Decadal climate prediction with GEOS-5

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The GEOS-5 AOGCM for CMIP5

GEOS-5 AGCM	➢ 2° lat. x 2.5° lon. X 72L ➢ surface to 0.01hPa ➢ Finite Volume Dynamical Core ➢ RAS convection scheme with stochastic Tokioka ➢ Bacmeister et al. prognostic clouds ➢ Chou-Suarez radiation ➢ Louis and Lock PBL schemes ➢ Monin-Obhukov type surface turbulence scheme ➢ Catchment Land Surface Model ➢ CMIP5 prescribed forcings	Lin et al. (2004) Bacmeister et al. (2006) Moorthi and Suarez (1992) Lock et al. (2000) Louis (1982) Chou and Suarez (1999) Chou et al. (2001) Koster et al. (2000)
GOCART Aerosols	➢ Dust: 5 bins ➢ Sea-salt: 5 bins ➢ Organic carbon: hydrophobic & hydrophilic tracers ➢ Black carbon: hydrophobic & hydrophilic tracers ➢ Sulfates: SO2, SO4, DMS, MSA	Colarco et al. (2010)
OGCM: MOM4	➢ MOM4p1 ➢ 1° lat. x 1° lon. with 1/3° equatorial refinement ➢ 50 vertical levels ➢ Tripolar grid ➢ z coord; conservative temp., KPP+tidal mixing	Griffies et al. (2004) Large et al. (1994)
CICE v4.1	➢ Sea-ice thermodynamics ➢ Sea-ice dynamics and advection ➢ Ridging parameterization	Hunke and Lipscomb (2010)

Air-sea coupling interval: 30 minutes

GMAO contributed to the Decadal Prediction Experiments of CMIP5

- an extension of our seasonal forecast effort, except that now we had to pay attention to the high latitudes!

- Forecast period : 10 years
- Initialization: 1 December
- Number of hindcasts : 61, every year from Dec. 1959 to 2009
- Number of ensemble members : 3 (Control & +/- pair of 5yr BVs)
- Initialization: GEOS Ocean Reanalysis and MERRA
- Forecasts had **no volcanic eruptions** (only continually outgassing volcanoes)

- **Comparison with free-running AOGCM (C20C, 2nd half)**
- 3-member ensemble
- RCP4.5 beyond 2010

Coupled A-L-O-S initialization of decadal predictions

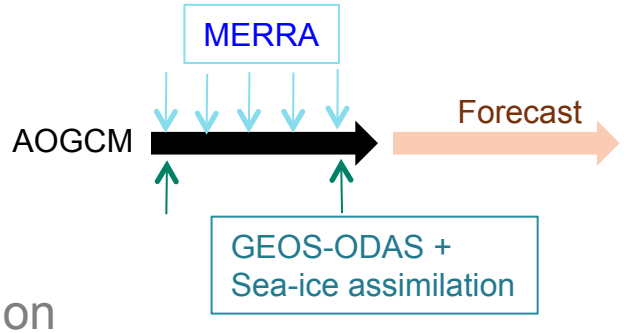
Atmosphere constrained by MERRA every 6 hours

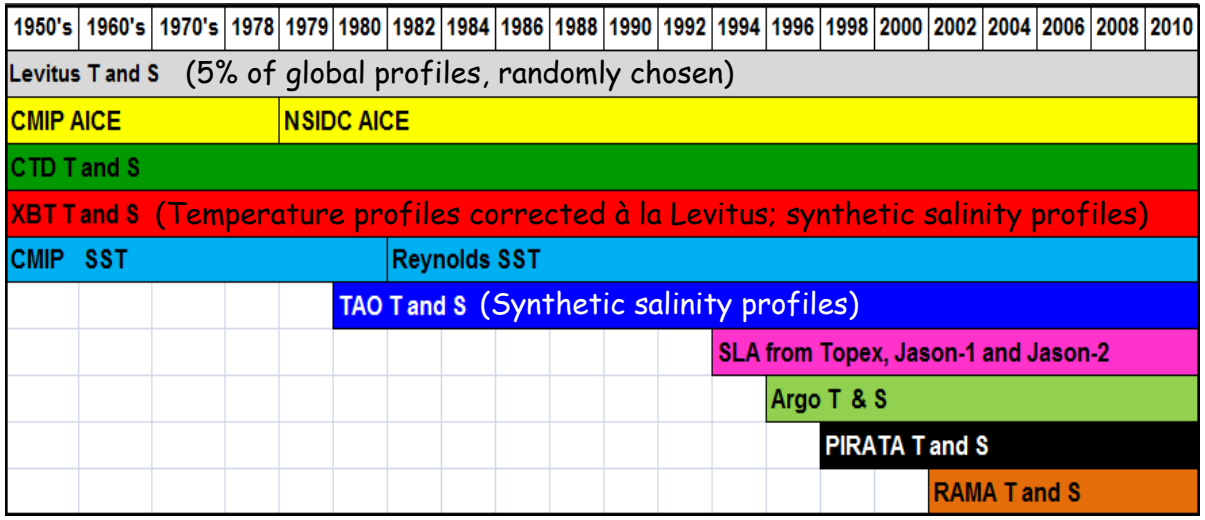
- Precipitation rescaled to GPCP for LSM

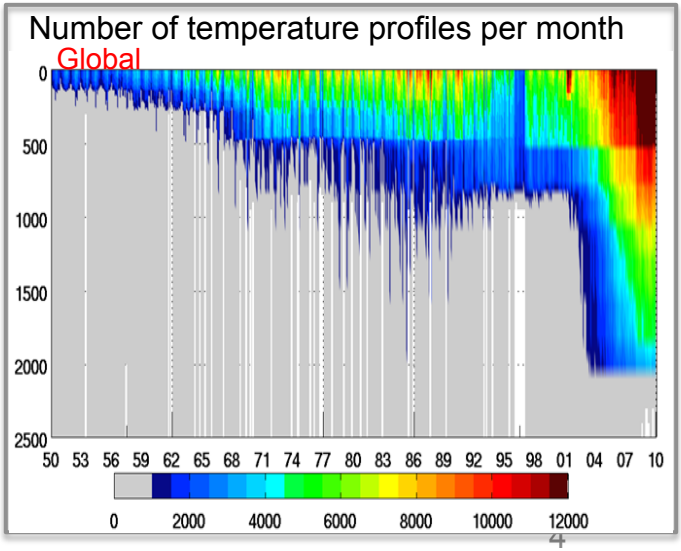
Ocean: daily assimilation

- Ensemble Optimal Interpolation (EnOI)
- State dependent localization based on density
- 1955 to present

Sea-ice: daily assimilation of sea-ice concentration used to constrain mixed layer temperature and salinity

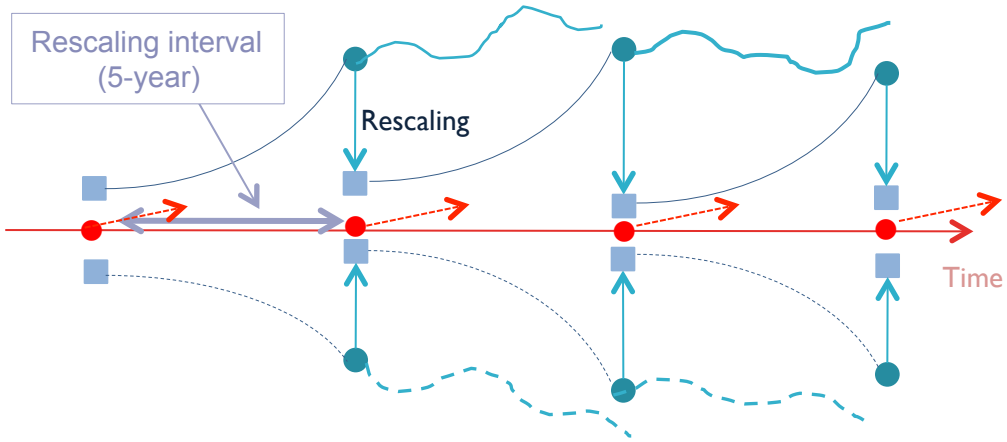


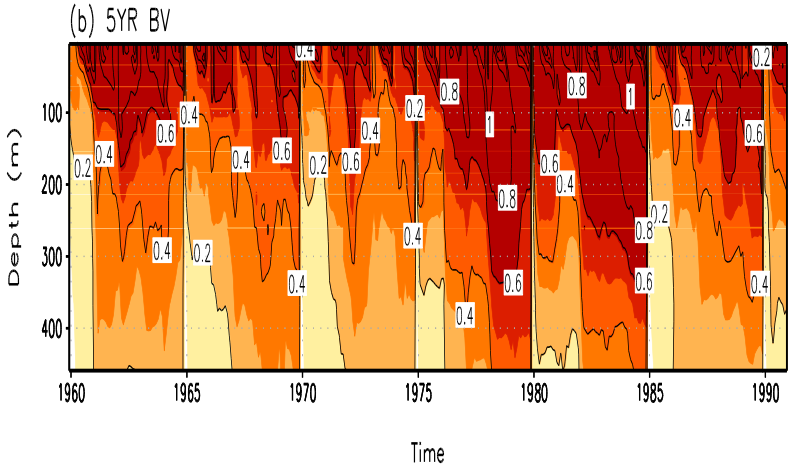




Generation of Perturbations

- Method : **Two-sided breeding**
- Norm variable : **HC500 (Averaged Temperature 0-500m)**
- Norm Regions : **Atlantic ocean (100W-20E, 20N-70N)**
- Initial BV magnitude : **Reduced to 10% of natural variability**
- Rescaling Interval : **5 years**
- Period : **Jan. 1954 – Dec. 2010**

