PROF. STEPHEN G. PENNY (UMD/NCEP)
10TH OOMD COMMUNITY WORKSHOP
NOAA SCIENCE CENTER, SILVER SPRING, MD, MAY 10, 2017

UPCOMING ADVANCEMENTS IN OCEAN DATA ASSIMILATION AT NCEP

OCEAN DA COLLABORATIONS:

- NCEP/CPC/EMC: operational replacement from the MOM3 3DVar-GODAS to MOM6 Hybrid-GODAS (Sluka, Xue, Behringer)
- NCEP/EMC: ocean initialization for coupled HWRF/HYCOM forecasts (Dong, Mehra)
- NCEP/EMC: wave model initialization for CFSv3 (Flampouris)
- NCEP/EMC: sea-ice model initialization for CFSv3 (Wu, Vernieres, Grumbine, Saha)
- NRL-Stennis: 1/12° Global HYCOM-based Ocean-LETKF (Wei)
- NASA GMAO: MOM5 configuration of Ocean-LETKF (matching CFSR 1/2° resolution) to be use for MERRA2 Ocean reanalysis, coupled with Sea-Ice LETKF. (Vernieres)
- INCOIS (India; Paul, Reddy), and INPE (Brazil): ROMS-based Ocean-LETKF (Lima)
- INCOIS nested 1/4° MOM4p1-LETKF inside global 1/2° MOM4p1-LETKF (Rahaman)

SUMMARY

- Brief DA overview
- Advancements at NCEP
- Future trends in ocean DA
- Needs from Ocean Observing System development to support DA

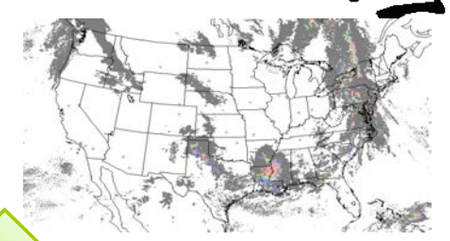
BRIEF DA OVERVIEW

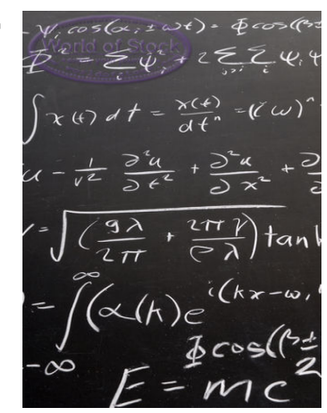
What is Data Assimilation?

Physical Atmosphere or Ocean

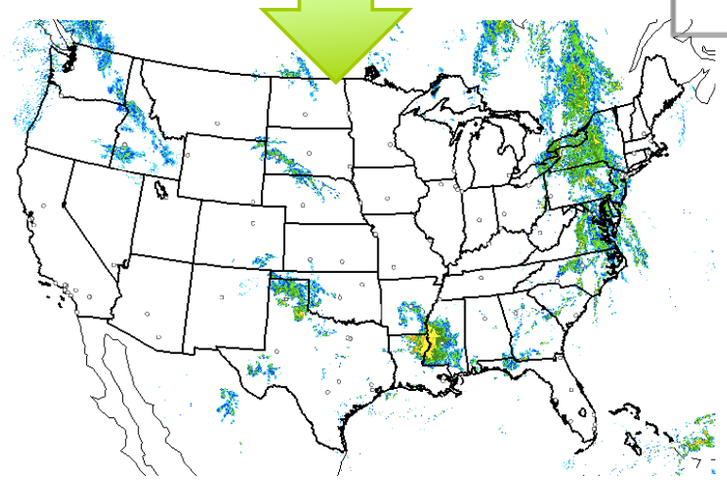
Observations

Data Assimilation





Computational Model



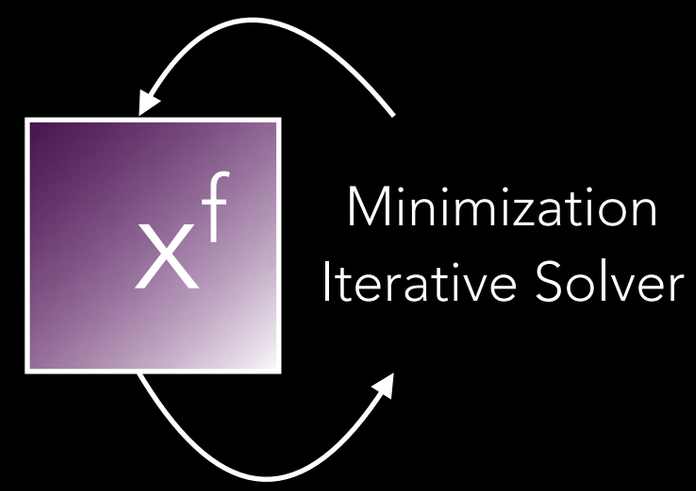
Improved estimate of the physical state

MOST COMMON DA METHODS

Ensemble-based (EnKF)

Dynamically varying estimate of forecast error ("errors of the day")

Variational



Climatological estimate of the forest error

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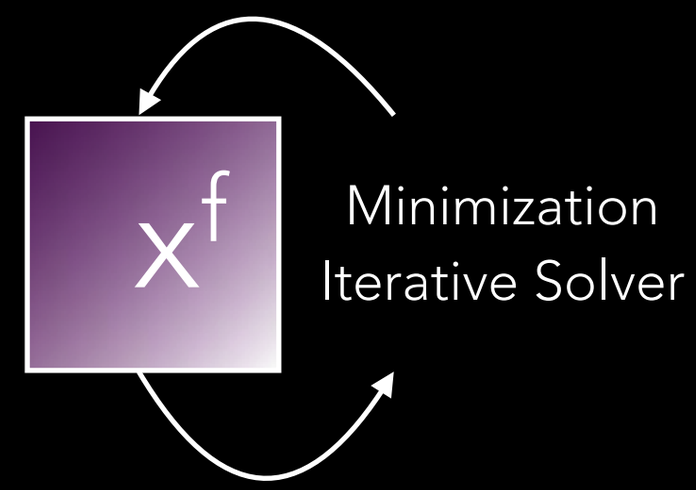
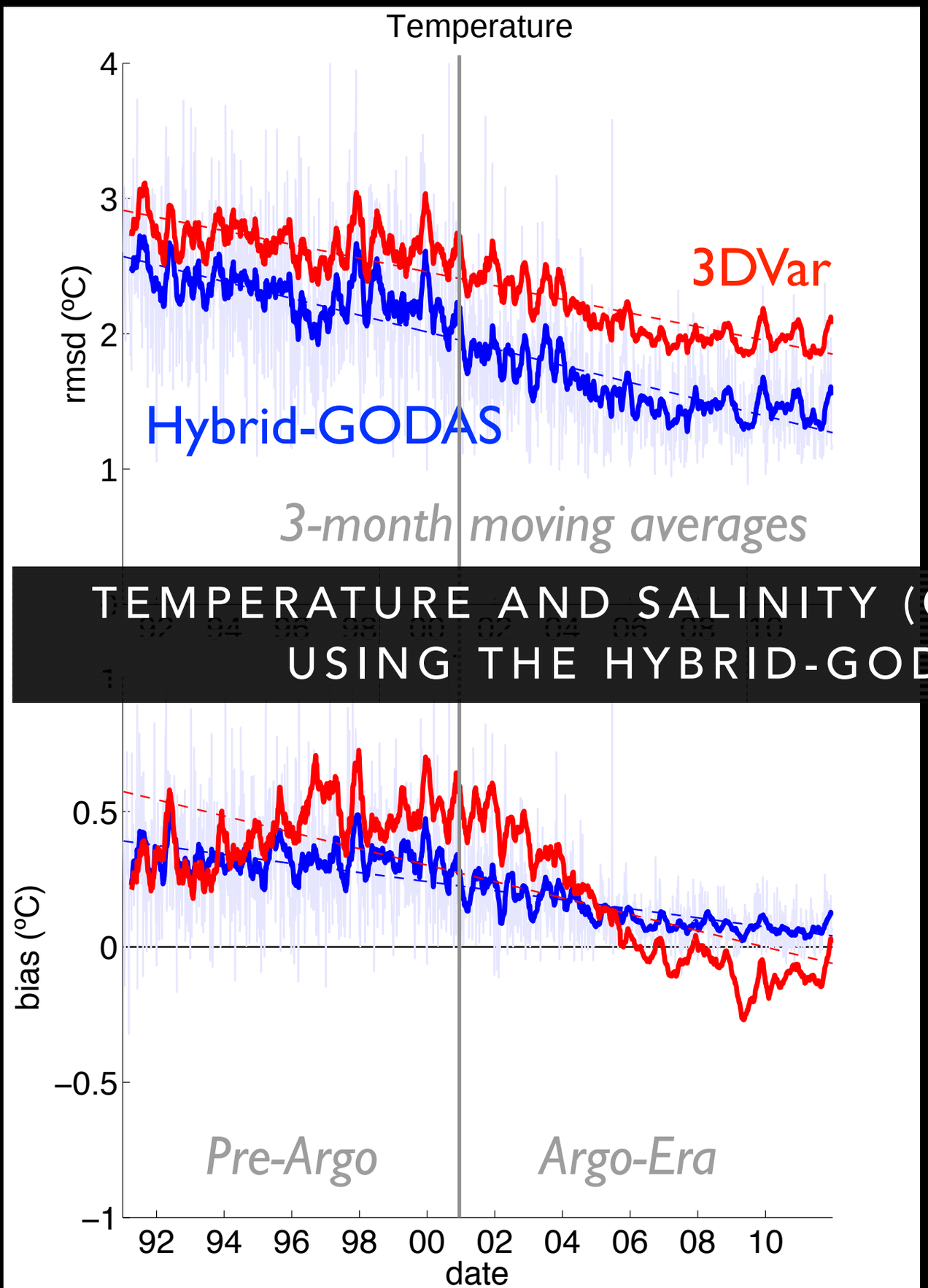


