Results from the CFSv2 CMIP5 Decadal Forecasts

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International Workshop on Seasonal to Decadal Prediction, Toulouse,
May 2013.

Basic Experiment: CMIP5 Decadal Forecasts

- Compare forecasts made with different ocean initial conditions (full initialization).
  - CFSR 1980- (“NCEP simulations”) assimilation in its native ocean model.
  - NEMOVAR 1960- (“COLA simulations”) interpolated to foreign ocean model grid.

Evaluation of the CFSv2 CMIP5 Decadal Predictions

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CMIP5 Model Description

CMIP5 Near-Term Players	CMIP5 official model_id	AGCM	OGCM	Initialization				Perturbation		Aerosol	
name of modeling center (or group)				Atmosphere/Land	Ocean	sea ice	anomaly assimilation?	Atmos	Ocean	Concentration(C) /Emission (E)	Direct(D)/ Indirect(I1 ,I2)
Beijing Climate Center, China Meteorological Administration (BCC) China	BCC-CSM 1.1	2.8°L26	1°L40	no	SST, T&S (SODA)	No	no	perturbed atmos/ocean		C	D
Canadian Centre for Climate Modelling and Analysis (CCCMA) Canada	CanCM4	2.8°L35	1.4°x0.9° L40	ERA40/Interim	SST (ERSST&OISST), T&S (SODA & GODAS)	HadISST1.1	no	ensemble assimilation		E	D, I1
Centro Euro-Mediterraneo per I Cambiamenti Climatici (CMCC-CM) Italy	CMCC-CM	0.75°L31	0.5-2° L31	no	SST, T&S (INGV ocean analysis)	CMCC-CM climatology	no	ensemble assimilation		C	D, I1
Centre National de Recherches Metéorologiques, andCentre Européen de Recherche et Formation Avancées en Calcul Scientifique (CNRM-CERFACS) France	CNRM-CM5	1.4°L31	1°L42	no	T&S (NEMOVAR-COMBINE)	No	no	1st day atmospheric conditions	no	C	D, I1
National Centers for Environmental Prediction and Center for Ocean-Land-Atmosphere Studies (NCEP and COLA) USA	**CFSv2-2011**	**0.9°L64**	**0.25-0.5° L40**	**NCEP CFSR reanalysis**	**NCEP CFSR ocean analysis (NCEP runs)** NEMOVAR-S4 ocean analysis (COLA runs)	**NCEP CFSR reanalysis**	**no**	**no**	**no**	**C**	**D, I1**
EC-EARTH consortium (EC-EARTH) Europe	EC-EARTH	1.1°L62	1°L42	ERA40/Interim	Ocean assimilation (ORAS4/NEMOVAR S4)	NEMO3.2-LIM2 simulation forced with DFS4.3 atmospheric fields through the CORE bulk formulae	no (KNMI & IC3) yes (SMHI)	start dates and singular vectors	Ensemble ocean assim (NEMOVAR)	C	D
Institut Pierre-Simon Laplace (IPSL) France	IPSL-CM5A-LR	3.8°L39	2°L31	no	SST anomalies (Reynolds observations)	No	yes	no	white noise on SST	C	D, I1
Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology	MIROC4h	0.6°L56	0.3°L48	no	SST, T&S (Ishii and Kimoto 2009)	no	yes	start dates and ensemble assimilation		E	D,I1,I2
	MIROC5	1.4°L40	1.4°L50								

CFS v2 (Saha et al. 2013)

1. An atmosphere of T126L64 (GFS)
2. An interactive ocean (MOM4) with 40 levels in the vertical, to a depth of 4737 m, and horizontal resolution of 0.25 degree at the tropics, tapering to a global resolution of 0.5 degree northwards and southwards of 10N and 10S respectively
3. An interactive 3 layer sea-ice model
4. An interactive land model with 4 soil levels

