Forced and internally generated 21st century decadal "potential predictability"

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Long timescale climate predictability

- "early days" of *coupled* climate change simulations
- other's interest in *forced signal*
- then, signal "contaminated" with internally generated natural variability *"noise"*
- but perhaps long timescale variability is *predictable*
- when forcing is weak one can investigate predictability of this *internally generated* component
- but for 21st century we want predictability of both *forced* and *internal components*

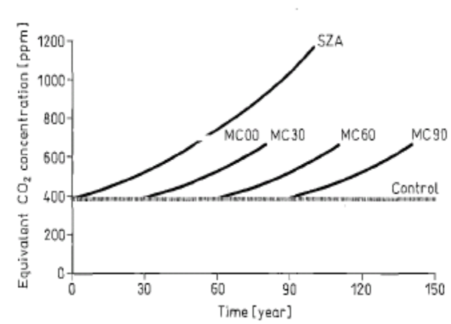
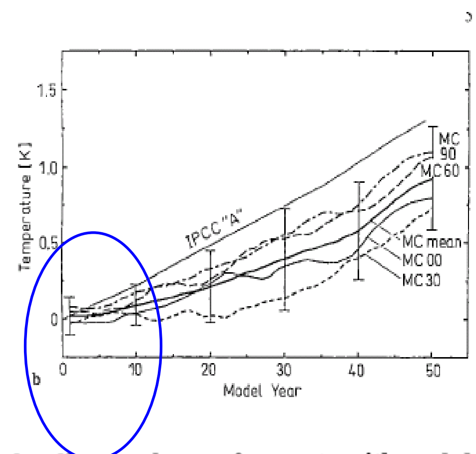


Fig. 1. Schematic diagram of the "Monte Carlo" climate forecasts



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

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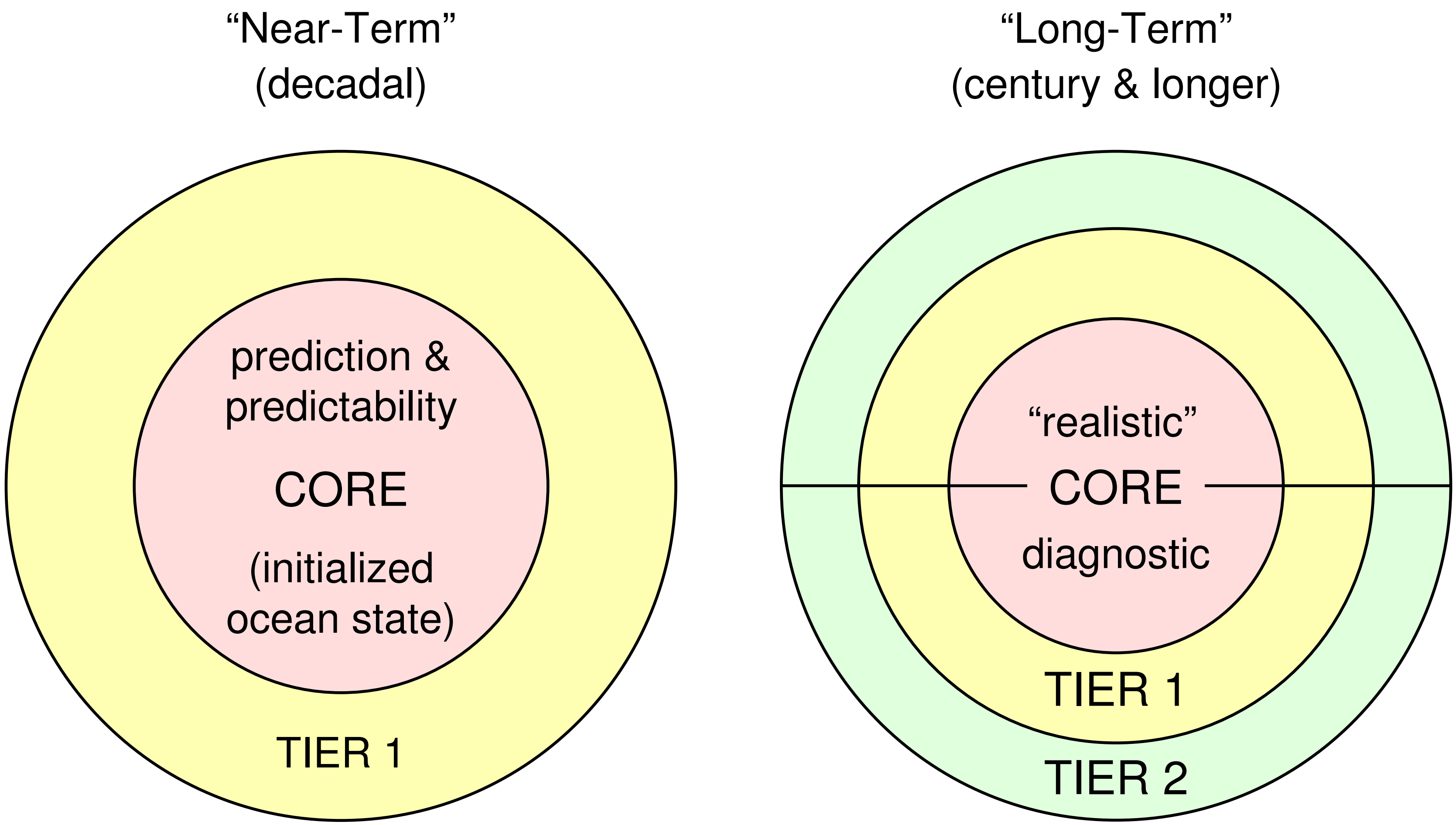
CMIP5 Experiment Design



