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OCEAN PREDICTION

PREDICTABILITY OF OCEAN PARAMETERS RELATED TO ATMOSPHERIC FORECASTS: *RESEARCH NEEDS, GAPS, AND RECENT ADVANCES*

JOINT PSMI/PPAI SESSION ON QUANTIFYING IMPROVEMENTS IN PREDICTION/PROJECTIONS
US CLIVAR SUMMIT, AUGUST 5, 2015, TUCSON, AZ

PHILOSOPHIES

- Use best available data assimilation methods from Geophysical Dynamical Systems Theory
- The Earth is one system
- Bridge disciplines
- Use all data
- Think Big

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DATA ASSIMILATION

- Reanalysis ≠ Observed
- Modeler perspective:
  DA initializes the model
- Observationalist perspective:
  DA interpolates the observations
- DA is a careful balance of observations, models, and theory, and experiences the strengths and weaknesses of these inputs.

OCEAN ASSIMILATION ADVANCEMENTS AT NCEP TO DATE:

- Oceanic Local Ensemble Transform Kalman Filter (Ocean-LETKF) system (Penny et al., 2013)

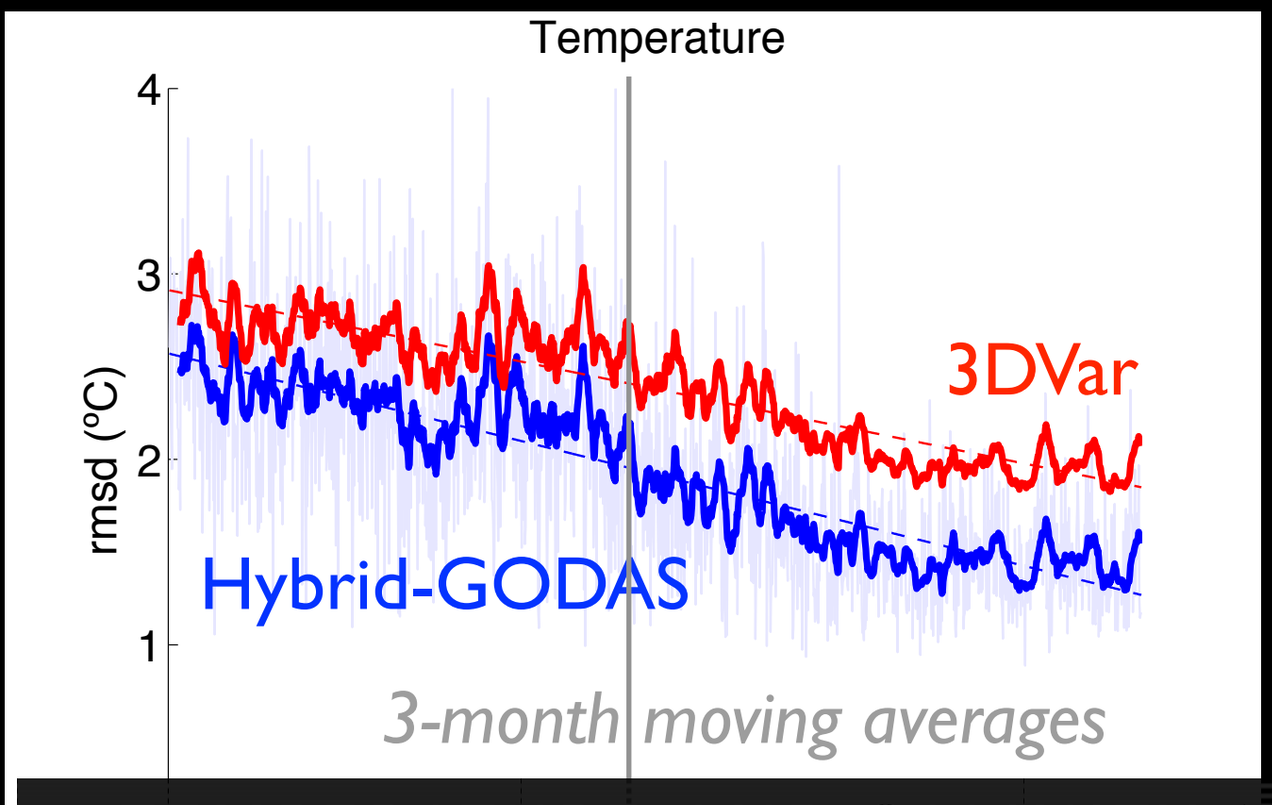
- Hybrid-Gain assimilation method (Penny 2014)

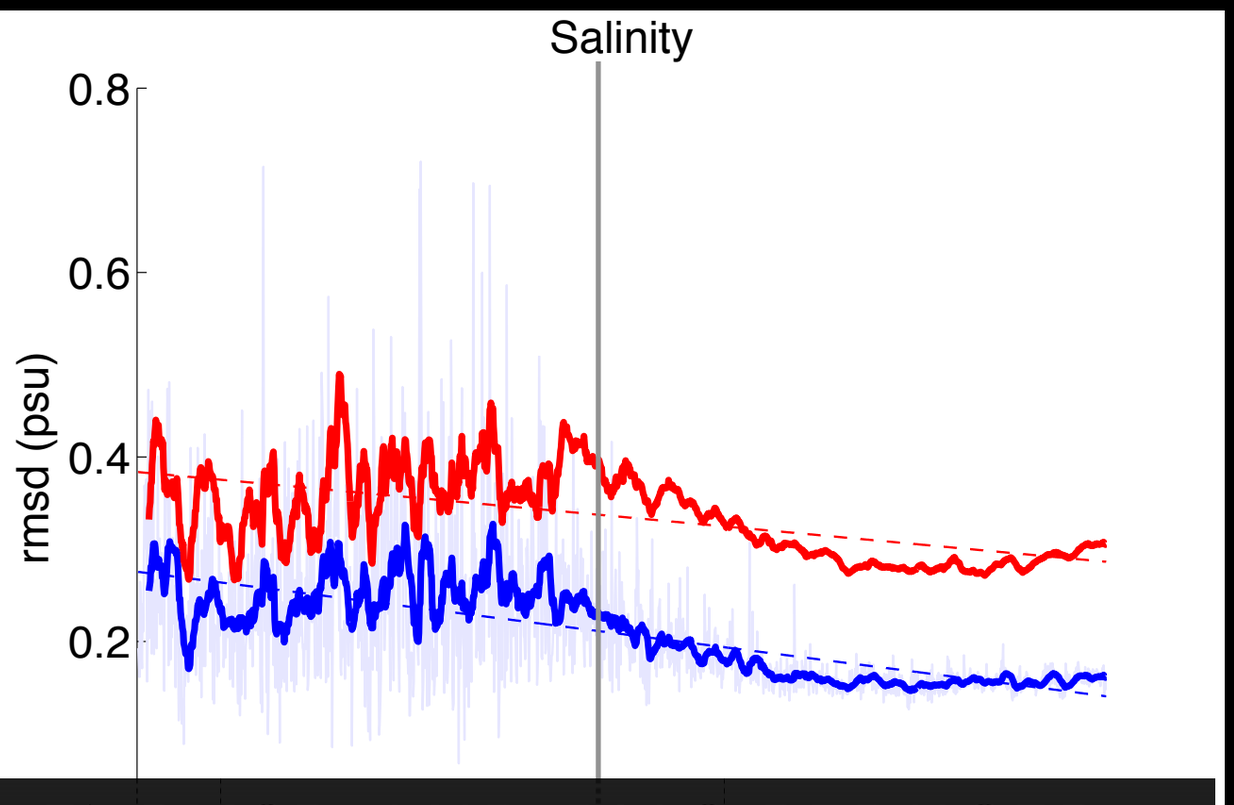
- Hybrid 3DVar/LETKF Global Ocean Data Assimilation System (Hybrid-GODAS) at NCEP (Penny et al., 2015)

