

Spatio-temporal Characteristics of an Unusual Wintertime Extratropical Weather System Causing Widespread Downpours over Pakistan

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Abstract

This study seeks to diagnose the development and intensification of a wintertime extratropical weather system that persisted from 16th to 21st December, 2008 and caused moderate to heavy downpours over various regions of Pakistan. The rainfall was widespread and the rainfall system moved from southwest to northeast, affecting Balochistan, Sindh, Punjab, Kashmir and KPK provinces and Northern Areas of Pakistan. The spatial and temporal features of various parameters of this westerly weather system have been analyzed using surface and upper air station-based observed data, acquired from the Climatic Data Processing Centre (CDPC) of Pakistan Meteorological Department (PMD) and NCEP/NCAR reanalysis. It has been diagnosed that overall the Positive Vorticity (PV) persisted from 18th to 20th December, 2008 up to 500 hPa level and especially its presence at lower levels over Persian Gulf and northeast Arabian Sea supported the weather system as constant source of moisture incursion. The presence of cut off lows over central parts of Pakistan at 925 and 850 hPa levels further enhanced the moisture convergence over Pakistan resulting in moderate to heavy rainfall. The core of Subtropical Westerly Jet Stream (STJ) was located over the central parts of Pakistan from 17th to 19th of December 2008 and then gradually shifted eastward. The temperature profile revealed the interaction of two contrasting air masses comprising of comparatively cold dry air from the west and warm moist air from the Arabian Sea towards Pakistan which triggered the rainfall activity. Considering these spatial-temporal features of various meteorological parameters, timely forecast for such heavy rainfall systems can be issued in future during winter season.

Key Words: Western Disturbances, Subtropical Westerly Jet Stream (STJ), Positive Vorticity (PV), Cut off lows

Introduction

The precipitation is the key factor which influences not only the agriculture sector but also socio economic conditions of Pakistan. Some time it becomes helpful but some time it causes a lot of damage to not only the agriculture sector but also the socio-economic conditions (Chaudhry and Rasul, 2004). In winter season, there is usually shortage of water and the timely forecast of rainfall spells can play a vital role in the proper management of water resources e.g. water storage and flow in the rivers, dams, distributaries, canals and barrages etc. in order to meet the agricultural, economic, food and hydro-electrical energy requirements of the country. Pakistan is an agrarian country and its agriculture sector is dependents both directly and indirectly on rainfall. The world's largest contiguous canal irrigation system also exists in Pakistan.

Northern regions of Pakistan consists Himalaya, Karakoram and Hindukush mountain ranges, which host the world's third largest snow/ice reserves. The winter snowfall over these mountains meets the requirements of water for agriculture as well as energy purpose (Rasul et al;2008).The "Western Disturbance" originates over the Mediterranean Sea, brings sudden winter rainfall in South West Asia. Extratropical storms are a global, rather than a localized phenomenon with moisture usually carried in the upper atmosphere (unlike tropical storms where it is carried in the lower atmosphere). These extratropical systems have frontal behavior. These fronts cause precipitation of different types, over northern areas of Pakistan and some parts of Balochistan (Shamshad, 1988).

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Pakistan has a diversified climate ranging from sub-humid to humid in the north to hyper arid in the south. Northeastern mountainous and sub-mountainous plains receive more than 1700 mm of rainfall, while low elevation plains of southwest Balochistan accumulate only 30 mm rainfall on the average during the whole year. (Chaudhry and Rasul, 2004). In northern parts of Pakistan, the rainfall activity continues throughout the year, but the amount is relatively small in April - May and October - November (Rasul et al., 2004). Some of the stations in northern areas at high elevations are not at all affected by the summer monsoons due to the presence of high mountains, therefore the only system of receiving precipitation comes from the westerlies while at lower latitudes of Azad Kashmir stations both summer and winter rainfall is recorded in sufficient amounts. Similarly, the rainfall trends over the northwestern mountains are also different from the Himalayan region and the upper Punjab due to different meteorological factors such as anabatic (wind that blows up a steep slope or mountain side. It is also known as an upslope flow), katabatic (winds are down-slope winds, frequently produced at night by the opposite effect, the air near to the ground losing heat to it faster than air at a similar altitude over adjacent low-located land) effects of wind, height of the peaks and moisture availabilities (Climatic Normals of Pakistan, 1971-2000).

Thermal regime also touches both extremes beyond human tolerance. Temperatures fall as low as -26°C over the northern mountainous parts of Pakistan and go as high as 52°C over central arid plains. El Nino phenomenon suppresses monsoon rainfall activity over Pakistan, whereas La Nina phenomena have a negative impact on winter precipitation over Pakistan (Chaudhry and Rasul, 2004). Recent history's worst drought (1998-2001) over Pakistan and most of South Asia is linked with La Nina phenomena (Chaudhry et al., 2001).

The most interesting and notable feature of the rain spell under study is its spatial and temporal distribution of rainfall during the period of study which is much more important than the amount of precipitation. Contrary to the normal pattern of rainfall in the month of December over Pakistan, the whole sequence has been shifted a lot to the southern half of Pakistan and rainfall activity started from the southern half of Pakistan instead of northern half of the country. The normal (1971-2000) rainfall for Sindh province is 0-10 mm during month months of December. In 2008 maximum rainfall occurred in upper part of sindh, the rainfall departure was 2000 % more than normal rainfall in these areas. The rainfall spell was spread over the country as shown in Figure 1 (a). No such event has been observed in last and current decades of this century.

