

Coupled Data Assimilation with CESM-DART: System Design and Evaluation

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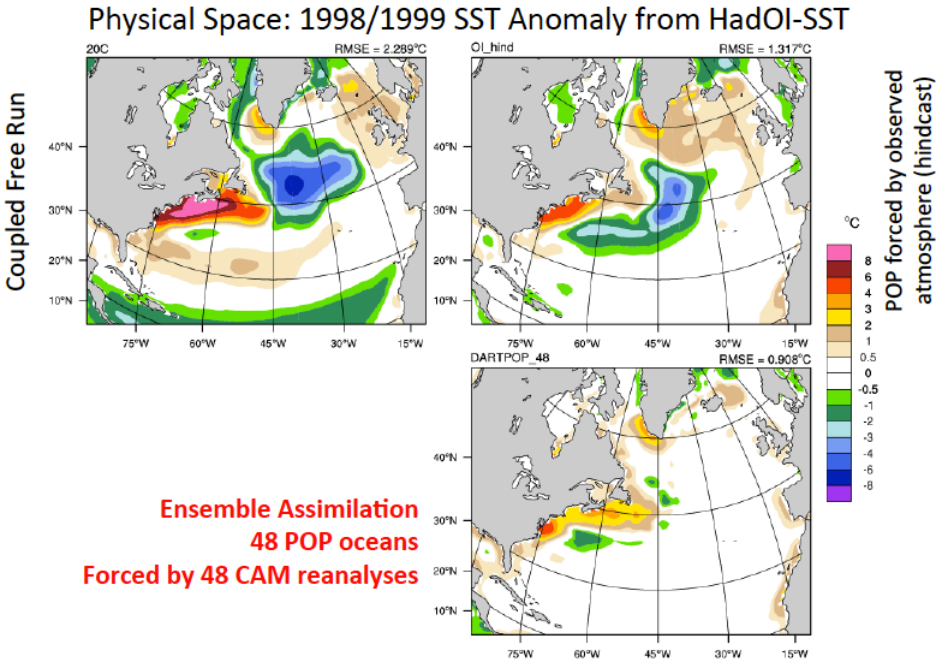
National Center for Atmospheric Research

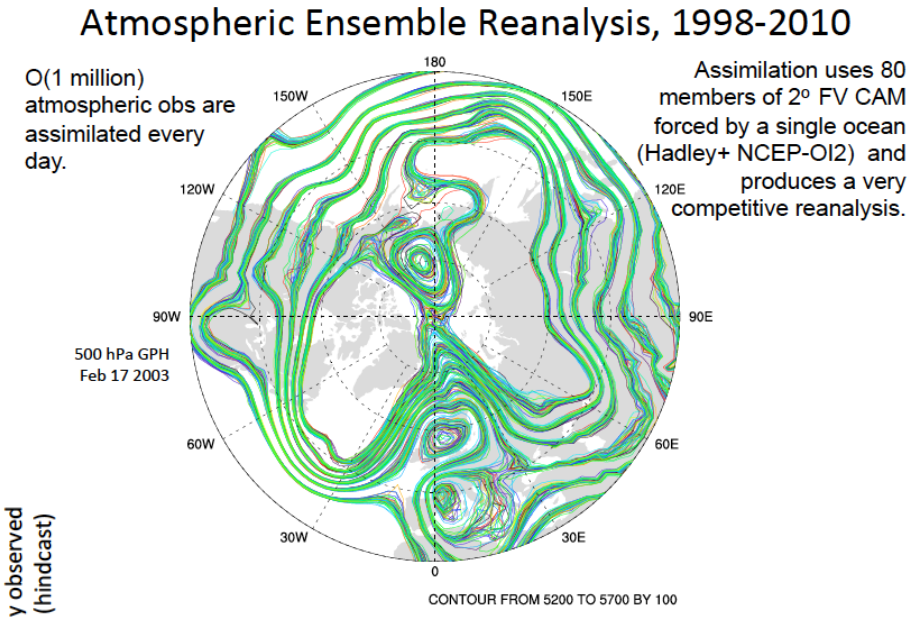
Ocean Model Working Group Meeting
January 16th - 17th 2014

Existing DART setups for CESM components

CAM-DART

- atmosphere component
- Raeder et al. (2012), *J. Climate*





POP-DART

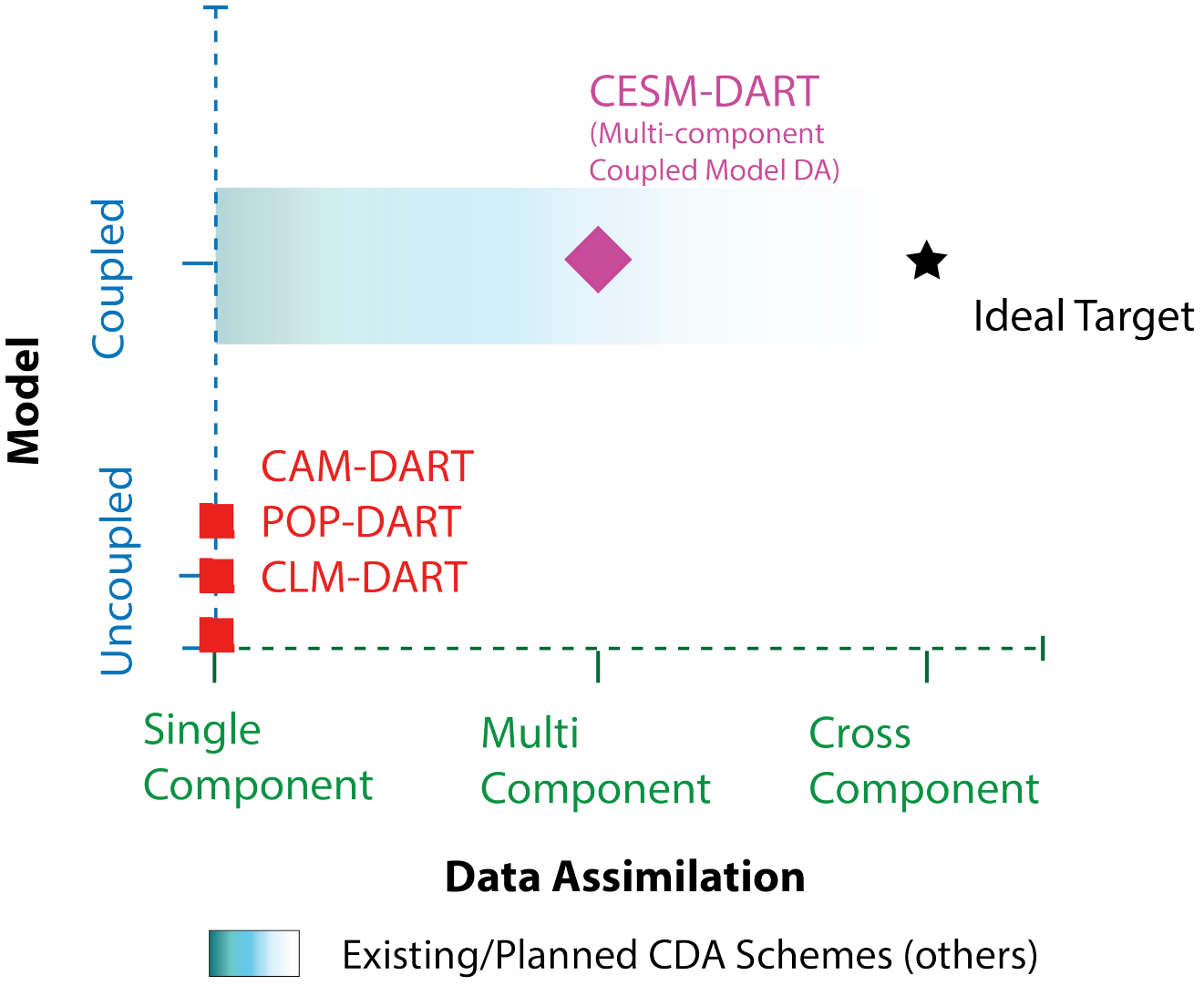
- ocean component
- Karspeck et al. (2013), *J. Climate*

Defining the Terminology for the Coupled Framework

Ideal Target
Cross-component
Coupled model DA

"Assimilation into a coupled model where observations in one medium are used to generate analysis increments in the other"

(from M. Rienecker, WMO CAS Workshop, Dec. 2010)





