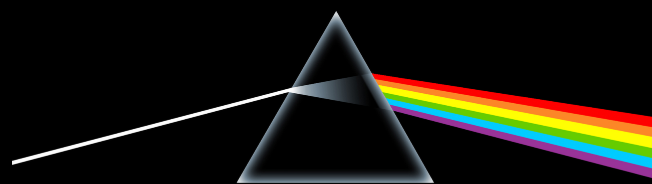
Timescales of variability discussion

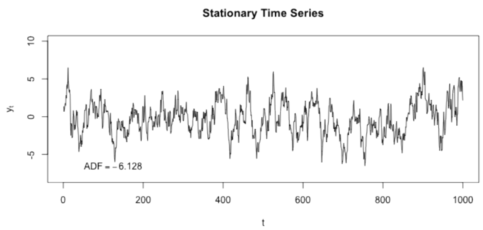


Stochastic process?

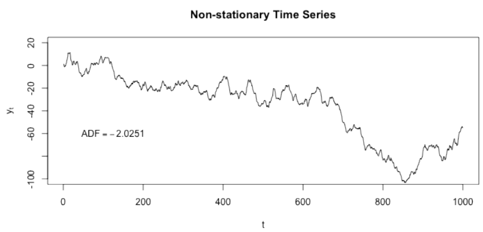
Randomly changing over time (at least in part)…..
(Probability distribution of time series)

Stationary process?

Statistics (e.g., mean and variance) don't change over time



Stationary

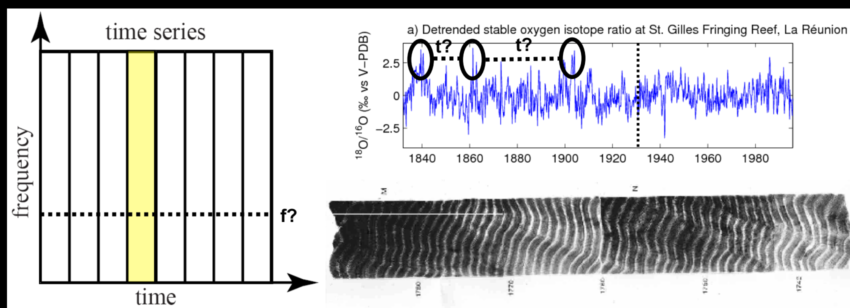


Non-Stationary

What are red, white and blue spectra?

