ORIGINAL ARTICLE

A blocking diagnosis method and its application in the blocking system over Europe in the Summer of 2010

Y. Y. Hafez[1] · H. M. Hasanean[1,2] (iD) · M. A. Hussein[1]

Abstract

The blocking phenomenon has received considerable attention from many researchers due to its impact on weather and human life. This paper aims to provide a new blocking definition with applicability to observations. The daily National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) reanalysis data for the Northern Hemisphere of geopotential height at a level of 500 hPa during the summer season of 2010 was used in this study. Additionally, observations for several meteorological variables over the Northern Hemisphere, including Europe, through that period were collected and analyzed. By applying the new blocking definition over the Northern Hemisphere, three blocking events persisted over Europe for a duration of 5, 17 and 36 days. The exact total days of blocking events that persisted over Europe was 58 days in the summer of 2010. Moreover, during the blocking events in the summer of 2010 abnormal weather conditions, extremely hot, dry and increased pressure over Europe observed.

Keywords Blocking diagnosis method · Europe · Summer of 2010 · Observation meteorological variables · Abnormal weather

1 Introduction

Atmospheric blocking formation, maintenance, and breakdown causes large-scale circulation anomalies and strongly affects weather patterns. Therefore, blocking regimes constitute a significant climatological characteristic (Liu 1994; Barriopedro et al. 2006; Cheung et al. 2013a). Mokhov et al. (2013) found that the persistence of blocking in the Northern Hemisphere extratropical regions increases under hemispheric warming. Atmospheric blocking events can be linked to extreme weather, for instance, severe cold spells in winter and drought and/or severe hot in summer (Mokhov et al. 2013). Many researchers investigated and discussed the climatological phenomenon, blocking formation, persistence, behavior

and the role these played in unusual weather and climate in the Northern Hemisphere (Elliott and Smith 1949; Rex 1950a, 1950b; Rex 1951; Namias 1964; Dickson and Namias 1976; Dole and Gordon 1983; Lejenäs 1989; Liu 1994; Lupo 1997; Cohen et al. 2001; Wiedenmann et al. 2002; Burkhardt and Lupo 2005; Athar et al. 2007; Schalge et al. 2011; Lupo et al. 2012; Fujii et al. 2012; Cheung et al. 2012, 2013b). Blocking episodes have a great impact on the weather and climate of several areas because they are accompanied by an abrupt change in the atmospheric flow, which affects the normal progression of synoptic systems (Sinclair 1996; Wiedenmann et al. 2002; Renwick 2005). Throughout their incidence, low-pressure systems are displaced and weakened due to the presence of a quasi-stationary anticyclone of great magnitude. Anticyclone movement is relatively slow and persists for many days (or may continue for several weeks) over the same region.

On an annual basis, blocking tends to occur in three major sectors: the Atlantic Ocean-European Continent, the Pacific Ocean, and the Ural Mountains over the Northern Hemisphere (Barriopedro et al. 2006; Diao et al. 2006; Tyrlis and Hoskins 2008; Cheung et al. 2013b). Activities and locations of atmospheric blocking show seasonal variation due to its thermodynamic background, which varies from season to season (Cheung et al. 2013b). When the ocean is

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✉ H. M. Hasanean
hhasanean@kau.edu.sa; hasanean1708@gmail.com

[1] Department of Meteorology, Faculty of Meteorology, Environment and Arid Land Agriculture, King Abdulaziz University, P.O. Box 80234, Jeddah 21589, Saudi Arabia

[2] Astronomy, Space Science and Meteorology Department, Faculty of Science, Cairo University, P.O. Box 12613, Giza, Egypt

warmer than the continent throughout cold seasons, oceanic atmospheric blocking is more effective, and when the continent is warmer than the ocean throughout the warm seasons, continental atmospheric blocking is more effective (Cheung et al. 2013b).

After the conventional definition by Rex (1950a), a blocking episode can be identified as a split flow regime in the middle troposphere, with a double jet noticeable over more than 45° in longitude and persisting for more than ten days. Several modifications were made to the original Rex (1951) definition of requirements. Treidl et al. (1981) modified the definition of blocking for lower durations and extensions. However, restrictions on latitude location were suggested by White and Clark (1975). Previous studies suggested numerous ways to define blocking. They were reviewed in detail by Barriopedro et al. (2010). Several criteria were suggested to objectively identify atmospheric blocked flows, most of them were based on zonal flow indices calculated from meridional height gradients at the middle troposphere (Lejenäs and Økland 1983; Tibaldi and Molteni 1990; Tibaldi et al. 1997; Trigo et al. 2004; Cheung et al. 2013b). Other methodologies detected blocking events as positive height anomalies at the mid-tropospheric flow persisting for several days (Charney et al. 1981; Dole and Gordon 1983). In addition, blocking was defined by using potential vorticity gradients (Pelly and Hoskins 2003; Schwierz et al. 2004; Small et al. 2014). All previous studies of summer 2010 blocking case over Eastern Europe and Russia could not catch all blocking days (Lupo et al. 2012). Lupo et al. (2012) studied the blocking system over Europe in the summer of 2010. They could not catch all the days of the blocking system through that season. They missed 10 days of blocking through summer season 2010. These 10 days are from 14 June to 18 June and 29 June to 3 July, which is omega shape blocking as shown in Fig. 1. Figure 1 illustrates omega shape blocking over European sector during ten days the first (a) from 14 to 18 June 2010 and the second (b) from 29 June to 3 July 2010.

The capture of the 10 missing days is very important to uncover the reason for the persistence of abnormal weather conditions at the surface through that period. However, the omega shape blocking episode is missing when applying "old" methods of blocking (zonal index) Barriopedro et al. (2010). Also, Hafez and Almazroui (2016) state that "The definition of blocking using of zonal index has problems with omega-shaped block and particularly difficult with meridional block. The blocking definition by zonal index must be used for Rossby wave-breaking only". Moreover, the previous studies of blocking indices are almost zonal indices methods which could not catch all the types of blocking systems (Barriopedro et al. 2010). Therefore, the authors try to innovate a new meridonal blocking index method to solve this problem. The difference between the zonal index and meridional index of blocking is: The zonal index define as the difference of geopotential height between two different latitudes simultaneously the difference between two different longitudes. Meanwhile, the meridional index of blocking is the difference between two different latitudes for only one longitude. Tibaldi and Molteni (1990) is a one dimension zonal index. The zonal index determine the blocking episodes change in the westerly air current (zonal flow) with the change of longitudes. Meanwhile the meridional index determine the blocking episodes as the change of meridional flow of the westerly air current only. The zonal index definitions of blocking missing the omega shaped blocking cases. The missing days characterized are related to abnormal weather conditions, which is the one condition of new criteria.

The present study aims to: (i) provide a physical meridional type blocking index, (ii) apply this new index for blocking systems that persisted over Europe in the summer season of 2010, and (iii) explore the weather which controlled blocking episodes during the said summer season in Europe. The article is structured in the following way: after a short description of the used data (section 2a), the new blocking index is introduced (section 2b). Results for the Summer 2010 are shown in section 3. The article is concluded by a discussion in Section 4.

2 Data and Methods

2.1 Data

The daily data set used in this study was obtained from the National Centers for Environmental Prediction (NCEP) and National Center for Atmospheric Research (NCAR) gridded reanalysis data (Kalnay et al. 1996; Kistler et al. 2001). In this study, a spatial resolution of the 500 hPa geopotential height value was 2.5° latitude × 2.5° longitude at 1200 UTC. In addition to the 500 hPa geopotential height, the surface parameters included surface air temperature (maximum and minimum temperature), zonal and meridional wind field, precipitation rate, relative humidity, and sea level pressure are used. Furthermore, the outgoing longwave radiation at the top of the atmosphere was also used. The daily summer time period from 1 June 2010 to 31 August 2010 was used in this study to define the blocking event.

