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On the Existence of Summer *Shamal Wind* Induced by the Zagros Mountains in the Middle East

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Key Points:

- A new structure is proposed to explain the mechanism governing the summer Shamal wind (SSW) formation in the Middle East (ME)
- The SSW forms by a unique semi-permanent regional atmospheric circulation due to an internal forcing
- The Zagros Mountains are the primary driver to generating a localized atmospheric circulation over the ME

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Abstract

A new structure is proposed to explain the mechanism governing the summer Shamal wind (SSW) formation in the Middle East (ME). Here, the irreplaceable role of the Zagros Mountains (ZAG) as the primary driver of a localized atmospheric circulation over the ME has been clarified. We show that the SSW is mainly established and maintained due to the local forcing of the ZAG. A background low-level easterly flow dominates on the east side of the ZAG which is basically from Turkmenistan Anticyclone. The flow in association with a vertical heat advection over the ZAG while generating Iran anticyclone (IA) in the middle troposphere, develops so-called regional atmospheric circulation over the ME. As a part of the localized circulation, descending air from IA establishes the Arabian anticyclone-Zagros Trough coupling pattern over Mesopotamia. This coupling pattern is the significant driver of SSW and its induced dust storms over the ME.

Plain Language Summary

Summer Shamal wind (SSW) is one of the local winds with high continuity and variability in the Middle East (ME), which frequently causes widespread dust storms in the region during the summer. Although the inhabitants of Mesopotamia have been familiar with the Shamal wind and its environmental effects since ancient times, there are still unknown aspects regarding the structure, formation, and development of the SSW. In this research, an attempt has been made to introduce a new structure for the occurrence of SSW. Here, we discuss how the thermal and mechanical forcings from local topography form a regional atmospheric circulation in the ME. In fact, the SSW is one of the components of this regional atmospheric circulation.

1. Introduction

Among the arid and desert regions of the world, east of MP and north of the Arabian Peninsula is known as a significant source area of dust storms. In this region, dust storms form along the ZAG in a corridor east of MP. In a relatively persistent pattern, they blow toward the Persian Gulf and northern Saudi Arabia during the warm period of the year. The high frequency of dust storms in the corridor mentioned above makes it one of the relatively permanent features visible in satellite images of the ME in boreal summer (Figure 1a). According to previous studies, the formation of dust storms in the Persian Gulf area and eastern Iraq, more than any other factor, is the result of the permanent presence of a regional-scale wind called the "Shamal Wind" (hereafter SHW) (Ali, 1994; Al senafi & Anis, 2015; Hamidi et al., 2013; Houseman, 1961; Membery, 1983, [hereafter MEM83]; Middleton, 1986; Mofidi & Jafari, 2011; Najafi et al., 2017; Yu et al., 2013, 2015).

1.1. SSW; an Overview

In the ancient Mesopotamian civilization©era, in which the principle astronomical directions (N, S, W, E) had not been developed, the SHW was one of the orientation determiners referring to the North direction (Neumann, 1977).

The SSW blows from May to July. This period, especially in June and the beginning of July, led the local inhabitants to call it *Forty-day Shamal* (Houseman, 1961). However, recent studies indicated that the wind is about 75 days long in its main blowing area, the eastern corridor of Iraq (Hassani, 2016; Yu et al., 2016). The SSW blows across regions spanning eastern Iraq, parts of southwestern Iran, the western Persian Gulf, Kuwait, and northern Saudi Arabia.

The SSW shows high interannual, intraseasonal, and diurnal variations. In addition, during June and July, the SHW frequently experiences a Nocturnal low-level jet (NLLJ) in its two preferred areas in the North and East of Iraq (Figure 1b; Ali, 1994; Al senafi & Anis, 2015; Francis et al., 2017; Giannakopoulou & Toumi, 2012; Hassani, 2016; Membery, 1983; Mofidi & Jafari, 2011). The formation of low-level jets in the two preferred areas

