A dynamic analysis of the role of the planetary and synoptic scale in the summer of 2010 blocking episodes over the European part of Russia.

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Abstract

During the summer of 2010, an unusually persistent blocking episode resulted in anomalously warm dry weather over the European part of Russia. The excessive heat and the resulting forest and peat fires destroyed terrestrial ecosystems, greatly increased pollution in urban areas, and increased mortality rates in the region during July and August. Using the National Center for Atmospheric Research (NCAR) National Centers for Environmental Prediction (NCEP) re-analyses, the climatological and dynamic character of blocking events in June-July-August and a pre-cursor May 2010 blocking event were examined. It was found that these events were stronger and longer-lived than typical warm season events. Then using the dynamic methods, it was demonstrated that the July 2010 event was a synoptic-scale dominant blocking event, which is unusual for the summer season. A subsequent analysis of phase diagrams demonstrated that the planetary-scale did not become stable until almost one week after block onset. For all other blocking events studied here and previously, the planetary-scale became stable around the onset time. Analysis using the area integrated regional enstrophy (IRE) demonstrated that for the July 2010 event, the synoptic-scale IRE increased at block onset. This was similar to the May 2010 studied here, but different from the case studies examined previously that demonstrated the planetary-scale IRE was prominent at block onset.

Key words: re-analysis data, extreme events, blocking episodes, scale analysis, Russian heat wave.

1. Introduction.

Blocking events are generally thought of as quiescent phenomena, which bring warmer and drier conditions to the areas that they impact. Their influence on weather upstream and downstream of the main event is well known [e.g., 1-7]. However, they can and do bring anomalous weather conditions and air pollution to the regions where they occur [e.g., 8-12]. The blocking episode that occurred over the European part of Russia during the summer of 2010 was devastating, especially over the western part of the country. It is estimated that more than 50,000 Russian people perished due to the blocking events, (see http://ifaran.ru/science/seminars/Summer2010.html) and mortality rates due to the unprecedented summer heat and air pollution associated with the forest and peat fires were greatly enhanced. Also, the dry conditions led to forest fires which caused extensive damage throughout west-central Russia, and air pollution episodes occurred in major urban areas such as Moscow. Additionally, the blocking episodes led to flooding in central Europe during the spring [13], and in the Pakistan region downstream of the blocking during the summer [14-16]

The dynamics of blocking events have been examined by partitioning the flow into the synoptic and planetary scale [17-22]. In many studies it has been shown that the synoptic scale plays a crucial role in the formation and maintenance of blocking events [18, 23-26]. The role of the planetary-scale, however, has also been confirmed [27-29]. In [22], it was proposed that there were four scenarios under which blocking events decayed. These can be described simply as whether the planetary-scale was steady state or underwent a change of phase or amplitude. Then, these were further classified as passive or active decay depending on the upstream cyclonic activity. This work also introduced the use of the phase diagrams and an area-integrated enstrophy index as a tool for examining the dynamics of two Southern Hemisphere winter season blocking events. The blocking area integrated enstrophy (IRE) is based on the conjecture found in [30]. It was found [22] that the IRE decreased during the time the blocking events persisted, and increased during large-scale regime transformations. This included the time period around the onset and decay of the blocking event, based on three winter season blocking events occurring in the Southern Hemisphere.

Then, [10] used the IRE as well as a scale partition of this quantity to examine a three year period of blocking occurrences across the entire Northern Hemisphere. This included a method for identifying blocking events as either synoptic- or planetary-scale dominant, or of mixed dominance. A summer season blocking case study was performed by utilizing these synoptic and planetary IREs. It was found that most blocking events (79%) were dominated by a single scale, either the planetary (44%) or synoptic-scale (35%) alone. The rest were of mixed scale dominance. Furthermore, it was found that the planetary-scale was more strongly influential during warm season blocking events. The IRE was also noted as a useful tool in identifying large-scale regime changes which corresponded to block formation or decay.