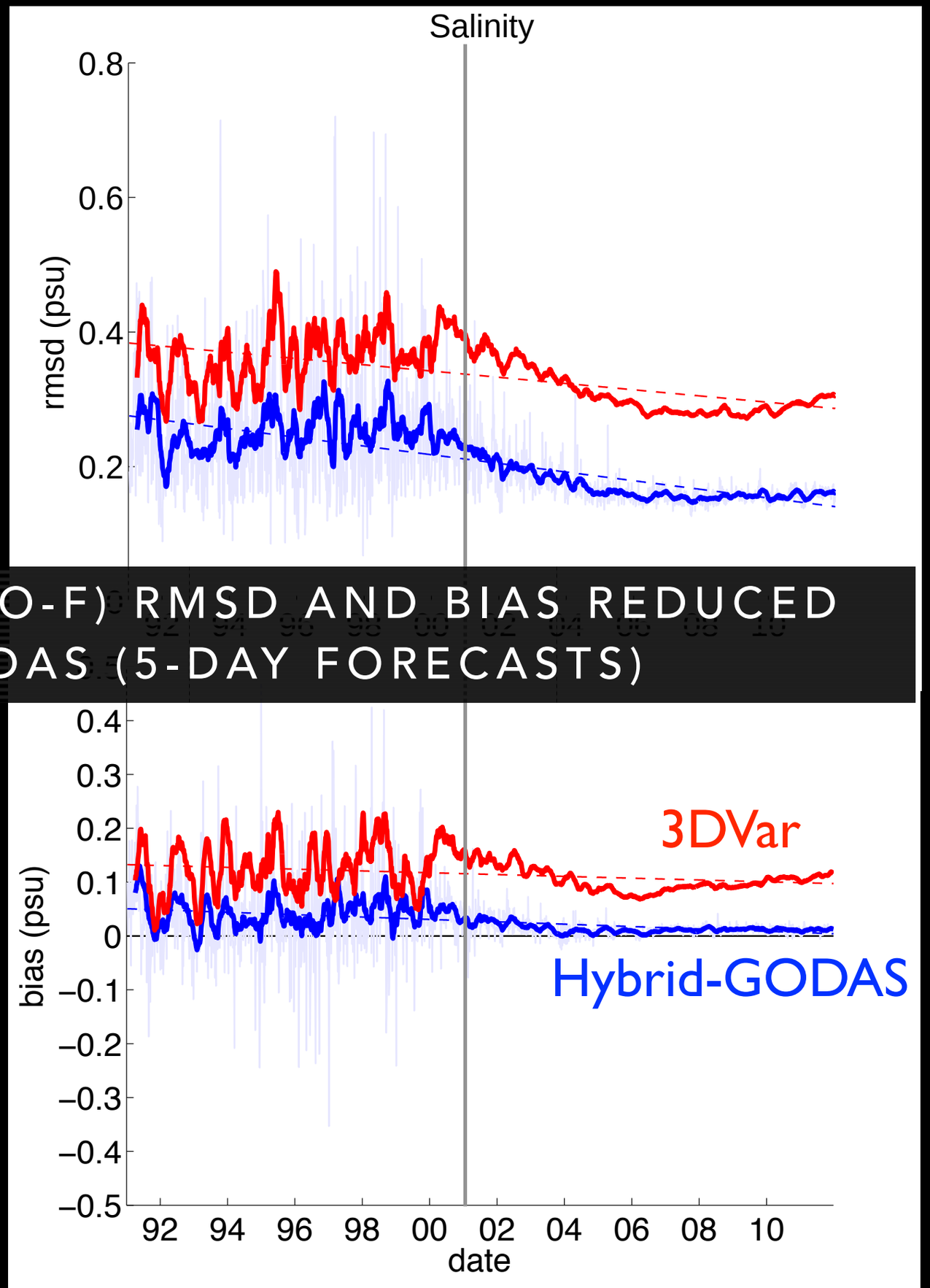
Climatological estimate of the forest error

HYBRID

ADVANCEMENTS AT NCEP

21-YEAR HYBRID-GODAS REANALYSIS





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

EQUATORIAL PACIFIC ADCP*

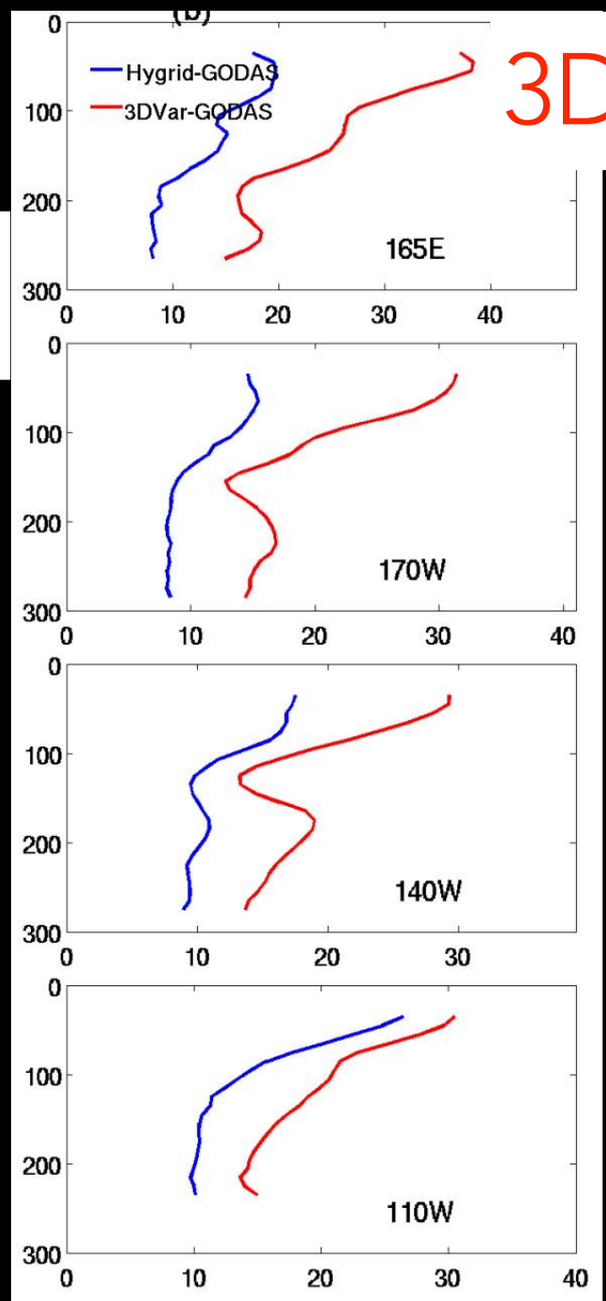
*Acoustic Dopler Current Profilers

RMSD (cm/s)

