Winter Lightning and North Atlantic Oscillation

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ABSTRACT

The relationship between the North Atlantic Oscillation (NAO) and total (in cloud and cloud to ground) lightning activity during the wintertime (December to March) is analyzed. Lightning data from the Optical Transient Detector were used and were studied in the North Atlantic and western European area. The southern half of the area analyzed (latitudes lower than −50°N) was observed to have an increased (decreased) lightning flash rate associated with negative (positive) NAO index values. The opposite relationship was found when the northern half (latitudes higher than −50°N) was considered. In both cases, the effect of the NAO on the lightning activity was stronger over the eastern area analyzed. Low (clearly <1) absolute values of the NAO index seem to be associated with minimum lightning activity.

1. Introduction

The North Atlantic Oscillation (NAO) is considered to be the main pattern of the variability of atmospheric circulation in the North Atlantic area. The effects of the NAO on precipitation and temperature have been analyzed in several publications (e.g., Hurrell 1995; Ulbrich et al. 1999), but studies on the relationship between the NAO and lightning are limited, perhaps because during the winter, when the NAO is stronger, lightning is at a minimum at middle and high latitudes. Rivas Soriano et al. (2004) analyzed the relationship between the NAO and winter convection in the North Atlantic and western European area. They focused their attention on convective precipitation, using diagnostic surface data, although they also considered the impact of the NAO on cloud-to-ground (CG) lightning. However, in that work the analysis was restricted to the Iberian Peninsula only because the authors used data from the Spanish lightning detection network. Rivas Soriano et al. (2004) found a negative correlation between the NAO and winter CG lightning flash rate. It should be mentioned here that Goodman et al. (2000) used data from the Lightning Imaging Sensor (LIS), a Tropical Rainfall Measuring Mission (TRMM) space-based instrument, to study the relationship between El Niño–Southern Oscillation (ENSO) and total winter lightning in the southeastern United States. They reported a 100%–200% increase in the wintertime lightning flashes, lightning days, and lightning hours within the northern Gulf of Mexico basin during 1997/98 and found that this was directly attributable to the enhanced synoptic-scale forcing associated with ENSO. In the present analysis, lightning data from the Optical Transient Detector (OTD), a scientific payload on the Microlab-1 satellite, were used. Owing to the global coverage of this dataset, it is possible to analyze the effect of the NAO on lightning over the whole North Atlantic region.

2. Data

The lightning dataset was obtained from space observations by the National Aeronautics and Space Administration’s (NASA) OTD (for a complete assessment, see Boccippio et al. 2000). The OTD was launched in April 1995, and data were collected from mission launch until April 2000. The OTD offers a unique opportunity for the detection of global lightning activity and is hence the only sensor that provides lightning data for the whole of the North Atlantic Ocean. The data from the OTD are the total (in cloud and cloud to ground) lightning activity, obtained with a detection efficiency varying between ~49% and 65% (64% for the 13 April–8 June 1995 period, 49% for the 9 June–19 July 1995 period, 56% for the 20 July 1995–
22 October 1996 period, and 62% for the 23 October 1996–end of mission). These percentages were estimated by Boccioppio et al. (2000) and have been used in other analyses of OTD data (e.g., Boccioppio et al. 2001; Christian et al. 2003). OTD detection efficiency varies between periods because it is a function of the sensor threshold (gain) setting and because four different threshold detection levels were applied during the mission. The OTD takes 55 days to fully sample the diurnal cycle at any given location. Accordingly, the data must be aggregated in 55-day blocks in order to minimize diurnal bias. The NAO is especially pronounced in the winter, and hence this study was performed during this season, usually defined as the months of December, January and February. Accordingly, the lightning data corresponding to five winters (1995/96 to 1999/2000) were available. Flash counts and view times of each winter were obtained for the 110-day (two 55-day blocks) time interval extending from 1 December to 20 March (19 March for the leap year). The flash data were corrected assuming a geographically invariant detection efficiency of 56% for the 1995/96 winter and 62% for the 1996/97 to 1999/2000 winters. The two most likely sources of potential systematic bias in the OTD data are a uniform bias in the estimated detection efficiencies and geographic variability in detection efficiency. However, Boccioppio et al. (2001) used a sensitivity analysis to demonstrate that spatial variability in the OTD data cannot be accounted for by such potential sources of bias. For each winter, the corrected flash count was divided by the view time to yield the winter flash rate. The area analyzed is the region located between 30° and 70°N and between 60°W and 20°E, corresponding to the North Atlantic and western European area. The lightning data were referenced to a 2° longitude × 2° latitude grid.

