Forced and internally generated 21st century decadal “potential predictability”

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Canadian Centre for Climate Modelling and Analysis (CCCma)

(in future CCCmap…?)

Motivations for decadal prediction

- Scientific interest
- *Existence of "long timescale" processes (of sufficient importance)*
- Results of predictability studies
- Demonstrations of forecast skill
- Societal importance of modestly skillful decadal prediction

Climate prediction of long timescale *internally generated* variability

- "early days" of *coupled* climate change simulations
- forcing is weak early in the simulation
- gives information on "predictability" of *internally generated* variability
- "long" timescales

Monte Carlo climate change forecasts with a global coupled ocean-atmosphere model

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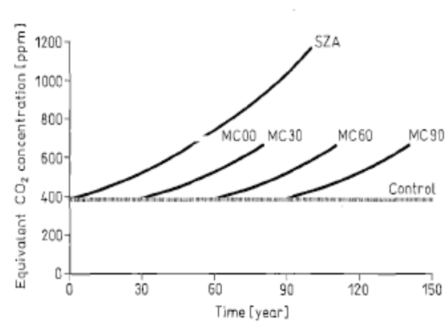
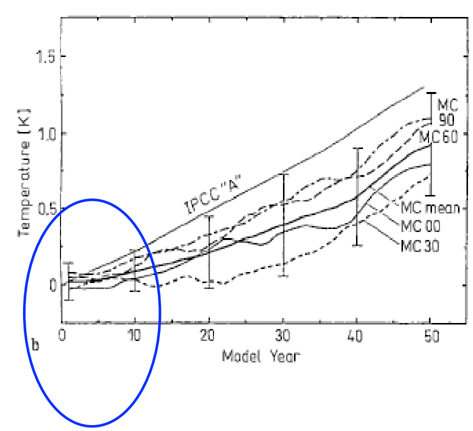


Fig. 1. Schematic diagram of the "Monte Carlo" climate forecasts

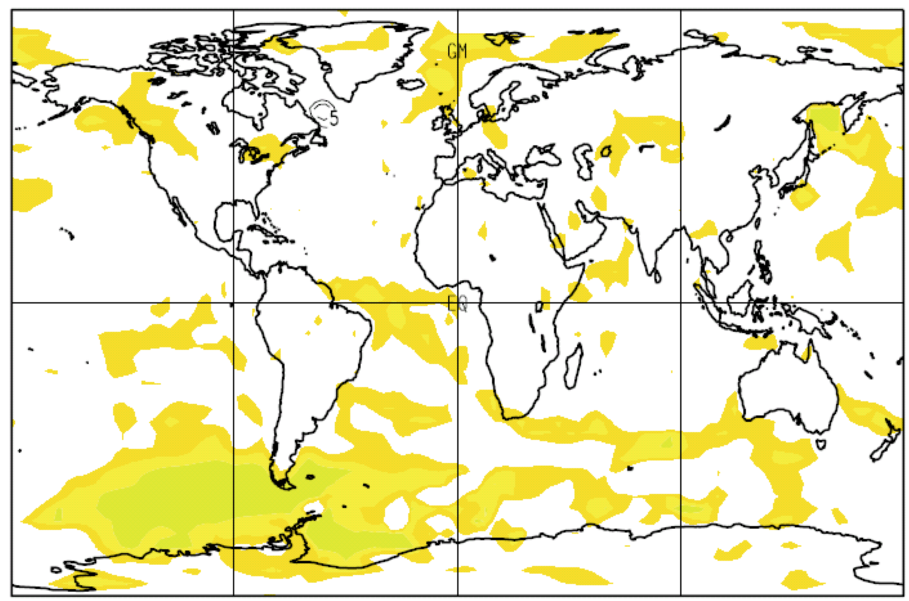


Long-timescale predictability study

- Not able to overcome the technical "culture shock" at MPI to use their utilities etc.
- Later, CCC managed to produce several runs
- Initial "perfect model" predictability estimates from CCCma model
- also "potential predictability" estimates

Decadal ***perfect model*** predictability

Cumulative "perfect model" predictability p > 0.4 at year 10



Boer,2000: Clim Dyn

WGCM/WGSIP and Decadal Predictability

INTERNATIONAL COUNCIL FOR SCIENCE

INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION

WORLD METEOROLOGICAL ORGANIZATION

WORLD CLIMATE RESEARCH PROGRAMME

JSC/CLIVAR Workshop on Decadal Predictability

Scripps Institution of Oceanography
La Jolla, CA, USA
October 4-6, 2000

Workshop on Decadal Climate Predictability

Executive Summary

Scripps Institution of Oceanography, La Jolla, CA, USA, 4-6 October 2000

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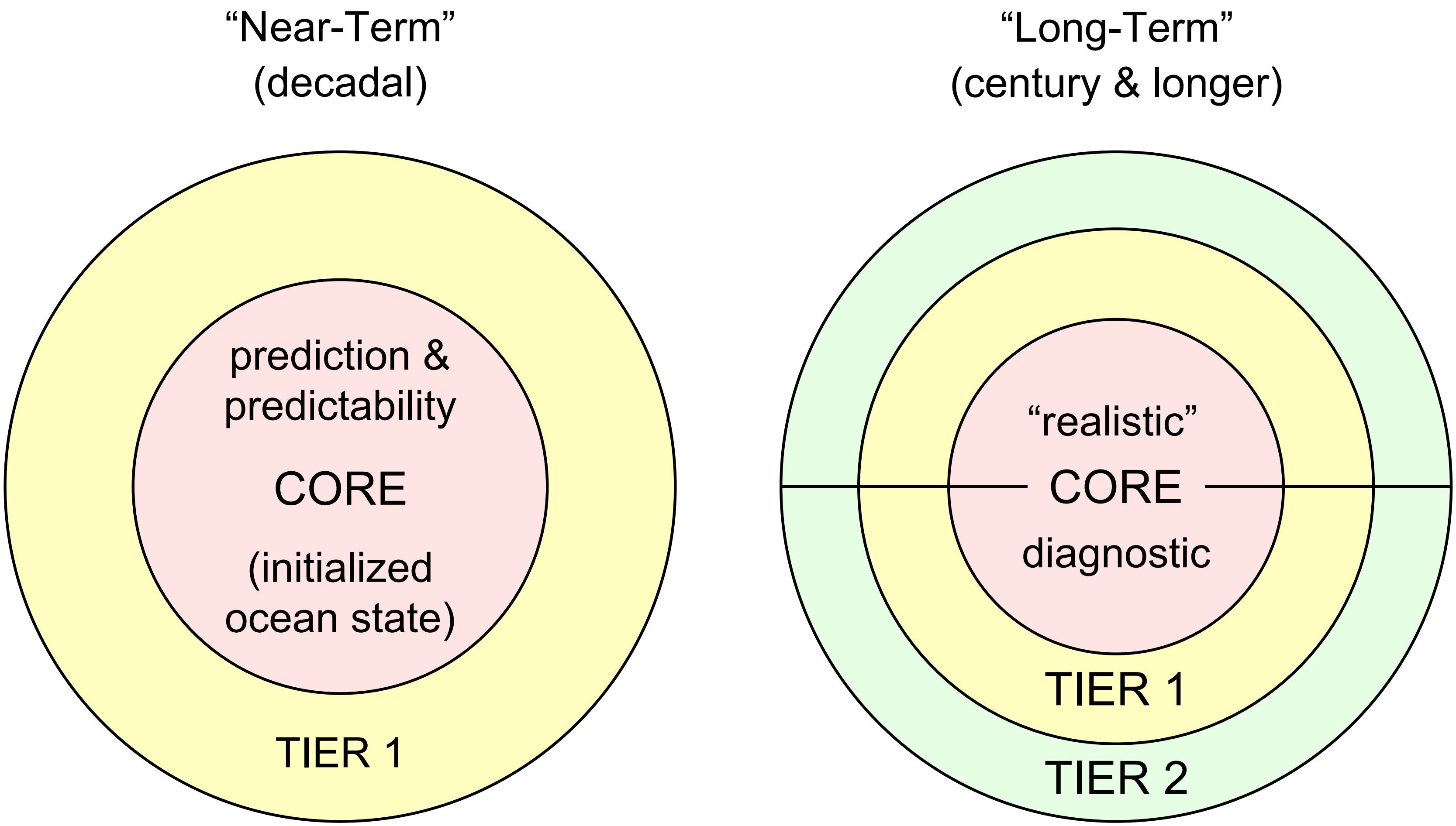
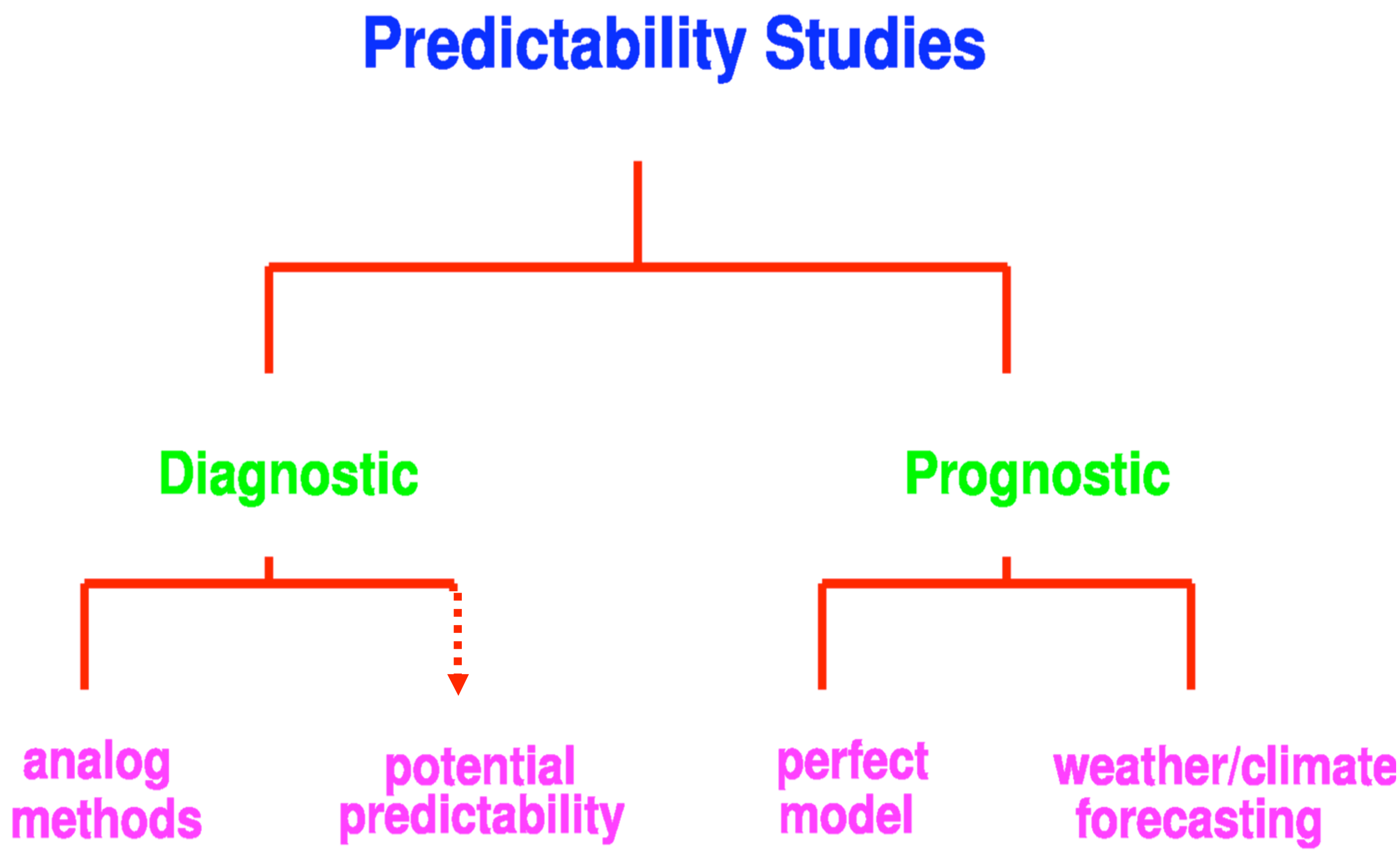
The joint WGCM/WGSIP Workshop on Decadal Climate Predictability took place at the Scripps Institution of Oceanography, La Jolla, CA, USA, from 4-6 October 2000. There were over 30 participants from 18 different scientific institutions, groups and organizations. The objective of the workshop was to form an overall sense of the "state of the art" in decadal predictability. Since this area of study is in its infancy, the intent was a true "workshop" which would explore observed and simulated decadal variability, decadal predictability, and such practical attempts to produce decadal forecasts as were available. The Workshop was organized into a series of presentations in these broad areas followed, on the final morning, by three break-out working groups. The groups summarised the status of observations and observed variability, simulations and simulated variability, and prediction/predictability and made recommendations and suggestions.