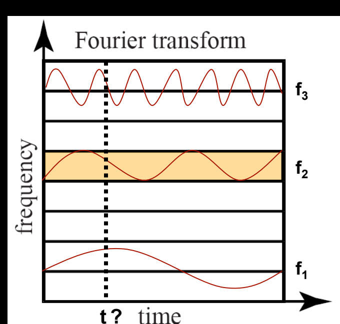
Spectral analysis

The time series

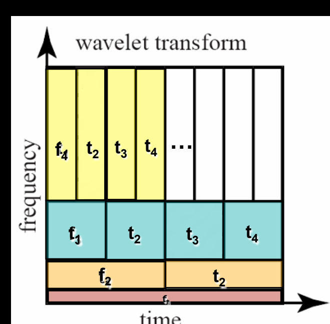


Günther, EuroLabCourse, Florence 2001

Spectral analysis

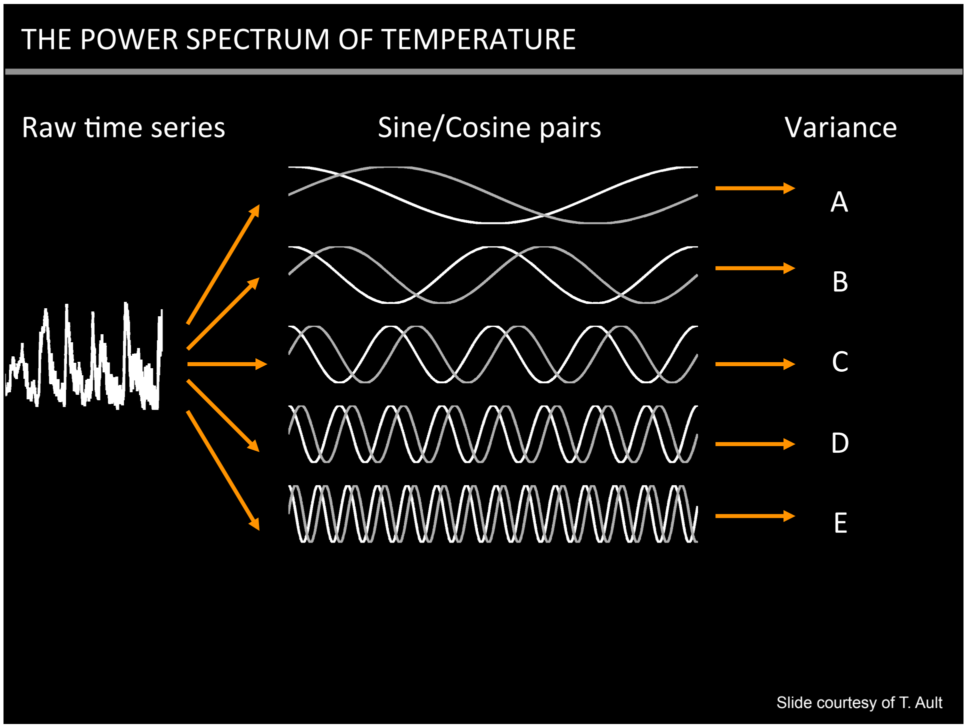


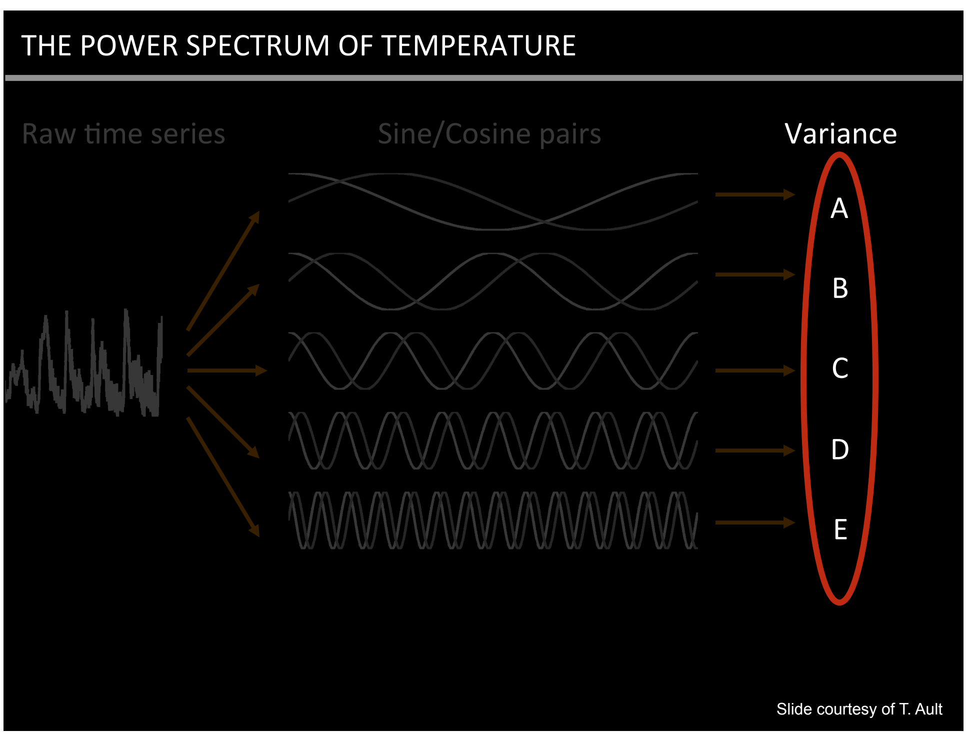
The Fourier Transform



The Wavelet Transform

Günther, EuroLabCourse, Florence 2001


THE POWER SPECTRUM OF TEMPERATURE
Raw time series
Sine/Cosine pairs
Variance
A
B
C
D
E
Slide courtesy of T. Ault


