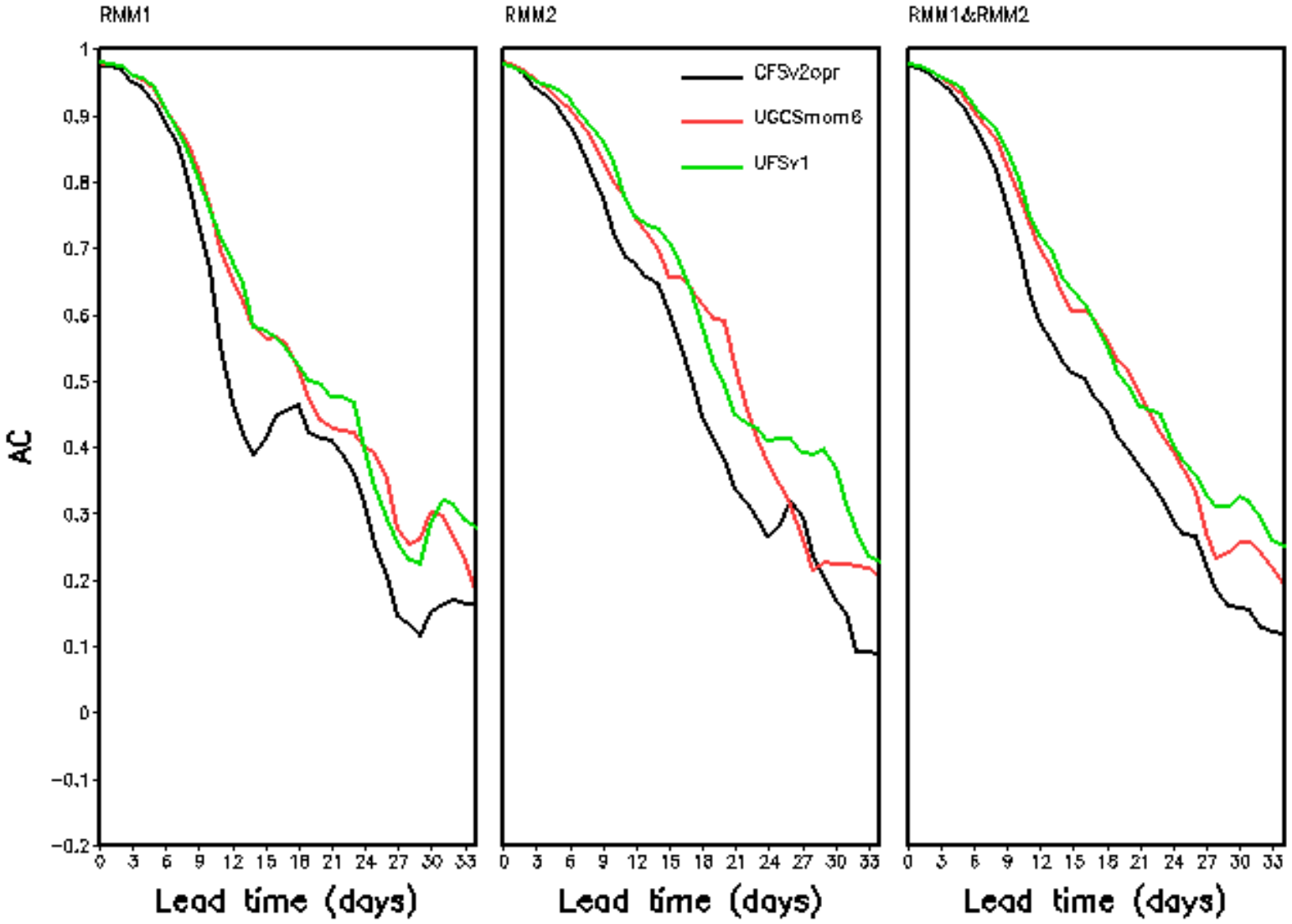


Data Source : NOAA/NSIDC Climate Data Record of Passive Microwave Sea Ice Concentration, Version 3 (https://nsidc.org/data/g02202/versions/3)

Sea Ice Extent (Antarctic)



Correlation Skill for MJO index RMM1, RMM2 and Bivariate Correction Skill for MJO index