- 21-Year Hybrid GODAS Reanalysis (Penny et al., in preparation)

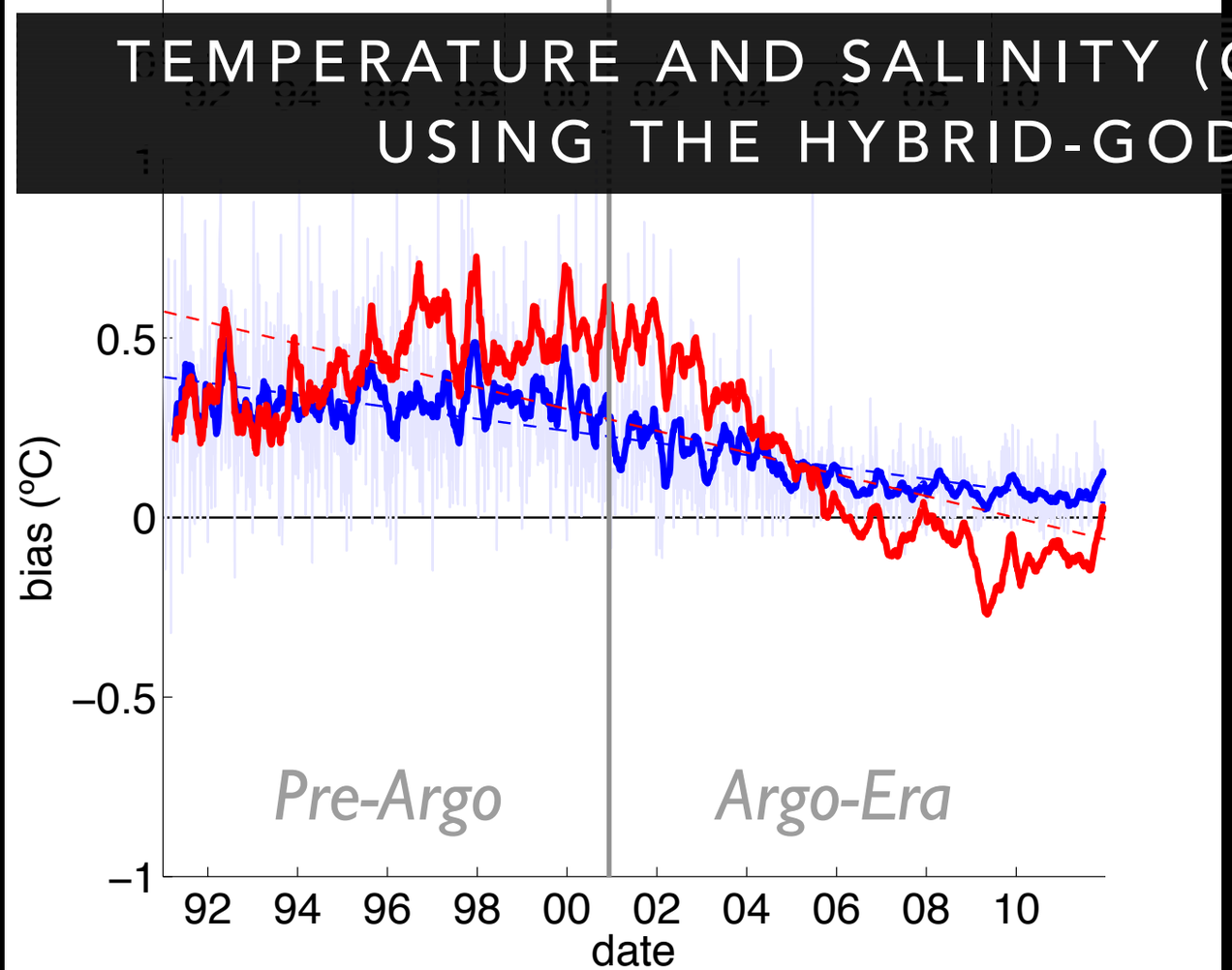
Collaborators: D. Behringer, J. Carton, E. Kalnay, T. Miyoshi, K. Ide, G. Chepurin, Y. Xue

