

Article

The Climatological Character of Simultaneously Occurring Blocking Events

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Abstract

In this work, the climatological character of simultaneously occurring blocking events will be examined. Some previously published papers have proposed without strong evidence that simultaneously occurring blocking events are stronger and more persistent than those that occur in isolation. Simultaneous blocking events are defined as those that occur at the same time but in different parts of the Northern or Southern Hemisphere. Using the NCEP reanalyses, and the blocking archive at the University of Missouri, the character of simultaneously occurring blocking events is examined from the late 1960's through 2025. Specifically, this study will examine the intensity, duration, and onset location of simultaneously occurring blocking events versus those that occur as singular events. This work found that the increase in block occurrences during the early 21st century has been, as expected, accompanied by an increase in simultaneously occurring blocking events in both the NH and SH. It was also found that in both hemispheres it is not generally true that simultaneously occurrence blocking events are stronger and more persistent than solitary blocking events. However, it may be true that simultaneous blocking events are either stronger and/or more persistent depending on the season or year. Additionally, in the Northern Hemisphere, Pacific Region blocking events have a greater chance of being part of a simultaneous blocking episode, while blocking in the European Sector has a greater probability of occurring as a singular event. In the Southern Hemisphere, blocking in the Western Pacific is less likely to be part of a simultaneous blocking episode. This information could be used to anticipate the weather for a region such as North America, which may experience more persistent weather regimes.

Keywords: blocking anticyclones; climate variability; ENSO; simultaneous; block persistence; block intensity



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1. Introduction

In [1], it was briefly noted that the occurrence of simultaneously occurring blocking events had increased significantly in the early 21st century in concert with a concomitant increase in blocking frequency. This work also listed the 10 most intense and 10 most persistent blocking events in their study period and noted that many of them were associated with a simultaneously occurring blocking event. Block intensity (BI) was measured using the [2] formulation. Both works [1,2] as well as earlier studies (e.g., [3,4]) noted that simultaneous events tended to be associated with stronger and/or more persistent blocking events based on observation alone.

The linkage between blocking occurring in one sector of the globe and another occurring remotely at the same time in another part of the world was first discussed by [5] or [6]. They determined statistically that there is little relationship between simultaneously occurring events in the Northern Hemisphere. Later [7] examined the case of three blocking events occurring simultaneously in the Southern Hemisphere. They determined the dynamics of each event were local, but that the presence of an amplified wave number three pattern opened the possibility that the three could occur simultaneously. This was also supported by [8]. Theoretical studies (e.g., [9–13]) published around the same time (or later e.g., [14–18]) suggested blocking was the result of the favorable superposition of synoptic and planetary-scale forcing supporting a more locally forced blocking occurrence paradigm. Numerous observational or modelled case studies over time have also supported this viewpoint (e.g., [19–29]).

The study of [30] examined the dynamic and thermodynamic forcing associated with two blocks that occurred simultaneously over the Atlantic and Pacific during November 1985. This study partitioned the forcing into a synoptic and planetary scale component as well as an interaction component that arose from forcing processes which are represented by products (flux or advective processes). The long-lived Atlantic event was supported by the synoptic and interaction processes while the planetary-scale opposed the maintenance of this event. The Pacific region event was supported similarly during its maintenance phase, while the synoptic-scale significantly opposed block formation early and supported decay late.

Studies such as [8,25] speculated that the large-scale flow may govern persistence of blocking and that the breakdown of a large-scale flow regime would lead to the decay of blocking. This view was supported by the observational case studies of [31,32]. Of these [31] stated that a change in the large-scale flow field would lead to the demise of an existing blocking event. This was shown dramatically by the collapse of two blocking events occurring simultaneously in the Northern Hemisphere during late March 2019 [33,34].

However, very early studies [35–40] focused on the role of the planetary-scale in forcing the occurrence of blocking. Studies such as [30,33,34,41] demonstrated that the large-scale was an important co-contributor with the synoptic-scale for the support of simultaneously occurring blocking events in the Northern Hemisphere. Further, ref. [42] demonstrated that a blocking event could survive the transition of one large-scale flow regime to another as long as there was serendipitously timed synoptic-scale upstream forcing.

The goal of this study is to examine the statistical character of simultaneously occurring blocking events over a 57-year period and compare these to those that occur in isolation. Blocking will be studied in general, by season, and with respect to interannual and interdecadal variability. This investigation will test for statistical significance the previously published notion from this research group that simultaneously occurring blocking events are generally stronger and more persistent in both hemispheres. A study of the trend in the occurrence of simultaneously occurring blocking events will also be examined.

2. Materials and Methods

2.1. Data

The data used to create the blocking climatology were obtained from the NCEP/NCAR reanalyses 500 hPa height fields on a 2.5° latitude by 2.5° longitude gridded dataset available at 6-h intervals (e.g., [43,44]). These reanalyses have been used in previous work from this group (e.g., [1]) and this means the comparison here to previous studies from this group will be consistent. The 1200 UTC data were used primarily in the calculation of intensity since these data tend to include the greatest number of observational data. The created climatology is available through the University of Missouri (e.g., [1]) which

contains a list of all blocking events and their characteristics since the beginning of the Wiedenmann et al. study [2] to the present time. The period of study here was 57 years. In the NH this included 1 July 1968 to 30 June 2025, while for the SH the period included 1 January 1969 to 31 December 2025. These reanalyses were used by earlier studies (e.g., [2]) and the rationale for defining a blocking year is found in that study.

The blocking seasons (regions) follow the blocking year (geographic boundaries) established by [2]. In particular, the boreal (austral) summer, fall, winter, and spring are July–September (January–March), October–December (April–June), January–March (July–September), and April–June (October–December), respectively. In the NH and SH, the Atlantic Region (ATL) is defined as 80° W to 40° E and 60° W to 30° E, respectively. The Pacific Region is defined as 140° E–100° W and 130° E to 60° W for the NH and SH, respectively. In the NH the Continental Region (CON) encompasses 100° W to 80° W and 40° E to 140° E, while in the SH the Indian Ocean Region (IND) is defined as 30° E to 130° E, respectively.

2.2. Methods

The blocking criterion and BI used here were established by [2], and references therein and described in detail here. From [2]:

- (1) The criterion of [3] must be satisfied at 500 hPa for an anticyclonic flow region, with the exception that the minimum duration must be five days.
- (2) A negative or small positive Legenas-Okland (LO) Index as in [5] or [6] index must be present on a Hovmoller diagram in the NH or SH.
- (3) Conditions one and two must be satisfied together from 24 h after onset to 24 h before termination.
- (4) The anticyclone should be poleward of 35° N or 30° S and the ridge should have an amplitude of greater than five degrees latitude.
- (5) Block onset is defined to occur when condition four and either conditions one or two are met.
- (6) Termination is defined at the time the event fails condition five for a 24-h period or longer.

The LO criterion is a variation of the zonal index and on a Hovmoller diagram, negative values tend to represent blocking events. Then [2] recognized that persistent weak non-translating LO index values could also represent blocking since the event may not be centered at the particular latitude specified in using the criterion of [5] or [6]. Since the LO index as defined above was used here, a subjective appraisal of potential blocking events was necessary in order to reject features that are clearly not blocking anticyclones such as cyclones.

In [2], BI was calculated by normalizing the central height value (MZ) using an automatically determined value that was proportional to the mean gradient of the flow in the upstream and downstream direction (RC). Thus, the formula for BI is:

$$BI = 100 * x[(MZ/RC) - 1.0] \quad (1)$$

where the numbers 100 and 1 produce a BI between 0.5 and 10. As shown in [2], BI is proportional to the strength of the mid-latitude height gradients. Then, RC was calculated using:

$$RZ = (((Z_u + MZ)/2) + ((Z_d + MZ)/2))/2 \quad (2)$$

where Z_u and Z_d represent the lowest height value upstream and downstream of the block center, respectively, and at the same latitude as MZ. Thus, BI can be used as a diagnostic

for examining the relative strength of large-scale flow regimes for each hemisphere within blocking regions, particularly when comparing observations to model results (e.g., [2]).

In previous studies (e.g., [1,5]), simultaneous blocking was counted as the number of days in which blocking occurred in two different parts of the NH or SH. Then, the frequency of simultaneous blocking was counted as a percentage of those days annually or seasonally. Here, we count simultaneous blocking events differently in order to obtain the number of individual events. In order to be counted as simultaneously occurring events, the two blocks had to overlap by a period longer than one-half the persistence time of the shorter-lived event. For example, if one event persists for eight days, and another forms on day five of the first event and persists for seven days, that would count as a simultaneously occurring blocking event. The same rules were applied if there were three simultaneously occurring events.

The above method results in a “overcount” of days for simultaneously occurring events as total number of days are counted for each event as compared to previous studies. However, this method allows for the count of individual events and then their characteristics (duration, intensity, genesis location) for comparison of these events to blocks occurring in isolation. Additionally, it results in a dramatic overcount of simultaneous blocking days compared to [1] or [2]. But, the goal here is to compare relative number of simultaneous blocking events across seasons and regions here and not necessarily comparing the exact number of days to those found in earlier studies. It also must be conceded here that a longer living event has a greater chance of overlapping with the occurrence of another blocking event. Thus, it is possible the definition of a simultaneous blocking episode may lead to the conclusion they are longer lived. This point will be discussed further following the results.