THE POWER SPECTRUM OF TEMPERATURE
Raw time series
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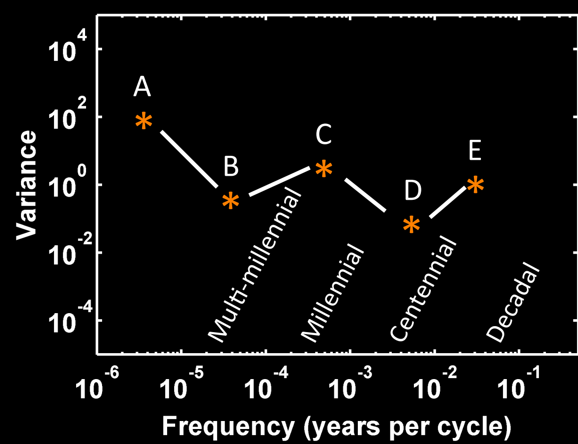
THE POWER SPECTRUM OF TEMPERATURE



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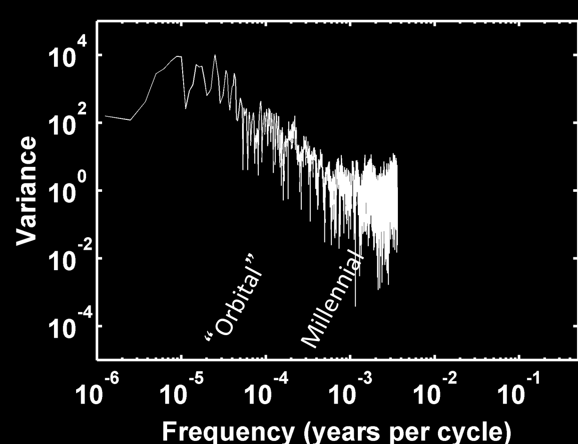
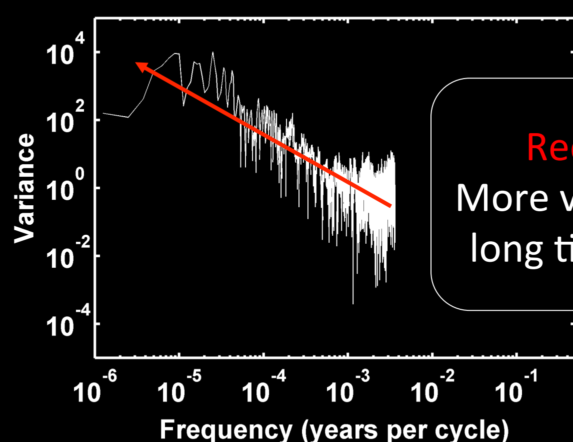
THE POWER SPECTRUM OF TEMPERATURE



Slide courtesy of T. Ault

What are red, white and blue spectra?

THE POWER SPECTRUM OF TEMPERATURE



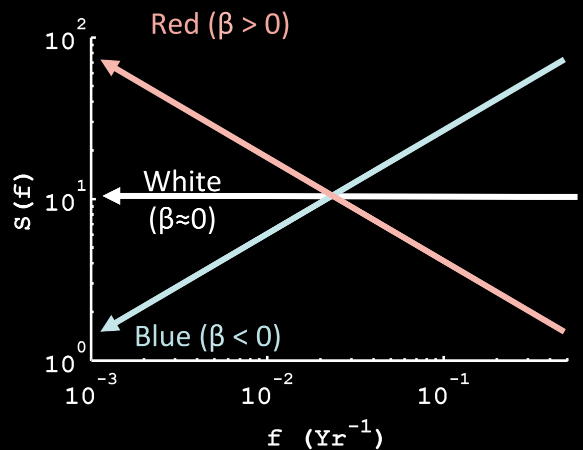
Redness:
More variance at long timescales