CFSv2 Biases

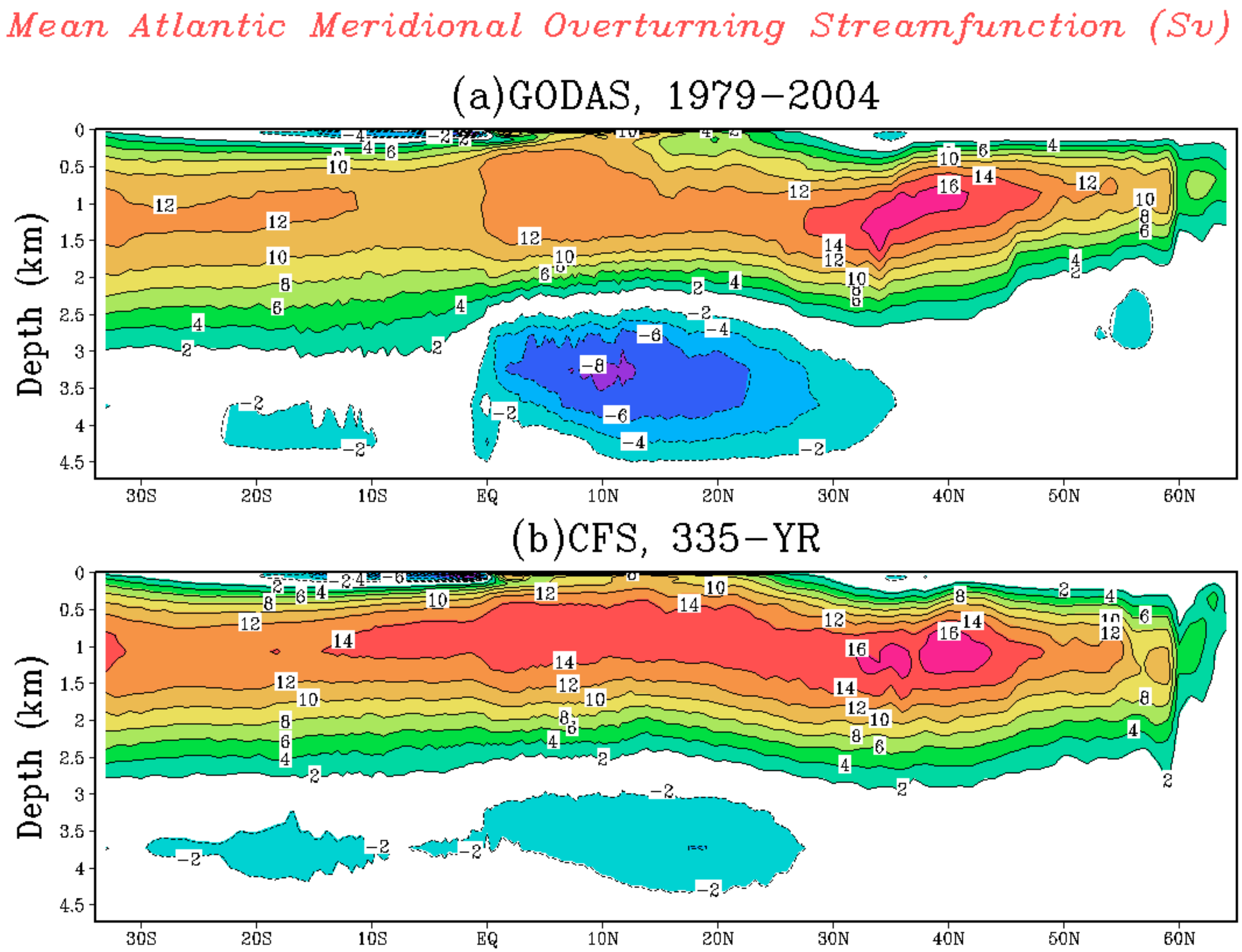
- TOA radiative imbalance

  +7.4 W m^{-2} downward, 3.6 W m^{-2} into ocean
- AMOC disappears

  Time scale of years
- Sea ice disappears

  Time scale of years

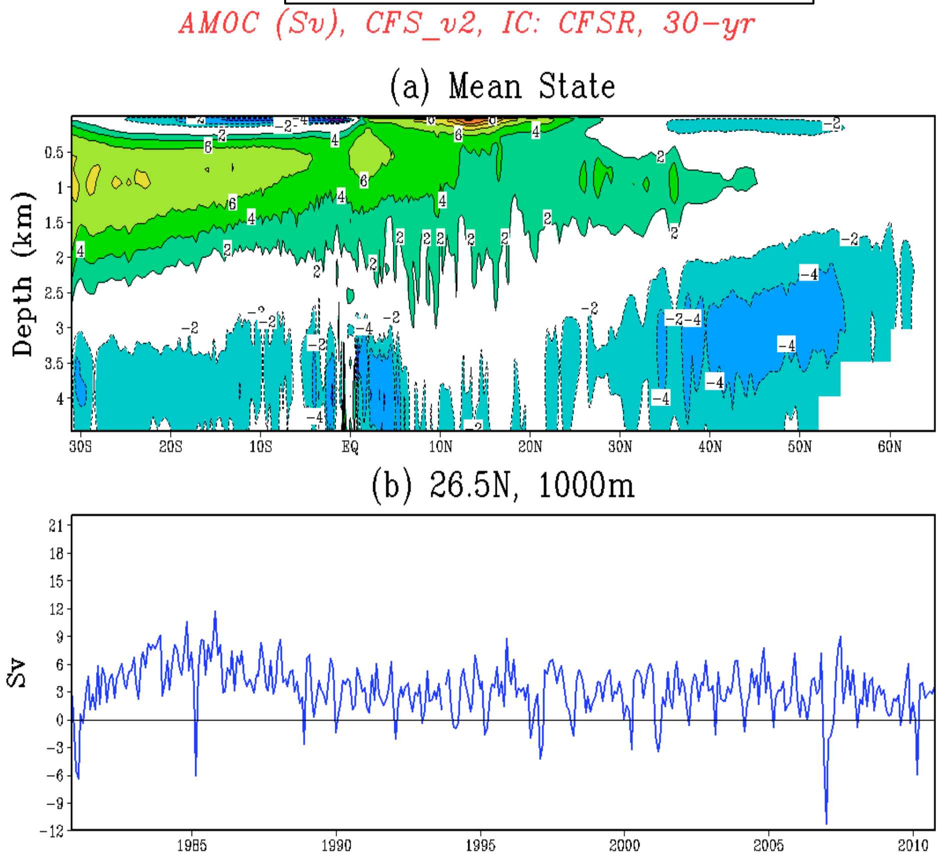
How Serious a Problem is CFSv2 AMOC bias? Consider AMOC in CFSv1



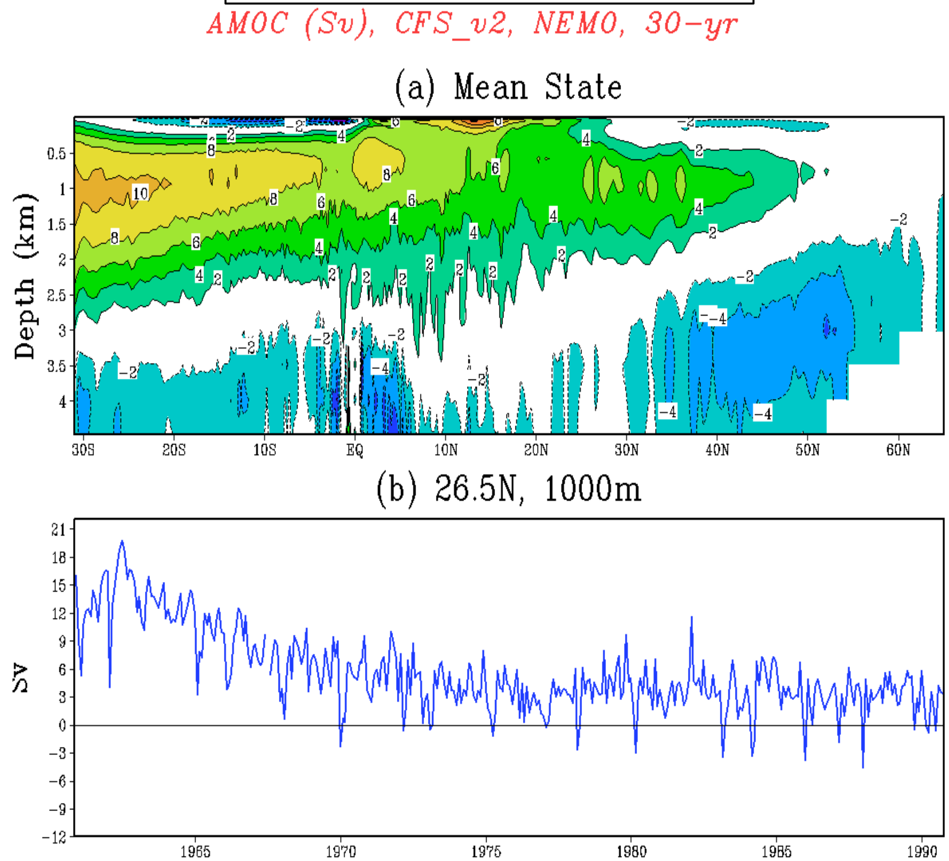
Huang, Hu, Schneider, Wu, Xue, and Klinger 2012

CFSv2 AMOC in 30-year runs

CFSR Ocean Initial Conditions



NEMOVAR Ocean Initial Conditions



Huang and Zhu

Question: What is the role of AMOC for Decadal Prediction?

CFSv2 Known Errors

- A serious code bug was identified by COLA scientists in the atmosphere-ocean coupling in the North Atlantic.
  - Large errors in surface fluxes as seen by the ocean. Location of errors depends on number of processors.
    - NE North Atlantic in COLA runs
    - NW North Atlantic in NCEP runs
  - Only small improvement in AMOC strength when error is corrected.

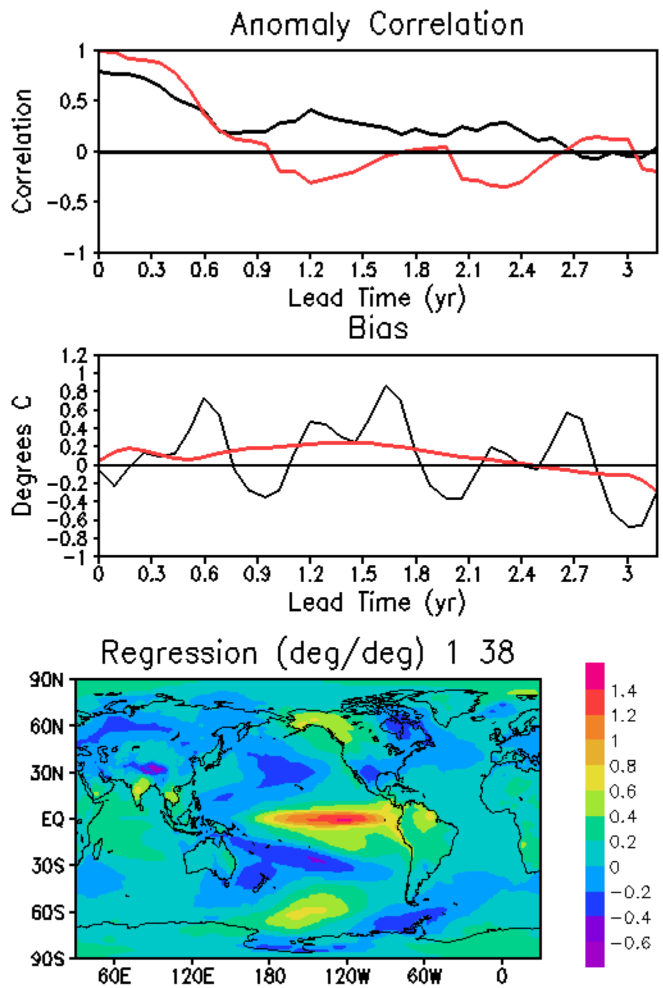
Experiments

Run	Initial Condition Years	Length (years)	Ensemble Members	Atmosphere ICs	Ocean ICs
NCEP Volc	1980-2005 every 5 years + selected years	10	4	CFSR	CFSR
COLA Volc	1960-1990 every 5 years	10	3		NEMOVAR
COLA NoVolc	1960-2005 every 5 years	10	4		
	1960-2005 yearly	3	2		
	1960-2005 yearly	10	1		
	1960, 1980, 2005	30	4		

NO HISTORICAL/UNINITIALIZED/FREE RUNS

Model Performance Interannual Time Scales (COLA NoVolc)

