Combining point correlation maps with self-organizing maps to investigate atmospheric teleconnection patterns in climate model data

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Method

AIM:
1) to find the teleconnections in global sea level pressure data
2) to find how well a medium complexity model (FORTE) reproduces the observed teleconnections

1) OBSERVED TELECONNECTIONS: Point correlation maps from NCEP/NCAR SLP

Use NCEP/NCAR point correlation maps to train a self organizing map (SOM)

Results in a grid of observed teleconnection patterns with similar teleconnections close together and different teleconnections far apart

WHAT IS A SOM?
A SOM is a non-linear neural network that is used to discover patterns in data and arrange those patterns topologically on a grid so that similar patterns are close together and different patterns are far apart

Assign each NCEP/NCAR correlation map to the SOM unit it is most similar to (i.e. which teleconnection found by the SOM has the shortest Euclidian distance to that correlation map)

2) MODELLED TELECONNECTIONS: Point correlation maps from FORTE SLP

Repeat assignment with the FORTE correlation maps

The number of correlation maps assigned to each SOM unit is a measure of how often that teleconnection occurred in the original data set

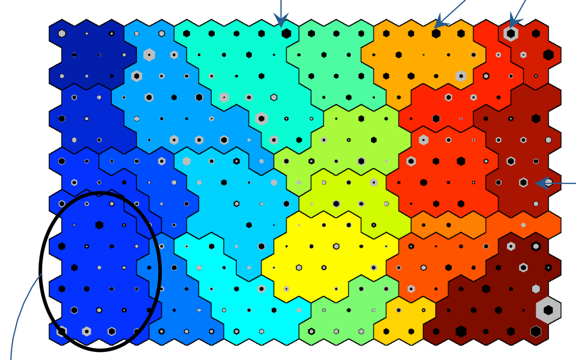
AKA the number of 'hits' a SOM unit received

The SOM is made up of a number of units. Each unit will contain a teleconnection pattern

Each unit is shown as a hexagon on the diagram. This SOM has 15x20 units

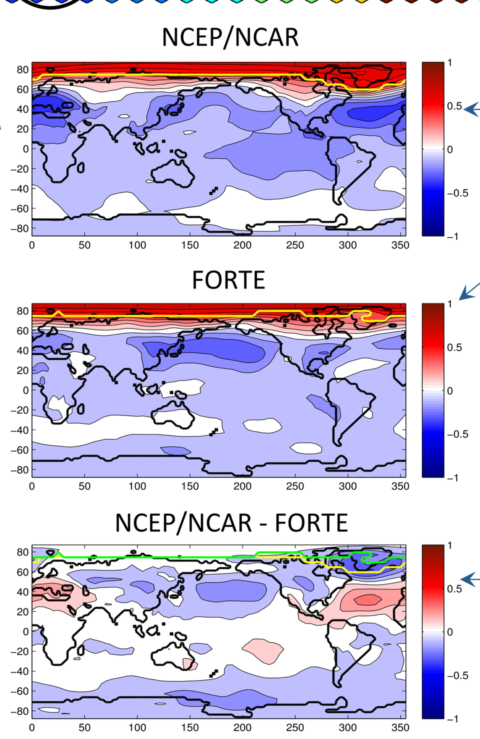
The number of hits a unit received is proportional to the size of the hexagon on each unit on the diagram. BLACK hexagons show NCEP/NCAR hits, GREY hexagons show FORTE hits

SOM units are clustered to group similar teleconnection patterns together



The units in each cluster are shown by the blocks of colour on the diagram

The teleconnection pattern represented by each cluster is found by averaging all the correlation maps that were assigned to the units within that cluster



This is done twice, once for the NCEP/NCAR correlation maps and once for the FORTE correlation maps to see how the observed teleconnections and the modelled teleconnections differ

The base points used to make the correlation maps in that cluster are identified by the yellow contour to show which regions are important for that pattern

