# Recent NAO changes and their Association with Net Surface Heat Flux

Amir Shabbar, Kaz Higuchi and C.W. Yuen
Meteorological Service of Canada, Environment Canada

## 1. Introduction

The North Atlantic Oscillation (NAO) has been described as the indicator of the seesawing strength of the zonal flow along the mid and high latitudes of the North Atlantic. Typically, it is accompanied by displacement of atmospheric mass between Iceland and the Azores. The NAO is one of the major modes of intermonthly to interdecadal variability in the Northern Hemisphere atmosphere, accounting for about one-third of the wintertime total variance. Interest in the NAO has been recently renewed mainly because of a trend towards the positive phase of the oscillation, particularly in the last two or three decades.

Can natural climate variation explain the recent behaviour of the NAO, or is this a reflection of the global warming signal which manifests itself by strengthening a natural mode of climate variability? Recently, Hoerling et al. (2001) attempted to answer this question. By projecting the tropical sea surface temperatures onto the wintertime NAO in both observed and AGCM simulation data, they concluded that the rising trend in the NAO is intrinsically linked to the warming in the tropical Pacific and Indian oceans. Their contention is that through changes in tropical rainfall and atmospheric heating, the ocean exerts an atmospheric pattern reminiscent of the NAO.

If this is true, then it is important to know the role that the surface net heat flux (NHF) plays in the tropical ocean-NAO connection. After all, the ocean communicates with the overlying atmosphere through changes in the heat fluxes. Moreover, heat flux is a more physically meaningful parameter than the SST in this regard. In this study, the relationship between the trend in the NHF and in the NAO is examined. By decomposing both fields on interannual and interdecadal basis, the possible linkages at these timescales are also examined. The analysis is based on 40 years (1958-1998) of daily data from NCEP/NCAR Reanalysis (Kalnay et al. 1996). Correlation, EOF and regression analysis are used to examine the connection between the NHF and the NAO.

## 2. Results

### *2.1 Structure of the NAO*

Variability in the NAO is represented by the leading principal component time series of the seasonal (DJF) mean Northern Hemisphere 500 hPa field. Fig.1a shows the structure of the NAO. Whereas the centre over the polar region is usually restricted to Greenland, the southern centre stretches from southern Europe through the mid-Atlantic, and into eastern North America. Fig. 1b shows that the NAO exhibits variability on all time scales. The index varies from year to year, but also exhibits a tendency to remain in one phase for intervals lasting several years (Higuchi et al. 1999).

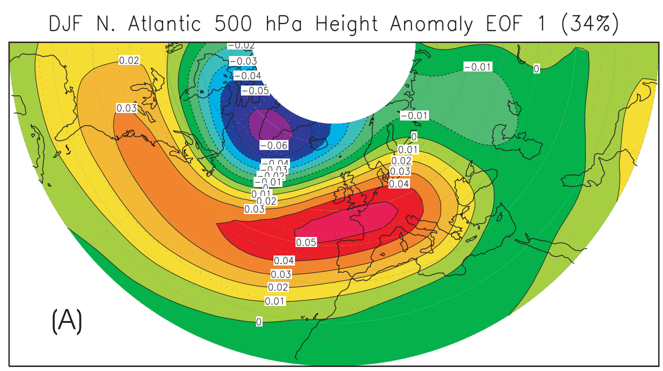


*Fig.1.(a) Structure of the leading mode of DJF 500 hPa height. This mode explains 34% of the variability.*

### *2.2 Trend and Correlation*

Fig.2 shows the NHF trend in the global oceans. In conjunction with the rising SSTs in the tropical Pacific, the NHF shows a decreasing trend. This indicates an increase in NHF from the atmosphere to the ocean which is mainly due to a decrease in the net ocean-to-atmosphere latent heat flux caused by an increase in relative humidity in the lower atmosphere (Curtis and Hastenrath 1999).

