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P2.14 THE GLOBAL INCREASE IN BLOCKING OCCURRENCES.

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1. INTRODUCTION

The climatological (Wiedenmann et al., 2002; Barriopedro et al., 2006) and dynamic (Lupo, 1997; Burkhardt and Lupo, 2005; Luo et al. 2007a,b; Lupo et al. 2007; and Hussain et al. 2007) behavior of blocking has been studied extensively over the past decade, and this has led to a better understanding of blocking in both hemispheres. Lupo (1997), and references therein, confirmed what earlier studies had tentatively shown, namely that blocking forms and is sustained by the interaction between a large-scale wave and individual synoptic-scale cyclones. These studies have all shown that a certain phase relationship between a developing upstream cyclone and the large-scale feature is necessary for block intensification. Lupo and Burkhardt (2005), using Potential Vorticity diagnostics, demonstrated that the planetary-synoptic-scale interactions are truly non-linear and synergistic in Northern Hemisphere (NH) blocking much of the time. In the Southern Hemisphere (SH), blocking is, much of the time, the result of superposition between the two scales.

Wiedenmann et al. (2002) and Barriopedro et al. (2006) both studied the climatological behavior of blocking as well as the trends and interannual variability in blocking occurrence. Both of these studies demonstrated that there was no statistically significant long-term trend in NH blocking occurrences, while the Wiedenmann et al. (2002) demonstrated that there was a long-term decrease in blocking occurrences in the SH. Clark et al. (2007) demonstrated that blocking in the SH was increasing between 2000 – 2006. However, it is not known why this increase was occurring. This increase is consistent with the results of Lupo et al. (1997) who suggested that a warmer climate would lead to an increase in the number and duration of blocking events.

Blocking in the NH demonstrated some interannual variability with blocking being more common in La Nina years and was significantly stronger, especially over the North Pacific. In the SH, blocking was more frequent, stronger, and more persistent in El Nino years. Since blocking is relatively rare outside the South Pacific region, these differences can be related to the interannual variability of the South Pacific storm track. Additionally, blocking in the SH is less frequent and has a stronger seasonal peak than in the NH (Wiedenmann et al., 2002).

Thus, there are two goals for this work. The first is to update the previous climatological work of this group to include recent years, especially for the NH. In performing this analysis we will note any resulting changes these years make to the previous climatologies. The second goal is to promote a blocking archive that will continuously be updated in a similar manner for that of, for example, hurricanes, and made available to the general public.

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2. METHODS AND ANALYSES

2.1. Analyses

The data set used here was 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 mass-store facility in Boulder, CO. 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, u and v wind components and surface information.

2.2. Methods

The blocking criterion of Lupo and Smith (1995) (*hereafter LS95*) was used here, and this can be summarized as a combination of the Rex (1950) subjective criterion and the Lejenas and Okland (1983) objective criterion, with the exception that a “block” is defined as persisting for five days or more. The Rex (1950) criterion used subjective map analysis, and in his study it was desirable that highly meridional split flow persists for 10 days or more. The Lejenas and Okland (1983) criterion is a zonal index plotted on a time-longitude or Hovmoller diagrams, and persistent weak or negative “non-translating” values can also represent blocking (LS95). A thorough description of the blocking criterion used here can also be found in Wiedenmann et al. (2002).

3. GLOBAL BLOCKING EVENTS: 2000-2007

3.1 Northern Hemisphere

In the Northern Hemisphere (NH), there was a distinct minimum in the number of blocking events during the late 1970s and early 1980s, and an upward trend following that period (Wiedenmann et al., 2002) (Fig. 1a). Since 1984, the NH trend has been upward and that trend continued for the 1998 – 2007 period (July 1998 – June 2007). For this period there were 313 events or a mean of 34.7 events per year (Table 1a). This is substantially more than the 25 events per year recorded during the 1968 – 1998 period. At this time, it is not clear whether this represents a change in climate, a very active short-term period, or flow variability or observation techniques or practices. Additionally for the 2007 – 2008 season, which is only half-way through, there have been 15 events to date.

In Atlantic, Pacific, and Continental regions there were 143, 95, and 74 events, respectively. This represents a mean of 15.9, 10.6 and 8.2 events during the recent period respectively, and these compare to 12.8, 6.6, and 5.4 events during the previous 30 years. The ratio of Pacific to Continental events was similar to the previous 30 year period (approximately 1.25 Pacific events to 1.0 Continental). However, the number of Atlantic events increased at a slower rate as the ratio of Atlantic events to those in the other regions is actually lower.

