Ongoing work in coupled data assimilation in POP/CESM2 and beyond

Dan Amrhein, Ben Johnson, Gokhan Danabasoglu, Jeff Anderson

with Tim Hoar, Kevin Raeder, Nancy Collins, Moha el Gharamti,
Fred Castruccio, Steve Yeager, Alicia Karspeck

NCAR CGD / CISL

Talk outline

Motivation for ocean and climate data assimilation in CESM

Previous and ongoing work on ocean and weakly coupled DA

First results from an updated CESM DA configuration

Challenges and opportunities for coupled climate DA

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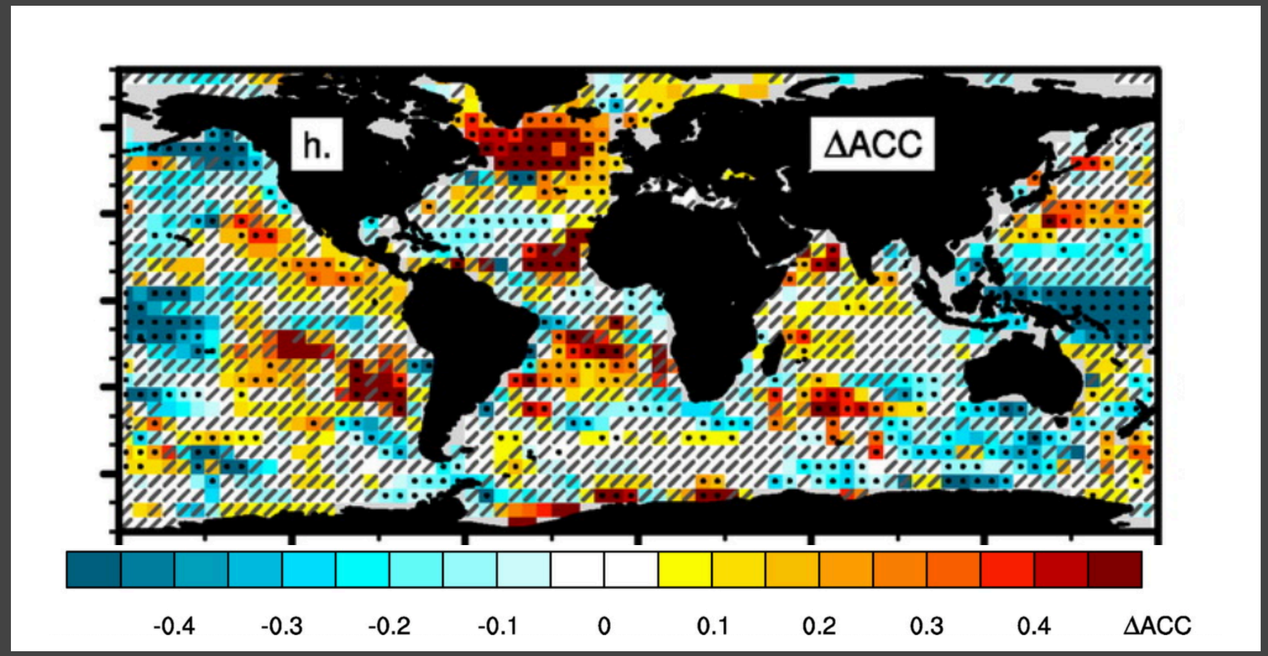
Motivation: Initialized prediction

How much can we improve predictability by initializing with a self-consistent, data-constrained, coupled state?

What are the limits of predictability for different components of the Earth system?



Difference in OHC forecast skill (3-7 year lag) between CESM Large Ensemble (forced, not initialized) and Decadal Prediction Large Esemble (forced + initialized)

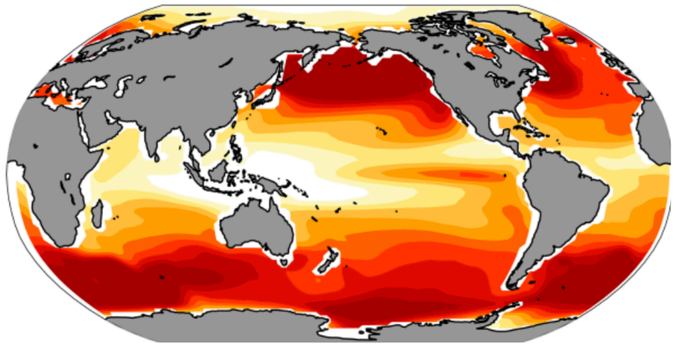
Yeager et al. 2018

Motivation: data assimilation across time scales

New tools for studying climate physics constrained by both data and models

How can we leverage paleoclimate data to train model parameterizations and improve representations of large-scale changes?

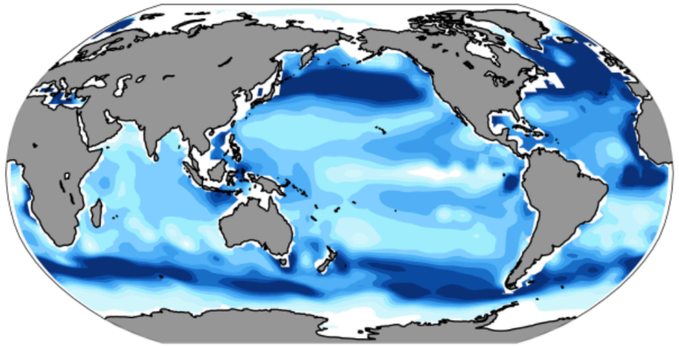
Pliocene sea-surface temperature anomaly
(Burls and Fedorov 2017)



-8 0 8

SST anomaly (ºC)

LGM sea-surface temperature anomaly
(Amrhein et al. 2018)



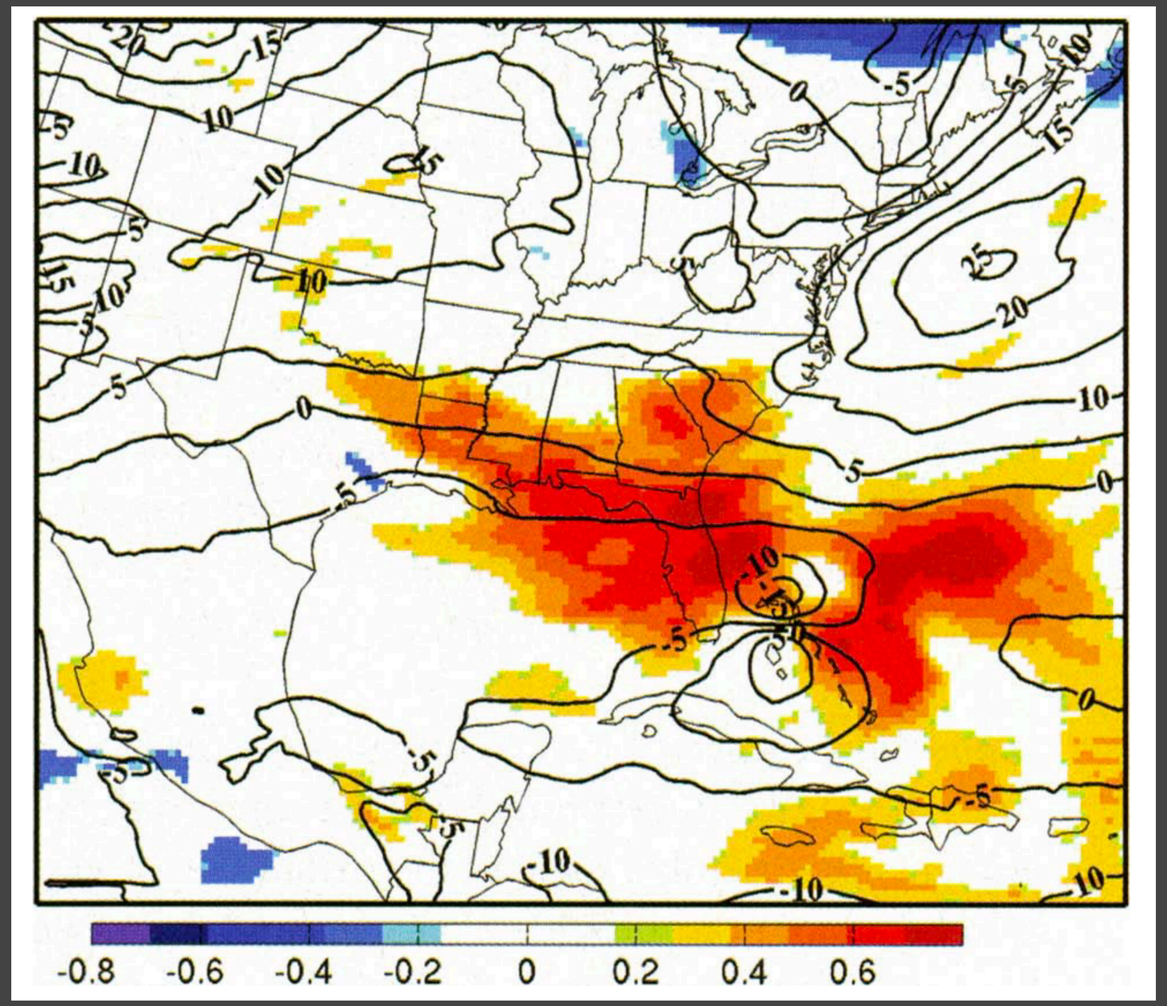
-4 0 4

SST anomaly (ºC)

Motivation: studying climate dynamics using sensitivities

Sensitivity of Hurricane Katrina's longitude at 48-hour lag to mean wind strength in the 850-250-hPa level derived from a 96-member assimilation.

Would be a powerful tool for coupled climate dynamics!



(Anderson et al. 2007; also Torn and Hakim 2008)

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How it’s done: data assimilation with DART + CESM

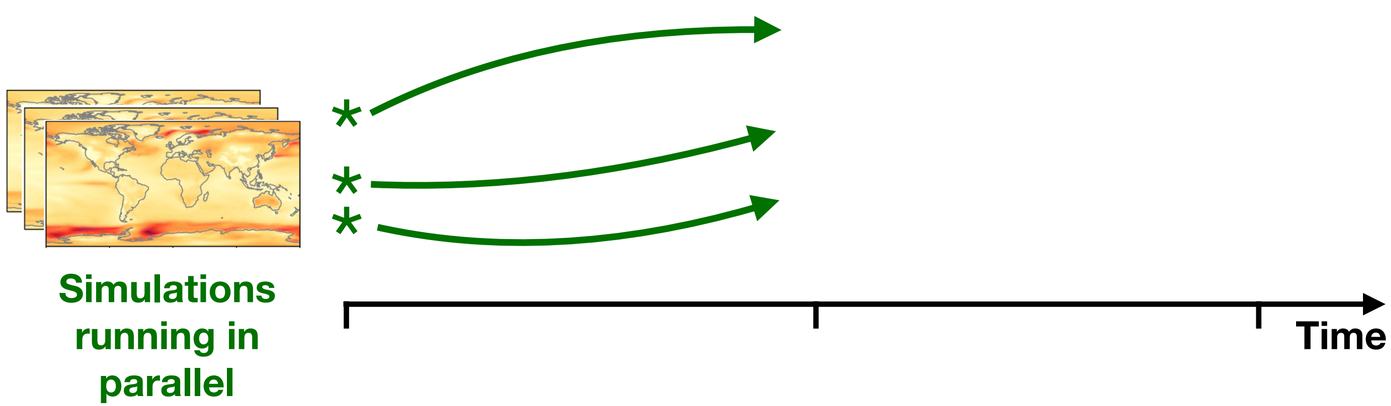
DART (Data Assimilation Research Testbed): modular framework for data assimilation. Allows for different assimilation algorithms as well as inflation, localization, etc.