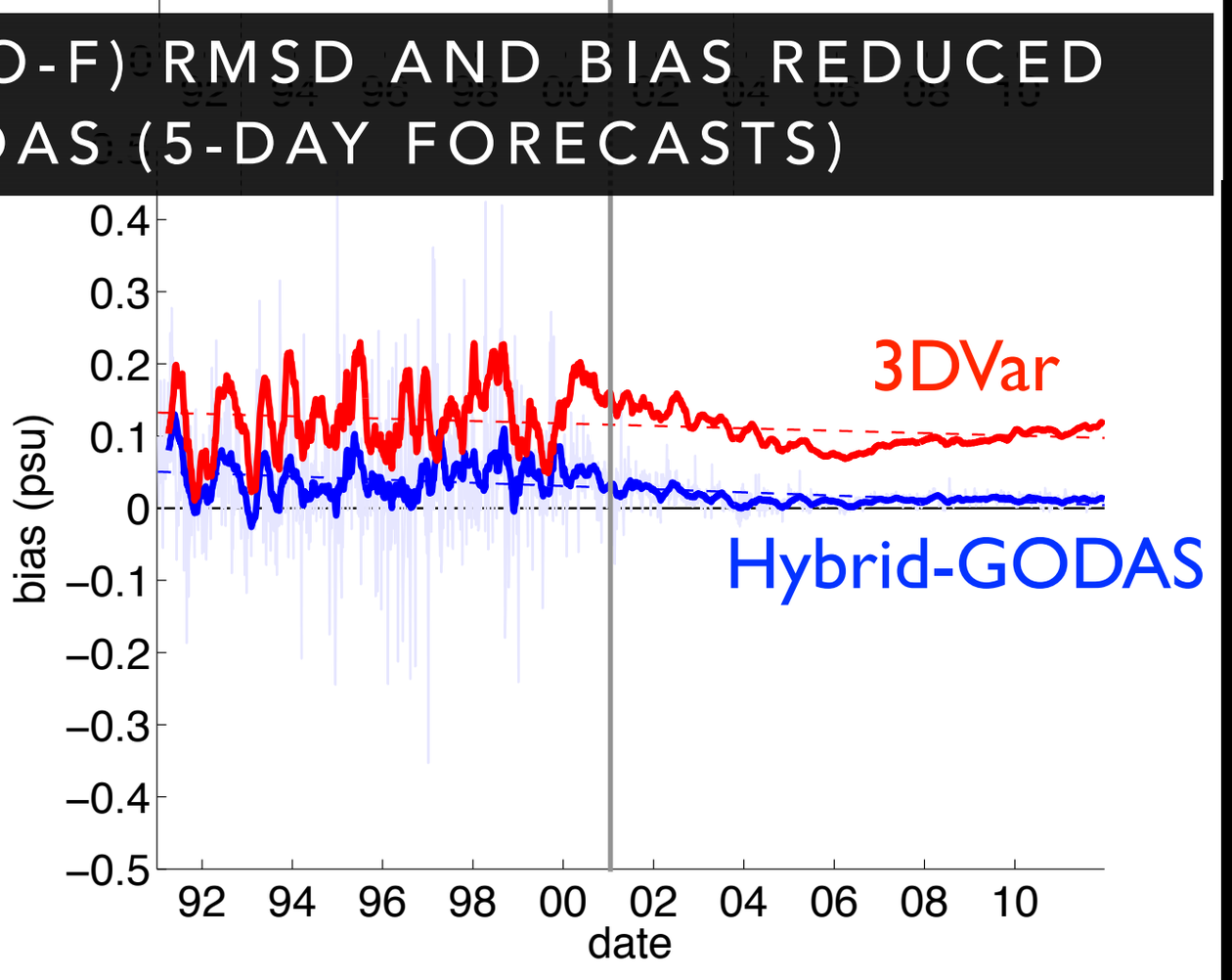
21-YEAR HYBRID-GODAS REANALYSIS





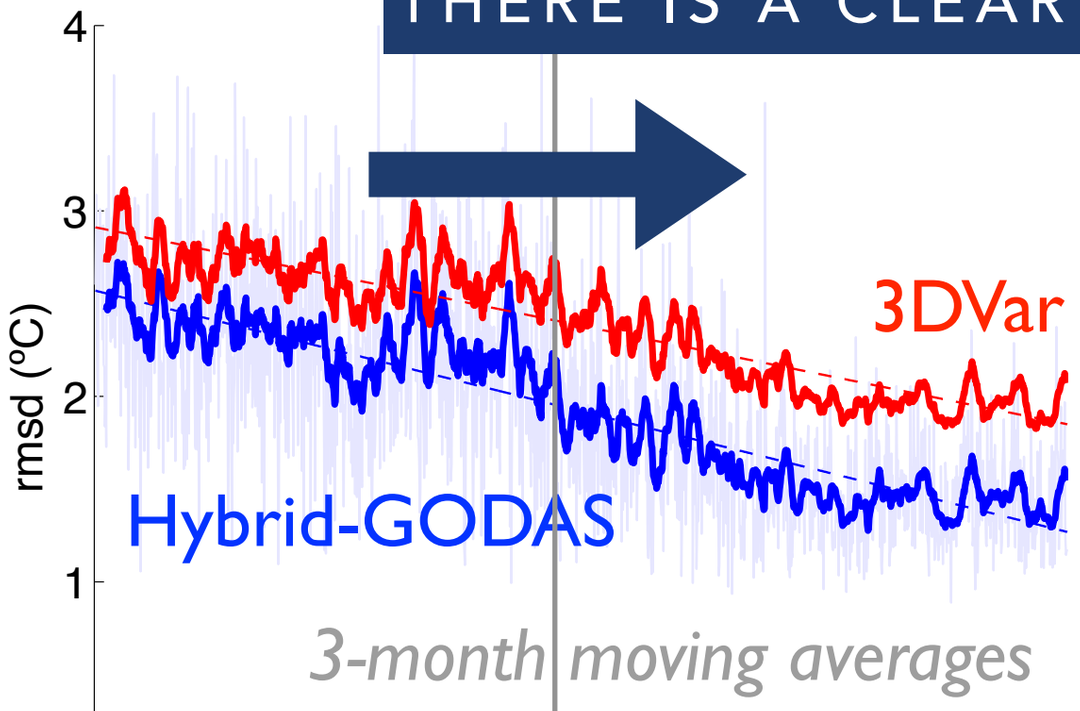
TEMPERATURE AND SALINITY (O-F) RMSD AND BIAS REDUCED USING THE HYBRID-GODAS (5-DAY FORECASTS)

