Third Successive Active Monsoon over Pakistan - An Analysis and Diagnostic Study of Monsoon 2012

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Abstract

In this research report an effort has been made to analyze and study main features of monsoon 2012 rainfall over Pakistan and its associated synoptic features. Monsoon 2012 was special due to the fact that it was the third consecutive monsoon, which recorded above normal rainfall. The seasonal monsoon 2012 rainfall of the country as a whole was 31 percent above long term normal (1961-2010) and is ranked 12th heaviest monsoon rainfall since 1961. The intensity of monsoon rainfall during the past two years (2010 & 2011) was 73% and 63% above than normal (1971-2000) respectively. The excessive monsoon 2012 rainfall, like monsoons of 2010 & 2011, again caused severe flash flooding in the country. The rainfall for month of September2012 was ranked highest ever recorded rainfall during the period 1961-2012. It was also recoded highest ever rainfall over Balochistan, second highest at Kyhber-Pakthunkhwa, third highest over Sindh and fifth highest over Azad Kashmir during past 52 years. It is investigated that the persistence of sea level monsoon trough over Central India that remained parallel to the latitudes, during second week of September 2012, caused weather systems which formed over North of Bay of Bengal/ northeastern parts of India to move westwards , resulting heavy down pour in the Southeastern parts of the country.

Key words: monsoon 2012, synoptic feature, sea level monsoon trough, heavy down pour

Introduction

The Asian monsoon is the most significant component of the global climate system. During recent two decades, concerned efforts have been made to investigate the Asian monsoon (Rasul and Chaudhry 2010).The Asian monsoon is characterized with a distinct seasonal reversal of wind and clear partition between dry and wet season in the annual cycle, which is related with the seasonal reversal of the large-scale atmospheric heating and steady circulation features (Webster et al. 1998; Ding and Chan 2005; Trenberth et al. 2006).

The monsoon precipitation plays a very important role in the social and economic development of Pakistan. Nearly 60 % of annual rainfall over most parts of Pakistan is received during summer (M. Muslehuddin and N. Faisal 2006). Rainfall occurs primarily due to differential heating of the area. Differential heating of the land and ocean creates pressure gradient that drives the winds from high pressure to low pressure. Air circulation will start if one region is heated or cooled more than some other region. Joshi et al (1988) noted the differential heating of the continents and the adjoining ocean to be the primary cause of the summer monsoon circulation over South Asia.

Over Pakistan, monsoon (July-September), normally reaches the eastern border of the country around first of July and persists up to the end of September (A. Mahmood et al., 2010). Analysis of 5-day rainfall of selected stations of eastern boundaries of country has also revealed that the dates of onset determined by pentad method were within 2 days of those declared by Pakistan Meteorological Department (N. Faisal & N. Sadiq, 2010). The onset of monsoon 2012 over Pakistan was delayed by 3 days. Monsoon rains started in northeastern parts of Punjab and adjoining areas from 4th July. The monsoon then slowly advanced to the rest of the country and started to withdraw from the region by18th September. On 20th September monsoon completely withdrew from whole of the country. The onset dates of previous two monsoons (2010 & 2011) were July 5 and 1, respectively.

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After the end of the La Niña in April 2012, the global land and ocean temperatures rose increasingly above the long-term average with each consecutive month. The six-month average of May–October 2012 was among the four warmest such periods on record (WMO 2012). "Naturally occurring climate variability due to phenomena such as El Niño and La Niña impact on temperatures and precipitation on a seasonal to annual scale." said WMO Secretary-General Michel Jarraud.

As a whole country the monsoon period for 1961-2012exhibit significant increasing trend (Figure-1). Interestingly, while analyzing the seasonal rainfall on provincial basis, significant increasing trends were observed over all provinces except Azad Kashmir. However the increase in precipitation over two provinces (Balochistan and Sindh) was not significant.

Seasonal Rainfall

Monsoon 2012 was special due to the fact that it was the third consecutive monsoon, which recorded above normal rainfall. The seasonal monsoon 2012 rainfall of the country as a whole was 31 percent above long term normal (1961-2010) and is ranked 12th heaviest monsoon rainfall since 1961.The intensity of monsoon rainfall during the past two years (2010 & 2011) were73 % & 63% above than normal (1971-2000) respectively (Table-1). The excessive monsoon 2012 rainfall, like monsoons of 2010 & 2011, again caused severe flash flooding in the country.

During the monsoon season of 2012, Azad Kashmir & Khyber-PK received slightly above than normal rainfall. Gligit-Baltistan, Punjab & Sindh received moderately above than normal and Balochistan received largely above than normal rainfall. Table-2 depicts the distribution of seasonal rainfall over the country and provinces.Figure-2 shows the spatial pattern of seasonal (July-September) rainfall departure, calculated by using stations' rainfall data. Seasonal rainfall was above normal over major parts of Punjab, upper Sindh and eastern parts of Balochistan. The western, southern and northern part of the country exhibited the magnitudes of negative rainfall.