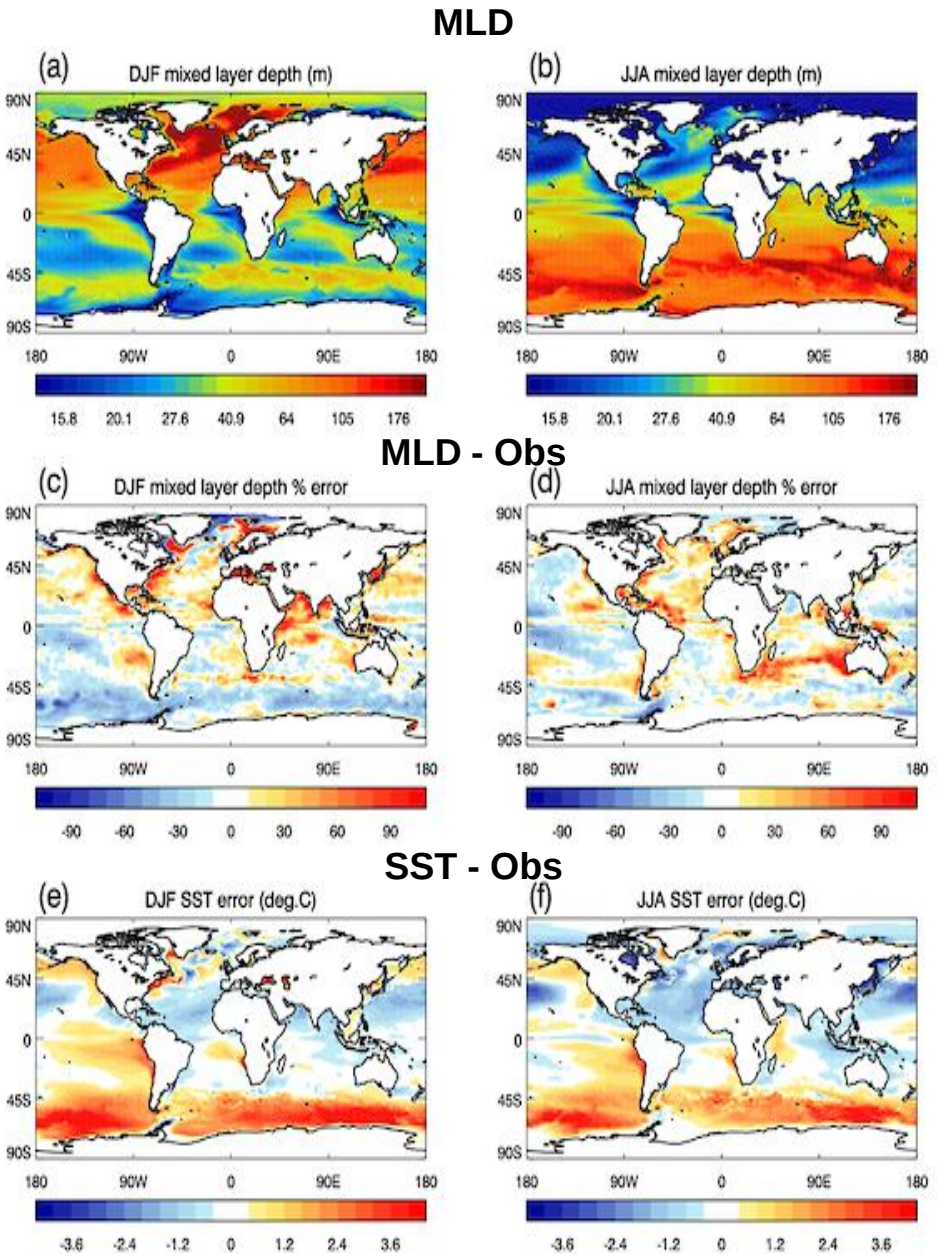


Week 3 & 4 AC Scores (Annually Aggregated)

	UFSv1	CFSv2ops	Region
Raw	**17.5**	10.7	T2m-land-CONUS
SEC	**20.0**	13.5	T2m-land-CONUS
Raw	2.2	**3.2**	Prate-land – CONUS
SEC	2.4	**3.6**	Prate-land – CONUS
Raw	53.0	**54.4**	Global Tropical SST
SEC	**70.2**	69.2	Global Tropical SST
Raw	**86.5**	87.6	Nino 3.4 SST
SEC	90.3	**90.6**	Nino3.4 SST
Raw	46.9	**48.0**	Nino 3.4 Prate
SEC	50.3	**51.6**	Nino3.4 Prate
Raw	**17.8**	12.7	NH Z500
SEC	**19.2**	14.3	NH Z500
Raw	**10.9**	9.7	SH Z500
SEC	**11.7**	11.1	SH Z500

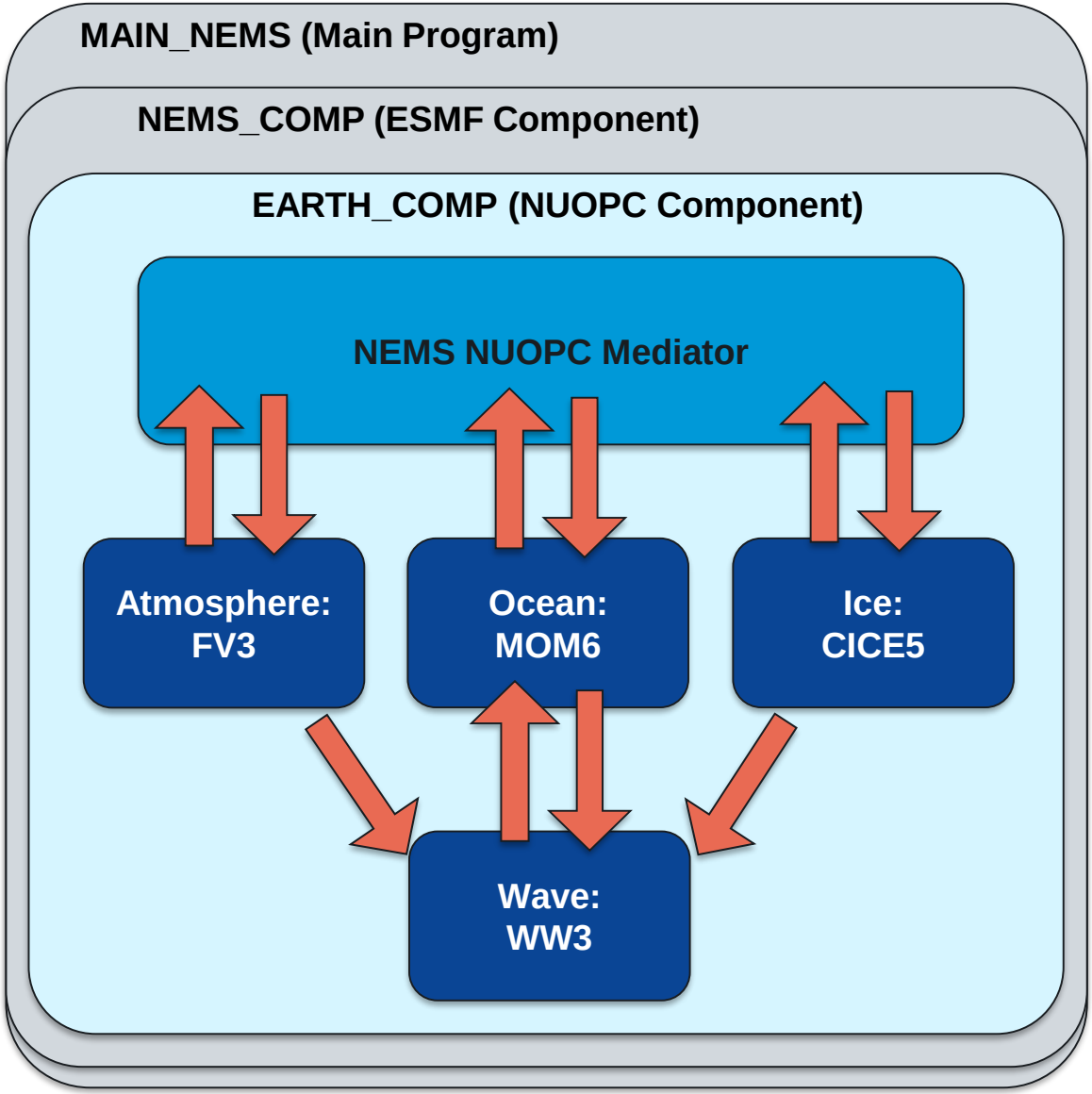
Wave Driven Mixing

- Motivation is to improve air-sea interactions with the inclusion of sea-state dependent Langmuir mixing.