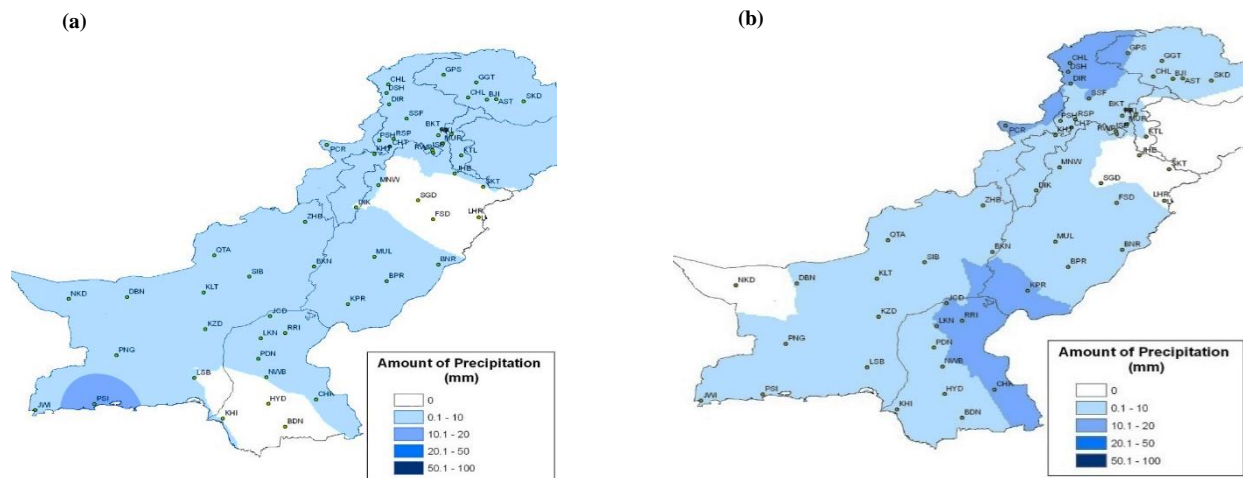


Figure 1: Spatial distribution of total rainfall (shaded) in 'mm' for selected stations of Pakistan
(a) December 17, 2008 (b) December 18, 2008.

In this research work, analysis has been carried out by using observed and NCEP reanalysis data along with satellite images in order to explore, identify and diagnose the causes of development and intensification of a winter rain spell that occurred and continued from December 16, 2008 to December 20, 2008 causing moderate to heavy rains over various regions of Pakistan. The rain was widespread and the rainfall region moved mainly from southwest to northeast covering Balochistan, Sindh, Punjab, Kashmir, KPK and Northern Areas of Pakistan. The spatial distribution of normal rainfall in “mm” during on 18th December 2008 is shown in Figure 1(b).

Data and Methodology

In order to analyze this wintertime extratropical weather system, causing widespread moderate to heavy downpours over various regions of Pakistan from December 16 to 20, 2008, first of all the station-based observed data acquired from Climatic Data Processing Centre (CDPC) of Pakistan Meteorological Department (PMD) has been analyzed by generating rainfall maps showing spatial distribution of “normal”, “totals of daily” and “percentage departure of totals of daily from normal” rainfall by using the software “ArcGIS” software. The observed data acquired from Main Analysis Centre (MAC) of PMD has also been analyzed by using the surface weather charts at 0000 UTC generated with the help of software, “Digital Atmosphere”. The manually prepared conventional synoptic weather charts, obtained from National Weather Forecasting Centre (NWFC) of PMD, were also analyzed in detail. The analysis of real time data helped to fill up the gaps left due to coarser resolution of NCEP / NCAR reanalysis data. For the investigation of spatio-temporal characteristics of different weather parameters at various pressure levels in the atmosphere, the NCEP / NCAR reanalysis data plots were prepared and visualized by using the graphics software GrADS (Grid Analysis and Display System). The NCEP / NCAR reanalysis data was acquired from the website <http://www.cdc.noaa.gov/cdc/data.ncep.reanalysis.pressure.html>. The NCEP/NCAR reanalysis 1 project is using a state-of-the-art analysis / forecast system to perform data assimilation using past data from 1948 to the present. The reanalysis data was available at four times daily basis with horizontal resolution of 2.5°. The reanalysis data of NCEP / NCAR was available at 17 vertical pressure levels from (1000-100) hPa. The domain selected for the study of this extratropical weather system was (10°-50°N , 30°-90°E). For this study, the NCEP / NCAR reanalysis data plots of 0000 UTC and 1200 UTC have been selected in order to observe the changing behavior of atmosphere during day and night times alternatively.

Results and Discussion

The temporal and spatial distribution of various weather parameters both at the surface and in the upper air has been discussed in this section.

Analysis of Surface Weather Charts

On 16th December, 2008 at 0000UTC, three low pressure systems were present over the Pakistan’s neighborhood. A weak low was persist over Indian territory close to the central east border of Pakistan. The 2nd low pressure area was present close to northwest part of Pakistan located over the upper parts of Afghanistan. This low affected the upper parts of Pakistan on 16th night and on 17th morning produced light rain over Islamabad and Murree. The most prominent is the third low present over the central parts of Iran. This low has formed as a cutoff low present in the trough of the low pressure present over central east Arabian Sea as shown in Figure 2 (a). This low affected the lower parts of Balochistan and produced rainfall of light to moderate intensity over the coastal areas. Jiwani received 28 mm of rainfall. Almost all parts of India are covered by a ridge except the north western parts located close to Pakistan border. Another high pressure area is present over the Arabian Sea close to Gulf of Aden. The cut off low present over Iran picked up moisture from two sources, one the Persian Gulf and other the northwestern parts of Arabian Sea.

On 17th December, 2008 at 0000UTC, as shown in Figure 2 (b) the situation is almost the same, but on 18th December, 2008 at 0000 UTC, the trough over the upper parts of is still very shallow. Another trough of the low present over central east Arabian Sea is extending up to the Iraq covering almost all

parts of Persian Gulf and Gulf of Oman. The coastal Areas of Pakistan and southern parts of Pakistan are also under the influence of this trough as shown in Figure 2 (C).

On 19th December 2008 the trough over Persian Gulf area is slightly shifted to northeast. The southeastern parts of Pakistan are under the influence of trough penetrating from Arabian Sea. This synoptic situation shows the eastward movement of the weather system, cessation of the system over Afghanistan and Iran with activation over Pakistan as shown in Figure 3 (a).