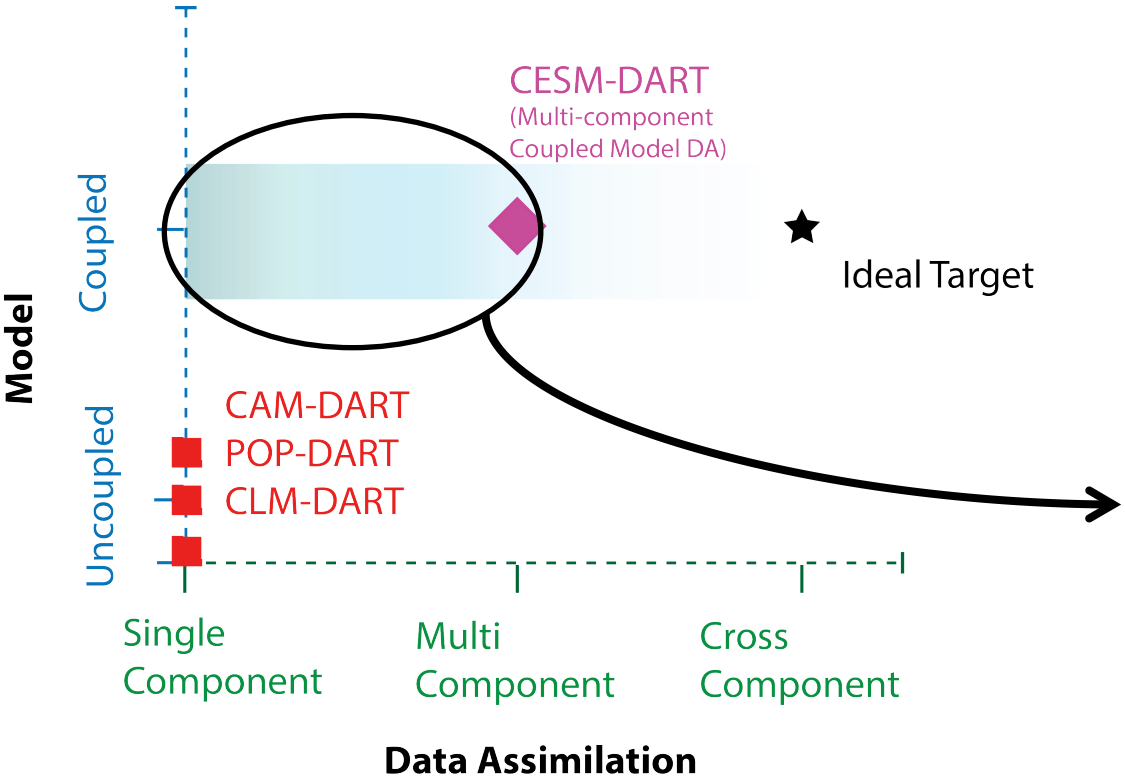
Motivation for a CDA Framework

- "*Seamless prediction*" – days to decades
  - better and more balanced ocean-atmosphere states - consistent surface fluxes, mass and energy budgets
  - reduce forecast initialization shocks

- Accurate representation of coupled phenomena, or processes linked by strong air-sea interactions
  - short-term – MJO
  - extreme events – tropical cyclones

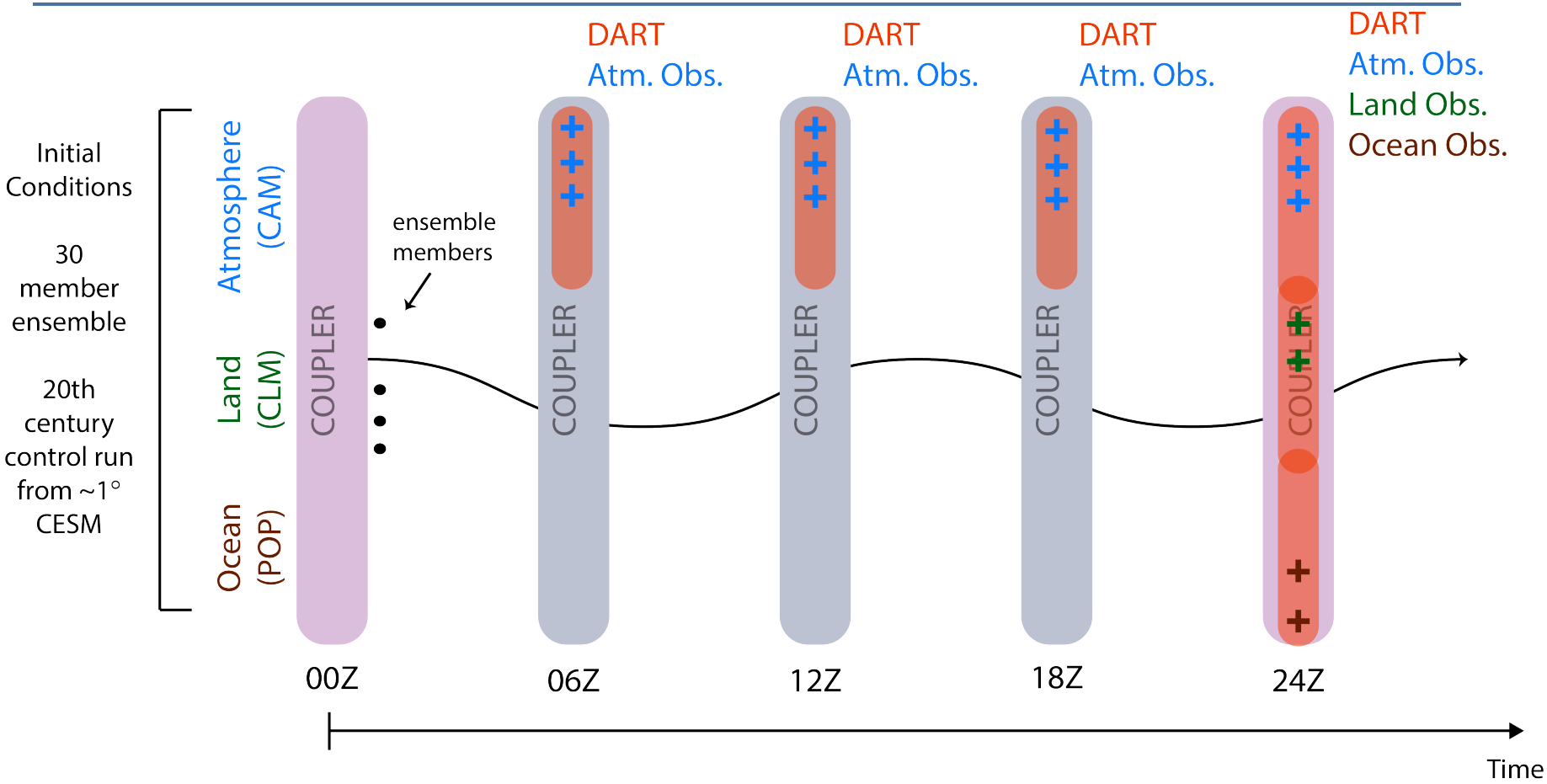
- Improve use of near surface observational data
  - let observations in boundary layers influence both fluids
  - capture the diurnal cycle in atmosphere-ocean interactions

Existing/Planned CDA Frameworks



- ECMWF
- Met Office
- NCEP CFSR
- Canadian Met Service Systems
- BMRC
- JAMSTEC
- JMA-MRI
- GFDL
- NRL

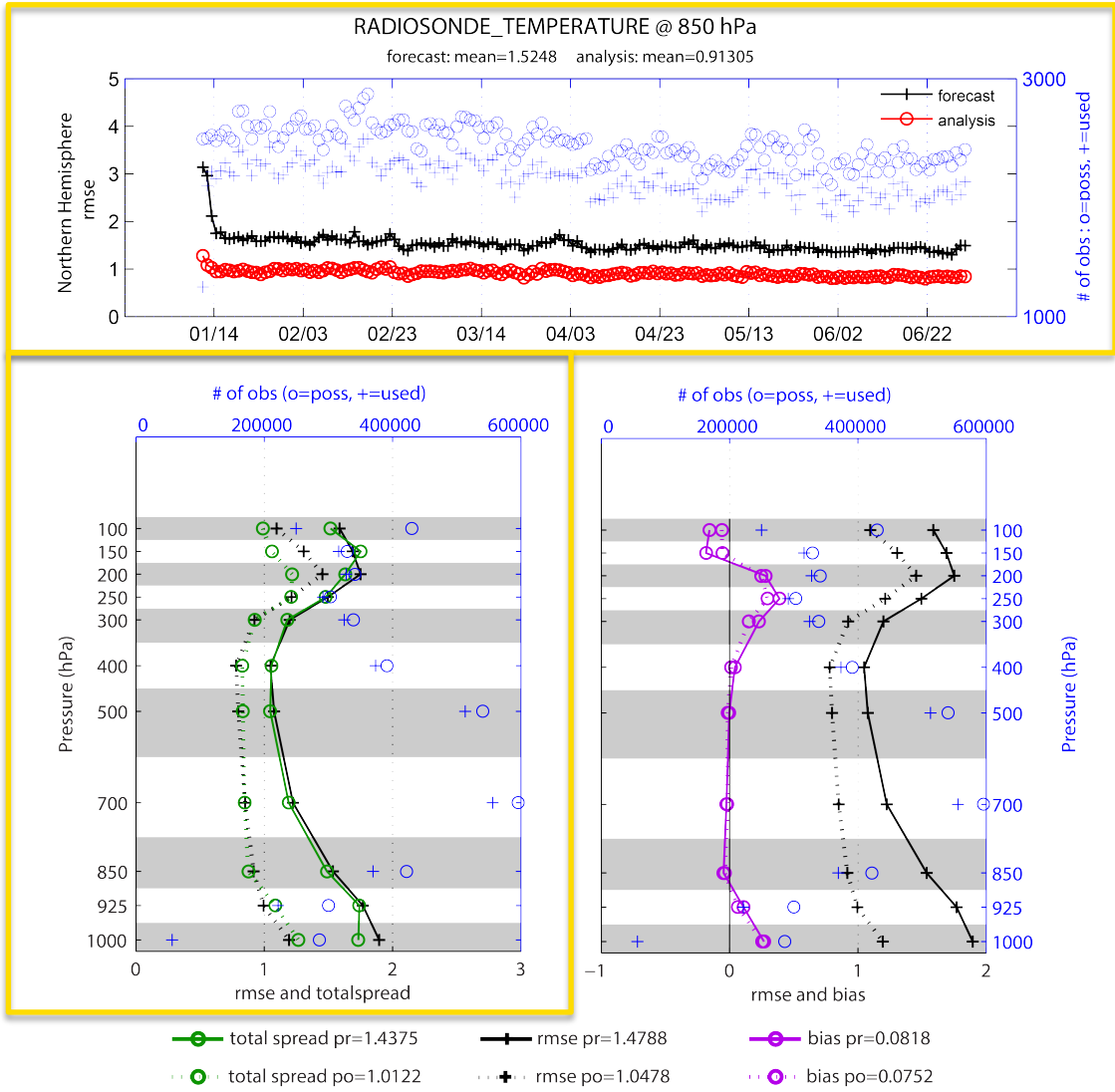
Multi-component Coupled Model Data Assimilation



