TROPICAL/EXTRATROPICAL FORCING OF THE AO/NAO REVISITED

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Whistler Workshop – April 2003
A collaboration of the Canadian Clivar Research Network
LE RÉSEAU CANADIEN RÉVA THE CANADIAN LIVAR RESEARCH NETWORK

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Abstract: *In two of our previous papers, we described the separate influence of tropical and extratropical forcing on the North Atlantic (NAO) and the Arctic (AO) Oscillation. Our basic tool was a dry, dynamical model of the atmosphere using diabatic forcing diagnosed from NCAR/NCEP reanalysis data. Here we point out a problem with the way the tropical/extratropical forcing split was carried out. In the corrected model results, we find that extratropical forcing dominates tropical forcing in accounting for interannual variance in both the observed NAO and AO indices. This finding is in general agreement with our previous results for the NAO index, but contrasts with our previous finding that extratropical forcing, independent of the tropics, could not account for significant variance in the observed AO index. Likewise, we find that the recent upward trend in the NAO index is driven from the tropics, in agreement with our previous finding, whereas for the AO index, we now find that extratropical forcing also contributes to the upward trend in the model. It follows that our corrected model results do not support a strong link between tropical forcing and the interannual variability of the wintertime AO, as claimed previously.*

Background

- Recent studies suggest that long time scale variability of the North Atlantic Oscillation (NAO) index may be recovered through the knowledge of global sea surface temperature (SST) and sea ice conditions *[Rodwell et al, 1999; Latif et al, 2000; Mehta et al, 2000]*.
- Other studies *[Hoerling et al, 2001]* have suggested that the recent upward trend in both the NAO and Arctic Oscillation (AO) indices are linked with SST changes in the tropical ocean.

Model

We use a simplified, dry, dynamical model of the atmosphere driven by constant forcing diagnosed from observations *[Hall, 2000; Hall et al, 2001a,b]*.

- Descendent of *Hoskins and Simmons [1975]*
- Forcing is diagnosed by initialising the unforced model with observed states interpolated to the model grid, and averaging the implied time tendency (assuming a statistically steady state):

Time evolution of model state variable Φ

$$\frac{d\Phi}{dt} = N(\Phi) + F$$

gives for a set of observations Φ_i on model grid

$$F = -\frac{1}{n}\sum_{i=1}^{n} N(\Phi_i) = -\overline{N(\Phi_i)}$$

- Model forcing is a proxy for the diabatic forcing of the atmosphere.
- For each of the winters 1948/49 – 1998/99, the 90 days (DJF) of daily average data from the NCAR/NCEP data reanalysis *[Kalnay, 1996]* is used to compute the forcing.
- Model resolution is T21 with 5 equally spaced σ levels.

Model Experiments

A typical set of model experiments consists of:

- Model is run individually for each of the 51 winters of available forcing.
- Each winter is run for a 120 day period with the analysis being performed using model variables averaged over the final 90 days (hereafter referred to as winter average).
- For each winter, a large ensemble is created using 30 such runs with initial conditions chosen randomly from the 4550 daily average conditions in the NCAR/NCEP data set.

Three sets of experiments are run:

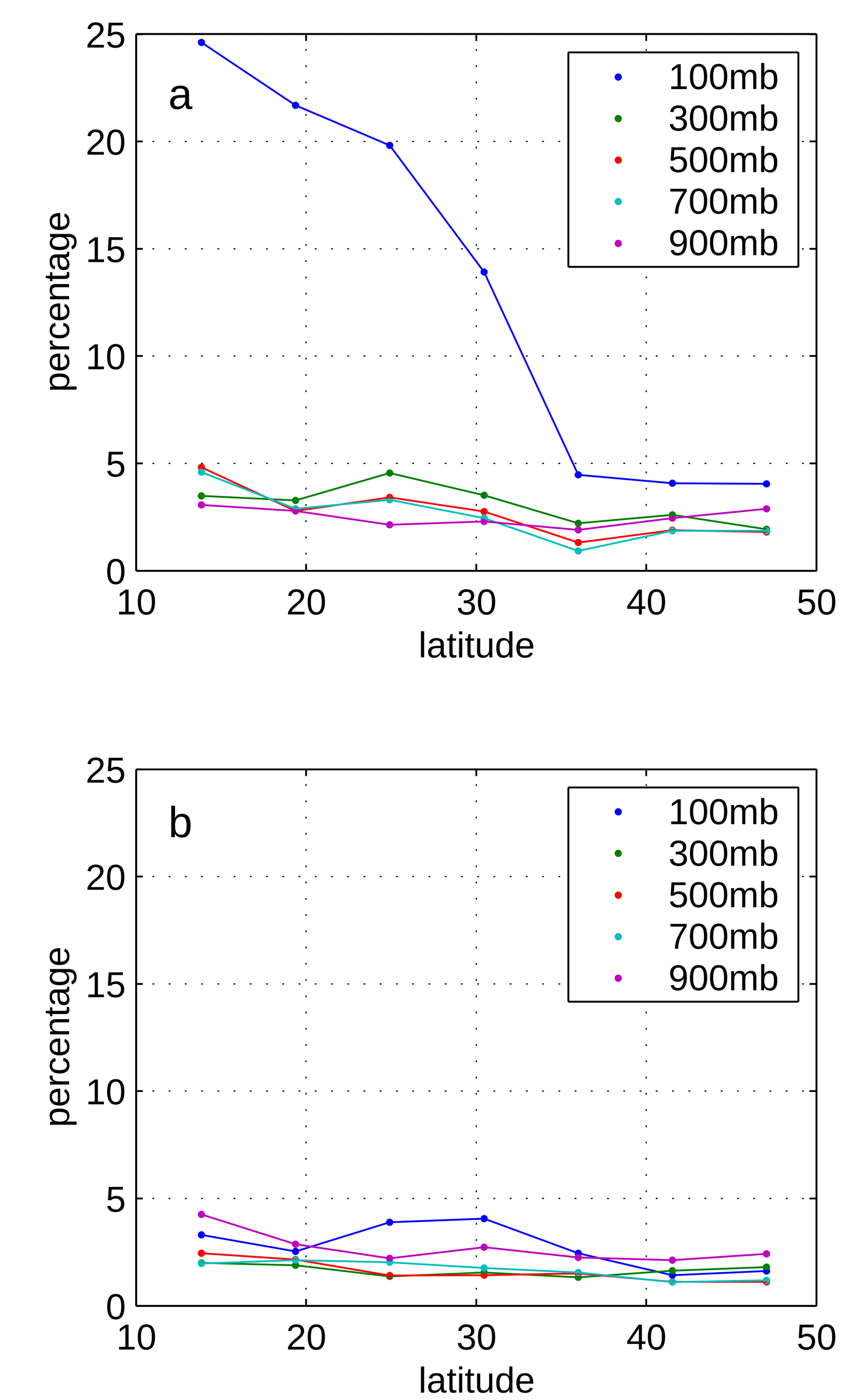
- **[Global]** has the diagnosed forcing for each year imposed throughout the entire globe.
- **[Tropical]** has the diagnosed forcing for each year imposed only in the tropics (36°S - 36°N). Elsewhere on the globe, the climatological average of the diagnosed forcing over the 51 winters is used.
- **[Extra-Tropical]** has the diagnosed forcing for each year imposed only in the extra-tropics (south of 36°S and north of 36°N). In the tropics (36°S - 36°N), the climatological average of the diagnosed forcing over the 51 winters is used.

The tropical/extratropical split:

- All prognostic model equations are forced, including the vorticity and divergence equations.
- The split must be applied to the forcing for all prognostic equations including the vorticity and divergence equations.
- In our previous papers *[Peterson et al., 2002; Lin et al., 2002]*, the split was applied to the equivalent forcing for the momentum equation.
- This introduces spurious "spikes" to the forcing for the vorticity and divergence equations along the latitude of the split.
- In the new results, the split is applied to the forcing for the vorticity and divergence equations directly. The global integral of the vorticity and divergence forcing has to be zero (or small) on each level. This is because the forcing is derived by taking the curl and divergence of an equivalent forcing for the momentum equations *[Bourke, 1974]*.
- The most significant departure from zero occurs on the top model level for the anomalous forcing of the divergence equation, and the value of the average is significantly reduced if the tropical/extratropical forcing split is carried out at 36°N and 30°S rather than at 30°N and 30°S (where the split was made in our previous papers).

Manuscripts

- Peterson, K.A., R.J. Greatbatch, J. Lu, H. Lin and J. Derome, Hindcasting the NAO using diabatic forcing of a simple AGCM, *Geophys. Res. Lett.*, **29 (9)**, doi:10.1029/2001GL014502, 2002.
- Lin H. and J. Derome, R.J. Greatbatch, K.A. Peterson, and J. Lu, Tropical Links of the Arctic Oscillation *Geophys. Res. Lett.*, **29 (20)**, doi:10.1029/2002GL015822, 2002.
- Greatbatch R., H. Lin, J. Lu, K.A. Peterson, and J. Derome, Tropical/Extropical forcing of the AO/NAO: A corrigendum *Geophys. Res. Lett.*, 2003 (submitted).

