Diagnosis of Potent Winter Weather Phenomenon Over South Asia During 11th January-13th January 2020

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Abstract

An exceptional heavy rain/snow event caused flooding and Avalanches over southeast Iran, Afghanistan, Pakistan, and Indian Himalayas from 11th January to 13th January 2020. As a result, there was a huge loss in lives and property. In Pakistan only, there were around 100 human deaths and more than 200 houses damaged. This unusual event was due to a Western Disturbance (WD) that developed over North Atlantic Ocean around 1st January 2020. It moved nearly eastwards and split into two components on 10th January 2020, one moved northeastwards and the other towards Indian Himalayas across Iran, Afghanistan, and Pakistan. It was a warm-core high at upper tropospheric levels and a cold-core low at mid-tropospheric levels with a sharp temperature gradient of about 20°C to 24°C. The system received very high moisture feed from the Arabian Sea at lower and upper tropospheric levels. In addition, the wind confluence between WD and the anti-cyclone at the Arabian Sea triggered intense weather activity over the region.

Keywords: Arabian sea • Heavy rain/snow • Himalayas • Trough and western disturbance

Introduction

There was exceptional heavy rain/snow activity over southeast Iran, Afghanistan, Pakistan, and Indian Himalayas from 11th January to 13th January 2020. As a result, there was heavy flooding in southeast Iran. Flooding destroyed many bridges, crops, and houses and dislodged thousands of people. Thereafter, there was a severe impact of this event on Afghanistan, Pakistan, and the Indian Himalayas. According to the Afghan Red Crescent Society (ARCS), heavy snowfall over Afghanistan during the study period has broken records for the last many years. Widespread damages occurred over Afghanistan due to heavy snowfall, flooding, and a large number of avalanches over the region. As per ARCS' initial report, more than 650 houses got damaged, 13 people died and 40 people got injured due to this event. As per National Disaster Management Authority (NDMA), Pakistan Report dated 15 January 2020, heavy snowfall supported by many avalanches occurred over north Pakistan from 11 January 2020-13 January 2020. As a result, there was a huge loss of property and livelihood in the region with around 100 human deaths, 90 injured and more than 200 houses damaged. In India, there was widespread precipitation with heavy falls which triggered avalanches over the Himalayan region on 13th January 2020. As per media reports, more than 10 people died due to avalanches over the region, particularly in Jammu & Kashmir. Considering the severity of this potent winter weather phenomenon over West and South Asia, a study is undertaken to diagnose the synoptic and thermodynamical features associated with this unprecedented event. Generally, weather in the Himalayas and adjoining areas during the winter (December to February) months is associated with WDs [1-5]. These are extra-tropical systems in the form of upper air troughs/Cyclonic circulations (CCs) moving from west to east across Iran, Afghanistan, Pakistan, and the Himalayan region of India [2, 3, 6-8]. These systems are responsible for extreme precipitation events over the Himalayan region [3, 6, 9-12]. Zafar and Rasul 2009, have studied the winter heavy precipitation event over northern parts of Pakistan and found the event associated with high divergence provided by the jet stream at upper tropospheric levels and strong convergence at lower tropospheric levels [13]. Kumar et al. (2015) carried out an analysis associated with extreme precipitation over Himachal Pradesh (Western Himalayan Region) during the winter months [2]. They found that a deep trough in mid and upper tropospheric levels or CC over north Pakistan and neighborhood with an induced CC at lower tropospheric levels over Central Pakistan and adjoining Rajasthan area along with high moisture feed from the Arabian Sea at lower and upper tropospheric levels are very much favorable for extreme precipitation over Himachal Pradesh. Kumar et al. (2017) studied the synoptic and thermo-dynamical features associated with unprecedented precipitation along with heavy falls over many parts of India, specifically northwest India from 28th February to 2nd March 2015 [3]. Hunt et al. (2018) studied the evolution, seasonality, and impacts of western disturbances over the region [4]. They found that these systems tilt northwestward with height, strong ascent ahead of the center, and a warm-over-cold and dry-over-moist structure. The frequency of these systems over north India is highly sensitive to the jet location over Eurasia. The objective of this study is to analyze the applicability of the understanding of physical processes as obtained from previous studies in the present case study and hence to identify the gaps in understanding to improve the forecasting technique.

