



# Spatio-temporal distribution of atmospheric blocking events in the Northern and Southern Hemispheres

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## Abstract

The current research aims at studying the spatio-temporal distribution of blocking events in the Northern and Southern Hemispheres from 1968 to 2018, for a period of 51 years based on the Wiedenmann block intensity (BI) index. The results showed that blocking events in the Northern Hemisphere are almost twice as often as in the Southern Hemisphere. This could be due to the uneven distribution of land and water areas, and resulted from the greater temperature differences in the Northern Hemisphere. Blockings in the Northern Hemisphere are also stronger than in the Southern Hemisphere in terms of intensity, strength, and durability. The reason can be attributed to the greater temperature difference between water and land in the Northern Hemisphere. In terms of seasonal occurrence of blockings, the highest frequency of blockings in the Northern Hemisphere is related to spring in the North Atlantic and in the Southern Hemisphere, it is related to winter in the South Atlantic region. The growth trend of blockings in the Northern Hemisphere was faster by 54% and in the Southern Hemisphere by 26%. The results also showed that the core of the blockings in the Northern Hemisphere corresponds to the three troughs of the Northern Hemisphere, but the core of the blockings of the Southern Hemisphere is formed at the southernmost lands of the Southern Hemisphere, i.e., at the coastal zones of the Southern Hemisphere continents where the temperature difference is maximum. These regions include the Philippine Archipelago, Indonesia, and Australia in the east of the Pacific Ocean, and the coasts of Chile and Peru in the west of the Pacific Ocean.

## 1 Introduction

Blocking events have large influence on the weather and climate of some regions, since they are characterized by an abrupt change in the atmospheric flow, affecting the normal passage of synoptic systems (Sinclair 1996; Wiedenmann et al. 2002; Renwick 2005). Due to the close relationship between atmospheric circulation patterns and extreme climatic phenomena,

phenomena such as wet periods and droughts can be attributed to changes in atmospheric circulation patterns. For this purpose, the role of atmospheric circulation patterns in creating and controlling dry and wet periods can be investigated by using indexes that are made based on changes in the rainfall element. One of these patterns that is most likely to have an effect on droughts/wet periods in the world is blocking systems. This phenomenon occurs when the westerly winds, which normally move from west to east, change their main direction to the north or south and affect the climate of the areas through which they had to pass. As a result, the regions located under the ridge undergo warm, dry weather conditions and the regions located under the trough experience unstable weather conditions, including cold temperatures and heavy rainfalls (Schwierz et al. 2004; Toulabi Nejad et al. 2019, 2021). Indeed, westerlies with several major waves called Rossby waves present in the middle and upper levels of the atmosphere around the Earth. Occasional breaks in the usual pathway of these currents give rise to the formation of a so-called atmospheric blocking event (Rex 1950a). Persistence of blocking systems for days or weeks significantly influences the weather conditions of the regions under their control.

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Global weather and climate are determined by different processes such as the jet stream, the storm tracks, and blocking. Blocking is a particularly important feature in many regions at mid-latitudes (Woollings 2010). It describes a synoptic situation, in which a strong and stationary high-pressure system weakens or reverses the climatological eastward flow at mid-latitudes (Rex 1950b; Tibaldi and Molteni 1990; Pelly and Hoskins 2003; Barriopedro et al. 2006; Croci-Maspoli et al. 2007; Oliveira et al. 2014). Due to its persistence of up to several weeks, atmospheric blocking significantly influences key atmospheric variables such as geopotential height (GPH), temperature, and humidity throughout the troposphere and lower stratosphere. Further impacts of blocking are surface extremes which can lead to severe damages on economy and society (e.g., García-Herrera et al. 2007; Gilbert 2010; Rodrigues and Woollings 2017).

Atmospheric currents in the middle latitudes have the usual west–east motion and usually move in waves. The wave motion of currents in mid-latitudes can be well observed in the middle and upper levels of the troposphere (Rex 1950a; Dole and Gordon 1983; Lupo and Smith 1995). Blocking systems are divided into five types: omega block, ring of fire or cut of high, Rex block, split flow, and cut of low (Azizi 1996). Given the importance of blocking events in creating weather anomalies lasting more than 5 days, the study of these events has received considerable attention since the 1950s. However, there is still no general agreement on its mechanism, creation, continuation, and death. A major weakness in dynamic meteorology is that there is currently no comprehensive theory of the various processes that indicate all stages of the life cycle of blockings, such as their onset, maintenance, and deterioration. A key characteristic of block onset is a rapid poleward displacement of subtropical air, setting up a large-scale extended ridge, within a Rossby wave pattern on the mid-latitude jet stream. Large-scale changes in Rossby waves in mid-latitudes are thought to be the main factor in the generation of blocking systems (Woollings et al. 2018). Other climatic researchers point to the major role of a rapid cyclonic event in the creation of blockings (Sanders and Gyakum 1980; Colucci 1985; Riviere and Orlanski 2007). An important point is that the slow movement of the cyclone allows air masses to travel long distances in the hot sector. Several studies have shown that changes in atmospheric circulation patterns play an important role in rainfall variability in different parts of the world. Therefore, the identification of the main atmospheric circulation patterns and their impact on atmospheric variables in a region leads to a more accurate calculation of the possibility of occurrence of regional atmospheric/climatic phenomena. Therefore, the reasons of fluctuations in atmospheric/climatic variables can be traced to changes and anomalies in atmospheric circulation patterns such as blocking systems. A better understanding of the blocking

mechanism can improve medium and short-range weather forecasting (Pavan et al. 2000; Shabbar et al. 2001; Trigo et al. 2004; Scherrer et al. 2006).

Due to the high importance of this climatic phenomenon, various criteria and methods have been proposed to identify the blocking phenomenon, which can be classified into two groups of qualitative or morphographic methods and quantitative methods. Qualitative criteria can be used and detected based on the analysis of topographic arrangement and morphology of geopotential height maps and while providing the possibility of observing and examining the various dimensions of the phenomenon, they require a lot of time and patience. However, quantitative methods of blocking detection are mainly based on raw data and calculation of positive anomalies of geopotential height and, while providing the possibility of using numerical calculations, are one-dimensional and at the same time neutral criteria. On a quantitative scale, using 500-hPa meters, we can easily identify whether a blocking has been formed (Watson and Colucci 2002). For this purpose, they use some relations to calculate the gradient value of the geopotential height at high and low latitudes. In the respective relations, GU and GL, respectively, represent the value of gradients in high and low, which are in terms of meters on the degree of latitude (BarboPedro et al. 2005). Among the researchers who developed blocking recognition criteria, one can refer to Rex (1950a), Tiedl et al. (1981), and Wiedenmann et al. (2002).

