



**NCAR**

NATIONAL CENTER FOR ATMOSPHERIC RESEARCH



# Progress on the CESM ocean-atmosphere coupled data assimilation efforts at NCAR

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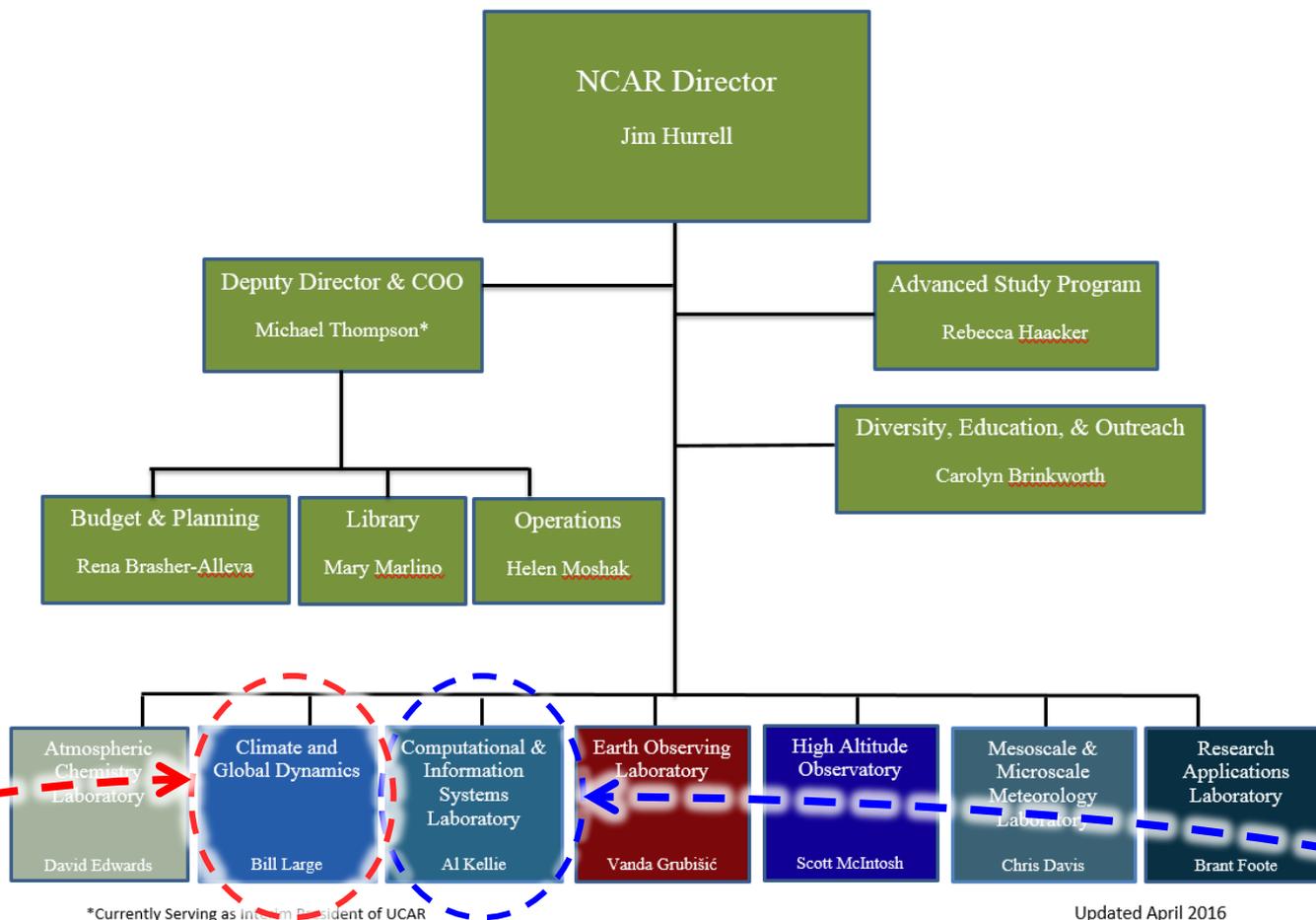
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Mariana Vertenstein, Steve Goldhaber, Brian Eaton

*CGD personnel:*

Gokhan Danabasoglu, Svetlana Karol, Joe Tribbia

# DA within the NCAR organizational structure



- Development of CESM Earth System Model
- DA applications with the CESM model

Development of generic DA algorithms/software -- "DART"

# Data Assimilation development within the Climate and Global Dynamics Lab (CGD)

*Build and support data assimilation tools and capabilities  
for the CESM research community*

Data Assimilation  
for

Climate science  
applications

including initialized  
coupled-model  
prediction\*

\*e.g.

- + Arctic sea-ice prediction
- + Subseasonal prediction
- + Seasonal prediction
- + Decadal prediction

- We *\*do not\** have mandated operational assimilation or prediction responsibilities
- This gives us the flexibility to explore challenging or high-risk projects that are relevant to the broader community --- on a shoestring!

# Modularity in Model and DA framework

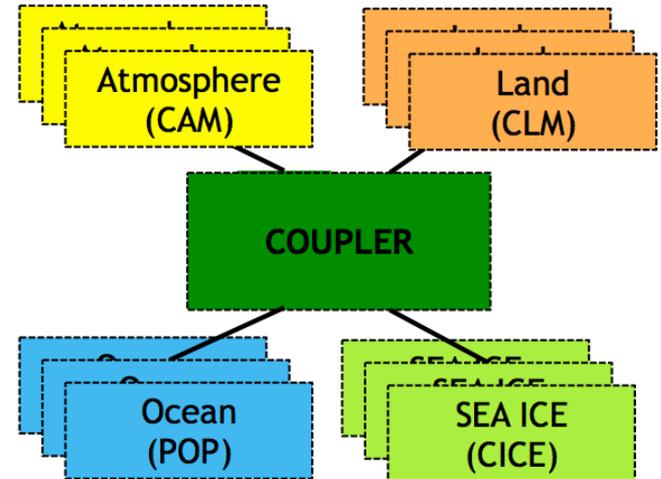
Ensemble  
Data Assimilation  
"DART"



## Modular data assimilation:

- Can be used with ANY model or combination of models
- Can be used with any observational data source (provided a forward operator can be coded)
- Can be used to test different algorithms (only ensemble-based at this point)
- Leverage methodological advances across a wide community