3) COMPARING OBSERVATIONS AND MODEL
Subtract the FORTE pattern from the NCEP/NCAR pattern to see how they differ

The green contour shows where the base points are the same in both cases
The red contour shows where the FORTE cluster includes base points that are not in the NCEP/NCAR cluster
The yellow contour shows where NCEP/NCAR has base points that are not in the FORTE cluster

Introduction

Teleconnections are one of the main sources of inter-annual to inter-decadal variations in weather and climate and, because of their medium term impact, are informative when producing seasonal and long-range forecasts. As the climate changes, the spatial and temporal structure of teleconnections may change, so it important to understand present day teleconnections and how they are represented in climate models.

This study identifies teleconnection patterns in 60 years of NCEP/NCAR sea level pressure (SLP) reanalysis data (Kalnay et al. 1996) and uses these patterns to assess the skill of the medium complexity climate model FORTE (Sinha and Smith, 2002; Wilson et al., 2009).

We use a new method combining point correlation maps, which identify the relationships in gridded data, with a self-organizing map (SOM) (Kohonen, 1982), which groups the large number of correlation maps into teleconnection types, arranges them topologically (similar patterns are close together, different patterns are far part) and provides a measure of frequency of occurrence for each pattern. See the box on the left for details.

Results

The SOM identifies many of the well known teleconnections, some of which are shown below, along with their corresponding locations on the SOM. The bottom left and top right corners of the SOM both represent the North Atlantic oscillation. As these patterns are made from correlation maps with base points in opposite centers of action (shown by yellow contours) the patterns are inverted. The SOM located them on opposite sides because they are opposite to each other. Similar patterns, such as the Indian and African Monsoons are located next to each other on the SOM.

Comparing the distribution of hits on the SOM (black and grey hexagons show NCEP/NCAR and FORTE hits respectively) reveals how well FORTE reproduces the observed teleconnections. For example cluster 2, near the top left of the SOM, which corresponds to the North Pacific oscillation, is reproduced well by FORTE, with a frequency of occurrence of 2.2% compared to NCEP/NCAR's 2.0%. The FORTE pattern and the location of the base points are also in good agreement. In contrast FORTE provides no hits for the Indian Monsoon cluster (top center of the SOM), indicating teleconnections in this region are poorly represented by FORTE.

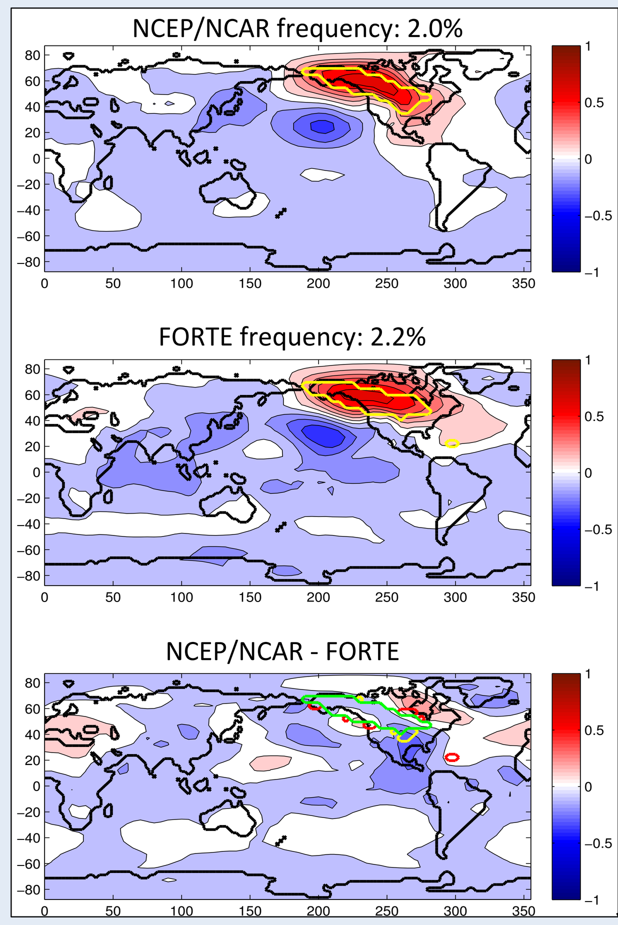
Discussion

The combination of correlation maps with SOMs can identify teleconnections in a gridded dataset and identify the regions that are important for their existence. The frequency of occurrence of any given pattern in the original dataset is useful when aiming to understand the influence of a pattern.