Anomaly Correlation

Hybrid

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

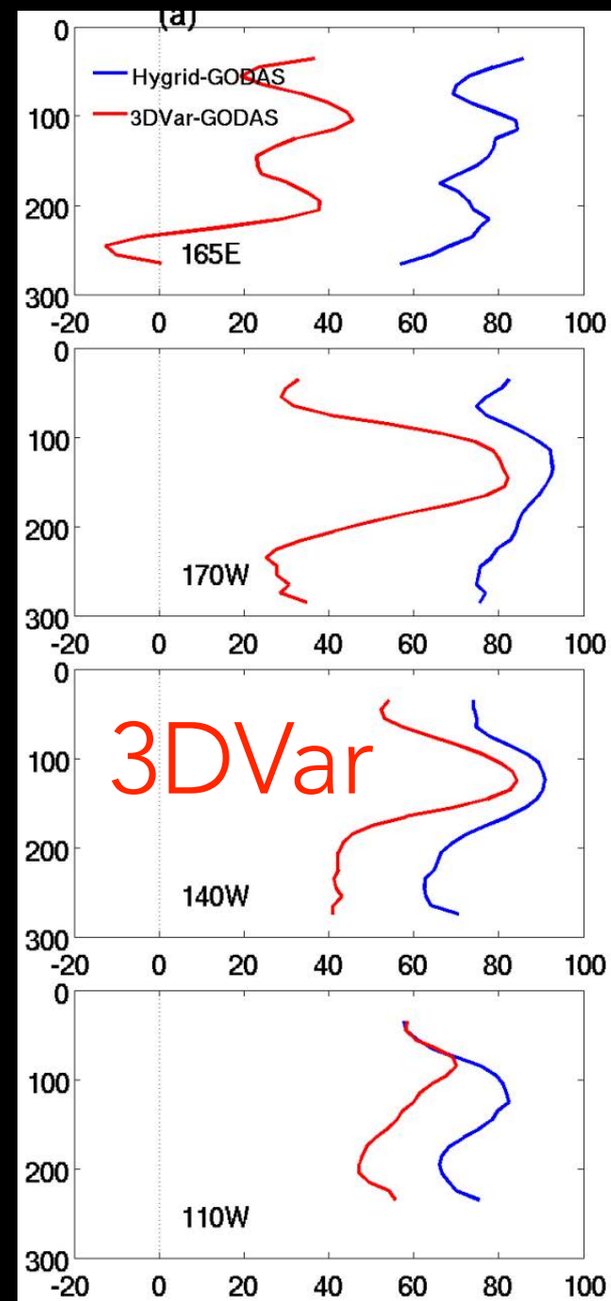


165E

170W

140W

110W



Hybrid

Improvement

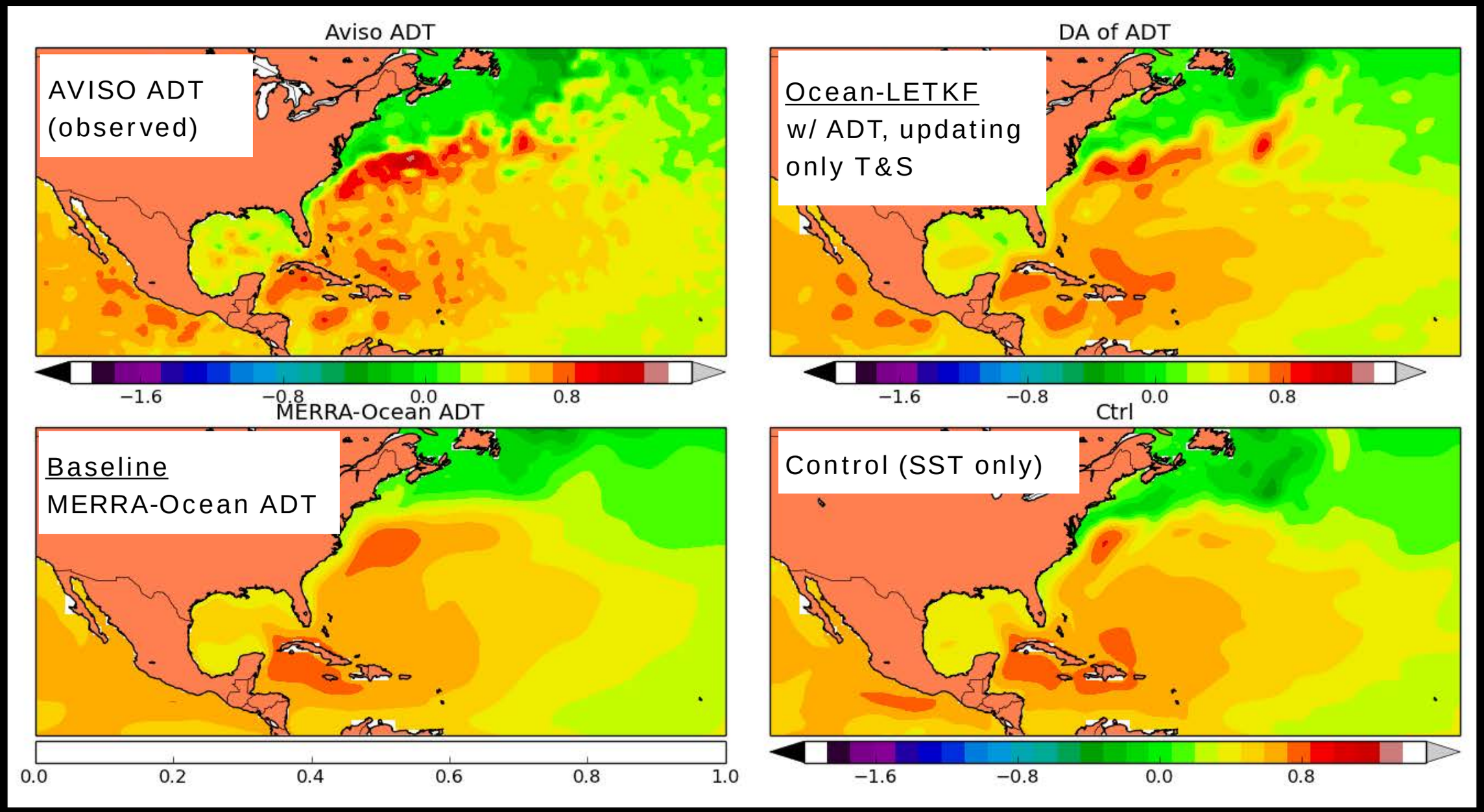
Improvement

ASSIMILATION OF ADT ALTIMETRY

N. Atlantic

After 1 month
w/ daily analysis cycle

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

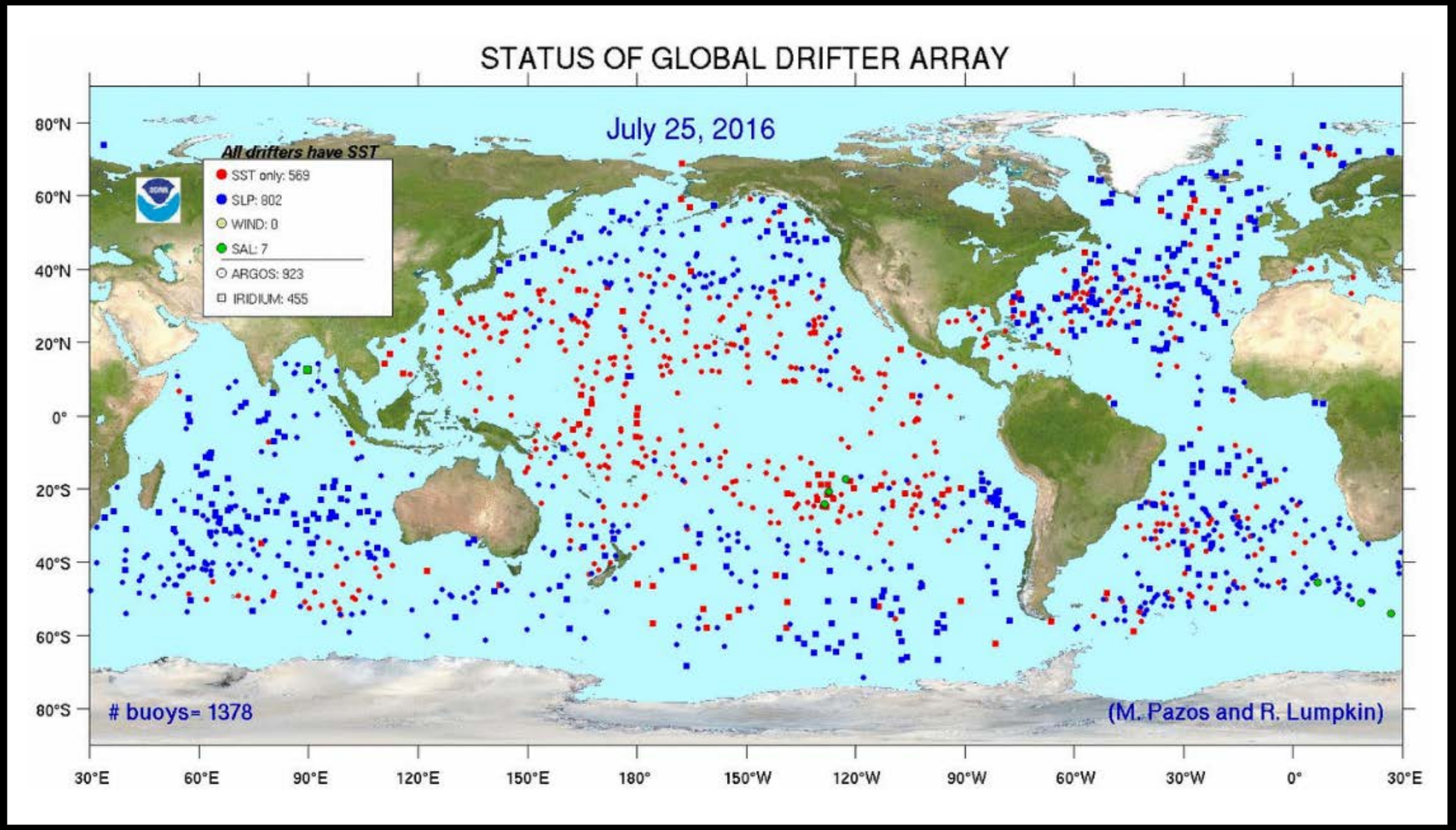


Thanks to: Guillaume Vernieres

GLOBAL DRIFTER PROGRAM (GDP) DATA

GOALS:

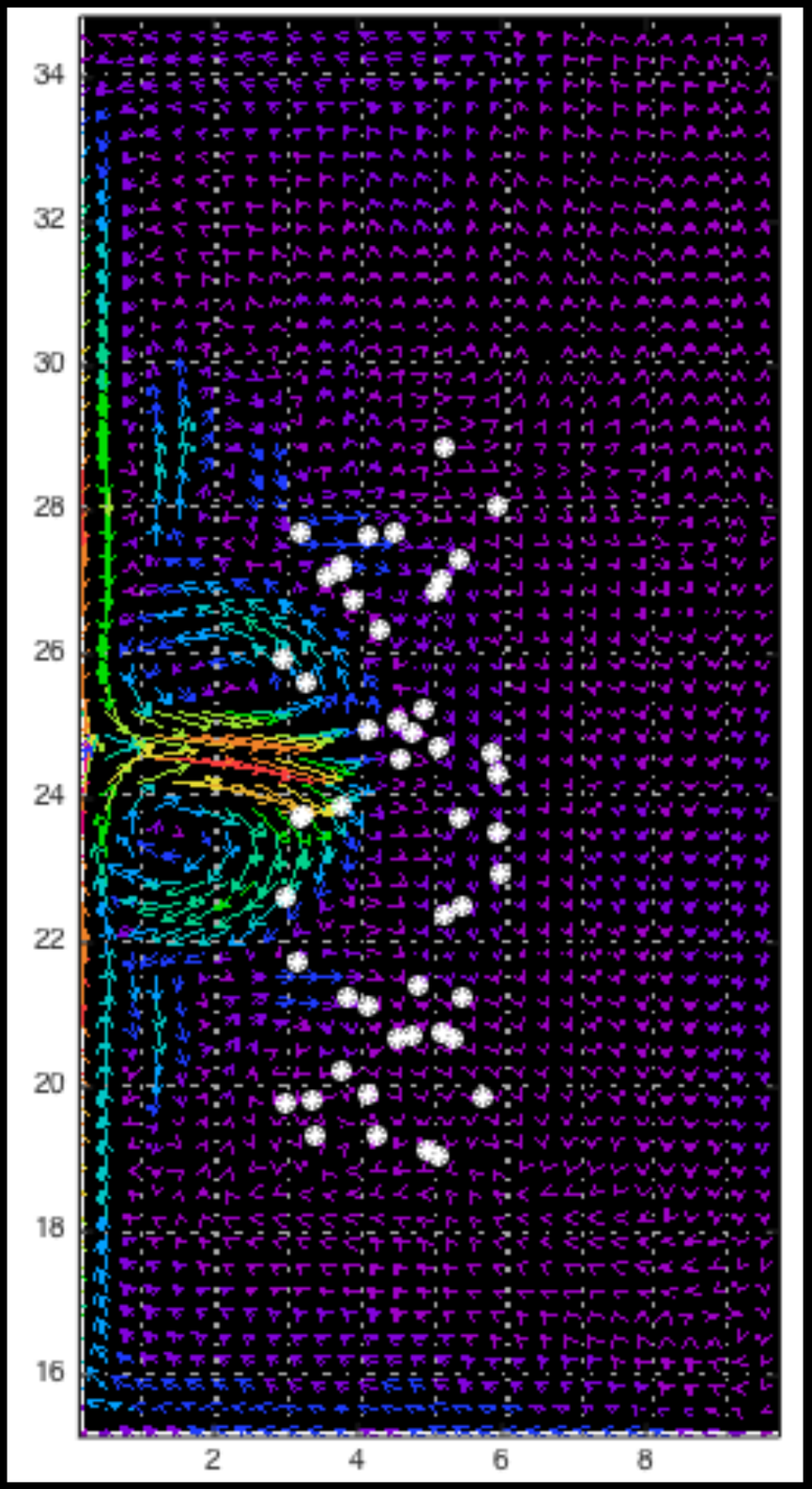
- Use drifter positions to improve near surface current estimates
- Update upper ocean T & S based on ensemble-derived error covariances
- Use GDP temperature measurements to bias-correct SST data