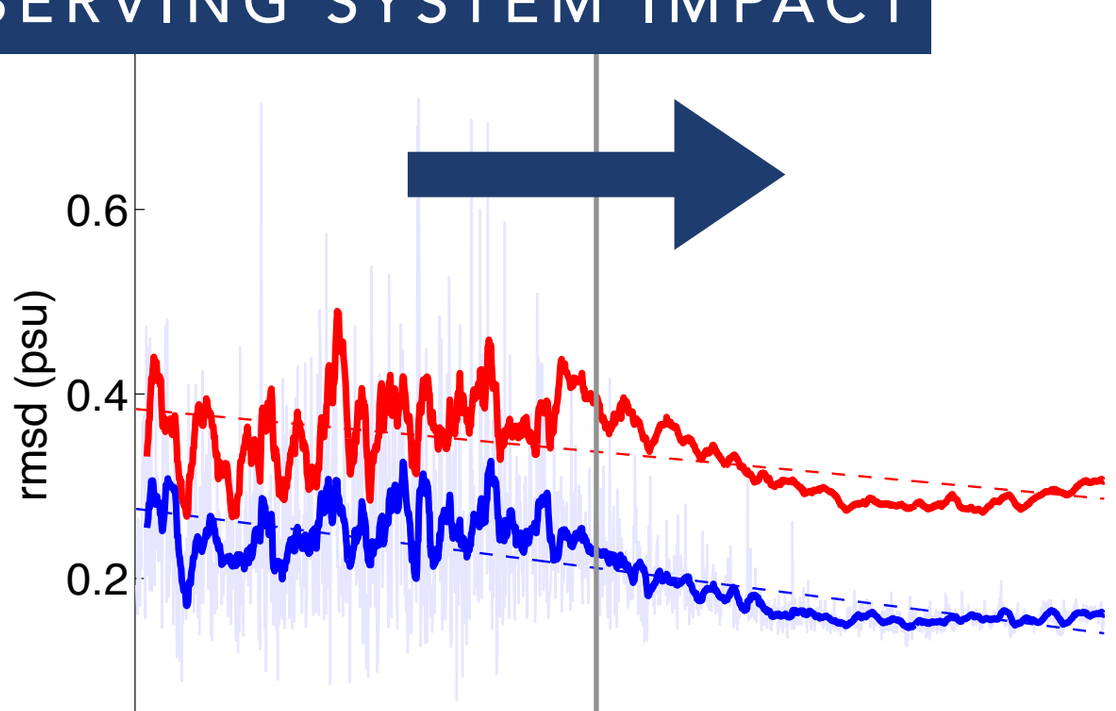




21-YEAR HYBRID-GODAS REANALYSIS

THERE IS A CLEAR OBSERVING SYSTEM IMPACT





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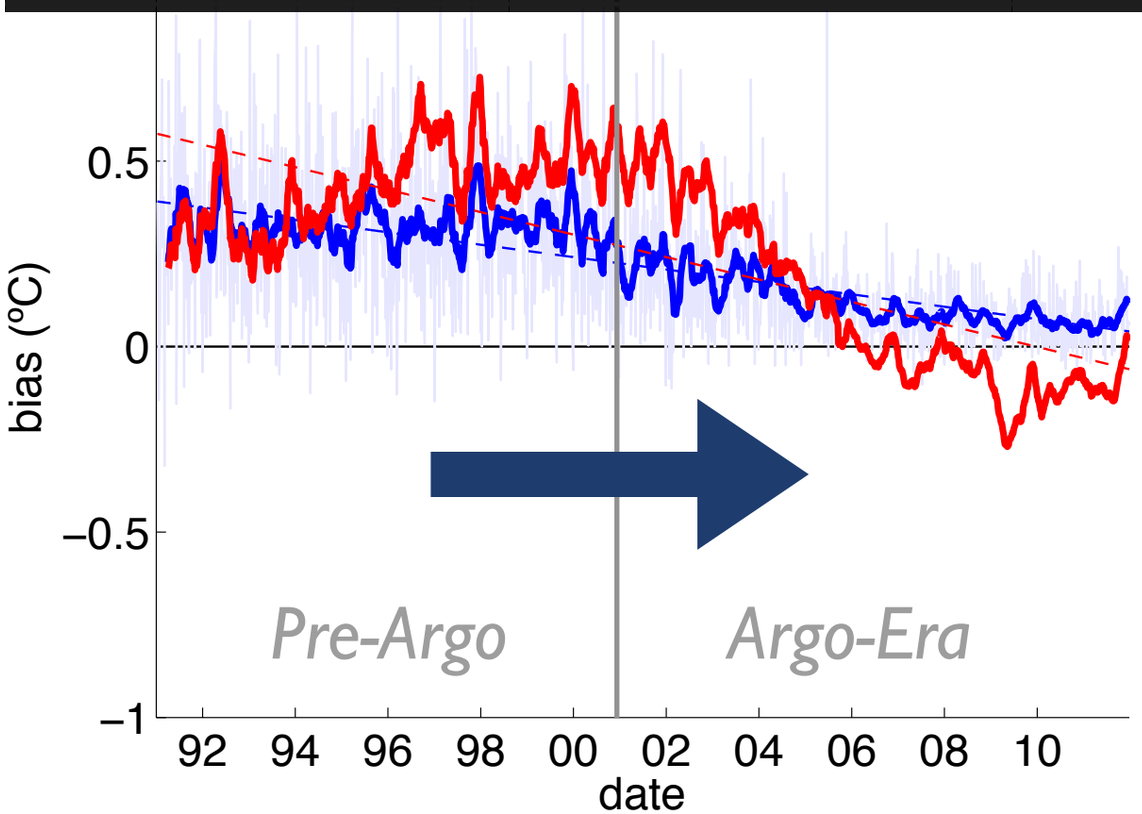