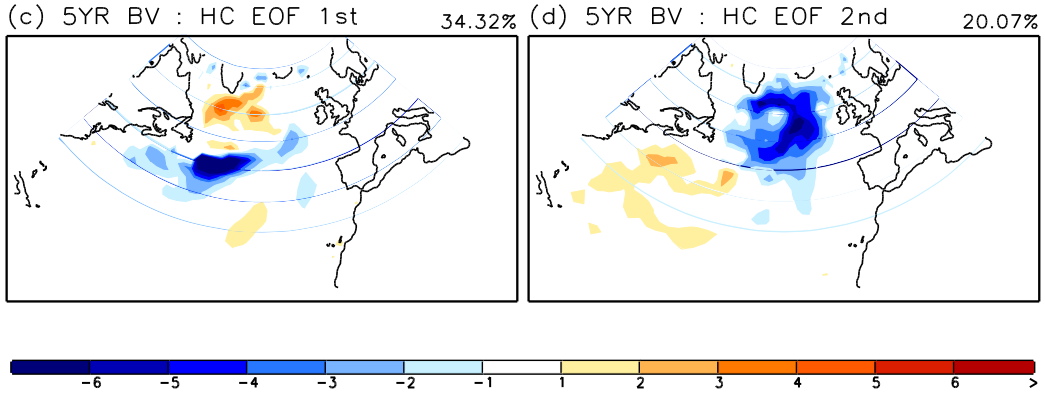




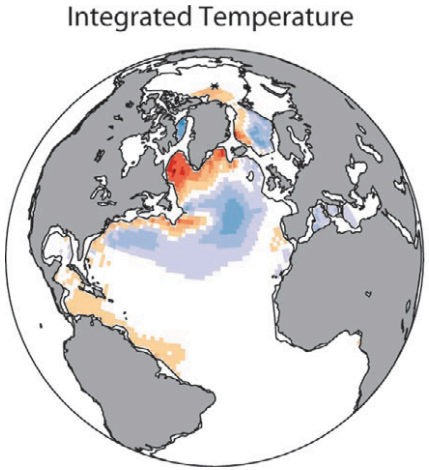
- IC: A-L-O-S Reanalyses
- Bred Vectors
- Perturbation from BV

The perturbations

GEOS-5
Bred Vectors
EOF of HC500



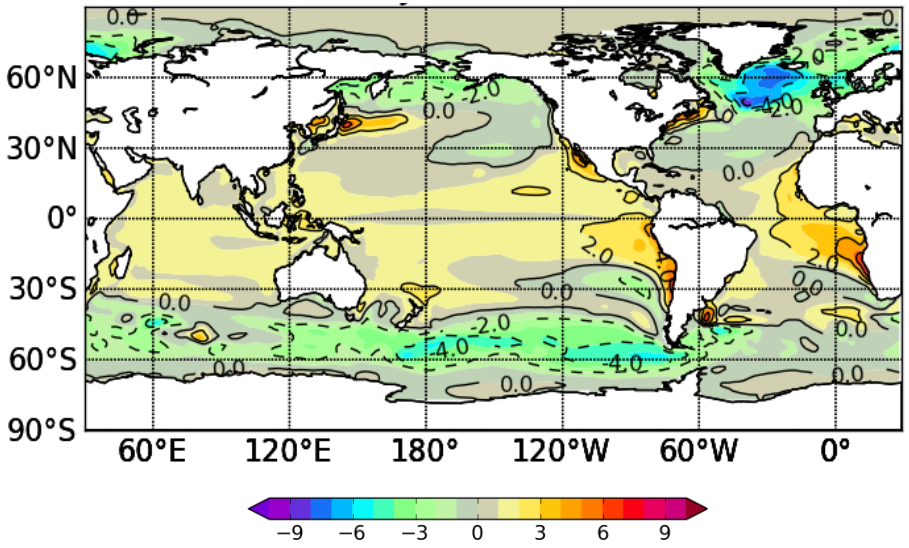
Optimal perturbation (HC1800) from the HadCM3 model (Hawkins and Sutton 2009)



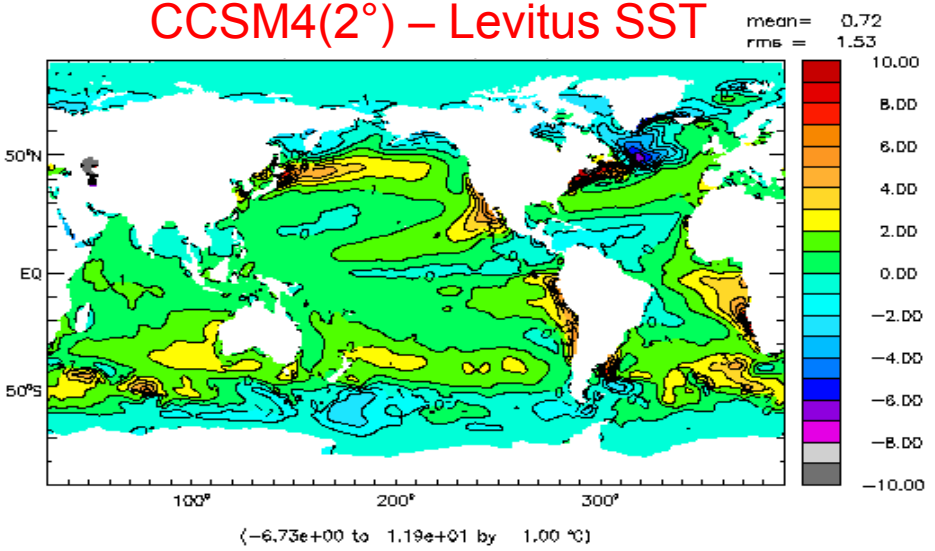
Annual Mean Model Bias – C20C simulation

