OCEAN DATA ASSIMILATION AT NCEP

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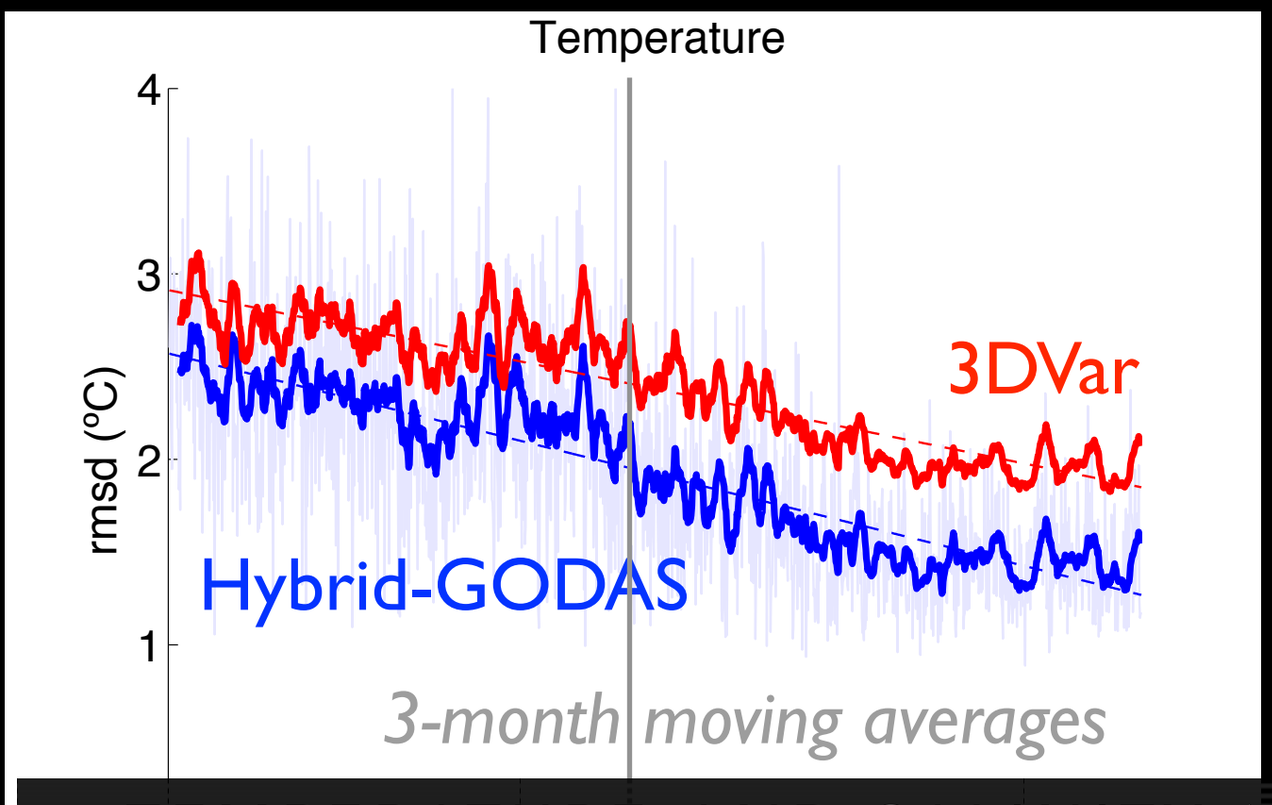
AUGUST 2, 2016

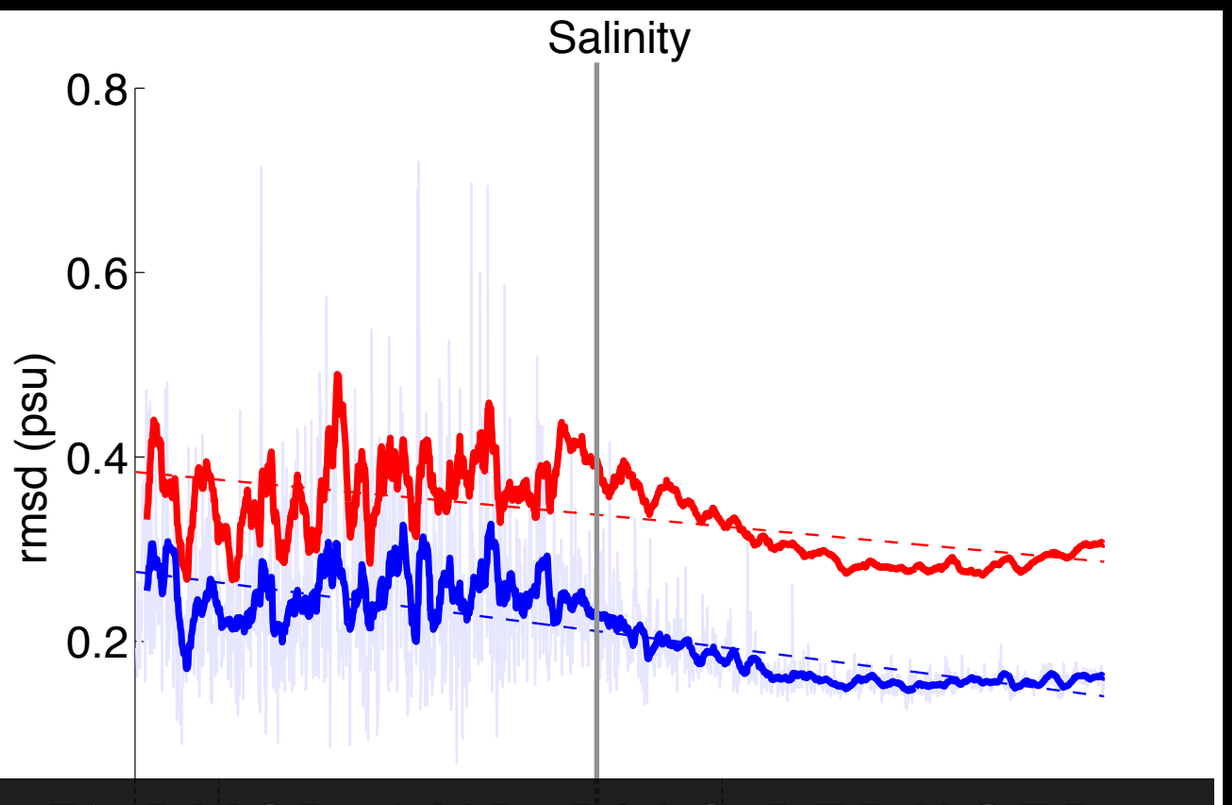
NOAA CENTER FOR WEATHER AND CLIMATE PREDICTION

DEVELOPMENTS

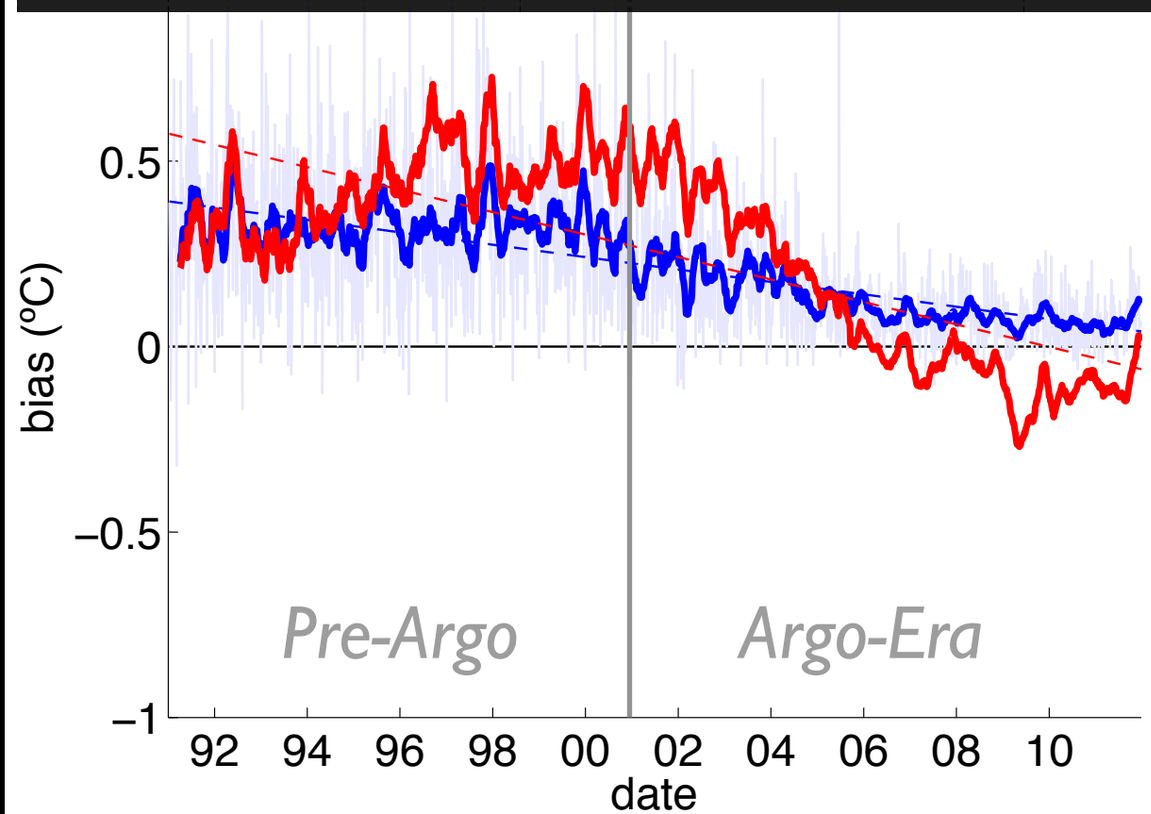
- We have demonstrated Hybrid-GODAS with 1/2° MOM4p1 model using two 21-year reanalysis runs (assimilating T&S, T&S+SSH)
- CPO MAPP award to transition the HYBRID-GODAS to operations (with additional funding provided from NESDIS). This will support implementation in operational environment and a 1979-present reanalysis to replace the 3DVar-GODAS. (+ 1.0 FTE new hire)
- This NGGPS project is now focused on testing and validating upgrades that can be adopted in the operational implementation:
  - add new observation datatypes: SST, SSH, drifters, near-surface atmospheric observations
  - upgrade from 1/2° MOM4p1 to 1/4° MOM6

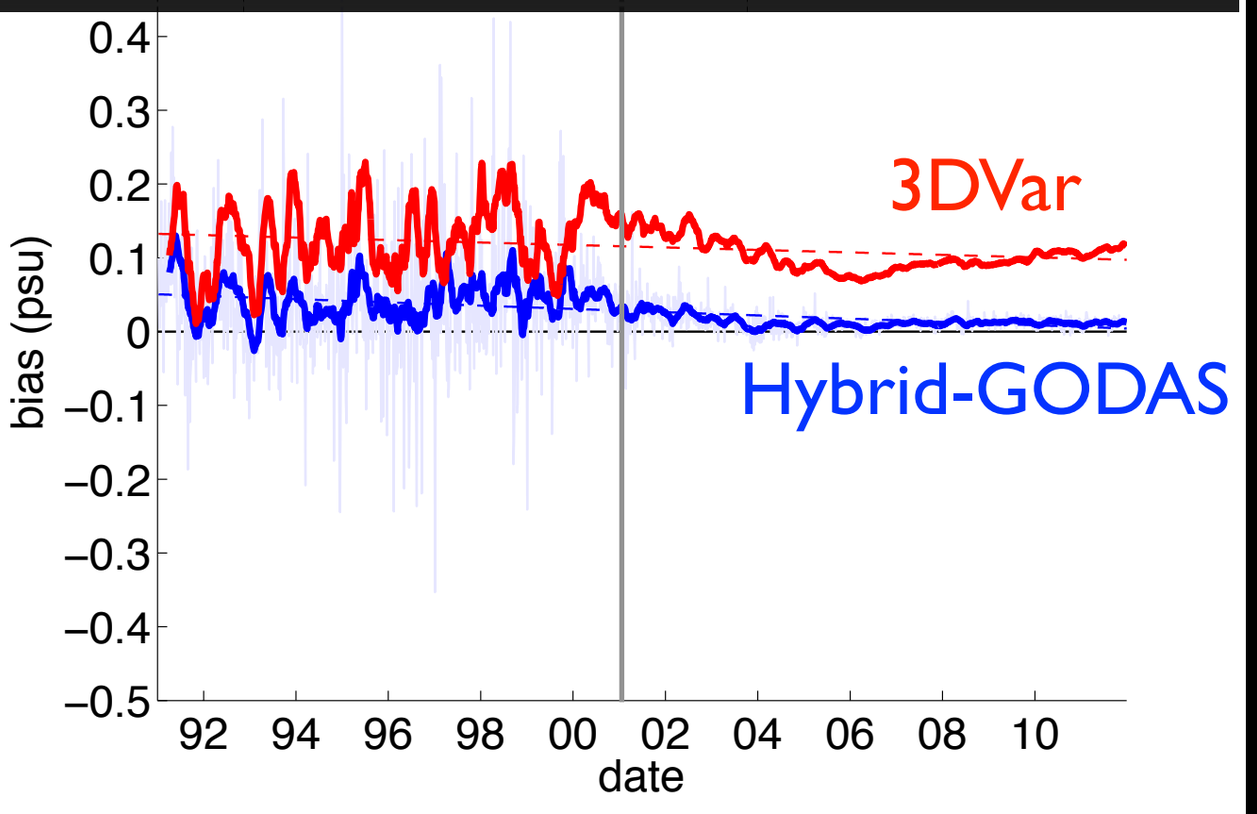
21-YEAR HYBRID-GODAS REANALYSIS





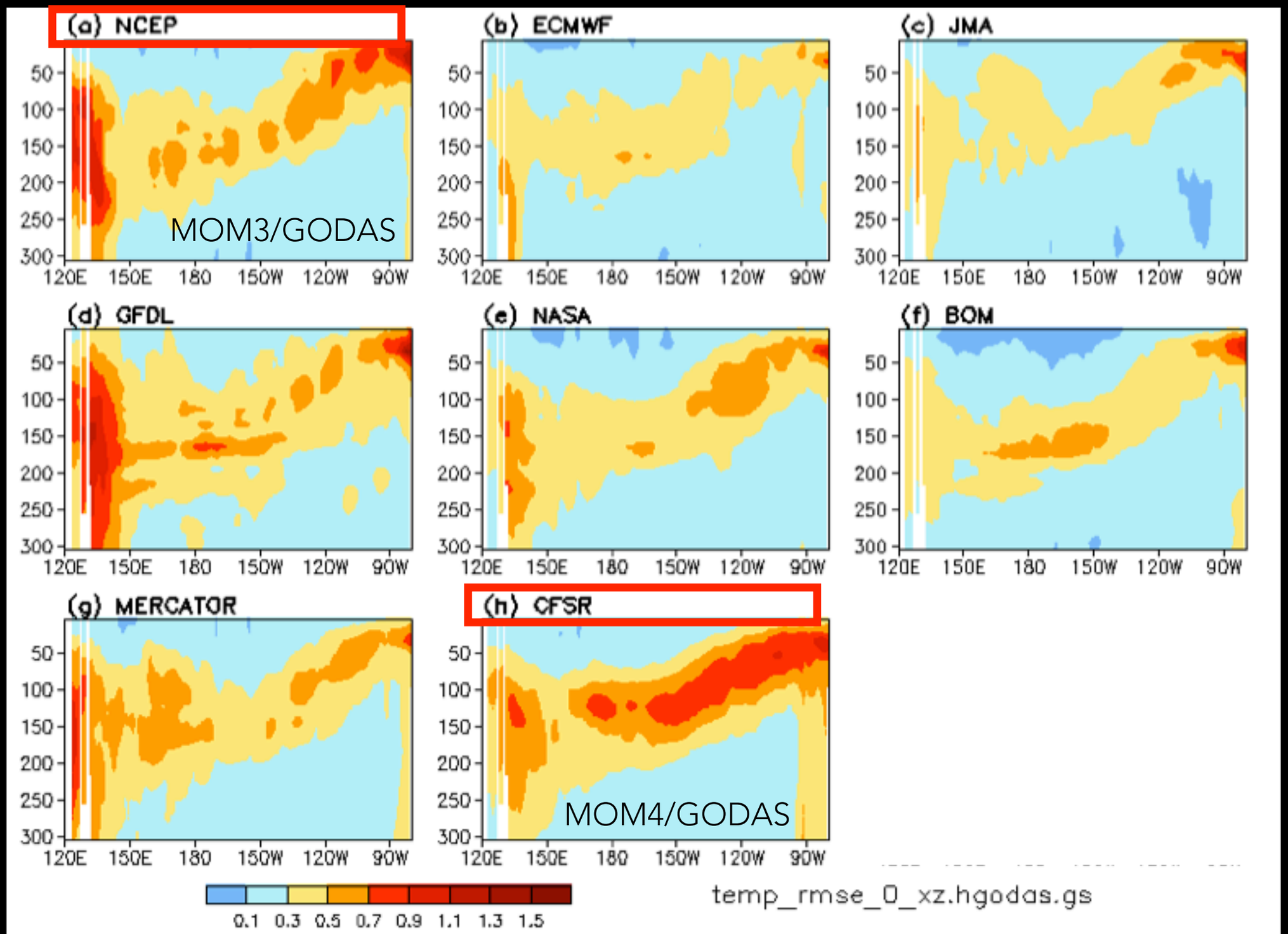
TEMPERATURE AND SALINITY (O-F) RMSD AND BIAS REDUCED USING THE HYBRID-GODAS (5-DAY FORECASTS)





INTERNATIONAL COMPARISON

Equatorial Pacific Thermocline

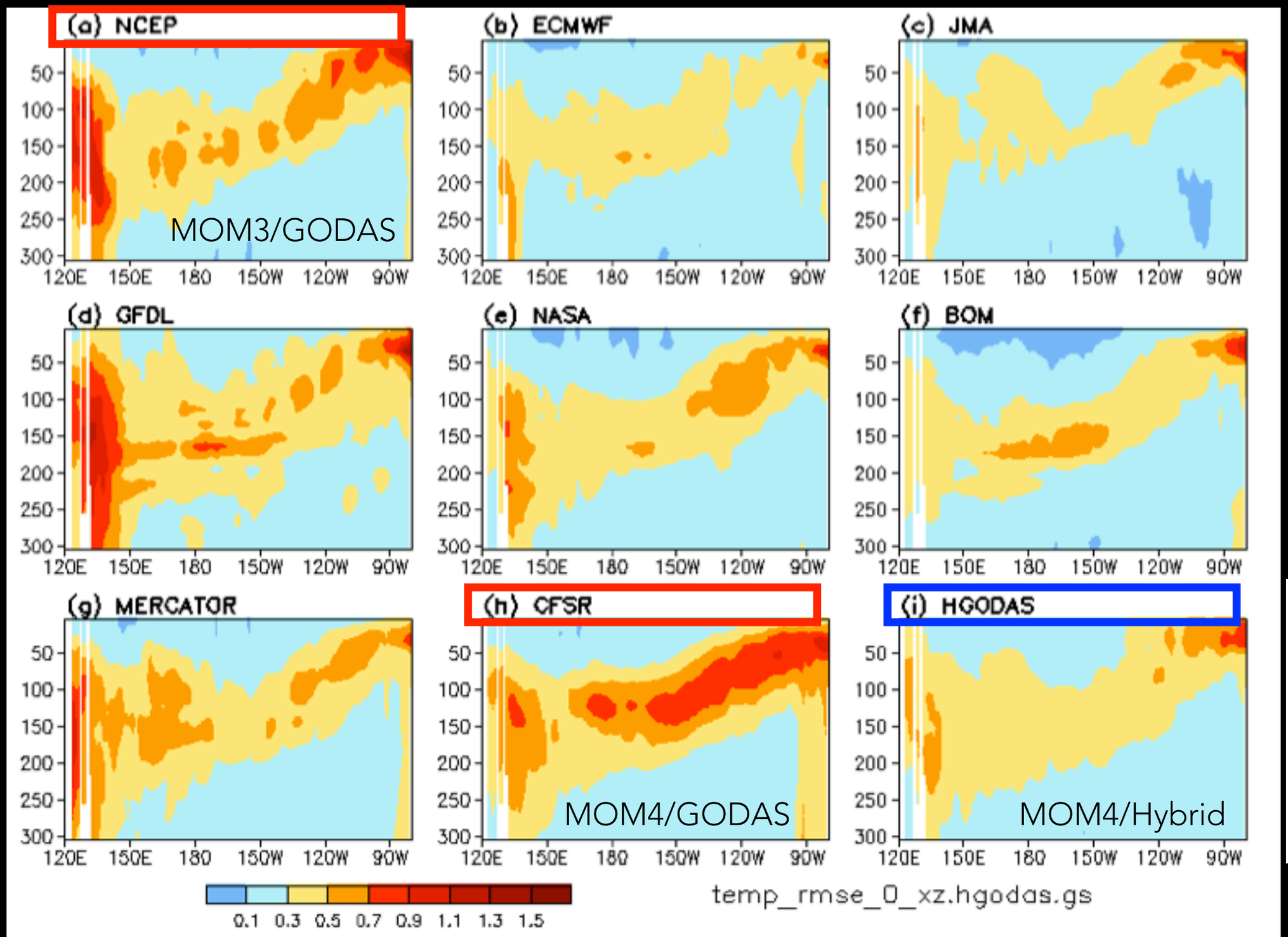


RMSD of anomaly versus ensemble mean

Thanks to: Yan Xue

INTERNATIONAL COMPARISON

Equatorial Pacific Thermocline



RMSD of anomaly versus ensemble mean

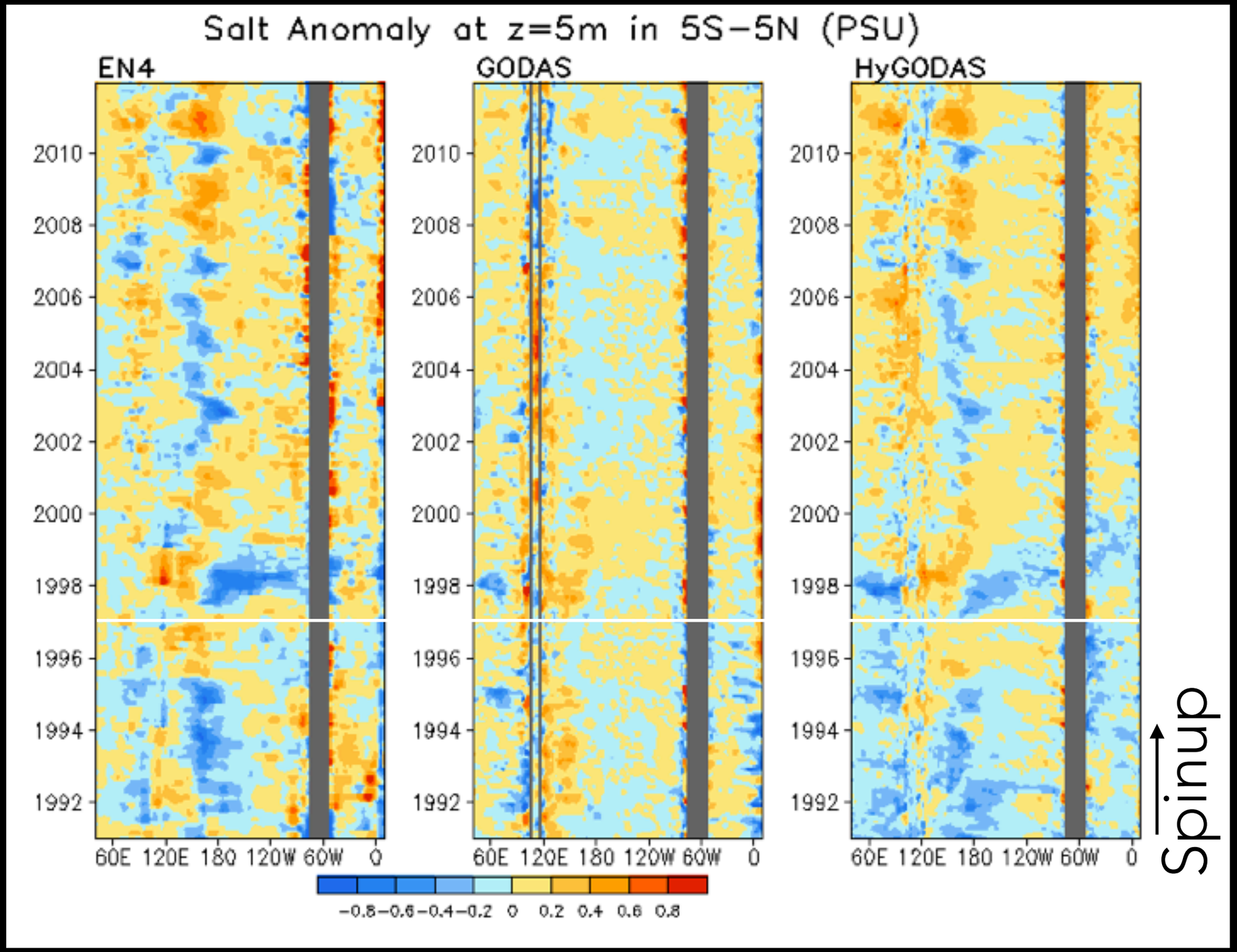
Hybrid-GODAS falls closer to international mean

Thanks to: Yan Xue

NEAR SURFACE SALINITY

Seasonal variability of the SSS is improved with the Hybrid-GODAS

EN4 3DVar Hybrid



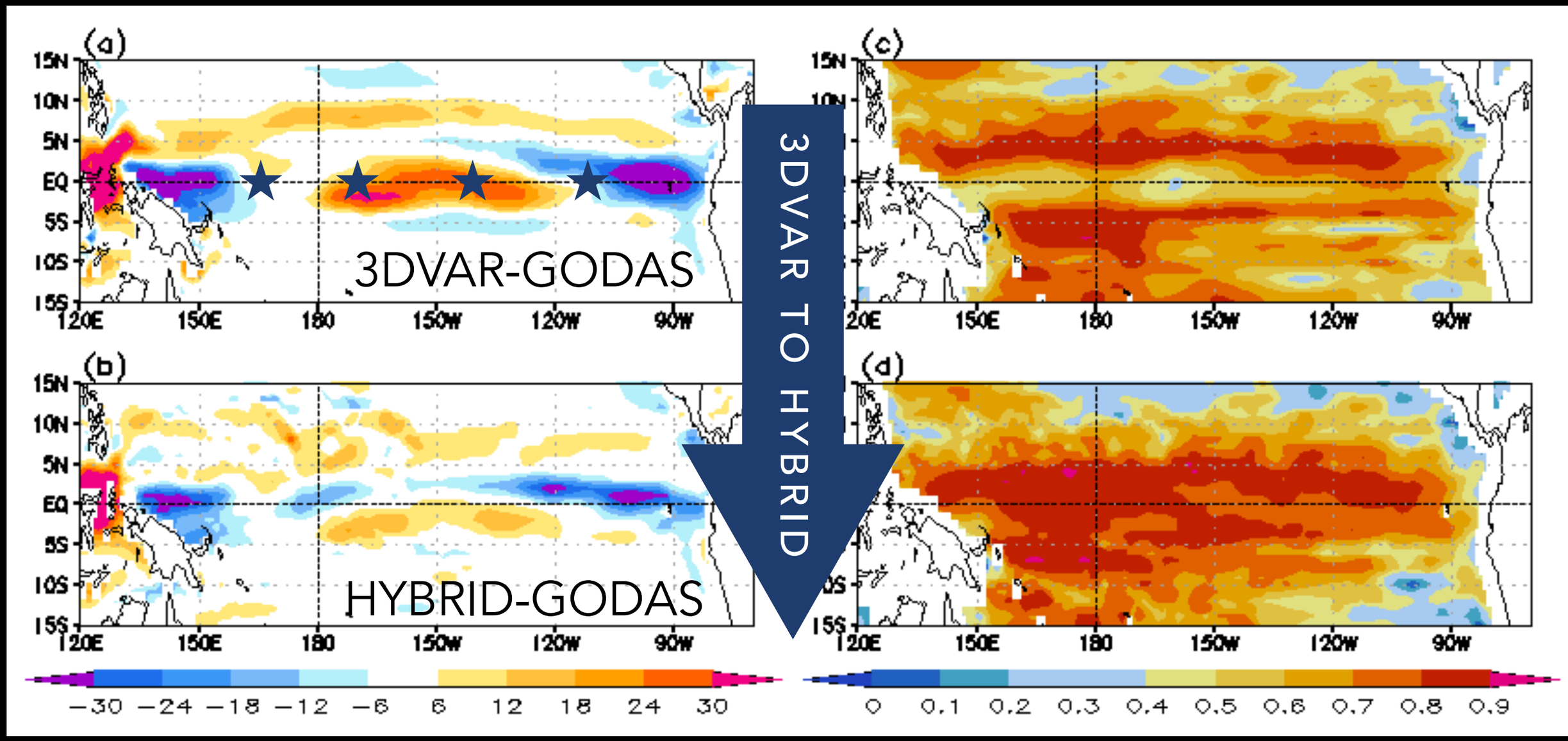
NEAR SURFACE OCEAN CURRENTS

Comparison to OSCAR* currents (~0-30m) from 1995-2011

Tropical Pacific

Mean zonal current differences (cm/s)