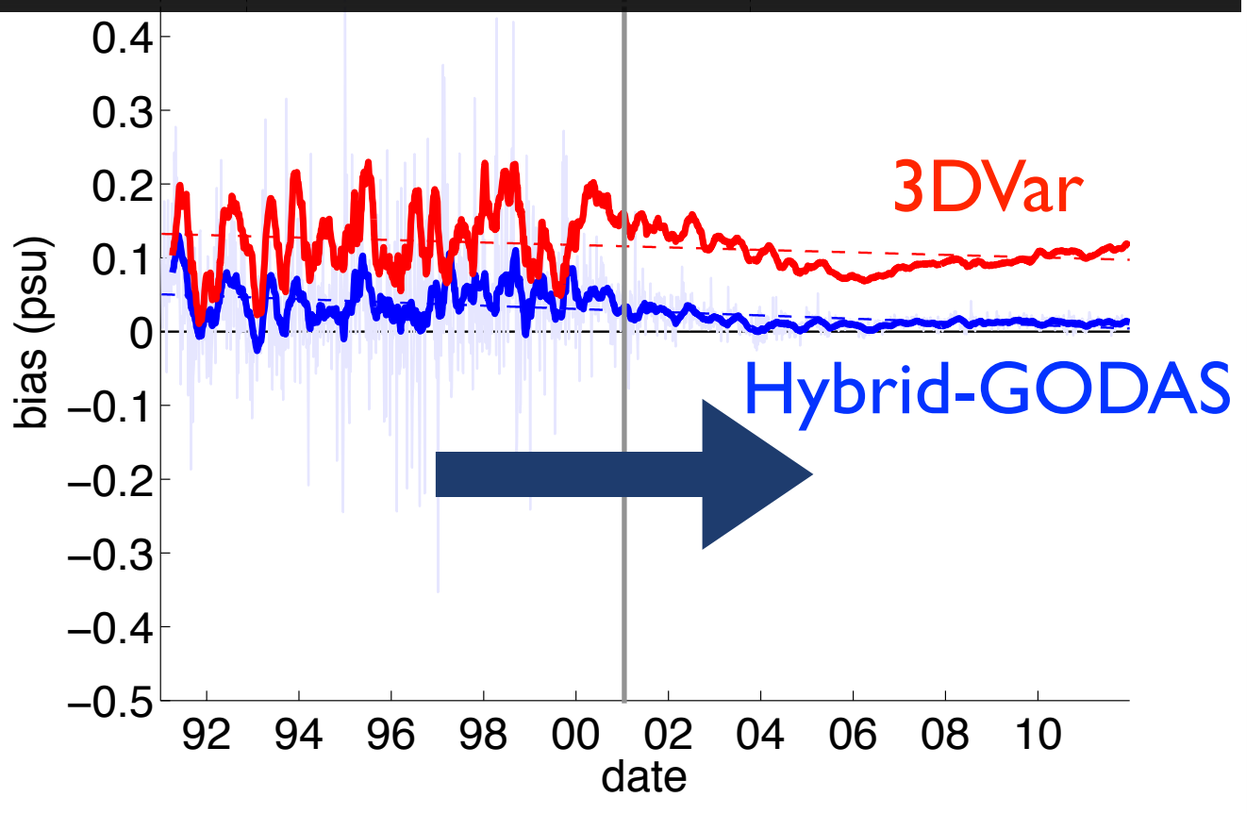

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THE EARTH IS ONE SYSTEM

- There are no boundaries, these are fictions.
- There are no ocean parameters that don't matter to atmospheric forecasts (at least on some timescale).
- NCEP is moving toward a fully coupled (via NEMS) Next Generation Global Prediction System (NGGPS) for 'seamless' ensemble-based prediction.
- That means: the same forecast system for weather, subseasonal, and seasonal timescales

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- Eliminate mental boundaries and explore ‘nearby’ disciplines.
- Observations must include those of the domain interfaces, and can and should bridge these interfaces.
- Models must revisit their boundary layer formulations

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USE ALL DATA

- The ocean is a drastically under-observed domain
- The ocean models can and must ‘learn’ from the atmosphere, land, aerosol, and sea-ice measurements
- Covariances across domain ‘boundaries’ are a statistical representation of physical processes

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‘THINK BIG’

- Stay ahead of future computing trends
- Pay attention to ‘Big-Data’ technology advancements
- Large amounts of metric data can be stored and mined for important error correlations, teleconnections, etc.

- GOES-R will produce 3.5 TB of data per day*
- The CERN Data Center processes 1 PB per day. The Meyrin site currently provides 45 PB of data storage on disk.
- The NSA’s Bumblehive is capable of storing a yottabyte of data (that’s one billion PB)**

* http://www.goes-r.gov/mission/top-five.html
** http://www.bbc.com/news/business-26383058

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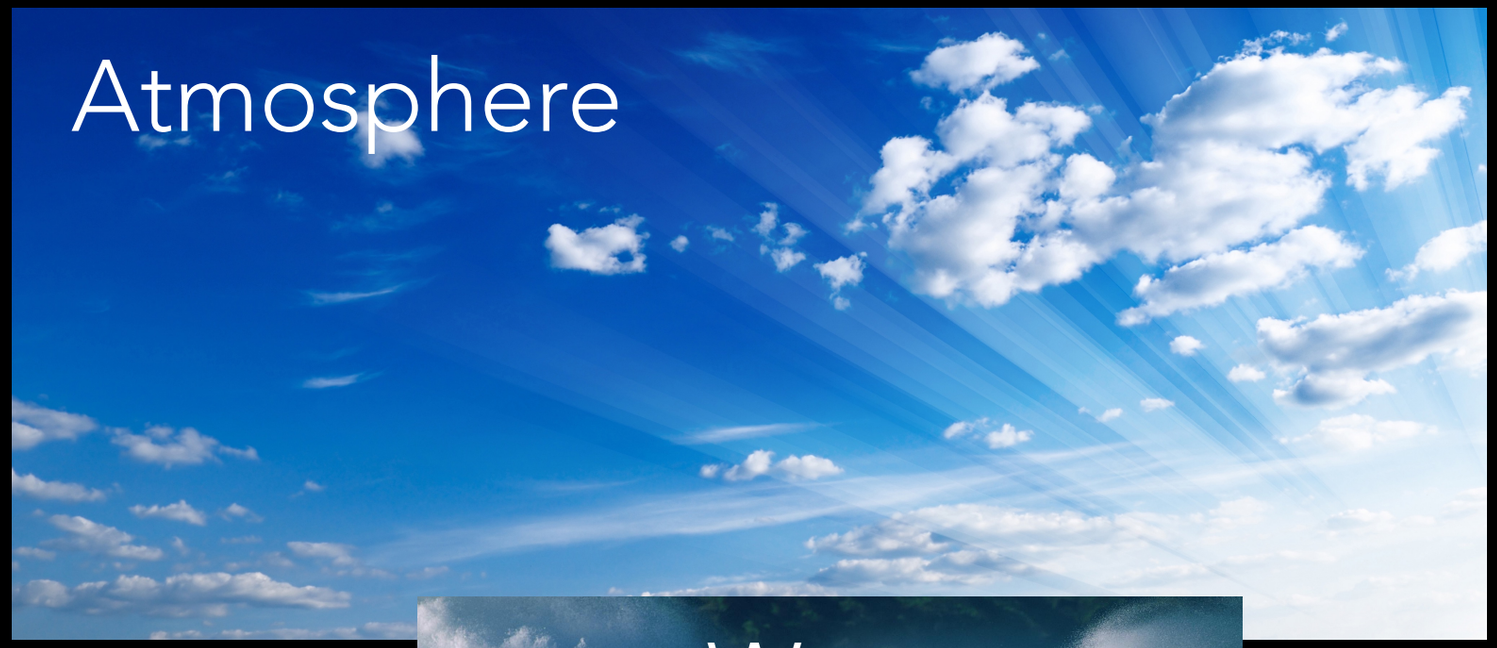
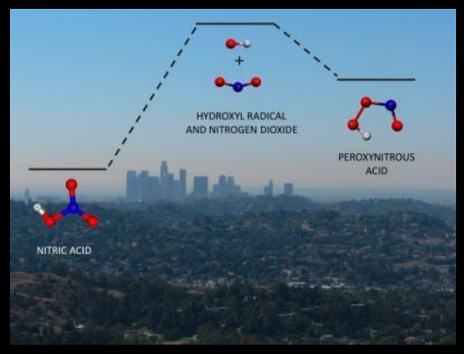
ENSEMBLE PREDICTION IS BECOMING THE STANDARD AT NCEP