Belcher et. al. "A global perspective on Langmuir turbulence in the ocean surface boundary layer." Geophysical Research Letters, Volume: 39, Issue: 18, First published: 21 September 2012, DOI: (10.1029/2012GL052932)

UFS Coupled Model Configuration



Atmosphere ➔Wave

- 10m Winds (u,v)

Ocean ➔Wave

- Currents (u,v)

Ice ➔Wave

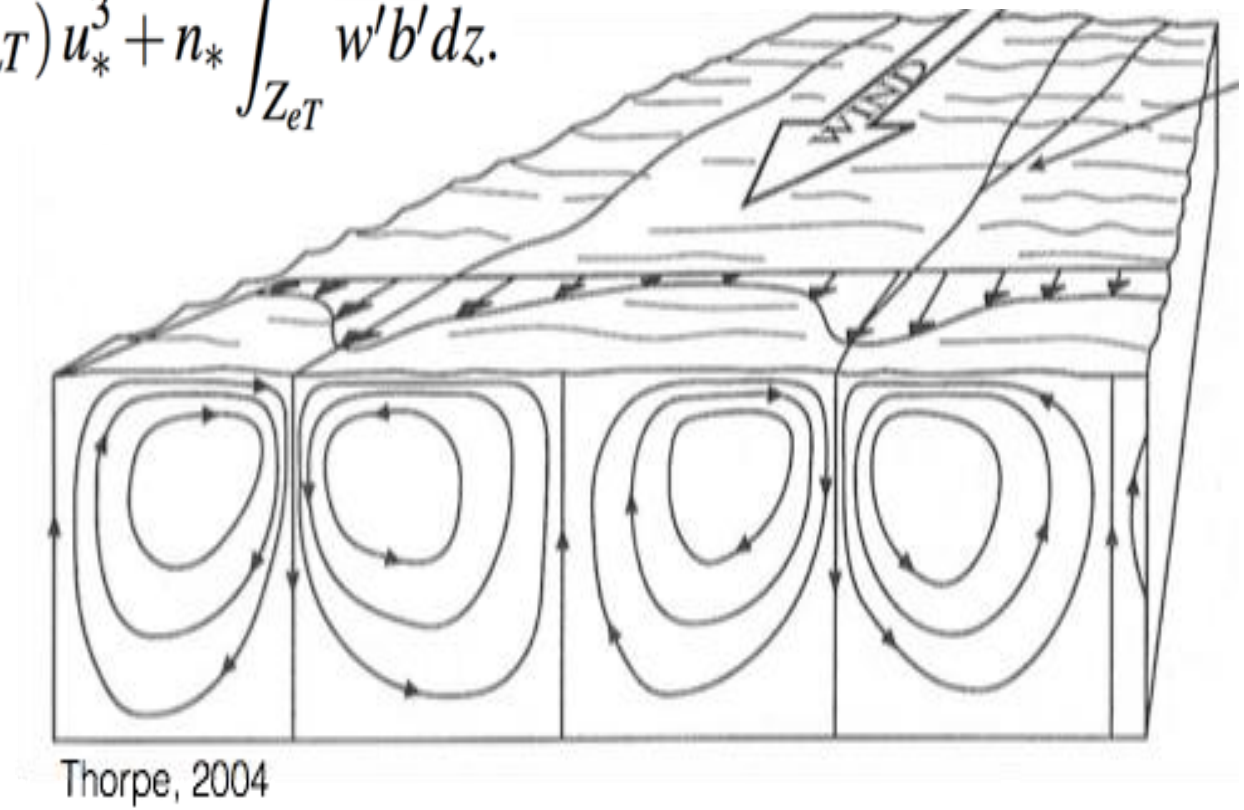
- Ice concentration

Wave ➔Ocean

- Stokes Drift (u,v)

Langmuir Turbulence

$$-M_e = (m_* + m_{*LT})\, u_*^3 + n_* \int_{Z_{eT}}^{0} \overline{w'b'}\, dz.$$



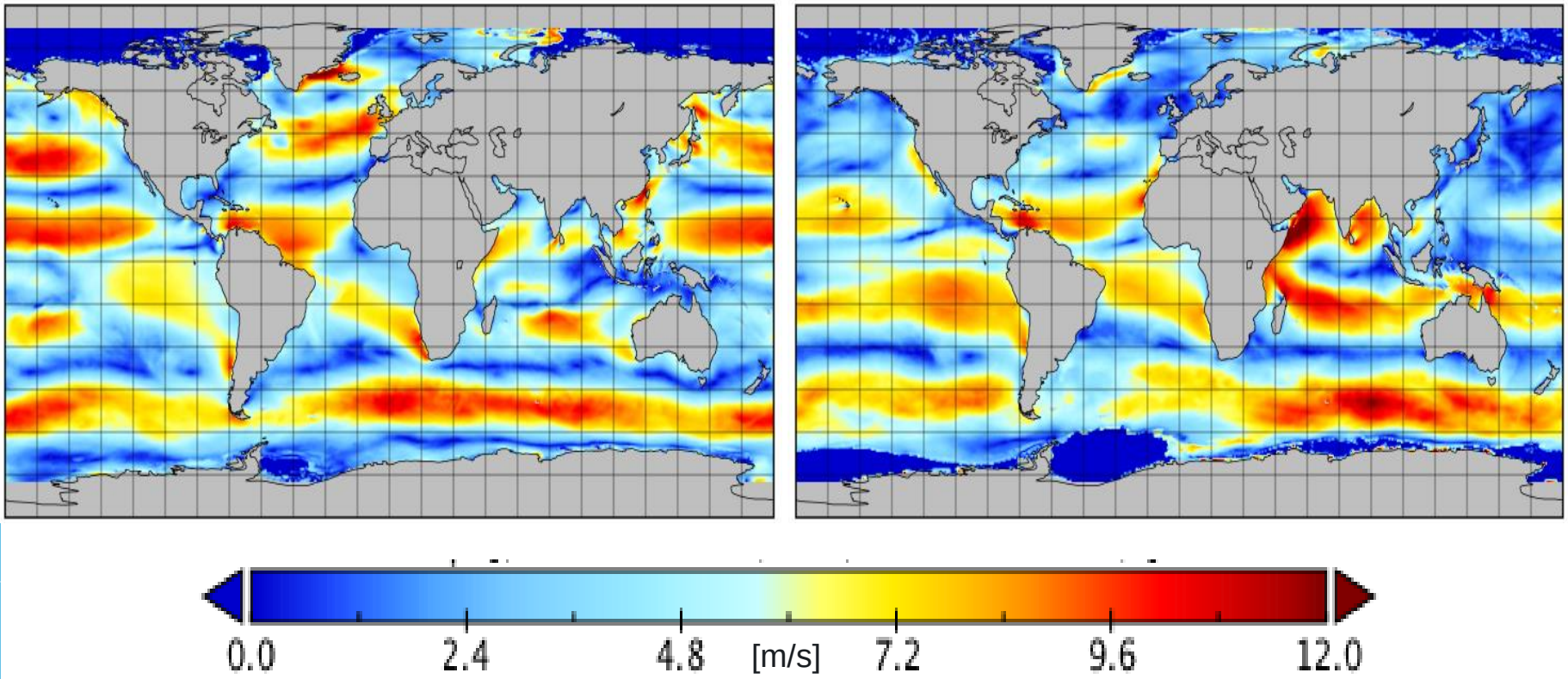
Thorpe, 2004

Reichl & Hallberg, 2018. A simplified energetics based planetary boundary layer (ePBL) approach for ocean climate simulations.,Ocean Modelling, 132:p112-129. https://doi.org/10.1016/j.ocemod.2018.10.004.