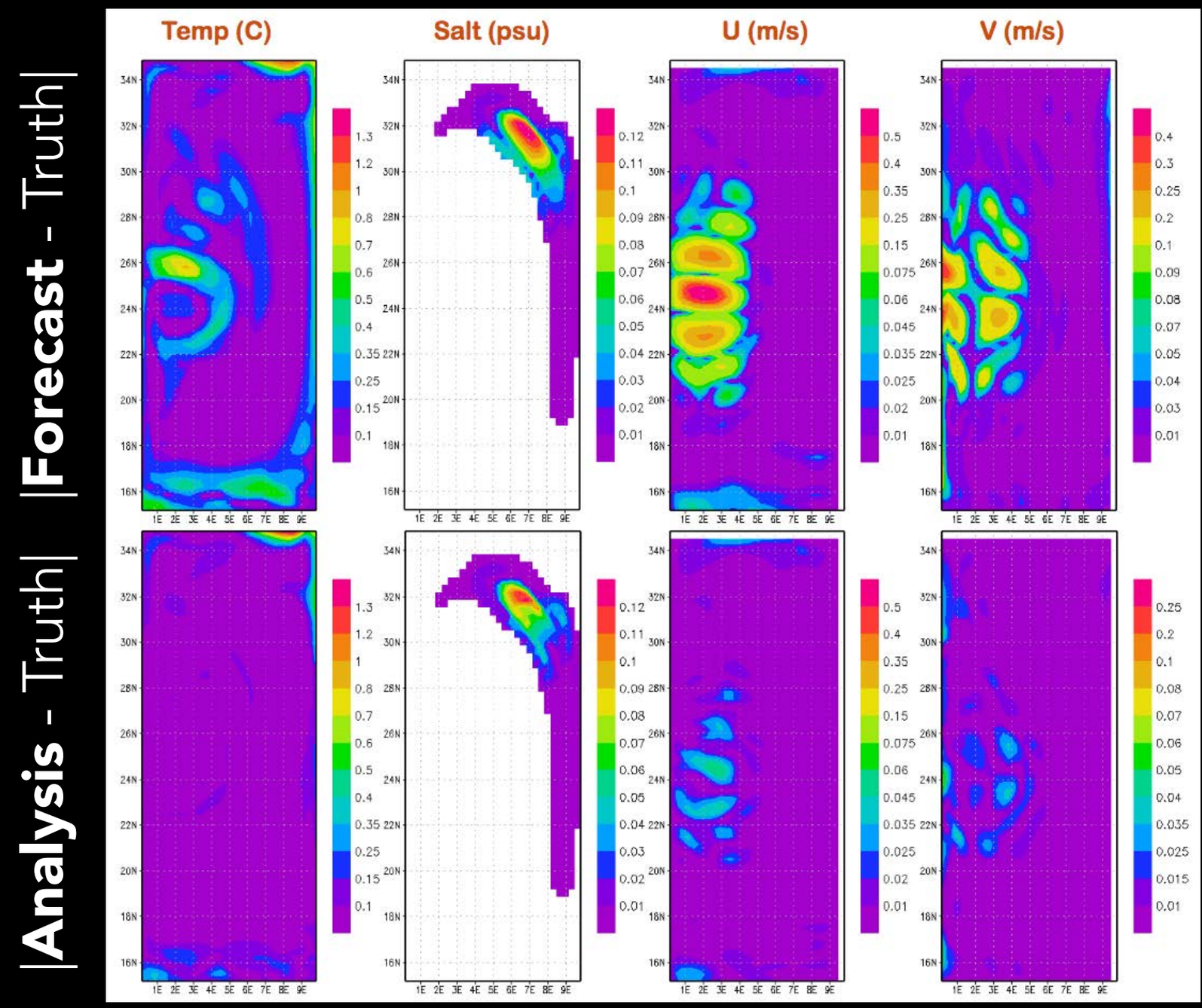
source: http://www.aoml.noaa.gov/phod/dac/index.php

SURFACE DRIFTERS - LAGRANGIAN DA

Depth: 15m



Depth: 105m

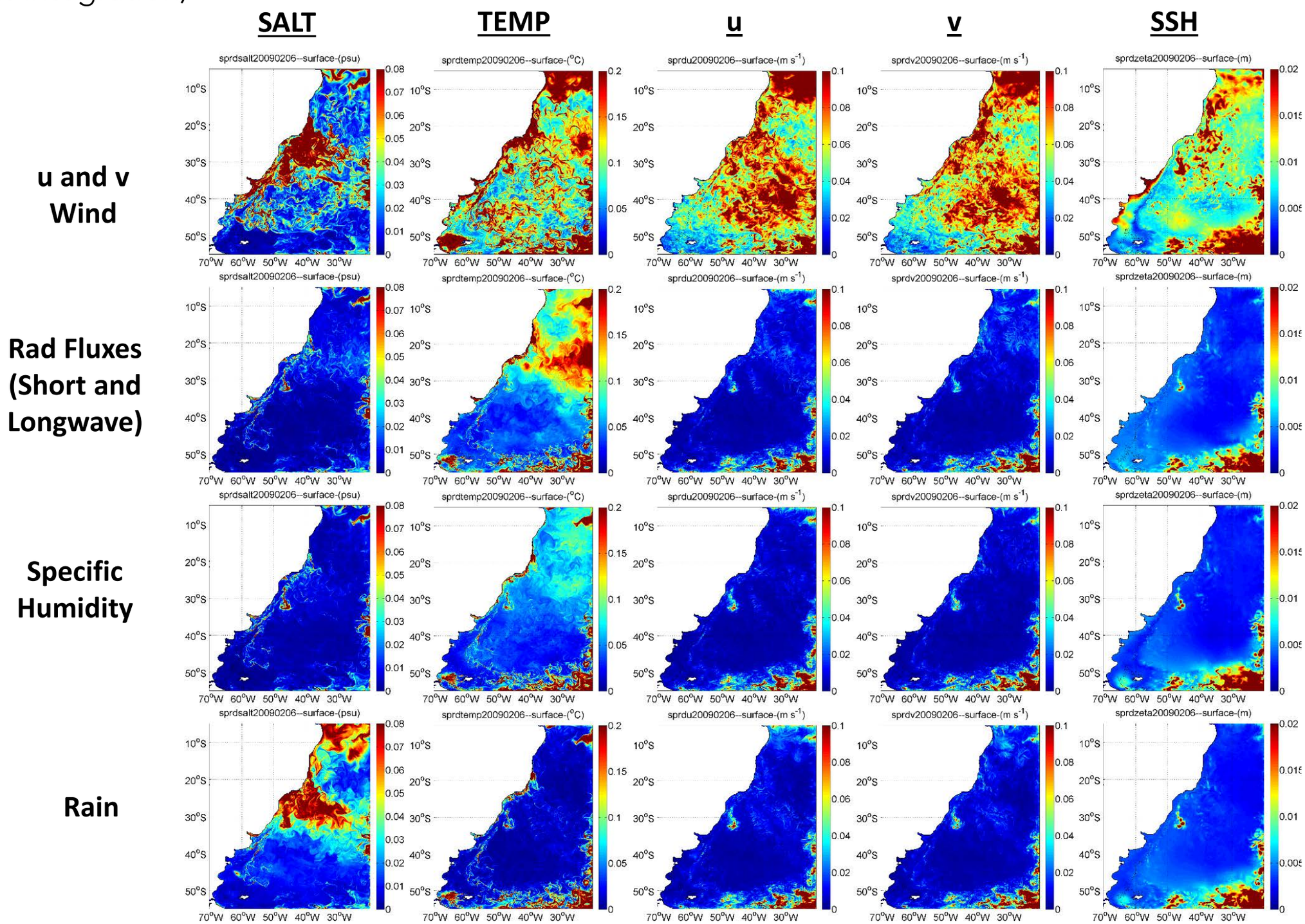


Thanks to: Luyu Sun, UMD

INVESTIGATION OF SOURCES OF UNCERTAINTY IN ENSEMBLE OCEAN DA

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

Spread on ocean surface – 06/Feb/2009



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

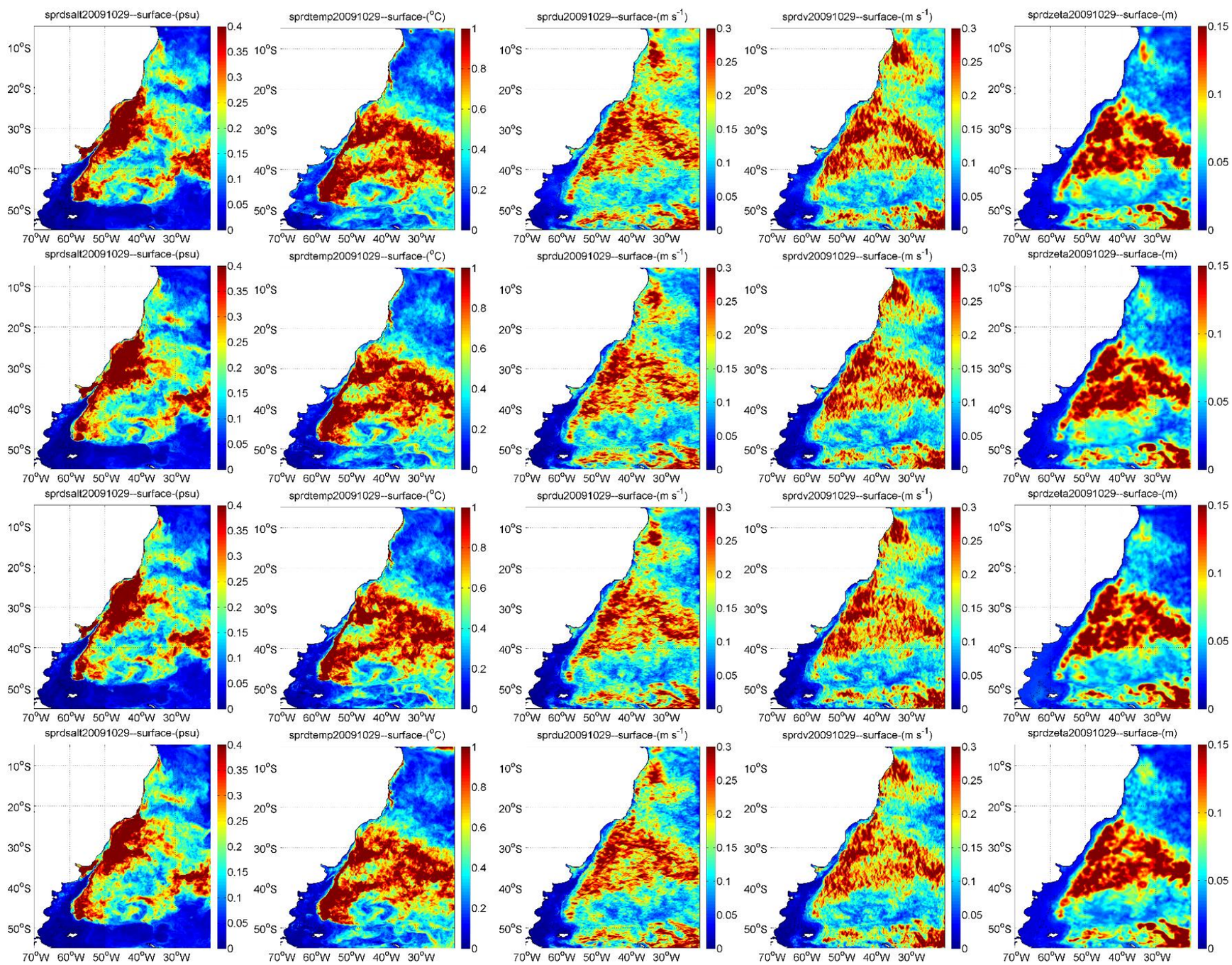
SALT | **TEMP** | **u** | **v** | **SSH**

u and v Wind

Rad Fluxes (Short and Longwave)

