Do ocean reanalysis products agree on the historical representation of the AMOC?

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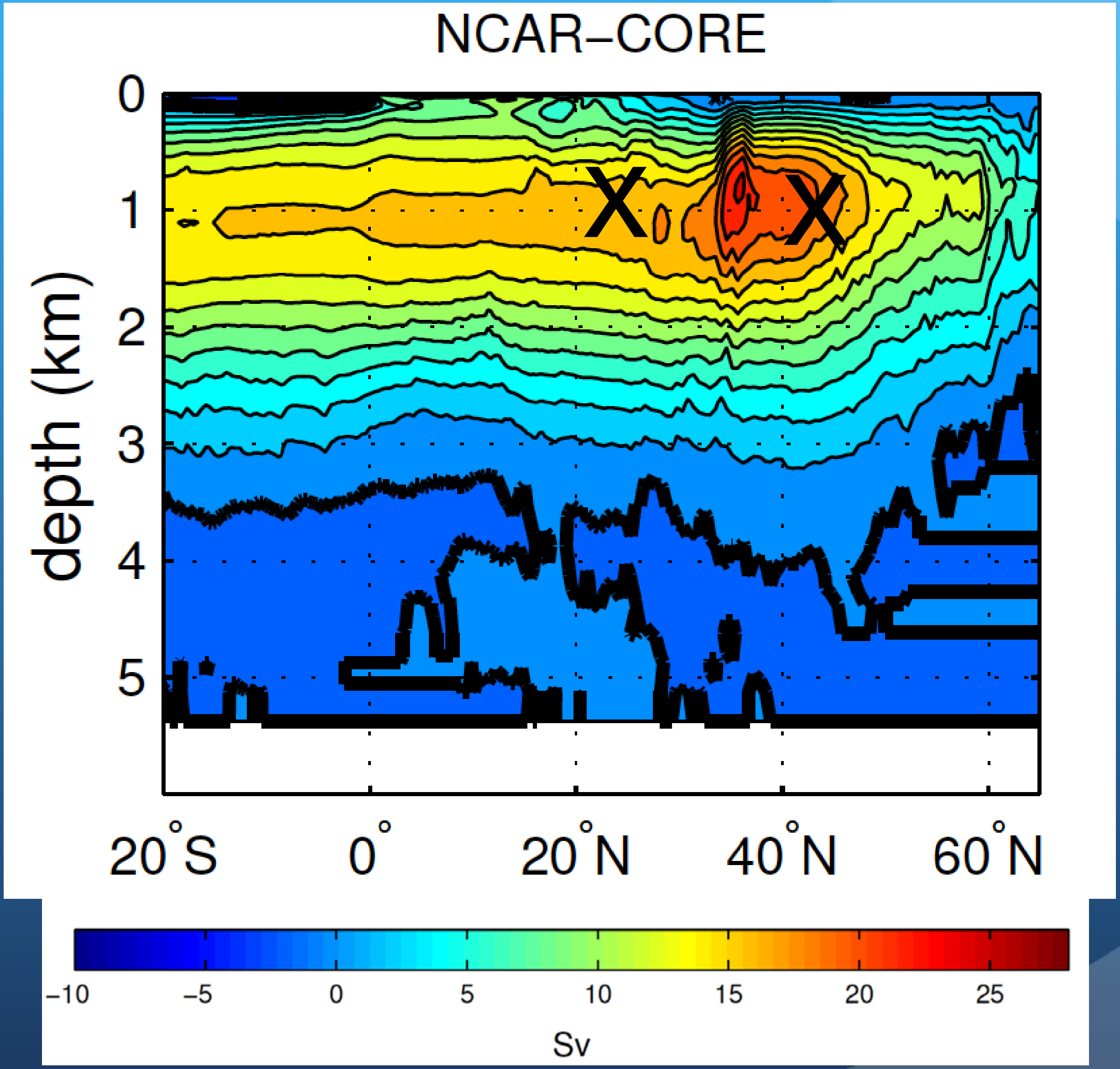
Thanks to Magdalena Balmaseda, Doug Smith ,Tony Rosati, Shaoquing Zhang, Armin Köhl, Keith Haines, Maria Valdivieso, Yosuke Fujii , Ben Giese for making AMOC data available

Why do we care about historical AMOC variability in ocean reanalysis products?

- **Process understanding**
- The AMOC state upon initialization is thought to play an important role in **decadal-scale climate prediction** in the North Atlantic. (Robson et al 2012; Yeager et al 2012, Matei et al 2012; Msadek et al 2014)
  - Retrospective prediction experiments are used to evaluate the performance of prediction systems.
  - **Ocean reanalysis products are used to initialize retrospective predictions**

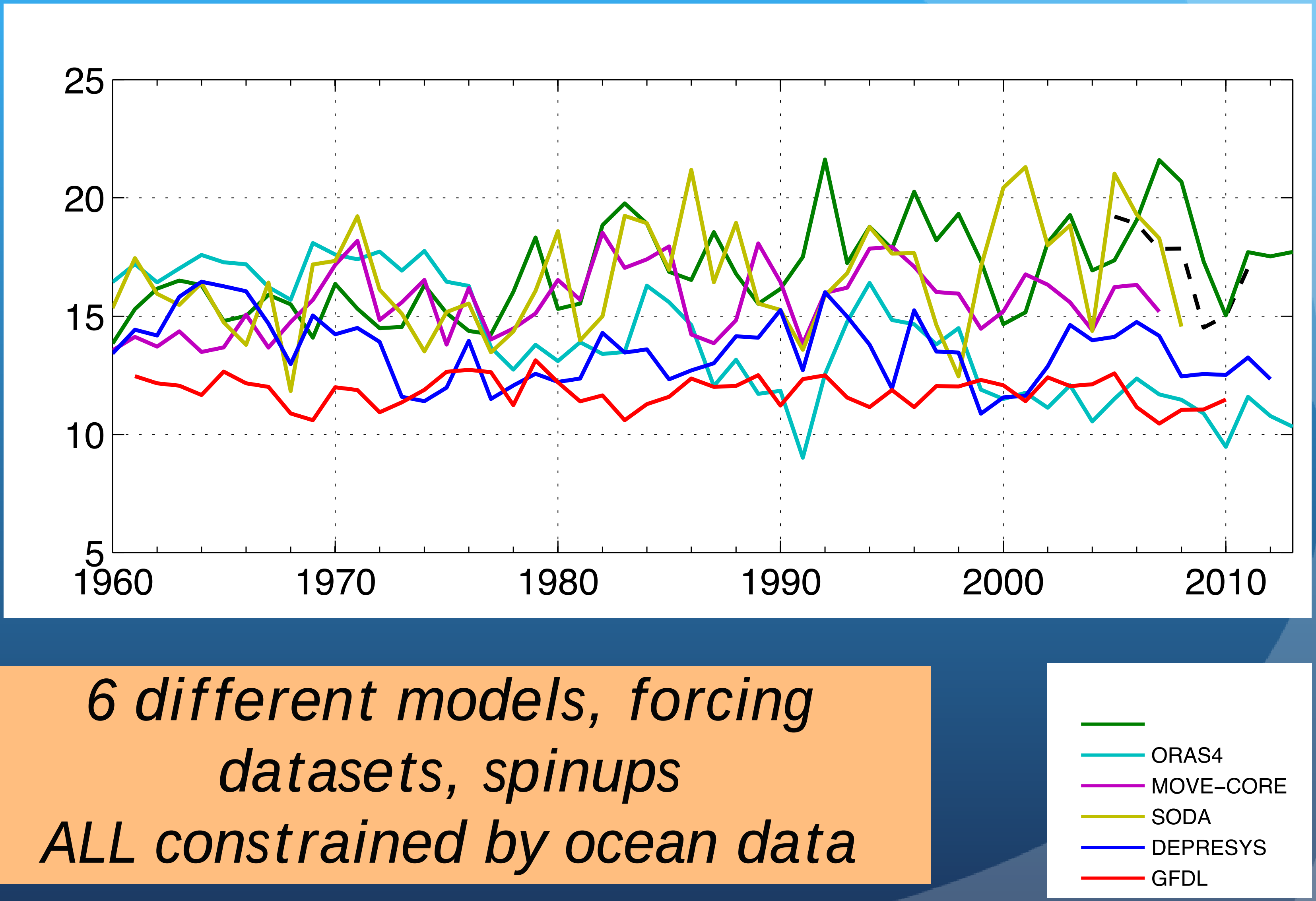
Atlantic Meridional Overturning Circulation



Groups that have contributed AMOC reanalyses

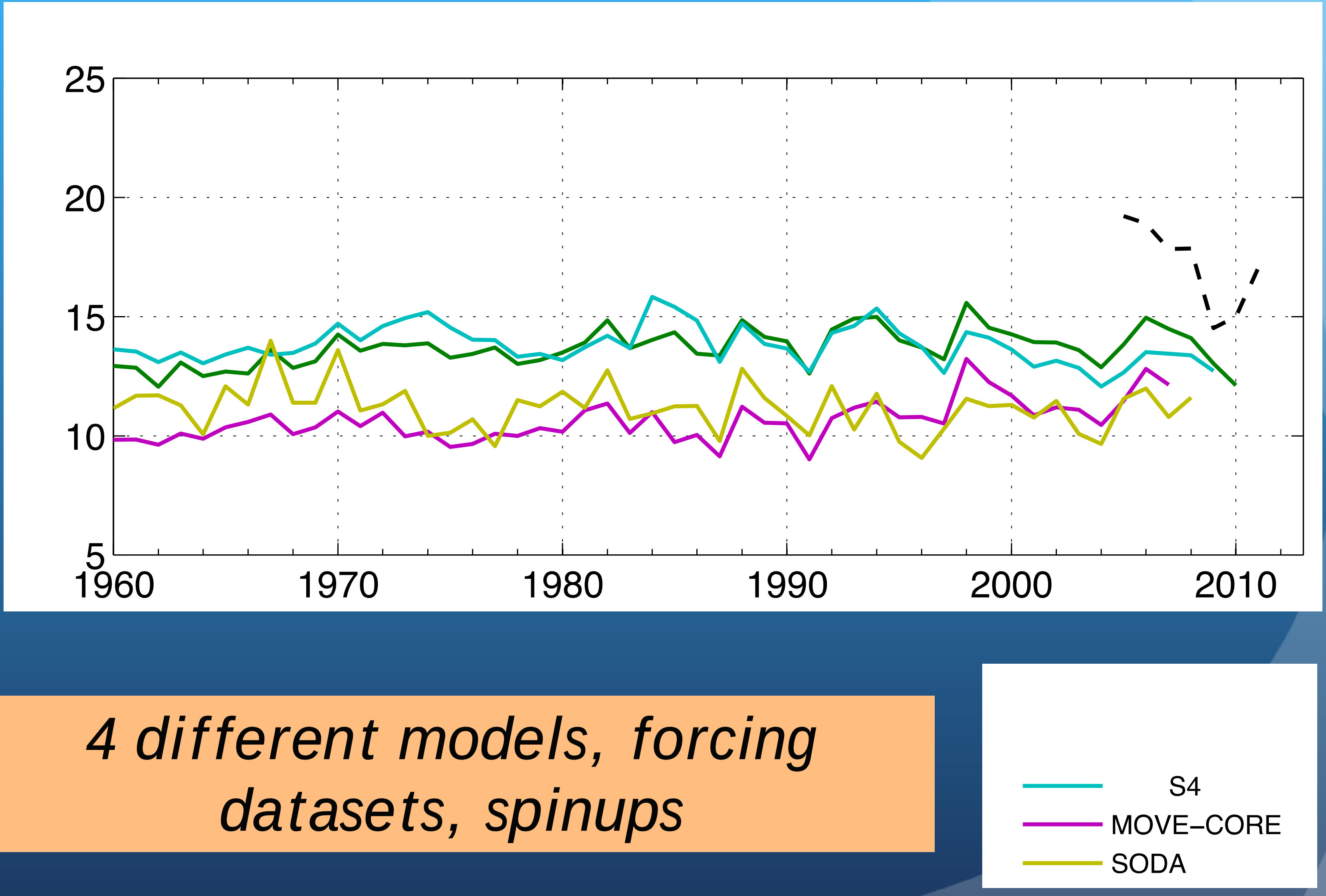
GROUP	METHOD	INSITU T/S	ALT	SST	NoAssim Control run?	Atm forcing	DP INIT?
GECCO2 (U. Hamburg)	4DVAR	YES	YES	YES	YES	NCEP	YES
ORAS4 (ECMWF)	NEMOVAR 3DVar	YES	YES	YES	YES	ERA-40/ERA-I	YES
MOVE-CORE (MRI)	3DVar	YES	YES	NO	YES	CORE II IAF	YES
SODA (U.Marylnd/TAMU)	OI	YES	NO	YES	YES	20-CR	YES
DePreSys (UKMET)	Coupled nudging to OI product	YES	NO	YES	NO	N/A	YES
ECDA3.2 (GFDL)	coupled EaKF	YES	INDIRECTLY	YES	NO	N/A	YES

