A Global Multi-Decadal Oscillation

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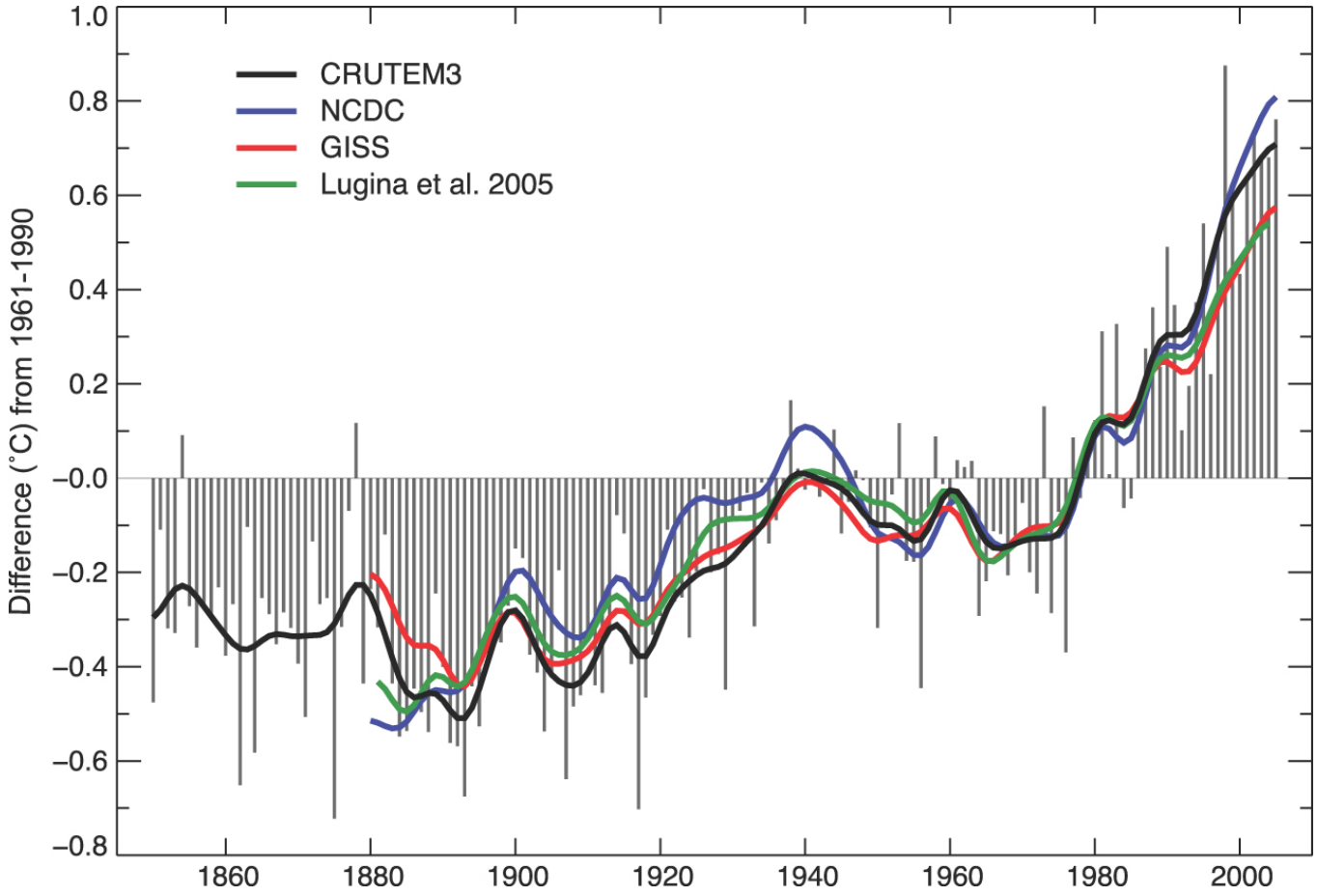
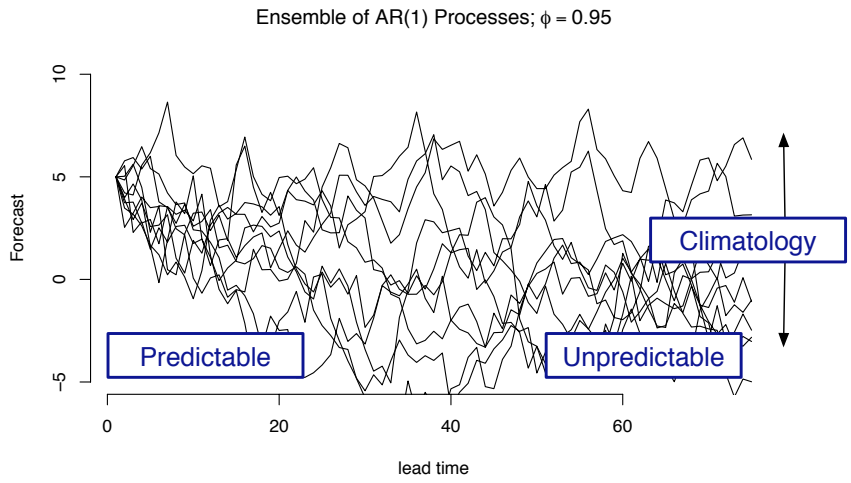