NINO3.4
SSTA ACC



Results Decadal Time Scales

Outline of Analysis

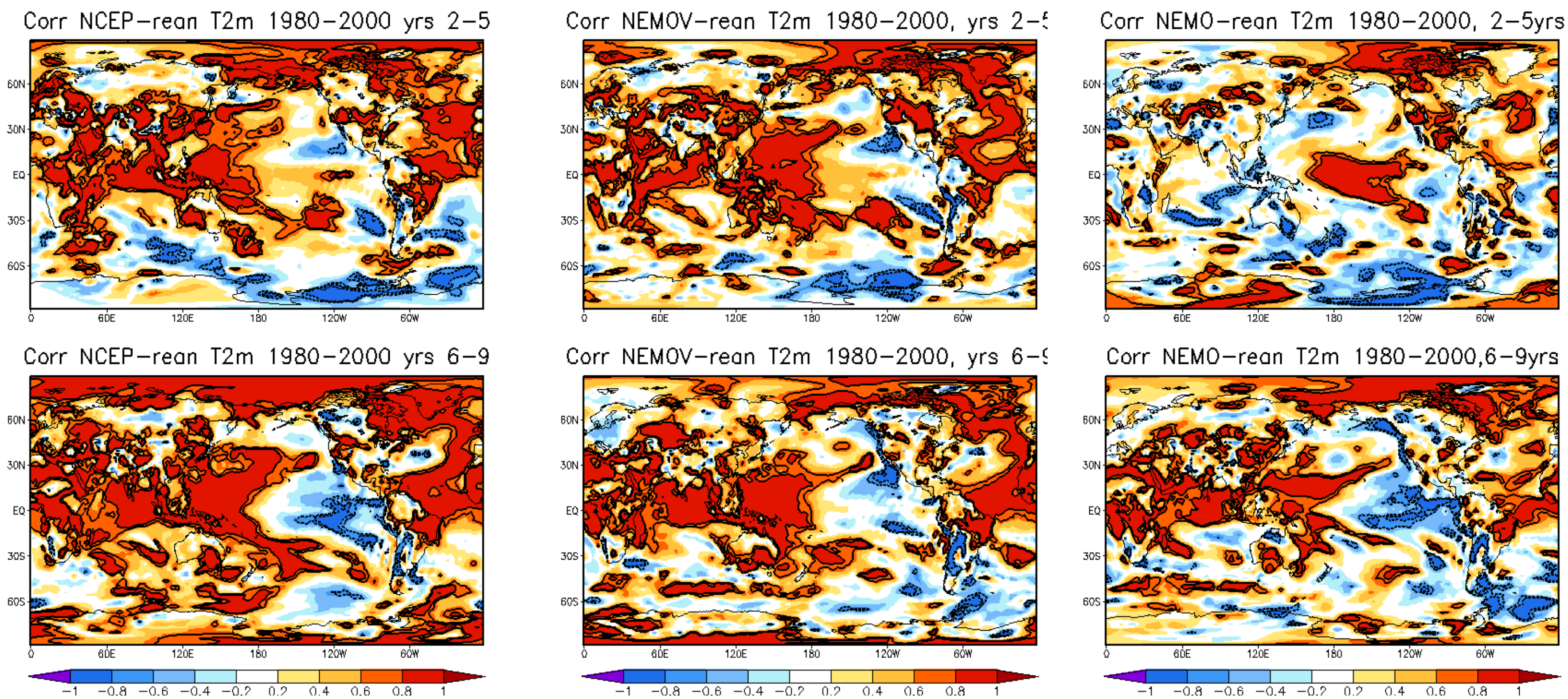
- Compare common cases for NCEP Volc, COLA Volc, and COLA NoVolc
  - CMIP5 ensembles for 1980, 1985,1990, 1995, 2000
  - Ensemble means
- Verification data
  - NCEP reanalysis for atmosphere
  - NEMOVAR reanalysis for ocean

