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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° lon $\times$ 0.94° 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°S and 20°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**

$$\mathbf{X} = \sum_{i=1}^{T_x} f_x^i \mathbf{e}_x^i + \mathbf{X}' = \mathbf{X}_{T_x} + \mathbf{X}' \qquad \textbf{Observations}$$

$$\mathbf{Y} = \sum_{i=1}^{T_y} f_y^i \mathbf{e}_y^i + \mathbf{Y}' = \mathbf{Y}_{T_y} + \mathbf{Y}' \qquad \textbf{Hindcasts}$$

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

$$\mathbf{X}_{T_x} = \sum_{i=1}^{T} v_x^i \mathbf{p}_x^i + \mathbf{X}'' = \tilde{\mathbf{X}} + \mathbf{X}'' \qquad \textbf{Filtered Observations}$$

$$\mathbf{Y}_{T_y} = \sum_{i=1}^{T} v_y^i \mathbf{p}_y^i + \mathbf{Y}'' = \tilde{\mathbf{Y}} + \mathbf{Y}'' \qquad \textbf{Filtered Hindcasts}$$

$T = \min(T_x, T_y)$

v's – Time dependent canonical variates

$\mathbf{p}$'s – Space dependent canonical patterns

Method: Skill decomposition

Each term of $\tilde{\mathbf{Y}}$ 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

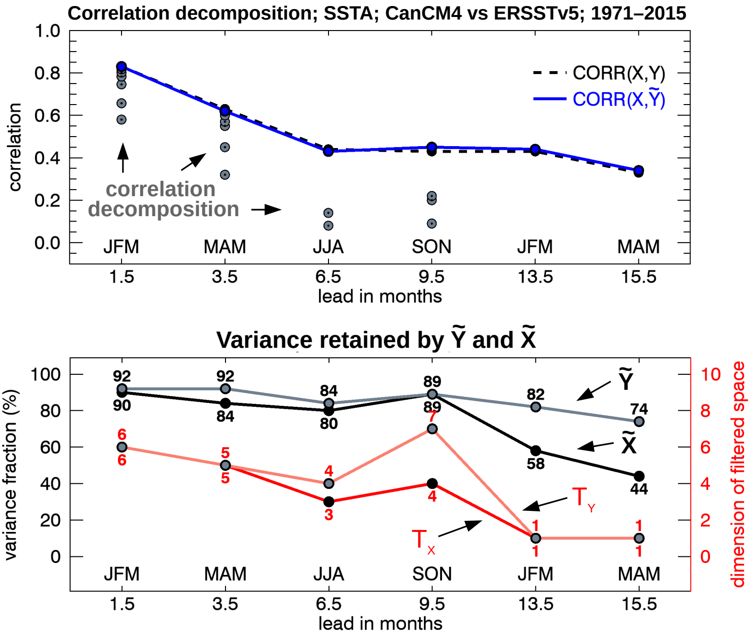
Decomposition of correlation skill

$$\overbrace{\mathrm{CORR}(\mathbf{X}, \mathbf{Y})}^{\text{raw correlation}} \approx \overbrace{\mathrm{CORR}(\mathbf{X}, \tilde{\mathbf{Y}})}^{\text{correlation of skilful variance}} \quad \text{for suitable } T_x \text{ and } T_y$$