mean: 0.23
std: 1.77

GEOS-5 – Reynolds SST

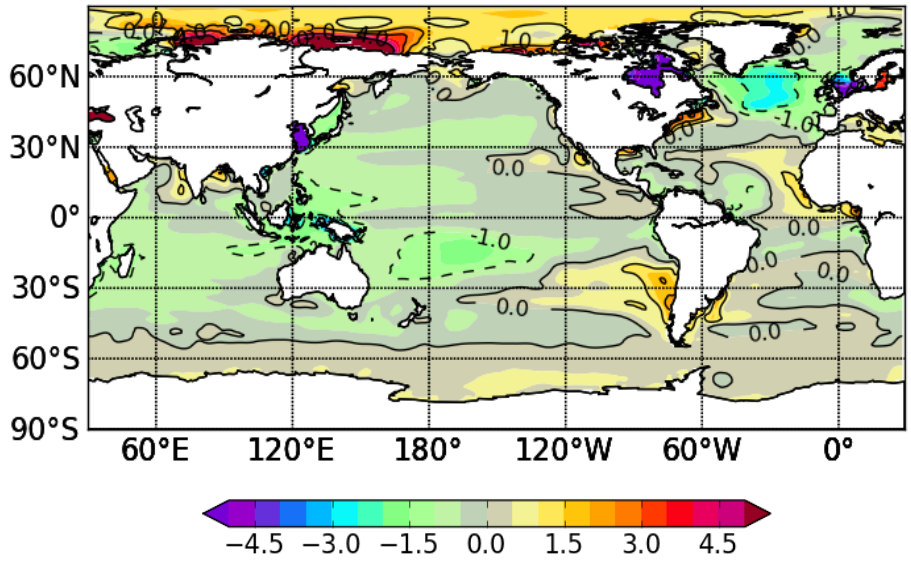


CCSM4(2°) – Levitus SST



mean: -0.25
std: 1.18

GEOS-5 – Levitus SSS



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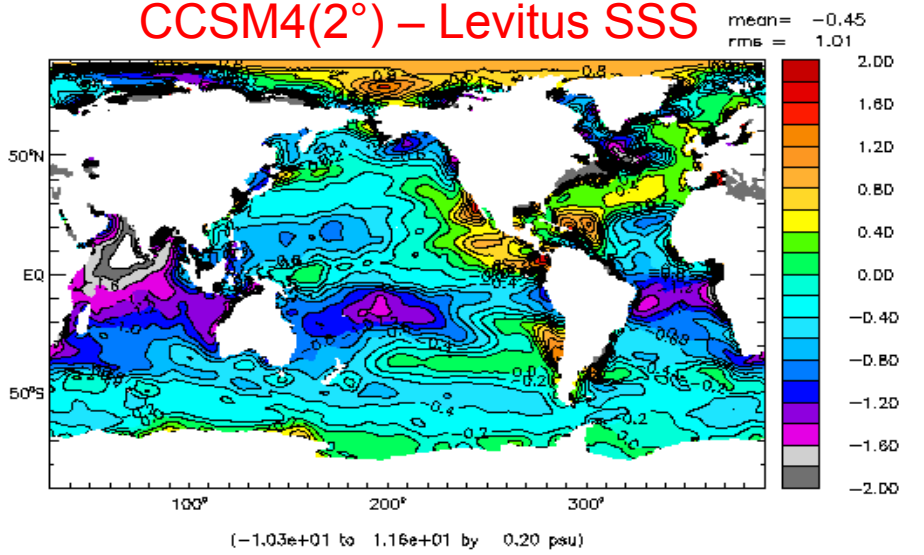
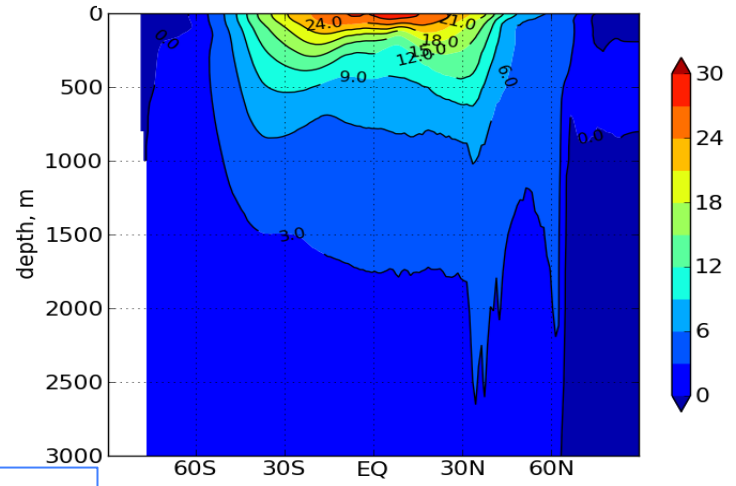


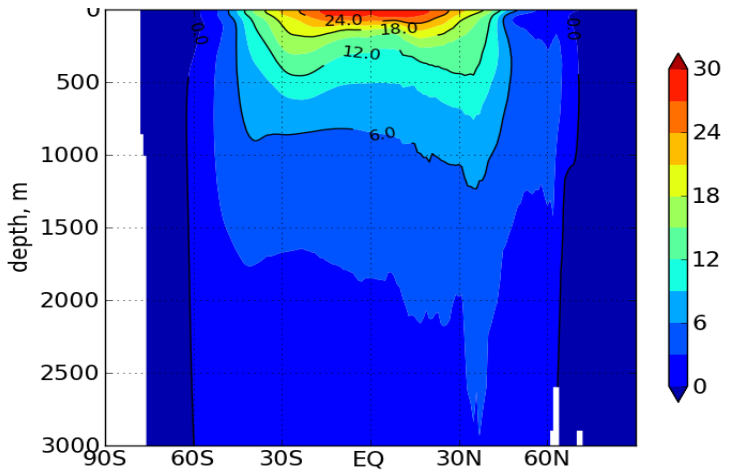
Annual Zonal Mean Structure – C20C climatology

