Decadal Multi-Model Potential Predictability

G.J. Boer
Canadian Centre for Climate Modelling and Analysis
Environment Canada
University of Victoria

Predictability approaches

- *Classical predictability*

  - feature of the physical system

  - measures the rate of separation of initially close states

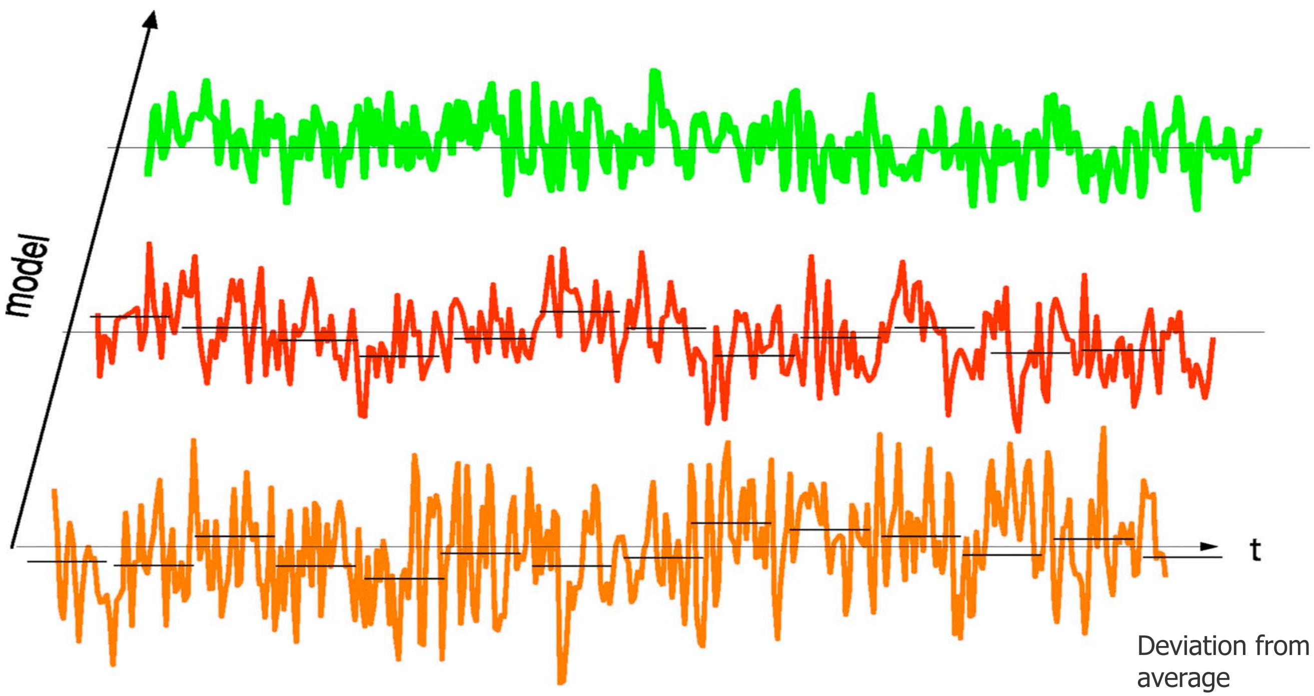
- *Potential* predictability

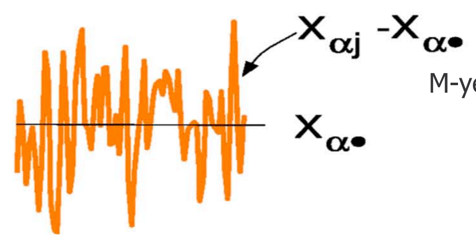
  - looks for the existence of deterministic long timescale variability

  - presumes this variability is "potentially" predictable with enough knowledge

  -location and nature of the potential predictability should suggest mechanisms and processes