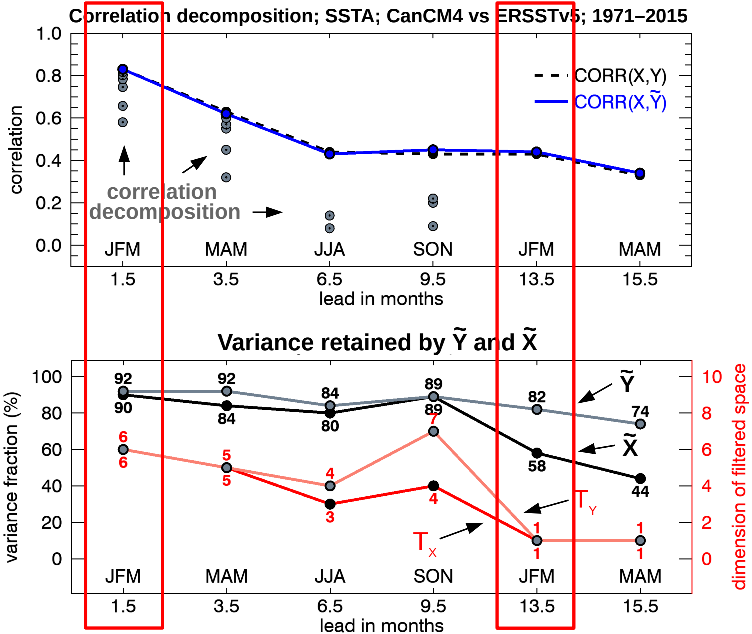
$$\mathrm{CORR}(\mathbf{X}, \tilde{\mathbf{Y}}) \approx \underbrace{\sqrt{\frac{\mathrm{VAR}(\tilde{\mathbf{X}})}{\mathrm{VAR}(\mathbf{X})}} \sum_{i=1}^{T} \omega_{x\,i} \omega_{y\,i} \mathrm{CORR}(v_x^i, v_y^i) \mathrm{CORR}(\mathbf{p}_x^i, \mathbf{p}_y^i)}_{\text{correlation decomposition}}$$

ω's = variance fraction retained by the canonical components

Results: Skill decomposition

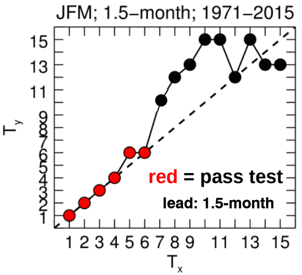


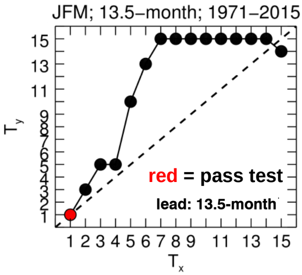
Results: Skill decomposition



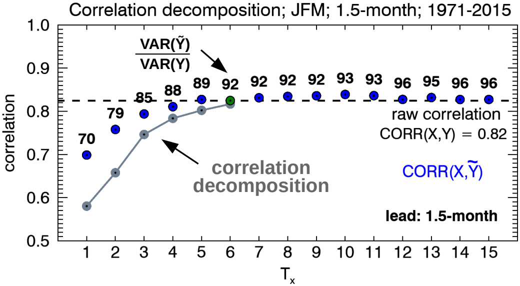
Results: Dimension selection and skill decomposition

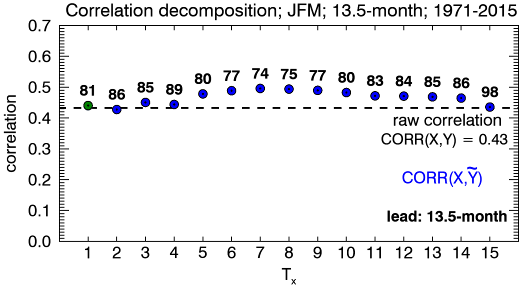
Estimated dimensions of filtered forecast and obs



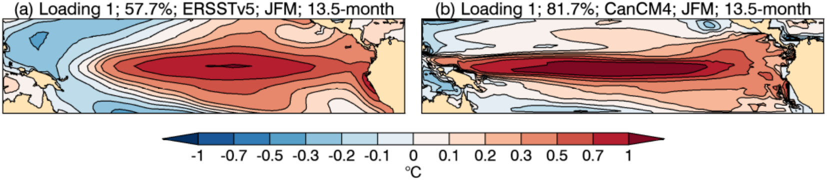


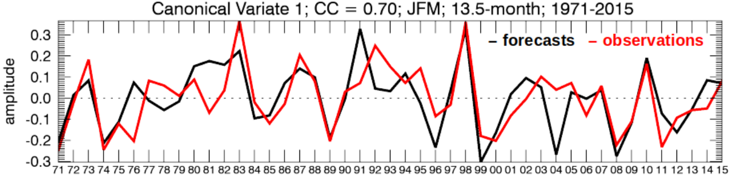
Verification of the estimated dimensions