Anomaly Correlation



*OSCAR currents derived from satellite altimeter, scatterometer, and SST data

*Acoustic Dopler Current Profilers

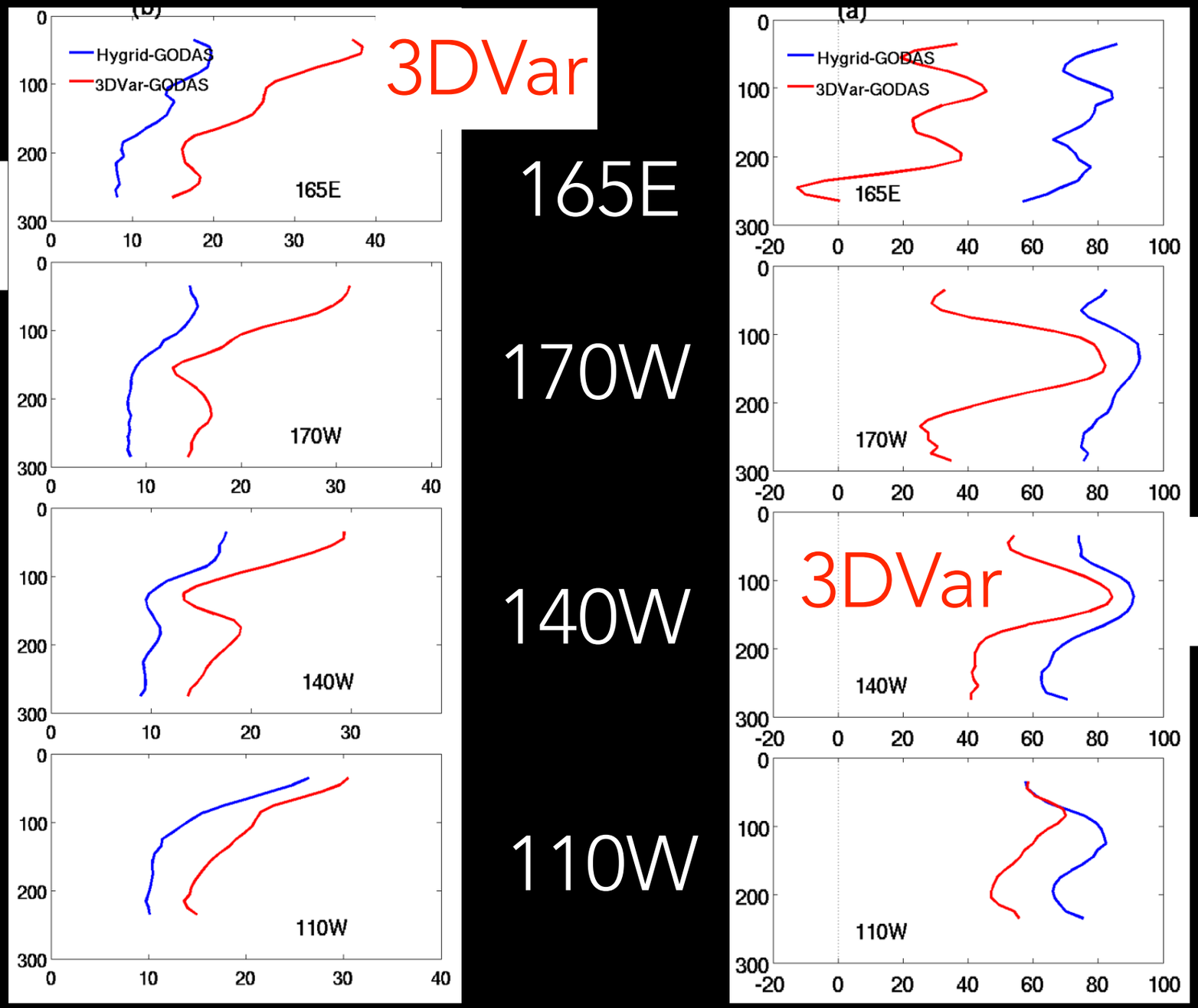
EQUATORIAL PACIFIC ADCP*

RMSD (cm/s)

Anomaly Correlation

Hybrid

3DVar



note: Hybrid-GODAS updates velocity field, 3DVar-GODAS does not.

3DVar

Hybrid

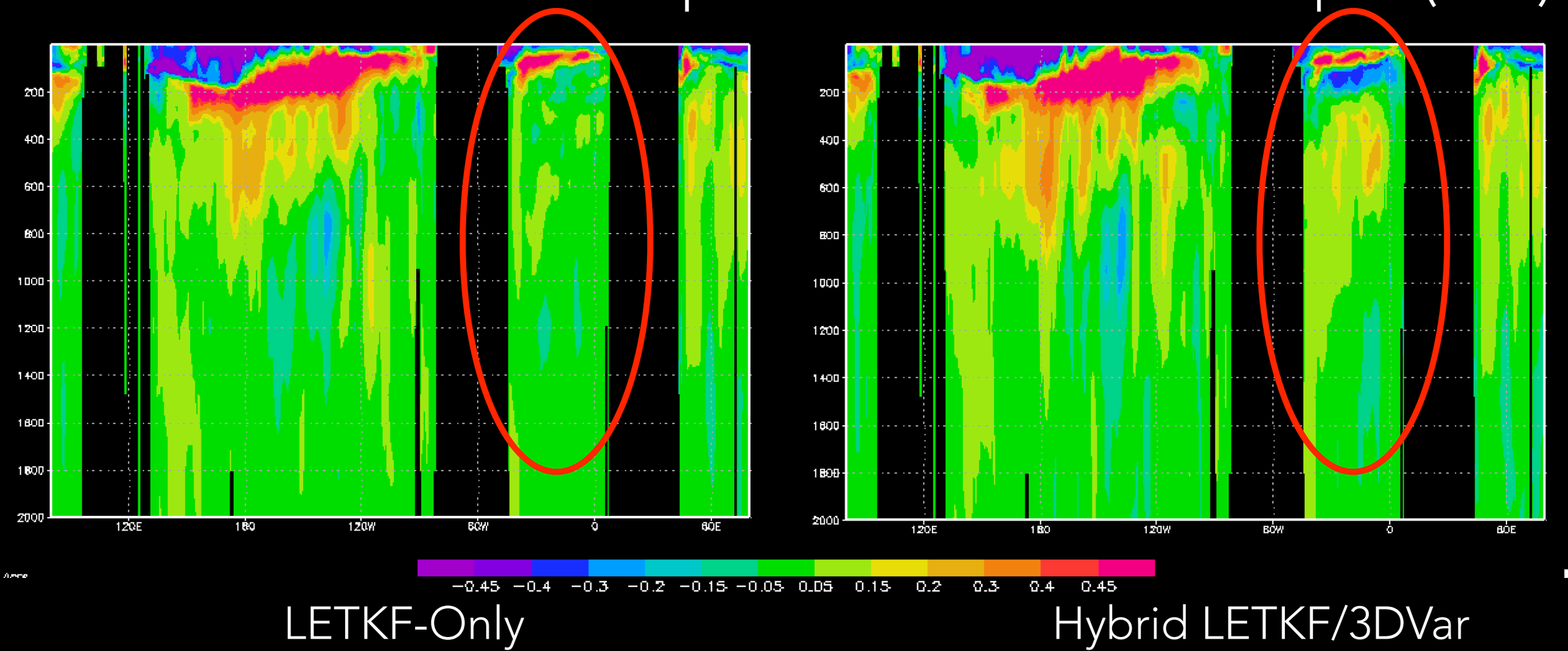
Improvement

Improvement

DEEP EQUATORIAL JETS

- Due to a model bias, deep equatorial jets in the Atlantic are weak or absent in the LETKF-Only reanalysis, but are present when with the Hybrid LETKF/3DVar

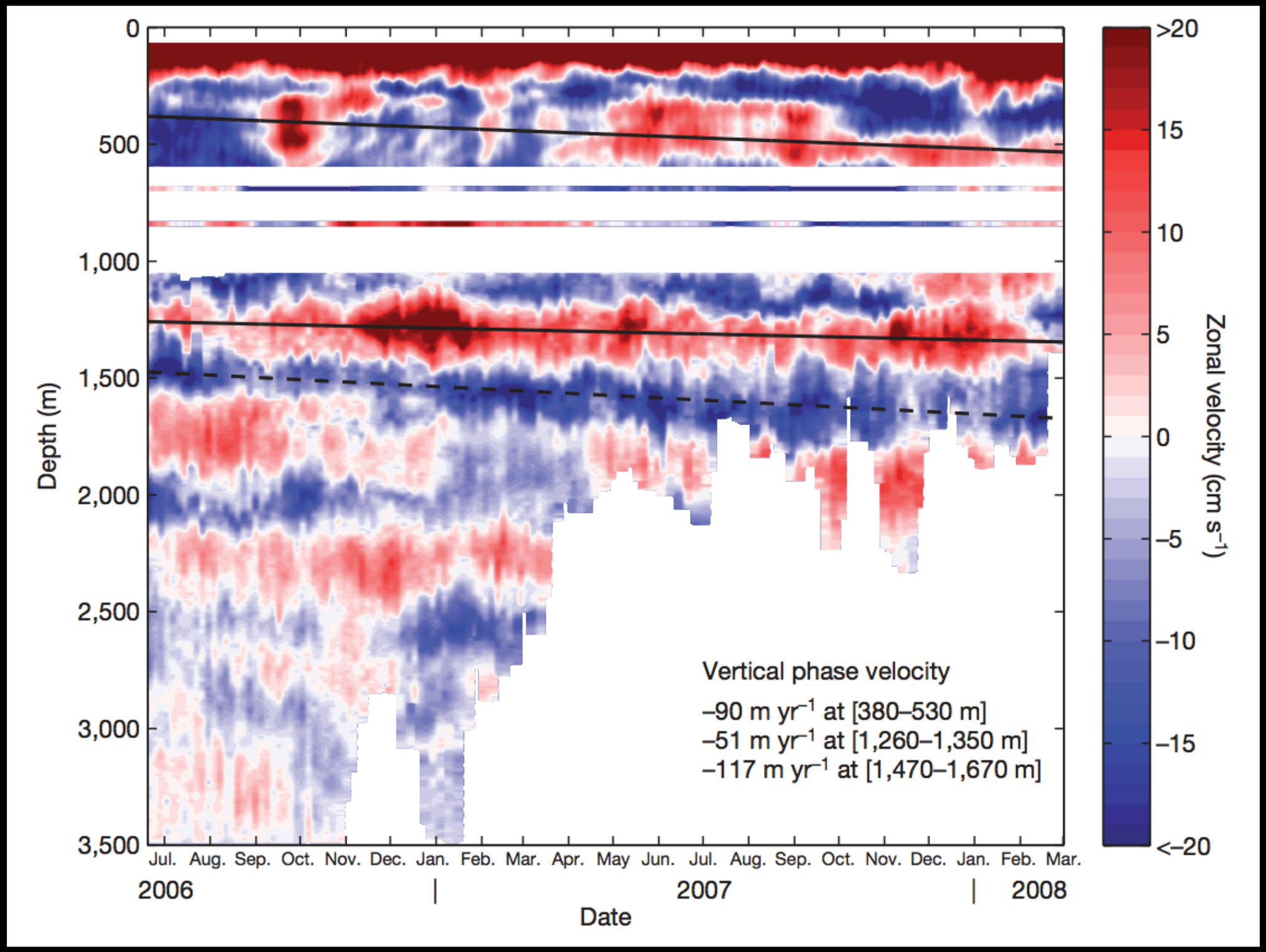
Zonal currents at the Equator from 0-2000m depth (m/s)



LETKF-Only

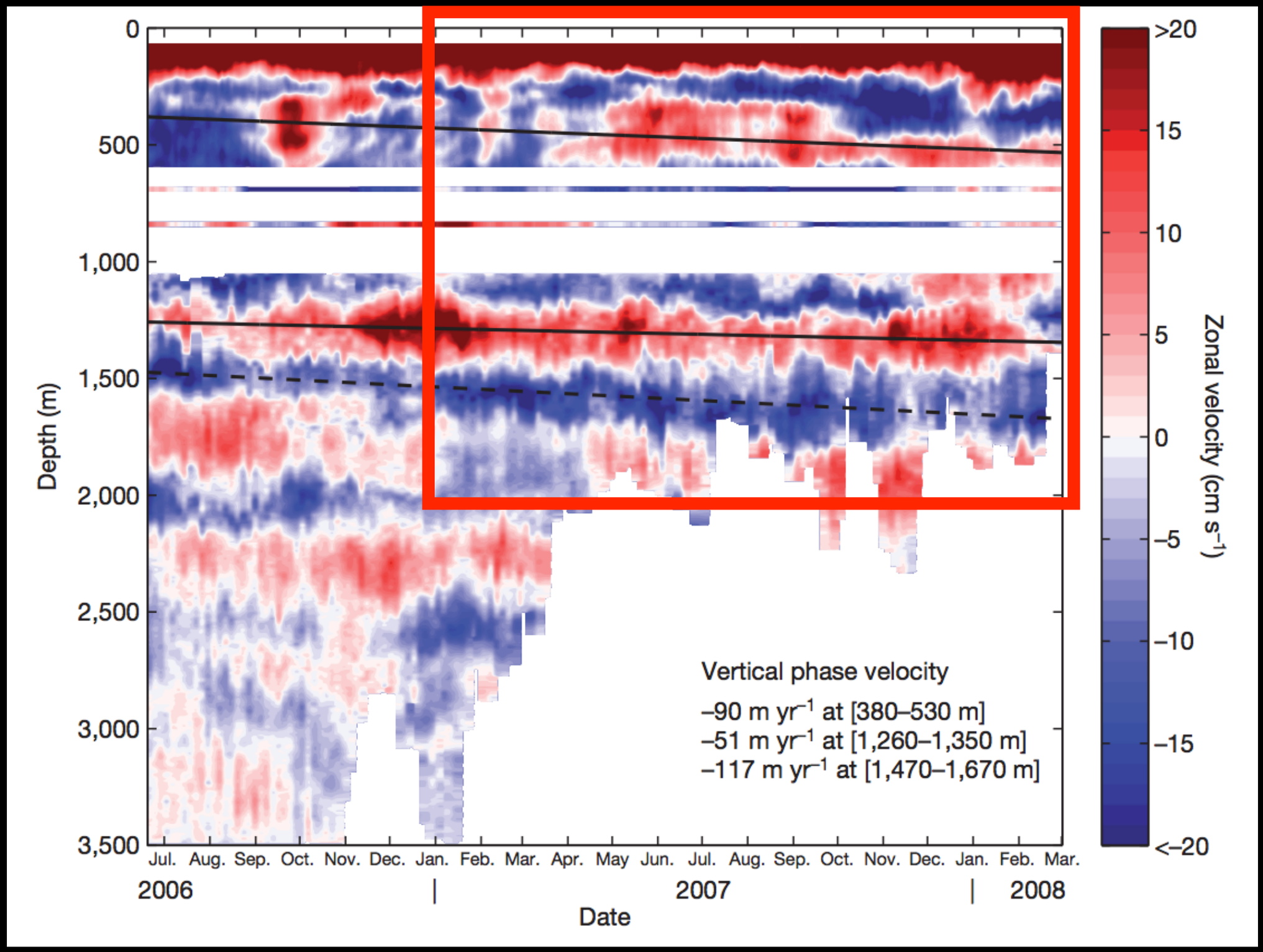
Hybrid LETKF/3DVar

OBSERVED EQUATORIAL DEEP OCEAN JETS AT 23°W



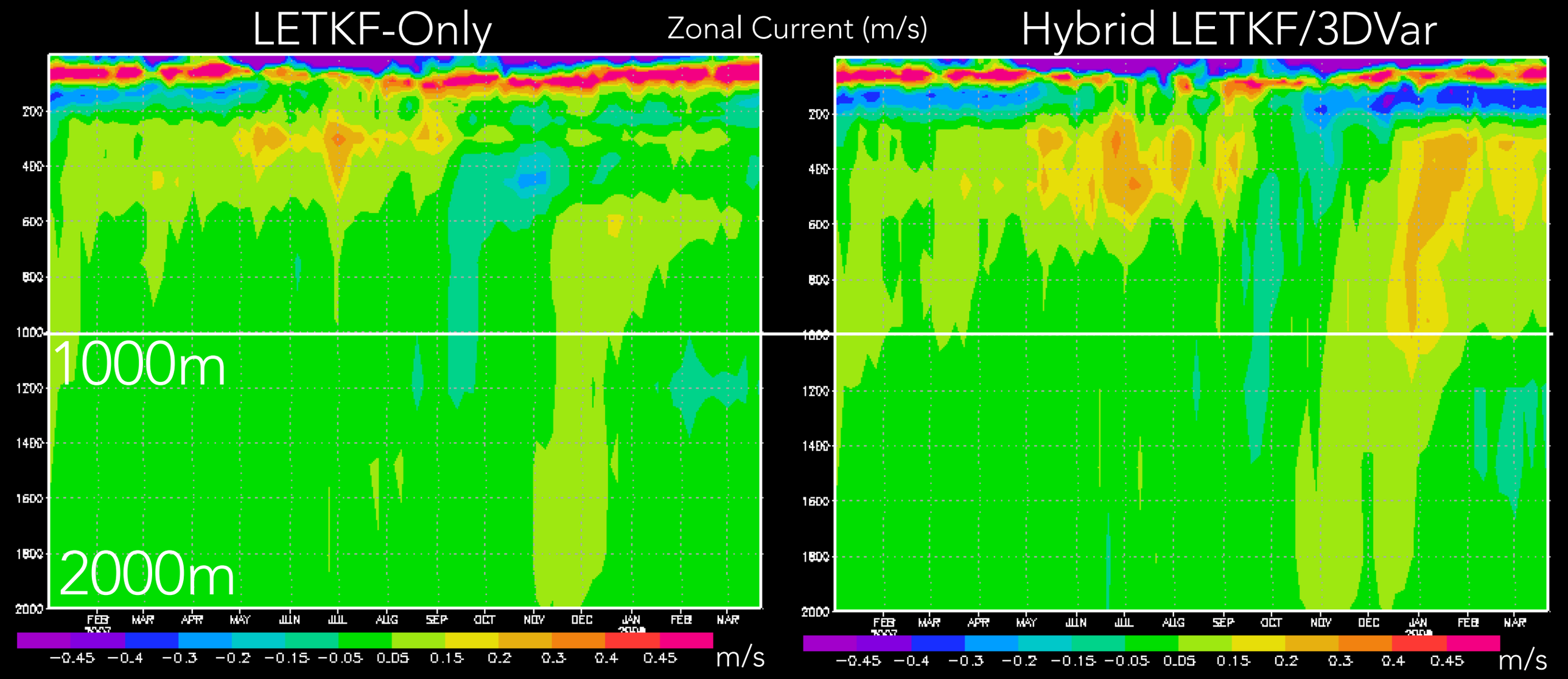
Source: Brandt et al., 2011; Nature

OBSERVED EQUATORIAL DEEP OCEAN JETS AT 23°W



Source: Brandt et al., 2011; Nature

REANALYSIS DEEP JETS AT 23°W



- The westward jet between 0-500m is recovered with the Hybrid
- The magnitude of the upper jets is closer to observations
- The deep ocean jets are still not recovered below 1000m.

TRANSITION TO OPERATIONS

- Companion CPO/MAPP project (year 1) will test the MOM4p1 1/2°x1/4° Hybrid-GODAS with operational surface forcing products, and operational data feeds.
- NGGPS project will simultaneously evaluate MOM6 1/4° global DA with new observation types.
- CPO/MAPP project (year 2) will execute a 1979-present reanalysis using the 1/4° MOM6 system in collaboration with Carton's UMD SODA team to develop a replacement to the GODAS historical reanalysis.

NEW OBSERVATION DATA TYPES

- Temperature profiles converted from potential to in situ
- SST w/ projection into the mixed layer using localization
- SSH via Sea Level Anomaly (SLA) and Absolute Dynamic Topography (ADT), globally de-biased
- Surface drifter position data to constrain surface currents, using Lagrangian data assimilation
- Near-surface atmospheric observations in strongly coupled DA

SSH ASSIMILATION

- Goal: Demonstrate positive impact of SSH assimilation
- We have demonstrated positive impact with SLA
- We have transition from assimilating SLA, which requires developing a representative model Mean Dynamic Topography (MDT) to assimilating Absolute Dynamic Topography (ADT).
- SSH = ellipsoid + ADT = ellipsoid + MDT + SLA

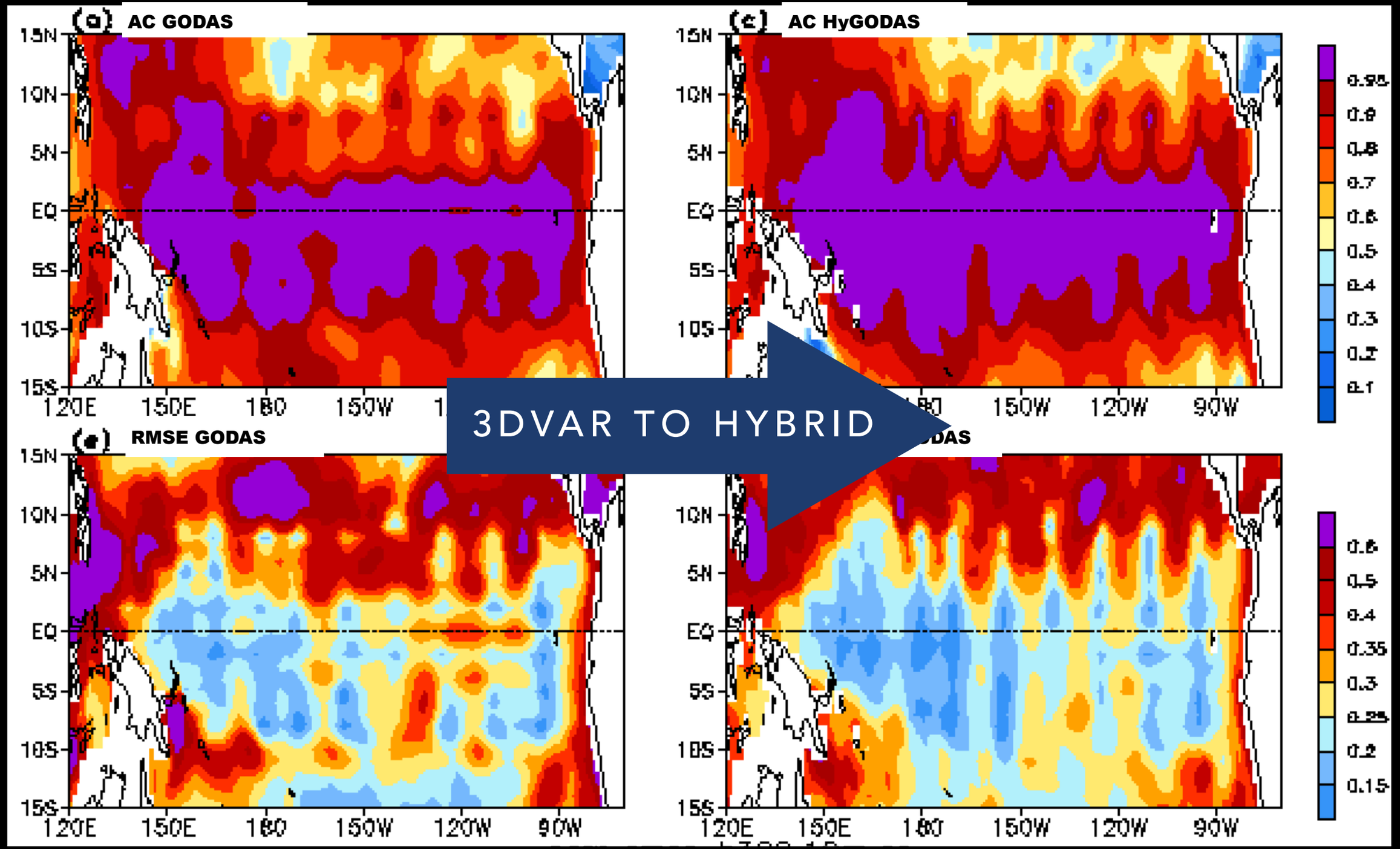
UPPER OCEAN HEAT CONTENT

300m Heat Content vs. EN4, 1995-2011

Tropical Pacific

Ano. Corr.

RMSD



3DVAR TO HYBRID

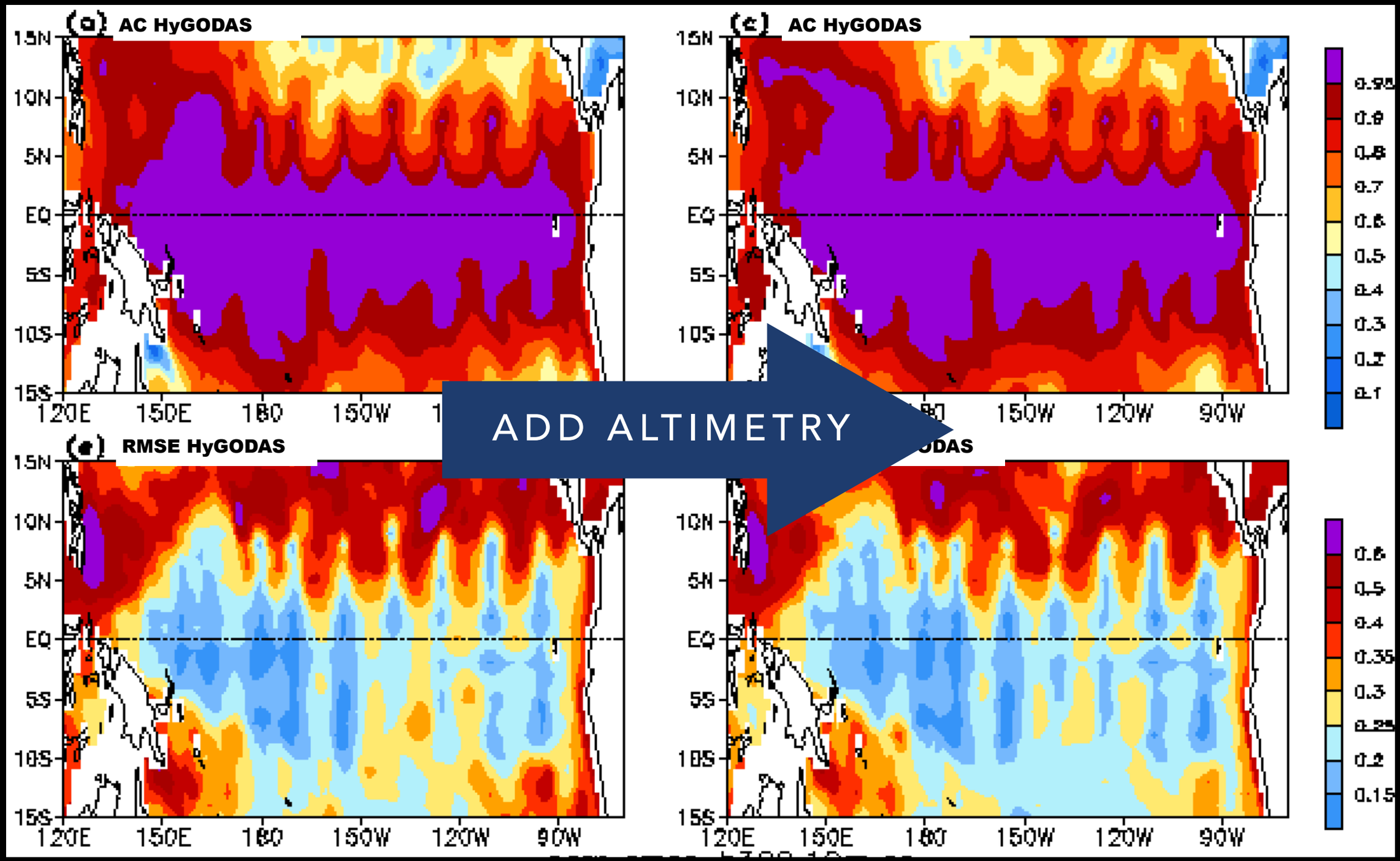
UPPER OCEAN HEAT CONTENT

300m Heat Content vs. EN4, 1995-2011

Tropical Pacific

Anom. Corr.

