A major deviation from the NAO temperature seesaw pattern

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The North Atlantic Oscillation (NAO) is known to be associated with specific patterns of northern hemisphere winter temperature and precipitation anomalies. The months of January and February 1984 had a clear positively phased NAO signal. However, compared to the expected NAO temperature anomaly pattern, both months showed patterns which were clearly distorted. The so called NAO temperature seesaw between western Europe and the Greenland west coast area broke down during the period. Extremely cold conditions in western Greenland were associated with below normal temperatures over the British Isles. This situation is found to be unique during the last 135 years. It does nevertheless cause great concern, as all efforts to reconstruct past NAO variability beyond the era of instrumental pressure observations, are dependent on the stability of the NAO temperature anomaly pattern.

1. Introduction

The North Atlantic Oscillation (NAO) is the most prominent pattern of northern hemisphere atmospheric variability [Hurrell, 1995; 1996; Hurrell and van Loon, 1997; Hurrell et al., 2003]. The NAO pressure anomaly pattern is indeed coupled to both the strength and direction of the storm track over the north Atlantic ocean. Hence large patterns of winter time precipitation and temperature anomalies can be explained by fluctuations in the NAO.

The winter temperature seesaw between Greenland and northern Europe is a major component of the hemispheric scale NAO temperature anomaly pattern [Van Loon and Rogers, 1978]. The seesaw is a consequence of the fact, that the same NAO conditions prompts temperature anomalies of opposite signs at these locations.

The large influence of the NAO on northern hemisphere atmospheric conditions has prompted a strong desire to gain knowledge of past NAO fluctuations. Unfortunately pressure observations at the centers of action of the NAO (Iceland and the Azores/Iberia) allows for only ∼180 years of NAO conditions to be firmly ascertained [Jones et al., 1997; Vinther et al., 2003b]. Therefore reconstructions of the NAO reaching further back in time have to rely on other observations.

Both temperature observations and natural proxies for atmospheric temperature do span a larger time frame than pressure observations. Hence NAO reconstructions tend to make use of such data [Cook et al., 2002; Luterbacher et al., 1999; 2002; Vinther et al., 2003a]. In doing so they do however become dependant on the stability of the NAO temperature anomaly pattern, including the winter temperature seesaw.

Using 135 years of temperature observations from the Greenland west coast and the British Isles we do examine the stability of the winter temperature seesaw between Greenland and northern Europe. Generally speaking the seesaw is very stable. One winter (1983/84) does however stand out. During this particular winter extremely cold conditions are observed over Greenland, while below normal winter temperatures also are observed at the British Isles.

The state of the NAO during 1983/84 should imply higher than normal temperatures at the British Isles. Hence a NAO reconstruction based on British Isles temperatures would clearly fail predict the correct state of the NAO.

Understanding the extreme event of the winter 1983/84 is therefore critical for the ongoing effort of reconstructing the NAO. Hence we do present a thorough analysis of the atmospheric conditions which prevailed during this particular winter.

2. The NAO Temperature Seesaw

Hann [1890] was the first to use systematic temperature observations to document the winter temperature seesaw between Greenland an northern Europe. Hann [1890] found that in 27 out of 41 winters temperatures deviated with opposite sign in Vienna and Ilulissat (Jakobshavn). Van Loon and Rogers [1978] investigated 129 years of Oslo and Ilulissat temperature observations. They found 53 clear seesaw winters (temperature anomalies of different sign and at least 4°C apart) and 22 clear non-seesaw winters (temperature anomalies of the same sign and both anomalies larger than 1°C).

From the observations of Hann [1890] and Van Loon and Rogers [1978] it is therefore clear that 20% to 30% of the winters cannot be related to the winter temperature seesaw. To gain further insight into the subject of non-seesaw winters it was decided to create a non-seesaw index using Central England (CET) [Manley, 1973] and Nuuk temperature observations [Frich et al., 1996; Peterson and Vose, 1997]. The non-seesaw index is simply calculated as the sum of the normalized CET and Nuuk temperature observations. Hence clear seesaw years with anomalies of the same relative magnitude in the CET and Nuuk temperature records will yield a non-seesaw index value of zero. If however, temperature anomalies at the two locations are of the same sign the non-seesaw index will be either negative or positive.