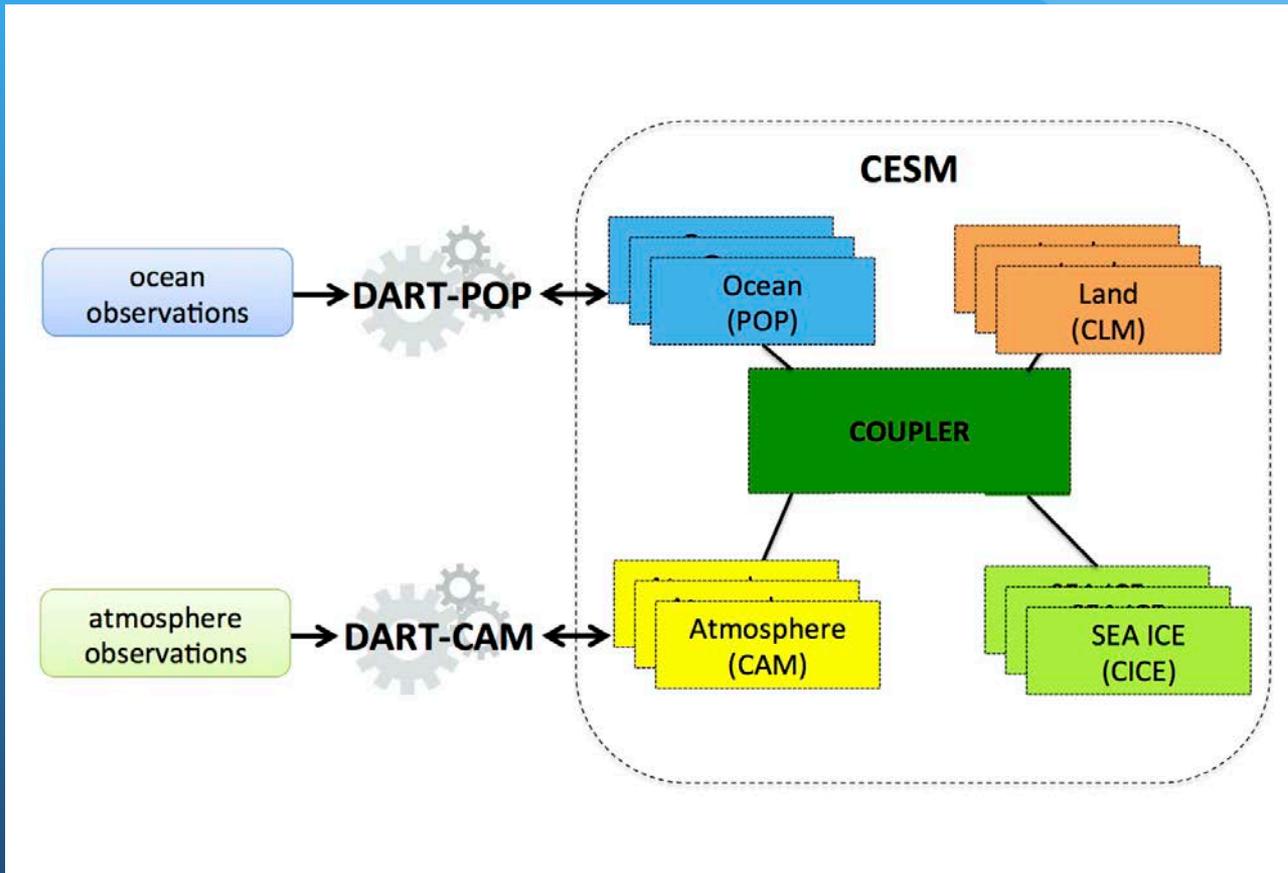
## Community Earth System Model



## Modular Earth System Model:

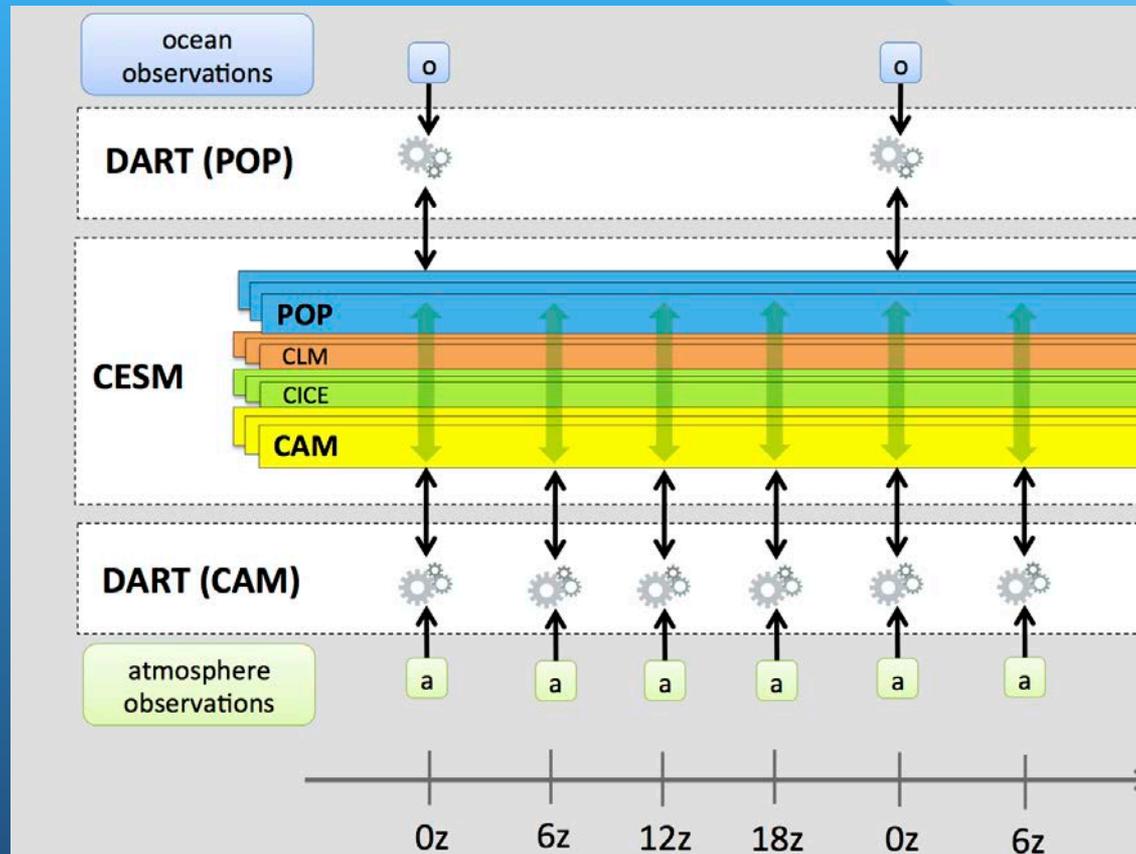
- Can be configured with different components of the climate system
- Different versions of the same component
- Broad community of scientific users from which to draw expertise

# Schematic of the CESM-DART weakly-coupled data assimilation



- ❖ Coupler exchanges fluxes between component models
- ❖ “weakly-coupled” DA system keeps operates separately for ocean and atmosphere

# Time-sequencing of the CESM-DART weakly-coupled data assimilation



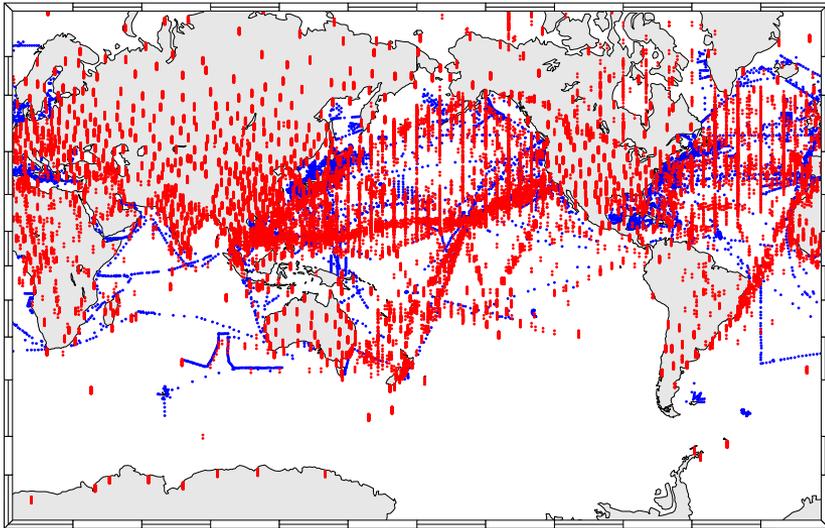
- ❖ Coupler exchanges fluxes between component models
- ❖ “weakly-coupled” DA system keeps operates separately for ocean and atmosphere

## Summary info on the CESMDART prototype weakly-coupled assimilation experiment

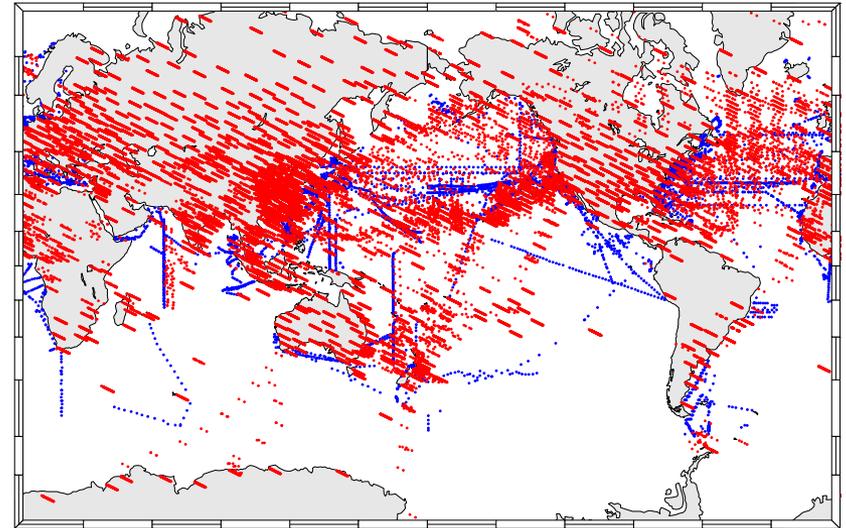
- Model** → CESM1 global coupled ocean/atm/ice/land  
Resolution: nominal 1° horizontal  
Vertical resolution: CAM5 30 levels  
POP2 60 levels  
6 hour ocean/atm coupling
- DA method** → 30 member "DART" ensemble adjustment Kalman filter (EAKF),  
"weakly coupled" framework
- Experiment interval** → 1970-1981
- Ocn obs** → 24 hour window in-situ temp and salinity  
[XBT, MBT, CTD, drifters, moorings, ARGO floats, ocean station]  
currently no SST products, no altimetry
- Atm obs** → 6 hour window temp and winds  
[radiosondes, aircraft, satellite drift winds, GPSRO-COSMIC,  
ACARS]  
currently no moisture, surface marine data, surface pressure,  
or radiance