Due to the important role of blocking in the evolution of atmospheric systems and climatic elements, several researchers have studied these systems. Rex (1950b) was one of the pioneers to study blocking and its effects on the land surface and climatic elements. Tiedl et al. (1981) then examined the performance of blockings in the Northern Hemisphere. Karaca et al. (2000) in a study examined the diversion of cyclones on Turkey and showed that blocking systems play an important role in creating dry cycles in this region during the period of operation. Lejenas (1984) examined the characteristics of the Northern Hemisphere blocking over a long period of time and found that more blockings were formed in the East Atlantic than in the Pacific. And in the western regions of the Pacific, more blockings are formed than in the eastern regions. Also, the continuity of the East Atlantic blockings is longer than in the Pacific. However, one of the pioneering studies investigating the blocking numerically was Wiedenmann et al. (2002), who studied the climatological occurrence of blocking in the Northern and Southern Hemispheres over a period of 30 years. In their study, the characteristics of blocking anticyclone including the frequency of the event, its formation area, the duration of the blocking days, and its intensity were studied and the results showed that the blocking events in the Northern and Southern Hemisphere

have the highest frequency and intensity in the cold season. Trigo et al. (2004) also found that blocking systems reach their maximum power in spring and late winter, with a minimum of days associated with these systems in the autumn and summer. He also investigated the relationship between blocking and temperature and precipitation anomalies, which showed significant results. BarrioPedro et al. (2006) used an automated algorithm to detect the blocking structure based on a modified version of the TM90 orbital index. Diao et al. (2006) also examined blocking characteristics such as frequency, duration, and severity of occurrence using a new two-dimensional index. They found that blocking parameters have a positive effect on rainfall. Also, based on a study by Clark et al. (2007), it was found that the incidence of blockings in the Southern Hemisphere increased between 2000 and 2006. Garcia-Herrera et al. (2007) studied atmospheric synoptic features of the 2004/2005 drought on the Iberian Peninsula and showed that blocking was the main cause of winter drought in the region. Wang et al. (2009) investigated blocking variability over the Ural Mountain region in the boreal winter and its relationship with the East Asian winter climate. The authors found that changes in Siberian hypertension have been to a large extent related to the Ural blocking. Their findings pointed that in the 1970s, the Ural blocking tended to the east and had a great climatic effect in the region. In the conditions of integration with Siberian high pressure, its effect became stronger and resulted in hot and dry winters in eastern Asia. Rimbu et al. (2015) investigated the links between blocking circulation and precipitation extremes over Romania in summer during the period 1962–2010 and found that there is a relationship between precipitation extremes over Romania in summer and blocking events. They investigated two distinct atmospheric circulation blocking patterns in  $0^{\circ}$ – $40^{\circ}$ E and  $50^{\circ}$ – $70^{\circ}$ E and found that these two distinct blocking patterns explain a substantial part of extreme precipitation variability in Romania during summer. Antokhina et al. (2016) investigated the effect of blocking on the spatial distribution of Eurasian summer rainfall using European Centre for Medium-Range Weather Forecasts (ECMWF). Their results showed that there is a correlation between precipitation anomalies over Eurasia and atmospheric blocking events. They also found that the blockings significantly affected the distribution of rainfall in all regions of Eurasia in the summer, which is due to changes in both the displacement and the structure of the bipolar blocking. Depending on the location of the blockings in Asia, heavy rains occur in an arid region. These regions include Kazakhstan, Mongolia, North China, and Baikal. Davini and D'Andrea (2016) applying model inter-comparison projects AMIP1 (Gates 1992), CMIP3 (Meehl et al. 2007), and CMIP5 (Taylor et al. 2012) studied 20 years of global climate model (GCM) developments

from the point of view of Northern Hemisphere atmospheric blocking simulation. They found that although large improvements are seen over the Pacific Ocean, only minor advancements have been achieved over the Euro-Atlantic sector. Some of the most recent GCMs still exhibit the same negative bias as 20 years ago in this region, associated with large geopotential height systematic errors. Jordan et al. (2018) examined a comprehensive list of characteristics that included block intensity and occurred during the late twentieth century. In addition to confirming the results of other well-known laboratories, they found that the blockings of the Northern Hemisphere were stronger than those of the Southern Hemisphere, and that winter events were stronger than those of summer. Woollings et al. (2018) in an article entitled “Blocking and its respond to change” studied high-impact atmospheric blocking events using numerical models in some mid-latitude climatic patterns and found that the term “blocking” covers a diverse array of synoptic patterns, and natural variability will likely dominate regional variations over the next few decades. Jordan et al. (2018) evaluated linkages between atmospheric blocking patterns and heavy rainfall events across the North-Central Mississippi river valley for different ENSO phases. The authors found that there is a relationship between the size, duration, and onset position of atmospheric blocking events and the frequency, duration, and intensity of heavy rainfall events across the Central United States. DeVondria et al. (2019) studied the predictability of blocking character in the Northern Hemisphere using an ensemble forecast system 500-hPa pressure level heights, and using the University of Missouri blocking archive, they found that there is a relationship between blockings and atmospheric variables, and a better understanding of the continuity and durability of blockings can help humans to reduce the damage caused by blocking anomalies. Therefore, due to the importance of blocking systems in climate change, this study aimed to examine and compare the two hemispheres.

## 2 Research methodology

In this study, the spatio-temporal distribution of blocking events in the Northern and Southern Hemispheres during the period 1968 to 2018 is studied by using the blocking index (BI) introduced by Wiedenmann et al. (2002). In this index, in order to identify the primary and secondary locations of block formation in the Northern and Southern Hemispheres, the Earth is longitudinally divided into three distinct regions: Atlantic ( $80^{\circ}$ W– $40^{\circ}$ E), Pacific ( $140^{\circ}$ E– $100^{\circ}$ W), and Continental (Northern Hemisphere)/Indian (Southern Hemisphere) ( $100^{\circ}$ – $80^{\circ}$ W and  $40^{\circ}$ – $140^{\circ}$ E) (Wiedenmann et al. 2002) (Fig. 1).