Data and Methodology

Meteorological analysis of the potent winter weather phenomenon is done using various parameters, like wind, temperature, Geo Potential Heights (GPH), and Vertical Velocity (ω) at different levels (surface to 200 hPa). Wind and temperature fields are taken from India Meteorological Department (IMD) Global Forecasting System (GFS)model (12 km resolution). GPH and Vertical Velocity (ω) are taken from NCEP/NCAR reanalysis data [14]. In addition to the above, upper-level divergence, lower-level convergence, and relative vorticity are also analyzed and are taken from the University of Wisconsin-CIMSS [15].

Result and Discussion

Brief History

The Western Disturbance was seen as a trough in westerlies, roughly along with Longitude 40°W and north of Latitude 35°N with an embedded CC in mid and upper tropospheric levels over North Atlantic Ocean on 1st January 2020 (Figure 1). Thereafter, it moved nearly eastwards with a speed of 10° per day and maintained its intensity with moisture feeding from the North Atlantic Ocean, Mediterranean Sea, Caspian Sea, and the Arabian Sea. On 10th January 2020, it was seen as a tilted trough roughly along with Longitude 50°E and Latitude 48°N to Longitude 10° W and Latitude 20°N with an embedded CC (Figure 1). WDs are seen as a trough in mid-tropospheric westerlies and are non-monsoonal precipitation systems that originate with moisture over the Mediterranean Sea and the Atlantic Ocean [16].

In Figure 1, 500 hPa trough is seen roughly along 40 W on 01st January. If we look at the Geo-Potential height anomaly (Figure 2) of the same, we find that a-200 m negative anomaly is there for 1981-2010 climatology. Similarly, a northeast-southwest 500 hPa trough is seen in Figure 1 on 10th January. If we look at the Geo-Potential height anomaly of the same, we find that a -150 m negative anomaly is there for the 1981-2010 climatology. Thereafter, while moving eastwards, it split into two parts; one part moved toward Iran, Afghanistan, Pakistan, and Indian Himalayas and the other moved northeastwards. Subsequently, it caused severe weather in the form of unusual rain/snow causing flooding

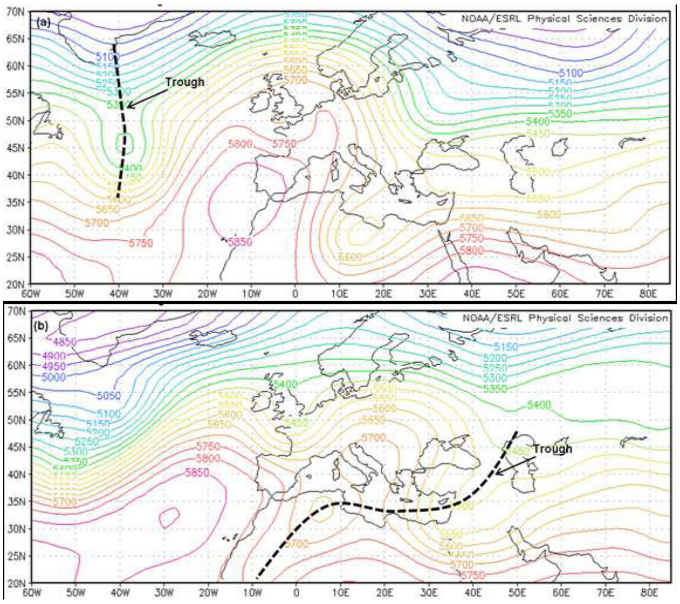

Figure 1. Geo-potential height (GPH) map at 500 hPa of 00 UTC (a) 01.01.2020 and (b) 10.01.2020.

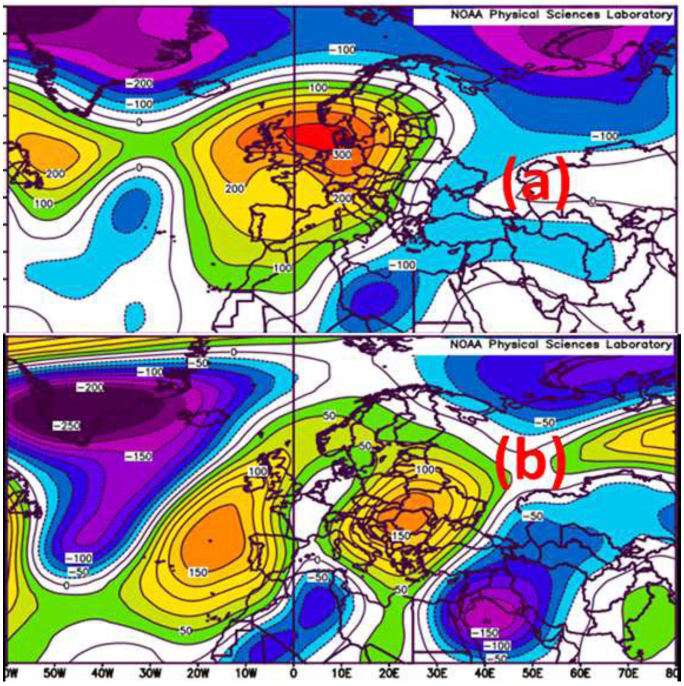

Figure 2. Geo-potential height (GPH) anomaly at 500 hPa of 00 UTC (a) 01.01.2020 and (b) 10.01.2020.