The definition for El Niño and Southern Oscillation (ENSO) used here is described in [45] and references therein and a short description is given here. The Japanese Meteorological Agency (JMA) ENSO index is available through the Center for Ocean and Atmospheric Prediction Studies (COAPS) [46] from 1868 to present. The JMA classifies ENSO phases using SST within the bounded 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 conclusion on 30 September of the next year. This index is widely used in other published works (see e.g., [47–49] and references therein), and a list of years is given in (Table 1). Also, ref. [50] found that while the JMA index is more sensitive to La Niña events than other definitions, it is less sensitive than other indices to El Niño events.

Table 1. List of ENSO years used in this study since those published in [1].

El Niño	Neutral	La Niña
2018	2019	2020–2022
2023		2024
		2025

The Pacific Decadal Oscillation (PDO) positive and negative modes are catalogued also by the Center for Ocean-Atmospheric Prediction Studies (COAPS). The most important impact of the PDO is the interaction with ENSO during certain phases, which creates either an enhanced effect on temperatures and precipitation variability over the central USA (e.g., [45,51,52]). The characteristics of these modes are less pronounced than those of ENSO due to the 50- to 70-year cycle of PDO (e.g., [51,52]). Here we used the index available through the Joint Institute for the Study of the Atmosphere and Ocean (JISAO) and defined the epochs following our previous studies [1]. The positive phase of the PDO is recognized as the period from 1977–1998, and the negative phases are recognized as the years 1947–1976 and 1999–2025.

Statistical testing was carried out here using similar tests used by [1,2] and found in textbooks such as [53,54]. Tests were carried out at standard levels of significance or confidence ($p = 0.1$, $p = 0.05$, and $p = 0.01$). Blocking trends were tested using Analysis of Variance (ANOVA) using the F-test for the regression lines. Means of blocking characteristics were tested using a simple two-sided standardized test statistic (z^*) for block occurrence and BI assuming a standard normal distribution. Correlations were tested using a Z score test found in the same texts and assuming the null hypothesis or that there was no a priori relationship between the two variables. Histograms or probability density distributions for blocking durations and BI were tested using both the chi-square goodness-of-fit and the Kolmogorov–Smirnov tests. For these tests, the distribution singular events (unapproximated) sample distributions served as the “standard” or “expected” frequency when testing for significance. This is preferable to using an approximated distribution since the actual observations may not adequately be represented by such distributions [2]. The Kolmogorov–Smirnov test is particularly useful in this regard. Testing the distributions of some blocking characteristics, rather than testing the means is more informative, since the sample size is larger.

3. Climatology of Simultaneously Occurring Blocking Events

The mean annual occurrence for blocking in the NH over the 57 years was 32.5 events per year, and these events persisted for 9.2 days per year. The mean BI was 3.12. These values compare well with [1] and their work showed a significant increase [$p = 0.05$] in blocking after 1999 as well as some complex interannual and interdecadal variability. For example, before 1999 the mean was 24 events per year and post 1999 the mean occurrence has been 41 events per year. These increases occurred over all three sectors of the NH as defined in Section 2. Durations also increased from 8.5 days to 9.5 days per event, but these were not statistically significant hemisphere-wide and only Pacific Region durations were significantly longer. BI actually decreased from 3.22 units to 3.06 units, this result significant at $p = 0.05$ ([1]), however, this weakening was not significant within the Pacific Ocean region. Over the entire period from mid-1968–2025, simultaneously occurring blocking accounted for 19.7% of days as found by [1], annually. However, before (after) the turn of the century, this average was 8.7% (31.5%) of all days annually [1].

It was noted that the number of blocking events increased (Figure 1a) over the period and this trend ($0.50 \text{ events } y^{-1}$) was statistically significant at $p = 0.01$ when using an F-test (e.g., [53,54]). The linear regression equations are shown in Table 2. A total of 1044 events were designated to be part of a simultaneous blocking episode versus 810 that were singular block occurrences. This means a majority of NH events were part of a simultaneous blocking episode (Figure 1b). Also, a recent study [55] demonstrated that there were an average of two block-like structures per 6-h analysis in their study from 2001–2025. The linear trend in the number of simultaneously occurring events showed a weaker increase ($0.28 \text{ events } y^{-1}$) and this was also significant at $p = 0.01$. The correlation between the two time series was 0.93, and this was significant at $p = 0.01$. Thus, the increase in simultaneously occurring blocking events is due likely to the increase in blocking events themselves. The quadratic fit showed a similar result to that shown in [1], in which they postulated showed possible long-term variability, or more blocking in the middle 20th century (the late 1940’s to the late 1970s) (e.g., [56–59]) that they associated with the PDO similar to [57].

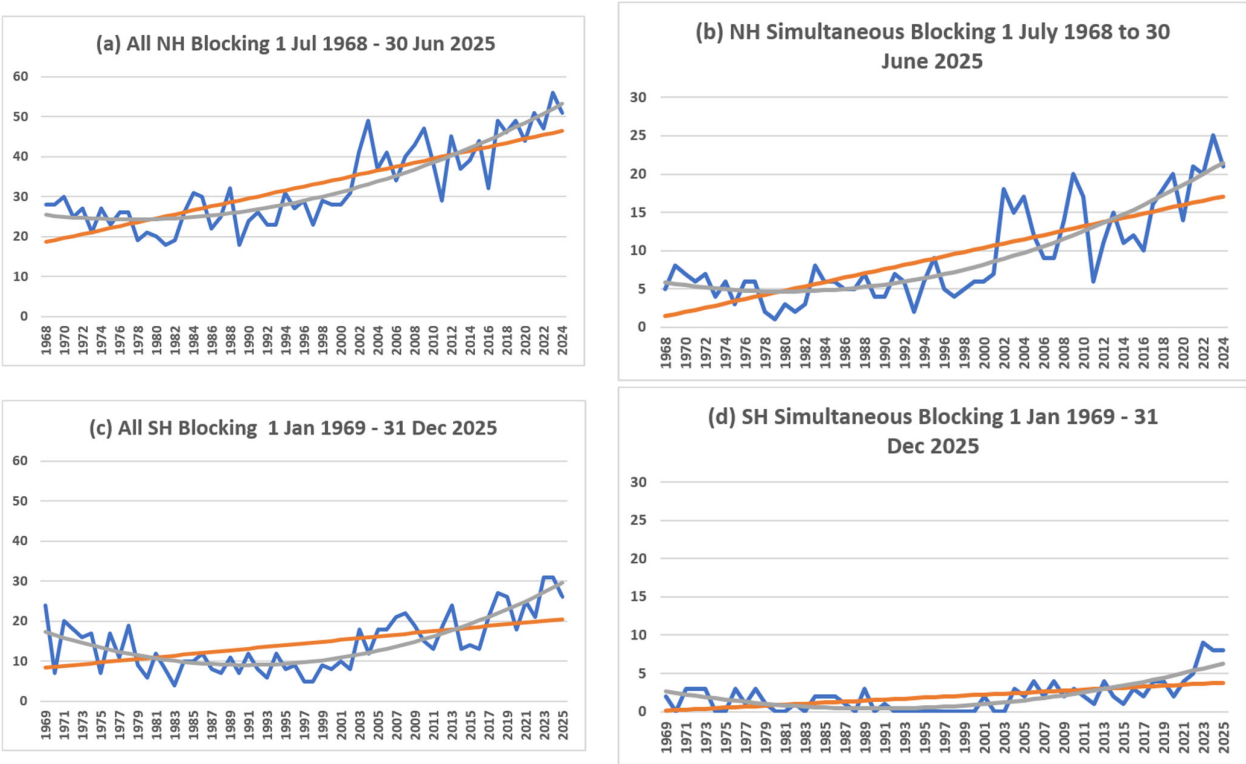


Figure 1. The number of blocking events (ordinate) per year (abscissa) for the (a) NH from mid-1968 to 2025 and (c) SH from 1969 to 2025 for the entire sample, and (b) NH and (d) SH simultaneously occurring episodes. The blue, orange, and grey curves are the number of events, a linear fit, and a quadratic fit, respectively.

Table 2. The linear and quadratic equations used in Figure 1. The variable y is the predictand, x is the predictor, and the subscript is i.

Figure	Equations
Figure 1a	$y_i = 0.496x_i - 957.064$ $y_i = 0.013x_i^2 - 0.268x_i + 25.661$
Figure 1b	$y_i = 0.279x_i - 547.697$ $y_i = 0.009x_i^2 - 0.218x_i + 6.061$
Figure 1c	$y_i = 0.217x_i - 419.280$ $y_i = 0.017x_i^2 - 0.793x_i + 18.104$
Figure 1d	$y_i = 0.066x_i - 128.899$ $y_i = 0.005x_i^2 - 0.219x_i + 2.858$

In Table 3, the seasonal distribution of simultaneous blocking is similar to that of the occurrence of all blocking events as in other studies (e.g., [1]) with a maximum in the NH winter and spring. As for all events, BI was strongest for simultaneous winter events and BI was stronger overall across all seasons except for summer in which BI was weaker than those of singular occurring events or to the total sample of blocking [1]. However, the simultaneous events were not stronger in the NH as conjectured by earlier studies. Also, the seasonal distribution of the number of simultaneous blocking days varied with the occurrences which was expected. The fall season showed the greatest difference in strength between singular blocking and simultaneous events (BI = 3.64) being 5.2% stronger than singularly occurring fall blocking events (3.46) and this was statistically significant at $p = 0.05$. Additionally, the data in Table 3 would suggest that simultaneous blocking events are not longer lived, 9.5 days versus 9.0 days for singular block occurrences overall. However,

simultaneous blocking events are more persistent across three seasons, especially summer which was significant at $p = 0.05$ when using a Z-score test for means (e.g., [53]). Conversely, singular events were significantly stronger in the spring season ($p = 0.05$).