Corresponding author: Amir Shabbar
4905 Dufferin St. Downsview, Ont. Canada M3H 5T4
email: amir.shabbar@ec.gc.ca

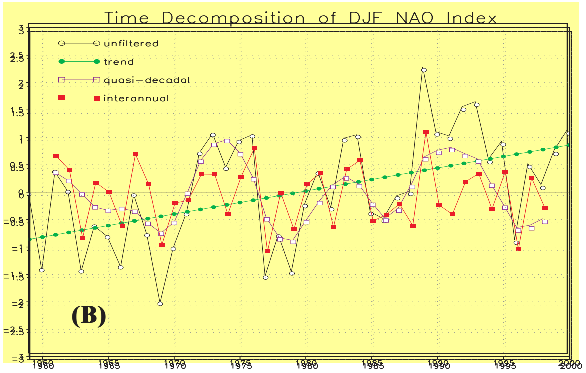


*Fig.1b. Principal component of the EOF shown in Fig. 1a. The NAO is defined by the unfiltered time series. Trend in the NAO is shown by green line, while the quasi-decadal and interannual component of the series are shown by purple and red lines respectively.*

Despite the rise of SSTs in the Indian Ocean, the NHF in the eastern regions of the basin shows a modest decrease in the atmosphere to ocean heat flux. The contribution of the solar heat flux and the ocean circulation may be responsible for the behaviour of the NHF.

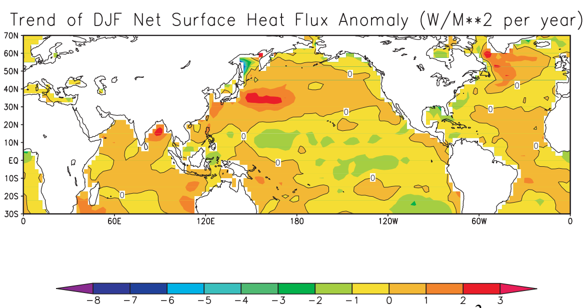


*Fig. 2. Trend in wintertime NHF in watts/m$^2$/year. Decreases in the tropical Pacific are attributed to decreases in the latent heat flux.*

The wintertime NAO correlates with the NHF most strongly in the trend component. Fig. 3 shows point correlation between the NAO and the NHF in which only quasidecadal and trend components are retained. With the aid of the Monte Carlo procedure (Livezey and Chen 1983), field significance is determined at 10%. The NAO shows significant correlation with the NHF in the North and tropical Atlantic both in the interannual and decadal scale, as well as in the trend component.

Through EOF analysis, low frequency modes of the NHF are obtained and related to various time

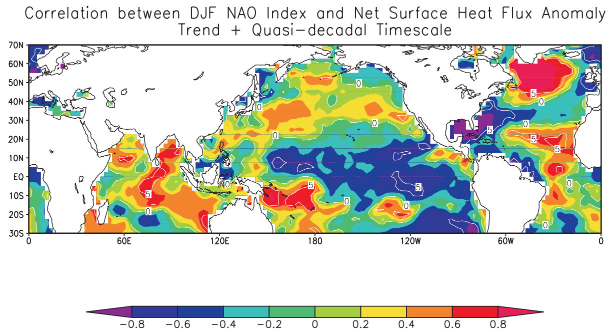


*Fig. 3. Correlation between the NAO and the trend plus quasi-decadal component of the NHF. Based on a sample of 1000 re-shuffled data, the map shows field significance at 10%.*

components of the NAO. It is found that the trend component of the NAO correlates in a significant way with the first principle component (PC) of the tropical NHF, (r = -0.71). Moreover, the trend in the NAO also relates to the first PC of the North Pacific NHF. In the Atlantic basin, the first PC correlates with the NAO on interannual, quasi-decadal and trend time scales.

### *2.3 Regression with 500 hPa Height (Tropics)*

In order to discern the impact of the tropical and North Pacific NHF on the 500 hPa heights, the leading mode of the NHF in the respective ocean basins are first isolated by the EOF analysis. Subsequently, the accompanying time series of these vectors are regressed onto the Northern Hemisphere 500 hPa heights. Fig. 4a shows the spatial pattern of the tropical NHF. This mode explains about 39% of the winter season variability.