2.2 Definition of a New Blocking Index

The definition of blocking indices have become in itself a major issue. There are many blocking indices that have been centering on different features of the blocks. Doblas-Reyes et al. (2002) illustrated that, although several blocking situations are successfully uncovered by many of the existing indices, some contradictions in the reported frequency and location are evident in the results of observational and modeling

Fig. 1 Omega shape blocking (black box) over European sector during composites mean of ten days the first (**a**) from 14 to 18 June 2010 and the second (**b**) from 29 June to 3 July 2010
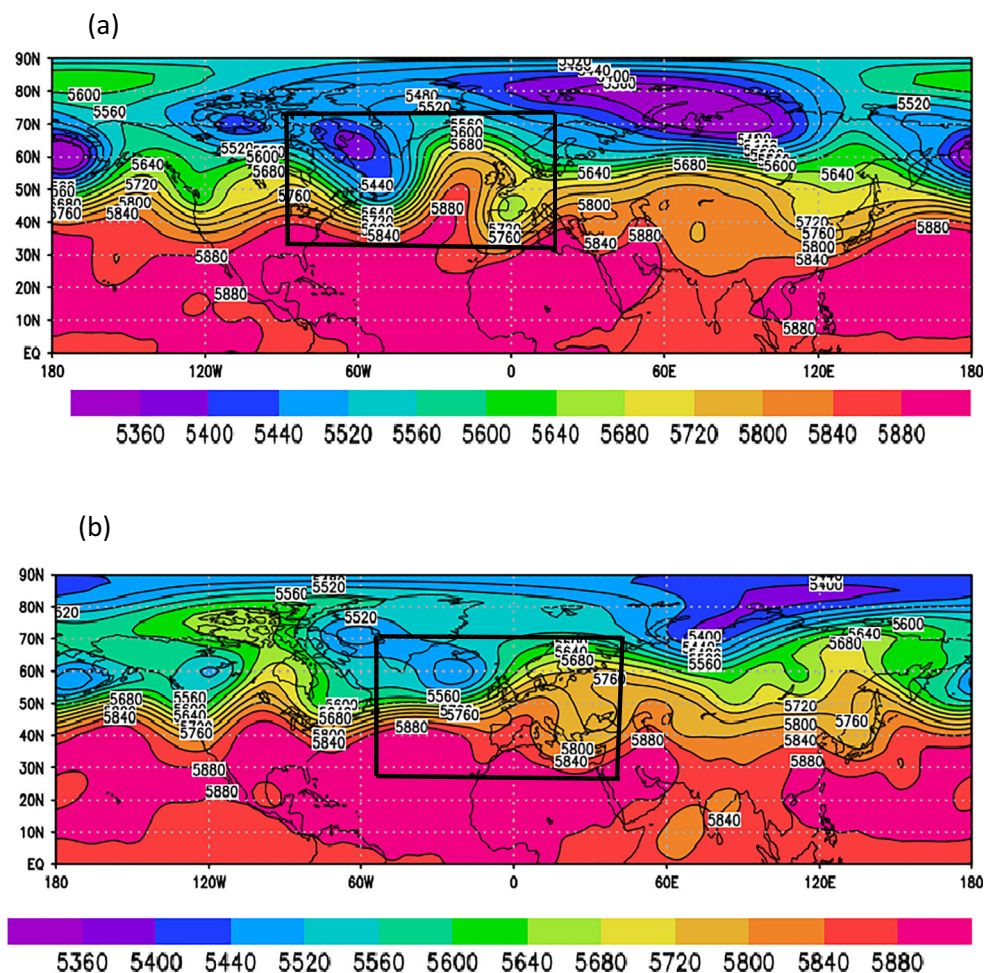
studies. To identify and follow the daily persistence of the blocking systems, synoptic and numeric criteria of the formation of blocking systems over the Northern Hemisphere have been used (Cheung et al. 2013b; Xiaolong et al. 2014). Barriopedro et al. (2010) illustrated that four general definitions of blocking events were used in various studies. The first is defined as regional and persistent meridional gradient reversals in the absolute geopotential height field, which reflect easterly geostrophic flows around a reference latitude representative of the jet stream (Lejenäs and Økland 1983; Tibaldi and Molteni 1990; Barriopedro et al. 2006; Diao et al. 2006). The second is defined as persistent positive or negative departures from the climatological height field (Dole and Gordon 1983; Shukla and Mo 1983; Knox and Hay 1985; Sausen et al. 1995; Schwierz et al. 2004). The third is defined as eddy fields identified as regions bounded by a southerly (northerly) wind upstream (downstream) (Kaas and Branstator 1993; Cash and Lee 2000) or as areas where the height field strongly exceeds the zonal mean in the surrounding sector (Hartmann and Ghan 1980; Mullen 1986, 1989). The fourth is defined as objective atmospheric circulation patterns derived from either statistical multivariate methods of weather regimes classification

(Vautard 1990; Michelangeli et al. 1995) or neural networks (Verdecchia et al. 1996).

Although there is no unanimity on the definition of atmospheric blocking, it is of necessity to set criteria for quantitative analysis of blocking. This paper proposes a new blocking index for the identification of blocking events in the Northern Hemisphere. The key point of this index is to consider the "reference" latitude of blocking events and the activity of blocking. The "reference" latitude of blocking events defined here was taken from a study by Liu (1994). In his research, the blocking Northern Hemisphere persistence for ten winter seasons, from 1982/83 to 1991/92 was studied and it was discovered that blocking and strong zonal flow have the same anomaly pattern but with opposite signs. Moreover, blocking anticyclones were centered at about 50°N with less transient eddy activity. In the present study, the modified blocking index is based on the distribution of geopotential height gradient closely around the center of blocking height at latitude 50°N over the 500 hPa level to capture the strong mass/pressure gradients. The dipole type of blocking event exists around 50°N axes. To calculate the blocking index (BI), the mass transfer for a 5° latitude around the reference latitude of 50°N is

estimated. BI is the net mass transfer between two distinct pressure belts external [Z(55°N) – Z(45°N)] and internal [Z(52.5°N) – Z(47.5°N)] to the reference latitude (50°N). Where Z represents the geopotential height. Also, BI criteria number 1, below, (BI <0.0) ensures the formation and dissipation of the blocking. In the blocking formation, the value of BI index is nearest or more than zero and in the blocking dissipation the BI value tends to zero. The BI determines the exact position of the large westerly air current aloft through a narrower band than the Lejenäs Index (Lejenäs 1984). However, this BI is a variant of the Lejenäs and Økland (1983), Tibaldi et al. (1997) and others. Also, the new index is a modification from the blocking index of Tibaldi and Molteni (1990) and Pelly and Hoskins (2003) who considered two prescribed latitudes as the central latitudes for computing the blocking index.

The blocking index (BI) is defined by the following equation:

$$BI = [Z(55°N)–Z(45°N)]–[Z(52.5°N)–Z(47.5°N)] \qquad (1)$$

Where Z (gpm) is the geopotential height at 500 hPa at any longitude in the Northern Hemisphere in the proximity of 50°N (see Fig. 2).

For a blocking event to arise, the following criteria should be met:

1- BI BI > 0.0> 0.0 at any longitude in the Northern Hemisphere
2- The first condition persists for at least five days.
3- Blocking episode should be associated with abnormal weather features over its location on the surface in general.

The anomaly method was used to capture the third condition, whereas the climatic mean values for meteorological variables were taken through the period 1981–2010.

According to this criterion (eq. 1), the 50°N is a suitable reference latitude for summer conditions that are due to the seasonal variability of the blocking lies inside BI (45°N to 55°N). Recently, researchers studied the blocking systems and heat waves over Europe and western Asia for the summer of 2010 (Barriopedro et al. 2011; Dole et al. 2011; Lupo et al. 2012; Fujii et al. 2012; Schneidereit et al. 2012; Hafez 2012; Hafez and Almazroui 2013). During the summer of 2010, the surface air temperature recorded above its normal value by 12 °C over Eastern Europe. The number of blocking episodes and their persistence days varied from one study to another for the summer of 2010 according to the criteria used. In the next section, the new index is applied to heat waves over Europe and western Asia in the summer of 2010. The blocking in summer 2010 over Europe and western Asia is a special case, which persists more than 6 weeks. Many researchers (e.g. Barriopedro et al. 2010; Dole et al. 2011; Lupo et al. 2012) studied the summer blocking 2010 over Europe and western Asia. Almost all blocking indices before new index such as Tibaldi and Molteni (1990) and others are zonal indices. These indices cannot catch all blocking days in summer 2010. The derived new blocking index and the anomalous meteorological quantities are presented in the following section. Moreover, the sensitivity test for the reference latitude for three distinct latitudes each 2.5 degrees (47.5°N, 50°N, and 52.5°N) is done.