Internally generated long timescale variability





$$X(t) = X_{\alpha\bullet} + (X_{\alpha j} - X_{\alpha\bullet})$$

$$S^2 = S_\nu^2 + S_\varepsilon^2$$

Statistical model

- Statistical model is

$$X = \Omega + \nu + \varepsilon$$

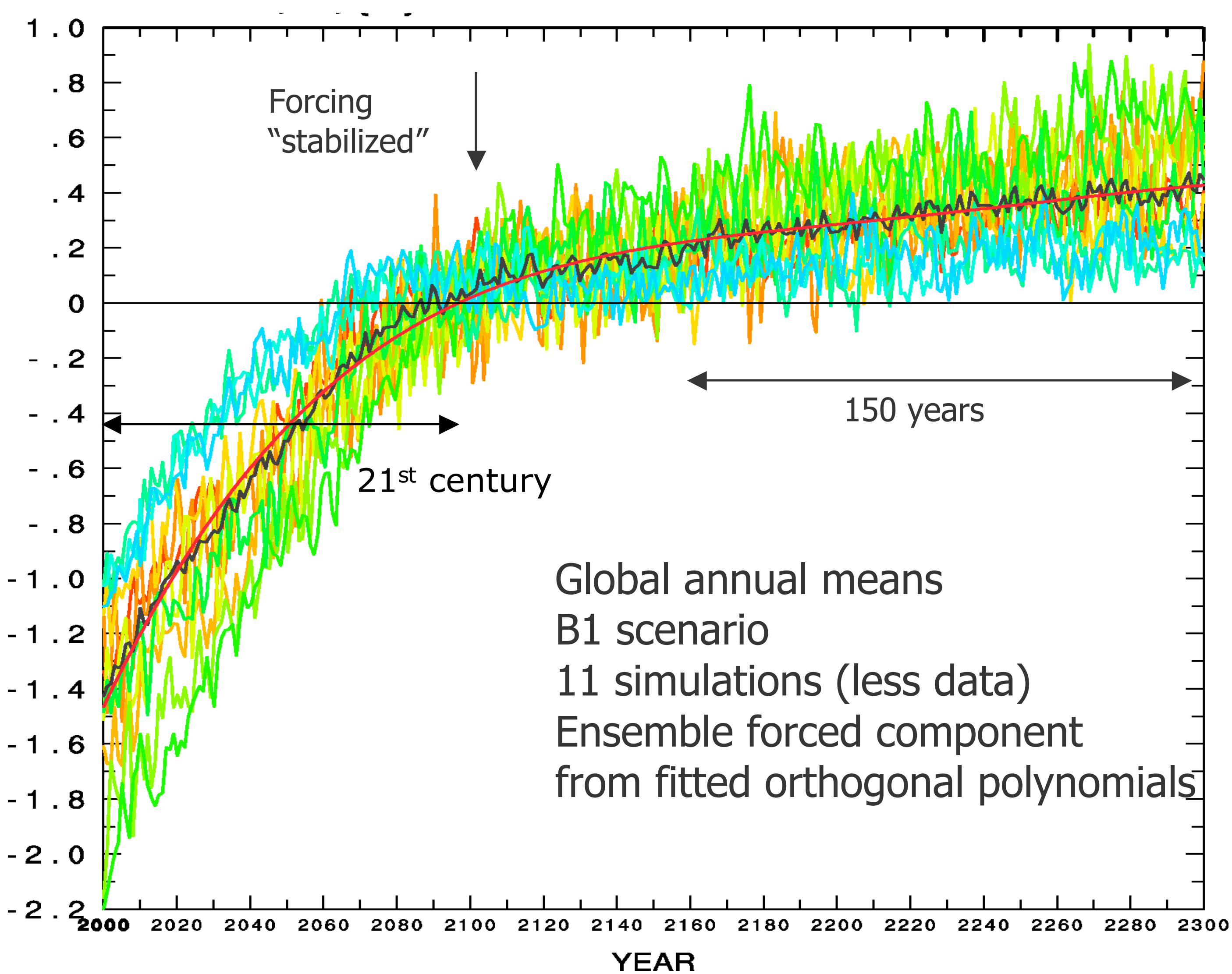
with associated variances

$$\sigma^2 = \sigma^2_\Omega + \sigma^2_\nu + \sigma^2_\varepsilon$$

  - Ω is long timescale *externally forced* variability (if present)
  - ν is long timescale *internally generated* variability
  - ε is short timescale *unpredictable "noise"* variability
- Potential predictability variance fraction is

$$p = (\sigma^2_\Omega + \sigma^2_\nu)/\sigma^2 = p_\Omega + p_\nu$$

Forced and internally generated variability



Approach

- Need suitable statistical tests and approaches
- Require lots of “observations” for statistical confidence
- Aim for geographic distribution of the *potential predictability variance fractions* (ppvf)
- We take a *multi-model ensemble approach* using CMIP3 data (IPCC AR4)

Statistics

$$X_i = X_{(\alpha-1)M+j} = X_{\alpha j}$$

i = 1 …. NM
α = 1 …. N
j = 1 …. M

$$X_{\alpha j} = P_\alpha + (X_{\alpha\bullet} - P_\alpha) + (X_{\alpha\bullet} - X_{\alpha j})$$

$$X_{\alpha\bullet} = \frac{1}{M}\sum_{j=1}^{M} X_{\alpha j}$$

is M-year average

$$S^2 = S_\Omega^2 + S_\nu^2 + S_\varepsilon^2 = \overline{X^2}$$

$$= \overline{P_\alpha^2} + \overline{(X_{\alpha\bullet} - P_\alpha)^2} + \overline{(X_{\alpha\bullet} - X_{\alpha j})^2}$$

$$P_\alpha = \sum_{k=1}^{K} a_k p_k(\alpha)$$

is orthogonal polynomial fit

Long TS forced (if present)