Table 3. The seasonal distribution of NH block occurrence (column 2), BI (column 3), number of days (column 4), and percent time (column 5). The bold values represent significance at $p = 0.10$ and the (*) significance at $p = 0.05$.

Season	Events/Events y^{-1}	Duration (Days)	BI	Event Days/Day y^{-1}
Simultaneous				
Summer	104/1.8	10.2 *	2.18 *	2106.5/37.0
Fall	88/1.5	9.3	3.64	1665.5/29.2
Winter	158/2.8	9.6	3.89	2936.0/51.5
Spring	178/3.1	8.7	2.75	3193.5/56.0
Total	528/9.3	9.5	3.12	9902.5/173.7
Singular				
Summer	192/3.4	8.3 *	2.53 *	1563.0/27.4
Fall	230/4.0	8.9	3.46	2012.0/35.3
Winter	203/3.6	8.9	3.70	1780.0/31.2
Spring	182/3.2	10.0	2.69	1775.0/31.1
Total	811/14.2	9.0	3.12	7130/125.1

The distribution for the duration of simultaneously occurring NH blocking events is shown in Figure 2. The number of events at longer durations decreases following Poisson-type distribution as in previous studies (e.g., [1]). In Figure 2a, the most persistent event lasted for 35 days. Figure 2b shows the normalized fraction of the total sample by day for the simultaneous blocking events (blue) and singular block occurrences (orange). It was clear that there were fewer short-lived simultaneously occurring events, but more longer-lived events. This is illustrated in Figure 2c, and the distributions are different when testing using a Chi-square goodness of fit test at $p = 0.01$. In order to confirm this result, the Kolmogorov—Smirnov test was used and tested at ($p = 0.05$ —confidence interval is 0.045) and it was clear from Figure 2c that there were more singular events outside the confidence interval of the simultaneous blocking cumulative probability function on day 5. Thus, it was clear from these tests that in the NH, simultaneously occurring events may be more persistent than singularly occurring blocking events. However, again, this could be a function of the definition outlined above. Additionally, the negative result for the spring season (longer lived singular events) could make the overall result (more persistent simultaneous blocking events) less robust.

The NH events were similar in strength to all blocking events and singular block occurrences. However, the distribution of BI for simultaneous and singular blocking events reveals a complex picture (Figure 3) and the distributions are statistically different at $p = 0.05$ using the Chi-square test. However, when testing using Kolmogorov—Smirnov, no significant differences in the BI distribution could be identified. The differences (Figure 3c) show that for the bins less than BI = 3.0, there are a greater percentage of simultaneous events that are weaker than singular events. For those bins above the mean, singularly occurring blocking events are a larger percentage except for those among the strongest events (see Appendix A Table A3). In Table A3 65% of the strongest events were part of a simultaneous blocking episode, which led earlier studies to believe simultaneous events were generally stronger. Simultaneously occurring blocking events constituted about 56% of the total sample. The evidence here suggests that simultaneous events are not stronger for the NH overall, but as found above there were some seasons where this was true such

as fall and winter (Table 3). However, as with duration the fact that singular spring events were stronger at $p = 0.05$ and this season tends to have the most block occurrences (see [1]) may contribute toward the overall results being less robust.

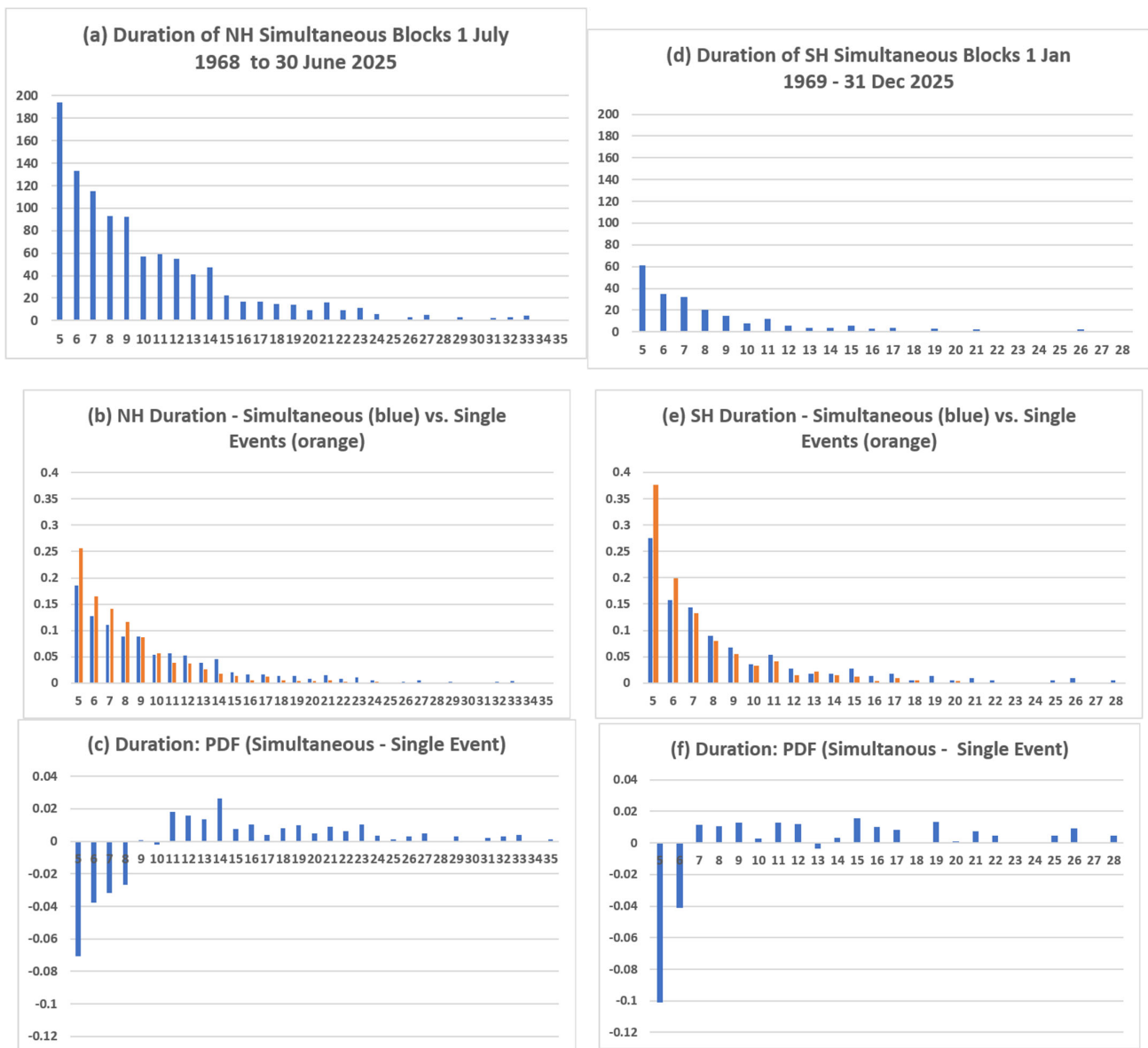


Figure 2. The duration of blocking events in days (abscissa) for the (a) NH and (d) SH simultaneous blocking events (ordinate is thenumber of events), (b) NH and (e) SH simultaneous blocking (blue) versus single blocking events (orange) where the ordinate is the percentage of events persisting for a certain number of days (abscissa), and (c) NH and (f) SH simultaneously occurring events minus single events from (b) and (e), respectively.

Lupo et al. [1] demonstrated that block onset longitudes did not change appreciably over the length of their study (at $p = 0.10$). This study shows similar results. When examining the onset longitudes of blocking events for simultaneous blocking episodes versus singularly occurring events, however, Figure 4a–c shows that from about 50° W—50° E (the Atlantic and the western part of the Continental Regions as defined in [2]) there was a larger fraction of blocking events that occur in isolation. The eastern Continental region and the entire Pacific region showed a greater tendency for blocking events to be

part of a simultaneous blocking episode. The distributions in Figure 4b are different at $p = 0.01$.