10 m Wind Speeds (Monthly Mean)

January 2016

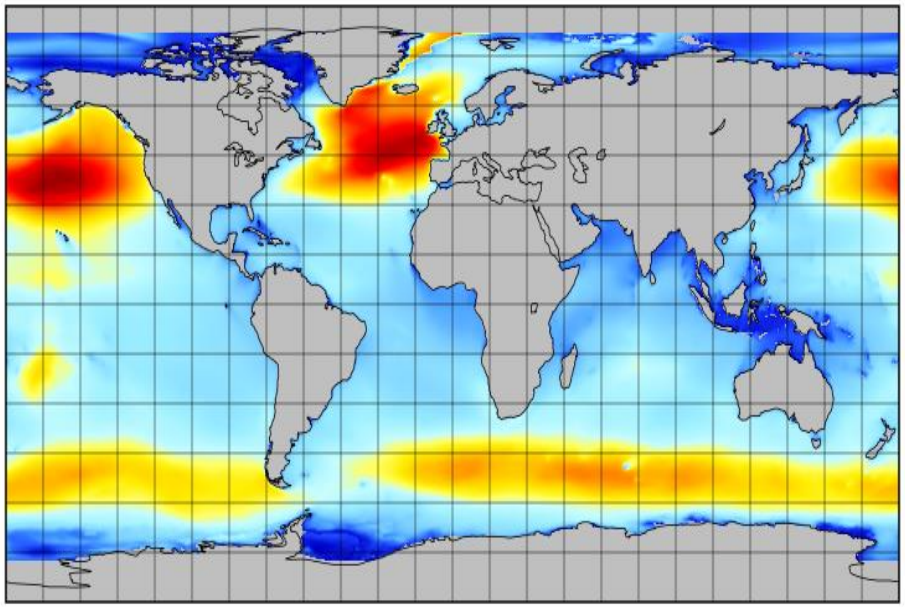
June 2016

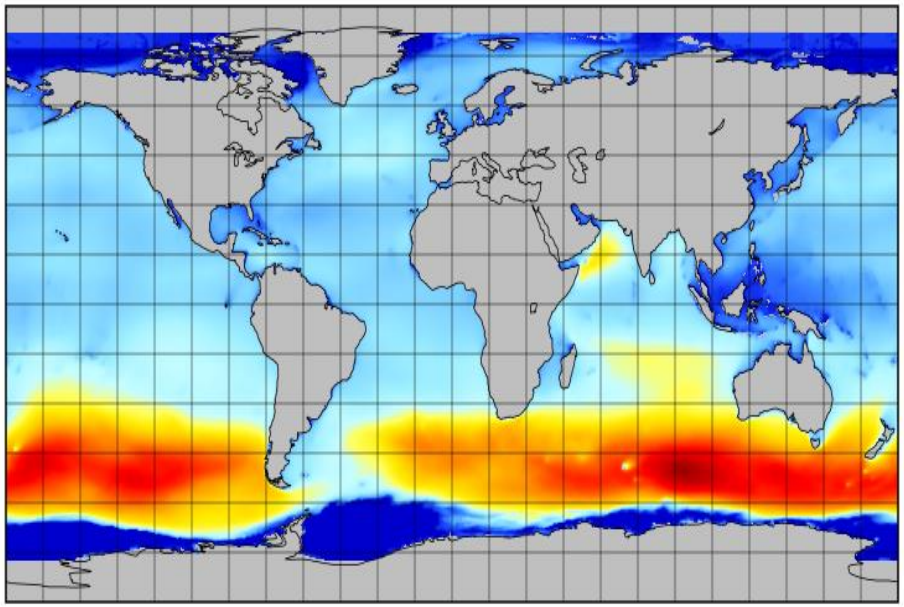


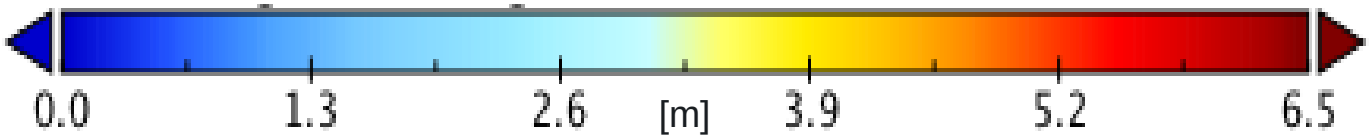
Significant Wave Height (Monthly Mean)