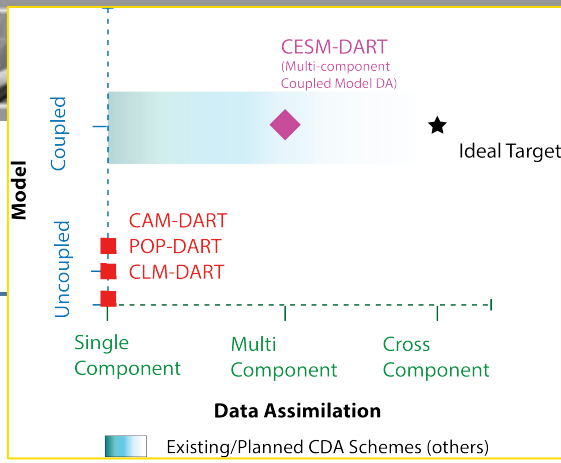
- Coupler exchanges fluxes and other necessary information between component models
- CESM 1_1_1 B-compset: several other models (e.g. sea/land-ice) that are active

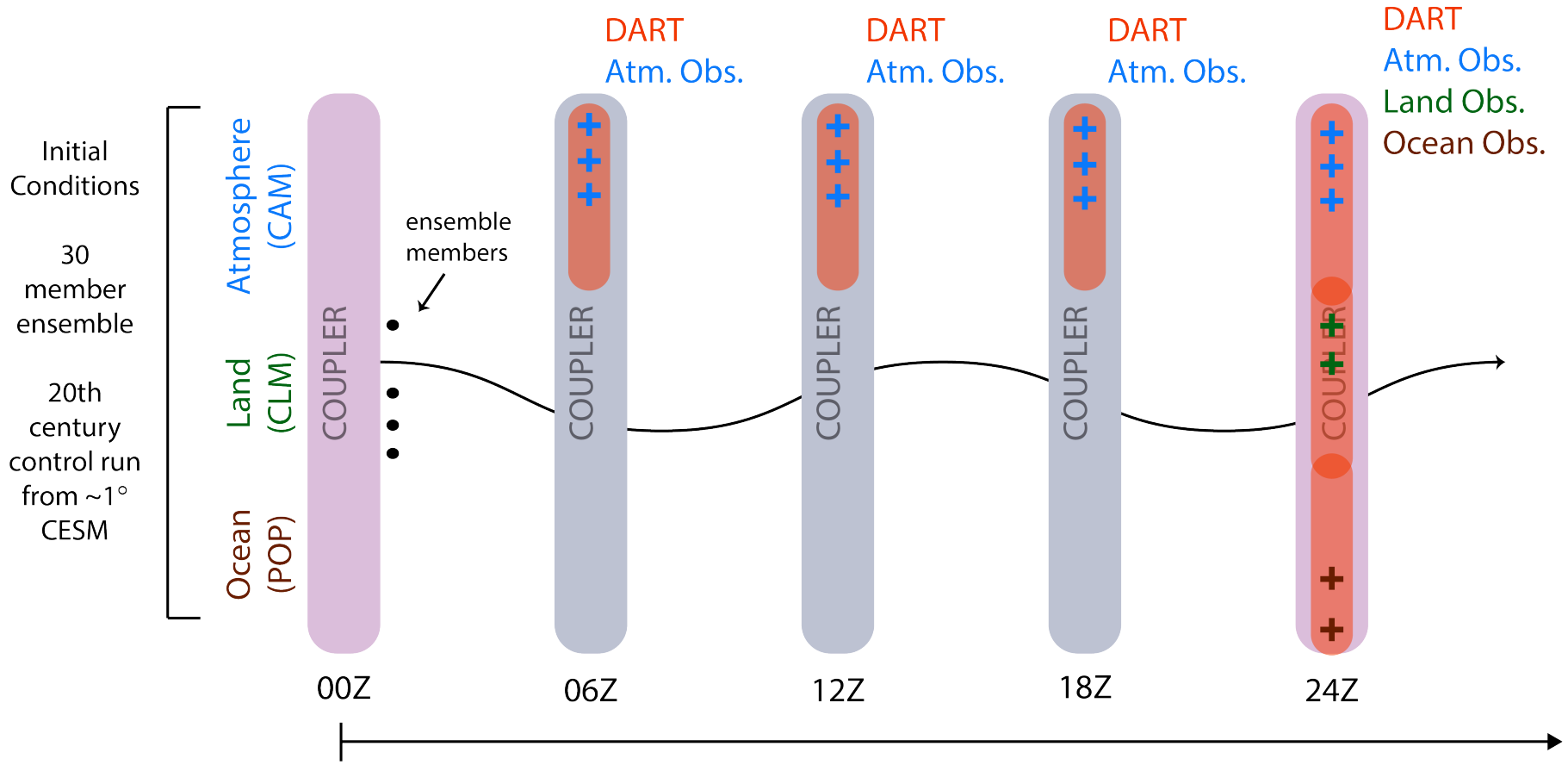
Evaluating Performance in Observation Space

- Ensemble analysis provides an estimate of analysis and forecast uncertainty
  - (Top Panel) evolution of prior and posterior RMS error
  - (Bottom Panels) profile of time-averaged prior and posterior RMS error, total spread and bias relative to the actual radiosonde T observations

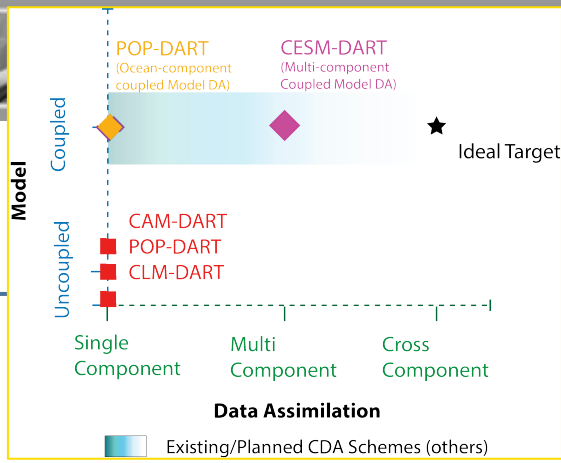


Multi-component (MuC) CDA





Ocean-component (Ocean-only) CDA



DART

Initial Conditions

30 member ensemble

20th century control run from ~1° CESM

Atmosphere (CAM)
Land (CLM)
Ocean (POP)