Temperature

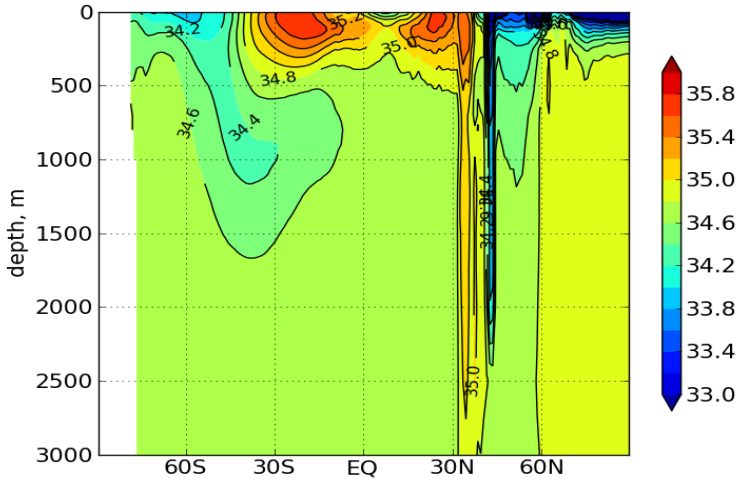
Levitus

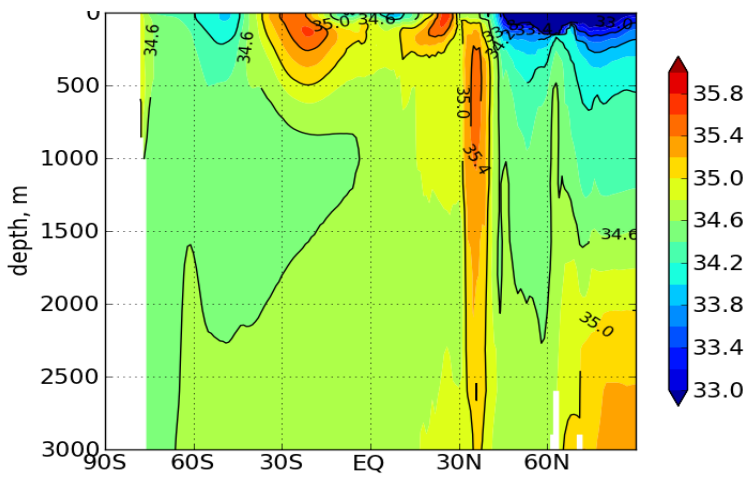


GEOS-5

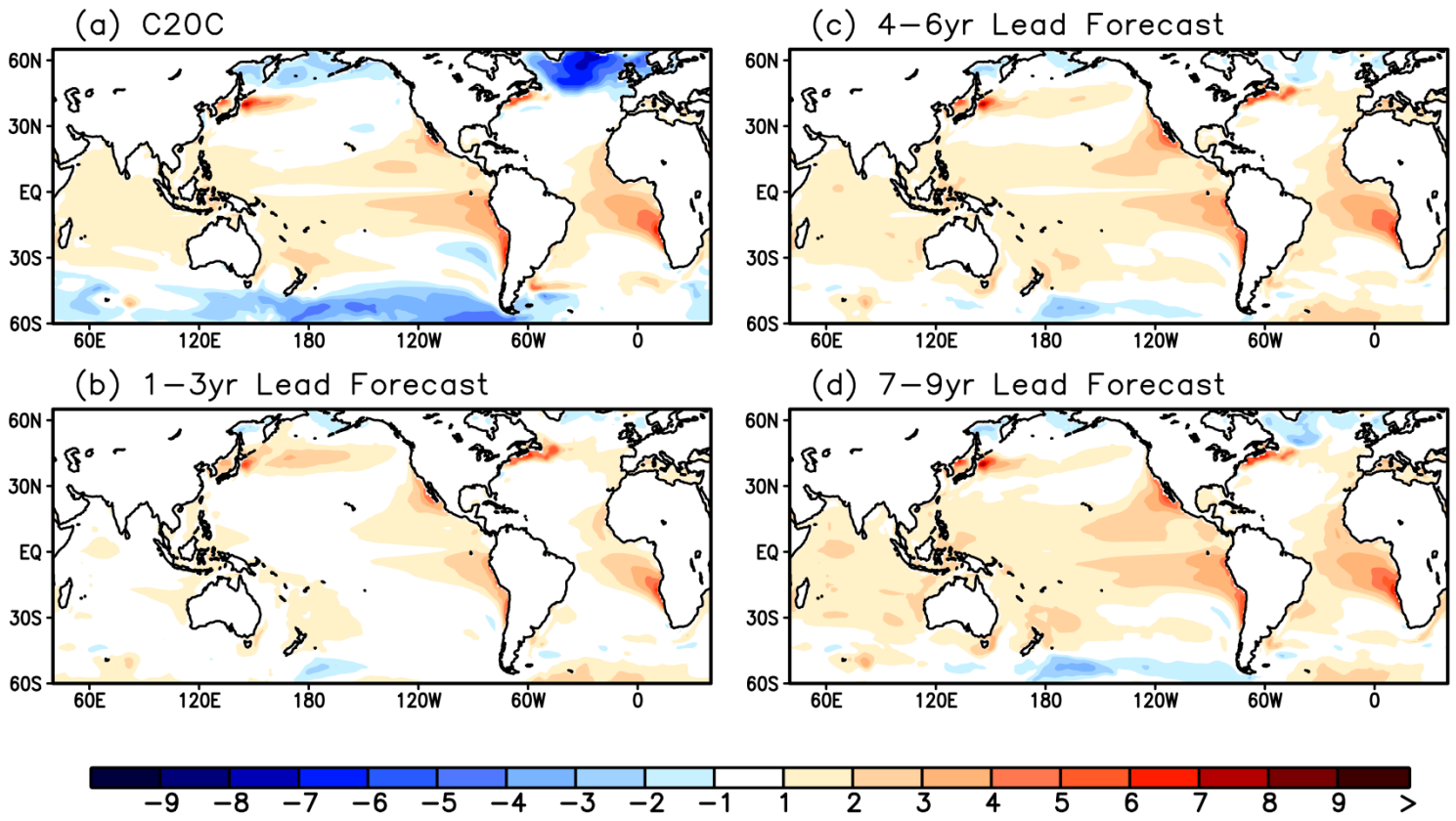


Salinity

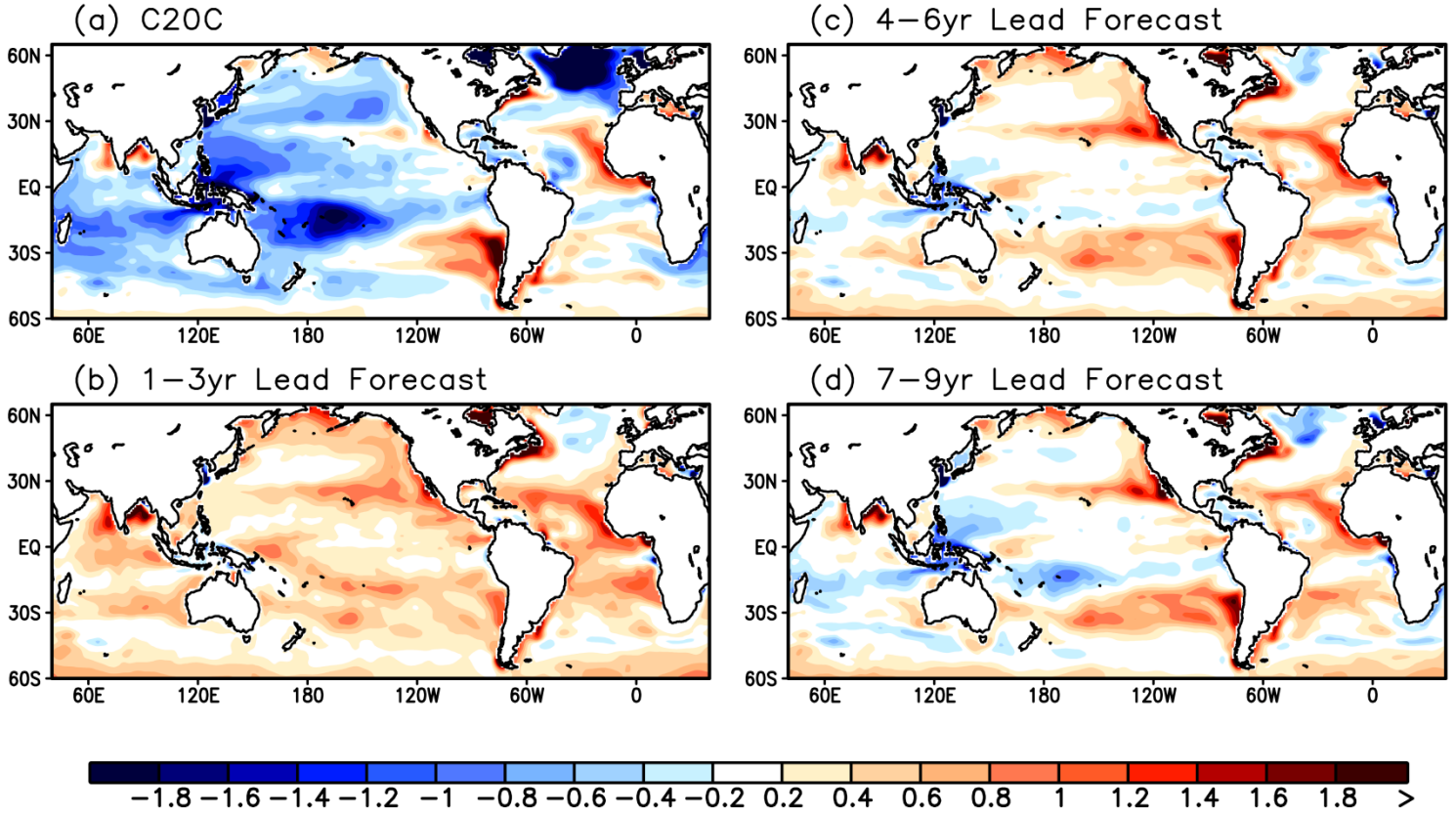




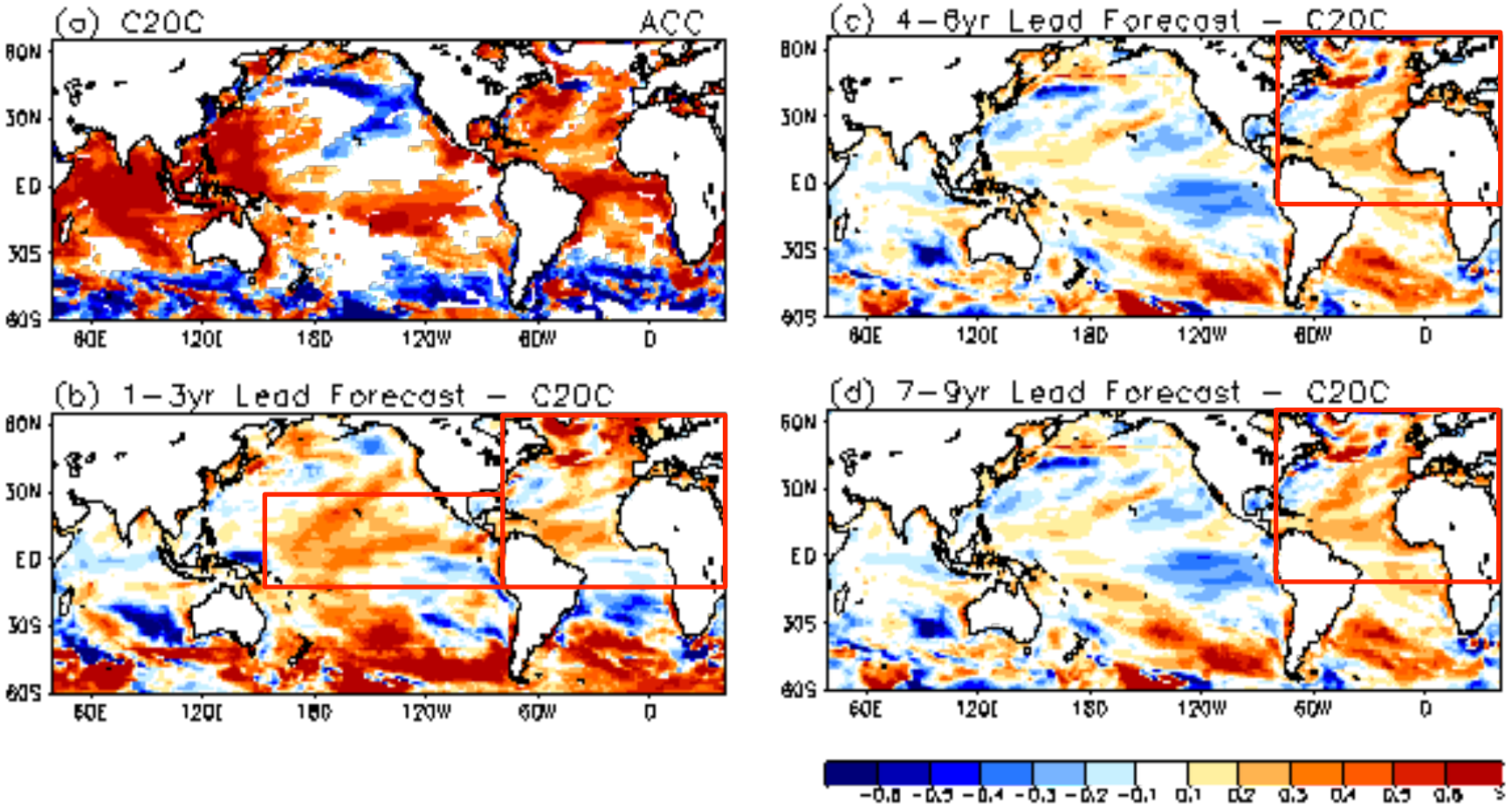
Evolution of Forecast SST Bias



Evolution of Forecast SSS Bias

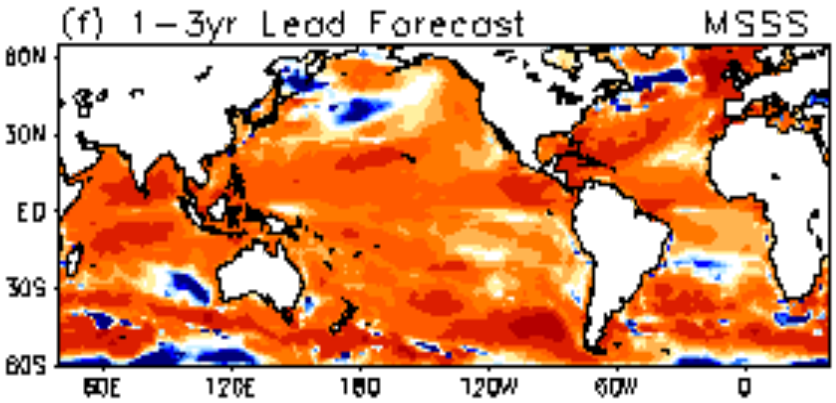


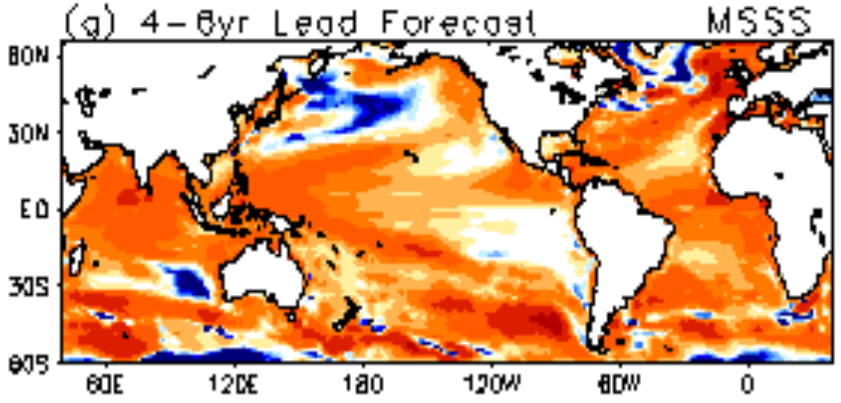
Anomaly correlation skill gained by initialization 3-year mean SST, with trend