CMIP5 Experiment Design



Decadal predictability and prediction

- Appeals to “long timescale” processes
  - *externally forced* (GHG+A, volcanoes, solar, ….)
  - *internally generated*
    - oceanic mechanisms (AMO, SO, …)
    - coupled processes
      - PDO, AMO, NPMO, PGO, ENSO…
      - modulation of “atmospheric” modes (PNA, NAO, NAM, SAM, ….)
    - atmospheric processes (QBO, …)


Predictability Studies
Diagnostic
Prognostic
analog methods
potential predictability
perfect model
weather/climate forecasting

Predictability and prediction

- predictability
  - a characteristic of a *physical system* itself
  - a measure of the *rate of separation* of *initially close* states
  - indicates the *possibility of prediction*
- prognostic predictability studies
  - typically use model to simulate “rate of separation”
  - presumption that the model “similar enough” to real system
- forecast skill
  - characterized by *error growth* rate, decorrelation, or other measure (rate of separation of actual and predicted states)
  - indicates the current *ability to predict*
- “potential predictability”
  - analysis of variance; measure of *signal to noise*
  - identifies regions where *decadal variability* is a useful fraction of the total variance
  - meant to indicate that prediction is *potentially possible*

How do we determine the *predictability* of the system on decadal timescales?

- Prognostic perfect model predictability studies
  - Griffies and Bryan (1997)
  - Boer (2000)
  - Collins (2002)
  - Collins et al. (2006)
  - Latif et al., (2006)
  - and others
- Diagnostic potential predictability studies
  - Boer (2000, 2004)
  - Pohlmann et al. (2004)
  - Predicate (2004…)
  - Boer and Lambert (2008)
  - and others
- Investigations of forecast skill
  - Smith et al. (2008)
  - Keenlyside et al. (2008)
  - Pohlmann et al. (2009)
  - CMIP5 (2009 ….)

Perfect model(s) predictability study

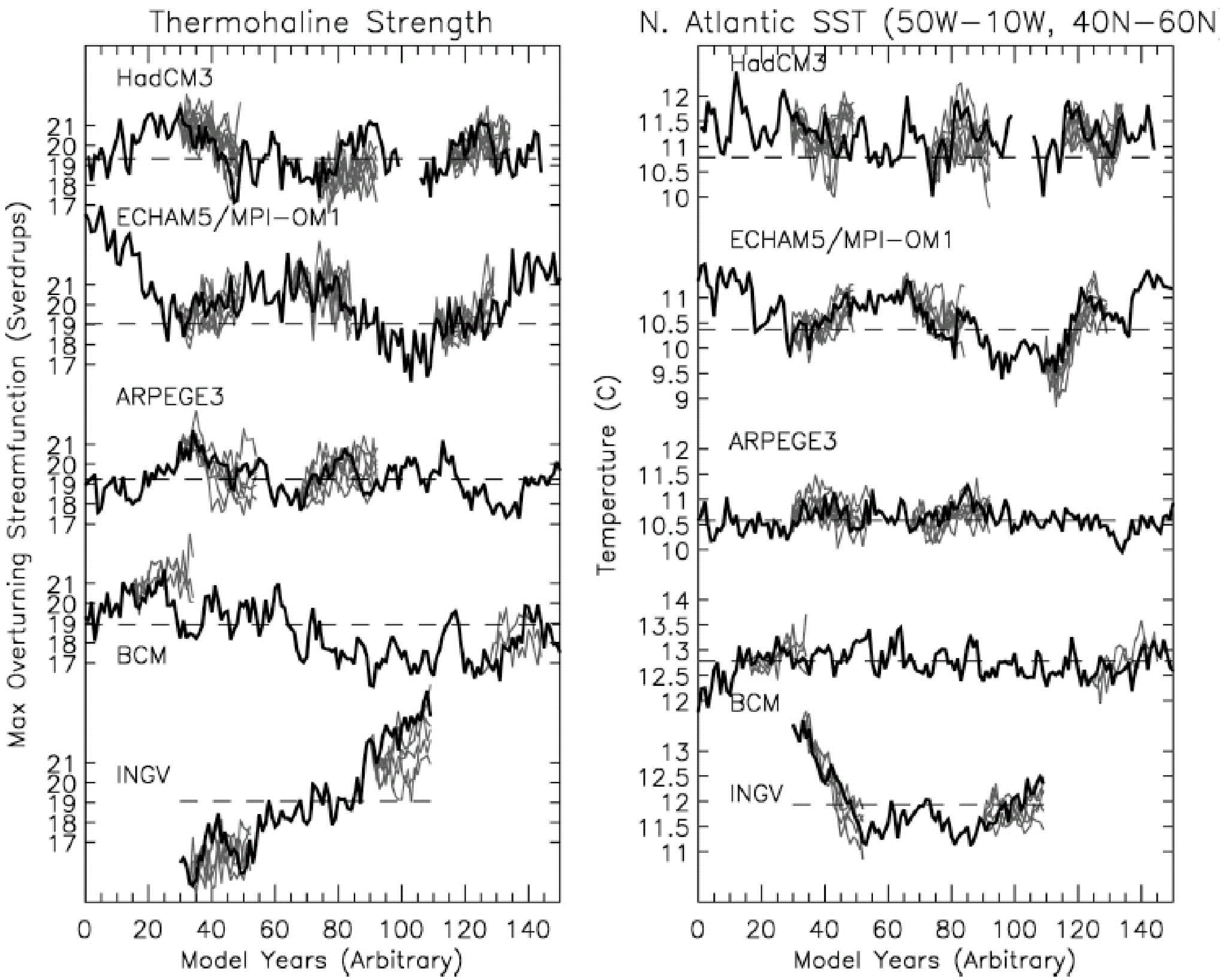
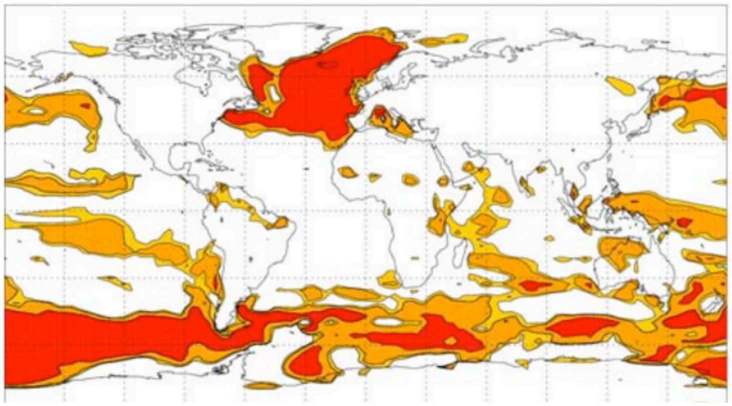


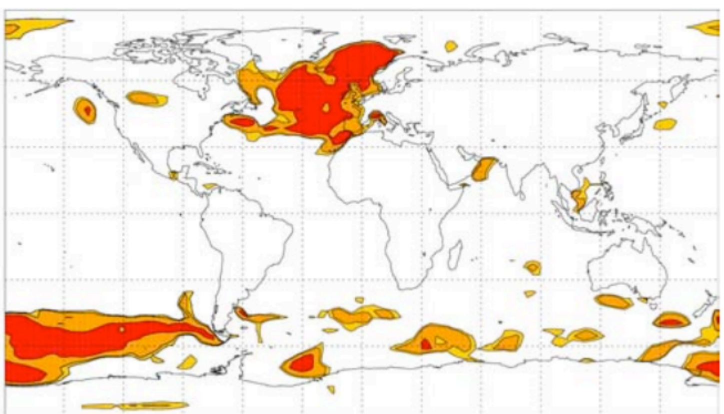
FIG. 9. Classical predictability experiments with five different European coupled ocean–atmosphere GCMs: (left) prediction of thermohaline strength and (right) prediction of North Atlantic SST. The ensemble experiments (thin gray) were initialized from control experiments (thick black) by only perturbing atmospheric initial conditions. The ensemble experiments indicate considerable predictability in the North Atlantic on decadal time scales. From Collins et al. (2006).