ensemble members

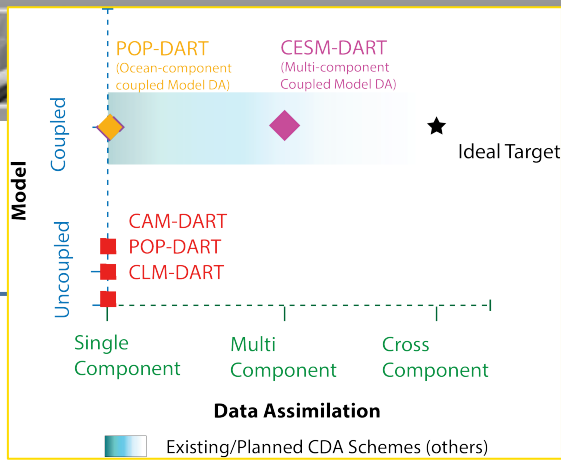
COUPLER

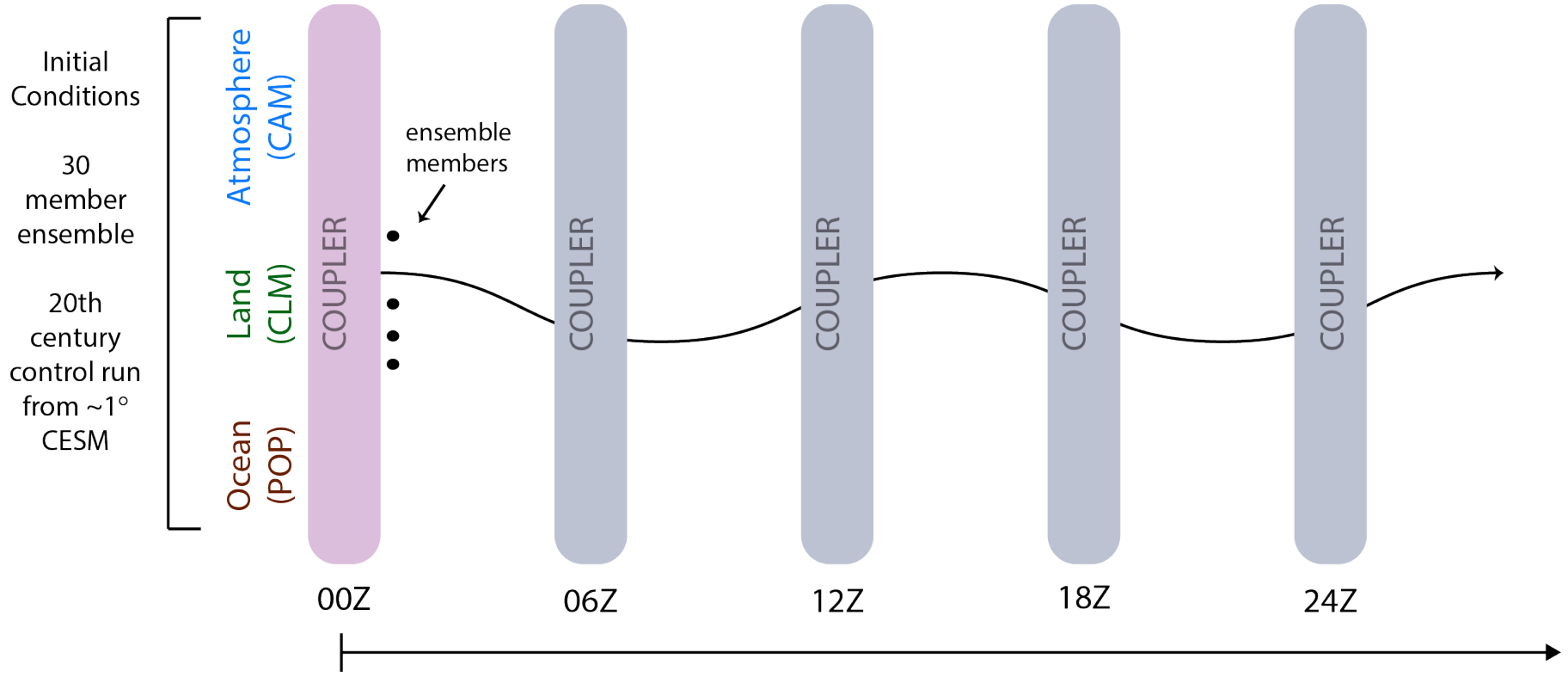
Ocean Obs.

00Z 06Z 12Z 18Z 24Z

Time

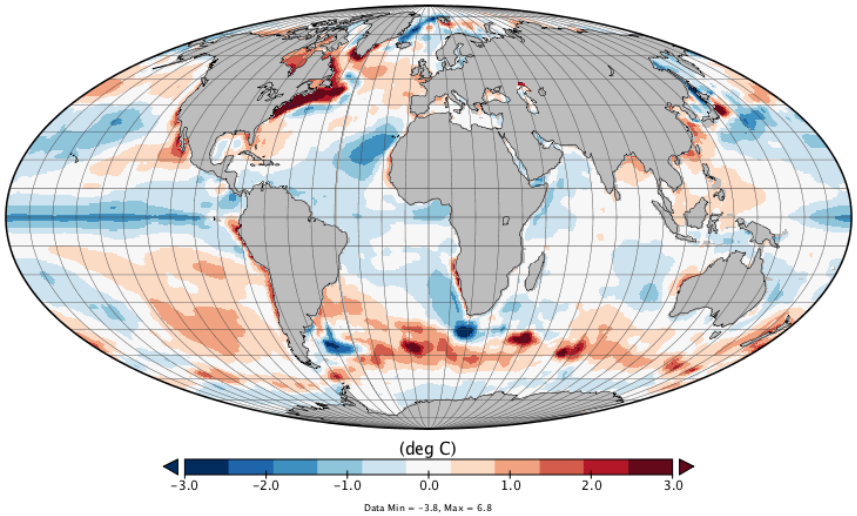
No-Assim. (Free) Coupled Model Run



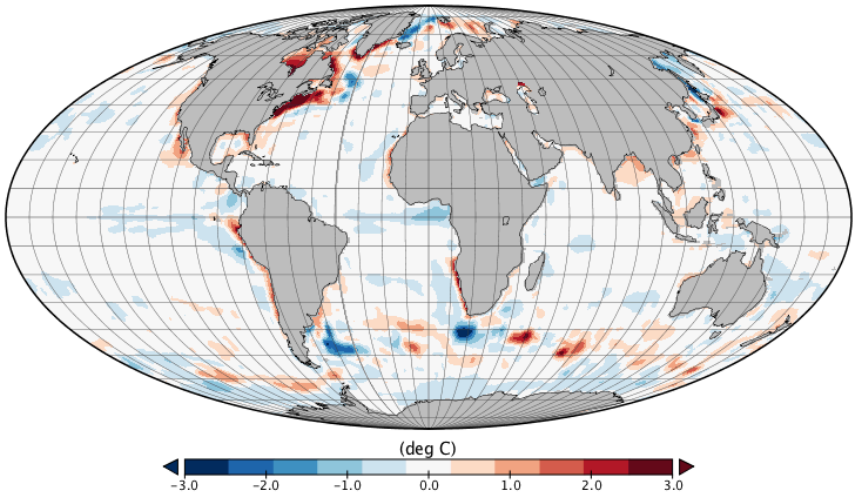


SST Evaluation (2004 Annual Mean)