Reanalyses set



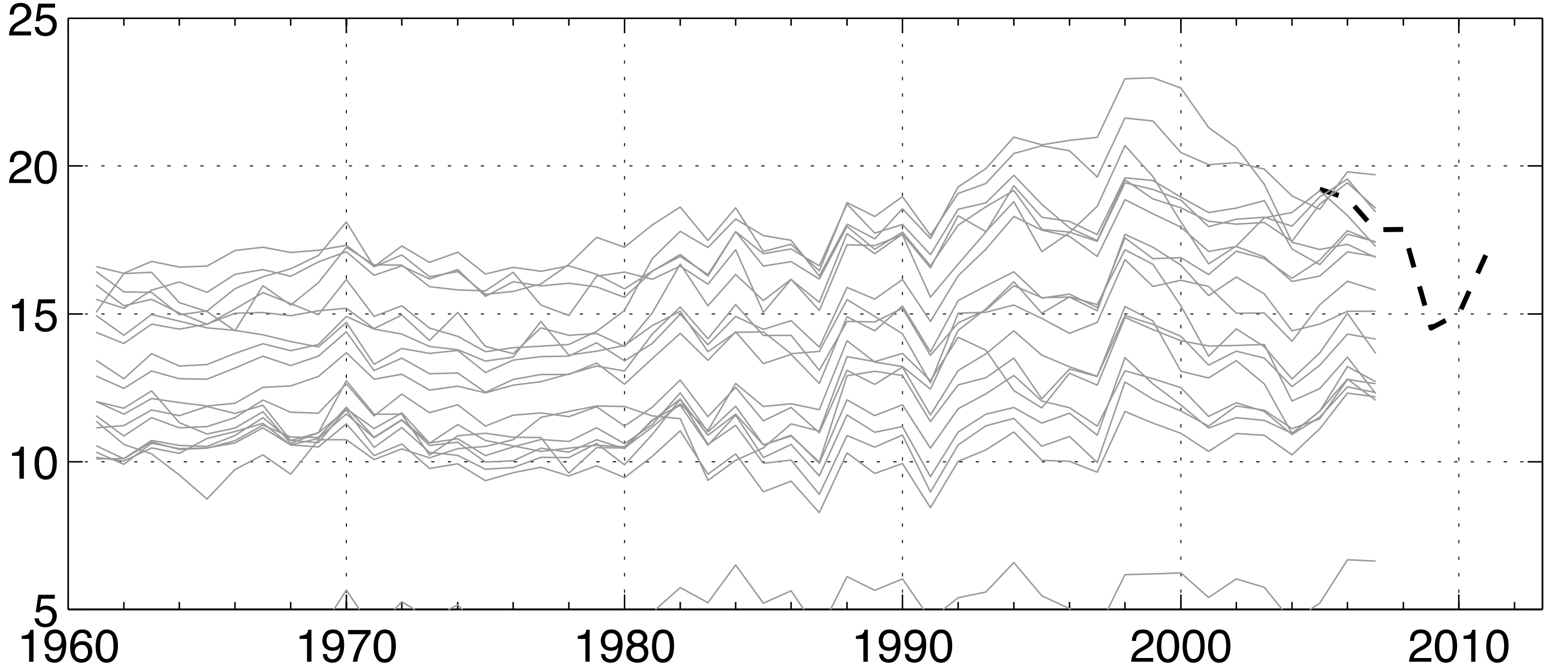
6 different models, forcing datasets, spinups
ALL constrained by ocean data

No Assimilation



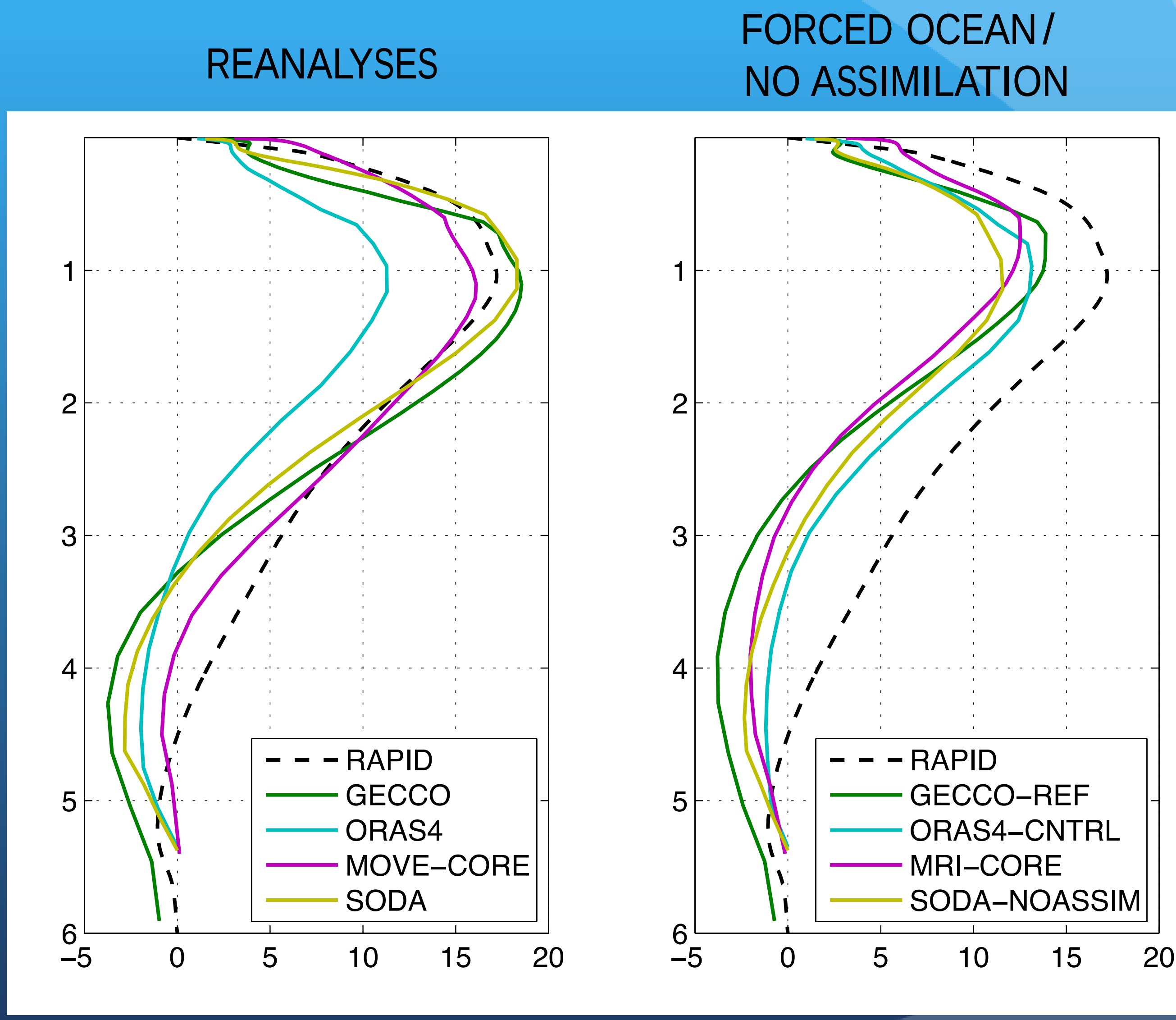
4 different models, forcing datasets, spinups