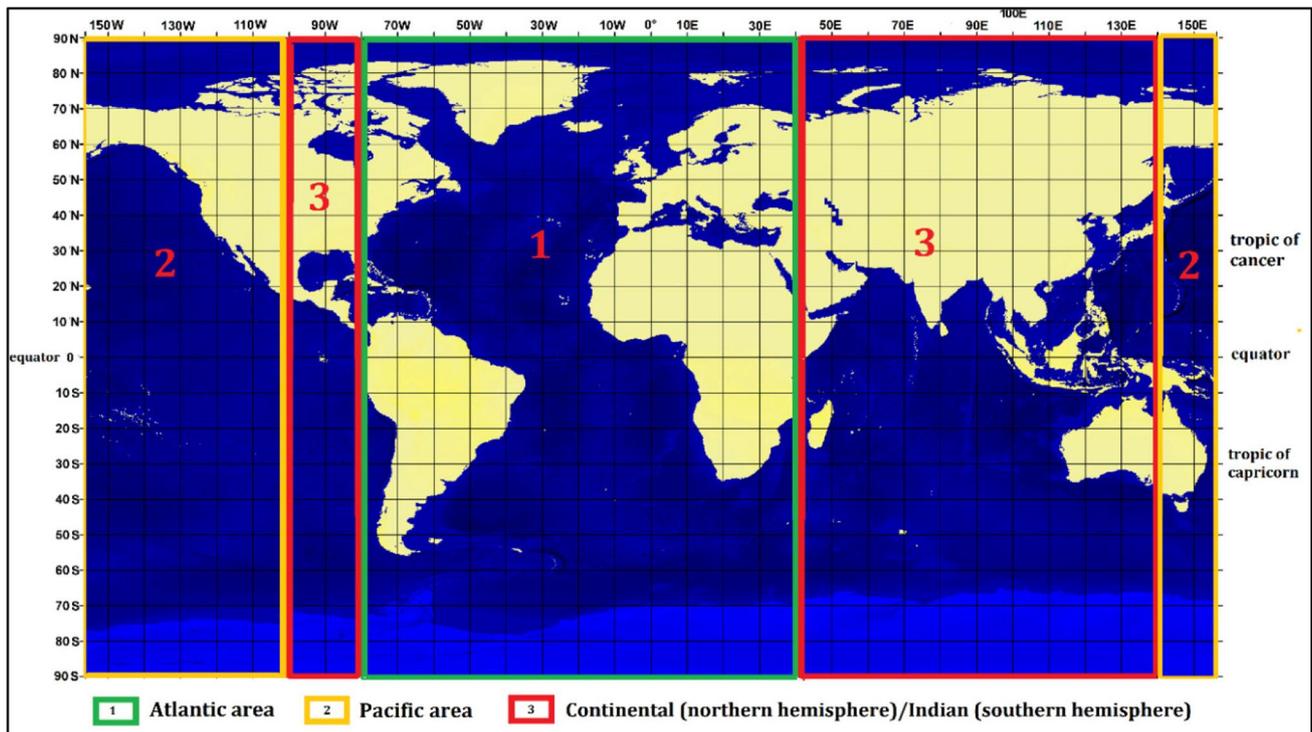


Fig. 1 Detachment of blocking formation nuclei in the two hemispheres

## 2.1 Blocking index

Blocking parameters were obtained from the Center for Blocking Studies (CBS) in the Atmospheric Science Research Program at the University of Missouri, USA. In this research, the archival information of the CBS for the years between 1968 and 2018 has been used. Since blocking patterns are characterized by an appreciable mass difference between high and middle latitudes (Namias and Clapp 1951; Austin 1980; Treidl et al. 1981) and anomalous easterly winds, the blocking index used here is an adapted version of the TM90 index (see Trigo et al. 2004), which is based on the original criterion proposed by LO83. According to the LO83 criterion, a blocking event can be identified when the averaged zonal index (referred to hereafter as LO), computed as the 500-hPa height difference between 40° and 60°N, is negative over 30° in longitude and during 5 or more days. However, TM90 noted that cutoff lows displaced poleward could also yield negative LO values. To exclude these, TM90 demanded an additional negative height gradient northward of 60°N. In agreement with that, a blocking event was detected when at least three consecutive longitudes appeared as blocked during at least 5 days. Following the TM90 methodology, two 500-hPa height geopotential gradients (GHGN and GHGS) have been simultaneously computed for each longitude and for

each day of study over the North Hemisphere in agreement with expressions (1) to (3):

$$\begin{aligned} \text{GHGN} &= \frac{Z(\lambda, \phi_N) - Z(\lambda, \phi_O)}{\phi_N - \phi_O} \\ \text{GHGS} &= \frac{Z(\lambda, \phi_O) - Z(\lambda, \phi_S)}{\phi_O - \phi_S} \end{aligned} \quad (1)$$

$$\begin{aligned} \phi_N &= 77.5^\circ\text{N} + \Delta \\ \phi_O &= 60.0^\circ\text{N} + \Delta \\ \phi_S &= 40.0^\circ\text{N} + \Delta \\ \Delta &= -5.0^\circ, -2.5^\circ, 0.0^\circ, 2.5^\circ, 5.0^\circ, \end{aligned} \quad (2)$$

where  $Z(\lambda, \phi)$  is the 500-hPa height geopotential at latitude  $\phi$  and longitude  $\lambda$ . GHGS is proportional to the zonal geostrophic wind component and provides a measure of the zonal flow intensity for each longitude, while the GHGN gradient is imposed in order to exclude nonblocked flows. This new version of the TM90 index is based on the availability of higher resolution for the NCEP–NCAR gridded data and latitudinal frequency distribution of blocking episodes than that used by Treidl et al. (1981) (Trigo et al. 2004). Thus, an arbitrary longitude is considered blocked when both GHGN and GHGS verify the condition expressed by Eq. (3) for at least one of the five  $\Delta$  values and simultaneously the  $\phi_0$  height anomaly is positive. This requirement minimizes the problem of identifying cutoff lows as blocked flows. Also,

the procedure incorporates better spatial resolution and more blocking opportunities by allowing five  $\Delta$  values instead of the three proposed by TM90;

$$\begin{aligned} \text{GHGN} &< -10\text{gpm}/^\circ\text{lat} \\ \text{GHGS} &> 0 \\ Z(\lambda, \phi_0) - Z(\lambda, \phi_0) &> 0. \end{aligned} \quad (3)$$

## 2.2 Wiedenmann criterion

This index was first calculated by Lupu and Smith (1995), but the adjusted BI index was later modified by Wiedenmann et al. (2002) to identify and compare the blocking incident. In this index, Wiedenmann et al. (2002) show that BI values are proportional to the altitude gradients of the blocking area. BI values increase during the cold season and when the altitude gradients of the Northern Hemisphere are higher (Lupo 1997). In this way, BI can be used as a diagnostic value in determining the relative intensities of large-scale regimes in both hemispheres in the blocked area, especially to compare observations with model results (Lupo and Burkhardt 2006). The numerical value of this index is between 1 and 10. Accordingly, the closer this value is to 10, the stronger the blockings, and the closer to 1, the weaker the blockings we have (Wiedenmann et al. 2002; Lupo 1997). Identifying blocking by the numerical method of Wiedenmann et al. (2002) is done through Eqs. (4) and (5):

$$\text{BI} = 100[\text{MZ}/(\text{RC}) - 1.0] \quad (4)$$

$$\text{RC} = \frac{\left(\frac{\text{ZU}+\text{MZ}}{2} + \frac{\text{Zd}+\text{MZ}}{2}\right)}{2} \quad (5)$$

BI Blocking intensity

RC Middle of the lowest curve of the axes of the troughs on both sides of the ridge at a given latitude

MZ The maximum 500-hPa height on a line associated with the ridge axis

Zu The lowest height value in the trough axis upstream at 500-hPa height

Zd The lowest height value in the trough axis downstream at 500-hPa height

Wiedenman et al. (2002) categorizes blocking events in terms of severity from 1 to 10 based on Eqs. (1) and (2)

**Table 1** Blocking intensity (BI) index in the Northern Hemisphere (Wiedenmann et al. (2002))

Blocking coefficient	Blocking intensity
BI < 2	Weak blocking
2 < BI < 4.3	Medium blocking
BI > 4.3	Severe blocking

(Table 1). In this method, the blockings that lasted more than 5 days would be analyzed and examined.

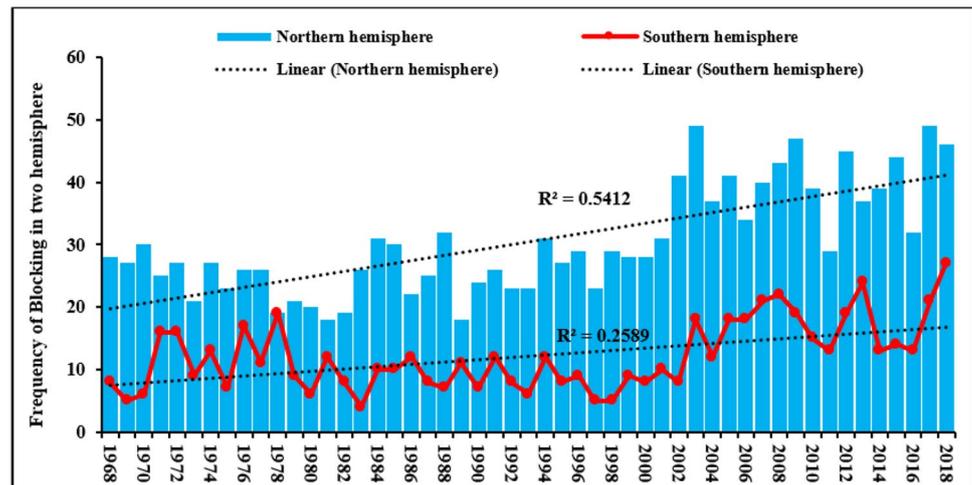
Please be aware that throughout this study, seasons are treated according to the following attribution: Spring is equivalent to April, May, and June; summer is equivalent to July, August, and September; autumn is equivalent to October, November, and December; and winter is equivalent to January, February, and March.

