7.6 THE INFLUENCE OF LOW FREQUENCY AND SYNOPTIC VARIABILITY ON THE TIMING, MAGNITUDE, AND GEOGRAPHICAL DISTRIBUTION OF EXTREME WIND EVENTS

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1. INTRODUCTION

One aspect of climate variability that is of societal and scientific interest is variations in the statistics of extreme events. Extreme wind events are of particular interest, because extreme extratropical windstorms have a significant economic impact on populated areas of midlatitudes in winter. For example, the windstorms Lothar and Martin that struck Europe in December 1999 caused $8.4 billion in insured damage (McCarthy et al. 2001). So far, most studies of extreme events have been statistical in nature, and few have attempted to study the dynamics that control the statistics of extremes. This study seeks to understand the dynamics that influence the timing, magnitude, and geographical distribution of extreme wind events, in order to provide a dynamical framework for understanding how the statistics of extreme wind events are affected by variability on different time scales.

Considerable work has been done on extremes of temperature and precipitation, but relatively little has been done on the extremes of wind. One reason for this may be the lack of homogeneity in observational wind data sets (WASA Group 1998). However, synoptic scale extreme wind events, such as the windstorms Lothar and Martin, are likely to be resolved even in relatively coarse-grained data sets, such as operational reanalyses or climate model output.

During Northern Hemisphere winter, extreme wind events tend to occur during strong synoptic scale storms. As a result, one may assume that extreme winds are primarily controlled by variability on synoptic time scales. However, synoptic variability is superimposed on variability that occurs at longer time scales, and wind extremes are strongly influenced by this low frequency variability. In addition, low frequency variability has a strong organizing influence on synoptic variability (e.g., Branstator 1995). Thus, low frequency variability can influence extreme winds in two ways: in an additive sense, by changing the magnitude of the low frequency wind that synoptic variability is superimposed upon, and in a multiplicative sense, by organizing the synoptic variability that is superimposed on the low frequency variability. In this study, we will investigate the geographical variations of the additive and multiplicative effects of low frequency variability on extreme wind events.

2. DATA

Because extreme events occur very rarely, it is difficult to characterize their dynamics using the short observational record. In order to alleviate this problem, this study takes advantage of the large sample size provided by the 9-member ensemble of Climate of the 20th Century experiments performed with the NCAR Community Climate System Model (CCSM3), which simulates the period 1870 to 1999. The data analyzed is from the Northern Hemisphere (NH) winter season, December-March (DJFM). These results will be compared with ECMWF Reanalysis (ERA-40) data (Uppala et al. 2005) interpolated to the T85 resolution of the model, to check that the relationships we find in the model are also found in nature. In the current phase of the study, we have focused on the relationships in CCSM3, leaving most of the comparisons to ERA-40 to be done in later stages of the study.

3. GEOGRAPHY OF EXTREMES

We will begin by defining extreme wind events as days where the 850 hPa wind speed (WS850), calculated from daily mean wind components, exceeds its 99th percentile at any given point. This study examines extremes in WS850 because surface wind gusts are often caused by transport of high velocity air from higher altitudes (Brasseur 2001), so extreme values of WS850 at the resolution of CCSM3 could be a good indicator of the potential for extreme surface wind gusts. The 99th percentile of WS850 for CCSM3 is shown in Fig. 1a, and can be compared to the same quantity for ERA-40 in Fig. 1b. Extreme wind events tend to be particularly strong in the oceanic storm tracks over the Pacific and Atlantic. Over land, they are strongest in the extension of the Atlantic storm track into western and northern Europe, which is consistent with the most damaging windstorms occurring in this region (McCarthy et al. 2001). Over North America, extreme wind events are strongest along its west coast at the downstream end of the Pacific storm track, and over the eastern part of the continent on the upstream end of the Atlantic storm track. Extreme wind events are also relatively strong in some regions on the poleward flanks of the storm tracks, particularly around the periphery of southern Greenland and in the vicinity of the Bering Strait. The region of strong extreme wind events over Alaska that appears in CCSM3 is absent in ERA-40, and extreme wind events in the lee of the Rockies are much weaker in ERA-40 than in CCSM3, particularly over Canada. Other than as noted above, the same general features of the geographical distribution of extreme wind events are seen in both CCSM3 and ERA-40.

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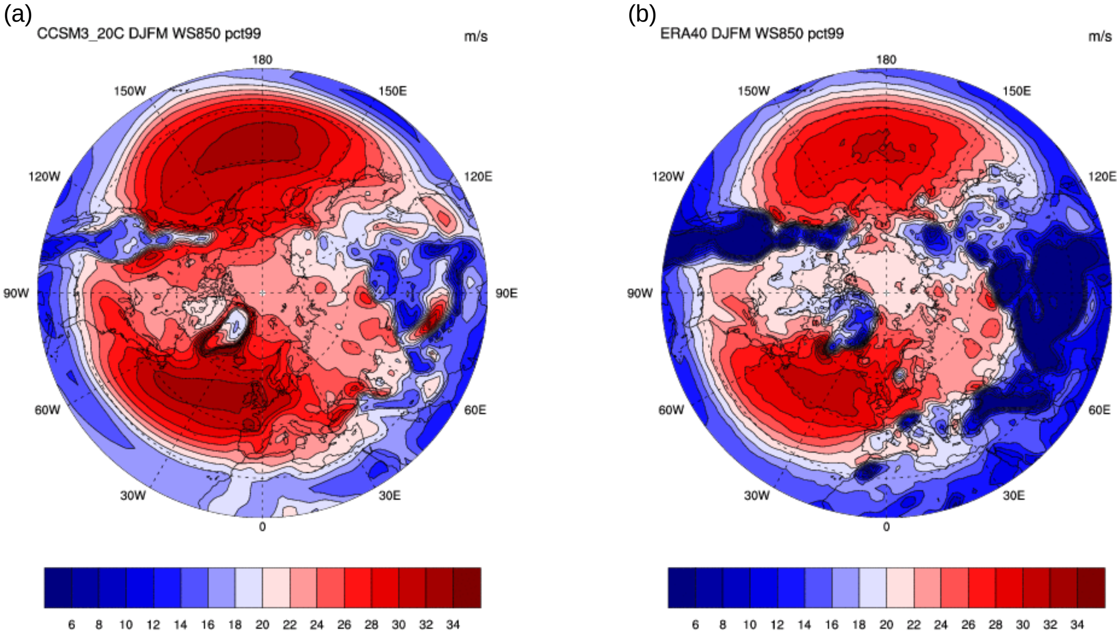


Figure 1. 99th percentile of 850 hPa wind speed (WS850), calculated from daily mean wind components. Units are m/s. (a) Calculated for 9 ensemble members of CCSM3 20C experiment, for the months December-March (DJFM), 1870-1999; (b) calculated from ERA-40, for DJFM, 1957-2002.

One may ask to what degree these extreme wind events are influenced by synoptic time scale variability, and to what degree they are influenced by variability on longer time scales. We will use 10-day high pass and low pass filters to define synoptic variability and low frequency variability, respectively. By separating the influence of synoptic and low frequency variability in this way, we are first considering just the additive effect of low frequency variability on extreme wind events; later, we will consider the multiplicative effect of low frequency variability through its organizing influence on synoptic variability.