January 2016

June 2016



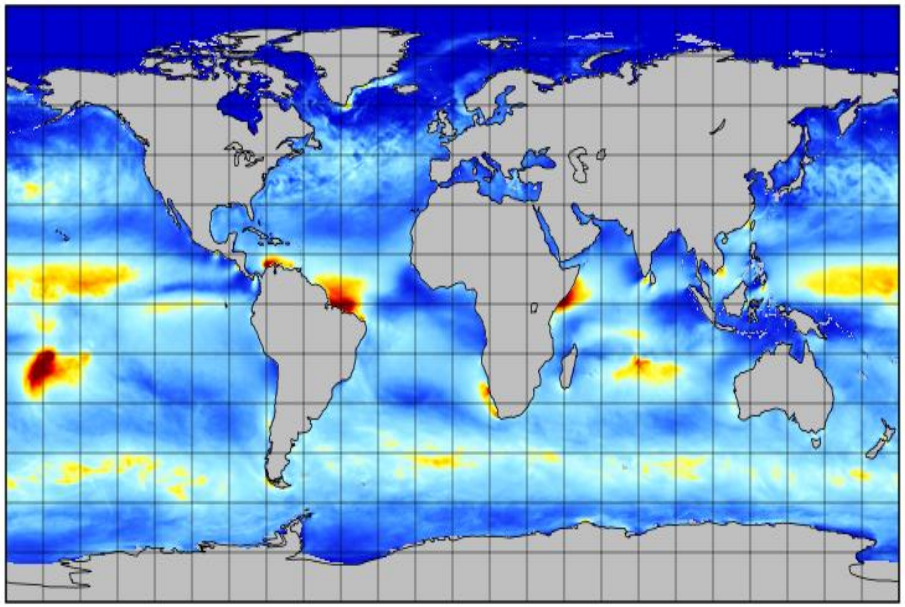


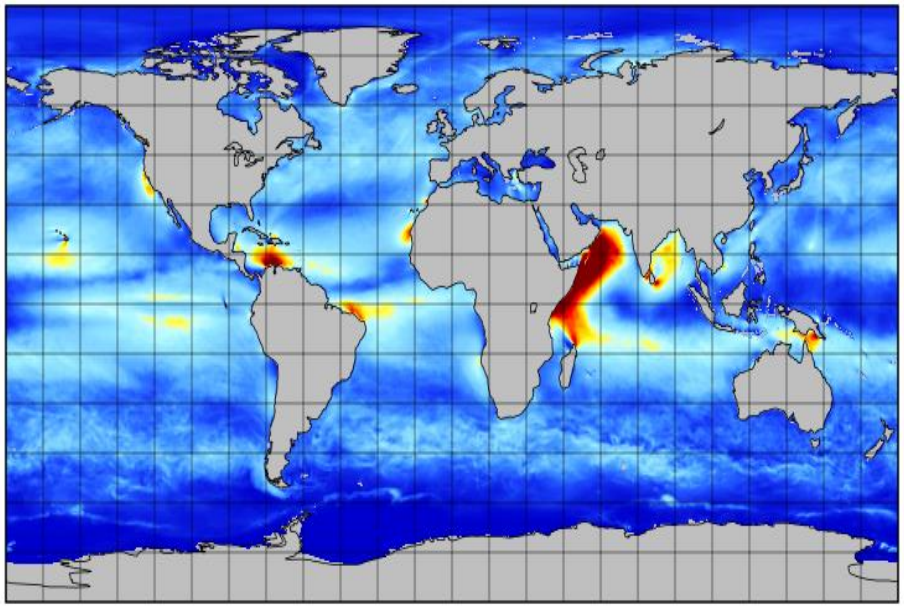


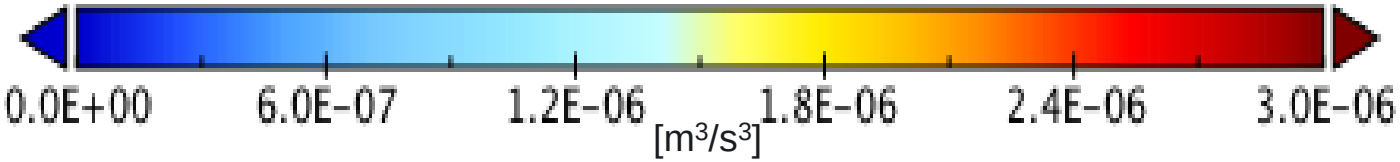
Mechanical Mixing Rate

January 2016

June 2016



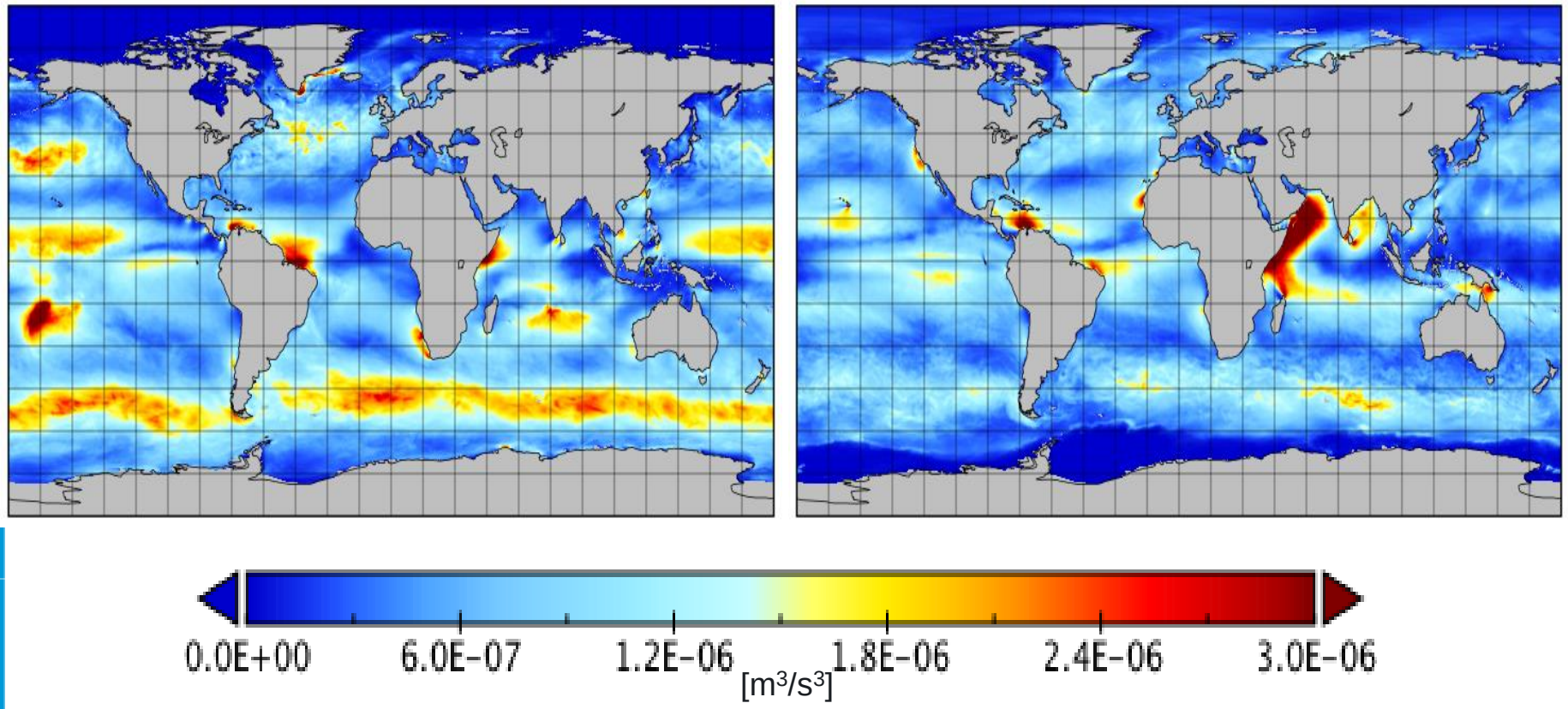




Mechanical Mixing Rate Including Enhancement from Langmuir

January 2016

June 2016

