Canonical skill analysis of tropical Pacific variability in the CCCma decadal hindcasts

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Content

- Prediction system and verifying observations used
- Brief description of Canonical Skill Analysis (CSA)
- Perform CSA of tropical Pacific sea surface temperature in CCCma decadal hindcasts
Prediction system and verifying observations used

- **Model**: CanCM4

- **Resolution**: Atmosphere: T63 L35 ($\approx 300$ km)
  Ocean: $1.4^\circ$ lon $\times$ $0.94^\circ$ lat, L40

- **Initialization**: Full field

- **Ensembles**: Separate coupled initialization run for each ensemble member

- **Hindcasts**: 10 members, 1960–2010, initialized every year in late December. CCCma’s contribution to CMIP5

- **Forecasts**: 10 members produced in real time initialized in late 2011–present. CCCma’s regular contribution to the Met Office Informal multimodel decadal forecast exchange

  Merryfield et al. 2013, MWR 141, 2910–2945
Prediction system and verifying observations used

- **Verifying Observations:** NOAA’s ERSSTv5
- **Resolution:** $2^\circ \times 2^\circ$

Huang et al., 2017, J Clim 30, 8179–8205

**In this talk we examine:**

- predictions of mean seasonal Tropical Pacific SST anomalies between $20^\circ S$ and $20^\circ N$
- target time period: 1971–2015
- lead times up to 10-years (only first 2 shown here)
- SST predictions given by the ensemble mean
- global averaged SST anomalies removed
- forecasts and obs regridded to the same space resolution
Canonical Skill Analysis (Skill = CORR or MSSS)

**Canonical Correlation Analysis** is used to examine the correlation structure of two fields.

**Canonical Skill Analysis** is used to examine the skill structure of a spatially variable anomaly forecast relative to observations.

With CSA, the forecast is decomposed into a sum of temporally uncorrelated components ordered from the most to the least skilful, plus an independent term that does not contribute to actual skill.

The verifying observations are similarly decomposed into a sum of temporally uncorrelated components predicted by the forecast, plus an independent term that is not predicted.
Method: Canonical Skill Analysis (Skill = CORR or MSSS)

Step 1  Pre-filter data: **Standard EOF decomposition**

\[ \mathbf{X} = \sum_{i=1}^{T_x} f_x^i e_x^i + \mathbf{X}' = \mathbf{X}_{T_x} + \mathbf{X}' \quad \text{Observations} \]

\[ \mathbf{Y} = \sum_{i=1}^{T_y} f_y^i e_y^i + \mathbf{Y}' = \mathbf{Y}_{T_y} + \mathbf{Y}' \quad \text{Hindcasts} \]

Step 2  **Skill-maximizing EOF decomposition** of \( \mathbf{X}_{T_x} \) and \( \mathbf{Y}_{T_y} \)

\[ \mathbf{X}_{T_x} = \sum_{i=1}^{T} \nu_x^i p_x^i + \mathbf{X}'' = \tilde{\mathbf{X}} + \mathbf{X}'' \quad \text{Filtered Observations} \]

\[ \mathbf{Y}_{T_y} = \sum_{i=1}^{T} \nu_y^i p_y^i + \mathbf{Y}'' = \tilde{\mathbf{Y}} + \mathbf{Y}'' \quad \text{Filtered Hindcasts} \]

\[ T = \min(T_x, T_y) \]

\( \nu \)'s – Time dependent canonical variates

\( p \)'s – Space dependent canonical patterns
Method: Skill decomposition

Each term of $\tilde{Y}$ is potentially skilful

Goal

Find the dimensions $T_x$ and $T_y$ of the filtered obs and forecasts such that only the terms with actual skill (if any) are retained

Decomposition of correlation skill

- Raw correlation
  \[ \text{CORR}(X, Y) \approx \text{CORR}(X, \tilde{Y}) \]

- Correlation of skilful variance
  \[ \text{CORR}(X, \tilde{Y}) \approx \sqrt{\frac{\text{VAR}(\tilde{X})}{\text{VAR}(X)}} \sum_{i=1}^{T} \omega_x \omega_y_i \text{CORR}(v_x^i, v_y^i) \text{CORR}(p_x^i, p_y^i) \]