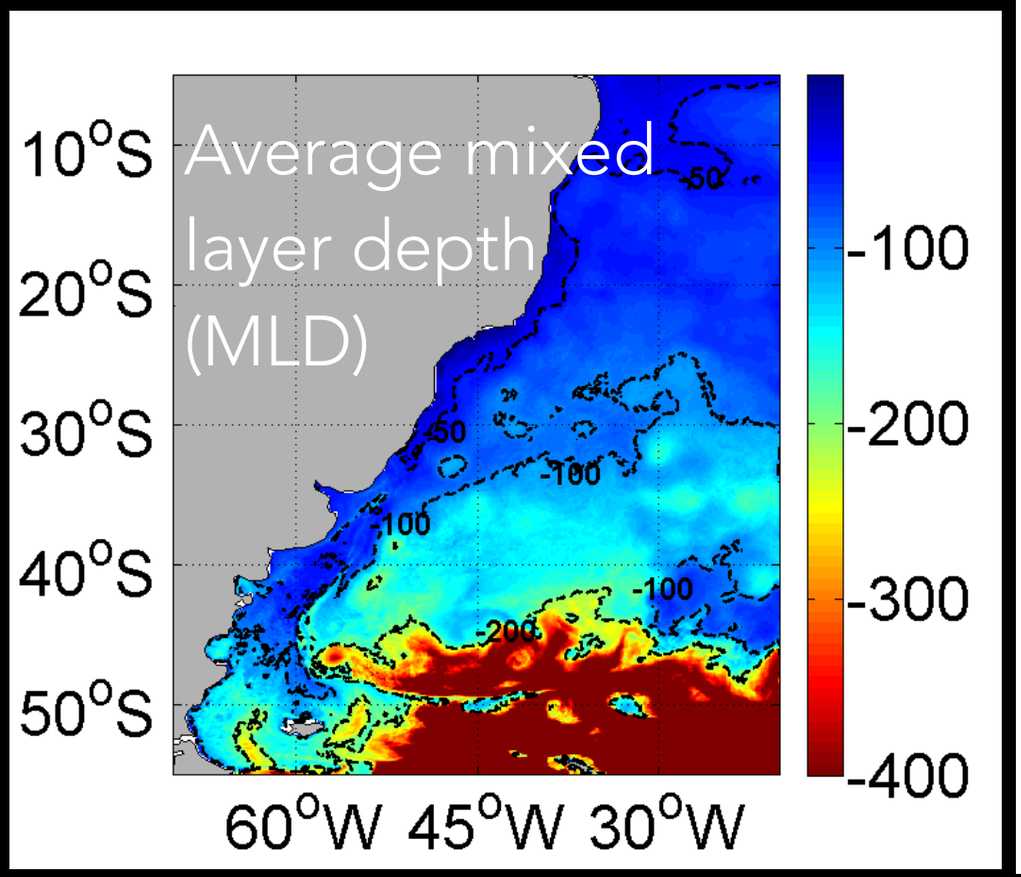
Specific Humidity

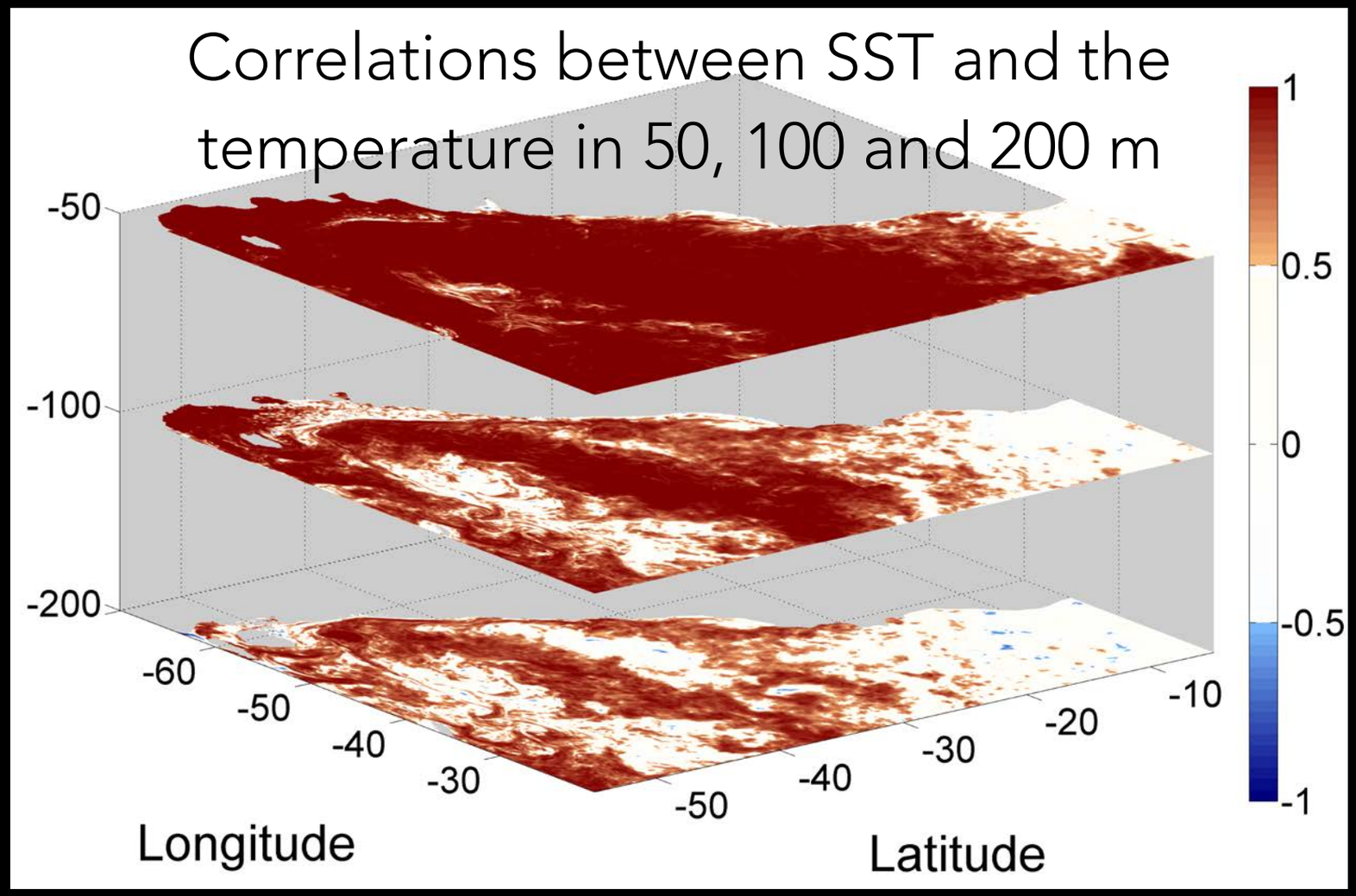
Rain



Thanks to: Leonardo Lima

ASSIMILATION OF BIAS-CORRECTED SST INNOVATIONS



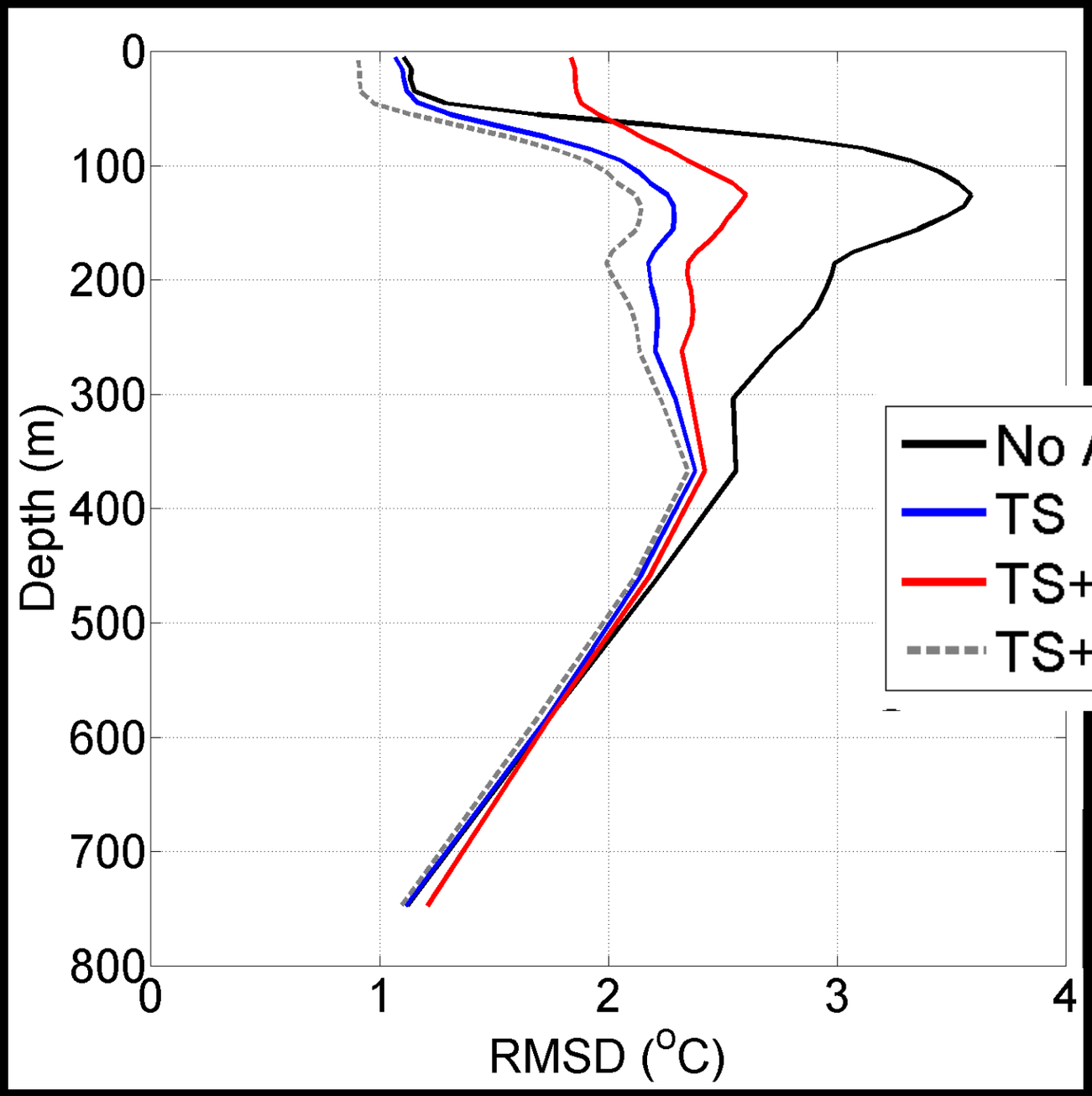


- highest correlations above MLD
- included a MLD calculation
- de-bias regional SST innovation
- split 2-layer localization