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, …)

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)
  - *Boer (2010)*
  - and others
- Investigations of forecast skill
  - Smith et al. (2008)
  - Keenlyside et al. (2008)
  - Pohlmann et al. (2009)
  - *Merryfield et al. (2010)*
  - CMIP5 (2010+ ….)

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

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

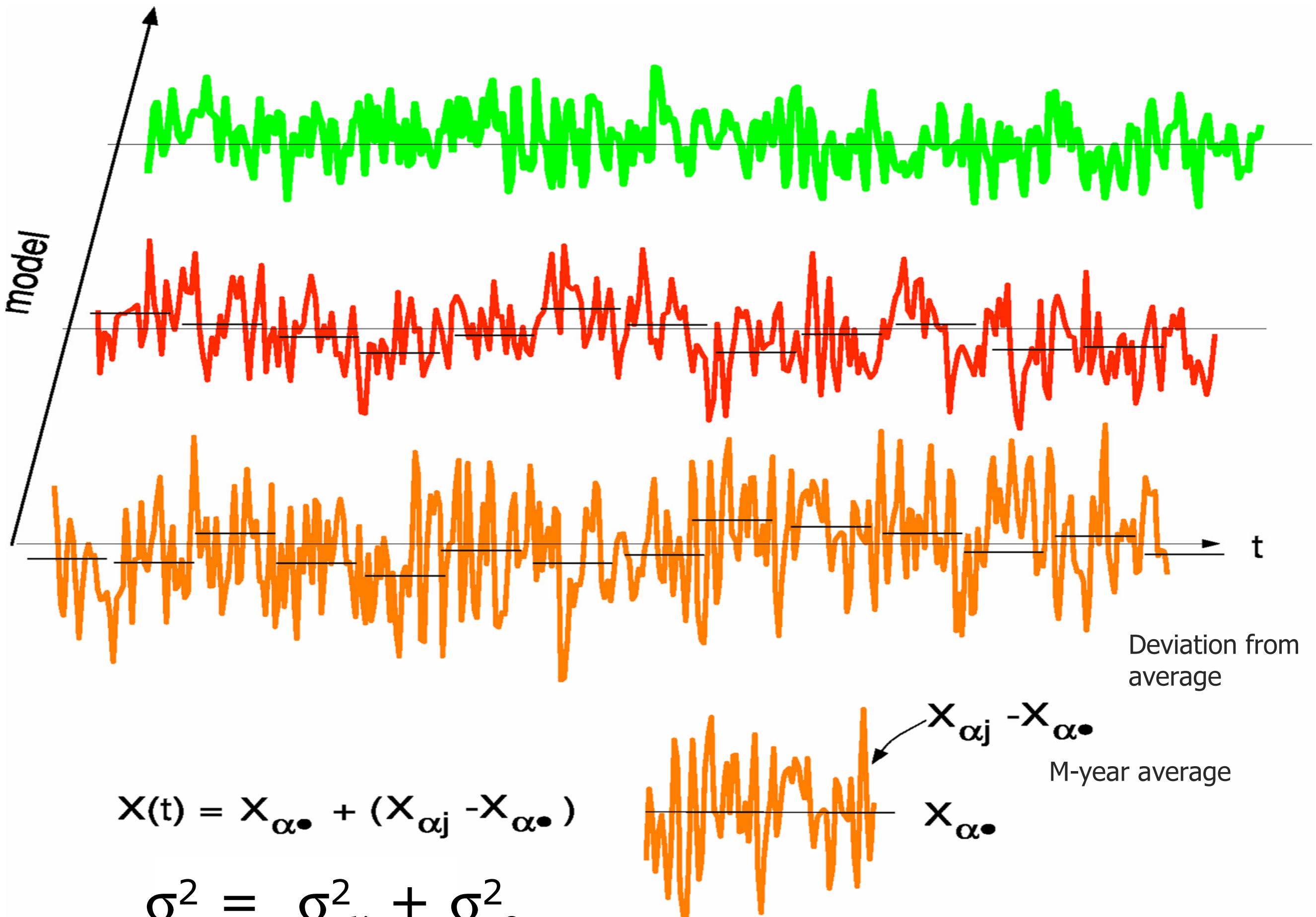
- in terms of a signal to noise measure

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

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

- 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*
  - *a variance measure (not a correlation like measure)*