## 3 Results

### 3.1 Long-term spatial distribution of blockings in the Northern and Southern Hemispheres

In order to provide a background on the difference between the formation of blockings in Northern and Southern Hemispheres, first a brief comparison is made between these two hemispheres, and then, the blockings of the study area are examined. Fifty-one-year data (from the establishment of the University of Missouri's center for blocking studies) were used to compare the two hemispheres. The results of the analysis of these data show that 2173 cases of blockings have been formed across the world during a period of 51 years. During these 51 years, 1555 blockings were formed in the Northern Hemisphere and 618 in the Southern Hemisphere. Considering the continuity of each blocking, it can be said that there were a total of 18,626 days of blocking on Earth, of which the share of the Northern Hemisphere was 75% (13,956 days) and the share of the Southern Hemisphere was only 25% or 4713 days with blocking. As a result, the Northern Hemisphere had three times as many days with blocking as the Southern Hemisphere, but in terms of percentage of frequency, it was about 2.5 times more likely to occur. The results of comparing the occurrence of blockings in the Northern and Southern Hemispheres showed that during the study period, blockings were formed more in the Northern Hemisphere, which could also be due to the unbalanced distribution of sea and land in this hemisphere (Knox and Hay 1985). As a result of this imbalance, climatic elements have more fluctuations compared to the Southern Hemisphere (Fig. 2; Table 2).

**Fig. 2** Comparison of the frequency of blocking formation in the Northern and Southern Hemispheres



**Table 2** Comparison of days with blockings in the Northern and Southern Hemispheres

Location	Frequency of blockings	Percentage of blockings	Frequency of days with blocking events	Percentage of days with blocking events
Northern Hemisphere	1555	71.6	13,956	75
Southern Hemisphere	618	28.4	4713	25
Total cycle	2173	100	18,626	100

### 3.2 Frequency of occurrence of blockings in both Northern and Southern Hemispheres

The results of the annual data analysis show that during the study period (51 years), 1555 cases of blockings were formed in the Northern Hemisphere, of which the highest frequency of blocking events was in 2003 and 2017 with 49 cases and the lowest frequency with 18 cases occurred in 1981 and 1989. The trend line of blocking occurrence also shows that blockings had a positive and increasing trend during the period under study with a coefficient of determination of 54%. This trend, although started in 1981, was accompanied by a more upward slope in early 1996 and reached its peak in 2000. In general, it can be said that the frequency of the blocking incident has been increasing, especially during the last two decades (Fig. 2).

The results of the annual data analysis show that during the 51 years, 618 cases of blockings have been formed in the Southern Hemisphere, of which the highest frequency of blockings occurred in 2018 with 27 cases and the lowest frequency with 4 cases occurred in 1983. The trend line of blocking occurrence also shows that blockings during the study period had an increasing trend with a coefficient of determination of 26%. This trend, although started in 1996, was accompanied by a higher upward slope in early 2003 and reached its peak in 2013. In general, it can be said that the frequency of blocking events in the Southern

Hemisphere, especially during the last decade, has been increasing (Fig. 2).

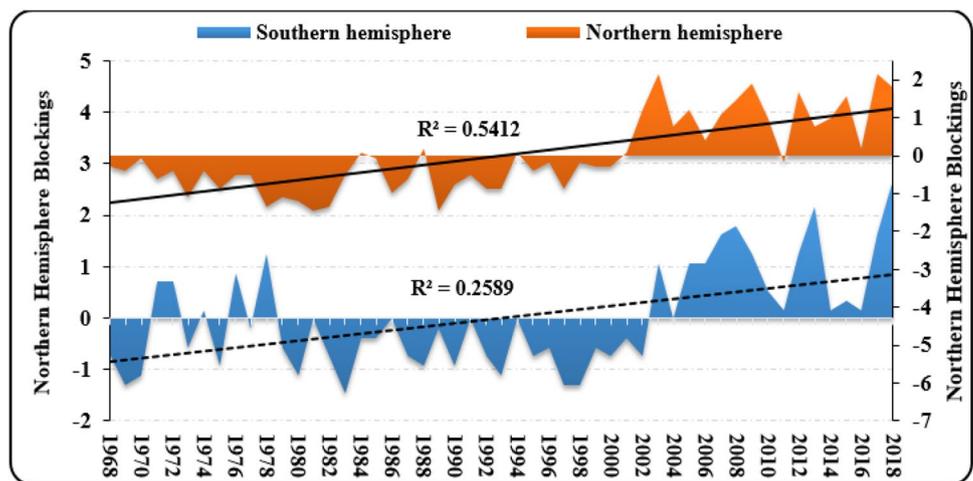
### 3.3 Trend of blocking occurrence in the Northern and Southern Hemispheres

The trend of blocking occurrence in the Northern Hemisphere shows that blockings had a positive and increasing trend during the period under study with a coefficient of determination of 54%, which was accompanied by a higher upward slope in early 2000. But in the Southern Hemisphere, the trend of blocking formation is less and its determination coefficient is 26%. In general, it can be said that the frequency of the blocking events in the two hemispheres has been increasing, especially during the last two decades (Fig. 3).

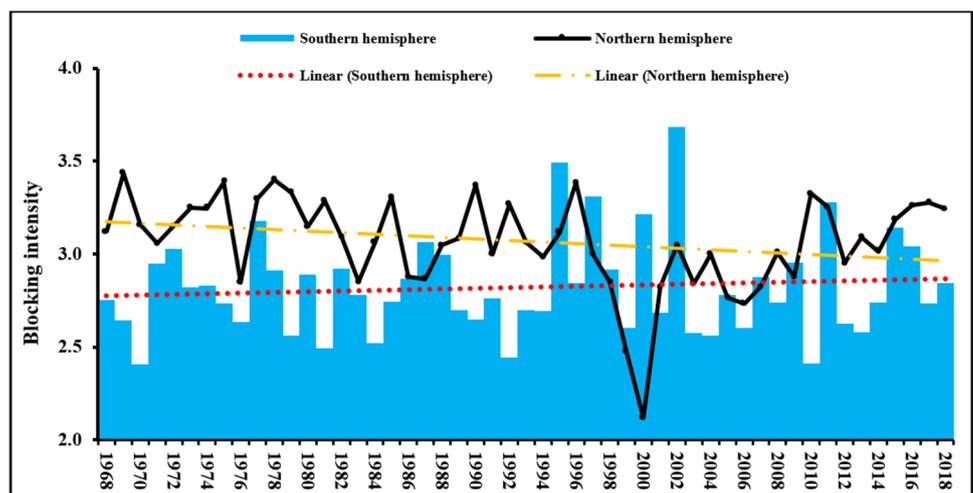
### 3.4 Annual BI in the Northern and Southern Hemispheres

Figure 4 shows the average annual BI in the two hemispheres. According to this figure, the long-term average blocking intensity in the Northern Hemisphere during the study period is 3.1 BI, but in the Southern Hemisphere, this value decreases to 2.8 BI. In terms of maximum annual average, the highest blocking intensities of the Northern Hemisphere are in 1965, 1975, 1978, 1990, and 1996 with an

**Fig. 3** Comparison of the trend of blocking occurrence in the Northern and Southern Hemispheres



**Fig. 4** Annual comparison of blocking intensity (BI) in the Northern and Southern Hemispheres



average of 3.4 BI and in the Southern Hemisphere, the highest intensity of 3.7 BI occurred in 2002. The minimum average value of BI in the Northern Hemisphere was recorded in 2000 with a value of 2.1 and the lowest value of this index was recorded in the Southern Hemisphere with an intensity of 2.4 BI in 1970. Although in both hemispheres the trend lines of blocking intensity are not significant, the trend line of intensity in the Northern Hemisphere tends to decline, but in the Southern Hemisphere, the trend tends to rise.