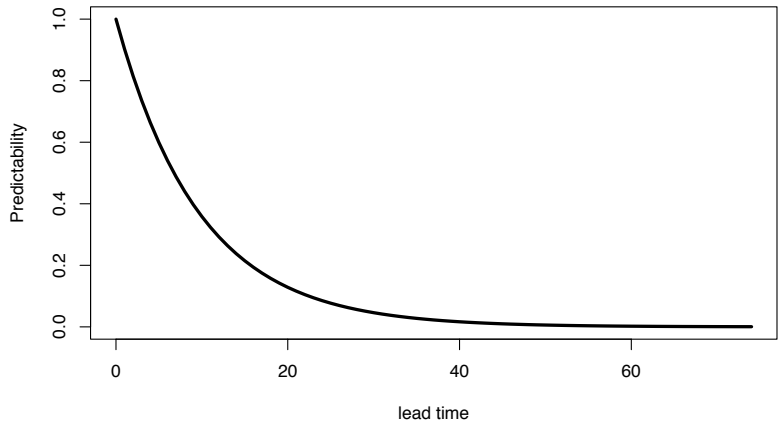
Figure: Annual anomalies of global land-surface temperature (from IPCC-AR4; figure 3.1)

Questions

- How much variability is forced?
- How much variability is due to internal mechanisms?
- How much of the internal variability is predictable?

Definition of Predictability





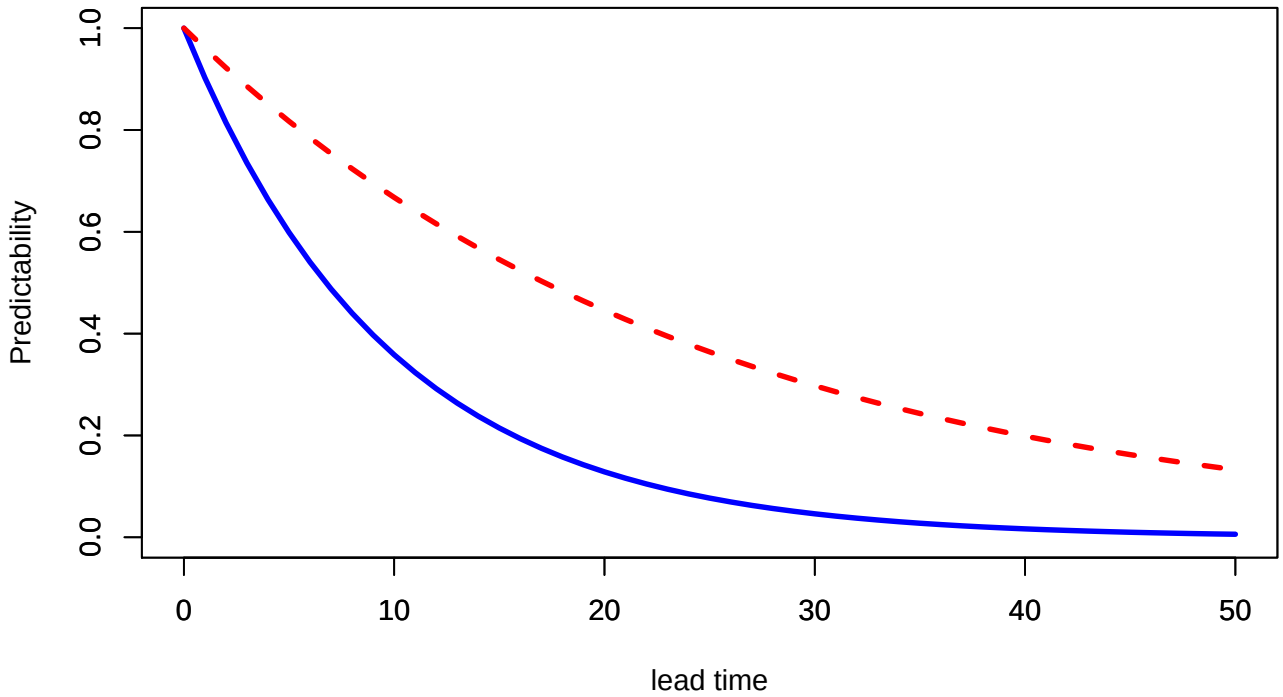
Measure of Predictability

$$P = \frac{\sigma_c^2 - \sigma_f^2}{\sigma_c^2}$$

σ_f^2: Variance of forecast.
σ_c^2: Variance of climatology.

Can predictability be characterized in a way that is independent of lead time?

Average Predictability Time (APT)



APT = integral of 2P over all lead times

$$APT = 2 \int_0^\infty \left(\frac{\sigma_c^2 - \sigma_f^2}{\sigma_c^2} \right) d\tau$$

Optimize APT

Find projection of the data that maximizes APT. Solution:

$$\left(2\int_0^\infty \mathbf{\Sigma}_c - \mathbf{\Sigma}_f d\tau\right)\mathbf{q} = \lambda\mathbf{\Sigma}_c\mathbf{q}$$

where $\mathbf{\Sigma}_f$ and $\mathbf{\Sigma}_c$ are the forecast and climatological covariance matrices.

- Eigenvalue λ gives the APT.
- Eigenvectors $\mathbf{q}$ are projection vectors for generating time series.
- Resulting time series are uncorrelated in time.
- Each projection vector is associated with physical pattern $\mathbf{p} = \mathbf{\Sigma}_c\mathbf{q}$.
- Physical pattern $\mathbf{p}$ is called a predictable component.
- Product of $\mathbf{p}$ * (time series), summed over all components, recovers original time series.

