

1 *Conference Proceedings Paper*

2 **Changes in Blocking Characteristics During the First** 3 **Part of the 21st Century.**

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15 **Abstract:** A global blocking climatology published by this group for events that occurred during the
16 late 20th century examined the comprehensive list of characteristics that included block intensity.
17 In addition to confirming the results of other published climatologies, they found that Northern
18 Hemisphere blocking was stronger than Southern Hemisphere events and winter events are
19 stronger than summer ones. This work also examined the interannual variability of blocking as
20 related to El Nino. Since this time, there is evidence that the occurrence of blocking has increased
21 globally. A comparison of blocking characteristics during the first part of the 21st century to those
22 in the late 20th century shows that the number of blocking events and their duration have increased
23 in the Northern and Southern Hemisphere. The intensity of blocking has decreased by about nine
24 percent in the Northern Hemisphere, but there was little change in the intensity of Southern
25 Hemisphere events. Additionally, there is little or no change in the genesis regions of blocking. An
26 examination of variability related to El Nino and Southern Oscillation reveals that the variability
27 found in the earlier work has reversed. This could either be the result of interdecadal variability or
28 a change in the climate.

29 **Keywords:** blocking; ENSO; climate change; Pacific Decadal Oscillation;

30 **1. Introduction**

31 Many recent studies have examined the climatological behavior of blocking in both the northern
32 and Southern Hemispheres in the later part of the 20th century [1-7]. Only a few have examined
33 blocking in the 21st century (e.g. [8], [9]). Many have also examined projections for the future
34 occurrence of blocking [7], [10-13]. Also, there is some evidence to suggest that there has been an
35 increase in the occurrence of blocking since 2000 in both the northern and Southern Hemispheres.

36 The study of [1] and [7] studies examine a long list of blocking characteristic including the number
37 of events, days, duration, intensity, and location at onset. Most other climatologies use only the
38 occurrence, day, and/or durations of blocking events. The work of [5] suggested interannual and
39 interdecadal variability in block occurrences. Then [6] implies that the number of Northern
40 Hemisphere blocking events is increasing, but that the period 1970-1999 was likely a period of low
41 blocking occurrence. Many authors projected that the occurrence of blocking many increase in a
42 warmer world [7], [10], [12], [13]. Others projected that far into the future the number of events may
43 decrease slightly [11]. Others, such as [8] and [9] suggest that the primary location for block
44 ccurrences would also change in a warmer world.

45 The goal of this work is to make a comprehensive comparison of the global occurrence of
 46 blocking since the end of the climatology of [1] to their work for the late 20th century. This work will
 47 examine the more comprehensive characteristics that they researched. This study will also determine
 48 if there has been any changes in the trends or interannual variability of any of these variables, as well
 49 as the possibility of interdecadal variability in these variables. This study is unique in that it is the
 50 only study that includes an examination of block intensity (BI). BI has been shown to be related to the
 51 500 hPa height gradients in each hemisphere [1]. This work will primarily use the National Centers
 52 of Environmental Prediction / National Center for Atmospheric Research (NCEP / NCAR) reanalyses.
 53

54 2. Data and Methods

55 2.1 Data

56
 57 The data used here were the NCEP / NCAR reanalyses 500 hPa height fields on a 2.5° latitude
 58 by 2.5° longitude gridded data set available at 6-h intervals [14], [15]. The 1200 UTC data was used
 59 primarily in the calculation of intensity since these tended to have the most number of observation
 60 data. This study also used data archived at [16] which contains a list of all blocking events since the
 61 beginning of the [1] study. The period of study in the Northern Hemisphere is from July 1998 to June
 62 2017 (19 additional seasons), while for the Southern Hemisphere included the period from January
 63 2000 to December 2016 (17 additional seasons). These time periods (spatial regions) follow the
 64 blocking year (geographic regions) established by [1].
 65

66 2.2. Methodology

67
 68 The blocking criterion and block intensity used here were established by [1] and references
 69 therein. The definition for ENSO used here is described in [17] and references therein and a short
 70 description is given here. The Japanese Meteorological Agency (JMA) El Niño and Souther Oscillation
 71 (ENSO) index is available through the Center for Ocean and Atmospheric Prediction Studies
 72 (COAPS) from 1868 to present [18]. The JMA classifies ENSO phases using SST within the bounded
 73 region of 4°S to 4°N, 150°W to 90°W, and defines the inception of an ENSO year as 1 October, and its
 74 conclusion on 30 September of the next year. This index is widely used in other published works (see
 75 [17] and references therein) and a list of years is given in (Table 1). Also, [19] found that while the
 76 JMA index is more sensitive to La Niña events than other definitions, it is less sensitive than other
 77 indices to El Niño events.

78 **Table 1.** List of ENSO years used here. The years are taken from [18].

