Changes in the odds of extreme events in the Atlantic basin depending on the position of the extratropical jet

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[1] In this study we establish a link between the position of the extratropical jet over the Atlantic and extreme temperature events (below the local seasonal 5% quantile or above the 95% quantile respectively) and wind events (above the local 98% quantile) in the Atlantic basin for the present climate. The strongest link between temperature extremes and the jet is found for the winter season. Extended areas in Europe, Greenland and North America see an increased or decreased chance of winter cold extremes depending on the jet position, even up to a week after the jet occupied the position of interest. Chances of warm temperature extremes in summer in southeastern Europe are higher several days after the jet was located in the central Atlantic. Chances of wind extremes are higher in Western Europe at the latitude of the jet and reduced to the north and south. **Citation:** Mahlstein, I., O. Martius, C. Chevalier, and D. Ginsbourger (2012), Changes in the odds of extreme events in the Atlantic basin depending on the position of the extratropical jet, *Geophys. Res. Lett.*, *39*, L22805, doi:10.1029/2012GL053993.

1. Introduction

[2] Extreme events are of great interest as they can have significant socio-economic impacts and sometimes even fatal consequences [*Hallegatte et al.*, 2007]. The occurrence of extreme events (temperature, wind, and precipitation) in specific geographic locations in Europe is influenced by large-scale circulation patterns. For example, *Kenyon and Hegerl* [2008] showed that chances for hotter (colder) temperatures over Europe increase when the phase of the North Atlantic Oscillation (NAO) is positive (negative) throughout the whole year. A similar study for precipitation extremes confirmed a significant link to the NAO [*Kenyon and Hegerl*, 2010]. *Scaife et al.* [2008] studied the change in extreme winter temperatures due to externally forced changes in the NAO and find significant signals. Furthermore, cold temperatures in winter are associated with blocking events. In Europe these stationary anticyclones prevent the transport of mild air from the Atlantic into the continent [*Masato et al.*, 2012; *Sillmann and Croci-Maspoli*, 2009; *Trigo et al.*, 2004].

[3] Similarly strong links exist for wind extremes. Extreme cyclones over northern Europe are linked to a NAO-like circulation pattern at upper-levels [*Raible*, 2007] and accordingly the frequency of storm events over Central Europe is also closely linked to the NAO pattern [*Donat et al.*, 2010]. Storms occur primarily during a moderate to strong positive NAO phase [*Donat et al.*, 2010].

[4] In this study these findings have been taken a step further. Over the Atlantic basin the extratropical jet stream connects the large-scale atmospheric variability, e.g., the NAO, to weather phenomena and therefore bridges the gap from the large-scale circulation to the individual weather event. The position of the jet is closely related to both the NAO and the East Atlantic (EA) variability patterns [*Woollings et al.*, 2010] and it also controls the location of the Atlantic storm track [*Pinto et al.*, 2007].

[5] These links serve as a basis for exploring the relationship between the jet position on a particular day and the odds of an extreme event occurring in a specific region on the same day, and up to 9 days later. Knowledge about dependencies between the jet position and extreme events is potentially useful for short to medium range forecasts of extreme events and for projections of extreme events in a future climate.

2. Data and Methodology

2.1. Jet Index

[6] The extratropical jet has three preferred latitudinal positions over the Atlantic, ranging from a southern position to a middle position and up to a northern position [*Woollings et al.*, 2010]. The daily jet latitudinal index of *Woollings et al.* [2010] is a proxy for the location of the extratropical jet stream. It provides the latitudinal position of the low-pass filtered, lower tropospheric maximum wind speeds in the Atlantic basin between 15°N and 75°N derived from the ERA-40 data set [*Uppala et al.*, 2005]. A seasonal cycle is subtracted from the daily indices, however, a weak seasonal cycle remains (see Figure S1 in the auxiliary material).[1] We use daily data from the period December 1, 1957 to November 30, 2001. The jet latitudes are categorized in three preferred positions (from now on referred to jet1, jet2 and jet3), where jet1 describes the southern position (south of 44°N), jet2 the position in the center (between 44°N and 53°N) and jet3 the northern position (north of 53°N).

2.2. Atmospheric Variables

[7] In order to assess the relationship between the jet position and extreme events reanalysis datasets are analyzed: ERA-40 daily mean 2-meter temperature is used to study

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temperature extremes. We use only data from grid-points over land north of 20°N. The zonal and meridional components of the 10-meter wind from the ERA-40 reanalysis are used to obtain daily maximum wind speeds. All data but the jet index data is linearly detrended on the grid cell level.

