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A low-level jet in eastern Iran: a possible factor in dust events in the region

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Abstract

One of the world's major mineral dust source regions lies along the border between Iran and Afghanistan. In this study it is hypothesized that a low-level jet may play in role in generating the intensity of this source region. The presence of a low-level jet east of the Seistan mountains is documented here for the first time. The jet exists mainly from May to September and has a core at 850 mb. Maximum speeds are at 18 UTC and 0 UTC and occur in July-August. In the mean the core speed attains 20 ms^{-1} in those months. The jet attains a maximum at night, a minimum during the day. However, the vertical motions associated with it do not fluctuate greatly over the course of the day. The development of the jet during a dust outbreak in 2002 is also described. It arises a day or so before the outbreak and disappears as the outbreak ends.

Keywords: Afghanistan; Iran; Low-level jet; Mineral dust; MODIS

1. Introduction

Low-Level jet streams are linked to many of the world's deserts. In some locations they play major roles in creating and maintaining the region's aridity. Examples are the Peruvian Jet, along the coastal Atacama Desert (Lettau, 1978), the Benguela Jet along the coastal desert of Namibia and Angola in southern Africa (Nicholson, 2010), a low-level jet in the Lut Valley of Iran (Liu *et al*., 2000), the California coastal jet (Parish, 2000) along the semi-arid coast of southern California, and the Turkana Jet (Nicholson, 2015), which appears to play a major role in the equatorial aridity of eastern Africa. In other locations, such as the Sahara, they play a major role in dust mobilization and transport. The Bodélé Jet (Washington and Todd, 2005), for example, is a major reason that the largest source region of mineral dust in the world is the Bodélé Depression (Prospero *et al*., 2002).

Another one of the major source regions of mineral dust lies along the border of Iran and Afghanistan (Prospero *et al*., 2002). This article documents for the first time the existence of a low-level jet in this region. It coincides with the area of maximum dust storm occurrence described by Middleton (1986). This article presents a complete climatology of the jet's horizontal and vertical structure, seasonal and diurnal variations, and associated patterns of divergence. It also presents evidence of its role in dust outbreaks in the region.

2. Data and Methodology

Figure 1 shows the location where analysis of the motion field will be carried out. The jet lies in the Dasht-e-Naomi region along the Iran-Afghanistan border just east of Birjand. It is roughly co-located with the major dust source region that is centered at 31N, 61.5E and straddles the border between

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Iran and Afghanistan. This basin receives much runoff from the Seistan Mountains to the west in Iran and the eastern mountains in Afghanistan. The basin is characterized by widespread ephemeral lakes and swamps; in the northern part, there are many salt/dry lakes. SeaWiFS often shows huge dust plumes emerging from three of the largest, Hamun-e Saberi (31.5ºN, 61.3ºE), Hamun-e Puzak (31.5ºN, 61.7ºE), and Daryacheh-ye-Hamun (31.7ºN, 61.1ºE) and from the Gowd-e Zereh depression a little farther to the south (29.8ºN, 61.8ºE). Zabol, a city located in the midst of these salt/dry lakes, reports 81 dust storms per year (Middleton, 1986).

MODIS (Moderate-Resolution Imaging Spectrometer, Levy *et al*., 2015) was used to examine a dust outbreak in August, 2002. The ERA-Interim Reanalysis Product (Dee *et al*., 2011) is used to derive the wind and vertical motion fields in this region. The data set covers the period 1979 to 2014, has a spatial resolution of roughly 80 km, and has 60 vertical levels form the surface up to 0.1 mb (Dee *et al*., 2011). It includes 3-hourly surface parameters and 6-hourly upper air parameters. Despite earlier availability of ERA-Interim data, the analysis period will be limited to 1998 to 2014, in order to provide direct comparisons at a later time with variables such as rainfall and dust that are only available for the more limited period.

Low-level winds are first examined throughout the year to determine the seasonal variation of the jet. Winds along the north-south and east-west axes of the jet will be examined, as will the vertical profile of the jet core. More detailed analysis is carried out for the months in which the jet is most intense, July and August. This includes an analysis of the diurnal cycle. The divergence and vertical motion fields are also evaluated for these two months. Then the relationship of the jet to a dust outbreak in August, 2002, is examined.