Results: Canonical Components – JFM at 13.5-month lead



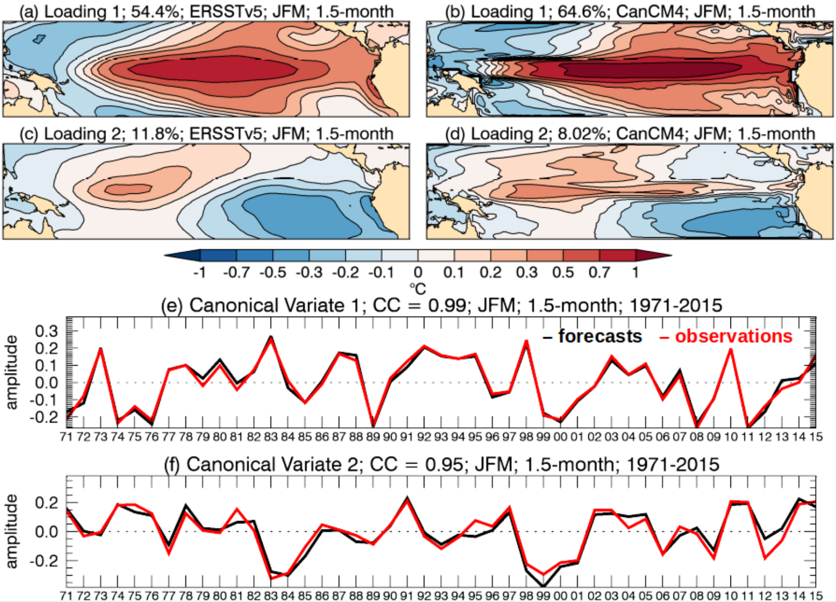


Because there is only one skilful component at this lead time, then

$$\underbrace{\mathrm{CORR}(\mathbf{X},\mathbf{Y})}_{0.43} = \underbrace{\sqrt{\frac{\mathrm{VAR}(f_x^1)}{\mathrm{VAR}(\mathbf{X})}}}_{0.76}\,\underbrace{\mathrm{CORR}(f_x^1, f_y^1)}_{0.70}\,\underbrace{\mathrm{CORR}(\mathbf{e}_x^1, \mathbf{e}_y^1)}_{0.83} + \underbrace{\epsilon}_{-0.01}$$

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



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

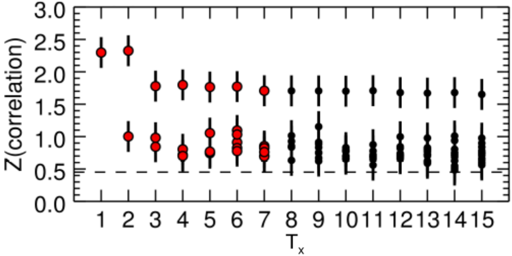
- **In the perfect model approach** where obs are realizations of the climate model, **the skilful variance is an estimate of the potentially predictable variance**

Appendix

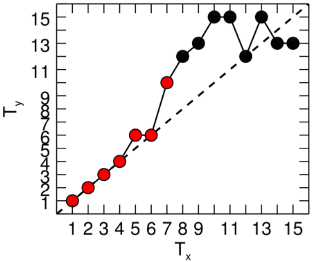
Results: The skilful and predicted components

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

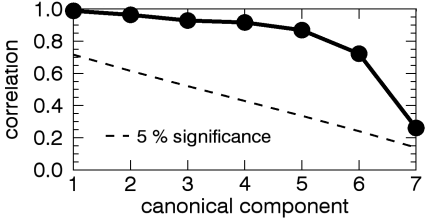
Correlation of the variates:
Spatial weights from training period: 1971–1994
Correlations from verification period: 1995–2015



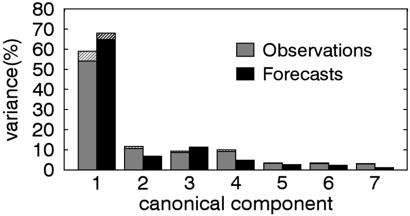
Dimension of filtered Spaces Model vs Obs