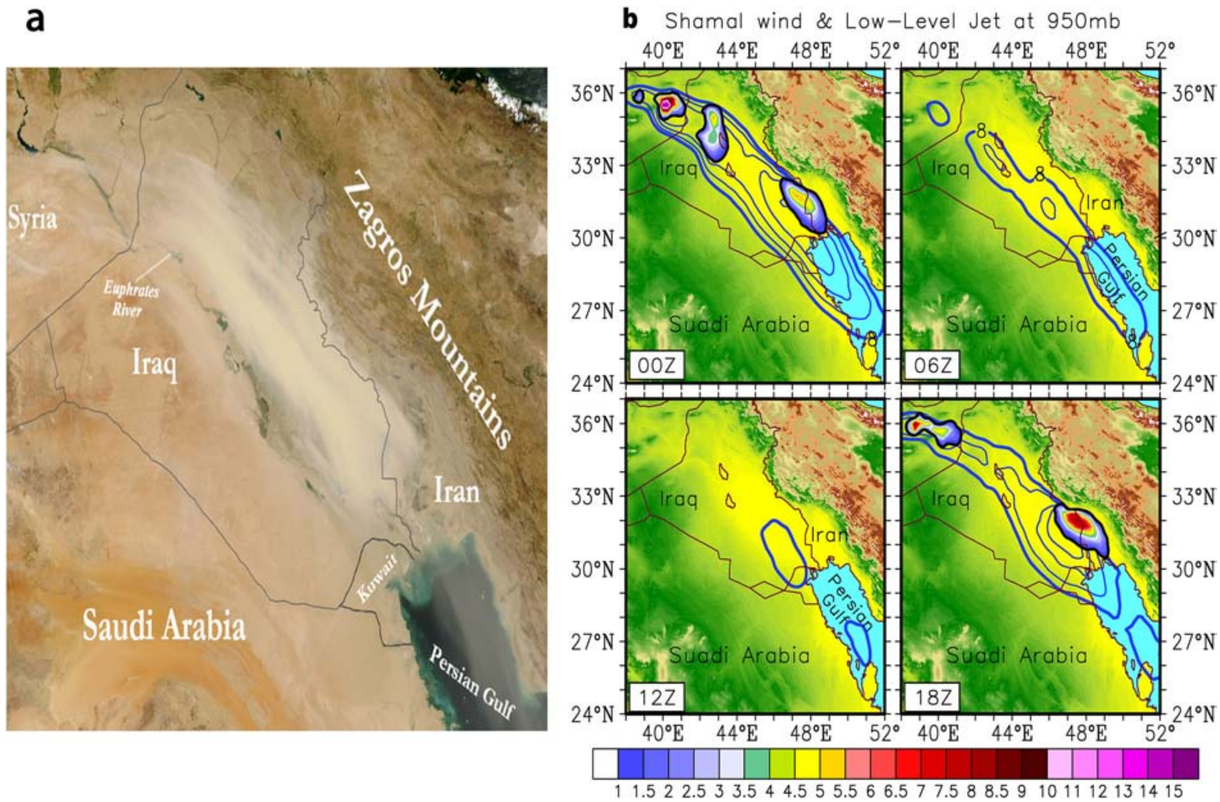

Figure 1. (a) Aerial view of the MODIS on NASA©sAqua satellite that shows a dust storm in the eastern corridor of Iraq (08 August 2005) (https://earthobservatory.nasa.gov/images/5745/iraq-dust-storm). (b) The mean frequency of low-level jet (shaded; threshold: 15 m s^{-1}) at different hours of the day for May–August based on the ERA5 data set at 950 hPa for 41 years (1980–2020). For comparison, blue lines are the long-term mean intensity of Shamal wind (≥8 m s^{-1}) for June–July. The topography is added to the background.

of the SHW is the fundamental cause of most summer dust storm events in the ME (Ali, 1994; Francis et al., 2017; Mofidi & Jafari, 2011). Although we witness different types of dust storms, including frontal (pre-frontal and post-frontal), cyclonic, convective, and Shamal dust storms due to different formation mechanisms and synoptic patterns throughout the year (Hamzeh et al., 2021; Karami et al., 2021; Mohammadpour et al., 2021), however, the intraseasonal variation and interannual activity of dust storms in the corridor of eastern Iraq are directly related to the Spatio-temporal variability of the SSW and its NLLJ core in MP during the summer and at the peak of dust activity (Ali, 1994; Al senafi & Anis, 2015; Najafi et al., 2017; Pye, 1987; Yu et al., 2013, 2015, 2016).

The SHW and its regional effects concerning dust activities have been widely studied in the last decades (Ali, 1994; Goudie, 2001; Goudie & Middleton, 2006; Hamzeh et al., 2021; Hassani, 2016; Houseman, 1961; Karami et al., 2021; Mohammadpour et al., 2021, 2022; Notaro et al., 2013; Pye, 1987; Rashki et al., 2019; Yu et al., 2016), whereas the regional-scale circulation that governs the formation and development of SSW is less well understood. In one of the few studies, MEM83 suggested that the SSW is the result of a simultaneous establishment of a semi-permanent high-pressure cell in northern Saudi Arabia, and a trough on the lee of the ZAG, which is connected to heat low over Pakistan and Afghanistan. Many studies have confirmed this result (Al-khalidi et al., 2021; Goudie & Middleton, 2006; Hamidi et al., 2013; Hassani, 2016; Najafi et al., 2017; Pye, 1987; Rao et al., 2003). Moreover, MEM83 reported a NLLJ at an altitude of 150–400 m above the ground in the SHW. Considering the vertical wind shear and the time of maximum wind speed, MEM83 suggested the theory of Blackadar (1957) as the primary mechanism for the formation of NLLJ in the SHW. Theoretically, the inertia oscillation in ageostrophic wind due to vanishing or a sudden decrease of turbulence in the planetary boundary layer hours after sunset would result in the formation of a very strong nocturnal wind on the bottom of the residual layer (Blackadar, 1957; Bonner & Paegle, 1970).