Thus, the goals of this study are to perform a dynamic study of the blocking events that occurred over the European part of Russia during the summer of 2010. Using the techniques developed in [10] and [22], and based on [30], these blocking events will evaluated in order to determine whether they were similar to previously studied winter and summer season events. In particular, the July 2010 event may have been different in a dynamic sense from typical summer season events in that the synoptic-scale was dominant in supporting this event. Such a study is timely and relevant, especially when given the suggestion that internal atmospheric dynamic processes produced and maintained these blocking events rather than the observed ocean or sea ice states or greenhouse gas concentrations/slowly varying boundary conditions based on model experimental studies [12]. Additionally, it will be indicated that the source of moisture during these events was of Atlantic origin. A similar study [6] demonstrated that blocking over far northern Europe was accompanied by Atlantic moisture during the 2005/06 European winter.

2. Data and Methods.

2.1 Data

The data set used in this study was the National Center for Environmental Prediction (NCEP) and National Center for Atmospheric Research (NCAR) gridded re-analyses data [31, 32]. These data were provided on the 2.5◦ by 2.5 latitude-longitude grids available on 17 mandatory levels from 1000 hPa to 10 hPa at 6-h intervals daily at (http://www.esrl.noaa.gov/psd/data/reanalysis/). In this study, the 500 hPa height values were used in order to identify the blocking events and make comparative calculations. The 500 hPa eddy heights were also obtained from this data set and used to represent the synoptic scale. The eddy heights are derived by removing the zonal mean from each point at a particular latitude from the daily height field. The planetary-scale heights were then determined by subtracting the synoptic-scale from the total height field.

2.2 Methods

The blocking definition and intensity calculation is found in [4] and is based on the definitions originally proposed by [26]. In [22], trajectories in the phase plane with the abscissa X(t) and the and the ordinate dX(t)/dt were analyzed by using a time series for the variable (blocking characteristic) X(t) analogously to those used in several studies [33–38]. A full explanation for their use and interpretation can be found in [22].

In [22] and [10], IRE was used and derived from [30], and [30] defined blocking as a meridional perturbation that destabilizes the zonal flow. Starting from the barotropic vorticity equation, the IRE was suggested as a measure for the change in the zonal flow that may lead to the blocking. Here, we make use of the conjecture proposed in [30] which suggests a relationship between the sum of the positive eigenvalues of the linearization operator of the barotropic flow and the blocking domain integrated regional enstrophy, that is;

$$\sum_i \lambda_i^+ \approx \int_D |\zeta^2| \, dxdy \quad (1)$$

where ζ is the vorticity and *D* is the blocking domain. The blocking domain *D* is defined as a latitude and longitude box encompassing the block center, here 20 degrees latitude by 20 degrees longitude. The vorticity in Eq. (1) is calculated by using the partitioned height fields as described in section 2.1. Also, as found by [10] the exact dimensions of the box in the blocking domain were not critical as long as the calculation was in the blocking region (not shown). Additionally, the right hand side of Eq. (1) is called the IRE. In region D, higher (lower) positive values of the IRE corresponded to more (less) unstable flow.

3. Climatological and Synoptic Analysis

During the summer of 2010, a blocking episode persisted from 19 June to 19 August, 2010 over Eastern Europe and the European part of Russia resulting in anomalously warm and dry conditions over the region. These dates include the formation period of the June blocking event and days following the eventual termination of the August event. A comparison of the monthly mean values temperatures and precipitation for summer 2010 to the mean values from 1970- 2010 are given in Table 1 for May through August. If one standard deviation from the mean represents unusual conditions [39], then May was unusually warm in the Moscow region while July and August were unprecedented and represent the extreme values for the 41 year period cited above (and also for the longer period of record) . While the summer period was dry, only July was unusually dry in the Moscow region.

Three distinct blocking events meeting the criterion of [4, 26] are given in Table 2 along with their characteristics. Also, given is a persistent event which dominated the region for the month of May and this event is referred to as a precursor blocking event. With the exception of the May event, all were weaker than a typical blocking event, and each persisted longer than a typical event except for event number two. The July event (event three) persisted for 26 days, which means it one of the most persistent event for the Northern Hemisphere since 1970 (see [4]). While each event was weaker than a typical event, they were stronger than the average summer season event, especially those occurring over continental regions. Additionally, a study by [40] identifies the blocking episode as occurring from late June to mid-August using a different blocking definition (see also [11]).