Long TS internally generated

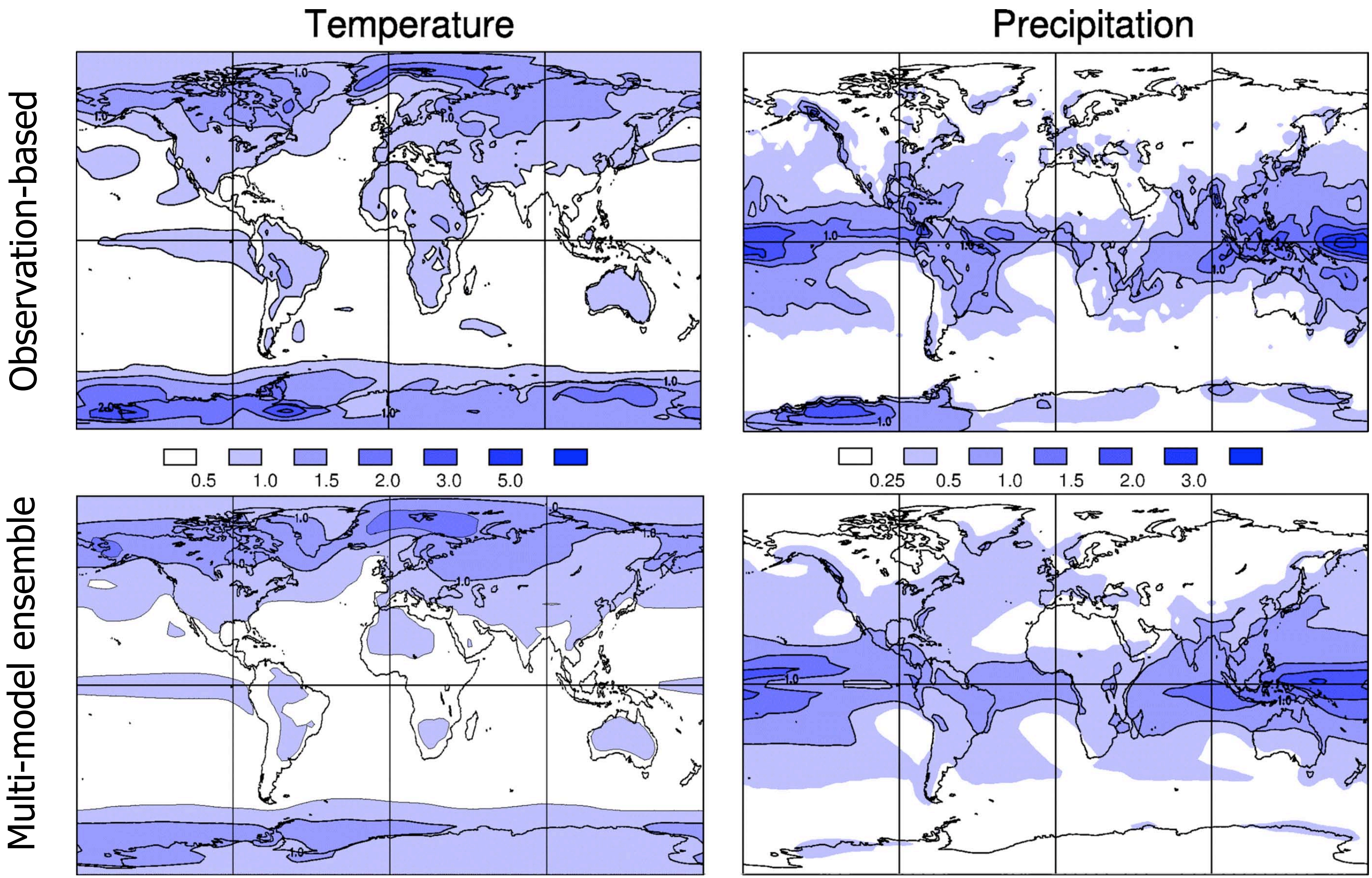
Short TS noise

Statistics are pooled across models in multi-model case

Apply to CMIP3 control climates

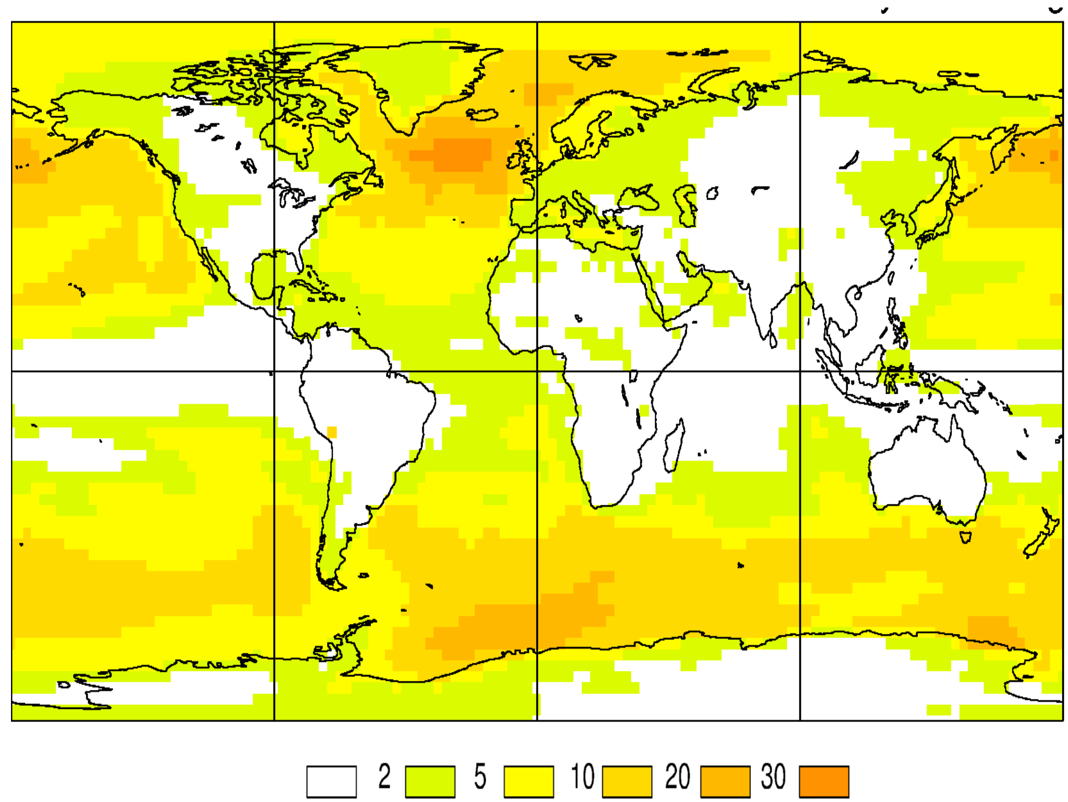
- (intended to be) equilibrium climate
- no external forcing – we consider the *internally generated* variability
- Potential predictability:
  - measured as *fraction of variance* $p_\nu = \sigma^2_\nu / \sigma^2$
  - indication of *relative importance*
  - expect low p_ν where σ^2_ν is low ***or*** σ^2 high
- results from 27 models
- simulations lengths from 100 to 1000 years
- we consider surface air temperature and precipitation (the two main climate parameters)
- measures potential predictability in the *model world*

Standard Deviation of annual means



Temperature: potential predictability variance fraction $p_\nu = \sigma^2_\nu/\sigma^2$ (%) for *decadal means*

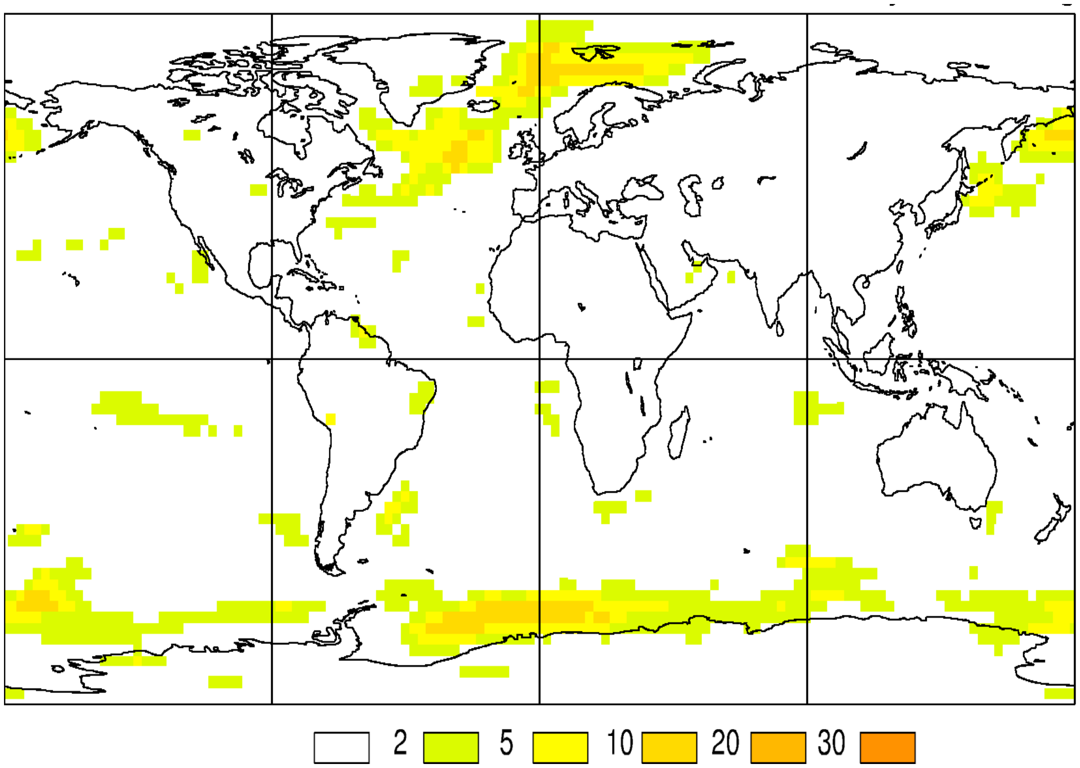
- Ratio of "predictable" to total variance
- MME provides stability of statistics: *ppvf* in white areas <2% and/or not significant at 98% level
- Long timescale predictability found mainly over oceans
- Some incursion into land areas but modest *ppvf* (*denominator* is large)