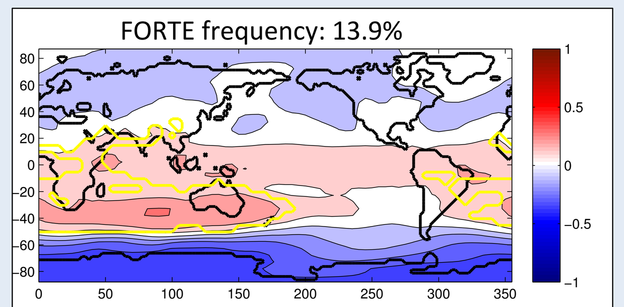
Using the method to compare NCEP and FORTE shows that FORTE is able to produce realistic teleconnection patterns, albeit generally too zonally orientated, with geographically variable skill. The Indian Ocean is a weak area for FORTE, while the North and equatorial Pacific and North Atlantic are reasonably well reproduced. The accuracy of frequency of occurrence is variable between patterns.

Future Work

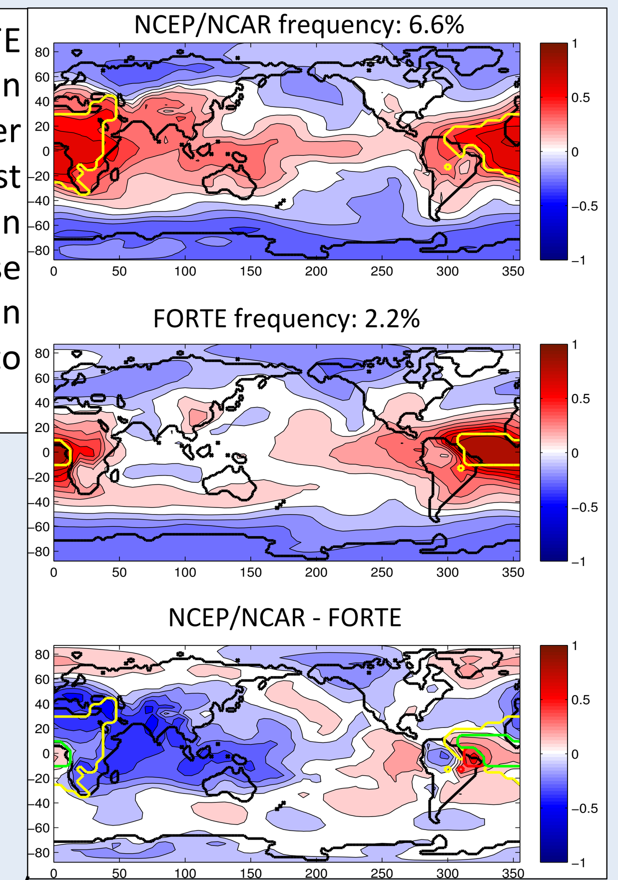
This method will be used to evaluate teleconnection representation in a subset of the CMIP5 suite of historical runs and to investigate how the structure of teleconnections are projected to change in the future. Additional variables will be included, such as geopotential height, temperature and precipitation, to gain an understanding of the impacts and 3D structure of teleconnections.