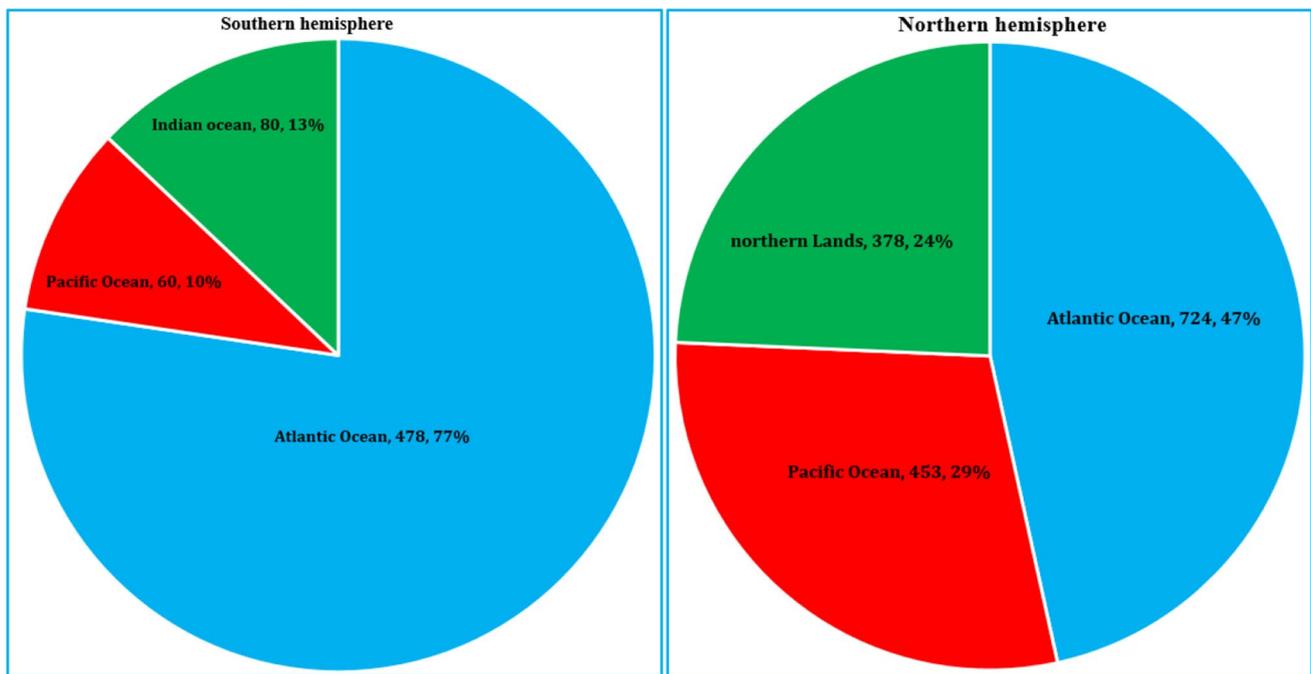
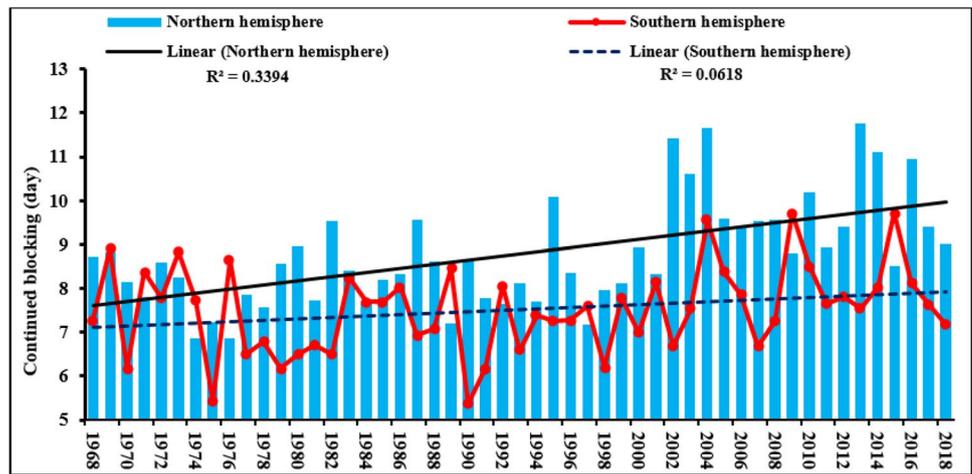
### 3.5 Annual continuity of blockings in the Northern and Southern Hemispheres

According to the research findings in Fig. 5, blockings with a duration of less than 5 days are not considered. In the definition of continuity, it can be said that the time from when a blocking is formed until it disappears is called continuity. Figures 5, 6, 7, 8, and 9 show the annual average of blocking continuity in the two hemispheres. According to this figure, the long-term average lifespan of blockings in the Northern

Hemisphere during the study period is 9 days, but in the Southern Hemisphere, this amount decreases to 7.6 days. The trend line is also upward in both hemispheres, but in the Northern Hemisphere, this trend is more intense (by 34%). Annually, the highest continuity of the Northern Hemisphere is related to 2013 with an average of 11.8 days, and in the Southern Hemisphere, the highest continuity of the blocking is 9.7 days in 2009 and 2015 (Fig. 5).

Table 3 shows the long-term spatial distribution of the occurrence of blockings in both the Northern and Southern Hemispheres. According to this table, it can be said that in both hemispheres most of the blockings are formed in the Atlantic region and then in the lands of the Northern Hemisphere and the Indian region of the Southern Hemisphere; so that in the Northern Hemisphere, out of 1555 cases of blockings, 724 cases (47%) and in the Southern Hemisphere, out of 618 cases, about 487 cases (77%) of the total number of blocking cases occur in this region. The lowest case of blocking formation in the Northern Hemisphere is related to the lands of this hemisphere with 378 cases (24%), but in

**Fig. 5** Comparison of annual continuity of blockings in the Northern and Southern Hemispheres



**Fig. 6** Spatial distribution of the location of initial formation of blockings in the Northern and Southern Hemispheres

the Southern Hemisphere, the lowest incidence of blockings with 60 cases (10%) is related to the Pacific region blockings (Table 3; Fig. 6).

**3.6 Seasonal distribution of blockings in the Northern and Southern Hemispheres**

As Table 4 shows, the coefficient of variation of blockings in the Southern Hemisphere is (45.4%), which is higher than of the Northern Hemisphere (28.3%). In the Northern Hemisphere, the highest number of cases occurred in spring with 456 cases and in the Southern Hemisphere, in winter with 208 cases. In terms of blocking intensity, Northern

Hemisphere blockings with a long-term average of 3.1 BI are more intense than Southern Hemisphere blockings with 2.8 BI. In terms of seasonal distribution, Northern Hemisphere blockings have a more uniform distribution than Southern Hemisphere blockings.