Anderson et al. 2007

How it's done: data assimilation with DART + CESM

Ensemble data assimilation:

Integrate ensemble of models



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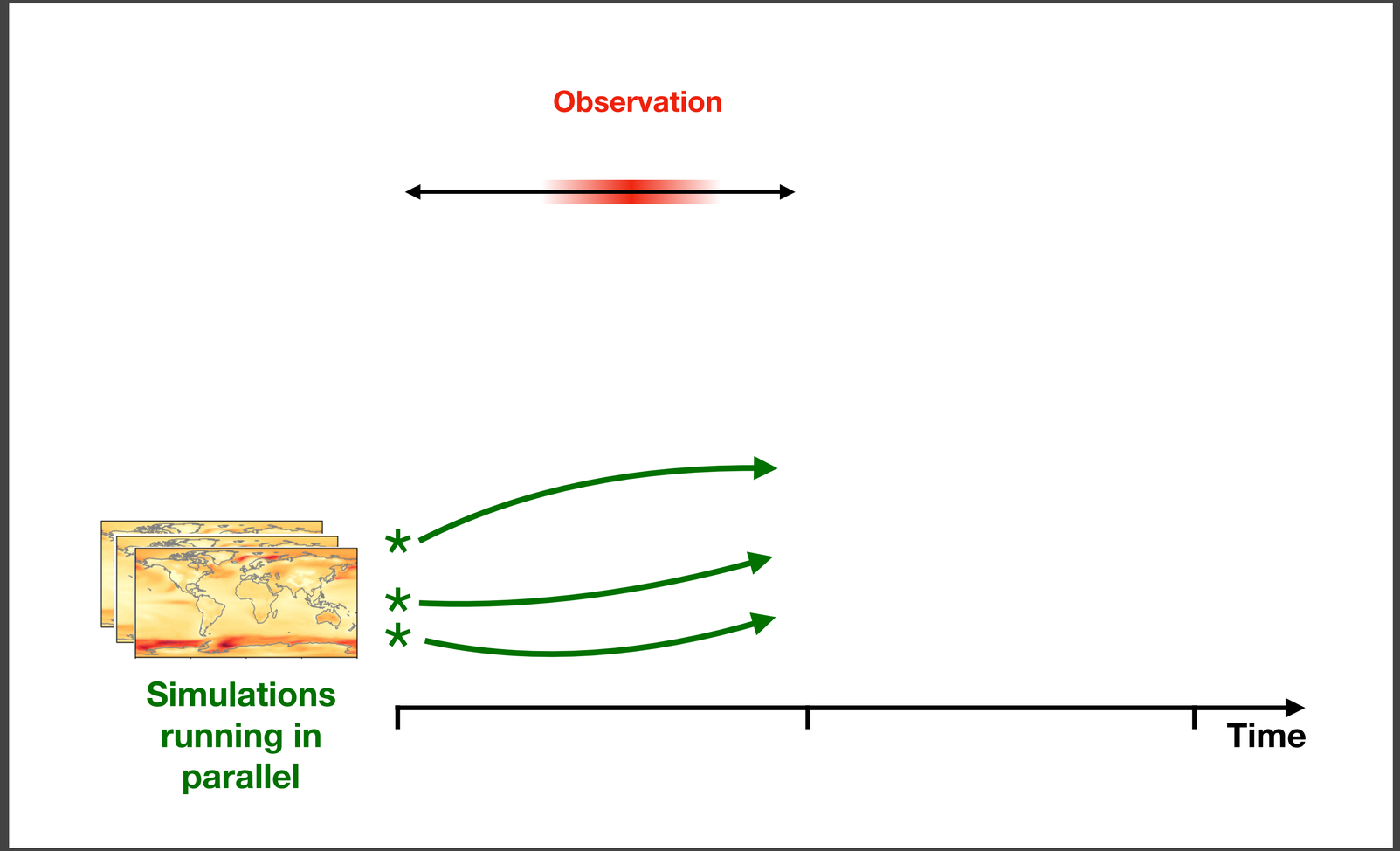

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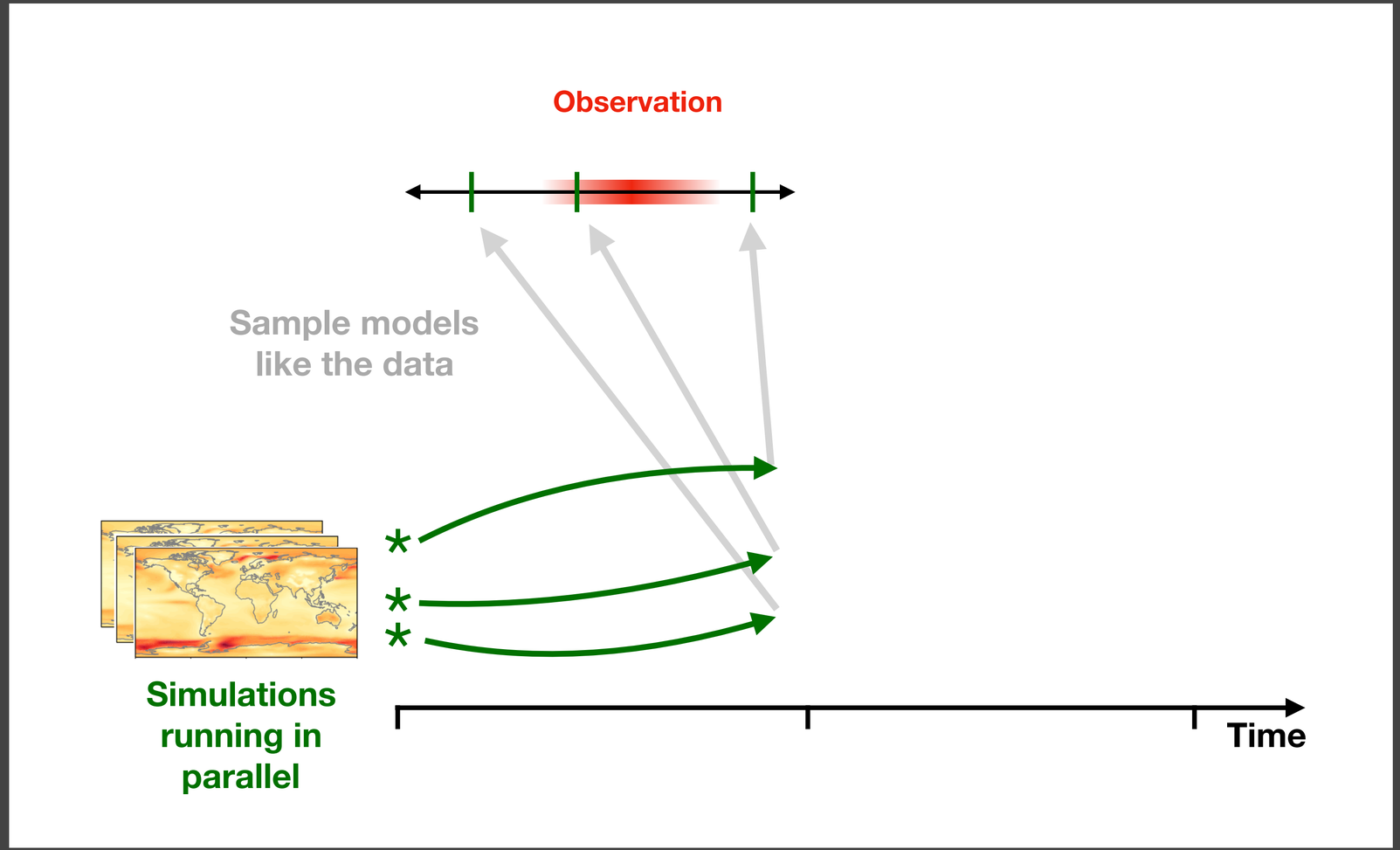

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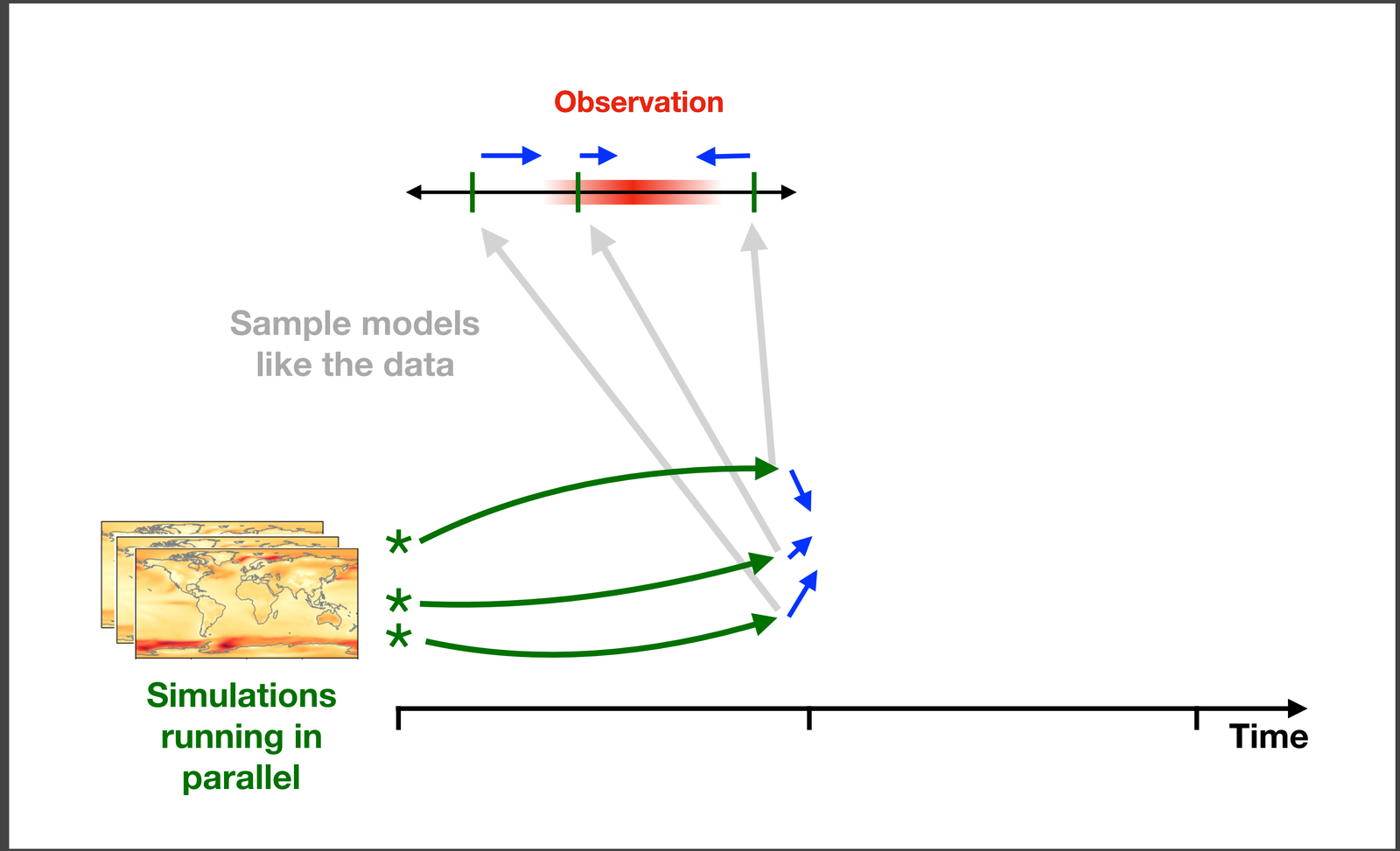