[8] To facilitate the interpretation of the results, we show composites of surface temperature, geopotential anomalies at 500 hPa, and wind speed at 850 hPa and 200 hPa for the three jet states as defined above.

2.3. Definition of Extreme Events and Statistical Methods

[9] Extreme events are defined as threshold exceedance of a locally, seasonally varying percentile value. For each day of the year these percentiles are determined by taking into account an eleven-day period centered on the day of interest over the 44-year time period. We use the 95% and the 99% quantile for hot temperature extremes, the 5% and the 1% quantile for cold temperature extremes, and the 98% quantile for wind speed. Over the entire 44-year period, this procedure identifies the same number of moderate extreme events in each of the four seasons.

[10] In a next step the link between an extreme event and the jet position is analyzed by fitting a logistic regression model to the data. To this end for every state of the jet (southern, central, northern) a binary time series is created indicating for every day of the 44-year period if the jet is in a particular state or not. The ERA-40 temperature and wind data are converted into binary time series at every grid-point. Here the binary information indicates if an extreme event as defined above occurs on a particular day or not. For each grid point and each state of the jet an autoregressive logistic regression model of the following form is fitted to the binary time series:

$$\mathrm{logit}\,(\mathrm{p(t)}) = \beta_0 + \beta_1\,\mathrm{y(t-1)} + \beta_2 \mathrm{y(t-2)} + \beta_3\,\mathrm{Jet(t)} \qquad (1)$$

where y(.) is a binary sequence indicating for all recorded days whether or not an extreme event occurred at the considered grid-point; Jet(.) is a binary sequence indicating for all recorded days if the jet was in the considered state.

$$\mathrm{logit}\,(\mathrm{p(t)}) := \log\,(\mathrm{p(t)}/(1\text{-}\mathrm{p(t)})) \qquad (2)$$

where p (t) := P (y (t) = 1 | y(t-1), y(t-2), Jet(t)), is the probability of observing an extreme event at time t, given the past two observations and the position of the jet (often denoted p in the sequel). For more details of the statistical methods see the auxiliary material.

[11] In this paper only the values of β_3 will be discussed. The figures show the odds ratio, which corresponds to $\exp(\beta_3)$. The odds ratio $\exp(\beta_3)$ can be seen as a multiplicative factor that increases (or decreases, if below 1) the odds, i.e., p/(1-p), of observing an extreme event at a specific grid-point given that the Jet(.) is in a particular state. Shown are results with a p-value at the 95% significance level (see auxiliary material for more information).

[12] The logistic regression coefficients, were calculated for every jet state (southern, central, northern), every ERA-40 grid-point north of 20°N, as well as for time lags between zero and nine days. The regression was calculated for all four seasons separately for temperature extremes, and for the entire year for the wind extremes.

3. Relationship Between the Jet Position and Temperature Extremes

3.1. Cold Extremes

[13] The focus of this discussion is on the behavior of moderate cold extremes during winter since these are potentially high impact events. Moderate cold extremes during spring, which might be relevant for agriculture, will be discussed briefly at the end of this section.

[14] The position of the jet over the Atlantic influences the odds of cold extreme events occurring. Interestingly, the influence is not restricted to Europe, but entails Northern Africa, Greenland and North America. Figure 1 shows the regions where the jet position significantly changes the odds of moderate cold extreme occurrence during December–January–February (DJF). For the southernmost jet position (jet1, 5% quantile) the odds of cold extremes increase over Western Europe (up to 300%) and decrease over North Africa and Greenland. The results are shown for lag zero, meaning that the cold extreme happens on the same day as the jet is in the southern position. The location of the statistically significant areas does not change for lags 1 to 9. The maximum change in the odds over central Europe is found for lag 2 and the odds ratios decrease afterwards for increasing time lags (not shown). A central jet position reduces the chances of cold extremes in Western Europe up to day 7. For the northernmost jet state, the odds for cold extremes are reduced in Scandinavia and in central North America and increased over North Africa and western Greenland. There is a downstream shift of the affected areas to the eastern US (decrease), eastern Greenland (increase) and central Russia (decrease) by lag 8 (not shown).