CORE-II

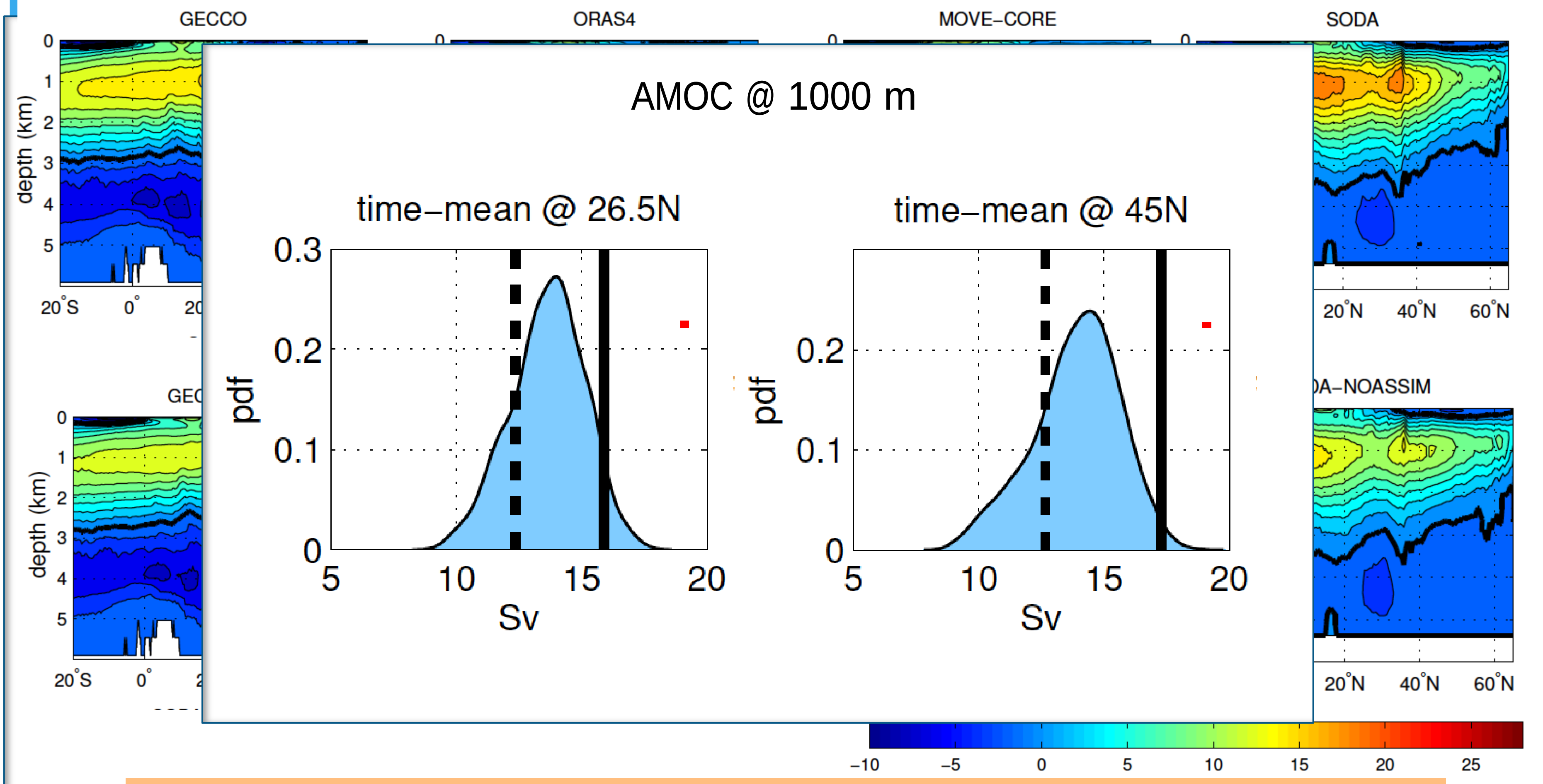


20 different models, identical CORE-IAF forcing, identical spinup procedures

Comparison to RAPID estimates @ 26.5N

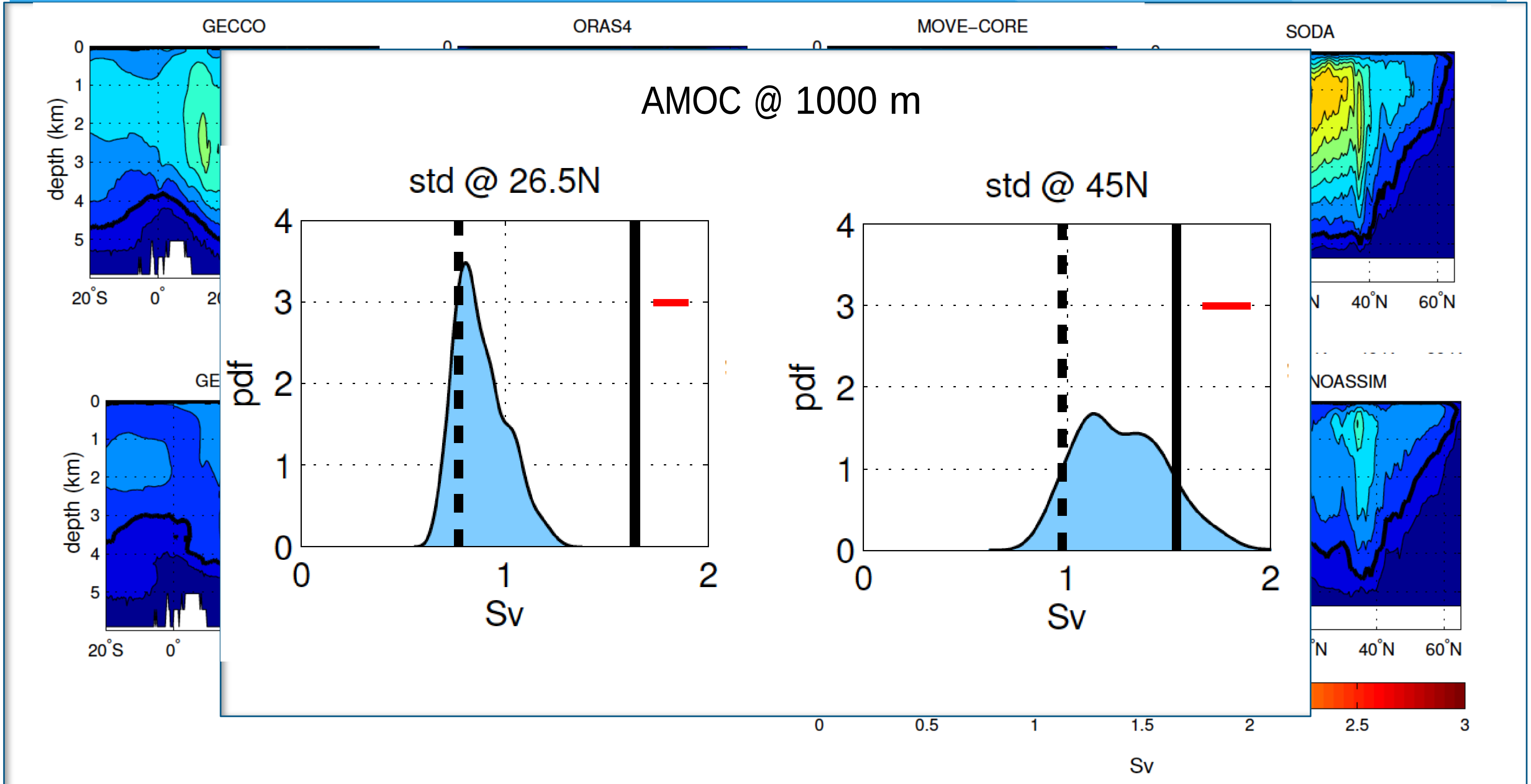


AMOC Time Mean



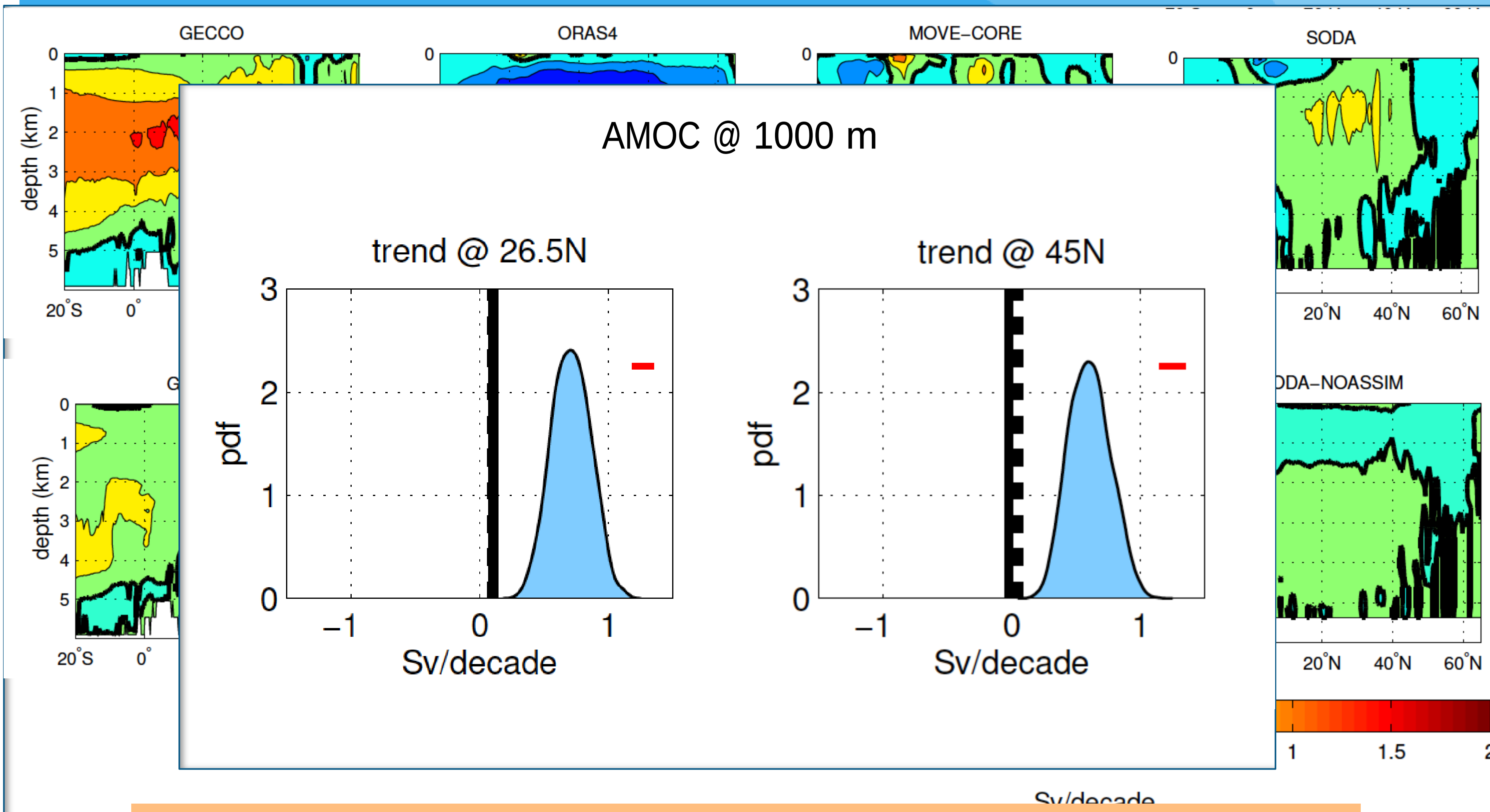
Data constraints lead to stronger mean AMOC, more consistent with RAPID

AMOC Variability



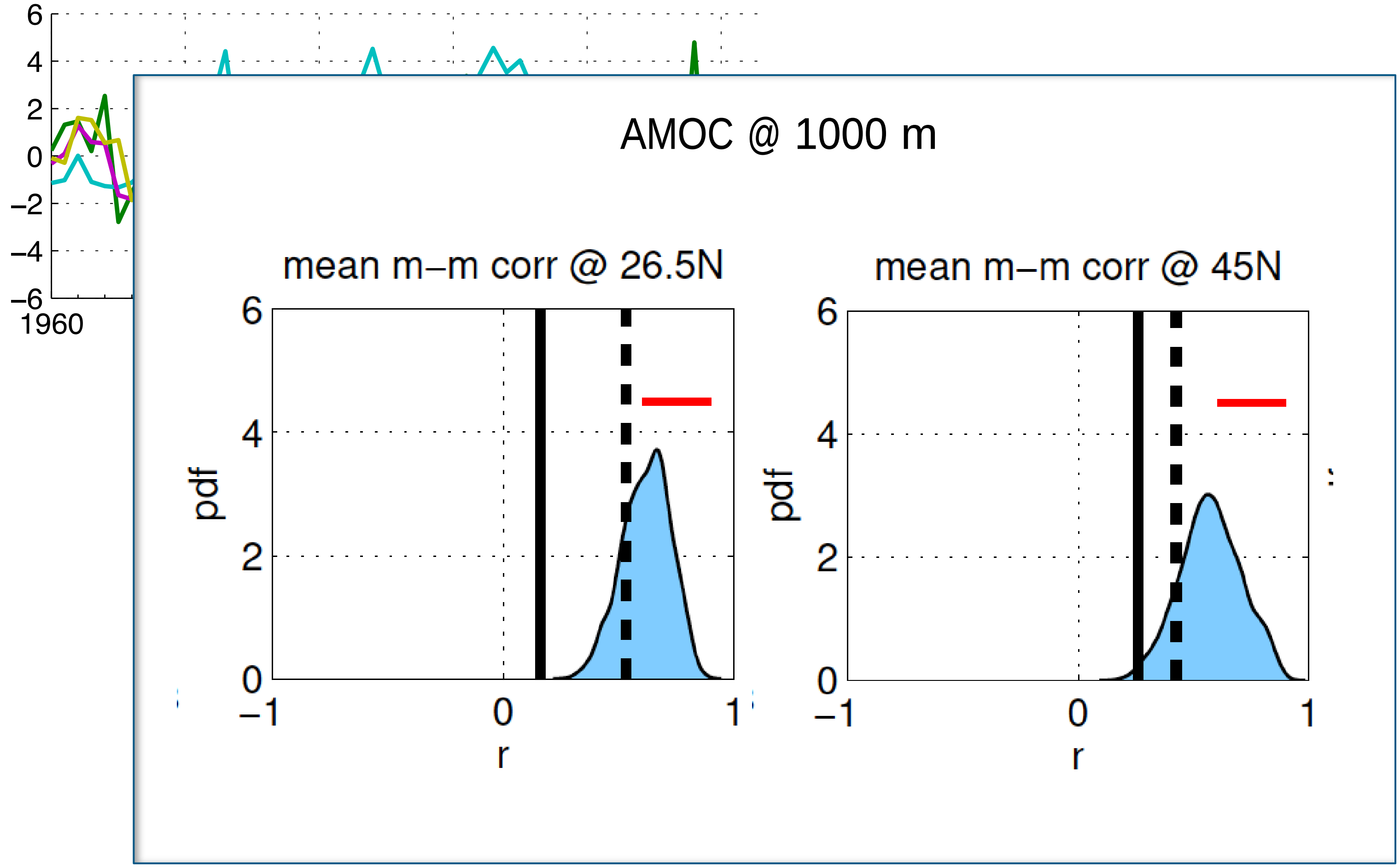
Data constraints increase variability, especially at lower-latitudes

AMOC Trend (1960-2007)



Data constraints increase trends
– and not consistently

Agreement in year-to year signal?