Collins et al., 2006

years 1-5

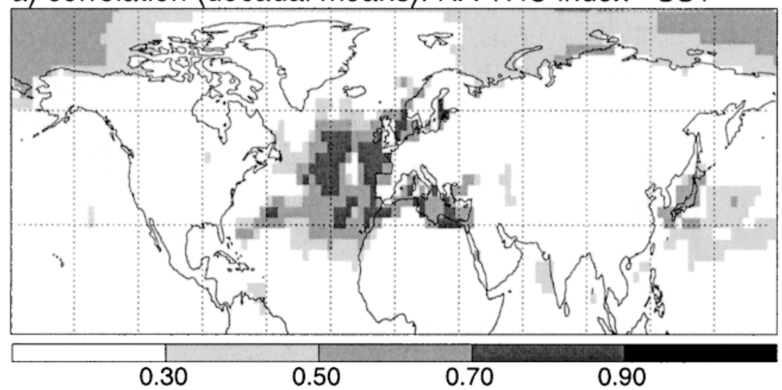


years 6-10

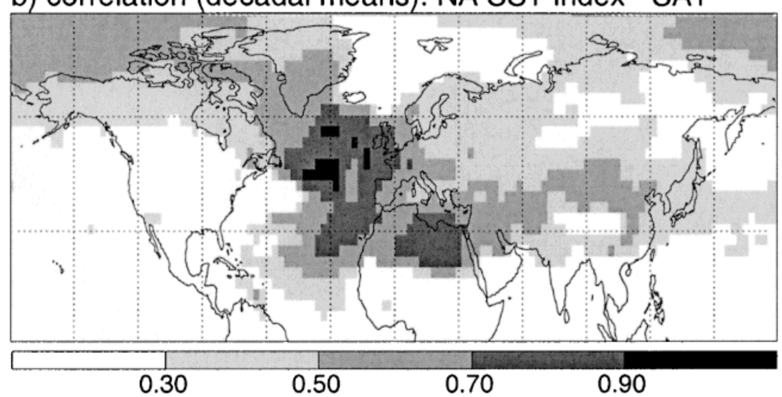


perfect model
predictability measure

a) correlation (decadal means): NA THC index - SST



b) correlation (decadal means): NA SST index - SAT



North Atlantic

Pohlmann et al. 2004

Potential predictability: internally generated component

- *decadal, diagnostic*, *multi-model*
- Model control runs (CMIP3) - no external forcing
- Annual means of variable X are expressed as

$$X = \mu + \nu + \varepsilon$$

  - μ is the long-term mean
  - ν is the long timescale *internally generated* component
  - ε is the short timescale *unpredictable "noise"* component
- Associated variances are

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

- Potential predictability variance fraction (*ppvf*) is

$$p = \sigma^2_\nu / \sigma^2$$

Internally generated multi-model potential predictability

- Potential predictability variance fraction

  $$p = \sigma^2_\nu / \sigma^2 = \sigma^2_\nu / (\sigma^2_\nu + \sigma^2_{\varepsilon})$$

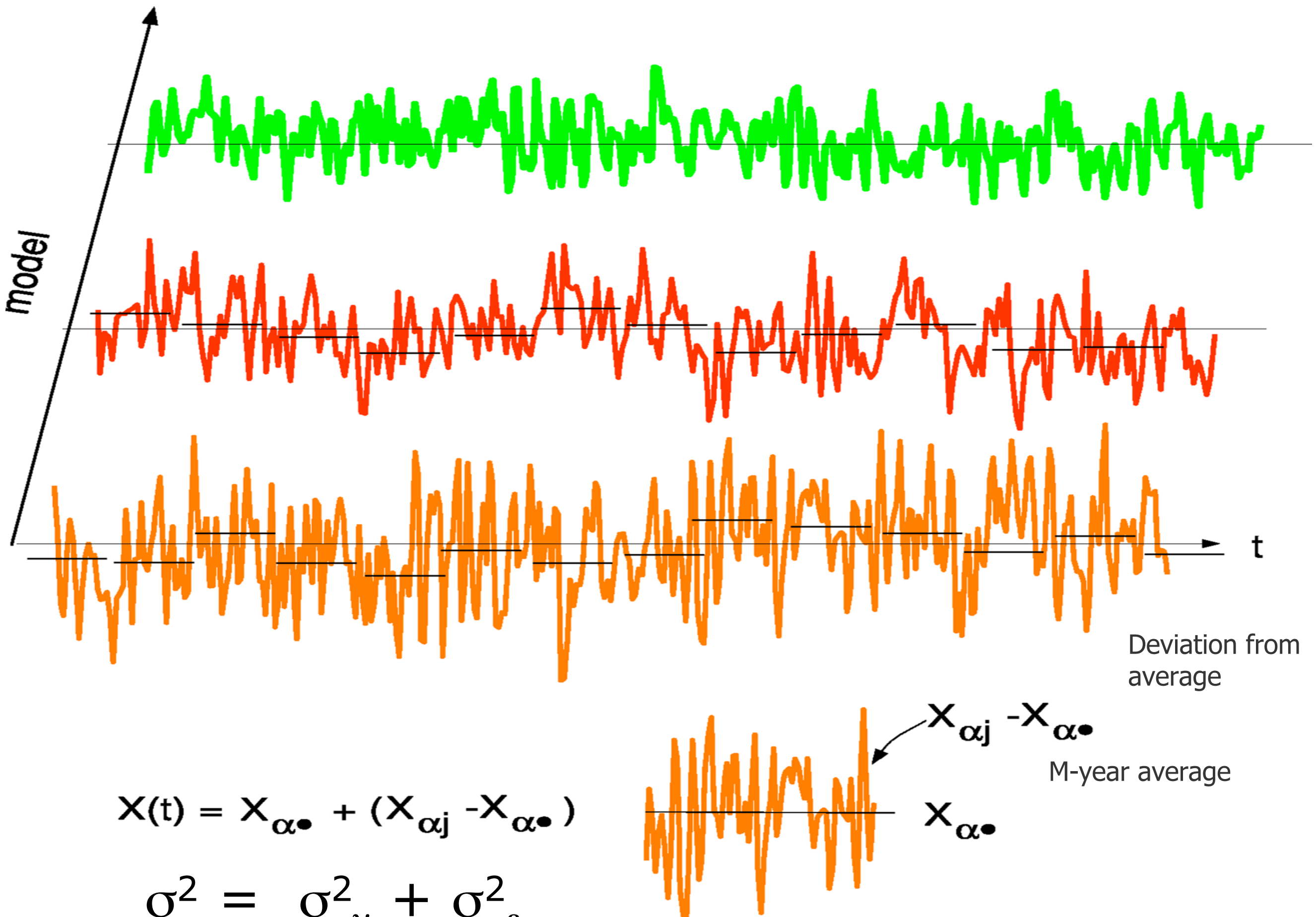
- in terms of a signal to noise measure

  $$\gamma = \sigma^2_\nu / \sigma_\varepsilon{}^2$$

  $$p = \gamma/(1+\gamma)$$

- *p* is small if signal is *small* or if noise is *large*
  - $0 < p < 1$
  - *not only existence of signal, however small, but its relative magnitude*