For the high winter (Jan-Feb, where NAO dominance is strongest) the non-seesaw index is presented in figure 1. From figure 1 it can immediately be seen that one Jan-Feb period in particular stands out. Having a non-seesaw index value of -3.42, Jan-Feb 1984 is extreme as compared to the total period of observations (1866-2000).

3. NAO/temperature relationships

In figure 2 we display the relationship between the NAO index and a) CET and b) the temperature in Nuuk. In the

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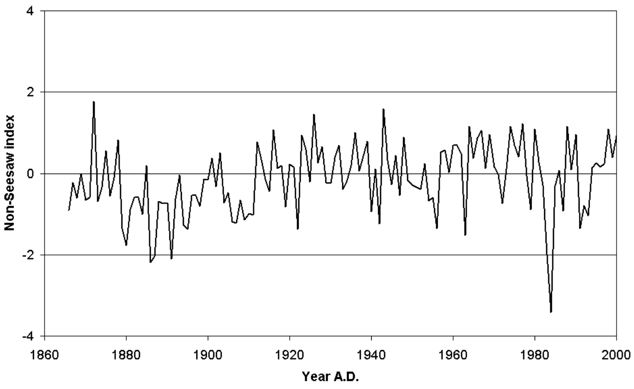

Figure 1. The Jan-Feb non-seesaw index is a measure of the strength of the Nuuk and CET temperature variability, which is not associated with the NAO temperature seesaw.

figure the best linear least square fit is shown together with a fit using a 5th order polynomium. The high order polynomium is used to highlight any important deviations of the observed values compared to the linear fit for extreme values of the NAO index. In figure 2a we see that the temperature in Central England does not show any "saturation" with extreme values of NAO. In fact one can argue that there is tendency to an even stronger dependence of temperature on the NAO index for high numerical values. This is not the case for the Nuuk. Apparently, the more negative the index becomes the warmer it may become in Nuuk. But with NAO in its positive phase there is a clear "saturation" with increasing NAO values. Figure 2b demonstrates that the coldest winters in West Greenland are associated with moderate positive NAO situations and not the most extreme cases.

Jan-Feb 1984 is a clear example of the temperature saturation. Having a mean temperature of -19.4°C this period is by a large margin the coldest high winter period registered in Nuuk, even though the Jan-Feb 1984 NAO index is only moderately positive.

The saturation is explained by the fact that in many winter situations Greenland is close to the cold polar vortex over NE Canada, therefore with very cold in the near vicinity of Nuuk the temperature cannot drop further by the action of dynamics alone. However during mild winters Greeland is still far away from the warm air source. England is also located far from the air mass sources, meaning the temperature anomalies will increase with the NAO index over the whole range of NAO values.

4. Jan-Feb 1984

The months of January and February 1984 were a period of moderately high index NAO conditions. From figure 2b it is seen that such periods can be associated with extremely cold Greenland conditions. It is however still surprising that CET also was below average. Westerly winds associated with the high index mode of the NAO would be expected to bring mild conditions to the British Isles.

The question to pose therefore is: what made the westerly flow colder than normal during Jan-Feb 1984? As North Atlantic sea surface temperatures (SST) during December 1983 were very near the December average (see figure 3, I-COADS data [Woodruff et al., 2001]), it seems fair to conclude that SST conditions did not play a significant role. Hence it was deemed reasonable to carry out a detailed analysis of atmospheric flow during Jan-Feb 1984.