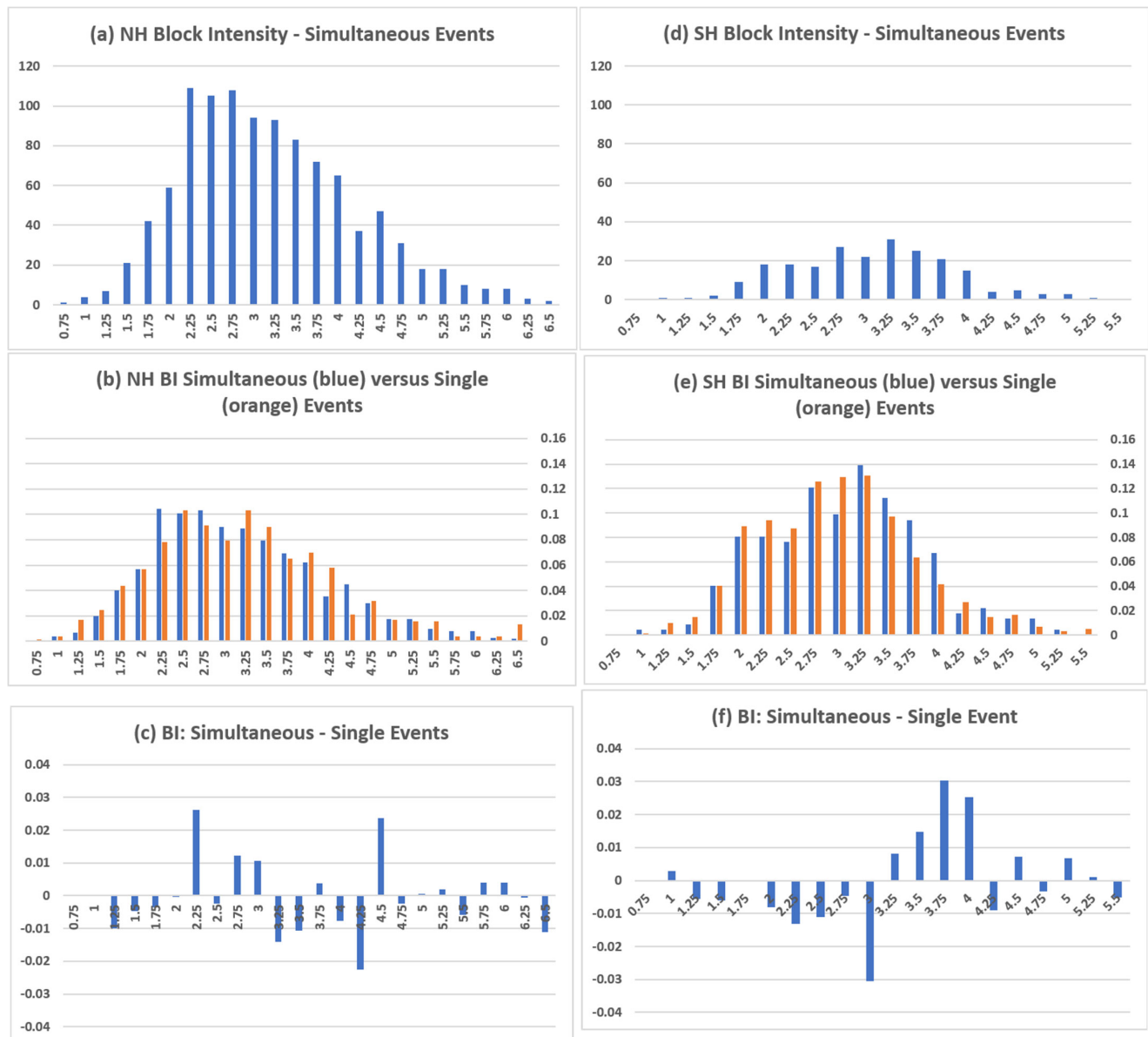


Figure 3. The distribution of BI (intensity is on the abscissa) for the (a) NH and (d) SH simultaneous blocking events (ordinate is the number of events), (b) NH and (e) SH simultaneous blocking (blue) versus single blocking events (orange) where the ordinate is the percentage of events per $BI = 0.25$ (bin width) dividing by the total number of sample events, and (c) NH and (f) SH simultaneously occurring events minus single events from (b) and (e), respectively.

For the SH in contrast, the mean annual occurrence for blocking was 14.5 events per year, and these events persisted for 7.7 days per year. The mean BI was 2.88. Lupo et al. [1] also showed a significant increase in SH blocking occurrence after 2000 across all regions and this was significant at $p = 0.05$. For example, before 2000 the mean was 11 blocking events per year and post 2000 the mean occurrence was 19 events per year. Durations and BI also increased modestly (0.4 days and 0.07 BI units). Over the entire period from 1969–2025, simultaneously occurring blocking accounted for 3.6% of days annually (see [1]). However, before (after) the turn of the century, this average was 1.9% (5.9%) of all days annually [1]. This much lower occurrence of simultaneously occurring blocking in the

SH supports earlier work that suggested simultaneous block occurrences are more likely when blocking events occur more often and are more persistent (e.g., [1,2,5,6]). This is also consistent with blocking being the result of local dynamics (e.g., [14–18]). Additionally, the annual variation of simultaneous SH blocking event occurrences, BI, and days (Table 4) are similar to those of the whole sample shown in previous studies (e.g., [1,2]).

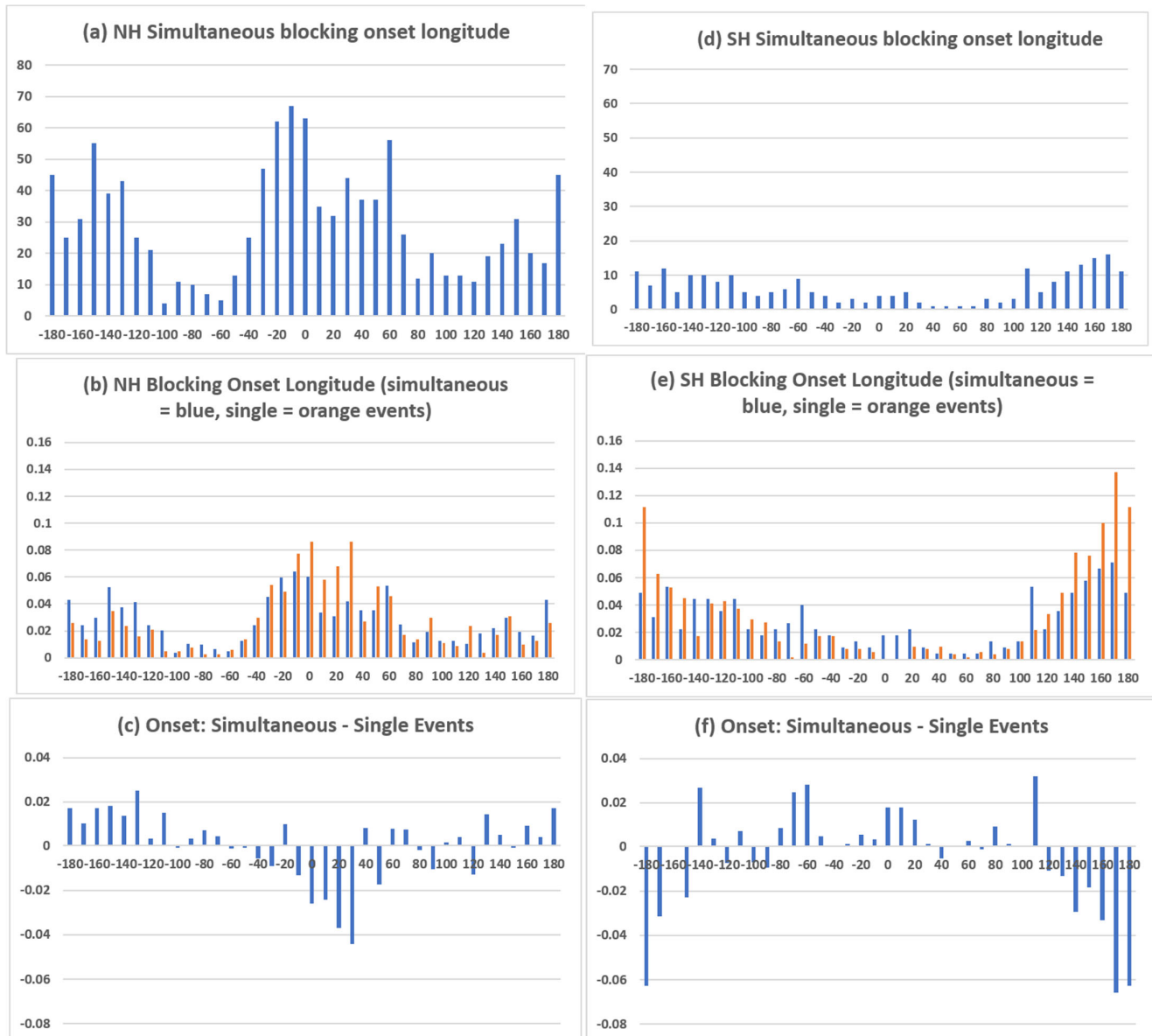


Figure 4. The distribution of block onsets (longitude is on the abscissa) for the (a) NH and (d) SH simultaneous blocking events (ordinate is the number of events), (b) NH and (e) SH simultaneous blocking (blue) versus single blocking events (orange) where the ordinate is the percentage of events per 10 degree longitude band, and (c) NH and (f) SH simultaneously occurring events minus single events from (b) and (e), respectively.

It was noted that the number of SH blocking events increased over the period (Figure 1c) and this trend ($0.22 \text{ events } y^{-1}$) was statistically significant at $p = 0.01$ when using an F-test. A total of 223 events were designated to be part of a simultaneous blocking episode versus 602 that were singular block occurrences. Unlike the NH, a much smaller fraction of SH blocking events were part of a simultaneous blocking episode. The linear trend in the number of simultaneously occurring events showed a weaker increase

(Figure 1d—0.07 events y^{-1}) and this was significant at $p = 0.05$. The quadratic fit showed a similar result to that shown in [1], which they postulated showed possible long-term variability that they associated with the PDO similar to [57]. The correlation coefficient between the data sets for overall and simultaneous blocking was 0.82 and this result is significant at $p = 0.01$ similar to the Northern Hemisphere.