in lower reaches and triggering avalanches in higher reaches of Iran and Afghanistan due to high moisture feeding on the Mediterranean and the Caspian Sea mainly on 11thand 12th January. On 13th January 2020, the system received fresh moisture feed from the Arabian Sea and caused heavy rain/snow over north Pakistan and Indian Himalayas. Thereafter, the system weakened and moved away east-northeastwards.

Air Temperature analysis at 200 hPa and 500 hPa

On 11th January 2020, there was a warm-core high at 200 hPa level with a core temperature of-44°C over central Iran with a gradient of order 10°C over the region in association with WD (Figure 2). As a result, a sharp pressure gradient is built up over the region which in turn created a high jet stream with a core wind speed of order 155 knots and high divergence of order $40x10^{-5}$ s^{-1} to $50x10^{-5}$ s^{-1} generated in the south of the warm-core high (as per METEOSAT 8 mid and upper-level winds). Subsequently, on 12th January warm-core high shifted to east Iran with the same intensity and gradient (Figure 2) and generated a high jet stream with a core wind speed of order 160 knots over southeast Iran and its neighborhood. On the 13th of January the warm-core high moved to Afghanistan with a core temperature of -46°C and a gradient of about 8°C over the region (Figure 2). The high jet stream continued to prevail with the core wind of about 160 knots shifted to Indian Himalayas. On this day, there was a very high divergence of order $60x10^{-5}$ s^{-1} to $70x10^{-5}$ s^{-1} over north Pakistan and adjoining Jammu and Kashmir. The warm-core high weakened significantly on 14th January 2020 and laid over central Pakistan with a core temperature of -50°C and a gradient of about 2°C over the region (Figure 2).

From Figures 3 and 4, it is clear that there is a 200 hPa Warm core high of -44°C with a temperature gradient of 10°C on 11th January. NCEP-NCAR Reanalysis suggests that this Warm core high is positively anomalous by 12°C for 1981-2010 climatology (NCEP-NCAR Reanalysis further suggests that the 200hPa Warm core highs of 12th, 13th, and 14th are positively anomalous by 10°C, 8°C, and 6°C respectively with respect to 1981-2010 climatology). On the other hand, at mid-tropospheric levels, an intense cold-core low was witnessed at 500 hPa level with its core temperature of -28°Cover northwest Iran and a temperature gradient of order more than 20°Cover the Iran region on 11th January. On 12th January it moved eastward with its core temperature of-28°C over central Iran and a temperature gradient of about 20°C over the Iran region (Figure 4). Thereafter, it moved further eastward and intensified with its core temperature of about -30°C over north Afghanistan and a temperature gradient of about 24°C over in the same region.

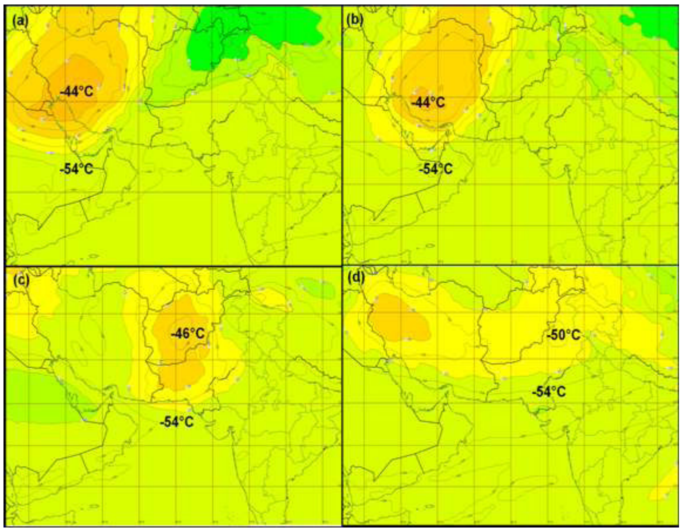

Figure 3. Air Temperature (°C) at 200 hPa of (a) 11.01.2020, (b) 12.01.2020, (c) 13.01.2020 and (d) 14.01.2020.