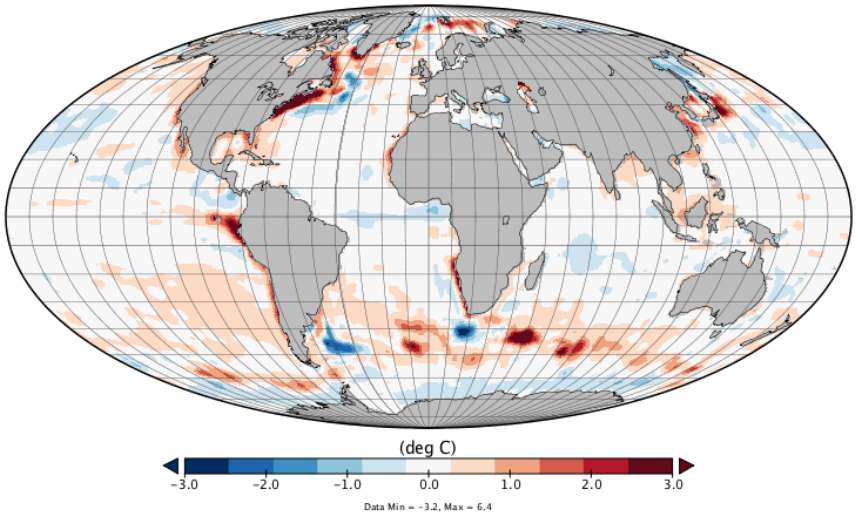
Free Run (minus) Hurrell SST



Ocean-only (minus) Hurrell SST



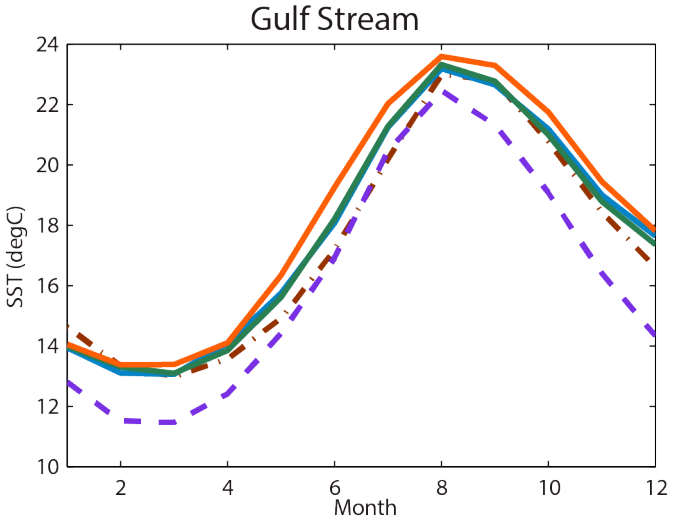
Multi-Component (minus) Hurrell SST

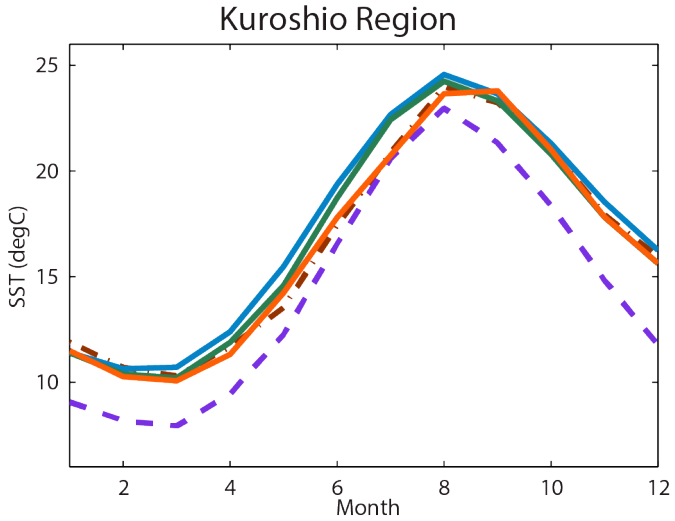


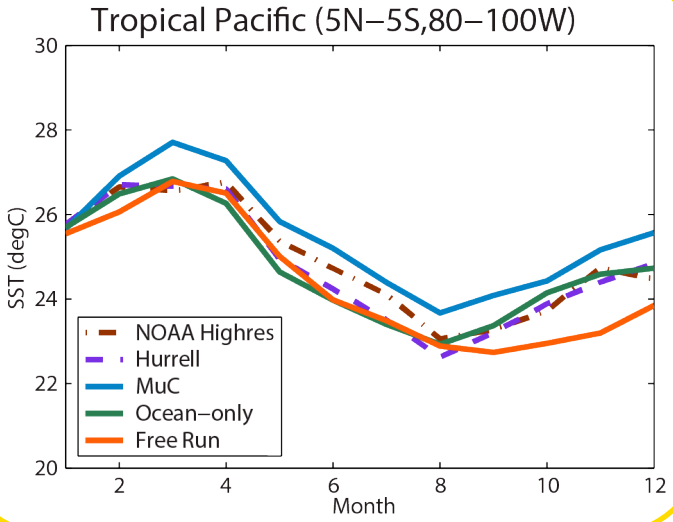
	Mean Diff.*	RMSE**
Free-run-HSST	+ 0.82	0.93
Ocean-only -HSST	+ 0.82	0.93
MuC - HSST	+ 0.93	1.06

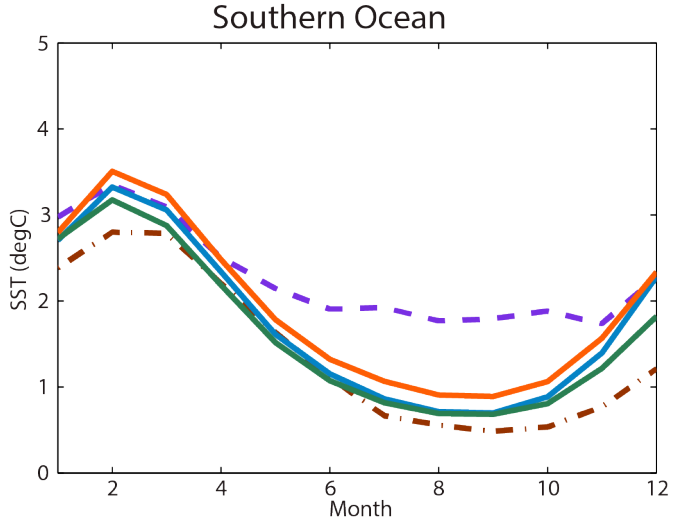
* Hurrell SST used as a 'reference' set
** Caveat - only 12 data points

SST Evaluation (2004 Time Series)



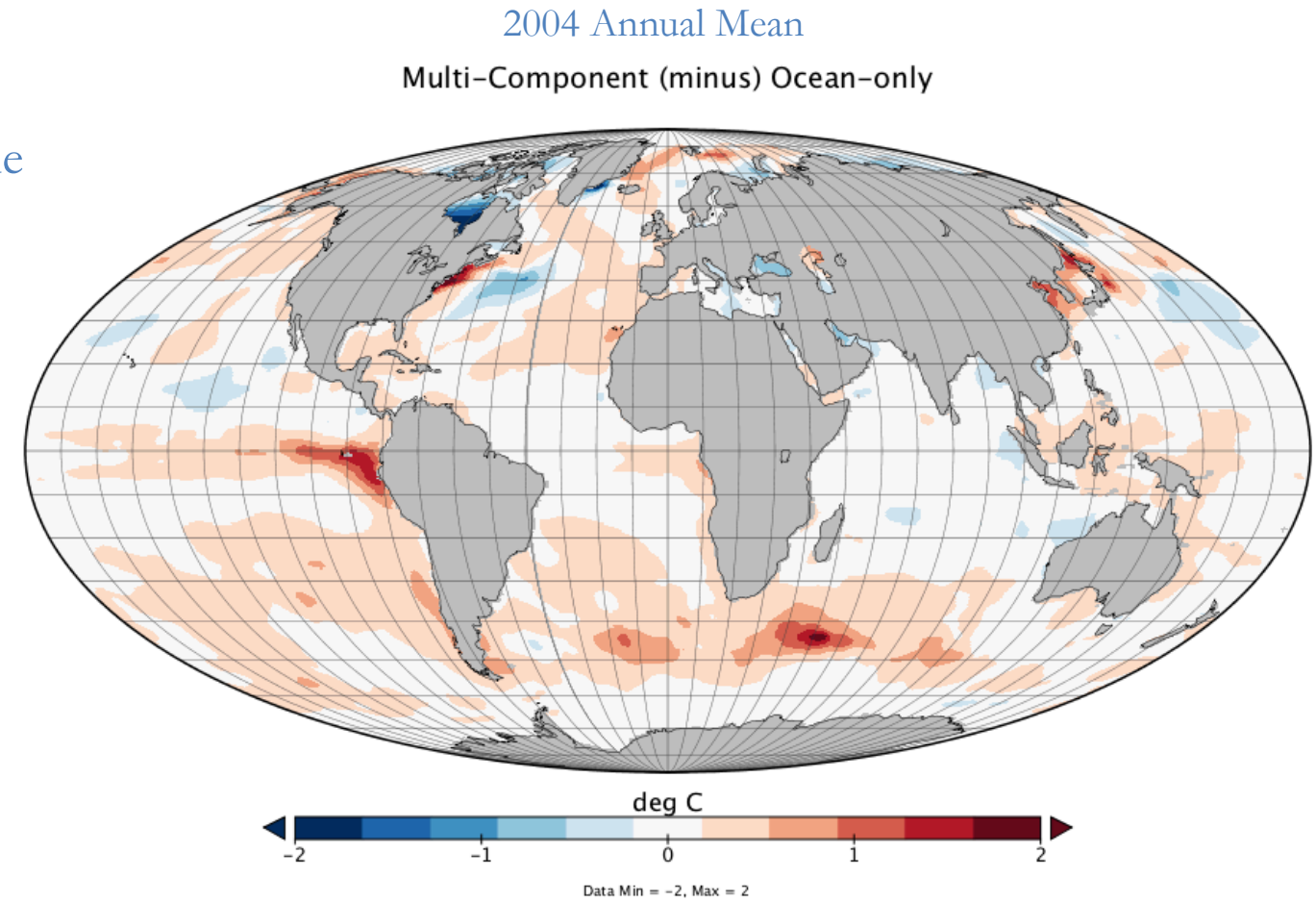






SST Difference between the two DA Experiments

- Pronounced differences in phase/amplitude in Tropical Pacific, western boundary currents
- Corrections (biases?) in SH
- Differences related to
  - Forcing fields
  - Ensemble spread