2m Air Temperature Predictions

Year 2-5, 6-9 Averages

T2m Anomaly Correlation

YEARS 2-5



NCEP Volc

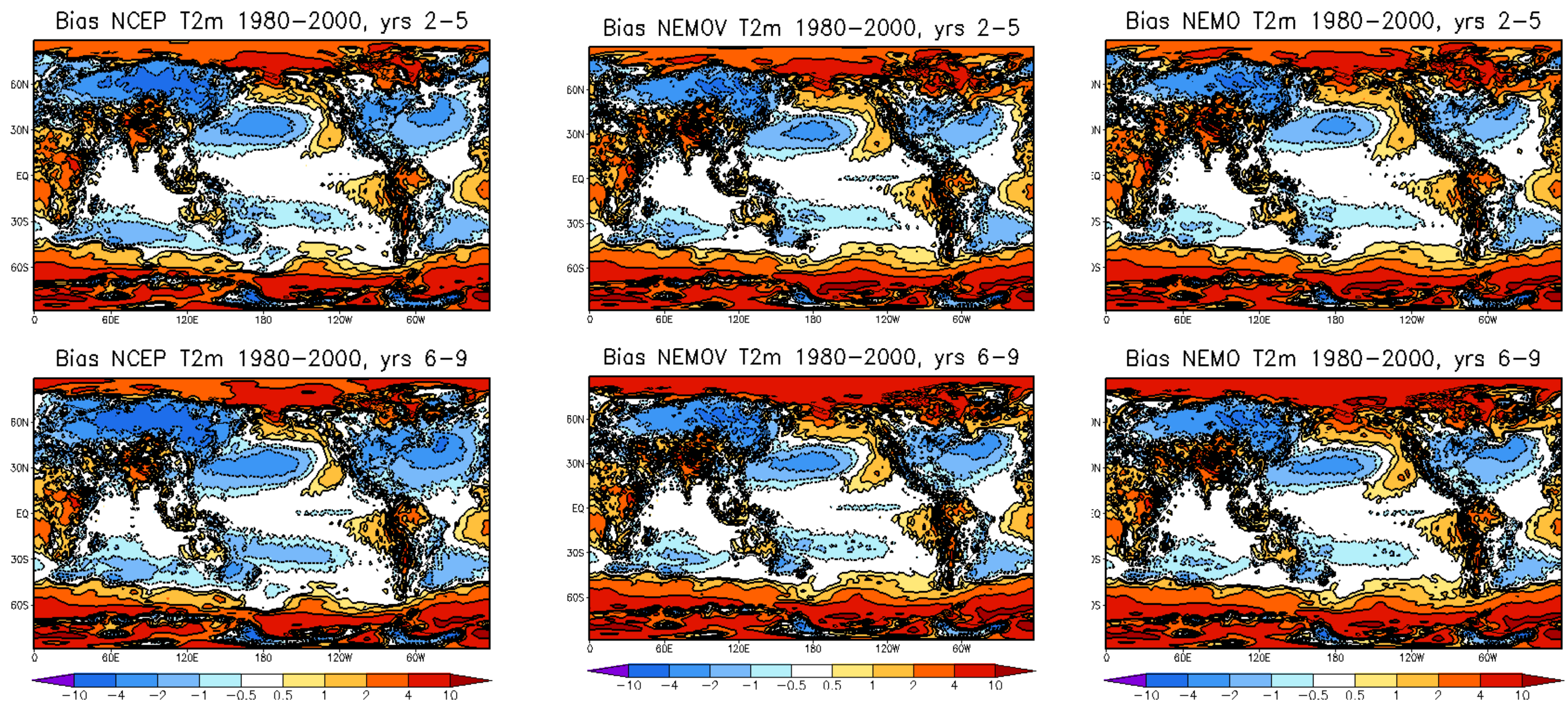
COLA Volc

COLA NoVolc

YEARS 6-9

T2m Biases

YEARS 2-5



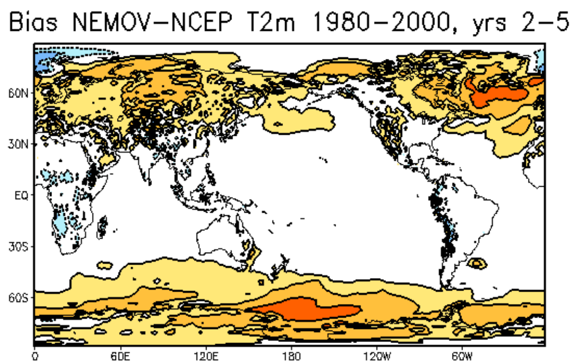
NCEP Volc **COLA Volc** **COLA NoVolc**

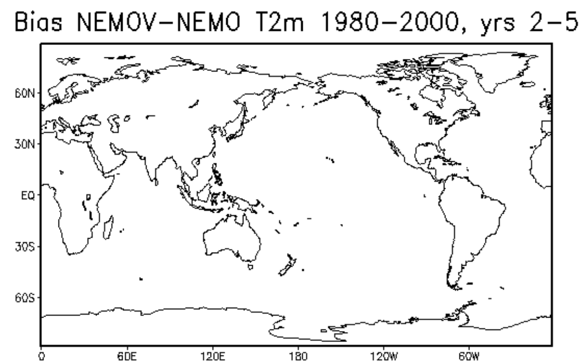
YEARS 6-9

T2m Bias Differences

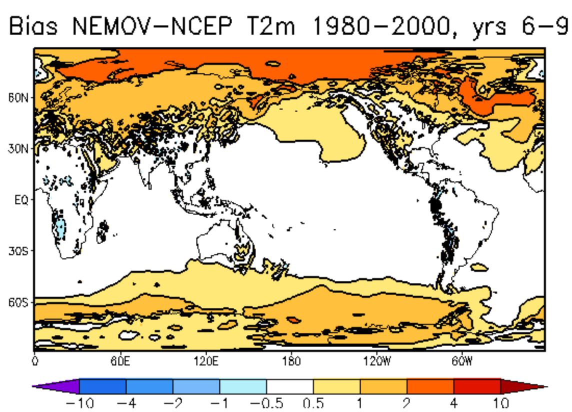
COLA Volc minus NCEP Volc

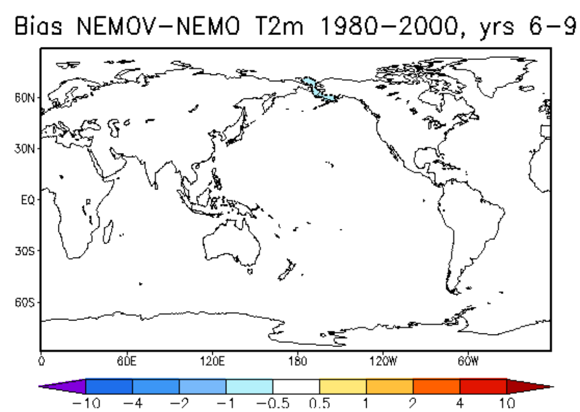
COLA Volc minus COLA NoVolc





Years 2-5

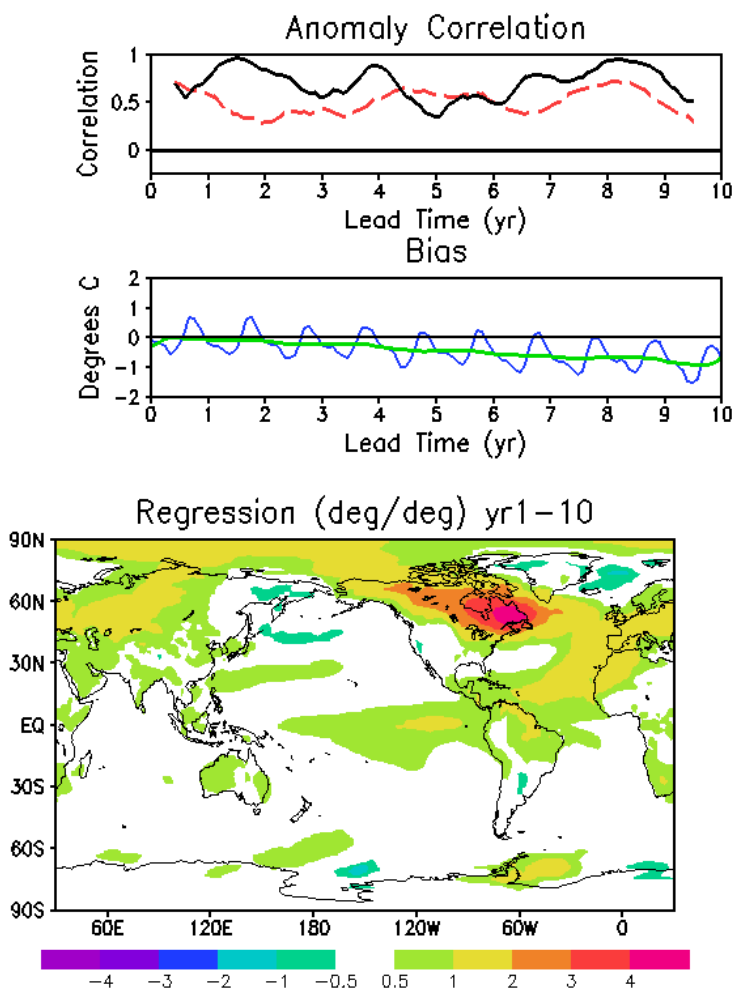




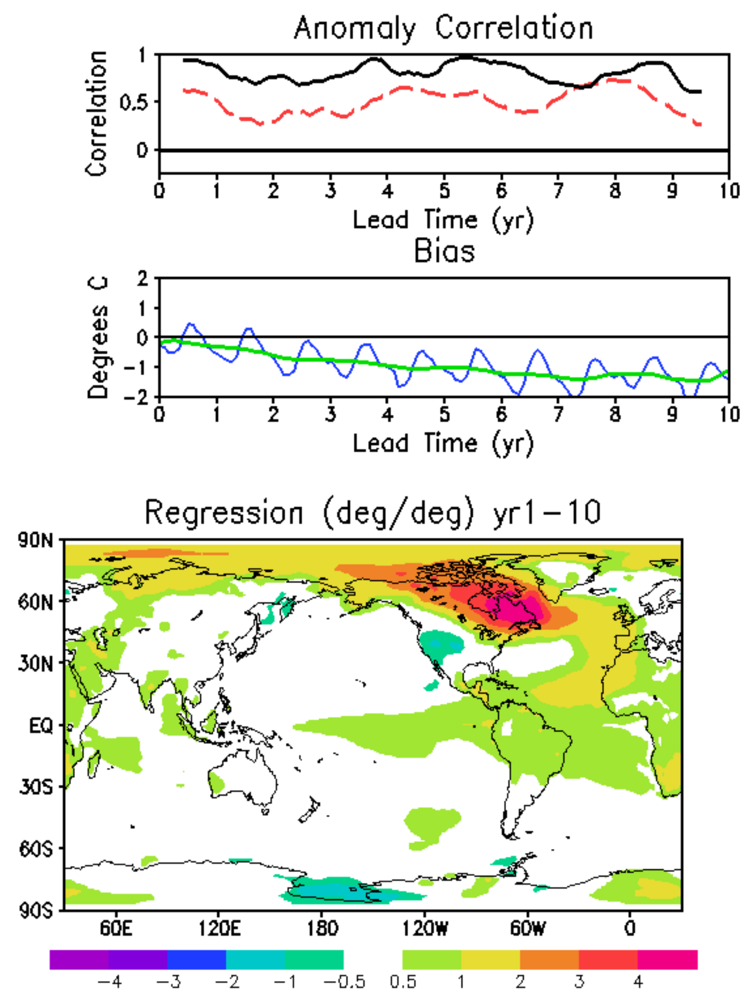
Years 6-9

Atlantic Multidecadal Variability SST Index 1980-2010

COLA NoVolc



NCEP Volc



What are the Mechanisms for the Decadal Predictability of T2m in these Experiments?

- The memory of the system is in the ocean’s thermal and mechanical inertia, which determines the time scales of the response to external forcing and of the internal variability.

- This suggests a heat budget analysis would be a good place to start.