# Representative in-situ network for one month in the mid-1970's

Network of ocean and atmosphere observations assimilated  
July 1971



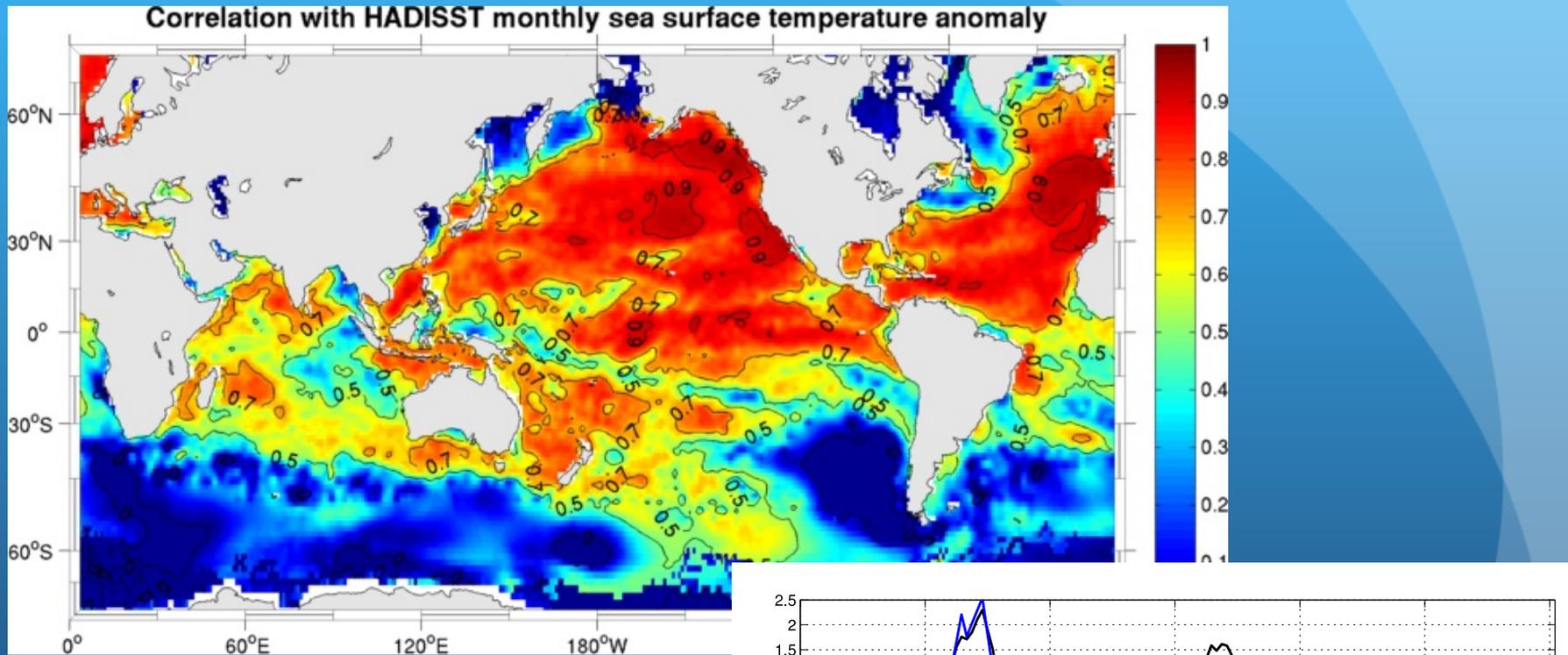
Network of ocean and atmosphere observations assimilated  
Jan 1975



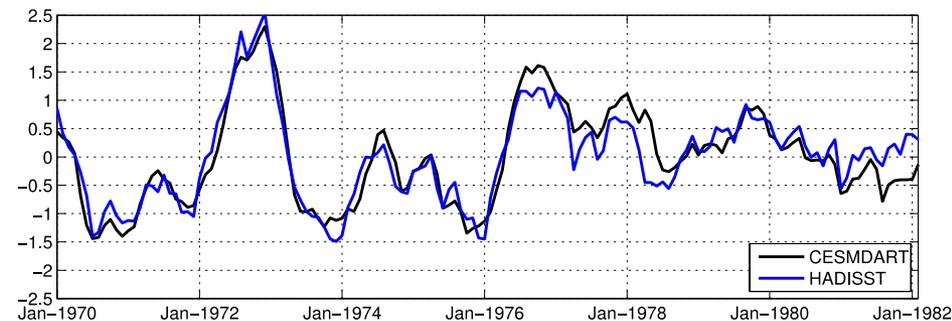
Red: atmospheric obs  
Blue: ocean obs

\*No SST products used

# Selection of results: monthly SST anomaly



High (anomaly) correlation  
with HADISST in the  
Northern Hemisphere  
\* SST product not assimilated

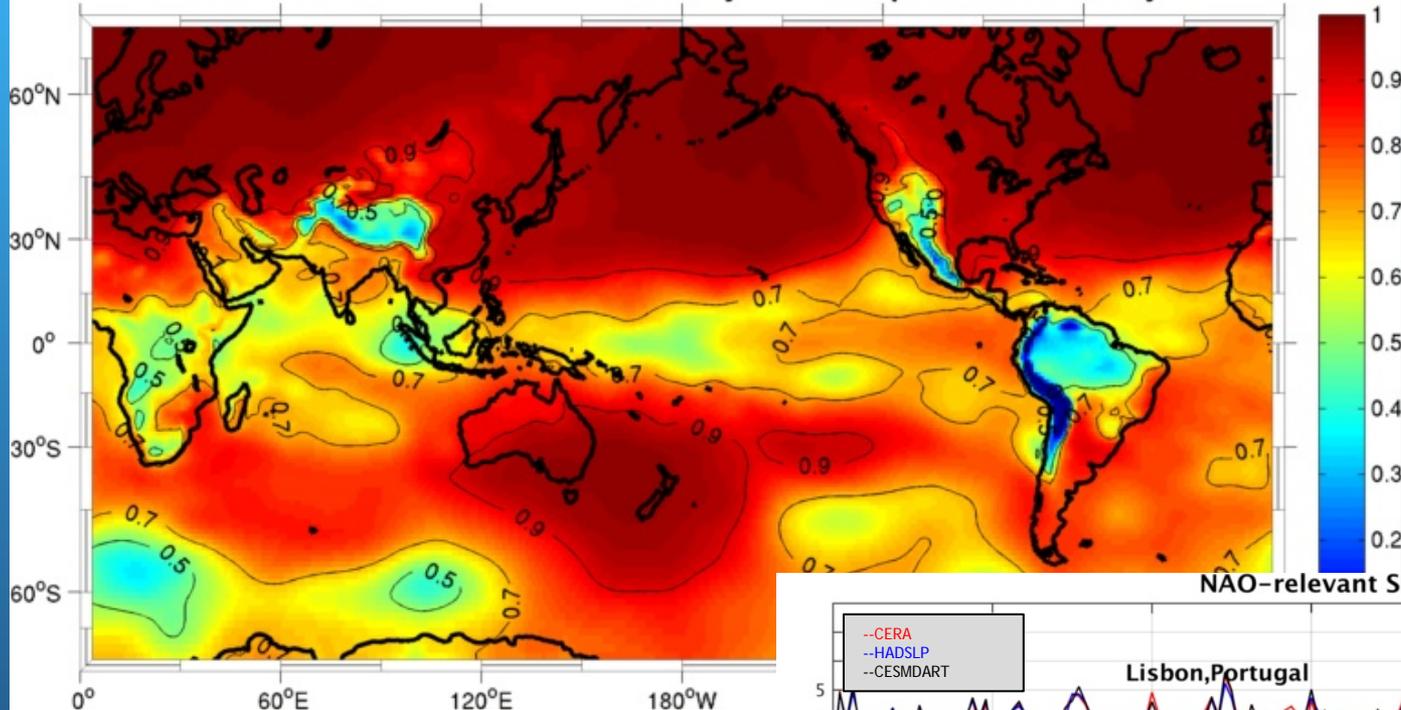


ENSO variability simulated

[1970-1981]

# Selection of results: monthly SLP anomaly

Correlation with CERA-20C monthly sea level pressure anomaly

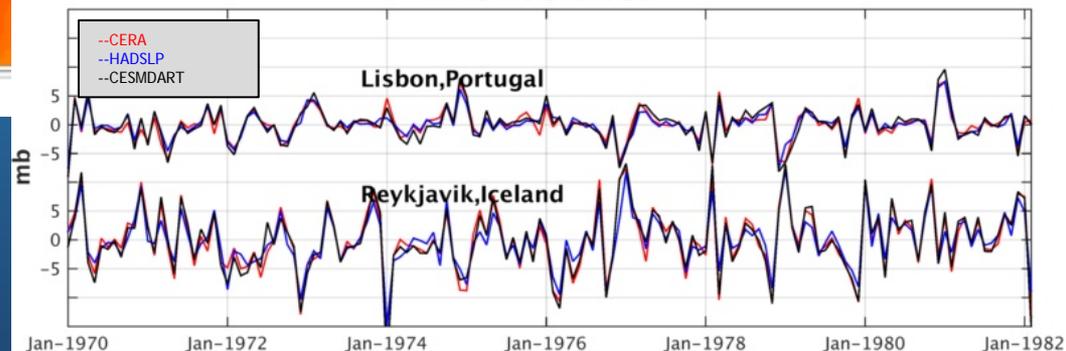


High anomaly correlation  
with existing SLP products  
in the Northern Hemisphere

\*SLP not assimilated

[1970-1981]