\( \omega \)'s = variance fraction retained by the canonical components
Results: Skill decomposition

Correlation decomposition; SSTA; CanCM4 vs ERSSTv5; 1971–2015

Variance retained by $\tilde{Y}$ and $\tilde{X}$

$\text{CORR}(X,Y)$

$\text{CORR}(X,\tilde{Y})$
Results: Skill decomposition

Correlation decomposition; SSTA; CanCM4 vs ERSSTv5; 1971–2015

Variance retained by $\widetilde{Y}$ and $\widetilde{X}$
Results: Dimension selection and skill decomposition

Estimated dimensions of filtered forecast and obs

Verification of the estimated dimensions

Correlation decomposition; JFM; 1.5-month; 1971-2015

Correlation decomposition; JFM; 13.5-month; 1971-2015
Results: Canonical Components – JFM at 13.5-month lead

Because there is only one skilful component at this lead time, then

$$\text{CORR}(X, Y) = \sqrt{\frac{\text{VAR}(f^1_x)}{\text{VAR}(X)}} \cdot \text{CORR}(f^1_x, f^1_y) \cdot \text{CORR}(e^1_x, e^1_y) + \epsilon$$

with $\epsilon = -0.01$

i.e., the overall skill is given by the leading PC, the leading EOF, and the variance fraction retained by the obs leading mode.
Results: Canonical Components – JFM at 1.5-month lead

(a) Loading 1; 54.4%; ERSSTv5; JFM; 1.5-month

(b) Loading 1; 64.6%; CanCM4; JFM; 1.5-month

(c) Loading 2; 11.8%; ERSSTv5; JFM; 1.5-month

(d) Loading 2; 8.02%; CanCM4; JFM; 1.5-month

(e) Canonical Variate 1; CC = 0.99; JFM; 1.5-month; 1971-2015

(f) Canonical Variate 2; CC = 0.95; JFM; 1.5-month; 1971-2015
Conclusions

- CSA decomposes the forecast variance into a part that has skill and a part that has not.

- CSA decomposes the obs variance into a part that is predicted by the forecast and a part that is not predicted.

- CSA effectively decomposes skill of raw forecasts into the skill of its canonical components i.e., into the sum of the correlation of the variates times the correlation of the canonical patterns weighted by the variance fraction retained by the canonical components.

- MSSS can be decomposed in the same fashion.
Conclusions:

- For tropical Pacific SST anomalies in CCCma decadal hindcasts:
  - Leading EOF mode carries most of the skill, but secondary modes (e.g., El Niño Modoki) also contribute to skill during first year of the forecast.
  - ENSO forecasts skilful at least 1–2 years in advance, but no skill at forecasting “flavors” of ENSO passed the first year.
  - Forecasts typically employ more variance to attain skill than it can predict, likely the result of model biases.

- In the perfect model approach where obs are realizations of the climate model, the skilful variance is an estimate of the potentially predictable variance.
Appendix
Results: The skilful and predicted components

JFM Tropical Pacific SSTs (1971–2015) – 1.5-month lead

Correlation of the variates:
- **Spatial weights from training period:** 1971–1994
- **Correlations from verification period:** 1995–2015

Dimension of filtered Spaces
- Model vs Obs

**Canonical Correlations 1971–2015**

**Variance fraction 1971–2015**

- **Observations**
- **Forecasts**
Results: The skilful and predicted components

JFM Tropical Pacific SSTs (1971–2015) – 1.5-month lead

Correlation of the variates:
Spatial weights from training period: 1971–1994
Correlations from verification period: 1995–2015

Dimension of filtered Spaces
Model vs Obs
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Appendix: Contribution by canonical components
Appendix: Skill decomposition – various lead times

(a) JFM; 1.5-month; 1971-2015

(b) MAM; 3.5-month; 1971-2015

(c) JJA; 6.5-month; 1971-2015

(d) SON; 9.5-month; 1971-2015

(e) JFM; 13.5-month; 1971-2015

(f) MAM; 15.5-month; 1971-2015
Appendix: Skill vs lead

(a) JFM; Init: Dec 31; 1971-2015

(b) MAM; Init: Dec 31; 1971-2015

(c) JJA; Init: Dec 31; 1971-2015

(d) SON; Init: Dec 31; 1971-2015