Quantifying the pattern effect for a climate model emulator

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Background

Changes in the spatial pattern of sea-surface temperatures (SST) have modulated radiation fluxes at the top of atmosphere (TOA) and affected global temperatures during the 20th and early 21st centuries[1]. This pattern effect[2] could exert a strong influence on near-term warming[3]. Here we demonstrate a method for quantifying how SST patterns affect global feedbacks and global temperature projections.

The aim is to use this method to represent pattern effects in a climate model emulator to improve near-term global temperature projections and better characterise uncertainty.

Methods and data

- Least squares regression is used to calculate the linear feedback relationship between the annual mean net radiation flux at the top of atmosphere (N) and the annual mean near-surface temperature (T) for each grid cell (i). The non-linear (pattern) variations are then derived

$$N^i_{linear} = \beta^i_0 + \beta^i_1 \times T^{global} \qquad N^i_{pattern} = N^i_{total} - N^i_{linear}$$

- $T^i_{pattern}$ is calculated similarly. Maximum covariance analysis is used to produce EOFs between $T^i_{pattern}$ and $N^i_{pattern}$ and principal components are calculated. The principal components are smoothed.
- N including a contribution from the pattern effect is estimated using the first three EOFs

$$N^i_{fitted} = N^i_{linear} + PC_1 \times EOF_1 + PC_2 \times EOF_2 + PC_3 \times EOF_3$$

- Data from the CMIP6 amip-piForcing simulations is used to demonstrate the method

Results: EOFs for the covariance between $T^i_{pattern}$ and $N^i_{pattern}$

- EOF 1 explains 10.8 % -13.8% of the covariance. The temperature patterns resemble spatial patterns of the PDO and ENSO. The spatial patterns in N differ between the models.
- EOF 2 explains 4.8% - 6.2% of the covariance. The strongest pattern in temperature occurs over the Maritime Continent and in some models there is a "horse shoe" pattern across the North Pacific. The associated patterns in N differ between the models.
- EOF 3 explains 4.5% - 5.1% of the covariance. The strongest pattern in temperature occurs over the tropical Atlantic Ocean. The associated patterns in N differ between the models.