The duration of the blocking circulation was persistent enough that the July event can be identified in the mean July 2010 500 hPa height field in the Northern Hemisphere (Fig 1). A ridge appears over western and extreme eastern Russia. The ridge in eastern Russia is also associated with blocking events (see the blocking archive at http://weather.missouri.edu/gcc), but these events are not studied here. Additionally, the monthly mean precipitable water for July 2010 (Fig. 2a) suggests that the high relative humidity and dewpoints that were associated with the July heat were likely due to moisture not only from the Mediterranean and the Black Sea, but also the Atlantic Ocean region. Precipitable water (PW) is shown here since it is the column integrated value of specific humidity (q) (kg kg^{-1});

$$PW = \frac{1}{g}\int_{psfc}^{ptrop} q\, dp \qquad (2)$$

where g is the gravitation constant, and q is integrated from the surface to the tropopause. The jet stream over Europe was quite active and resulted in wet conditions for central Europe in May and June [13], and a moisture plume can be seen connecting Atlantic moisture to the western Russia region (Fig. 2a,b). This result would be consistent with [6] who showed that European blocking can ingest moisture from across the northern Atlantic. Additionally, Fig. 2c shows the zonal momentum flux for July 2010. Note that the zonal momentum flux was a maximum on the upstream flank of the block in Fig 1 over eastern Europe and western Russia, and this was likely associated with the upstream cyclones sustaining the block. This result is consistent with earlier studies [18-20, 24, 25], and these transients would also be carrying water vapor into the region.

These events were then examined following [10] in order to determine whether or not they were dominated by either, the planetary-scale, synoptic-scale, or were alternating scale dominant events (Table 3). The results here are consistent with the climatological behavior in that only one of these blocking events were alternating in their scale dominance [10], while the May (spring) and August (summer) events were dominated by the synoptic and planetary-scale, respectively. The July blocking event, however, was dominated by the synoptic-scale (Fig. 3), and [10] showed that it is more usual for the synoptic-scale to predominate during this season. Thus, the dynamics of this event warrant closer examination.

Further, for the July 2010 blocking event, the series of the total center point heights correlate very strongly to the planetary-scale center point heights (correlation coefficients greater than 0.95), while the synoptic-scale center point heights correlate to the total and planetary-scale at 0.62, and 0.60, respectively. This is significant at the 95% confidence level (using the Pearson test for the significance of the correlation coefficient). The other longer-lived events showed a similar result. The center point 24-hour height tendencies were then calculated for each event, and these were also partitioned into their planetary-scale and synoptic-scale height tendencies. The correlation between the total and planetary-scale height tendencies were significant at the 95% confidence level as well, while the planetary and synoptic-scale height tendencies correlated negatively at the 95% confidence level. There was no correlation between the total tendencies and the synoptic height tendencies except for the July blocking event in which these two-scales correlated positively at the 90% confidence level. This provides further evidence that this blocking event is not a typical summer season event.

4 Dynamic Analysis

The climatological and synoptic analysis demonstrated that the July 2010 blocking event was unusual in that it was stronger and longer-lived than a typical summer season event. Using the analysis for scale dominance proposed by [10], this event was also unusual in that it was a synoptic-scale dominant summer event. Thus, using the techniques developed by [22], the July and August events will be examined in more detail here in order to provide a comparison between synoptic and planetary scale dominant summer season events. The May and June events were also examined (not shown), but the dynamics were similar to the events analyzed in [22], and were consistent with the results of previous blocking studies.

In [22], phase diagrams were used by plotting the blocking region planetary-scale 500 hPa height tendencies for two Southern Hemisphere winter season events. Here the technique is applied to the Northern Hemisphere summer season events, and the synoptic-scale 500 hPa block region heights are examined as well. The May and June blocking events were consistent with the results of [22] for both scales. Figs. 4 and 5 show these diagrams for the July and August events. Note in Table 2, the July and August events occur in a similar area, and that the decay of the July event overlaps with the onset of the August event. Correspondingly, the trajectory end in Fig. 4 overlaps with the beginning of that in Fig. 5. In Fig. 4, the planetary-scale was unstable during the first six days of the block life cycle, or long after block onset, and then becomes more stable for about 10 days. During the last ten days, the planetary-scale again becomes unstable. In [22], and for the May and June event here, the planetary-scale trajectory indicated that the flow becomes stable at the time of block onset. However, the planetary scale does move to a new regime before block termination in a fashion similar to the two consecutively occurring blocking events in [22]. Then Fig. 5a shows that the planetary-scale flow finds a new equilibrium during the second blocking event. This equilibrium persists until the decay of the August block. Fig. 3a shows a planetary-scale that is increasing over the life-time of the July event, while the planetary-scale flow during the August event was stable (no trend) until the final days of the blocking episode (not shown). The synoptic-scale trajectories (Fig. 4b, 5b) demonstrate stability for this scale in the blocking region after the onset of the July event and then remaining in quasi-equilibrium until the decay of the August event.