Slide courtesy of T. Ault

Power-Law

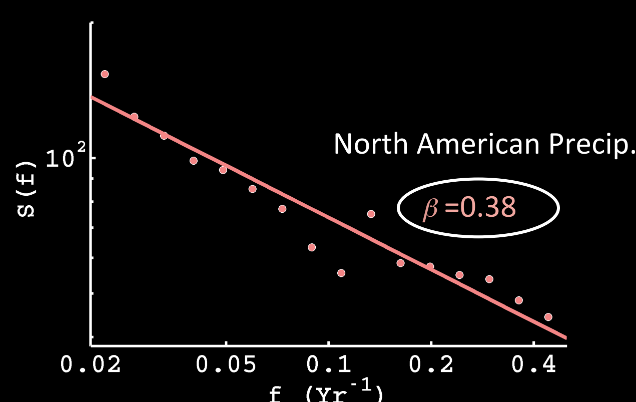
Power-Law (β):

$S(f) \propto f^{(-\beta)}$



Slide courtesy of T. Ault

OBSERVATIONAL POWER-LAWS



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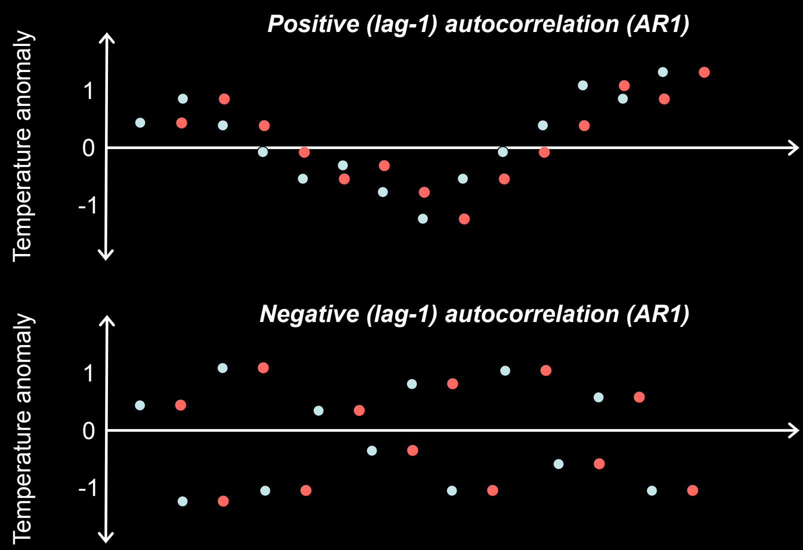
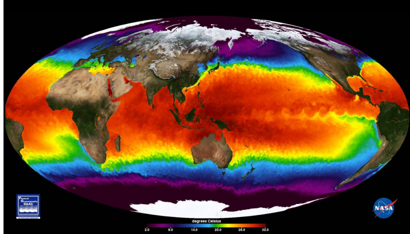
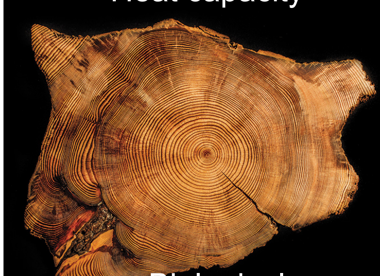
Autocorrelation



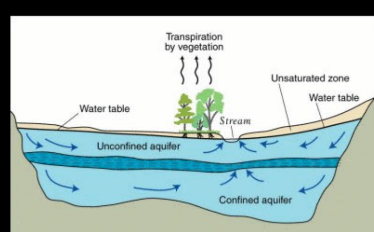
Sources of “redness”, “memory” or autocorrelation in nature?