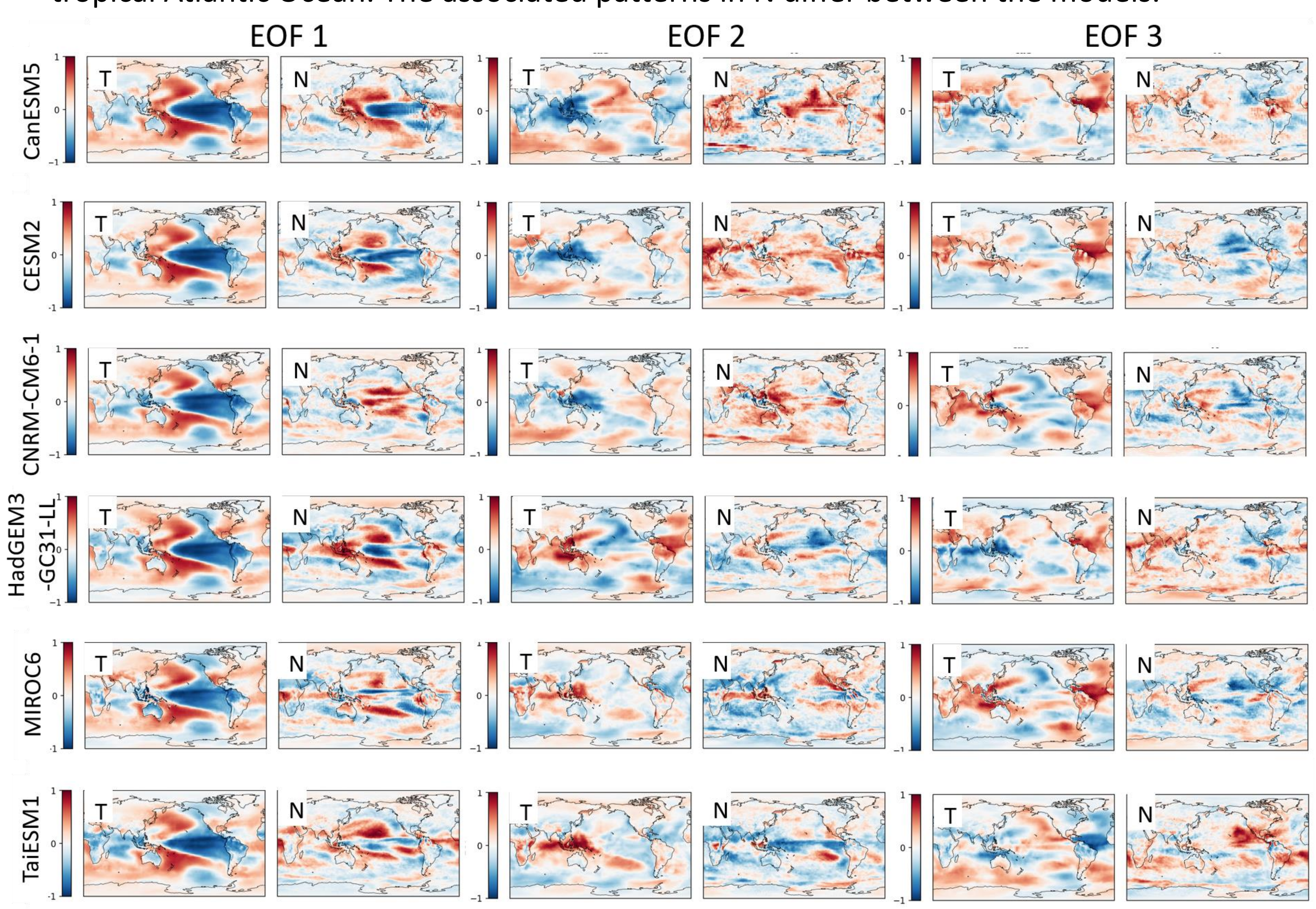

Fig. 1. Empirical orthogonal functions from the maximum covariance analysis of temperature and N.

Results: Allowing for the pattern effect improves the projections of N

- The variance explained increases for all climate models (Fig. 2)
- The improvements mainly occur during years 1940-1980 and from 2000 onwards (shown for one model in Fig. 3)

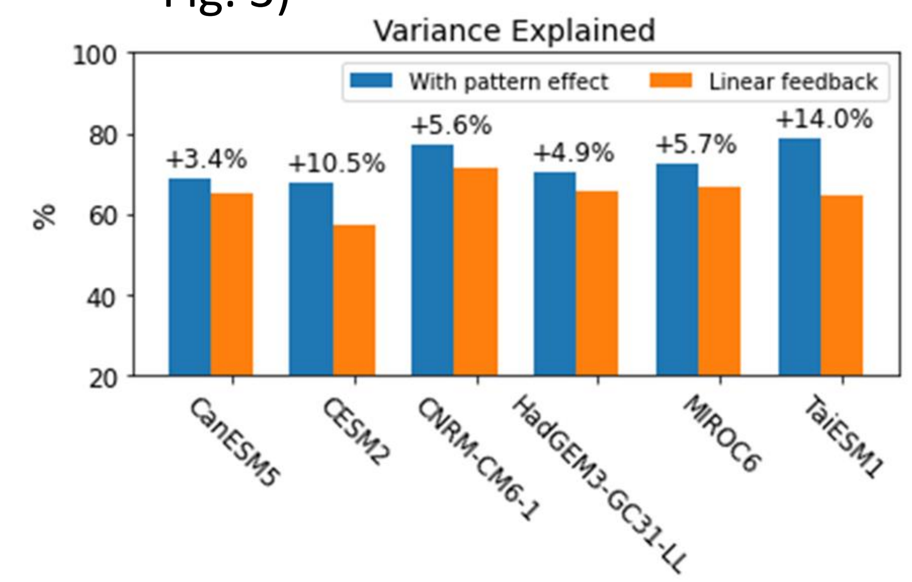

Fig. 2. Variance explained for N with and without allowance for the pattern effect.

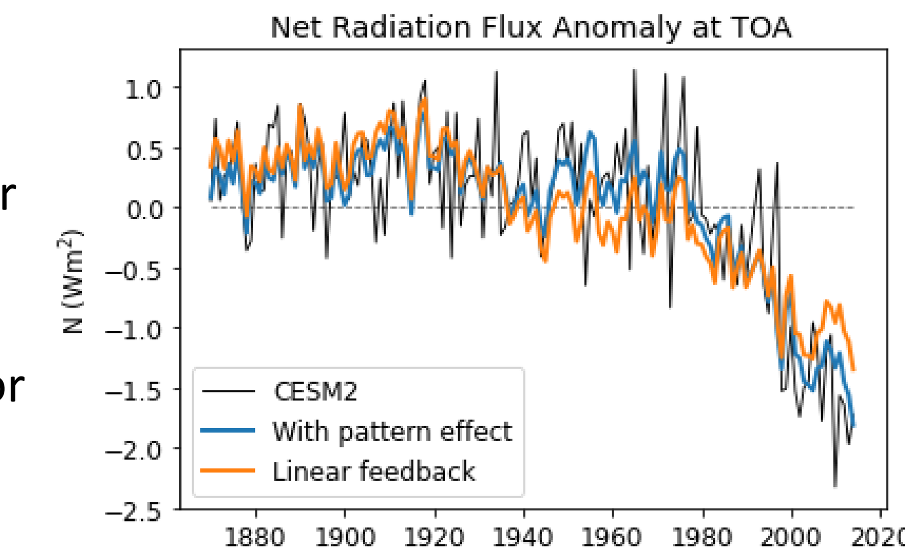

Fig. 3. N from a simple linear feedback relationship with T (orange) and a linear feedback relationship with pattern effects based on 3 EOFs (blue).