The IRE was examined as was presented by [22] and partitioned by [10] and is shown in Fig. 6. In [10], it was conjectured that the IRE showed some promise as an indicator of flow regime change, and that there was a tendency for the IRE to increase near the block onset and again before the block decay. The results of [22] suggested that the IRE was lower (higher) when the flow was stable (unstable). Here it is found that the IRE behaves in a similar manner in general for the August event (Fig. 6b) and the June event (not shown). However, for the July event (Fig. 6a), and the May event, the synoptic-scale IRE was unstable at block onset, and then remains relatively low for the rest of the event increasing slightly again at decay. During the May event (not shown), the synoptic-scale IRE increased at onset and increased again substantially near decay. In both the May and July events, the planetary-scale IRE indicates unstable flow during the first part of the event following the unstable synoptic-scale flow, and then the planetary-scale becomes unstable at decay. This behavior contrasts with the August event and the summer season event shown in [10].

The correlation between the total IRE and the planetary-scale IRE was greater than 0.68 for all cases, and this was significant at the 99% confidence level. However, there was no correlation between the synoptic-scale IRE and either the total and planetary-scale IRE. This suggests that, when using the IRE, the May and July 2010 blocking event behaved in a different manner. It is suggested here that in synoptic-scale dominant events, the increase in the synoptic-scale IRE may play the key role in indicating block formation and decay, while in planetary-scale dominant and alternating-scale events, the planetary-scale IRE is a better indicator of block onset. This refines the conclusions of [10] who studied a planetary-scale dominant event.

Additionally, as a synoptic-scale dominant event, the July 2010 event was different from the event studied by [10] but behaved similar to the summer season event studied in [20]. Also, [16] suggested that the synoptic-scale played the dominant role in determining onset and the decay is similar to that for Southern Hemisphere events [21]. All of these results suggest that winter season Northern Hemisphere events are dynamically different from these events studied here and by [20] in that the interaction processes were prominent. However, additional cases should be examined to confirm these results.

New results published recently [40] showed that, by using several medium range operational ensemble forecasts, the predictability of blocking has improved to the point that the events studied here were predicted very well even at 144 – 216 h before onset. Of the events studied here, the August event was the least predictable in [40] at medium ranges. The models all predicted decay too early in each of them [40]. If the results of this study are an indication, onset is easier to predict as the IRE and phase diagrams indicate block onset very close to that identified using the criterion of [4]. If the models forecast the decay of the July blocking event too early and the August blocking event, which followed the July event in rapid succession similar to the events studied in [22], then it is not surprising that the results of [40] did not forecast the onset of the August blocking event very well.

5 Summary and Conclusions

The blocking events that impacted the European part of Russia bringing anomalously high temperatures during the summer of 2010 were studied here. These events resulted in many deaths and devastating forest and peat fires in the European part of Russia, including the Moscow region. This study identified the blocking episode using the NCAR-NCEP 500 hPa heights archived in Boulder, CO. Using the criterion of [4], three distinct blocking events occurring from late June to mid-August were identified. Additionally, a precursor blocking event which occurred in May 2010 over the same region was included in this study. These events were, in general more persistent than typical blocking events for spring or summer seasons. These blocking events were weaker than a typical blocking event, but stronger than warm season events when comparing to the climatology of [4].