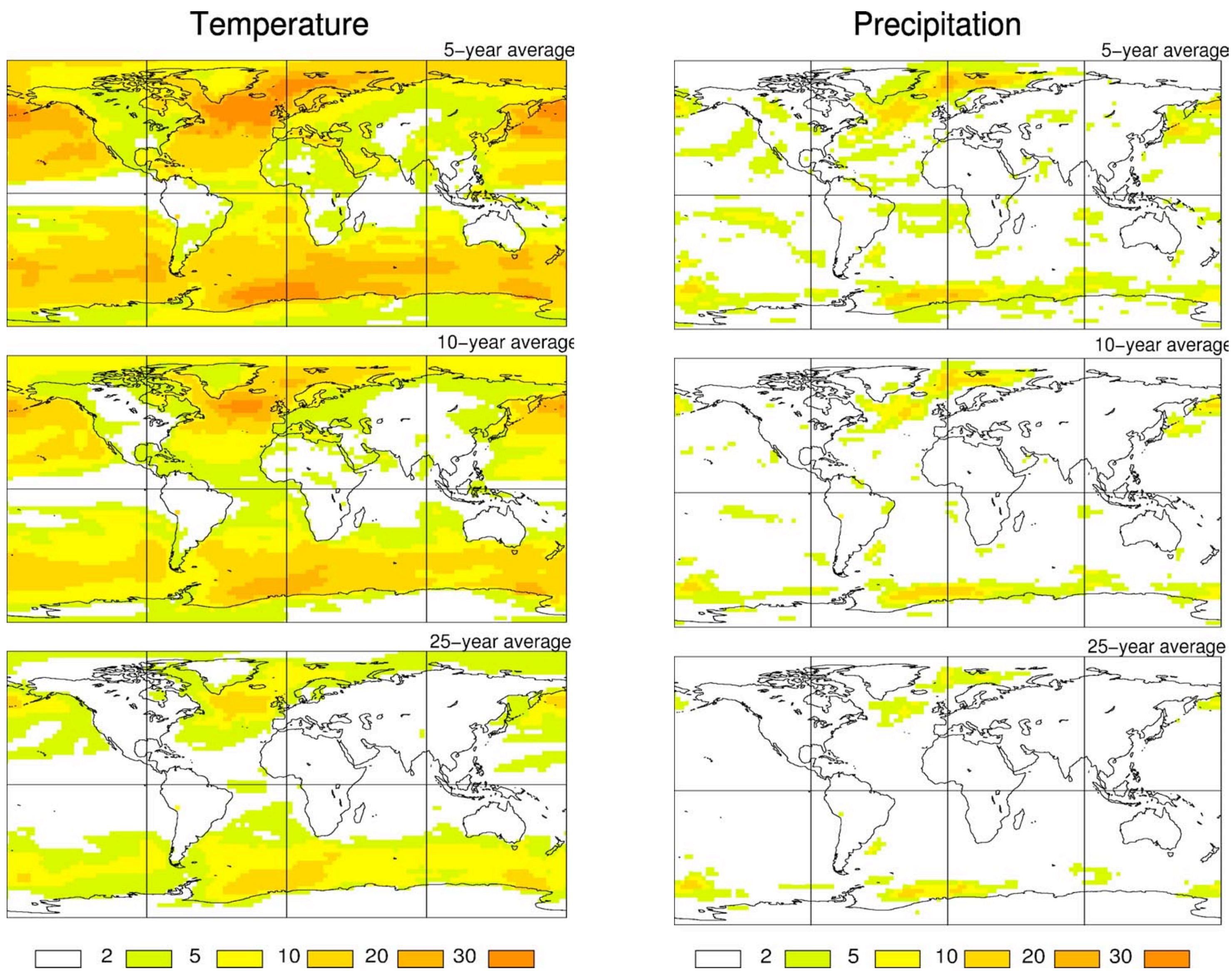
Control simulations

Precipitation: potential predictability variance fraction $p_\nu = \sigma^2_\nu/\sigma^2$ (%) for decadal means

-MME provides "some" significant areas of precipitation
-Much less potentially predictable than temperature
- Little incursion into land areas
- Precipitation predictability a weakened version of temperature predictability at these timescales



