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4.15 QUASI-STATIONARY ANTICYCLONES IN THE NORTHERN HEMISPHERE:AN ANALYSIS OF INTERANNUAL AND INTERDECADAL VARIABILITY AND LONG-TERM TRENDS AT 1000 hPa AND 500 hPa USING A GEOMETRIC DEFINTION.

Mikhail Bardin[1,2] George V. Gruza[1] Anthony R. Lupo[3]* Igor I. Mokhov[4] Vladimir A. Tikhonov[4]

[1]Institute for Global Climate and Ecology
[2]Institute of Geography
[4]A.M. Obukhov Institute of Atmospheric Physics
Russian Academy of Sciences
Moscow, Russia

[3]Department of Soil, Environmental, and Atmospheric Science
302 E ABNR Building
University of Missouri-Columbia
Columbia, MO 65211

1. INTRODUCTION

In recent years, many studies have been performed to investigate the climatological characteristics of blocking in both the Northern Hemisphere (e.g., Barriopedro et al., 2005), the Southern Hemisphere (e.g., Renwick, 1998), and blocking events in both Hemispheres (e.g., Wiedenmann et al. 2002). Included in these more recent studies cited here have been an analysis of long-term trends in blocking activity and interannual variations as they relate to the El Nino and Southern Oscillation (ENSO). Interdecadal variations in blocking activity as related to the North Atlantic Oscillation (NAO) have also been addressed recently (e.g., Shabbar et al., 2001; Barriopedro et al., 2005).

Indeed one of the major problems that have plagued the study of blocking events has been establishing a commonly agreed upon definition for what constitutes a blocking event. The subjective definition of Rex (1950) continues to be used in the operational community to define blocking. Many objective blocking criteria have been developed in order to facilitate the climatological and the dynamical study of blocking events. These include the use of thresholding techniques (e.g., Renwick, 1998), objective techniques that are proportional to the zonal wind (e.g., Lejenäs and Økland, 1983; Tibaldi et al., 1994; Lupo and Smith, 1995; Wiedenmann et al., 2002; Barriopedro et al., 2005), and even potential vorticity techniques (Pelly and Hoskins, 2003; Schwierz et al., 2004). However, none of these definitions has proven as of yet to be satisfactory.

None of the studies cited above have used or developed an objective definition for blocking based on the geometrical character of the blocking system itself as defined as a closed region of high pressure. All of the definitions described above are based on dynamic or thermodynamic aspects of the flow field such as the geostrophic wind, the potential temperature field, or the intensity of the ridge as related to some climatological value. Here, an index is developed that uses the geometric properties of the event itself. This definition can be used to deduce also the intensity of the blocking event in an objective manner. Thus, this new definition is similar to the Lupo and Smith (1995) blocking criterion, in which an intensity measure called block intensity (BI) was introduced. Additionally, the long-term trends and interannual variability will be examined using this new index as well.

*Corresponding author address: Anthony R. Lupo, Department of Soil, Environmental, and Atmospheric Sciences, 302E ABNR Building, University of Missouri-Columbia, Columbia, MO 65211. E-mail: LupoA@missouri.edu.

2. METHODS AND ANALYSES

2.1. Analyses

The data set used here was provided by the National Center for Environmental Prediction (NCEP) and National Center for Atmospheric Research (NCAR) gridded re-analyses (Kalnay et al., 1996). These data were archived at NCAR and obtained from the National Oceanic and Atmospheric Administration (NOAA) Climate Diagnostics Center (CDC) website (http://www.cdc.noaa.gov). These re-analyses were the 2.5^{o} by 2.5^{o} latitude-longitude analyses available on 17 mandatory levels from 1000 to 10 hPa at 6-h intervals. These analyses include the standard atmospheric variables geopotential height, temperature, relative humidity, vertical motion, $\boldsymbol{u}$ and $\boldsymbol{v}$ wind components and surface information.

2.2. Methods

In this paper, an anticyclone event is defined as a domain – (So) in Fig. 1, that contains a single local maximum in the height field (e.g., at the 1000 hPa level), and which is enclosed by an outermost contour Z(So) such that it contains the center point and the other closed contours.