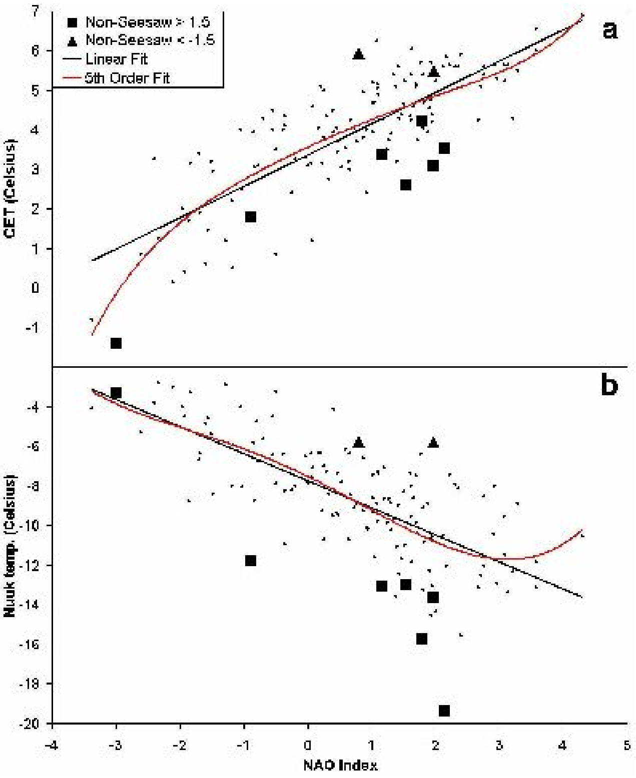

Figure 2. Scatter plot of Jan-Feb mean values of the NAO index versus CET (a) and Nuuk temperature (b) (1866-2000). Both linear and a 5th order fits are shown. Years of extreme value in the non-seesaw index are indicated by squares and triangles.

A study of daily meteorological charts (Europäische Wetterbericht) was carried out. Using the daily observed heights of the 500hPa surface, day by day movements of cyclones were recorded. Figure 4 shows all the cyclone tracks in the North Atlantic and European region during two Jan-Feb periods; 1984 (a) and 1989 (b). Both periods are characterized by high index NAO conditions. Jan-Feb 1989 does however

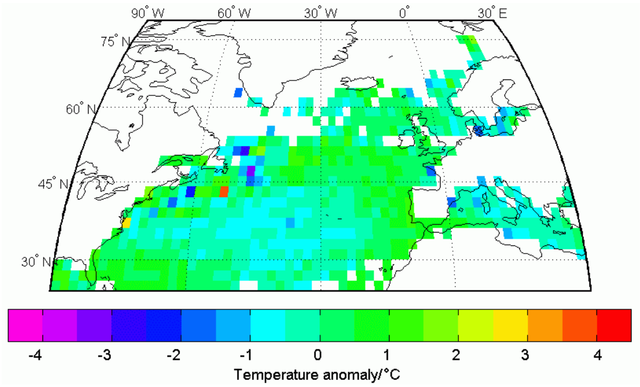

Figure 3. I-COADS SST anomaly data for the month of December 1983.

have a non-seesaw index close to zero and is therefore a typical example of the NAO temperature seesaw.

The difference between the non-seesaw winter of 1984 and the seesaw winter of 1989 is great indeed. The main cyclone path during Jan-Feb 1989 is directed towards northern Scandinavia, while Jan-Feb 1984 are characterized by cyclones pouring in over central Europe. These cyclones form a direct pathway towards the British Isles for extremely cold air masses of Greenland origin.

The non-seesaw conditions of 1984 are therefore associated with a marked difference in the direction of cyclone tracks as compared with the normal NAO temperature seesaw winter of 1989.

5. Discussion

Only a single example of a major deviation in the NAO temperature pattern have been found during the past 135 years. The mere fact that such a strong deviation could be found is however of immense importance for the ongoing NAO reconstruction effort. Many such reconstructions have been based on data from Europe only [Luterbacher et al., 1999; 2002] or Greenland only [Vinther et al., 2003a]; i.e only one end of the NAO temperature seesaw.