- NCEP weather forecasts (today)
- Hybrid-GODAS ocean prediction (near future)
- Next Generation Global Prediction System (NGGPS) and Climate Forecast System (CFSv3) (future)
- That means uncertainty in surface fluxes (heat, momentum, freshwater), ocean parameters (SST, SSS, SLA), thermocline depth, and more, can be represented and propagated until sufficiently constrained by observations.

CLIMATE FORECAST SYSTEM V3

Atmosphere





Aerosol

Land

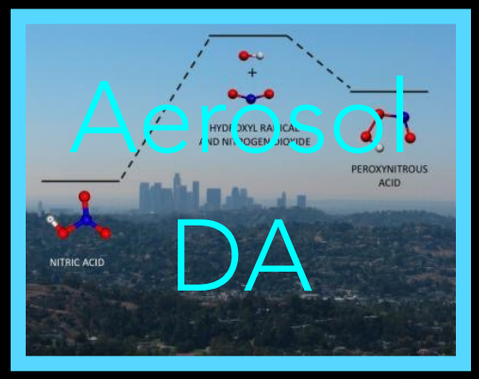
Wave

Sea Ice

Ocean

Current CFSv3
components

WEAKLY COUPLED DATA ASSIMILATION



Aerosol

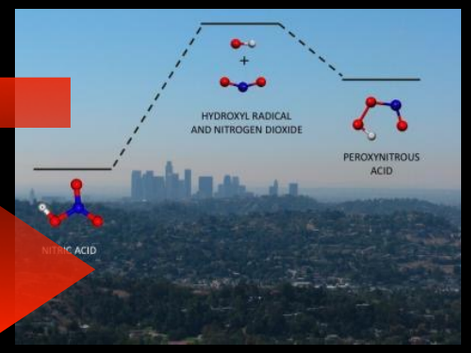
Land

Sea Ice

Current CFSv3 components

COUPLING ONLY ON FORECAST

Atmosphere



Aerosol

Land

Wave

Ocean