One measure of the influence of synoptic variability on extreme wind events is the degree of correspondence between extreme wind events and extreme 10-day high pass WS850. The median percentile of the 10-day high pass WS850 for the days of extreme wind events at each point is mapped in Fig. 2a. This percentile is above 95% over much of the regions of large baroclinic growth near the east coasts of the continents, indicating that more than half of the extreme wind days occur on days where the 10-day high pass WS850 exceeds its 95th percentile. It is below 90% on the equatorward flanks of the Pacific and Atlantic storm tracks, and on the downstream end of the Atlantic storm track; note that this percentile has spuriously low values over high terrain, where the land surface is near or above 850 hPa. This can be compared to the median percentile of 10-day low pass WS850 for extreme wind events shown in Fig. 2b. This percentile is above 95% over a much larger area, and is below 90% only near Japan and in very small areas of the Atlantic storm track and over Asia.

Fig. 2 indicates that synoptic variability has the greatest influence on extreme wind events in regions of large baroclinic growth, particularly in the Pacific storm track, while low frequency variability has the greatest influence on extreme wind events on the downstream ends of the storm tracks, particularly on their equatorward flanks. Just poleward of the baroclinic growth regions, near the Sea of Okhotsk and Greenland, both synoptic and low frequency variability appear to strongly influence extreme wind events. Near the axis of the downstream ends of the storm tracks, near the coast of British Columbia and over the United Kingdom, neither synoptic nor low frequency variability appears to have a particularly strong influence on extreme wind events. While the corresponding plots for ERA-40 (not shown) are noisier, due to the shorter record, the same general features are found on those plots.

One reason for the geographically varying influences of synoptic and low frequency variability on extreme wind events is the geographical variation in the strength of variability on these time scales. Fig. 3a shows the 10-day high pass eddy kinetic energy at 850 hPa (EKE850), and Fig. 3b shows the 10-day low pass EKE850, calculated using the deviations of the 10-day low pass wind components from their climatological means. Near the east coasts of the continents, particularly near Japan, 10-day high pass EKE850 is relatively large compared to 10-day low pass EKE850, and this contributes to the greater influence of synoptic variability on extreme wind events in these regions. In contrast, 10-day low pass EKE850 is relatively large over the eastern half of the ocean basins, which

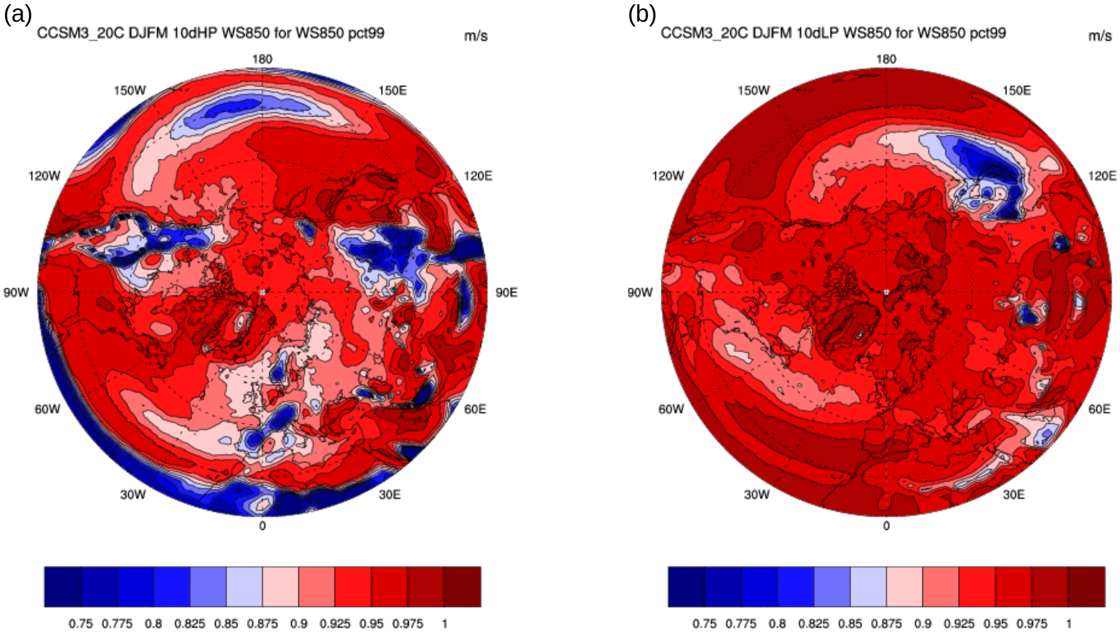


Figure 2. Median percentile of (a) 10-day high pass WS850 or (b) 10-day low pass WS850 for days where total WS850 exceeds its 99th percentile. Calculated for 9 ensemble members of CCSM3 20C experiment, for the months December-March (DJFM), 1870-1999.

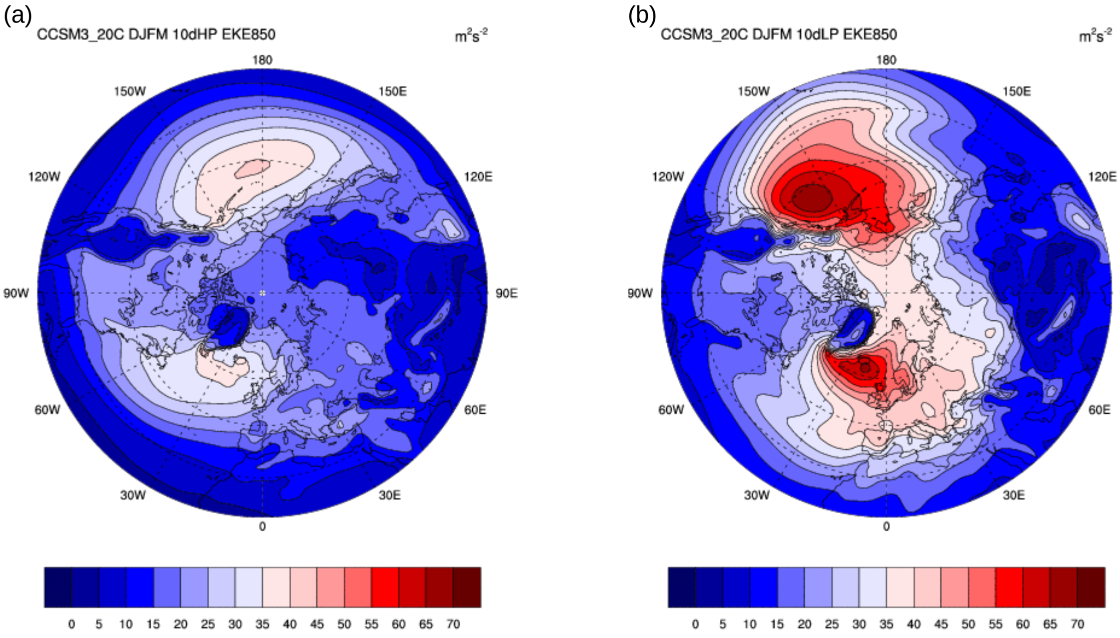


Figure 3. Climatological mean (a) 10-day high pass 850 hPa eddy kinetic energy (EKE850) and (b) 10-day low pass EKE850. Units are m^2/s^2. Calculated for 9 ensemble members of CCSM3 20C experiment, for the months December-March (DJFM), 1870-1999.

contributes to the greater influence of low frequency variability on extreme wind events in these regions. However, this is partially offset by the large synoptic variability in the northeast portions of the ocean basins at the end of the storm tracks; the large synoptic and low frequency variability in these regions contributes to neither time scale having a dominant influence on extreme wind events.