There has been no appreciable change in the duration of blocking events (8.4 days – Table 1a), and thus, there has been a large increase in the number of blocking days. There has been no appreciable change in the block intensity either, and thus, only an increase in the number of days has been reported. This does not agree with the finds of Lupo et al. (1997) which showed using a model that there may be an increase in the number of events in a warmer world, and these events may be more persistent and weaker than observed.

ENSO variability did not change appreciably by adding the data from the current period. There were more blocking events in La Nina and neutral years in the NH. However, when looking at the variability due to the PDO, there were more events during PDO2 (30.5 per year) than during PDO1 (24.6 per year), although this result was not significant at the 90% confidence level (85%). This difference was not spread out evenly through each region. Both the Atlantic and Pacific experienced larger differences, those in the Atlantic being significant at the 90% confidence level (15.1 events in PDO2, versus 12.1 in PDO1). There was no difference among continental region events.

Additionally, the ENSO variability during each phase of the PDO was different. During PDO2 there was no significant ENSO variations in NH blocking. During PDO1, however, there were 30.6 events per La Nina year compared to 24.5 and 22.6 events per neutral and El Nino years, respectively, and this difference is significant at the 90% confidence level. This difference in ENSO variability during each phase of the PDO is consistent with those of previous studies in this group of different phenomena such as hurricanes (Lupo and Johnston, 2000) or Midwestern snow events (Lupo et al. 2005).

Table 1. The regional and seasonal distribution of the number of blocking events/average duration in days of each blocking event occurring in the NH (top – 1968 – 2007) and the SH (bottom - 1970 – 2007).

Region	summer	fall	Winter	spring	Total
all	227 / 8.4	235 / 8.2	284 / 9.1	313 / 8.1	1059/ 8.4
Atl	90 / 8.6	137 / 8.7	150 / 9.7	148 / 8.4	525 / 8.9
Pac	54 / 7.6	60 / 7.6	93 / 8.5	87 / 7.5	294 / 7.9
Con	83 / 8.7	38 / 7.4	41 / 8.2	78 / 8.1	240 / 8.2

Region	summer	fall	Winter	spring	Total
all	48 / 6.3	141 / 7.6	140 / 8.0	76 / 6.8	405 / 7.4
Atl	4 / 5.4	13 / 5.9	17 / 6.0	7 / 5.8	41 / 5.9
Pac	43 / 6.5	103 / 7.9	112 / 8.5	58 / 7.0	316 / 7.8
Ind	1 / 5.0	25 / 7.2	11 / 6.0	11 / 6.3	48 / 6.7

3.2 Southern Hemisphere

During the 1980s and 1990s, there was a clear trend toward fewer blocking events in the Southern Hemisphere (Wiedenmann et al., 2002). Then, for the 2000-2007 period, there were 113 new blocking events tallied (about 14 per year). This compares to the 1970 – 1999 yearly mean of 10 events per year, and could be partly accounted for by a greater than typical tendency for Atlantic and Indian Ocean region blocking (12 and 21, respectively, and the 1970 – 1999 avereage for these two regions was 1 event per year). Overall, therefore, the 38 year mean occurrence increased to 10.7 events per year (Table 1b).

The 113 events that occurred during this period was not unprecedented, and was similar to that which occurred from 1971 – 1978 (106 events). While this may suggest that blocking frequency is on the rise during this decade, there is some evidence that the increase may be linked to the Pacific Decadal Oscillation (PDO). The increase in blocking has occurred since the switch in phase of the PDO to the cool phase in 1999 (Fig. 1b), and there is no longer a significant downward trend overall in SH blocking occurrences (Fig. 1b). The earlier period of active SH blocking overlaps with the cool phase of the PDO which occurred from 1947 – 1976. The decrease in SH blocking occurred during the warm phase of the PDO (1977 – 1998). During the warm (cold) phase, there were roughly 9.1 (13) events per year in the SH. This difference in the means during these periods is not statistically significant at the 90% confidence level (85%). This result is similar across all regions of the SH. Further, the increase in blocking occurrences could be linked to climate change (global warming - Lupo et al. (1997)).