3 Results

3.1 Blocking Systems Persisting over Europe during the Summer of 2010

By applying the new definition of blocking criteria over the Northern Hemisphere for the period 1 June 2010 to 31 August 2010, three blocking episodes are observed over Europe (15°W - 70°E, 70°N - 30°N). Figure 3 illustrates the daily variation of BIBI over Europe during the study period. Three periods of blocking, according to the new index, are clearly visible in Fig. 3. The first blocking period was initiated on 14 June 2010, dissipated on 18 June 2010 and persisted for 5 days. The second blocking period commenced on 20 June, dissipated on 6 July and persisted for 17 days. The third episode commenced on 8 July and dissipated on 12 August

Fig. 2 The location of latitudinal positions of grid points around the core latitude. Green lines for latitudes 55°N and 45°N, red lines for latitudes 52.5°N and 47.5°N, and blue line for the reference latitude 50°N
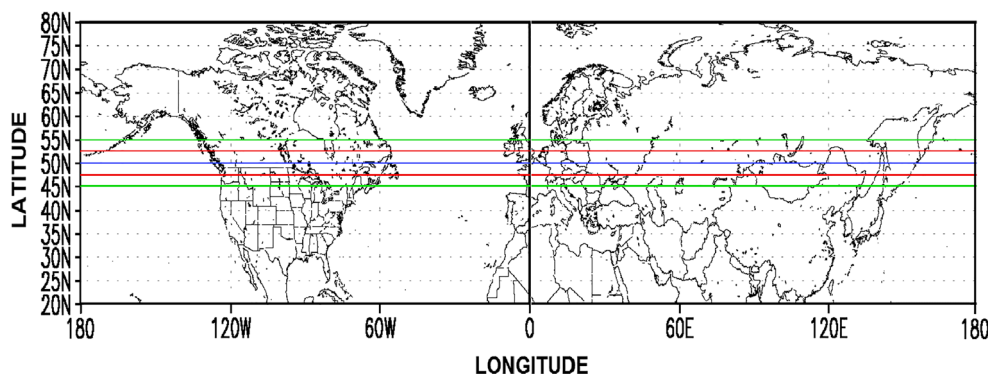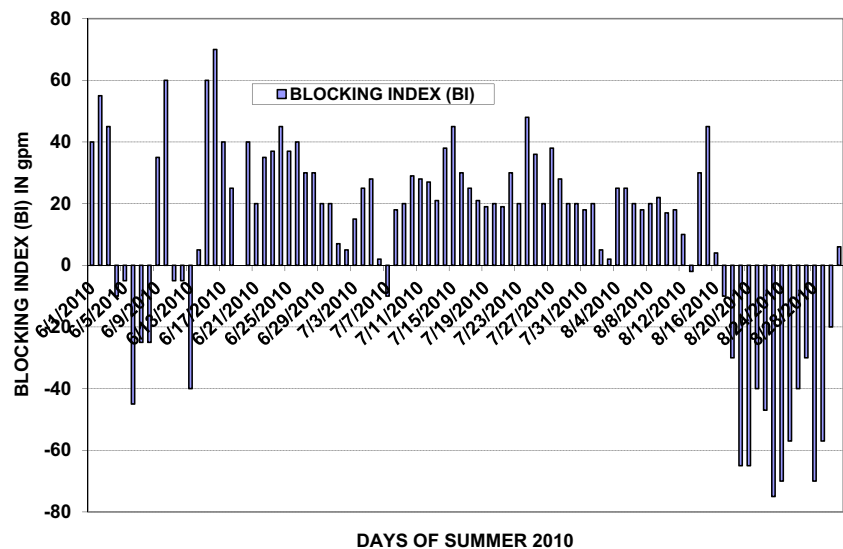
Fig. 3 The daily blocking indexing (BI) in gpm values over Europe during the summer season

2010 with a duration of 36 days. However, the total days of the three blocking events over Europe were 58 of the 92 days in the summer season, 2010. Meanwhile, the study of Lupo et al. (2012) on blocking summer 2010 over Europe and western Russia showed that the blocking episodes persisted for 48 days only. Figure 4 illustrates the formation days of the three episodes of blocking over Northern Hemisphere for the summer of 2010. It is evident from Fig. 4 that BI is greater than zero over Europe. From Fig. 4a and Table 1, the BI is greater than zero over 7.5°W. It is clear from Fig. 4b and Table 1 the BI displaced eastward to be over east of Greenwich line at 7.5°E. In addition, Fig. 4c and Table 1 illustrate BI is greater than zero and displaced faster eastward to reaches 27.5°E.

Figure 5 illustrates the day of the maximum (MAX. BI) of each blocking episode of the three cases. The characteristics of these blocks are tabulated in Table 1. From Fig. 5a and Table 1 the maximum BI is greater than zero in many areas of the Northern Hemisphere, and it reaches 70 gpm over Greenwich line on 16 June 2010. Also, one can see that from Fig. 5b and Table 1 the maximum BI is 45gpm and displaced eastward to be over 42.5°E on 24 June 2010. Moreover, Fig. 5c and Table 1 exhibit BI is greater than zero and reached to 48gpm on 24 July 2010.

According to the definition of BI in the present study, the persistence days of blocking episodes were in total 58 days (three different episodes with 4 days of interruption, Table 1). During the summer of 2010, blocking was observed between 15°W and 60°E from "mid-June" to the "mid-August" Table 1. From 14 to 18 June, Atlantic-European blocking was located at around 7.5°W, and from 20 June to 6 July, the European blocking was located at around 7.5°E); subsequently, it moved eastward in 8 July and remained near 27.5°E, as Ural blocking, until the beginning of 12 August. This result is in agreement with the result of Matsueda (2011). Elansky et al. (2011) demonstrated that the blocking height

over the European part of Russia recorded in the summer of 2010, significantly exceeded those previously recorded, in its duration. When applied the new definition of the blocking index, which described in Section 2b three different blocking episodes are observed, their features are given in Table 1. The July–August episode (episode 3) persisted for 36 days, which implies that it is one of the most persistent events in the Northern Hemisphere since 1970 (see Wiedenmann et al. 2002; Lupo et al. 2012). Moreover, studies by Tilly et al. (2008) and Matsueda (2011) identified the blocking episode that occurs from mid-to-late June to early-to-mid-August, using a different blocking definition (see also Elansky et al. 2011).

3.2 Blocking Index and Abnormal Weather over Europe during the Summer of 2010

To study the impact of blocking systems during the summer of 2010 (1 June −31 August 2010) on weather over the Northern Hemisphere, including Europe (15°W - 70°E, 70°N - 30°N)**Error! Digit expected.**, time/longitude cross-section analysis of BI and operational data of weather variables over Europe was conducted. These meteorological variables are geopotential height at 500 hPa level, surface air temperature, daily maximum temperature, daily minimum temperature, zonal and meridional wind field, daily precipitation rate, surface relative humidity, outgoing long-wave radiation at the top of the atmosphere, and sea level pressure. The anomaly methodology was used in the present study, with the following results:

1- Comparison between anomaly of geopotential height over Europe region and BI (Fig. 6) BI revealed that positive anomaly in geopotential height reached +120 gpm

Fig. 4 Blocking index BI in gpm distribution in the blocking formation days for the three cases of blocking episodes during the summer season, (**a**) 14 June 2010 (first case), (**b**) 20 June (second case) and (**c**) 8 July (third case)
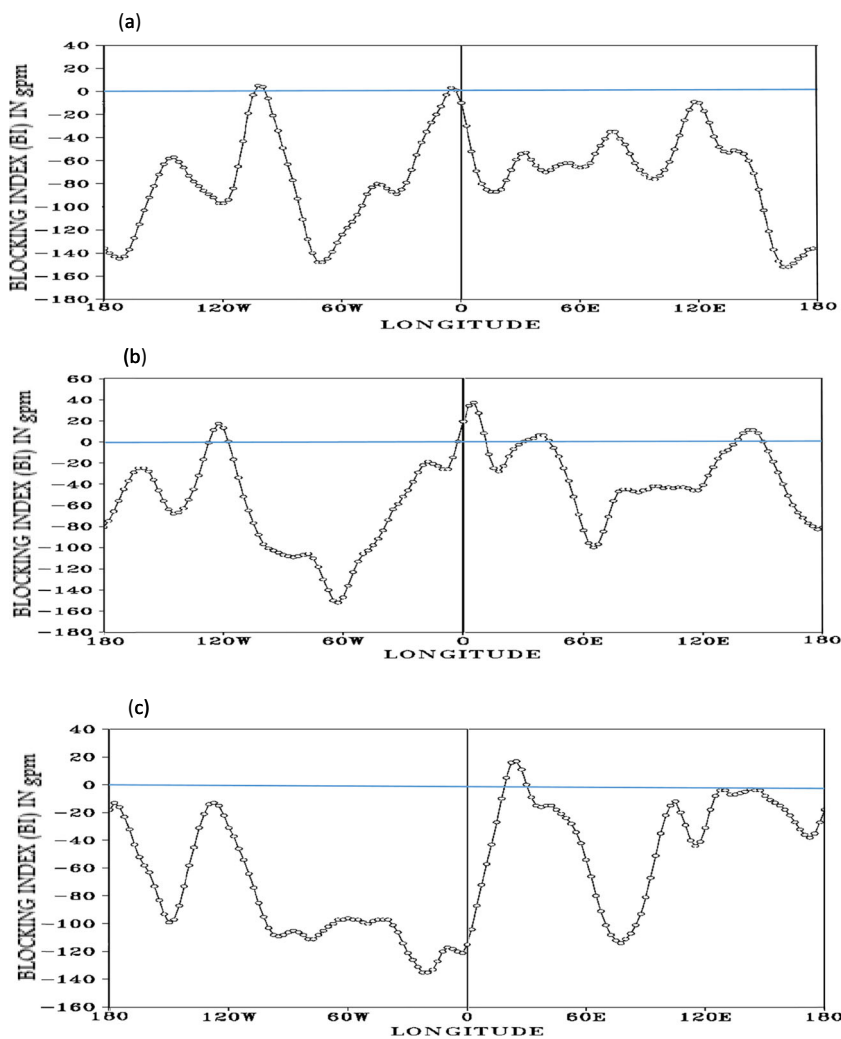
over Europe during the duration of the three blocking events existing over Europe in the summer of 2010.