The NAO index was computed as the difference in surface pressure between Gibraltar and Reykjavik (Jones et al. 1997; Vinther et al. 2003) in order to include the whole of western Europe.

3. Results and discussion

The values of the normalized NAO index for the five winters considered in this study are shown in Table 1. It should be noted that the NAO only exhibited a relatively strong value during the 1995/96 (negative) and 1999/2000 (positive) winters. For the other winters, the NAO index was positive but lower than 1, especially for 1996/97 and 1997/98.

The spatial patterns of flash rates are depicted in Fig. 1. The values are very low in all cases, as is expected for winter. Flash rates higher than $10^{-2}$ flashes per second were only observed during the 1996/97 and 1997/98 winters, concentrated in cores over the southwest of the area analyzed, northern Italy, and the western part of the Iberian Peninsula (in this case only for 1997/98). However, these cores of relatively high flash rates were the result of thunderstorms that occurred in only 1 week: from 1 to 5 December in both cases. If these exceptions are not considered, comparison of Table 1 and Fig. 1 suggests that wintertime lightning activity increases with the absolute value of the NAO index.

It is difficult to observe differences in the spatial distributions of flash rates in Fig. 1. As reported by many authors (e.g., Christian et al. 2003), lightning activity increases toward the equator and mainly occurs over landmasses. Both effects, seen in Fig. 1, may mask the possible relationship between the NAO and lightning activity. To remove these effects and gather clearer information, we used anomalies. These anomalies were calculated by subtracting the 5-yr mean of the flash rates from the data for each winter and dividing the result by the 5-yr standard deviation. The spatial distributions of the anomalies are shown in Fig. 2. During the 1995/96 winter, when the NAO index had a strong negative value, the anomalies were mainly positive over the southern half of the area considered (latitude $<50°N$). Over the northern half (latitude $>50°N$) negative anomalies occupied larger spatial extensions, especially over the western zone (eastern North Atlantic Ocean and western Europe). During the 1996/97 and 1997/98 winters, the expected cores of high positive anomalies associated with the above-mentioned high lightning activity in the first week of December are clearly visible. Excluding these zones, the anomalies are negative over most of the area studied. The 1996/97 and 1997/98 winters show the lowest absolute values of the NAO index (see Table 1). This suggests that an NAO index close to 0 would be associated with low lightning activity in the wintertime. For the 1998/99 winter (NAO index $\sim$1), the pattern of the spatial distribution of the anomalies is very different from that of the 1995/96 winter, because positive anomalies moved northward. This suggests that the positive NAO phase would have been associated with increasing (decreasing) lightning activity over the northern (southern) area analyzed. In

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<th>NAO index value</th>
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<td>1995/96</td>
<td>−2.32</td>
</tr>
<tr>
<td>1996/97</td>
<td>0.18</td>
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<tr>
<td>1997/98</td>
<td>0.80</td>
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fact, the spatial pattern of the anomalies for the 1999/2000 winter (corresponding to the highest positive NAO index value) is nearly opposite that of the 1995/96 winter. The correlation coefficient between the domain average flash rates for the 1995/96 and 1999/2000 winters is $\sim-0.6$. The differences between both spatial patterns in Fig. 2 are specially seen over the eastern North Atlantic Ocean and western Europe.