**3.7 Seasonal spatial distribution of the location of the blockings in the Northern and Southern Hemispheres**

Table 5 shows the annual and seasonal spatial distribution of the occurrence of blockings in the Northern and Southern Hemispheres. According to this table, it can be said that in

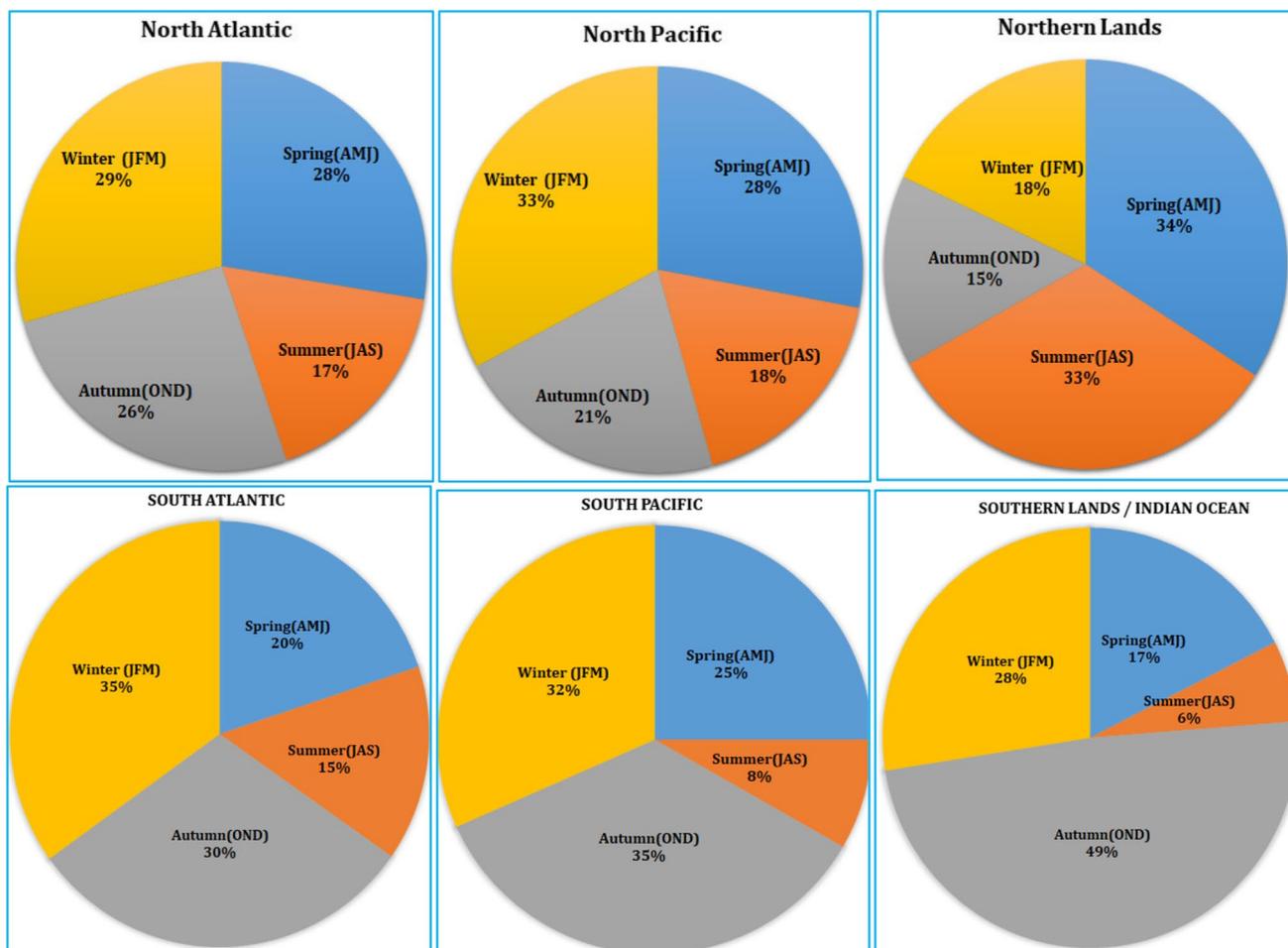
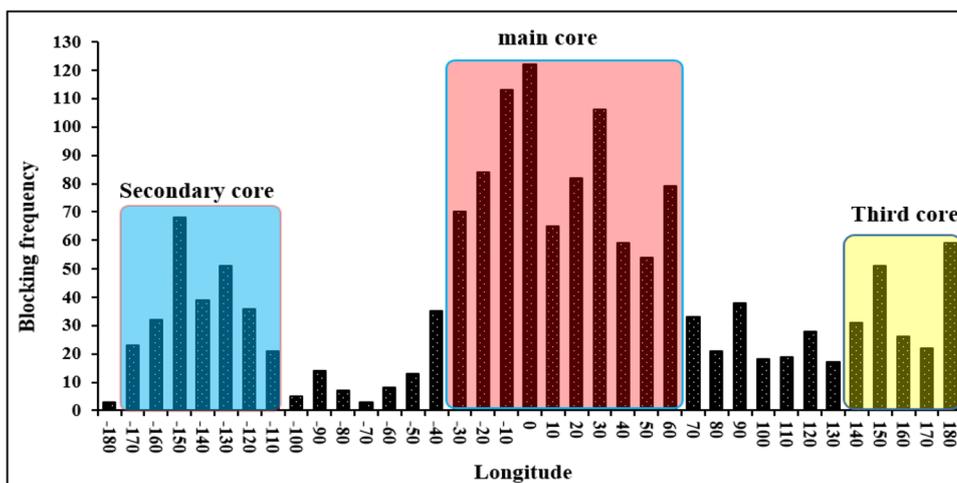


Fig. 7 Spatial distribution of the location of blockings in different seasons in the Northern and Southern Hemispheres

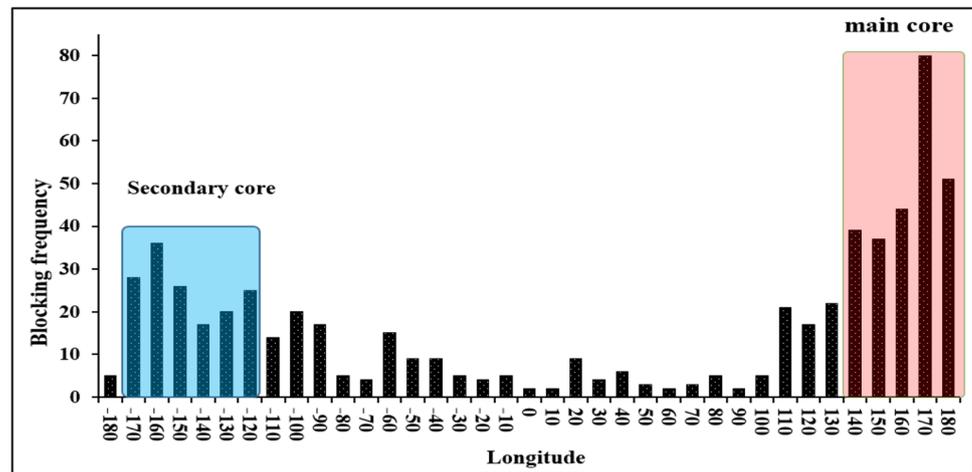
Fig. 8 Primary and secondary core of the formation of the northern blocking based on longitude



both hemispheres, most of the blockings are formed in the Atlantic region and then in the lands of the Northern Hemisphere and the Indian Ocean in the Southern Hemisphere.