Internally generated long timescale potential predictability



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

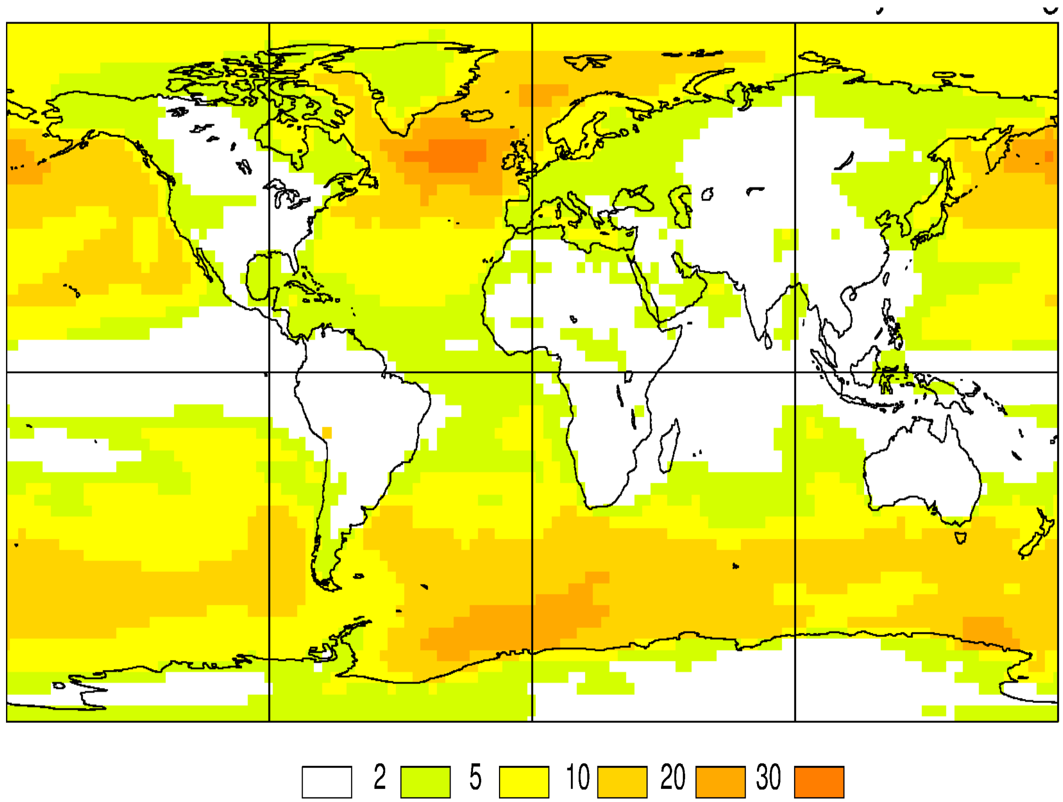
$$\sigma^2 = \sigma^2_{\nu} + \sigma^2_{\varepsilon}$$

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)