Another factor which makes the monsoon rainfall 2012 more special was the September rainfall over the country as a whole, which ranked the highest ever recorded monthly rainfall during the period 1961-2012. Similar position had been observed over the provinces during this month, when it recoded highest ever rainfall over Balochitistan, second highest at Kyhber-Pakthunkhwa, third highest over Sindh and fifth highest over Azad Kashmir, during past 52 years. During monsoon 2012 season, very heavy rainfall events were reported by many stations. Extreme rainfall in 24 hours and monthly heaviest rainfall were also reported at a number of stations. Table-3 illustrates the month, season and station wise distribution of extremely heavy rainfall events during the season.

Heavy monsoon rains over Jacobabad, Khanpur, Sukkur, Larkana and the adjoining areas claimed 571 lives, in addition to injury to 3,000 people. Most of the casualties were mainly due to drowning in swelling rivers and flash floods. Severe floods caused by these heavy downpours affected five million people in the area. These floods also damaged 11 million acres land of standing crops besides large-scale damages to property and cattle forms (NDMA 2012). Individual stations' month and season wise actual, normal and percentage departure rainfall is depicted in Table-4.

Monthly Rainfall

July 2012

In Pakistan, July is considered to be the rainiest month of the year and it has significant contribution to annual and seasonal rainfall. On the national scale, the distribution of July the rainfall (Figure-2) over the country was deficient and was moderately below normal (-42 %). During the month, rainfall distribution, over six divisions of the country, was moderately to largely below normal.Table-2 shows the actual, normal and deviation from normal rainfall in the month on national and provincial basis. Major amount of rainfall, ranging between 200 to 260 mm, recipient stations during July 2012 were Kotli, Silakot, Jhelum, Muzffarabad & Sialkot.

July 2012 Synoptic Features

Five westerly low pressure waves passed across northern parts of the country from 5th to 10th, 11th to 17th, 19th to 21st, 25th to 27th and 30th to 31st. Monsoon trough at sea level remained close to the foot hills of Himalayas during first week of July. The persistence of low pressure areas, over central parts of India and southern parts of Rajasthan which were extended up to mid-tropospheric level during second week of July, caused deflected monsoon currents which penetrated over eastern parts of the country during the above period. Monsoon trough then again shifted close to the foot hills of Himalayas and the deflected monsoon currents affected mostly the northeastern parts of Punjab and adjoining areas during rest of the month. Some stations of northern areas received heavy to very heavy rainfall which was the combined effect of westerly waves and deflected monsoon currents during the month of July.

August2012

The month of August is also one of the wettest month of Pakistan, like July. The month of August exhibited spatially variable rainfall distribution over the country. The southeastern region and some packets of central and northwestern parts of the country received deficient amount of rainfall, while elsewhere the regions received normal or above than normal rainfall (Figure-2).

August 2012 Synoptic Features

Five westerly low pressure waves passed across northern and central parts of the country from 2nd to 6th, 9th to 13th, 14th to 17th, 20th to 23rd & 24th to 31st. Monsoon trough, at sea level, remained close to the foot hills of Himalayas during first week of August; however, the incursion of westerly wave with the deflected monsoon currents gave heavy to very heavy rainfall over northern parts of the country on 4th & 5th August. Three monsoon lows moved from Head Bay of Bengal/northeastern parts of India and persisted over central parts of India during 9th to 17th. Monsoon currents penetrated into northeastern parts of the country and simultaneously a westerly wave moved across northern parts of the country. Due to the interaction of these systems, moderate to heavy rain occurred at a number of places to almost at all the places in northern and central parts of the country during that period. Monsoon trough then moved northwards and lay close to the foot hills of Himalayas up to 28th August; even then the combined effect of westerly wave and deflected monsoon currents, over extreme northeastern parts of the country, gave heavy to very heavy rains in northern and central parts of the country from 20th to 28th August. During last three days of the month, a low pressure area, extended up to mid tropospheric level, was formed over Indian Gujrat and adjoining Sindh causing some rainfall in Sindh

September 2012

Generally, the month of September is not like the remaining two wettest months of the season and hence normally its monthly rainfall contribution to the season is less (A. Mahmood et al., 2010). Rainfall activity over the country for this month, however, as a whole, was exceptionally very high. During September, rainfall activity over the central, eastern and southeastern parts of the country was very intense (Figure-2). For September 2012, rainfall for the country as a whole was 337 % of its long period of normal value (Table-2). The September rainfall was ranked highest ever recorded rainfall during the period 1961-2012. Similar position had been observed for the provincial rainfall, when it recoded highest ever rainfall over Balochistan, second highest at Kyhber-Pakhtunkhwa, third highest over Sindh and fifth highest over Azad Kashmir during past 52 years. Heavy rains during the month over Jacobabad, Sukkur, Khanpur and adjoining areas, caused flash floods and inundated large area resulting in loss of lives besides damages to property and land. Monthly rainfall totals for this month generally ranged between 0-25 mm in these areas, with some occasional little higher amount. Accumulated monthly rainfall records for September were broken at several locations of Jacoabad, Larkana, Rohri, Sukkur, Nawabshah, Chhor and Mithi, when it received monthly total rainfall ranging 150-450 mm.