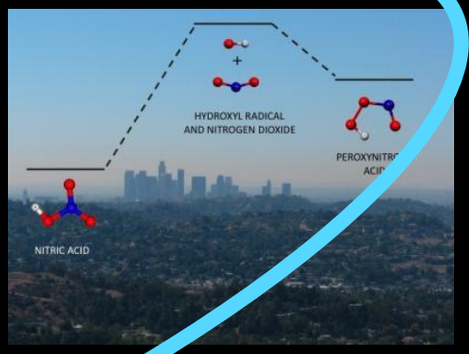
Sea Ice

Current CFSv3 components

STRONGLY COUPLED DATA ASSIMILATION

Atmosphere

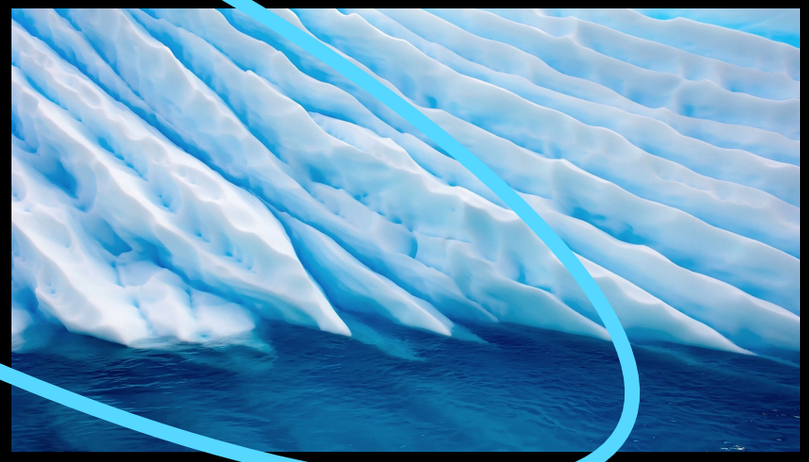
EACH DOMAIN IS INFLUENCED BY OBSERVATION INNOVATIONS FROM ALL OTHER DOMAINS



Aerosol

Land

Wave DA



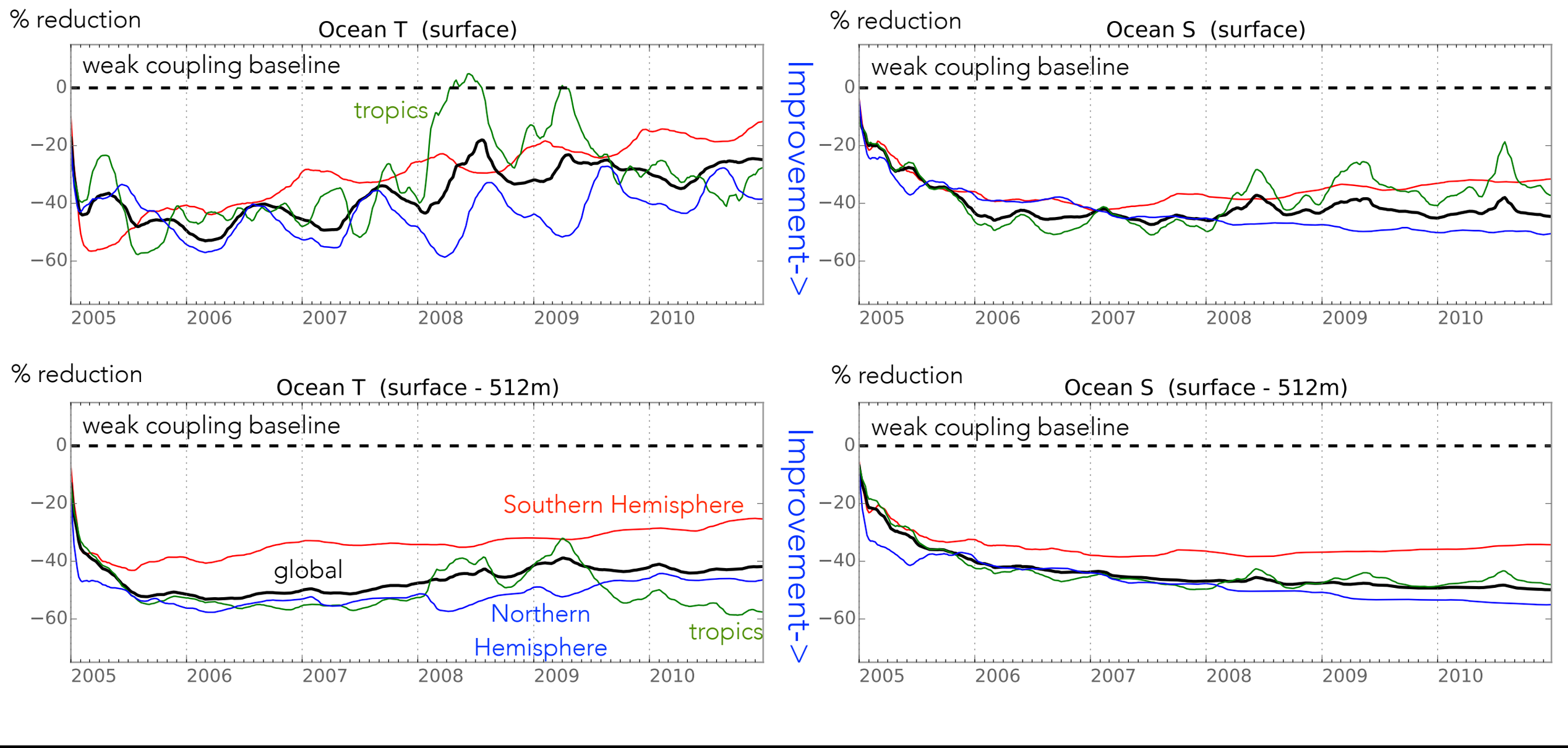
Ocean

Sea Ice

Current CFSv3 components

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

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



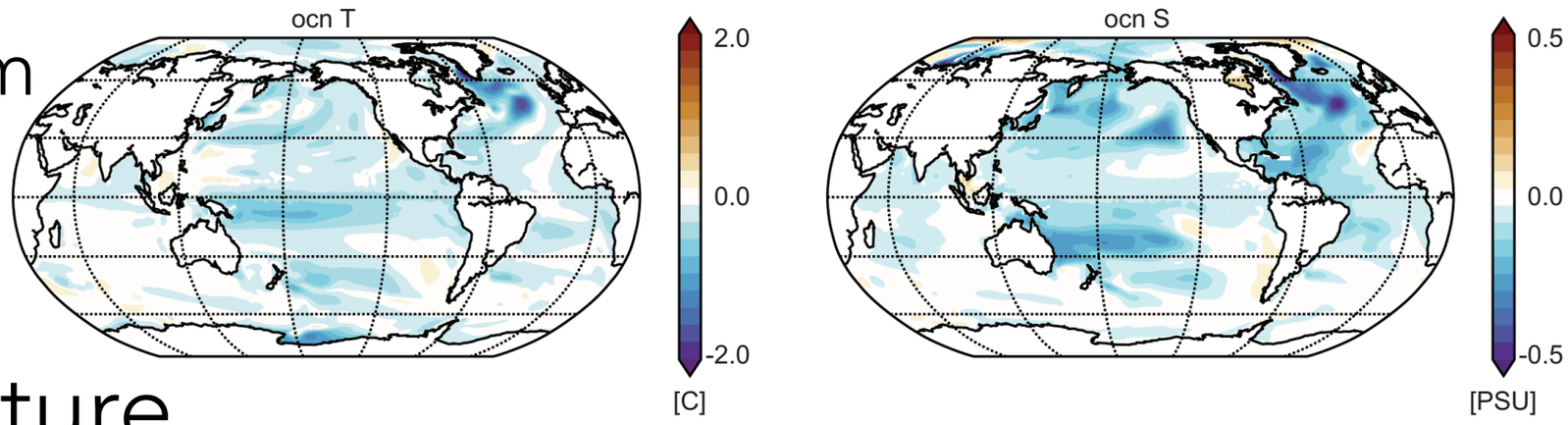
(Note: Observing System Simulation Experiments (OSSEs), not real data)

Experiments by Travis Sluka with coupled SPEEDY/NEMO, UMD PhD Student

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

Again, assimilating only atmospheric observations:

