Decadal Predictability in CCSM3

Haiyan Teng and Grant Branstator

NCAR CGD

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Two Limits of Initial-value Decadal Predictability

**Total predictability:** $P_e(t)$ vs. $P_c(0)$

**Initial-value predictability:** $P_e(t)$ vs. $P_c(t)$

**Forced predictability:** $P_c(t)$ vs. $P_c(0)$

\[
R = \int_P P_x(s) \log_2 \left[ \frac{P_x(s)}{P_b(s)} \right] ds
\]

*For normal distribution: Kleeman (2002)*

\[
R = \frac{1}{2} \log_2(e) \left\{ \ln \left[ \frac{\det(\sigma_b^2)}{\det(\sigma_x^2)} \right] + \text{trace} \left( \frac{\sigma_b^2}{\sigma_x^2} \right) + (\mu_x - \mu_b)^T \left( \sigma_b^2 \right)^{-1} (\mu_x - \mu_b) - n \right\}
\]

$P_x(s)$: prediction

$P_b(s)$: base

**dispersion**

signal
**Model & Experiments**

- **CCSM3.0, T42 atm, 1deg ocn**

- **40-member ensemble run**
  - A1B, Commitment
  - 2000-2061
  - atm perturbed ICs
  - Same ocn/Ind/ice ICs

- **A1B (II), A1B(III), A1B (IV)**
  - Different ocn/ice/Ind ICs
  - 20 years

- Last 700 yrs of the 1000-yr control
- Annual mean ocn T0-300

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**CO2 Concentrations**

![CO2 Concentration Graph](image)
Basins and Bases

T0-300 variance-weighted frequency => period

Calculated from 700-year control run
Predictability Measured by Relative Entropy

Based on leading 15 EOFs in T0-300 in each basin.
Sensitivities & Robustness

**Insensitive to**
- Layer depth
- The two scenarios
- The four ocean ICs
- Prominent modes
- Temporal smoothing

**Sensitive to**
- Basin to basin variations
- Sample size

*Branstator and Teng, 2010: Two limits of initial-value decadal predictability in a CGCM. J. Climate*
Leading EOFs in the North Pacific

From 700-year control
Evolution of T0-300, SST and SLP
Based on EOF1&EOF2 of T0-300

composite based on 10-30-yr filtered data
Predictability of the North Pacific Leading EOFs

A1B

PC1

A1B(II)

PC2

Ensemble I

PC1&PC2

A1B(III)

Ensemble II

Ensemble III

Year

$R$, $R_{\text{signal}}$, $R_{\text{dispersion}}$
Predictability of the Leading EOFs from LIM

Teng and Branstator, Climate Dynamics in press
Lag regression from PC1 of the AMOC

T0-300 similar to T0-500
Teng, Branstator, and Meehl 2011, submitted to J. Climate
Lag regression from PC1 of the AMOC
R15 of NH (20-90N)
R Signal (15 EOFs)

Annual/seasonal mean

Five year running mean
Summary

• **In CCSM3**, information from the ocean *initial* condition exceeds that from the forced response for about seven years. After about a *decade*, prediction becomes a **boundary condition problem**.

• The leading EOFs are not necessarily the most predictable modes. **Propagating modes** need to be taken into account when quantifying predictability.

• Decadal variability in both NP and NA can bring surface climate predictability beyond ENSO time scale. However, the resulting initial-value **predictability** in the atmosphere is **very weak**.
Ongoing & future work ...

Low-pass T0-300 variance
Thank you!
AMOC Leading EOF/CEOF Modes
Signal and Dispersion Components of Initial-value Predictability
Two Limits of Initial-value Decadal Predictability
Assumptions:
1. Gaussians
2. Covariance does not change with time.
3. Climate mean can be well approximated by an analytical function of time.

Time evolving climate mean:

\[
T_{A1B}(t) = T_{1999} + k(t - 1999)
\]

\[
T_{\text{commit}}(t) = T_{1999} + A(1 - e^{-t/\tau})
\]

✓ Initial-value components
✓ Forced response
Heat Budget Analysis

\[ \frac{\partial T_{0-300}}{\partial t} = -\frac{Q_{\text{net}}}{\rho_0 C_p H} + A + B + \text{res} \]

A,B: horizontal and vertical convergence of temperature flux, averaged over 300m

Teng and Branstator (2010)
Linear Inverse Model (LIM)
Penland (1989)

\[ \frac{dX}{dt} = BX + \xi \]

\[ X(t + \tau) = e^{B\tau} X(t) \]

\[ B = \tau_0^{-1} \ln \{ C(\tau_0)C(0)^{-1} \} \]

\[ C(\tau_0) = \langle X(t + \tau_0)X^T(t) \rangle \]

\[ C(0) = \langle X(t)X^T(t) \rangle \]

\[ G \equiv \exp(B\tau) = [G(\tau_0)]^{/\tau_0} \]

- For initial state \( \tilde{X}(t) \), forecasts at \( t+\tau \) has mean

\[ \bar{X}(t + \tau) = G(\tau)\tilde{X}(t) \]

and covariance

\[ \langle X(t + \tau)X^T(t + \tau) \rangle = C(0) - G(\tau)C(0)G^T(\tau) \]
Predictability Measured by Mean

- North Pacific
- North Atlantic
- Tropical Pacific
- Tropical Atlantic

RMS (°C) vs Year

Graphs show the RMS (Root Mean Square) temperature deviations from 2000 to 2020, with different scenarios and regions indicated.