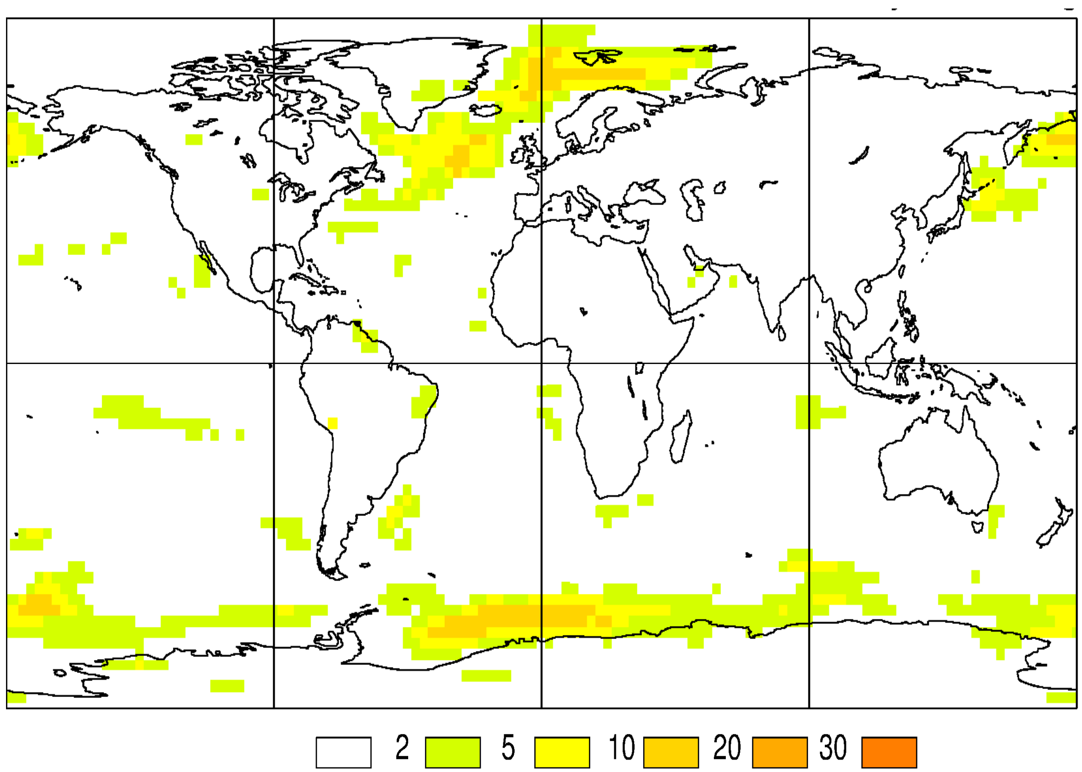


Control simulations

Boer and Lambert, 2008

Precipitation: potential predictability of internally generated variability $p_\nu = \sigma^2_\nu/\sigma^2$ (%) 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

21^{st} Century decadal potential predictability

- Variable *now has forced component*

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

with associated variances

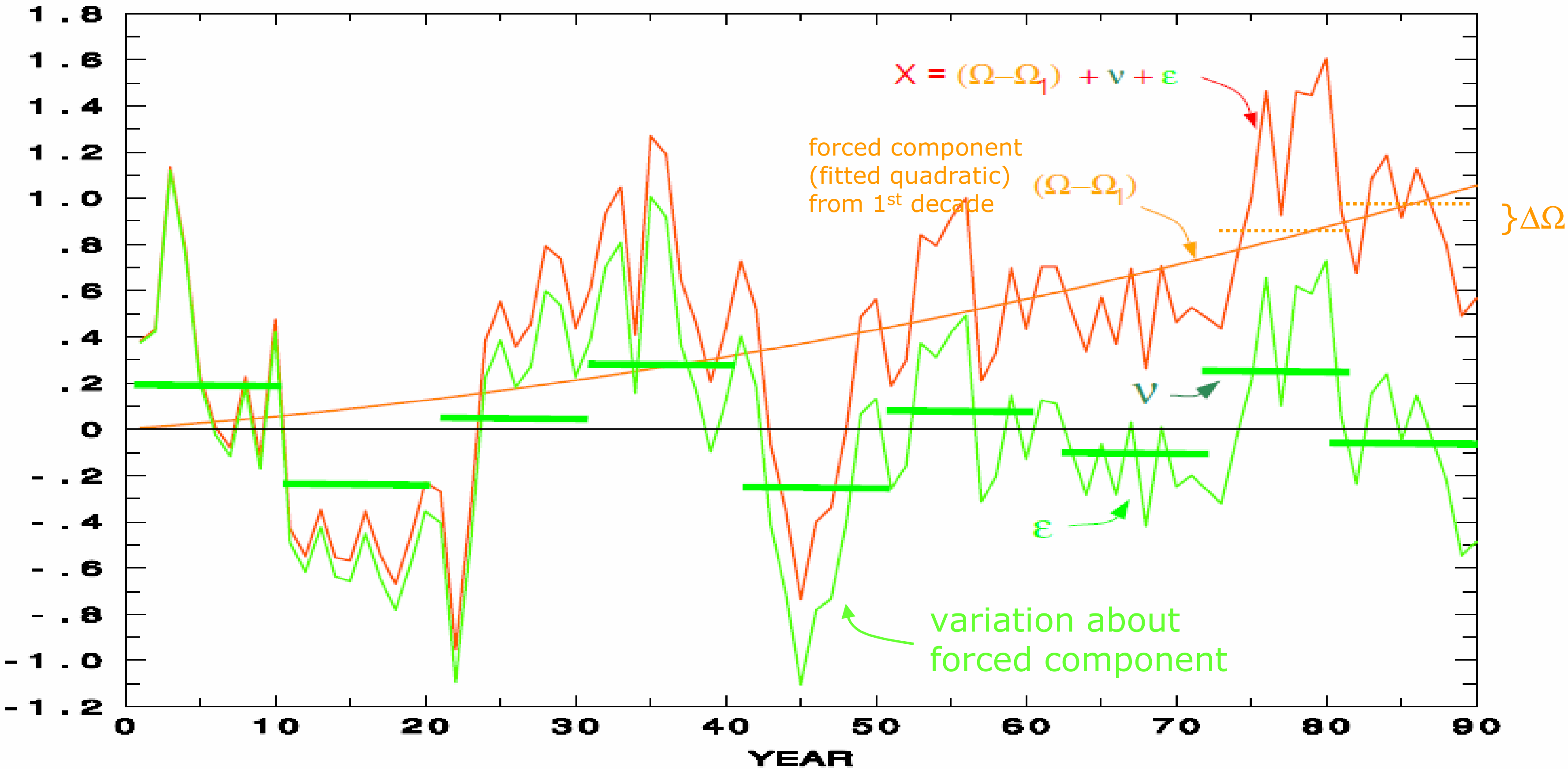
$$\sigma^2 = \sigma^2_{\Omega} + \sigma^2_{\nu} + \sigma^2_{\varepsilon}$$