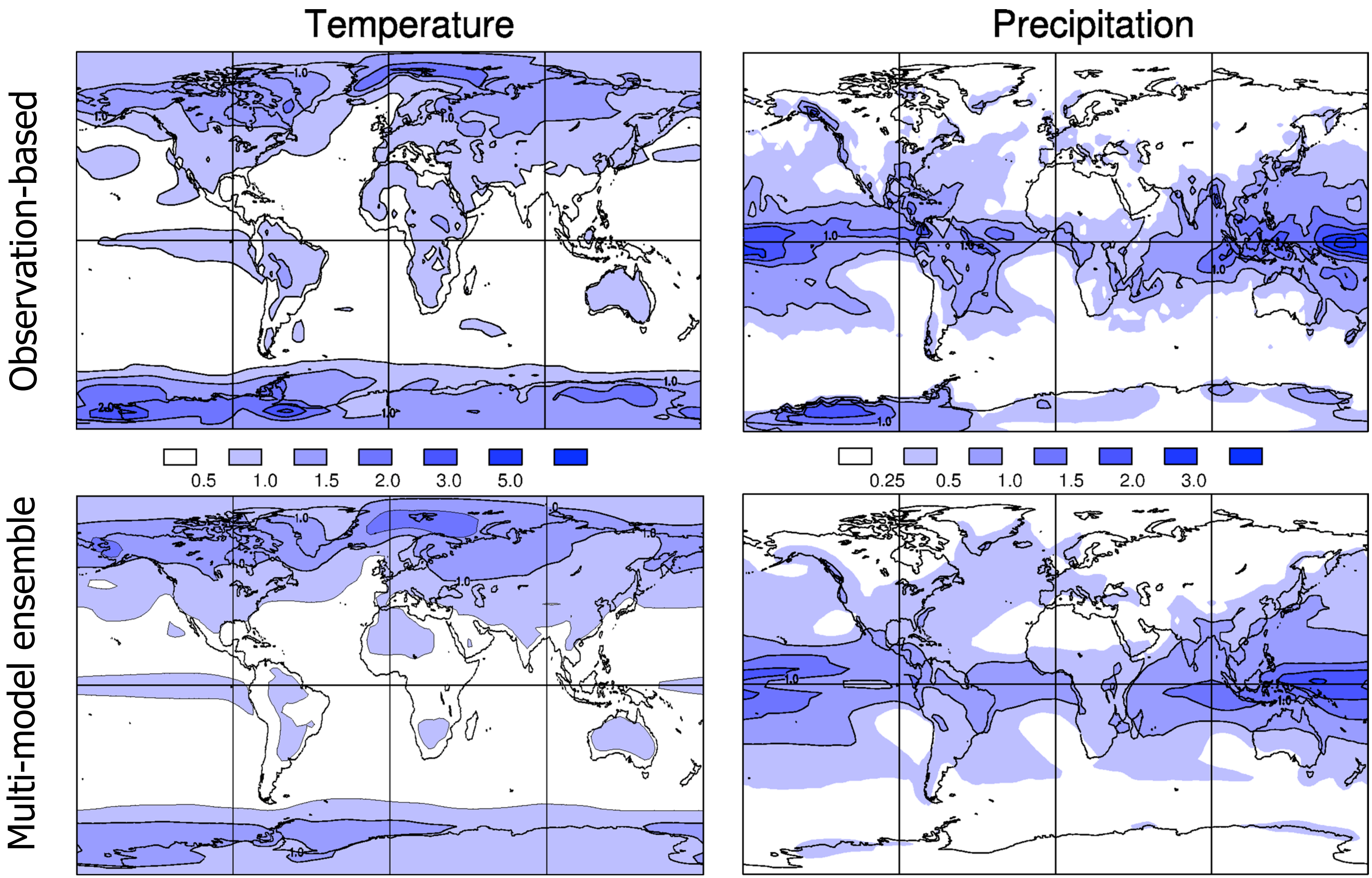
Internally generated long timescale potential predictability



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

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

Standard Deviation of annual means

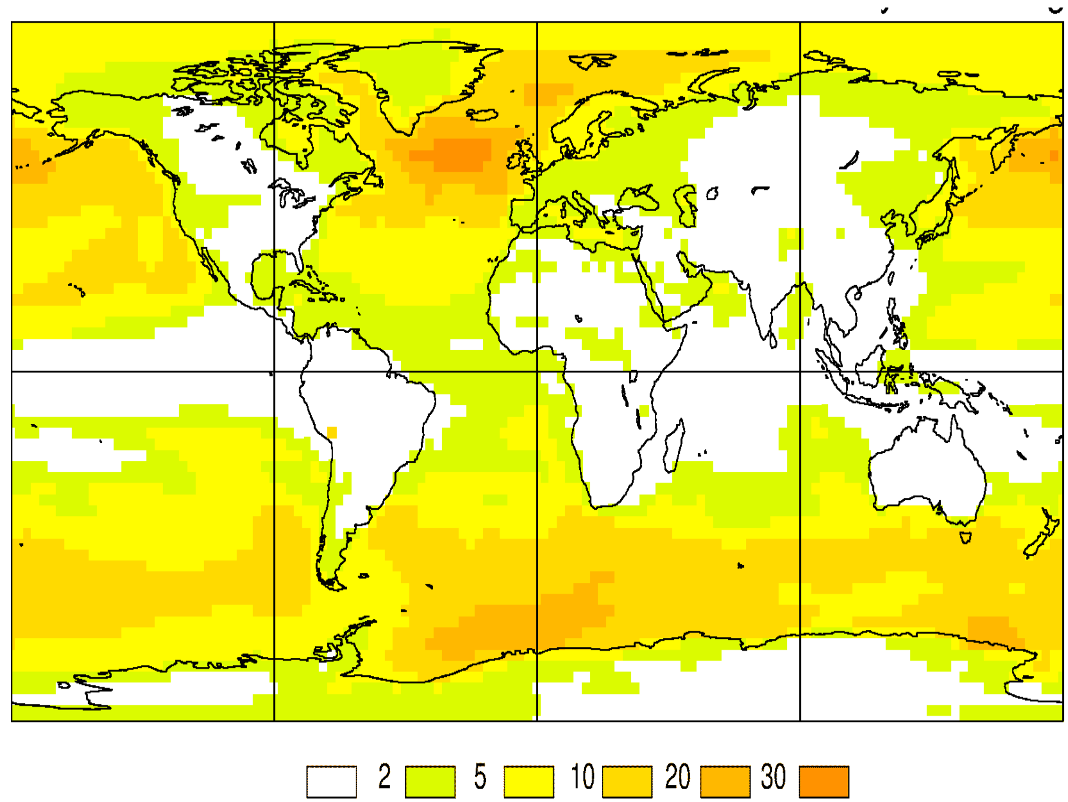


Virtues of multi-model approach

- the “multi-model” is generally the “best model”
  - no individual model “best” in all regards
  - the “*n*-best” models differ with criterion used
  - pooled climate statistics (means, variances, covariances) generally closer to observed
  - applied to seasonal forecasting
  - applied to climate change (Chapter 10, AR4)
- increased the amount of data for statistical stability

Temperature: potential predictability of *internally generated* variability $p_\nu = \sigma^2_\nu/\sigma^2$ (%) for *decadal means (CMIP3 multi-model control runs)*

- Ratio of long timescale 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)

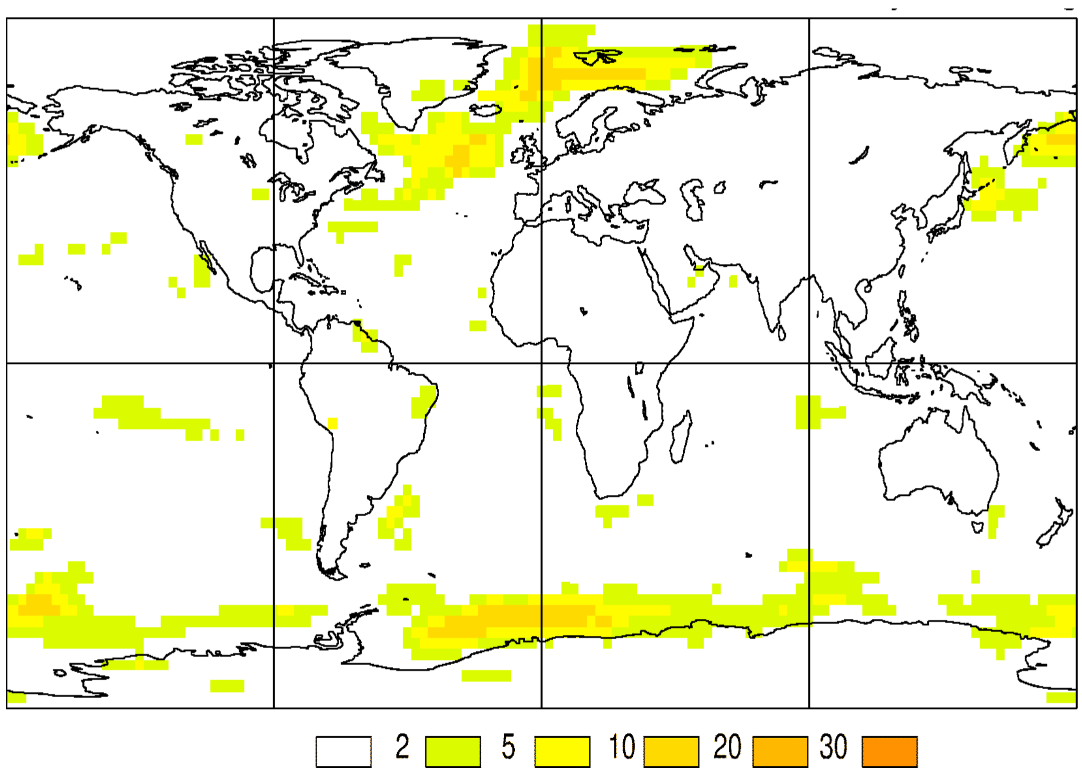


Control simulations

Boer and Lambert, 2008

Precipitation: potential predictability of internally generated variability $p_v = \sigma^2_v/\sigma^2$ (%) 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