Examining the dynamics using techniques developed by [22] and further refined by [10] shows that, in many respects, the dynamics of these blocking events were similar to that of previously studied events. However, some important results emerged here. First, the phase diagrams developed by [22] were partitioned into planetary and synoptic-scale components here. The July 2010 blocking event showed that the planetary-scale became stable more than six days after block onset. The other events, as well as those studied previously, became stable at or just following onset. This is the only one of seven events studied here and in [22] that exhibit this behavior and thus, the flow becoming stable many days after onset may be fairly uncommon. Examining the IRE developed by [22] and modified by [10] demonstrated that the May and July event studied here showed synoptic-scale dominance, and the synoptic scale IRE increased markedly at onset followed by an increase in the planetary-scale IRE. The IRE then decreased and stayed low until decay for both scales. This behavior is different from that suggested by [10] which showed that for a planetary-scale block, the planetary-scale increase of IRE at onset was an important indicator of flow transformation to the blocking state. Finally, our results here can be used to demonstrate why predictability by operational models fared more poorly in forecasting the August event, which followed rapidly behind the July event. While the models did not predict the onset of August event as well, the IRE did indicate the onset of blocking.

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Tables

Table 1. The temperature (^{o}C) and precipitation (mm) for May – August 2010 for the Moscow, Russia.

Month	Normal (^{o}C / mm)	Observed (^{o}C / mm)	Anomaly (^{o}C / mm)
May	13.0 / 51.8	16.8 / 59.0	+3.8 / +7.2
June	16.9 / 78.2	18.7 / 62.0	+1.8 / -16.2
July	18.9 / 86.3	25.7 / 12.0	+6.8 / -74.3
August	16.8 / 79.6	22.0 / 68.0	+5.2 / -11.6

Table 2. The blocking events studied here and their characteristics such as duration, intensity, and formation longitude.

Event	Onset / Termination	Duration	Intensity	Formation (longitude)
1	12Z 2 May / 00Z 24 May	21.5	3.08	40 E
2	00Z 22 June / 00Z 28 June	6	1.69	50 E
3	00Z 4 July / 00Z 30 July	26	2.44	20 E
4	12Z 31July / 00Z 16 August	15.5	2.50	45 E

Table 3. Scale dominance for the spring and summer 2010 blocking events studied here following the methodology of [10].

Event	Planetary-scale dominant	Synoptic-scale dominant
1	negative	positive
2	alternating	alternating
3	negative	positive
4	positive	negative

Figures

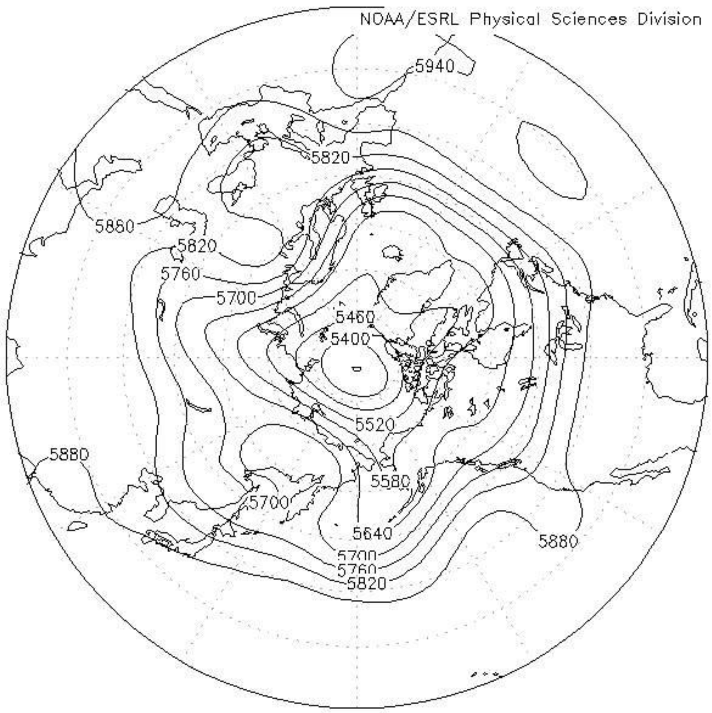
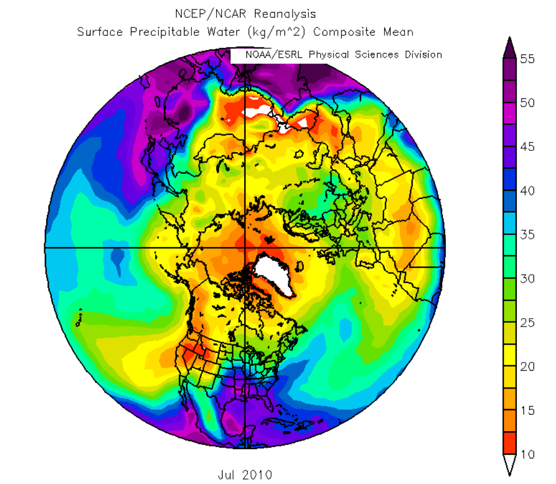
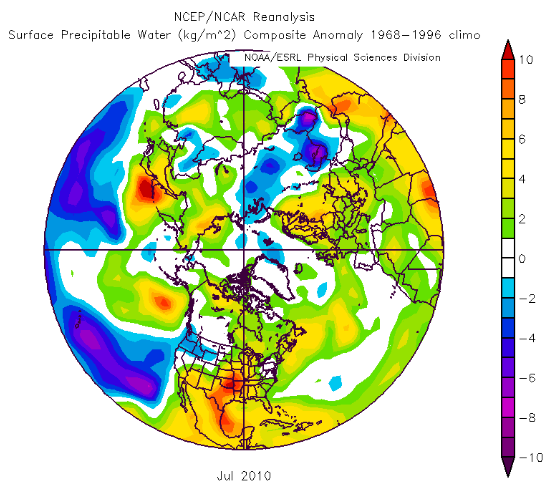