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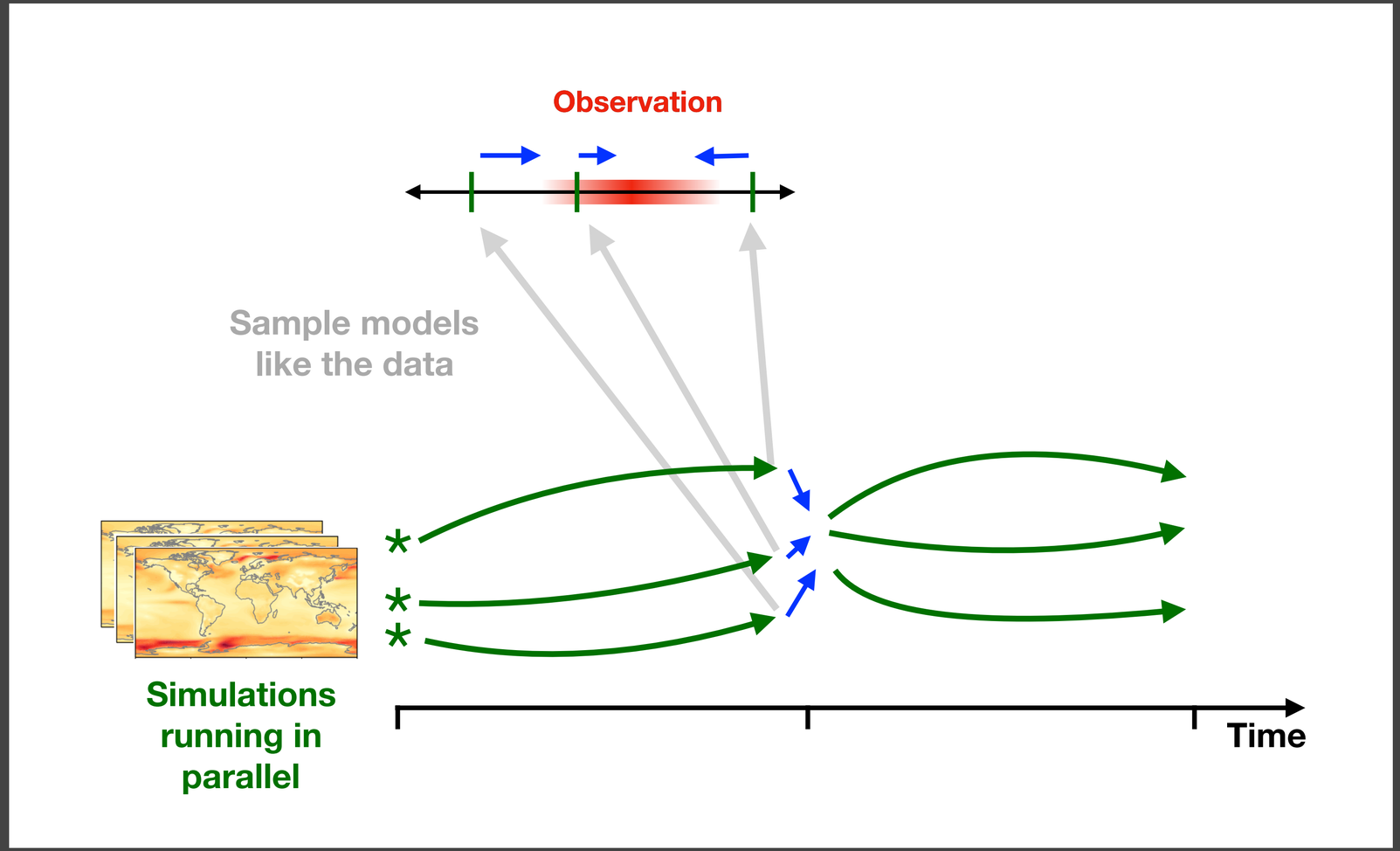

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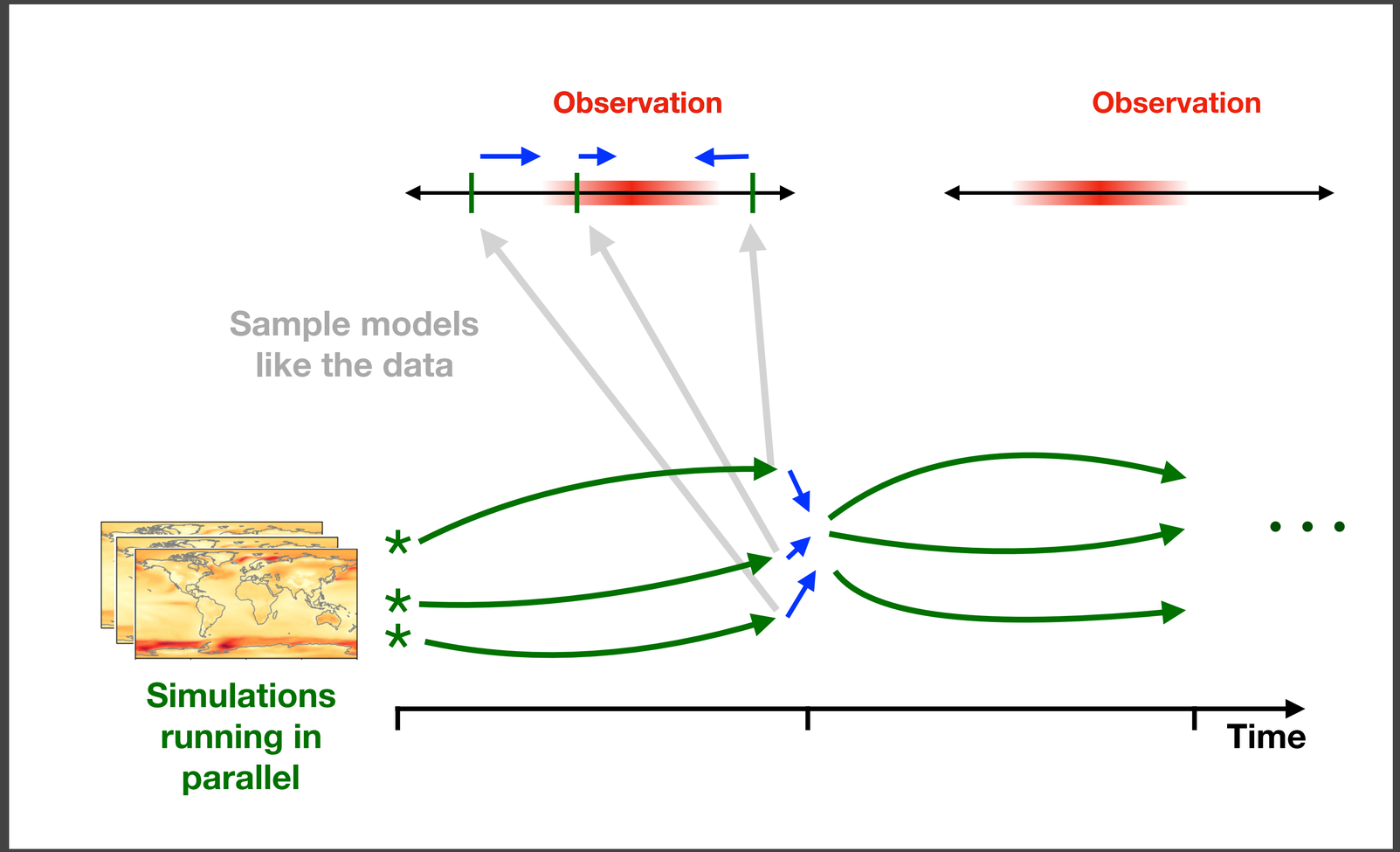
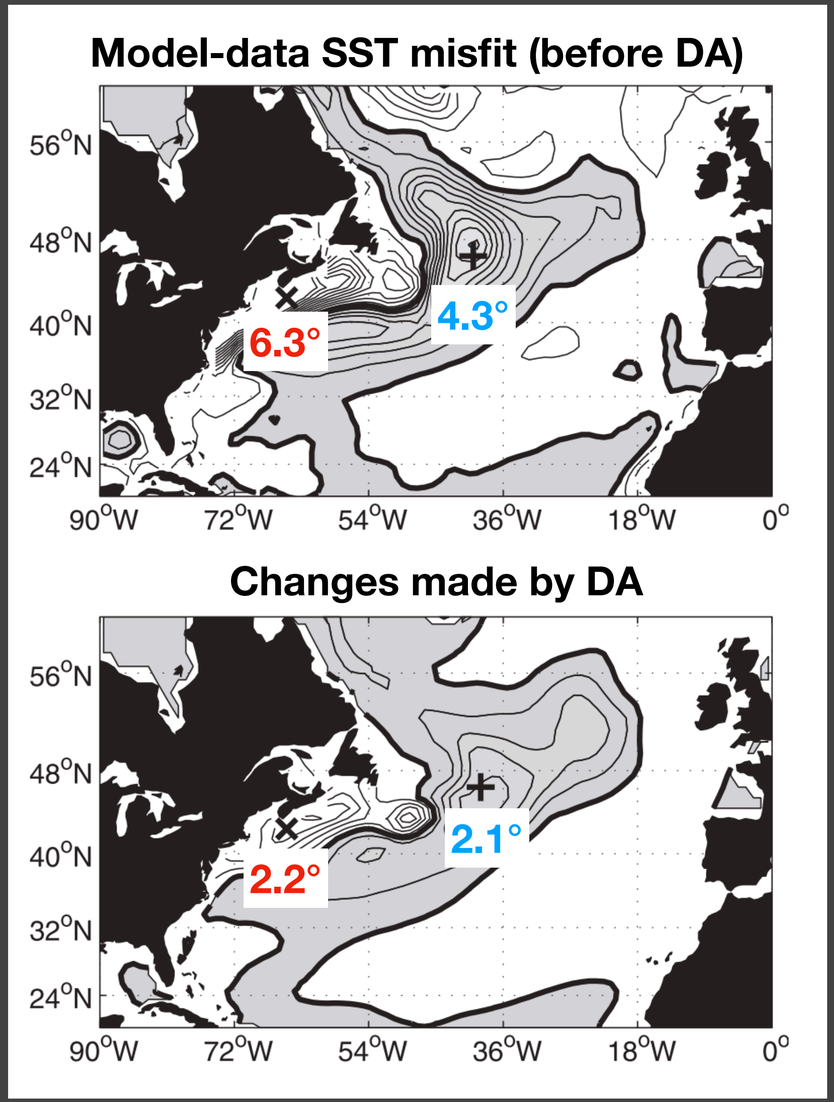


Anderson et al. 2007

Assimilation of WOD09 data into 1 degree POP2

- Assimilation of subsurface T/S from WOD09
- 8-year simulation
- 48 ensemble members forced by members of CAM4 atmospheric reanalysis (Raeder et al. 2012)



Karspeck et al. 2013

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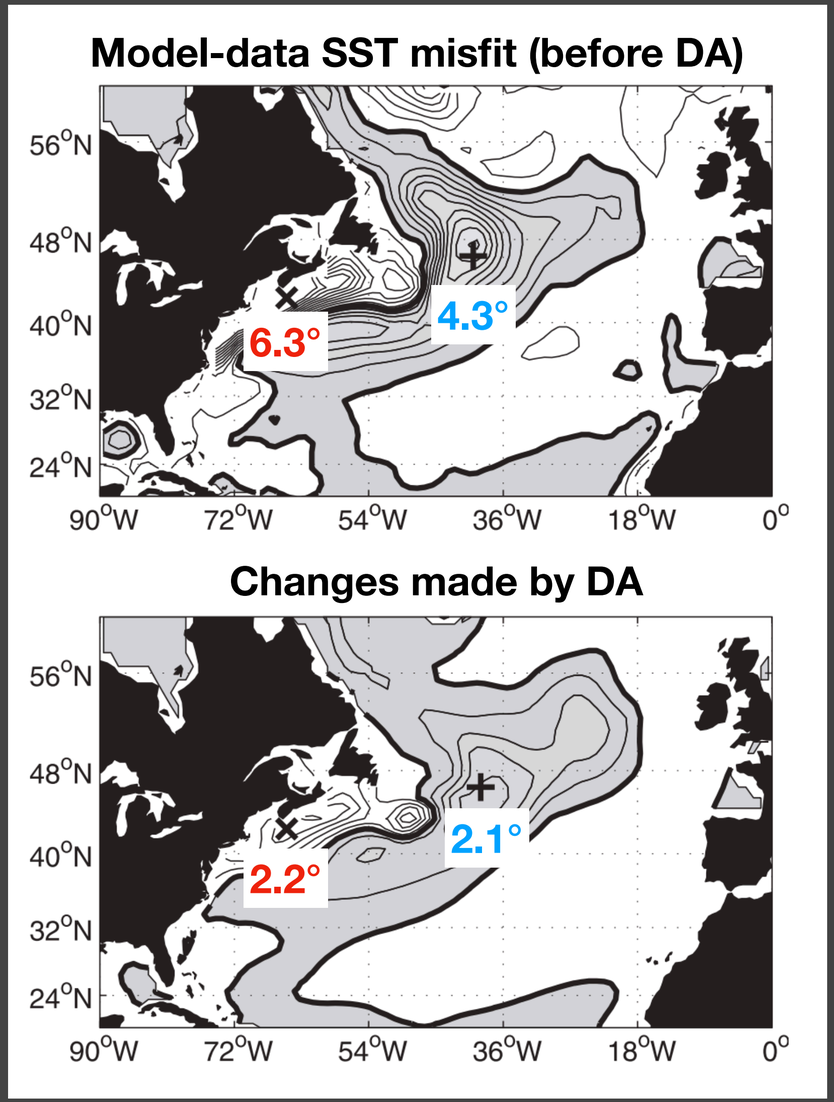
Biases in western boundary currents