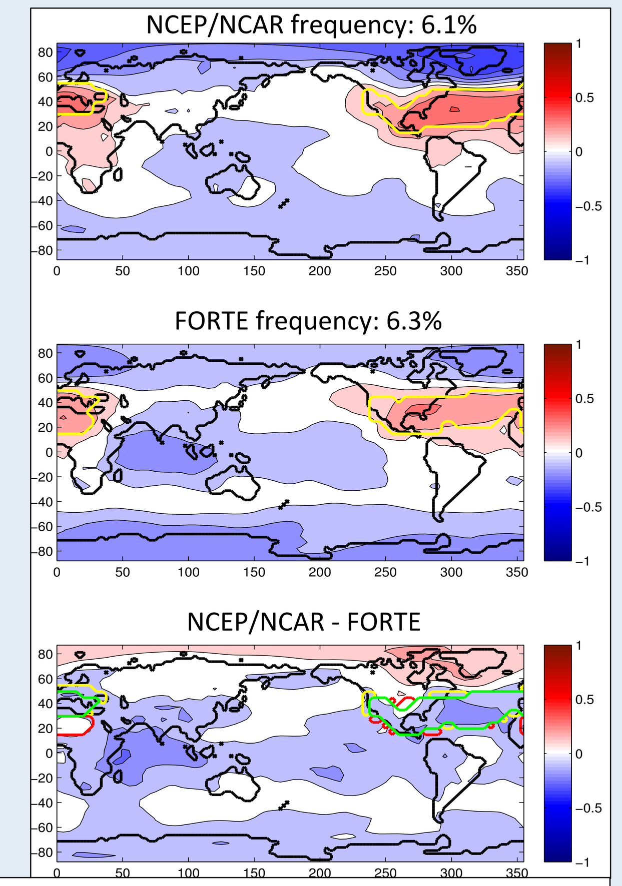


NORTH PACIFIC OSCILLATION: This is captured very accurately by FORTE, with the main difference a stronger connection to the North Atlantic in the FORTE pattern.

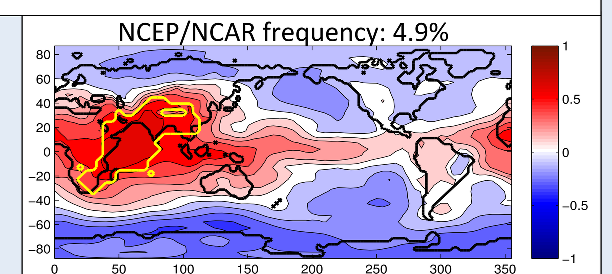


AFRICAN MONSOON: FORTE shows a more localized African monsoon pattern with a greater connection to the equatorial east Pacific than the Indian Ocean. This is probably because the base points over the African continent are not contributing to this cluster pattern for FORTE.