Estimating APT With Only One Ensemble Member

- Project data onto M principal components $\mathbf{r}(t)$.
- Construct multivariate linear regression model

$$\mathbf{r}(t+\tau) = \mathbf{L}_\tau \mathbf{r}(t) + \boldsymbol{\epsilon}(t).$$

- Determine forecast variance from standard regression formula

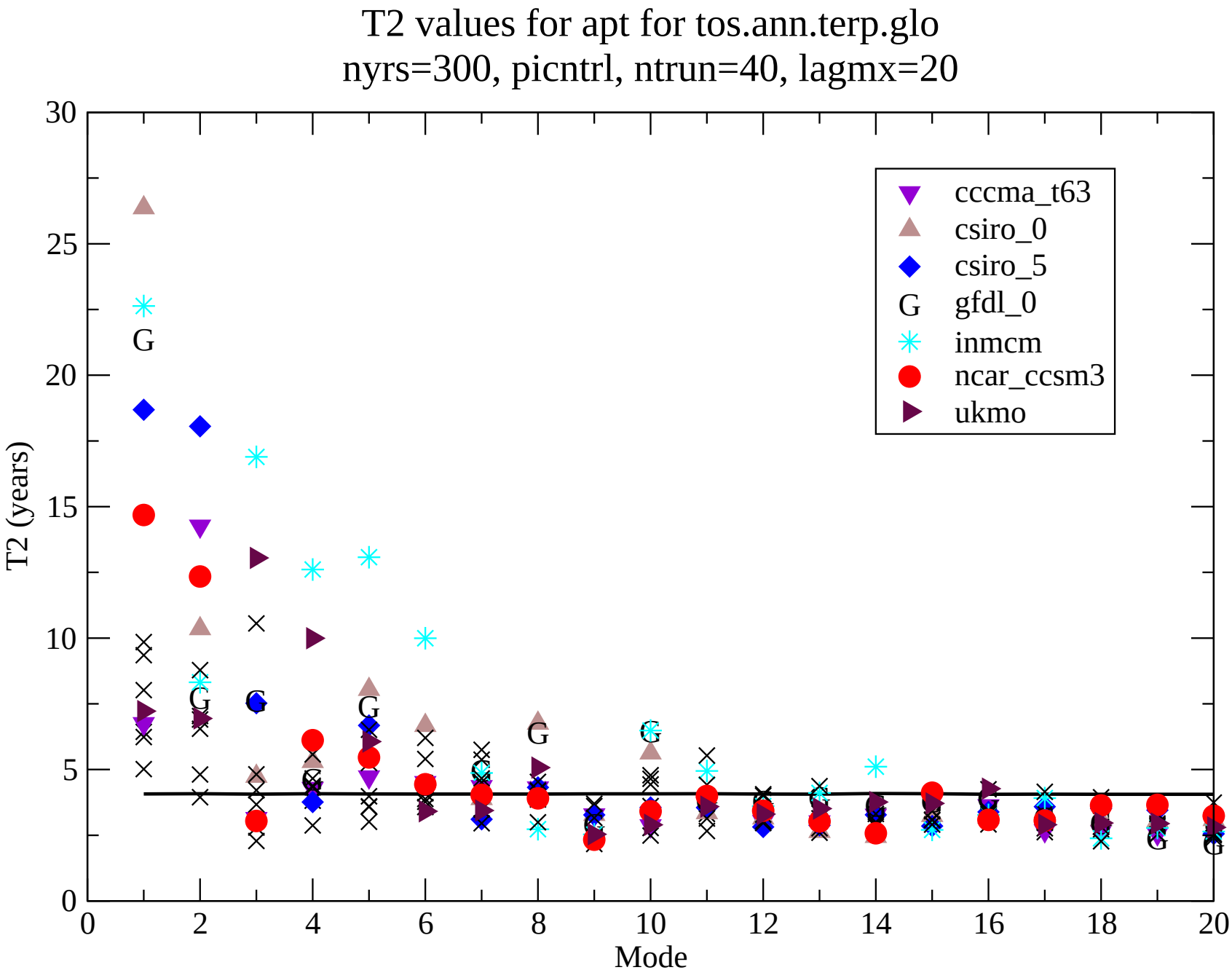
$$\boldsymbol{\Sigma}_f = \boldsymbol{\Sigma}_r - \mathbf{L}_\tau \boldsymbol{\Sigma}_r \mathbf{L}_\tau^T.$$

  where $\boldsymbol{\Sigma}_r$ is the covariance matrix of $\mathbf{r}$.
- Optimize APT using $\boldsymbol{\Sigma}_f$ defined above and $\boldsymbol{\Sigma}_c = \boldsymbol{\Sigma}_r$.
- **Limitations:** May miss non-linear predictability.