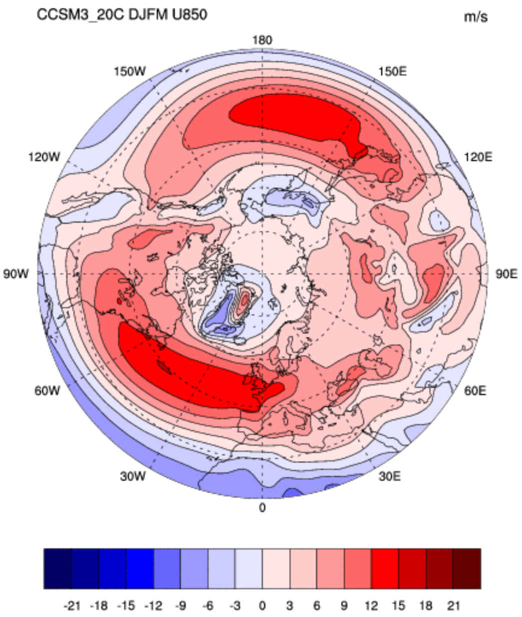


Figure 4. Climatological mean 850 hPa zonal wind. Units are m/s. Calculated for 9 ensemble members of CCSM3 20C experiment, for the months December-March (DJFM), 1870-1999.

As mentioned earlier, low frequency variability not only has an additive effect on extreme wind events; it also has a multiplicative effect on extreme wind events through its organizing influence on synoptic variability. Thus, regions of large synoptic variability are also regions where the multiplicative effect of low frequency variability has the potential to be large. The multiplicative effect is most strongly expressed in the organization of the extratropical storm tracks by the midlatitude jets. In general, the strongest synoptic variability in the storm tracks tends to be centered somewhat downstream and poleward of the maxima of zonal wind in the jets; this can be seen by comparing Fig. 3a with Fig. 4. As low frequency variability affects the jets, it will also tend to affect the storm tracks in corresponding ways. For example, if the jet shifts poleward or equatorward, the storm track will tend to shift in the same direction. Also, a stronger jet tends to suggest a stronger storm track, although the midwinter suppression of the Pacific storm track while the Pacific jet is at its strongest illustrates that the relationship between jets and storm tracks is not always simple and straightforward (e.g., Nakamura 1992).

Because the location of the jets is indicated by the strength of the zonal wind, one may expect the strength of the zonal wind to be related to the synoptic variability at a given location. Fig. 5 shows the anomaly in 10-day high pass EKE850 for days where the local 10-day low pass 850 hPa zonal wind (U850) exceeds its 90th percentile or is below its 10th percentile. This relationship varies from location to location, with EKE850 being positively correlated with low pass U850 in some locations and negatively correlated in others. In still other regions, the relationship is even highly nonlinear. In the baroclinic growth regions on the upstream ends of the Pacific and Atlantic storm tracks, there is a relatively linear negative correlation between EKE850 and low pass U850, since EKE850 tends to be large for 10-day low pass easterly anomalies and small for westerly anomalies. At the downstream end of the storm tracks, the relationship between EKE850 and low pass U850 varies strongly with latitude. On the equatorward flank of the jet exit, there is a relatively linear positive correlation between EKE850 and low pass U850. However, on the poleward flank of the jet exit, EKE850 tends to be below average for both strong westerly and strong easterly anomalies, suggesting a highly nonlinear relationship between EKE850 and low pass U850.

Fig. 6 indicates that synoptic variability is also strongly influenced by the meridional component of the 850 hPa wind (V850). In particular, southerly low pass V850 anomalies are associated with stronger EKE850 on the poleward flank of the storm track, and weaker EKE850 on the downstream end of the Atlantic storm track. Northerly low pass V850 is associated with weaker EKE850 near both storm track entrance regions and at the downstream end of the Pacific storm track. The relationship between EKE850 and V850 appears to be relatively linear in the storm track entrance regions, but not in other locations along the storm tracks, where EKE850 anomalies for northerly and southerly low pass V850 anomalies do not simply have opposite signs.

Figs. 5 and 6 show that low pass U850 and V850 have similar levels of influence on high pass EKE850, suggesting that they have similar multiplicative effects on extreme wind events. As a result, one might expect that they have similar levels of influence on the probability of extreme wind events. However, this is not the case. This can be seen by comparing Fig. 7, which shows the probability of extreme wind events on days where the local 10-day low pass U850 exceeds its 90th percentile or is below its 10th percentile, and Fig. 8, which shows the probability of extreme wind events on days where the local 10-day low pass V850 exceeds its 90th percentile or is below its 10th percentile. Nearly all of the NH has increased probability of extreme wind events for either strong westerly or strong easterly low pass wind anomalies, depending on the sign of the mean zonal wind. Over large regions, the probability of an extreme wind event approaches 0.1 when low pass U850 is in its top or bottom 10 percent, indicating that nearly all of the extreme events are captured by choosing days where low pass U850 exceeds its 90th percentile or is below its 10th percentile. The regions where strong northerly or southerly low pass wind anomalies have a strong influence on the probability of extreme wind events are much more limited. Notable exceptions include the northern edge of the Pacific storm track, the west coast of North America, the eastern United States, and the periphery of Greenland.

The geographically varying influences of low pass U850 and V850 on extreme wind events can be understood by considering the additive and multiplicative effects of each low pass wind component.

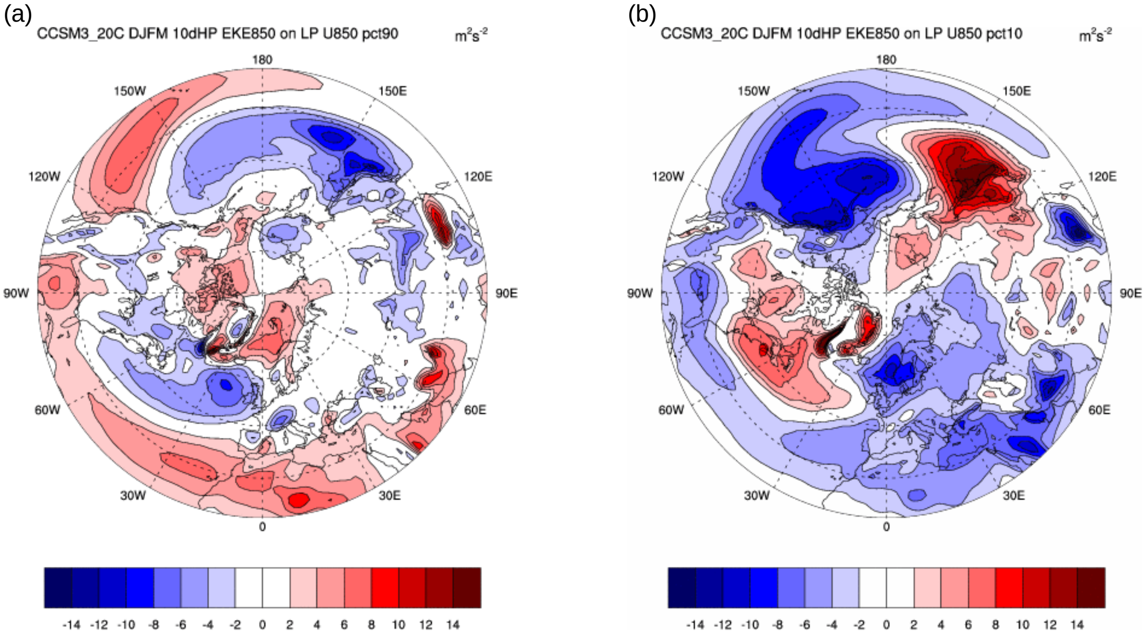


Figure 5. Anomaly in 10-day highpass EKE850 for days where 10-day lowpass U850 is (left) above its 90th percentile or (right) below its 10th percentile. Units are m^2/s^2. Calculated for 9 ensemble members of CCSM3 20C experiment, for the months December-March (DJFM), 1870-1999.