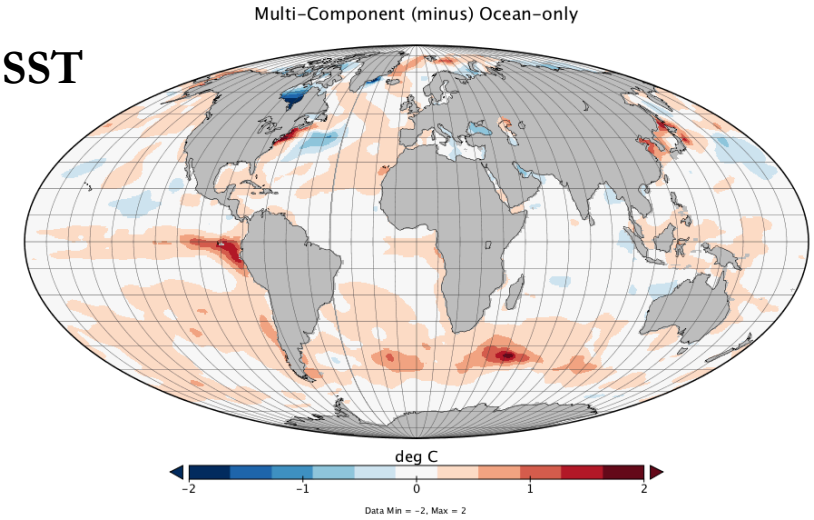


Multi-component CDA estimates a higher SST

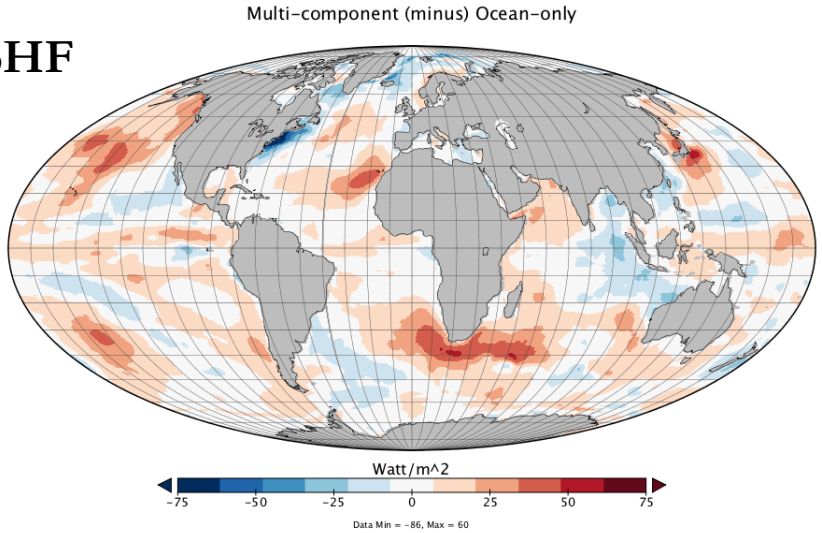
Impact of Changes in Forcing fields

- Differences in SST corresponds to differences in surface heat flux, sea surface height → changes in wind fields

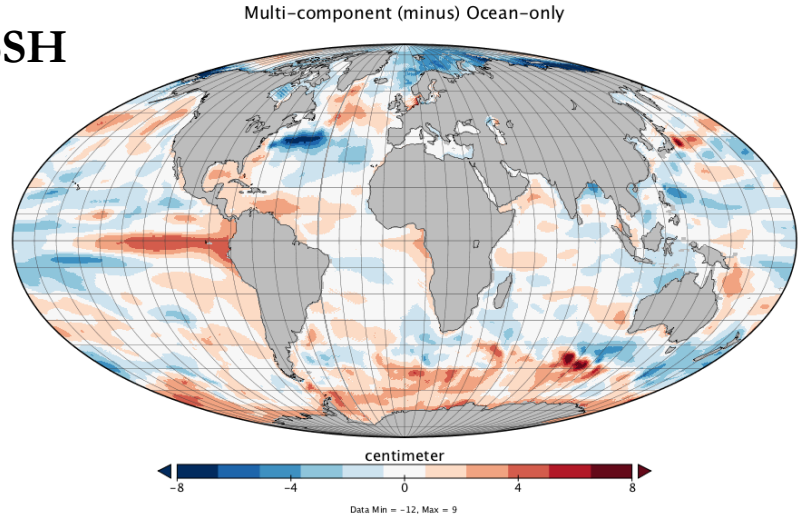
SST



SHF



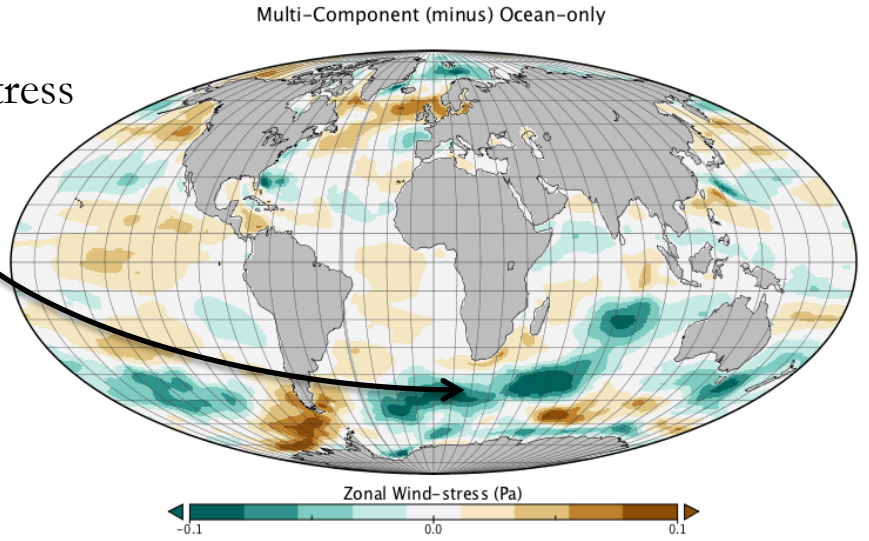
SSH

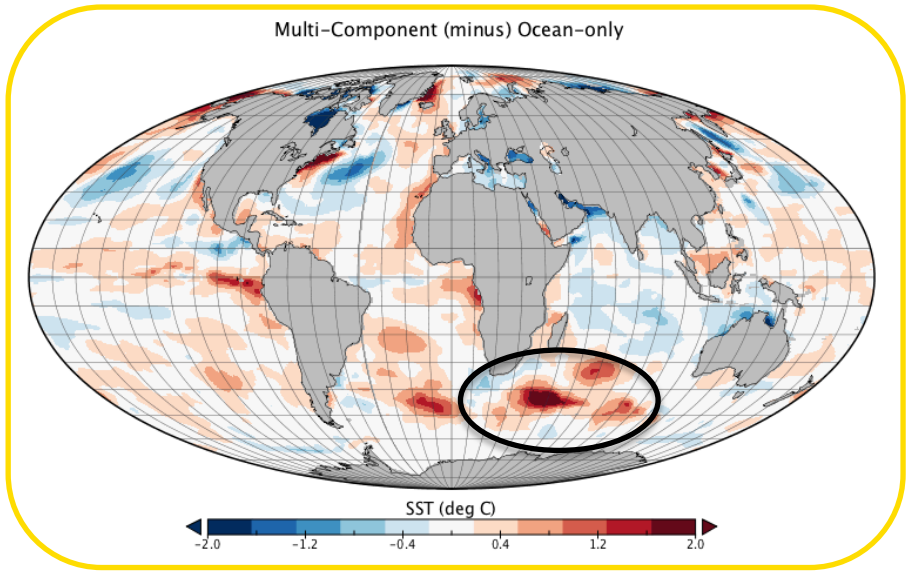


Impact of Changes in Forcing fields (contd.)