Control simulations

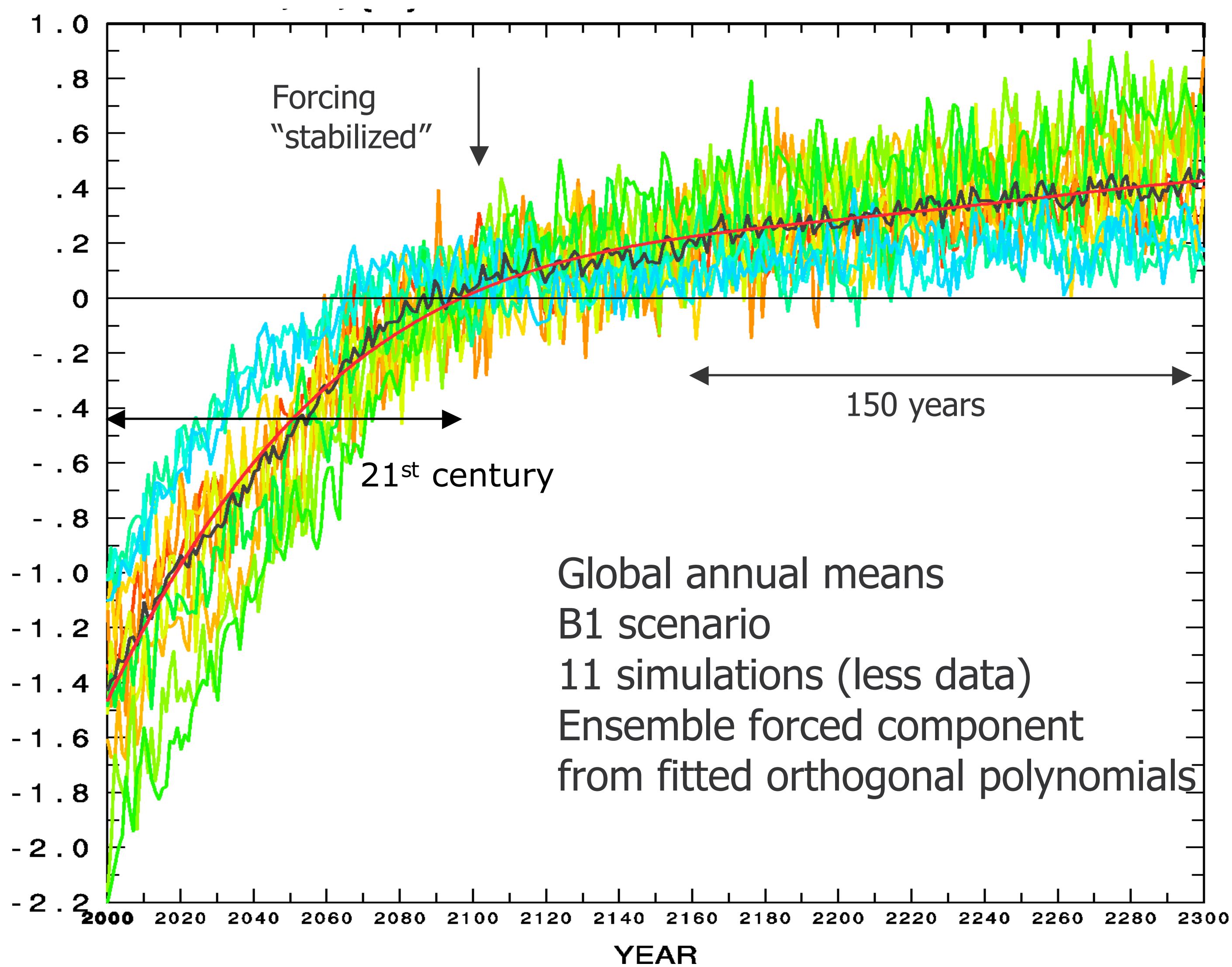


Proposed experiment allows us to consider also “pentades

21^{st} Century potential predictability of forced and internal decadal variability

- B1 Scenario
- period is from 2000 to 2100
- CMIP3 multi-model approach
- only 11 simulations for full data period (up to 2300)
- initial illustrative calculation of variance components

Forced and internally generated variability



Variances

- $X_{ij} = W_{ij} + x_{ij}$
  - i is decade number and j year within it
  - W_{ij} is representation of *forced component* from polynomial fit
  - x_{ij} is variation about forced component
- $Y_{ij} = W_{i}. + x_{i}. + (x_{ij} - x_{i}.)$
  - $W_{i}. + x_{i}.$ are contributions to decadal potentially predictable variance from forced and internal variability
  - $(x_{ij} - x_{i}.)$ is noise

Multi-model ensemble approach

- potential predictability without the statistics (i.e. approximate)
- $\{Y^2\} = \{W_i.^2\} + \{x_i.^2\} + \{(x_{ij} - x_i.)^2\}$

  forced internal noise
  - { } is average over j and over ensemble
- Variance fractions for each decade

  $p_F = \{W_i.^2\} / \{Y^2\}$

  $p_I = \{x_i.^2\} / \{Y^2\}$

  $p = p_F + p_I$
- forced component dominates for longer prediction times

Predicting for the next decade

- $Z_{ij} = (W_{i}. - W_{i-1}.\ ) + x_{i}. + (x_{ij} - x_{i}.)$
  - take the decadal *change* in forced component to be the forecast information for the next decade
- $\{Z^2\} = \{(W_{i}. - W_{i-1}.\ )^2\} + \{x_{i}.^2\} + \{(x_{ij} - x_{i}.)^2\}$

- Variance fractions each decade

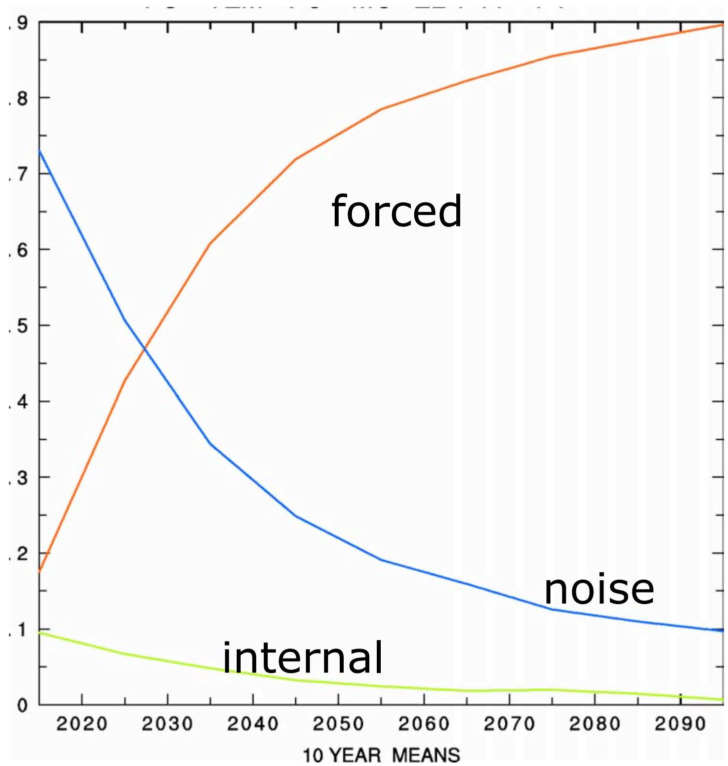
$p_F = \{(W_{i}. - W_{i-1}.\ )^2\} / \{Z^2\}$