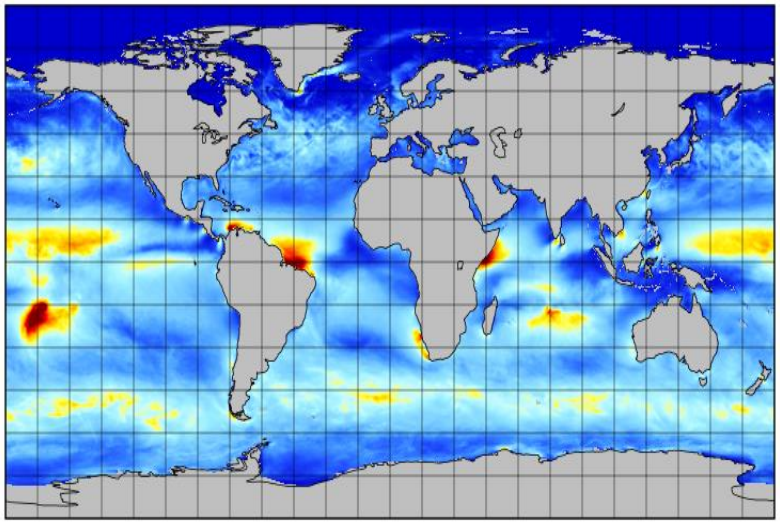


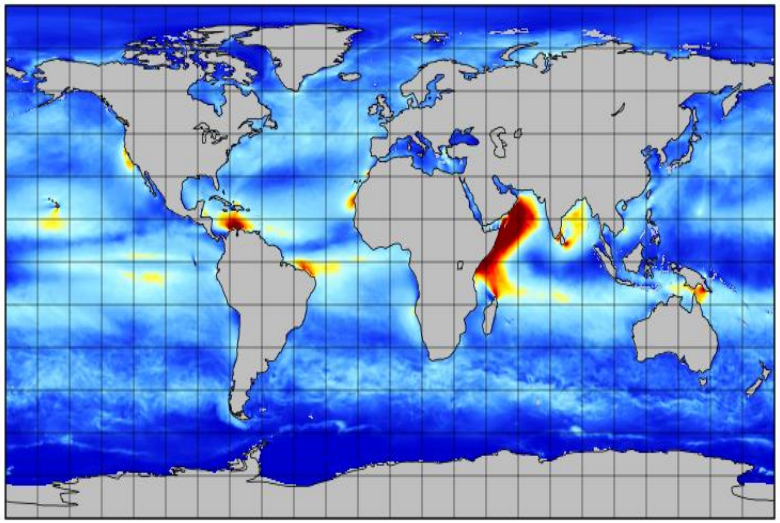
Mechanical Mixing Rate

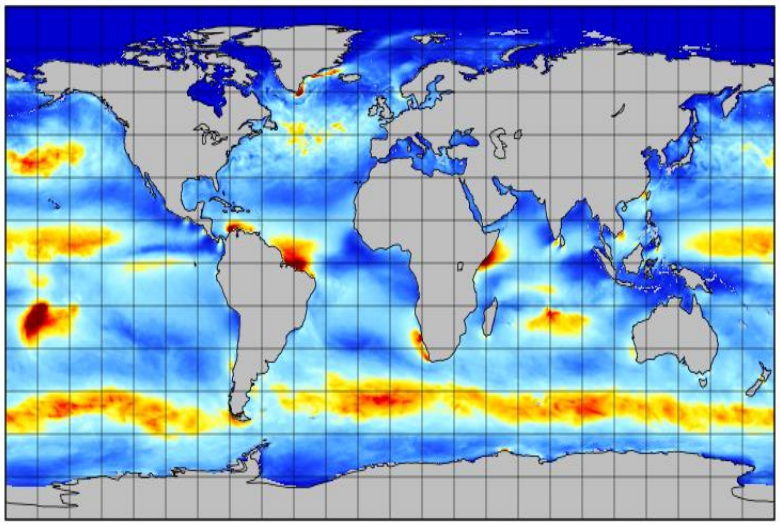
January 2016

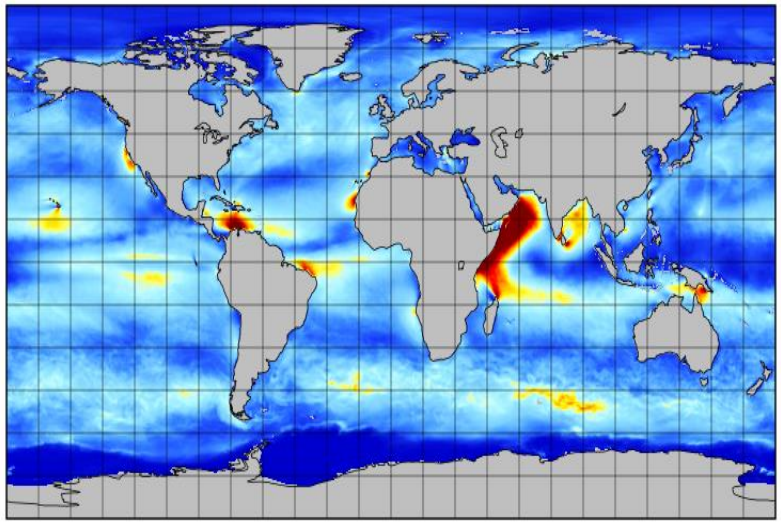
June 2016

Including Enhancement from Langmuir





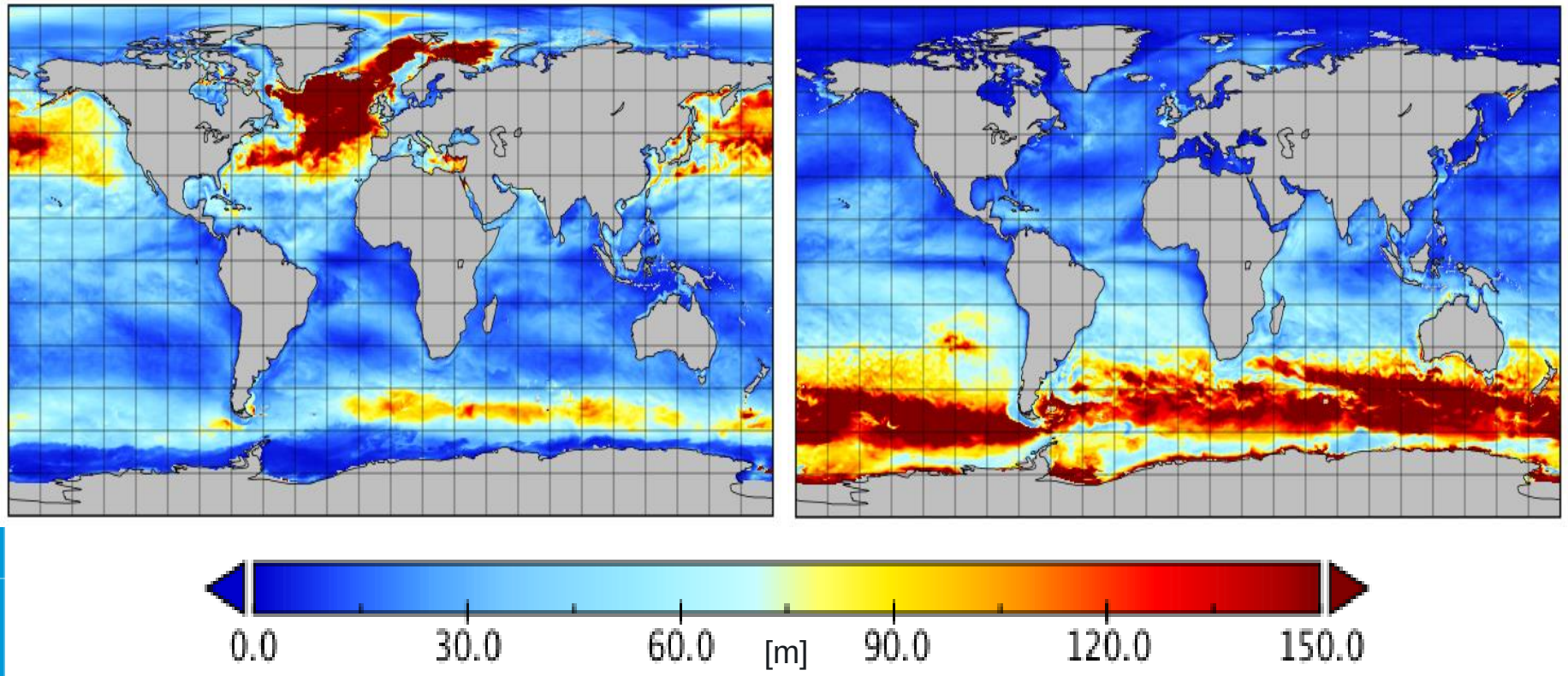




Mixed Layer Depth (30 day mean)