Table 4. The seasonal distribution of SH block occurrence (column 2), BI (column 3), number of days (column 4), and percent time (column 5). The bold values represent significance at $p = 0.10$ and the (*) significance at $p = 0.05$.

Season	Events/Events y^{-1}	Duration (Days)	BI	Event Days/Day y^{-1}
Simultaneous				
Summer	7/0.1	7.2	2.66	100.5/1.8
Fall	46/0.8	9.0 *	3.05	824.5/14.5
Winter	45/0.8	8.7	3.00	781.5/13.7
Spring	14/0.3	8.3	2.58	223.0/3.9
Total	112/2.0	8.7 *	2.96	1929.5/33.9
Singular				
Summer	96/1.7	7.3	2.67	691.0/12.1
Fall	186/3.2	7.3 *	2.98	1341.5/23.5
Winter	188/3.3	7.4	2.91	1382.0/24.2
Spring	132/2.3	7.2	2.60	940.0/16.5
Total	602/10.6	7.3 *	2.84	4354.5/76.4

The distribution for the duration of simultaneously occurring SH blocking events is shown in Figure 2. The number of events at longer durations decreases following Poisson type distribution as in previous studies and for the NH (e.g., [1]). In Figure 2c, the most persistent event lasted for 28 days. Figure 2e shows the normalized fraction of the total sample by day for the simultaneous and singular blocking events similar to Figure 2b. For the shortest duration SH blocking events, there were more singularly occurring events while from seven days on, there were more simultaneously occurring events. The Chi-square goodness of fit test demonstrates the distributions are similar at $p = 0.01$. The Kolmogorov—Smirnov test (at $p = 0.05$, confidence interval = 0.09) demonstrates that there were more singular events outside the confidence interval at day 5. Additionally, when comparing the mean duration of SH simultaneous events (8.7 days) versus singularly occurring events (7.3 days) a difference that is significant at $p = 0.05$ when testing the sample means. Also, 14 of the 20 most persistent events (Appendix A Table A4) were part of simultaneously occurring events. Thus, in the SH, simultaneously occurring events are more persistent than singularly occurring blocking events. This is especially true for all seasons except summer and the result is significant at $p = 0.10$ for the fall and winter seasons and these events are the largest fraction of annual occurrences.

In the SH, the case for stronger (BI) blocking events being associated with simultaneous events is clearer than for the NH but may not be significant overall. In Figure 3d–f, the distribution of BI is shifted toward stronger BI and the distributions are different at $p = 0.01$ using the Chi-square test. However, the Kolmogorov—Smirnov test shows the distributions are only different if tested at a level higher than $p = 0.10$, confidence interval = 0.08. Nonetheless, Figure 3f shows clearly a greater frequency of singular (simultaneous) blocking events with BI less (greater) than 3.0. Additionally, the mean BI of simultaneous blocking events is 2.96, while for singular events BI = 2.84. The values are significantly different at $p = 0.10$. It was fall and winter season events that were stronger in the SH. In the list of the 20 strongest events (see Appendix A Table A3) 30% of the strongest events were part of a simultaneous

blocking episode. This is a similar fraction when comparing the top 20 events versus the number of blocking events that were considered to be simultaneously occurring (27%) for the entire sample. The evidence here suggests that simultaneous events are stronger in SH.

In [1], SH block onset longitudes did not change appreciably over the length of their study (at $p = 0.01$). This study shows similar results). However, when examining the onset longitudes of blocking events for simultaneous blocking episodes versus singularly occurring events, Figure 4d–f shows that from about 120° E–150° W (Australia and the West Pacific as defined in [2] there was a larger fraction of blocking events that occur in isolation. The eastern Pacific and all of the Atlantic and Indian Ocean region region showed a greater tendency for blocking events to be part of a simultaneous blocking episode. The distributions in Figure 4e are not the same at a statistically significant level $p = 0.10$.

4. Interannual and Interdecadal Variability

Here we compare the interannual and interdecadal variability of simultaneously occurring blocking events as in [1] with respect to ENSO and phase of the PDO for the NH. As shown in Figure 1, a quadratic fit to blocking occurrences and simultaneously occurring blocking events for both hemispheres show a minimum in occurrence during the last two decades of the 20th century. In the NH, block occurrences were more common in La Niña years during the +PDO. This variation was turned 180° for -PDO years or blocking events were more common in El Niño and neutral years. Additionally, the total number blocking events occurred more often in -PDO years. The results here (Table 5) were similar to those for the whole sample for block occurrences.

Table 5. The annual distribution of NH and SH Simultaneous block characteristics separated by phase of ENSO and PDO. Results are presented as +PDO/−PDO for block occurrence (column 2), BI (column 3), number of days (column 4), days per year (column 5) and percent time (column 6). Bold values are significant at $p = 0.1$ and value with a (*) are significant at $p = 0.05$. N/A indicates no result.

ENSO Phase	Events y^{-1}	BI	Duration (Days)	Days	Event Days/Day y^{-1}
NH					
EN (6/9)	5.0/14.2	3.07/ 3.19 *	8.5/ 10.3 *	486.5/2450.5	81.1/272.3
LN (2/13)	6.0/11.8	3.16/3.12	7.5 /9.4	173.5/2790.5	86.8/214.7
NEU (15/12)	4.7/10.3	3.37 */ 3.10 *	8.8/9.5	1286.5/2656.0	85.8/221.3
SH					
EN (5/10)	1.0/3.2	3.03/ 3.06	8.5 */ 9.2 *	85.0/614.5	17.0/61.5
LN (2/14)	0.0/2.7	N/A/2.90	N/A/8.5	N/A/632.5	N/A/45.2
NEU (15/11)	0.8/2.3	2.92 */2.87	7.2 / 9.0 *	165.5/461.0	11.0/41.9

The interannual variability of BI for simultaneously occurring blocking events was also consistent with that of the total sample ([1]). Blocking was generally stronger in +PDO years than that for -PDO years which was generally due to stronger +PDO neutral year events. In fact, for simultaneous events, neutral year blocking events were stronger across both phases of the PDO at $p = 0.05$. The BI was stronger for simultaneous blocking during El Niño (-PDO) and La Niña years (+PDO) and this tendency was opposite for singular blocking events. However, the relative difference in BI was only significant ($p = 0.05$) for El Niño (-PDO years). Thus, as in Section 3, simultaneously occurring blocking events were not significantly stronger than singularly occurring events. For duration, the interannual and interdecadal variability is similar to that in [1]. However, for all categories except +PDO La Niña years (8.3 days total versus 7.5 days for simultaneous samples) blocking events persisted for up to two days longer than those of the total sample.

The results for simultaneously occurring blocking in the SH were largely consistent with that of the total sample analyzed in [1] or the study of [60]. Their study [1] found that the occurrence and duration of blocking during the -PDO phase was greater than the same characteristics during the +PDO period. They also found no real change in the BI across each phase of the PDO. They also found that during either phase of the PDO, blocking was more frequent, more persistent and more intense during El Niño and Neutral years than during La Niña years.

Similar results were found in the SH for the number of events and persistence of simultaneously occurring blocking. Blocking persisted generally for 1–2 days more for simultaneous blocking events and the results were significant at $p = 0.05$ for all El Niño years and neutral -PDO years. BI was significantly greater for only for neutral +PDO and El Niño -PDO years at $p = 0.05$. La Niña season blocking events were of similar intensity to neutral season events. Additionally, simultaneous block occurrences were stronger (by 0.1 BI units of more) for +PDO Neutral and -PDO El Niño years (Tables 5 and 6). The BI shown for these seasons in Table 5 is similar to that for the total sample [1].

Table 6. The annual distribution of NH and SH singular block characteristics separated by phase of ENSO and PDO. Results are presented as +PDO/−PDO for block occurrence (column 2), BI (column 3), number of days (column 4), days per year (column 5) and percent time (column 6). Bold values are significant at $p = 0.1$ and value with a (*) are significant at $p = 0.05$.

ENSO Phase	Events y^{-1}	BI	Duration (Days)	Days	Event Days/Day y^{-1}
NH					
EN (6/9)	14.0/13.8	3.05/ 2.96 *	7.7/ 8.5 *	655.5/1053.5	109.3/117.1
LN (2/13)	19.0/13.7	3.08/3.15	8.9 /9.3	333.5/1660.0	166.8/127.7
NEU (15/12)	14.7/14.0	3.17 */ 2.92 *	7.9/10.7	1714.5/1798.0	114.3/149.8
SH					
EN (5/10)	7.0/12.2	3.02/ 2.92	6.6 */ 7.4 *	231.0/899.0	46.2/89.9
LN (2/14)	6.0/12.9	2.74/2.85	6.7/7.5	80.5/1357.5	40.3/97.0
NEU (15/11)	7.9/12.0	2.73 */2.84	7.2/ 7.1 *	856.5/941.5	57.1/85.6

5. Discussion

In section three and four, the seasonal distributions of simultaneous blocking events and their characteristics were similar to the overall sample for both the Northern and Southern Hemispheres annually and interannually. However, the increased occurrence of blocking has been accompanied by a concomitant increase in the number of simultaneous blocking events. As shown in Figure 1 (and [1]) there were likely more simultaneous blocking events which occurred in the middle part of the 20th century as shown by [60–63] and references therein. Previous climatological studies done by our research group had claimed anecdotally that blocking events occurring as part of a simultaneous blocking episode were stronger and longer-lived than blocking occurring in isolation. Here it was shown that simultaneously occurring events in both hemispheres were likely more persistent and this result is statistically significant. However, when comparing intensity by using BI as the metric, only SH simultaneous blocking events were stronger than individually occurring events in a statistical sense using the Chi-Square test, but not the Kolmogorov-Smirnov test.