$p_I = \{x_{i}.^2\} / \{Z^2\}$

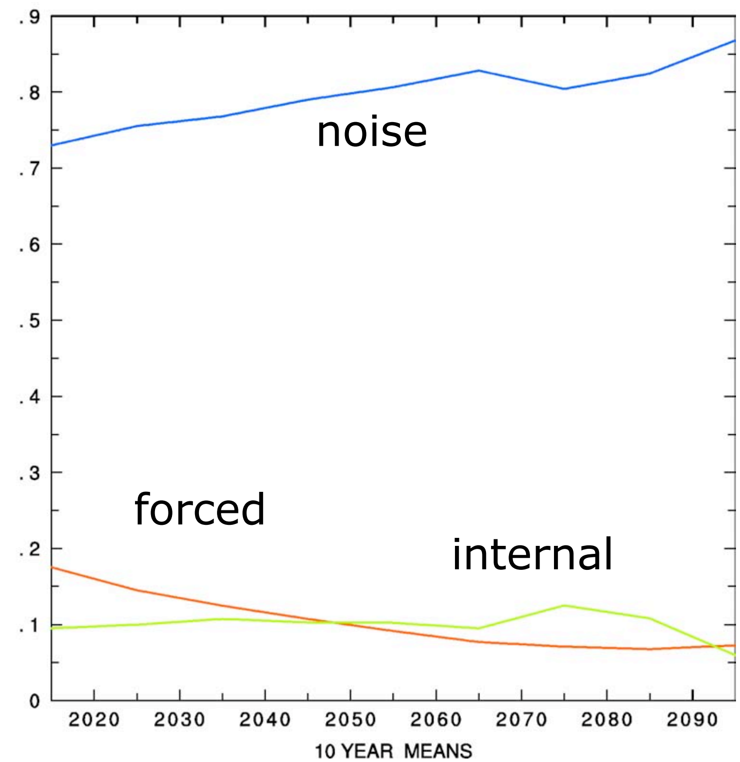
$p = p_F + p_I$

Decadal variance *fractions*: Temperature

Multi-decade from end of 20th century

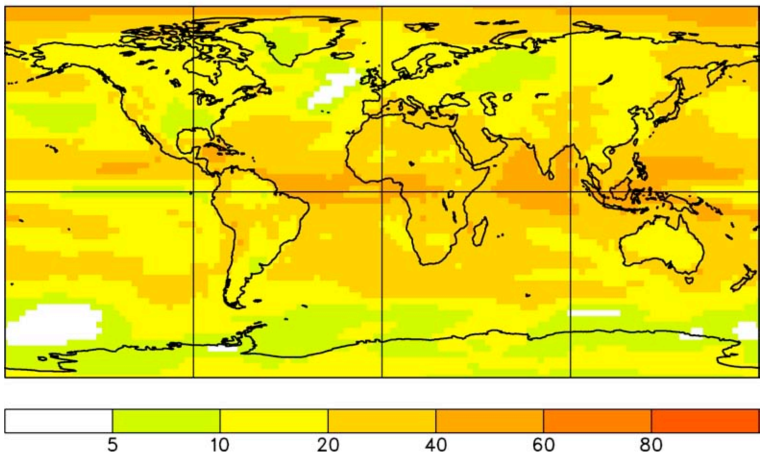


Next decade within the 21st century

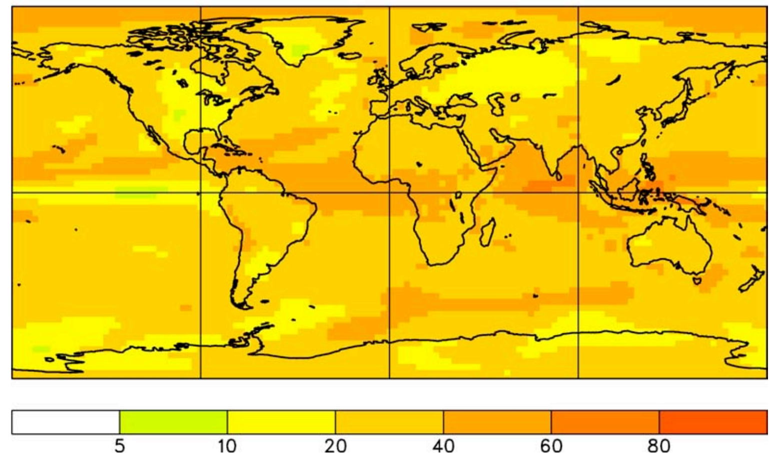


Variance fractions for decade 2010-2020: Temperature

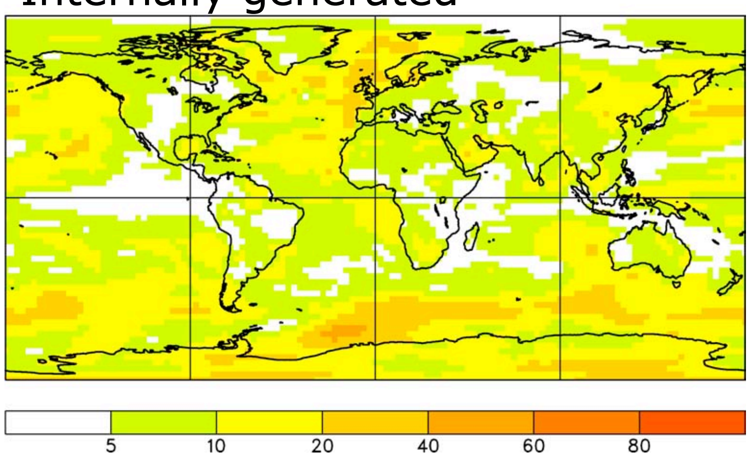
Forced



Net



Internally generated



-Although forced component is largest over high latitude land, *fractional* variance component is not