Despite the findings mentioned earlier, there are still some open questions to be addressed regarding the mechanism of SSW formation. How may a high-pressure center form at the lowest atmospheric levels on the north side of the Arabian Peninsula at the peak of summer when the surface is extremely hot due to very high incoming solar radiation? Why do the SSW and its NLLJ core orientation blow precisely along the axis of the ZAG? Why does the SSW persistent in the eastern corridor of Iraq each year, only for approximately two months (beginning of June to early August)? In addition, some other questions arise. For example, what causes intraseasonal and interannual variations in the intensity and frequency of SSW? Why does NLLJ appear only on a few numbers of windy summer days in the corridor of eastern Iraq?

The above-unanswered questions, along with recent findings on the role of the ZAG as the main driver of the SSW (Giannakopoulou & Toumi, 2012), bring this idea to mind that the formation of this wind relates to the thermal and mechanical forcings of local topography that affect the regional atmospheric circulation over the ME. Recent studies have made it clear that the ZAG affect the regional circulation of the atmosphere in the ME during the summer both as an elevated heat source (Mofidi & Zarrin, 2012; Zaitchik et al., 2007; Zarrin et al., 2011) and as a mechanical forcing (Rodwell & Hoskins, 1996, 2001; Simpson et al., 2015). More than any other factor, the formation of mid-tropospheric anticyclone in western Iran refers to the ZAG and its fundamental role in favoring a regional atmospheric circulation in summer. The evidence presented in the above research led us to assume that the ZAG favoring westward regional circulation play a key role in the formation and maintenance of SSW.

Here it is necessary to explain that the structure of summer atmospheric circulation over the ME is traditionally considered to be the result of large-scale external forcing rather than local forcing. Based on a traditional view traced back to the works of Sawyer (1947) and Snead (1968), many Middle Eastern climatologists consider summer subtropical anticyclones of ME as an extension of the Azores High. Or, in a more general view, they believe that the formation of subtropical anticyclones and atmospheric circulation on the synoptic-scale in the ME are strongly influenced by the descending branch of the Hadley cell during the summer. Also, almost all climatologists believe that the low pressure systems in the lower troposphere in the heart of the ME including the Persian Gulf trough, are the extension of the South Asian Summer Monsoon (SASM) (Alpert et al., 2004; Bitan & Saaroni, 1992; Pye, 1987; Ziv et al., 2004). Furthermore, the recent findings on the role of SASM in the formation of summer regional atmospheric circulation over the ME have re-emphasized the prominent effect of external forcing from tropics (i.e., Monsoon-Desert mechanism) (Attada et al., 2019; Liu et al., 2017; Mofidi & Zarrin, 2012; Rizou et al., 2018; Rodwell & Hoskins, 1996, 2001; Sooraj et al., 2021; Tyrlis et al., 2013; Wu et al., 2012; Ziv et al., 2004). The combination and synergy of these views have led to the conclusion that the ME climate is controlled by large-scale external forces during the warm period of the year. Although we may identify the role of tropical external forcing in the upper troposphere, its footprint is not so clear in the middle, and in particular, in the lower troposphere. Instead, an internal forcing with the origin of the ME highlands, mainly from the ZAG may be considered the primary driver of localized atmospheric circulation, which governs the region. Accordingly, under the pretext of identifying the structure of summer shamal wind, we hereby present a new structure for atmospheric circulation in the middle and lower troposphere of the ME region, a structure that basically has a local and independent origin and nature.

In this research, we first briefly discuss the characteristics of the SSW. Then, we reveal the relationship between the SHW and the circulation influenced by the ZAG. Finally, we explain the role of the ZAG in the formation and maintenance of the SSW.

2. Materials and Methods

2.1. Data

In this research, 4-time daily data for a period of 41-year (1980–2020) is obtained from the Copernicus Climate Change Service through the CDS website (https://climate.copernicus.eu). To investigate the characteristics of the SSW, we used -zonal and meridional wind components at different levels from the fifth-generation ECMWF atmospheric reanalysis (ERA5) with a horizontal resolution of 0.25° (Hersbach et al., 2020). In addition, for the investigation of regional-scale atmospheric circulation, the ERA5-ensemble mean of air temperature, relative vorticity, divergence field, and vertical velocity in 0.5° horizontal resolution are used at different pressure levels for the same period and time steps.