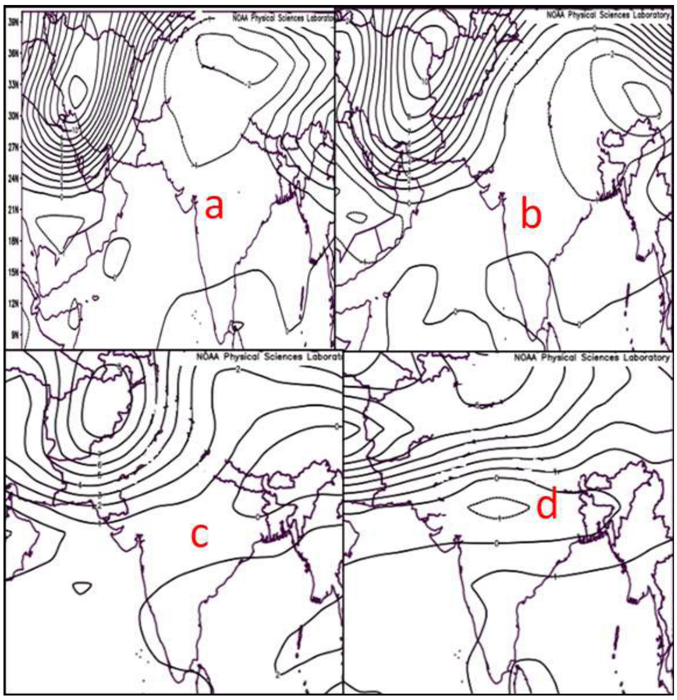

Figure 4. Air Temperature Anomaly (°C) at 200 hPa of (a) 11.01.2020, (b) 12.01.2020, (c) 13.01.2020 and (d) 14.01.2020.

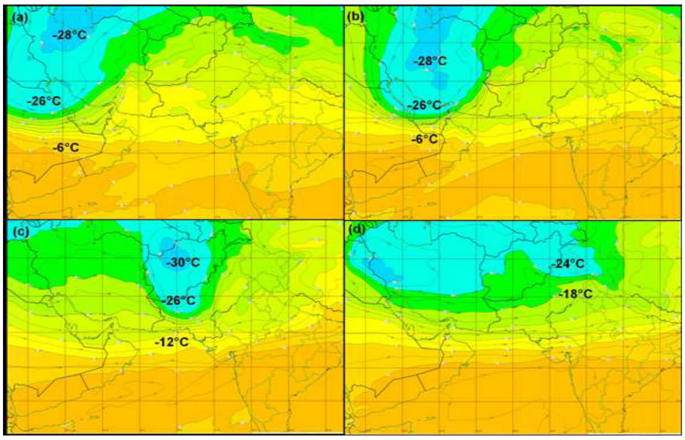

Figure 5. Air Temperature (°C) at 500 hPa of (a) 11.01.2020, (b) 12.01.2020, (c) 13.01.2020 and (d) 14.01.2020.

In Figure 4, No cold-core low was seen on 14th January 2020. Thus, very high divergence on 13th January 2020 may be associated with a very intense cold-core low at 500 hPa and an intense warm-core high at 200 hPa.

From Figure 4, it is clear that there is a 500 hPa Cold Core Low of -28°C with a temperature gradient of 22°C on 11th January. NCEP-NCAR Reanalysis suggests that this Cold core low is negatively anomalous by 10°C with respect to 1981-2010 climatology (Figure 4). NCEP-NCAR Reanalysis further suggests that the 500 hPa Cold core Lows of the 12th, 13th, and 14th are negatively anomalous by 6°C, 5°C, and 3°C respectively with respect to 1981-2010 climatology (Figures 3-5).

Thus, the temperature gradient of the order of 6°C to 8°C in warm-core high at 200 hPa and more than 20°C in cold-core low at 500 hPa were highly favorable for the generation of the high jet stream of about 150 knots and high upper-level divergence. These were the primary causes of extreme weather associated with WD. Earlier Kumar et al. (2017) found that the temperature gradient of order 5°C in warm-core high at 200 hPa is favorable for the generation of the high jet stream [3].