Large areas of negative loadings in the tropical Pacific signify a net increase in the energy transfer from the atmosphere to the ocean. Fig. 4b shows the ac-companying time series. In agreement with increasing trend in the sea surface temperatures, the NHF show negative values, indicating an increase in the net gain of energy by the ocean. Fig. 4a also identifies a positive loading pattern in the western regions of the Indian Ocean. Even though the SSTs have increased in this region, the loadings show a positive value, indicating a decrease in the net transfer of energy to the oceans from the atmosphere. The internal circulation in the Indian Ocean may play a role in this seeming-

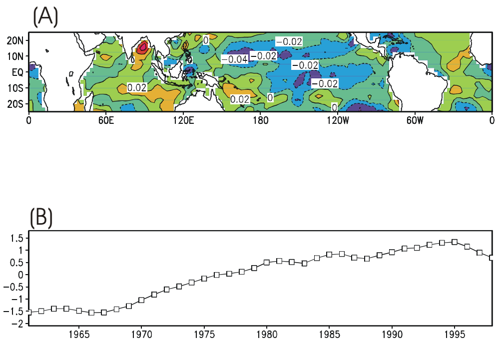


*Fig.4. (a) Leading EOF of the tropical wintertime NHF. In the Indian Ocean, however, both NHF and the SSTs show positive trends.. (b) time series of the corresponding normalized PC.*

ly contradictory trend in the SSTs and the NHF.

Fig. 4c shows the regression of the normalized PC1 with the 500 hPa height anomaly field. The map has a strong NAO signature pattern in its configuration. The regression map also shows a well-organized area of negative values over the North Pacific. The North Pacific anomaly centre is likely a reflection of the tropical Pacific influence from the stronger and more frequent El Nino-Southern Oscillation events since the mid-1970s.

### *2.4 Regression with 500 hPa (North Pacific)*

A similar exercise is carried out for the North Pacific basin. Shown in Fig. 5a is EOF1 of the North Pacific NHF, which accounts for 45% of the wintertime variability.

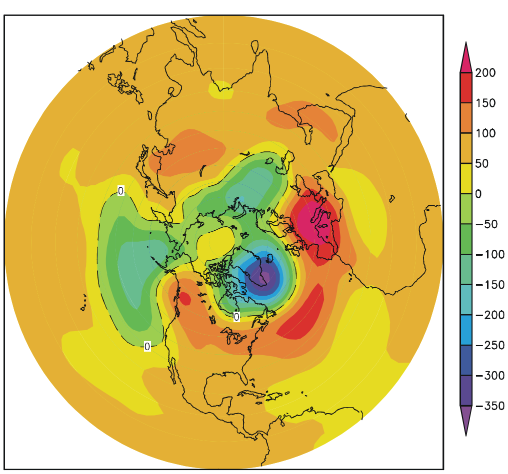

*Fig. 4c. Regression of tropical PC1 with the wintertime 500 hPa height anomaly field.*

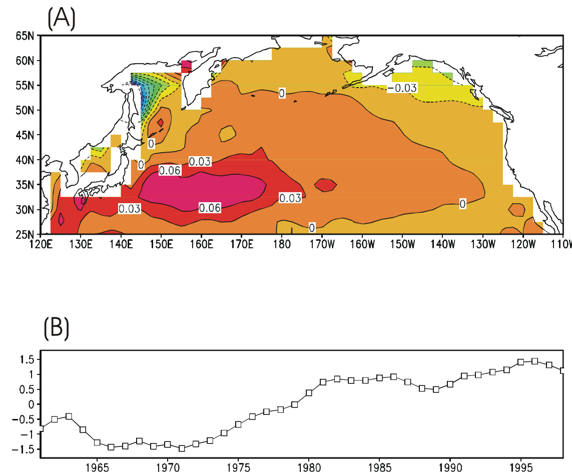


*Fig.5. (a) Leading EOF of the tropical winter-time NHF. Negative values of the NHF are in agreement with increasing SSTs in the tropical Pacific. In the Indian Ocean, however, both NHF and the SSTs show positive trend. (b) time series of the corresponding normalized PC.*

Strong positive loadings are present in the western areas of the subtropical latitudes (west of the Dateline). These positive loadings may be attributed to the strengthening of the Kuroshio current.