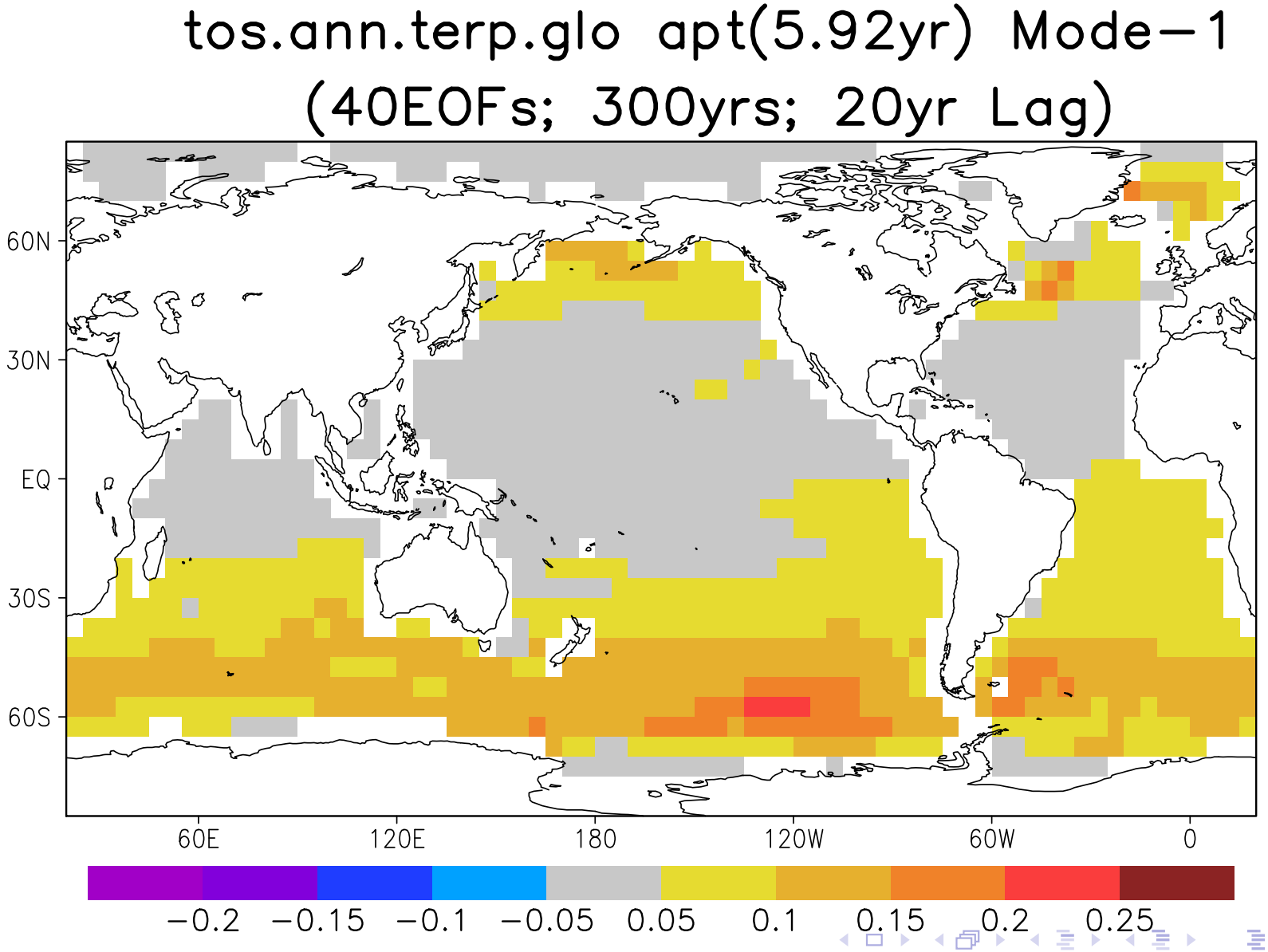
Optimize APT in Unforced Climate Runs

- Last 300 years of PICNTRL are used (13-16 models).
- Model grids interpolated onto HADCRUT3 grid.
- Annual averaged sea surface temperature.
- Each model's climatology subtracted out.
- All runs pooled to compute "total EOF" and "total APT."
- Effective length = 4500 years.
- 40 EOF truncation, 20-year maximum lag for APT.
- IAP, GISS-EH dropped due to significantly different variability.
- No Detrending
- Test hypothesis that time series is white noise when sampled every 2 years (use Monte Carlo to estimate sampling distribution of APT).

APT Values for Individual Models



Leading Predictable Component (The "Global Multidecadal Oscillation")