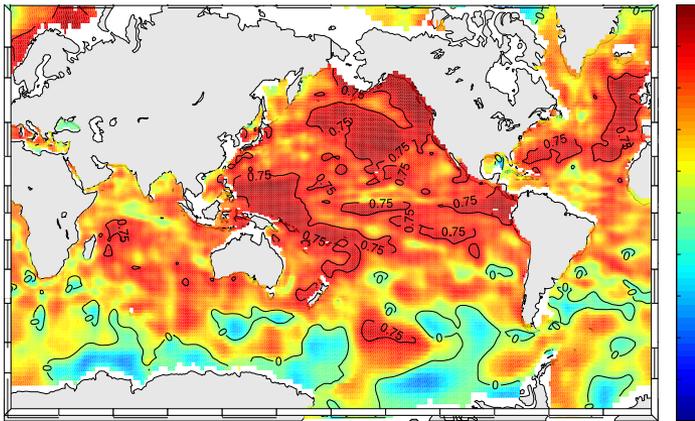
NAO-relevant SLP



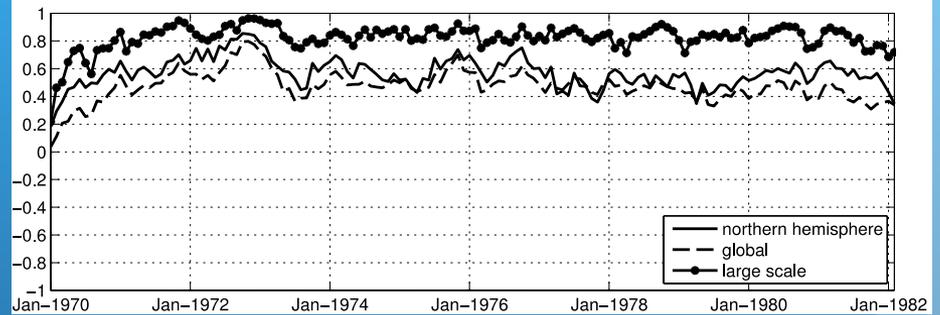
NAO variability simulated

# Monthly averages: Comparison to EN4 subsurface ocean OI product

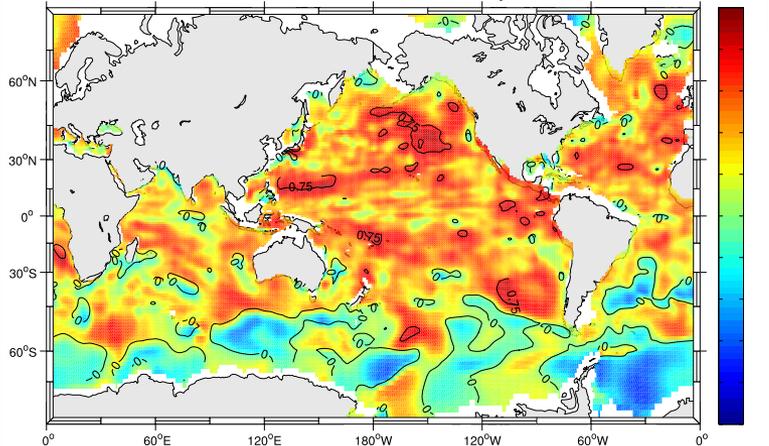
time correlation w/ EN4 upper 250 m temperature



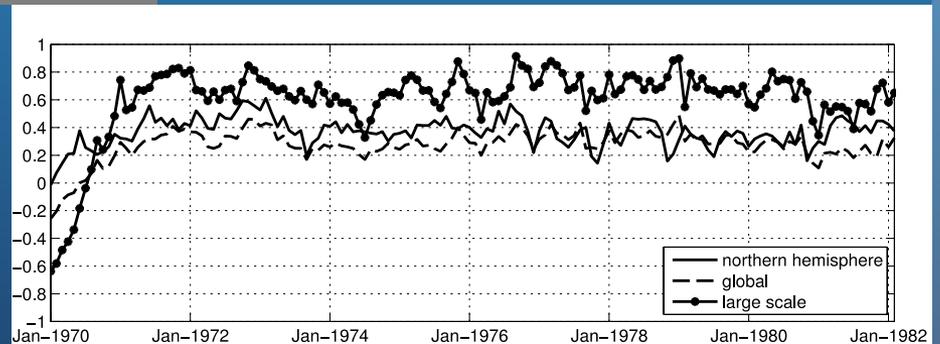
0-250m



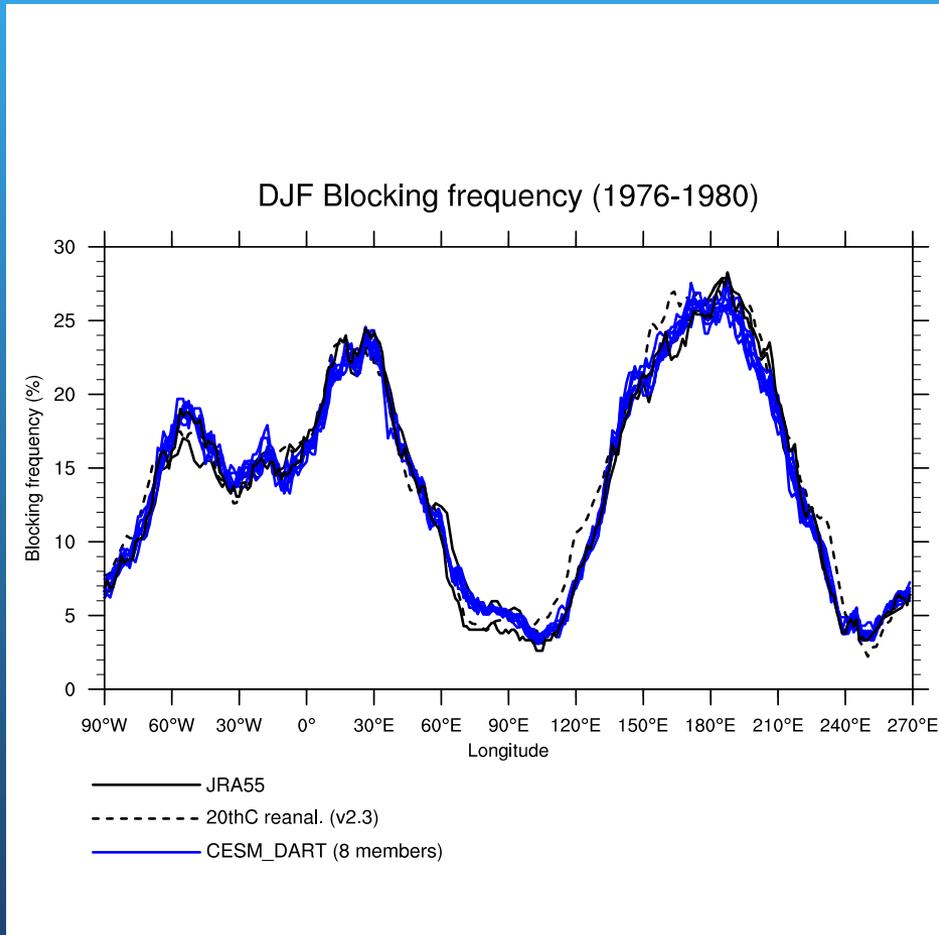
time correlation w/ EN4 250-500 m temperature



0-500m



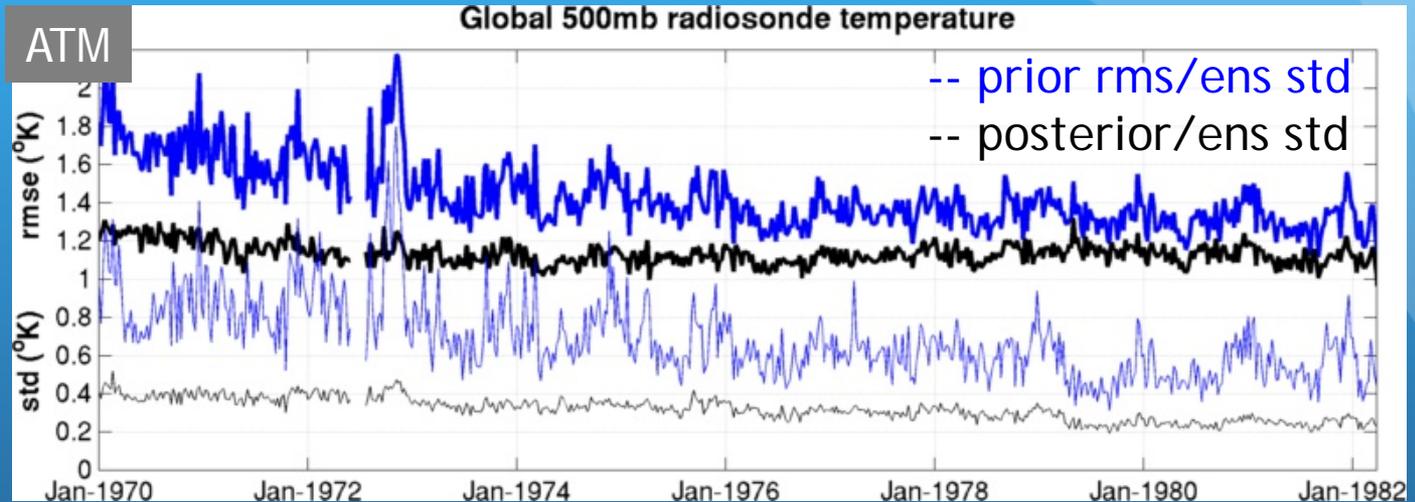
# Atmospheric blocking comparison with 20CR and JRA 55:



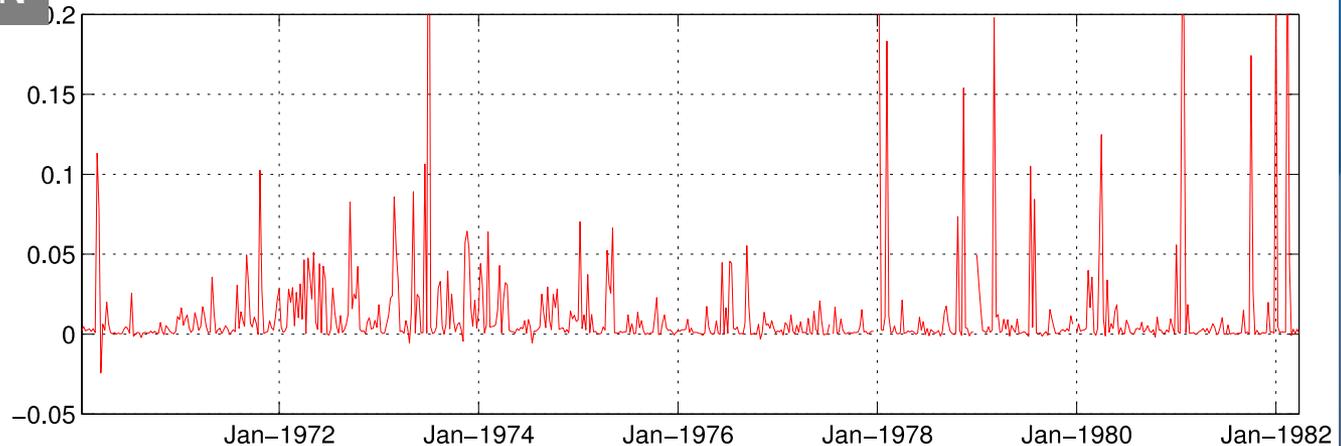
Blocking frequencies similar to 20CR and JRA55

*Plot courtesy of R. Neale, NCAR*

# observation space diagnostics



OCN



# Observation-space performance benchmarked to published estimates from existing products



+ JRA55 (atm-only)  
6-hr background forecast  
(Fig 8; Kobayashi et al. 2015)

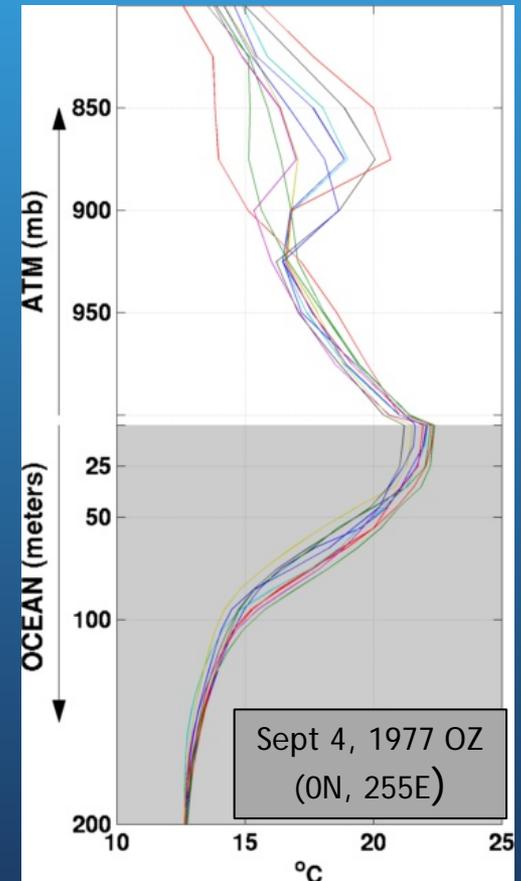
O ERA40 (atm-only)  
9-hr NH 12z background forecast  
(Fig. 8; Uppala et al. 2015)

X CFSR/NCEP (weakly-coupled)  
9-hr background forecast  
(Fig. 3; Saha et al. 2010)

- prior (6-hr forecast)  
- posterior  
-- 24 hr persistence

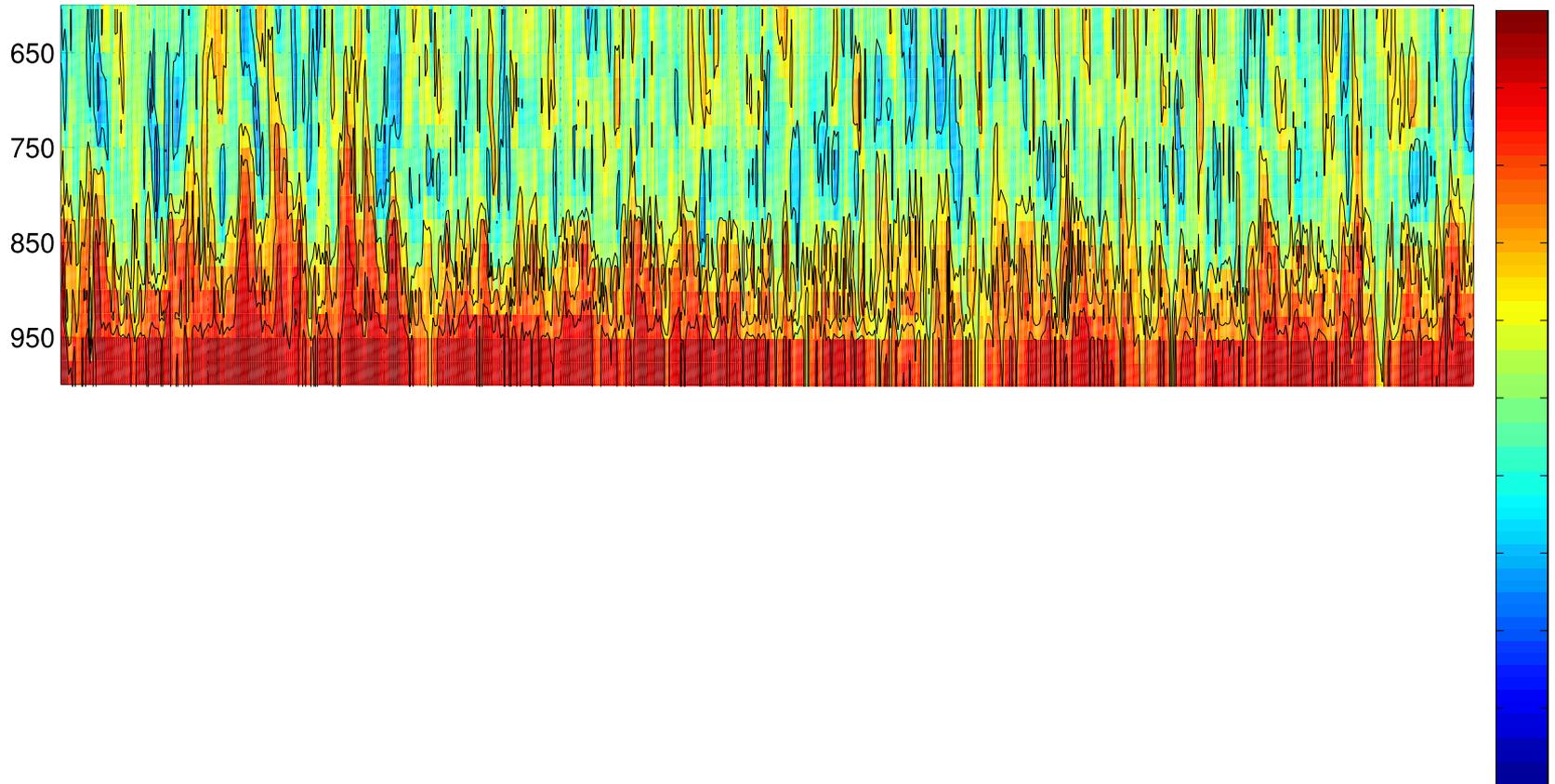
# Diagnosing the cross-interface ensemble correlations from the weakly coupled system

- The forecast ensemble correlations can be diagnosed as they evolve in time.
- Indicate where there may be potential for a benefit from strongly-coupled system.