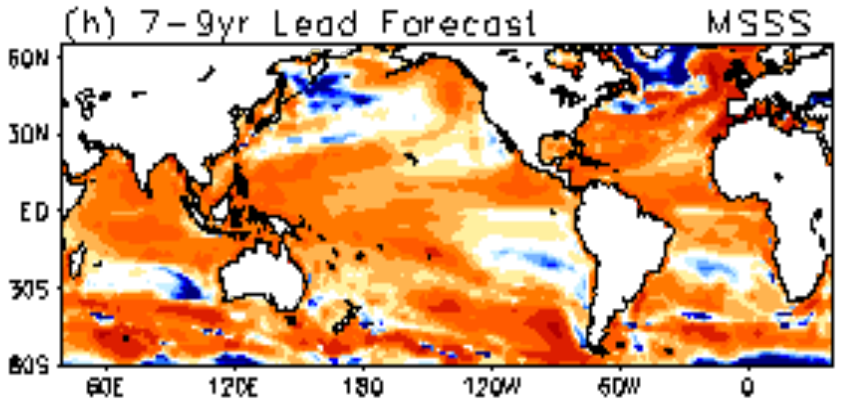


MSSS of SST anomaly, with trend

$$\mathrm{MSSS} = \frac{\mathrm{MSE}_{\mathrm{C20C}} - \mathrm{MSE}_{\mathrm{Fcst}}}{\mathrm{MSE}_{\mathrm{C20C}}}$$

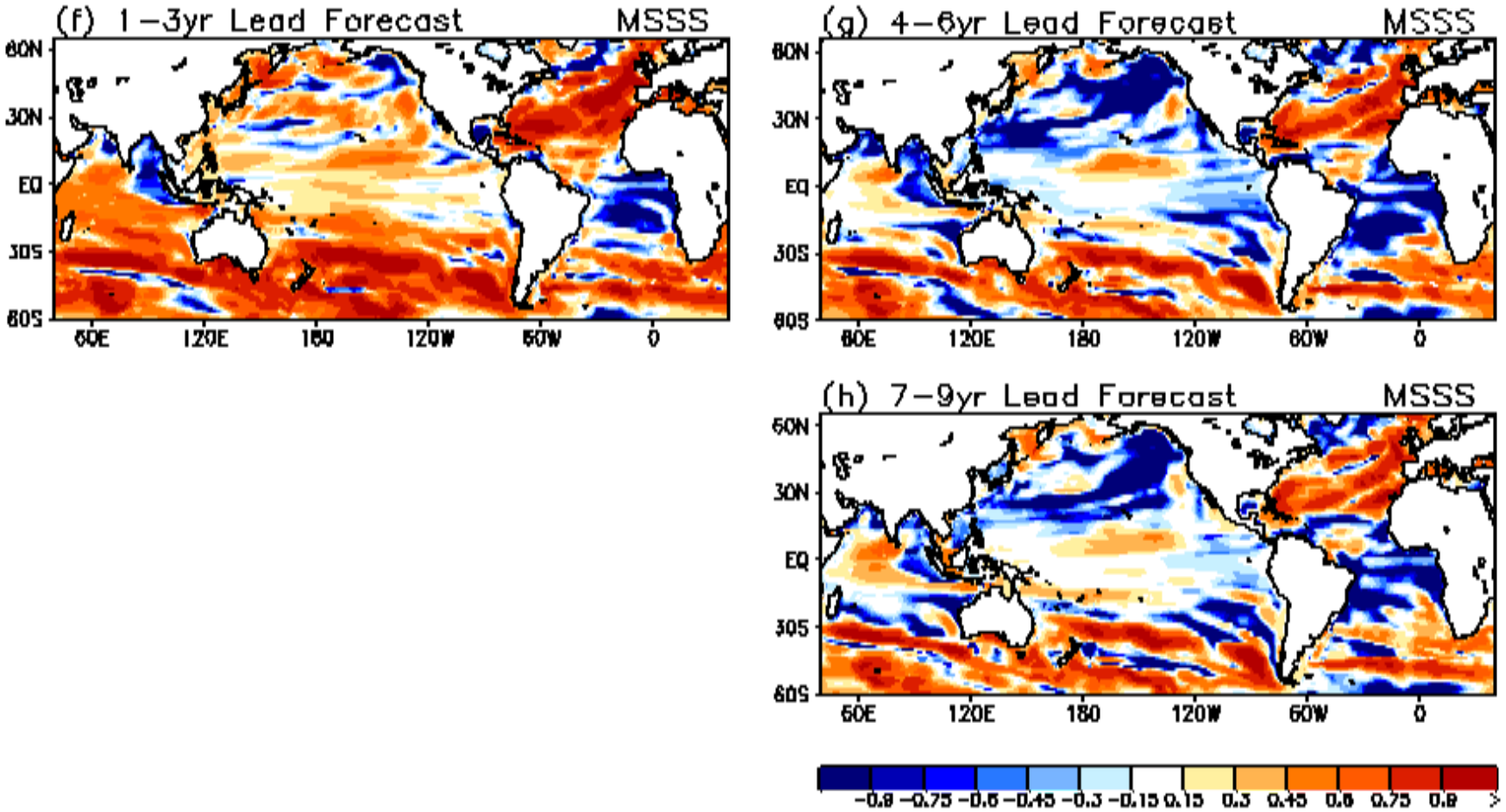






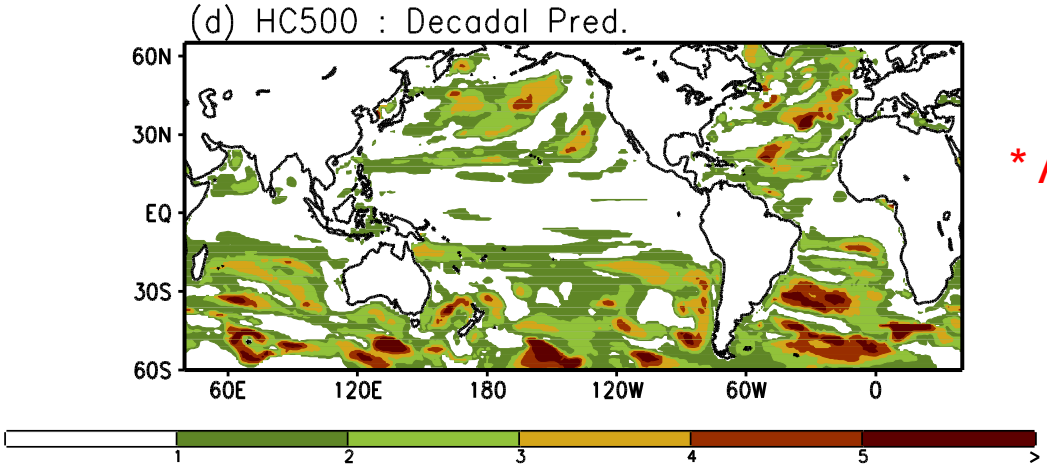
MSSS of HC500 anomaly, with trend

$$\mathrm{MSSS} = \frac{\mathrm{MSE}_{\mathrm{C20C}} - \mathrm{MSE}_{\mathrm{Fcst}}}{\mathrm{MSE}_{\mathrm{C20C}}}$$