- Ω is long timescale *externally forced* variability
  - obtained by fitting 2^{nd} order orthogonal polynomial
- 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

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

21^{st} century temperature at a point

- forced component from 1^{st} 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

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

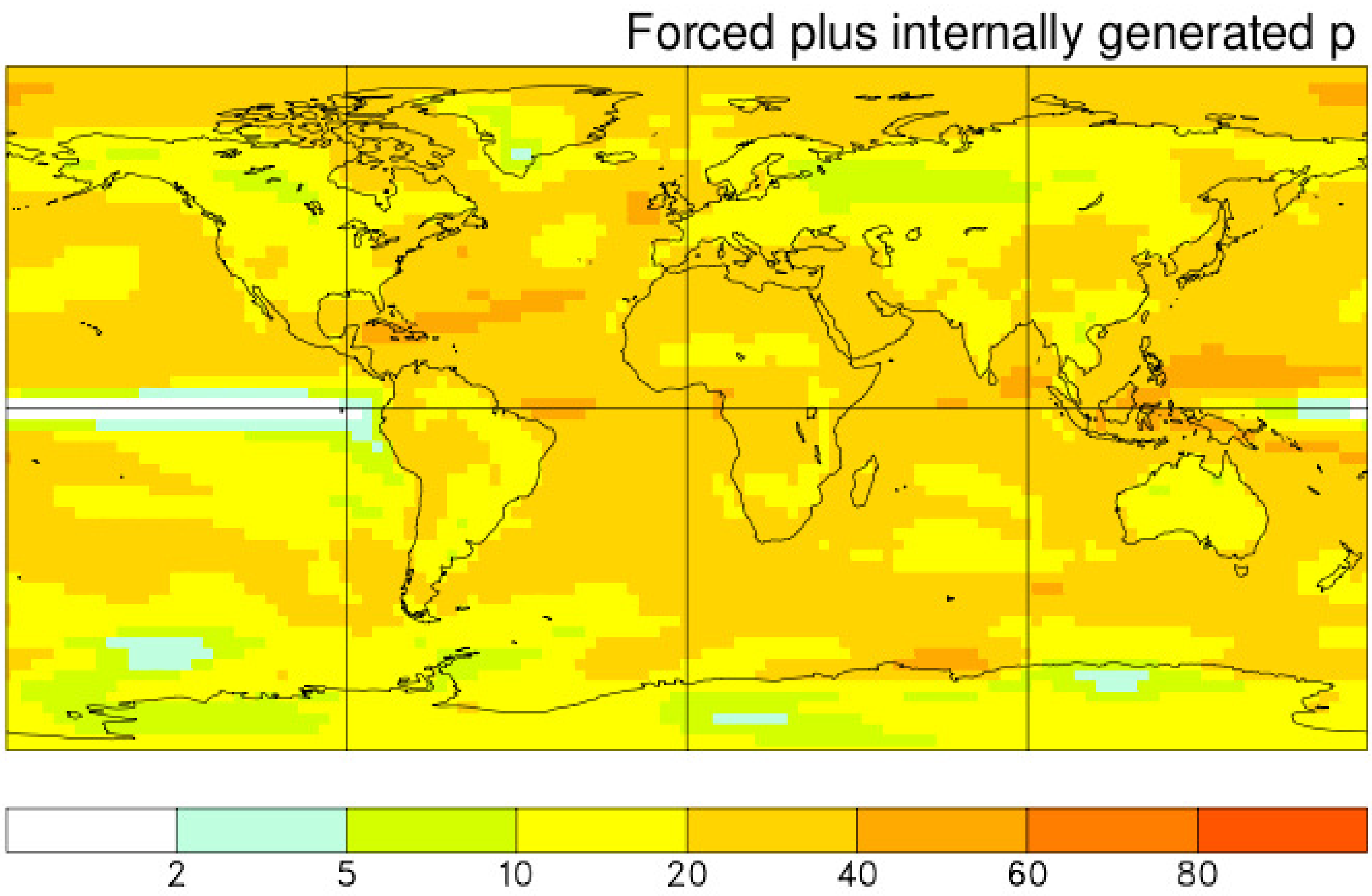
$$\hat{\sigma}_{\nu}^{2} = \frac{n}{n-(b+1)} S_{\nu}^{2} - \frac{S_{\varepsilon}^{2}}{m-1}.$$