2- The surface air temperature anomaly ranges from 0 °C to 4 °C over most parts of Europe during summer 2010 (Fig. 7). The maximum air temperature anomaly at the surface reached 6 °C on July 27th, considering the latitudinal average between 30°N-70°N.

3- Eastern Europe registered extremely high values of maximum surface air temperature (40 °C) and the minimum surface air temperature was only as low as 21 °C for

almost every day during the duration of the blocking episode over Europe, during the study period. So, the daily minimum temperature almost not reached 20 °C not shown.

4- Zonal wind at 500 hPa level was mainly less than normal values (-4.8 m s^{-1}) during the days of blocking that persisted over Europe (see Fig. 8).

5- For meridional wind, there is an opposite direction between western and eastern Europe. Over western Europe, meridional wind exceeded its normal values by

Table 1 The blocking events formed and their characteristics such as dates, duration, formation, maximum (BI) for each case over Europe during summer of 2010

Event	Dates	Duration (days)	Formation (longitude)	Max. (BI) value (m)	Max. (BI) (longitude)
1	14 June to 18 June	5	7.5°W	70 On 16 June	0° Greenwich
2	20 June to 6 July	17	7.5°E	45 On 24 June	42.5°E
3	8 July to 12 August	36	27.5°E	48 On 24 July	42.5°E
Total		58 days			

Fig. 5 The distribution of maximum blocking indexing (Max. BI in gpm) for three blocking episodes that existed over the Northern Hemisphere, during the summer season (**a**) on 16 June (first case) (**b**) on 24 June (second case) (**c**) on 24 July (third case)
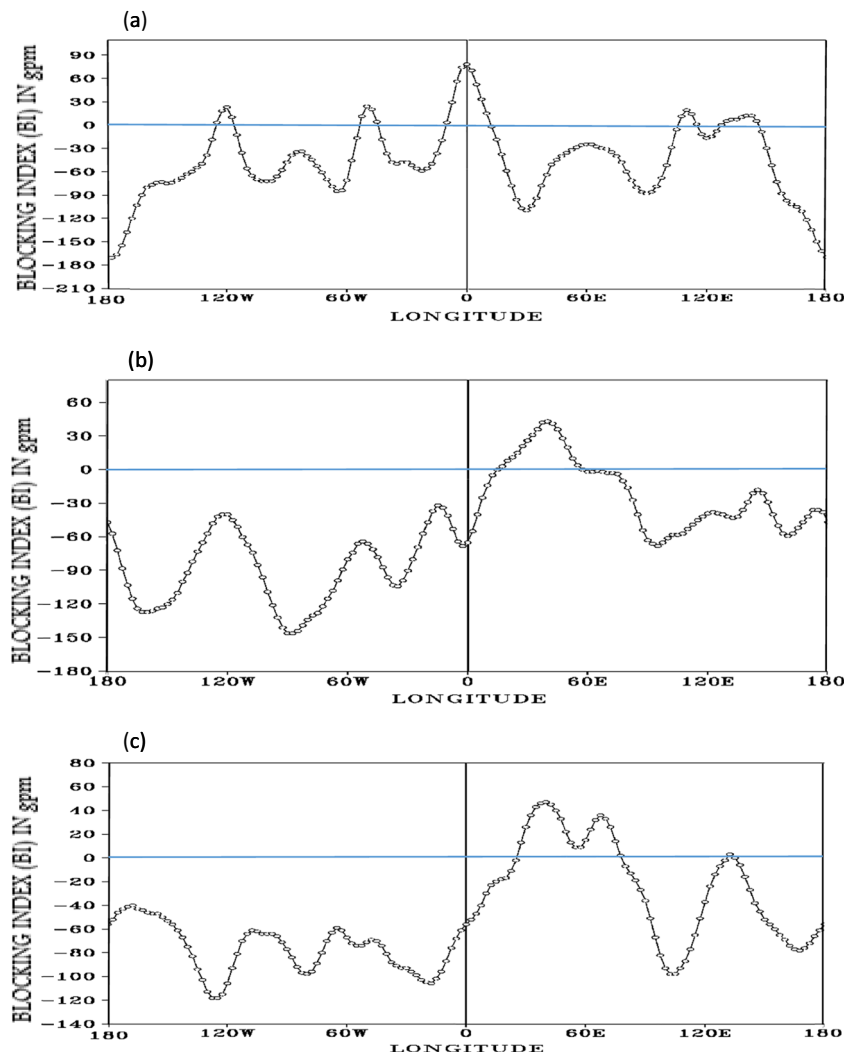
+13.5 m s^{-1}. Therefore, the direction of the wind is toward the north. Meanwhile, in the eastern part of Europe, it was less than its normal values (−15 m s^{-1}) during the persistent blocking events (see Fig. 9). Therefore, the direction of the wind is toward the south that explain an anticyclonic circulation.

6- Associated with the prevailing anticyclonic circulation over Europe, increased precipitation and increased relative humidity are observed west of the BI, while lower than normal conditions are observed east of the anticyclone (Figs. 10 and 11).

7- Mainly over central and eastern Europe regions, during the days of blocking episodes, a strong positive anomaly outgoing longwave radiation (OLR) was > +25 W/m^2 (see Fig. 12). The maximum anomaly of the OLR appears far away from the blocking region that is meaning this area has no clouds. OLR is really closest to a measure of cloudiness. The average of the OLR is around 5 W/m^2 in the area of blocking high that has a much cloudy. So, OLR is decreased over the blocking high (around 60°E)

due to cloud cover is trapping OLR while OLR is increased over none blocking area (around 120°E) due to the absence of cloud cover.

8- Near longitude 60°E, there was a positive anomaly of sea level pressure, which reached +10 hPa during the blocking episodes over Europe (see Fig. 13). Increase of mean sea level pressure reflects the stability of the atmosphere in the region of blocking high.

4 Discussion and Conclusion

Several challenges were encountered in the preparation of this study, and they include, the definition and application of the new blocking criteria over the Northern Hemisphere (including Europe); detection of the blocking episodes that existed over Europe during the summer of 2010; and the study of abnormal weather that existed over Europe through the