Vertical velocity (ω): The vertical velocity is the key parameter for understanding the intense area of cloudiness and precipitation. The high negative values of vertical velocity at a particular region indicate the area of high rainfall [3]. Generally, the negative vertical velocity is associated with Low-Level Warm Air Advection (WAA), circulation at lower tropospheric levels, and divergence at upper tropospheric levels. From 11th January 2020 to 13th January 2020, the vertical velocity was negative and of high magnitude order over the area of heavy falls with its maximum magnitude at 500 hPa followed by 700 hPa in the area of maximum precipitation. The vertical velocity was between-0.11 Pa/s to-0.56 Pa/s from 925 hPa to 200 hPa levels (Figure 6) on 11-01-2020 with maximum magnitude at 500 hPa and minimum at 200 hPa which indicates the highest WAA and intensity of the system at 500 hPa level. Also, there was WAA from the Arabian Sea to the center of the system from 925 hPa to 200 hPa level causing high moisture feeding at lower and upper tropospheric levels from the Arabian Sea to the system. This feature was also seen in the relative vorticity field at 850 hPa, 700 hPa, and 500 hPa. This was one of the primary causes of exceptionally heavy rain/snow over these regions. A similar pattern was repeated on 12.01.2020. Thereafter, the magnitude of vertical velocity further increased and varies from -.11 Pa/s to -.57 Pa/s between 925 hPa to 200 hPa levels on 14.01.2020 with the moisture feeding on the Arabian sea at 700 and 500 hPa levels (Figure 6). Generally, the vertical velocity of order-.33 Pa/s or less at the mid-tropospheric level is favorable for heavy precipitation over the region [3].

From Figures 4 and 5, it is clear that 500 hPa vertical velocities are-0.561 Pa/sec and-0.566 Pa/sec on 11th and 13th January respectively. These vertical velocities are anomalous by-0.6 Pa/sec and-0.7 Pa/sec respectively for 1981-2010 climatology (Figure 7).

Wind analysis at different levels

Mostly westerly systems are seen as a trough in mid and upper tropospheric levels [2-4]. On the 11th, the Western Disturbance (WD) was seen as a trough between 500 hPa to 200 hPa levels and as a cyclonic circulation at lower levels (Figure 8). At 200 hPa, jet stream core winds were 150 knots to 155 knots in the right entrance and left exit of the trough which was roughly along with Longitude 50°E and north of latitude 26°N.

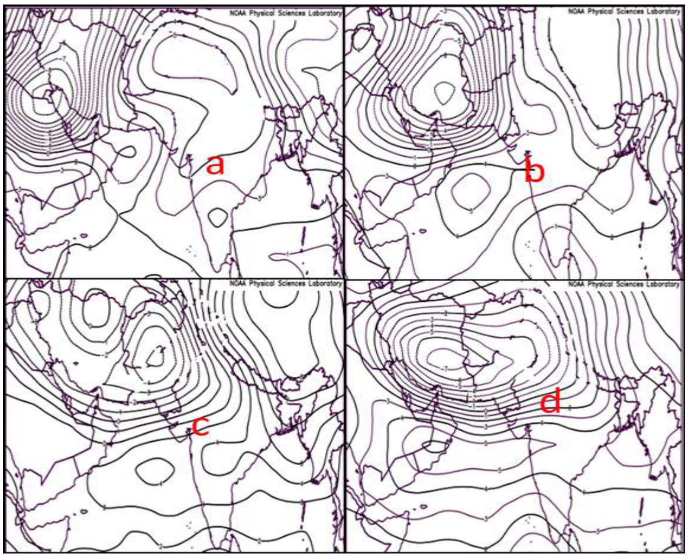

Figure 6. Air Temperature Anomaly (°C) at 500 hPa of (a) 11.01.2020, (b) 12.01.2020, (c) 13.01.2020 and (d) 14.01.2020.