*Data constraints **reduce** year-to-year consistency*

A–NOASSIM (11.9,11.1) [–0.1,–0.2]

Summary

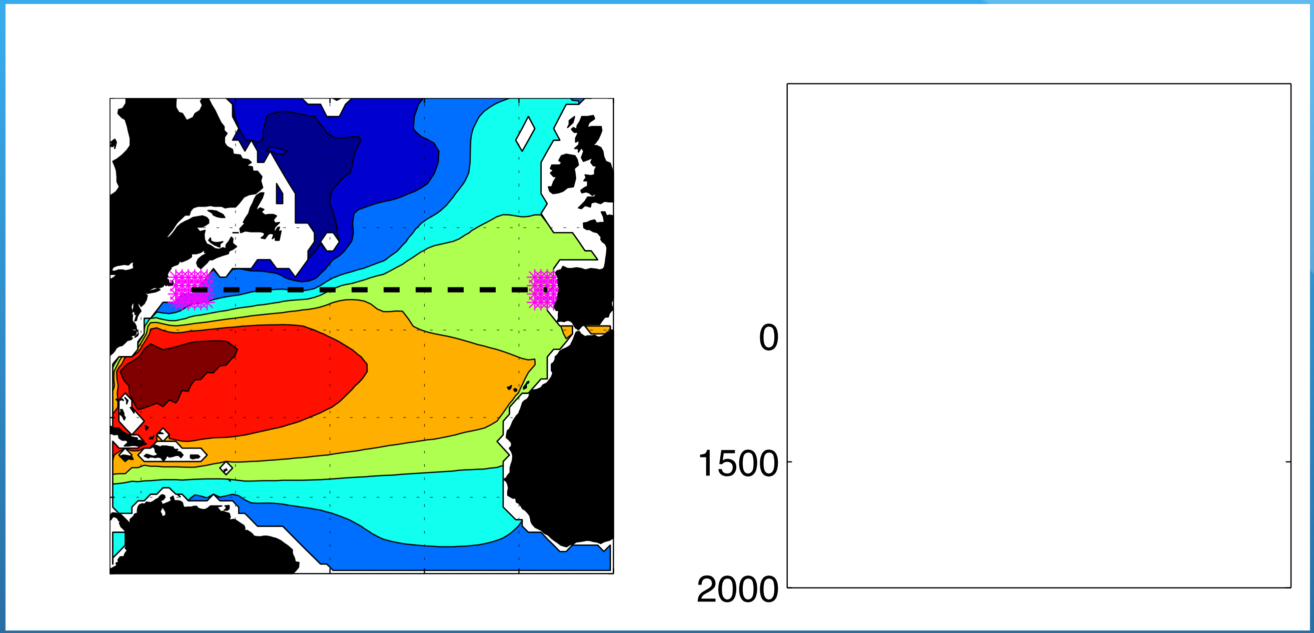
- Ocean data constraints tend to increase mean AMOC strength (closer to RAPID observations)
- Ocean data constraints tend to increase trends and variability strength but..
- AMOC variability/trends are *less* consistent within ocean reanalysis products than in forced-ocean runs.

Are the current generation of reanalysis products useful to inform our understanding of AMOC variability and initialize decadal predictions?

Can they be used indiscriminately?

End

The geostrophic shear @ 41N



$$\Psi_{total} \approx \Psi_{Ekman} + \Psi_{shelf} + \Psi_{geostrophic}$$

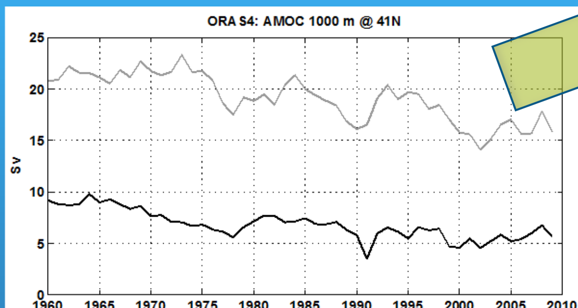
$$\Psi_{geostrophic} = \int_{-H}^{0} \overline{v}_g^x dz$$

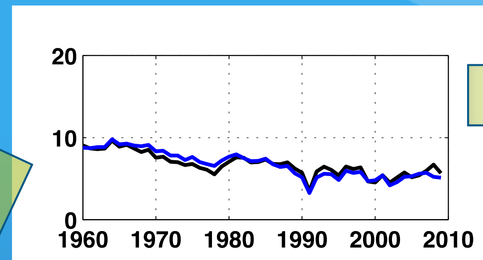
$$= \int_{-H}^{0} \frac{g}{f\rho_o} \int_{-H}^{z} \rho_w(z') - \rho_e(z') dz' dz \quad + \quad H\overline{v}_{-H}^x$$

$$\begin{aligned} \rho_w &= f(T_w, S_w) \\ &= f(\overline{T_w} + T'_w, \overline{S_w} + S'_w) \end{aligned}$$

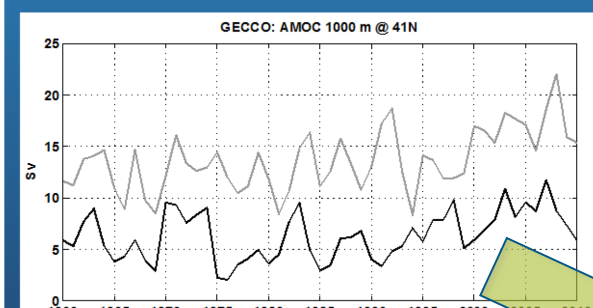
$$\begin{aligned} \rho_e &= f(T_e, S_e) \\ &= f(\overline{T}_e + T'_e, \overline{S}_e + S'_e) \end{aligned}$$

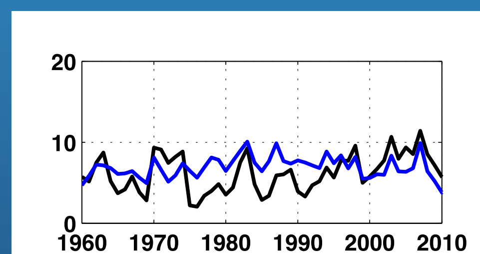
ORAS4


ORA S4: AMOC 1000 m @ 41N
Sv


20
10
0
1960
1970
1980
1990
2000
2010

GECCO


GECCO: AMOC 1000 m @ 41N
Sv


20
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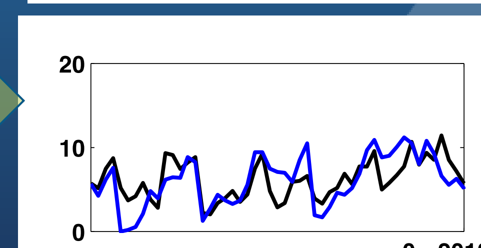
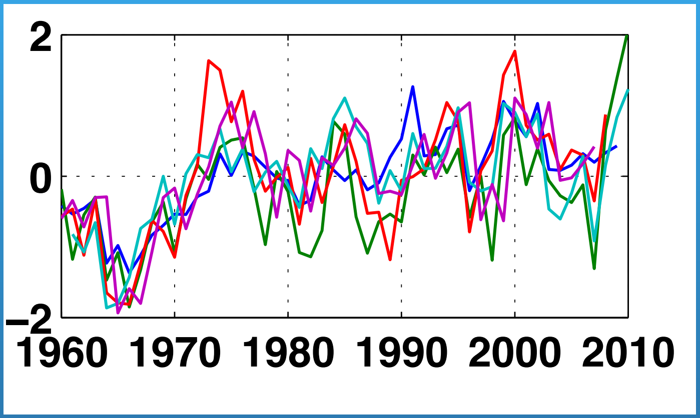

20
10
0
0 2010

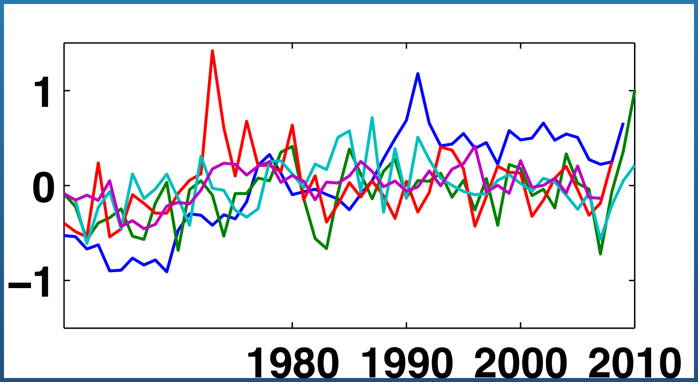
Is the temperature at the eastern/western boundary in agreement?

WESTERN BOUNDARY

EASTERN BOUNDARY



0-250 m

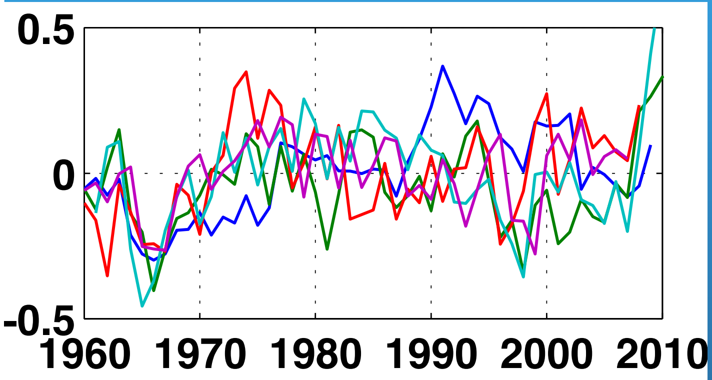


250-1000 m

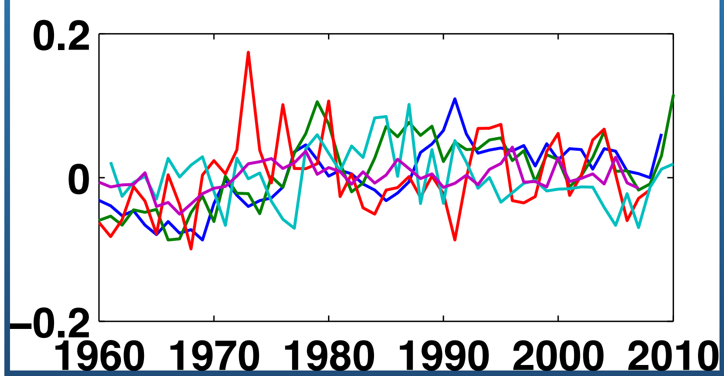
Is the salinity at the eastern/western boundary in agreement?