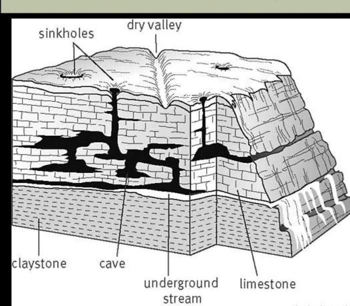


Heat capacity



Biological



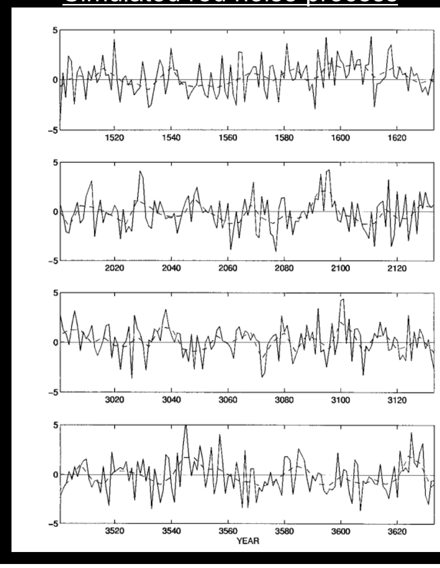


Storage/ signal integration e.g. Soil moisture (top) & Karst processes (bottom)

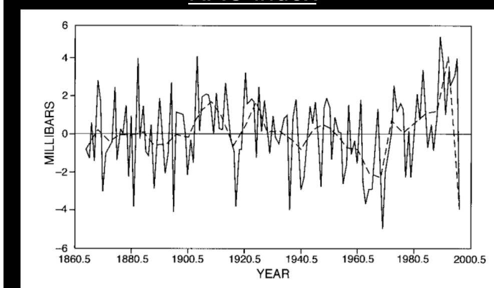
Implications for interpreting climate signals?

1. Regime shifts?

Simulated red noise process



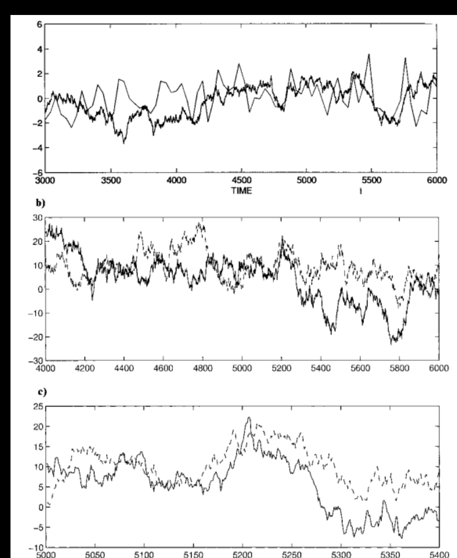
NAO index



Wunch 1999

Implications for interpreting climate signals?

2. Visual correlations?



Wunch 1999

Impact of record length?

For systems with long memory, larger deviations from the mean ***are expected*** as the record length grows

"***Short*** records of processes that are even ***slightly reddish*** in spectral character can easily lead to ***unwarranted, and incorrect, inferences*** if simple stochastic superposition is confused with deterministic causes….Sometimes there is no alternative to uncertainty except to await arrival of ***more and better data***."

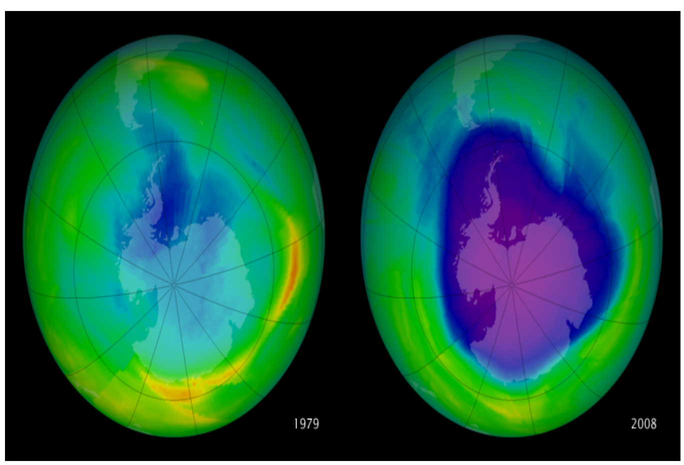
Wunch 1999

Deser et al. 2012…

- But first– a couple of model design questions!