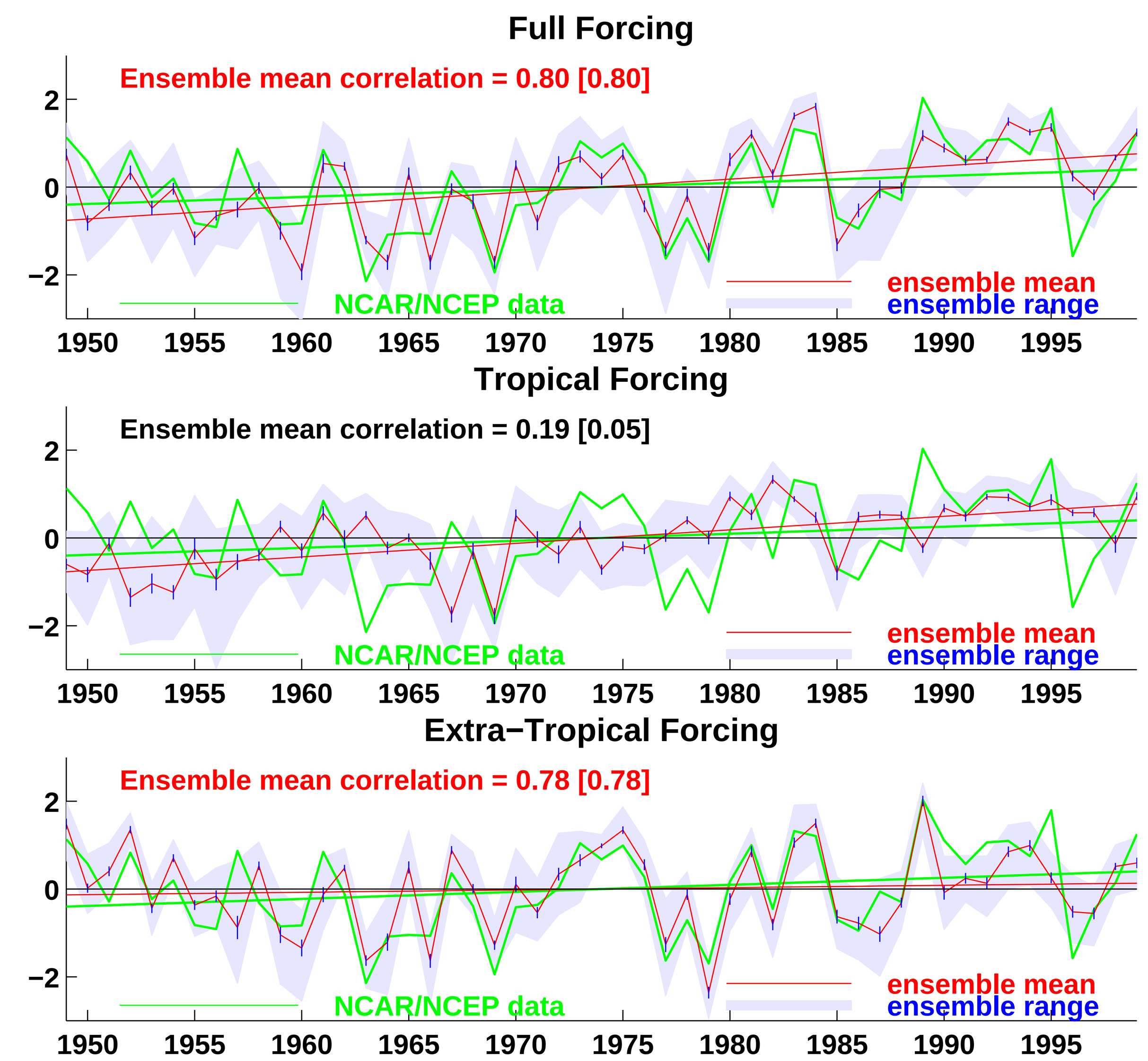


The average of the anomalous forcing for (a) the divergence and (b) the vorticity equations on each model level and within a latitude band centered on the equator, plotted as a function of the outer bounding latitude, averaged over all 51 winters, and expressed as a percentage of the area-weighted standard deviation of the forcing over the globe.