Regardless, it is an overstatement to state that simultaneous blocking would be stronger and more persistent in general. This perception was likely driven by the fact that many studies that commented on this issue were done during the fall or winter season (e.g., [4,31]) In the NH, simultaneous blocking is stronger during the fall and winter seasons at $p = 0.10$, but weaker during the summer season at $p = 0.05$. Summer season simultaneous

events were more persistent during the summer at $p = 0.05$, but weaker during the spring season at the same level. In the SH, blocking was stronger overall, and this was the result of fall and winter season events being stronger. Overall, the test of the SH mean BI suggested stronger events, and the Chi square test seems to support this, but the Kolmogorov Smirnov test does not support this result.

A characteristic not commented on previously examines where blocking events form (genesis regions). Perhaps not coincidentally, blocking occurs more often in isolation where block formation is most frequent, which in the Northern Hemisphere is from the East Atlantic to roughly the leeward side of the Ural Mountains and in the Southern Hemisphere is the far East Indian Ocean Region and the Western Pacific Region. As summarized by many studies (see [61] and many others), the occurrence of blocking is the result of the favorable superposition of large and synoptic-scale wave features. Thus, the occurrence of simultaneous events results from this favorable superposition in more than one place globally.

Also, the occurrence of blocking events in isolation or as part of a simultaneous episode can generally be associated with weather types in certain parts of the globe. Generally, the middle part of the United States will experience colder than normal conditions associated with blocking over the East Pacific or Western North America, especially in the winter season (e.g., [62–64]). Record setting cold events which can be quite persistent were associated recently with simultaneous blocking events (e.g., [34]). Also, ref. [64] show a significant negative correlation between East Pacific Region blocking and temperature anomalies for the central USA as well as positive correlation to Atlantic region blocking.

During the summer season, wetter than normal conditions over the same regions of North America have occurred with blocking over the East Pacific and/or the East Atlantic (e.g., [45,65]). A strong example was August 2005. This month followed a very dry period from 15 June to 10 August. Normal rainfall across the Central USA during this period should be approximately 210 mm (214 mm for Columbia, MO). Most places experienced less than 20 mm of rain regionally. A simultaneous blocking episode occurred over the East Atlantic and Europe from 6–19 August. Then the period 12–26 August experienced over 200 mm of precipitation.

For nations such as Türkiye or those in Eastern Europe which are located where singular blocking events occur more regularly, the occurrence of simultaneously occurring events may not be as important. Efe et al. [66,67] examined the impact of blocking on temperature and precipitation anomalies across Türkiye and there did not seem to be a preferred simultaneous blocking regime for the region associated with temperature. The two case studies associated with anomalous warmth and cold were not part of a simultaneous blocking regime. For precipitation, when examining the wettest and driest blocking episodes, approximately 60% of these occurred with singular blocking occurrences which is suggested by Figure 4.

6. Summary and Conclusions

This work examined the occurrence and characteristics of simultaneously occurring blocking events in the Northern and Southern Hemispheres from 1968–2025 using the NCEP/NCAR reanalyses and the blocking climatology housed at the University of Missouri. During this period, more than 1000 NH events occurred as part of a simultaneous blocking episode (528 occurrences) and in the SH there were 223 events which were part of 112 simultaneous blocking episodes. Previous studies in this group have stated without statistical evidence that blocking events which occurred as part of a simultaneous episode were stronger and more persistent than blocking events occurring singularly.

The results here showed that while the occurrence of simultaneous blocking events were more frequent when blocking was more frequent (e.g., in the NH, during the winter and spring seasons), only SH blocking events were more persistent than singularly occurring events at statistically significant levels. Thus, it was not true generally that simultaneous blocking events were stronger and more persistent than singularly occurring events. It was only true in some seasons. In fact, for a few seasons the opposite was true (summer season singular events were stronger and spring season events were more persistent in the NH). When examining the persistence characteristic, this was true for the NH summer season, and the SH fall and winter seasons. Also, only in the SH were they stronger overall than singularly occurring events. Although this was not true for each season. Also, in the NH, fall and winter season simultaneous blocking events were stronger than singular events and this may have led earlier studies to draw the general conclusion regarding simultaneous blocking.

Also, it was clear that where blocking is most frequent, there was a greater tendency for singular blocking occurrences. In the NH this was the East Atlantic to the Urals and in the SH the Eastern Indian Ocean and West Pacific Regions. Also, while there has been a significant increase in the number of blocking events from the late 20th century through the first quarter of the 21st century using a linear trend line, these results demonstrate the occurrence of blocking may be associated with decadal variability as shown in our earlier studies.

When examining the interannual variability of simultaneous events versus singular blocking events by phase of ENSO, neutral year simultaneous events were significantly stronger in the NH. Also, El Niño years during -PDO were both stronger and more persistent in the NH. In the SH, El Niño and neutral -PDO simultaneous blocking were more persistent than singular events, while El Niño -PDO and neutral +PDO simultaneous blocking events were stronger than singular events.

Additionally, as discussed in Section 5, simultaneously occurring blocking events can be associated with certain weather regimes in North America as suggested by previous studies, thus the appearance of simultaneous or singularly occurring blocking events can be helpful in anticipating the occurrence and persistence of weather regimes associated with them.

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Appendix A

This section will show the top 20 strongest (BI), most persistent, and time weighted strength (BI x duration) for the Northern and Southern Hemispheres for simultaneously occurring blocking events as well as all blocking events covering the period 1968–2025. These events can be found <https://weather.missouri.edu/gcc> (accessed 23 September 2026).

Table A1. The top 20 strongest (BI) combined simultaneous NH and SH blocking events from 1968–2025. Column 2 (NH) and 5 (SH) is the month and year, column 3 (NH) and 6 (SH) is the combined BI for the two events.

Rank	Date	Combined BI	Rank	Date	Combined BI
1	March 1996	11.80	1	July 2023	9.86
2	January 1991	11.75	2	May 2022	7.89
3	February 1975	11.55	3	July 2016	7.88
4	February 1986	11.47	4	June 2022	7.85
5	February 1991	10.59	5	June 2007	7.76
6	February 1989	10.51	6	October 2018	7.74
7	January 2017	10.48	7	September 2024	7.66
8	February 1993	10.42	8	July 2024	7.62
8	January 2007	10.42	9	August 2008	7.35
10	November 1969	10.37	10	June 2024	7.31
11	February 2012	10.27	10	July 2024	7.31
12	January 2016	10.23	12	June 2023	7.27
13	February 2019	10.18	13	June 2005	7.26
14	November 1969	10.15	14	April 2019	7.21
15	January 2014	10.03	15	June 1976	7.19
16	December 2010	9.87	16	June 2023	7.18
17	January 1982	9.85	17	June 2023	7.12
18	December 2010	9.83	18	August 2025	7.10
19	February 1972	9.74	19	July 2008	7.07
20	January 2018	9.70	20	August 2009, July 2024	7.03

Table A2. The top 20 strongest (BI) times persistence for combined simultaneous NH and SH blocking events from 1968–2025. Column 2 (NH) and 5 (SH) is the month and year, column 3 (NH) and 6 (SH) is the combined BI for the two events.

Rank	Date	Combined BI	Rank	Date	Combined BI
1	January 2014	266.22	1	June 2005	128.12
2	December 2002	218.92	2	May 2016	117.63
3	February 2005	210.39	3	July 2015	111.44
4	December 2010	207.49	4	May 1972	100.78
5	December 2016	192.55	5	July 1976	100.44
6	November 2010	189.21	6	May 1972	100.26
7	December 2013	186.00	7	May 2009	98.63
8	February 2015	181.14	8	May 1972	97.61
9	December 2010	179.54	9	May 2022	94.41
10	February 2005	172.28	10	October 2018	92.94
11	January 2005	167.06	11	June 2006	92.86
12	December 2022	166.56	12	August 2025	92.58
13	January 1974	164.49	13	September 1969	86.29
14	March 1996	161.40	14	June 2023	85.65
15	January 2023	160.30	15	June 2023	84.71
16	January 2018	155.82	16	May 2022	80.19
17	November 2022	151.36	17	May 1973	78.46
18	December 1995	147.40	18	August 1986	77.51
19	February 2017	147.03	19	June 2023	77.49
20	March 2011	141.25	20	July 2024	74.69

Table A3. The top 20 strongest (BI) individual NH and SH blocking events from 1968–2025. Column 2 (NH) and 5 (SH) is the month and year, column 3 (NH) and 6 (SH) is the BI for the event. * indicates the event was part of a simultaneous blocking episode as defined here.