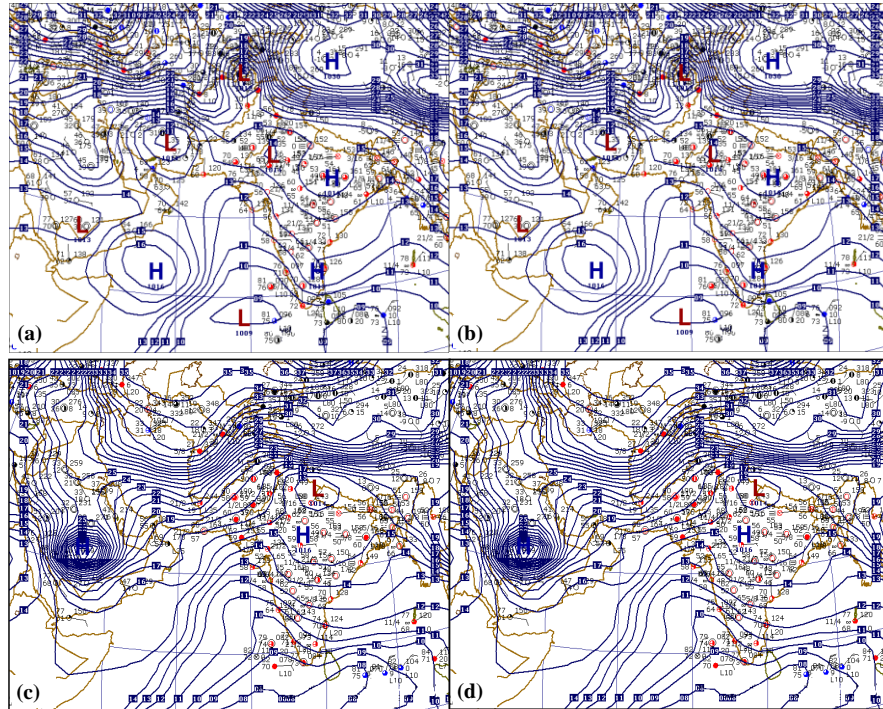


Figure 2: Surface weather chart showing pressure pattern (isobars at 01 hPa interval) over the region of study at 0000 UTC (a) December 16, 2008 (b) December 17, 2008 (C) December 18, 2008 (d) December 17, 2008.

On 20th the trough over southern parts of Iran, as shown in Figure 2(d), is still present and has become shallow, the low over northwestern India is present in the form of trough only. This trough is still affecting the upper half of the country. The high present over Saudi Arabian peninsula is now present in the form of ridge only. Another ridge is present over Afghanistan area and the southwestern parts of Pakistan. Gradual eastward movement of this ridge will replace the trough over upper parts of Pakistan thus the rainfall activity will stop in coming 12 to 18 hours.

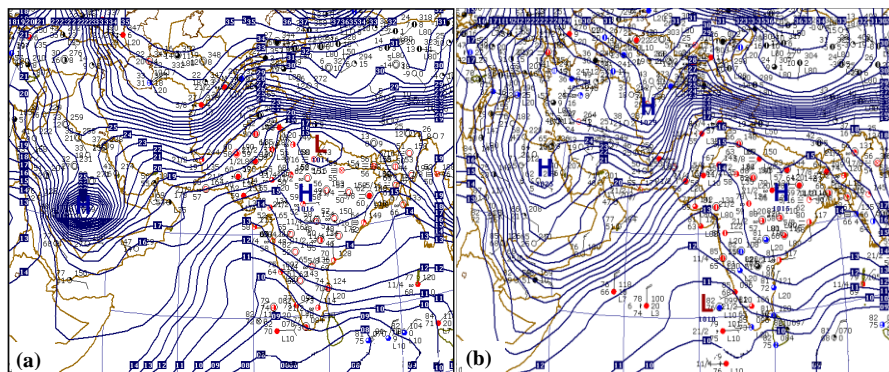


Figure 3: Surface weather chart showing pressure pattern (isobars at 01 hPa interval) over the region at 0000 UTC (a) December 19, 2008 (b) December 20, 2008.

Analysis of Vorticity and Geopotential Height at Different Pressure Levels

The 300 hPa level shows the presence of negative vorticity over most parts of Pakistan on 18th & 19th. When the rain stopped on 21st December, 2008 this area was totally replaced by negative vorticity especially at 1200 UTC on 21st December, 2008. On 20th December, 2008, when there were wide spread rains over Pakistan, whole of the Area was covered with positive vorticity while it was intensified on 21st December, 2008 at 1200 UTC with the end of this rain spell. No proper correspondence of vorticity at 200 hPa level with rainfall at the surface is observed for 200 hPa level. but the main trough has been moved a little south eastward as depicted in Figure 4 (c-d) for two different days at 00UTC.

Analysis of Vertical Profile of Relative Humidity at Different Pressure Levels.

On 16th December, 2008 at 1200 UTC surface level the average relative humidity over upper half of Pakistan is 60-70 % and lower half is 40-60 %. Upper parts of the country show good moisture content from surface level at to upper levels. Southeastern parts of the country represent the 55 % relative humidity and upper Punjab, KPK represent the 65 % relative humidity in upper air. If we go from surface to upper levels at 700 hPa, the lower half of the country is representing 45 % relative humidity and upper half of the country indicates the 60 % relative humidity. Near 500 hPa level, lower half of the country is indicating 60 % relative humidity and upper half shows 70 % relative humidity.

On 17th December, 2008 at 1200UTC surface level relative humidity has increasing tendency in lower and upper parts of the country. From surface to 850 hPa level, on the average, both upper and lower parts are representing the 60 % relative humidity. This is an indication that moisture is penetrating in lower layers of the atmosphere. From 850 hPa to 700 hPa level, southwestern parts of the country are representing up to 80 % relative humidity and same is the case with western border of Pakistan central and eastern parts representing 50 % relative humidity. From 700 hPa to 500 hPa level, most moisture is concentrated along the western boarder of the country. Northern parts are representing 40 % relative humidity. Eastern parts of the country are representing 50 % relative humidity. This shows stronger instability in western sector and central parts of the country.

On 18th December, 2008 at 1200 UTC surface chart, the relative humidity of Balochistan, KPK and Upper Punjab reaches to 80 %. It shows more moisture incursion in these areas at surface level with certainly brought good rain fall in the country. The source of this moisture is moisture laden winds from the Arabian sea. From surface to 850 hPa level, whole Pakistan shows good moisture contents Western parts of the country shows up to 80 % relative humidity. Eastern parts represent 70 % moisture. From 850 hpa to 700 hpa level, both lower and upper parts are representing 70 % relative humidity. On the average, good moisture supply up to this level favors the surface of features and enhance the weather condition. From 700 hPa to 500 hPa level, southeastern part shows relative humidity up to 80 %. Northern parts represent relative humidity with 50 % decrease in moisture contents are decreasing in western parts. This represents the shifting of weather system towards east. On 18th December, 2008 all charts show good moisture contents over Pakistan Area and most favorable condition for precipitation.

On 19th December, 2008 at 1200UTC surface charts, central parts of Pakistan show 90 % relative humidity. KPK, Punjab and some parts of Balochistan shows 80 % relative humidity. Southwestern parts indicate 50 % relative humidity, over all good moisture contents are present on 19th December, 2008 at surface level. From surface to 850 hPa level, upper Sindh, Punjab, KPK and Northeast Balochistan represent 90 % relative humidity. The remaining parts also show a good moisture at this level. This chart supports the surface feature and help in transporting the moisture to upper levels. From 850 hPa to 700 hPa level, whole Pakistan is representing the relative humidity more than 90 %. Central parts of the country show 100 % relative humidity. This is most favorable condition for good rainfall conditions in the country, as all surface, 850 hPa level and 700 hPa level are supporting

each other. From 700 hPa to 500 hPa level, Northeast Balochistan, Punjab and KPK are showing 90 % relative humidity. Other parts of the country also show good moisture content. This chart shows enhanced weather features at lower levels as lower levels represent rainy weather so the rain is enhanced by the features at 500 hPa level.