The PC of this vector (Fig. 5b) displays a marked rise since the 1970s. The increased NHF to the atmosphere is due mostly to the enhanced release of latent and sensible heat fluxes from the ocean.

Regression of the North Pacific PC with the Northern Hemisphere 500 hPa heights shows a strong positive configuration of the NAO. Evident also is a pattern over North America that is reminiscent of the Pacific-North American teleconnection pattern.

## 3. Conclusions

The wintertime NAO index as determined by the leading EOF of the Northern Hemisphere 500 hPa height field show significant point correlation with the tropical NHF. This result, along with finding of Heorling et al. (2001) which showed a concurrent rise in the NAO index and the tropical SSTs, provided the motivation for this study.

Trend component of the tropical and North Pacific NHF are first isolated by the EOF analysis. Regression of the principal component of the

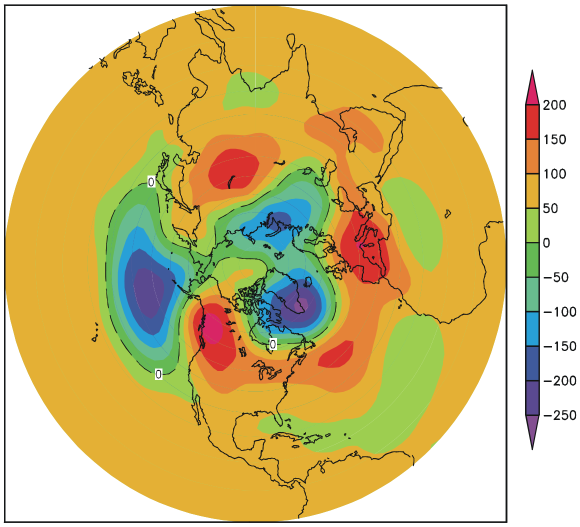


*Fig. 5c. Regression of North Pacific PC1 with the wintertime 500 hPa height anomaly field.*

leading EOFs from the tropical and the North Pacific basins NHF with the 500 hPa heights produced patterns strongly resembling the positive phase of the NAO teleconnection. Additionally, regression with the North Pacific NHF produced a PNA-like pattern, though with a weaker south-eastern U.S. anomaly center

It is also worth noting that the resultant 500 hPa regression pattern bears a resemblance to the trend pattern of the Northern Hemisphere 500 hPa circulation (Fig. 6). Thus the recent changes in the Northern Hemisphere circulation could be identified with the low frequency variability in the tropical and the North Pacific NHF.

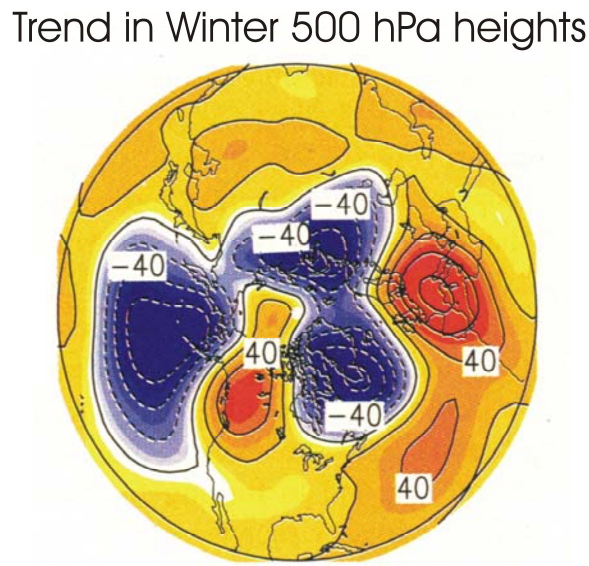


*Fig. 6. The linear trend of wintertime 500 hPa height field over the 1950-99 period, in m/50 yrs . From Heorling et al. (2001).*

## 4. References

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