Canonical Correlations 1971–2015

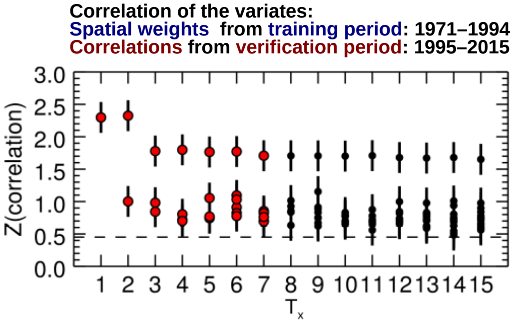


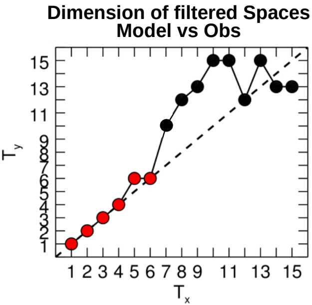
Variance fraction 1971–2015

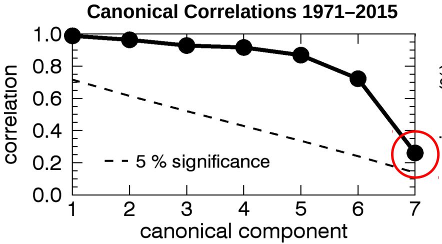


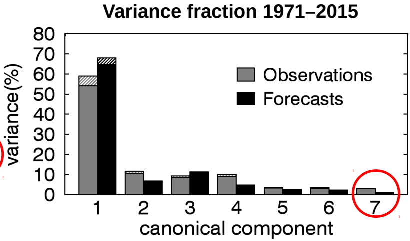
Results: The skilful and predicted components

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

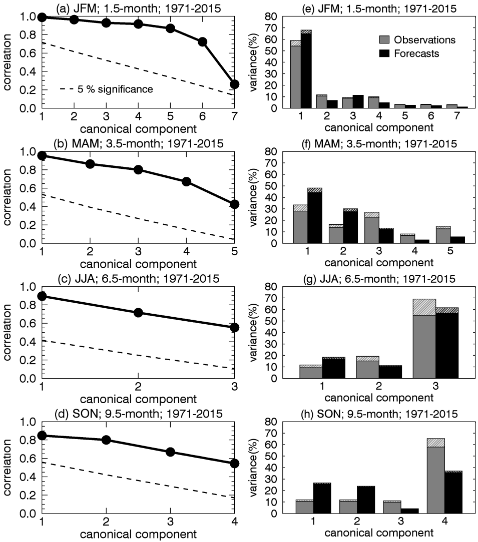




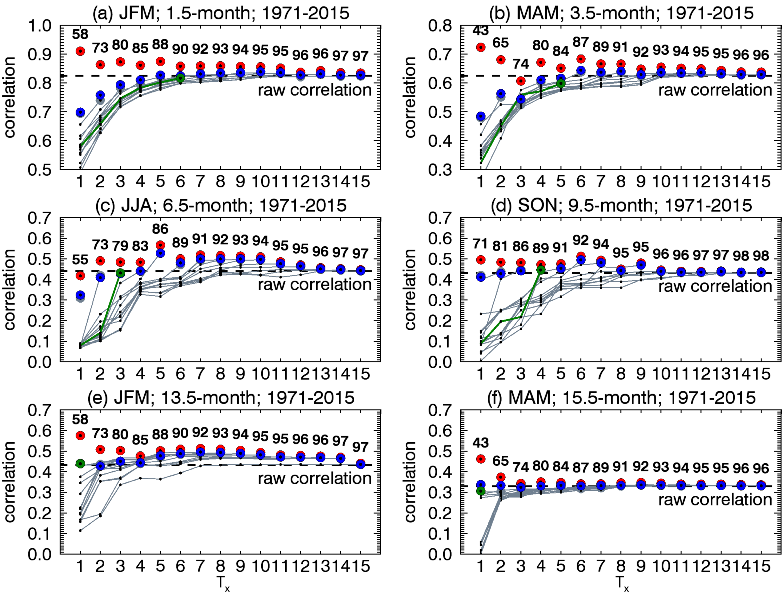




Appendix: Contribution by canonical components



Appendix: Skill decomposition – various lead times



Appendix: Skill vs lead