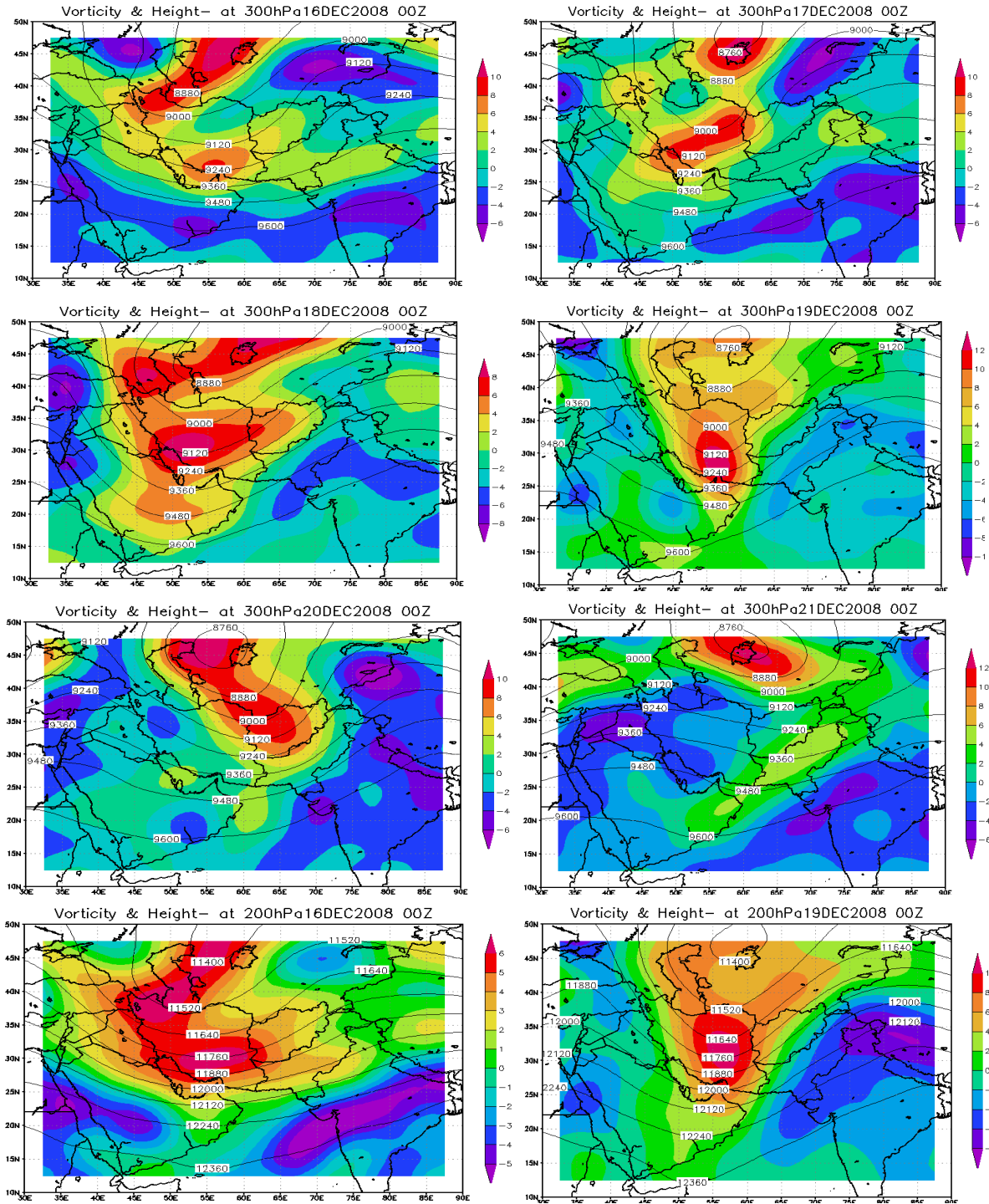


Figure 4: 300 hPa geopotential height contours (labels in gpm) superimposed on 300 hPa relative vorticity (shaded; 10^{-5} in units of s^{-1}) from December 16th to 21st, 2008 at 0000 UTC (ad), 300 hPa geopotential height contours (labels in gpm) superimposed on 300 hPa relative vorticity (shaded; 10^{-5} in units of s^{-1}) for 16th & 19th Dec, 2008.