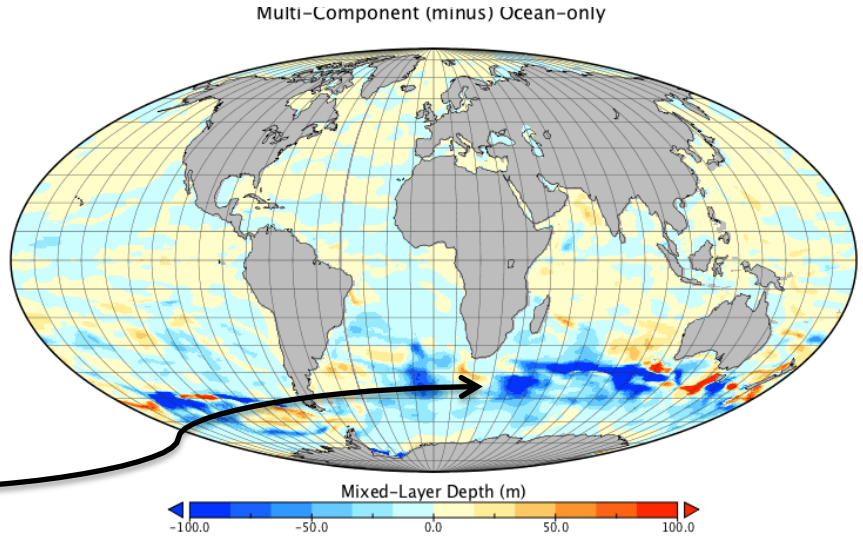
September 2004

Lower wind-stress in MuC

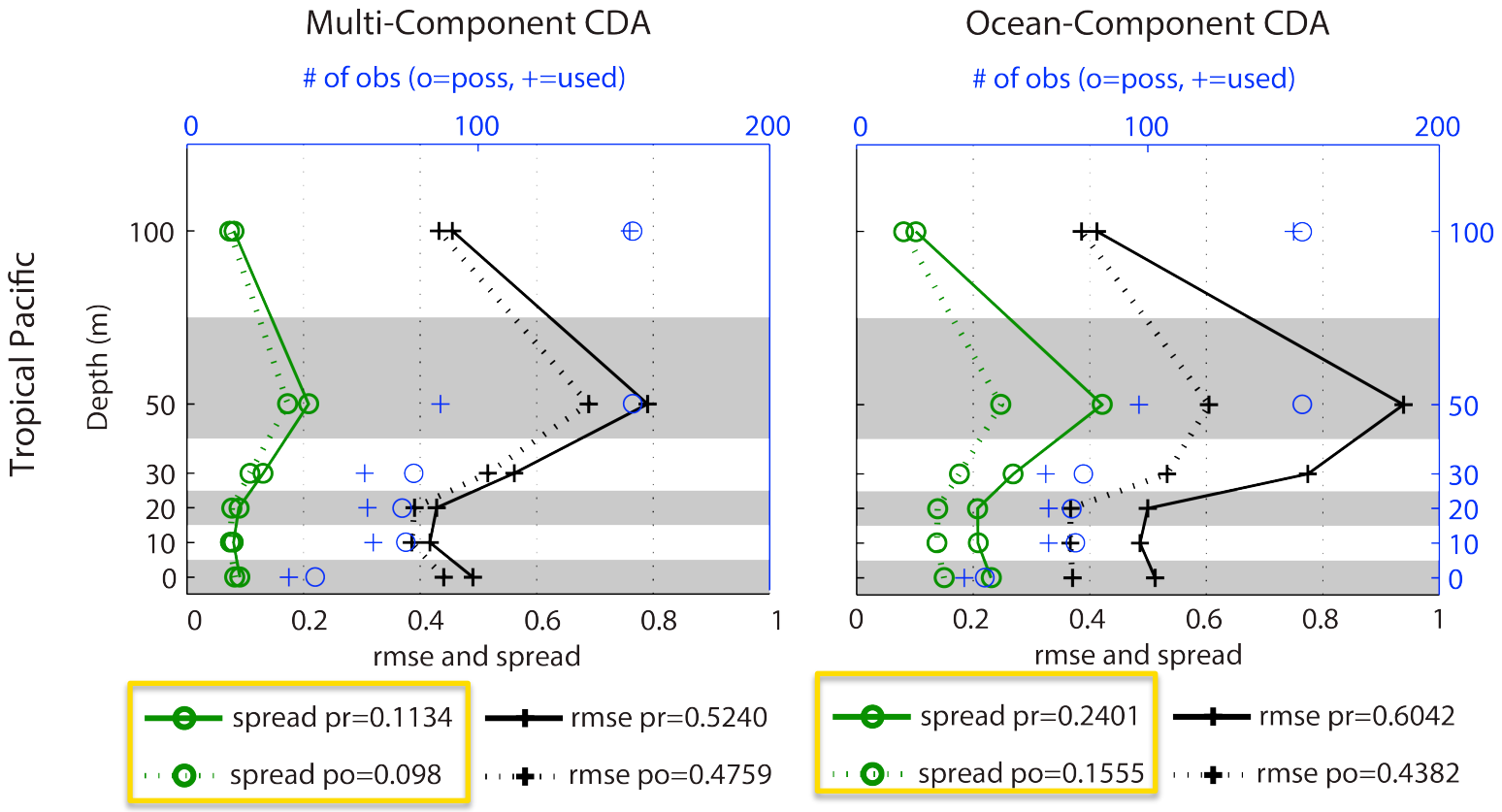




Shallower MLD in MuC



Impact of an Unconstrained Atmosphere



- Evaluation in observation space of the prior and posterior RMS error and the ensemble spread for float temperatures
  - Tropical Pacific (5S-5N, 80-100W)



Ongoing/Planned Activities

- 4 different experiments covering January – December 2004
  - multi-component (MuC) CDA ✓
  - ocean-component (ocean-only) CDA ✓
  - atmosphere-component CDA
  - no-assimilation (free) run ✓

- Planned prediction experiments
  - short-term: MJO, seasonal forecasting (e.g. ENSO)
  - long-term: decadal forecasting (e.g. AMOC)

- Improving/initiating new schemes for CESM-DART
  e.g. for POP-DART
  - accounting for representativeness error (A. Karspeck)
  - inclusion of BGC tracers (very initial discussions with K. Lindsay)



Summary

- Successful implementation of coupled DA with CESM-DART
  - multi-component coupled model framework
  - test-bed for transitioning to cross-component coupled model scheme
- Results from initial implementation-
  - demonstrates **differences** in multi-component vs. single-component frameworks
  - demonstrates strong **impact** of boundary forcing fields, esp. changes to wind fields when atmospheric observations are assimilated
  - part of the differences can be attributed to the response of the ensemble filter to constrained vs. unconstrained atmosphere
- Multiple configurations have been setup to explore-
  - potential strategies for initializing near-term climate prediction



Acknowledgements

- NOAA Climate and Global Change Postdoctoral Program, Visiting Scientists Program, UCAR
- CESM project is supported by the National Science Foundation and the Office of Science (BER) of the U.S. Department of Energy
- Frank Bryan, Tony Craig, Clara Deser, Brian Eaton, Jim Edwards, Peter Gent, Michael Levy, Keith Lindsay, Mitch Moncrieff, Nancy Norton, Chris Snyder, Mariana Vertenstein, and others
- Funding sources:

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NOAA NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION U.S. DEPARTMENT OF COMMERCE

NASA

NSF



QUESTIONS?

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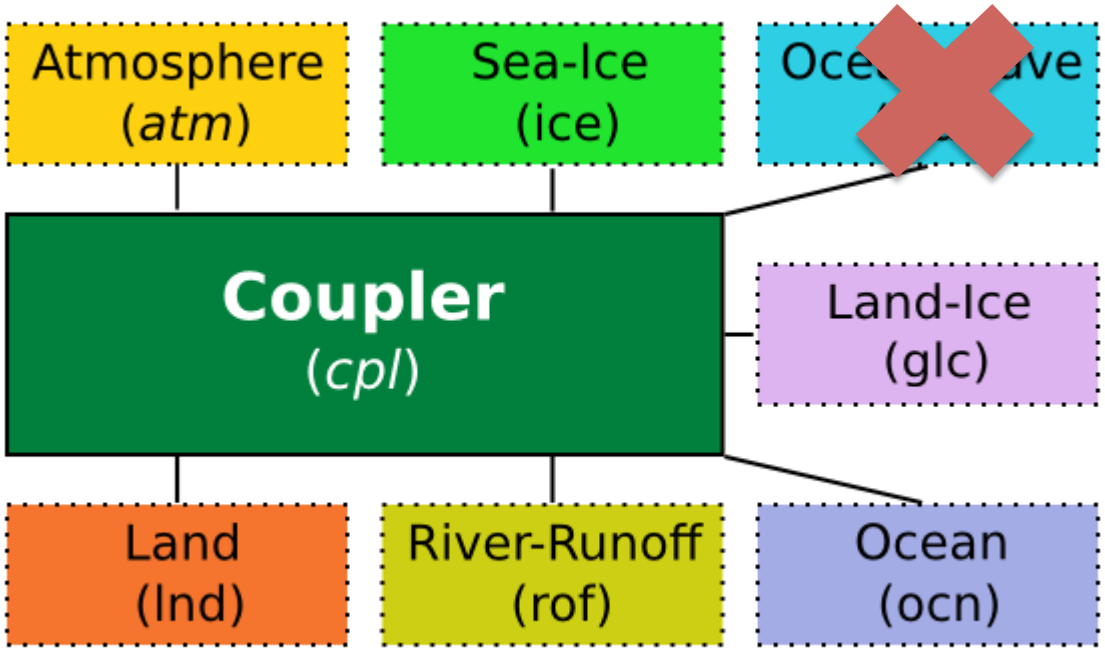
BACKUP

CESM Model Components

- All active components (B COMPSET)
- Present day with CAM5 physics (CAM5 FV core)
- Horizontal Res: Nominal ~1°
- Vertical Discretization:
  CAM – 30 levels
  POP – 60 levels with 10 m resolution in the upper 200 m, gradually expanding to 250 m resolution below 3000 m depth