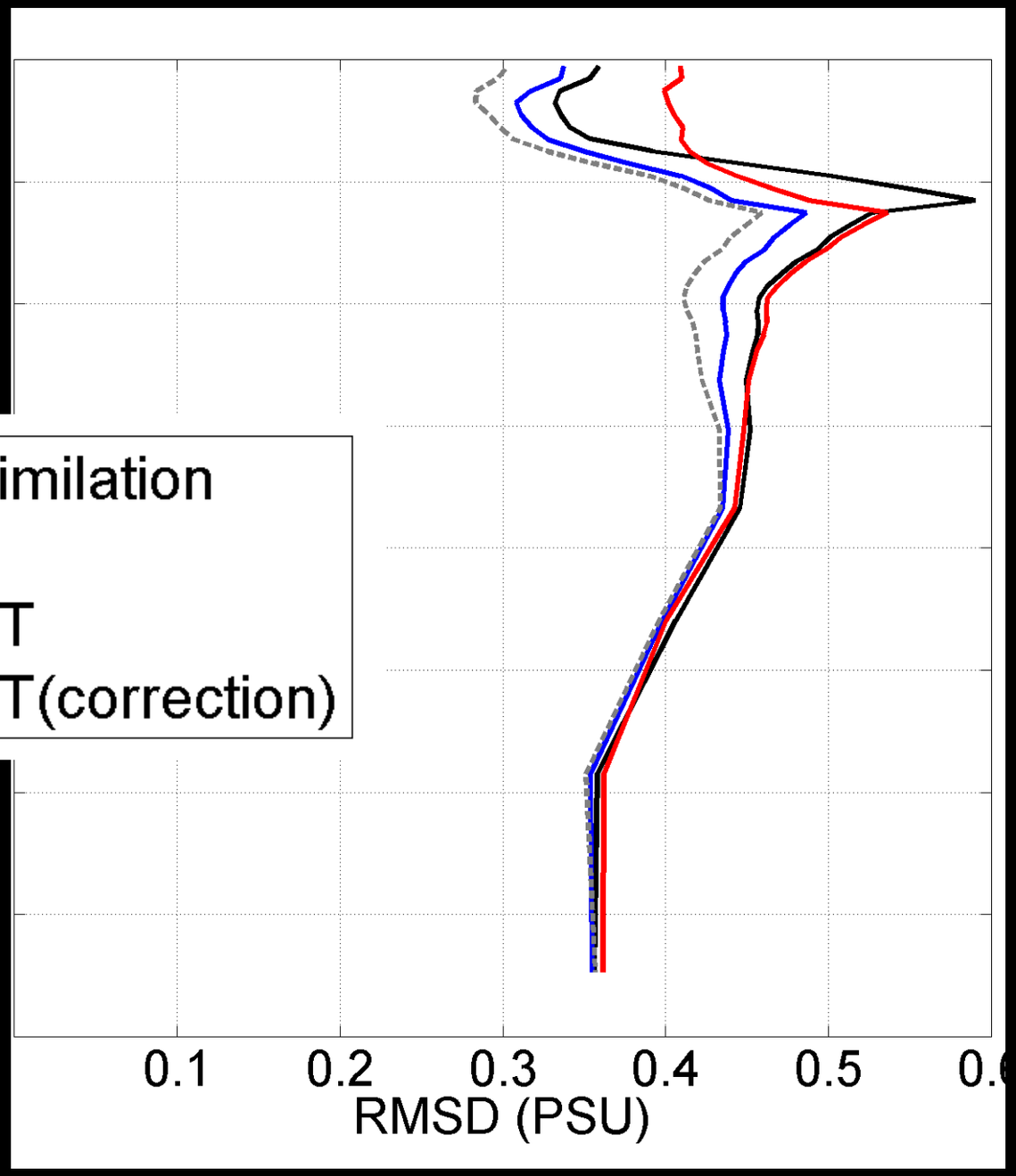
Thanks to: Leonardo Lima

ASSIMILATION OF BIAS-CORRECTED SST INNOVATIONS: RMSD

Temperature Profiles



Salinity Profiles

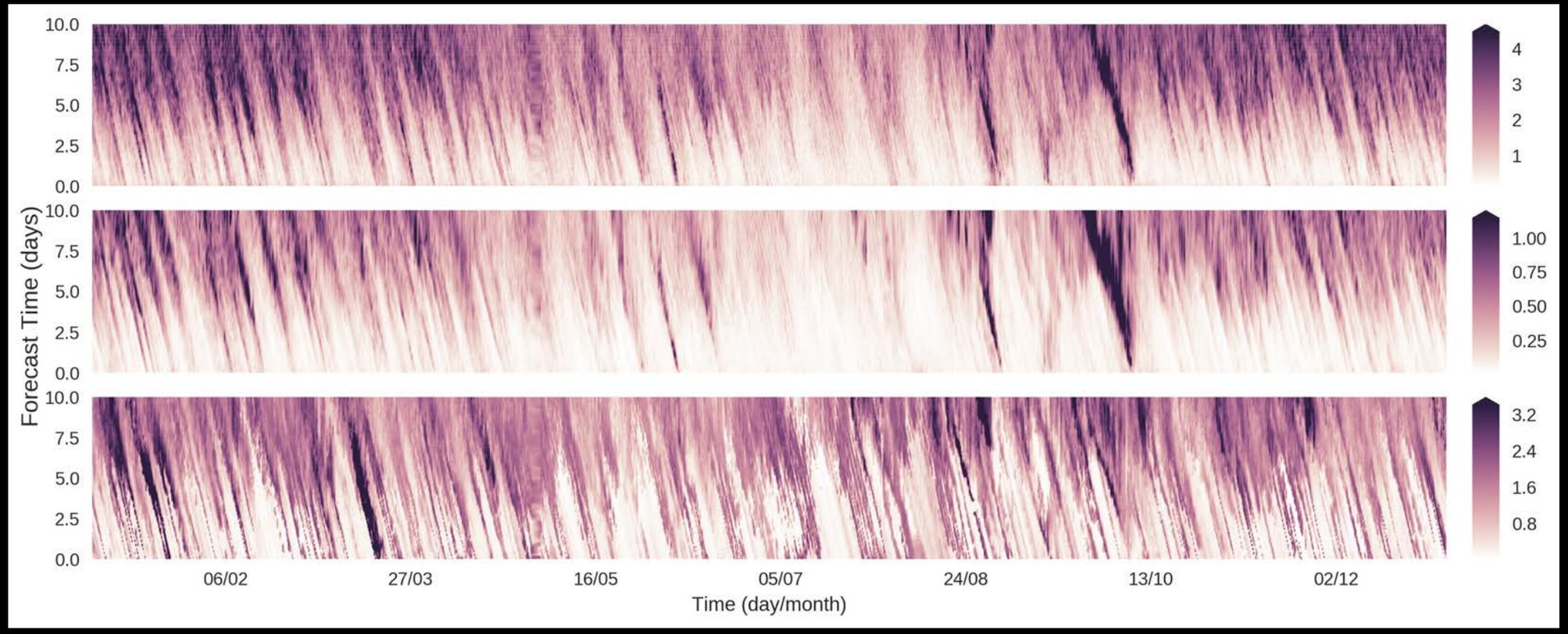


Regional average after 15 days assimilation

WAVE FORECAST BIAS CORRECTION USING NEURAL NETWORKS

- Ensemble Wave Data Assimilation (LETKF)
- Biased Corrected forecast (Neural Network)

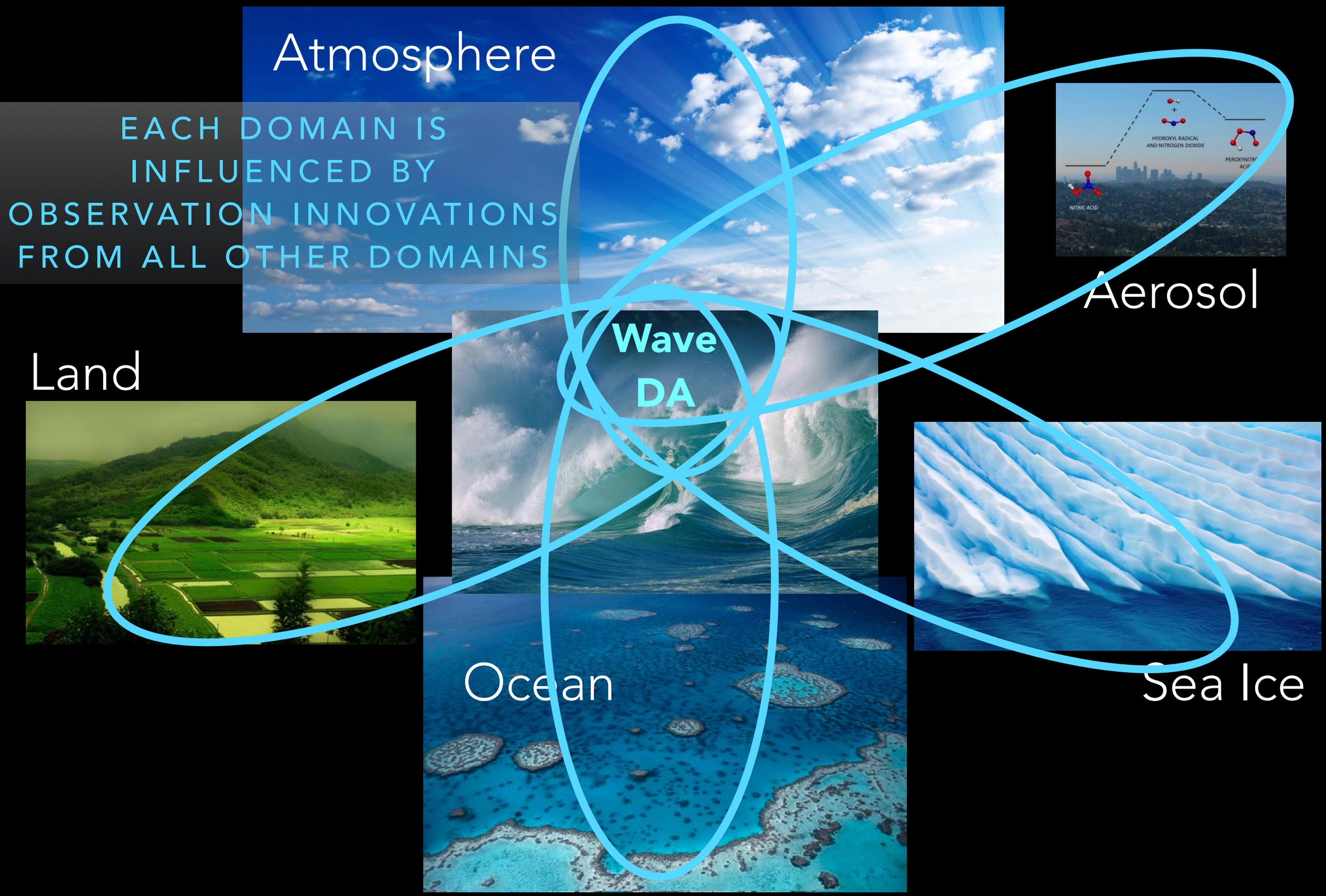
Ensemble Spread over forecast lead times 0-10 days