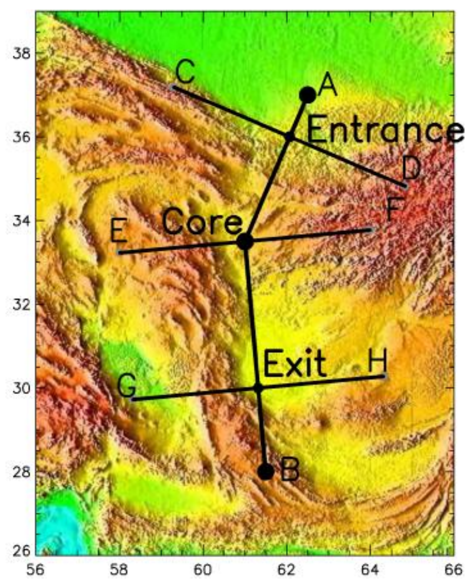

Fig. 1. Map of location of the Iranian low-level jet and the four analysis transects

3. Results

3.1. Seasonal means

Figure 2 shows the mean low-level vector winds averaged for November to March and for May to September, the periods of weakest and strongest winds. April and October are omitted as these are transition periods between two very different wind regimes. Winds are generally weak from November through March and the low-level maximum occurs at 925 mb. The region lies under the southwestern edge of the intense Siberian High, where large-scale winds are exceedingly weak. From May to September, when the low-level maximum occurs at 850 mb, a northerly jet is well developed in the long-term mean. Its core is at roughly 33.5 N and 61 E and core speeds averaging over 15 ms^{-1}. The jet develops from the northerly flow associated with a thermal low over Pakistan and western India.

Figure 3 shows vertical cross-sections through the core of the jet for November to March and May to September. During the former period a very weak core at about 925 mb is evident, with maximum core speeds of 2 to 3 ms^{-1}. From May to September, a very well developed core is apparent at 850 mb with core speeds on the order of 13 ms-1. The vertical profile of the winds in the core underscores the contrast between the two seasons (Fig. 4). A very slight wind maximum is apparent at about 900 mb in the November to March season and wind increases steadily upward from 825 mb. During May to September a pronounced maximum is observed at 850 mb, with mean speeds of over 14 ms-1. From there, wind speed decreases steadily upward to 600 mb. For comparison, the mean profile averaged for July and August is also shown. In these months, the mean core speed reaches 20 ms^{-1}.

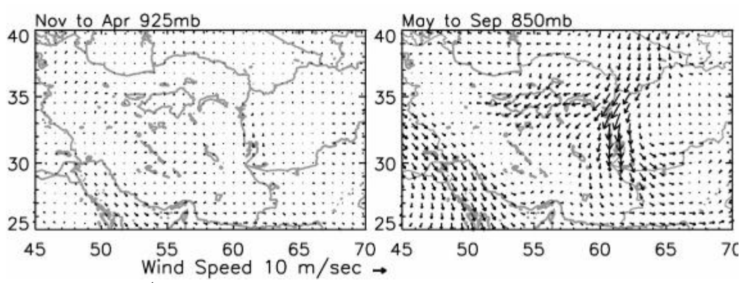

Fig. 2. Mean low-level winds (ms^{-1}) for November to March at 925 mb (left) and for May to September at 850 mb (right)

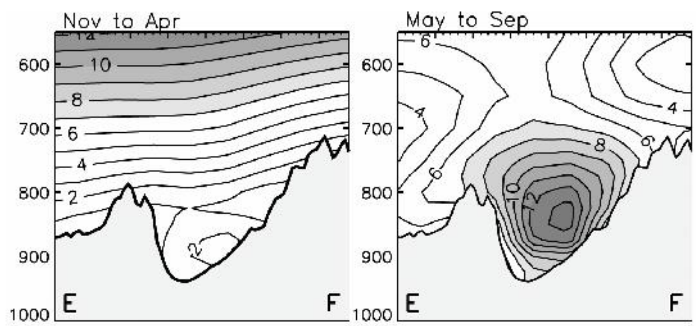

Fig. 3. Vertical cross-section of horizontal wind speed along a transect perpendicular to the jet core (see Fig. 1 for location). Left: for November to April. Right: May to September

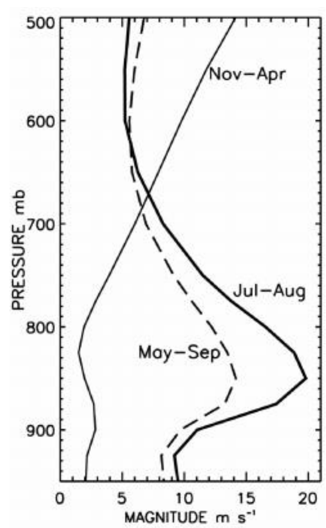

Fig. 4. Vertical profile of wind speed (ms^{-1}) at 33° N, 61.5° E for November to April, May to September, and July-August. The July-August mean is for 18 UTC. Others are a daily average, based on four times per day