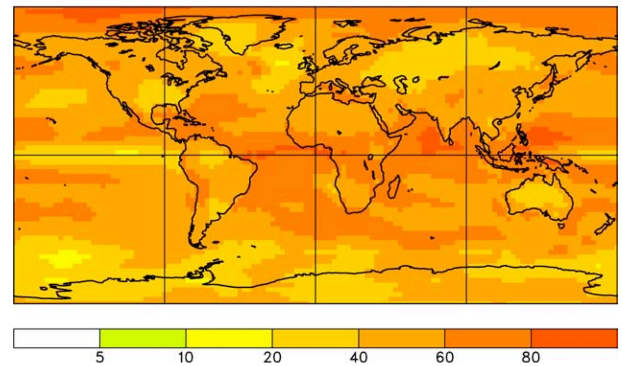
- Internally generated component of "similar" size (and resembles control run results)

-Net fractional decadal variance largest over tropical oceans

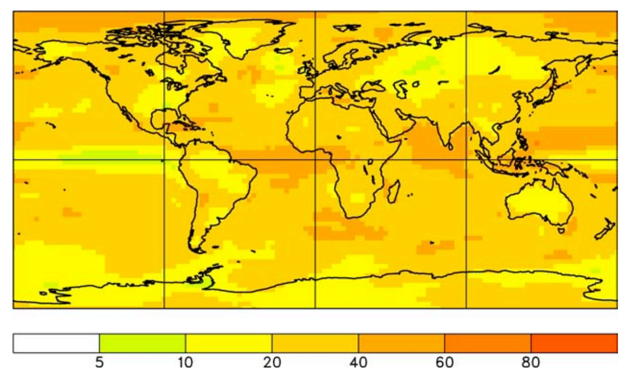
Net variance fractions for decade 2020-2030: Temperature

- early 21st century
- "multi-year" view
  - forced component grows and soon dominates
  - *fractionally* is largest over tropical oceans
  - internal variability diminishes as a *fraction*
- for "next decade" view
  - forced component comparable to internal

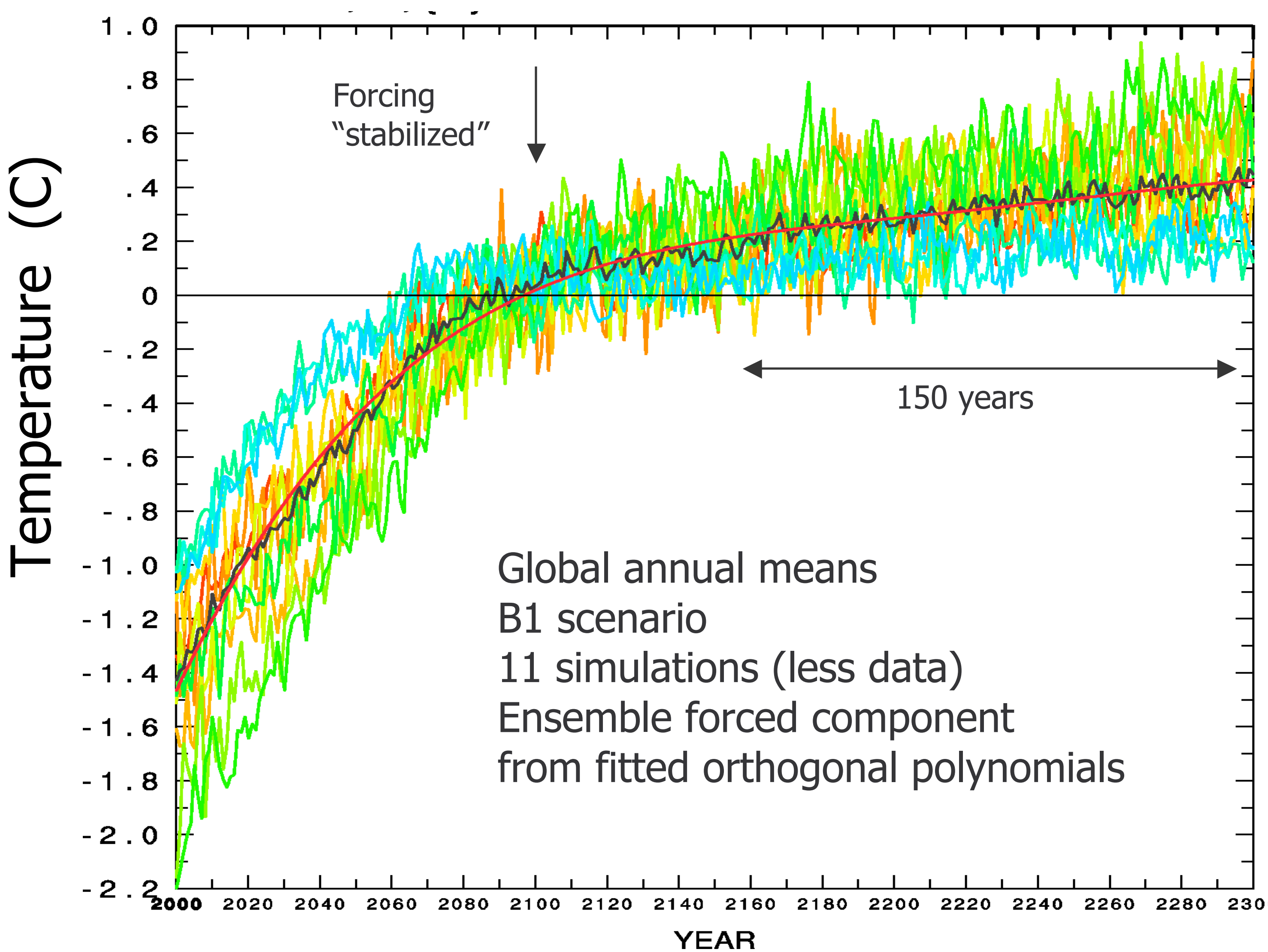
multi-decade



next decade



Potential predictability of internal component for a warmer world



Potential predictability in a warmer world (stabilization case)