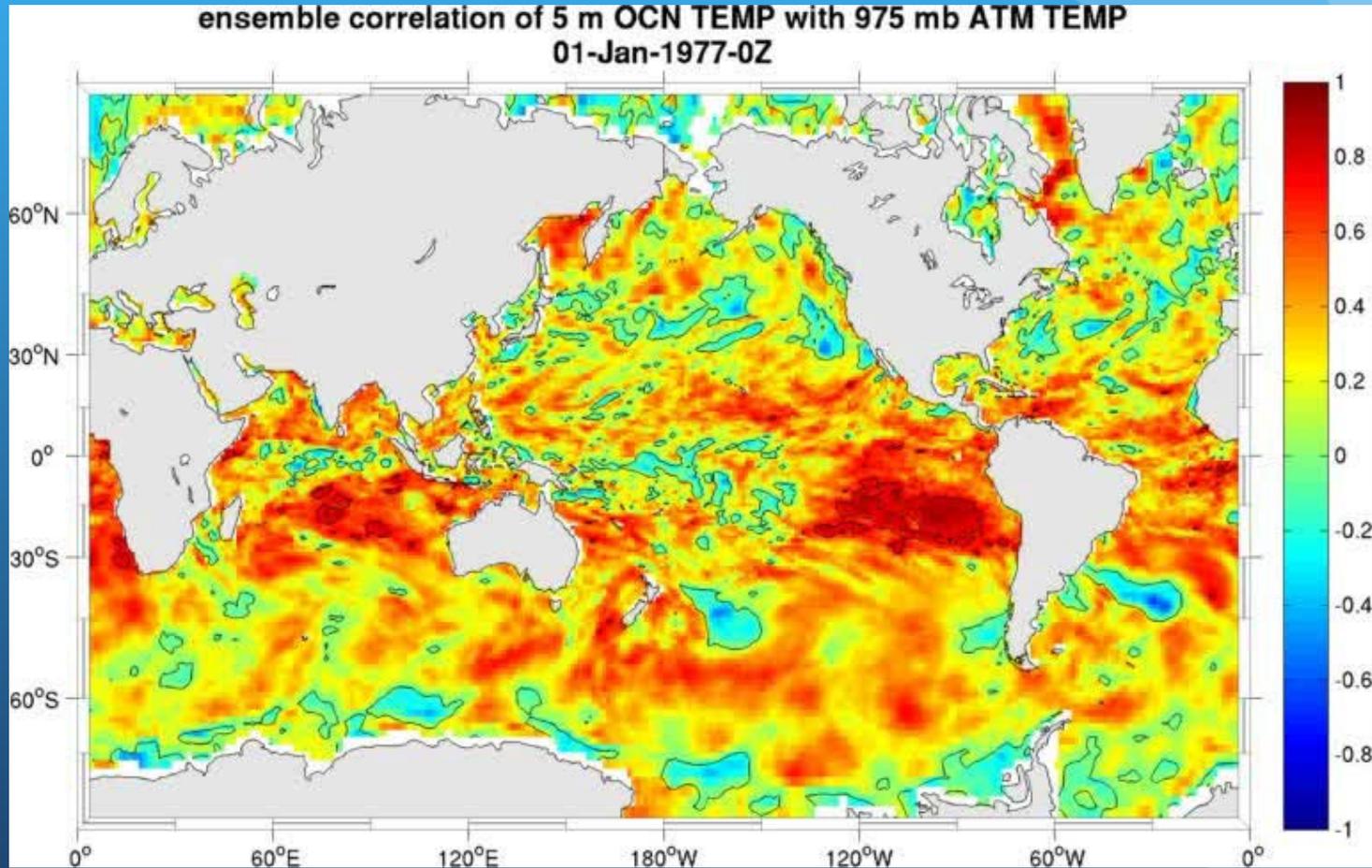
# vertical correlation 5 m ocean T in tropical S. Pacific

correlation with 5 m ocean temperature  
@ 15°S, 105°W

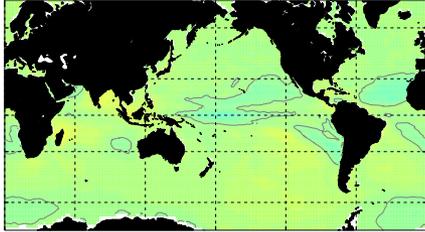


*Instantaneous ensemble correlations reveal the different time scales and dynamics within the ocean and atmosphere and highlight the non-stationarity of coupled covariances.*

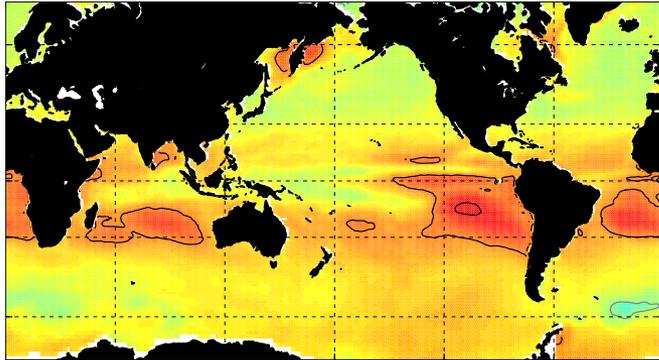
# 1 year of vertical correlations diagnosed from weakly-coupled CESMDART



# Time-average correlation



# Seasonal cycle (5m ocean temp 1000mb atm temp)



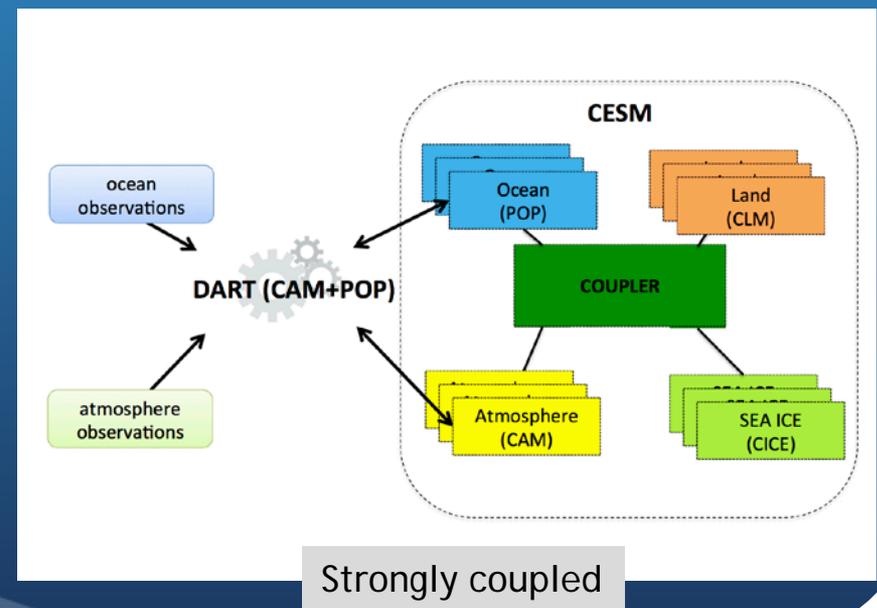
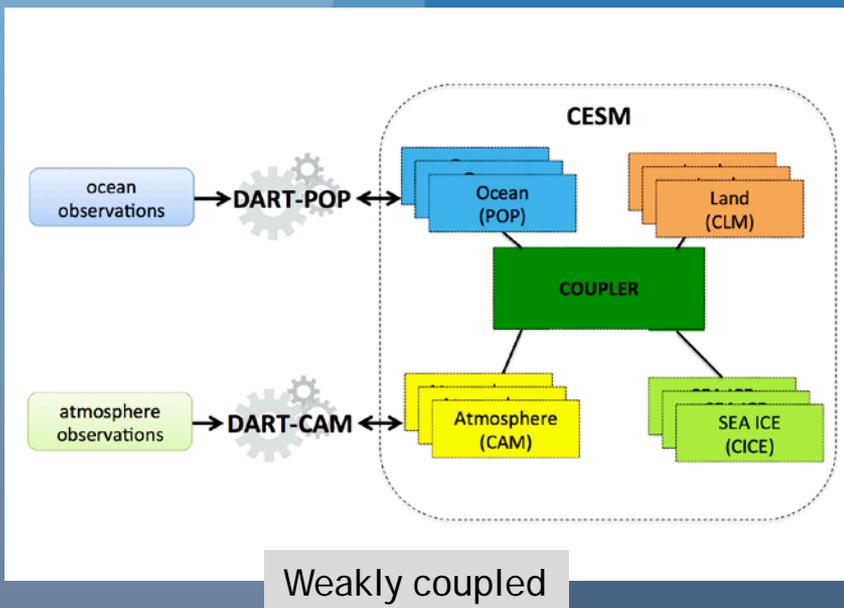
$$r(U_{\text{atm}}, T_{\text{ocn}})$$

$$r(V_{\text{atm}}, T_{\text{ocn}})$$

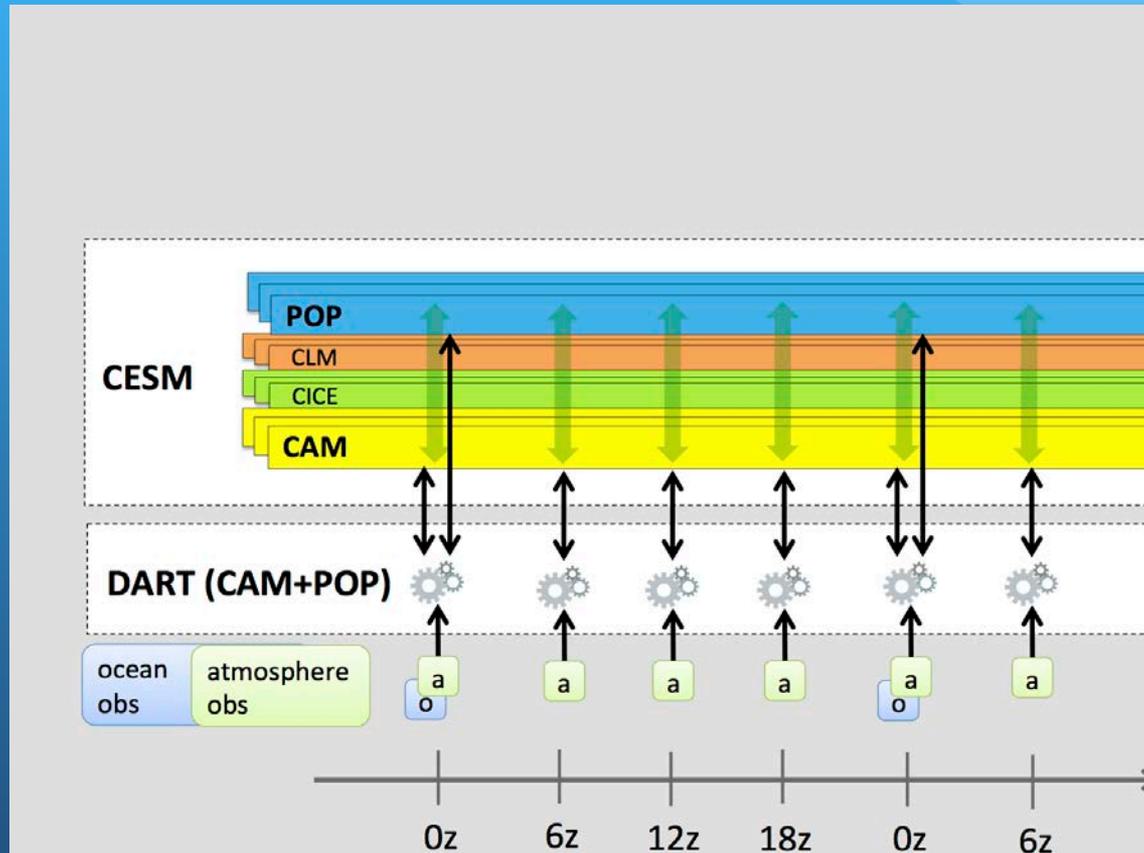
*Indicates that incrementally cooler surface temperatures are associated with stronger wind-speed*