RMSD



ADD ALTIMETRY

SST ASSIMILATION

- Goal: Produce 1/4° Global SST analysis and forecast products derived from full-scale ocean data assimilation

- SST data is frequent and has high spatial coverage relative to the sparser in situ profiles.

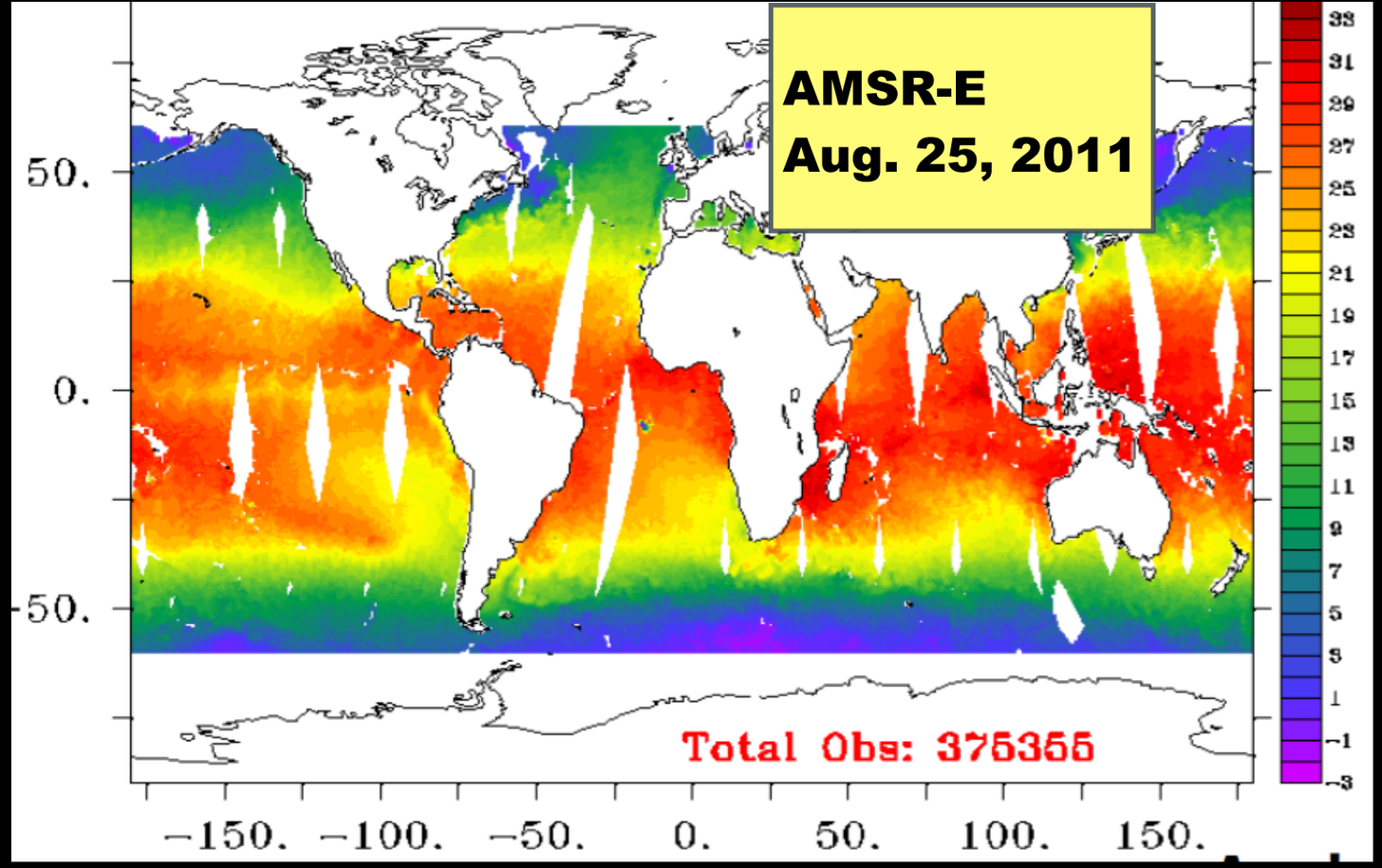
- Without localization and careful tuning of observational errors, the SST obs may dominate the analysis.

- We have transitioned from relaxing to the Reynolds OI SST analysis to directly assimilating Level-2 SST observations and projecting through the mixed layer.

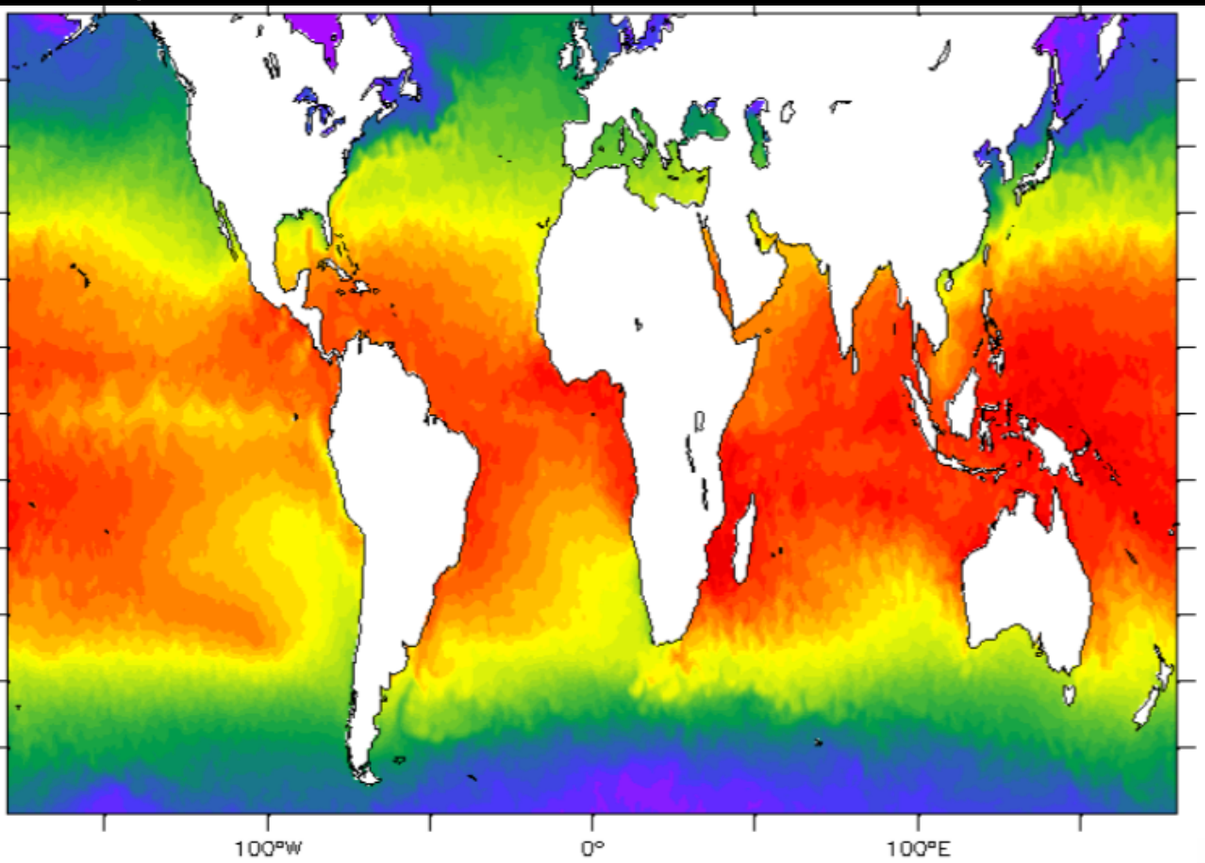
L2 SST

- 1/2°x1/4° MOM4 Global
- Analyze SST, loop, and relax re-forecast to SST analysis.

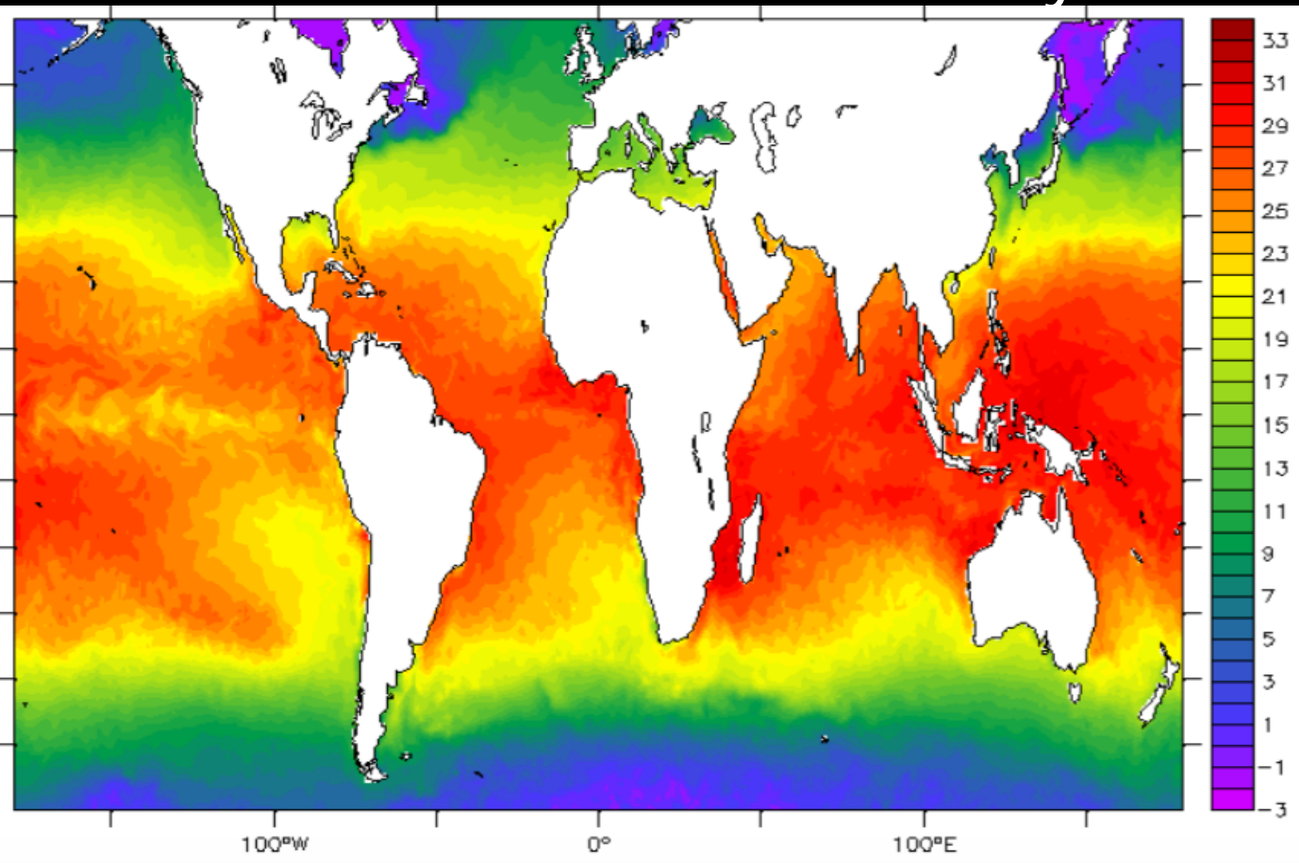
Thanks to: Arya Paul and Siva Reddy at INCOIS



Reynolds OI.v2

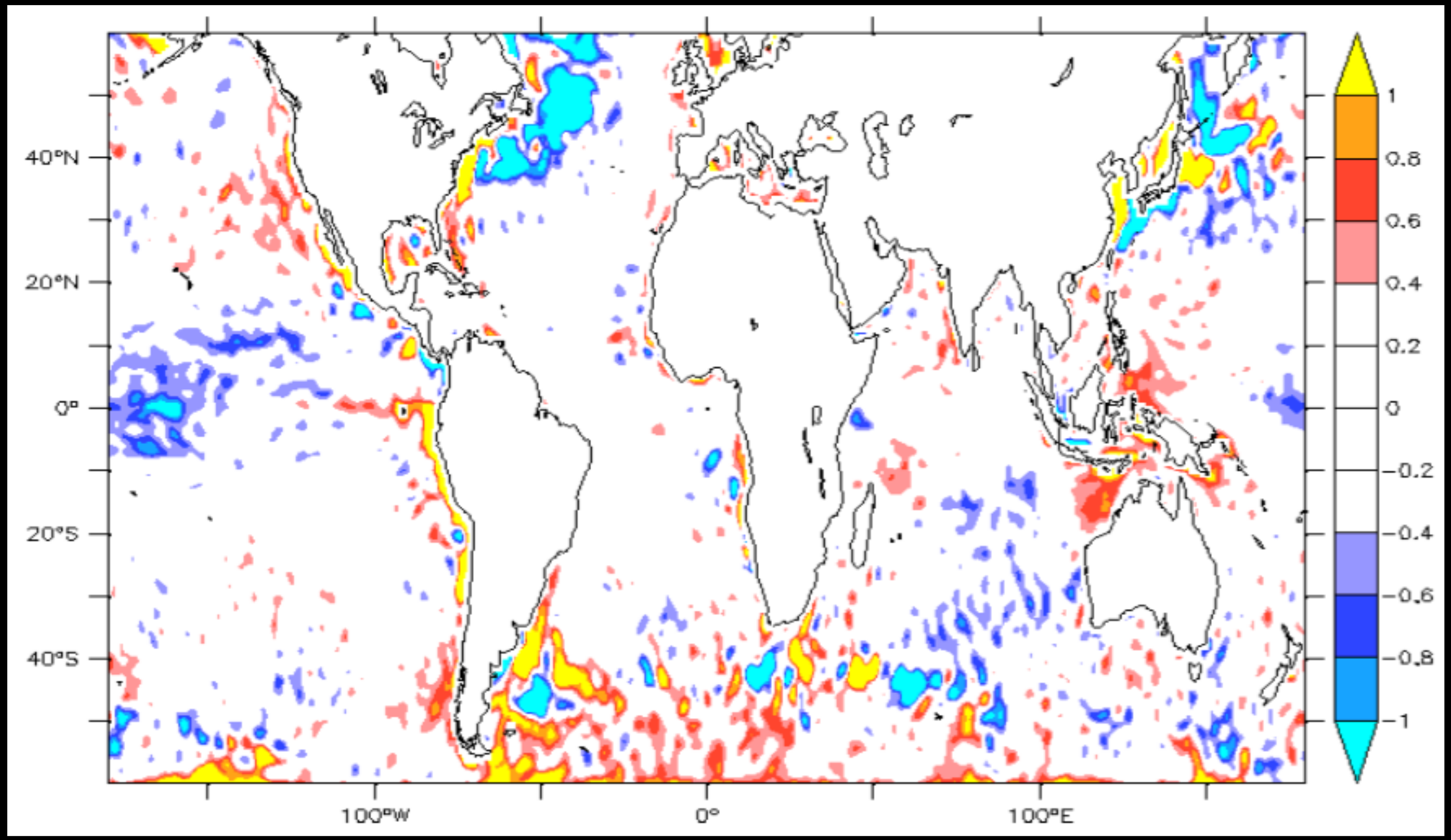


Ocean-LETKF SST analysis



L2 SST, ANALYSIS-MINUS-REYNOLDS

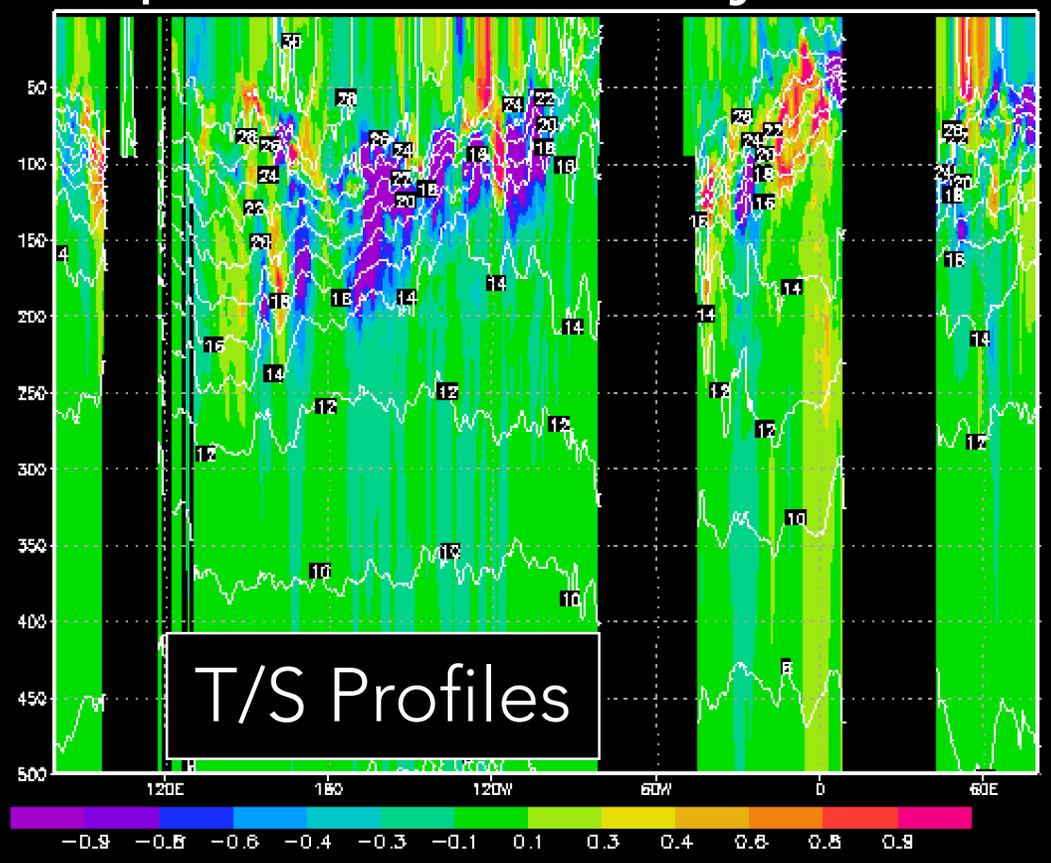
- Difference after 2 months (March/April, 2011)
- 1/2° MOM4p1 (CFSR resolution)

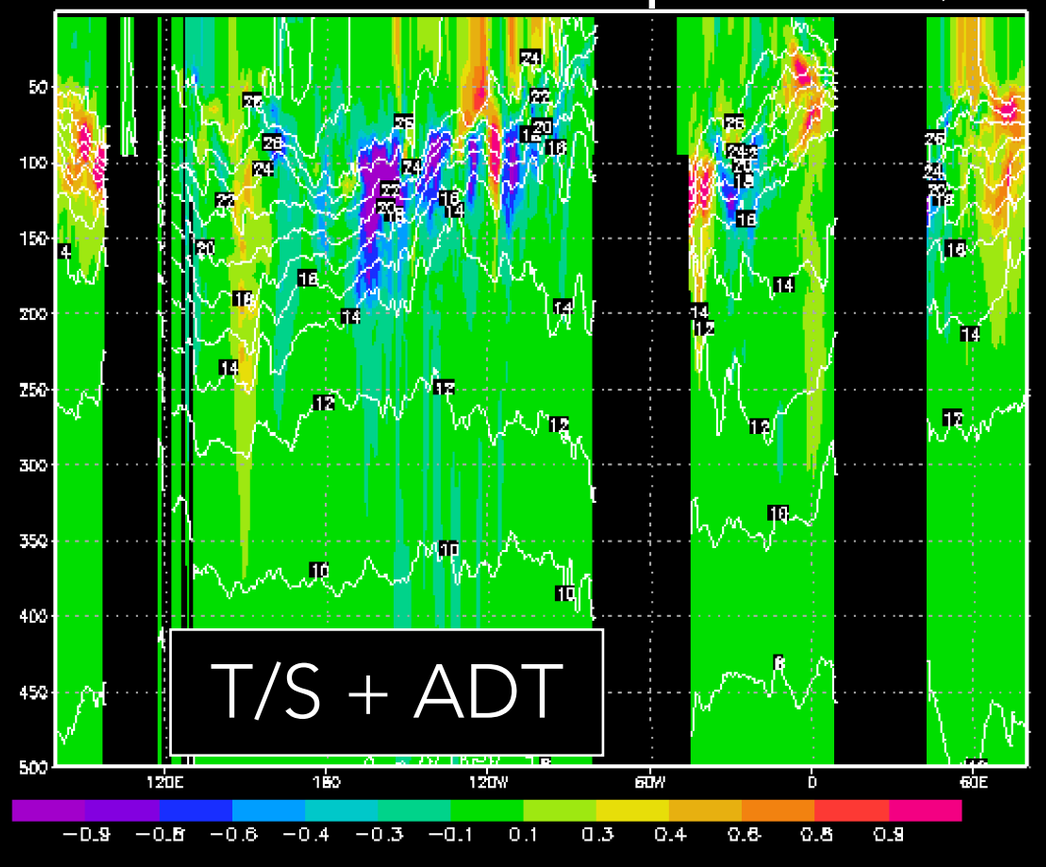


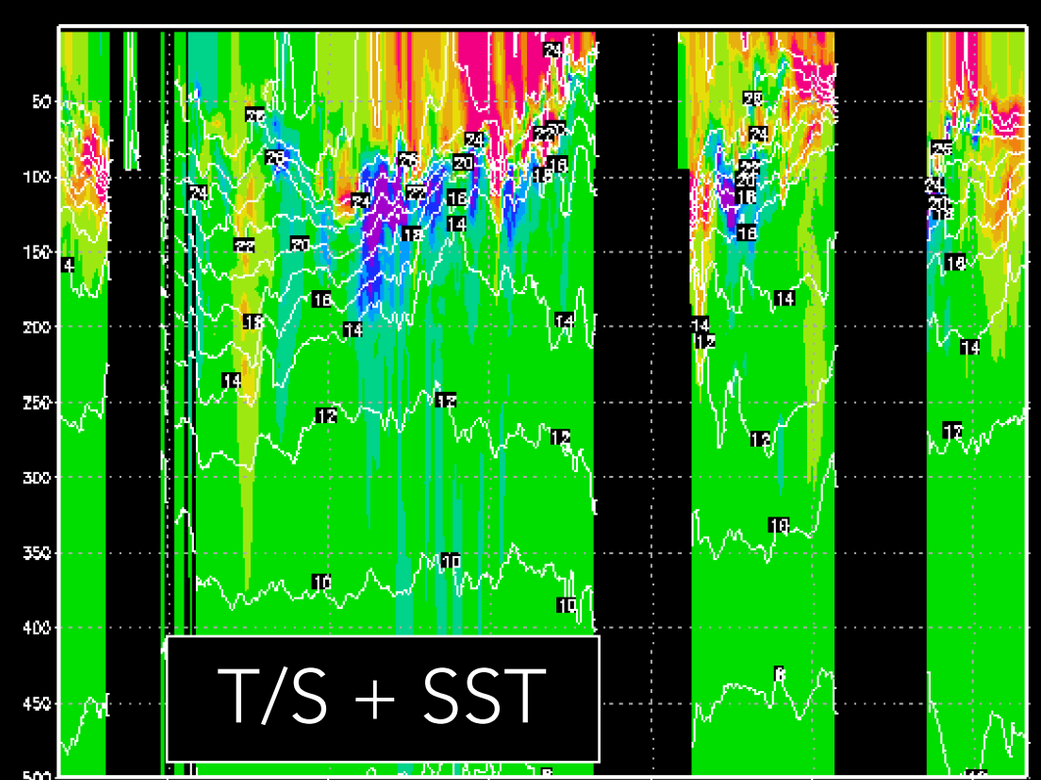
ASSIMILATION OF L2 SST & ADT

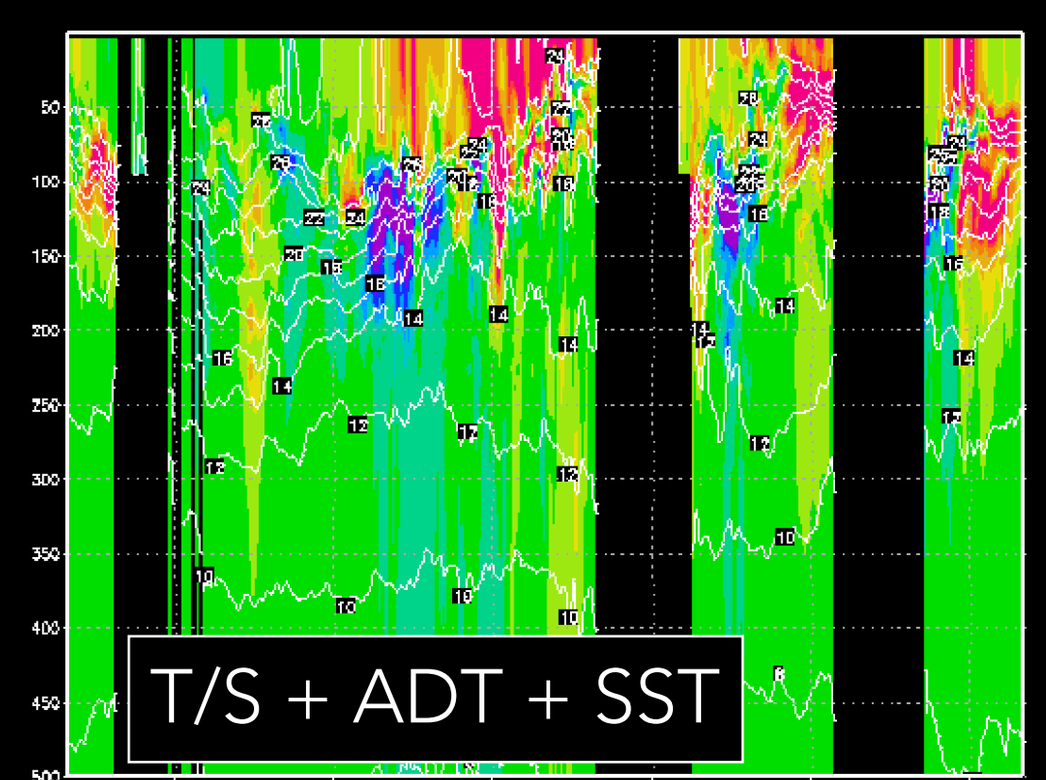
Temperature analysis increments at the Equator (°C)