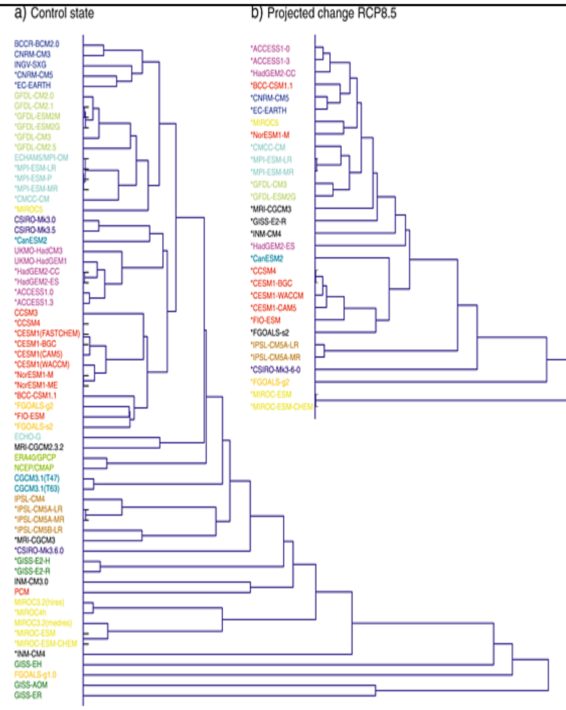
Is the ozone actually going to recover?

- Model has stratospheric ozone recovery by 2060
- Realistic?? See GFDL animation here



“Each ensemble member’s epoch difference (or trend) values are assumed to be independent”

Based on the history of climate models, is this a valid assumption??



What is EOF analysis??

- Empirical orthogonal function analysis
- Field is partitioned in to independent (orthogonal) modes (EOFs/eigenvectors) that explain the variance of the dataset
- Principal components (PCs): time series of the modes
- Eigenvalues: % variance explained by each PC

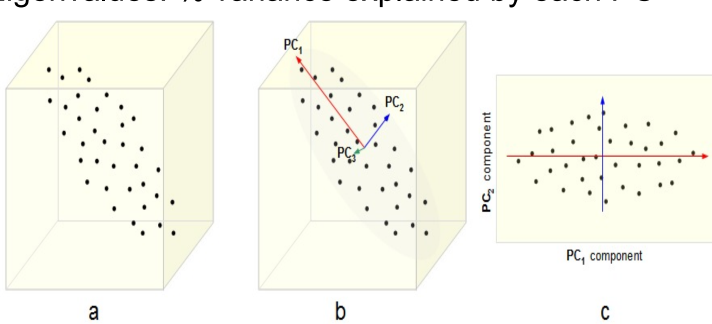
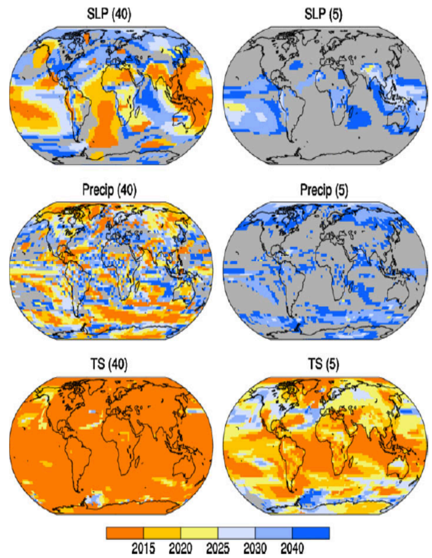
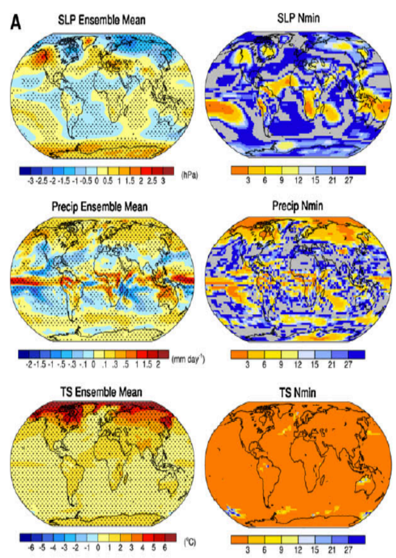


Fig. 3 Decade when the ensemble mean change relative to the period 2005–2014 first becomes detectable at the 95% significance level for an ensemble size of 40 (*left*) and 5 (*right*), based on annual averages subject to a 10-year running mean for SLP (*top*), Precip (*middle*) and TS (*bottom*). Year indicated denotes the mid-point of the 10-year period. *Gray areas* indicate locations where the ensemble mean response is not significant at the 95% confidence level



Why can temperature changes be detected sooner (and with fewer models) than precip or SLP changes?