3.2. Mean for July-August

Figure 5 shows cross-sections of mean wind speed along three transects perpendicular to the jet core during July-August. These lie at the core itself and in the entrance and exit regions of the jet (Fig. 1). At the entrance region, where the northeasterly flow enters the channel between the Seistan Mountains in Iran and the Paropamisus Mountains in Afghanistan, a very weak core is already apparent. The mean speed reaches 9 ms^{-1}. In the absolute core of the jet, near 33.5 N, the maximum core speed exceeds 16 ms^{-1}. At the exit region, the core speed is reduced to 9 ms^{-1}. A similar transect parallel to the jet is shown in Fig. 6. The jet is well developed from at least 30 N to 36 N. Speeds in excess of 14 ms^{-1} are evident from roughly 31 N to 35 N and up to 750 mb. In contrast, speeds of less than 6 ms^{-1}prevail above around 600 mb.

Most low-level jets show a pronounced diurnal variation. This is shown in Figure 7, which depicts 850 mb vector winds, and in Figure 8, which shows the vertical wind profile at the core. Speed maxima in the core range from 13 ms^{-1} at 06 UTC and 12 UTC to 19 ms^{-1} at 18 UTC and 00 UTC. Note that local time is three and one half hours later. The jet is clearly evident throughout the day. This suggests that mountain/valley breezes do not play a big role in its development.

The vertical profile of wind in the core and exit region provide further support for this conclusion. The pattern of vertical motion does not show a diurnal cycle consistent with upslope and downslope winds (Fig. 9). Instead there is subsidence on the left side and ascent on the right side, although the magnitudes vary during the day. This is consistent with the ascent being triggered by the winds encountering the high terrain in the west. The ascent is notably stronger at 18 UTC, when the jet is strongest, than at other times.

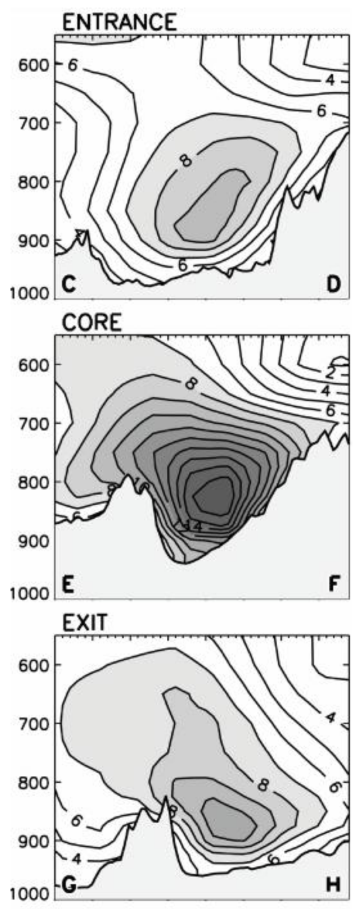

Fig. 5. Vertical cross-section of horizontal wind speeds along transects perpendicular to the jet core, averaged for July and August. These are shown for the entrance and exit regions of the jet and for the jet core (see Fig. 1 for location of transects)

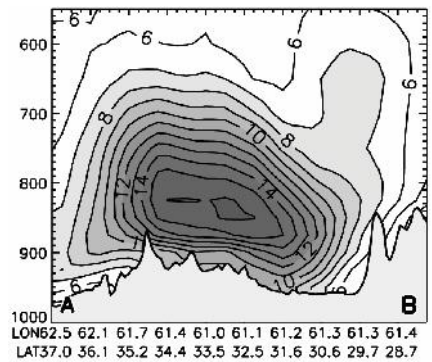

Fig. 6. Vertical cross-section of horizontal wind speed along a transect parallel to the jet core, averaged for July and August (see Fig. 1 for location)