21^{st} *Century decadal potential predictability*

- Variable now has forced component

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

with associated variances

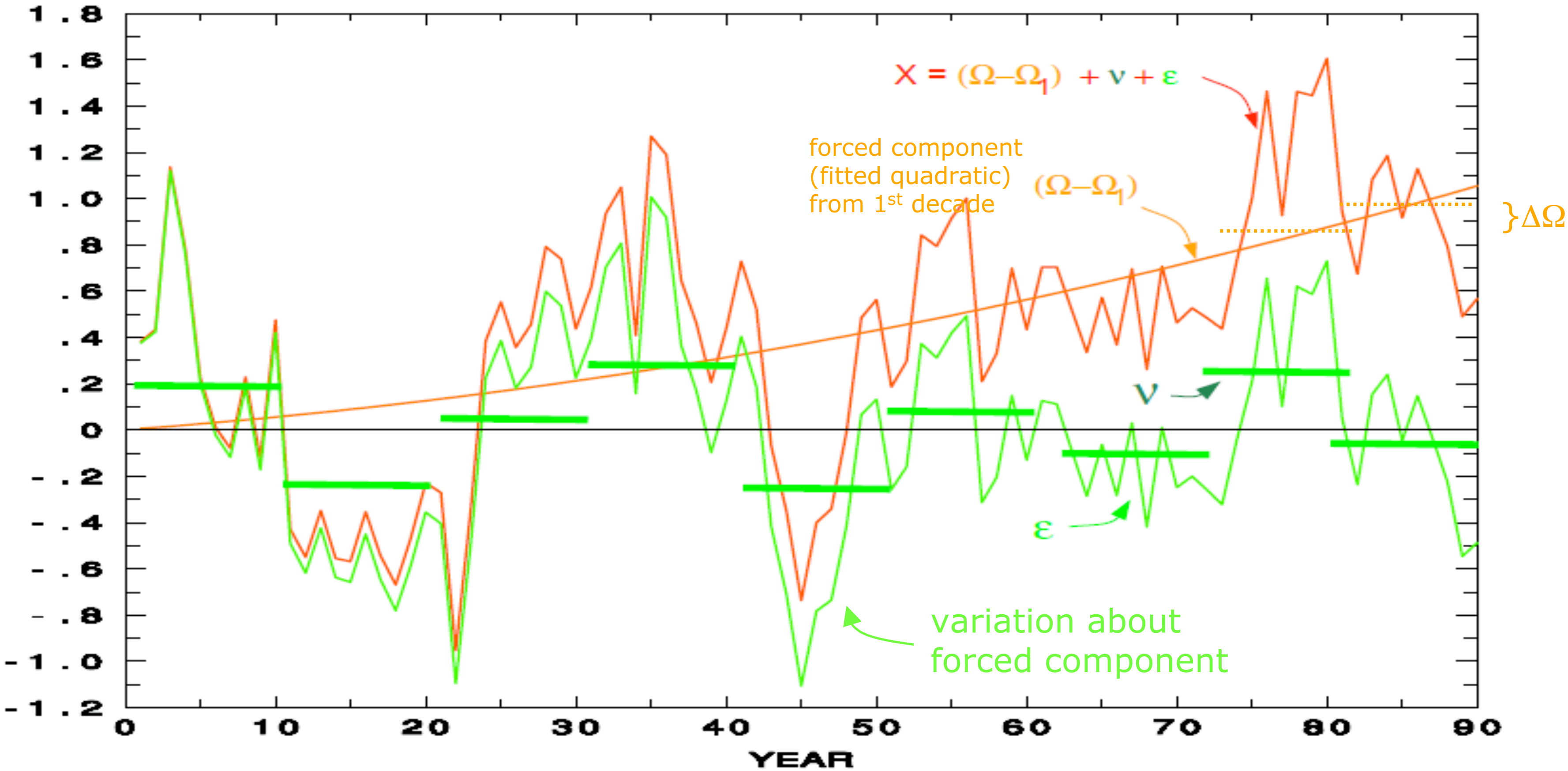
$$\sigma^2 = \sigma^2_\Omega + \sigma^2_\nu + \sigma^2_\varepsilon$$

- Ω is long timescale *externally forced* variability
- ν is long timescale *internally generated* variability
- ε is short timescale *unpredictable "noise"* variability
- statistics pooled across models
- Potential predictability variance fraction now has two components

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

21st century temperature at a point

- forced component from 1st decade



$$\sigma_1{}^2 \;=\; \sigma^2{}_{\Omega 1} + \sigma^2{}_{\nu} + \sigma^2{}_{\varepsilon}$$ multi-decade

$$\sigma_\Delta{}^2 \;=\; \sigma^2{}_{\Delta\Omega} + \sigma^2{}_{\nu} + \sigma^2{}_{\varepsilon}$$ next-decade

Forced component

- Potential predictability variance fraction

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

- *multi-decade* view of forced contribution

  - difference from 1st decade

  $\sigma^2_{\Omega 1} = (\Omega_k - \Omega_1)^2$

  $p = (\sigma^2_{\Omega 1} + \sigma^2_\nu)/(\sigma^2_{\Omega 1} + \sigma^2_\nu + \sigma_\varepsilon^2) = p_{\Omega 1} + p_{\nu 1}$

- *next -decade* view of forced contribution

  - difference from previous decade

  $\sigma^2_{\Delta\Omega} = (\Omega_k - \Omega_{k-1})^2$

  $p = (\sigma^2_{\Delta\Omega} + \sigma^2_\nu)/(\sigma^2_{\Delta\Omega} + \sigma^2_\nu + \sigma_\varepsilon^2) = p_{\Delta\Omega} + p_{\Delta\nu}$

- both numerator and denominator differ so *p* components differ depending on treatment of forced component

Estimate statistics from sample variances

$$\hat{\sigma}_{\varepsilon}^2 = \frac{m}{m-1} S_{\varepsilon}^2$$

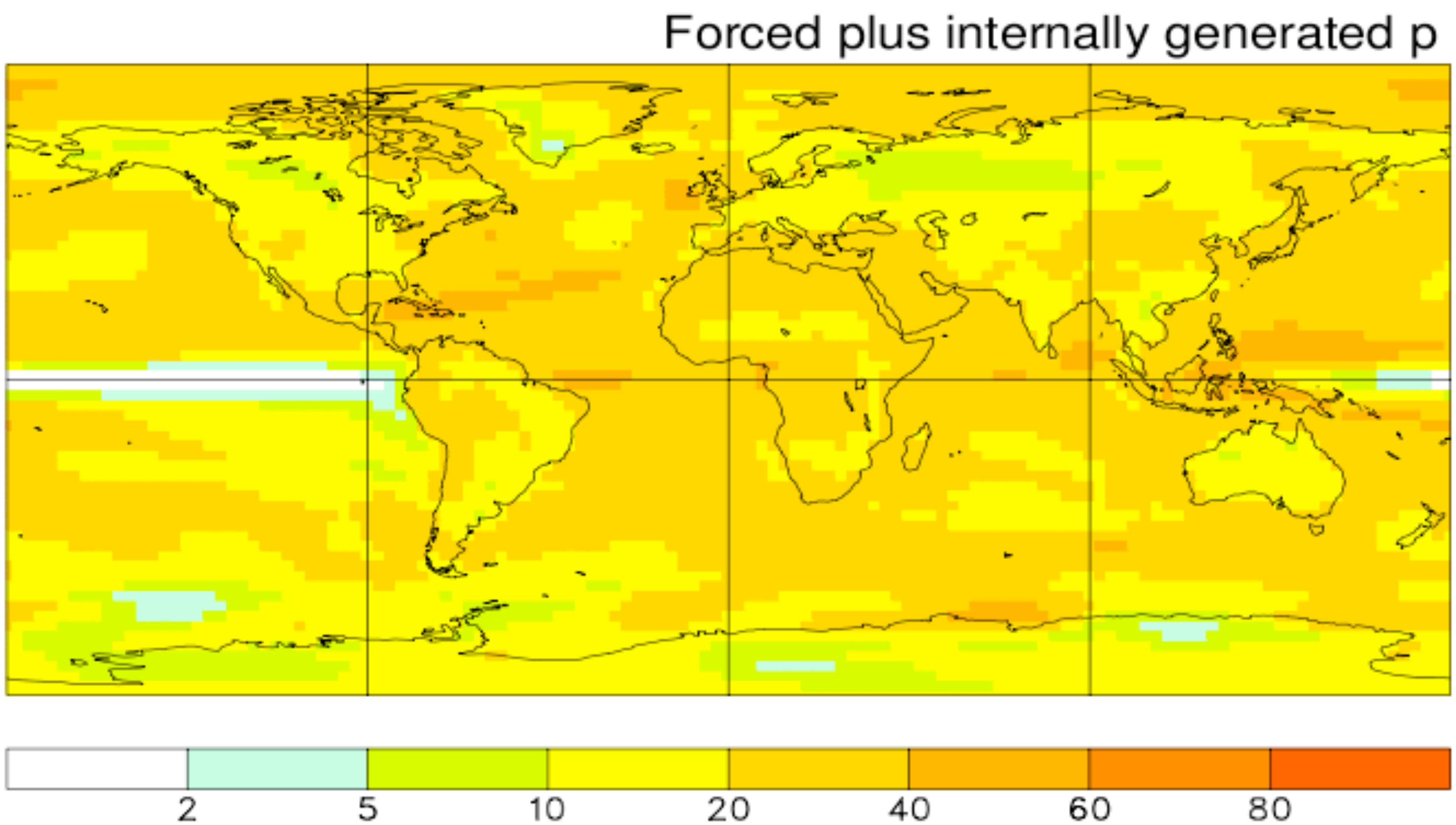
$$\hat{\sigma}_{\nu}^2 = \frac{n}{n-(b+1)} S_{\nu}^2 - \frac{S_{\varepsilon}^2}{m-1}$$