# Expanding CESM-DART capabilities toward strongly-coupled data assimilation

- From a software perspective this is a (relatively) straightforward extension of the DART state-vector from single to multiple components
- 6 month strongly-coupled assimilation experiment (Jan-July 1980) for comparison to weakly-coupled prototype experiment

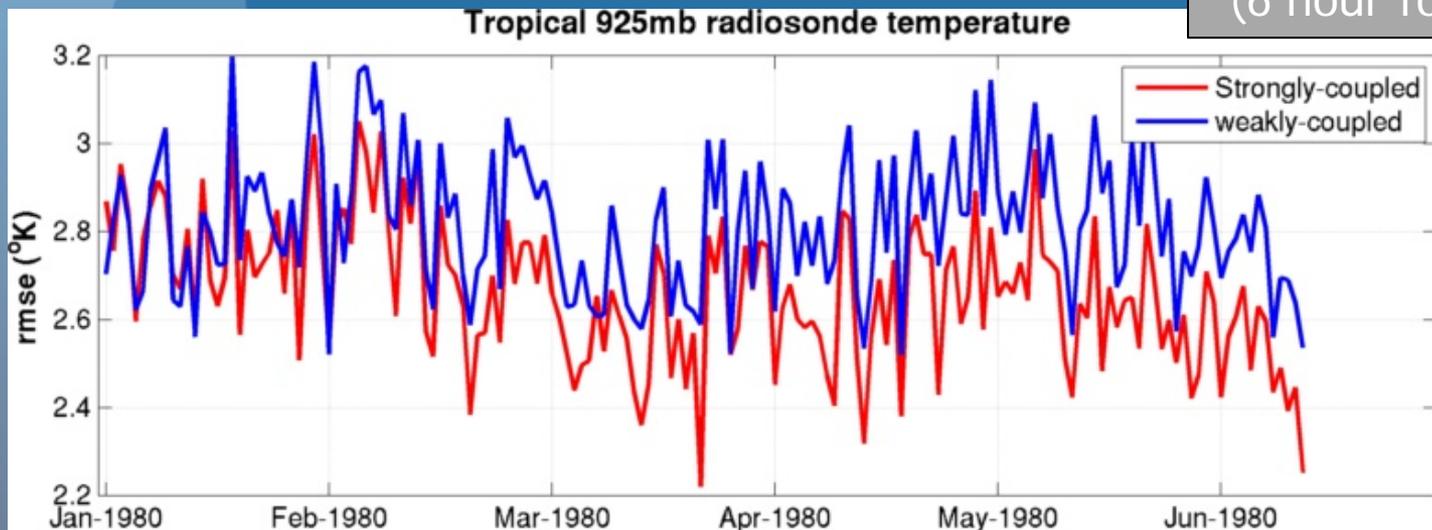
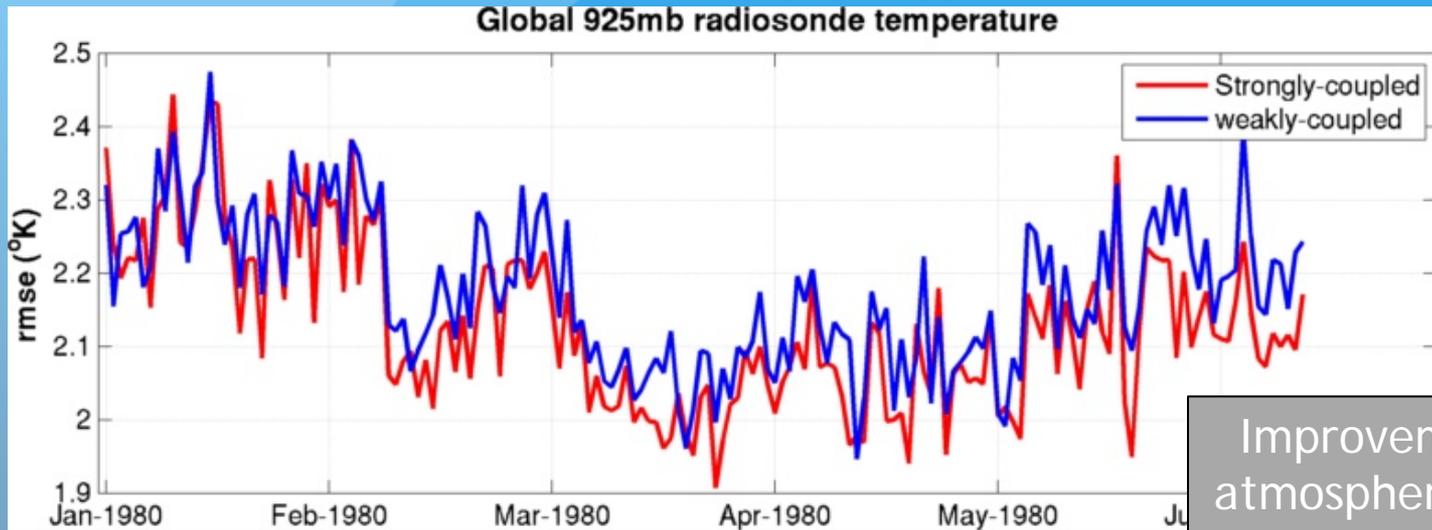


# Time-sequencing of the CESM-DART strongly-coupled data assimilation

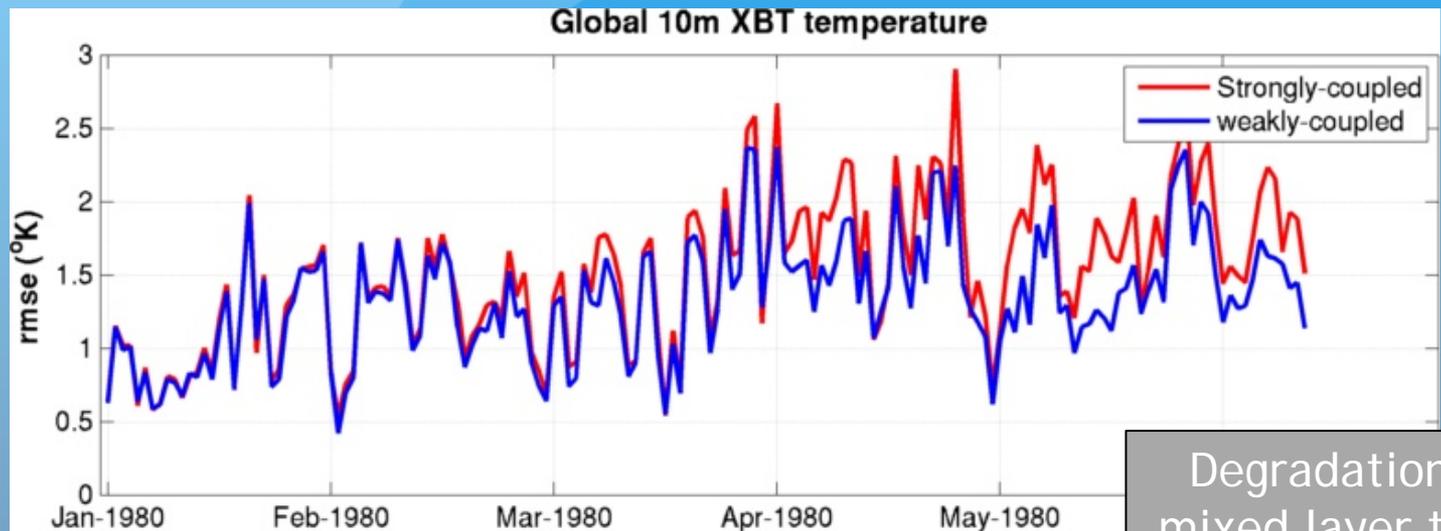


- ❖ Coupler exchanges fluxes between component models
- ❖ “weakly-coupled” DA system keeps operates separately for ocean and atmosphere
- ❖ “strongly-coupled” DA system allows observations to impact across interface