Pathfinder nighttime SST







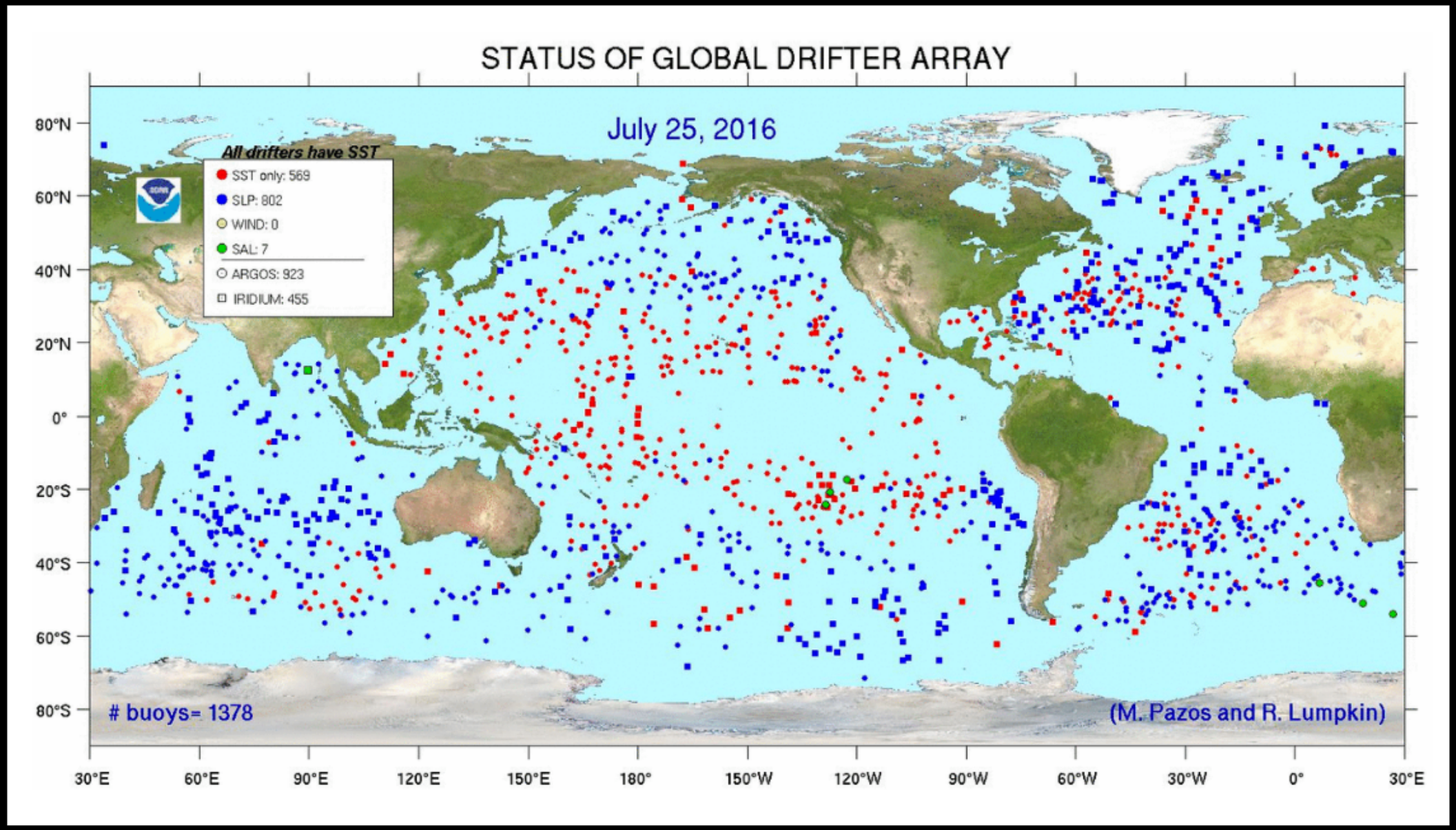


2007-01-06

GLOBAL DRIFTER PROGRAM (GDP) DATA

GOALS:

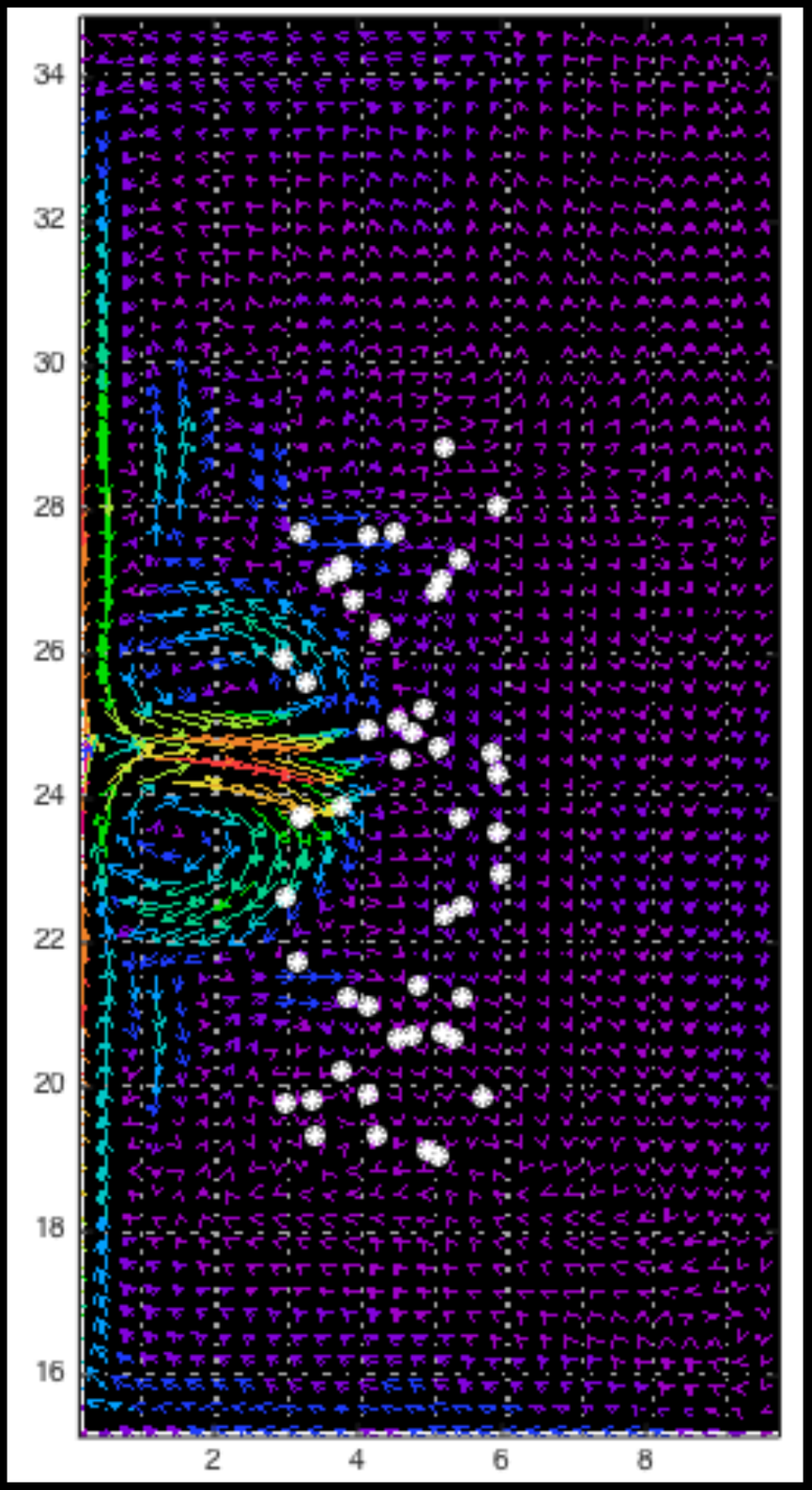
- Use drifter positions to improve near surface current estimates
- Update upper ocean T & S based on ensemble-derived error covariances
- Use GDP temperature measurements to bias-correct SST data



source: http://www.aoml.noaa.gov/phod/dac/index.php

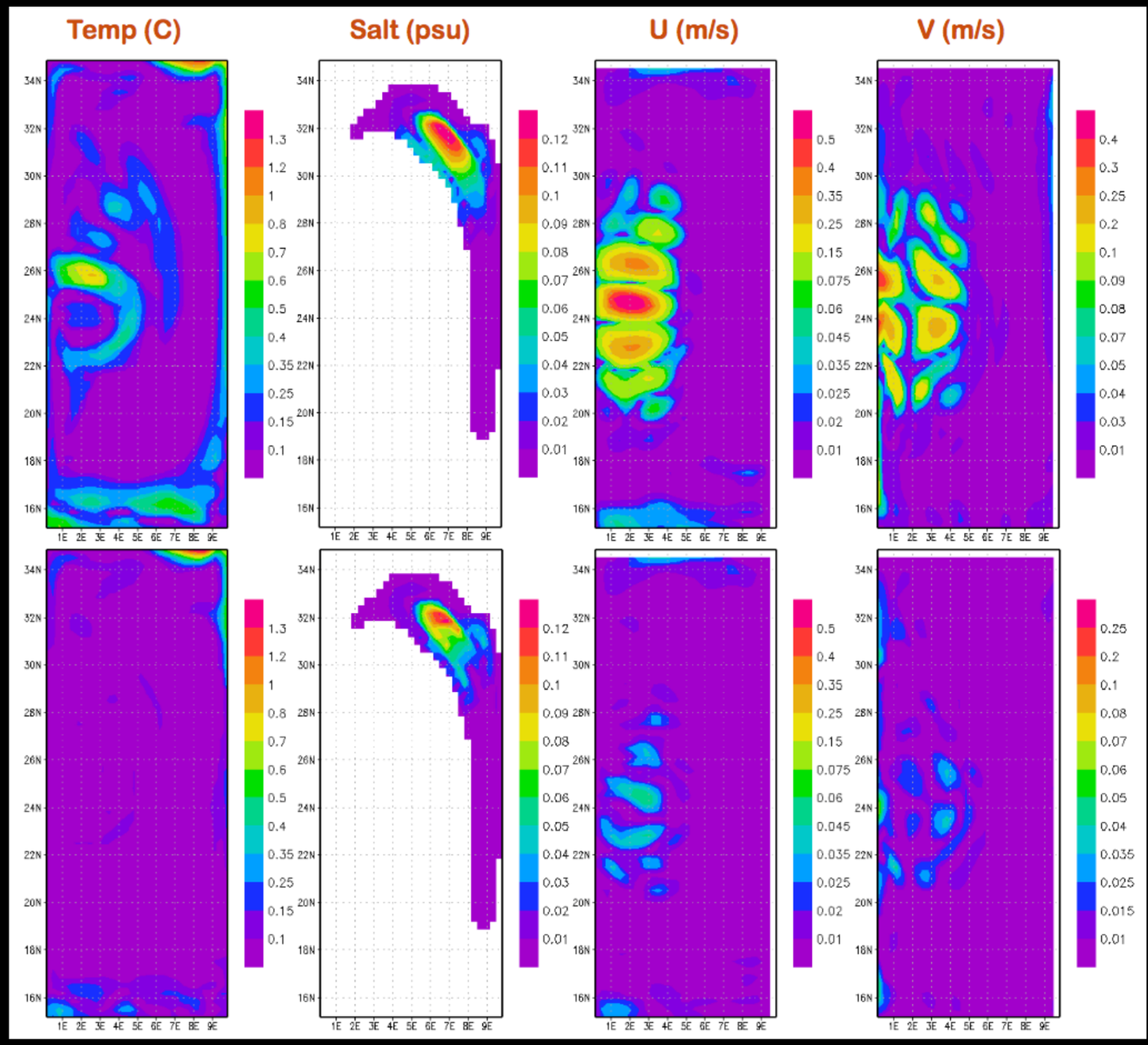
SURFACE DRIFTERS - LAGRANGIAN DA

Depth: 15m



|**Analysis** - Truth| |**Forecast** - Truth|

Depth: 105m

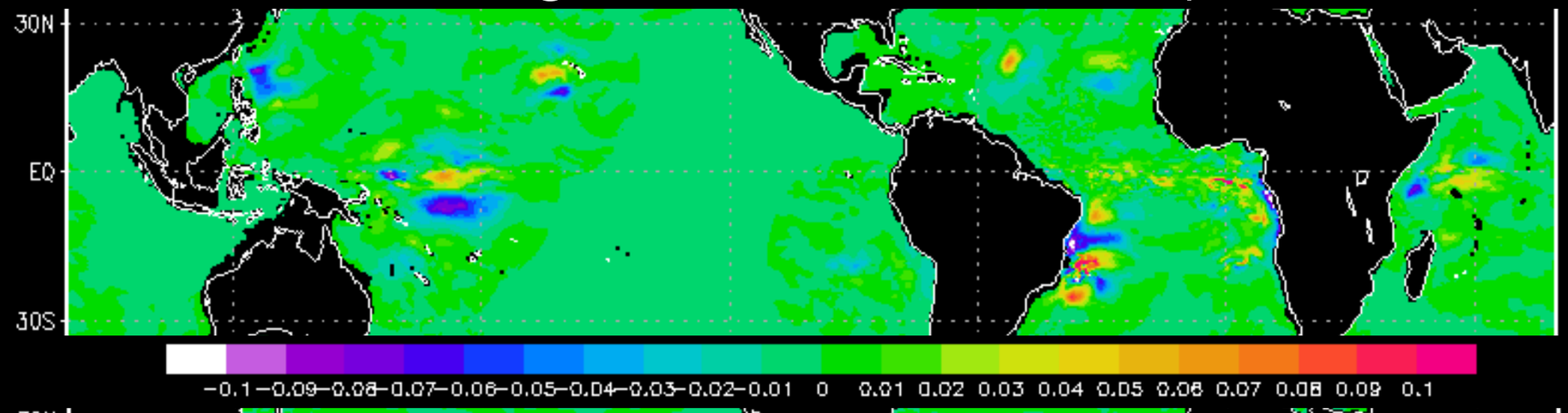


Thanks to: Luyu Sun, UMD

GDP SURFACE DRIFTERS - LAGRANGIAN DA

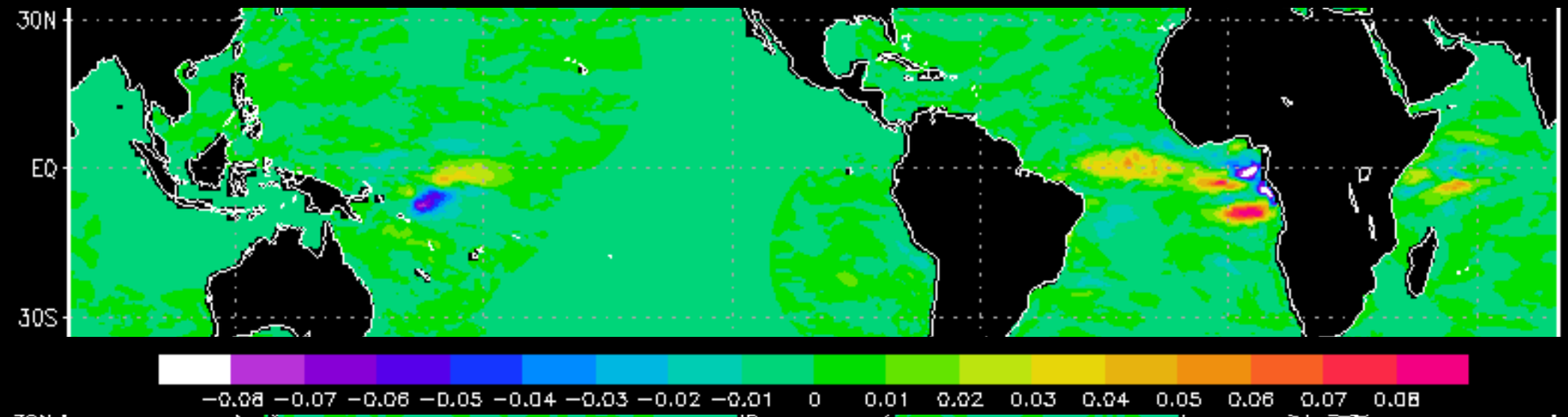
Preliminary real-data global experiments: Analysis Increments assimilating GDP surface drifter positions

T

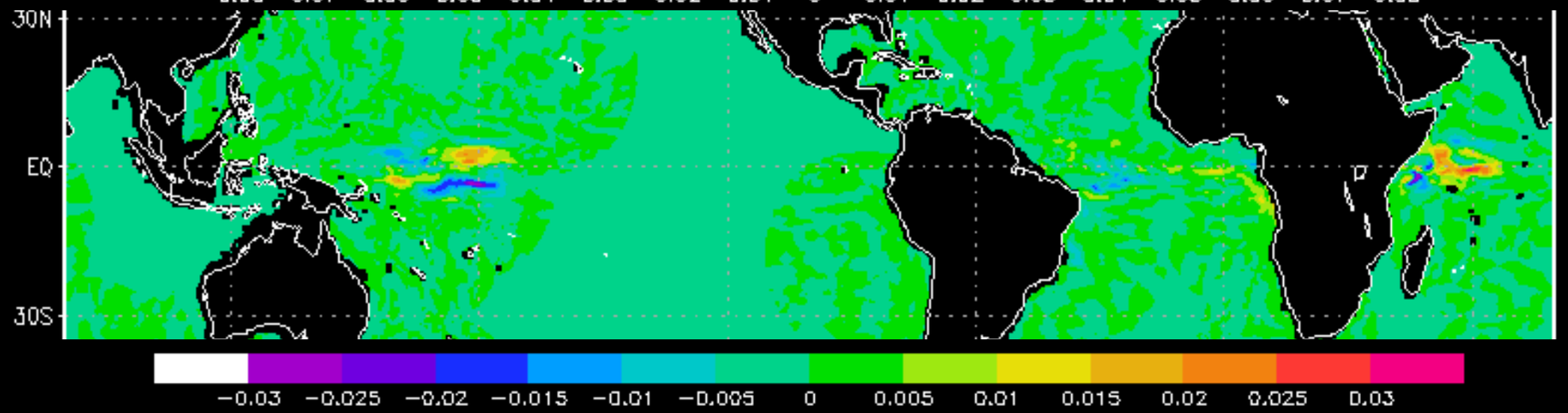


Increments at 5m depth

u



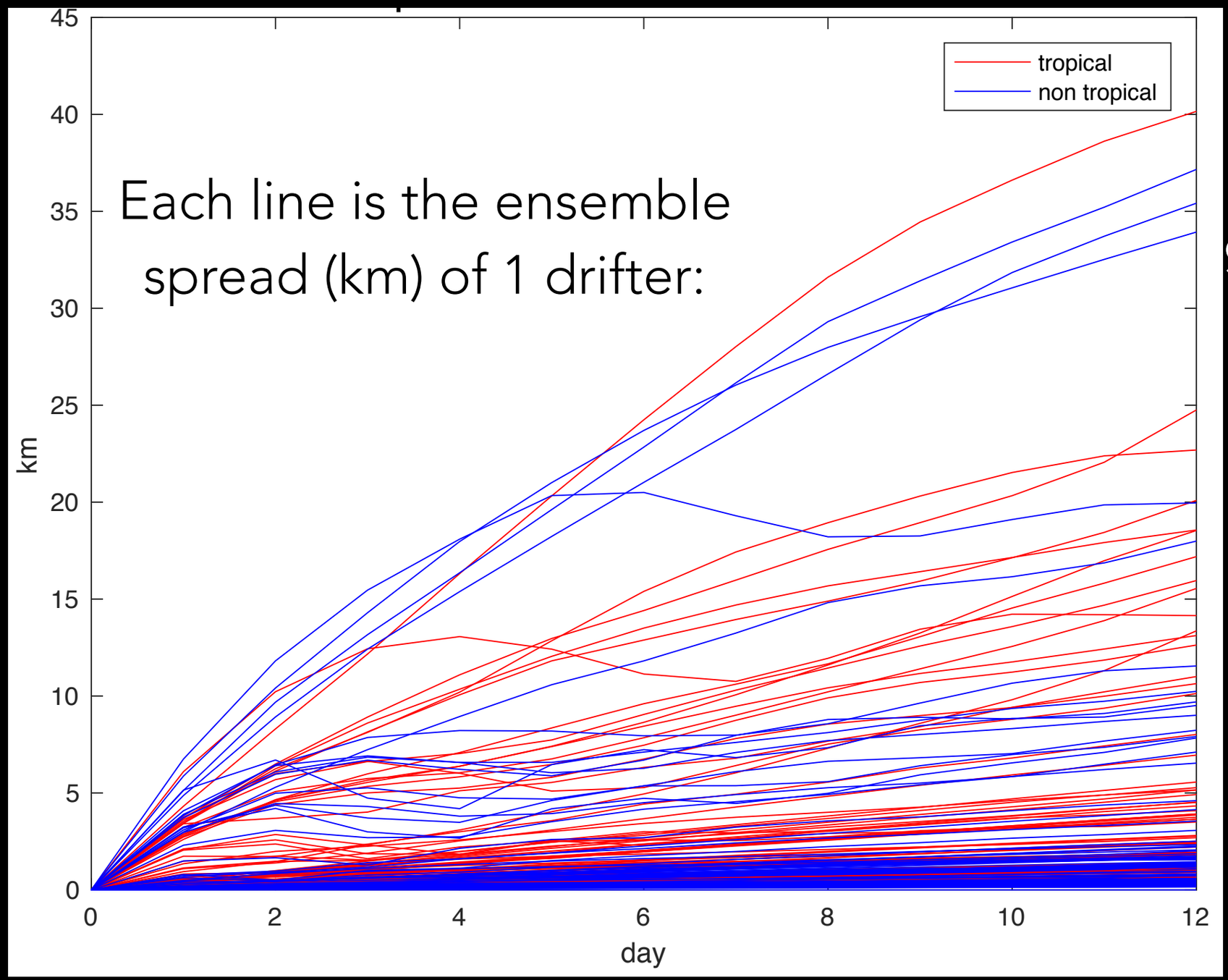
v



Thanks to:
Luyu Sun (UMD)

GLOBAL DRIFTER SPREAD

Spread of 56-member ensemble for 251 drifters initialized at observed GDP drifter locations



We are evaluating the spreading potential given the 1/2° (shown) or 1/4° model resolutions to estimate the appropriate timescales for the analysis cycle.

Thanks to:
Luyu Sun (UMD)

ATMOSPHERIC OBSERVATIONS VIA STRONGLY COUPLED OCEAN/ATMOS DA

- 40% improvement versus weakly coupled system in OSSE using atmospheric obs to improve ocean state in a coupled SPEEDY/NEMO model
  (Sluka, Penny, Kalnay, Miyoshi, 2016; GRL)

- New implementation with CFSv2 leveraging Ocean-LETKF and GFS-LETKF systems developed by Penny et al. (2013;2015) and Lien et al. (2013)

- Preliminary OSSE experiments, with Real-data reanalysis experiments underway using the CFSv2-LETKF

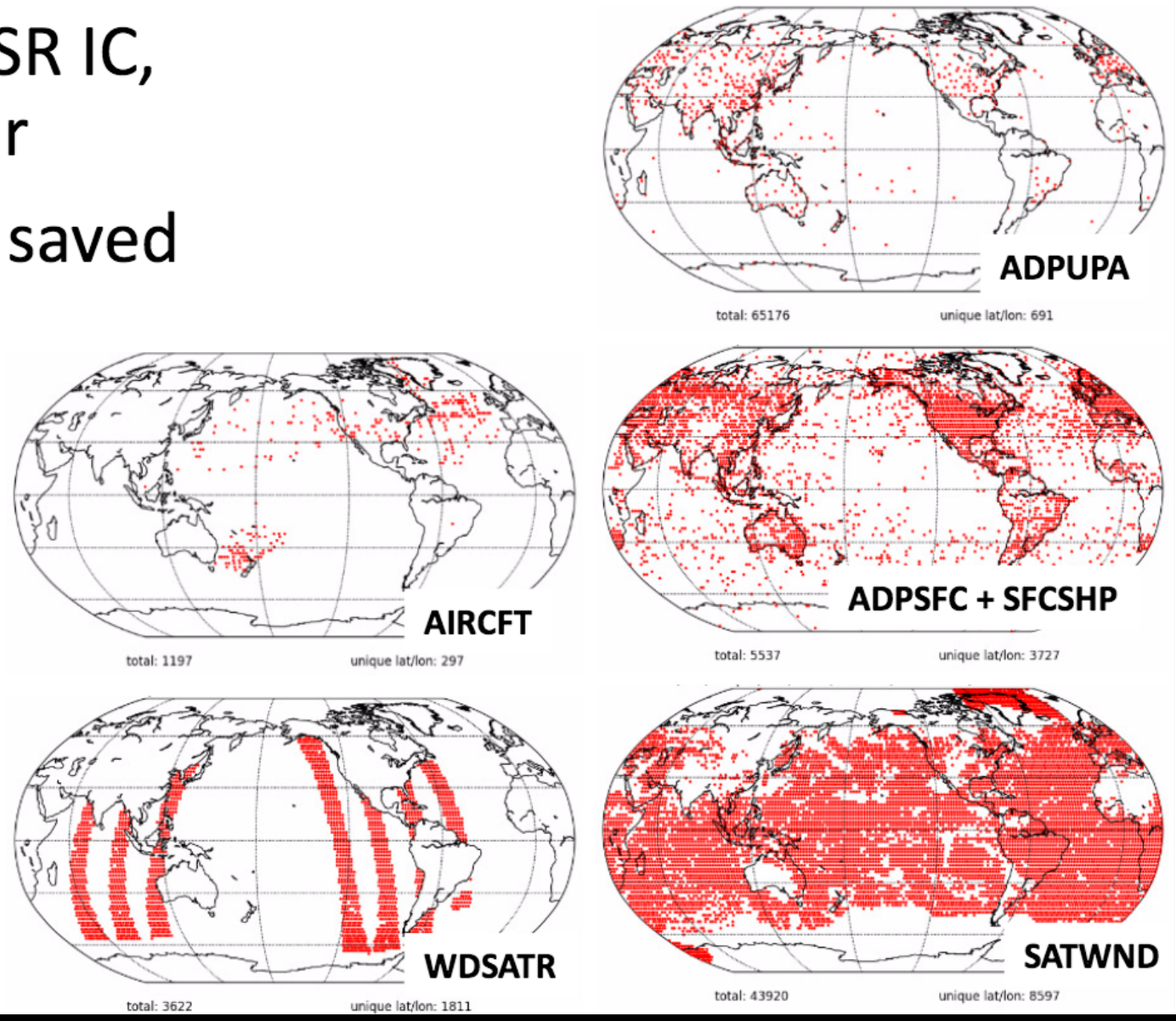
STRONGLY COUPLED OCEAN/ATMOS DA

CFSv2-LETKF OSSE

- Free run initialized from Jan 1, 2009 of CFSR IC, spun up for 1 year
- After Jan 1, 2010 saved as **nature run**

- Synthetic observations generated from, real PREPBUFR (thinned) and ocean profile locations and errors, but with nature run values.