Figure 1. The NCEP-NCAR re-analyses for the Northern Hemisphere 500 hPa heights for July, 2010. The contour interval is 60 dam.


NCEP/NCAR Reanalysis
Surface Precipitable Water (kg/m^2) Composite Mean
NOAA/ESRL Physical Sciences Division
Jul 2010
55
50
45
40
35
30
25
20
15
10


NCEP/NCAR Reanalysis
Surface Precipitable Water (kg/m^2) Composite Anomaly 1968–1996 climo
NOAA/ESRL Physical Sciences Division
Jul 2010
10
8
6
4
2
0
−2
−4
−6
−8
−10

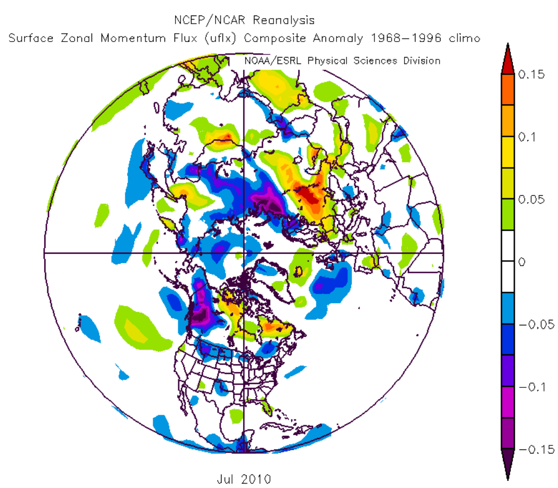

NCEP/NCAR Reanalysis
Surface Zonal Momentum Flux (uflx) Composite Anomaly 1968–1996 climo
NOAA/ESRL Physical Sciences Division
Jul 2010
0.15
0.1
0.05
0
−0.05
−0.1
−0.15

Figure 2. The Northern Hemisphere a) precipitable water (mm), b) precipitable water anomalies (mm), and c) zonal momentum flux ($m^2 s^{-2}$) for July 2010.

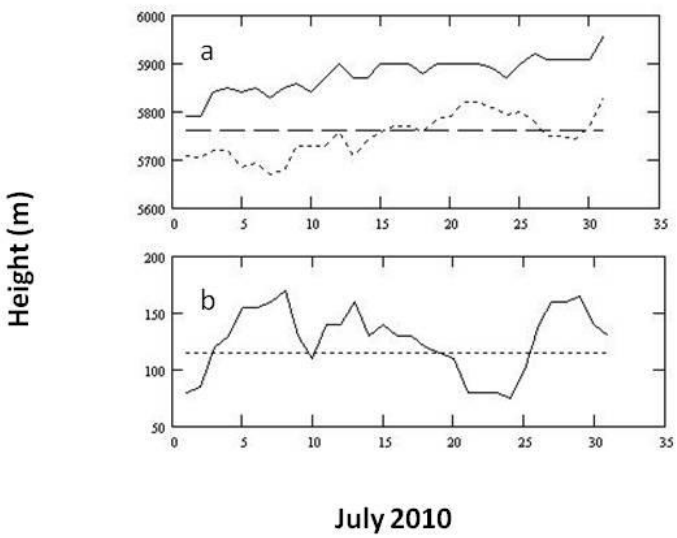


Figure 3. The block center region heights for July 2010 following [10] showing a) the total height field (m) (solid) and planetary-scale heights (m) (dots), and b) synoptic-scale height (m) (solid). The straight lines show the monthly mean a) planetary-scale, and b) synoptic-scale heights.