In the Northern Hemisphere, out of a total of 1555 cases, 724 cases (46.6%) and in the Southern Hemisphere, out of 618 cases, about 487 cases (77.4%) of all blocking cases

**Fig. 9** Primary and secondary core of the formation of the southern blocking based on longitude



**Table 3** Long-term spatial distribution of blocking nuclei in the two hemispheres

Hemisphere	Area of occurrence	Total annual frequency
Northern Hemisphere	North Atlantic	724
	North Pacific	453
	Lands	378
	Seasonal sum	1555
Southern Hemisphere	South Atlantic	478
	South Pacific	60
	Southern lands/Indian Ocean	80
	Seasonal sum	618

**Table 4** Statistical comparison of blockings in the Northern and Southern Hemispheres

Frequency	Northern Hemisphere	Southern Hemisphere
Total	1555	618
AMJ	456 (29.3%)	124 (20.1%)
JAS	340 (21.8%)	81 (13.1%)
OND	329 (21.2%)	205 (33.2%)
JFM	430 (27.7%)	208 (33.6%)
Mean	30.5	12.1
Standard deviation	8.6	5.5
Max	49	27
Min	18	4
cv	28.3	45.4
Blocking intensity mean	3.1	2.8

occur. The lowest case of blocking formation in the Northern Hemisphere is related to the lands of this hemisphere with 378 cases (24.3%), but in the Southern Hemisphere, the lowest occurrence of blockings with 60 cases (9.7%) is

related to blockings in the Pacific region (Table 5). In terms of seasonal total sum, in the Northern Hemisphere, the highest incidence of blockings was recorded in spring with a total of 456 cases and the lowest occurrence in summer with 329 cases. However, in the Southern Hemisphere, the highest frequency of blockings was recorded in winter with a total of 208 cases and the lowest formation of blockings with a frequency of 81 cases was recorded in summer.

Figure 7 and Table 5 show the spatial distribution of the location of blockings in different seasons in both the Northern and Southern Hemispheres. In the Northern Hemisphere, out of a total of 724 cases of blocking occurrence in the North Atlantic region, 28% (200 cases) occur in the spring. In this region, 17% (125 cases) of blockings occurred in summer, 26% (186 cases) in autumn, and 29% (213 cases) in winter. Also, out of 453 cases of blocking occurrence in the North Pacific region, 28% (127 cases) occurred in spring, 18% (80 cases) in summer, 21% (97 cases) in autumn, and 33% (149 cases) in winter. Also, out of 453 cases of blocking cases in the North Pacific region, 28% (127 cases) occurred in spring, 18% (80 cases) in summer, 21% (97 cases) in autumn, and 33% (149 cases) in winter.

Out of 453 cases of blocking events in the Northern Hemisphere, out of 378 cases of blocking occurrence, 34% (129 cases) occurred in spring, 33% (124 cases) in summer, 15% (57 cases) in autumn, and 18% (68 cases) in winter. In general, it can be said that in the Northern Hemisphere, the North Atlantic region experiences the highest incidence of blocking in winter. But in the Southern Hemisphere, out of a total of 478 blocking events in the South Atlantic region, 20% (95) occur in the spring. In this region, 15% (71 cases) of blockings occurred in summer, 30% (145 cases) in autumn, and 35% (167 cases) in winter. Also, out of 60 cases of blocking events in the South Pacific region, 25% (15 cases) occurred in spring, 8% (5 cases) in summer, 35% (21 cases) in autumn, and 32% (19 cases) in winter. Out of 453 cases of blocking occurrence in the lands of the Southern

**Table 5** Seasonal spatial distribution of blocking areas in the two hemispheres

Hemisphere	Area of occurrence	AJM frequency	JAS frequency	OND frequency	JFM frequency	Total annual frequency/percentage
Northern Hemisphere	North Atlantic	200	125	186	213	724 (46.6%)
	North Pacific	127	80	97	149	453 (29.1%)
	Lands	129	124	57	68	378 (24.3%)
	Seasonal sum	456	329	340	430	1555
Southern Hemisphere	South Atlantic	95	71	145	167	478 (77.4%)
	South Pacific	15	5	21	19	60 (9.7%)
	Southern lands/Indian Ocean	14	5	39	22	80 (12.9%)
	Seasonal sum	124	81	205	208	618

**Table 6** Continuity and intensity of blocking in the two hemispheres and its degree of correlation

Season	Northern Hemisphere		Southern Hemisphere	
	Continuity (days)	BI	Continuity (days)	BI
AMJ	8.8	2.6	7.3	2.6
JAS	8.9	2.2	6.7	2.7
OND	8.9	3.5	7.9	2.9
JFM	9.3	3.8	7.8	2.8
Seasonal average	9	3	7.4	2.8
$R^2$	<b>0.71</b>		<b>0.68</b>	

Hemisphere and India, out of a total of 80 cases of blocking occurrence, 17% (14 cases) occurred in spring, 6% (5 cases) in summer, 49% (39 cases) in autumn, and 28% (22 cases) in winter. In general, it can be said that in the Southern Hemisphere, the South Atlantic region experiences the highest occurrence of blockings in winter (Fig. 7).

### 3.8 Comparison of seasonal BI and duration in the Northern and Southern Hemispheres

Analysis of the data of the seasonal average of blocking intensity (BI) index in the two hemispheres (Table 6) shows that the maximum average BI index in the Northern Hemisphere in winter is 3.8, but the lowest value of this index, which is also the weakest type of blocking, has an intensity of 2.2 BI, which occurs in summer. The maximum value of BI in the Southern Hemisphere was recorded in autumn with a value of 2.9 and the lowest value of this index was recorded with an intensity of 2.6 BI in spring.

The results of calculating the seasonal continuity of blockings show that in the Northern Hemisphere, winter blockings with 9.3 days have the longest life span and spring blockings with 8.8 days have the lowest duration. In

the Southern Hemisphere, the highest durability of blockings is in autumn with 7.9 days and the lowest duration is in summer with 6.7 days. Therefore, it can be said that in both hemispheres, the lifespan of the blockings is longer in the cold season and shorter in the warm season. The long-term seasonal correlation between continuity and BI in the two hemispheres shows that the correlation between these two variables is 71% in the Northern Hemisphere and 68% in the Southern Hemisphere.

### 3.9 Monthly distribution of frequency, BI index, and duration of blocking in Northern and Southern Hemispheres

The results of the long-term monthly frequency show that during the study period (51 years), out of 1555 cases of blockings formed in the Northern Hemisphere, the highest frequency of blocking events occurred in May with 162 cases and the lowest frequency with 95 cases occurred in August. However, during the same study period (51 years), out of 618 cases of blocking events in the Southern Hemisphere, the highest incidence of blocking occurred in February with 81 cases and the lowest frequency with 23 cases occurred in August (Table 7). Analysis of the monthly average of the BI index in the two hemispheres (Table 7) shows that the averages of maximum BI index in the Northern Hemisphere were 4 and 3.9 and related to February and January; but the lowest value of this index, which is also the weakest type of blocking, has an intensity of 2 BI, which occurred during the month of July. The maximum value of BI in the Southern Hemisphere was recorded in December with a value of 3 BI, and the lowest value of this index occurred with an intensity of 2.4 BI in May.