$$\hat{\sigma}_{\Omega 1}^2 = S_{\Omega 1}^2 - \frac{d_1}{n-(b+1)} S_{\nu}^2$$

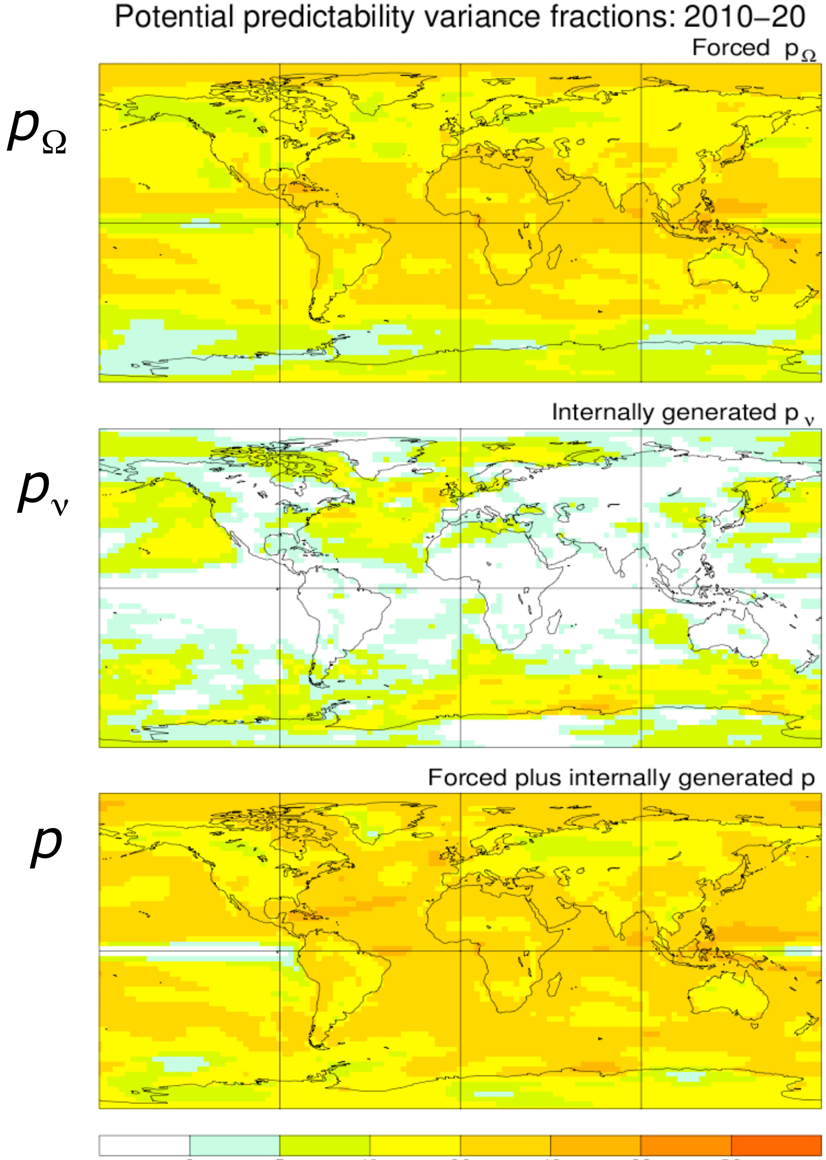
$$\hat{\sigma}_{\Delta\Omega}^2 = S_{\Delta\Omega}^2 - \frac{d_{\Delta}}{n-(b+1)} S_{\nu}^2$$

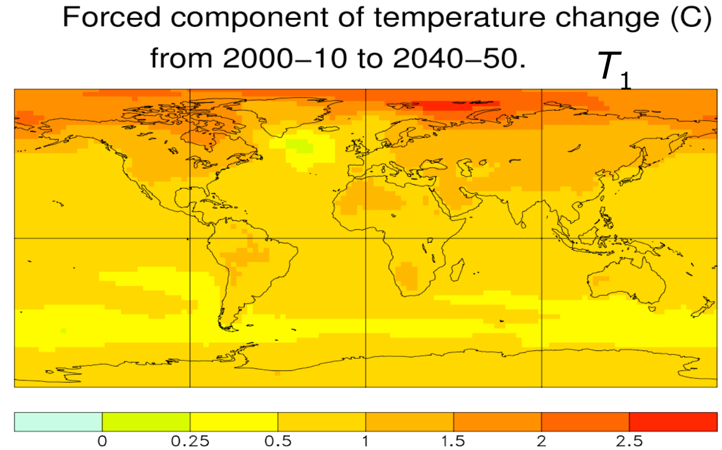
- S^2 are sample variances pooled across models
- m = 10 years in a decade; n = 10 decades in 21st century
- b, d's arise from the fitting polynomial for the forced component
- decadal sample variance is discounted by part of noise variance
- decadal forced variance discounted by part of decadal variance

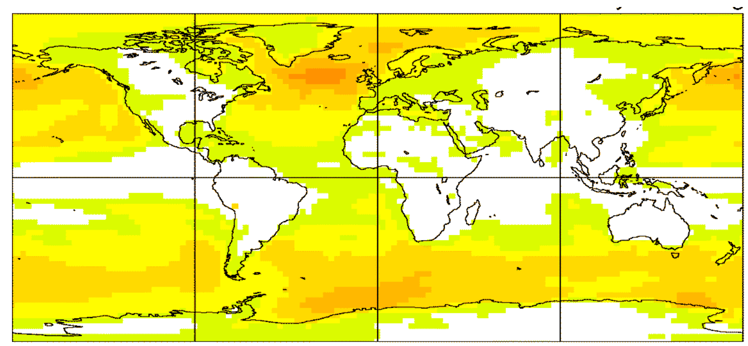
Potential predictability of temperature for *2010-20*
(or "next decade" result generally)



Potential predictability of temperature for *2010-20*
(or next decade result generally)



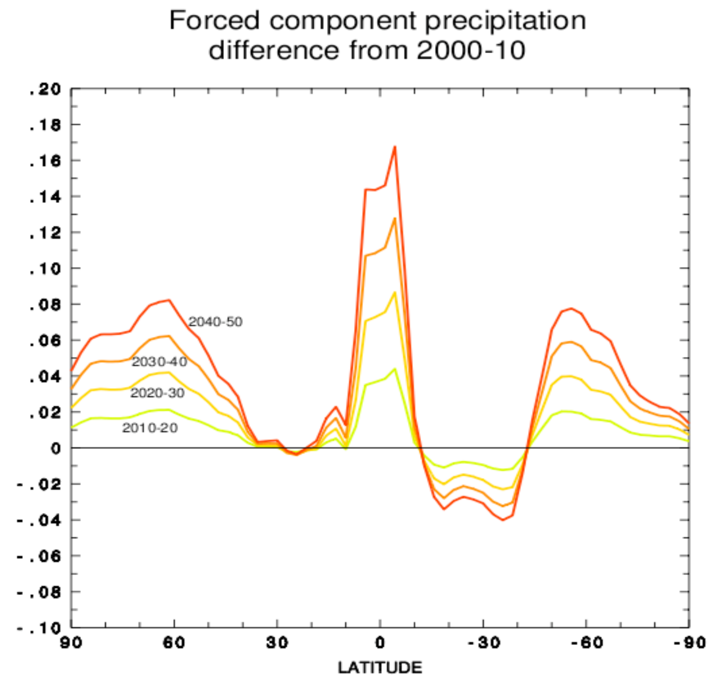


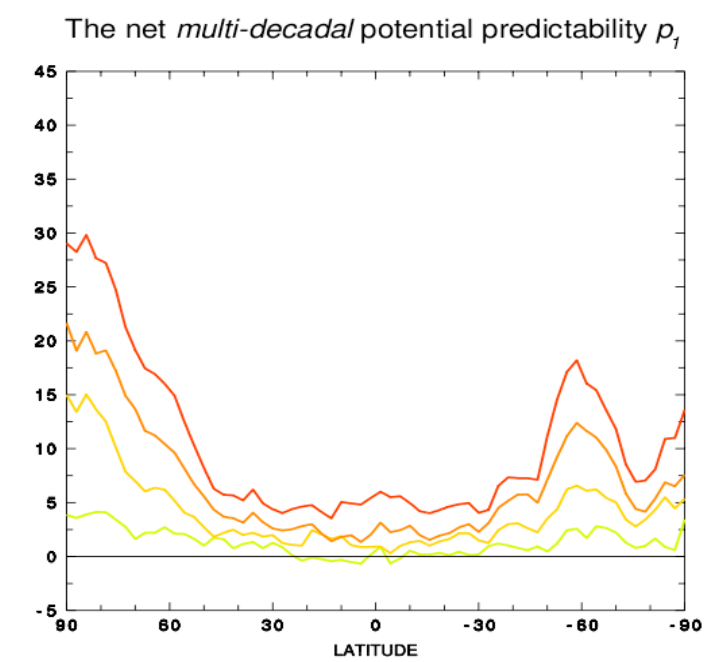


Unforced internally generated p_ν from control simulations

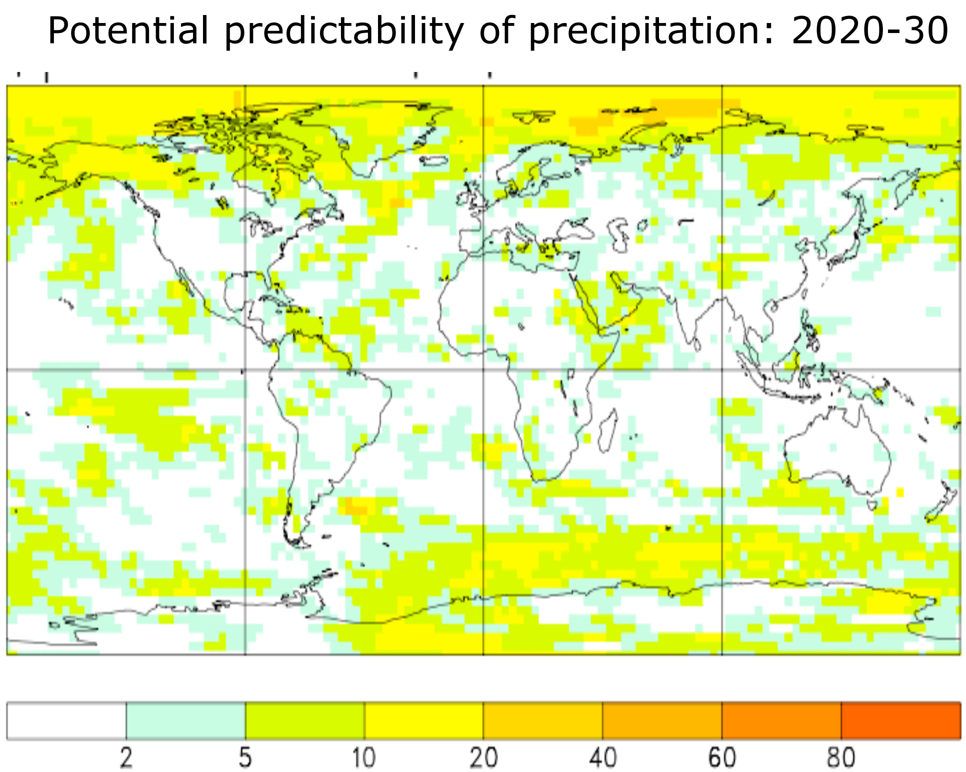
- forced p_Ω differs from ΔT
  - discounted by noise variance
- internally generated p_ν similar to unforced control simulations
- net potential predictability amalgam of both