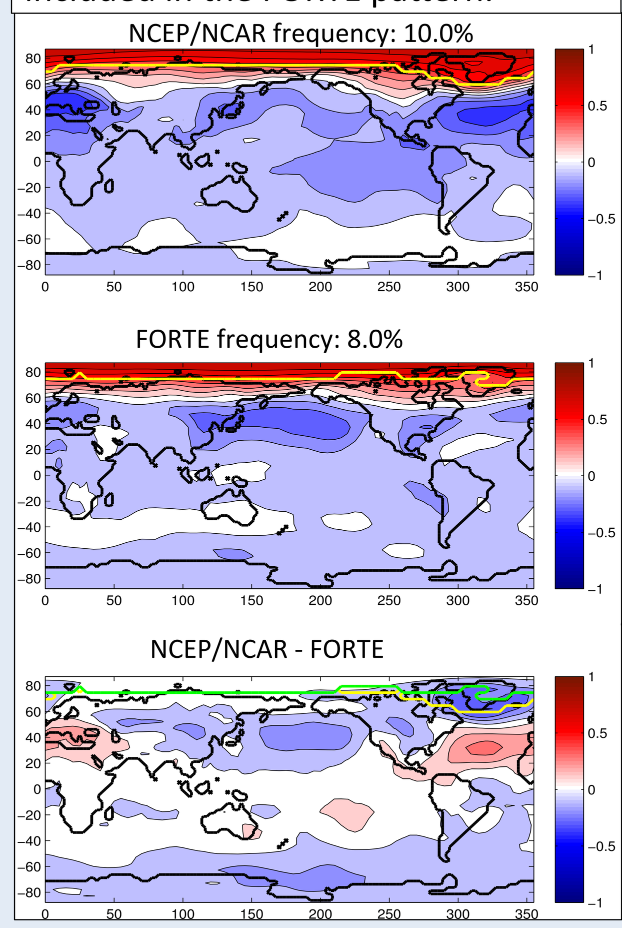




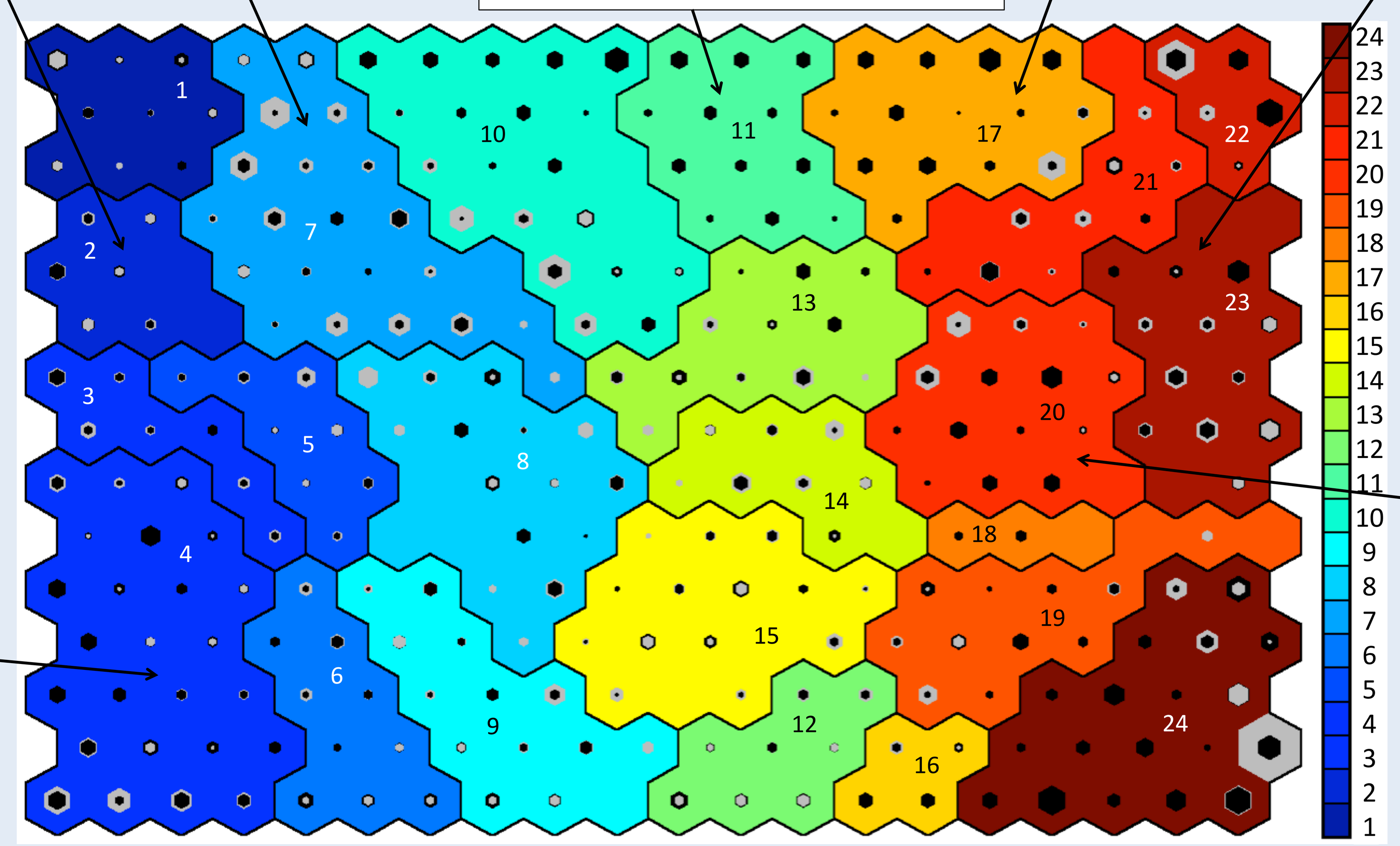
INDIAN MONSOON: There are no grey hits on this cluster so FORTE does not reproduce this Indian Monsoon pattern (shown below) at all. Instead the base points that should contribute to this pattern in FORTE map to an Indian Ocean/Antarctica dipole (cluster 7, FORTE pattern shown above), suggesting there may be errors in the way FORTE handles convection in the Indian ocean.