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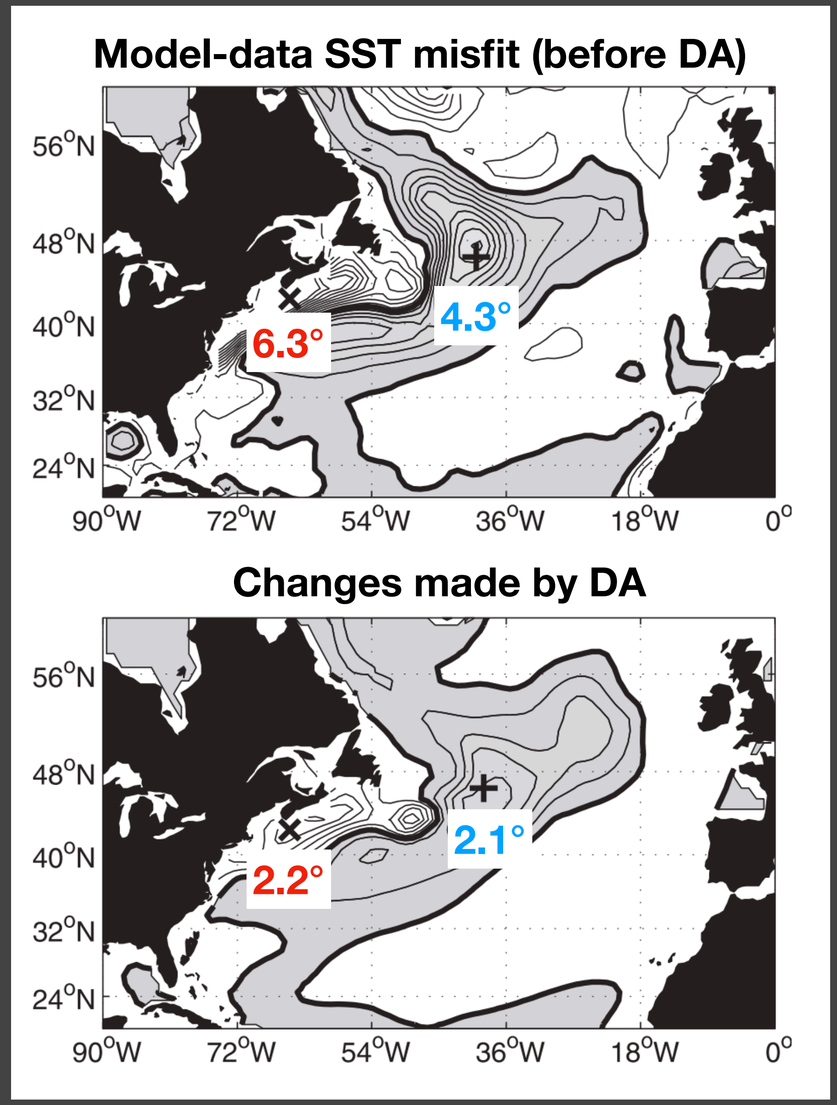

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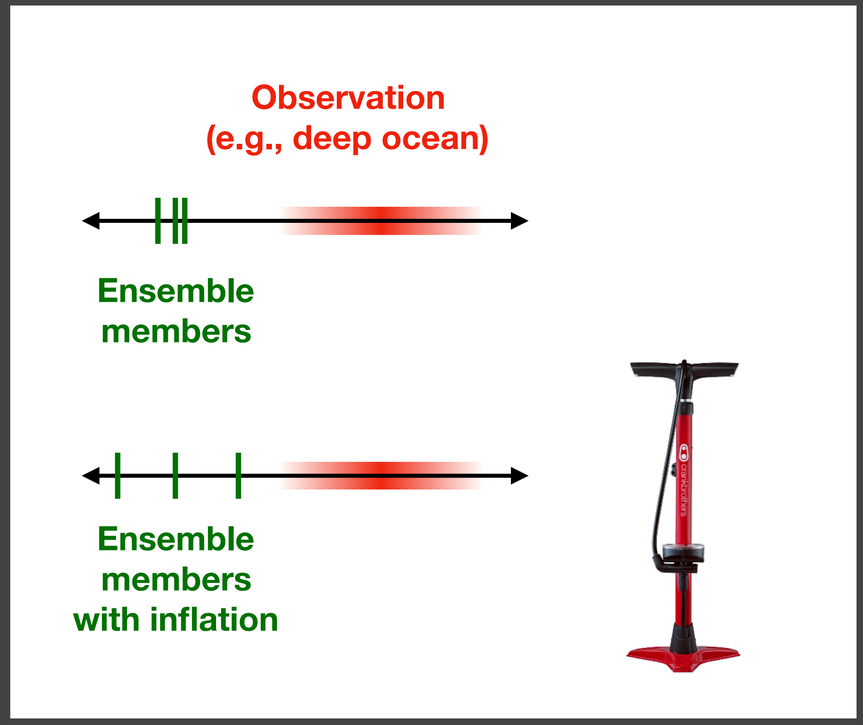
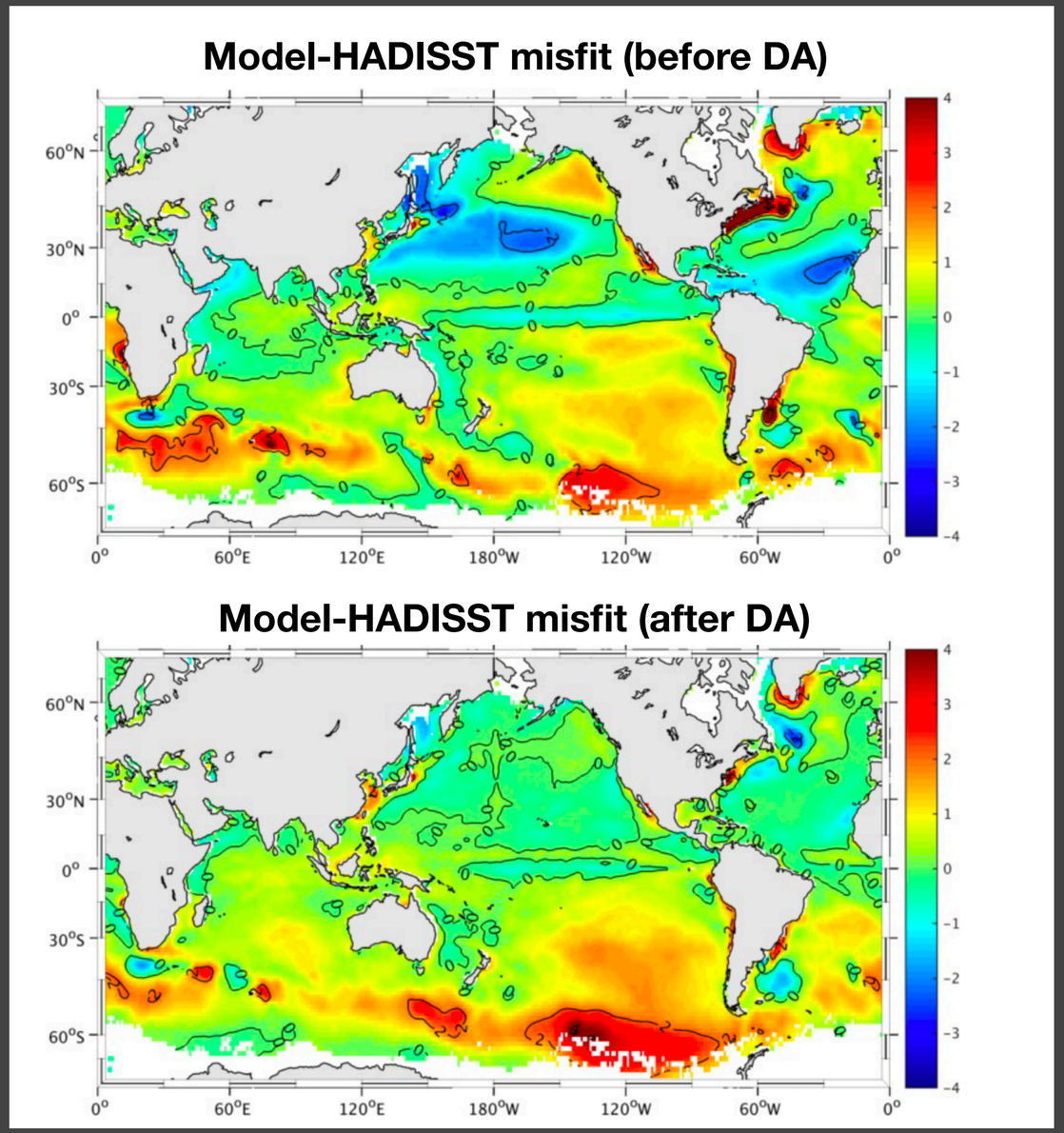


Karspeck et al. 2013

Coupled assimilation in CESM1

- CESM1 with active ocean, atmosphere, land, sea ice
- 30 members
- Assimilation of subsurface T/S and atmospheric winds/T/humidity
- Prototype 12-year simulation (1970-1982)



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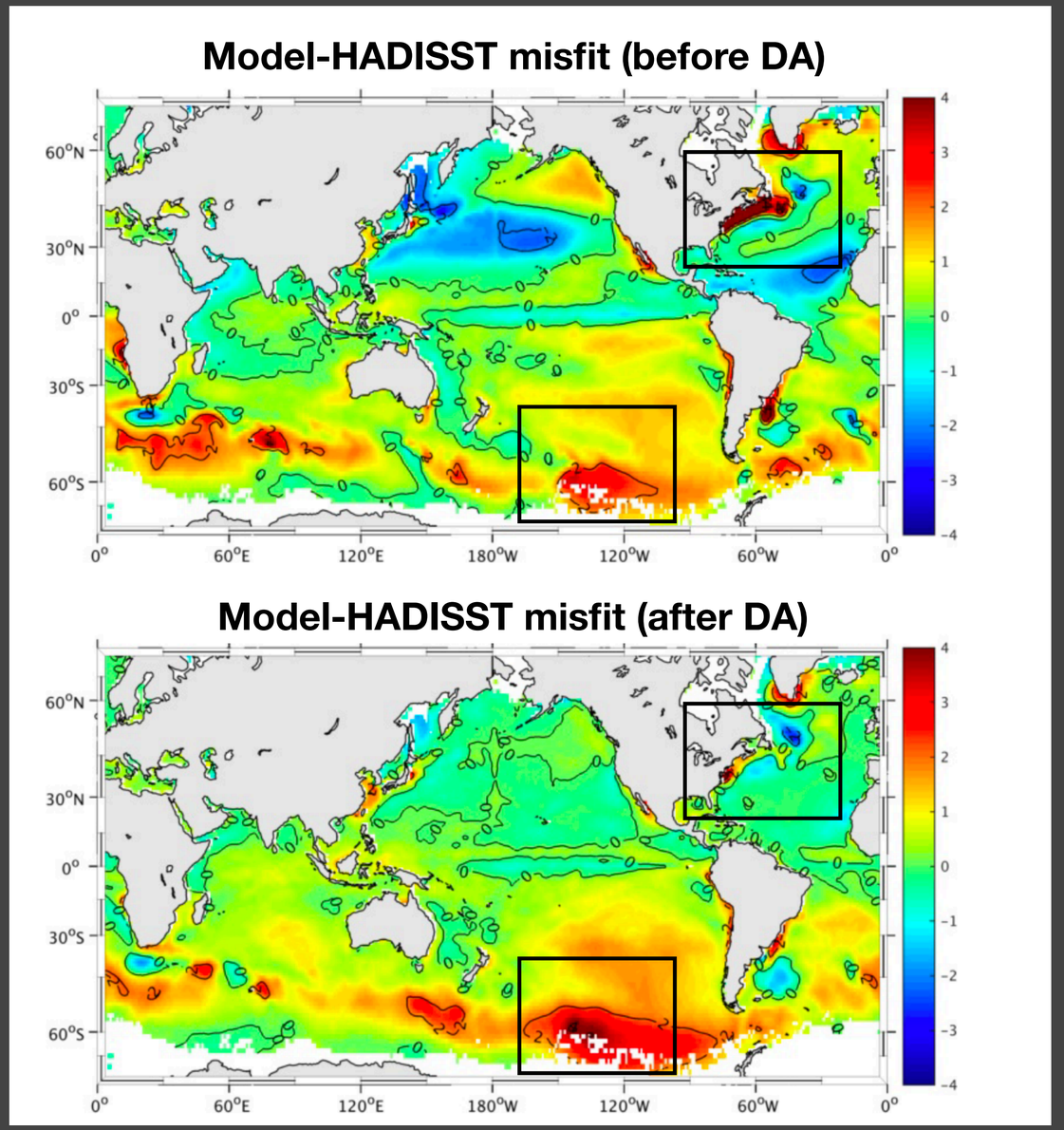
Challenges:
Cost of running a large ensemble, memory redistribution, and CESM re-initialization