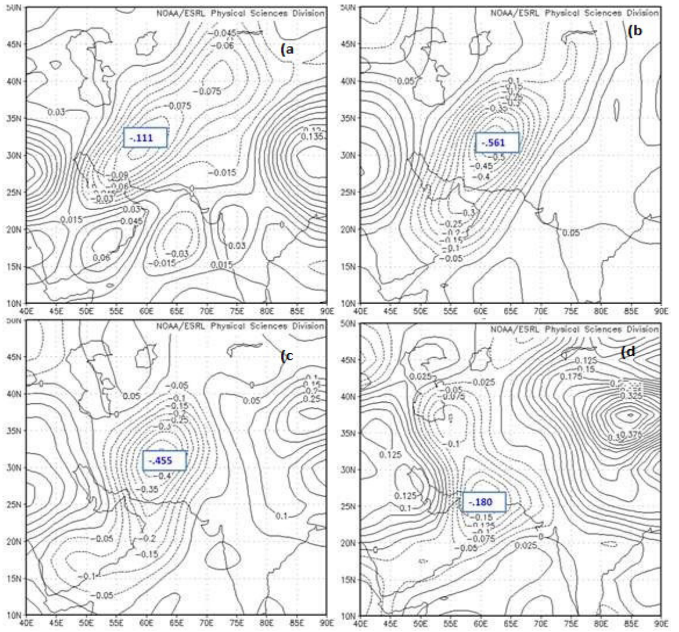

Figure 7. Mean Omega (Pa/s) of 11.01.2020 at (a) 200 hPa, (b) 500 hPa, (c) 700 hPa and (d) 925 hPa.

Hence it created a high divergence of order 4 $x10^{-5}$ s^{-1} to $50x10^{-5}$ s^{-1} in the forward sector (east Iran) of the trough as mentioned in para 3.1 and seen roughly along with Longitude 54°E and north of latitude 24°N at 500 hPa with winds up to 110 knots in the right exit of the trough. The WD was seen as a CC between 925 hPa to 700 hPa tilting westwards with height over northeast Iran and neighborhood along with high wind convergence and confluence between winds from the anti-cyclone over the central Arabian Sea and winds associated with WD over Iran. At the surface, it was seen as low over southeast Iran, which was about 800 km southeast of the system position at 200 hPa. It conforms with the earlier finding of Hunt et al. (2018) [4]. According to the nomenclature and SoP of IMD, the system formed at lower tropospheric levels (850 hPa or less) in connection with WD is called induced Cyclonic Circulation (CC) or induced low at the surface. On 12.01.2020, the system moved eastwards and intensified further due to an increase in meridional flow at upper tropospheric levels with a trough along with Longitude 52°E and north of latitude 21°N with jet cores wind speed up to 160 knots in the right exist of the westerly trough at 200 hPa. It lay like a deep trough roughly along with Longitude 54°E and north of latitude 18°N with core wind speed up to 115 knots in the forward sector of the system at 500 hPa (Figure 9), as a cyclonic circulation over northeast Iran and neighborhood at 700 hPa and 925 hPa with a deep trough from the center of CC to the Arabian Sea.

In addition, there was high wind convergence from the winds from the Arabian Sea and wind confluence between winds associated with system and anti-cyclone over the west-central Arabian Sea along with high moisture feeding on the Arabian Sea specifically over West Iran and eastern parts of Afghanistan. It was in the form of a low-pressure area over West Afghanistan and adjoining areas of Iran, about 800 Km to 900 Km southeast of the system at upper tropospheric levels. On 13.01.2020, it further moved eastwards and become more intensified with an increase in divergence at upper tropospheric levels with trough roughly along with

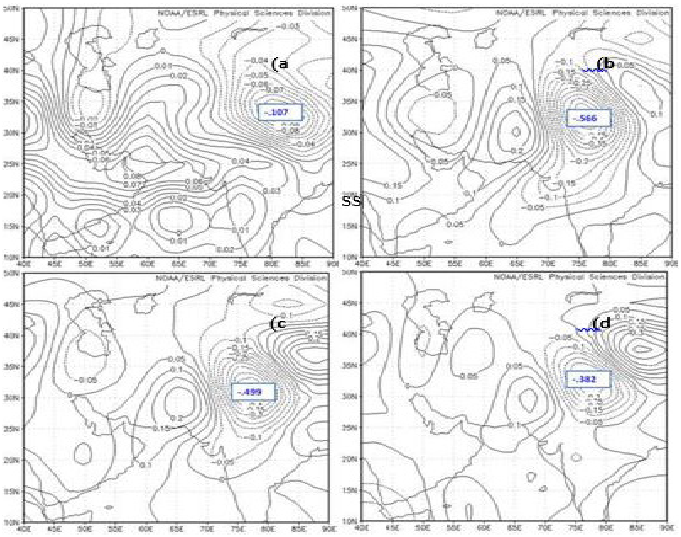

Figure 8. Mean Omega (Pa/s) of 13.01.2020 at (a) 200 hPa, (b) 500 hPa, (c) 700 hPa and (d) 925 hPa.