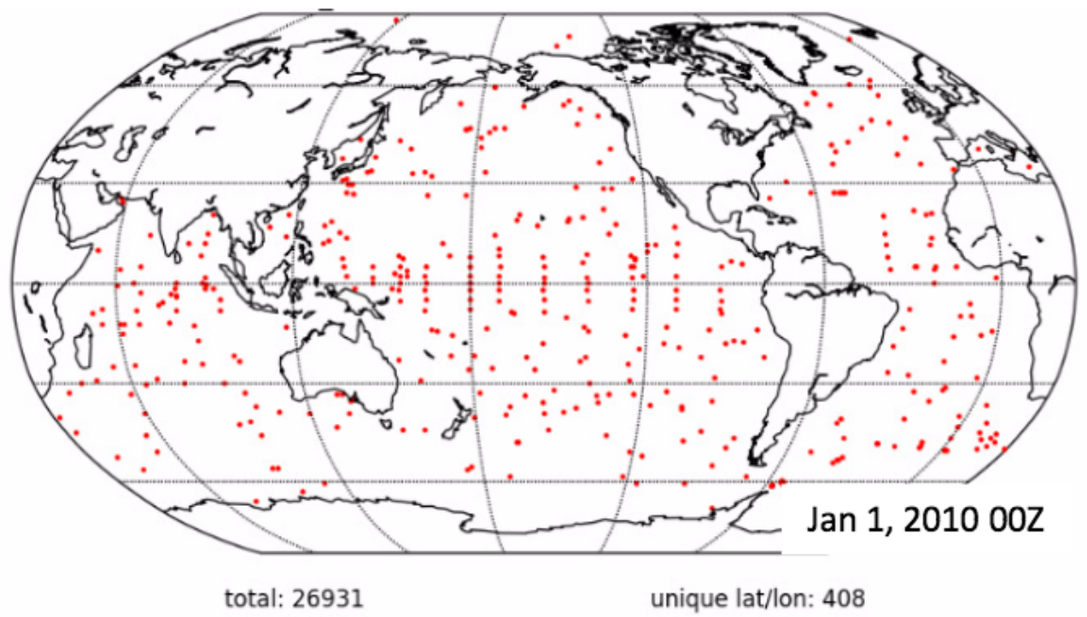
ATM obs locations for 6 hours

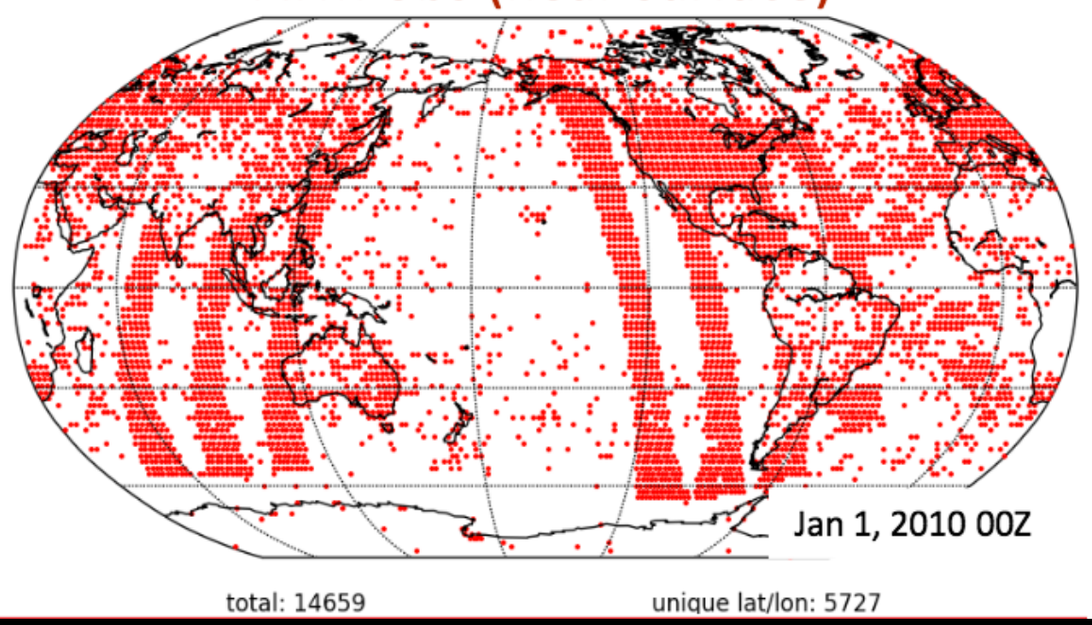


Thanks to: Travis Sluka

STRONGLY COUPLED OCEAN/ATMOS DA

- 50 member ensemble
- Weakly coupled DA with **all observations** performed for 1 month to spinup, 3D-LETKF, 6 hour cycle



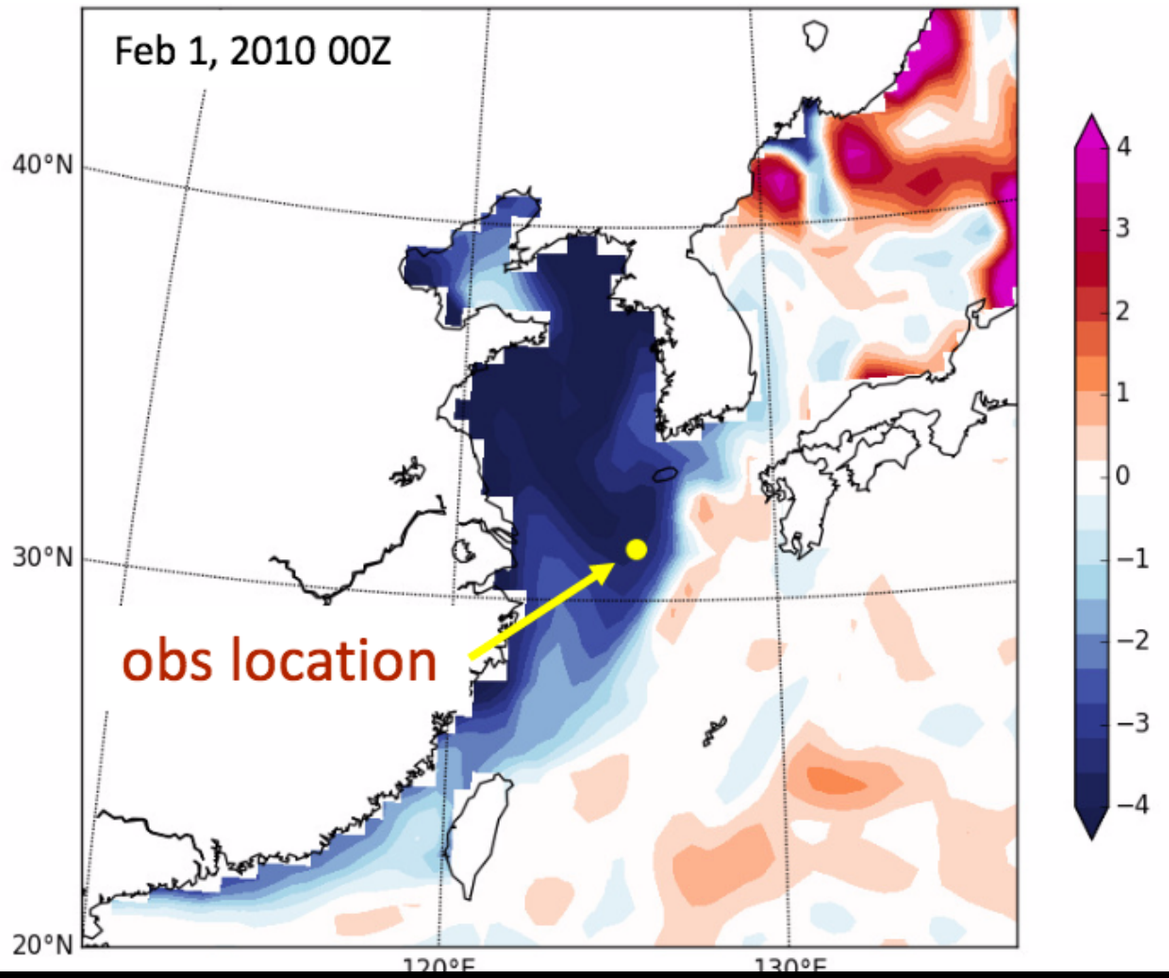


Thanks to: Travis Sluka

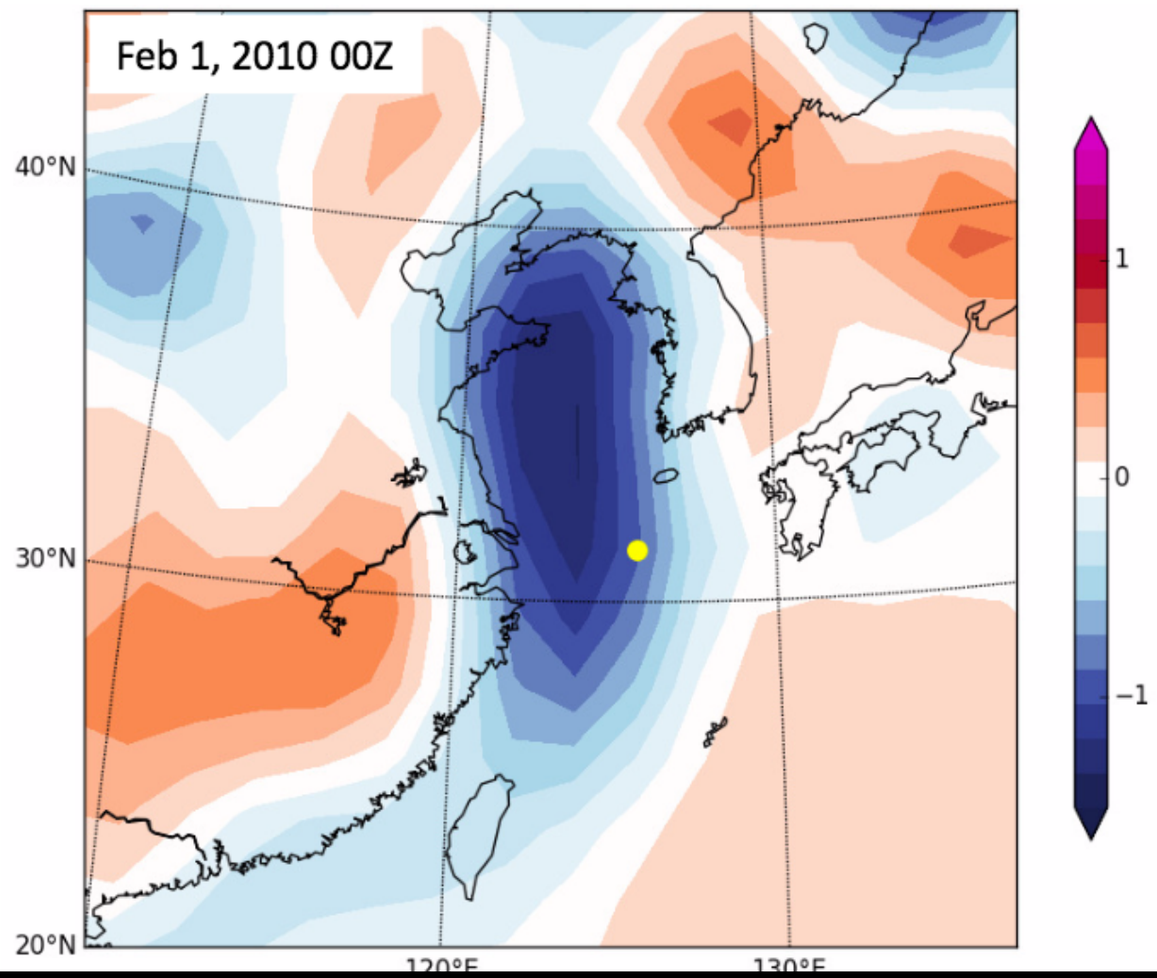
STRONGLY COUPLED OCEAN/ATMOS DA

- After 1 month of **weakly coupled DA**, several locations, especially near coasts, exhibit large SST errors.

SST background error



Surface **atmosphere T** error



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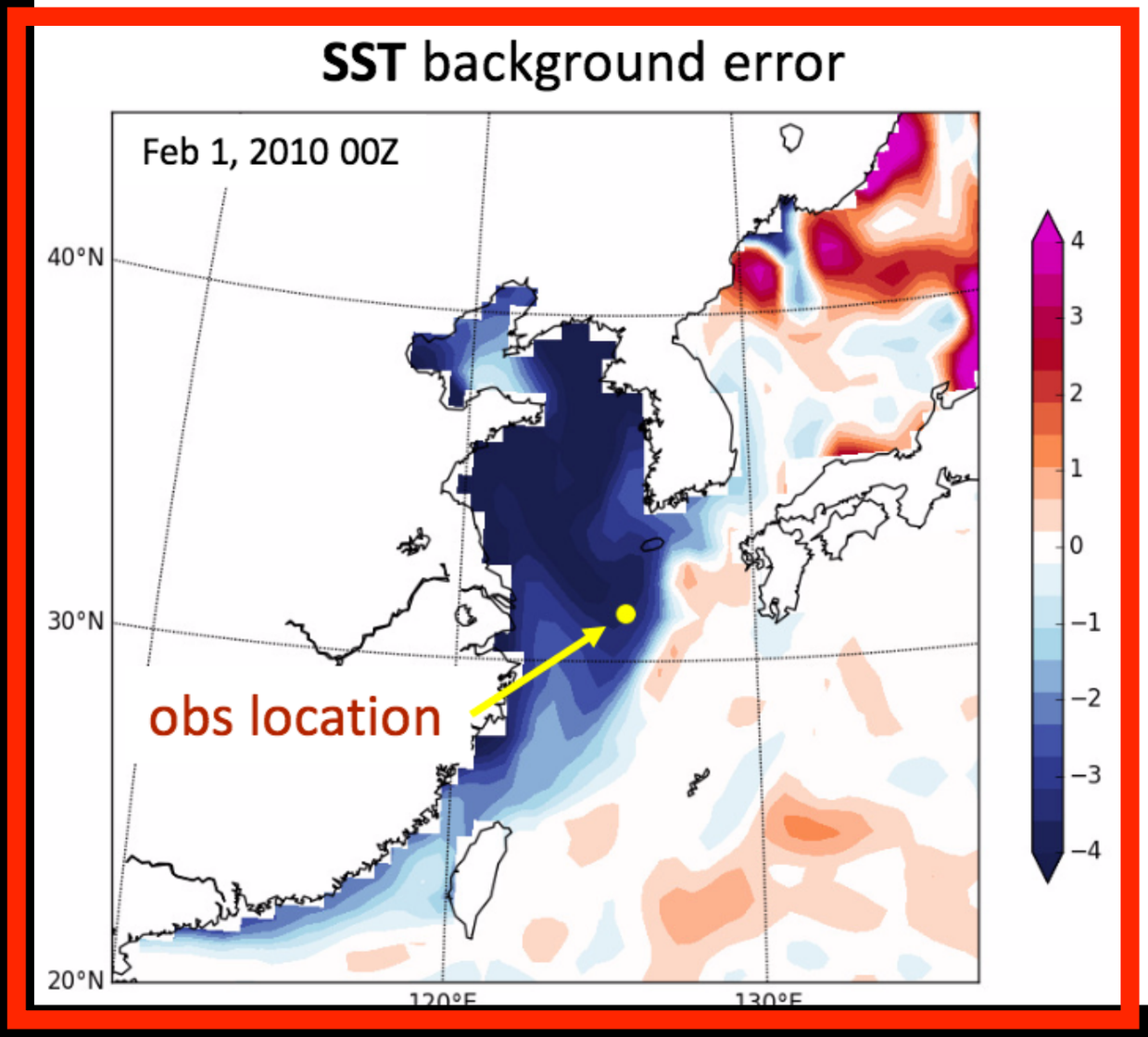
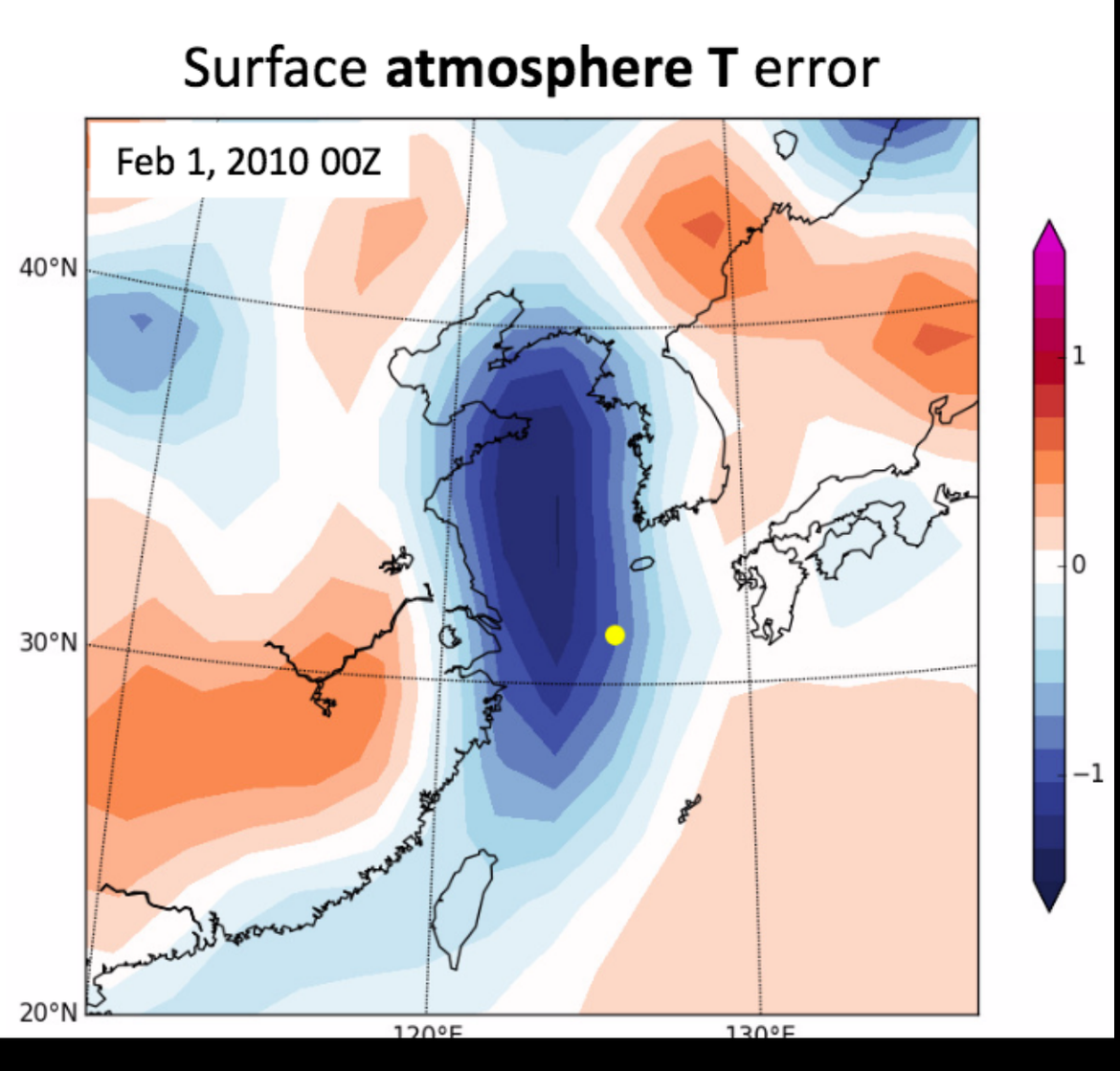
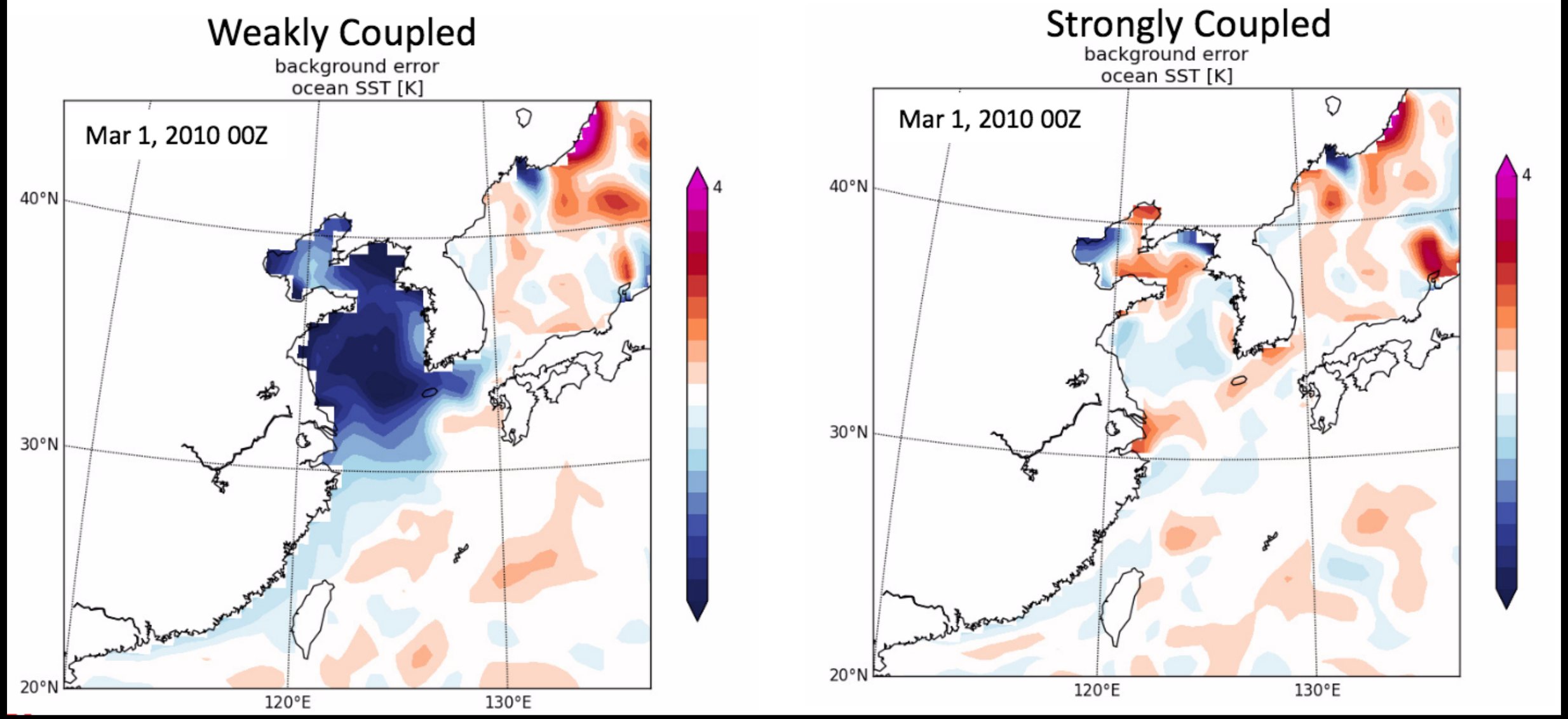




Thanks to: Travis Sluka

STRONGLY COUPLED OCEAN/ATMOS DA

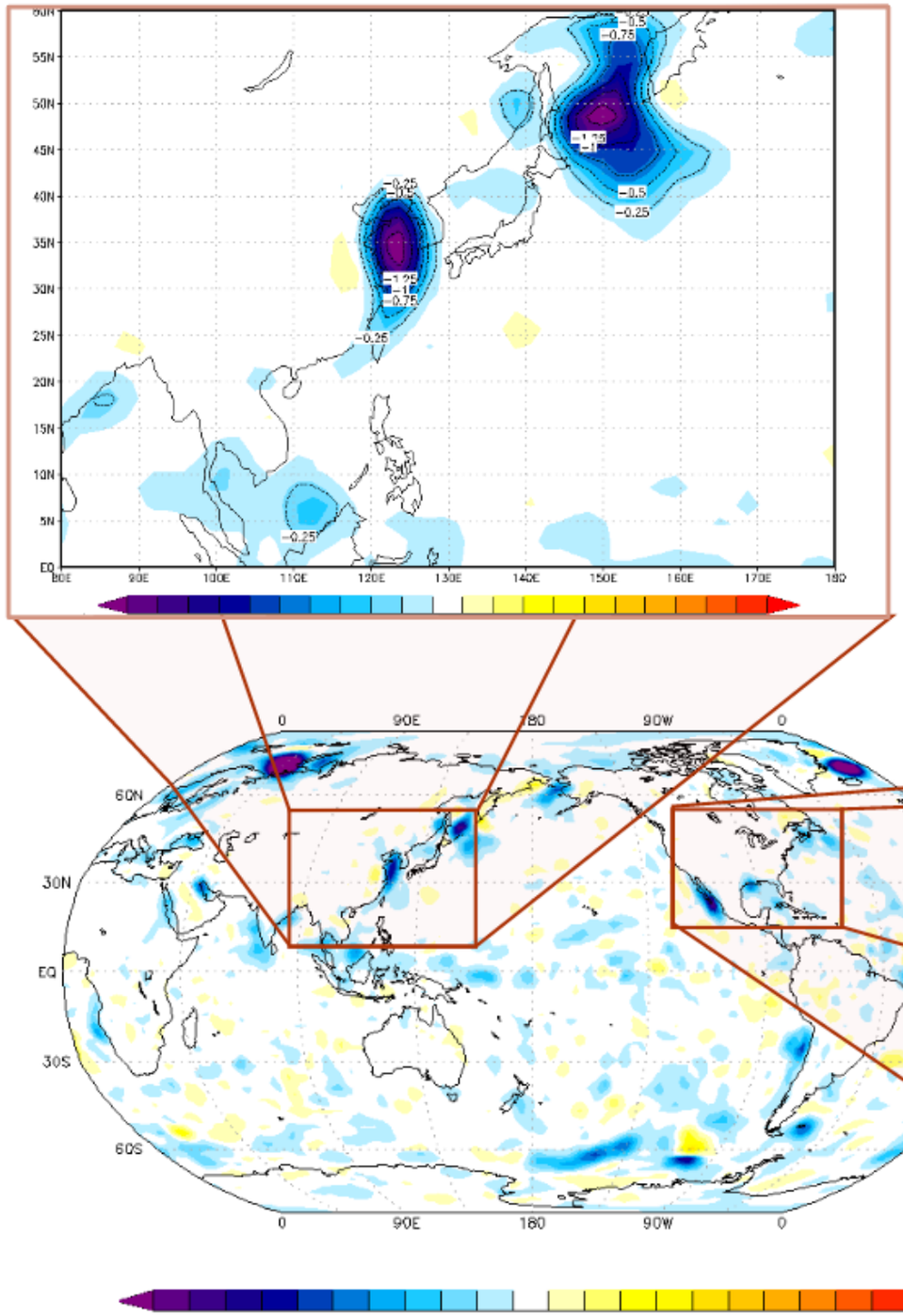
- After 1 month of **strongly coupled** DA with **all** observations, SST bias in Yellow Sea largely removed with strongly coupled DA



Thanks to: Travis Sluka

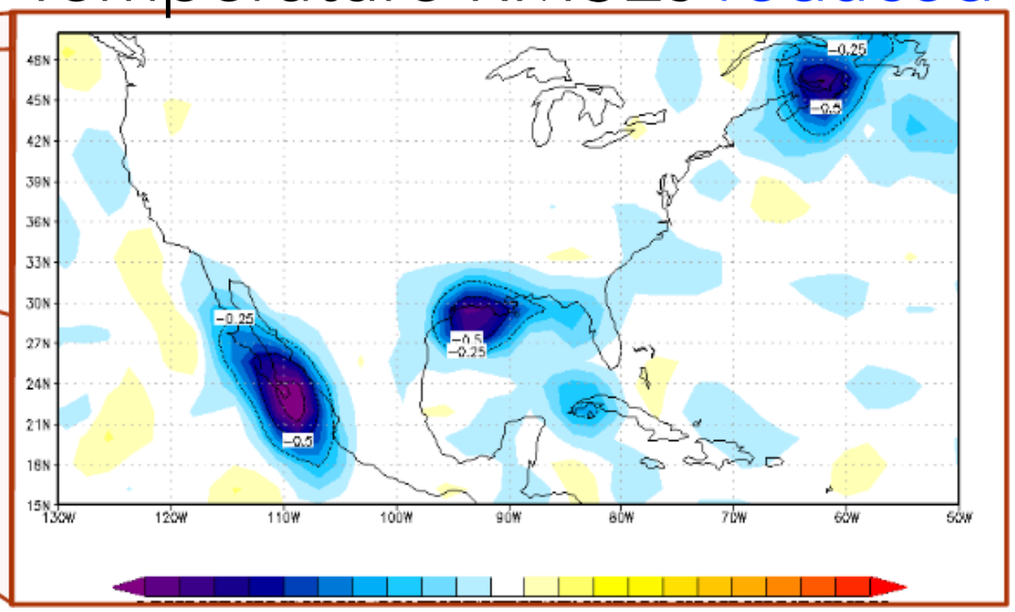
STRONGLY COUPLED OCEAN/ATMOS DA

Background RMSE difference, **BLUE** is better



- Global reduction in atmosphere RMSE, especially near coastlines where higher ocean biases were