[15] For the more extreme case of the lowest 1% quantile, the area with a significant change in the odds is smaller, but the chances of an extreme event are greatly increased (odds ratio of up to more than 400%; see Figure 1). The spikiness of the odds ratio map in some places may be imputed to the greater difficulty to draw statistical conclusion of more rare events (only a few extreme days available at each grid point). The presence of spatial clusters, notably over Europe for Jet 1, gives credence to those results.

[16] The results shown in Figure 1 (left) were reproduced using the European Climate Assessment& Dataset (ECAD) station dataset (see Figure S3). The overall agreement between the two datasets for central and northern Europe is very good, indicating that the results found in this study are robust. Unfortunately, only very few stations were available for North Africa.

[17] For spring (March–April–May; MAM) the spatial patterns of the statistically significant changes in the odds are very similar to the winter ones, however, the positive change in the odds is located further north over England and Scandinavia. The odds ratios are generally smaller and the

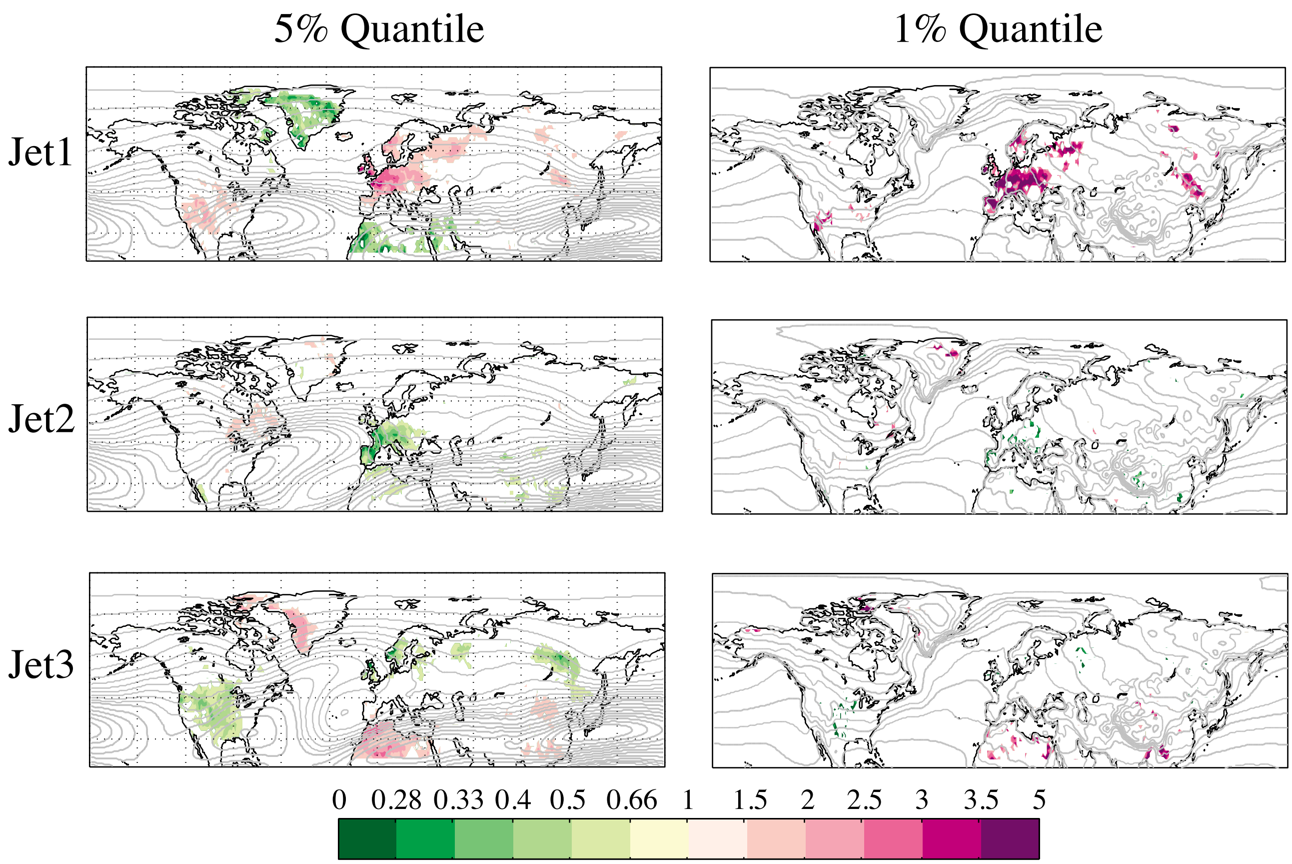

Figure 1. Areas with statistically significant changes in the odds of cold extremes in DJF for lag = 0 days (shaded). The green colors indicate a reduction (e.g., a value of 0.5 means a reduction of the odds by 50%), one means no change, and the purple colors indicate an increase (e.g., a value of 2 means a doubling of the odds) of cold extremes. (left) The results for the 5% quantile and the grey contours show the wind speed at 200 hPa (spacing 0:2:24 ms^{-1} followed by 26:4:60 ms^{-1} in thicker lines). (right) The results for the 1% quantile with surface temperatures shown in grey contours (spacing −40:5:40°C, −40:10:40 shown as thick lines, −35:10:35 shown as thin lines). (See Figure S2 for changes in the odds of all land area, including the non-significant areas.)

central jet state shows no areas with significant changes in the odds (not shown).

3.2. Hot Extremes