WESTERN BOUNDARY

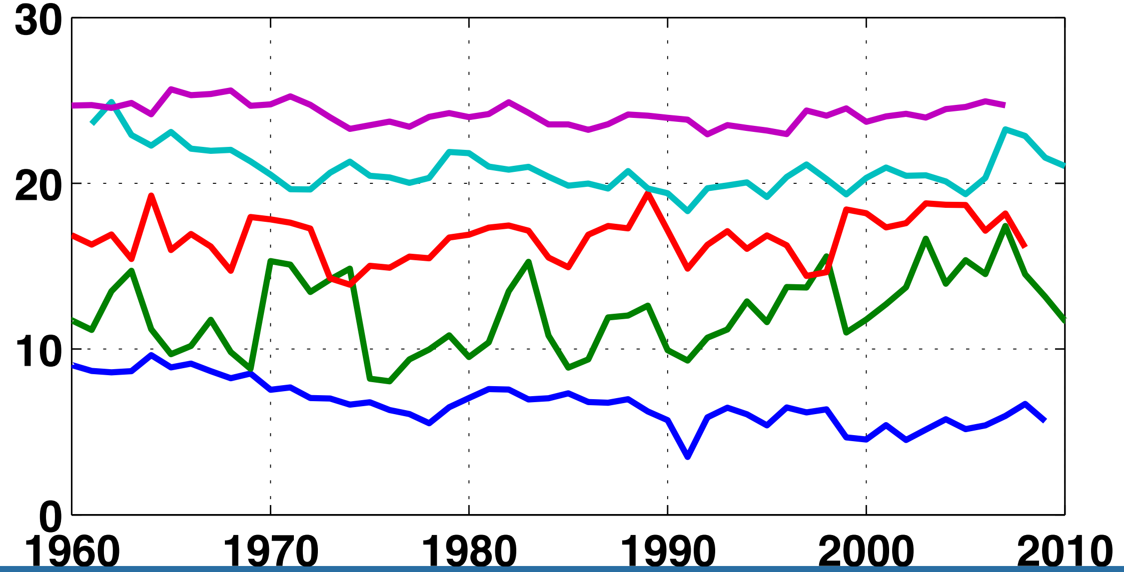
EASTERN BOUNDARY



0-250 m



250-1000 m



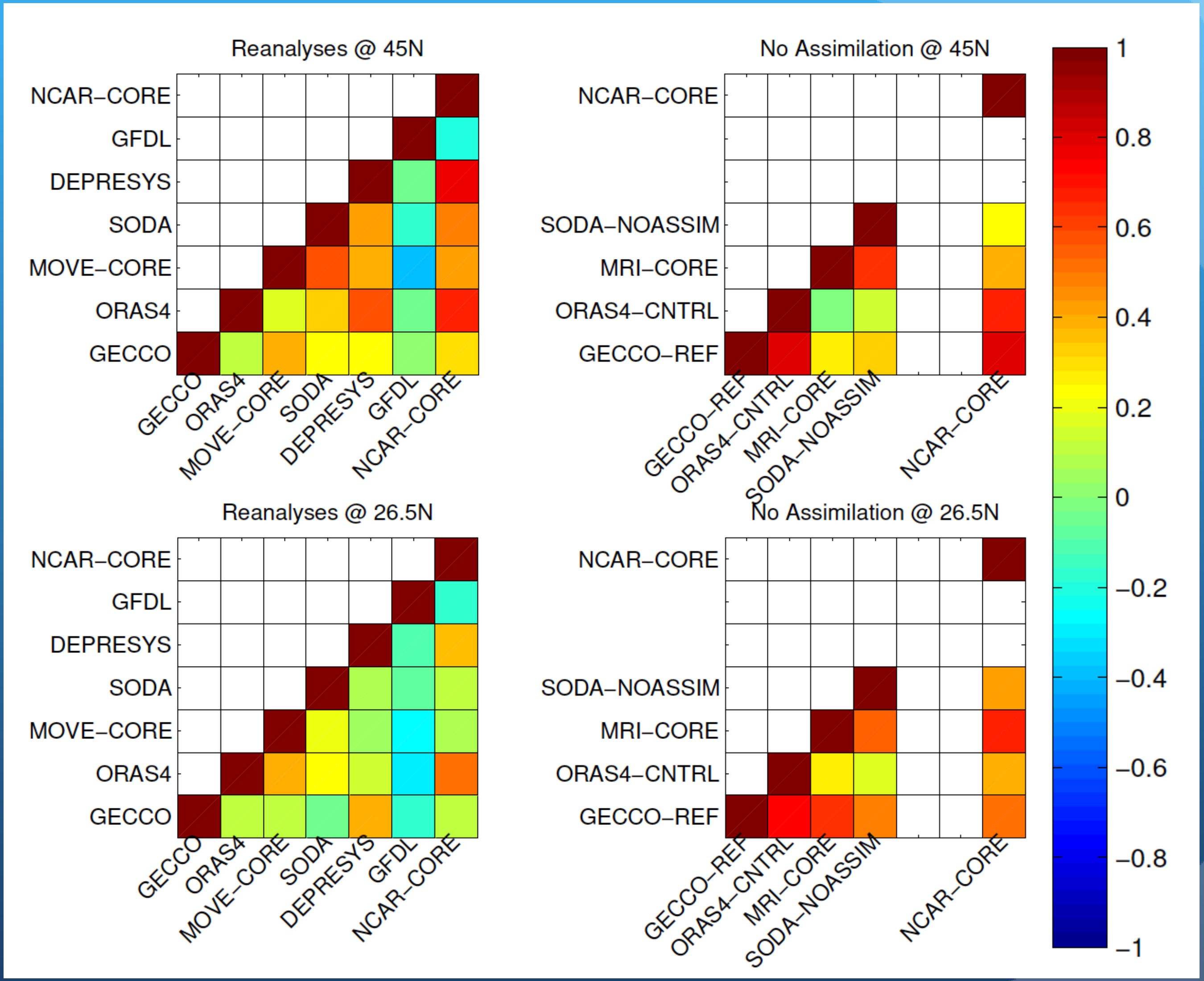
Trends in the
geostrophic shear component of AMOC
in the upper ocean are inconsistent

What do we know so far about why?

In a preliminary analysis at 41N we found disagreement that

- 1) whether density variations on the east or west boundary were dominating the trends
- 2) whether density variations were primarily driven by temperature or salinity.
- 3) temp/salinity variability on the boundaries, especially below 250m

model-model correlation



End

An overview of experimental reanalysis efforts at NCAR

Alicia R. Karspeck, Abhishek Chatterjee

Data assimilation key personnel:

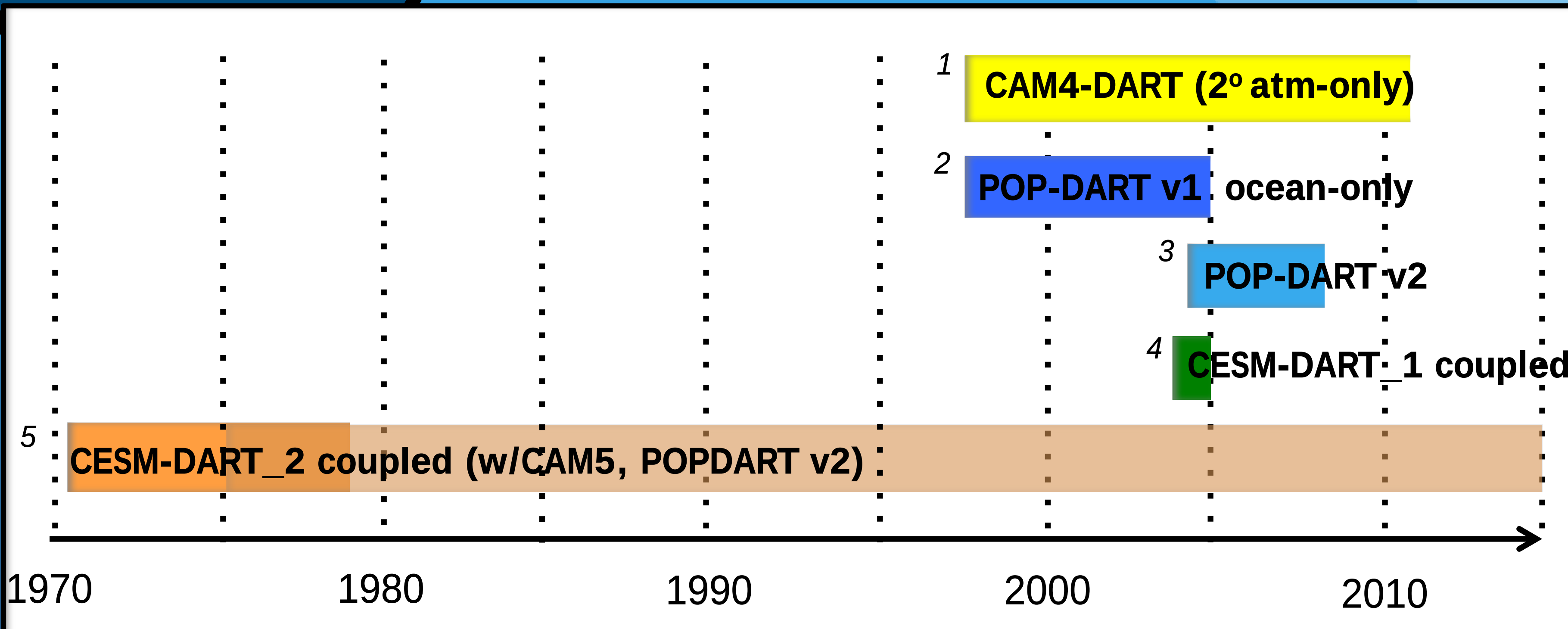
Jeff Anderson, Nancy Collins, Tim Hoar, Helen Kershaw, Kevin Raeder

Climate modeling key personnel:

Gokhan Danabasoglu, Joe Tribbia, Steve Yeager, Svetlana Karol

Formal
Data Assimilation
activites
led by CGD scientists

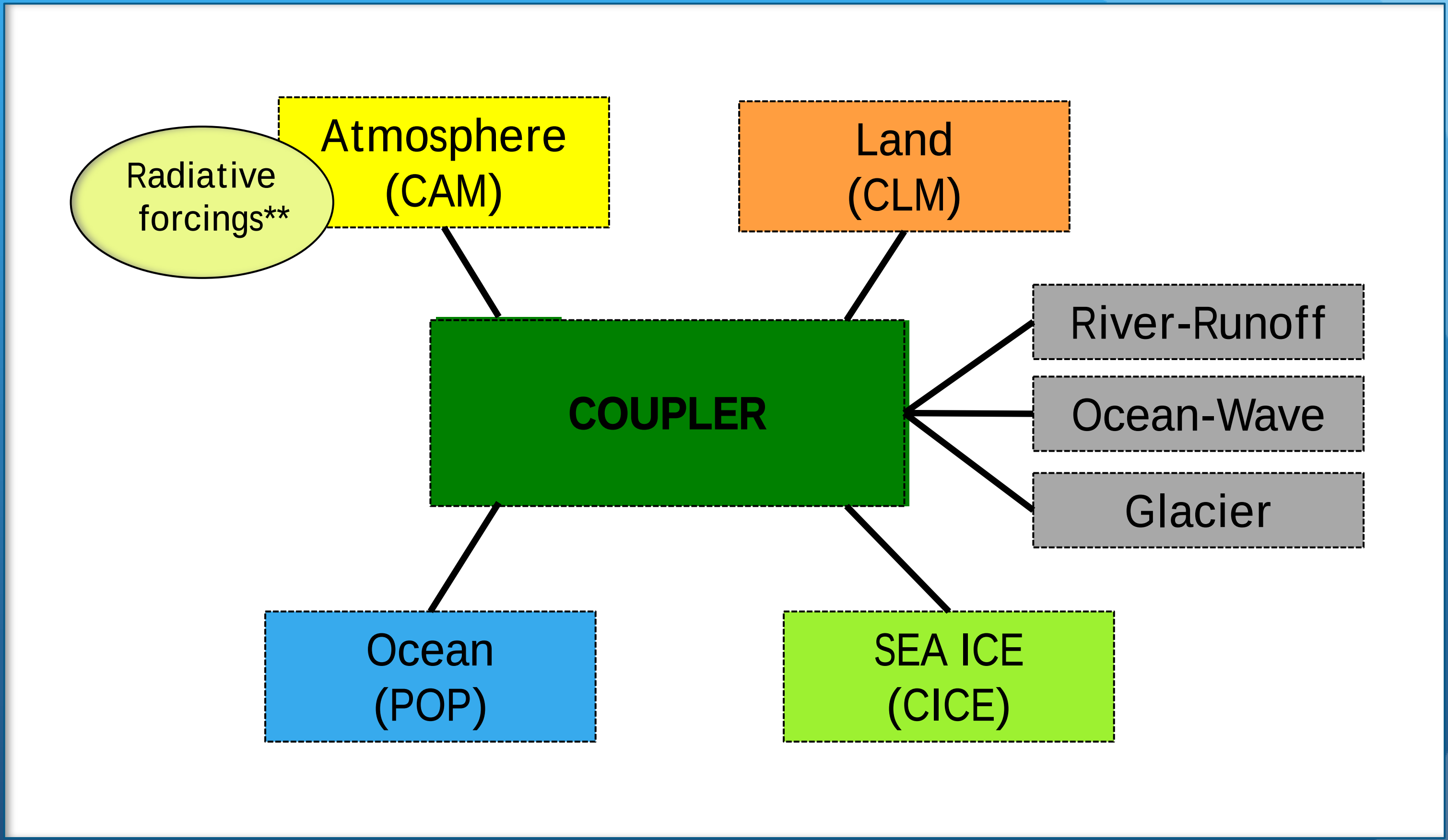
POP/CAM/CESM DART: experimental climate reanalyses