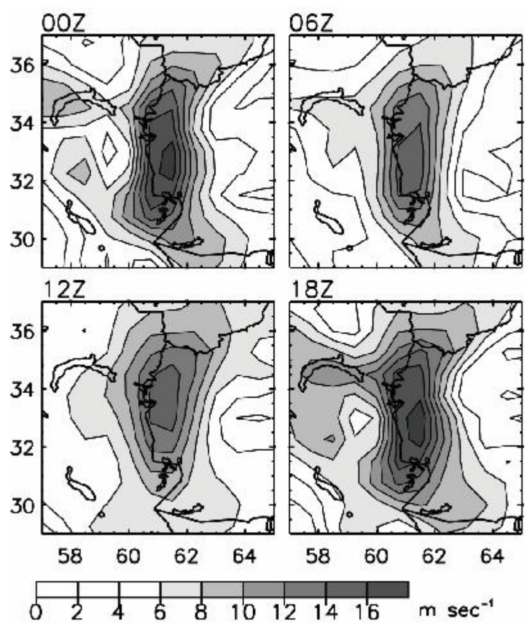

Fig. 7. Mean 850 wind (ms^{-1}) at four times per day and averaged for July and August

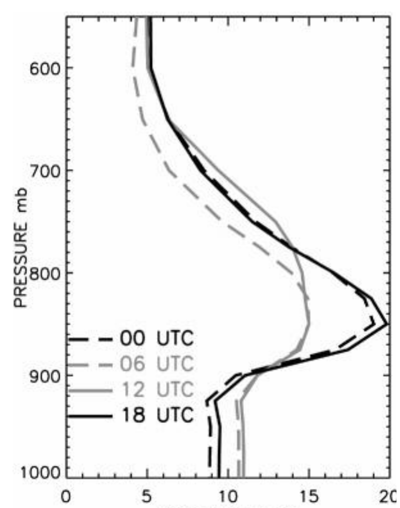

Fig. 8. Vertical profile of wind speed (ms^{-1}) at 33° N, 61.5° E at four times per day and averaged for July and August

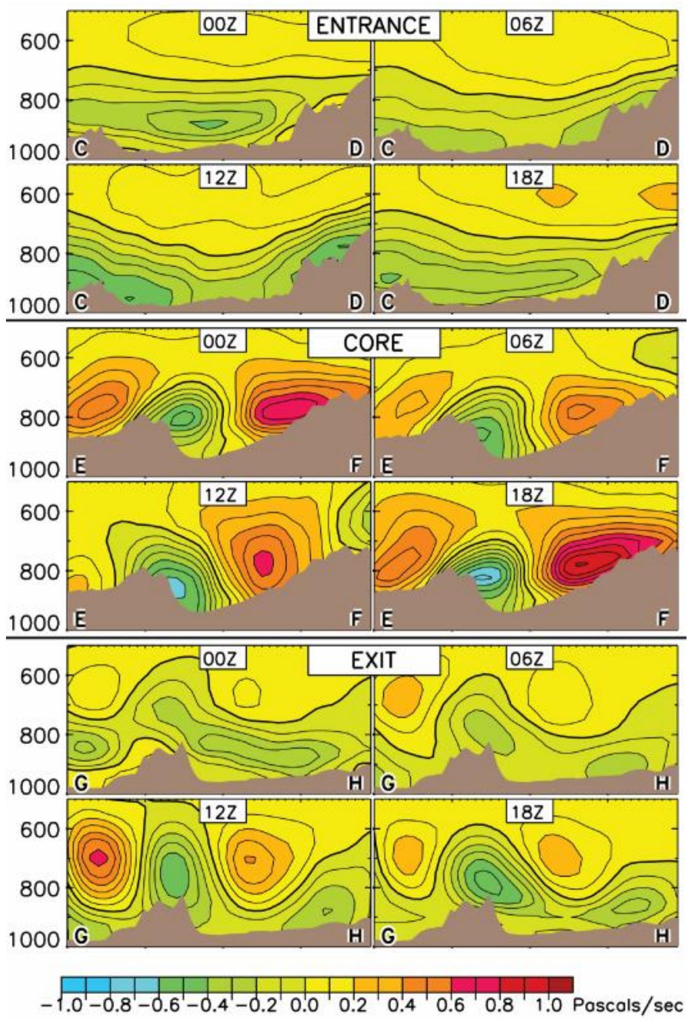

Fig. 9. Mean vertical motion (omega, pascals per second) along three transects perpendicular to the jet core at four times per day (see Fig. 1 for location). Data are averaged for July and August

3.3. Relationship to dust outbreaks

The area where the jet occurs is known to be one of the major source regions globally for mineral dust. The frequency of occurrence of dust storms shows a strong maximum in the heart of this region (Fig. 10). To test whether the jet might play some role in the outbreaks, the wind regime during a prominent dust outbreak is evaluated.