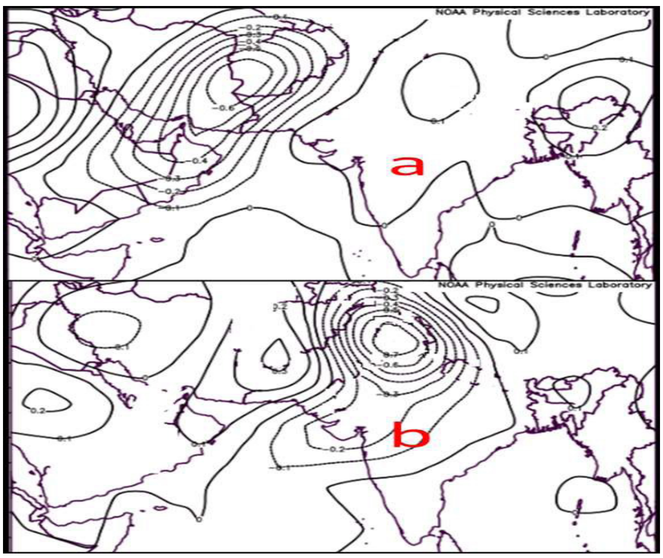

Figure 9. Omega (Pa/s) Anomaly at 500 hPa of (a) 11.01.2020 and (b) 13.01.2020.

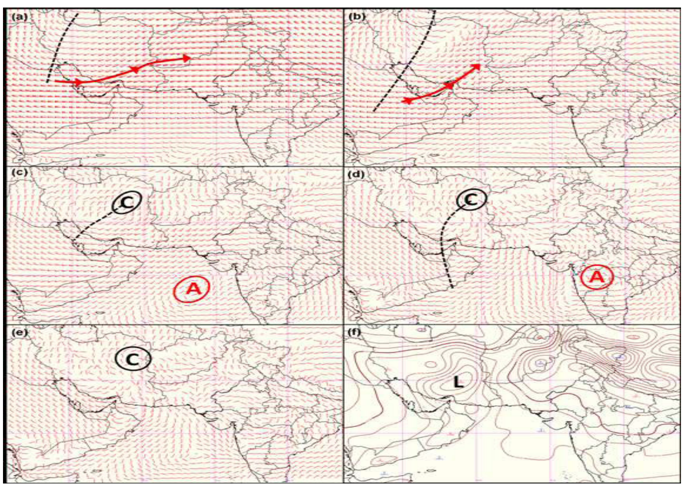

Figure 10. Wind chart of 11.01.2020 at (a) 200 hPa, (b) 500 hPa, (c) 700 hPa, (d) 850 hPa, (e) 925 hPa and (f) MSLP chart.

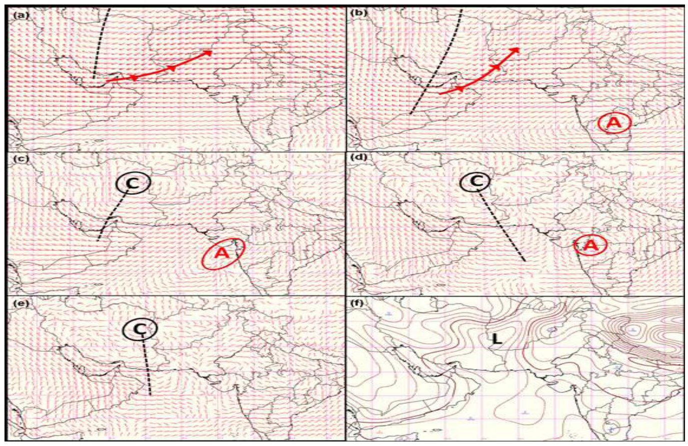

Figure 11. Wind chart of 12.01.2020 at (a) 200 hPa, (b) 500 hPa, (c) 700 hPa, (d) 850 hPa, (e) 925 hPa and (f) MSLP chart.