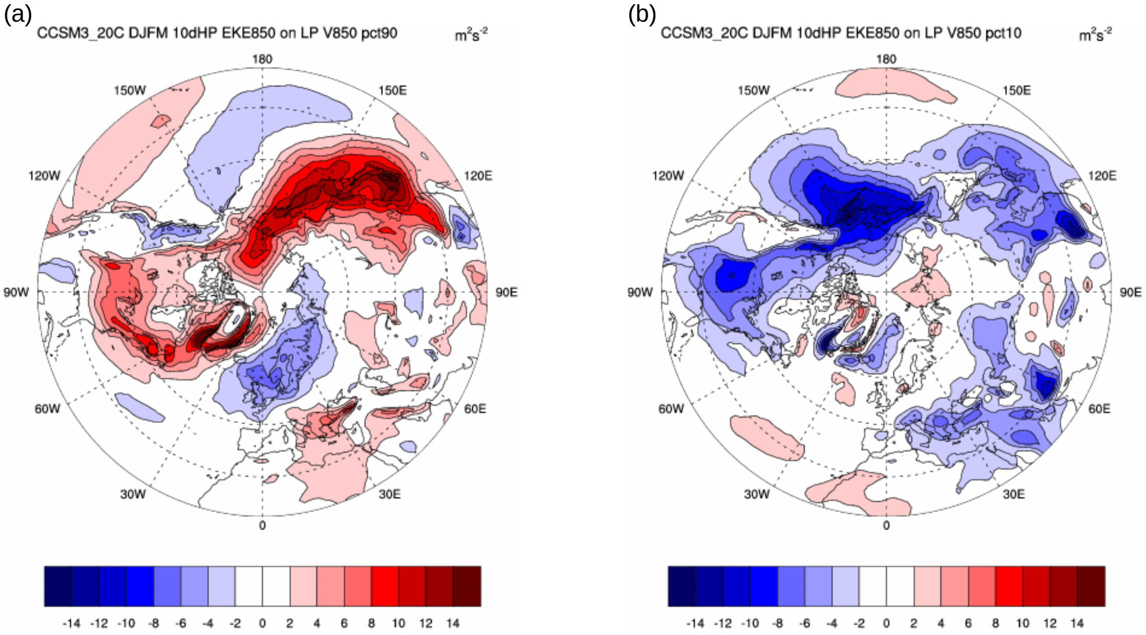


Figure 6. Anomaly in 10-day highpass EKE850 for days where 10-day lowpass 850 hPa meridional wind (V850) is (left) above its 90th percentile or (right) below its 10th percentile. Units are m^2/s^2. Calculated for 9 ensemble members of CCSM3 20C experiment, for the months December-March (DJFM), 1870-1999.

Fig. 9 shows the ratio of low pass V850 variance to low pass U850 variance, illustrating that U850 has greater low pass variance over most of the NH, and thus should have a greater additive effect on extreme wind events where this is the case. In fact, the regions in Fig. 8 where low pass V850 has a strong influence on extreme wind events nearly all correspond to the few regions where low pass V850 variance exceeds low pass U850 variance, and thus should have a greater additive effect on extreme wind events. One exception is along the east coast of Asia, where Fig. 6a shows that low pass V850 is expected to have a positive multiplicative effect

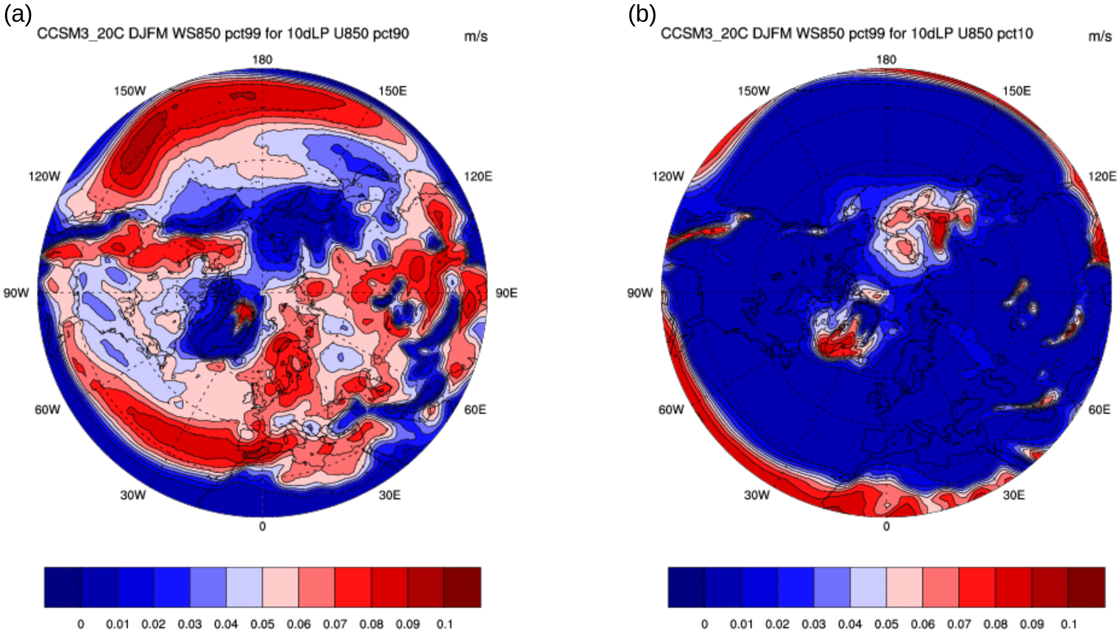


Figure 7. Probability of WS850 exceeding its 99th percentile for days where lowpass U850 is (left) above its 90th percentile or (right) below its 10th percentile. Calculated for 9 ensemble members of CCSM3 20C experiment, for the months December-March (DJFM), 1870-1999.