2.2. Methodology

Long-term means of the wind intensity, relative vorticity, divergence field, and vertical velocity were computed to show the climatology of summer atmospheric circulation and underlying mechanisms over the ME. Furthermore, to recognize the thermal forcing conditions over the area, we calculated the total diabatic heating (Q), as a residual of the thermodynamic Equation 1 as follows (Liu et al., 2022; Yanai et al., 1973; Zarrin et al., 2011):

$$Q = c_p \left(\frac{p}{p_0}\right)^k \left(\frac{\partial\theta}{\partial t} + \vec{V}.\nabla\theta - \omega\frac{\partial\theta}{\partial p}\right) \quad (1)$$

Where θ is the potential temperature (units: K), V is the horizontal velocity (units: m/s), ω is the vertical p-velocity (units: Pa/s), and p is the pressure (units: Pa). In the equation, k = R/Cp (units: J/(kg K)), where R and Cp are, respectively, the gas constant and the specific heat at a constant pressure of dry air, P_0 = 1,000 hPa and ∇ is the isobaric gradient operator. On other hand, the first term $\left(\frac{\partial\theta}{\partial t}\right)$, considers local heating, the second term $\left(\vec{V}.\nabla\theta\right)$, indicates horizontal advection, which is equal to $\left(u\frac{\partial\theta}{\partial x} + v\frac{\partial\theta}{\partial y}\right)$, and the last term $\left(-\omega\frac{\partial\theta}{\partial p}\right)$ demonstrates vertical advection. The total diabatic heating is the sum of the heating obtained from the three terms including local heating, horizontal advection, and vertical advection (Duan & Wu, 2005; Rodwell & Hoskins, 2001; Zhang et al., 2002). Considering total diabatic heating allows us to clarify the role of the ZAG as an elevated heat source on a regional scale.

To recognize the connection between the intensity and variability of SSW at its most enhanced level (950 hPa) (HS16) and regional atmospheric circulation in the ME, the Pearson correlation is calculated between wind intensity in a yellow box (Figure 2a) as a representative of SSW and relative vorticity, divergence field, and vertical velocity for June and July. In the same way, to recognize the connection between the ZAG and regional atmospheric circulation, we used a blue box (Figure 2a) over the ZAG at 750 hPa. A 5-member moving average is adopted to the ERA5 4-time daily time series to eliminate the diurnal fluctuations noise. Attempting to show the best climatological configuration of regional atmospheric circulation, most of the figures are shown at 18.00 UTC (21.30 LST), in which the lower and middle tropospheric circulation over the area are in their strongest conditions.

3. Results

3.1. SSW Formation; a New Structure

From a dynamical point of view, the SHW blows in an area between two semi-permanent pressure centers; the Arabian Anticyclone (AA) and the Zagros trough (ZT) during the summer. In this area, the relative vorticity remains zero (Figures 2a and 2b). The SHW follows the northwest-southeast direction of the two above-mentioned pressure systems, and its diurnal and seasonal wind speed variabilities are a function of the horizontal pressure and vorticity gradients between them in MP (Figures 2a–2c). Also, the SHW prominently follows the Spatio-temporal variabilities of the horizontal vorticity gradient between the AA and the ZT in the vertical profile (Figure 2c). Following the above-mentioned semi-permanent pressure systems, the SHW appears as a continuous shallow wind in the eastern corridor of Iraq (Figures 2b and 2c). Thus, the occurrence of summer dust storms at the lowest levels of the atmosphere, as well as their orientation and intensity in MP, depends on the structure of the SHW rather than any other factors.

On the other hand, we witness the formation and persistence of a mid-tropospheric anticyclone (*Iran anticyclone* in Zarrin et al., 2011; Mofidi & Zarrin, 2012) on top of the ZAG during the summer. The IA experiences its maximum anticyclonic circulation and the highest divergence values around the level of 500 hPa (Figures 2d–2f). Recent studies indicate that the formation of IA has more resulted from local forcing of the ZAG (Mofidi & Zarrin, 2012; Simpson et al., 2015; Zaitchik et al., 2007; Zarrin et al., 2010; Zarrin et al., 2011), rather than due to the sinking arm of the Hadley cell or the Monsoon-Desert mechanism (Rodwell & Hoskins, 1996, 2001). Here, we demonstrate that high values of upward motion, significant surface convergence, and positive vorticity above the ZAG confirm the role of regional topography in the formation of the IA in the middle troposphere (Figures 2d–2f). The maximum convergence, significant upward motion, and cyclonic circulation at the level of 750 hPa (on top of the ZAG) are favored by the maximum anticyclonic circulation and maximum divergence (positive values) at the level of 500 hPa (Figures 2d and 2e).