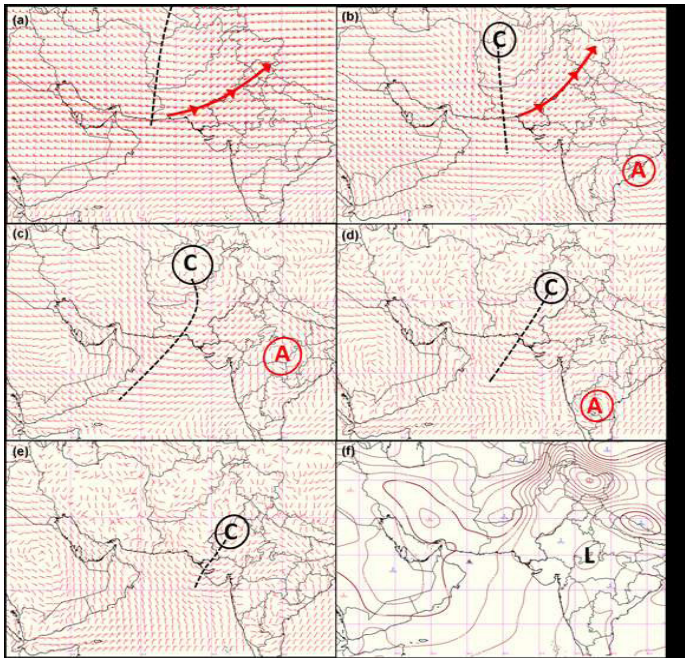

Figure 12. Wind chart of 13.01.2020 at (a) 200 hPa, (b) 500 hPa, (c) 700 hPa, (d) 850 hPa, (e) 925 hPa and (f) MSLP chart.

Longitude 60°E and north of latitude 20°N with jet core winds of order 150 knots to 160 knots over north Pakistan and Western Himalayan region at 200 hPa and as a CC between 500 hPa to 925 hPa levels tilting northwestwards with height (Figure 10-12). At all the levels, the trough extended from the center of the CC to the Arabian Sea pumping high moisture feed at lower and upper tropospheric levels. It was very much favorable for high precipitation over the Himalayas [2, 17].

Conclusion

The study scrutinized the different synoptic, dynamic, and thermodynamic features associated with potent winter weather phenomena that occurred over the west and south Asia from 11th January 2020 to 13th January 2020. This phenomenon is attributed to a WD developed over North Atlantic Ocean around 1st January 2020. It moved nearly eastwards with a speed of about 10° till 10th January and split into two components thereafter. Its one component moved northeastwards and another towards the Indian Himalayas with a speed of about 5°per day; the reduced speed may be due to the interaction of the system with orography. Earlier studies found its movement by about 5°per day. Generally, WDs are seen as trough/CC at mid and upper tropospheric levels. But, the present system was in the form of the trough in mid and upper tropospheric levels, as CCs at lower tropospheric levels and low pressure over the surface from 11th January 2020 to 13th January 2020 indicated the higher intensity of the system. The position of the system at the surface was roughly 700 Km to 900 Km southeastwards of its position at 200 hPa, earlier Hunt et al. (2018) also mentioned tilting of WDs northwestwards with height. Thus the present study endorses the earlier study of Hunt et al (2018). Interestingly, the system was a warm core high at 200 hPa with a temperature gradient of order 8°C -10°C around the system center and an intense cold-core low at mid-tropospheric levels with a very sharp temperature gradient of order 20°C to 24°C around the system Centre with its peak on 13th January 2020. As a result, there were high jet stream winds with its core speed of order 150 knots to 160 knots in the right exist of trough associated with WD at 200 hPa level and created a very high divergence of order up to $60x10^{-5}$ s^{-1} to $70x10^{-5}$ s^{-1} at upper tropospheric levels. The vertical velocity is also a key parameter to understand the area of high rainfall. Generally, the vertical velocity of order -.33 Pa/s or less at the mid-tropospheric level is favorable for heavy precipitation [3]. In the present case, vertical velocity was between-.11 Pa/s to-.57 Pa/s in lower and upper tropospheric levels with its maximum magnitude at 500 hPa and minimum at 200 hPa showing the highest WAA and intensity of the system at 500 hPa level. The high divergence at upper tropospheric levels supported by the high magnitude of negative vertical velocity at mid-tropospheric levels produced intense upward motion and strengthened the lower tropospheric CCs and lows. Also, there was WAA from the Arabian Sea to the center of the system in lower and upper tropospheric levels that provided high moisture feeding at all levels from the Arabian Sea to the system, which was one of the primary causes of exceptionally heavy rain/snow from southeast Iran to Indian Himalayas. Adding to the above facts, as the WD was in the form of the trough at mid and upper tropospheric levels and as a CC lower tropospheric level from 11th January 2020 to 13th January 2020, the southern end of the trough was deep in the Arabian Sea. In addition to CC at lower levels, there was a trough from the center of CC to the Arabian Sea causing high moisture feed from the Arabian Sea to the region. Earlier Kumar et al. (2015 and 2017) and Yadav et al. (2015) found that the CC at lower levels with moisture feed from the Arabian Sea is very much favorable for heavy precipitation over Indian Himalayas. Also, there was wind confluence between westerlies (due to WD) and easterlies (due to ant-cyclone over the Bay of Bengal) specifically at lower tropospheric levels that further triggered the intense weather activity over the region.

Disclaimer

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