[18] The position of the jet is also important for hot temperature extremes. Hot extremes are of particular interest during the summer season (June–July–August; JJA), as they could be part of heat waves and droughts. Generally fewer areas show a statistically significant increase or decrease in the odds for hot extremes for a particular state of the jet during summer. Figure 2 (bottom) shows a substantial increase (odds ratio greater than 3) of hot extremes in southern central Europe for the central jet on lag 5, i.e., 5 days after the jet was in the middle position over the Atlantic. This pattern is present from lag 2 to lag 9, but strongest on lag 5. In parts of northeast America there is a slight reduction of hot extremes for the same jet position and lag 5. The pattern is almost perfectly reversed when the jet is in the north (not shown). During September–October–November (SON) the number of hot extremes is also increased over central and eastern Europe for the central jet location (not shown).

[19] During the other seasons the following interesting patterns are found: during DJF the southern jet position greatly increases the chances of very mild temperatures in Greenland (odds ratio >3; see Figure 2, top). A similar strong increase in hot extremes over Greenland for the southern jet position is also found in MAM and SON and slightly weaker in JJA (not shown).

4. Wind Extremes

[20] The analysis for the wind is shown for the entire year since the patterns vary little throughout the seasons. Compared to the temperature extremes the statistically significant areas are spatially more confined and for increasing time lags the statistically significant areas decrease rapidly. Areas where the chances of high wind speeds are increased are located slightly north of the mean jet axis along the west coast of Europe for the southern and central jet state (Figure 3). Chances for high wind speeds are reduced over central Europe, the UK and southern Scandinavia for the southern jet state. For the northern jet state, areas of increased high wind occurrence are found over northern Germany, Scotland, Scandinavia,