El Niño	Neutral	La Niña
1969	1968	1967
1972	1977-1981	1970-1971
1976	1983-1985	1973-1975
1982	1989-1990	1988
1986-1987	1992-1996	1998-1999
1991	2000-2001	2007
1997	2003-2005	2010
2002	2008	
2006	2011-2013	
2009	2016	
2014-2015		

79 The Pacific Decadal Oscillation (PDO) positive and negative modes are catalogued also by the
 80 Center for Ocean-Atmospheric Prediction Studies (COAPS). The most important effect of PDO is
 81 how it interacts with ENSO during certain phases to create an enhanced effect on temperatures and
 82 precipitation variability (e.g. [20], [21]). The characteristics of these modes are less pronounced than
 83 those for ENSO due to the fifty-to seventy-year cycle of PDO [22], [23]. The positive phase of the PDO
 84 is recognized as the period 1977-1998, and the negative phase is recognized as the years 1947 – 1976,
 85 and 1999 – 2017.
 86

87 3. The Climatology of Blocking in the Early 21st Century

88 3.1 The Northern Hemisphere.

89 The noteworthy character of blocking at the start of the 21st century (Table 2) is the increases in
 90 the occurrence, number of blocking days and durations. In all regions and seasons, these increases
 91 are statistically significant at the 95% confidence level, using the Z-score test for means [24]. The
 92 Atlantic region showed the weakest increases which is consistent with the results of [7]. The large
 93 increase in the occurrence and days within Pacific Region Blocking is consistent with the results of
 94 [17] who examined spring and summer blocking in this region. The work of [25] also showed a large
 95 increase in blocking for the eastern Europe and western Russia region for the spring and summer
 96 seasons as well. Only the block intensity (BI) showed a decrease over the first part of the 21st century.
 97 This decrease is not significant at any standard level of statistical significance.
 98

99 **Table 2.** Character of Northern Hemisphere blocking events per year as a function of region and
 100 season for all characteristics since the study of [1]. The change in the value is expressed as a
 101 percentage.

Region	Occurrence	Duration	Days	Intensity
Atlantic	15.6 / +21.9	10.5 / +24.5	163.8/+42.3	
Pacific	11.8 / +77.9	9.5 / +25.0	112.1/+111.4	
Continental	10.1 / +84.7	9.0 / +10.8	90.9/+81.1	
Total	37.6 / +56.0	9.5 / +11.8	356.3/+67.9	3.02 / -6.3
Season	Occurrence	Duration	Days	Intensity
Summer	7.9 / +51.0	10.0 / +30.7	79.3 / +85.5	
Fall	8.3 / +52.7	9.7 / +19.8	80.5 / +71.3	
Winter	10.1 / +42.3	9.7 / +9.0	98.0 / +46.1	
Spring	11.2 / +53.4	9.7 / +23.4	109.2 / +72.4	

102 Such increases across all regions and seasons were surprising, however, as shown above, several
 103 studies have examined blocking over limited regions and seasons and shown similar strong increases.
 104 While [17] and [25] showed increases within the warm season in recent decades, on the other hand,
 105 [6] showed that over the Atlantic for the winter season that blocking days over the same period
 106 covered by [1] was associated with a significant minimum. Additionally, [7] showed an increase in
 107 blocking since 2000 as shown with three blocking indexes including the index used here. Taken
 108 together, these provide confidence that the increases in Northern Hemisphere blocking occurrence is
 109 likely real. Finally, the mean number of simultaneous blocking days (defined as the number of days
 110 with two or more blocking events occurring concurrently in any sectors) per year since [1] is 102.1
 111 days or 28.0% of the year. This represents a large increase over [1] who found the number to be
 112 approximately 8.7% of the year.
 113

114 3.2 *The Southern Hemisphere*

115

116 Examining blocking in the Southern Hemisphere (Table 3) and comparing with the work of [1]
 117 shows similar results to the Northern Hemisphere above. The weakest increases occurred within the
 118 Pacific Region, and unlike the Northern Hemisphere this region is the predominant blocking region
 119 accounting for about three-quarters of all events when counting events and blocking days. The Pacific
 120 Region increases in the Southern Hemisphere were weaker than their Northern Hemisphere
 121 counterparts, but still statistically significant at the 95% confidence level. Increases within the Atlantic
 122 or Indian Ocean Regions were very large, however, blocking in this region is not as prominent. Only
 123 BI showed no significant change in the Southern Hemisphere. Lastly, the number of simultaneous
 124 blocking days per year since [1] in the Southern Hemisphere is 15.8 days per year (4.3%) which is
 125 higher than the 1.5% found by [1] and this will be discussed more below.

126

127 **Table 3.** Character of Southern Hemisphere blocking events per year as a function of region and season
 128 for all characteristics since the study of [1]. The change in the value is expressed as a percentage.