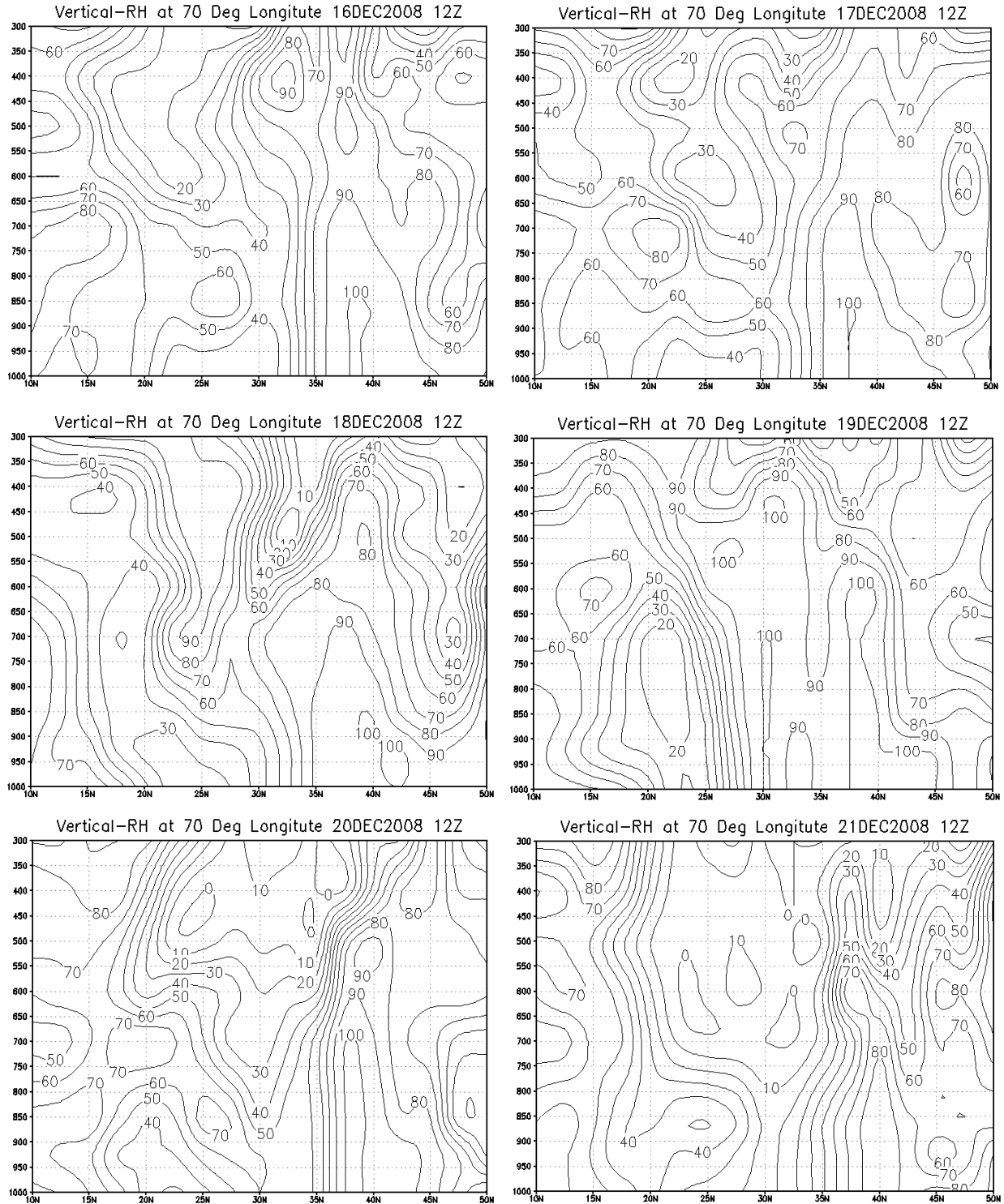


Figure 5: Vertical Cross section of Relative Humidity (percentage) along 70°E from 1000 hPa at 300 hPa level from December 16th to 21st, 2008 at 1200 UTC.

On 20th December, 2008 at 1200 UTC surface level, there is a decreasing tendency in relative humidity in central parts of the country with moisture content over Upper KPK, Upper Punjab and Northern Areas. This chart shows that rainy conditions at surface are shrinking to some parts of the country. From surface to 850 hPa level, relative humidity has decreasing tendency over upper parts of

the country represent 50 % relative humidity. Extreme southwestern parts shows 70 % relative humidity and Northern parts show 60 % relative humidity on the average. From 850 hPa to 700 hPa level, KPK and Punjab has relative humidity upto 50 %, south western parts are showing 40 % relative humidity and northern parts are showing 50 % relative humidity. As a whole, there is a decreasing tendency in relative humidity. This is an indicator that weather system is in the weakening state. From 700 hPa to 500 hPa level, relative humidity has decreasing tendency. This shows that moisture transport to upper level is decreasing and is due to the fact that all levels below 500 hPa are not transporting water content to upper atmosphere.

On 21st December, 2008 at 1200 UTC surface level, the extreme northern parts are still under the grip of westerly wave and this region has good moisture content confined over small area. From surface to 850 hPa level, in central parts of Pakistan, the moisture content is very less. There is good moisture concentration in extreme northern parts while over southern parts relative humidity is 40 %. From 850 hPa to 700 hPa level, moisture is concentrated in the extreme northern parts of the country and southern half of the country has less than 30 % relative humidity. From 700 hPa to 500 hPa level, the relative humidity is less than 15 % over almost all the parts of Pakistan.

On 21st December, 2008 only northern parts have good moisture content up to 700 hPa level. This shows retreat of weather system over Pakistan and its remaining part is affecting only the northern parts of the country.

Vertical Profile of Temperature at Surface, 850, 700 and 500 hPa Levels

In this context, temperature analysis is very important to differentiate between the two air masses. Temperature gradient analysis can help indicate the potential of rainfall in these air masses. It can also help in understanding the modification of air with time. Temperature gradient is a useful tool, the higher the temperature gradient, stronger would be the instability in a weather system and hence more potential to lift the moisture from surface to upper level. The isotherms at Surface, 850, 700 and 500 hPa levels at 1200 UTC, have been analyzed to study the behavior of rain spell between 16th to 21st December, 2008 in the context of relative humidity analysis of the system at the same levels and for the same time.

On 16th December, 2008 at 1200 UTC at surface level, 25 °C isotherm is crossing over the southeastern parts of Pakistan and 20 °C isotherm is crossing over the Northern parts of Pakistan on the average. As warm air has more capacity to hold moisture, therefore higher temperature near coastal area favours the rain fall situation, if it is blocked by cold air from north to trigger the rain fall. At 850 hPa level, upper half of the country is colder than the lower half of the country by the difference of 5 °C with most cold air over north of Iran. At 700 hPa level, 0 °C isotherm is crossing over mid of Pakistan and lower half is warmer than upper half. At 500 hPa level, 18 °C isotherm is crossing over Rahim Yar Khan and Bahawalnagar areas and 9 °C isotherm is passing over the Arabian Sea near our coastal area. Our Northern parts have 20 °C temperature. The coldest area of the westerly wave is located near Caspian Sea. All above levels are showing that cold air is penetrating into the northern parts whereas moist and warm air is invading our region from the south.

On 17th December, 2008 at 1200 UTC at surface level, approximately same situation is prevailing like the previous day. Near the Caspian Sea, colder air is shifting slightly southward. At 850 hPa level, temperature profile is also similar to previous day. At 700 hPa level, temperature profile of the same region is similar to previous day but colder air is approaching the western boundaries of Pakistan. At 500 hPa level, upper half is colder than the lower half and it is a favorable condition for rain fall in the region.

On 18th December, 2008 at 1200 UTC at surface level, surface feature with reference to temperature are not changing. It means that rain bearing system is effecting different parts of the country. Temperature contrast in North and South is causing rain fall in different parts. At 850 hPa level, again

temperature profile in our region is similar to the previous day. At 700 hPa level, 0 °C isotherm is shifting towards the western parts. Same trend of temperature is followed by the isotherms at 500 hPa level also.