Theoretically, we can enumerate two main mechanisms for the formation of IA. These two mechanisms include the thermal forcing of the ZAG as an *elevated heat source* (Mofidi & Zarrin, 2012; Zaitchik et al., 2007; Zarrin

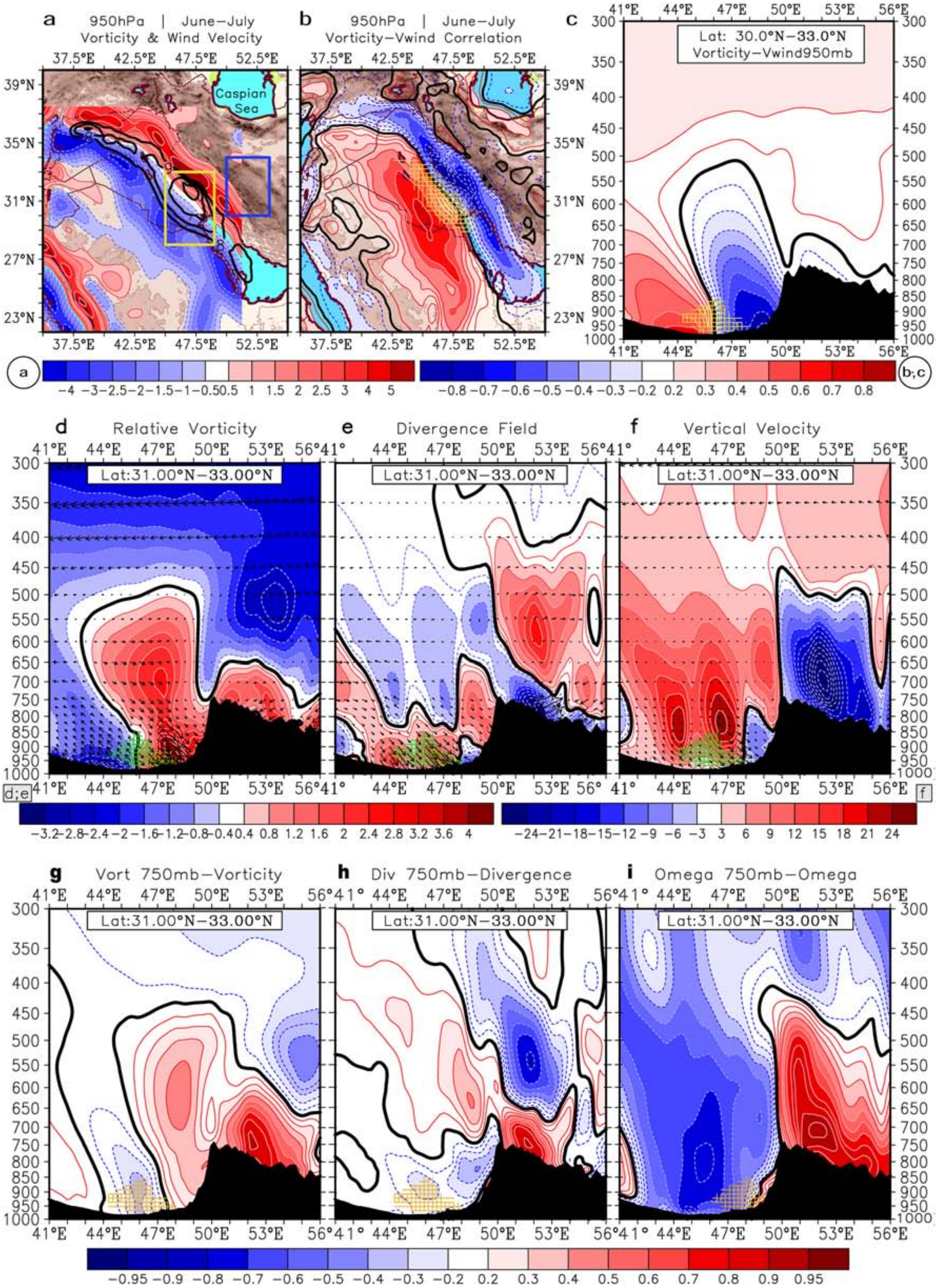
a 950hPa | June–July
Vorticity & Wind Velocity
Caspian Sea
b 950hPa | June–July
Vorticity–Vwind Correlation
c
Lat: 30.0°N–33.0°N
Vorticity–Vwind950mb
d Relative Vorticity
Lat:31.00°N–33.00°N
e Divergence Field
Lat:31.00°N–33.00°N
f Vertical Velocity
Lat:31.00°N–33.00°N
g Vort 750mb–Vorticity
Lat:31.00°N–33.00°N
h Div 750mb–Divergence
Lat:31.00°N–33.00°N
i Omega 750mb–Omega
Lat:31.00°N–33.00°N

Figure 2.