Thanks to: Flampouris (DA) and Campos (NN)

COUPLED DATA ASSIMILATION

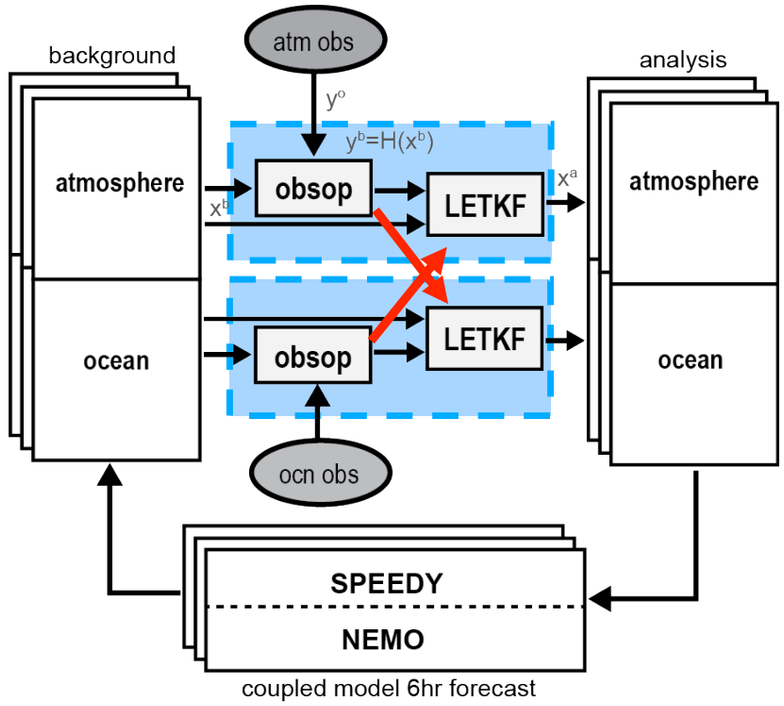
STRONGLY COUPLED DATA ASSIMILATION



IMPLEMENTATION OF THE STRONGLY COUPLED LOCAL ENSEMBLE TRANSFORM KALMAN FILTER (LETKF)

Strongly Coupled LETKF

- Sharing of observational departures allows system to act as single **strongly coupled** system.
- Separate LETKF for each domain helps keep implementation simpler. **Ocean LETKF and Atmosphere LETKF can be developed independently.**



Data assimilation systems, normally separate
"weakly coupled DA"

Sluka, T. C., S. G. Penny, E. Kalnay, and T. Miyoshi (2016), Assimilating atmospheric observations into the ocean using strongly coupled ensemble data assimilation, *Geophys. Res. Lett.*, *43*(2), 752–759, doi:10.1002/2015GL067238.

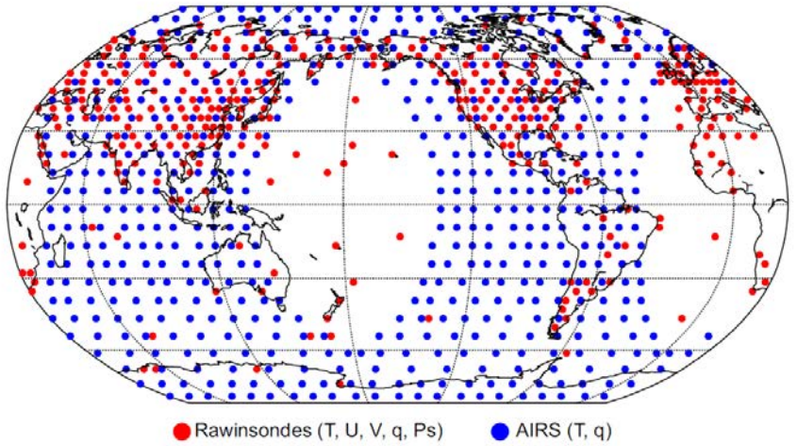
Thanks to Travis Sluka

EXPERIMENT SETUP WITH SPEEDY/ NEMO COUPLED SYSTEM

SPEEDY-NEMO OSSE

Using the fast SPEEDY-NEMO (one year run takes only 12 hours on 1 core)

- Perfect model OSSE conducted using **only atmospheric observations**



SPEEDY-NEMO

- T30 atmosphere
- 2 degree ocean
- Coupling every 6 hours

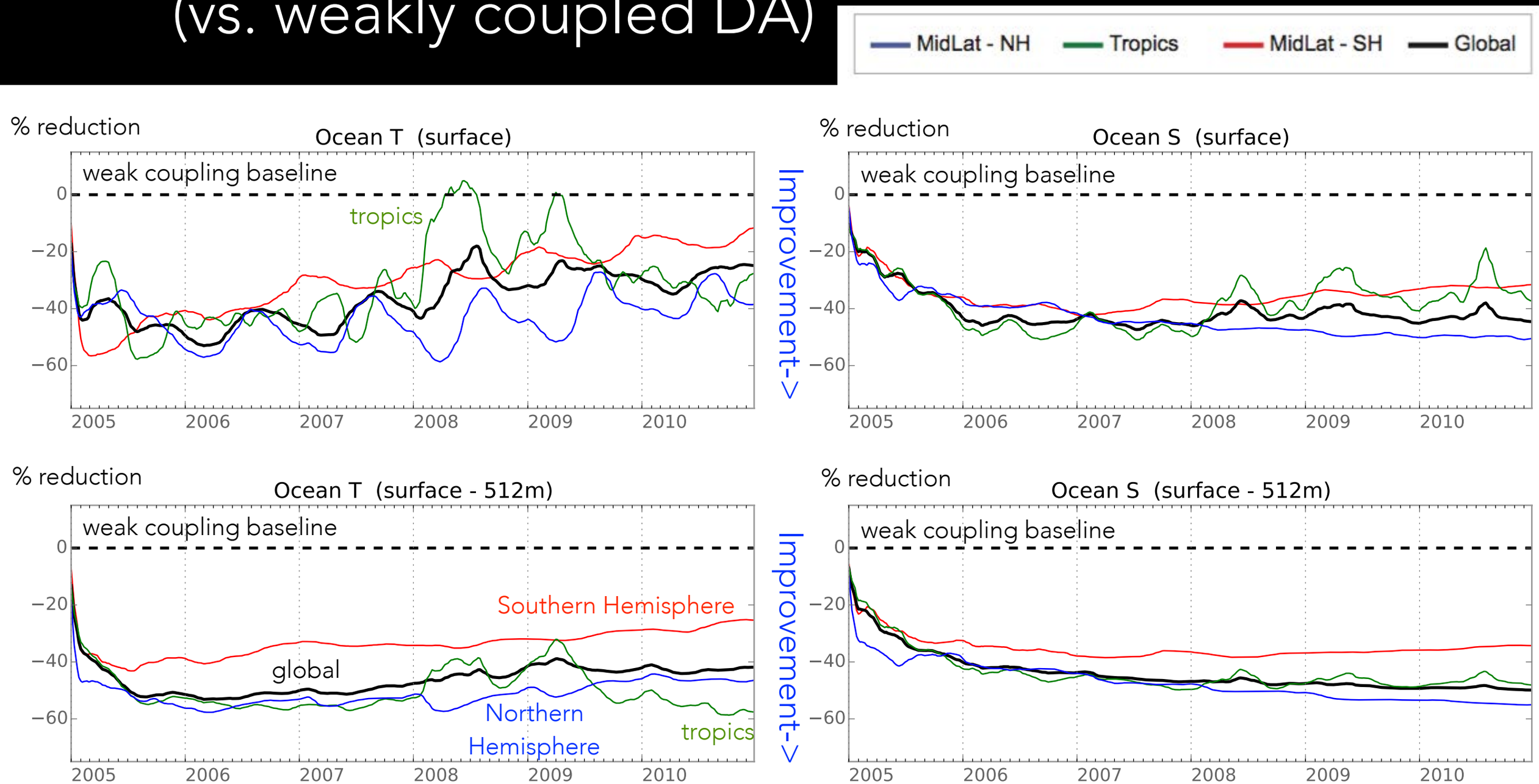
Experiment parameters

- 40 ensemble members
- Localization: 1000km Hz
- Relaxation to prior spread: 90% for ocn 60% for atm

Thanks to Travis Sluka

STRONGLY COUPLED DA REDUCES ERRORS (vs. weakly coupled DA)

For example, assimilating only atmospheric observations leads to significant improvements in ocean:



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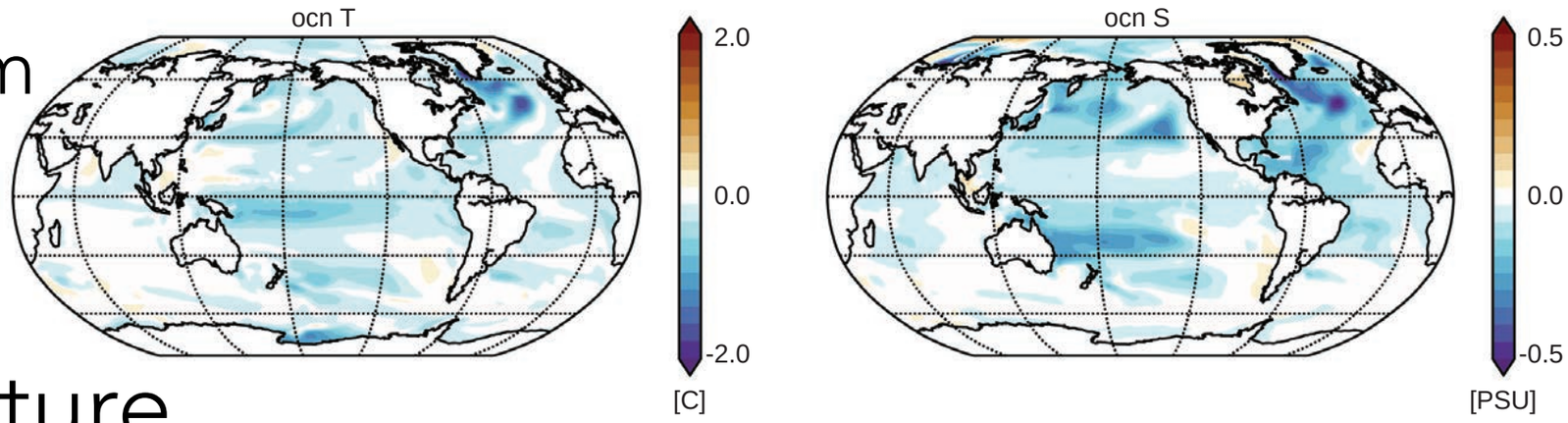
STRONGLY COUPLED DA REDUCES ERRORS (vs. weakly coupled DA)