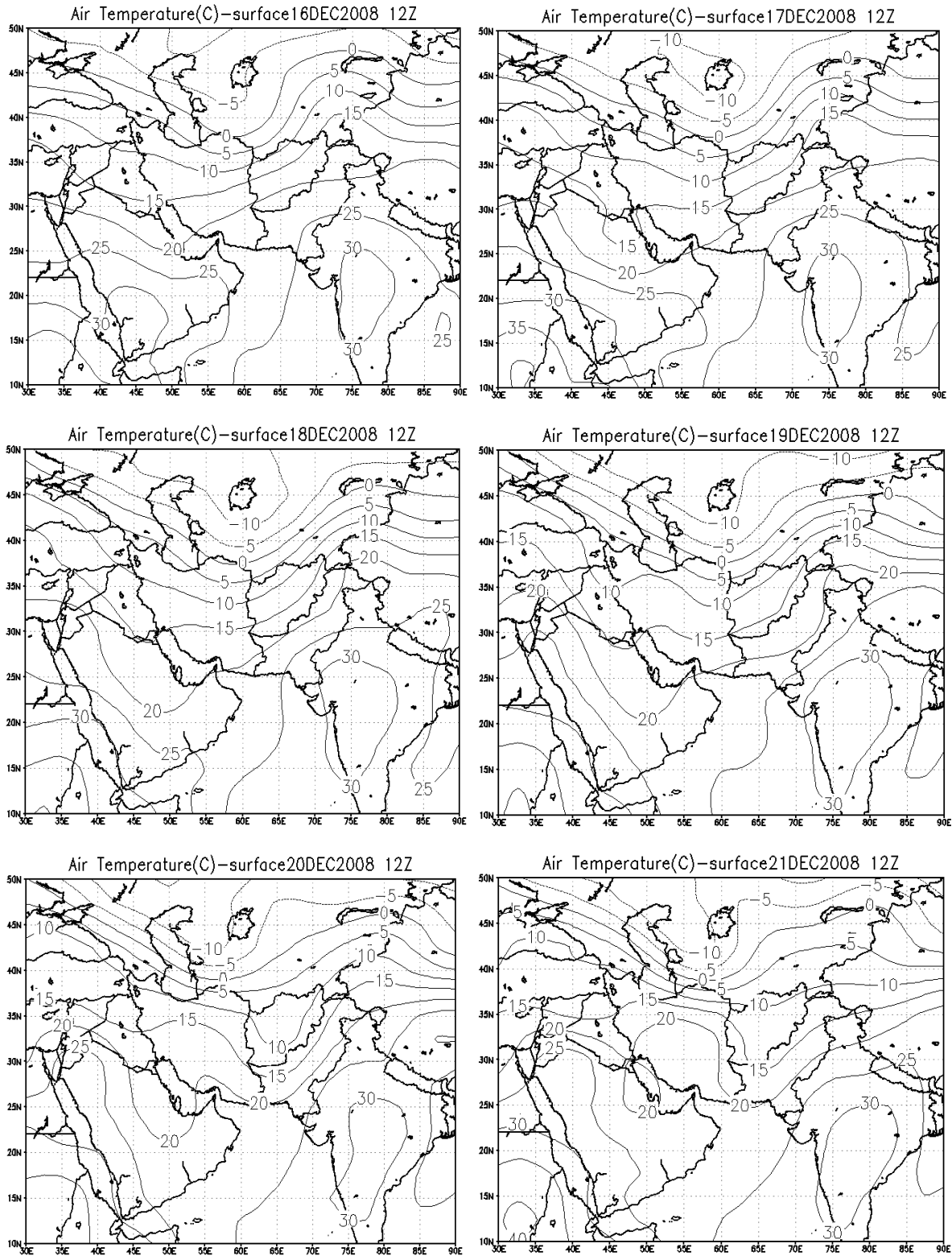


Figure 6: Isotherms showing surface air temperature (units in °C) from December 16th to 18th, 2008 at 1200 UTC.

On 19th December, 2008 at 1200 UTC at surface level, the whole country shows a decrease temperature trend by 04 °C, western boundaries of Pakistan are showing colder air is invading Pakistan. This cold air along with the moist air from the Arabian Sea is causing rain in the country. At 850 hPa level 10 °C isotherm is crossing over central parts of Pakistan and 0 °C isotherm is crossing over north of Afghanistan. At 700 hPa level, the temperature profile is similar to previous day. At 500 hPa level, 20 °C isotherm is touching the western boundaries and 12 °C isotherm is touching eastern boundaries of Pakistan, overall situation indicates that persistent rainy weather conditions are prevailing over the country. On 20th December, 2008 at 1200 UTC at surface level, central parts of Pakistan are representing 15 °C temperature. This means that cold air is moving from west to east. It also shows that now system is moving from west to east and persistency is reducing. At 850 hPa level, now 10 °C isotherms is replaced by 05 °C isotherm that endorses the surface pattern in upper layer also, the cold air is moving from west to east. At 700 hPa level, 0 °C isotherm has moved slightly towards east, 5 °C isotherm which was at western boundaries on previous chart, has extended into the North western parts of Pakistan. At 500 hPa level, cold air has been penetrating to lower parts of the country. This is enhancing feature for rainfall however as system is moving from west to east, the moisture from the Arabian Sea to different parts of the country is reducing.

On 21st December, 2008 at 1200 UTC at surface level, cold dry air has entered into the country and system is just leaving the country. Now dry continental air is prevailing over the whole country. Trough located over upper parts of the country is still producing rainfall over there. On 850 hPa level, isotherms are shifting from west to east to introduce more and more cold air in the country in lower layer of the atmosphere. At 700 hPa level the temperature profile is similar to previous chart. On 500 hPa level, the temperature profile is similar to previous level. It means that system has departed from the country. A trough is persist in upper parts of country which is providing uplift to the remaining moisture content and is causing rainfall in northern parts of the country.

Analysis of Subtropical Westerly Jet Steam (STJ) at 200 hPa Level

Subtropical westerly jet steam (STJ) is a narrow core of very high wind speed with magnitude of 60 knots. It has the area of thousands of Km, width hundreds of Km and depth in some Km. The vertical wind shear is of the order of 5-10 m/sec per Km, while horizontal wind shear as 5 m/sec per 100 m. Subtropical westerly jet steam (STJ)s are of four types and each type has its own importance for the formation of weather. Subtropical Westerly Jet Steam (STJ) are associated with strong divergence at the upper level and corresponding low pressure areas at surface. Subtropical westerly jet steam (STJ)s exhaust the air from the lower level to upper atmosphere. Subtropical westerly jet steam (STJ)s provide instability and provide uplift to moisture at different levels. In this case study, 200 hPa level has been used to study the impact of Subtropical Westerly Jet Steam (STJ) in upper atmosphere.