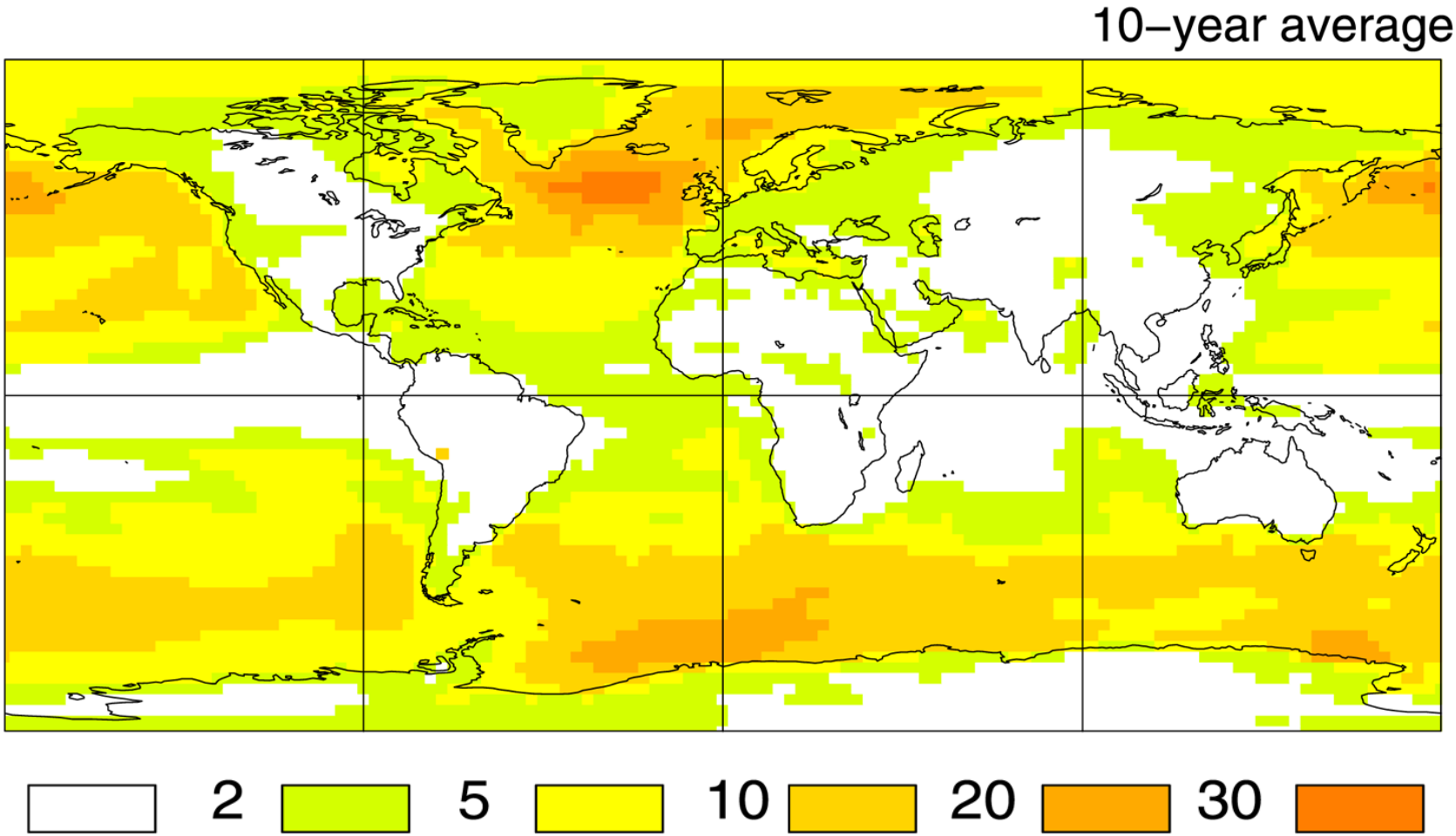
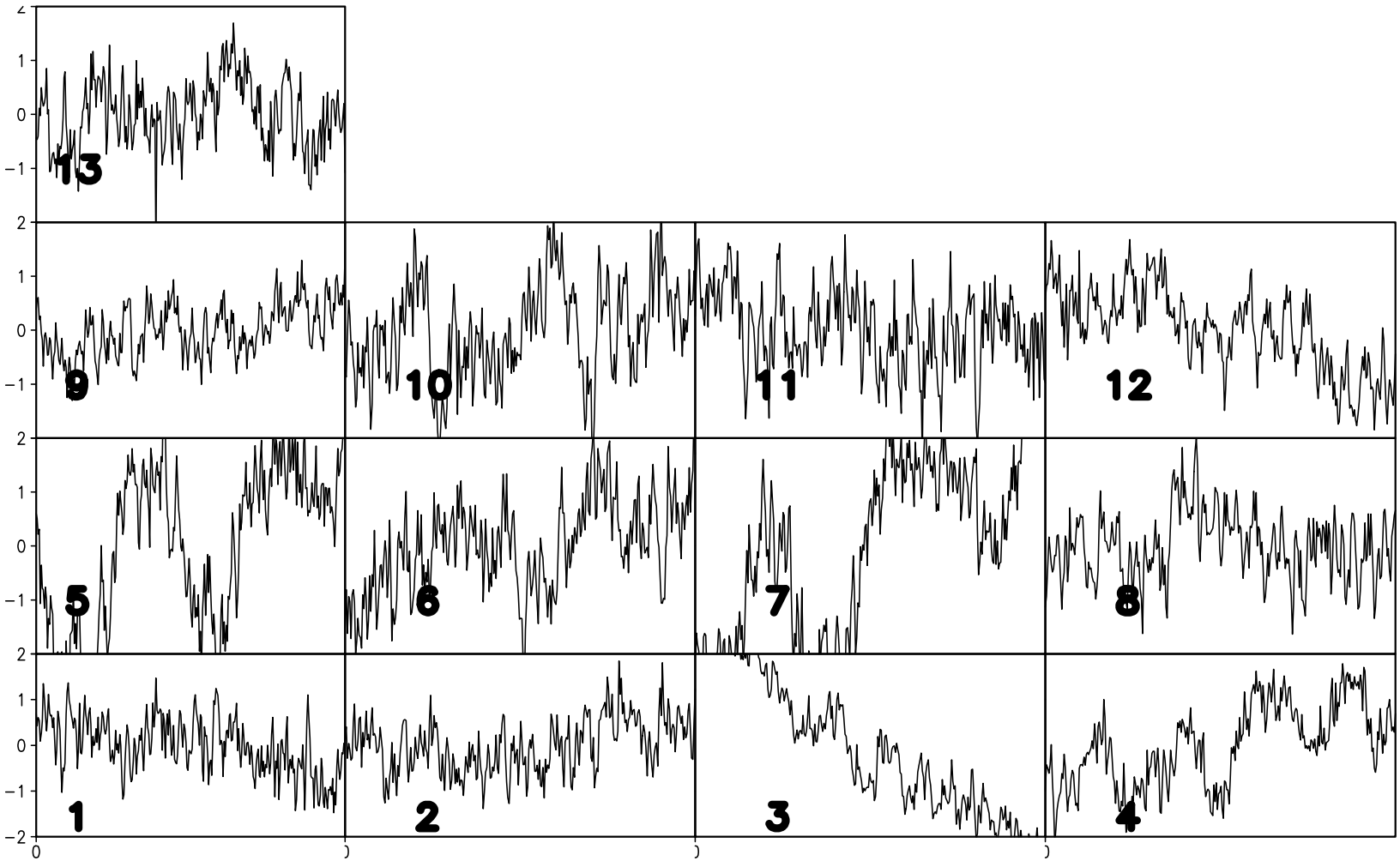


Figure: Estimated percentage of variance of 10-year mean temperature that is potentially predictable (Boer and Lambert 2008).