- Precipitation
  - forced component dominates
  - *next-decade p* is small (noise is large)
  - *multi-decade p* depends on growing *forced* component



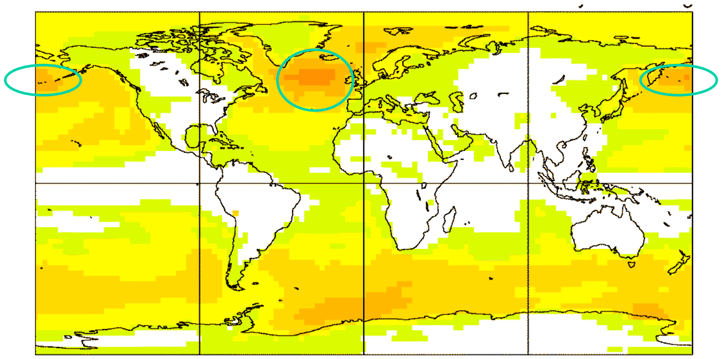


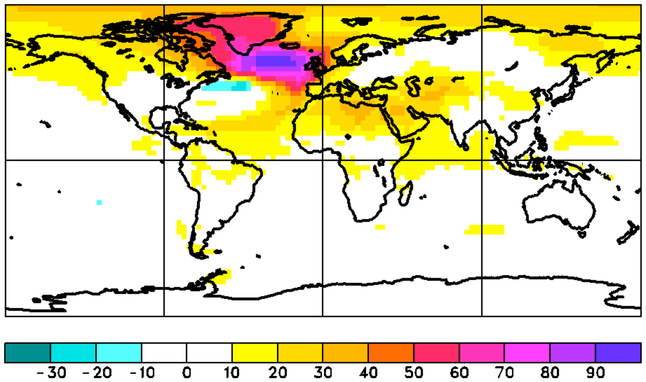
Potential predictability of precipitation



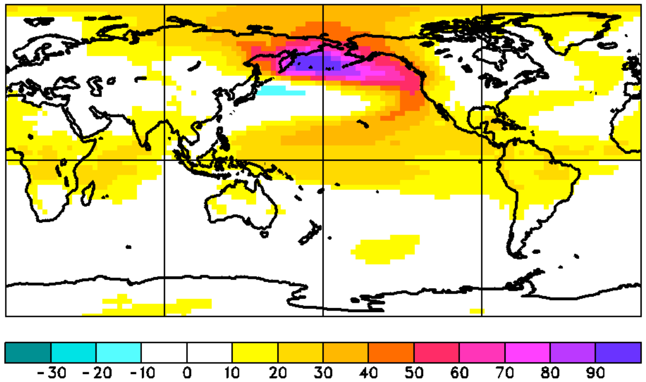
- *due to forced component*
- noise variance for precipitation is large
- internally generated p_ν is small as a result
- only *multi-decade* $p_{\Omega 1}$ contributes and then only modestly

Centres of potential predictability





- "centres" are regions where long timescale *internal* variability exists that is not "masked" by noise variability
- suggests that the system should "see" these centres more clearly
- patterns remarkably(?) similar
  - dipole structure
  - connection to eastern sides of basins
  - connections to tropics
  - inter-ocean connections not immediate

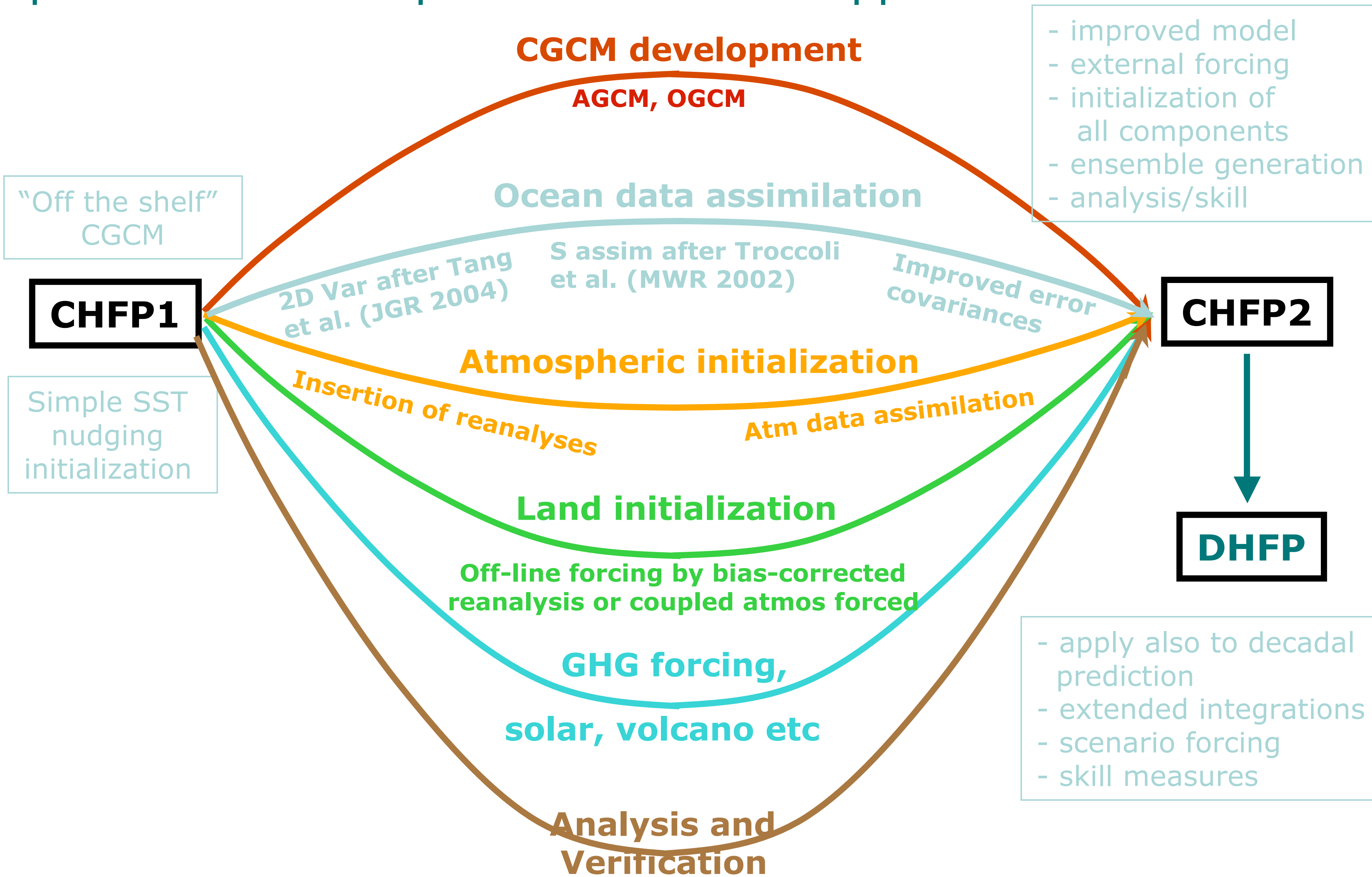


correlation maps of decadal mean temperatures of "centres"

The challenges and caveats of predictability studies

- to identify the mechanisms associated with regions/modes of predictability
- to assess "perfect model" and "potential" vs "actual" predictability
- to investigate predictive *skill* of both forced and internally generated variability

Coupled "seamless" forecast system parallel development path at CCCma represents "scientific opportunities"



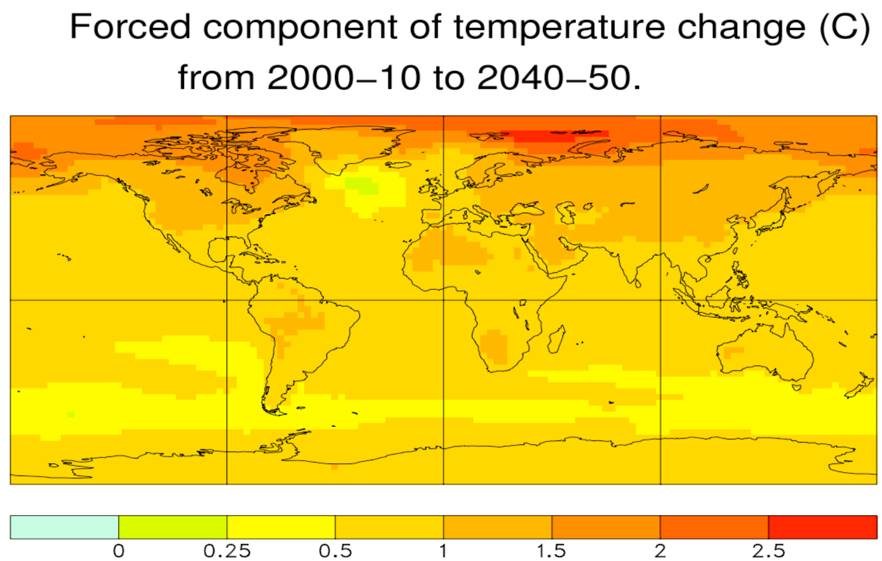
Prospects for decadal prediction

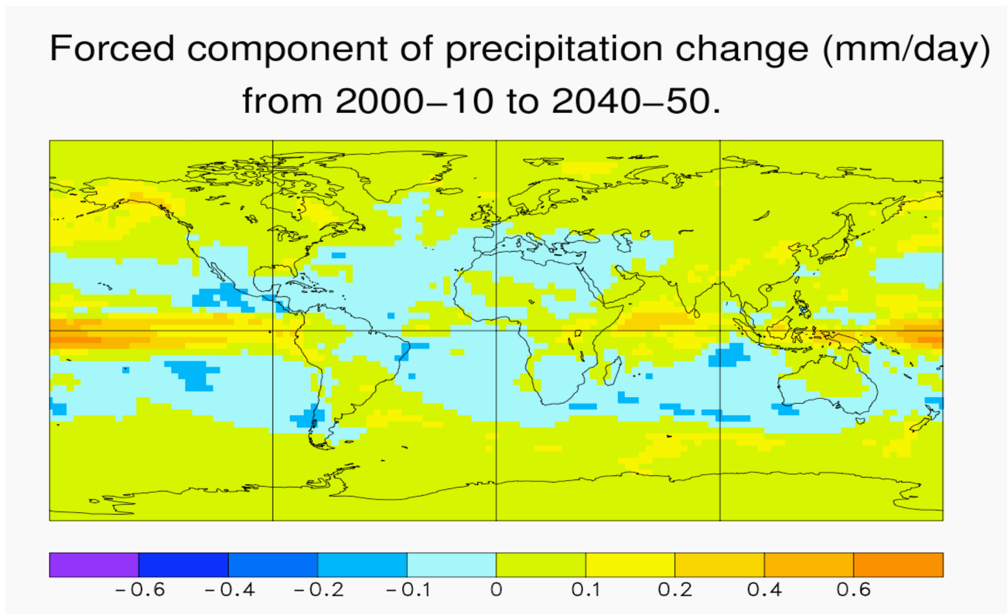
- *Scientific interest* - ☑
- *Existence of long timescale "potentially predictable" processes* – ☑
- Results of predictability studies
- Demonstrations of forecast skill
- Societal importance of modestly skillful decadal prediction

end of presentation

Multi-model forced climate change: B1

- *multi-decadal* forced change to mid-century
- temperature change largest
  - over land
  - at high northern latitudes
- precipitation change largest
  - tropical oceans
  - mid-high latitudes