Atmospheric Surface Temperature RMSEs reduced

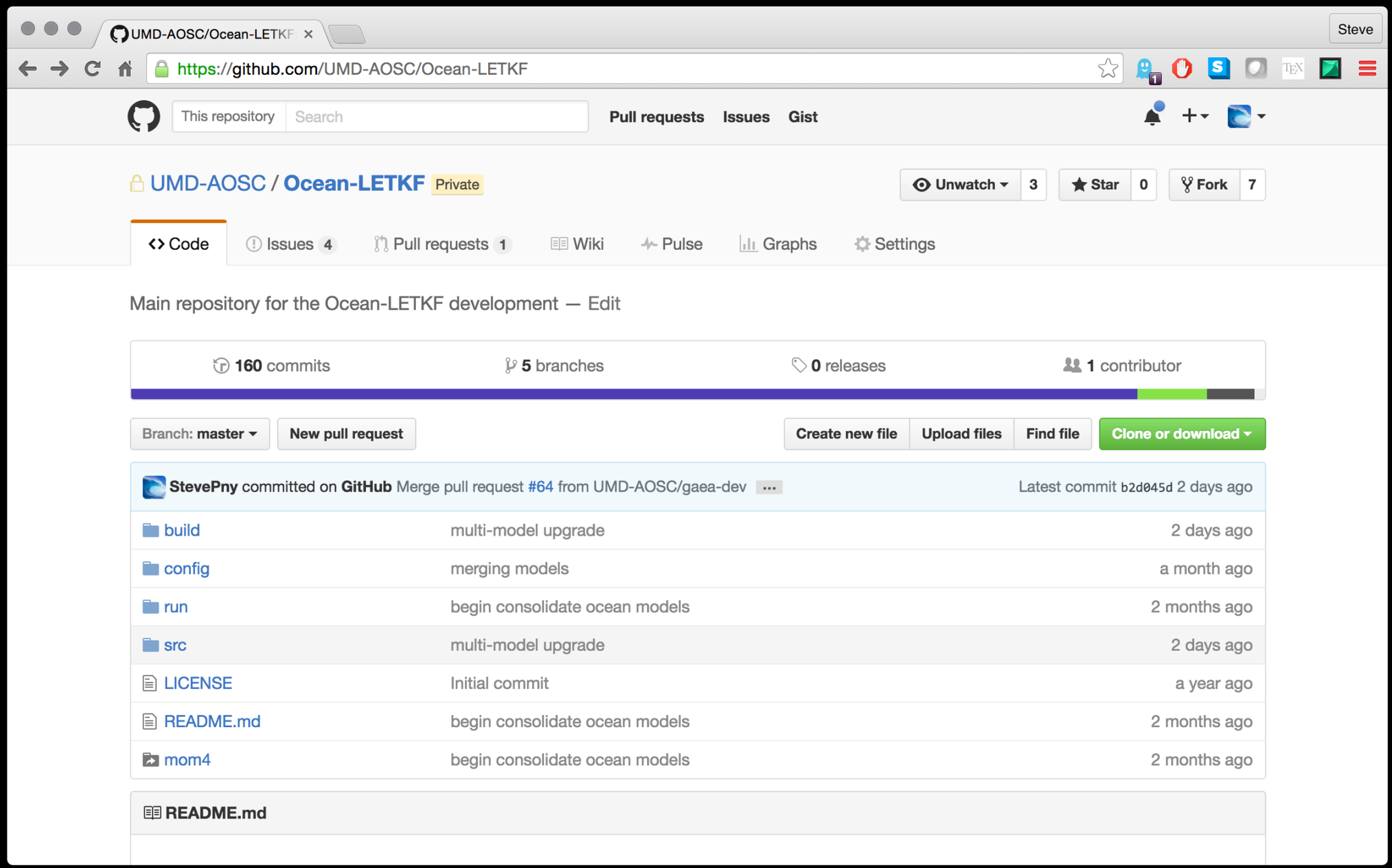


Thanks to: Travis Sluka

SOFTWARE DEVELOPMENT

- LETKF analysis cycle runtime has been reduced from 8-10 minutes to about 45 seconds on 256 cores:
  - Adopting new MPI approach developed by Lien (RIKEN)
  - Implementing 3-Dimensional kd-tree localization approach (Sluka & Penny)
  - Judicious use of ‘pure’ fortran subroutines

GITHUB PRE-PUBLIC RELEASE



Contact Steve.Penny@noaa.gov for access:
https://github.com/UMD-AOSC/Ocean-LETKF

MERGING IN GITHUB REPOSITORY

- Different versions of Ocean-LETKF (e.g. supporting mom4p1/mom5, mom6, hycom, and roms) have been merged into a single package with shared core routines

- Synchronizes development streams

- Establishes rapid transfer of both new capabilities and bug fixes to all user groups

- Allows specific user-supplied enhancements to benefit the entire user community

COLLABORATIONS

- NCEP/CPC/EMC: operational replacement to the 3DVar-GODAS
- NCEP/EMC: ocean initialization for coupled HWRF/HYCOM forecasts
- NCEP/EMC: wave model initialization for CFSv3
- NCEP/EMC: sea-ice model initialization for CFSv3

- NRL-Stennis: 1/12° Global HYCOM-based Ocean-LETKF
- NASA GMAO: MOM5 configuration of Ocean-LETKF (matching CFSR 1/2° resolution) to be use for MERRA2 Ocean reanalysis, coupled with Sea-Ice LETKF.
- INCOIS (India) and INPE (Brazil): ROMS-based Ocean-LETKF
- INCOIS nested 1/4° MOM4p1-LETKF inside global 1/2° MOM4p1-LETKF

COLLABORATIONS

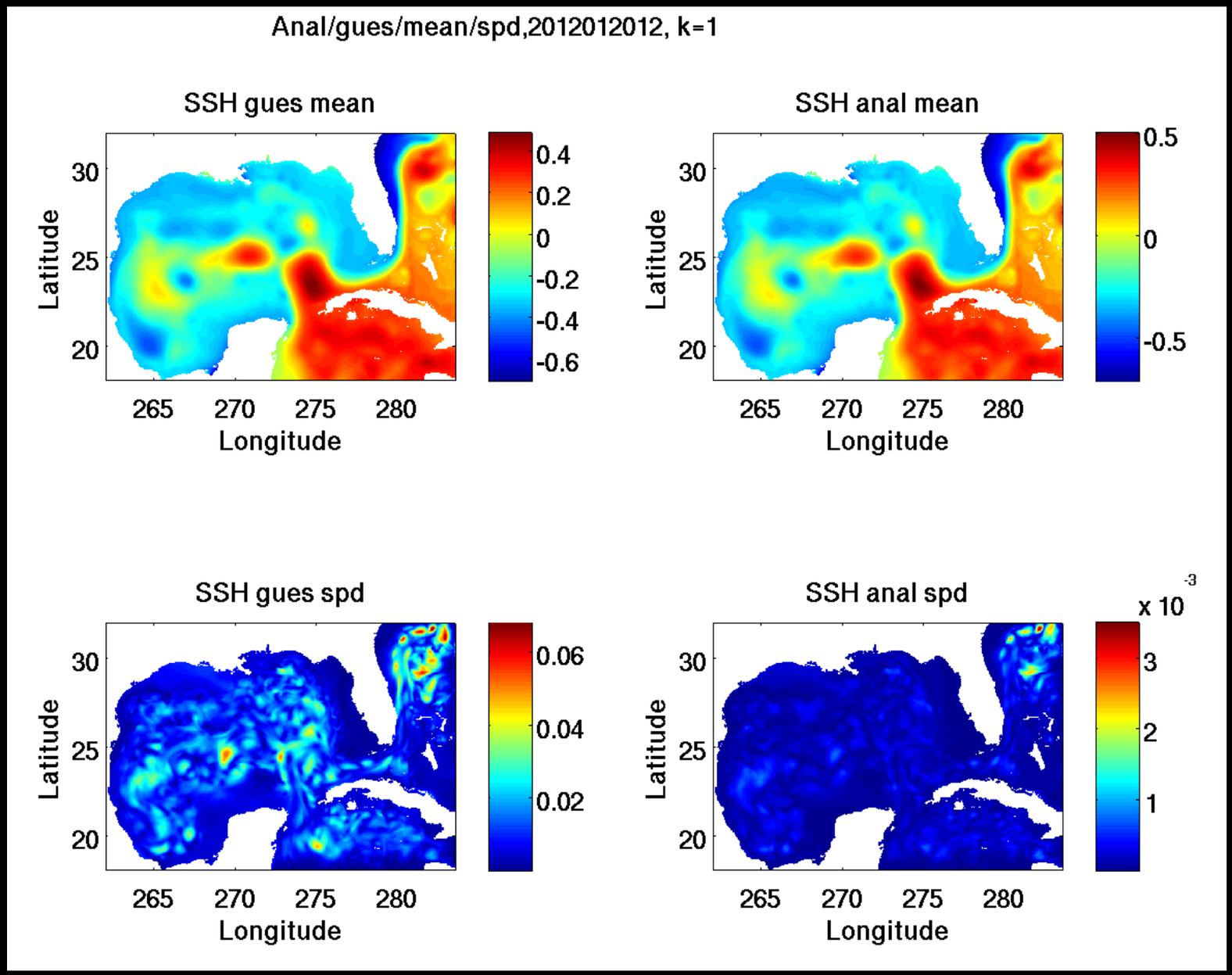
- NCEP/CPC/EMC: operational replacement to the 3DVar-GODAS — **Discussed previously**
- *NCEP/EMC: ocean initialization for coupled HWRF/HYCOM forecasts* — **Commencing**
- *NCEP/EMC: wave model initialization for CFSv3* — **Commencing**
- *NCEP/EMC: sea-ice model initialization for CFSv3* — **Commencing**

- **NRL-Stennis: 1/12° Global HYCOM-based Ocean-LETKF**
- **NASA GMAO: MOM5 configuration of Ocean-LETKF (matching CFSR 1/2° resolution) to be use for MERRA2 Ocean reanalysis, coupled with Sea-Ice LETKF.**
- **INCOIS (India) and INPE (Brazil): ROMS-based Ocean-LETKF**
- **INCOIS nested 1/4° MOM4p1-LETKF inside global 1/2° MOM4p1-LETKF**

COLLABORATION: NRL-STENNIS

- Goal: 1/12° Global HYCOM-based Ocean-LETKF

- Currently testing regional Gulf of Mexico Configuration:



Thanks to: Mozheng Wei

COLLABORATION: NASA GMAO

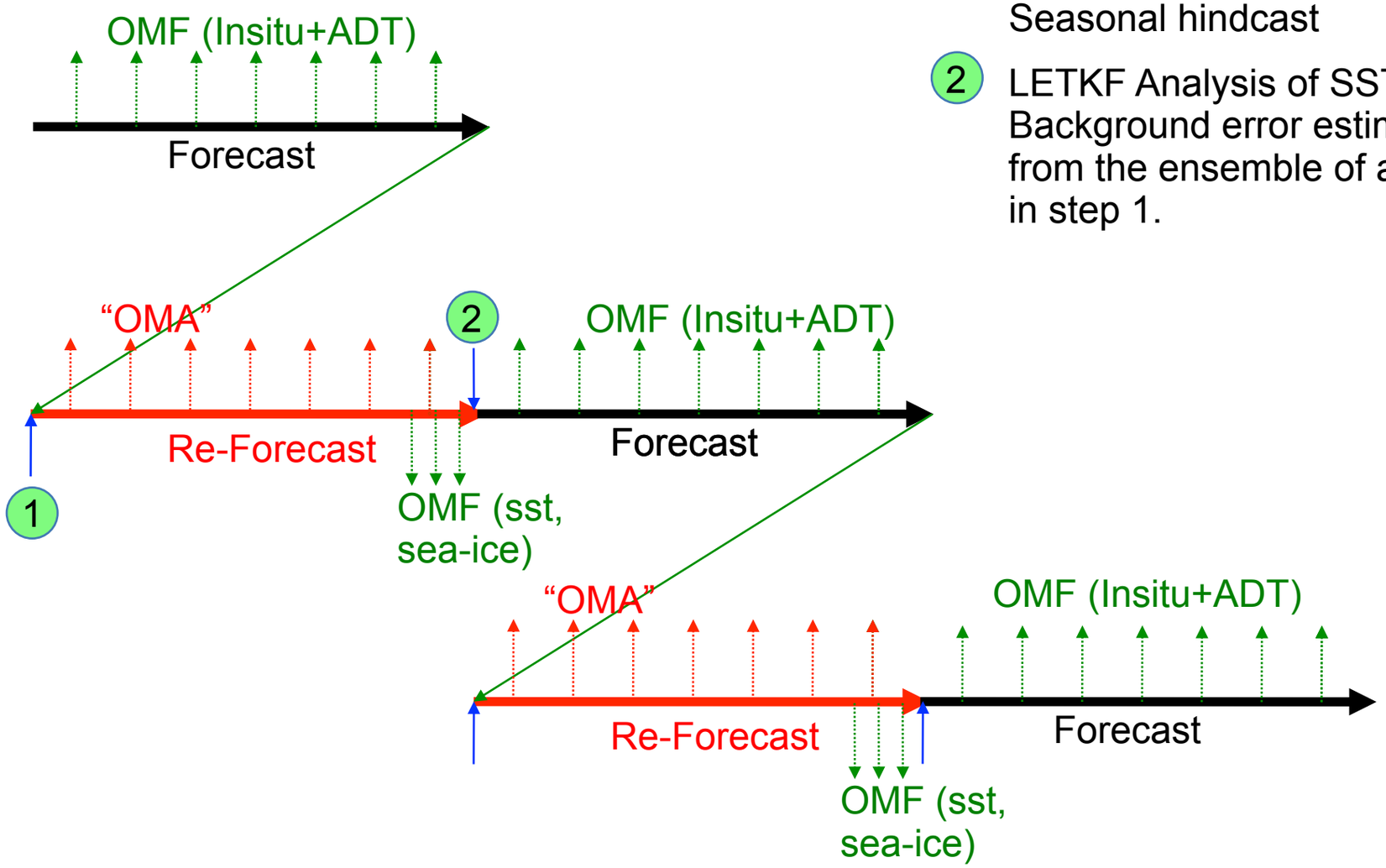
- Goal: EnOI configuration 1/2°x1/4° MOM5-based Ocean-LETKF for quasi-operational use

- Ocean Reanalysis for MERRA-2

- Sea-ice analysis with CICE

WEAKLY COUPLED OCEAN/SEA-ICE DA

Analysis setup



1. LETKF Analysis of T, S, ADT. Uses ensemble of forecast anomalies from Seasonal hindcast
2. LETKF Analysis of SST, AICE. Background error estimated from the ensemble of analysis in step 1.

Thanks to: Guillaume Vernieres

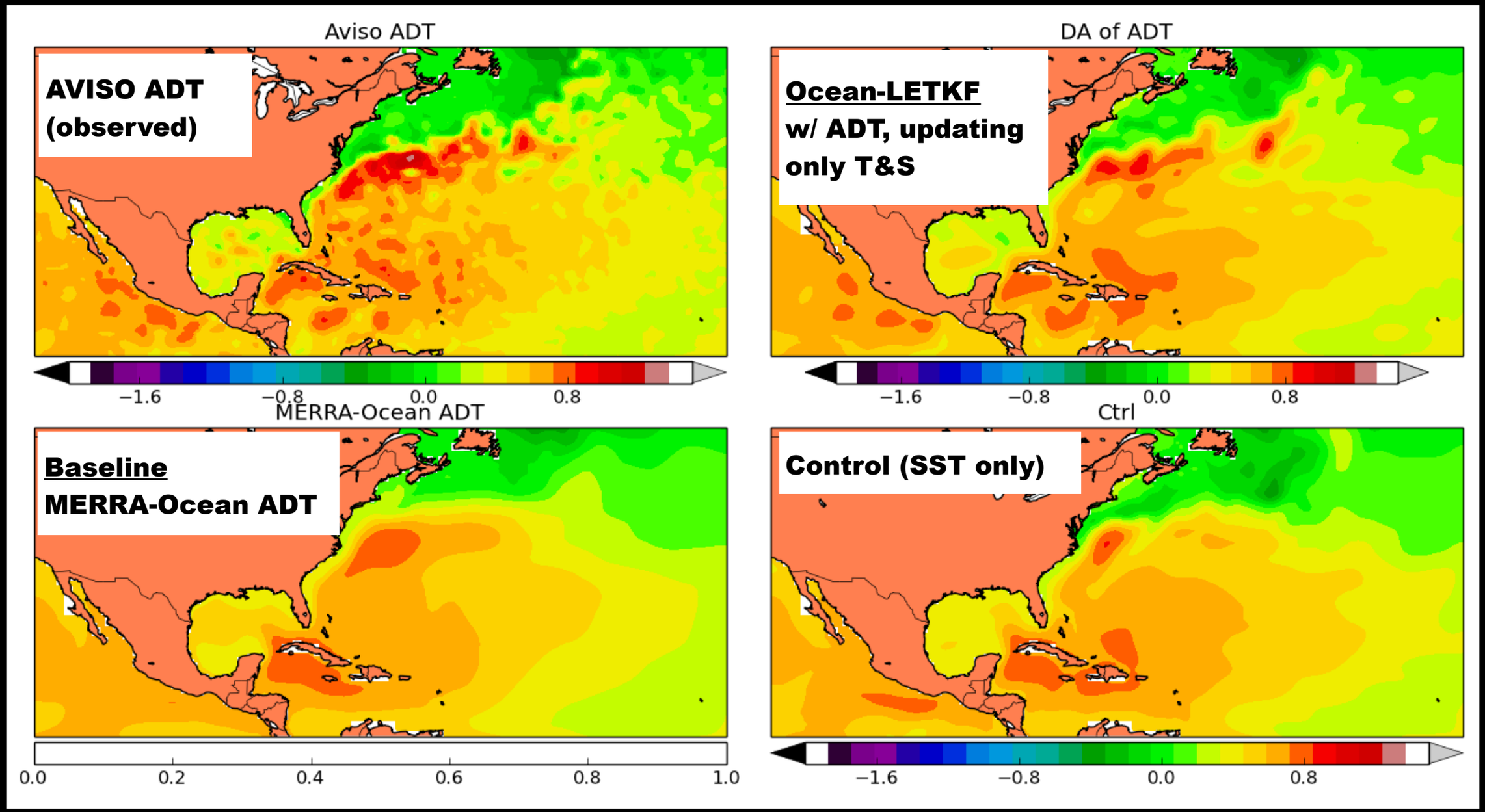
ASSIMILATION OF ADT ALTIMETRY

N. Atlantic

After 1 month
w/ daily analysis cycle

Assimilating:

Along-track Jason-2 & Cryosat2 plus gridded OSTIA SST

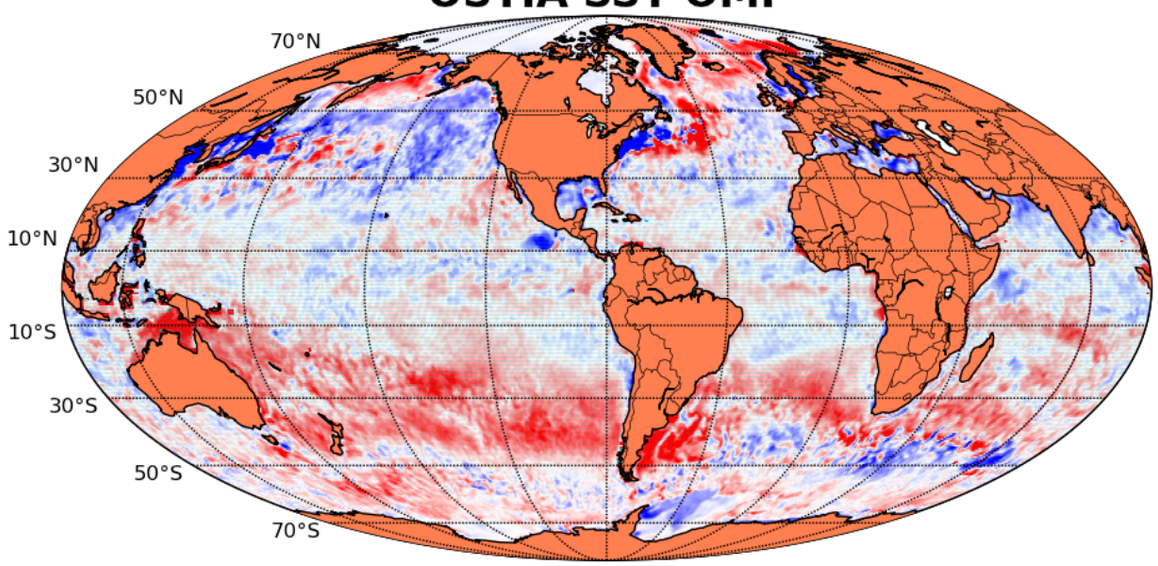


Thanks to: Guillaume Vernieres

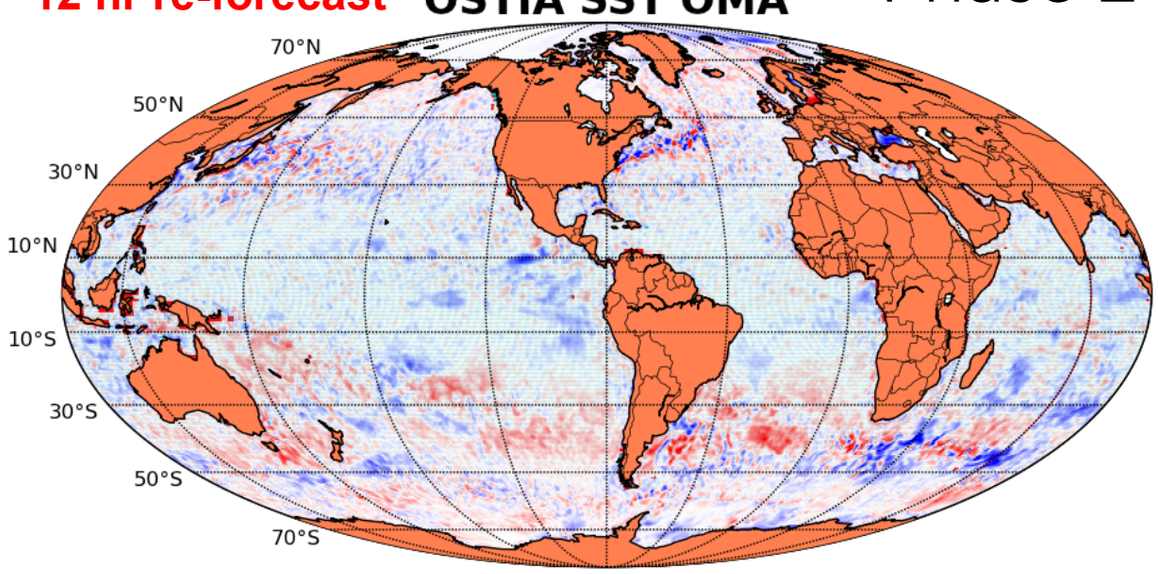
2-PHASE ASSIMILATION OF SST

Analysis Cycle 1

Phase 1

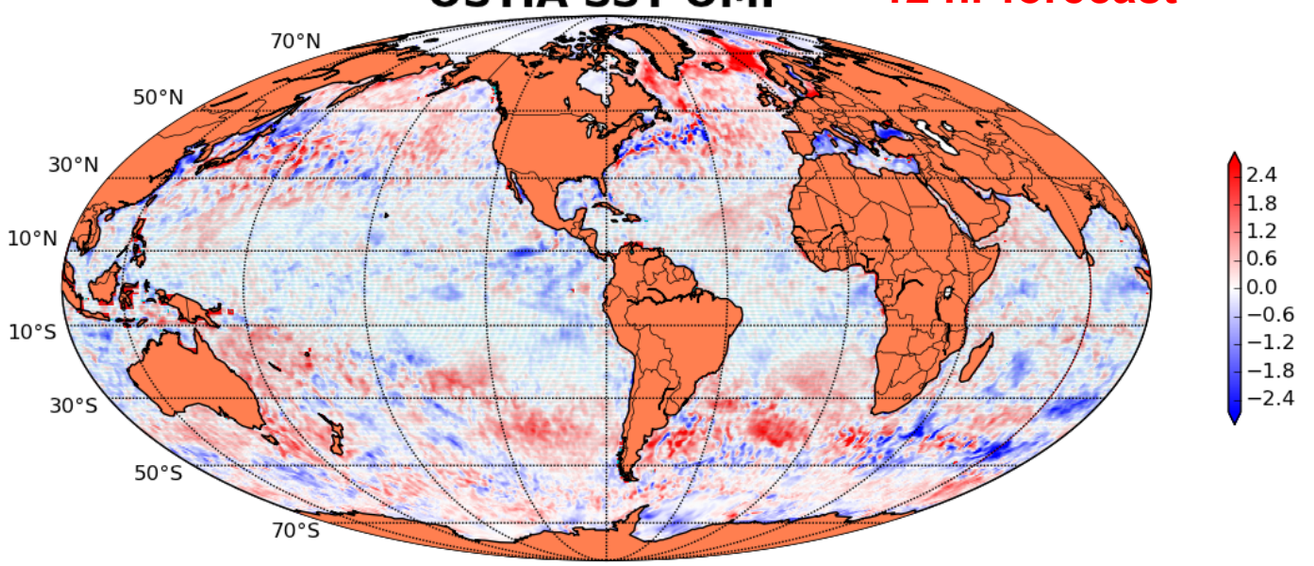


Phase 2

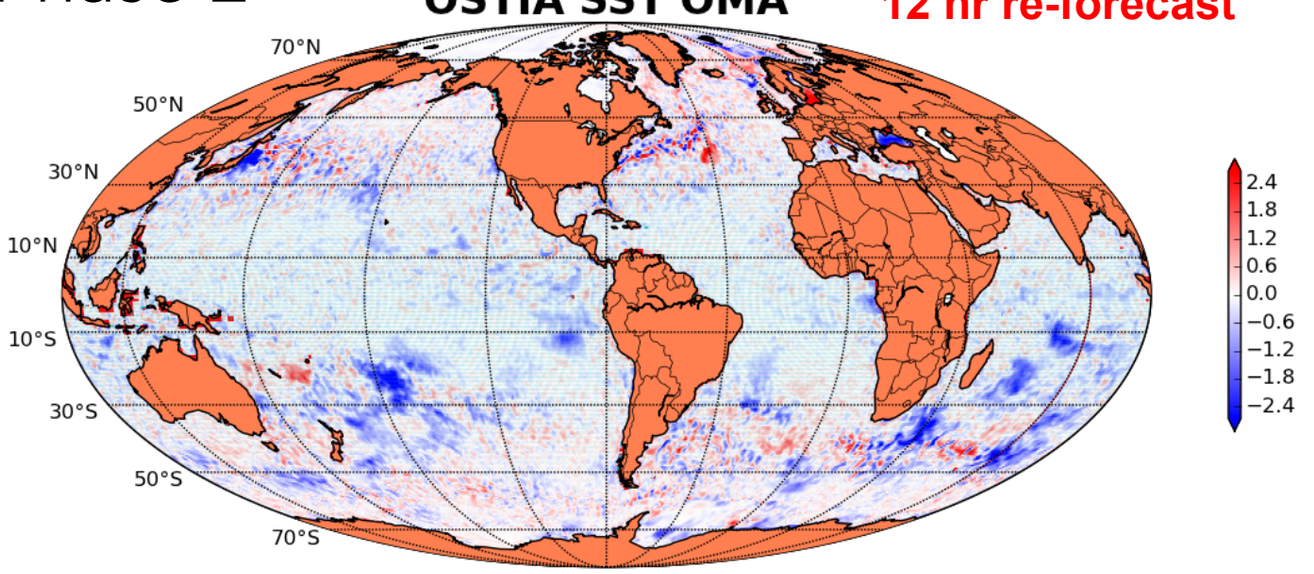


Analysis Cycle 2

Phase 1

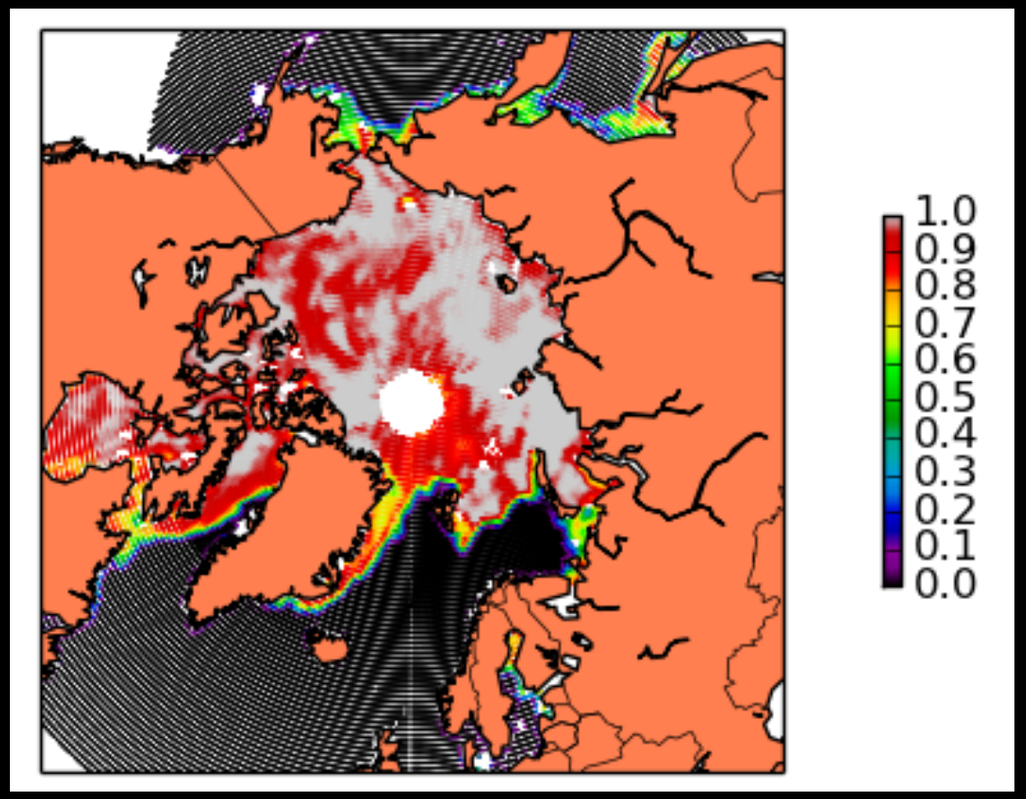


Phase 2

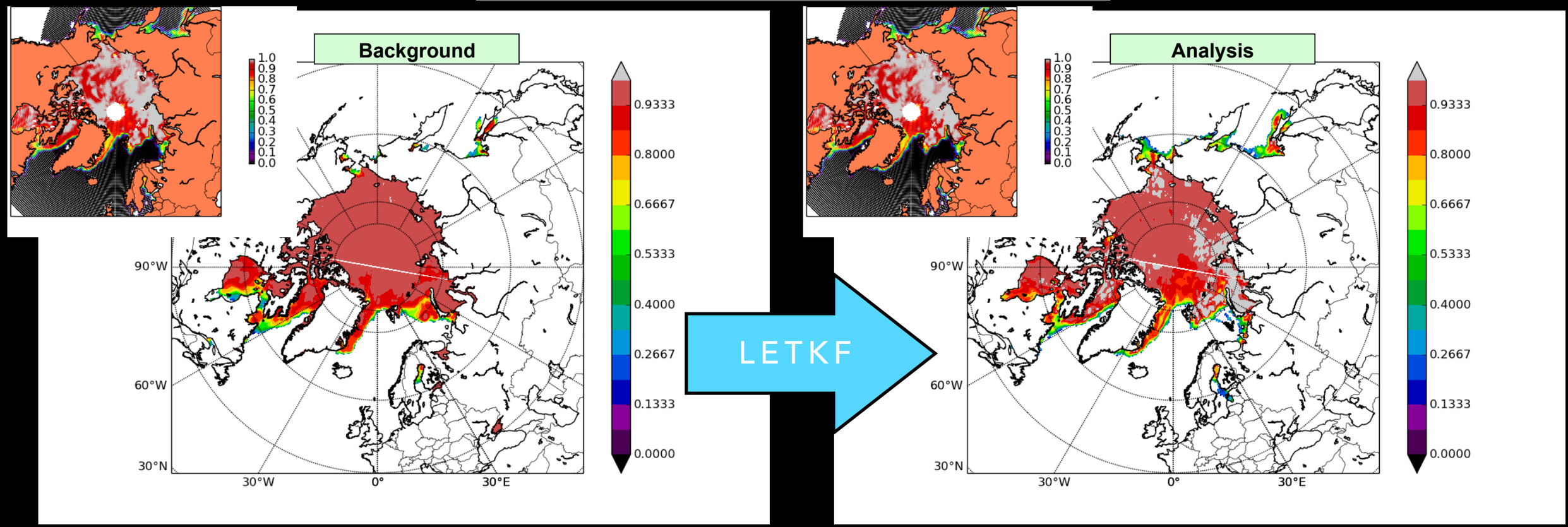


Thanks to: Guillaume Vernieres

SEA-ICE LETKF DA: ARCTIC

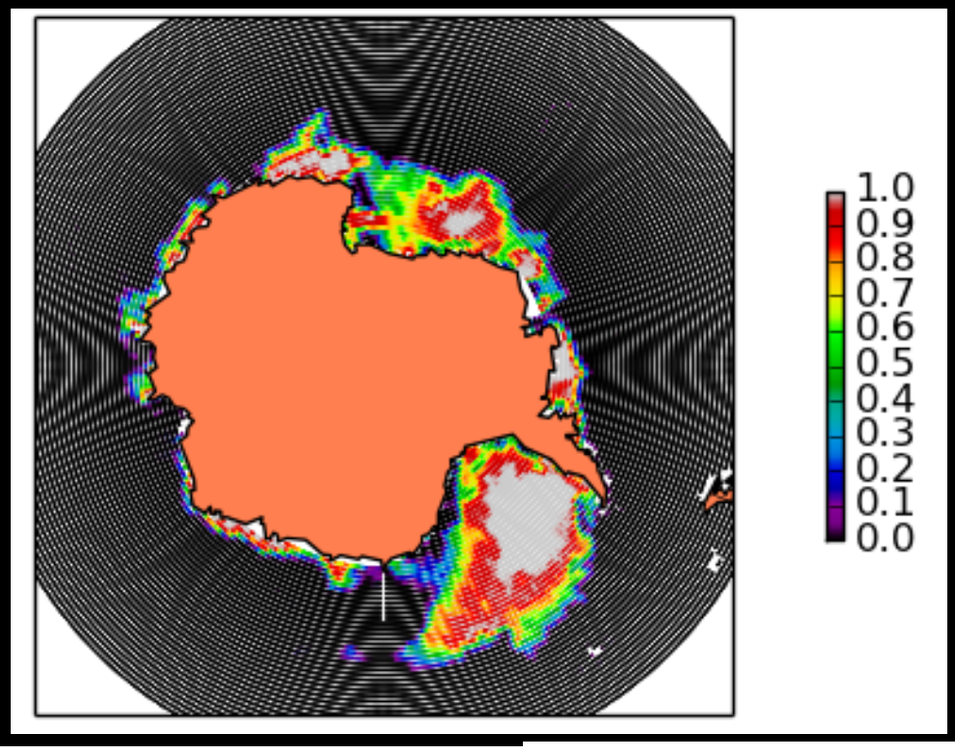


Observed Sea-ice concentration (NSIDC)

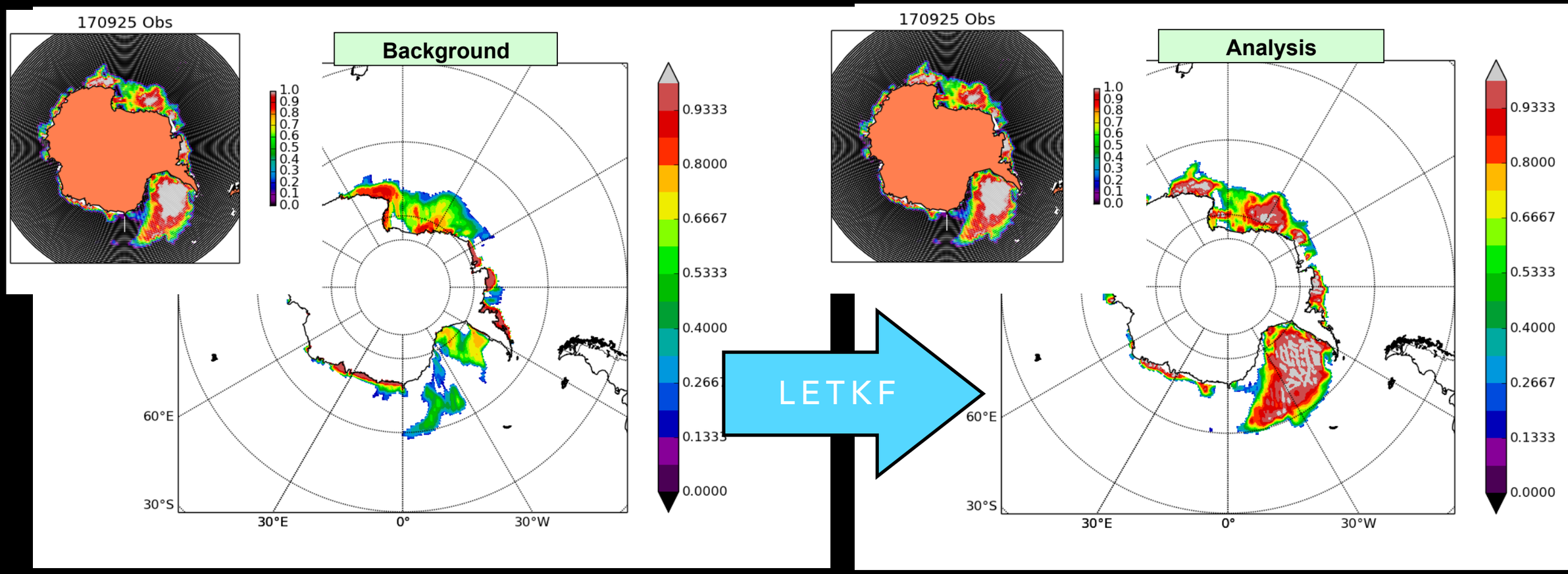


Thanks to: Guillaume Vernieres

SEA-ICE LETKF DA: ANTARCTIC



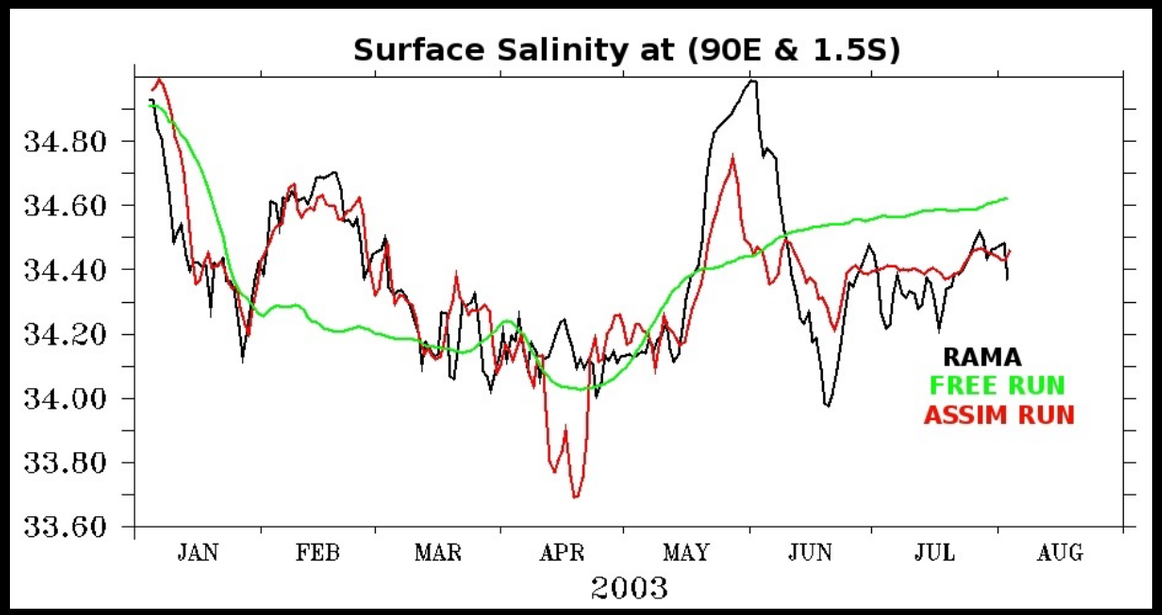
Observed Sea-ice concentration (NSIDC)

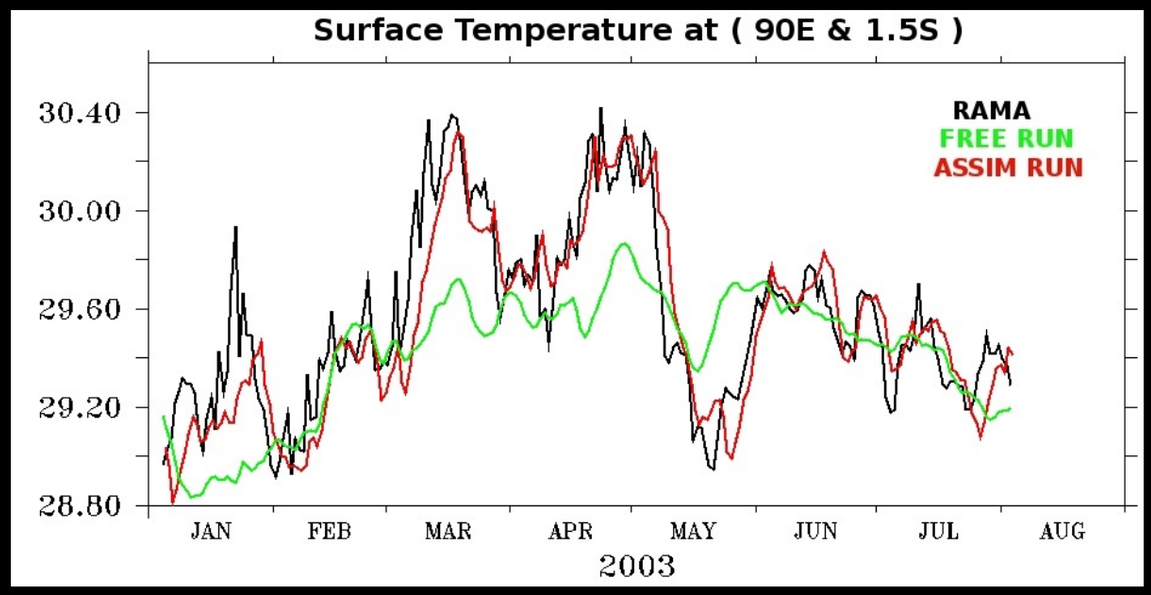


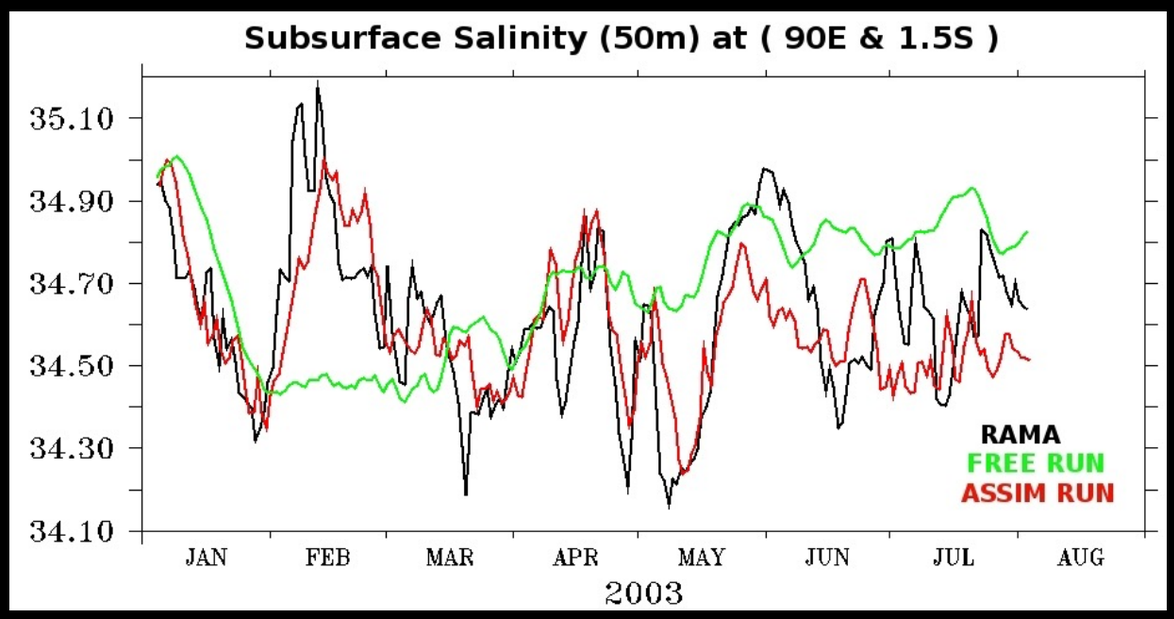
Thanks to: Guillaume Vernieres

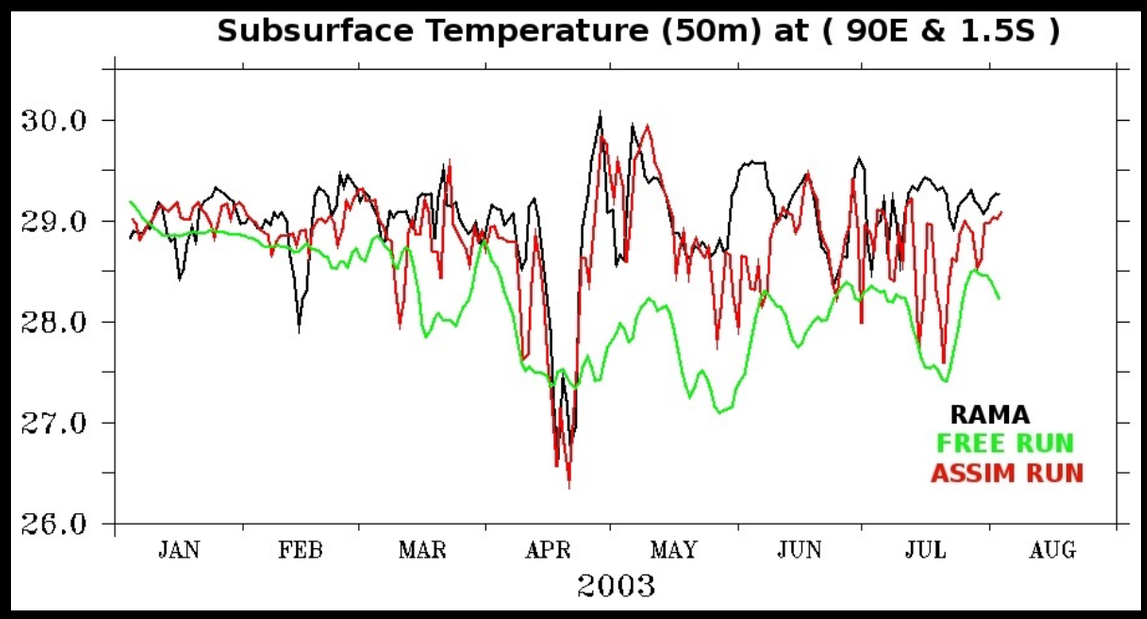
COLLABORATION: INCOIS

- 1/4° Regional Indian Ocean Configuration (ROMS)
- Example results for 2003 at (90E, 1.5S):





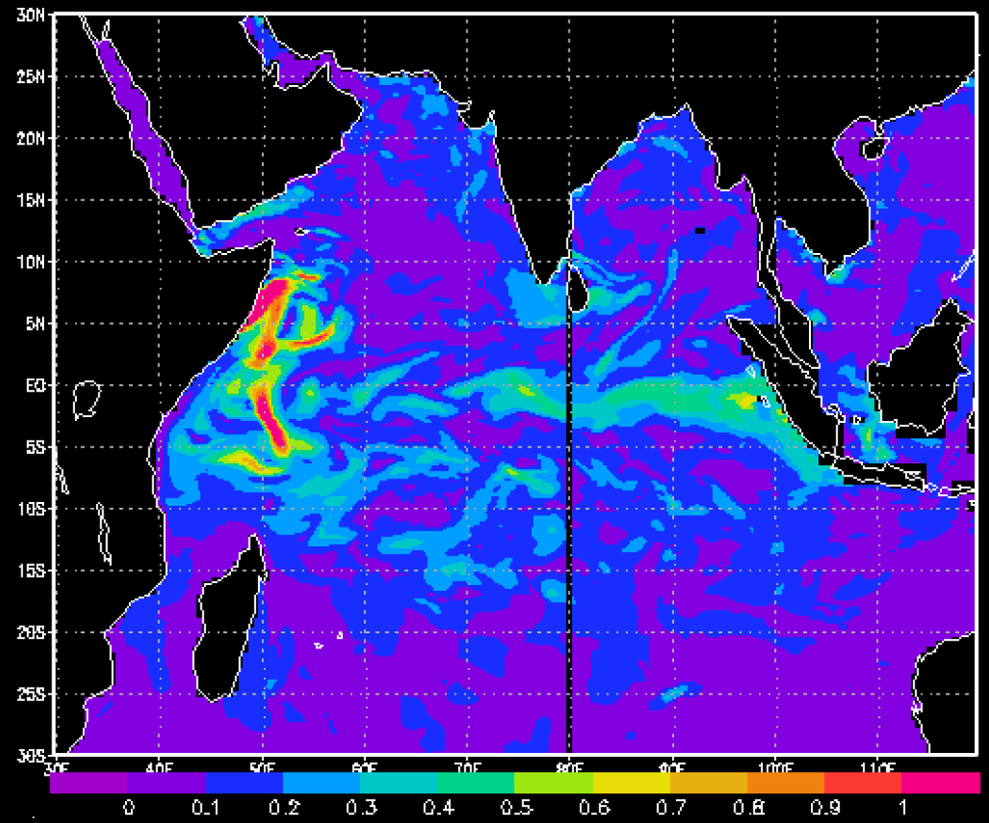




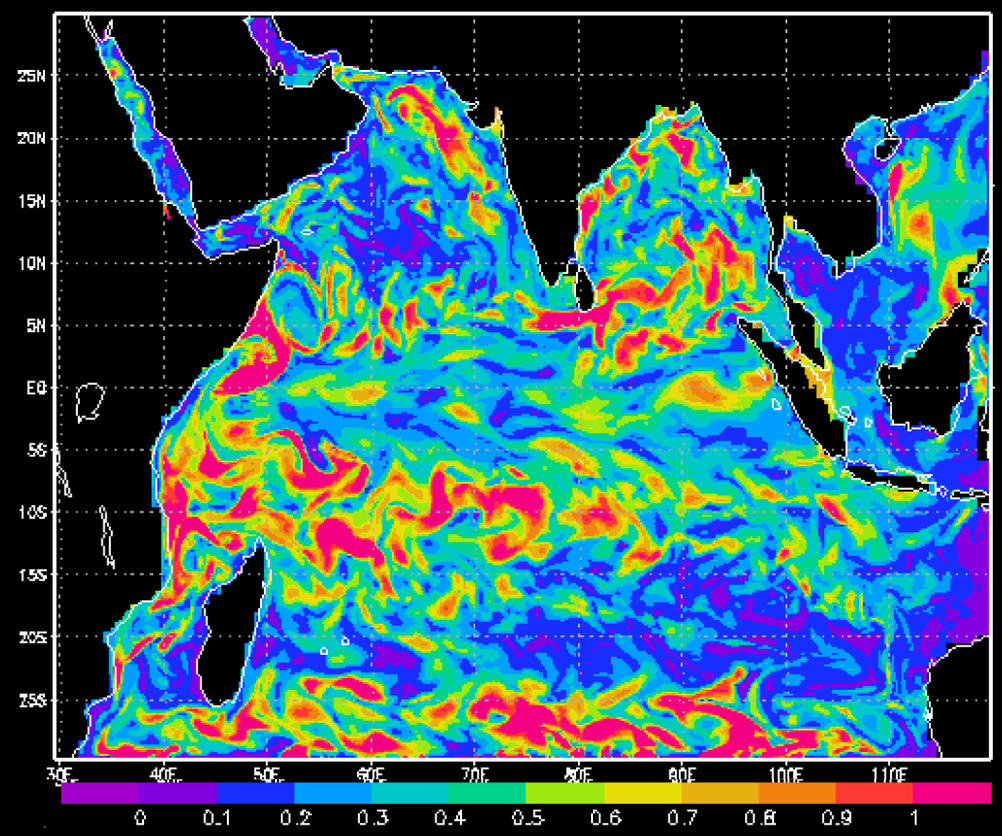
Thanks to: Arya Paul and Siva Reddy

COLLABORATION: INCOIS

- 1/4° Nested MOM4p1 inside global CFSR resolution (1/2°)



1/2°x1/2° with refinement to 1/4° latitude at the equator (CFS GODAS resolution)

