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. This pattern effect could exert a strong influence on near-term warming. 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
  $$N_{\text{pattern}}^i = N_{\text{linear}}^i + \beta^i \times T_{\text{global}}^i$$
  $$N_{\text{pattern}}^i = N_{\text{total}}^i - N_{\text{linear}}^i$$
• EOFs are calculated similarly. Maximum covariance analysis is used to produce EOFs between T and N. The principal components and EOFs are calculated from the maximum covariance analysis.
• N including a contribution from the pattern effect is estimated using the first three EOFs
  $$N_{\text{fitted}}^i = N_{\text{linear}}^i + P_{C_1} \times EOF_1 + P_{C_2} \times EOF_2 + P_{C_3} \times EOF_3$$
• Data from the CMIP6 ampipiForcing simulations is used to demonstrate the method

Results: EOFs for the covariance between $T^i$ and $N^i$
• 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.

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).

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

References

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