The outbreak occurred along the Iran/Afghanistan border around the 14th of August, 2002 (Fig. 11). It commenced around August 13 and continued through the August 15 (Fig. 12). The source region of the dust is clearly the dry lakes in the deep desert basin, just north of Zabol. By August 15, some dust is still emanating from this region, but most has moved into eastern Afghanistan. By August 16, the outbreak has ended.

Figure 13 shows 850 mb vector winds on August 10, prior to the outbreak, on August 13, in the heart of the outbreak, and on the 15th, as it was ending. The low-level jet had become strong late in the night of August 11 and was in full force by August 12 (not shown). The low-level jet had markedly diminished late on August 14 and was no longer evident on August 15. This sequence and its relationship to the dust outbreak suggests that the low-level jet plays some role in creating the intensity of this dust source region.

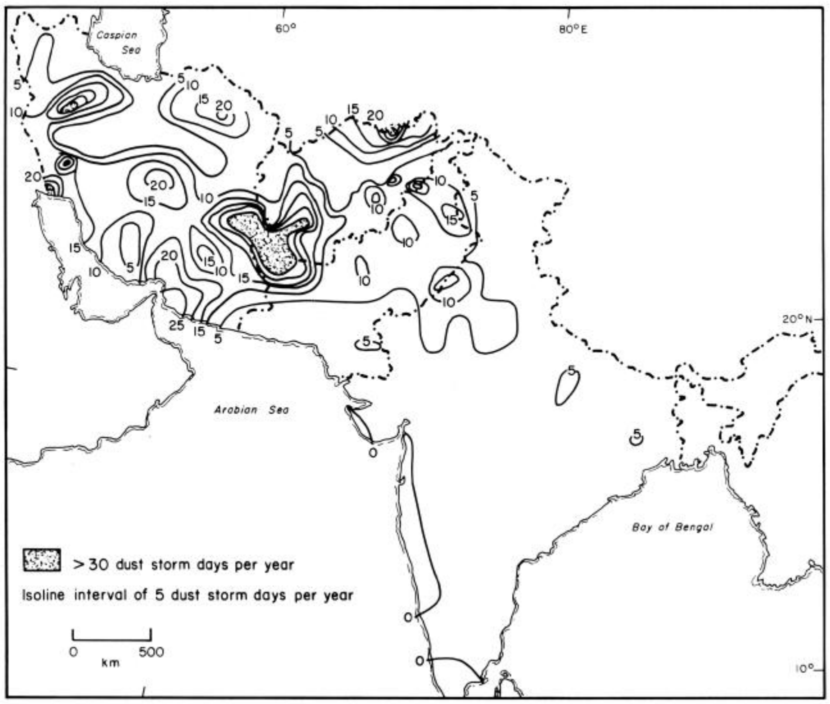

Fig. 10. The frequency of dust storms over Iran and Afghanistan. Units = number of days per year (Middleton 1986)