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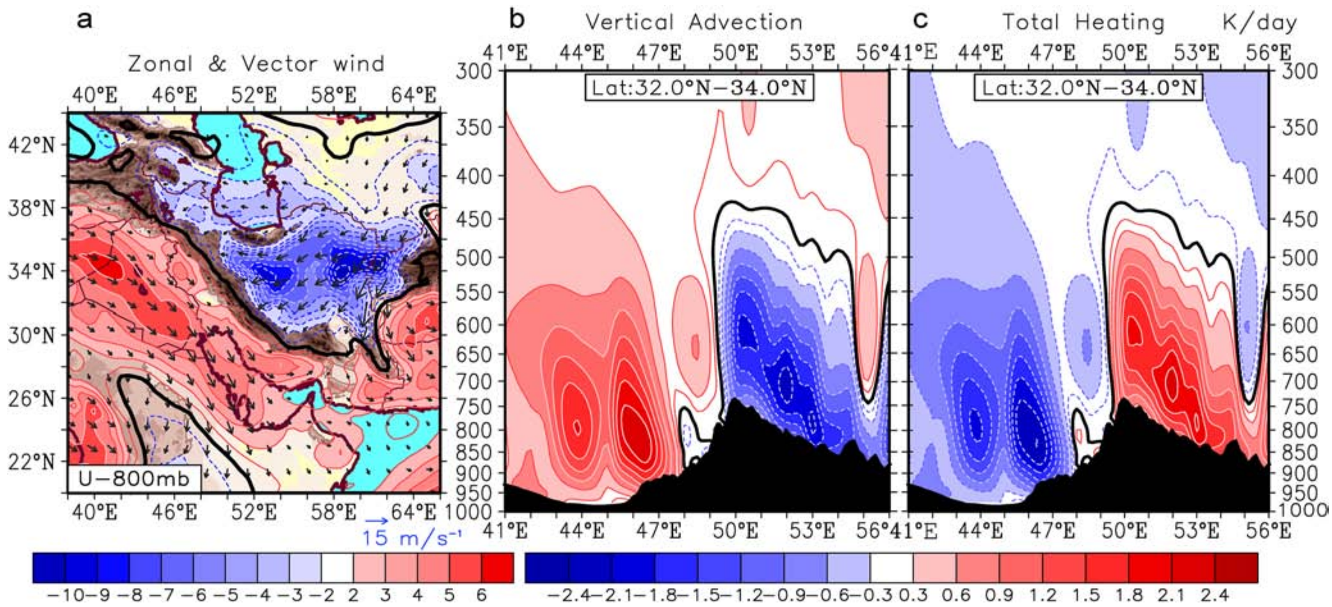

Figure 3. (a) Long-term mean zonal wind component (shaded; m s^{-1}) and wind vectors at 800 hPa. Easterlies and westerlies are marked with a range of blue and red colors, respectively. Long-term mean profiles of (b) vertical advection and (c) total diabatic heating (Q); units: K/day, averaged for 32°N–34°N. Black lines in panels indicate zero.

et al., 2011) and the mechanical forcing due to the dominance of an underlying flow in the lower troposphere. In previous research, the mechanical forcing of the ZAG was linked to the dominance of the eastward background flow (Rodwell & Hoskins, 1996, 2001) from one side and to the dominance of the westward background flow as an extension of the SASM (Simpson et al., 2015) from another side. However, we hereby show that both mechanisms (i.e., thermal and mechanical forcings) simultaneously contribute to the formation of IA in the ME. On one hand, we see a westward continuous background flow on the east side of the ZAG in summer due to the existence of an anticyclone on the east side of the Caspian Sea so-called, *Turkmenistan anticyclone* (*TKA*) (Mofidi & Zarrin, 2012), or *Caspian Sea High* (Kaskaoutis et al., 2016, 2017; Li et al., 2021; Y. Li et al., 2021) (Figure 3a). On the other hand, considering the diabatic heating equation (Q), we see significant values of negative vertical advection $\left(-\omega\frac{\partial\theta}{\partial p}\right)$ (about 2 K/day) from the top of the ZAG to the middle troposphere (Figures 3b and 3c). Thus, the ZAG play a crucial role in the formation of the IA due to its mechanical forcing and the continued dominance of the low-level easterlies, based on the mechanism described by Simpson et al., 2015. Moreover, the significant values of negative vertical advection (heat transfers by upward advection) (He et al., 1987; Rodwell & Hoskins, 2001), indicate the vital importance of thermal forcing in the formation of IA in summer. Contrary to the research of Simpson et al., 2015, the low-level easterlies dominating the ME are not directly related to the SASM, but they are related to the locally flavored TKA on the eastern side of the Caspian Sea (Figure 3a). The present results suggest that the formation of the IA on top of the ZAG causes a mid-tropospheric westward flow, accompanied by a mid-tropospheric convergence and descending air over MP (Figures 2e and 2f). This result is in accordance with previous research (Simpson et al., 2015; Zaitchik et al., 2007). In agreement with Rodwell and Hoskins, 1996 and 2001, the anticyclonic circulation generating in the eastern margin of IA has the potential ability to enhance the subsidence farther east, to the south of the Aral Sea, in the Turkmenistan region. Therefore, a large-scale upper-troposphere descending from the SASM (Mofidi & Zarrin, 2012; Rodwell & Hoskins, 1996) in combination with mid-tropospheric descending air from IA might be the primary driver for the formation of