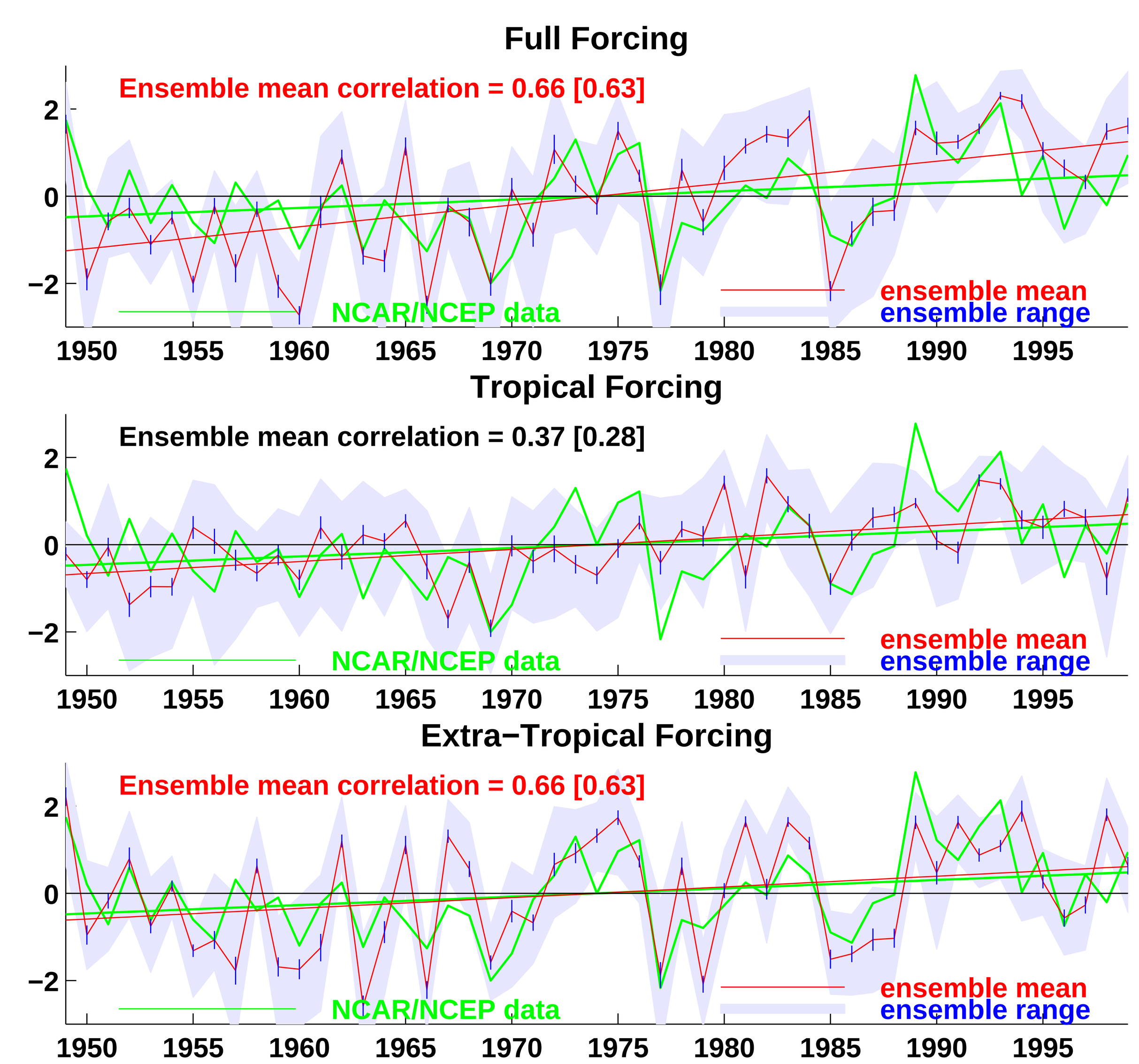
Conclusions

- Interannual variability in both the AO and NAO is influenced predominantly by extratropical forcing, suggesting an important role for the midlatitude storm tracks.
- The upward trend of the NAO is associated with tropical forcing, while for the AO, extratropical forcing also plays a role in trend.
- The new results do not support the claim in *Lin et al.(2002)* of a strong link between tropical forcing and the interannual variability of the AO.
- The new results do not clearly distinguish between the AO and NAO in terms of the relative importance of tropical and/or extratropical forcing in accounting for the variance of their respective indices.

NORTH ATLANTIC OSCILLATION (NAO)



ARCTIC OSCILLATION (AO)



The red lines show the time series of the ensemble mean NAO and AO indices. The green lines show the observed winter (DJF) indices computed from the NCAR/NCEP reanalysis. Shading indicates the spread of the individual ensemble members. The straight lines indicate the trend. Also shown are the correlations between the ensemble mean and the observed indices. Correlations for the detrended time series are shown in brackets.