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

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

- 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

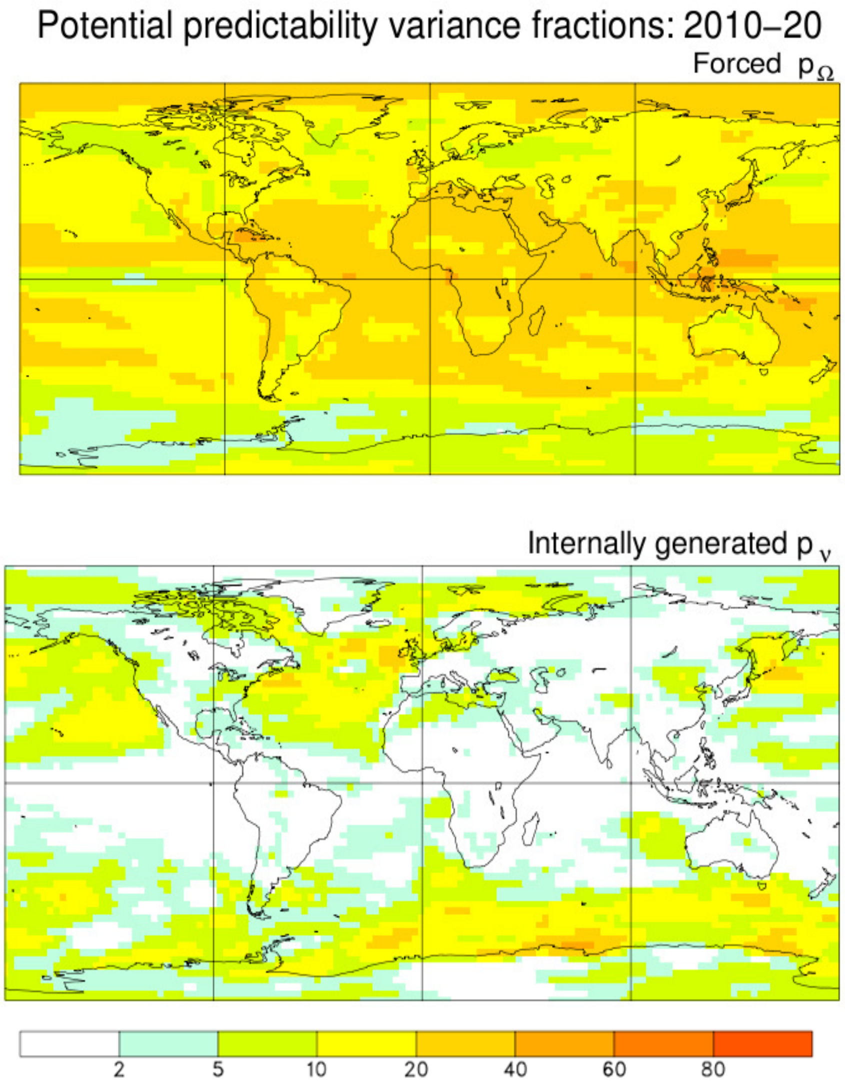
Net potential predictability of temperature for *2010-20 (or "next decade" result generally)*



Forced component of potential predictability for temperature and *forced component* of temperature change for *2010-20*