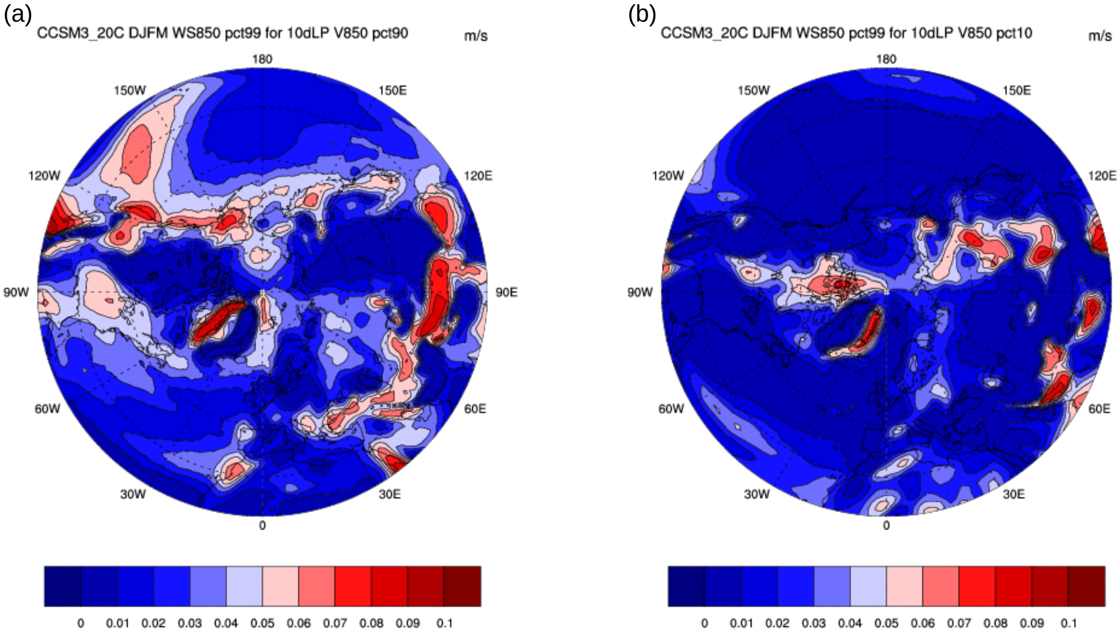


Figure 8. Probability of WS850 exceeding its 99th percentile for days where lowpass V850 is (left) above its 90th percentile or (right) below its 10th percentile. Calculated for 9 ensemble members of CCSM3 20C experiment, for the months December-March (DJFM), 1870-1999.

on extreme wind events due to the large increase in 10-day high pass EKE850 associated with southerly low pass wind anomalies. Where low pass U850 has a particularly strong influence on extreme wind events, on the equatorward flanks of the storm tracks and at the downstream end of the Atlantic storm track, Fig. 9 shows that low pass U850 has a larger additive effect than low pass V850. On the equatorward flanks of the storm tracks, Fig. 5 shows that the additive effect is also enhanced by the positive multiplicative effect of westerly wind anomalies on high pass EKE850.

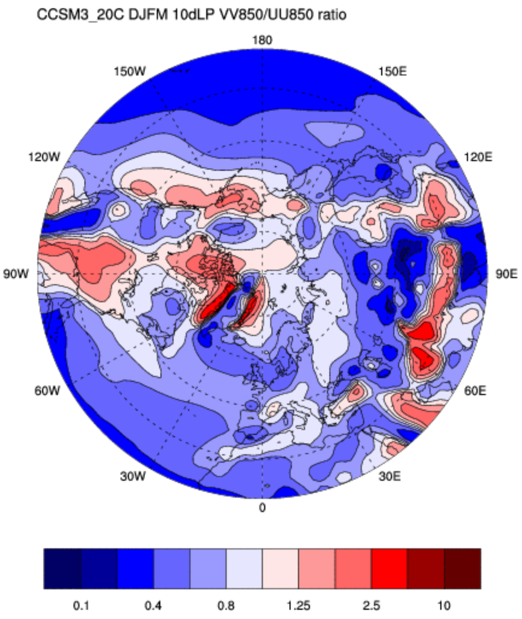


Figure 9. Ratio of the climatological mean variance of 10-day low pass V850 divided by the climatological mean variance of 10-day low pass U850. Calculated for 9 ensemble members of CCSM3 20C experiment, for the months December-March (DJFM), 1870-1999.

4. DYNAMICS OF EXTREMES AT SELECTED POINTS

In this section, we will look in more detail at the additive and multiplicative effects of low frequency variability at selected geographical points. Any number of points could have been chosen, but we show examples of points that are representative of the dynamics in different regions near the upstream and downstream ends of the storm tracks.

4.1 *Downstream End of Atlantic Storm Track*

We will first examine the additive and multiplicative effects of low frequency variability on extreme wind events at 3 points near the downstream end of the Atlantic storm track. The first is Lisbon, Portugal, which was chosen to represent the regions on the equatorward flanks of the storm tracks where there is a strong relationship between extreme wind events and low pass westerly anomalies; this strong relationship is shown by the circles in Fig. 10a. Note that, in Fig. 10, each symbol represents the mean for a 1 percentile interval of the variable on the x-axis, either low pass U850 or V850. Thus, Fig. 10a shows that an extreme wind event occurs on nearly 30% of days where the low pass U850 at Lisbon is above its 99th percentile. It also illustrates the nearly linear positive correlation between low pass U850 and high pass EKE850, which results in a positive multiplicative effect of westerly anomalies on extreme wind events. Fig. 10b shows little relationship between high pass EKE850 and low pass V850, although extreme wind events are more likely for southerly anomalies than northerly anomalies; perhaps this is because southerly anomalies have a slight tendency to be accompanied by westerly anomalies (not shown). Because the low pass U850 is relatively large in magnitude compared to synoptic variability or low pass V850, and synoptic variability increases as low pass U850 becomes more strongly westerly, the additive and multiplicative effects of low pass U850 both tend to increase the probability of extreme wind events as U850 becomes more westerly, resulting in a strong relationship between low pass westerly anomalies and extreme wind events.

The second point is Galway, Ireland, which was chosen to represent the region on the poleward flank of the jet exit where the relationship between extreme wind events and low pass westerly anomalies is relatively weak, and there is a strong reduction of EKE850 for low pass westerly anomalies. The nonlinear relationship between EKE850 and U850 inferred from Fig. 5 is shown in more detail in Fig. 10c; while increasing low pass U850 reduces high pass EKE850 over most of the range of U850, EKE850 also decreases for the most easterly percentiles of low pass U850. This relationship will be examined in more detail shortly. Nevertheless, the reduction of EKE850 as low pass U850 becomes more westerly has a negative multiplicative effect that counters the strong additive effect due to the large magnitude of low pass U850 for westerly anomalies, resulting in a weaker relationship between westerly low pass anomalies and extreme wind events relative to Lisbon. Fig. 10d shows a very weak relationship between low pass V850 and extreme wind events, perhaps because low pass U850 tends to be larger in magnitude than low pass V850.

The third point is Bergen, Norway, which was chosen to represent the region on the poleward flank of the jet exit where, like Galway, the relationship between extreme wind events and westerly anomalies is also relatively weak, but there is a strong reduction of high pass EKE850 for low pass easterly anomalies. As for Galway, Fig. 10e shows a nonlinear relationship between EKE850 and U850, but this time the correlation between the two is positive over most of the range of U850, with a negative correlation only for the most westerly percentiles of U850. This relationship will also be examined in more detail shortly. However, like Galway, the negative correlation between EKE850 and U850 for the most westerly percentiles of U850 tends to weaken the relationship between westerly low pass anomalies and extreme wind events, resulting in a similar negative multiplicative effect for strong westerly anomalies. Fig. 10f shows a relatively strong relationship between southerly low pass anomalies and extreme wind events, probably because the most southerly percentiles of V850 have comparable magnitude to the most westerly percentiles of U850.