There were few changes in any other characteristic such as overall duration (Tables 1b,2) or intensity (Table 3). Even within each region and season, there were few significant changes, with the exception of the intensities in the Atlantic and Indian regions where a decrease of 0.1 and 0.2 units in each region, respectively. There was also little change in the overall ENSO variations in SH blocking as well. There were still more blocking events in El Nino years (11.5 versus 9.6) as compared to La Nina years (though not significantly more in a statistical sense). The El Nino – La Nina difference has become smaller in the 2000-2007 period, and this is consistent with the results of other studies which examined hurricane frequency (Lupo and Johnston, 2000) and demonstrated that the interannual variability in hurricanes was smaller during the cool phase of the PDO. During the PDO1 period there were 50% more blocking events in El Nino years versus La Nina years. The ENSO variation was weaker (28%) in PDO2 years.

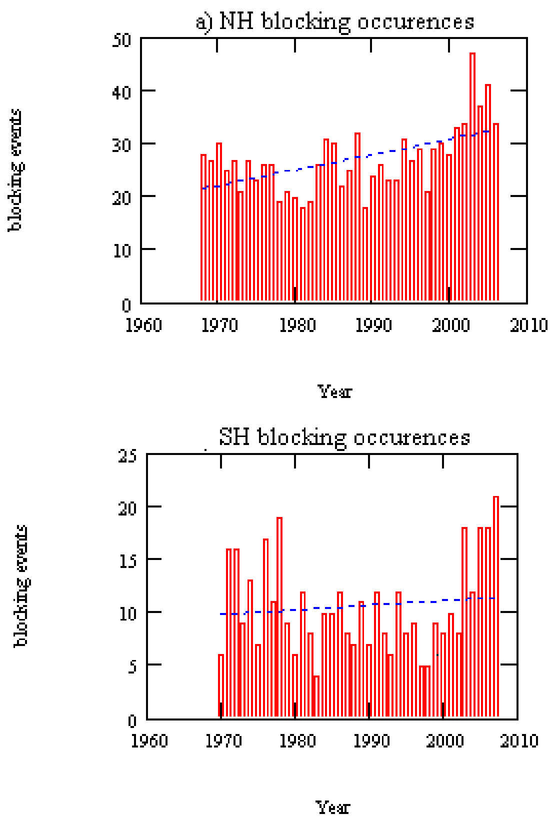

Figure 1. A time series of the annual number of blocking events in a year from 1970 – 2007 for the NH (top) and SH (bottom). The blue dashed line is a linear trend line.

Interestingly, an update of the "top ten" most persistent and strongest events from Wiedenmann et al. (2002) was updated in Tables 4 and 5 for both Hemispheres. In the NH (SH), six (four) of the top 12 (10) most persistent blocking events have occurred over the last seven years, although in the SH another four of these persistent events did occur within the 1972-1978 active period (Table 4b). In the NH (SH), eight (all) of these events are Atlantic (Pacific) region events. Five (Eight) of the 10 strongest events have occurred since 1990 in the NH (SH), and these have been predominantly Pacific Region events (Table 5). It is interesting to note that the strongest SH blocking event occurred in July 2006, and the strongest simultaneous events occurred in June 2005. This corresponds to anecdotal evidence that the SH flow has had a stronger meridional character (Lupo and M. Bodner, 2007, personal communication).

Table 2. The number of Southern Hemisphere blocking days from 1970 – 2006.

Region	summer	Fall	winter	spring	total
all	304.5	1073	1115	516.5	3009
Atl	21.5	76.5	102	40.5	240.5
Pac	278	817.5	946.5	407	2449.5
Ind	5	179	66.5	69	319.5

Table 3. As in Table 2, except for Block Intensity (BI).

Region	Summer	fall	winter	spring	total
All	2.63	2.99	2.84	2.57	2.81
Atl	2.70	3.11	3.11	3.32	3.11
Pac	2.65	3.02	2.82	2.52	2.81
Ind	1.80	2.80	2.55	2.36	2.62

4. A NEW ARCHIVE PRODUCT

Currently, there are various archives of weather events such as hurricanes (http://weather.unisys.com or from the National Hurricane Center), or tornadoes (http://www.spc.noaa.gov – the Storm Prediction Center, or http://www.ncdc.noaa.gov – the National Climatic Data Center). There is no repository for cataloging individual blocking events, currently available for public use. The center for blocking studies (CBS) in the Atmospheric Science Research Program at the University of Missouri - Columbia has made this archive for global blocking events available as of 1 March, 2007 (http://weather.missouri.edu – then "click" on Global Climate Change under "Research").