Karspeck et al. 2018



DA reduces ocean model-data bias where there are data, with some increases elsewhere

Data assimilation in high-resolution POP2

High-resolution POP2
(0.1 degree)

Assimilation of satellite
and in situ ocean
observations

2005-2011

Castruccio et al., in prep

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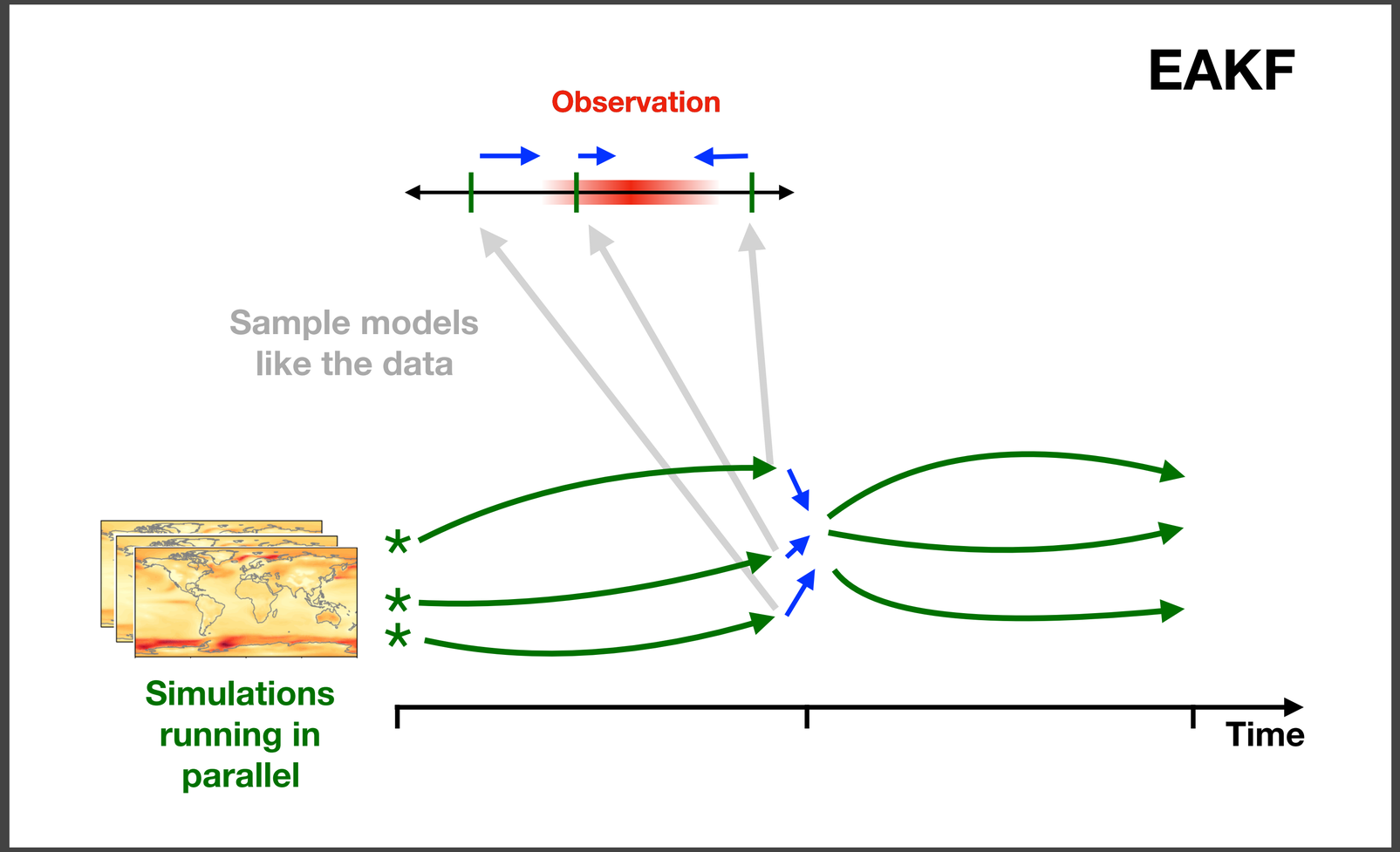
84-member Ensemble Optimal Interpolation

EnOI: Factor ~N_{ens} reduction in cost



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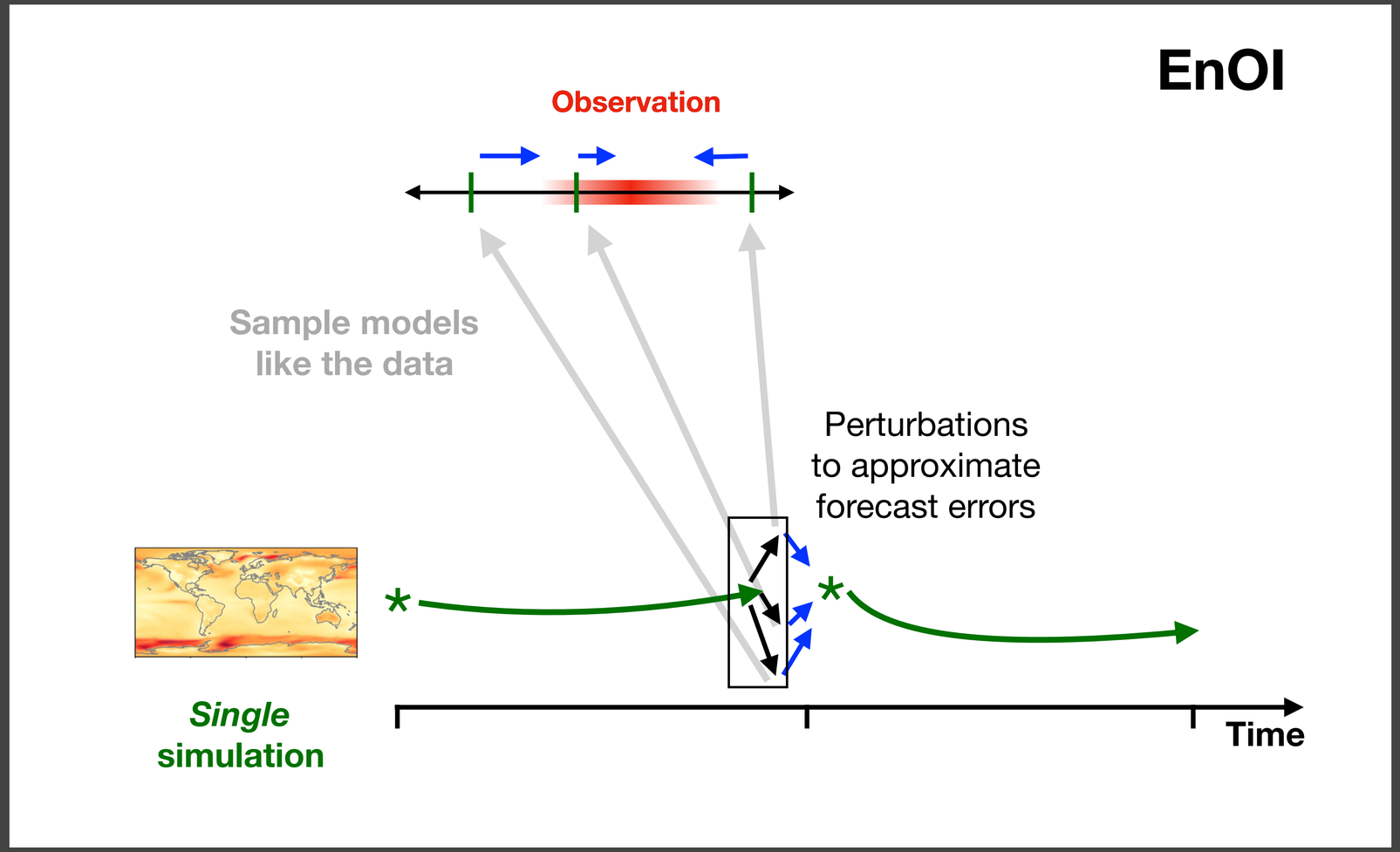
Downside: no "errors of the day"



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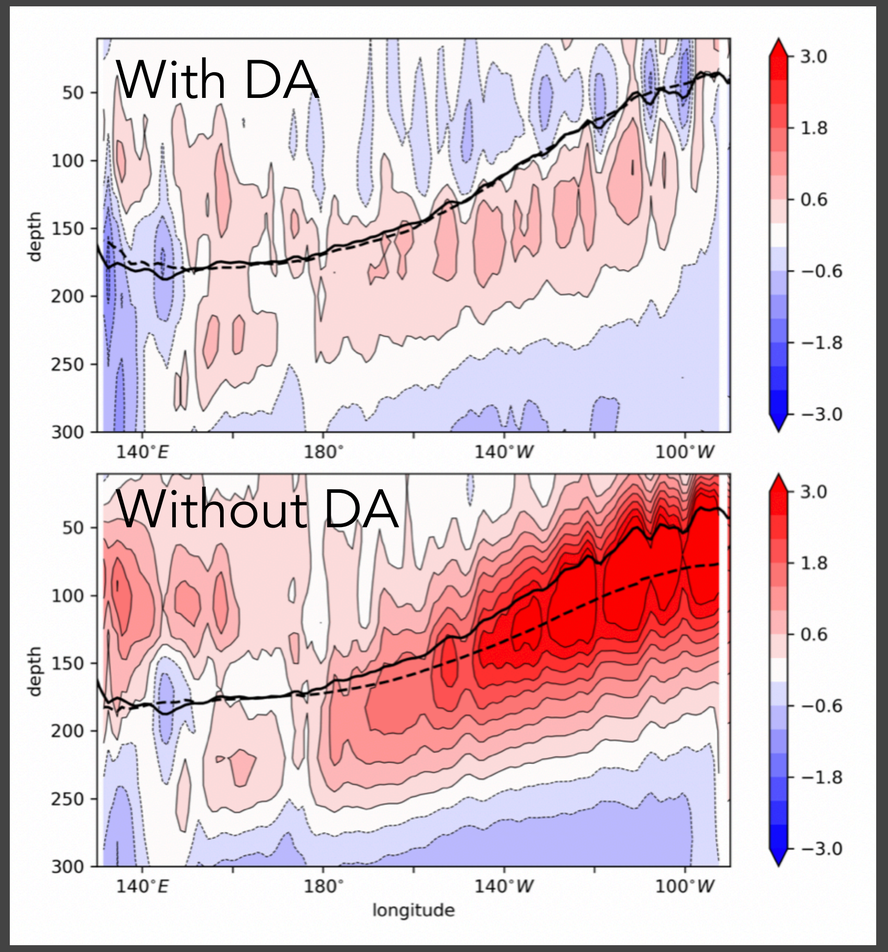
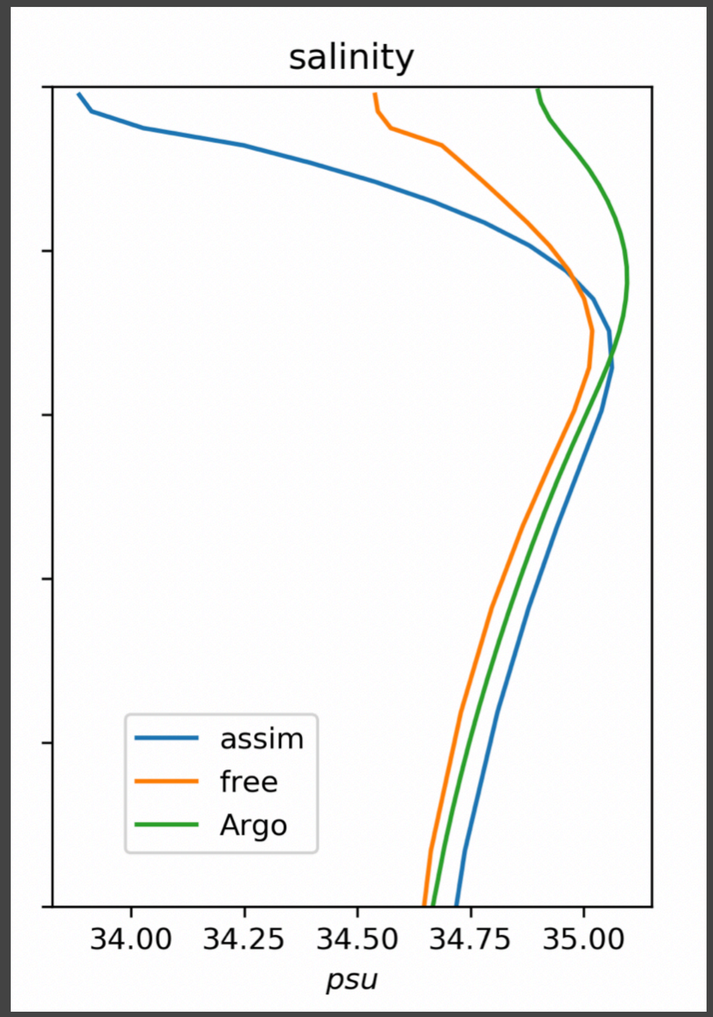