Heat Content Predictions

- Heat content *H* is vertical integral of internal energy :

$$H(x,y) = \int_{z=-D(x,y)}^{z=0} \rho c T \, dz \approx \rho c D(x,y) \bar{T}(x,y)$$

where $\bar{T}$ is the vertically averaged temperature, and

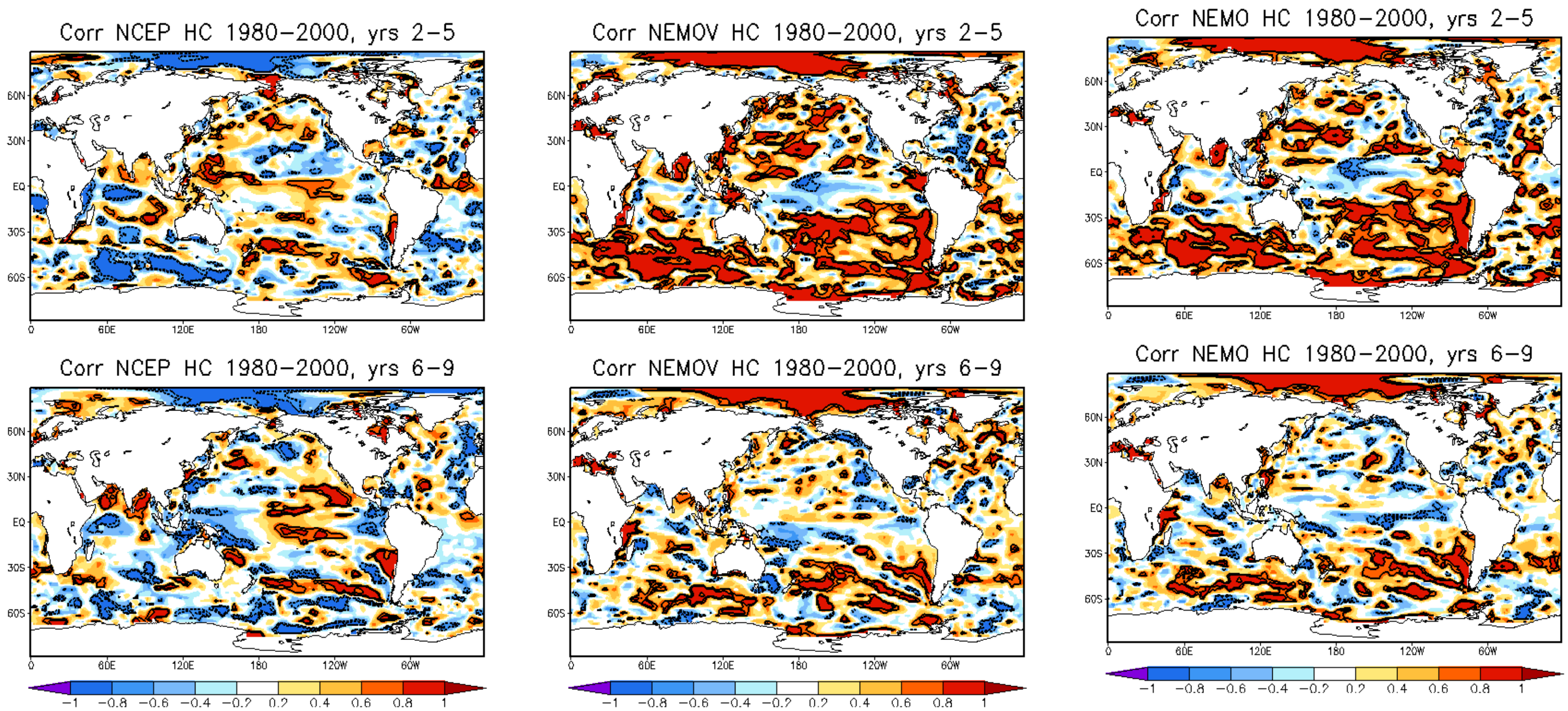
$D(x,y)$ <u>is taken to be the full depth of the ocean</u>.

Year 2-5, 6-9 Averages

- Verification against NEMOVAR Ocean Analysis.

Heat Content Anomaly Correlation

YEARS 2-5



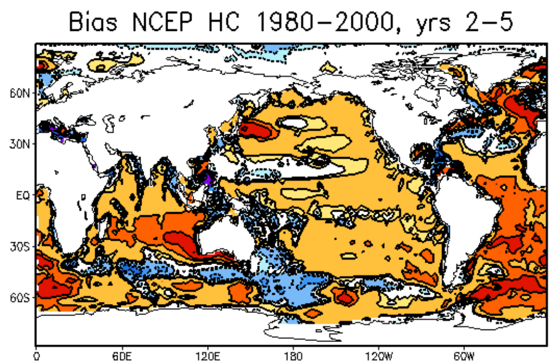
NCEP Volc **COLA Volc** **COLA NoVolc**

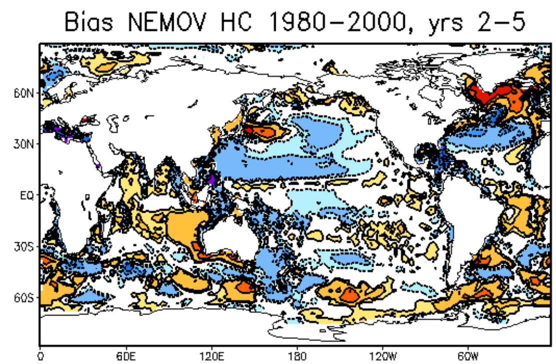
YEARS 6-9

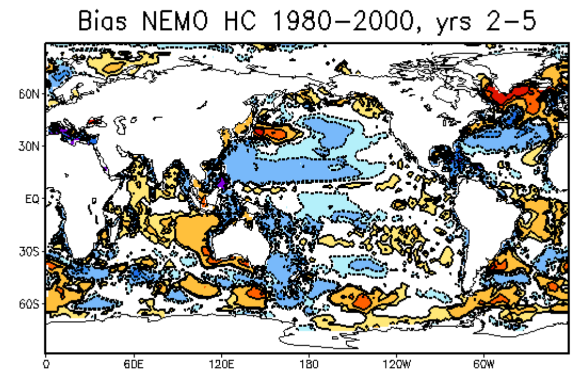
Heat Content Biases

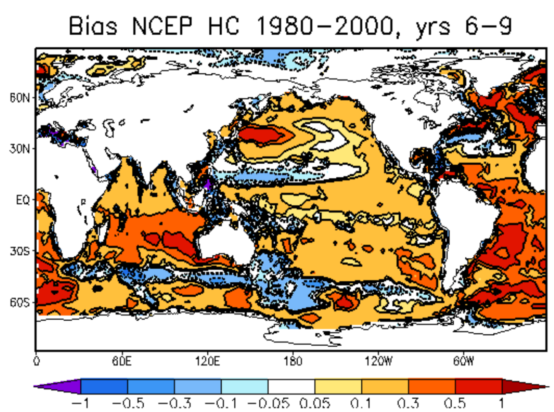
YEARS 2-5

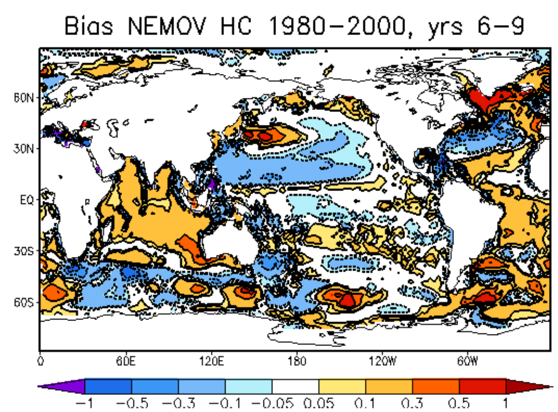
NCEP Volc | **COLA Volc** | **COLA NoVolc**