Fig. 1 **a** (*Left*) CCSM3 40-member ensemble mean epoch differences (2051–2060 minus 2005–2014) in DJF for (*top*) SLP, (*middle*) Precip and (*bottom*) TS. *Stippling* indicates where the ensemble mean response is statistically significant at the 95% confidence level relative to the spread amongst the ensemble members. (*Right*) minimum number of ensemble members needed to detect a significant epoch difference response. *Gray areas* indicate locations where the 40-member ensemble mean response is not significant at the 95% confidence level. **b** As is in **a** but for JJA



Why can temperature changes be detected sooner (and with fewer models) than precip or SLP changes?

Signal to noise!

Fig. 4 Time series of annual mean (*left*) TS and (*right*) Precip anomalies averaged over the (*top*) globe, (*middle*) land and (*bottom*) ocean for the 40-member ensemble mean (*thick black curve*) and the first 10 ensemble members (*thin colored curves*). The *green shaded curve* shows the minimum number of ensemble members needed to detect a 95% significant change relative to 2005 as a function of time

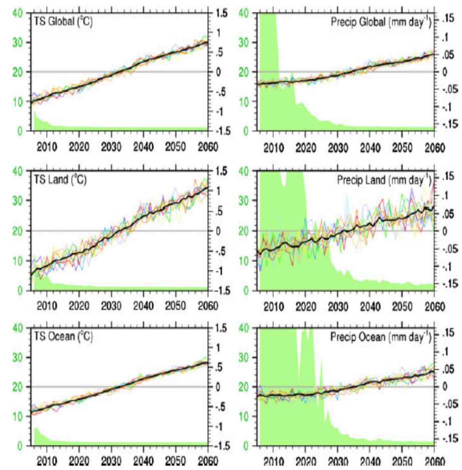
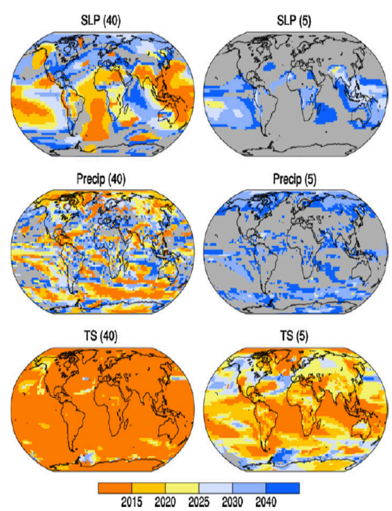


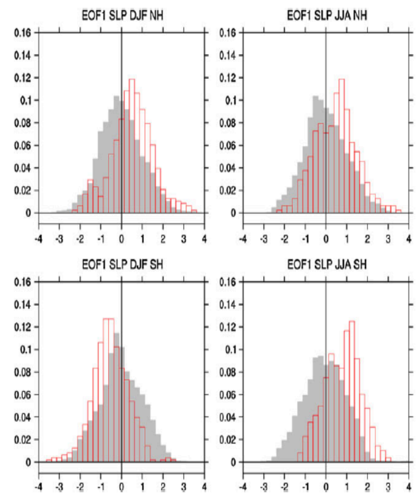
Fig. 3 Decade when the ensemble mean change relative to the period 2005–2014 first becomes detectable at the 95% significance level for an ensemble size of 40 (*left*) and 5 (*right*), based on annual averages subject to a 10-year running mean for SLP (*top*), Precip (*middle*) and TS (*bottom*). Year indicated denotes the mid-point of the 10-year period. *Gray areas* indicate locations where the ensemble mean response is not significant at the 95% confidence level



Why is the detection year different with a different number of ensemble members (40 vs 5)?