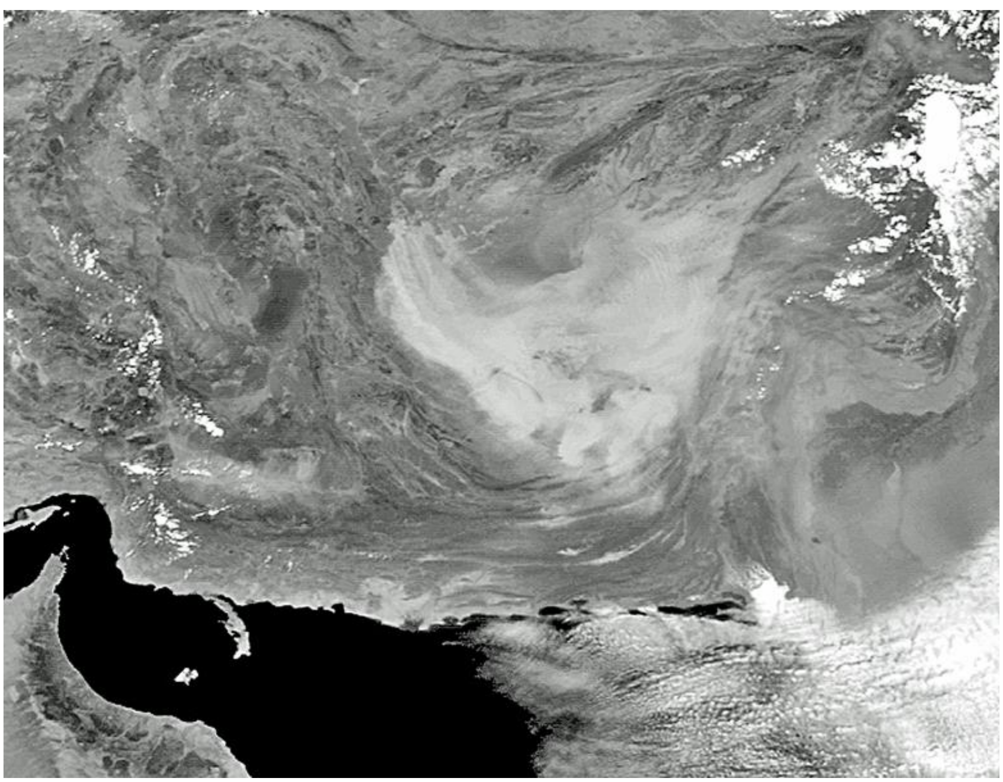

Fig. 11. Visible image of aerosols on August 14, 2002, from Meteosat-5. This occurred along the border of Iran and Afghanistan

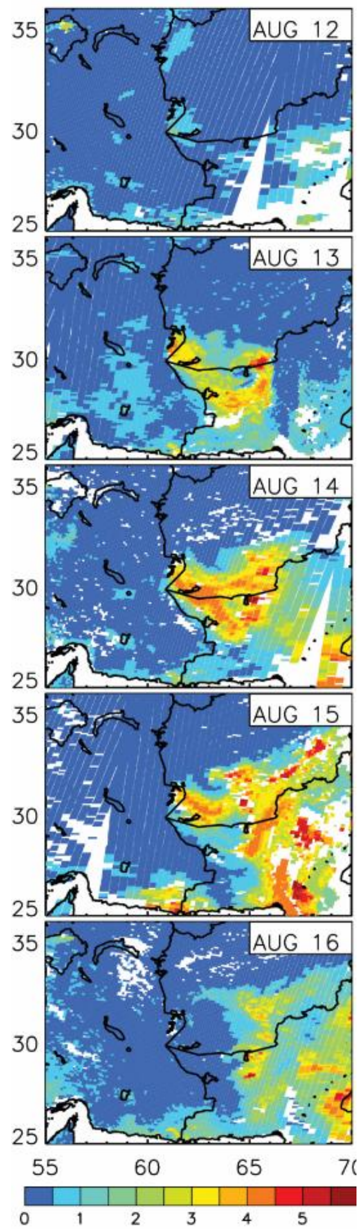

Fig. 12. Aerosols over Iran/Afghanistan on August 12 through 16, 2002, based on MODIS. Units are optical depth times ten

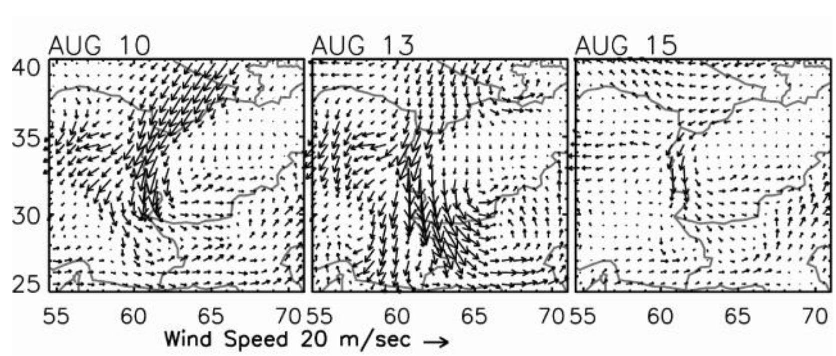

Fig. 13. 850 mb vector winds at 18 UTC on August 10, 13, and 15, 2002, based on ERA-Interim

4. Summary and Conclusion

A low-level northerly jet stream exists in the channel east of the Seistan Mountains, along the border between Iran and Afghanistan. The jet is well developed from May through September and reaches its maximum in July and August. This jet is extends from roughly 30 N to 38 N, with a maximum around 850 mm. It is also strongest at 18 UTC and 0 UTC, generally being weak during the daylight hours. In those months the mean core speed is 20 ms^{-1}. The jet appears to play a role in creating the very intense dust source in the region.

Acknowledgements

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