Time-mean equatorial θ difference vs Roemmich and Gilson (2009)



Time-mean salinity profile

Castruccio et al., in prep

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First results from an updated CESM2 + DART configuration

CESM2 with DART Manhattan — credit to Ben Johnson for updating scripts, running test cases

Improved memory handling, tools for strongly coupled DA, new adaptive inflation (Gharamti et al. 2018)

POP2 forced by 80 ensemble members of CAM6 reanalysis (run by K. Raeder)

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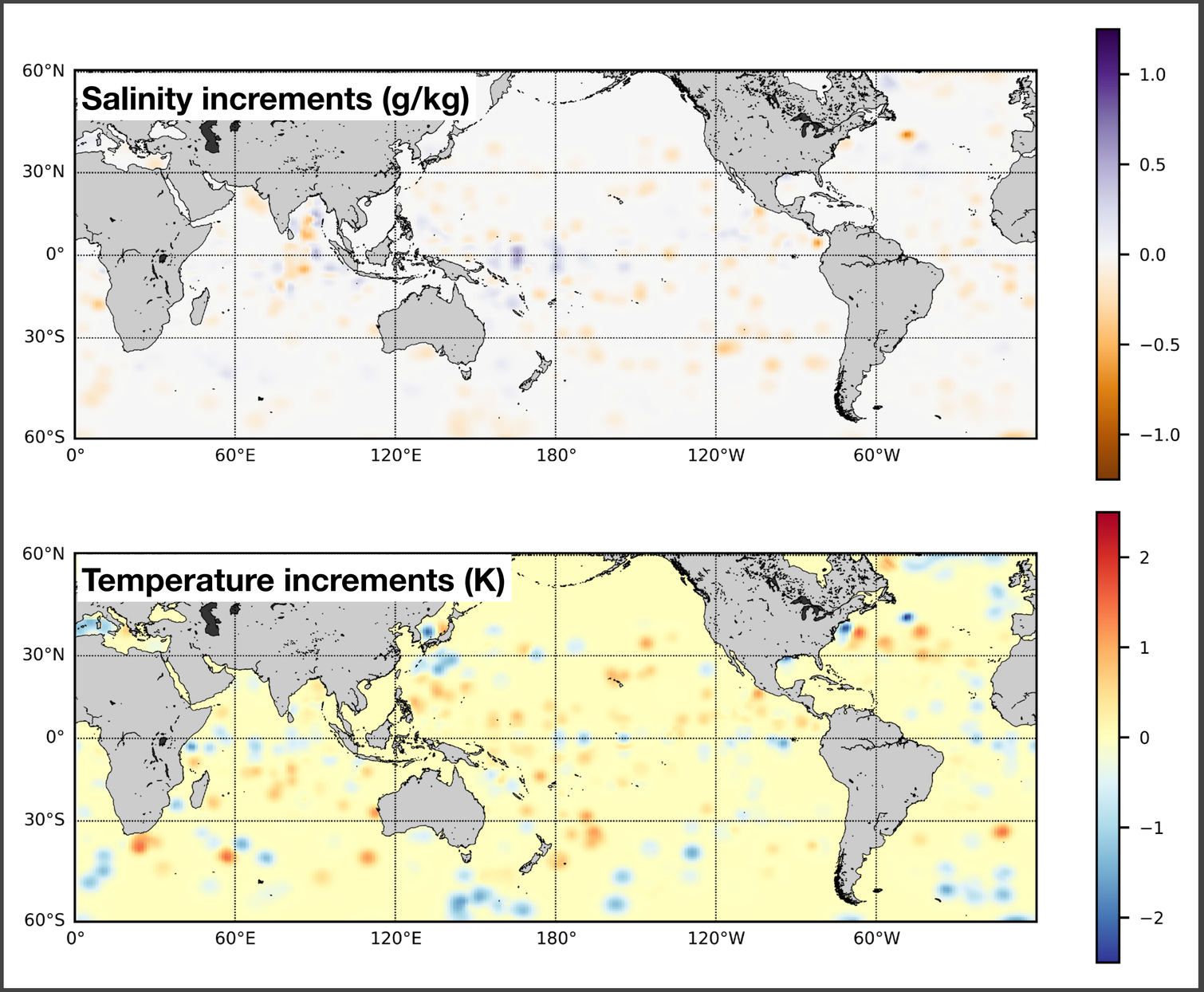
DA increments: Changes made to surface ocean quantities on day 5 of assimilation Jan 1-6 2014 (short!). Changes reflect data availability, localization length scales.

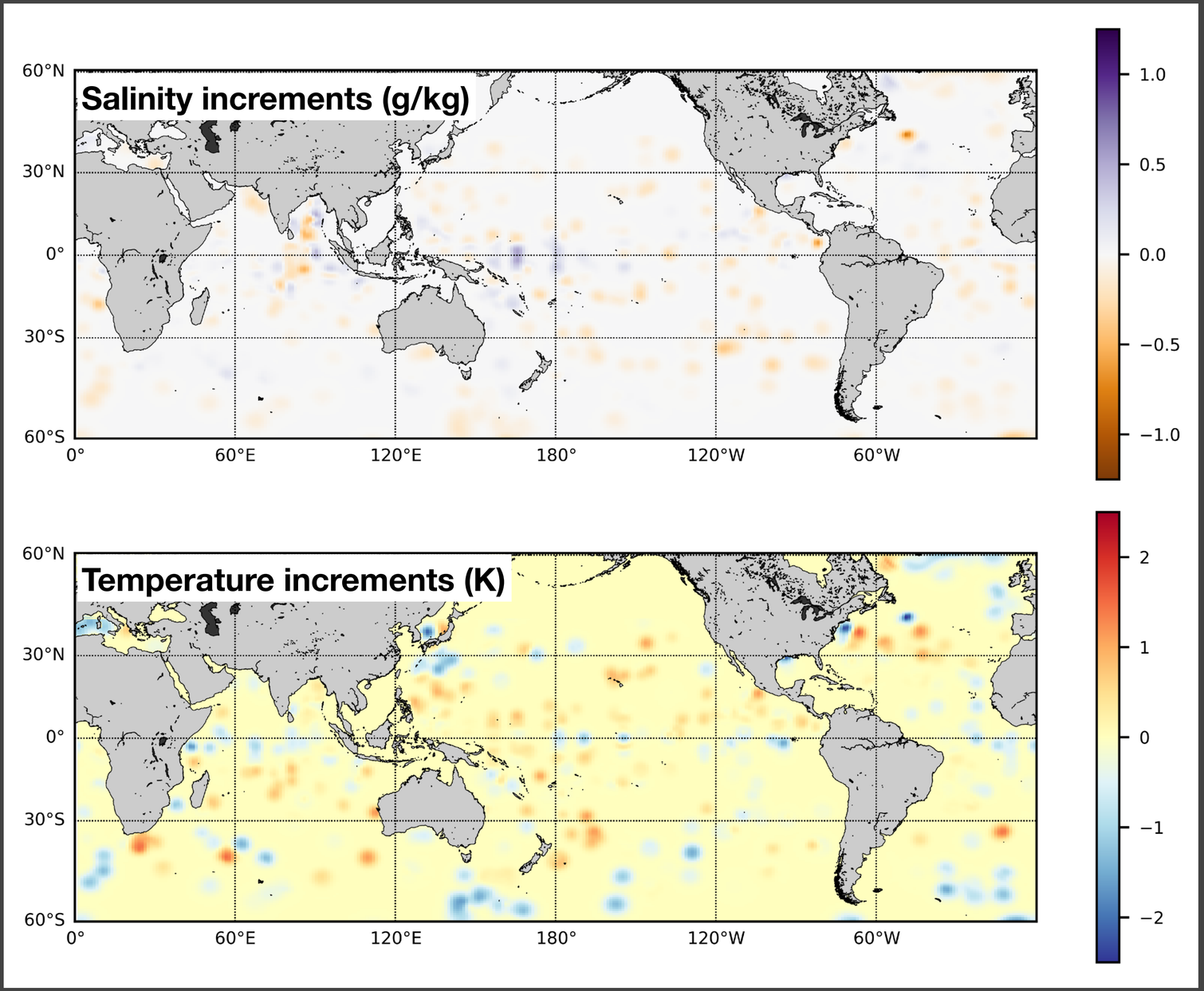


First results from an updated CESM2 + DART configuration

Short term: Investigate DA ensemble initialization for the N. Atlantic 2015 “cold blob” (cf work by Maroon, Yeager et al.)

Near term: Weakly coupled DA with CESM2 / DART Manhattan (assimilate both ocean/atm data)

Longer term: incorporate MOM6



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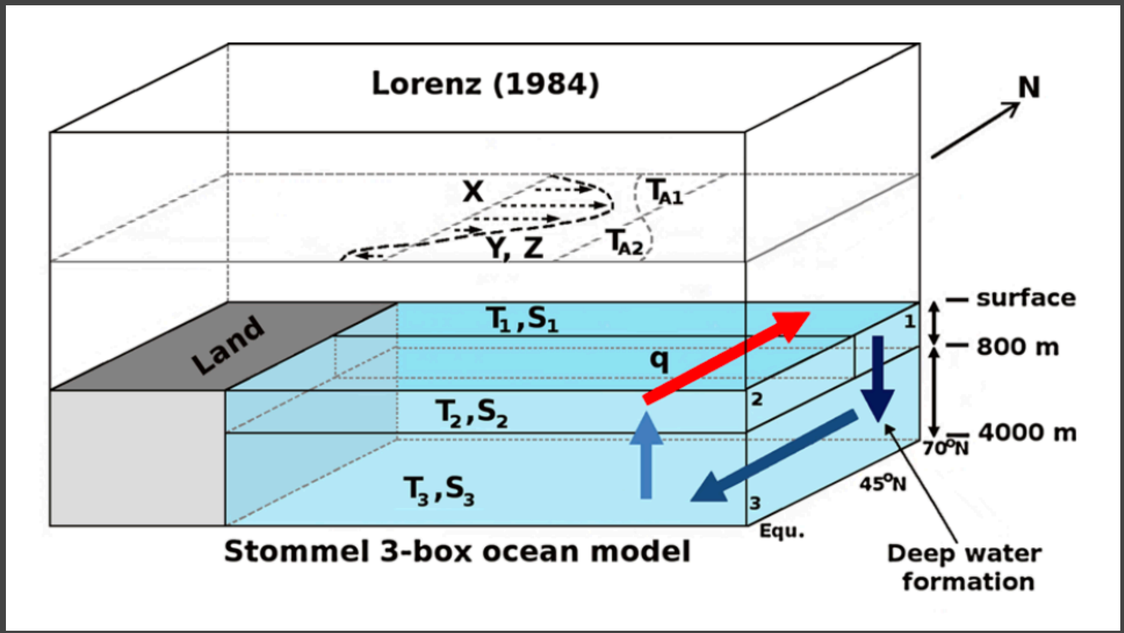
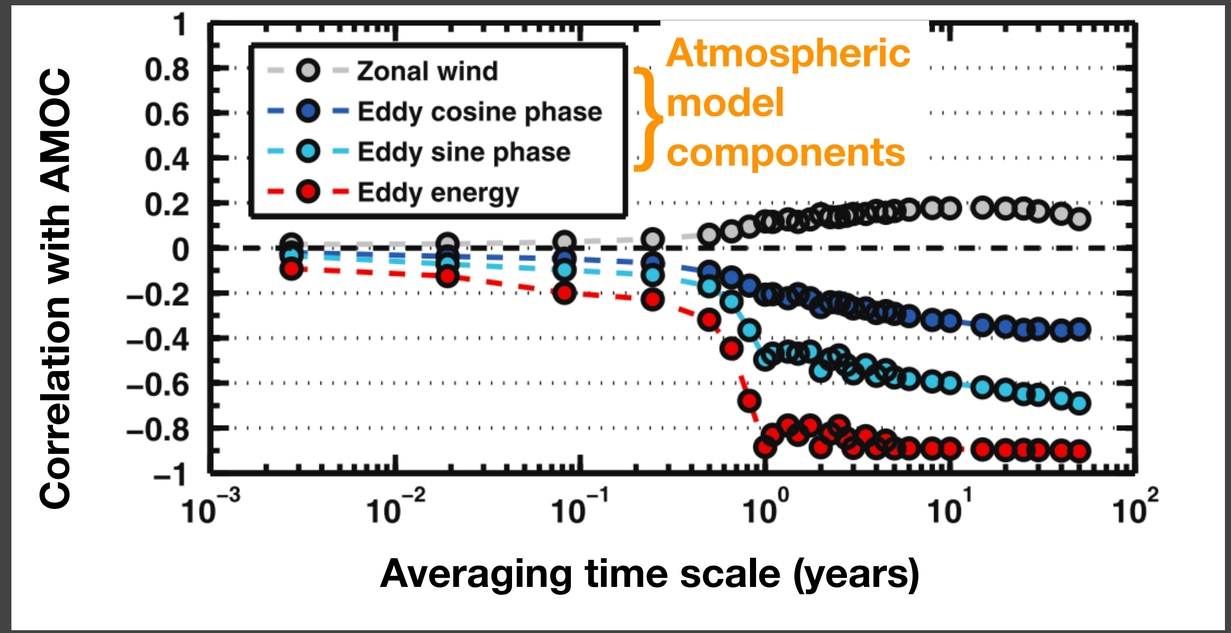
Different time scales in coupled media