What does the comparison of CCSM3 and CAM3 (control) trend projections histogram tell us?

Fig. 11 Histograms of the SLP 2005–2060 trend projections onto EOF1 from the CAM3 control integration for the (*top*) NH and (*bottom*) SH in (*left*) DJF and (*right*) JJA. The *red open bars* show results from the 40-member CCSM3 and the *grey filled bars* from the 178-member CAM3 control. The *x* axis is in units of standard deviations of the CAM3 control integration, and the *y* axis is frequency (number of ensemble members divided by the total number of ensemble members)



Does CESM capture the correct range of variability? Spatial pattern?

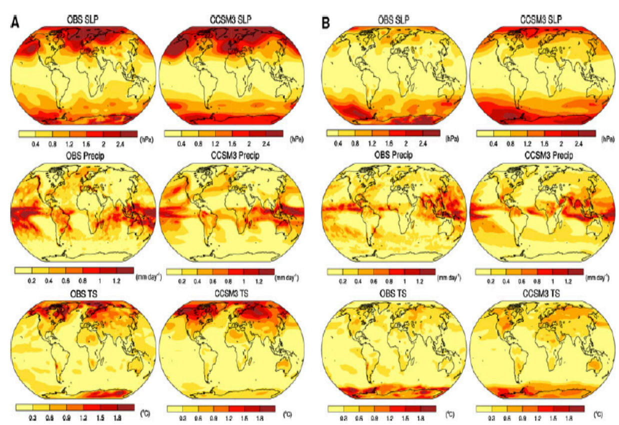


Fig. 16 **a** Standard deviation maps of 8-year low-pass filtered SLP (*top*), Precip (*middle*) and TS (*bottom*) anomalies in DJF from observations (*left*) and the 40-member CCSM3 ensemble (*right*). For observations, the linear trend over the period 1979–2008 was removed from each ensemble member at each time step, and the standard deviations averaged across the 40 ensemble members. SLP and TS observations are from the NCEP/NCAR Reanalysis, and Precip observations are from the Global Precipitation Climatology

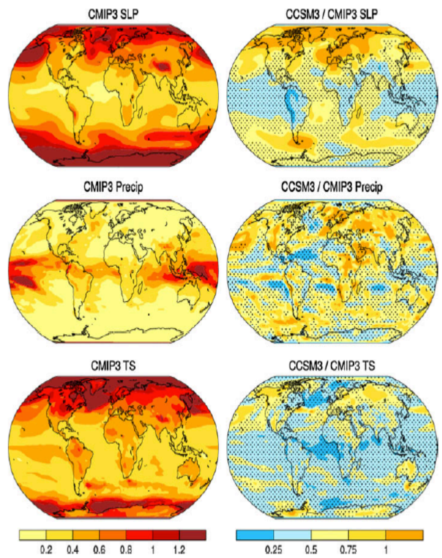


Fig. 17 (*Left*) Trend standard deviation maps from the 21-member CMIP3 ensemble and (*right*) the ratio of the trend standard deviations from the 40-member CCSM3 ensemble and the 21-member CMIP3 ensemble, based on annually-averaged data for (*top*) SLP, (*middle*) Precip, and (*bottom*) TS. Trends are computed over the period 2005–2060 for both model ensembles. *Stippling* indicates where the ratios are significantly different from one at the 95% confidence level. Units for the plots in the left column are hPa 56 $year^{-1}$ (SLP), mm day^{-1} 56 $year^{-1}$ (Precip), and °C 56 $year^{-1}$ (TS)

Where is internal variability most important (relative to model spread)?

What are the take-home messages?

- What are the implications of their conclusions for detection & attribution studies of climate change?
- If we were the committee discussing CMIP6 design, what would we recommend each modeling center to contribute?
- If we were to analyze global temperature trends, what types of ensembles might we use? Precip? SLP? How many ensemble members are needed for each?
- Do you think we have enough ensemble members to accurately sample the actual distribution?