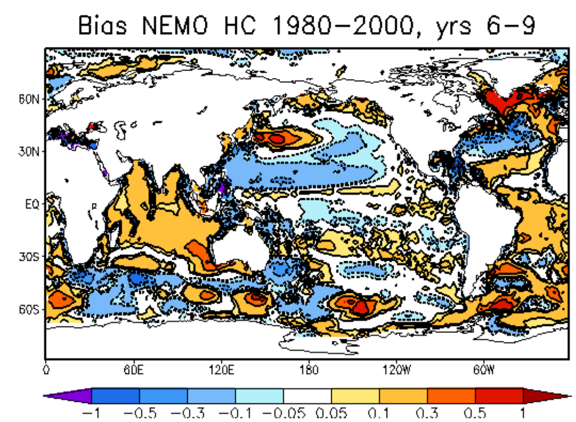












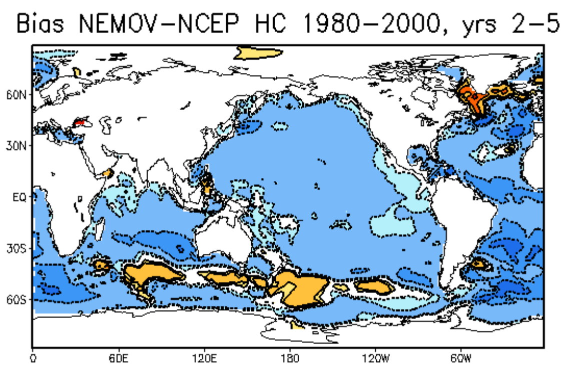
YEARS 4-9

Plots are of H/(4500ρc), units °K

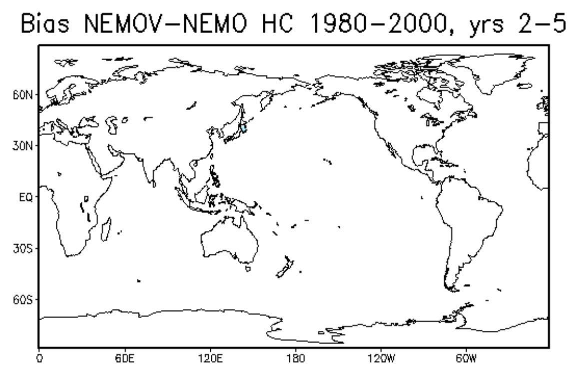
Heat Content Bias Differences

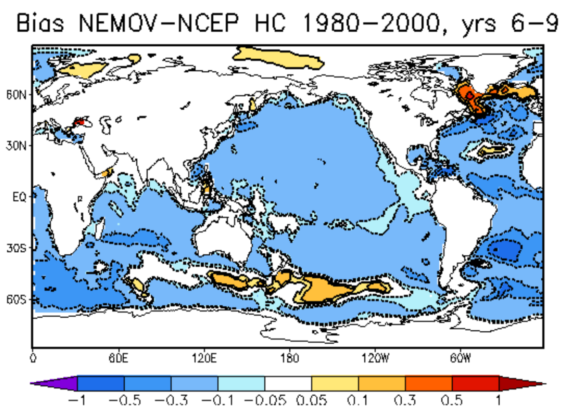
COLA Volc minus NCEP Volc

COLA Volc minus COLA NoVolc

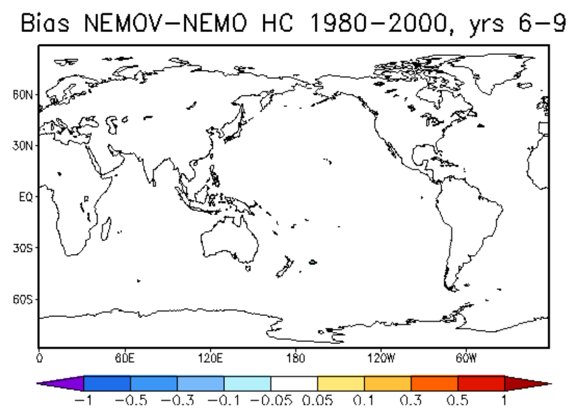


Years 2-5





Years 6-9



Heat content biases show substantial ocean memory, because differences between the CFSR and NEMOVAR ocean reanalyses are so large,

Anomalies do not demonstrate much memory.

Heat Content Budget

- *H* Satisfies the 2-dimensional energy budget:

$$\frac{dH}{dt} = NHF + O \qquad (1)$$

NHF is net surface heat flux

O is the tendency due to ocean dynamics and physics

Global Mean Ocean Heat Content Diagnosis

- Compare dH/dt and NHF

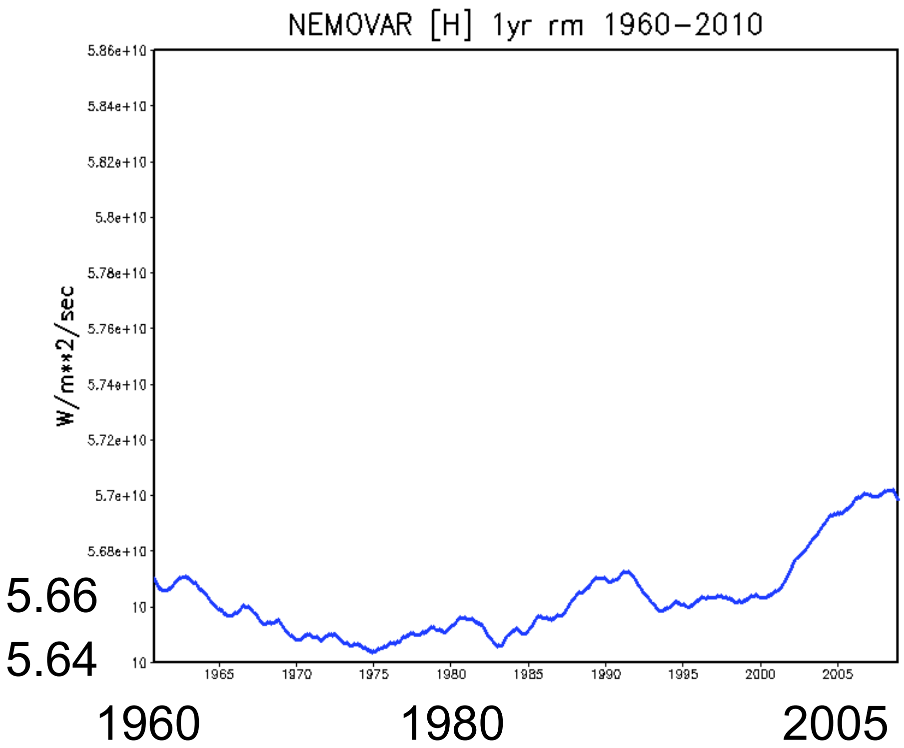
  [ ] = global mean

$$\left[\frac{dH}{dt}\right] = \left[NHF\right] \qquad (2)$$

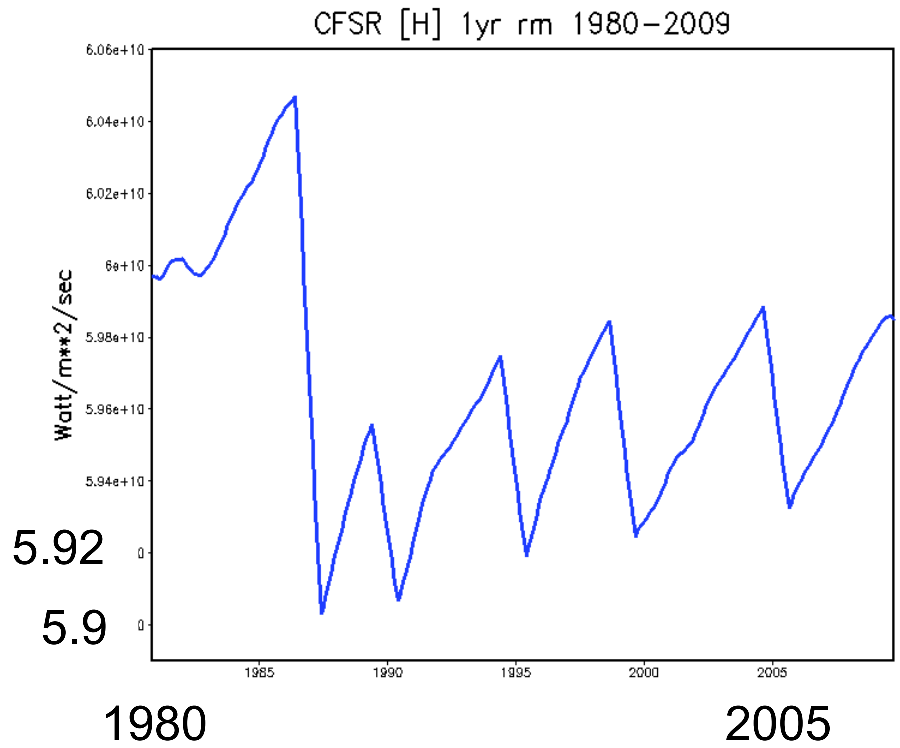
- **Verified**: CFSv2 results satisfy (2).
- Examine [*H*], [*dH/dt*] for CFSR and NEMOVAR reanalyses, NCEP and COLA forecasts.