We now examine the dynamics of the multiplicative effect of low pass U850 on extreme wind events through its influence on high pass EKE850 at these three points. Figs. 11a, 11d, and 11g show the composite low pass U850 for days when the low pass U850 exceeds its 90th

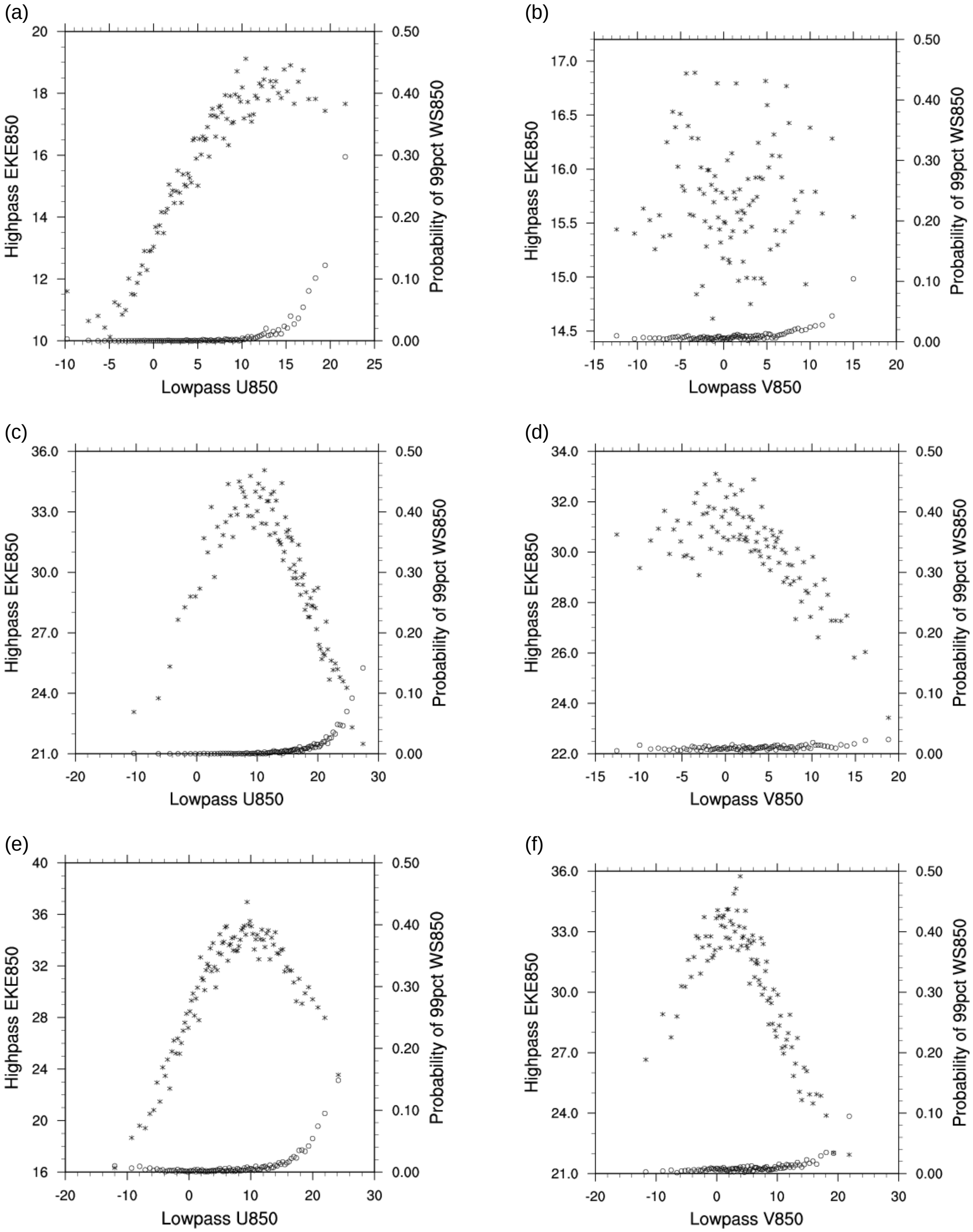


Figure 10. 10-day high pass EKE850 (asterisks; units are m^2/s^2) and probability of exceeding the 99th percentile of WS850 (circles) scattered against (left column) 10-day low pass U850 and (right column) 10-day low pass V850. For the x-axis, units are m/s. From top to bottom, the rows represent grid points near (a-b) Lisbon, (c-d) Galway, (e-f) Bergen, (g-h) Tokyo, and (i-j) Magadan. Results have been averaged over each 1 percentile of low pass U850 and V850. Calculated for 9 ensemble members of CCSM3 20C experiment, for the months December-March (DJFM), 1870-1999.

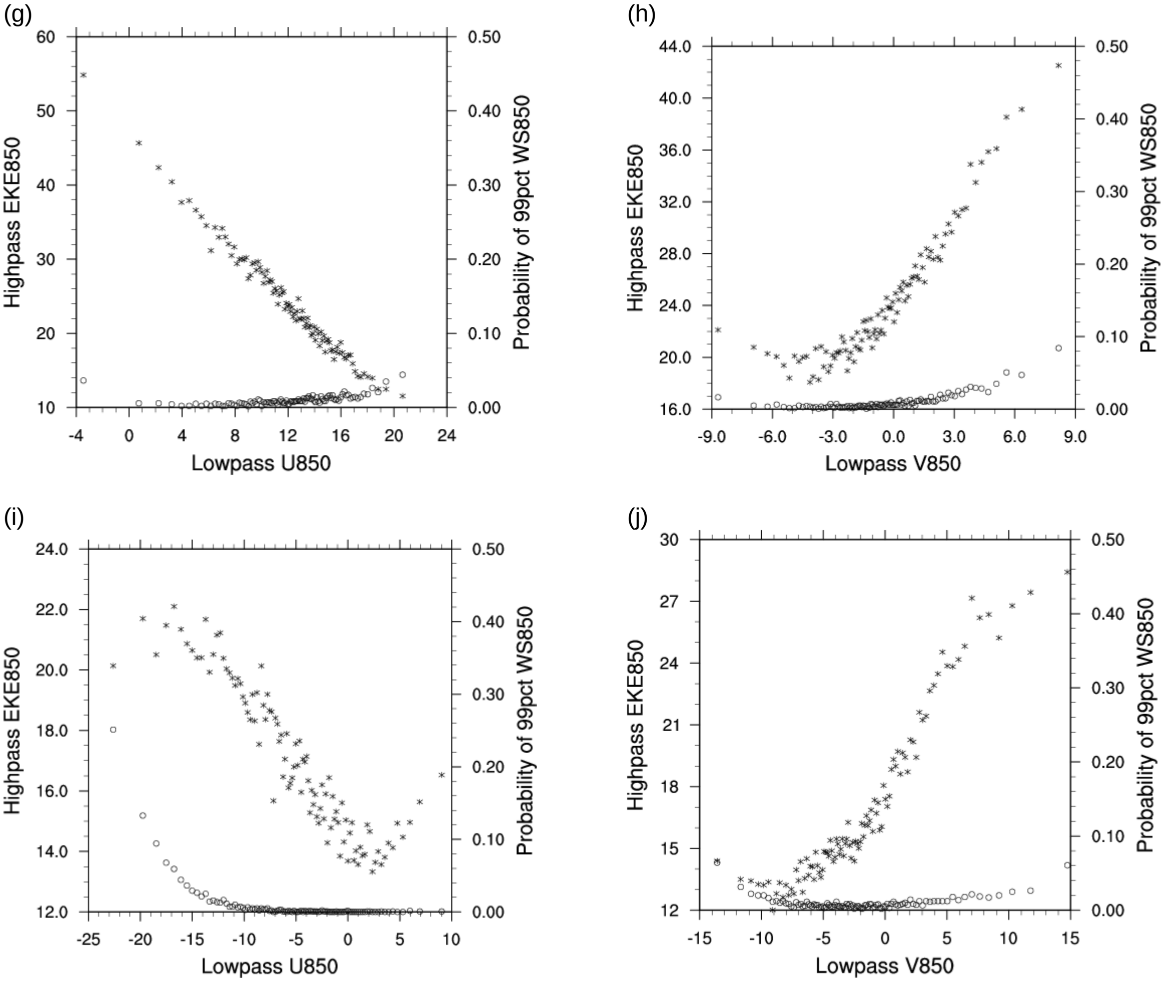


Figure 10. Continued from previous page.