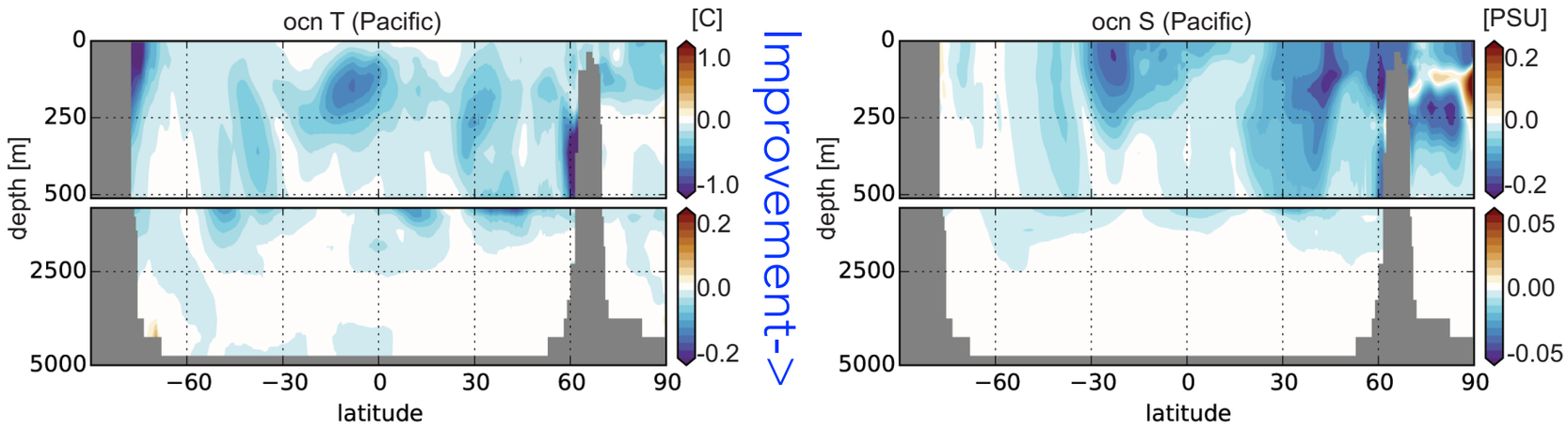
Upper 500m



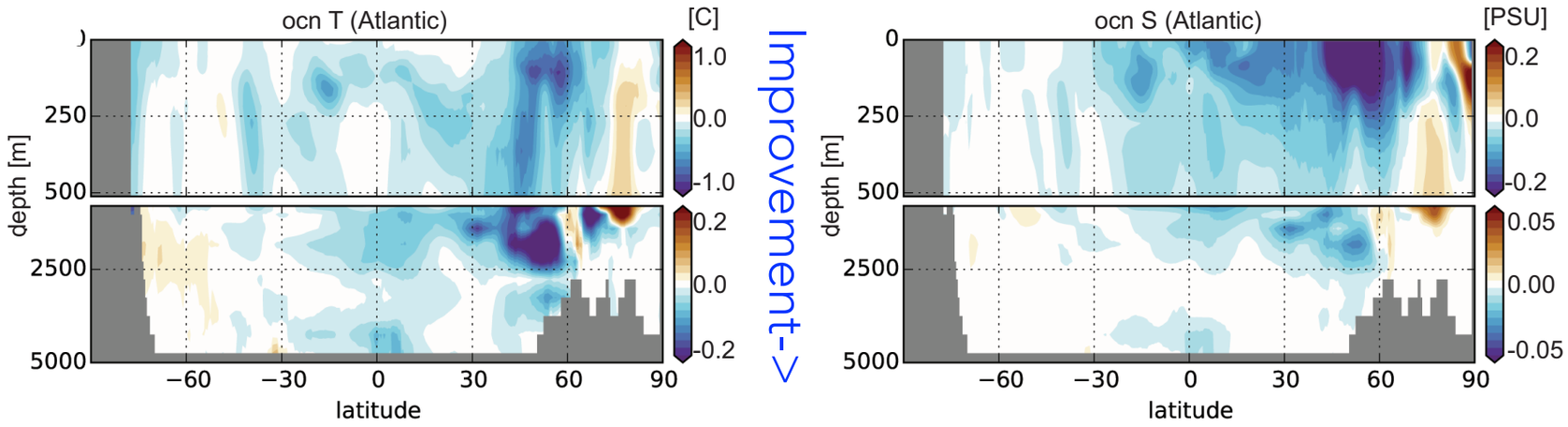
Temperature

Salinity

Pacific



Atlantic



Again, these are OSSEs. Real-data experiments with the CFSv2 will come next.

OBSERVING / MODELING GAPS

- All new instruments should have a forward model constructed (mapping a simulated earth system state to a simulated observational value)

- Comparisons between models and new observed quantities can be made more more easily

- These data can more readily be included into operational data assimilation

REALTIME DATA METRICS

- The CFSv3, for example, will produce a set of *observation-space* metrics that will be valuable for model and forecast evaluation

- For example, the following may imply:

  $||O\text{-}F||_i >> 0$ and $||A\text{-}F||_i << 1$ => poor model uncertainty

  $||O\text{-}A||_{i-1} << 1$ and $||O\text{-}F||_i >> 0$ => model off true attractor or obs error is large

  (let i = timestep)

  $EnsStDev(\{O\text{-}F\}_i) << ||O\text{-}F||_i$ => not enough dynamical instability in model

NEED DEEP OCEAN MEASUREMENTS

- The deep ocean is invisible to most operational DA implementations: neither resolved by observations or models.
- Need more, e.g.

(DEEPSEA CHALLENGER)

- Expanded Deep Argo (perhaps varying drift depths)
- North Atlantic deep convection and overflow regions
- Deep equatorial currents

NEED NEAR SURFACE MEASUREMENTS

- To best resolve the diurnal cycle:
- Need more, e.g.
  - High spatial and temporal resolution upper ocean measurements
  - Especially in the tropics
  - Evaluating surface ocean, atmosphere, and fluxes

RESEARCH NEEDS FOR IMPROVED METRICS

- Greater attention is needed toward estimating the instantaneous statistical modes

- Error in the instantaneous 1st moment (ensemble mean) creates the short-timescale model biases that compound to form long-term model drift

- Error in the instantaneous second moment (ensemble variance) leads to diverging attractors and thus to poor prediction skill

MODELING GAPS: TO SUPPORT ENSEMBLES

Last Slide!

- Mixed-resolution ensembles are inevitable. This requires statistics of the low-res models to match the statistics of the high-res model ensembles.
  (e.g. Parameterizations determining uncertainty at low resolution must correspond to uncertainties at higher resolutions. e.g. stochastic parameterizations.)

- Automated 'model output statistics' act as a transformation from the model attractor to the true attractor.
  (improvements to the hindcast/reforecast approach needed)

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