Time scales* of forecast skill
Detrended upper ocean heat content

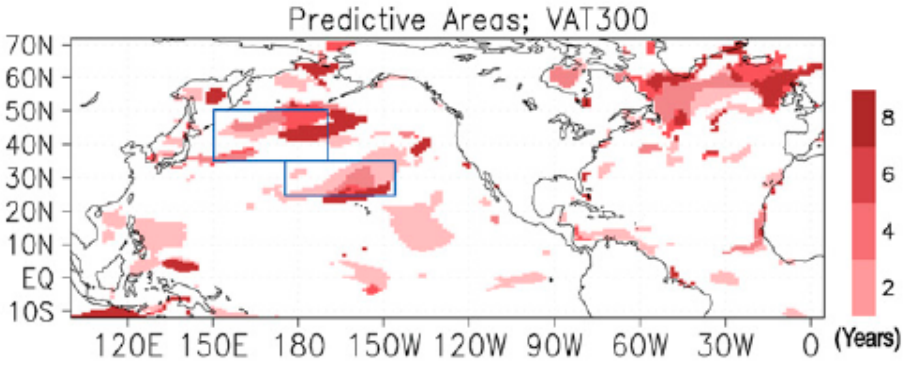
GEOS-5
HC500



* ACC reaches 1/e

JAMSTEC
HC300

From Mochizuki et al 2010



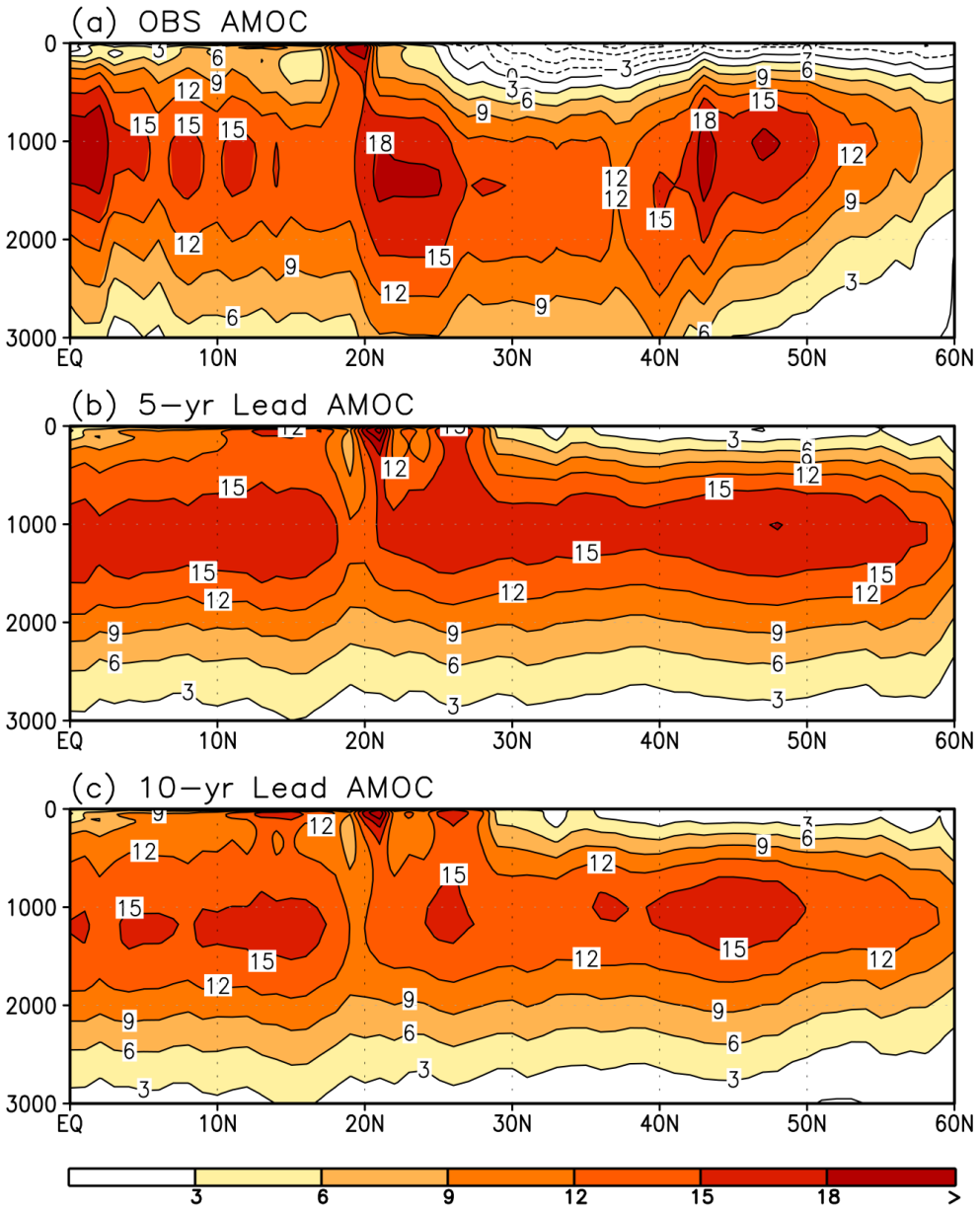
* Areas where the ACC of 5-year-mean detrended HC300 is significant at 90% confidence levels at forecast leads of 2, 4, 6, 8 years

The AMOC in GEOS-5

GMAO
Ocean analysis

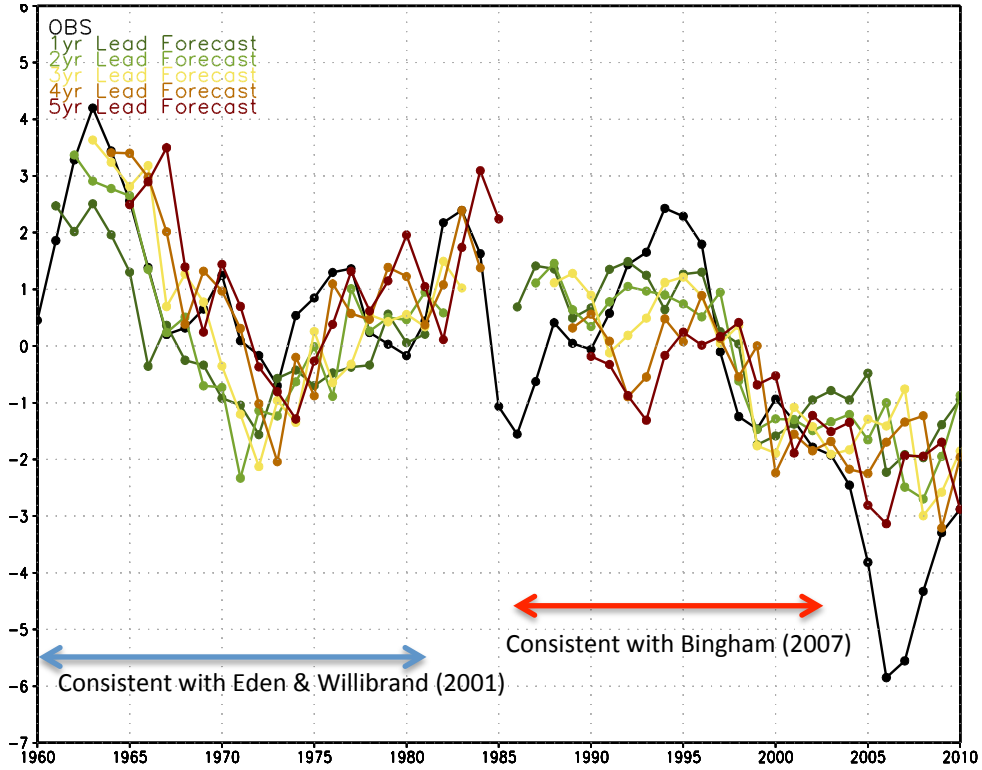
GEOS-5
Climatology
at 5-year lead
forecast