The information which will be available will be: region (0 = Atlantic, 1 = Pacific, and 2 = Indian), duration (days), onset and termination time (UTC and date), onset location (longitude - negative is west longitude), block intensity (BI), season of occurrence (1 = summer, etc), month of occurrence (1 = January, etc.), and blocking year (calendar year). This catalog is available for public use in identifying particular blocking events which meet the criterion of Lupo and Smith (1995) and Wiedenmann et al. (2002), and each event has been examined manually for quality control purposes. There are some issues that need to be resolved for some NH years, however, the archive is complete for the SH

5. SUMMARY AND CONCLUSIONS

The climatology of blocking events was updated to include the years 2000 – 2007 for both the NH and the SH. The NCEP – NCAR 500 hPa gridded height fields were used, and blocking events were identified using the criterion of LS95 and Wiedenmann et al. (2002).

Table 4. The 10 longest lived NH (top) and SH (bottom) blocking events from 1970 – 2009.

Rank	Event	Days	Region
1.	Jun 2003	35	CO
2.	Dec 2002	32.5	AR
3.	Jul 2003	32	CO
4.	Feb 2005	31.5	AR
5.	Feb 2005	31	AR
6.	Dec 1995	29	AR
7.	Dec 2005	27	AR
8.	Jan 1996	27	AR
9.	Apr 1973	26	AR
10.	Oct 1987	24	AR

Rank	Event	Days	Region
1.	Jul 1976	26	PR
2.	Jun 2005	22.5	PR
3.	May 2009	21	PR
4.	May 1973	20.5	PR
5.	Aug 2004	20.5	PR
6.	Jun 1981	20	PR
7.	May 2009	19.5	PR
8.	Jul 1973	18	PR
9.	Aug 2003	18	PR
10.	Dec 1972	17.5	PR
11.	Aug. 1989	17	PR
12.	Jun 1992	17	PR
13.	Jul 2004	17	PR

While it was not expected that these seven years would substantially impact the earlier long-term climatology of blocking, the one result that was noteworthy was the increase in NH and SH blocking from 2000 – 2007 reversing two decades of decreases. In the SH, this eight year period is not unprecedented however, as during the 1971 – 1978 period, a similar number of blocking events occurred. There was increased Atlantic and Indian Ocean region blocking activity (10 and 15, respectively), and this is also similar to the earlier period (11 and 13, respectively). In the NH, the most important result was that the recent increases in blocking were hemisphere-wide, but the increase was slower in the Atlantic region. These increases in blocking occurrence this study agreed with the results of the Lupo et al. (1997) which implied more blocking activity in a warmer world.

While it would require more study, it is hypothesized here that there was interdecadal variability in blocking occurrence that is likely related to the PDO. In both hemispheres, there was more blocking activity apparent in PDO2 years, however, there was greater ENSO related variability in the in both hemispheres during PDO 1 and in the NH this was significant at the 90% confidence level.

An examination of other blocking characteristics, including their interannual variability, revealed that there were no significant changes in the long-term blocking climatology characteristics. This is not consistent with Lupo et al. (1997) which showed blocking in a warmer world would be weaker and more persistent.

Finally, this publication described a new archive product which chronicles the character of each individual blocking event from 1968 - 2007, which is available for public use. There is currently no available archive for blocking events as there is for other phenomena such as hurricanes or tornadoes.

Table 5. The 10 strongest SH (top) and NH (bottom) blocking events from 1970 – 2009.

Rank	Event	BI	Region	Smltn?
1.	Jul 2006	5.46	PR	Yes
2.	Oct 1995	5.40	AR	No
3.	May 1991	5.30	PR	No
4.	Sep 1996	5.00	PR	No
5.	Jun 1995	4.83	PR	No
6.	Jun 2005	4.80	PR	Yes
7.	May 2000	4.71	PR	No
8.	Jun 2007	4.68	PR	Yes
9.	Jun 2005	4.65	PR	Yes
10.	Aug 1984	4.64	AR	Yes

Rank	Event	BI	Region	Smltn?
1.	Feb 1991	6.42	PR	Yes
2.	Mar 1996	6.40	PR	Yes
3.	Nov 1997	6.31	AR	No
4.	Feb 1989	6.2	PR	Yes
5.	Jan 1985	6.17	PR	Yes
6.	Dec 1996	6.16	PR	Yes
7.	Jan 1979	6.09	PR	No
8.	Dec 1983	6.08	PR	Yes
9.	Feb 1975	6.08	AR	Yes
10.	Jan 2008	5.99	AR	No

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