Leading Predictable Component

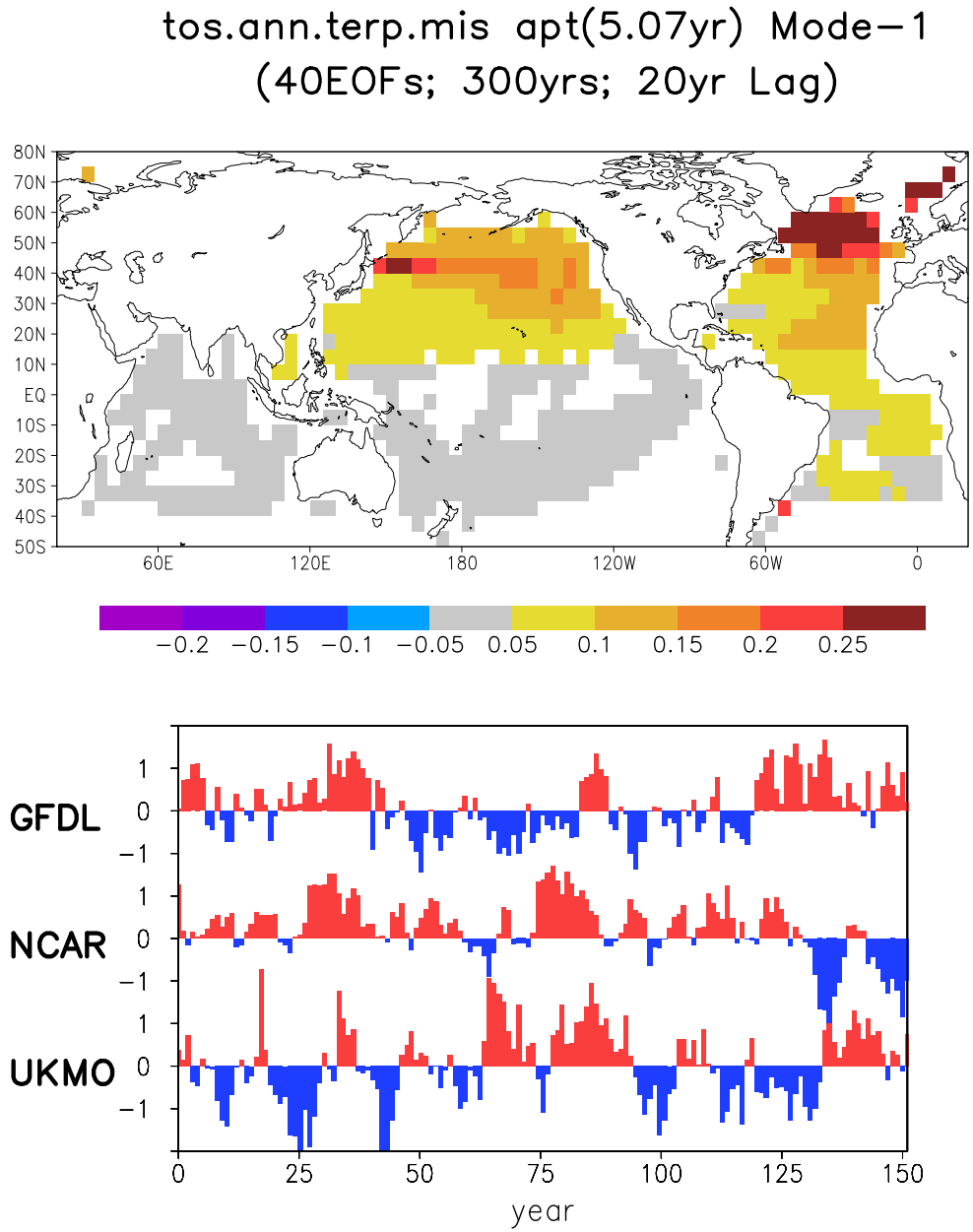


Horizontal axes: time (0-300 years); Vertical axes: amplitude (-2,2)