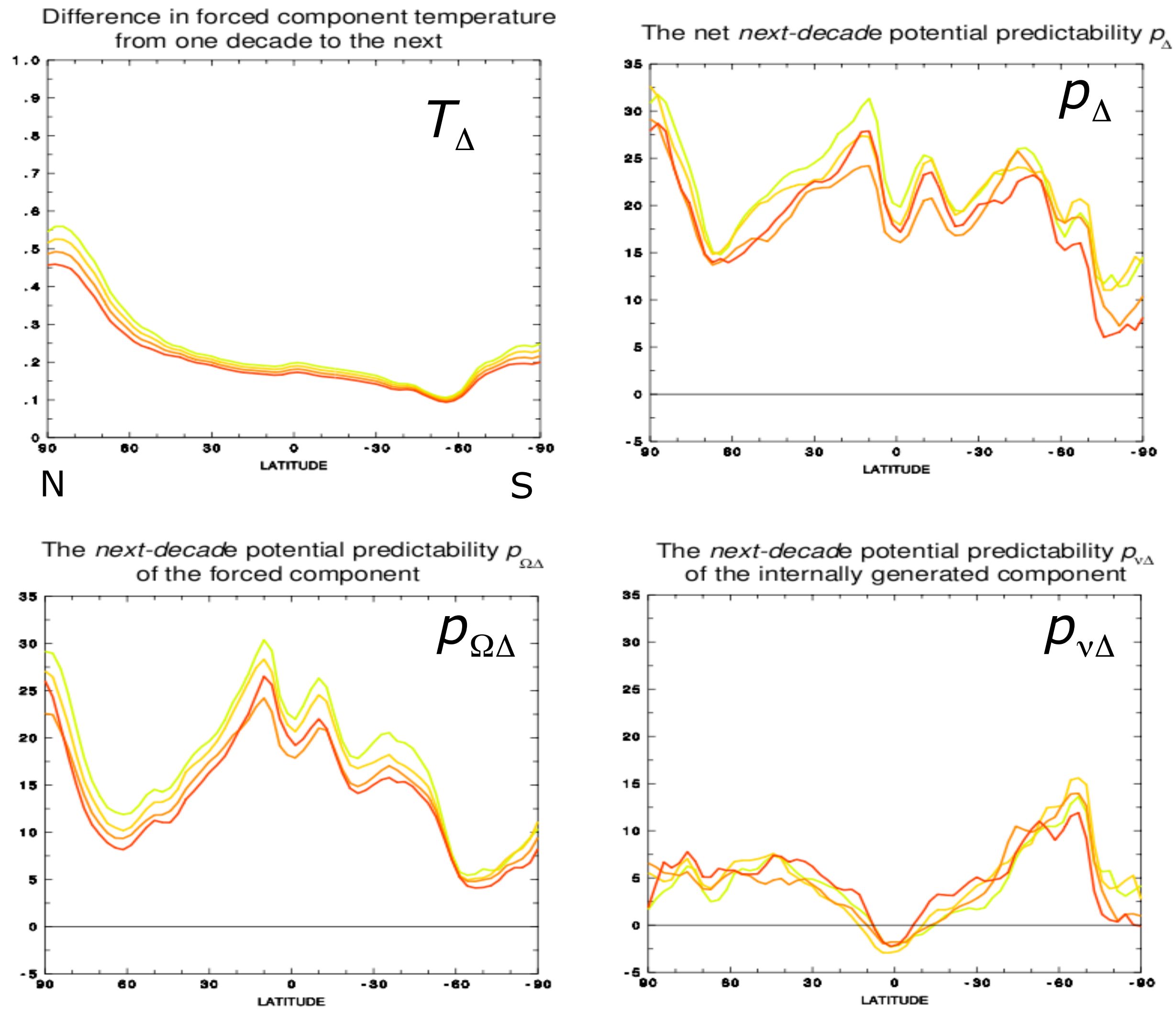


Zonally averaged *next-decade* results: Temperature

$$\sigma^2 = \sigma^2_{\Delta\Omega} + \sigma^2_{\nu} + \sigma^2_{\varepsilon}$$

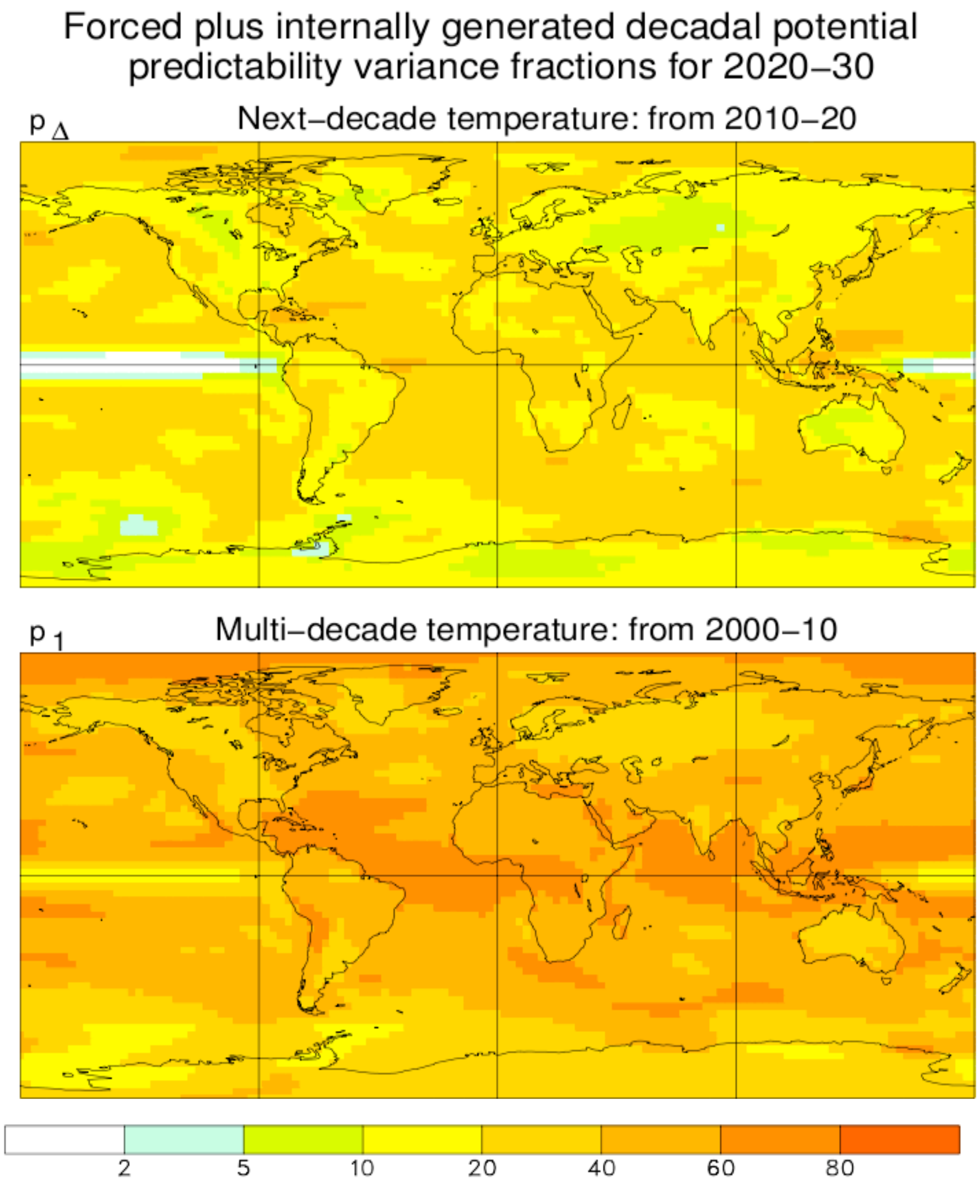
$$p_\Delta = p_{\Delta\Omega} + p_{\nu\Delta}$$
$$= \sigma^2_{\Delta\Omega}/\sigma^2 + \sigma^2_{\nu}/\sigma^2$$

- change in forced component almost constant
- $p_{\Delta\Omega}$ and $p_{\nu\Delta}$ more commensurate
- both contribute
  - tend to be complementary
  - $p_{\Delta\Omega}$ in tropics
  - $p_{\nu\Delta}$ in extra tropics



- decade to decade changes in forced component

Potential predictability of temperature for 2020-30



- *next-decade* similar as century evolves
  - change in forced component similar
  - internally generated component similar
- *multi-decade* result sees increasing effect of forced component
- multi-decade results becomes climate change simulation