In Fig. 1, several quantities are calculated following Bardin (2004) and these are:

1) the coordinates of the anticyclone are determined as the geometric center of the figure enclosed within the innermost closed contour (fh and lh in Fig. 1, and h is the local maximum on the pressure surface), or:

$$fh = \iint_{So} f(x)ds, \quad lh = \iint_{So} l(x)ds$$

2) depth (d) (gpm) is calculated as: | h –Z(So) |

3) area (a) is calculated the area within the outermost contour or: $\iint_{So} ds$

4) volume (v) is calculated as the volume integral:

$$\int \left[Z(x) - Z(So)\right]dv$$

5) intensity = volume / area which is considered to be the mean height of the anticyclone

This new definition has been used successfully to track transient cyclone and anticyclone events (Bardin, 2004) near the surface. This definition was then adjusted in order to capture quasi-stationary events, such as blocking events. In this study, an event was determined to be a blocking event if the center at each successive time does not propagate further than the radius of Z(So) for a minimum period of 5-days.

Since this technique was originally developed for the 1000 hPa surface to track near-surface transient events, the criterion was first tested on the 1000 hPa surface in order to identify blocking events. This is not unprecedented in the literature as the definition of Triedl et al (1981) identifies blocking events simultaneously at 1000 hPa and 500 hPa. Also, dynamic studies such as Lupo (1997) and Lupo and Bosart (1999) suggest that blocking events have a strong barotropic component. Then, using this criterion first at 1000 hPa was the strategy used here. After testing at the 1000 hPa level, the criterion will be used to examine closed 500 hPa height anomalies.

In this study, the seasonal and regional definitions of Wiedenmann et al. (2002) were used. These seasons are, January to March, April to June, July to September, and October to December representing winter, spring, summer, and fall, respectively. The regions are defined using the longitudes; 80^o W to 40^o E, 140^o E to 100^o W, and the remaining area representing the Atlantic, Pacific, and Continental regions, respectively.

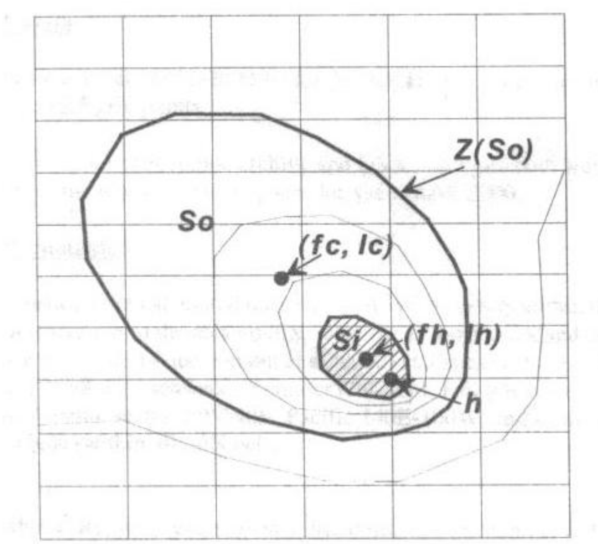

Figure 1. A schematic showing the geometry of the definition proposed here.

3. 1000 hPa CLIMATOLOGICAL ANALYSIS

A total of 49 years of Northern Hemisphere height fields were examined and the statistics were then compared to the results of Wiedenmann et al. (2002) over the same 30 year period (1968 – 1998). The definition described in section 2 allows for the definition of onset and termination time, mean center locations, durations, mean area, and mean depth.

The initial comparison (Table 1) demonstrates that the comparison overall was similar in that the total number of events was slightly higher for this study, and the durations were close to eight days each. Also, the Atlantic region experienced more events than the Pacific region, while the continental region observed the fewest events. Continental region events were the least persistent blocking events, while Atlantic and Pacific region events were similar in duration.

Table 1. Regional and seasonal distributions of the number and mean durations (days) of the 1000 hPa quasi-stationary blocking anticyclone events.

Region	Summer	Fall	Winter	Spring	Total
NH	262/8.3	228/7.0	196/7.2	181/8.8	867/7.8
Atlantic	107/7.6	108/7.3	94/7.5	92/8.7	401/7.7
Pacific	129/9.2	50/6.6	37/6.6	58/10.4	274/8.6
Cont.	26/6.4	70/6.8	65/7.3	31/5.9	192/6.3

However, there were significant differences in the statistics as well when comparing to Wiedenmann et al. (2002). In this study, the summer season experienced the most number of blocking events and spring and summer events were of the longest duration. These annual distributions were nearly opposite to those of most published blocking climatologies, but were similar to the blocking occurrences found in earlier versions of the CCM model (Lupo et al., 1997).