Fig. 6 The daily (time/ longitude) cross-section distribution of BI index in gpm (black closed isolines) and geopotential height positive anomaly (gpm) at 500 hPa level in the Northern Hemisphere during the summer season, averaged for the European region (30°N to 70°N). The anomaly is defined as departure from climatology (1981–2010)
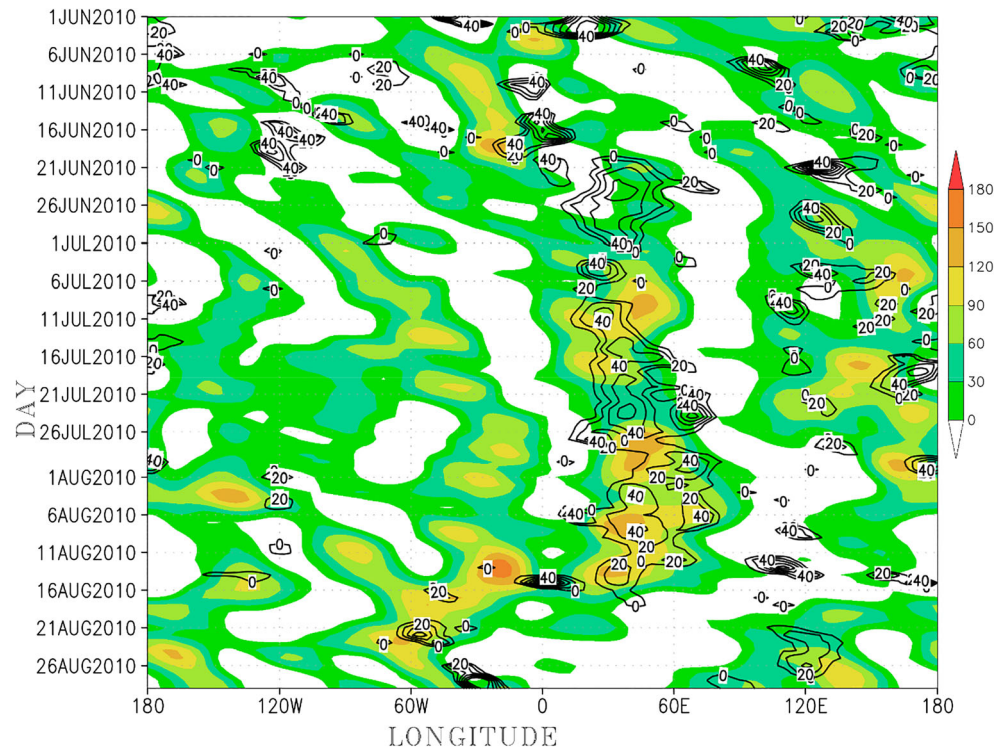
blocking persistence days. Due to the different definitions of blocking indexing, there exist differences in the duration of blocking episodes. Lupo et al. (2012), as an example, took the minimum duration of five days. They illustrated that during the summer of 2010, blocking episodes persisted for 48 days over Europe and the European part of Russia, and resulted in anomalously warm and dry conditions over the region.

The results of the study show that all of Europe suffered from very hot weather during the persistence of the blocking events. There have been studies of weather conditions and the

Fig. 7 The daily (time/ longitude) cross-section distribution of BI index in gpm (black closed isolines) and surface air temperature positive anomaly (°C) in the Northern Hemisphere during the summer season, averaged for the European region (30°N to 70°N)
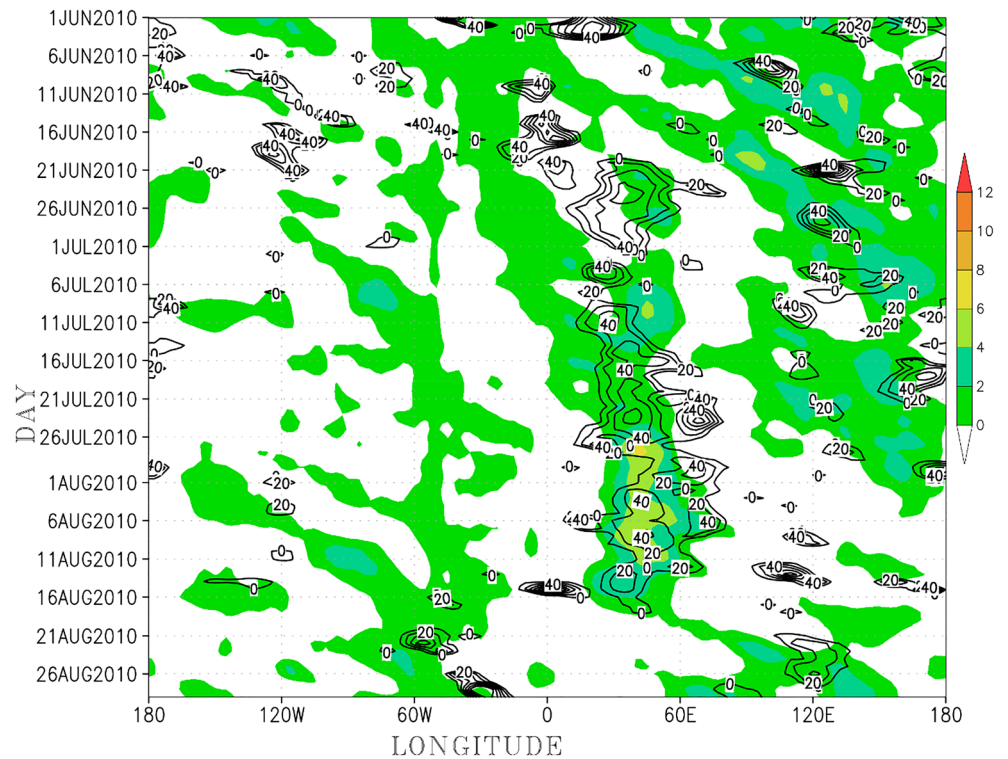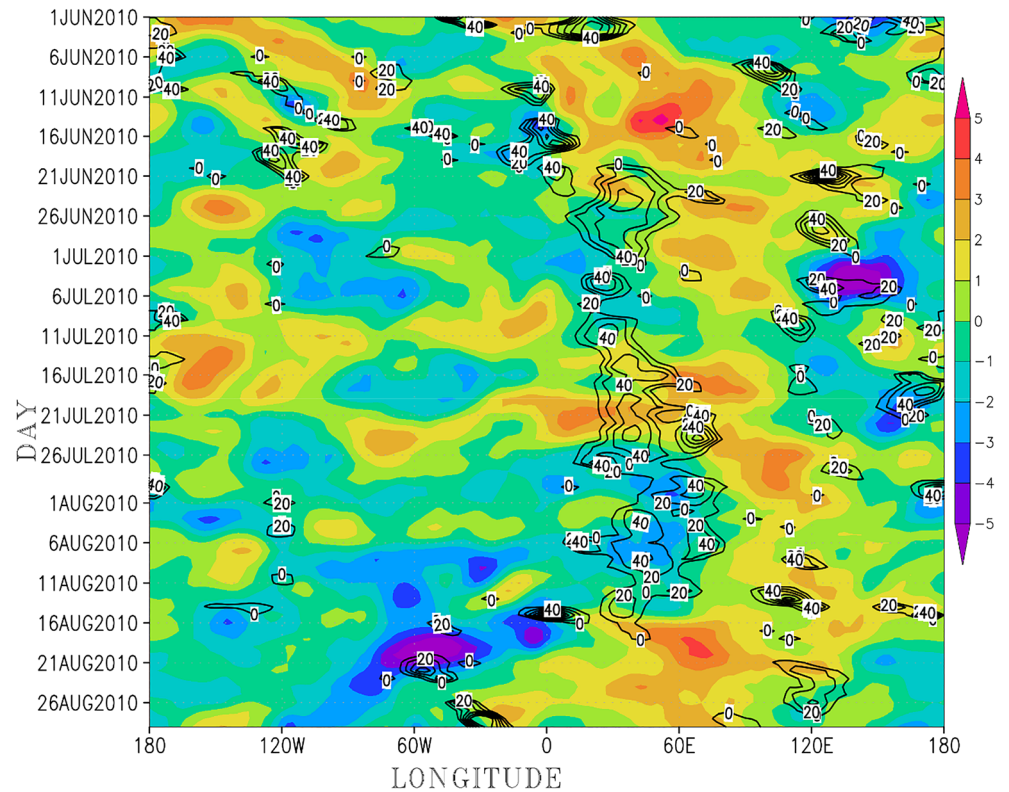
Fig. 8 The daily (time/ longitude) cross-section distribution of BI index in gpm (black closed isolines) and zonal wind anomaly (m s⁻¹) at 500 hPa level in the Northern Hemisphere during the summer season, averaged for the European region (30°N to 70°N)

identification of blocking index over Europe using NCEP/ NECR reanalysis and operational data obtained from Boulder, Colorado, USA, and it becomes clear that:

1- The new BI over Europe, from 1 June to 31 August 2010 gives three distinct blocking episodes with a duration of 5 days, 17 days and 36 days, with a total of 58 days out of