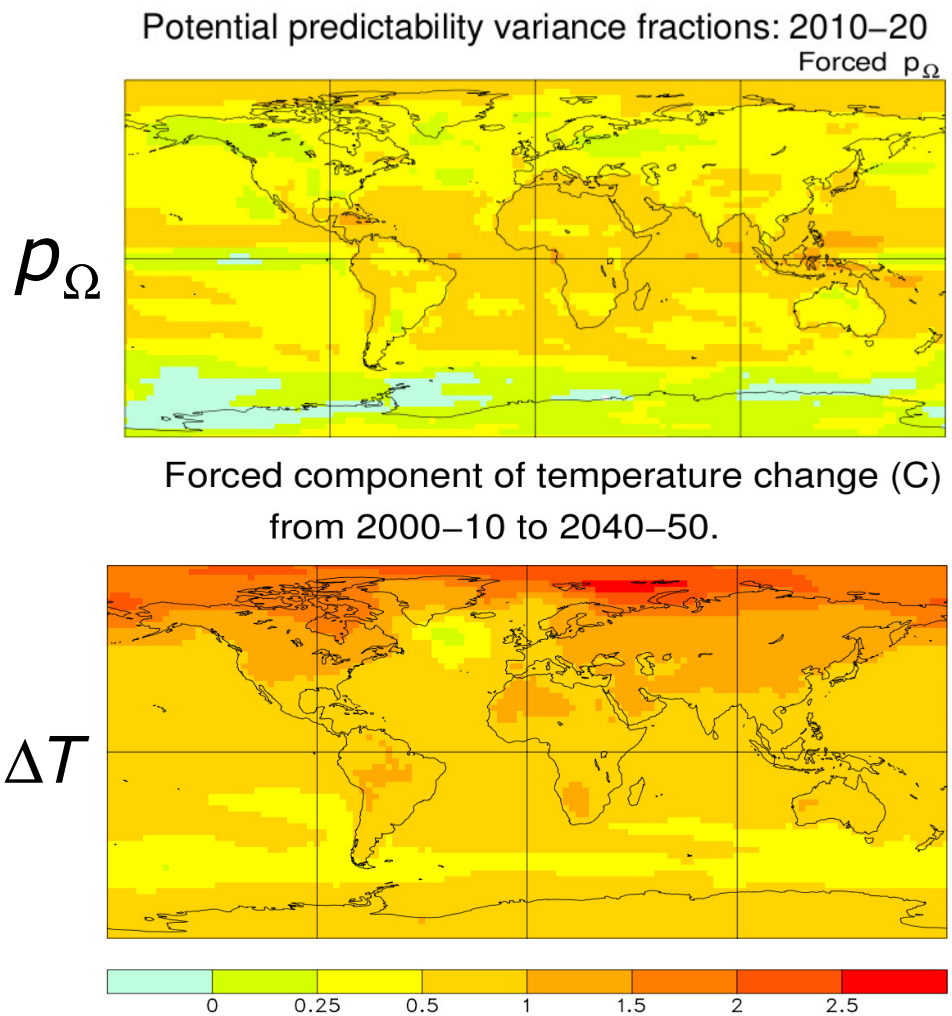
p_Ω

p_ν



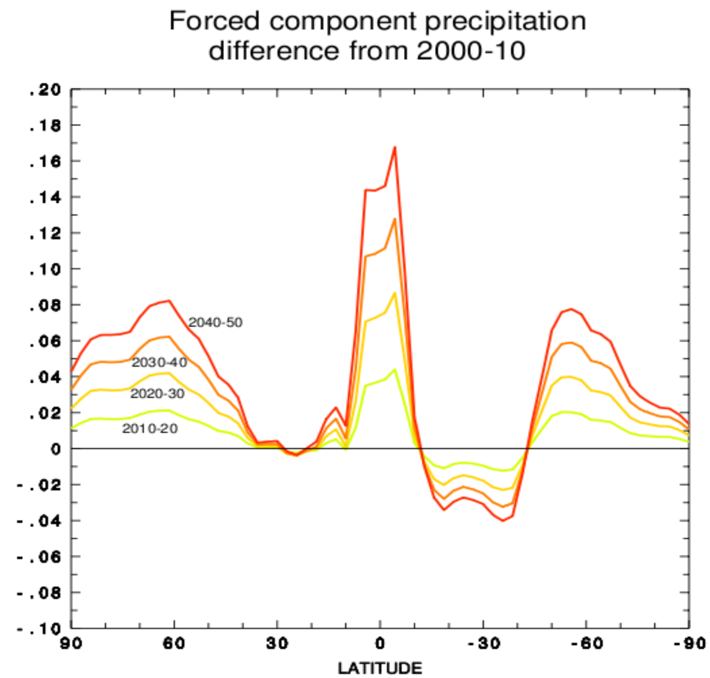
- percentage of total variance over decade
  - associated with forced component
  - associated with internal variability
- p_Ω and p_ν tend to be inverses of one another so $p = p_\Omega + p_\nu$ is more uniform than either