These results suggest that the negative phase of the NAO seems to be related to increased (decreased) lightning activity over the southern (northern) North Atlantic area. The opposite effect would be associated with the positive phase of the NAO. The NAO is related to the variability in atmospheric conditions that contribute to convective development and hence lightning activity. The negative phase of the NAO is associated with cold and dry winters in northern Europe and wet winters in southern Europe. The opposite ef-
fect is associated with the positive phase. High moisture contents and temperatures at low levels contribute to convective development. Thus, it is to be expected that negative NAO index values will be associated with increased (decreased) convection, and hence lightning, over the southern (northern) North Atlantic area. The opposite would be related to positive NAO index values.

Hurrell and Van Loon (1997) found that the positive NAO phase is related to increases (decreases) in storm tracks and cyclonic vorticity over the northern (southern) North Atlantic area. The opposite is associated with the negative phase. This would increase (decrease) convection, and hence lightning, over the northern (southern) North Atlantic area during the positive NAO phase. By contrast, the negative NAO phase

Fig. 2. Spatial distributions of flash-rate anomalies during winter (DJFM) in the 1995–2000 period. Positive anomalies are contoured in bold. Horizontal and vertical labels are longitude and latitude, respectively. The agglomeration of lines associated with the high lightning activity from 1 to 5 Dec (see text) is the reason for the dark shading in the 1996/97 and 1997/98 maps.
would be related to decreases (increases) in lightning activity over the northern (southern) North Atlantic area. These observations are consistent with the above-mentioned relationship between the NAO and lightning activity.

In fact, this is similar to what was reported by Rivas Soriano et al. (2004) for the relationship between the NAO and winter convective precipitation. This is not surprising, because both lightning and convective precipitation are physically related to convection (i.e., Petersen and Rutledge 1998; Soula and Chauzy 2001). Consequently, the same physical arguments used by Rivas Soriano et al. (2004) to explain their results can be invoked here to account for the relationship between the NAO and lightning activity.

The effect of the NAO on lightning may be quantified using the correlation between the normalized NAO index and the lightning flash rate. The spatial distribution of the correlation coefficients $|F|>0.4$ is shown in Fig. 3. It can be seen that over the southern half (south of $\sim50^\circ$N) of the area studied, the correlation coefficients are negative. The zones of positive correlations occupy a small area but tend to be concentrated in the northern half (north of $\sim50^\circ$N). It should be noted that the highest correlation coefficients (both negative and positive) are mainly seen east of $\sim40^\circ$W. Because the change in the NAO phase is associated with changes in the intensity of the westerlies, its effect on heat and moisture fluxes will be stronger downwind, that is, over the eastern North Atlantic Ocean and western Europe. The correlation coefficients are higher for latitudes lower than $50^\circ$N, but it should be remarked that at higher latitudes the low lightning activity makes it difficult to observe variations in flash rate.

4. Conclusions

Lightning data from the Optical Transient Detector (OTD) for the North Atlantic Ocean and western Europe were analyzed in relation to the NAO. The results reveal a relationship between the NAO and total (in cloud and cloud to ground) lightning activity during the winter (December to March). This relationship seems to be opposite at latitudes lower and higher than $\sim50^\circ$N. When the southern half of the area studied was considered, the negative (positive) NAO phase was associated with increased (decreased) lightning activity. The opposite effect was seen when the northern half was considered. These results are consistent with the variability in atmospheric conditions related to the NAO and are similar to those reported by Rivas Soriano et al. (2004) for the relationship between the NAO and convective precipitation during winter. The effect of the NAO on lightning is stronger over the eastern North Atlantic Ocean and western Europe and it is more clearly seen at latitudes lower than $\sim50^\circ$N, probably due to the low lightning activity at high latitudes.

It should be emphasized that these conclusions were obtained over the 5-yr period (April 1995 to April 2000) of data collection by the OTD. This time period is probably not long enough to make the results statistically significant.

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REFERENCES


![Fig. 3. Spatial distribution of correlation coefficients between NAO index values and flash rate. Boldface lines mark positive values. Only correlation coefficients $|F|>0.4$ are contoured.](image-url)
observations from Gibraltar and south-west Iceland. *Int. J. Climatol.*, **17**, 1433–1500.