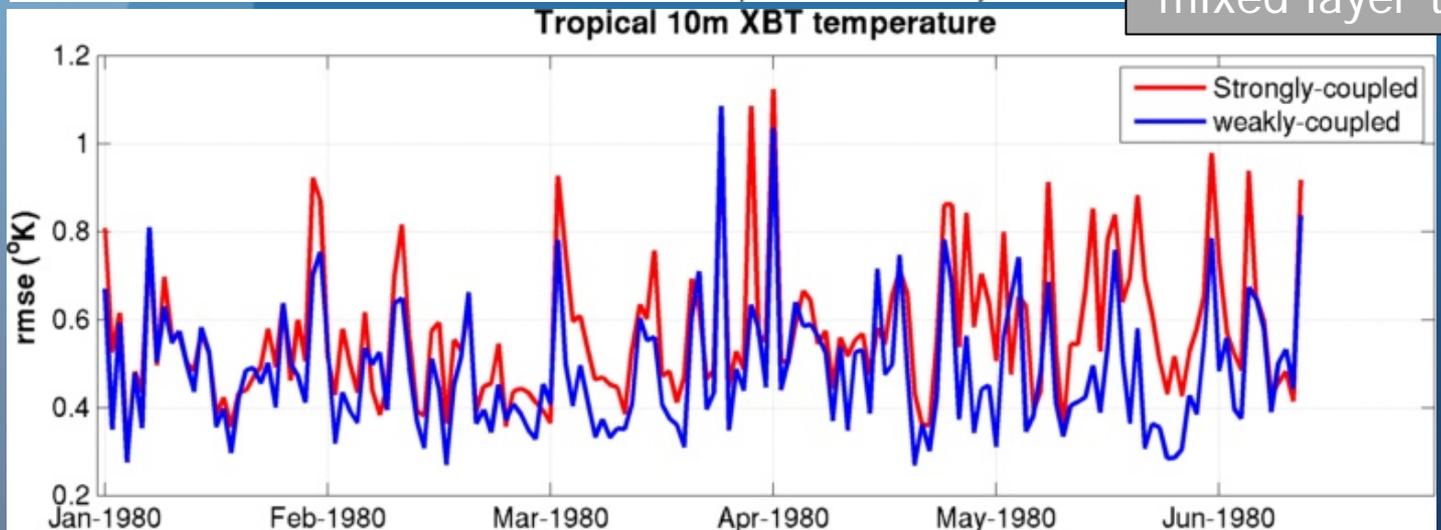
# Preliminary results from strongly-coupled data assimilation



# Preliminary results from strongly-coupled data assimilation



Degradation of mixed layer temp



How can we interpret this result?

## Interesting data-point but inconclusive

### Could be an artifact of the experiment:

- Difficult to control the spread of our ensemble such that they were approximately equal in weakly and strongly coupled systems.
- Experiment is too short
- We don't understand the effect of ensemble size (sampling error) on this result

### Could be a robust result:

- Indication of model covariance bias relative to reality?  
Atmospheric constraints may be effectively adjusting the upper ocean to a preferred (but wrong) state

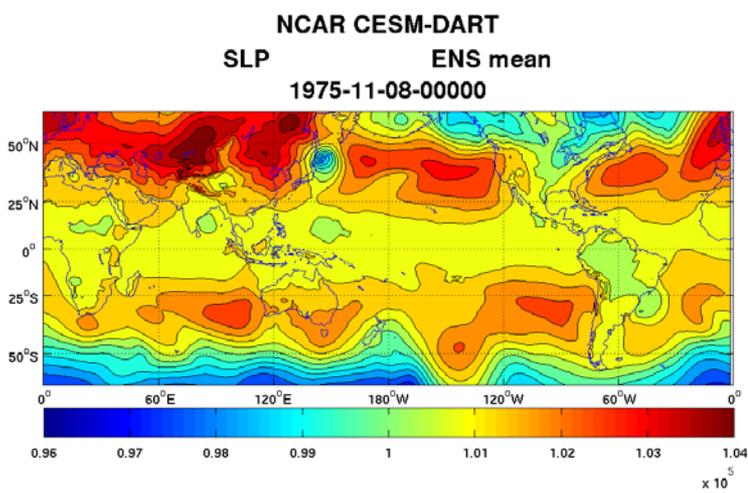
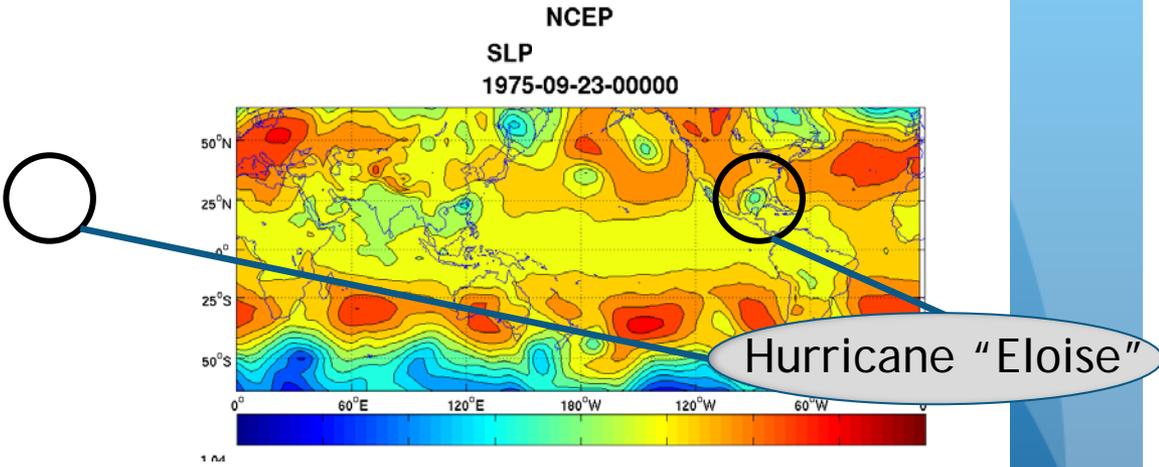
## Summary statements

- “Weakly coupled” CESMDART results are promising
  - Efforts to reduce the cost of our system to facilitate more rapid research cycles has become a priority.  
(see me for details)
- Preliminary tests with “strongly coupled” DA reveal the complexity of the problem.
  - Highlights research needs into
    - cross-interface localization strategies (see me for a discussion of how we did this)
    - covariance inflation strategies that satisfy the needs of each components.

Questions/ideas/comments contact: [aliciak@ucar.edu](mailto:aliciak@ucar.edu)

Extra slides

# 6hr SLP visual comparison to NCEP/R1



X10<sup>3</sup> mb

5m

45m

95m

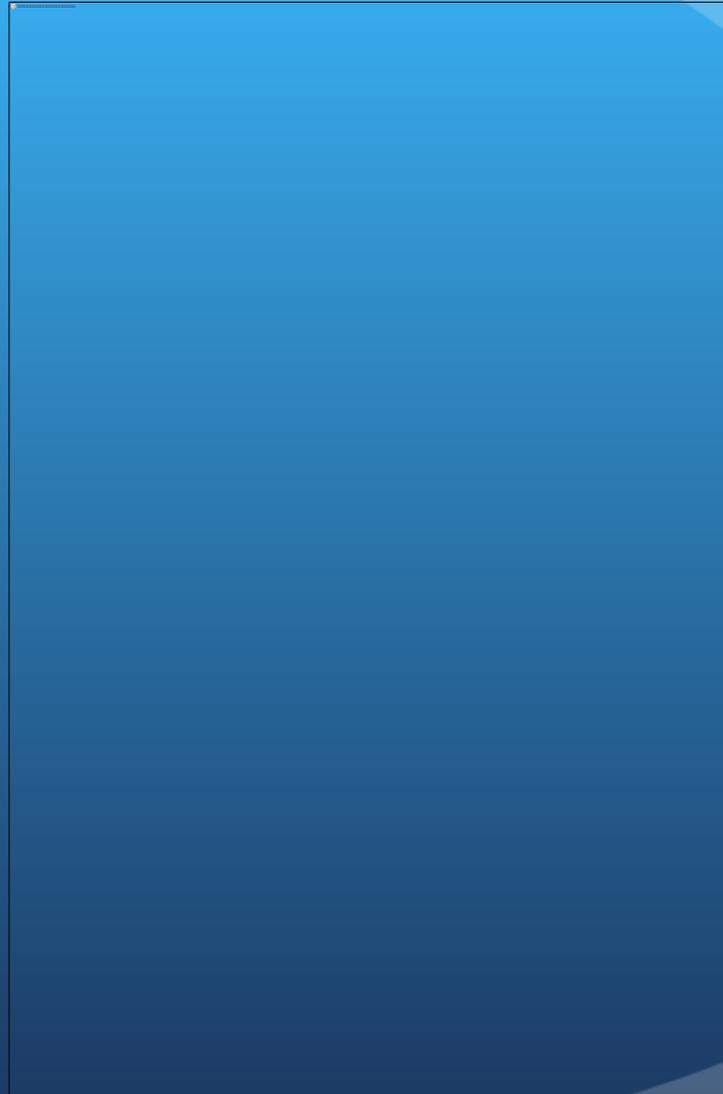
Results from  
strongly-coupled experiments:  
Ocean increments

\*Contour at 0.01 °C

percent of days with correlations  $> .25$



# Example of non-stationarity in the ocean/atm: Tropical Instability Waves



# Examples of physical continuity across the ocean/atm interface