Figure 2. (a) The long-term mean relative vorticity (colors × 10^{-5} s^{-1}) and the maximum core of wind speed (black lines; m s^{-1}) at 950 hPa. The yellow box (45°E–49°E; 28°N–33°N) and the blue box (50°E–54°E; 30°N–34°N) are the area used to calculate spatial correlation in Figures 2b–2c and 2g–2i, respectively. (b) The spatial correlation coefficient between SHW diurnal intensity and variability (yellow box) and relative vorticity. (c) Same as Figure 2b, but in vertical cross-section. The second row shows the long-term mean for relative vorticity (d), divergence field (e), and vertical velocity/omega (f), and the bottom row indicates the correlation coefficient of relative vorticity (g), divergence field (h), and the omega (i), in the blue box (Figure 3a) at 750 hPa and the same variable at the vertical profile. The correlation coefficient was calculated by applying a five-member moving average on 4-time daily data. The vertical profiles are plotted by latitudinal averaging (31°N–33°N). The hatched area is the long-term mean wind intensity with a threshold ≥8.5 m s^{-1}; the shaded area represents a significant correlation (±0.20), and the thick black line indicates zero values. Topography is added to the background.

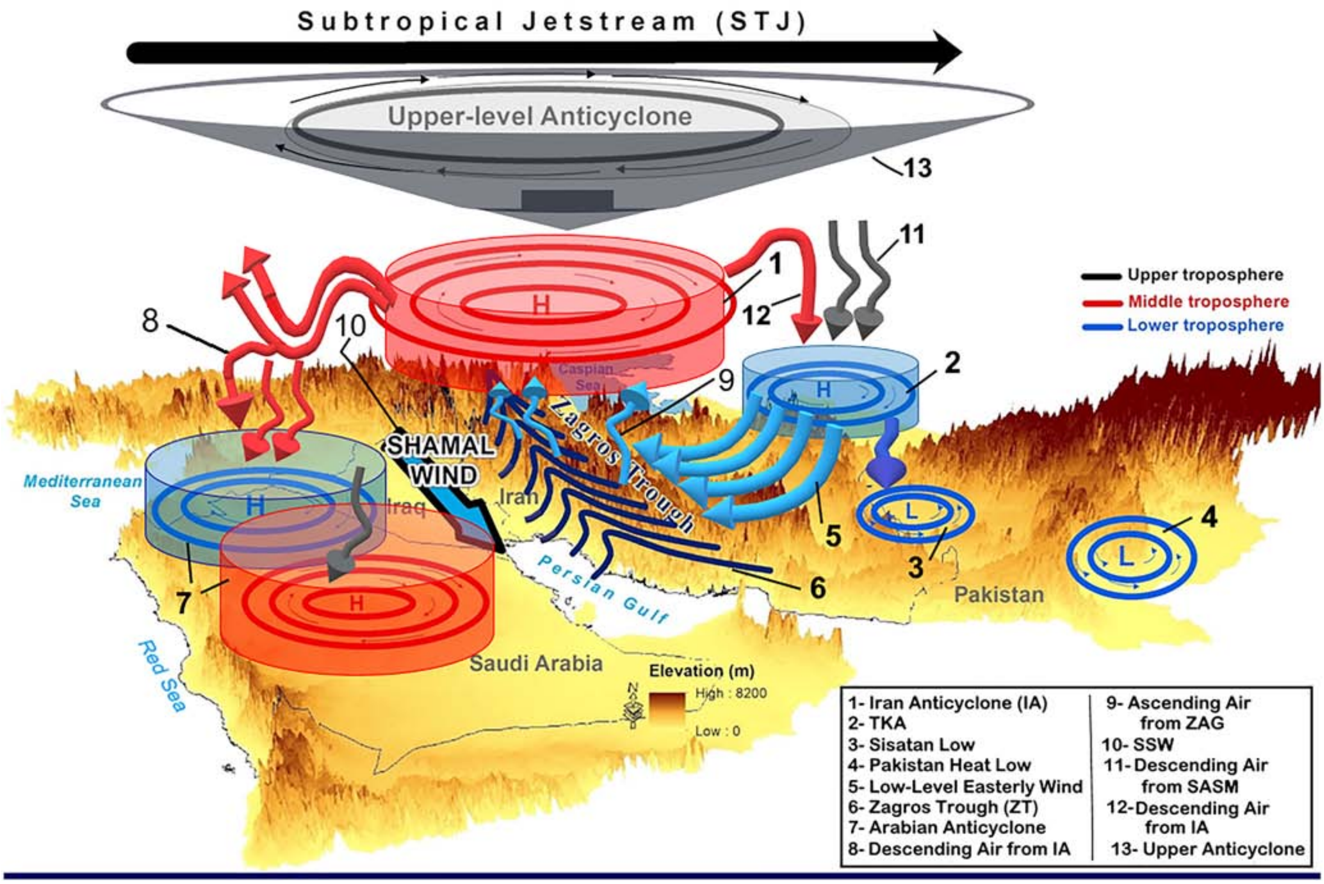

Figure 4. Schematic depiction of regional atmospheric circulation and the location of synoptic-scale systems as well as Shamal wind in the Middle East for the boreal summer. The numbers show the synoptic systems and the way in which they act.