Region	Occurrence	Duration	Days	Intensity
Atlantic	1.8 / +81.4	6.6 / +11.4	11.7/+101.7	
Pacific	11.3 / +43.1	8.4 / +11.4	95.0/+59.9	
Indian	2.5 / +181.1	7.3 / +9.8	18.4/+206.7	
Total	15.6 / +59.9	8.0 / +9.6	124.7/+75.1	2.86 / +1.2
Season	Occurrence	Duration	Days	Intensity
Summer	1.9 / +52.8	7.0 / +9.4	13.1 / +67.9	
Fall	5.1 / +47.3	8.2 / +8.5	41.8 / +60.2	
Winter	5.4 / +65.6	8.5 / +11.2	47.2 / +90.3	
Spring	3.2 / +80.0	7.5 / +10.0	24.2 / +96.7	

129

130 **4. Interannual and Interdecadal variability**

131 In this section, the change in ENSO variability as well as PDO variability will be examined. In
 132 order to accomplish the latter, the data from [1] will be reanalyzed by stratifying the blocking years
 133 using the PDO epochs defined in Section 2.2. The change in phase of the PDO occurred near the end
 134 of the [1] study, thus it might be reasonable to assume that the recent increases in blocking are related
 135 to the change in phase of the PDO. The results from the Northern Hemisphere are shown in Table 4.
 136 The results show that the total number of blocking events, days, and durations were higher for the –
 137 PDO, but the BI indicated weaker events similar to the occurrence of blocking after the [1] study.
 138 Additionally, during the +PDO, the ENSO variability matched that of [1] which implied that La Nina
 139 years were associated with more blocking events and days and which were slightly stronger. Then
 140 during the –PDO phase the ENSO variability was the opposite in that El Nino years were associated
 141 with the greater number of blocking events, days, and slightly stronger. Thus, by examining the
 142 overall set of years (49) there was little ENSO variability overall.

143 In the Southern Hemisphere (Table 5), as in the Northern Hemisphere, the occurrence of
 144 blocking was greater during the –PDO phase. In this part of the world, however, the ENSO variability
 145 did not change across the phase of the PDO. During both PDO epochs, blocking occurred more often,
 146 was more persistent and more intense in El Nino and Neutral years as compared to La Nina years.
 147 This variability is reflected across each region as well. The study of [1] speculated that blocking was
 148 on the decrease during the late 20th century. Lastly, [26] showed that there was a reversal in the
 149 proportion of east Pacific blocking occurrences when compared to those of the west Pacific Region.

150 During the +PDO phase there were a larger fraction of east Pacific Region blocking during La Nina
 151 and Neutral years, while the opposite was true during the –PDO epoch (La Nina years showed the
 152 smallest fraction of east Pacific blocking).

153 **Table 4.** Character of Northern Hemisphere blocking events per year as a function of ENSO and
 154 PDO. The number of years in each category is shown in parenthesis.

+ PDO	Occurrence	Duration	Days	Intensity	% Simult.
El Nino (6)	23.5	8.1	190.4	3.06	7.6
Neutral (15)	24.4	8.2	200.1	3.26	8.9
La Nina (2)	30.5	8.3	253.3	3.11	12.7
Total (23)	24.7	8.2	202.5	3.20	8.9
- PDO	Occurrence	Duration	Days	Intensity	% Simult.
El Nino (7)	37.0	9.6	355.2	3.13	24.4
Neutral (11)	36.4	10.0	364.0	3.01	28.2
La Nina (8)	29.1	8.4	244.4	3.08	13.9
Total (26)	32.8	9.9	323.7	3.07	21.7

155 **Table 5.** Character of Southern Hemisphere blocking events per year as a function of ENSO and
 156 PDO. The number of years in each category is shown in parenthesis.

+ PDO	Occurrence	Duration	Days	Intensity	% Simult.
El Nino (5)	9.0	7.0	63.0	3.02	1.7
Neutral (15)	9.5	7.1	67.5	2.76	1.4
La Nina (2)	6.0	6.7	40.2	1.87	0.0
Total (22)	9.0	7.1	63.9	2.81	1.3
- PDO	Occurrence	Duration	Days	Intensity	% Simult.
El Nino (8)	14.8	8.4	124.3	2.96	3.9
Neutral (9)	16.0	7.8	124.8	2.80	4.2
La Nina (8)	12.0	7.6	91.2	2.75	2.7
Total (25)	14.3	8.0	114.4	2.85	3.6

157 The work of [1] speculated that the greater occurrence of simultaneous blocking events in
 158 the Northern Hemisphere versus those in the Southern Hemisphere was due to the greater
 159 number of occurrence of blocking since previous work demonstratd that the occurrence of
 160 blocking was caused local synoptic processes rather than hemisphere-wide planetary-scale
 161 processes. The results here show a similar result since the fewest number of blocking events
 162 occurred during the Southern Hemisphere +PDO epoch as well as the fewest number of
 163 simultaneous days. The opposite was true in that the largest number of simultanous blocking
 164 days occurred during the Northern Hemisphere –PDO epoch which showed the largest number
 165 of blocking occurrences. The correlation between the number of simultaneous blocking days and
 166 the number of events was 0.89 in the Northern Hemisphere and 0.76 for the Southern
 167 Hemisphere and both results are statistically significant at the 99% cofidence level.