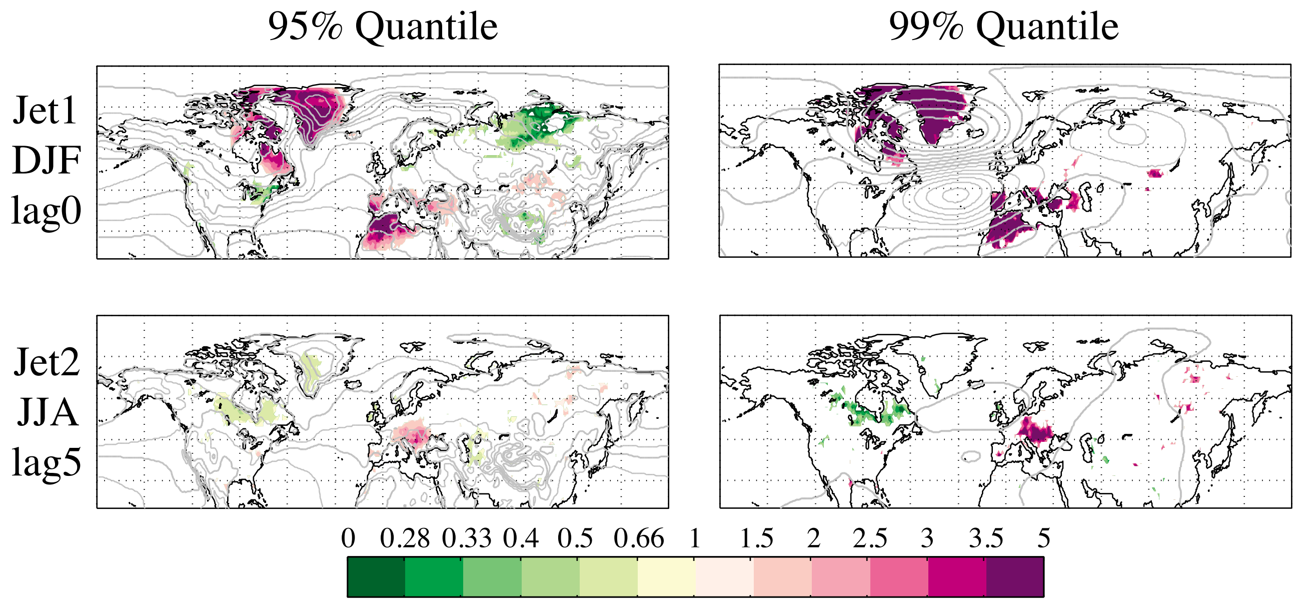

Figure 2. Statistically significant changes in the odds of hot extremes (top) for DJF and lag = 0 days and (bottom) for JJA and lag = 5 days. (left) The results for the 95% quantile with temperature contours shown in grey (spacing −40:5:40°C, −40:10:40 shown as thick lines, −35:10:35 shown as thin lines), (right) the 99% quantile with geopotential anomalies on the 500 hPa level (−2000:200:0 m^2s^{-2} followed by 0:200:2000 m^2s^{-2} in thicker lines) overlaid in grey. (See Figure S4 for changes in the odds of all land area, including the non-significant areas.)

and over the eastern Mediterranean; A reduction in the odds for high wind events is found over western France, Portugal, and Spain.

5. Discussion

[21] Overall the spatial patterns for the cold and warm extremes are similar (with reversed sign) but not exactly symmetric (see, for example, Figures 1 (top left) and 2). Furthermore, the southern and the northern jet show often almost inverted patterns, which differ quite substantially from those of the central jet. The central jet, however, exhibits the strongest links to the occurrence of extreme wind events over central Europe.

[22] The southern jet state corresponds to a predominantly negative NAO and positive EA pattern, the northern jet mainly to a positive NAO and negative EA pattern and the central jet occurs preferentially during a positive NAO and positive EA phase [*Woollings et al.*, 2010]. These links allow comparing our results with previous findings. A positive NAO is associated with a reduction of cold extremes over northern Europe and an increase of cold extremes over North Africa in the winter months [*Kenyon and Hegerl*, 2008]. This is in good agreement with our results.

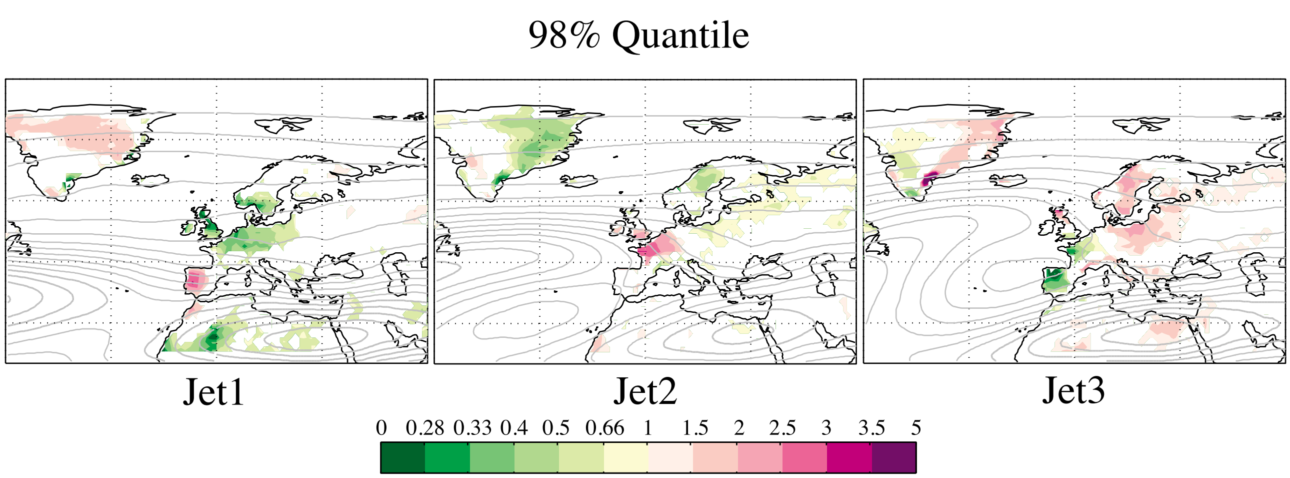

Figure 3. Changes in the odds of wind extremes (98% quantile) depending on the jet position. Shown are the three jet positions at lag = 0. The grey contours show the wind speed at 200 hPa (spacing 0:2:24 ms^{-1} followed by 26:4:60 ms^{-1} in thicker lines). (See Figure S5 for changes in the odds of all land area, including the non-significant areas.)