Again, assimilating only atmospheric observations:

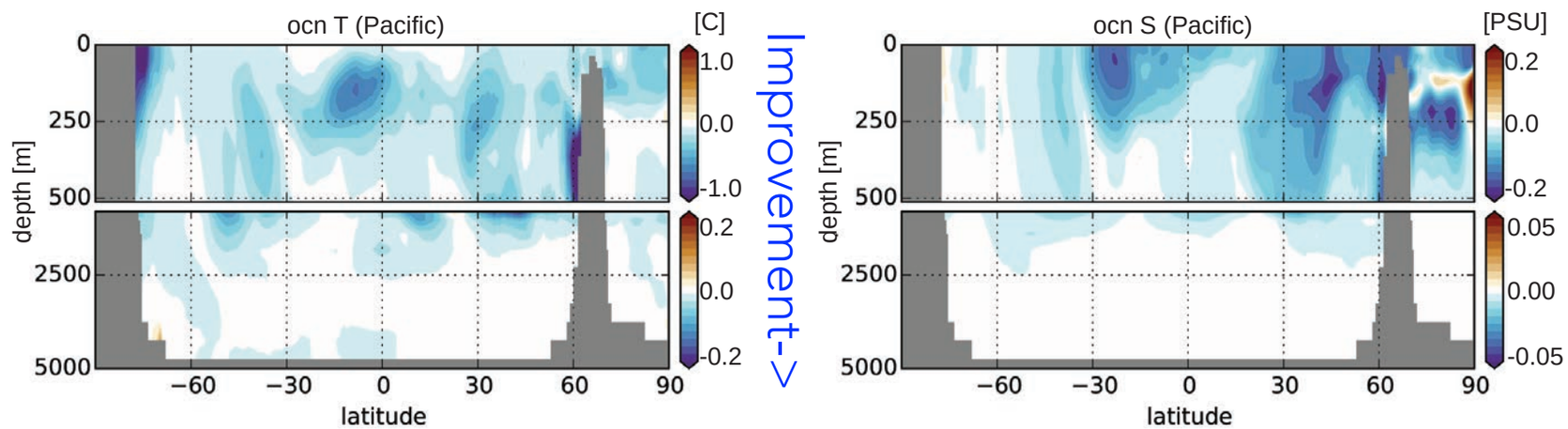
Upper 500m



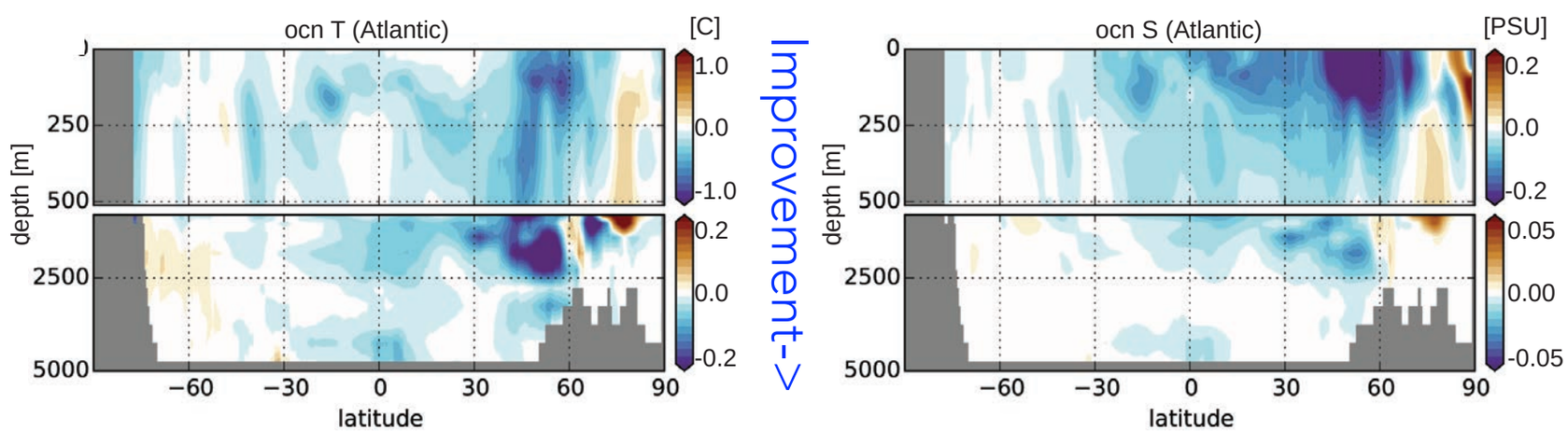
Temperature

Salinity

Pacific

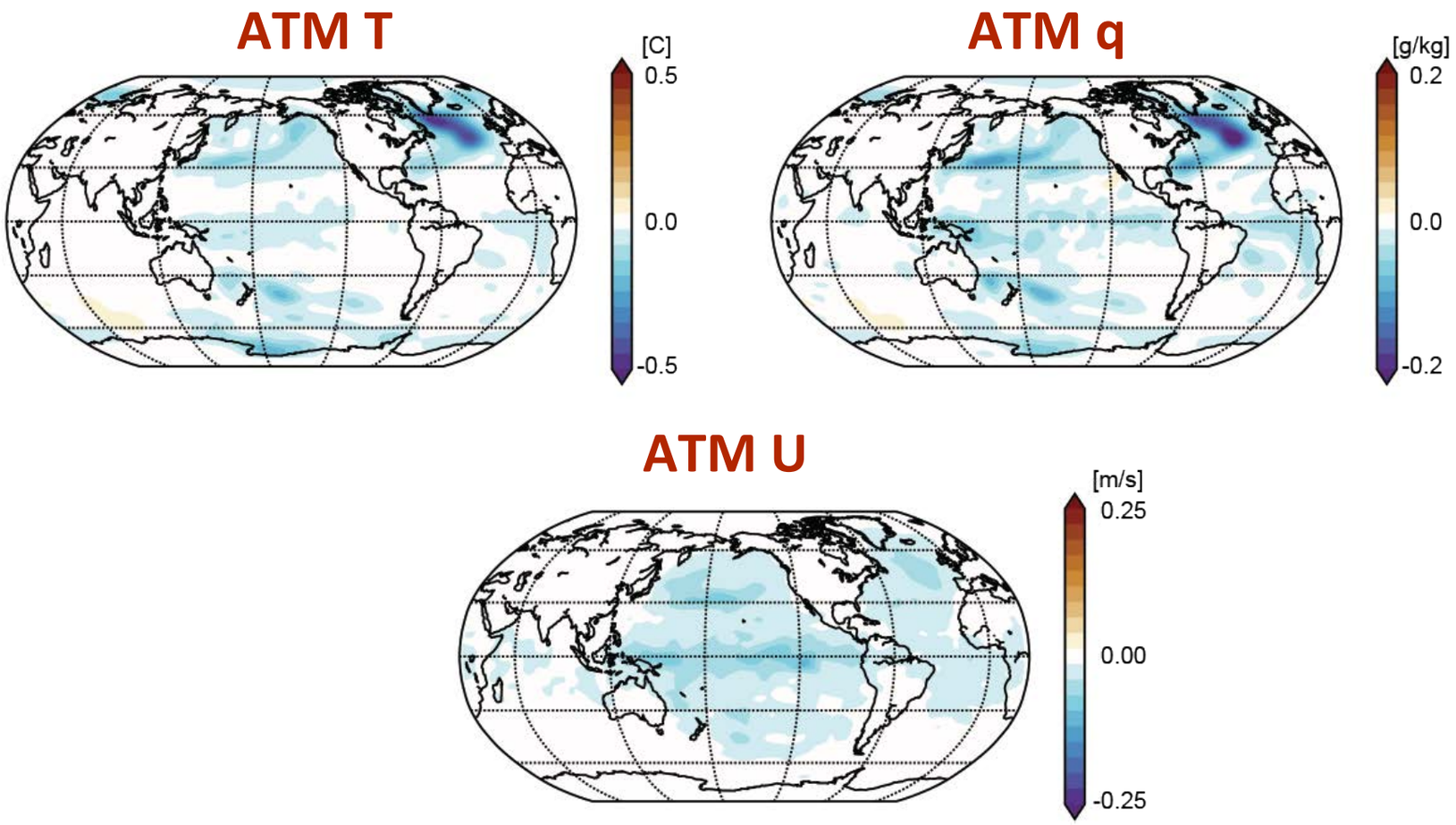


Atlantic



Time mean over last 5 years of 10-year experiment.

ATMOSPHERIC SURFACE VARIABLES IMPROVED DUE TO MODEL FEEDBACKS



Error reduction due to strong coupling vs. weak coupling is reflected in atmosphere as well

FUTURE TRENDS IN OCEAN DA

- DA solutions that maintain balance between ocean and external forcing via **coupled analyses** (and improve fluxes that ultimately drive the forecast in the short-term)
- **Higher resolution models** and effectively **lower resolution** 'top-heavy' **observing networks**
- Incorporation of **new and underutilized observation types** (e.g. satellite gravity field data, in situ drifters/floats/gliders, surface winds, observed fluxes)
- Incorporation of **biogeochemistry** into ocean DA
- **Neural network / machine learning** pre- and post-processing within the DA cycling, and bias-correcting observations and model forecasts
- New DA methods to explicitly **analyze multiple spatial and temporal scales**

GENERAL NEEDS FROM OCEAN OBSERVATIONS TO SUPPORT DA

- **Ideal Goal: maintain comparative resolution** between feasible operational model resolutions and global observing system resolution
- **Increased in situ observation coverage**, including beneath sea ice, deep ocean currents, active dynamical regions like western boundary currents, southern ocean
- Redundant observing network design to **calibrate and bias-correct measurements** globally, **improve agreement** between different sources of measurements, **and estimate errors** of these measurements
- **Improved observing of air-sea interface** (fluxes), as well as Sealce-ocean, land-ocean, biogeochemical fluxes, etc. to help isolate model biases
- Co-located observations and observation-based estimates of **cross-covariance relationships** across domain boundaries (e.g. air-sea)

IN CONCLUSION

- Future advancements in ocean DA can be accelerated by active collaboration between observing, modeling, and DA communities

- Viable ocean model resolution is increasing faster than observing system resolution, which creates new challenges and requires:
  (1) new DA approaches (like coupled DA) and
  (2) more non-traditional observations to be included in ocean DA

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