percentile at Lisbon, Galway, and Bergen, respectively. These shifts of jet latitude are reminiscent of the North Atlantic Oscillation, and, as shown in Figs. 11b, 11e, and 11h, these jet shifts are accompanied by corresponding shifts in the latitude of the storm track measured by high pass EKE850. Because the storm track is centered poleward of the jet on the downstream end of the Atlantic storm track, the location of each point in relation to the climatological storm track and jet determines the relationship between U850 and EKE850 at that point. For example, because Lisbon is equatorward of the jet, westerly U850 anomalies tend to be the result of an equatorward shift of the jet. This brings the storm track closer to Lisbon and tends to increase EKE850, resulting in a positive multiplicative effect on extreme wind events. Galway is poleward of the climatological jet but equatorward of the climatological storm track, so westerly U850 anomalies tend to be the result of a poleward shift of the jet. This pushes the storm track farther away from Galway and tends to reduce EKE850, resulting in a negative multiplicative effect. Bergen is poleward of the climatological jet and near the latitude of the climatological storm track, so westerly U850 anomalies associated with poleward shifts of the jet tend to push the storm track away from Bergen and reduce EKE850. Unlike Galway, equatorward shifts of the jet also tend to move the storm track away from Bergen, so EKE850 decreases for more easterly U850 across most of the range of U850. However, because extreme wind events are most likely to occur at Bergen for strong westerly low pass U850, the negative correlation between U850 and EKE850 for strong westerly U850 yields a negative multiplicative effect. Figs. 11c, 11f, and 11i illustrate the weaker relationship between westerly anomalies and extreme wind events for the regions near Galway and Bergen compared to Lisbon, reflecting the different signs of the multiplicative effect in these regions.

4.2 *Upstream End of Pacific Storm Track*

We will now examine the somewhat different additive and multiplicative relationships between low frequency variability and extreme wind events near the upstream end of the Pacific storm track. The first point that we will examine is Tokyo, Japan, which was chosen

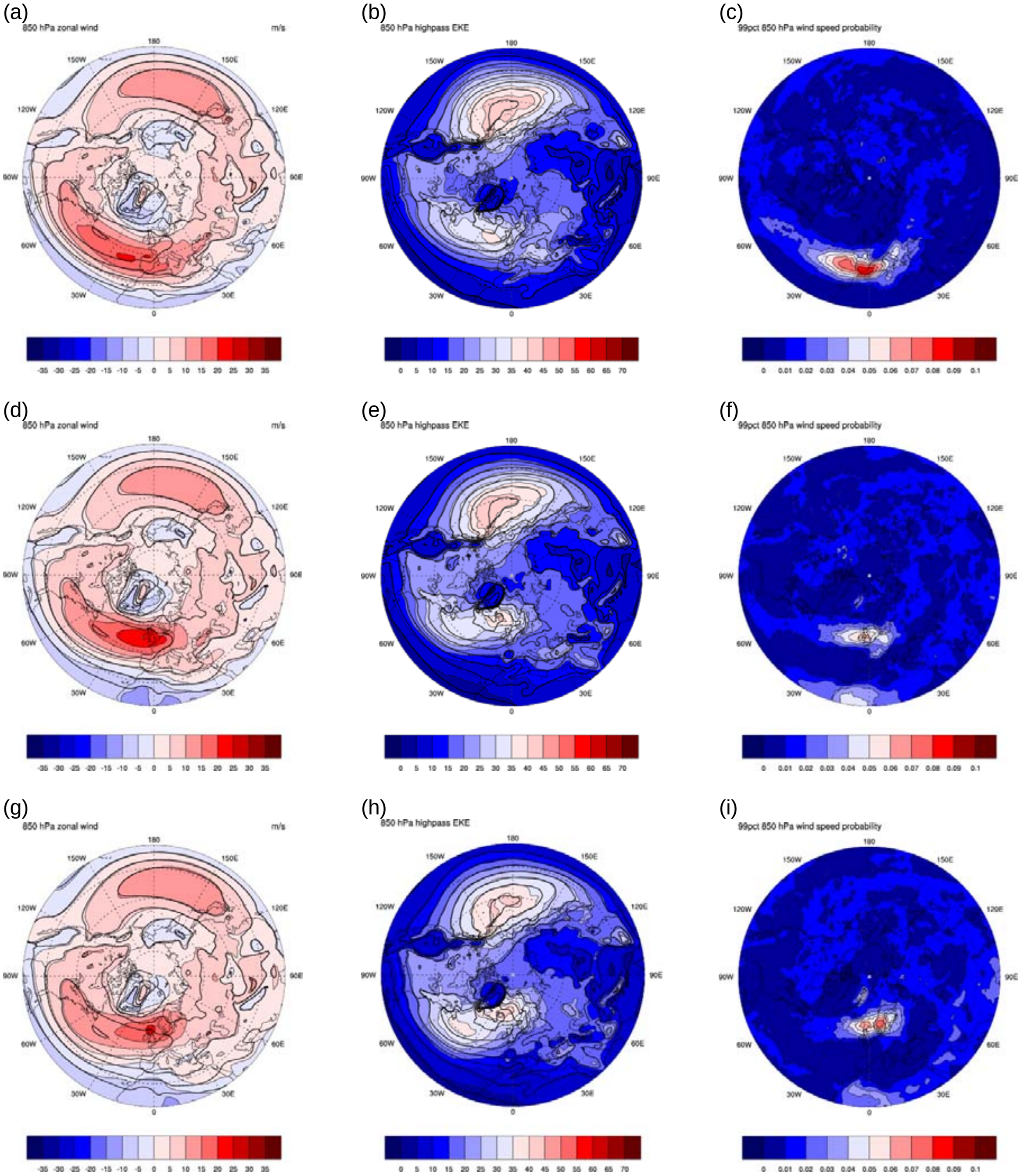
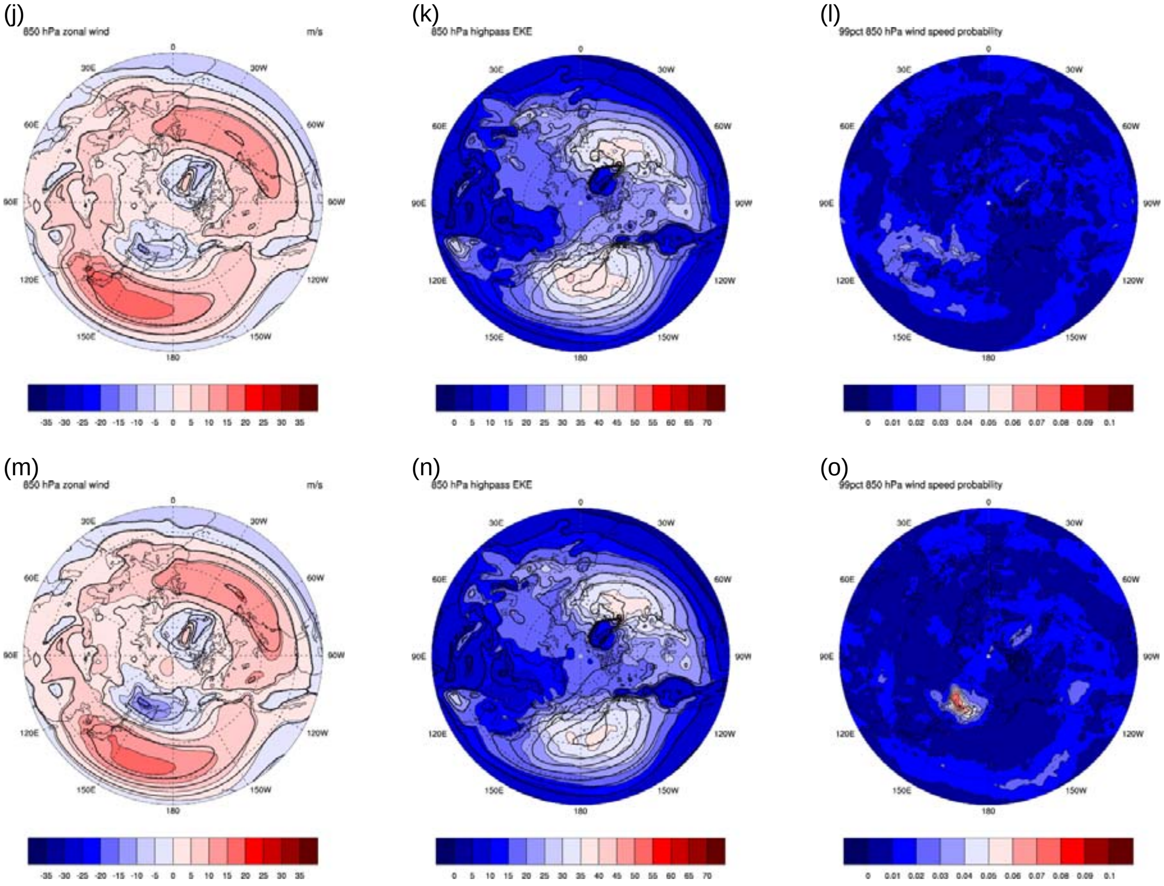