Global Mean *H* From Ocean Reanalyses

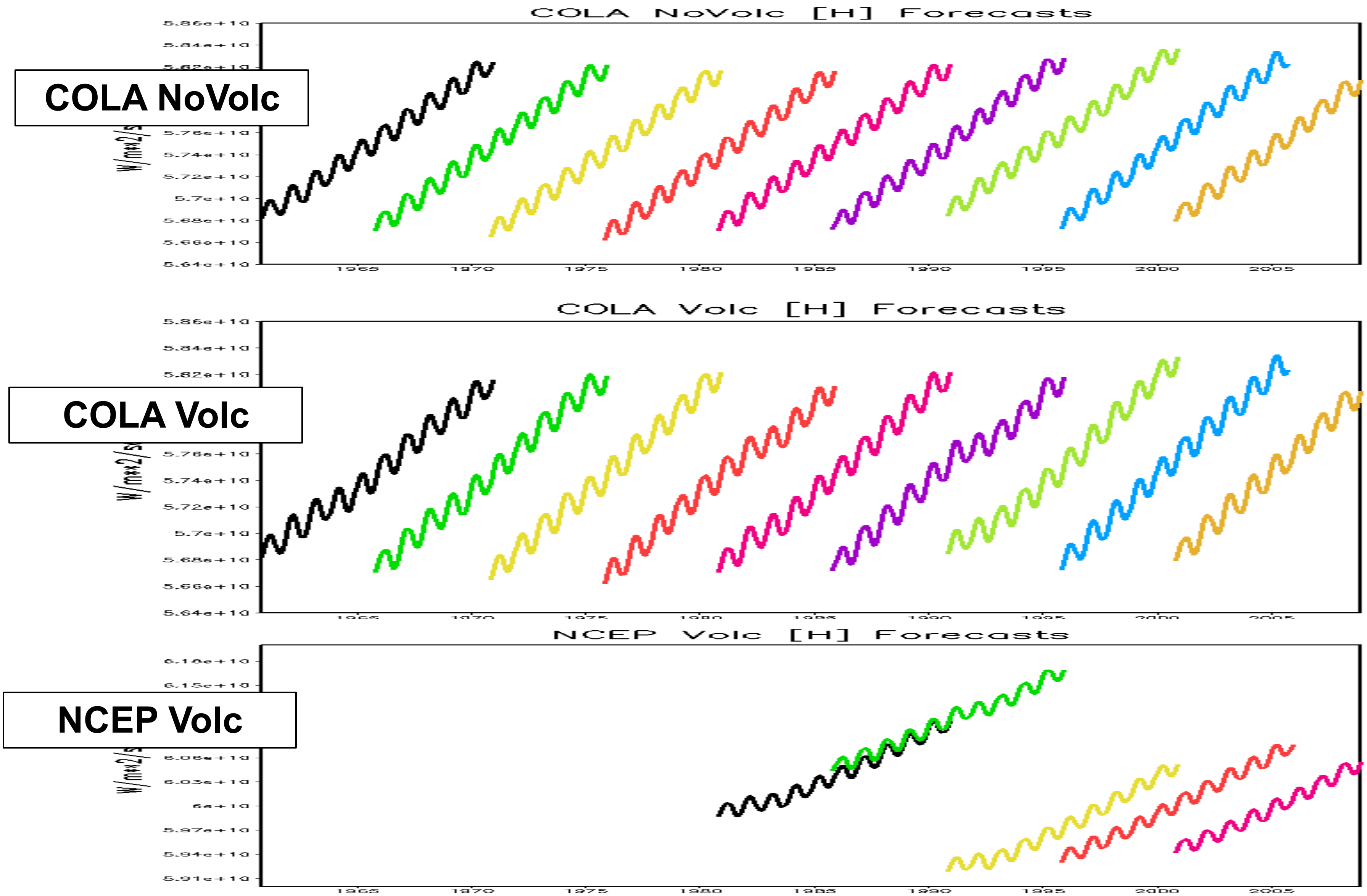
NEMOVAR



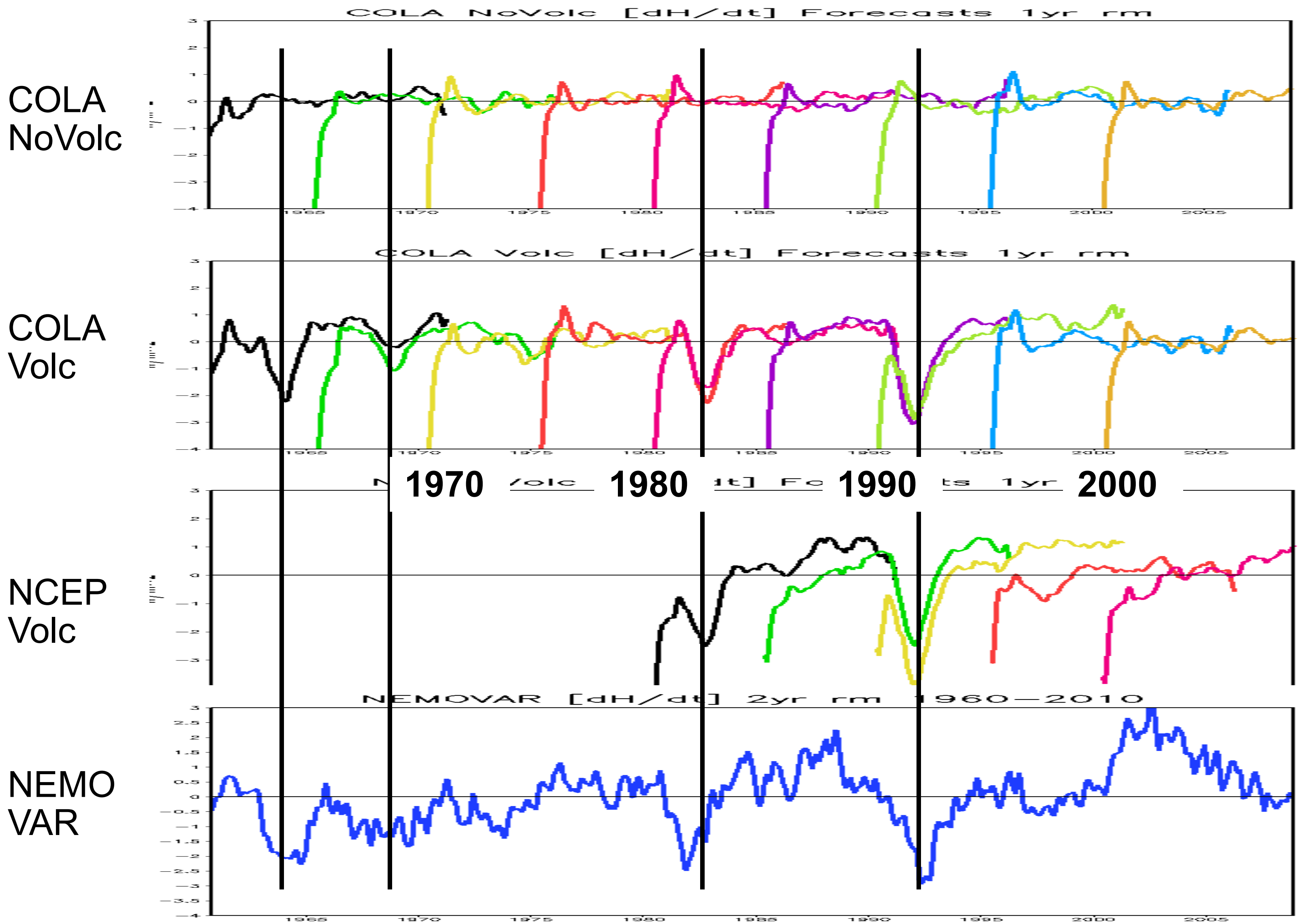
CFSR



[*H*] Predictions



[dH/dt]