168

169

170 5. Discussion, Summary, and Conclusions

171 This study examined the occurrence of blocking over the entire globe since the study of [1], and
172 including such characteristics as occurrence, duration, blocking days, block intensity (BI), and the
173 number of simultaneous blocking days. The data set used here was the NCEP/NCAR re-analyses and
174 the archive of blocking events are found at [16]. Then, the long term trends as well as interannual and
175 interdecadal variability were examined.

176 The study here showed statistically significant increases in block occurrences, days, and
177 duration since the end of the 20th century. In the Northern Hemisphere there was a slight decrease in
178 BI, which was not statistically significant. There was little change in the Southern Hemisphere BI. In
179 the Northern Hemisphere, the increases found here were consistent with the results of others [6], [7],
180 [17], [25] who examined ‘partial’ climatologies examining only certain regions during certain
181 seasons. The work of [6] implied that the period 1970 – 1999 showed a relative minimum in Atlantic
182 Region winter season blocking. Thus, there is strong evidence to support the results here. In the
183 Southern Hemisphere, Pacific Region blocking showed increases that were not as strong as their
184 Northern Hemisphere counterparts.

185 Separating the occurrence of blocking by ENSO and PDO showed that the +PDO epoch
186 interannual variability in the occurrence, duration, and BI were similar to those found in [1] as
187 expected. In the Southern Hemisphere the interannual variability was the same in the –PDO epoch
188 albeit with increases in occurrence, duration, and days. But, within the Pacific Region, the relative
189 occurrence of East Pacific blocking was greater in La Nina and Neutral years than during El Nino
190 years for the +PDO epoch. The opposite occurred during the –PDO phase. In the Northern
191 Hemisphere, the interannual variability of these characteristics was opposite during the –PDO epoch.
192 Finally, an examination of the occurrence of simultaneous blocking events was greater with a greater
193 frequency in blocking occurrence, supporting the conjecture of [1].
194
195

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198 **Author Contributions:** All four authors conceived and designed the experiments; performed the experiments;
199 all four co-authors analyzed the data; and A.R. Lupo wrote the paper.

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201

202 Appendix A

203 The top ten longest lived blocking events in the Northern Hemisphere (top) and Southern Hemisphere
204 (bottom) from 1968 – present.

205

Rank	Event	Days	Region
1.	June 2003	35.0	Co
2.	December 2016	33.5	AR
3.	December 2010	33.0	AR
	May 2013	33.0	PR
	July 2013	33.0	PR
6.	December 2002	32.5	AR
7.	July 2003	32.0	Co
8.	February 2005	31.5	AR
9.	February 2005	31.0	AR
10.	May 2014	29.5	Co

Rank	Event	Days	Region
1.	July 2015	28.0	IN
2.	July 1976	26.0	PR
3.	May 2016	25.0	PR
4.	June 2005	22.5	PR
5.	May 2008	21.0	PR
6.	May 1973	20.5	IN
7.	August 2004	20.5	PR
8.	June 1981	20.0	PR
9.	June 2012	20.0	PR
10.	May 2009	19.5	PR
	October 2010	19.5	PR

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208

209 **Appendix B**

210 The top ten strongest (BI) blocking events in the Northern Hemisphere (top) and Southern Hemisphere
 211 (bottom) from 1968 – present.

212

Rank	Event	BI	Region
1.	February 1991	6.42	PR
2.	March 1996	6.40	PR
3.	November 1997	6.31	AR
4.	March 1989	6.20	PR
5.	January 1985	6.17	PR
6.	December 1996	6.16	PR
7.	January 1979	6.09	PR
8.	February 1975	6.08	AR
	December 1983	6.08	PR
10.	January 2008	5.99	AR

Rank	Event	BI	Region
1.	July 2006	5.46	PR
2.	October 1995	5.40	AR
3.	May 1991	5.30	PR
4.	May 2016	5.08	PR
5.	September 1996	5.00	PR
6.	July 2016	4.85	PR
7.	June 1995	4.83	PR
8.	June 2005	4.80	PR
9.	May 2000	4.71	PR
10.	June 2007	4.68	PR

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215 **References**

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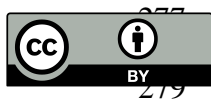
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