- Consider long timescale *internally generated* natural variability σ^2_ν

  - last 150 years of stabilization simulations

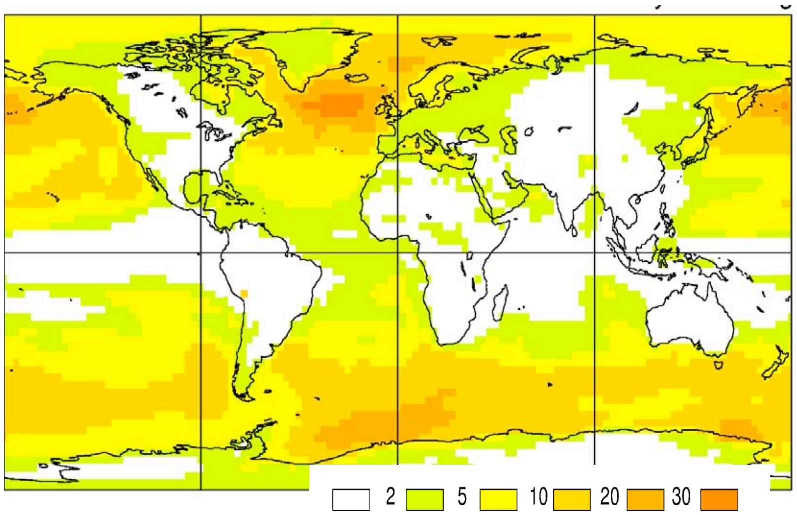
  - remove *forced polynomial trend*

  - estimate potential predictability in warmer world

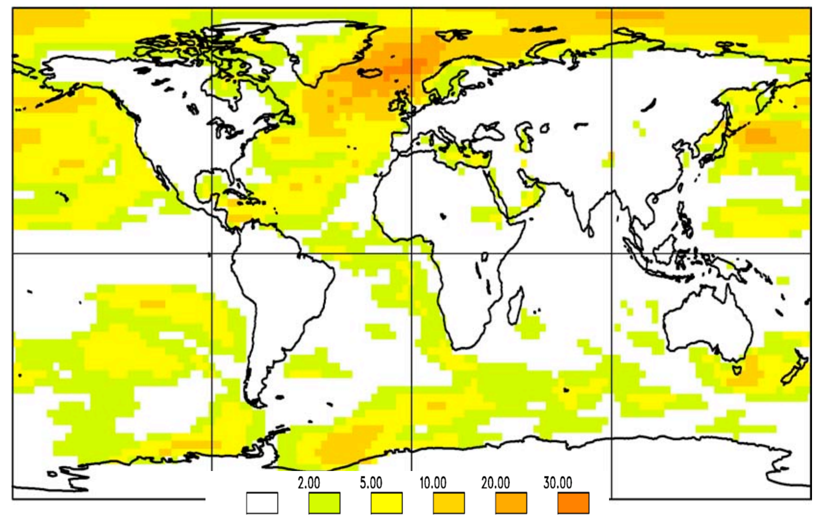
  - estimate change in potential predictability from control case

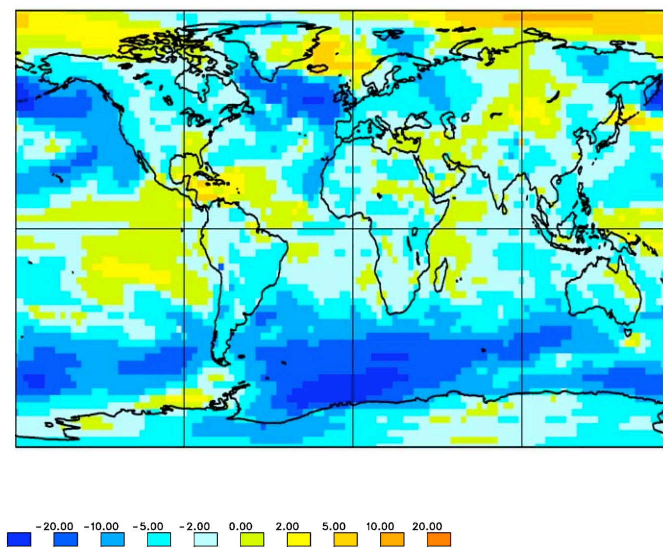
Decadal potential predictability p_ν for *Temperature*

Control simulation

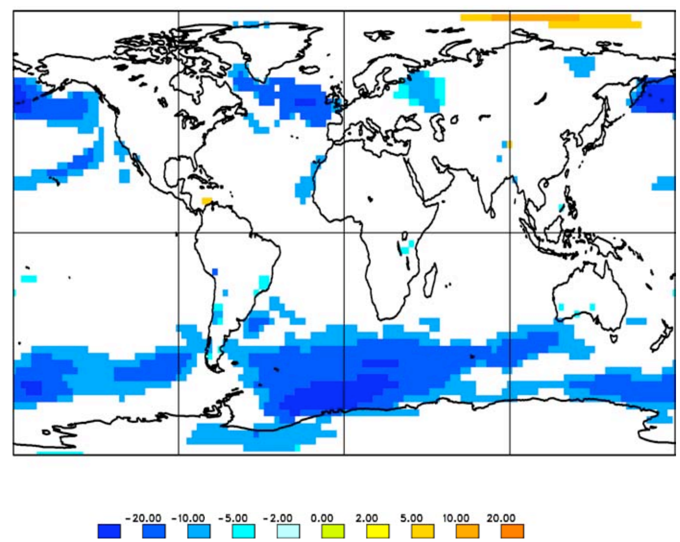


B1 stabilization scenario





Difference in warmer world



Where confidence bands *don't* overlap

MME decadal potential predictability of temperature and precipitation

- model based measure
- potential predictability of the *unforced control* climate
  - fish over folk (especially for precipitation)
  - shorter the better
  - “hot spots” over extratropical oceans for both temperature and precipitation
  - comparatively little potential predictability over land and tropical oceans
  - predictability found for regions/processes where surface connects to deeper ocean

MME decadal potential predictability of temperature and precipitation

- potential predictability in the 21st century
  - adding forced component alters picture
  - tropics become more important
  - forced component soon dominates for *multi-decadal* forecasts
  - forced component and internal component comparable for *next decade* forecast
- potential predictability of unforced variability *decreases* in warmer world

The challenges of potential predictability

- to identify the mechanisms associated with regions of high potential predictability
- to understand the lack of potential predictability over land and, for unforced variability, tropical oceans
- to test potential predictability results by means of (multi-model) prognostic decadal predictions

End of presentation