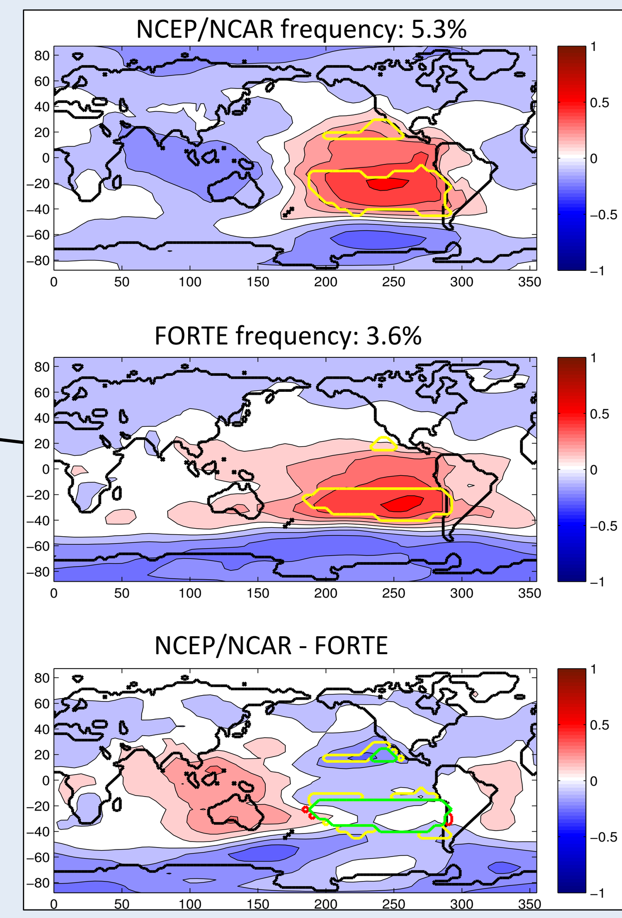
NORTH ATLANTIC OSCILLATION: FORTE captures the polar aspect of the NAO but the North Atlantic center is shifted to the North Pacific, possibly as fewer Icelandic base points are included in the FORTE pattern.



NORTH ATLANTIC OSCILLATION: Note how the inverse NAO patterns are on opposite sides of the SOM. The FORTE pattern is more zonal than NCEP/NCAR and features a negative correlation with the Indian Ocean, not seen in the NCEP/NCAR data.



SOM trained with NCEP/NCAR SLP point correlation maps. Colour blocks show clusters. Size of hexagons proportional to number of hits, black: NCEP/NCAR, grey: FORTE



EL NINO/SOUTHERN OSCILLATION: The NCEP/NCAR pattern captures the seesaw of pressure between the east Pacific and the western Pacific/Indian Ocean. In contrast FORTE shows more of a dipole relationship between the south Pacific and the Southern Ocean and Antarctica.

References

Kalnay, E. et al. 1996. The NCEP/NCAR 40-year Reanalysis Project. *Bulletin Of The American Meteorological Society*, **77**, 437-471.

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