The mean depth of the events (Table 2) found here roughly corresponds to the Wiedenman et al. (2002) definition of intensity. The seasonal variation of depth demonstrates that fall and winter season events are the strongest events, and this is true for each region. In general Atlantic and Pacific region events were of similar strength overall, while continental events were a bit weaker. Atlantic events were strongest during the fall and winter, while the weakest events were continental warm season events. All these results are also similar to Wiedenman et al. (2002). Additionally, the mean depths of the events were close to being normally distributed as in the Wiedenmann et al. (2002) study.

Table 2. As in Table 1, except for mean depth (gpm).

Region	Summer	Fall	Winter	Spring	Total
NH	68.7	81.0	82.0	70.9	75.4
Atlantic	65.1	83.5	86.6	70.1	76.2
Pacific	72.6	79.8	76.5	79.9	76.0
Cont.	64.3	78.0	78.4	56.7	72.8

The distribution of duration and the longitudinal distribution of the occurrence of these events were similar to that of Wiedenmann et al. (2002) (not shown). Most events persisted for just over five days, while the longest event persisted for 26 days. The most persistent event in Wiedenmann et al. (2002) lasted for 26 days as well, and the distribution in each study resembled a Markov-type process. In this study, as in Wiedenmann et al. (2002), there was a pear in persistent anticyclone occurrence west of the prime meridian and over Eastern Europe and western Russia. There was also a peak near 90° E. Over the Pacific, there were more block occurrences east of the dateline found here as well.

Finally, the long-term trends found here (Fig. 2) were similar to that found in Wiedenmann et al. (2002). In fact, the overall trend was close to zero, and the trends in each region mirrored those of the earlier study. Additionally, the trends found here, as they were in the Wiedenmann et al. (2002) study were not statistically significant. An initial analysis suggests that there are interannual variations in this study related to ENSO and the NAO as found by Wiedenmann et al. (2002), Bardin (2004), and Barriopedro et al. (2005).

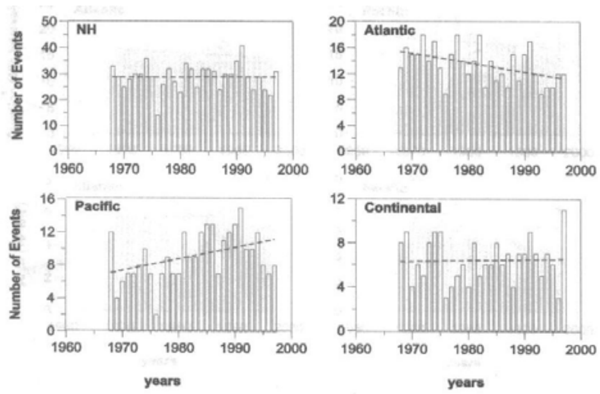

Figure 2. A time series of the annual number of quasi-stationary anticyclone events for the a) Northern Hemisphere, b) Atlantic, c) Pacific, and d) Continental regions.

4. 500 hPa CLIMATOLOGICAL ANALYSIS

Given the relative success of this new definition to identify quasi-stationary anticyclones at the 1000 hPa level over a long time period, and find similar characteristics to those of Wiedenmann et al. (2002) is encouraging. The study of Wiedenmann et al. (2002) yielded results similar to those of previous studies of Northern Hemisphere blocking events. Thus, the next step is to apply this definition at 500 hPa, which at the time of this writing was not completed. Such a test may bring the final climatology in closer alignment with previous studies.

Also, applying this definition to Southern Hemisphere events may be problematic since these events have been shown to propagate more than their Northern Hemisphere counterparts. Further testing is underway.

5. SUMMARY AND CONCLUSIONS

A blocking definition that uses the geometric characteristics of a quasi-stationary anticyclone is unveiled here. This definition is based on a similar definition for 1000 hPa transients as used in Bardin (2004). This definition is adjusted to only track events in which the center point of the event does not propagate beyond the radius of Z(So) from the previous time.

Initially, this definition was applied to the 1000 hPa NCEP/NCAR re-analysis height fields from 1952 – 2000. The results from the 30-year subset consistent with the Wiedenmann et al. (2002) study was then examined and compared to that study. The initial results are encouraging as the climatological characteristics (e.g., intensity) of the events found here were very similar to those of Wiedenmann et al. (2002). The most egregious differences were found in the annual distribution of occurrences and durations. Finally, climatological characteristics such as interannual variability and long-term trends were similar to those of the Wiedenmann et al. (2002) study.

These results were encouraging, and this definition will be applied to the NCEP/NCAR 500 hPa heights, and eventually, applied to Southern Hemisphere data.

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