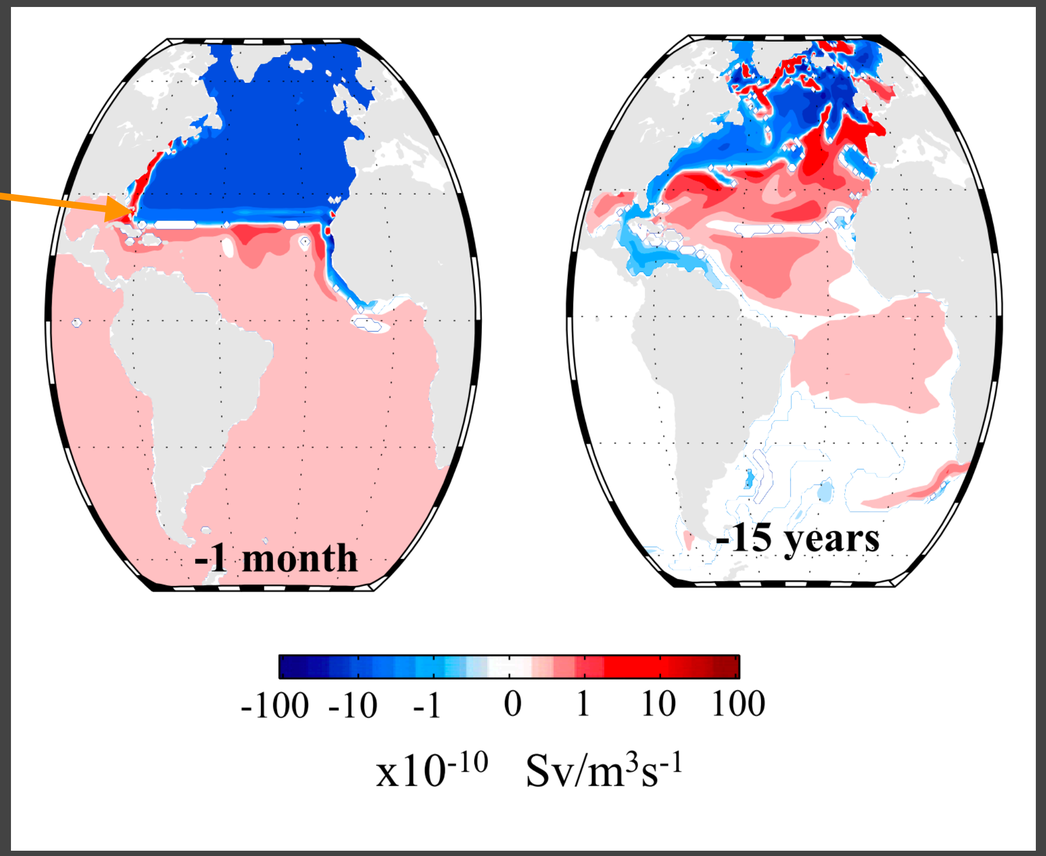




Relationships between fast and slow components are stronger over longer durations. How to leverage in a system with many time scales?

Tardif and Hakim, 2014

The ocean integrates the *time history* of atmospheric forcings



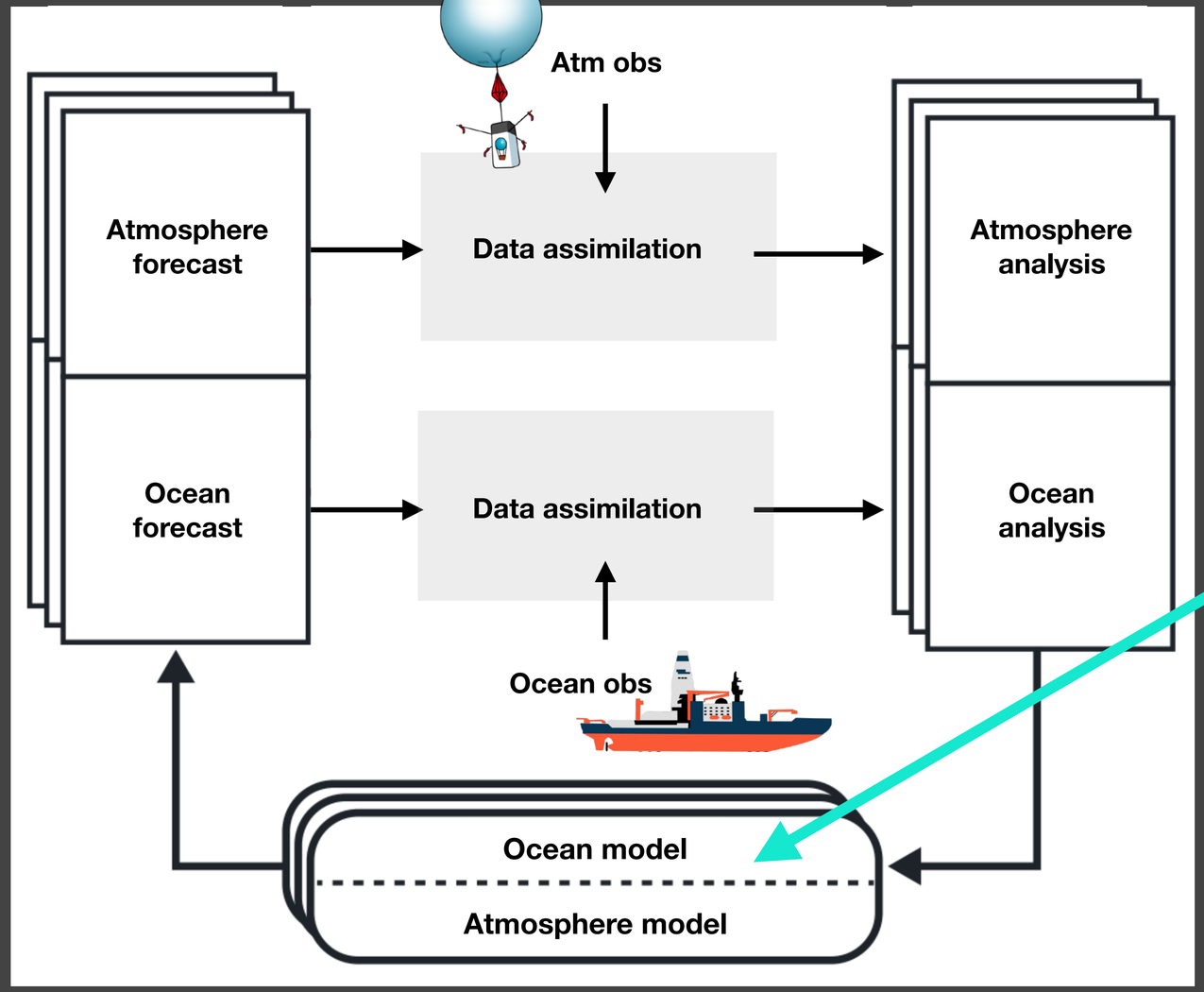
Adjoint (MITgcm) sensitivity of AMOC strength at 26° N to surface freshwater input at lead times of 1 month and 15 years.

Is ensemble spread too small because low-frequency atmospheric variability is too low?

Can we implement a Kalman smoother on climate time scales to reduce the nonconservative effects of increments?

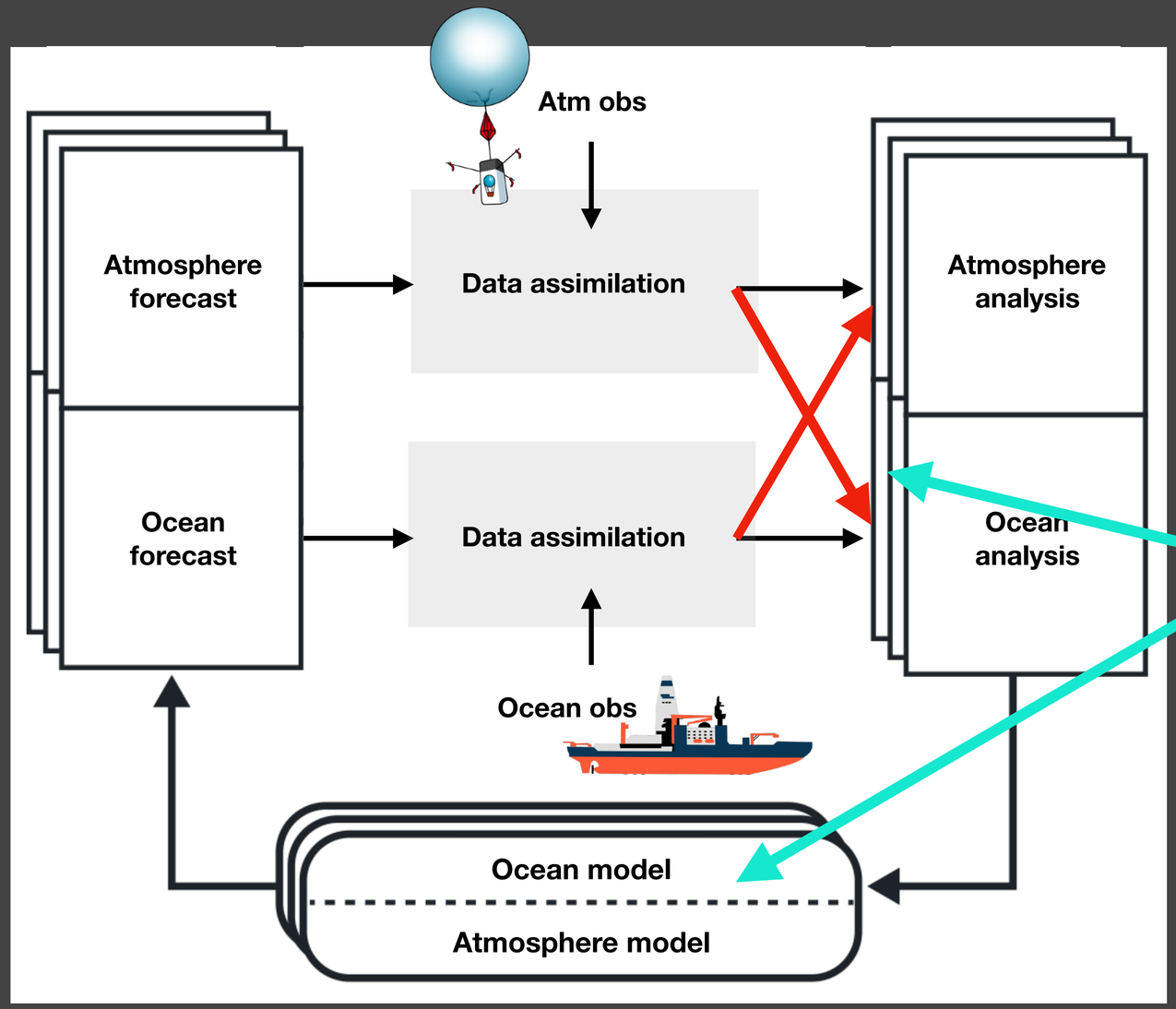
Pillar et al. 2016

Strong coupling spreads observational information across components, including opposite the direction of physical causality.