Fig. 9 The daily (time/ longitude) cross-section distribution of BI index in gpm (black closed isolines) and meridional wind anomaly (m s⁻¹) at 500 hPa level in the Northern Hemisphere during the summer season, averaged for the European region (30°N to 70°N)
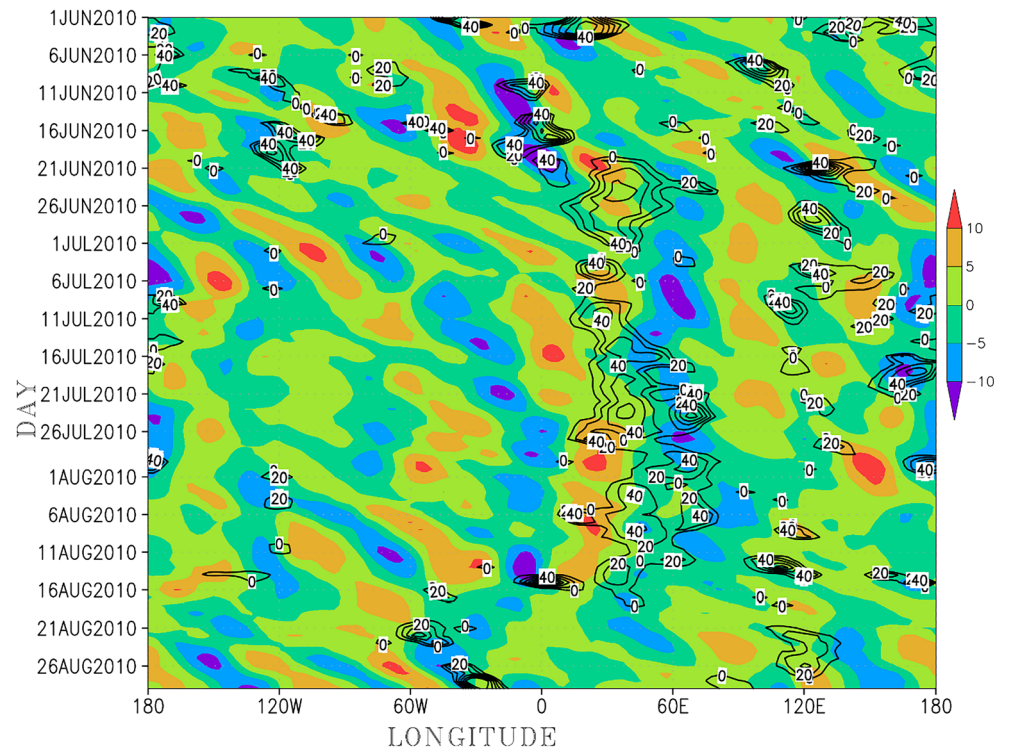
Fig. 10 The daily (time/longitude) cross-section distribution of BI index in gpm (black closed isolines) and anomaly of daily precipitation rate (mm/day) in the Northern Hemisphere during the summer season, averaged for the European region (30°N to 70°N)
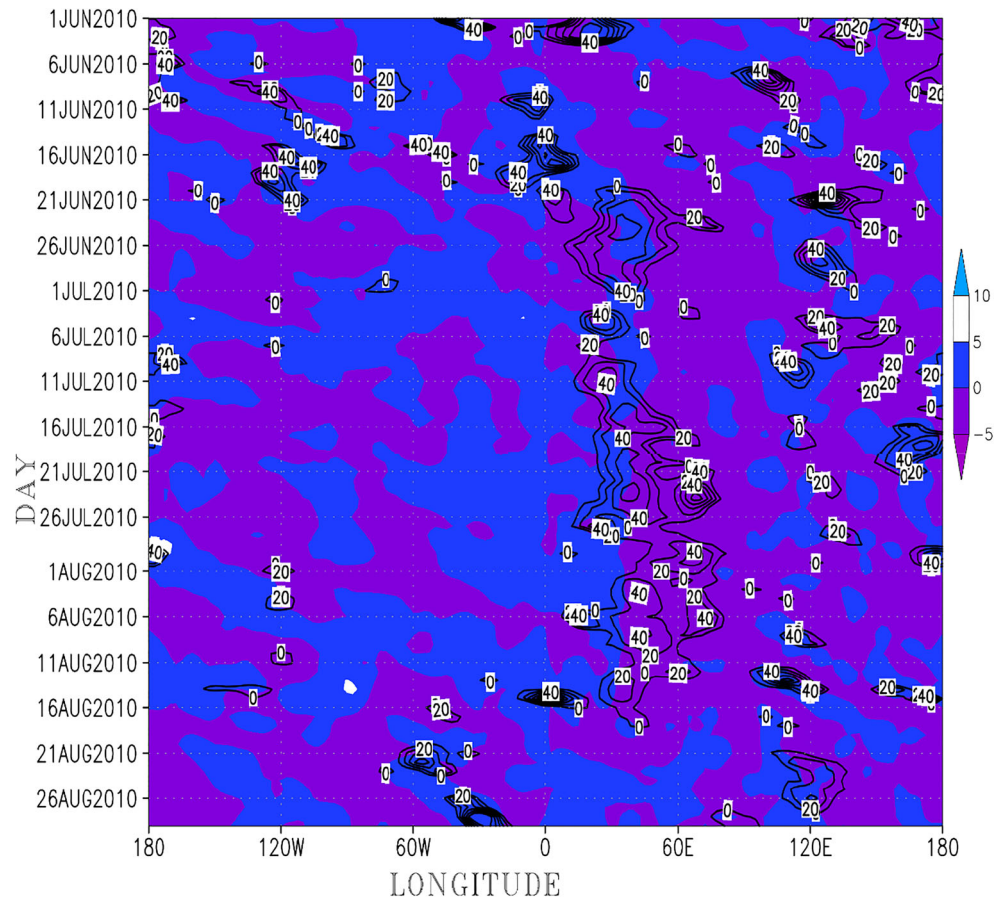

Fig. 11 The daily (time/longitude) cross-section distribution of BI index in gpm (black closed isolines) and positive anomaly relative humidity (%) at the surface in the Northern Hemisphere during the summer season, averaged for the European region (30°N to 70°N)
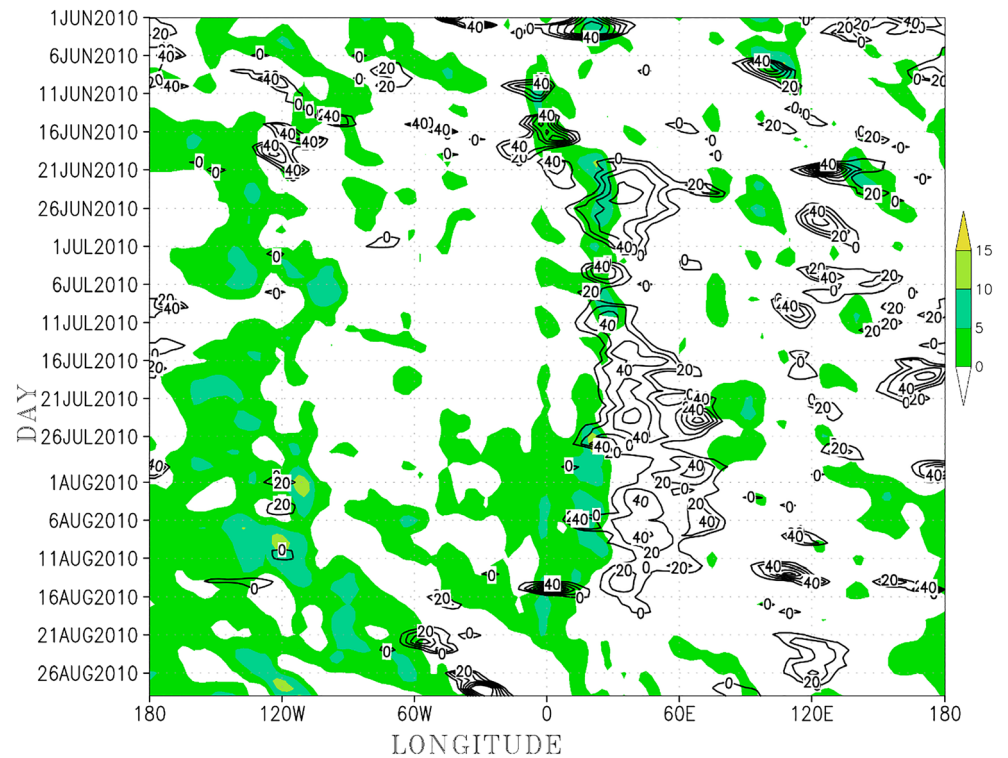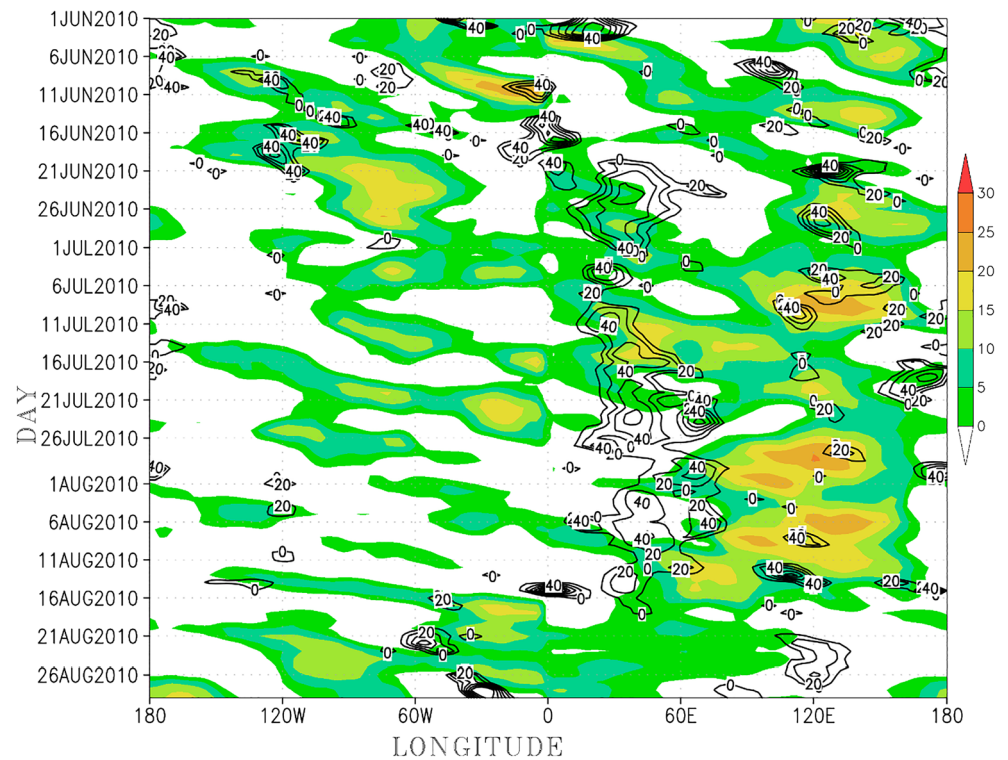
Fig. 12 The daily (time/longitude) cross-section distribution of BI index in gpm (black closed isolines) and OLR (Wm^{-2}) in the Northern Hemisphere during the summer season, averaged for the European region (30°N to 70°N)