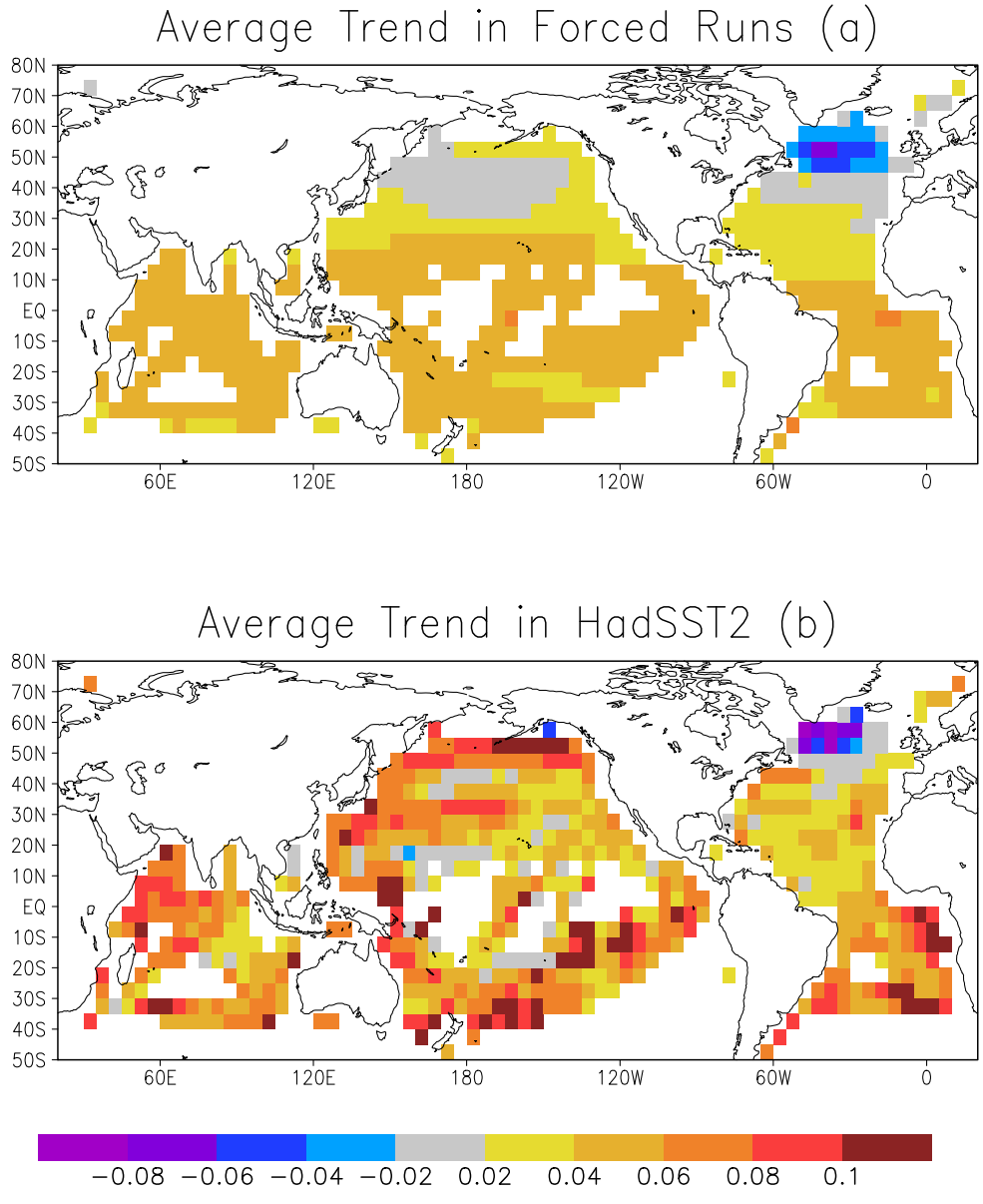
Models and the APT of the Most Predictable Component

Index	Model	APT-1D
1	cccma_cgcm3_1	6.4
2	cccma_cgcm3_1_t63	6.7
3	csiro_mk3_0	26.4
4	csiro_mk3_5	18.7
5	gfdl_cm2_0	21.3
6	gfdl_cm2_1	9.8
7	inmcm3_0	22.6
8	ipsl_cm4	6.2
9	miroc3_2_medres	8
10	miub_echo_g	9.3
11	mri_cgcm2_3_2a	5
12	ncar_ccsm3_0	14.7
13	ukmo_hadcm3	7.2