On 16th December, 2008 at 0000 UTC, when a cut off easterly low is present over Iran, southern Afghanistan and extreme south eastern parts of Balochistan the core of subtropical westerly jet steam (STJ) was located over plains of the southeastern parts of Pakistan, extending towards the northern parts of India. At 1200 UTC, these strong winds shifted towards eastern parts of Pakistan.

On 17th December, 2008 at 0000 UTC, a prominent strong wind core started affecting the central and eastern parts of Sindh and some parts of Balochistan at 1200 UTC also. This condition favours the surface features i.e. arrival of moisture laden winds in Pakistan to cause the rainfall. On 18th December, 2008 at 0000 UTC, the strong winds are accumulating in Sindh, Balochistan, Punjab and KPK. But at 1200 UTC, the whole Pakistan is under the grip of these strong winds with rising tendency in the magnitude. On 19th December, 2008 at 0000 UTC, all Pakistan is under the influence of strong winds with core crossing over the northeastern parts of Balochistan, KPK and northern parts of Pakistan. This indicates the shifting of weather intensity from southern parts to upper parts of the country. At 1200 UTC, the stronger conditions are persisting over the country.

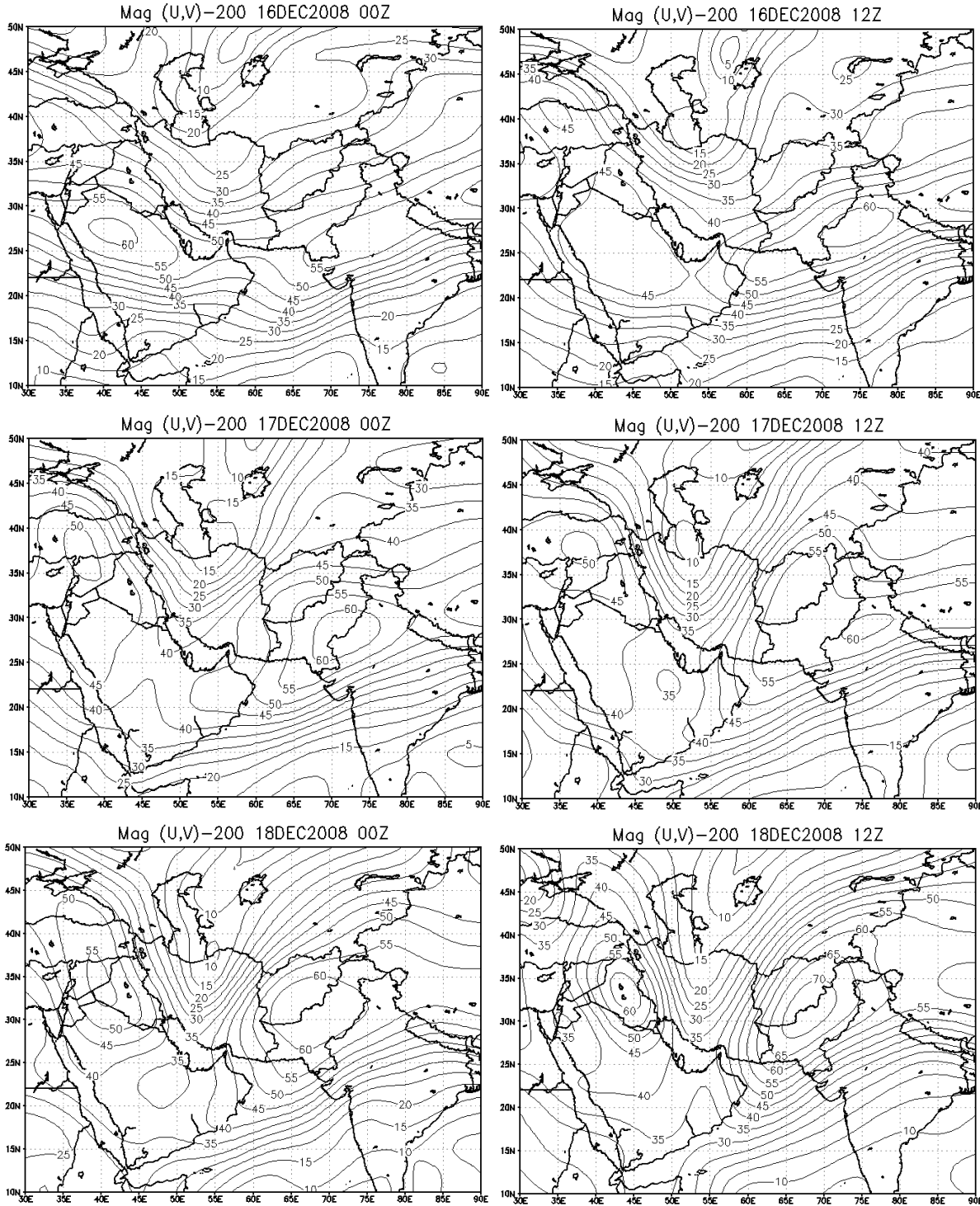


Figure 7: Subtropical westerly jet steam (STJ) wind magnitude (contours; speed in Knots) at 200 hPa level from December 16th to 18th, 2008 (left hand panel) at 0000 UTC (right hand panel) at 1200 UTC.

On 20th December, 2008 at 0000 UTC under the influence of strong winds is decreasing with decrease in magnitude. The core of the strong winds lies over northern parts of Pakistan. At 1200 UTC, the strong winds are shifting towards India with decreasing tendency in magnitude with high magnitude over northern parts of India. This indicates the weakening of weather system in Pakistan. On 21st December, 2008 at 0000 UTC, 50 Knot winds are crossing over eastern and northern parts of country.

The core of strong winds is laying on northern parts of India at 1200 UTC charts i.e. strong winds are departing from Pakistan. This is an indication of departure of rainy system from Pakistan.