[1] Kevin Raeder (DAReS-CISl)
[2] Alicia Karspeck (Ocean-CGD)
[3] Alicia Karspeck (Ocean-CGD)
[4] Abhishek Chatterjee(CGD/DAReS-CISL)
[5] Alicia Karspeck (Ocean-CGD)

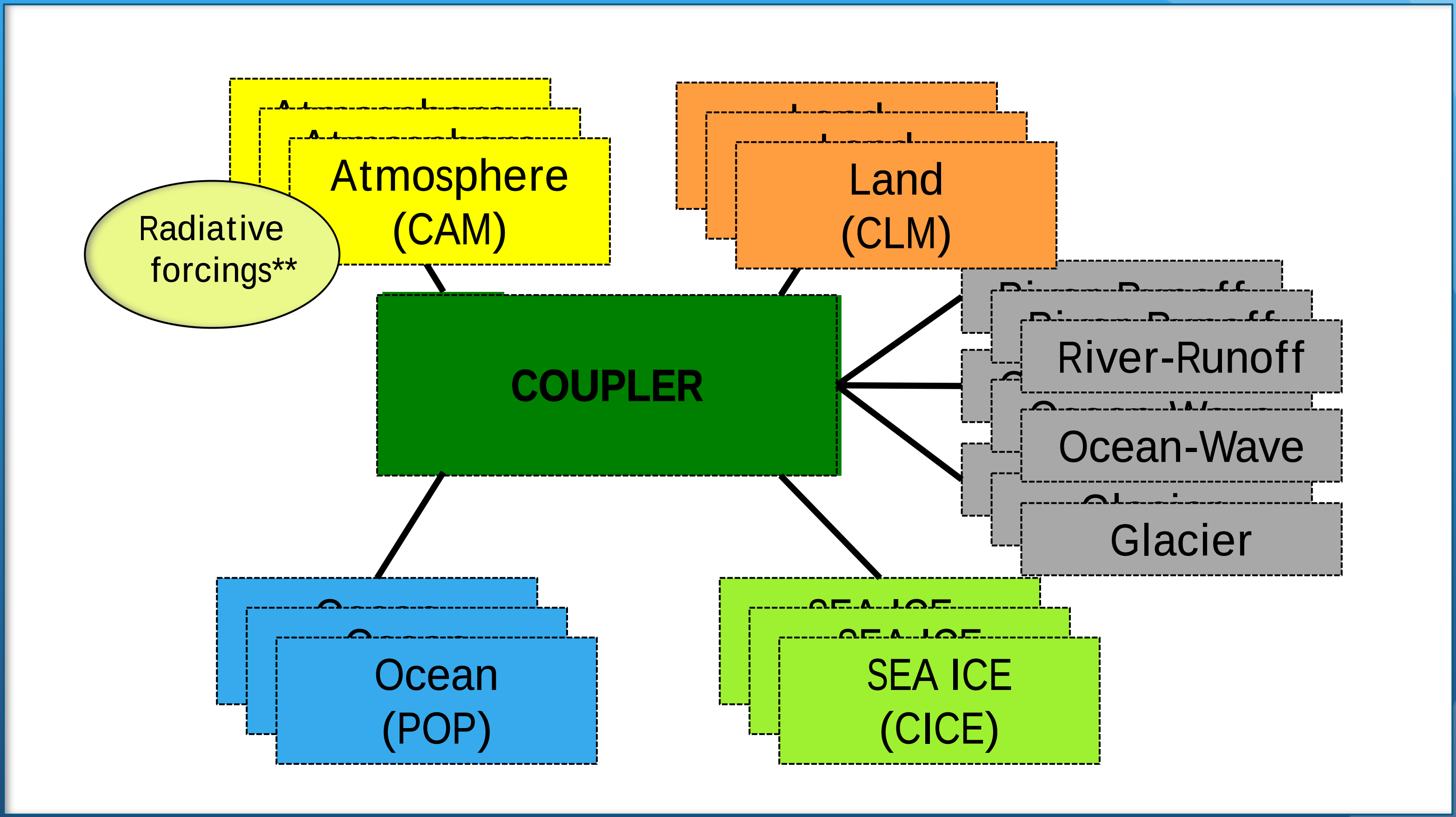
All methods use the DART implementation of the Ensemble Adjustment Kalman Filter

Community Earth System Model



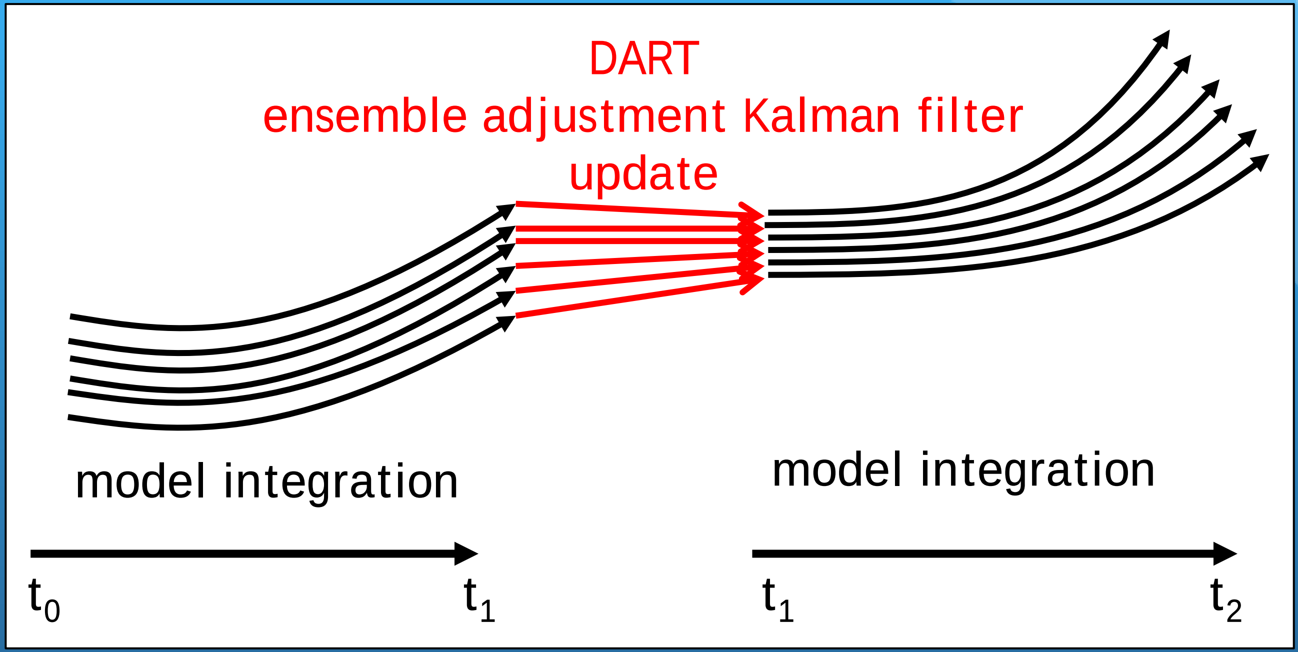
** Greenhouse gases, manmade aerosols, volcanic eruptions, solar variability

Community Earth System Model "multi-instance"



** Greenhouse gases, manmade aerosols, volcanic eruptions, solar variability

Data Assimilation Research Testbed

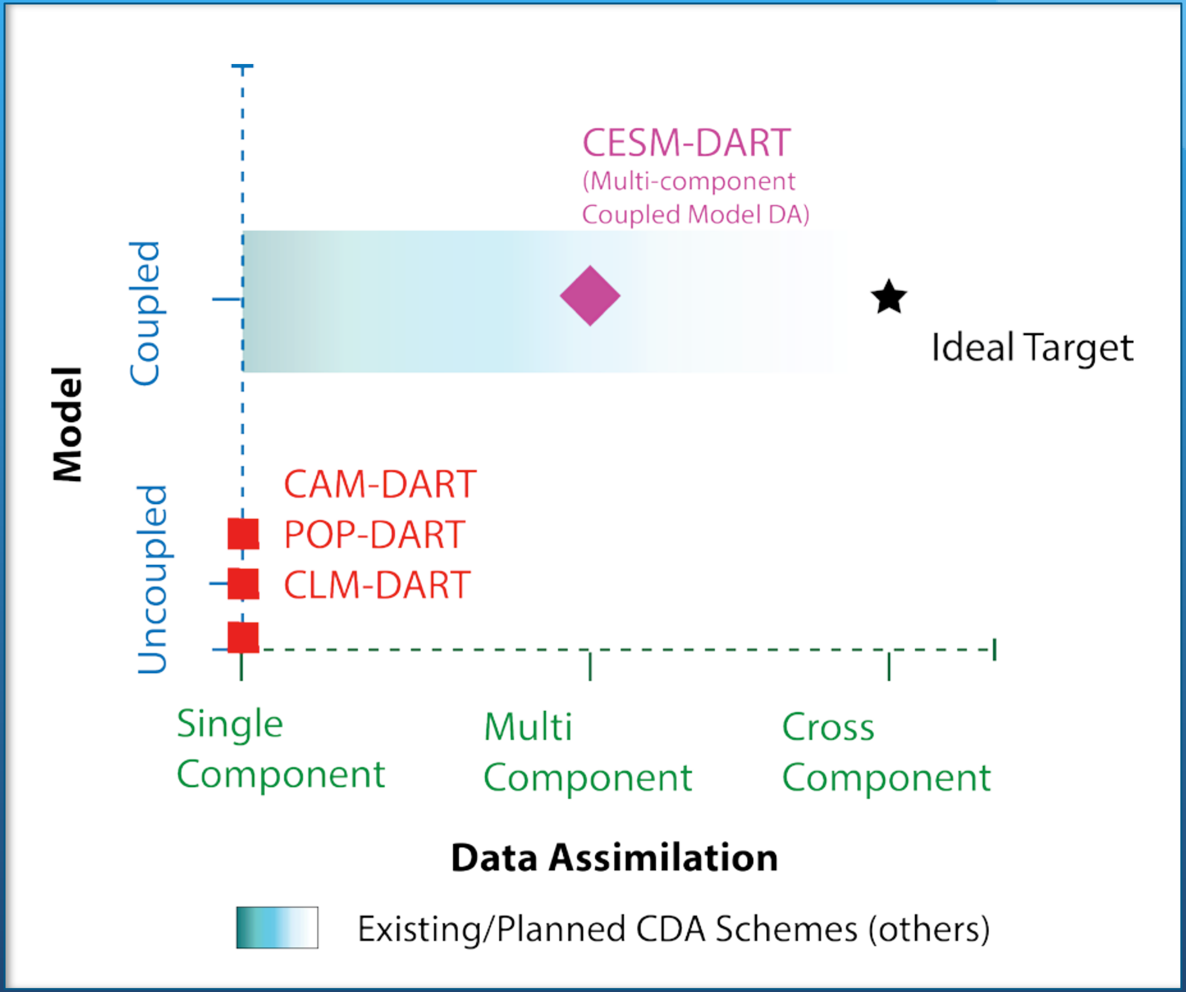


DART is a generic ensemble filter; necessary ingredients:

- ***Model forecasts***
  - In a coupled framework -- model state can be defined independently for each component or jointly across components.
- ***Forward operators*** to map from the model state vector to the observation space
- ***Observations***

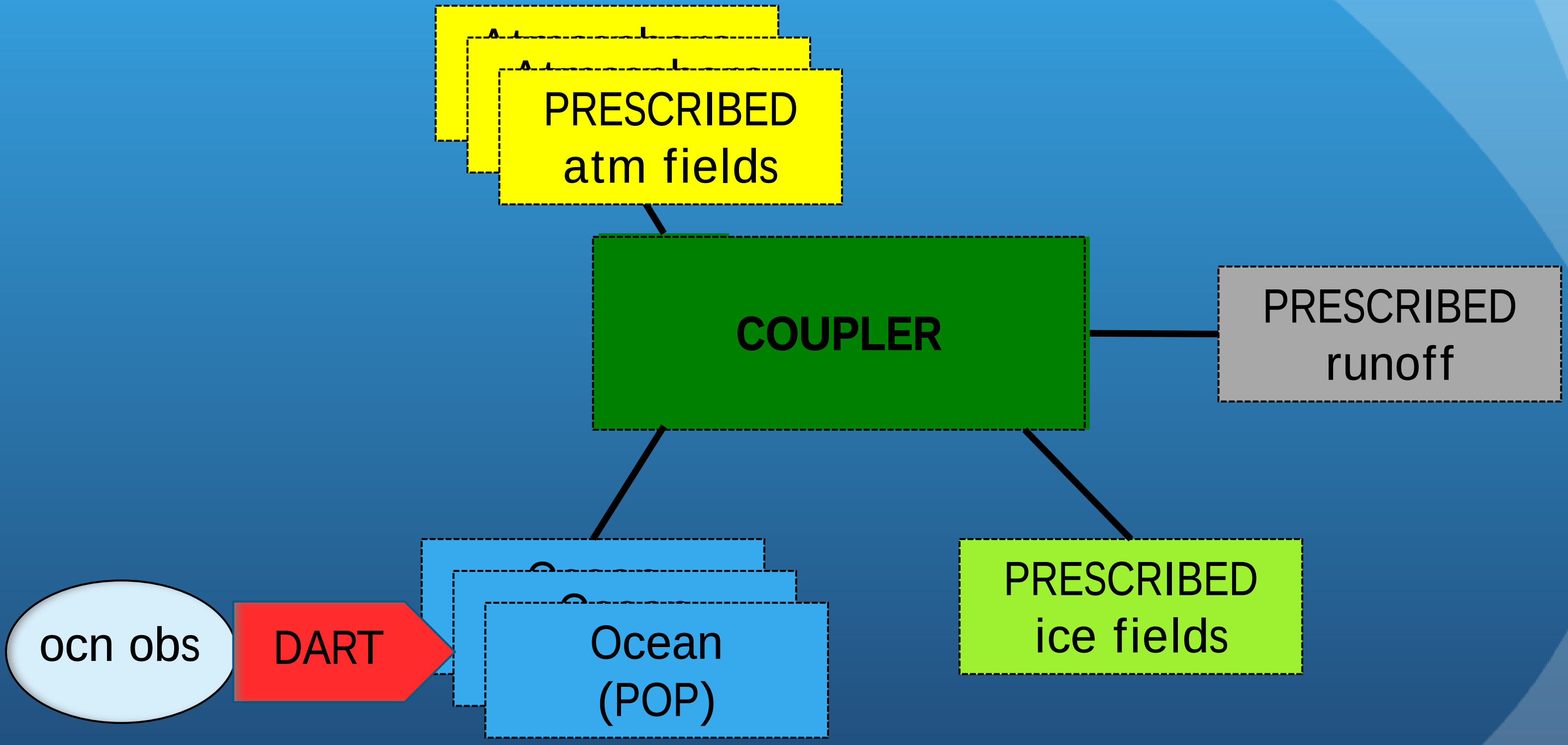
(http://www.image.ucar.edu/DAReS/DART)

Frameworks for data assimilation

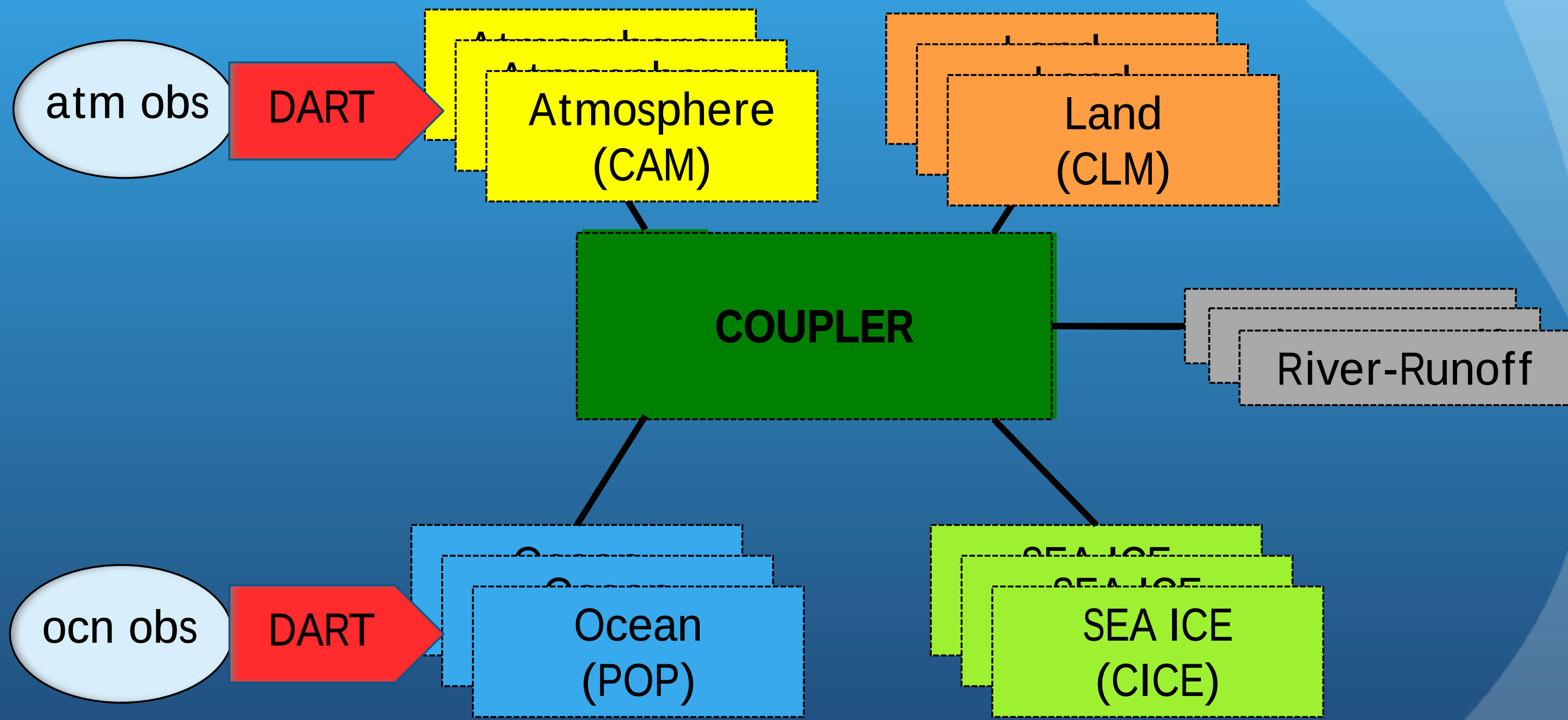


Schematic courtesy of A. Chatterjee

Community **E**arth **S**ystem **M**odel interfacing with DART in a "single-component" DA uncoupled framework



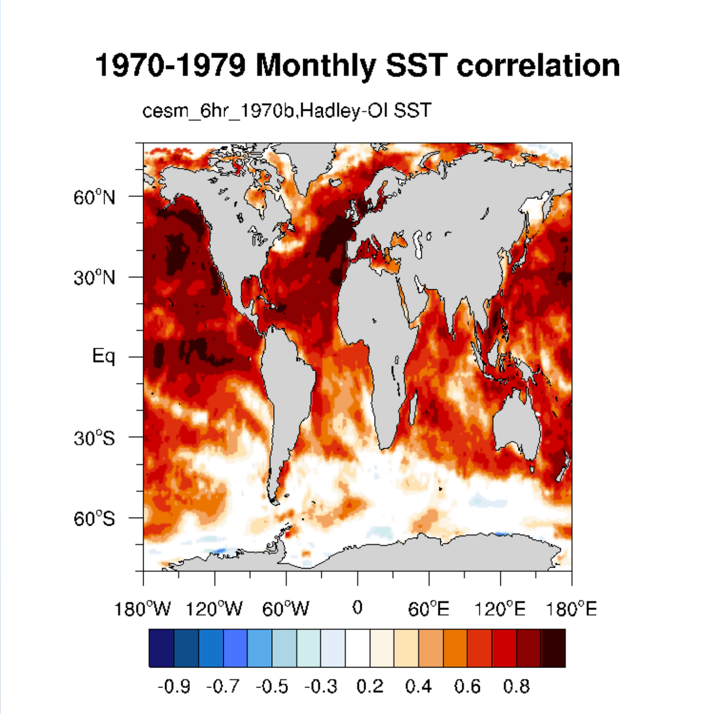
Community Earth System Model interfacing with DART in a "multi-component" DA coupled framework

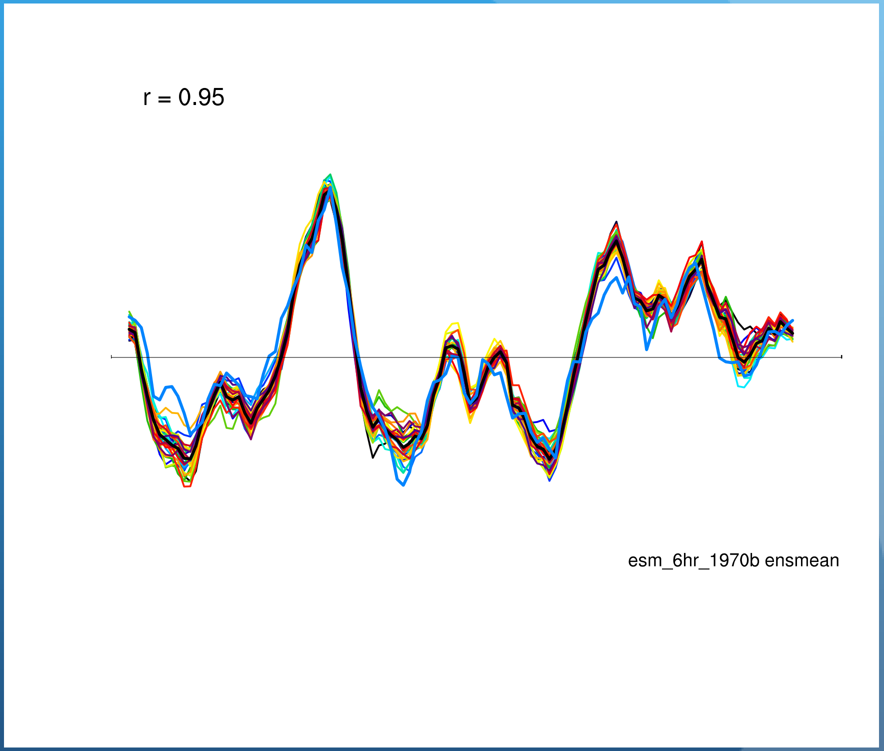


Summary info on the CESM-DART coupled assimilation system

Model:	CESM global coupled ocean/atm/ice/land Horizontal resolution: nominal 1º Vertical resolution: CAM5 30 levels (~2hPa) POP 60 levels (10 m upper to ~250m deep)
DA method:	30 member DART ensemble adjustment Kalman filter (EAKF)
Ocean obs:	In-situ temp and salinity (XBT, MBT, CTD, drifters, floats, moorings, ARGO floats, ocean station; **no SST, no altimetry**)
Atm obs:	temp and winds (radiosondes, aircraft, satellite drift winds, GPSRO-COSMIC, ACARS; currently no moisture, surface pressure, or radiometer retrievals)