92 days of the summer season. The first case identified was from 14 June to 18 June, which formed over western Europe (7.5°W). The BI reached its maximum value on 16 June when the block persisted over 0° longitude. The second episode initiated on 20 June in 7.5°E longitude and dissipated on 6 July, while BI reached its maximum value on 24 June, when the block persisted that day over 42.5°E longitude. The third event was formed on 8 July over 27.5°E longitude and dissipated on 12 August. The BI reached its maximum value on 24 July, when the block

Fig. 13 The daily (time/longitude) cross-section distribution of BI index in gpm (black closed isolines) and mean sea level pressure positive anomaly (hPa) in the Northern Hemisphere during the summer season, averaged for the European region (30°N to 70°N)
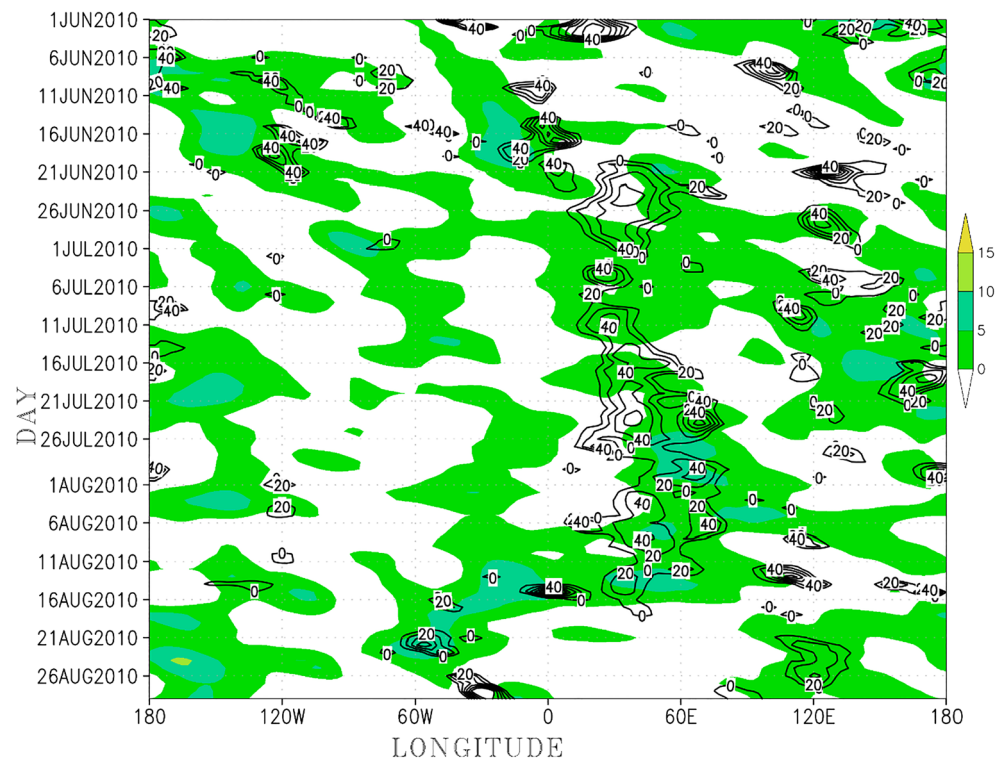
was located over 42.5°E longitude. The results revealed that the blocking systems were initiated over western Europe, and persisted for 5 days and moved toward the east to persist for over 53 days, over eastern Europe. These results correspond to the abnormal weather that first occurred over western Europe and later on moved to eastern Europe during the summer of 2010.

2- The results of Lupo et al. (2012) on the summer of 2010 demonstrated that the total duration of blocking episodes that occurred over Europe was 48 days. Their method, however, could not detect the remaining ten days of persistent blocking episodes over Europe with abnormal weather. The missing ten days in the results of Lupo et al. (2012) is due to the method used is a zonal blocking method. According to Barriopedro et al. (2010), zonal blocking methods failed to catch the omega shape block. On another hand, the current study detected the 58 days of blocking events.

3- During the summer of 2010, the Northern Hemisphere including Europe had observed a new record of exceptionally abnormal high surface air temperature and extreme weather conditions. In general, severe heat waves had impacted most of the European countries. However, the forest fires occurred when Russia was experiencing its worst drought in just over 100 years (see Grumm 2011; Barriopedro et al. 2011).

4- Through a time / longitude cross-section analysis of the BI distribution and the meteorological weather variables (geopotential height, temperature, wind, OLR, humidity, precipitation rate, surface pressure) over the Northern Hemisphere, including Europe for the study period. It is observed that the anomalies in the meteorological variables occurred completely during the anticyclone blocking high episodes over European region. It is noticed that in the case of summer 2010, the surface temperature is the most element affected by the anticyclone rather than the other weather elements.

5- The distribution of the meteorological parameters over Europe during summer 2010 of blocking episodes illustrates day by day the impacts of that block in the weather elements. Analysis of the meteorological parameters revealed that the extreme values of the weather elements existed mainly over Eastern Europe during the persistence of that summer block. Heatwaves, drought, extreme surface and upper air pressure distribution, and extreme energy distribution observed over the flank of the blocking through that season. Also, the changes of the weather elements over Europe for the region (from 10-degree longitude west to 30 degrees east of Greenwich) are not in the same manner to the changes for the region from longitude 30 degrees east to longitude 60 degrees east. This different arises from the shape of the wave train through the region from 10°W to 60°E.

6- There are different mechanisms, which are responsible for the generation and maintenance of blocking highs. Approaching wave trains are one of these mechanisms. The Rossby wave train identifies as a difference notably between positive anomaly (yellow color) and negative anomaly (approximately cyan color) of the meridional wind as shown in Fig. 9 through the area of blocking from approximately 10°W to 60° E. In addition, the precipitation rate (Fig. 10) increases on the western side of the blocked region, which could be a result of wave trains. Moisture is transported just towards to western side of the block. Moreover, the convergence of wave activity density flux associated with incoming quasi-stationary Rossby wave train is emphasized for the blocking formation over Europe (Naoe and Matsuda 2002.)

7- The anomalies of the surface pressure (Fig. 13) are close to 60°E, which could reflect a quasi-barotropic structure of the anticyclone. A coincidence of positive SLP anomalies and the BI indicates the barotropic nature of the anticyclone.