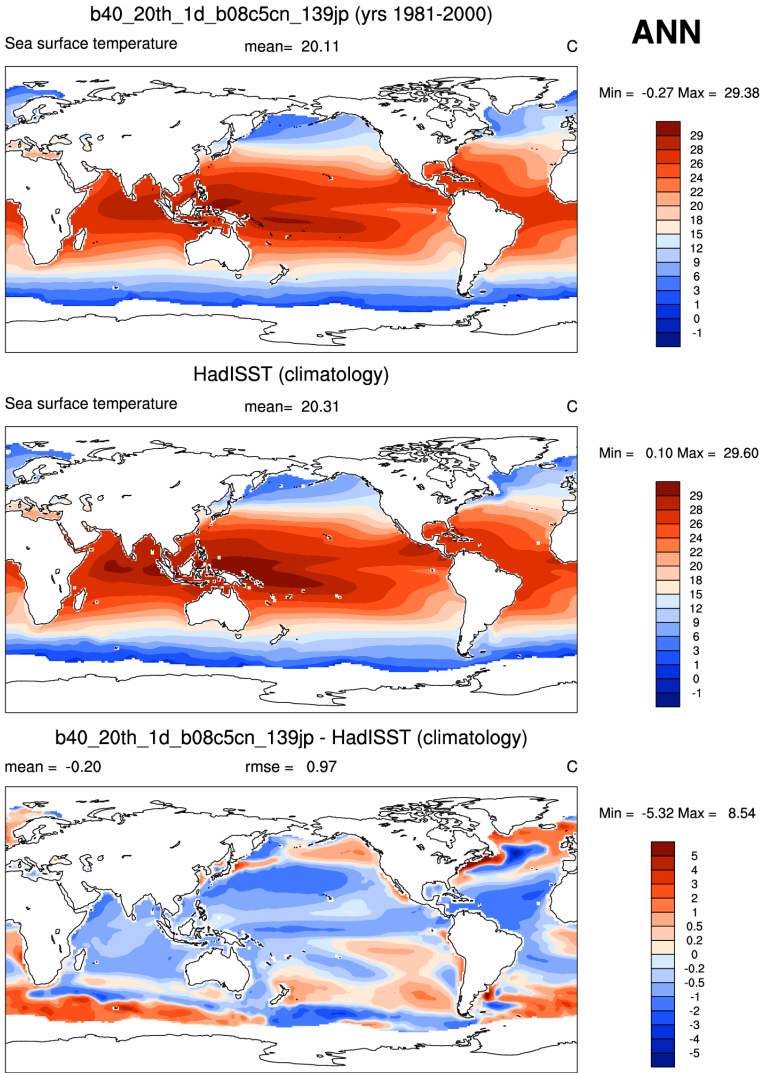
CESM Components – High Level Diagram
The coupler is in the middle and communicates with all other components
(adapted from - https://summerofhpc.prace-ri.eu)



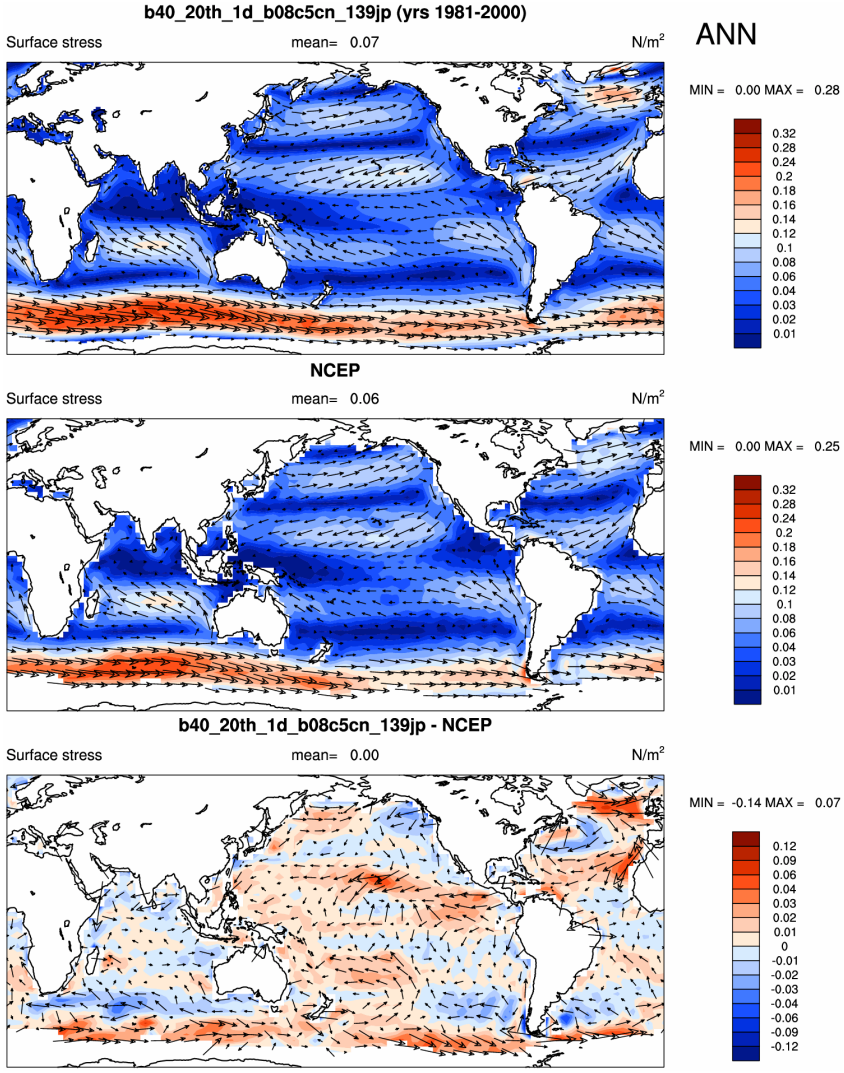
BACKUP

CESM Model Bias

SST



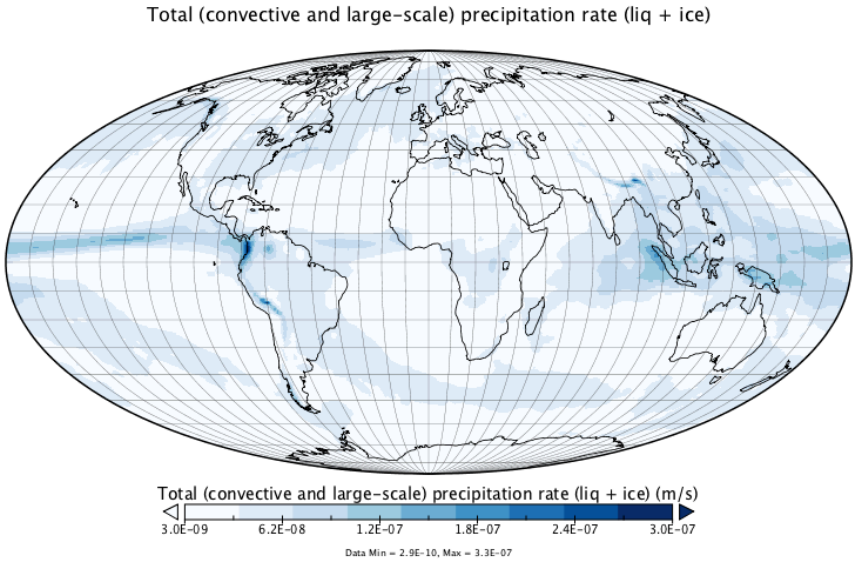
Surface Stress

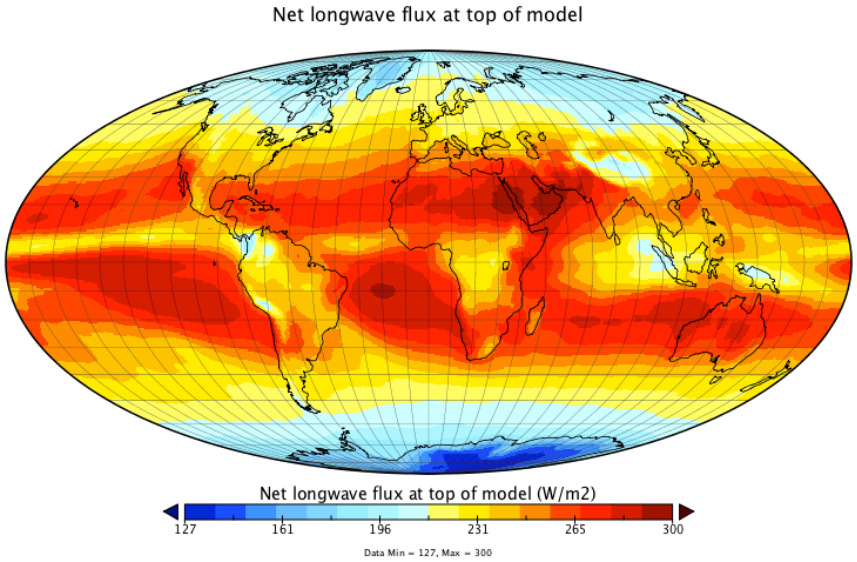




BACKUP

Estimated Atmospheric Model States





- **Suite of variables from atmosphere, ocean, land and other model components**
- Quantitative examination ongoing
  - need a larger timespan of runs to assess any systematic drifts
  - qualitatively fields for the first set of runs look ok!