Figure 11. Climatological mean (thick black contours) and composite (thin contours with color fill) of the following variables: (left column, units are m/s) 10-day low pass U850, (middle column, units are m^2/s^2) 10-day high pass EKE850, and (right column, units are probability) probability of exceeding the 99th percentile of WS850. From top to bottom, the rows represent: (a-c) days that exceed the 90th percentile of low pass U850 at Lisbon; (d-f) days that exceed the 90th percentile of low pass U850 at Galway; (g-i) days that exceed the 90th percentile of low pass U850 at Bergen; (j-l) days that exceed the 90th percentile of U850 at Tokyo; and (m-o) days that are below the 10th percentile of low pass U850 at Magadan. Calculated for 1 ensemble member of CCSM3 20C experiment, for the months December-March (DJFM), 1870-1999.



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because of its extremely weak relationship between low frequency wind variability and extreme wind events. Fig. 10g shows that there is a very strong negative correlation between U850 and EKE850; as a result of this large negative multiplicative effect, strong westerly anomalies produce relatively small increases in the probability of extreme wind events. In addition, the small magnitude of low pass U850 relative to the strong synoptic variability for weak easterly U850 means that the additive effect of low pass U850 is also relatively weak, resulting in nearly the same probability of an extreme wind event for the most easterly and westerly percentiles of low pass U850. The combination of the weak additive effect and negative multiplicative effect for westerly low pass anomalies causes extreme wind events to depend much more strongly on synoptic variability at Tokyo than at any other point. Fig. 10h shows that the positive correlation between low pass V850 and high pass EKE850 yields a positive multitplicative effect that tends to make extreme wind events more likely for low pass southerly anomalies, despite the weak additive effect due to the small magnitude of low pass V850.

The other point chosen near the upstream end of the Pacific storm track is Magadan, Russia, on the north shore of the Sea of Okhotsk, which was chosen because of its strong relationship between easterly low pass anomalies and extreme wind events. Fig. 10i shows that there is a small negative correlation between EKE850 and U850, but that synoptic variability is relatively weak, so the multiplicative effect is likely to be positive but weak for easterly low pass anomalies. The relatively large magnitude of low pass easterlies results in a strong additive effect, so the probability of extreme wind events is strongly influenced by the magnitude of low pass U850. Despite the positive correlation between EKE850 and V850 shown in Fig. 10j, synoptic variability has little impact on the relationship between extreme wind events and V850, because the relatively weak synoptic variability results in a weak multiplicative effect. However, the magnitude of low pass V850 is small relative to the magnitude of the most easterly percentiles of low pass U850, so extreme wind events at Magadan are most strongly related to low pass easterly anomalies, primarily due to their strong additive effect.

Figs. 11 j-o show composites for days where low pass U850 at Tokyo exceeds its 90th percentile and where low pass U850 at Magadan is below its 10th percentile. The low pass U850 and high pass EKE850 anomalies for these two sets of days are quite similar. Both have strengthened westerlies in the Pacific jet near Tokyo, and strengthened easterlies poleward of the jet near Magadan. The upstream end of the Pacific storm track is shifted poleward, strongly reducing EKE850 near Tokyo and slightly increasing it near Magadan. The reason for the reduction of the synoptic variability near Tokyo on days of unusually strong westerlies is not obvious, but additional composites (not shown) indicate that lower tropospheric EKE is reduced when storms are advected more quickly by stronger westerlies, which do not give the storms as much time to develop a low-level circulation in the strong baroclinic growth region just off the Asian coast. Comparing Figs. 11l and 11o, extreme wind events are much less strongly related to westerly anomalies near Tokyo than they are to easterly anomalies near Magadan, due to the large negative multiplicative effect resulting from the strong negative correlation between EKE850 and U850 near Tokyo.

5. SUMMARY AND CONCLUSIONS

We have found that extreme wind events in the midlatitude storm tracks are not only influenced by synoptic variability, but in most locations are influenced even more strongly by low frequency variability at periods longer than 10 days. Low frequency variability affects extreme events not only in an additive sense, by changing the magnitude of the low frequency wind that synoptic variability is superimposed upon, but also in a multiplicative sense, by influencing the synoptic variability that is superimposed on the low frequency variability. At the downstream end of the Atlantic storm track, we found that the relationships between extreme wind events and low frequency variability depended largely upon the location of the point of interest relative to the climatological jet and storm track. All points near the downstream end of the Atlantic storm track exhibited strong additive effects due to westerly low pass anomalies; however, the positive multiplicative effect on the equatorward flank of the jet resulted in a strong relationship between westerly anomalies and extreme wind events, while the negative multiplicative effect on the poleward flank of the jet resulted in weaker relationships. The region near Tokyo at the upstream end of the Pacific storm track has an unusually weak relationship between extreme wind events and low frequency variability, because of the overriding negative multiplicative effect due to the strong negative correlation between the synoptic variability and the strength of the jet in that region.

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