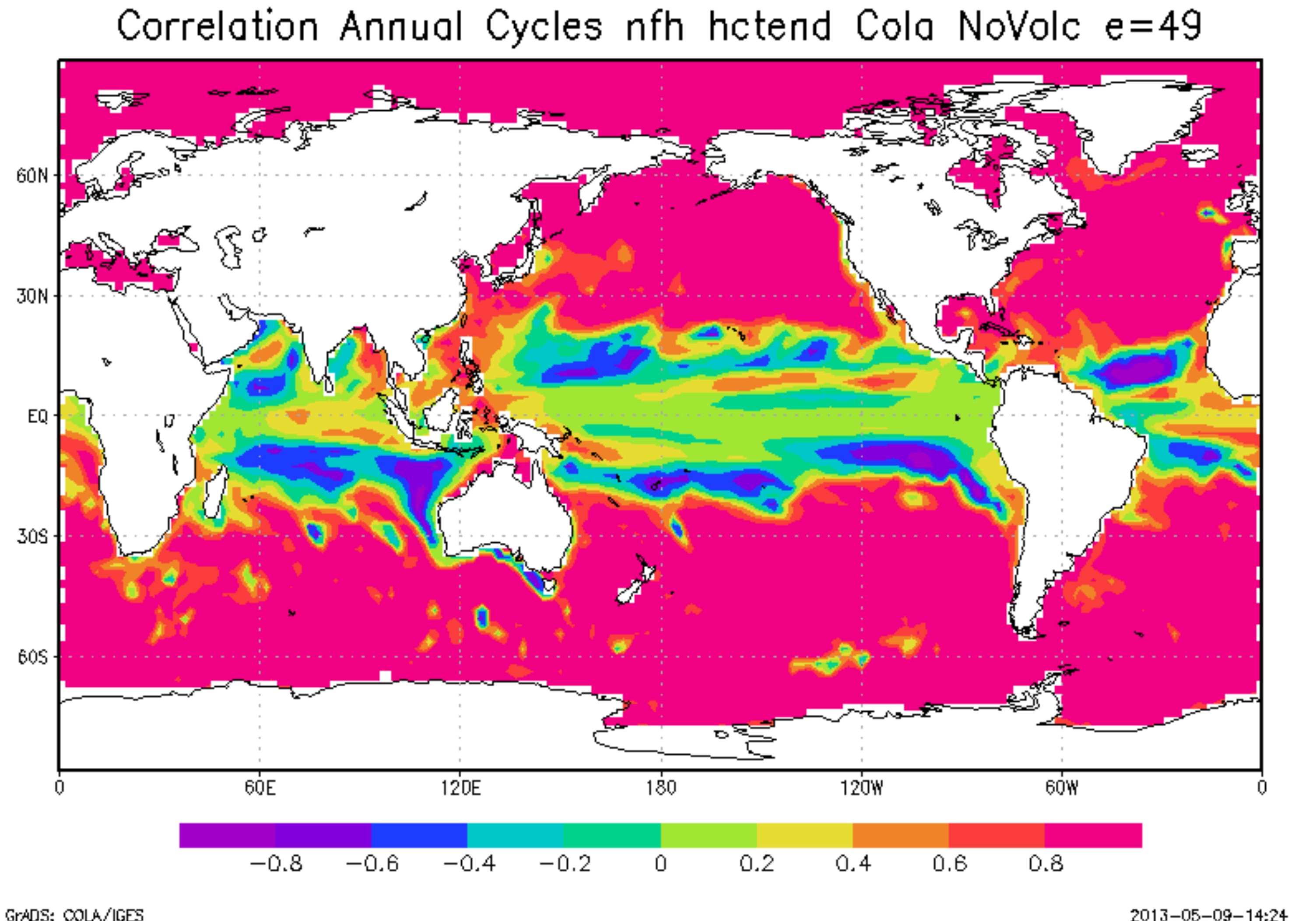


COLA NoVolc [dH/dt] Forecasts 1yr rm
COLA Volc [dH/dt] Forecasts 1yr rm
NEMOVAR [dH/dt] 2yr rm 1960–2010
COLA NoVolc
COLA Volc
NCEP Volc
NEMO VAR
1970
1980
1990
2000

Local Heat Content Partial Diagnosis

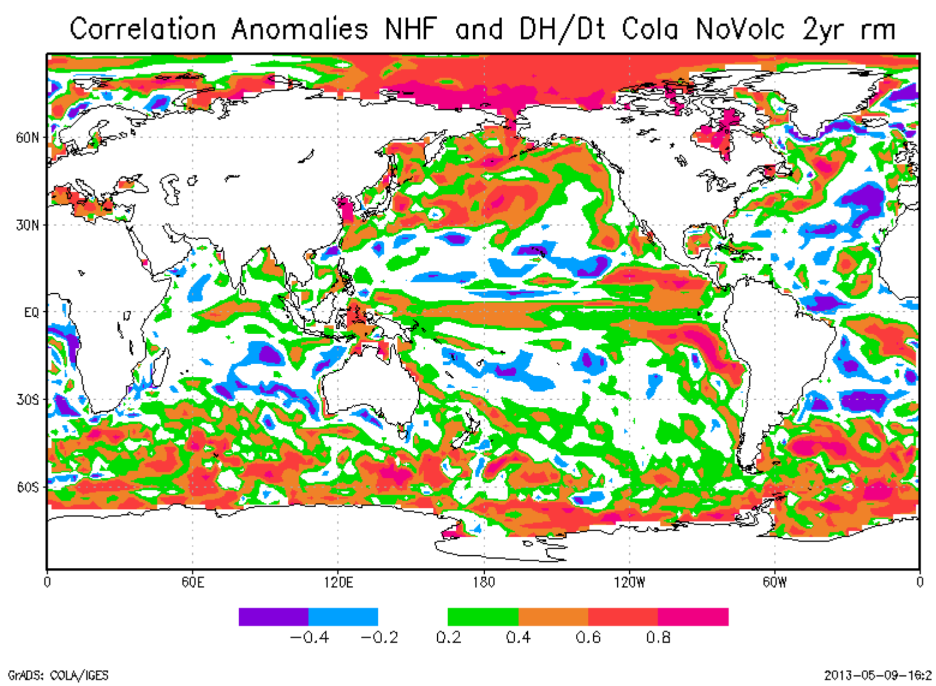
- Compare dH/dt and NHF
  - Local case: consider the correlation of dH/dt and NHF
    - If O=0, the correlation is 1.
    - The difference of the correlation from 1 is a measure of the importance of ocean dynamics in the heat content budget.
    - Can calculate O as a residual to explicitly examine the role of ocean dynamics.

Example: Correlation of H and NHF Annual Cycles

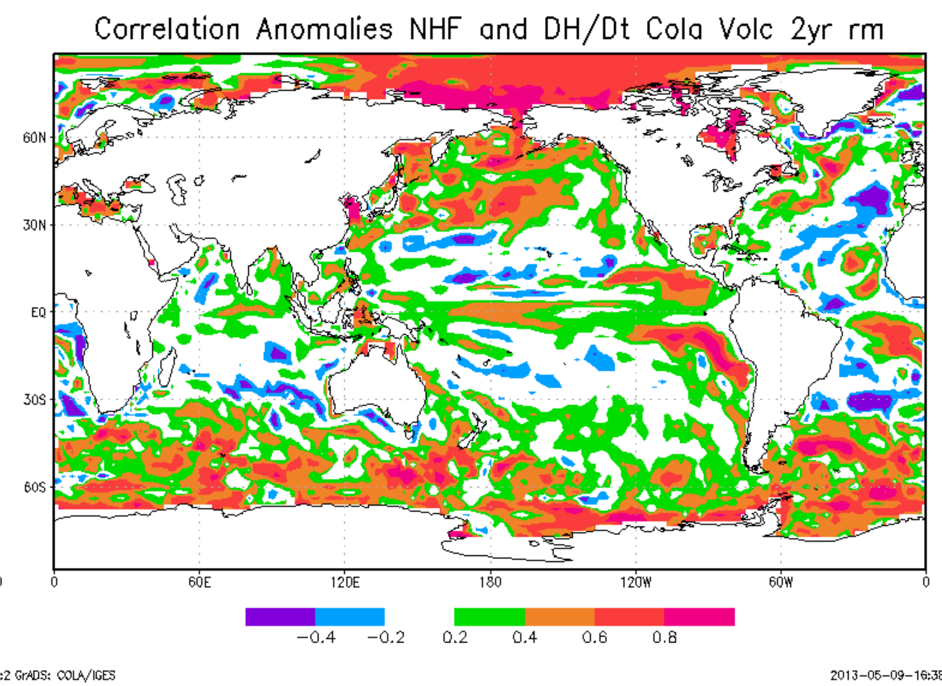


Correlation NHF and dH/dt, 2 year running means

COLA NoVolc



COLA Volc



Summary/Conclusions

1. Versions of CFSv2 used for COLA and NCEP predictions seem to be similar.
2. NCEP and COLA VOLC have similar skill for 2m air temperature decadal, despite large biases and strong differences in ocean heat content initialization.
3. Volcanic forcing is a strong contributor to “skill” for the CMIP5 experimental design.
4. Heat budget diagnosis shows promise for understanding mechanisms.