GEOS-5
Climatology
at 10-year
lead forecast



AMOC Index (43-45N), with trend

AMOC Anomaly

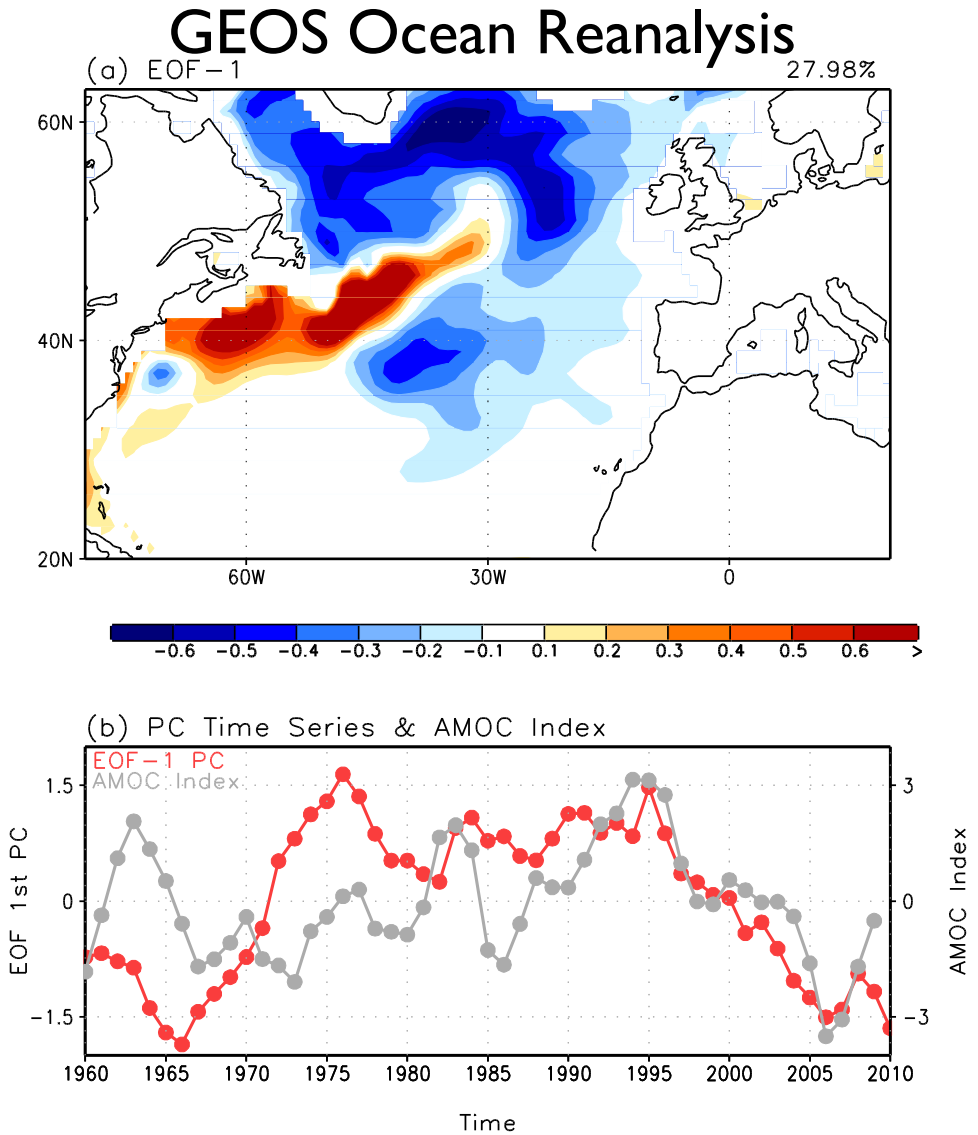


Correlation Skill

Forecast Lead Year	Decadal Forecast	Persistent Forecast
1 year	**0.74**	**0.90**
2 years	**0.78**	**0.70**
3 years	**0.75**	0.52
4 years	**0.73**	0.43
5 years	**0.66**	0.40
6 years	0.41	0.37
7 years	0.25	0.33
8 years	0.25	0.24
9 years	0.30	0.09
10 years	0.33	-0.01

AMOC index : the maximum of the zonally-integrated annual mean overturning streamfunction averaged over 43-45N

Variations in HC500 and AMOC, detrended Dominant Decadal Mode

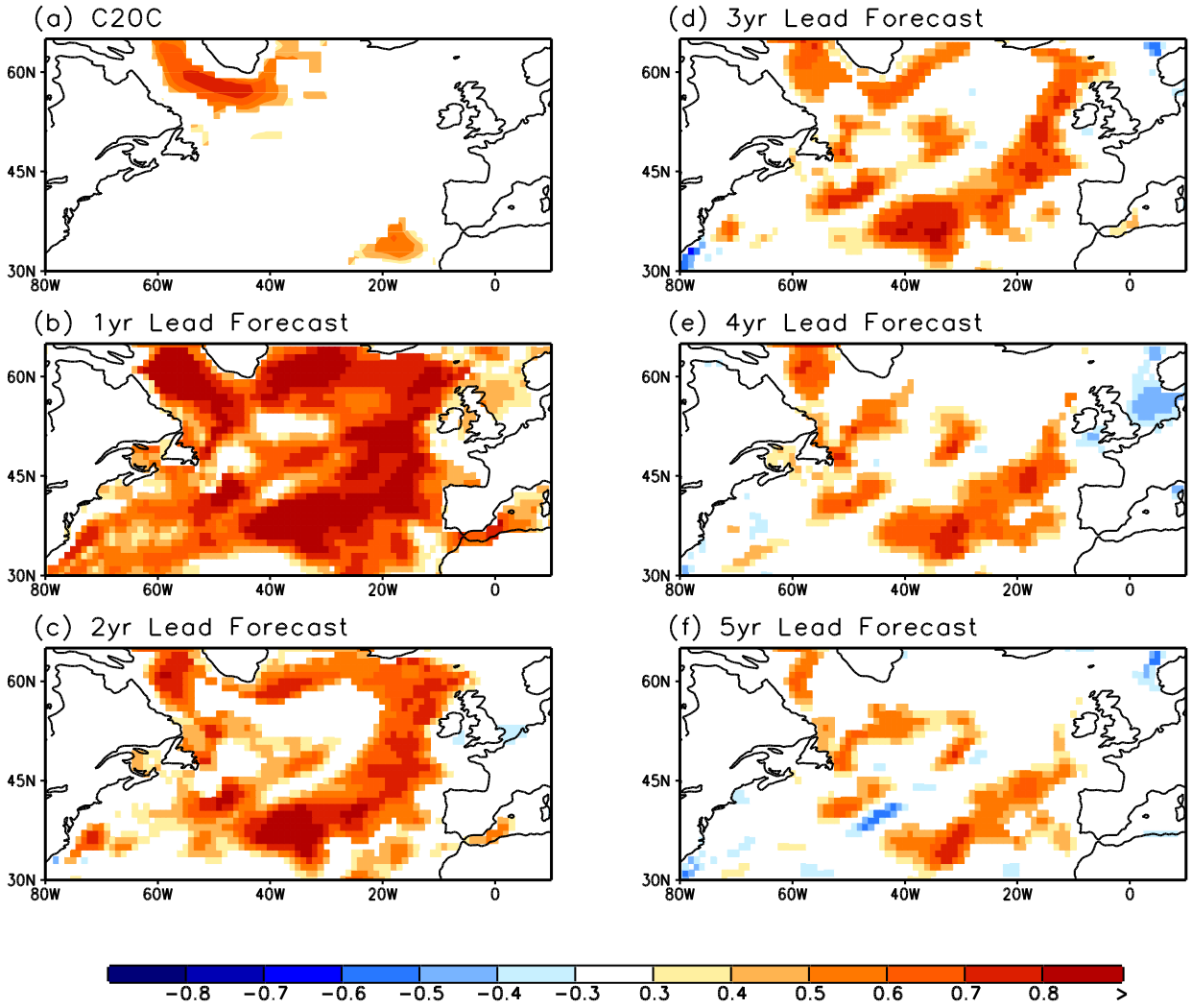


Zhang (2008)