Results: EOFs 2 and 3 make the largest contributions to changes in N

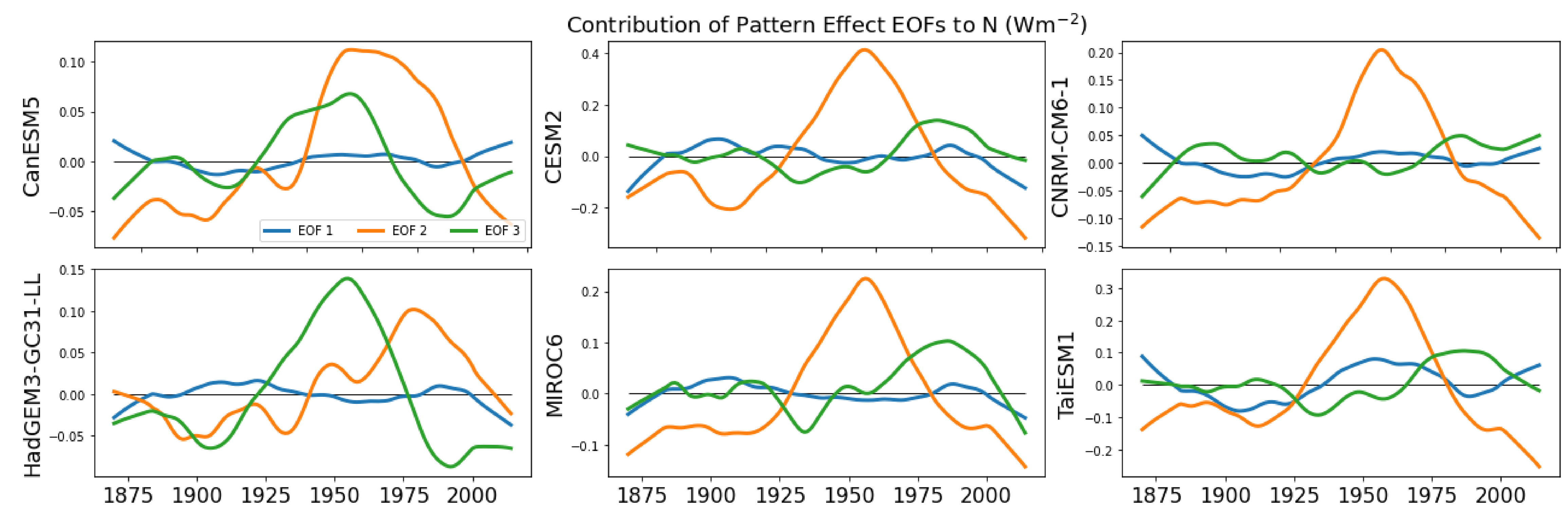

Fig. 4. Contribution of the 3 EOFs to changes in N. The contributions are calculated by multiplying the EOF spatial weights (Fig. 1) and their smoothed principal component time series.

- EOFs 2 (5 models) and EOF 3 (HadGEM3-GC31-LL) have strong spatial patterns in temperature over the west Pacific Ocean/Maritime Continent/Indian Ocean. Variations in deep convection over these regions may play a key role in the pattern effect
- For all 6 climate models EOF 1 (with PDO & ENSO like temperature patterns) makes a relatively small contribution to pattern effect driven changes in N

Next steps

- Apply the method to observations of temperature and TOA radiation fluxes
- Address outstanding questions:
  - Alternative approaches to elucidate the relationship between the spatial patterns of N and T?
  - How best to incorporate into a climate model emulator?

Please get in touch if you have comments or suggestions

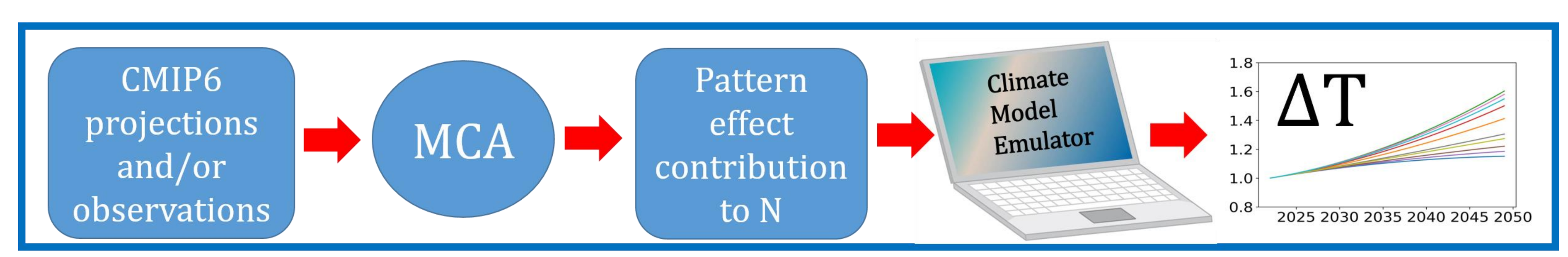

Fig. 5. Include the pattern effect contribution to N in a climate model emulator e.g. treat its changes as an annually varying "forcing"

References

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3. Chou et al. (2021) Greater committed warming after accounting for the pattern effect. Nature Climate Change, https://doi.org/10.1038/s41558-020-00955-x.

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