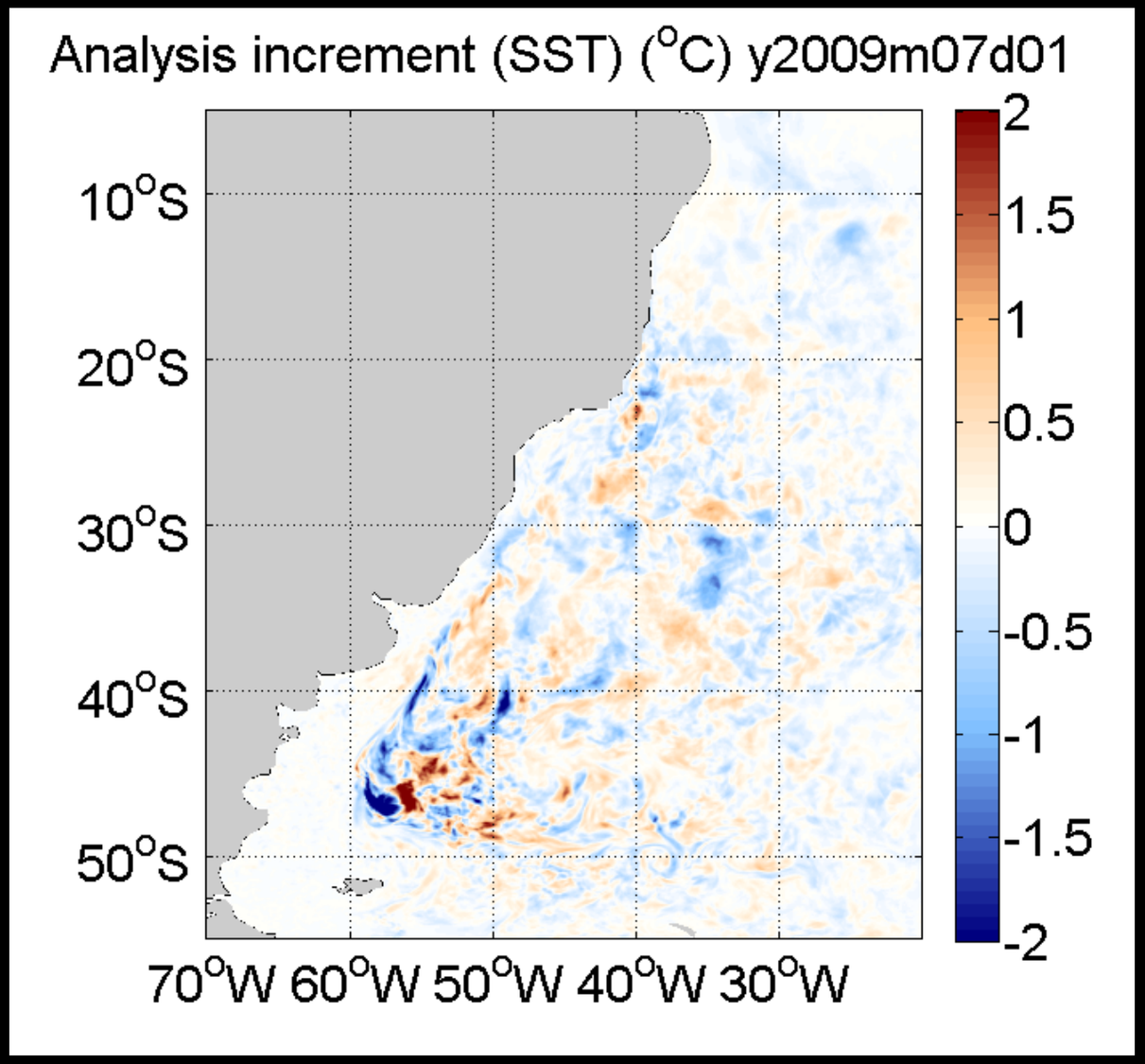


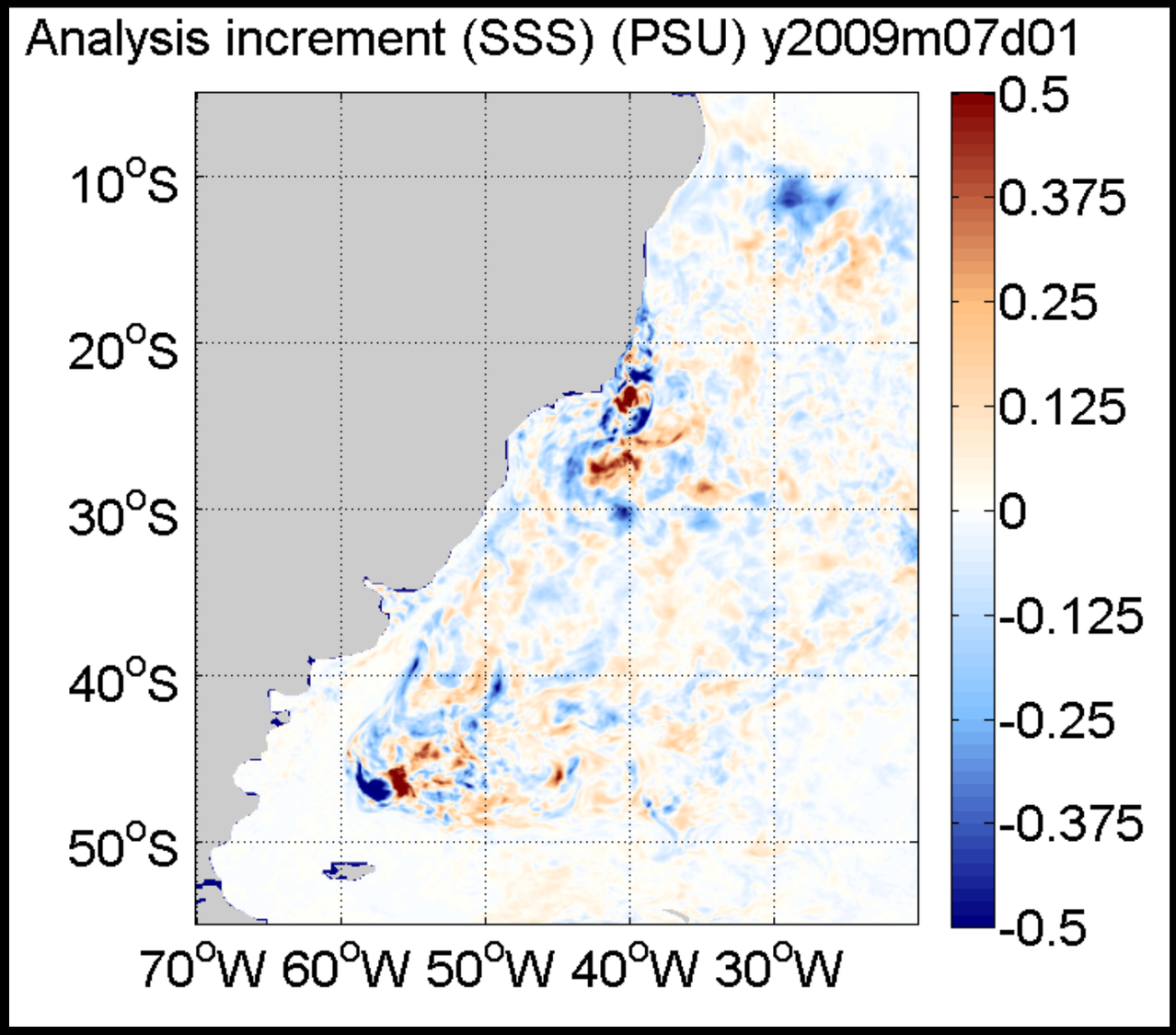
1/4°x1/4° with increased vertical resolution near the surface

Thanks to: Hasibur Rahaman

COLLABORATION: INPE

- Goal: Southwestern Atlantic Regional 1/12° ROMS-based Ocean-LETKF
- Study sources of uncertainty in ensemble ocean DA





Thanks to: Leonardo Lima

INVESTIGATION OF SOURCES OF UNCERTAINTY IN ENSEMBLE OCEAN DA

(After **1 month** of model integration)

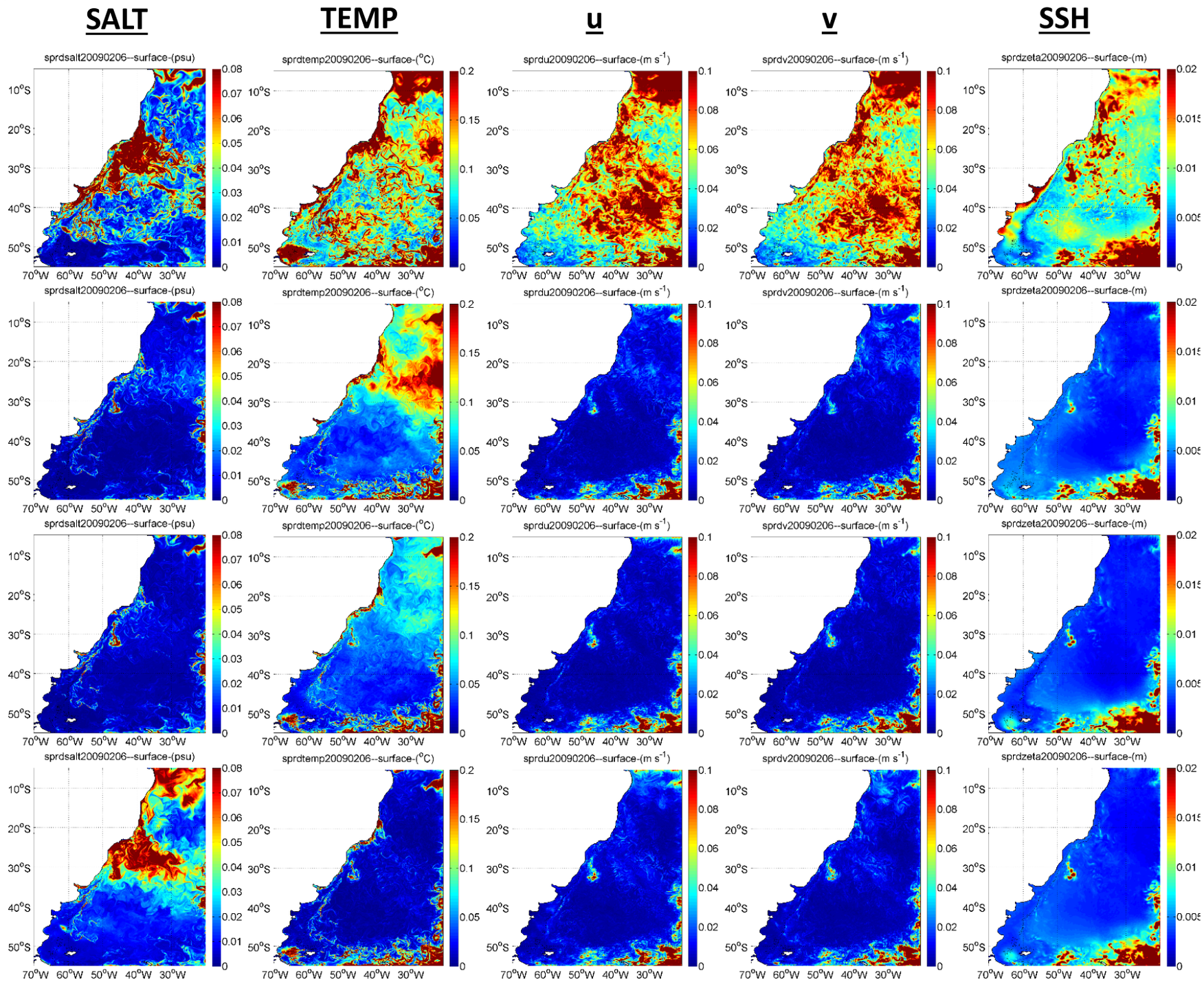
Spread on ocean surface – 06/Feb/2009

u and v Wind

Rad Fluxes (Short and Longwave)

Specific Humidity

Rain



Thanks to: Leonardo Lima

INVESTIGATION OF SOURCES OF UNCERTAINTY IN ENSEMBLE OCEAN DA

(After **10 months** of model integration)

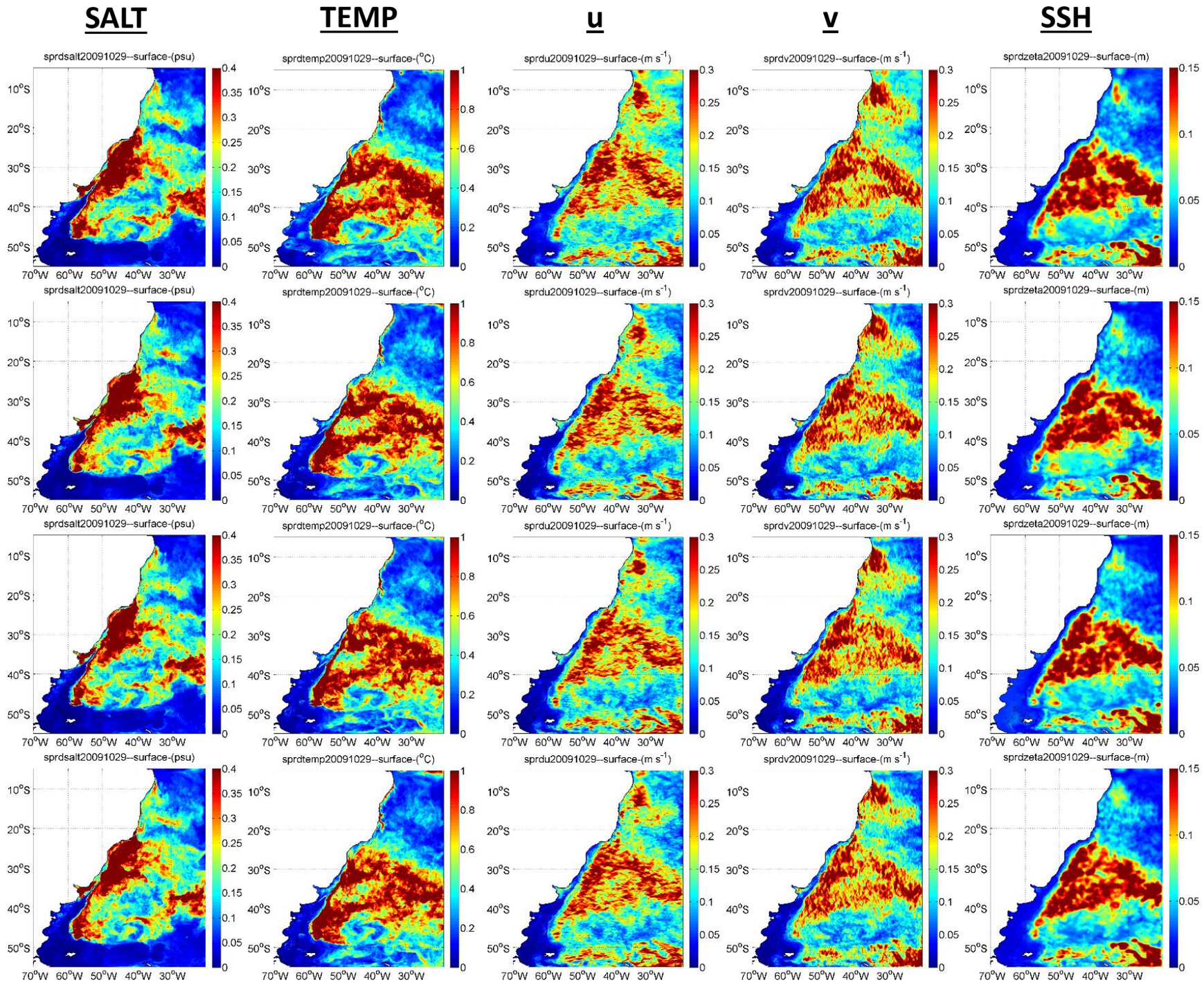
Spread on ocean surface – 29/10/2009

u and v Wind

Rad Fluxes (Short and Longwave)

Specific Humidity

Rain



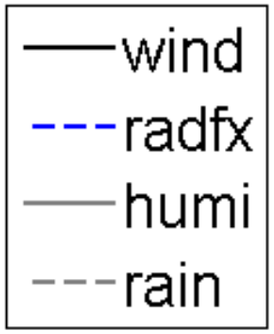
Thanks to: Leonardo Lima

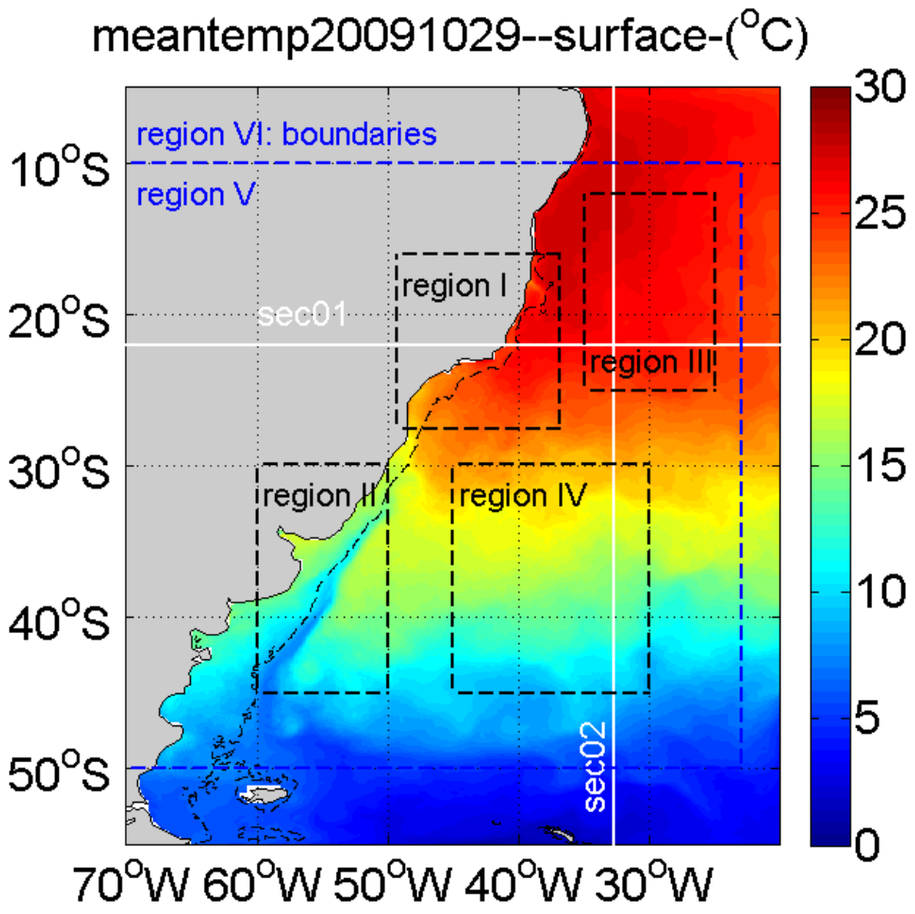
ERROR SATURATION: FORCING VS. DYNAMICS

2-Dimensional Spread average

curves indicate each experiment

Source of surface forcing uncertainty:



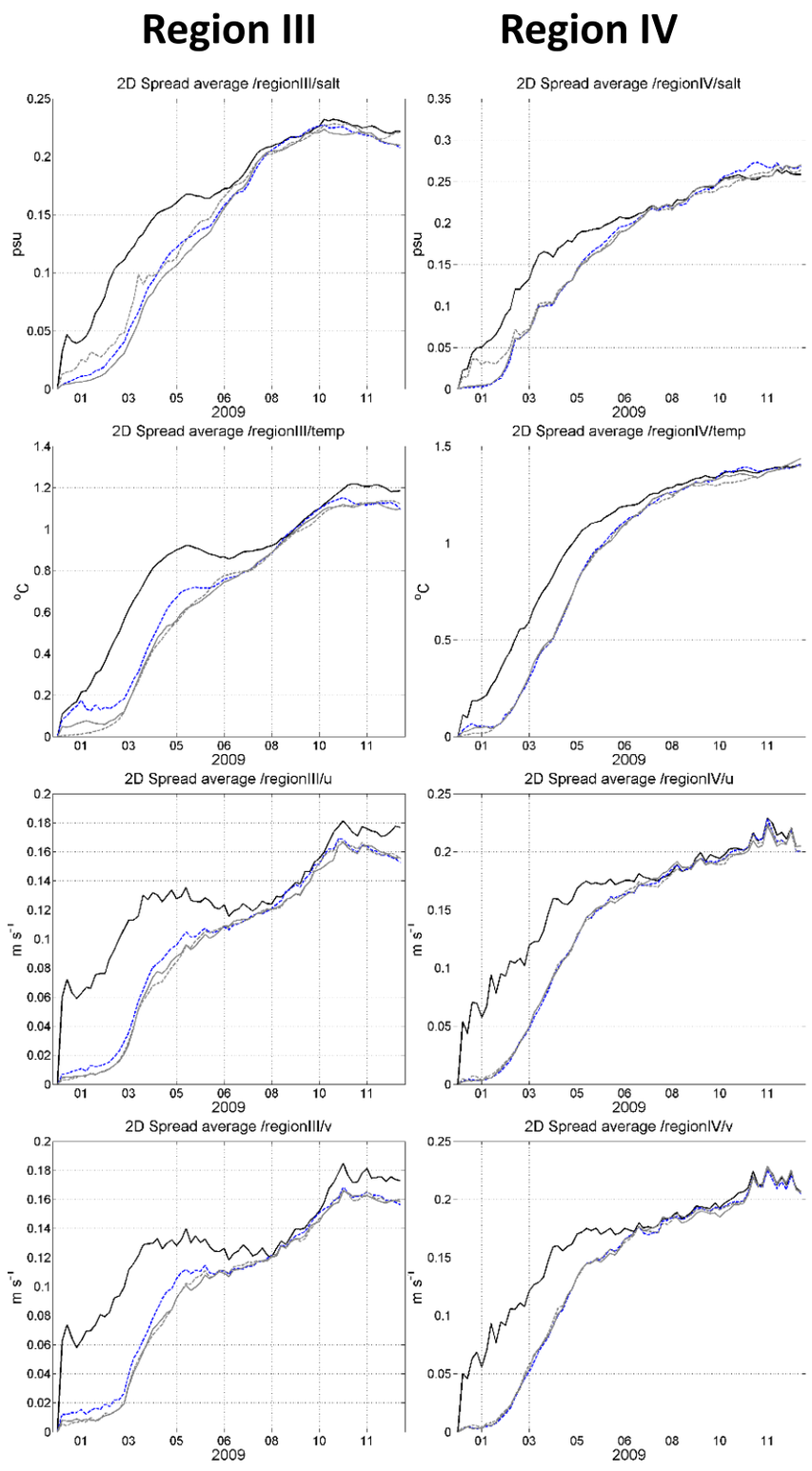


SALT

TEMP

u

v



Thanks to: Leonardo Lima

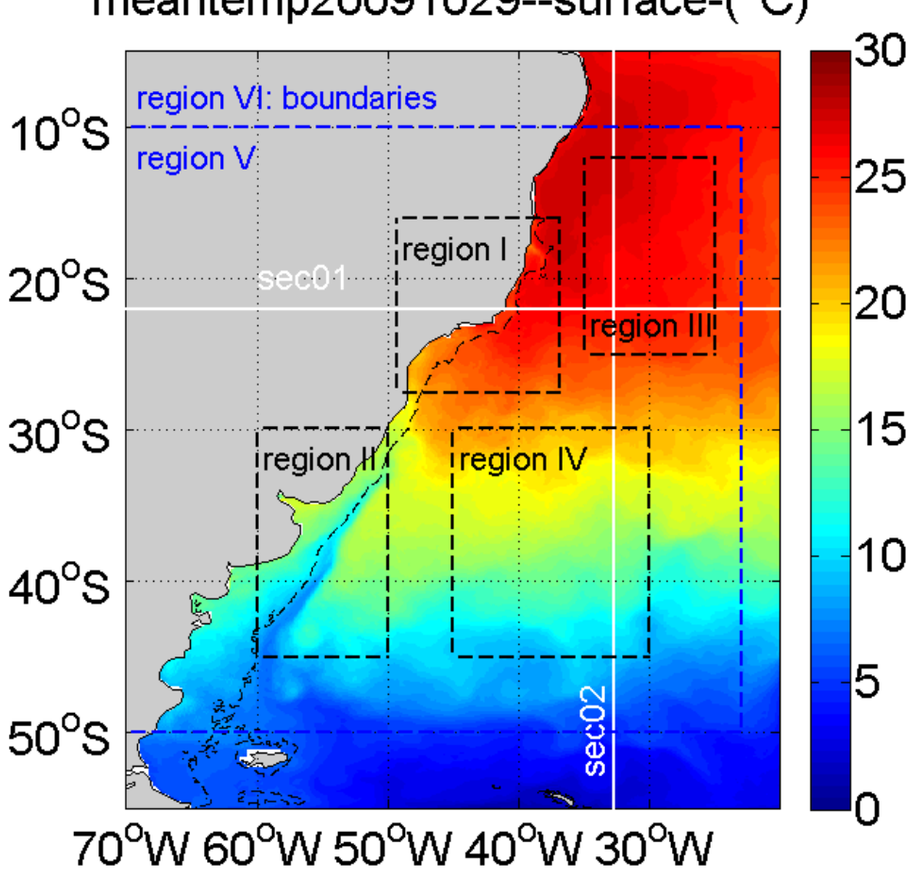
ERROR SATURATION: FORCING VS. DYNAMICS

2-Dimensional Spread average

curves indicate each experiment

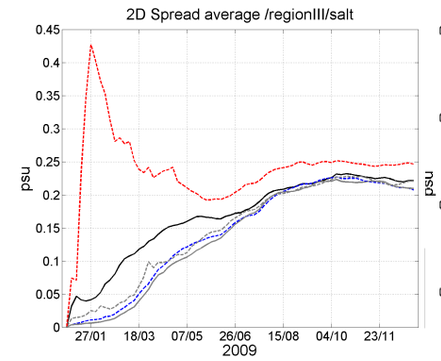
Source of surface forcing uncertainty:

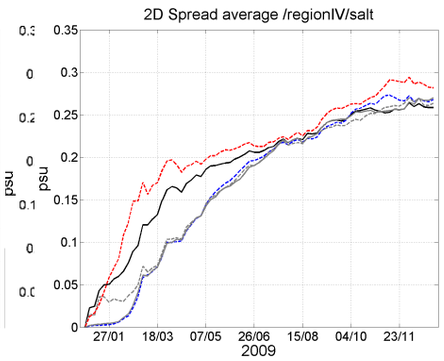
wind
radfx
humi
rain
bathy



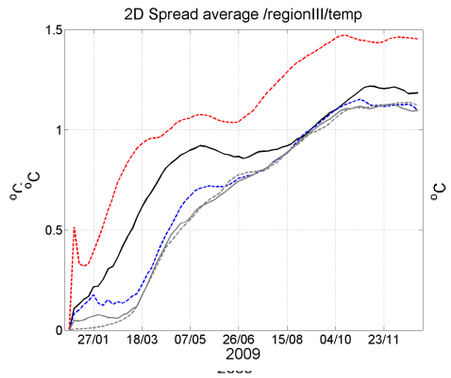
Region III **Region IV**

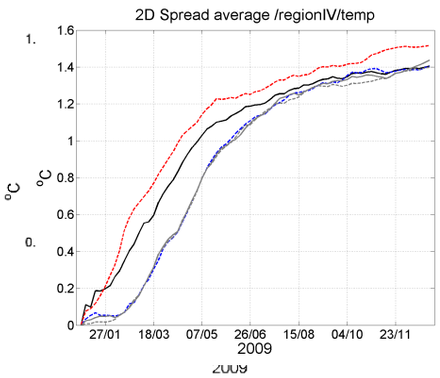
SALT



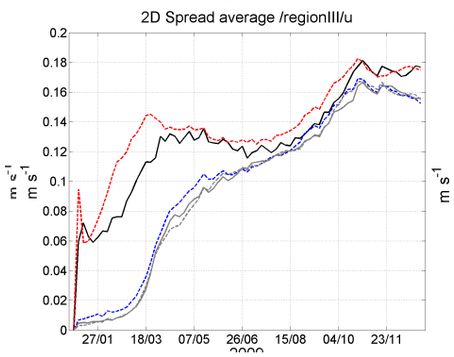


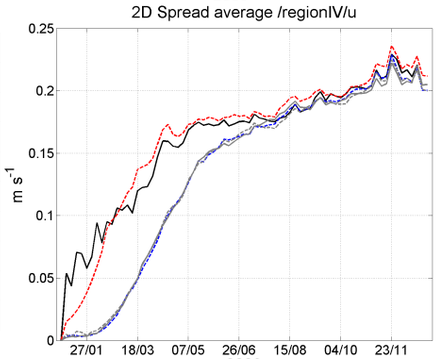
TEMP



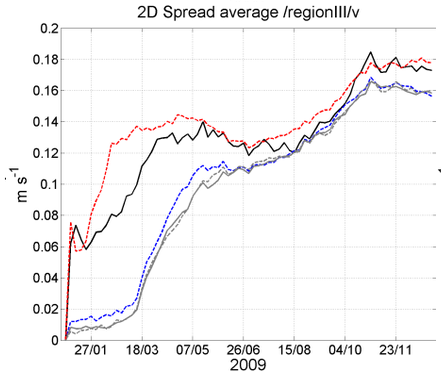


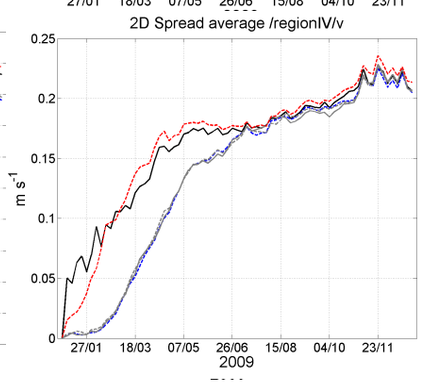
u





v





Thanks to: Leonardo Lima

NEXT PHASE

- Test upgrade to 1/4° MOM6 with a series of validation experiments
- Estimate observation errors using EFSO/EFSR or automated estimation of observation errors
- Continue to collaborate with external projects:
  - NCEP operational implementation and reanalysis effort with MOM6 at 1/4° to replace the operational GODAS (MOM3 at 1°)
  - Coupled HYCOM/HWRF ocean initialization at EMC
  - GMAO implementation of Ocean-LETKF w/ MOM5
  - NRL-Stennis implementation of Ocean-LETKF with global 1/12° HYCOM
- Upcoming International Workshop on Coupled Data Assimilation (Oct. 18-21, 2016): http://www.meteo.fr/cic/meetings/2016/CDAW2016/