8- One can concluded from the discussion of the relationship between blocking event and anomalies of weather elements that the existence of blocking change the westerly air current aloft and causes retardation of Rossby wave. The changes of the westerly air current impacts on the weather conditions to create an outstanding anomaly in the meteorological weather elements over European sector during summer 2010.

9- A sensitivity test study of the reference latitude for three distinct latitudes each 2.5 degrees (47.5°N, 50°N, and 52.5°N) is done. It is clear that the blocking index value is very sensitive to the reference latitude. The blocking days change far from its exact days for the two reference latitudes 47.5°N and 52.5°N as shown in Fig. 14 and Table 2.

From Table 2, three distinct cases for each reference latitude (47.5°N, 50°N, and 52.5°N) is found. There are different durations and total days for each reference latitude. For 47.5°N reference latitude, the duration days are (1 June - 8 June) with 8 days, (15 June - 1 July) with 17 days, and (8 July - 12 August) with 36 days. While for 50°N reference latitude, the duration days are (14 June - 18 June) with 5 days, (20 June - 6 July) with 17 days, and (8 July - 12 August) with 36 days. Moreover, for 52.5°N reference latitude, the duration days are (20 June −1 July) with 12 days, (3 July - 1 August) with 30 days, and (4 August - 10 August) with 7 days. From the comparative references, latitudes one can be observed that the change of reference latitudes leads to the change of the duration of blocking episodes in general. Additionally, these results revealed that the 50°N reference latitude represents the duration time of blocking episodes more than the other reference latitudes 47.5°N and 52.5°N.

Fig. 14 The distribution of blocking index BI in gpm for the Northern Hemisphere at three distinct reference latitudes (**a**) 47.5°N latitude, (**b**) 50°N latitude, (**c**) 52.5°N latitude
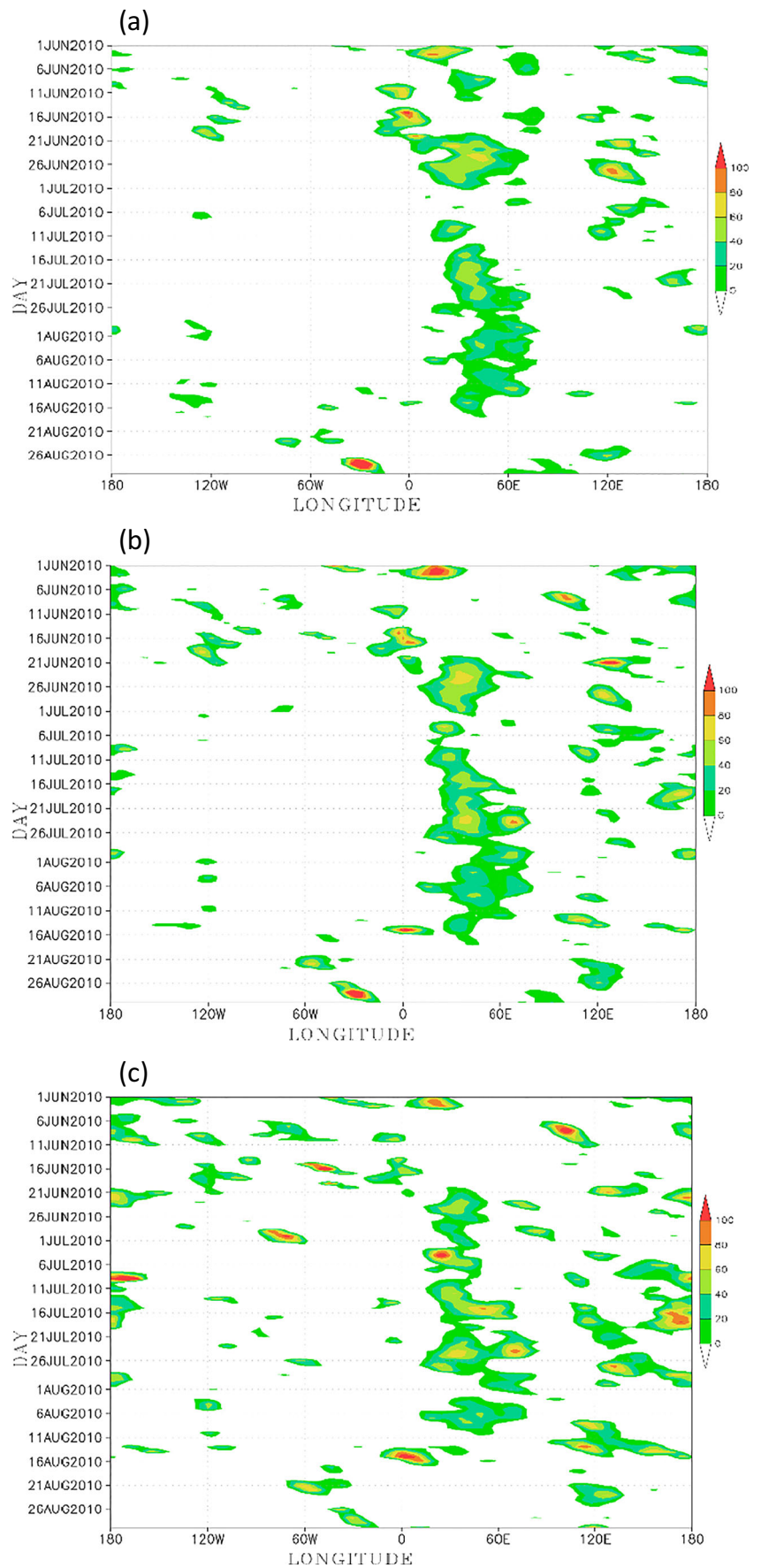
Table 2 The blocking events their characteristics such as dates, duration, (BI) for each references latitude (47.5°N, 50.0°N, and 52.5°N) over Europe during summer of 2010

Reference latitude	blocking events						Total Days
	Case 1		Case 2		Case 3		
	Dates	Duration (days)	Dates	Duration (days)	Dates	Duration (days)	
47.5°N	1 June - 8 June	8	15 June −1 July	17	8 July - 12August	36	61
50.0°N	14 June - 18 June	5	20 June - 6 July	17	8 July - 12August	36	58
52.5°N	20 June −1 July	12	3 July - 1 August	30	4 August - 10 August	7	49

The three references latitude (47.5°N, 50°N, and 52.5°N) are catching the existence of blocking area from 10°W to 60°E longitude during the summer season 2010. The longest duration of the blocking case from 8 July - 12 August was detected for the two references latitude 47.5°N and 50°N only. The duration from 1 June to 8 June is an unrealistic blocking event (Lupo et al. 2012), which caught at 47.5°N reference latitude. Statistically, the percentage of the blocking persistence days are 67%, 64% and 54% for the three reference latitude (47.5°N, 50°N, and 52.5°N) respectively through the 92 days of summer season 2010. The average percentage of the blocking persistence days is 62%, which is the nearest one to the percentage of the 50°N reference latitude and far away from the 52.5°N and 47.5°N reference latitude. Therefore, one can conclude that the reference latitude 50°N is more suitable than the other reference latitudes.

Moreover, the missing ten days in the results of Lupo et al. (2012) is due to the method that used is a zonal blocking method. According to Barriopedro et al. (2010), zonal blocking methods failed to catch the omega shape block.

The sensitivity test of reference latitude for omega block cases clarifies that the new method (reference latitude 50°N) catch-all ten days (14 to 18 June and from 29 June to 3 July 2010), which BI <0.0. Meanwhile, for the reference latitude 52.5°N, BI <0.0 for the period from 15 to 17 June and from 29 June to 2 July. Also, for the 47.5°N reference latitude the BI <0.0 for the period from 15 to 18 June and from 29 June to 2 July 2010. Therefore, the new method is more sensitive and relevance to all types of blocking events including omega shape blocking.

Other algorithms have problems with that specific days due to the other algorithms have a zonal indices. Omega block (Fig. 1a) over the North Atlantic is important for the heatwave over Europe due to the persistence of blocking high over the North Atlantic that affects the westerly air current over Europe. The omega block increases the persistence of high-pressure systems over Europe, which leads to an increase in the subsidence air aloft that leads to an increase in the surface temperature to become above

normal and maybe create the heat waves over Europe.

It is concluded that the weather over Europe in summer season 2010 was unique and abnormal, which the surface air temperature exceeds its normal value by 12 °C over eastern Europe. The revised blocking criteria succeeded in defining and capturing precisely the blocking systems that occurred in the summer of 2010 and matched to the abnormal weather over Europe during that period. In the future, we will study several blocking cases for several seasons and long period years and tested the appropriate reference latitude.

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