TKA. This result is confirmed by significant downward vertical advection (positive values) in MP (Figures 3b and 3c) as well as a robust correlation coefficient between convergence and ascending air on top of the ZAG and the divergence and descending air in MP (Figures 2g–2i). Thus, the descending air from the IA leads to a lower level anticyclonic circulation in the northern Arabian Peninsula (AA). In return, it intensifies the cyclonic circulation along the ZAG (Figure 2d) and strengthens the ZT and surface convergence over the ZAG (Figure 2e). Accordingly, the occurrence of SHW is directly related to descending air originating from the IA (Figure 2i).

The mechanism described above causes a normal SSW. However, in the extreme cases with strong SSW, we witness the significant strengthening of TKA and its southward displacement in northeastern Iran (figure not shown). Strengthening of TKA, while intensifying the low-level easterly winds and increasing the role of the mechanical forcing of the ZAG, will reinforce the entire circulation system described above. This mechanism guarantees a stronger SSW and the formation of Shamal dust storms over the ME.

4. Conclusions

We demonstrated that the ME experiences a regional independent atmospheric circulation by a regional-scale internal forcing in the middle and lower troposphere in summer. The results emphasized the irreplaceable role of the ZAG in the formation of a regional atmospheric circulation in the ME. The findings indicated how the ZAG had developed a mid-tropospheric anticyclone involving mechanical and thermal forcings in a physical synergy, namely the IA. Meanwhile, the SHW and its diurnal and seasonal variabilities are primarily dependent on the spatial-temporal variations of IA.

A schematic figure is given to illustrate the proposed structure and understand the governing mechanism for the formation of the SHW (Figure 4). Figure 4 shows the structure of regional atmospheric circulation and the location of synoptic-scale systems in the ME for the boreal summer. A large-scale anticyclone dominates over the whole area in the ME in the upper troposphere (No. 13). The low-level easterly flow from TKA ascends over the ZAG when it hits the mountain ranges from the east (light blue arrows; No. 5). At the same time, upward vertical advection from an elevated heat source (light blue arrows; No. 9) enforces the ascending air to generate a mid-tropospheric synoptic-scale anticyclone (IA) over the ZAG (No.1). Air from IA flows westward and descends over MP (No. 8), where it generates an anticyclone in the lower troposphere called AA (No.7). The formation of the AA significantly strengthens the ZT (No.6) and generates a permanent coupling pressure pattern in which a northwesterly wind (SHW) appears as a result (No. 10). A more intense horizontal pressure and vorticity gradients between the two pressure systems in MP influence the whole circulation system by strengthening the ZT. On the other hand, descending air that originates from the SASM in the upper troposphere (No. 11) in collaboration with descending air from the IA (No.12) generates TKA in the lower troposphere (No.2). The formation and maintenance of the coupling pattern over MP and the TKA in the east of the Caspian Sea throughout the summer, guarantee the persistence of a localized atmospheric circulation with the centrality of the ZAG.

Apart from the above findings, there is much evidence indicating that summer circulation over the ME has a significant effect on large-scale atmospheric circulation in the tropics and extra-tropics. The Bonin high in eastern Asia is formed by the propagation of stationary Rossby waves along with the Asian jet. For the proposed formation mechanism, the TKA and AA in the Aral Sea region and the eastern Mediterranean area are known as the Rossby-wave source region. These two regional pressure systems generate such circulation by producing a waveguide through the Asian jet, which is called the Silk Road pattern (Ding & Wang, 2005; Enomoto, 2004; Enomoto et al., 2003; Li et al., 2021; Y. Li et al., 2021). In addition, TKA is also recognized to generate a quasi-stationary mid-tropospheric trough over the Caucasus during the summer by blocking the westerlies (Mofidi, 2007). Moreover, recent studies emphasize the significant effect of the north westerlies with SHW origin on the weakness and strength of the SASM, by the intensification of the lower level monsoon circulation and moisture supply from the Arabian Sea (Jin et al., 2014, 2015, 2021; Lau, 2014; Liu et al., 2017; Rashki et al., 2019; Wu et al., 2012; Yadav, 2017). These findings confirm the results of previous studies on the important role of the lower atmosphere circulation over the ME as a source of variability for the SASM (Aboobacker et al., 2011; Jin et al., 2021; Liu et al., 2017; Vinod Kumar et al., 2014; Vinoj et al., 2014; Wu et al., 2012).

Data Availability Statement

All data used in this article are available from the Copernicus Climate Change Service via the Climate Data Store website (https://climate.copernicus.eu). The following links provide direct access to the data used in the research: Era5 hourly data on pressure levels (Reanalysis and Ensemble mean): https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-pressure-levels?tab=form. Era5 hourly data on single levels (Reanalysis and Ensemble mean): https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-single-levels?tab=form.

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