Rank	Date	Combined BI	Rank	Date	Combined BI
1	February 1991 *	6.42	1	July 2006	5.46
2	March 1996 *	6.40	2	October 1995	5.40
3	November 1997	6.31	3	May 1991	5.30
4	February 1989 *	6.20	4	July 2023 *	5.24
5	January 1985	6.17	5	May 1969	5.08
6	December 1996	6.16	5	May 2016	5.08
7	January 1979	6.09	7	September 1996	5.00
8	February 1975 *	6.08	8	July 2016 *	4.85
8	December 1983 *	6.08	9	June 1995	4.83
10	January 2008	5.99	9	October 2018 *	4.83
11	February 2014 *	5.93	9	July 2025	4.83
12	January 2018 *	5.92	12	June 2005	4.80
13	January 1991 *	5.91	13	May 2022 *	4.77
14	January 1971	5.88	14	September 2019	4.75
15	January 1991 *	5.84	15	November /2023	4.74
16	January 1987 *	5.83	16	May 2000	4.71
17	March 2015	5.82	17	June 2017	4.68
18	February 1986 *	5.81	18	December 2013	4.66
18	January 2017 *	5.81	19	June 2025 *	4.65
20	December 2007 *	5.78	20	August 1984 *	4.64

Table A4. The top 20 most persistent (days) individual NH and SH blocking events from 1968–2025. Column 2 (NH) and 5 (SH) is the month and year, column 3 (NH) and 6 (SH) is the number of days for the event. * indicates the event was part of a simultaneous blocking episode as defined here.

Rank	Date	Days	Rank	Date	Days
1	June 2003 *	35.0	1	July 2015 *	28.0
2	December 2016 *	33.5	2	May 1972 *	26.0
3	December 2010 *	33.0	2	July 1976 *	26.0
3	April 2013 *	33.0	4	May 2016 *	25.0
3	July 2013 *	33.0	5	June 2005 *	22.5
6	December 2002 *	32.5	5	February 2021	21.5
6	July 2023 *	32.5	7	May 1973 *	21.0
8	July 2003 *	32.0	7	May 2008 *	21.0
9	March 2005 *	31.5	9	August 2004 *	20.5
10	February 2005 *	31.0	10	January 1978	20.0
11	May 2014 *	29.5	10	June 1981	20.0
12	December 1995 *	29.0	12	September 1969 *	19.5
12	January 2014 *	29.0	12	May 2009 *	19.5
14	November 2002 *	27.5	12	October 2010 *	19.5
15	January 1996 *	27.0	15	July 1973 *	18.0
15	December 2005 *	27.0	15	August 2003	18.0
15	July 2022 *	27.0	15	June 2009	18.0
15	June 2023 *	27.0	15	June 2009	18.0
19	January 2023 *	26.5	19	December 1972	17.5
20	April 1973 *	26.0	19	May 2011 *	17.5
20	July 2010 *	26.0	19	June 2023 *	17.5

References

1. Lupo, A.R.; Jensen, A.D.; Mokhov, I.I.; Timazhev, A.V.; Eichler, T.; Efe, B. Changes in global blocking character during the most recent decades. *Atmosphere* **2019**, *10*, 92. [\[CrossRef\]](#)
2. Wiedenmann, J.M.; Lupo, A.R.; Mokhov, I.I.; Tikhonova, E. The climatology of blocking anticyclones for the Northern and Southern Hemisphere: Block intensity as a diagnostic. *J. Clim.* **2002**, *15*, 3459–3473. [\[CrossRef\]](#)
3. Rex, D.F. Blocking action in the middle troposphere and its effect upon regional climate: II. The climatology of blocking action. *Tellus* **1950**, *3*, 275–301. [\[CrossRef\]](#)

4. Quiroz, R.S. Travelling waves and regional transitions in blocking activity in the Northern Hemisphere. *Mon. Weather Rev.* **1987**, *115*, 919–935. [\[CrossRef\]](#)
5. Lejenas, H.; Okland, H. Characteristics of Northern Hemisphere blocking as determined from a long time series of observational data. *Tellus* **1983**, *35A*, 350–362. [\[CrossRef\]](#)
6. Lejenas, H. Characteristics of Southern Hemisphere blocking as determined from a time series of observational data. *Quart. J. R. Meteor. Soc.* **1984**, *110*, 967–979. [\[CrossRef\]](#)
7. Trenberth, K.E.; Mo, K.C. Blocking in the Southern Hemisphere. *Mon. Weather Rev.* **1985**, *113*, 3–21. [\[CrossRef\]](#)
8. Lejenas, H.; Madden, R. Travelling planetary-scale waves and blocking. *Mon. Weather Rev.* **1992**, *120*, 2821–2830. [\[CrossRef\]](#)
9. Kalnay-Rivas, E.; Merkin, L.O. A simple mechanism for blocking. *J. Atmos. Sci.* **1981**, *38*, 2077–2091. [\[CrossRef\]](#)
10. Frederiksen, J.S. A unified three-dimensional instability theory of the onset of blocking and cyclogenesis. *J. Atmos. Sci.* **1992**, *39*, 969–982.
11. Frederiksen, J.S. A unified three-dimensional instability theory of the onset of blocking and cyclogenesis II. Teleconnection Patterns. *J. Atmos. Sci.* **1983**, *40*, 2593–2609. [\[CrossRef\]](#)
12. Shutts, G.J. The propagation of eddies in diffusive jet streams: Eddy vorticity forcing of blocking flow fields. *Quart. J. R. Meteor. Soc.* **1983**, *109*, 737–761. [\[CrossRef\]](#)
13. Legras, B.; Ghil, M. Persistent anomalies, blocking, and variations in atmospheric predictability. *J. Atmos. Sci.* **1985**, *42*, 433–471. [\[CrossRef\]](#)
14. Arai, M.; Mukougawa, H. On the effectiveness of the eddy straining mechanism for the maintenance of blocking flows. *J. Meteor. Soc. Jpn.* **2002**, *80*, 1089–1102. [\[CrossRef\]](#)
15. Luo, D. A barotropic envelope Rossby soliton model for block–eddy interaction. Part I: Effect of topography. *J. Atmos. Sci.* **2005**, *62*, 5–21. [\[CrossRef\]](#)
16. Chen, G.; Lu, J.; Burrows, D.A.; Leung, L.R. Local finite-amplitude wave activity as an objective diagnostic of midlatitude extreme weather. *Geophys. Res. Lett.* **2015**, *42*, 10952–10960. [\[CrossRef\]](#)
17. Huang, C.S.Y.; Nakamura, N. Local finite-amplitude wave activity as a diagnostic of anomalous weather events. *J. Atmos. Sci.* **2016**, *73*, 211–229. [\[CrossRef\]](#)
18. Luo, D.; Zhang, W. A nonlinear multi-scale theory of atmospheric blocking: Propagation and energy dispersion of blocking wave packet. *J. Atmos. Sci.* **2020**, *77*, 4025–4049. [\[CrossRef\]](#)
19. Colucci, S.J. Explosive cyclogenesis and large-scale circulation changes: Implications for atmospheric blocking. *J. Atmos. Sci.* **1985**, *42*, 2701–2717. [\[CrossRef\]](#)
20. Konrad, C.E.; Colucci, S.J. Synoptic climatology of 500-mb circulation changes during explosive cyclogenesis. *Mon. Weather Rev.* **1988**, *116*, 1431–1443. [\[CrossRef\]](#)
21. Tsou, C.H.; Smith, P.J. The role of synoptic/planetary-scale interactions during the development of a blocking anticyclone. *Tellus* **1990**, *42A*, 174–193. [\[CrossRef\]](#)
22. Tracton, M.S. Predictability and its relationship to scale interaction processes in blocking. *Mon. Weather Rev.* **1990**, *118*, 1666–1695. [\[CrossRef\]](#)
23. Colucci, S.J.; Baumhefner, B.P. Numerical Prediction of the Onset of Blocking: A Case Study with Forecast Ensembles. *Mon. Weather Rev.* **1998**, *126*, 773–784. [\[CrossRef\]](#)
24. Marques, R.F.C.; Rao, V.B. A diagnosis of a long-lasting blocking event over the Southeast Pacific Ocean. *Mon. Weather Rev.* **1999**, *127*, 1761–1776. [\[CrossRef\]](#)
25. Luo, D.; Cha, J.; Zhong, L.; Dai, A. A nonlinear multiscale interaction model for atmospheric blocking: The eddy-blocking matching mechanism. *Quart. J. R. Meteor. Soc.* **2014**, *140*, 1785–1808. [\[CrossRef\]](#)
26. Yamazaki, A.; Itoh, H. Vortex–vortex interactions for the maintenance of blocking. Part I: The selective absorption mechanism and a case study. *J. Atmos. Sci.* **2013**, *70*, 725–742. [\[CrossRef\]](#)
27. Hwang, J.; Martinaeu, P.; Son, S.-W.; Miyasaka, T.; Nakamura, H. The Role of Transient Eddies in North Pacific Blocking Formation and Its Seasonality. *J. Atmos. Sci.* **2020**, *77*, 2453–2470. [\[CrossRef\]](#)
28. Kurgansky, M.V. Atmospheric Circulation Response to Heat Flux Anomalies in a Two-Dimensional Baroclinic Model of the Atmosphere. *Izv. Atmos. Ocean. Phys.* **2020**, *56*, 33–42. [\[CrossRef\]](#)
29. Steinfeld, D.; Boettcher, M.; Forbes, R.; Pfahl, S. The sensitivity of atmospheric blocking to upstream latent heating—Numerical experiments. *Weather Clim. Dyn.* **2020**, *1*, 405–426. [\[CrossRef\]](#)
30. Lupo, A.R. A diagnosis of two blocking events that occurred simultaneously in the mid-latitude Northern Hemisphere. *Mon. Weather Rev.* **1997**, *125*, 1801–1823. [\[CrossRef\]](#)
31. Haines, K.; Holland, A.J. Vacillation cycles and blocking in a channel. *Quart. J. R. Meteorol. Soc.* **1998**, *124*, 873–897. [\[CrossRef\]](#)
32. Tilly, D.E.; Lupo, A.R.; Melick, C.J.; Market, P.S. Calculated height tendencies in a Southern Hemisphere blocking and cyclone event: The contribution of diabatic heating to block intensification. *Mon. Weather Rev.* **2008**, *136*, 3568–3578. [\[CrossRef\]](#)