Early results from the CESM-DART coupled assimilation



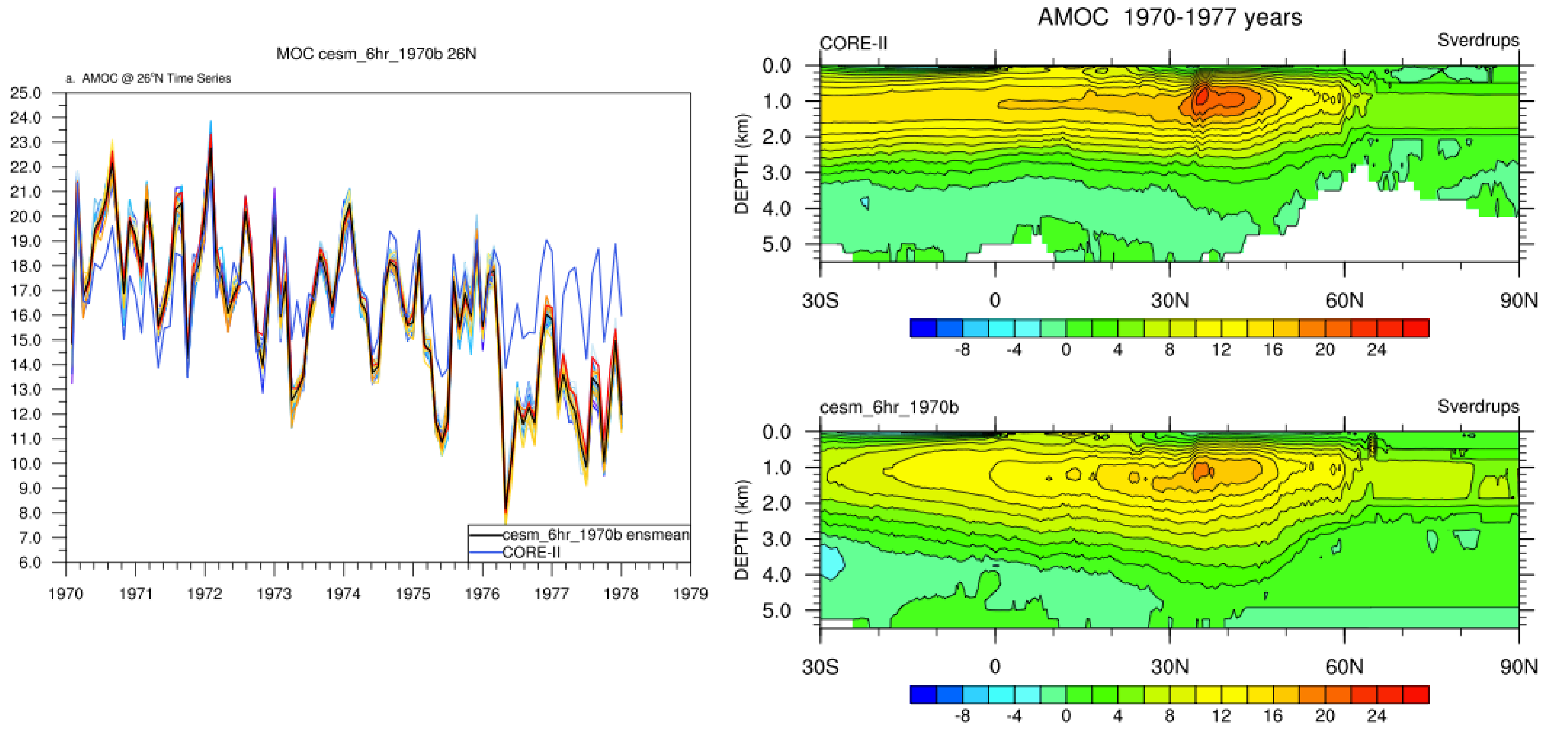


Generally high correlation with HADISST

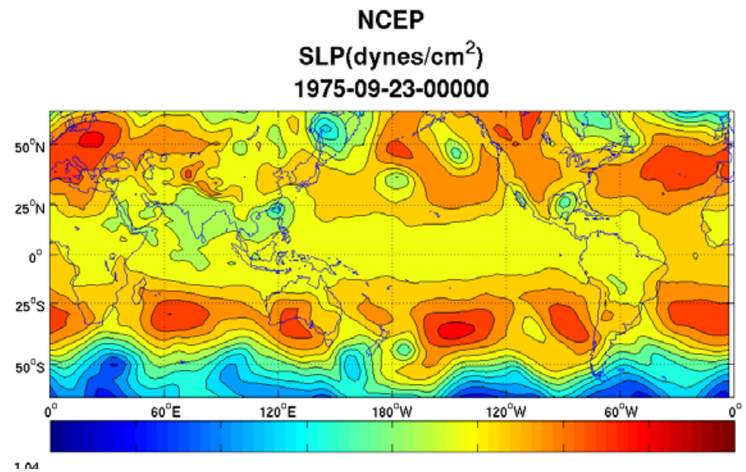
1972-73 El Nino event simulated

Plots courtesy of S. Karol

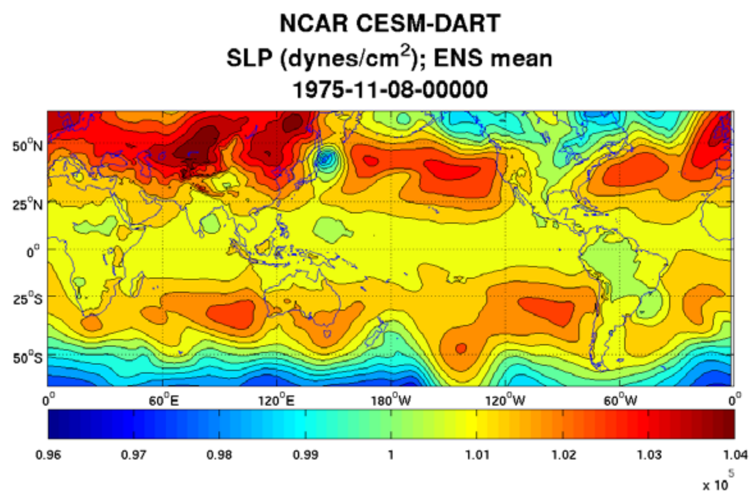
AMOC


MOC cesm_6hr_1970b 26N
a. AMOC @ 26°N Time Series
cesm_6hr_1970b ensmean
CORE-II
AMOC 1970-1977 years
CORE-II
Sverdrups
DEPTH (km)
30S
0
30N
60N
90N
cesm_6hr_1970b
Sverdrups

Ski-hourly snapshot of SLP from CAM5



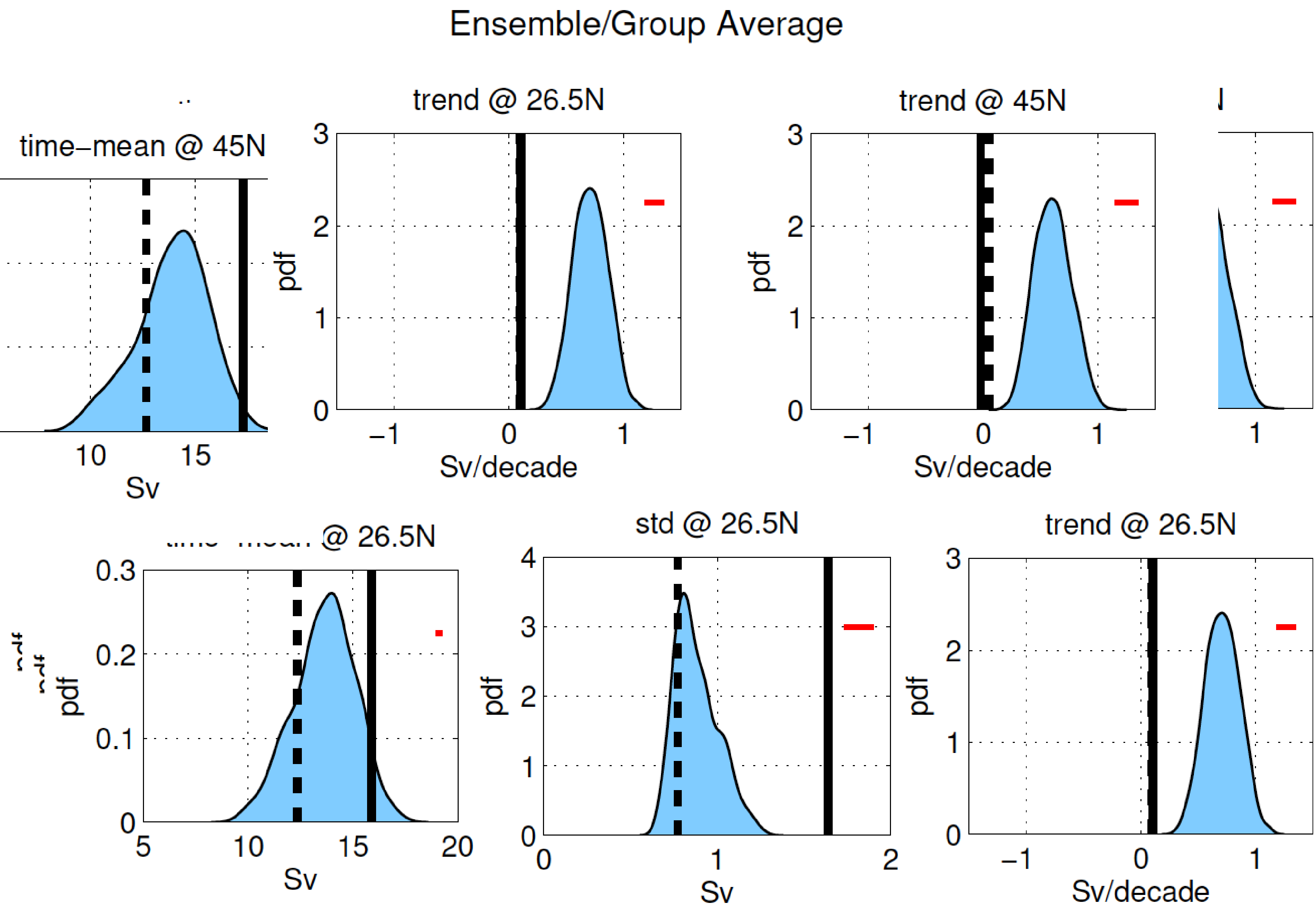
NCEP



- Reasonable AMOC/variability (albeit with a drfit)
- Skill in 6 hourly forecast in atmosphere comparable to the stats published by NCEP
- Reasonable SST variability

Plans in the next 5 years:

- Complete coupled-model, multi-component assimilation
- Develop coupled-model cross-component assimilation (cross component covariances / increments)
- Software advances for speeding-up the assimilation
- Include altimetry in ocean assimilation
- Global ocean assimilation with eddy-resolving model
- **Investigate the ways that coupled assimilation may be advantageous for state estimation and prediction**



Ensemble/Group Average
time−mean @ 45N
trend @ 26.5N
trend @ 45N
time−mean @ 26.5N
std @ 26.5N
trend @ 26.5N
pdf
Sv
Sv/decade

Time-Mean AMOC