The results of calculating the monthly continuity of blockings show that in the Northern Hemisphere, blockings of January with 9.7 days have the longest duration and August blockings with 7.9 days have the lowest duration. But in the Southern Hemisphere, the longest duration is in

**Table 7** Intensity and monthly continuity of blockings in the Northern and Southern Hemispheres

Month	Northern Hemisphere			Southern Hemisphere		
	Frequency	Continuity (days)	BI	Frequency	Continuity (days)	BI
January	159	9.7	3.9	73	8.4	2.8
February	139	9.2	4	81	7.7	2.9
March	132	8.9	3.6	53	7.6	2.9
April	137	8.6	3	45	7.3	2.7
May	162	9.2	2.7	43	6.9	2.4
June	157	8.6	2.3	37	7.8	2.6
July	133	9.6	2	29	7.1	2.7
August	95	7.9	2.2	23	6.2	2.8
September	101	8.8	2.6	29	6.6	2.7
October	116	8.2	3.1	51	7.2	2.7
November	100	8.8	3.5	77	7.7	2.9
December	124	9.5	3.8	77	8.5	3
Monthly average	1555	9	3.1	618	7.4	2.8

December with 8.5 days and the lowest duration is in August with 6.2 days. Therefore, it can be said that in both hemispheres, the life span of the blockings is longer in the cold months than in the warm months of the year.

### 3.10 The spatial core of the blockings in the two hemispheres

Figure 8 shows the spatial core of the long-term blocking events (in longitude) in the Northern Hemisphere. According to this figure, the main core of the blockings in the Northern Hemisphere is located between the lengths of 60 degrees east and  $-30$  degrees west longitude (the long landing point of the Mediterranean) on land and the secondary core of the blockings is located in the ocean between  $-20$  and  $-160$  degrees Western longitude (East American landing). According to the data, the blockings whose cores are formed in the ocean are more intense and durable than the ones whose cores are formed on land. The third core is formed along the east longitude between 140 and 180, which is the long landing point of East Asia, which is less than the other two cores in terms of the frequency of blocking formation. During the study period, the Mediterranean landing area was more active in terms of blocking formation than the other two areas.

Figure 9 shows the spatial core of the long-term blocking events (longitude) in the Southern Hemisphere. According to this figure, in the long run, the main cores of the blockings in the Southern Hemisphere are concentrated between 140 and 180 degrees east longitude, and the secondary cores of the blockings, which are located on land, are located between  $-120$  and  $-170$  degrees west longitude in the Pacific Ocean. According to the studied data, in the Southern Hemisphere, the nuclei of the blockings are mostly

formed at the edge of the oceans. These edges include the Philippine Archipelago, Indonesia, and Australia in the east of the Pacific Ocean, and the coasts of Chile and Peru in the west of the Pacific Ocean.

## 4 Conclusion

The aim of this study was to study the spatio-temporal distribution of blocking events in the Northern and Southern Hemispheres from 1968 to 2018, for a period of 51 years, based on the Wiedenmann blocking intensity (BI) numerical index. The results of the comparison between the Northern and Southern Hemisphere blockings showed that during 1968 to 2018, the blockings in the Northern Hemisphere with 1555 cases occurred almost 2.5 times more than those in the Southern Hemisphere with 618 cases. The growth trend of blockings in the Northern Hemisphere (with a coefficient of determination of 54%) is also 2 times as much as the growth of blockings in the Southern Hemisphere (with a coefficient of 26%). In the Northern Hemisphere, the frequency of blockings is higher in spring, but in the Southern Hemisphere, blockings are more common in winter. Regionally, the blockings of both hemispheres are mostly formed in the Atlantic Ocean (north and south). Also, the comparison of the duration of the blocking showed that the average life of each blocking in the Northern Hemisphere is about 9 days, but in the Southern Hemisphere, it reaches 7 days. The trend of blocking continuity is also higher in the Northern Hemisphere than in the Southern Hemisphere. Also, in the Northern Hemisphere, the days with blockings are 3 times more than in the Southern Hemisphere. This difference in the formation and days of blocking can be attributed to the unevenness and unbalanced distribution of water and land in

the Northern Hemisphere. Because, the difference between sea and land and as a result the temperature difference play an effective role in the formation of atmospheric fronts. The formation of atmospheric fronts will eventually cause the formation of cyclones (vortices) whose centers coincide with the nuclei of the blockings, as a result of which the western waves will fluctuate along the wavelength (i.e., the meridional component will be stronger than the orbital component; Yarnal 1993) and gradually, the waves become deeper and the blocking nucleus will be formed; but in the Southern Hemisphere, due to the greater water area, these features are less visible and as a result, fewer blockings are formed.

In terms of the severity of the blockings, those in the Northern Hemisphere are more intense than in the Southern Hemisphere and in fact, the strength of the blockings located in the Northern Hemisphere is more than in the Southern Hemisphere; but the severity of the blockings in winter is higher than in other seasons. The results showed that the nuclei of the blockings in the Northern Hemisphere consist of three separate nuclei. The first and main core is located at the edge of the Atlantic water zone and northern mainland at 30 degrees east longitude, where the temperature difference between sea and land reaches its peak. The core of the blockings is located around this area between 30 degrees west longitude and 50 degrees east longitude. This core corresponds to the site of a long Mediterranean landing. The second core is between 110 and 150 degrees west longitude and corresponds to the long landing of the USA, and the third core locates between 140 and 180 degrees east longitude corresponding to the long landing of East Asia. But in the Southern Hemisphere, the main core of the blockings is located between 120 and 170 degrees west longitude and 140 to 180 degrees east longitude in two regions, which are the border between land and water.

The results of the spatial analysis showed that the cores of the Northern Hemisphere blockings are formed on land and their secondary nuclei are formed in the water areas of the Northern Hemisphere, but in the Southern Hemisphere, the nuclei of the blockings are mostly in the oceans. The results of seasonal correlation between BI and duration in the two hemispheres show that the relationship between these two variables in the Northern Hemisphere is 71% and in the Southern Hemisphere 68%, at a confidence level of 99%. But in terms of the monthly correlation of the Southern Hemisphere with 47 and the Northern with 38%, the results do not point to a significant relationship between these two variables. In general, it can be said that the differences between sea and land in the Northern Hemisphere have led to the emergence of diverse climate systems and imbalances in the formation of a climate system. These systems, in turn, have changed the climate of different parts of the world, and as a result, various climates have been formed in the long run in different regions that affect human life. In terms of seasonal

occurrence of blockings, the highest frequency in the Northern Hemisphere is related to spring in the North Atlantic and for the Southern Hemisphere, the highest frequency was in winter in the South Atlantic region.

By comparing the results of this study with global research, it can be said that the results of the present study are consistent with research such as Wiedenmann et al. (2002). They showed that blockchain events in the Northern and Southern Hemisphere have the most frequency and severity in the cold season. Also, Trigo et al. (2004) showed that blocking systems reach the maximum in spring and late winter and in the fall and summer to their minimum power and confirm their results. The results of this study are in line with the research of Lupo et al. (2017). They showed that the Northern Hemisphere blocks were stronger than the South Hemisphere and winter blockages are stronger than summer blocks.

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**Author contribution** All authors conceived of the presented idea, developed the theory, and performed the computations.

**Data availability** The data used in this article from the University of Missouri to address: <http://weather.missouri.edu/gcc/> received. Also, the HGT data of the 500 level from the NOAA site was received to the <https://psl.noaa.gov/data/gridded/data.ncep.reanalysis.pressure.html> address.

**Code availability** In this research, the SPSS and Excel software have been used. But the code is not used.

## Declarations

**Ethics approval** Not applicable, because this article does not contain any studies with human or animal subjects.

**Consent to participate** The data of this research were not prepared through a questionnaire.

**Consent for publication** The authors of the article make sure that everyone agrees to submit the article and is aware of the submission.

**Competing interests** The authors declare no competing interests.

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