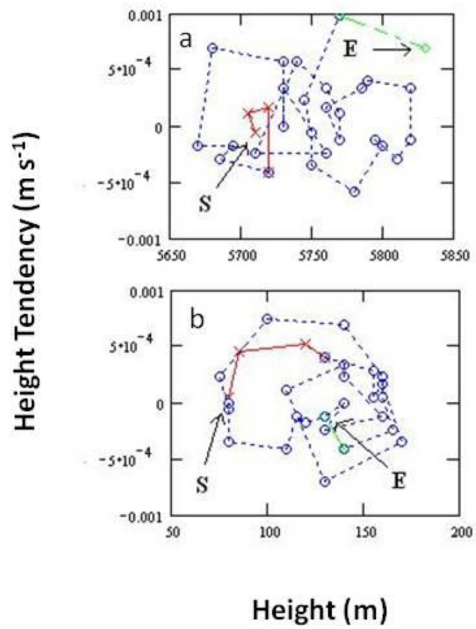


Figure 4. Phase trajectories for the 500-hPa heights in the central part of the blocking region for July 2010 for the a) planetary-scale, and b) synoptic-scale, during the pre-block (solid, red – X), the block lifecycle (dots, blue – O), and decay (dash, green - diamond). The trajectory begins at (S) and ends with (E).

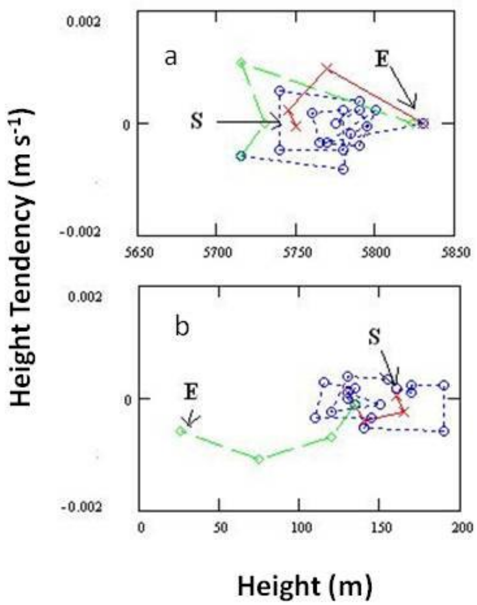


Figure 5. As in *Fig. 4*, except for the August 2010 blocking event.

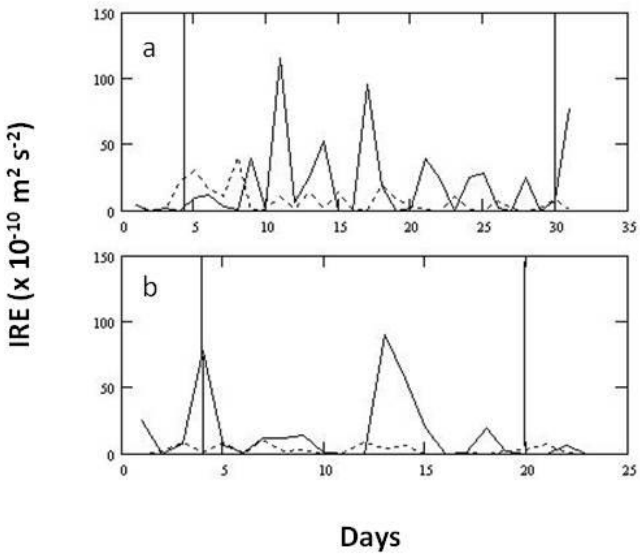


Figure 6. The IRE (x 10^{-10} m^2 s^{-2}) for the a) July 2010 blocking event, and b) August 2010 blocking event where the solid line is the planetary-scale IRE and the dotted line is the synoptic-scale IRE. The vertical lines represent block onset and termination.