33. Klaus, E.M.; Market, P.S.; Lupo, A.R.; Bodner, M.J.; Kastman, J.S. Projecting Northern Hemisphere flow regime transition using integrated enstrophy. *Atmosphere* **2020**, *11*, 19. [\[CrossRef\]](#)
34. Est, M.A.; Mount, S.; Steward, C.A.; Lebedeva, M.G.; Lupo, A.R. Northern Hemisphere flow regime transitions, blocking, and the onset of spring in the central USA during Late Winter 2019 and 2021. *Meteorology* **2022**, *1*, 45–63. [\[CrossRef\]](#)
35. Charney, J.G.; DeVore, J.G. Multiple flow equilibria in the atmosphere and blocking. *J. Atmos. Sci.* **1979**, *36*, 1205–1216. [\[CrossRef\]](#)
36. Austin, J.F. The blocking of middle latitude westerly winds by planetary waves. *Quart. J. R. Meteor. Soc.* **1980**, *106*, 327–350. [\[CrossRef\]](#)
37. Tung, K.K.; Lindzen, R.S. A theory of stationary long waves, part I: A simple theory of blocking. *Mon. Weather Rev.* **1979**, *107*, 714–734. [\[CrossRef\]](#)
38. Fleirl, G.; Larichev, V.; McWilliams, J.C.; Reznik, G. The dynamics of baroclinic and barotropic solitary eddies. *Dyn. Atmos. Oceans* **1980**, *5*, 1–41. [\[CrossRef\]](#)
39. Mc Williams, J.C. An application of equivalent modons to atmospheric blocking. *Dyn. Atmos. Oceans* **1980**, *5*, 43–66. [\[CrossRef\]](#)
40. Agayan, G.M.; Mokhov, I.I. Quasistationary autumn regimes of the Northern Hemisphere atmosphere in FGGE. *Izv. Atmos. Ocean. Phys.* **1989**, *25*, 1150–1156.
41. Woollings, T.J.; Hoskins, B.J. Simultaneous Atlantic Pacific blocking and the Northern annular mode. *Quart. J. R. Meteorol. Soc.* **2008**, *134*, 1635–1646. [\[CrossRef\]](#)
42. Jensen, A.D. A dynamic analysis of a record breaking winter season blocking event. *Adv. Meteorol.* **2015**, *2015*, 634096. [\[CrossRef\]](#)
43. Kalnay, E. and Coauthors, The NCEP/NCAR 40-year reanalysis project. *Bull. Am. Meteor. Soc.* **1996**, *77*, 437–471. [\[CrossRef\]](#)
44. NCEP/NCAR Reanalyses. 2025. Available online: <https://psl.noaa.gov/data/reanalysis/reanalysis.shtml> (accessed on 19 March 2026).
45. Newberry, R.G.; Lupo, A.R.; Jensen, A.D.; Rodgriges-Zalipynis, R.A. An analysis of the spring-to-summer transition in the West Central Plains for application to long range forecasting. *Weather Clim. Sci.* **2016**, *6*, 373–393.
46. Center for Ocean-Atmosphere Prediction Studies. 2025. Available online: <https://www.coaps.fsu.edu/jma> (accessed on 19 March 2026).
47. Bove, M.C.; Elsner, J.B.; Landsea, C.W.; Niu, X.; O'Brien, J.J. Effects of El Niño on U.S. Landfalling Hurricanes, Revisited. *Bull. Am. Meteor. Soc.* **1998**, *79*, 2477–2482. [\[CrossRef\]](#)
48. Pielke, R.A.; Landsea, C.N. La Niña, El Niño and Atlantic Hurricane Damages in the United States. *Bull. Am. Meteor. Soc.* **1999**, *80*, 2027–2033. [\[CrossRef\]](#)
49. Huang, D.; Ni, X.; Tang, Q.; Zhu, X.; Xu, D. Spatial and Temporal Variability of Sea Surface Temperature in the Yellow Sea and East China Sea over the Past 141 Years. In *Modern Climatology*; Wang, S.-Y., Gillies, R.R., Eds.; Intech Open: East Providence, RI, USA, 2012; pp. 213–234, Chapter 8.
50. Hanley, D.E.; Bourassa, M.A.; O'Brien Smith, S.R.; Spade, E.R. A quantitative evaluation of ENSO Indices. *J. Clim.* **2003**, *16*, 1249–1258. [\[CrossRef\]](#)
51. Mantua, N.J.; Hare, S.R.; Zhang, Y.; Wallace, J.M.; Francis, R.C. A Pacific Interdecadal Climate Oscillation with impacts on salmon production. *Bull. Am. Meteorol. Soc.* **1997**, *78*, 1069–1079. [\[CrossRef\]](#)
52. Minobe, S. A 50–70-year climatic oscillation over the North Pacific and North America. *Geophys. Res. Lett.* **1997**, *24*, 683–686. [\[CrossRef\]](#)
53. Neter, J.; Wasserman, W.; Whitmore, G.A. *Applied Statistics*, 3rd ed.; Allyn and Bacon Press: Boston, MA, USA, 1988; 1006p.
54. Wilks, D.S. *Statistical Methods in the Atmospheric Sciences*, 2nd ed.; International Geophysics Series Number 91; Academic Press: Cambridge, MA, USA, 2006; 627p.
55. Liu, P. A definition of blocking. *Bull. Am. Meteor. Soc.* **2026**, *107*, in press.
56. Häkkinen, S.; Rhines, P.B.; Worthen, D.L. Atmospheric Blocking and Atlantic Multidecadal Ocean Variability. *Science* **2011**, *334*, 655–659. [\[CrossRef\]](#) [\[PubMed\]](#)
57. Mokhov, I.I.; Akperov, M.G.; Prokofyeva, M.A.; Timazhev, A.V.; Lupo, A.R.; LeTreut, H. Blockings in the Northern Hemisphere and Euro-Atlantic region: Estimates of changes from reanalyses data and model simulations. *Doklady* **2012**, *449*, 430–433. [\[CrossRef\]](#)
58. Barnes, E.A.; Dunn-Sigouin, E.; Masato, G.; Woollings, T.J. Exploring recent trends in Northern Hemisphere blocking. *Geophys. Res. Lett.* **2014**, *41*, 638–644. [\[CrossRef\]](#)
59. Yao, Y.; Luo, D.; Dai, A.; Simmonds, I. Increased quasi stationarity and persistence of Ural blocking and Eurasian extreme cold events in response to Arctic warming. Part I: Insight from observational analyses. *J. Clim.* **2017**, *30*, 3549–3568. [\[CrossRef\]](#)
60. Oliveira, F.N.M.; Carvalhoc, L.M.V.; Ambrizzi, T. A new climatology for southern hemisphere blockings in the winter and the combined effect of ENSO and SAM phases. *Int. J. Clim.* **2014**, *34*, 1676–1692. [\[CrossRef\]](#)
61. Lupo, A.R. Atmospheric blocking events: A review. *Ann. N. Y. Acad. Sci.* **2021**, *2021*, 5–24. [\[CrossRef\]](#) [\[PubMed\]](#)
62. Quiroz, R.S. The climate of the 1983–84 winter. A season of strong blocking and severe cold in North America. *Mon. Weather Rev.* **1984**, *112*, 1894–1912. [\[CrossRef\]](#)

63. Whan, K.; Zwiers, F.; Sillmann, J. The Influence of Atmospheric Blocking on Extreme Winter Minimum Temperatures in North America. *J. Clim.* **2016**, *29*, 4361–4381. [[CrossRef](#)]
64. Renken, J.D.; Herman, J.J.; Bradshaw, T.R.; Market, P.S.; Lupo, A.R. The utility of the Bering Sea and East Asian Rules in long range forecasting. *Adv. Meteor.* **2017**, *2017*, 14. [[CrossRef](#)]
65. Lupo, A.R.; Kelsey, E.P.; Weitlich, D.K.; Davis, N.A.; Market, P.S. Using the monthly classification of global SSTs and 500 hPa height anomalies to predict temperature and precipitation regimes one to two seasons in advance for the mid-Mississippi region. *Nat. Weather Dig.* **2008**, *32*, 11–33.
66. Efe, B.; Lupo, A.R.; Deniz, A. The relationship between atmospheric blocking and precipitation changes in Turkey between 1977–2016. *Theor. Appl. Clim.* **2019**, *138*, 1573–1590. [[CrossRef](#)]
67. Efe, B.; Sezen, I.; Lupo, A.R.; Deniz, A. The relationship between atmospheric blocking and temperature observations in Turkey between 1977–2016. *Int. J. Clim.* **2020**, *40*, 1022–1037. [[CrossRef](#)]

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