50s-60s, 96-05:
Subpolar gyre weaker
NRG , AMOC stronger

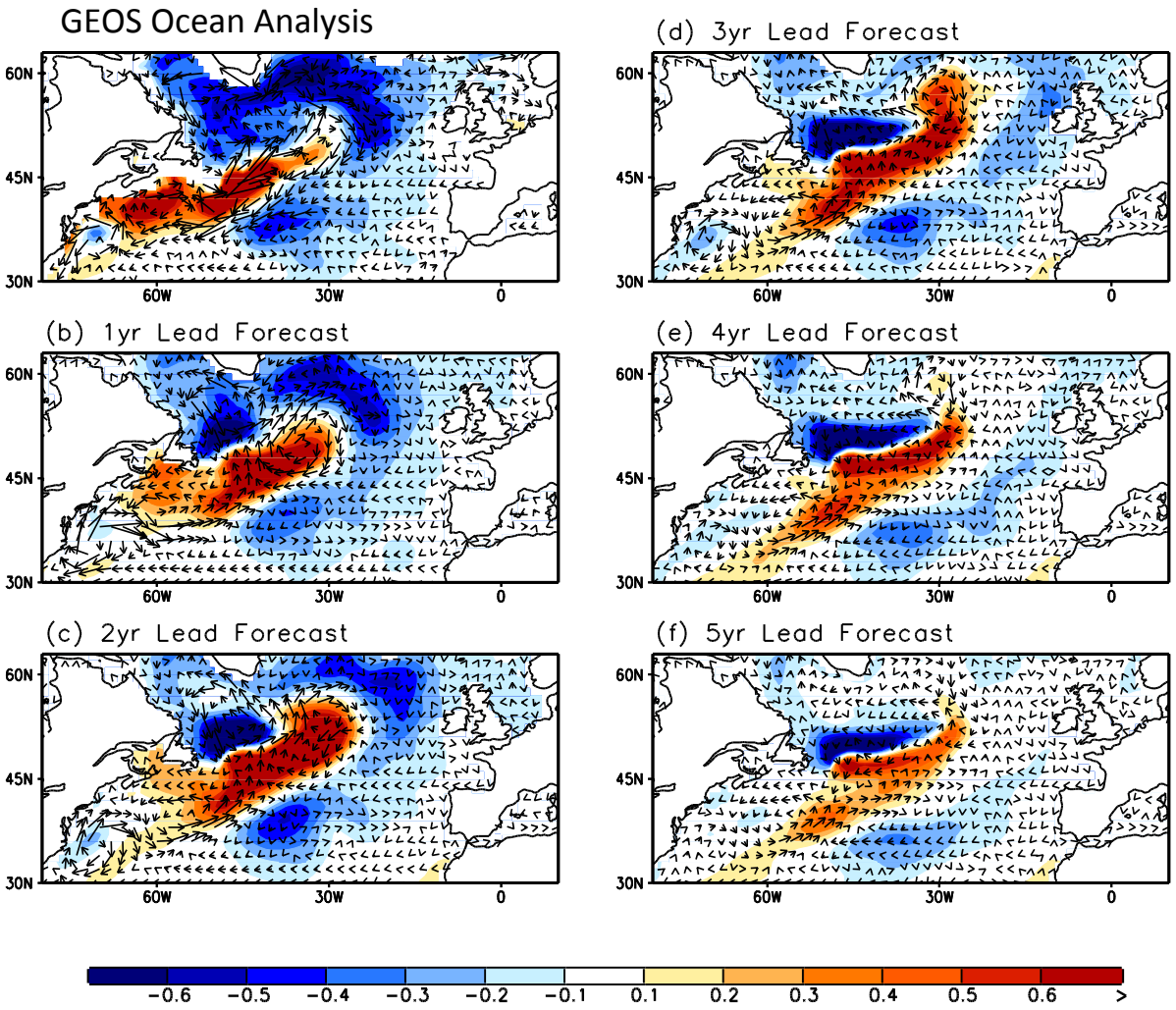
70-80s:
Subpolar gyre stronger
NRG, AMOC weaker

Correlation skill of HC500 anomalies, de-trended

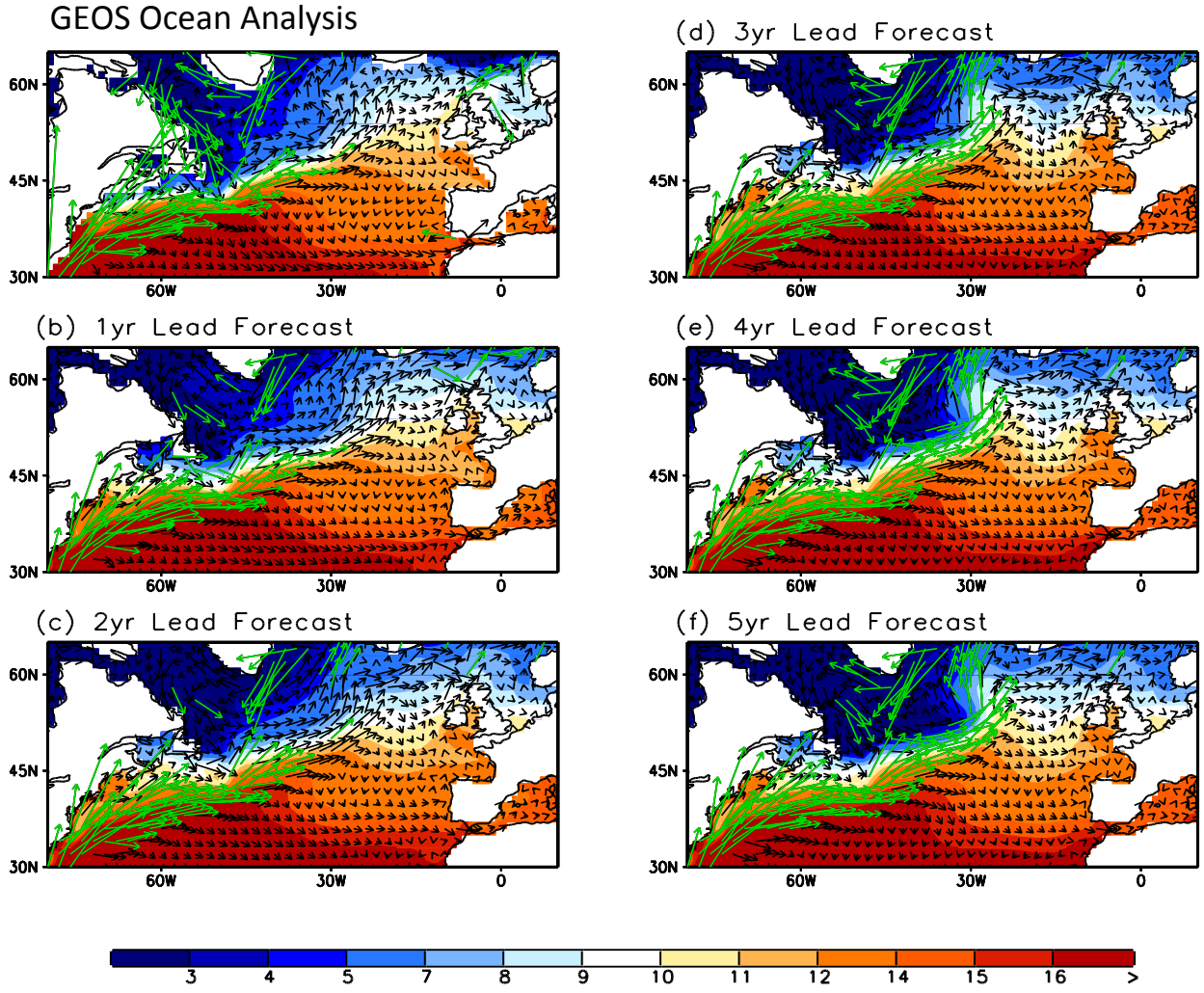


* Masked by 90% significance level

Forecast of Dominant Mode, HC500



Evolution of forecast Nth Atlantic climate



Model transport bias impacts decadal forecast
Warming along the NAC extends too far to the North

Summary

- The MSSS for 3-year-averaged SST shows that there are improvements for several years over the Atlantic, Indian Ocean, and the tropical western Pacific in the initialized forecasts.

- The MSSS for HC500 shows there is about 50% improvement over the subtropics and mid-latitude Atlantic at 4-9 year leads in the initialized forecasts. This metric tends to overemphasize negative scores.

- The annual-mean Atlantic Meridional Overturning Circulation (AMOC) index for the subpolar branch of the AMOC has some predictable skill for up to 5-year leads.

- The low skill in the subpolar North Atlantic is related biases in the modeled climatological North Atlantic Current. *A posteriori* removal of the climatological bias is not enough!

Our CMIP5 experience

- Excessive output requirement – we trimmed to monthly-mean output only for ESG. Should restrict high frequency output to basic fields.
- Iterated with Karl Taylor on some item specifications.
- No problem converting to required format.
- For decadal predictions, need to de-trend. Output on ESG is full field. Users need to de-trend themselves and they should be made aware of that. If only anomalies are provided, then there is the issue of how the drift is removed.

- CMIP5 forcings: Volcanic aerosols not available as emissions as needed for GOCART. We used only permanently outgassing volcanoes for which we had emissions.

Our CMIP5 experience

- We had several false starts and had to iterate: Confusion in start year - “1960” really meant 1961 as first full year – also tuning of analysis and model.

- A valuable experience for GMAO since we looked at GEOS-5 performance in areas that had not received attention in the past. Planning to re-do entire sequence and continue contributions to CMIP.

Comments/suggestions on future decadal prediction efforts

- One area for attention is better initialization. Forecasts in the early "unobserved" period:
  - Is better initialization possible?
  - How does one validate? Really validating against free-running model [a predictability experiment?]

- Validation can be an issue in extratropics, particularly at high latitudes. Usually (self-)validate against ocean or atmospheric reanalyses. External efforts (e.g., GSOP) to evaluate/compare reanalyses should include metrics relevant to validation of decadal prediction (uncertainty, biases, etc.).

- Much to be gained by focusing on shorter leads (1-5 years, larger ensembles, more experiments) rather than using computer time for longer leads. [Comparison: seasonal-to-interannual forecasts focus on 9-month forecasts]
- Reduction of model bias has to be a priority – model bias overwhelms decadal anomalies.