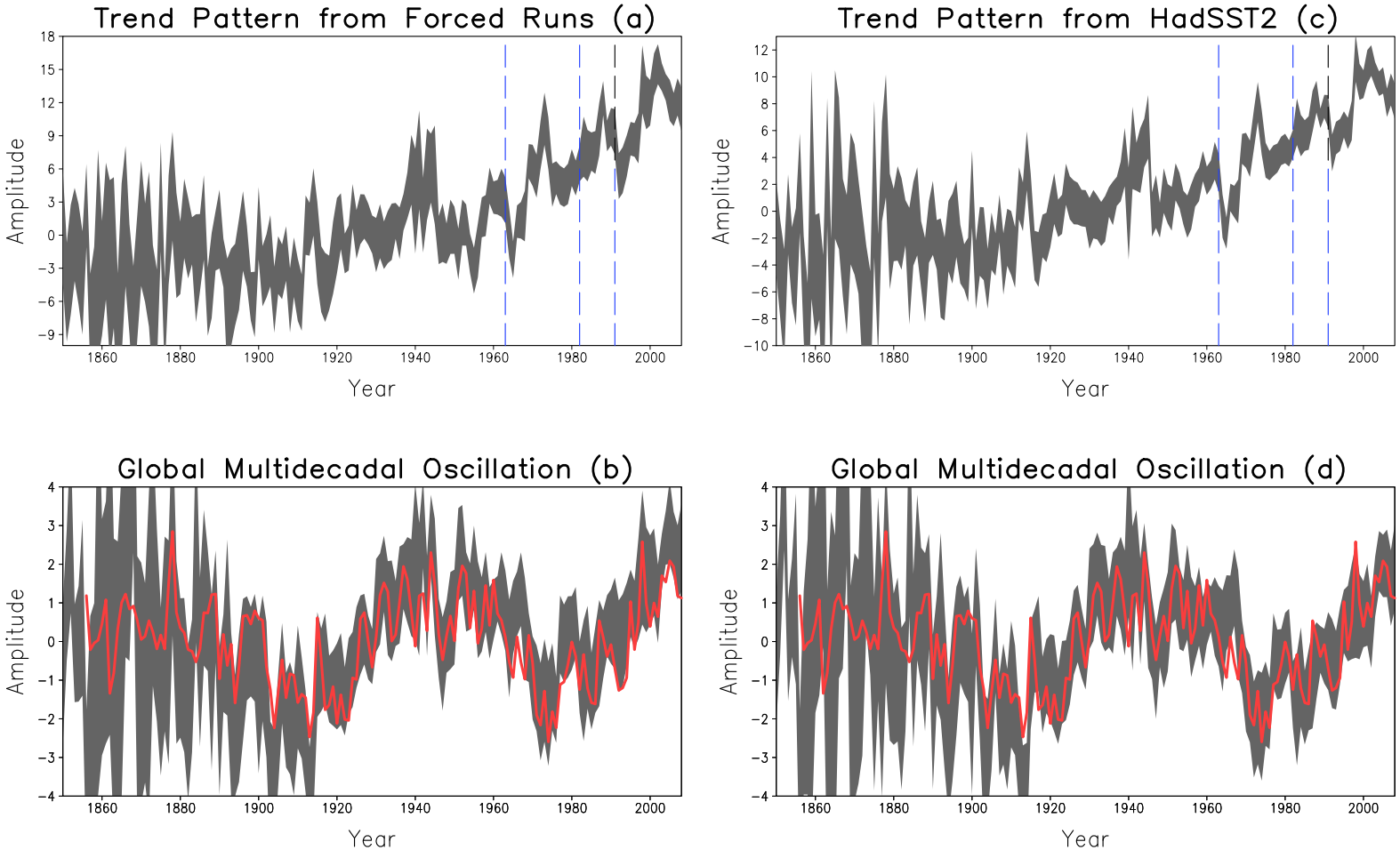
Optimize APT on "Well-Observed" Grid



Estimates of the Forced Response



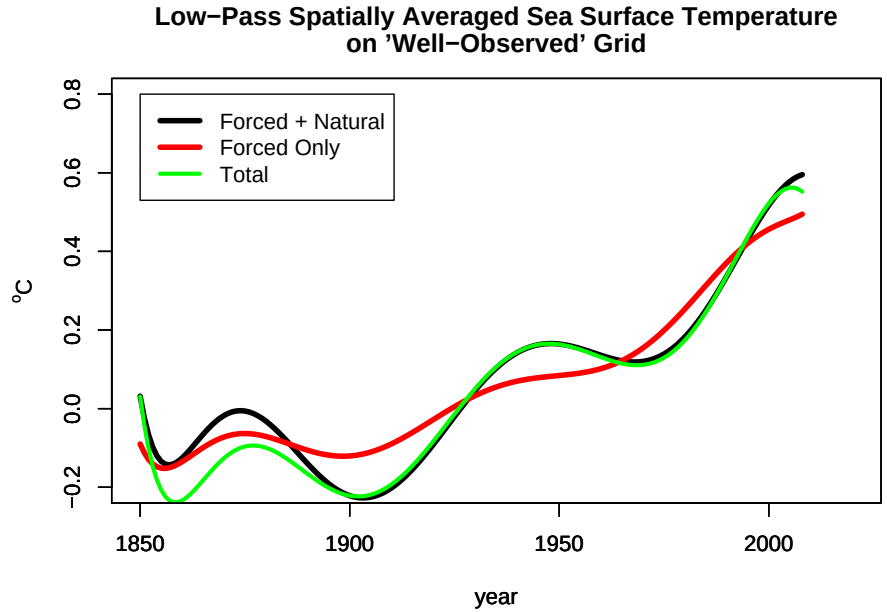
Fingerprint Analysis

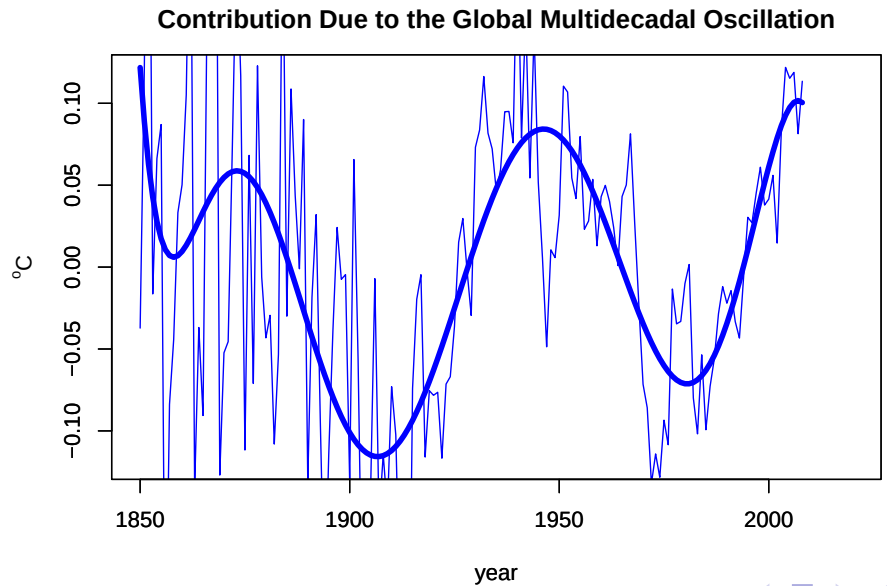


red curves: annual average Atlantic Multidecadal Oscillation Index

blue lines: Mt. Agung (1961), El Chichon (1982), Mt. Pinatubo (1991)

Global Average Temperature





Summary

- We have introduced a new method for seamlessly diagnosing predictability on multiple time scales.
- The most predictable component in the IPCC-control runs (the "GMO") is statistically significant in all models.
- The GMO is of single sign and global in spatial extent.
- Decomposing observed SST into forced and GMO components:

  Forced component: multidecadal trend plus volcanic cooling.
  GMO component: strongly correlated with AMO.
- GMO component explains 0.1° fluctuations in low-pass, global average SST (on "well observed grid"), including
  - all the cooling between 1940-1970.
  - half of the warming in the past 25 years.
- The GMO component is currently at a peak and may decay in the next 20 years, leading to little or no warming in the next 20 years.