The strong 1984 deviation of the NAO temperature pattern underlines the importance of having data from both ends of the NAO temperature seesaw. If only CET data were to be used for the reconstruction of the NAO during a period as Jan-Feb 1984, a positive NAO period would indeed be reconstructed as having negative NAO conditions. In the worst case scenario, a series of positive NAO winters having the same conditions as the Jan-Feb 1984 period could be interpreted as a climatic trend towards the negative phase of the NAO.

The nonlinearity discovered in the relation between positive NAO conditions and Nuuk winter temperatures should also be a cause for concern. It is obvious that linear reconstruction techniques would lead to misinterpretations of past positive NAO conditions if only Nuuk temperature data were to be used.

Nonlinearities and deviations in the NAO winter temperature pattern could therefore be an explanation to the instabilities in correlations in between different NAO reconstructions [Schmutz et al., 2000; Vinther et al. 2003a]. A comparison between the Vinther et al. [2003a] NAO reconstruction (based on Greenland ice core data) and the Luterbacher et al. [2002] reconstruction (based on a variety of European data) did indeed show the weakest relations during a period (1686-1715 A.D.) where the Luterbacher et al. [2002] reconstruction were heavily dependent on CET data [Vinther et al. 2003]. Further a detailed examination of the two reconstructions shows that six winters during the 1686-1715 A.D. period were predicted by the Greenland based reconstruction to be strongly positive NAO winters, while the reconstruction based on European data suggests negative or near neutral NAO conditions in accordance with CET data. This is exactly the discrepancy one would expect if these winters were similar to the winter of 1984.

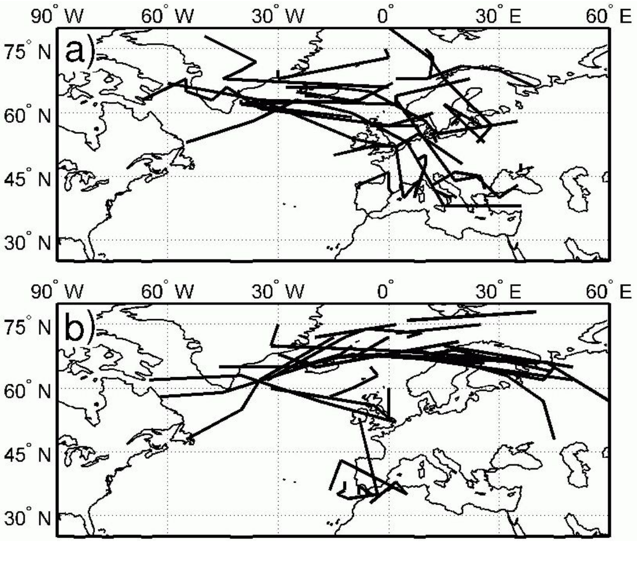

Figure 4. Jan-Feb cyclone tracks for 1984 (a) and 1989 (b).

The difficulty of reconstructing the NAO from its effects on northern hemisphere winter temperatures has also been studied in a 500 year run of a fully coupled global circulation model [Zorita and González-Rouco, 2002]. They found that temperature anomaly patterns could change on centennial time scales, such that the stability of a NAO reconstruction was dependant on the area chosen for the temperature observations.

6. Conclusion

Using more than 100 years of Greenland west coast and Central England temperature data the stability of the NAO winter temperature seesaw was examined.

The period of Jan-Feb 1984 was found to be a violent example of a NAO winter temperature seesaw breakdown. A steady movement of cyclones from southern Greenland to the British Isles took place during this period. Hence very cold air of Greenland origin was moved rapidly across the Atlantic. This led to cooler than normal winter temperatures both in Greenland and the British Isles; a clear deviation from the normal NAO winter temperature pattern.

It was further shown that the relation between Greenland winter temperatures and the NAO is nonlinear for moderately to strongly positive NAO conditions; with the high winter of 1984 being an outspoken nonlinear example.

As many NAO reconstructions are based on temperature related data, the period of Jan-Feb 1984 shows that it is of the utmost importance that such reconstructions uses data from areas affected oppositely by the NAO temperature seesaw. To faithfully reconstruct the NAO of the past the issue of nonlinear NAO/temperature relations must also be considered.

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