Decadal Multi-Model Potential Predictability

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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

\[ X(t) = X_{\alpha} + (X_{\alpha_j} - X_{\alpha}) \]

\[ S^2 = S^2_v + S^2_e \]
Statistical model

- Statistical model is
  \[ X = \Omega + \nu + \epsilon \]

  with associated variances
  \[ \sigma^2 = \sigma^2_\Omega + \sigma^2_\nu + \sigma^2_\epsilon \]

  - \( \Omega \) is long timescale *externally forced* variability (if present)
  - \( \nu \) is long timescale *internally generated* variability
  - \( \epsilon \) 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

Global annual means
B1 scenario
11 simulations (less data)
Ensemble forced component from fitted orthogonal polynomials
Approach

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

\[ X_i = X(\alpha - 1)M + j = X_{\alpha j} \]

\[ X_{\alpha j} = P_\alpha + (X_{\alpha \cdot} - P_\alpha) + (X_{\alpha \cdot} - X_{\alpha j}) \]

\[ S^2 = \frac{S^2}{\Omega} + S^2_B + S^2_\varepsilon = \overline{X^2} \]

\[ = \frac{P^2_\alpha}{\Omega} + (X_{\alpha \cdot} - P_\alpha)^2 + (X_{\alpha \cdot} - X_{\alpha j})^2 \]

Long TS forced (if present)
Long TS internally generated
Short TS noise

Statistics are pooled across models in multi-model case

\[ i = 1 \ldots NM \]
\[ \alpha = 1 \ldots N \]
\[ j = 1 \ldots M \]

\[ X_{\alpha \cdot} = \frac{1}{M} \sum_{j=1}^{M} X_{\alpha j} \]

is M-year average

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

is orthogonal polynomial fit
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* $p_v = \sigma^2_v / \sigma^2$
  - indication of *relative importance*
  - expect low $p_v$ where $\sigma^2_v$ is low or $\sigma^2$ 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*
Observation-based Multi-model ensemble

Standard Deviation of annual means

Temperature

Precipitation
Temperature: potential predictability variance fraction $\rho_{\nu} = \frac{\sigma_{\nu}^2}{\sigma^2} (%)$ for decadal means

- Ratio of “predictable” to total variance
- MME provides stability of statistics: \textit{ppv}f 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 \textit{ppv}f (denominator is large)
**Precipitation**: potential predictability variance fraction $\rho_\nu = \sigma_\nu^2/\sigma^2$ (%) 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"
21st 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

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Ensemble forced component from fitted orthogonal polynomials
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 20\textsuperscript{th} century

Next decade within the 21\textsuperscript{st} century
Variance fractions for decade 2010-2020: Temperature

- 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
Potential predictability of internal component for a warmer world

Global annual means
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Ensemble forced component from fitted orthogonal polynomials
Potential predictability in a warmer world (stabilization case)

- Consider long timescale *internally generated* natural variability $\sigma^2_v$
  - 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 $p_{\nu}$ 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