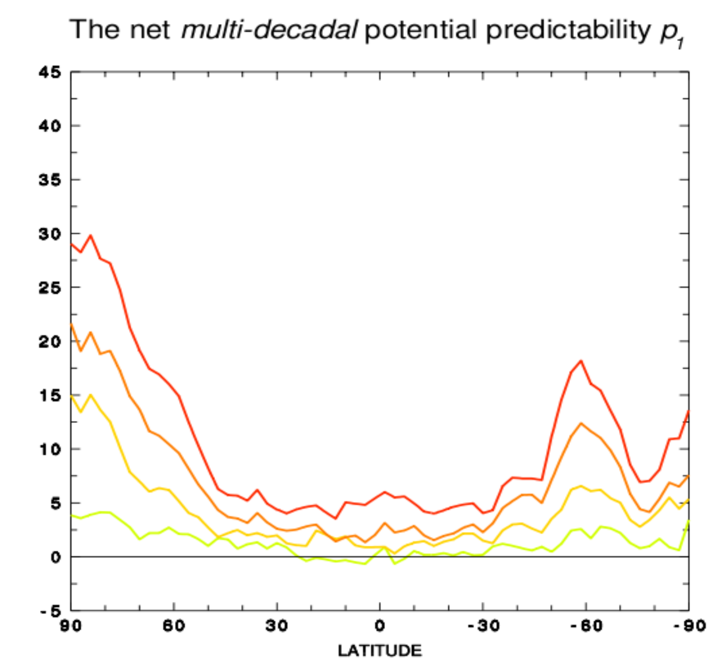
Forced component of potential predictability for temperature and *forced component* of temperature change for *2010-20*



- forced p_{Ω} differs in pattern from forced ΔT
- $p_{\Omega} = \sigma^2_{\Omega} / (\sigma^2_{\Omega} + \sigma^2_{\nu} + \sigma_{\varepsilon}^2)$
  - for σ^2_{Ω} => ΔT^2
- noise variance σ_{ε}^2 in the denominator discounts ΔT over northern land

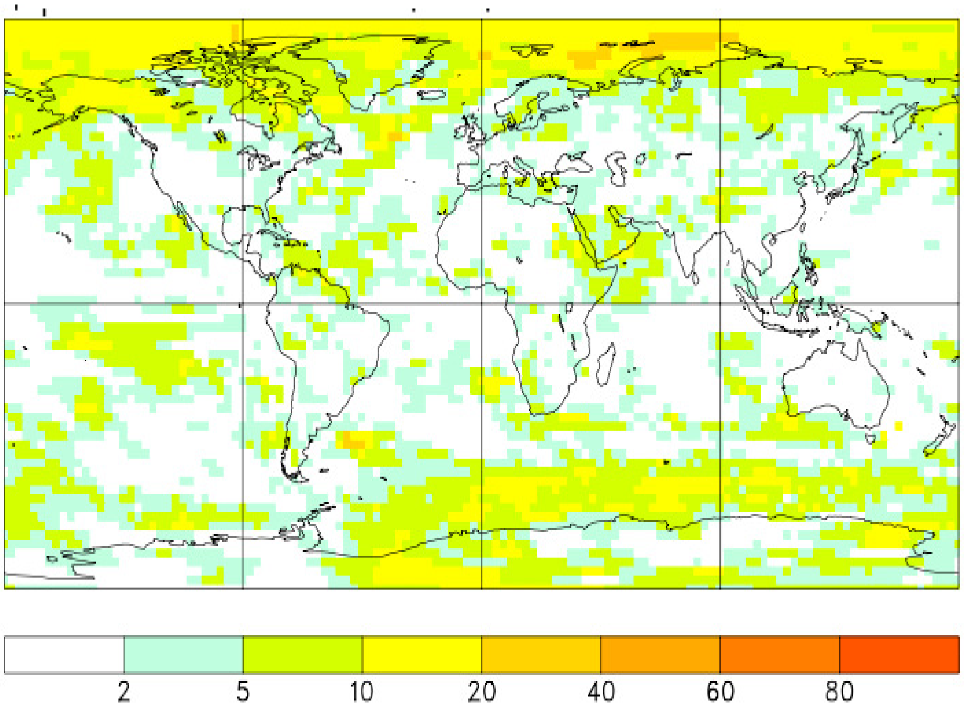
- Precipitation
  - *forced component* dominates
  - *no* potential predictability for *internally generated* component
  - *next-decade* p_{Ω} is small (noise is large)
  - *multi-decade* p_{Ω} depends on growing *forced* component





Potential predictability of precipitation

Potential predictability of precipitation: 2020-30 (i.e. for *second* decade)



- *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

The challenges and caveats of potential predictability studies

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

end of presentation