January 2016

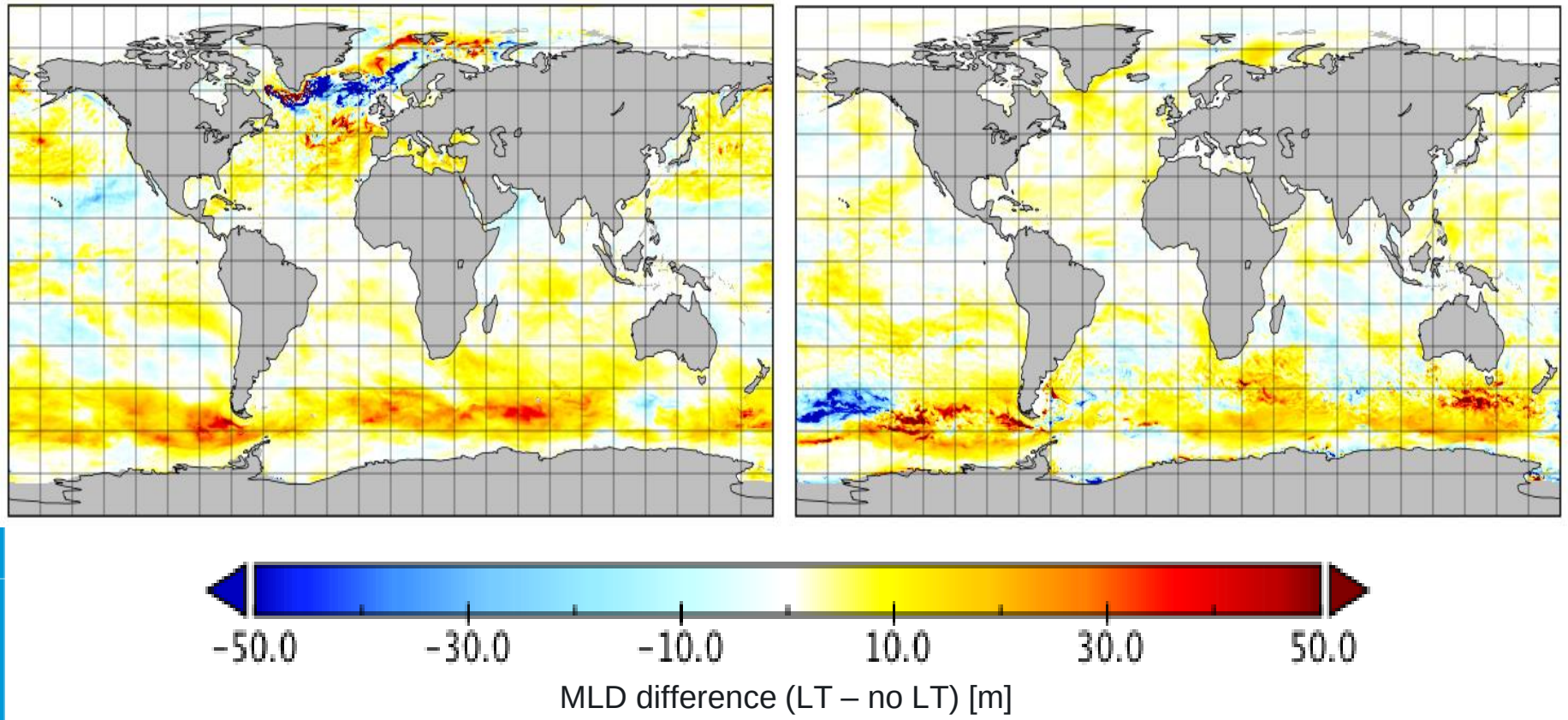
June 2016



Effect of Langmuir Turbulence on MLD

January 2016

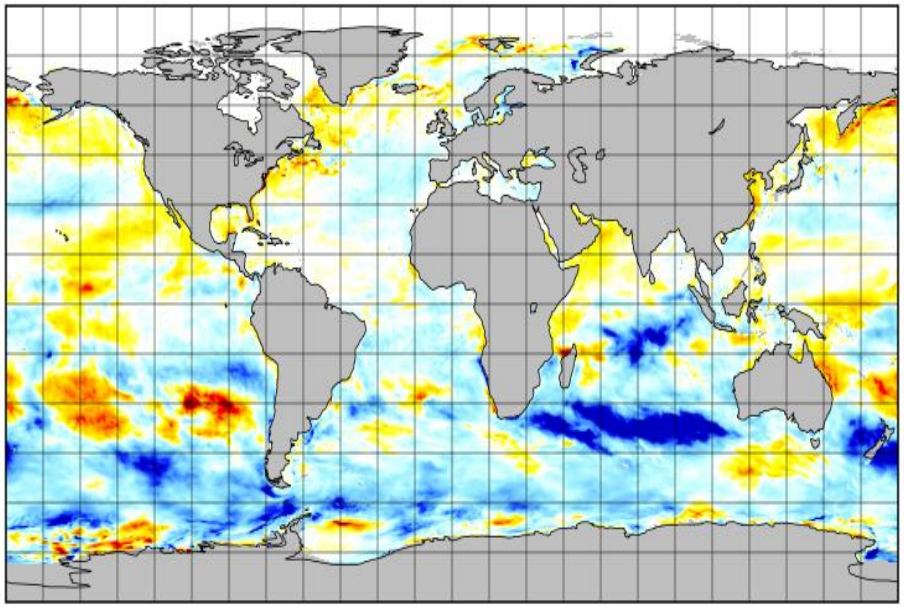
June 2016

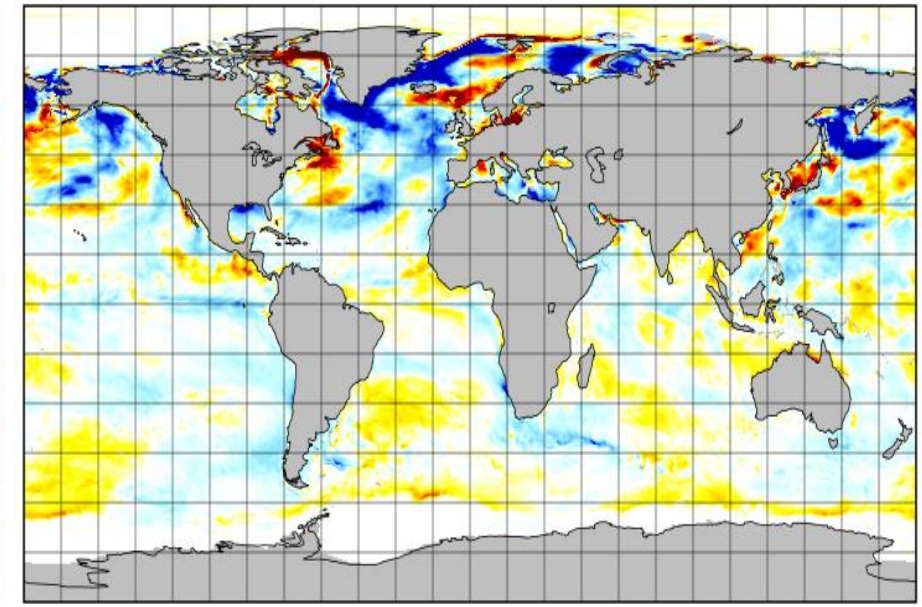


Effect of Langmuir Turbulence on SST

January 2016

June 2016





Fractional Grids

A mixed FV3 atm grid cell

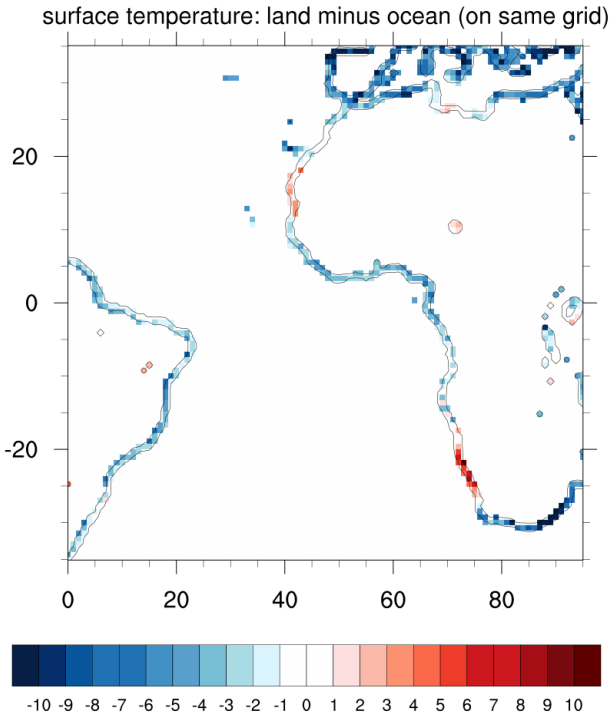
Compute flux **F** on FV3 grid cell by compositing (weighted) fluxes from land, open water, and sea-ice:

$$F_{atm} = w_{lnd}*F_{lnd} + w_{opw}*F_{opw} + w_{ice}*F_{ice}$$

where $(w_{lnd} + w_{opw} + w_{ice}) = 1$

Using Fractional Grid Allows

- Major reduction of coastline ambiguities on atm and ocean grid;
- Up to 3 different temperatures in each grid cell, one for each surface type;
- Up to 3 different heat fluxes in each grid cell, one for each surface type;
- Only heat flux over open water and under sea ice will be sent to ocean model -- no contamination by land surface fluxes.



Summary

- EMC with its collaborators are building the coupled Unified Forecast System (UFS) for sub seasonal to seasonal time scales
  - Target GEFS FY22 (Sub seasonal range)
- First benchmark tests show
  - Skill comparable to operational CFS (global and CONUS)
  - Skill in polar domains significantly better
- Series of benchmark runs with new capabilities/physics (in partnership with OAR labs) are planned for the upcoming months
  - Second benchmark with improved slow/fast coupling, improved ocean initial conditions and updated codes are over halfway done.
- A parallel effort is ongoing to build a DA capability for the marine components to enable fully cycled end to end testing

Upcoming Benchmarks

FY19

- **Benchmark 2:** FV3GFS+MOM6+CICE5 with ocean ICs from 3DVAR (pre-JEDI)
- **Benchmark 3:** Benchmark 2+ CPC ice analysis
- **Benchmark 4:** FV3GFS+MOM6+CICE5+WW3
- **Benchmark 5:** Benchmark 4 + Fractional land/sea masks

FY20

- **Benchmark 6:** FV3GFS+MOM6+CICE5+WW3 (weakly coupled w/marine JEDI)
- **Benchmark 7:** Physics Tuning Experiments
- **Prototype GEFSv13:** Marine Component Perturbations
- Extend benchmark runs to 9 months and longer, physics tuning, optimization (**seasonal scales**)