"Weakly coupled:"
Cross-component effects only in coupled model

Strong coupling spreads observational information across components, including opposite the direction of physical causality.



"Strongly coupled:"
Cross-component effects in coupled model **and** in data assimilation

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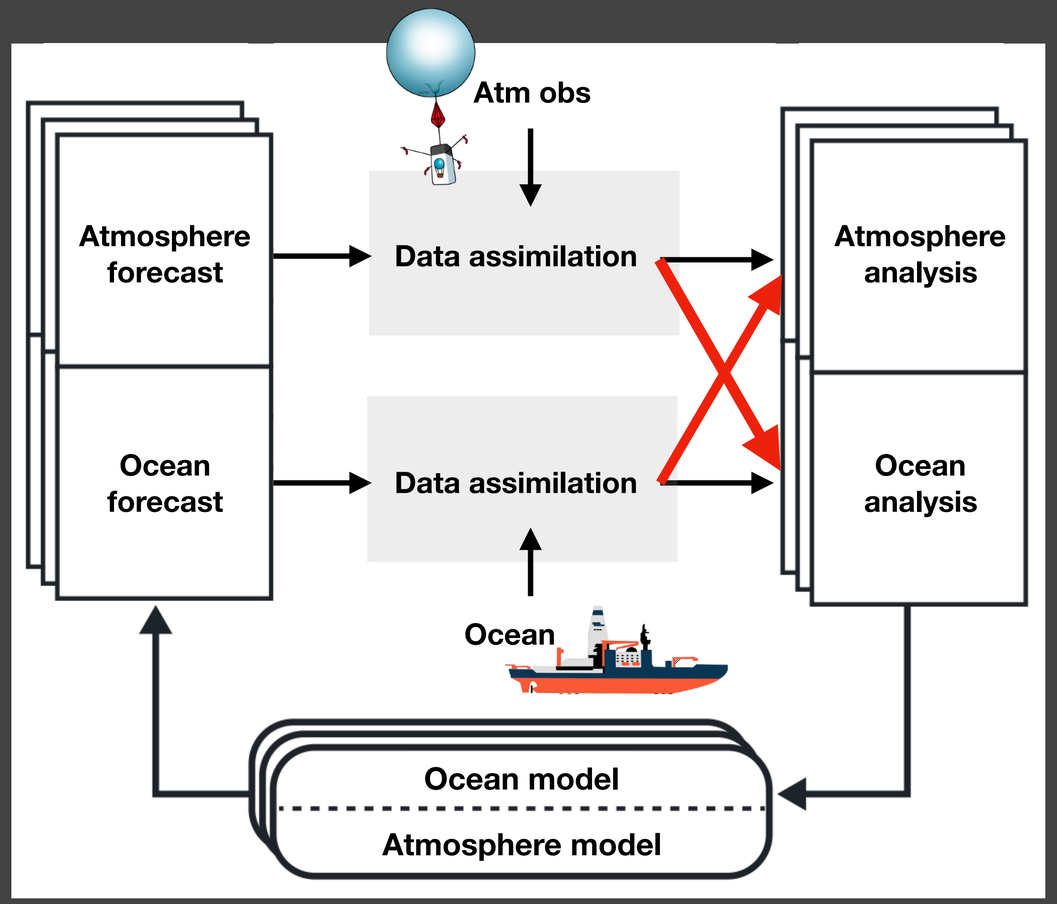
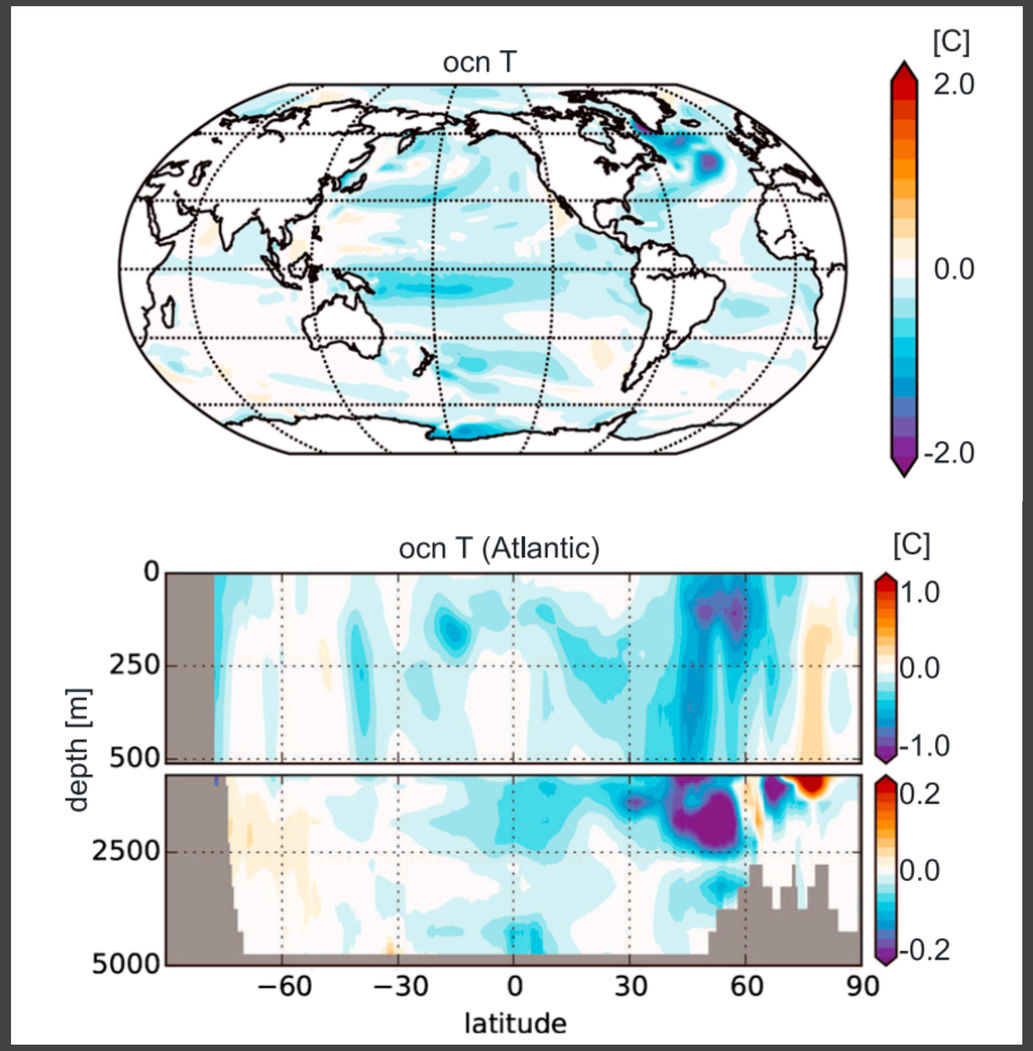


Sluka et al. (2016, 2018), Penny et al. (2017, 2019)



Blue regions: Strong coupling improves perfect-model analysis.

How important is strong coupling for initialization and state estimation?

Summary and conclusions

Coupled DA in CESM: opportunities for model training and basic science

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Recent milestone: Updating configuration to CESM2 + DART Manhattan, working towards coupled DA

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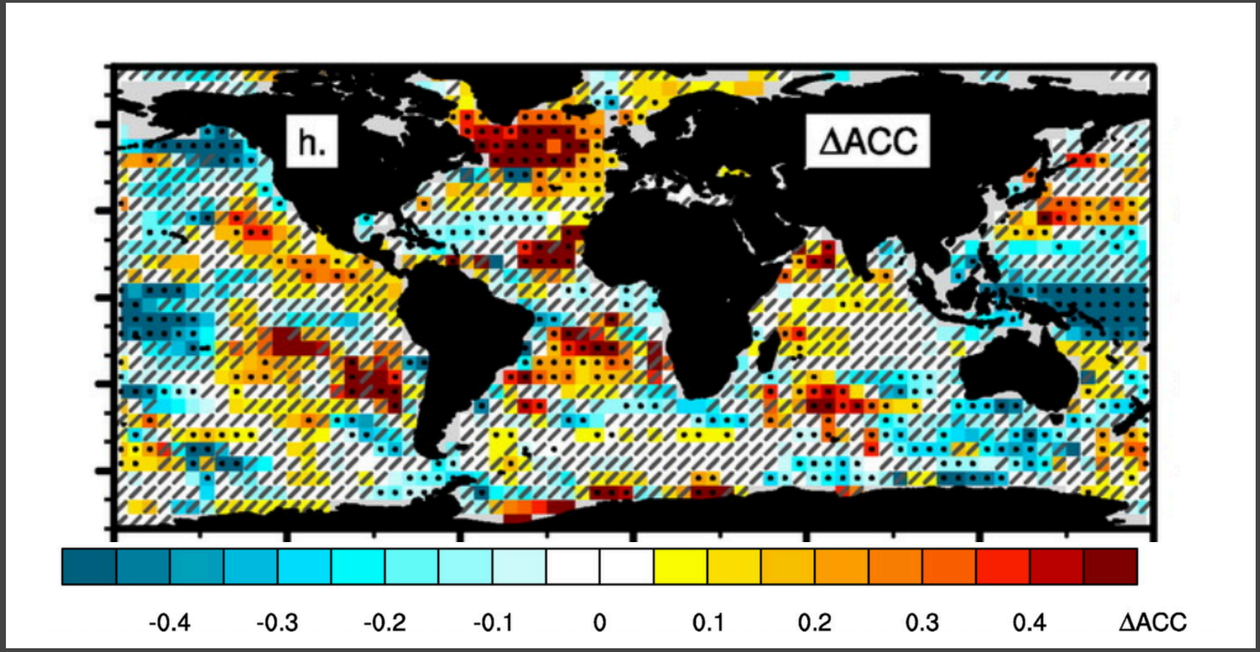

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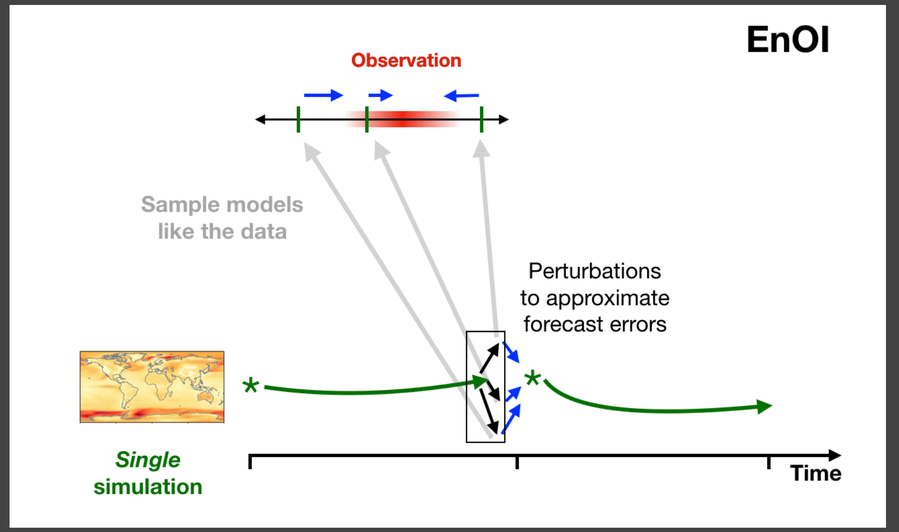
Research goals:

How does DA improve initialized predictability?

What combination of tools and approaches (smoothers, parameter estimation, EnOI, adaptive inflation / localization, …) is best suited to the unique DA challenges inherent in coupled climate?



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