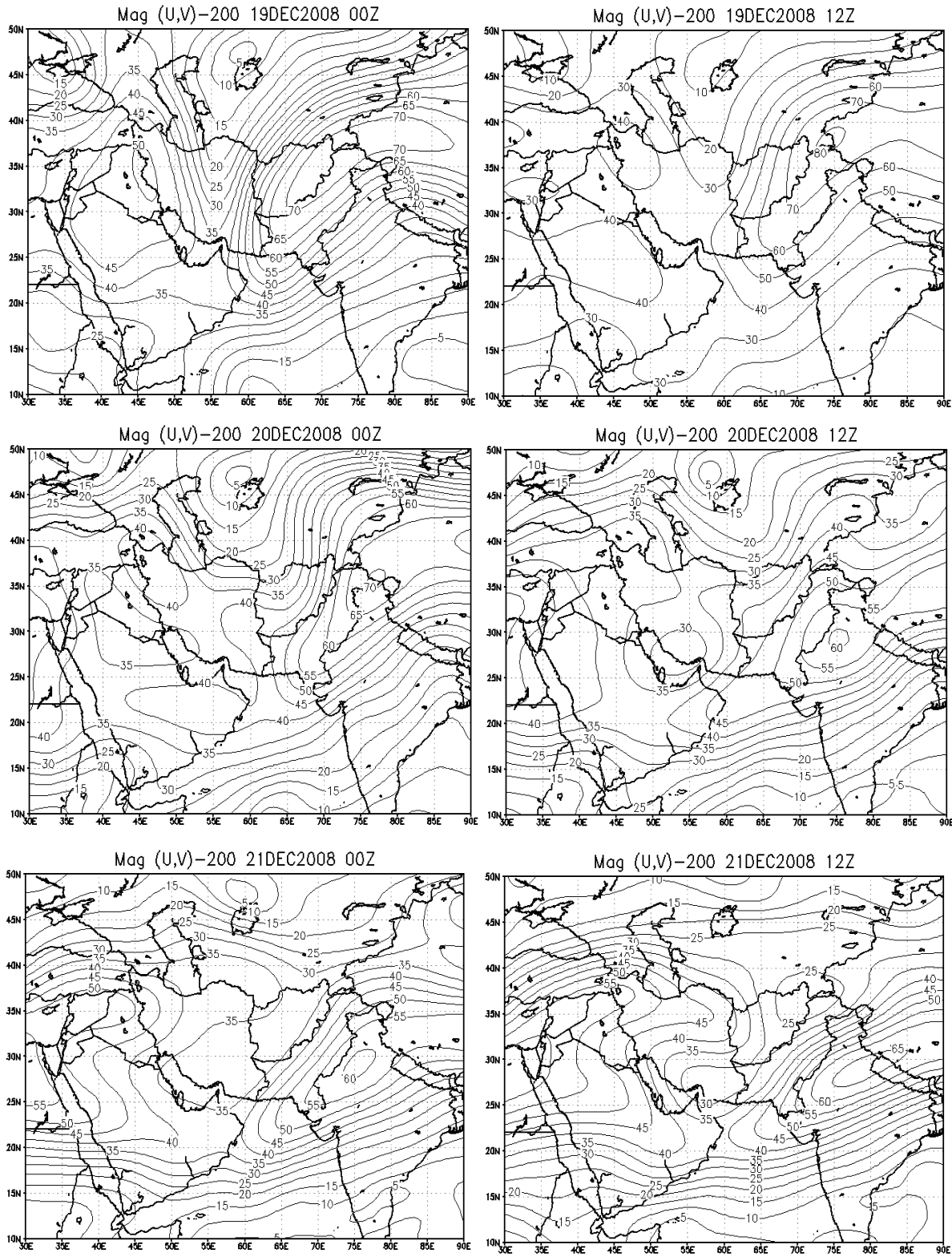


Figure 8: Subtropical westerly jet stream (STJ) wind magnitude (contours; speed in Knots) at 200 hPa level from December 19th to 21st, 2008 (left hand panel) at 0000 UTC, (right hand panel) at 1200 UTC.

Conclusions

Strong Positive Vorticity (PV) remained present over Persian Gulf in the Northwest-Southeast orientation and remained exactly aligned for almost whole of the period from 17th December 2008 to 20th December 2008. This synoptic situation helped in accentuation of the system persist over Iran. When this system approached Pakistan it already had enough moisture content, it was due to this moisture that caused moderate to heavy rainfall, recorded at most stations of South Punjab, upper KPK, Kashmir and Sindh.

From surface up to 700 hPa level, Positive Vorticity (PV) due to trough present over Northeast Arabian Sea and surrounding areas from 16th December 2008 to 18th December 2008 except on 17th December 2008 at 1200 UTC, uplifted and transported the moisture from Northeast Arabian Sea to the upper and central parts of the country, thus enhancing the rainfall amounts.

The strong positive vorticity cells were present over the southern parts of the country on 19th December 2008 at 1200 UTC. The intensity and orientation at 925 hPa level was almost along 25 °N latitude (along the coastal areas of Pakistan) while at 850 hPa level, the area of strong positive vorticity was centered over central parts of Balochistan and it covered almost all parts of Pakistan except some parts of southeast Punjab on 20th December 2008 at 0000 UTC.

At 850 hPa level, closed low was present over Iran and Persian Gulf on 16th December 2008 at 0000 UTC and 1200 UTC and again on 17th December 2008 at 1200 UTC. Afterwards trough which persisted over this region as well as Pakistan. On 19th December 2008 at 1200 UTC, two low pressure cells formed, one over central parts of Balochistan and the other over upper parts of the country. After only six hours, the low over Balochistan dissipated and a high appeared over the area over the junction of Afghanistan, Iran and Pakistan borders. For further six hours entire area of Afghanistan, Iran, Persian Gulf and Saudi Arabia was covered by a high.

The system was much prominent at 925 and 850 hPa levels where cut-off lows were observed, while at 700 hPa, 500 hPa and higher levels, the deep trough gradually moved from Northwest to Southeast and remained prevalent over Pakistan from 18th December 2008 to 21st December 2008.

From 16th December 2008 to 21st December 2008, the relative humidity profile was highly supporting the westerly weather system. Relative humidity started increasing from 16th December 2008 reaching its peak value on 19th December 2008 at surface level, which supported good rainfall in the area. Wind profile shows that the sources of moisture were Arabian Sea and Persian Gulf.

On vertical profile, the relative humidity had an increasing trend up to 500 hPa level, which indicates that moisture was reaching sufficiently at upper level. This moisture along with other favorable synoptic features at surface and upper air caused a rainfall in different parts of the country.

Temperature profile shows that cold dry air was entering the country from the west, while warm moist air was approaching from Arabian Sea. This contrast in temperature helped in triggering the rainfall.

After 20th December 2008, the temperature profile from surface to 500 hPa level remained almost similar except the shifting of low temperature isotherm from west to east. This is due to the fact that after 19th December 2008; the weather was shifting from west to east.

On 21st December 2008, temperature profile showed that the cold continental air replaced moist air as indicated by the weather pattern.

The current rainfall system benefit the major crop of Rabi season i.e wheat in the whole country. "Wheat needs both water and the cold weather, which are being provided by rains during the season. This rainfall spell was also beneficial for sunflower, major crops of the Rabi season, as these were in the first stage of sowing process.

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