[23] It is now interesting to briefly discuss the mechanisms and potential implications of these findings.

5.1. Mechanisms

[24] Temperature advection is a crucial source of temperature variability [*de Vries et al.*, 2012]. The decrease of extreme cold temperatures during DJF over North Africa, Western Europe and Scandinavia for the southern, central and northern jet state respectively is likely due to the advection of relatively warm air from the ocean (see Figures S6 and S7). The strong increase of very cold temperatures over central Europe during the southern jet state, is in good agreement with the recent very cold winter of 2009/2010, when the jet was also in a southerly position [*Seager et al.*, 2010]. The absence of advective processes might partially explain the increase in cold extremes over Central Europe since the lower tropospheric winds are very weak in that area (see Figure S6).

[25] A southerly jet is often connected with blocking over Greenland [*Croci-Maspoli et al.*, 2007] and blocking over Greenland is accompanied by warm temperature anomalies over Greenland [*Masato et al.*, 2012]. During the southerly jet state a flow directed from the southeast brings warm air from the Atlantic toward Greenland, which is in good agreement with the presence of blocking over Greenland. In the northerly jet state the dominant flow toward Greenland is very weak and from the west and southwest where temperatures are colder (see Figures S6 and S7). It is worth noting that the changes in the odds of very cold temperatures are also reflected in the mean temperatures (e.g., the mean temperatures in Greenland are about six degrees colder during the northern jet state than during the southern jet state; see Figure S7).

[26] Weak winds and the absence of advection from the oceans are also one possible explanation for the increased occurrence of warm extremes over southeastern Europe during summer and fall for the central jet regime (see Figure S8).

[27] The link between the jet state and the occurrence of temperature extremes are weakest during summer. Potential explanations for this fact are a generally much weaker jet stream in summer, weaker land-sea temperature contrasts and hence weaker temperature advection by the jets, and the important role of blocking anticyclones for warm extremes [*Dole et al.*, 2011].

5.2. Potential Implications

[28] The jet is an important driver of temperature extremes over the Atlantic basin and Europe and future changes in the jet position will affect the frequency and location of climate extremes. For example the high number of hot temperature extremes in Greenland for the southern jet position may be interesting in the context of the melting of the ice sheets. On the other hand parts of northern Russia see a reduction in mild winter, fall, and spring temperatures for the same jet position for the 5% quantile (Figure 1).

[29] In a future climate the zonal mean extratropical jet is projected to move northward [*Intergovernmental Panel on Climate Change*, 2007; *Yin*, 2005]. However, the signal is less clear in the Atlantic [*Woollings et al.*, 2012] and the jet might shift more to a central rather than a northern position. This would imply that areas that show increased odds for extreme events for jet2 in Figures 1–3 might see an increase in the frequency of extreme events as defined for present day climatological conditions, whereas areas that show a reduction of an extreme event for this jet position might be affected less by extremes in a changing climate.

6. Summary

[30] In this study, the link between extreme events in the Atlantic basin and the position of the extra-tropical jet were analyzed in order to understand better why and when extreme events occur. The following four main results are found: (1) Statistically significant links between the Atlantic jet position and the odds for extreme events are found for coherent and large areas over Europe, Asia and even North America. For example, the chances of a cold extreme are either greatly enhanced or reduced in Western Europe, depending on where the jet is located over the Atlantic on a particular day. (2) For increasing rarity of the extremes, the statically significant areas become smaller but the odds ratios for extreme events increase indicating that very extreme events can only occur for specific jet configurations. (3) Statistically significant links with temperature extremes are not only found for lag = 0 but also for time lags of up to one week, indicating a potential for medium range predictability of these events. (4) For central Europe significant differences of the links between jet position and extreme events for the four seasons are found.

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