September 2012 Synoptic Features

For September 2011, rainfall over the country as a whole was near to normal value. All provinces received normal or excessive rainfall except the province of Sindh, where it was largely deficit (Table-2). Muzaffarabad, Murree, Islamabad & Mandibahuddin received total monthly amount of rainfall between 400-500 mm, while Balakot, Kotli, Mangla & Kakul recorded the rainfall ranging 300-400 mm. Three westerly low pressure waves passed across northern parts of the country from 1st to 11th, 13th to 19th and 25th to 27th. The monsoon low, which was formed over Sindh during last three days of August, remained over there and gave some rainfall in southeast Sindh on 1st. Two monsoon lows moved westwards from India and simultaneously a low pressure area extending up to mid tropospheric level, was formed over Saurashtra-Kutch and adjoining southeast Sindh caused moderate to very heavy rains in the country during first two weeks of September. The monsoon tilts towards the Sindh as a result convergence zone exist over the South eastern part of the country , the same feature also represented in High resolution model (HRM) and satellite images as shown in Figure5. These low pressure systems are visible up to 500hPa.The 200 hPa charts shows that Tibetan high has been tilted south west from normal position as shown in Figure 5, dotted lines represent actual position of Tibetan High (TH) in the month of September where as solid line represent Tibetan High position during 2012 Monsoon. This high pressure blocked the monsoon currents to reach up to the Northern parts of Country. Deflected monsoon currents, along with the movement of a westerly wave over Northern parts of the country, caused heavy to very heavy rains at a number of places to almost at all the places in northern and central parts of the country during middle of the month. Monsoon withdrew from the country from 20th September. Weather remained mostly dry during last ten days except some rainfall activity, was seen over northern parts of the country, which was the outcome of a shallow westerly wave.

Season's Significant Features

- No significant monsoon activity was seen in July 2012. One of the reasons may be that only two monsoon lows formed over northeastern parts of India, moved westwards and reached up to the central parts of India. Ultimately less amount of deflected monsoon currents were produced, resulting in less monsoon rains in Pakistan.
- No monsoon depression was formed over India during the whole southwest monsoon season of 2012, whereas normally 4 to 6 monsoon depressions are formed during the monsoon season. Moreover, not a single low pressure area was formed in June 2012 over India. These two reasons may also be the cause of less monsoon rains over Pakistan in July.
- The monsoon trough remained close to the foot hills of Himalayas on most of the days during July which confined the deflected monsoon currents only up to the sub-mountain Punjab and adjoining areas.
- During August, the orientation of sea level monsoon trough was in such a position i.e. southeast to northwestwards, that the deflected monsoon currents together with the westerly waves affected northern and central parts of the country on most of the days during August; that is why rainfall remained normal in Khyber Pakhtunkhwa and Punjab during this month.
- Series of the upper air charts (Figure-3(a) & (b)) for the active period of monsoon indicates the presence of a well marked low pressure area over Saurashtra Kutch and adjoining southeastern parts of Pakistan and was extended up to mid-tropospheric level. Tremendous amount of moisture mainly from North Arabian Sea inducted to the system cause heavy to very high rains in South Punjab and Sindh mostly during second week of September.
- The orientation of the sub tropical high at 200 hPa level remained northeast to southwest during the first fortnight of September and the monsoon trough at sea level remained east-west in lower latitudes

over India. As such, the lows formed over Head Bay of Bengal/eastern parts of India moved westwards instead of their normal northwest movement and when these lows reached over Indian Gujrat and adjoining Sindh, they received lot of moisture from Arabian Sea and intensified into well marked lows and ultimately produced heavy to very heavy rains in Sindh and southern parts of Punjab. The incursion of westerly waves, along with the deflected monsoon currents, played a vital role in producing heavy rains in northern parts of the country during first 18 days of September 2012.

Daily Rainfall

Comparison of daily area weighted rainfall of the monsoon season (1st July to 30th September) along with its normal values, calculated over the period of 50 years (1961-2010) for the country as a whole and for its six provinces is depicted in Figure-4. Over all the rainfall in the season was below normal, most of the time, in the first two months and exceptionally on very higher side in the two patches of September. Significant variability was observed in the daily rainfall on the first two months of the season over Azad Kashmir, Khyber-Pakhtunkhwa and Punjab, whereas below normal rainfall was observed over Balochistan, Gilgit-Baltistan and Sindh in the same two months. Exceptionally very higher rainfall was observed over all provinces in some days of September. One day heaviest rainfall records were broken during the month of September in many places. Some are: Jacobabad 305 mm, Khanpur 173 mm, Sukkur 164 mm, Rohri 152 mm & Rahim Yar Khan102 mm.

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Table 1: Historical driest & wettest monsoon (1961-2012)

Driest		Wettest	
Year	Dep (%)	Year	Dep (%)
1963	-52	1994	80
1987	-51	2010	73
2002	-45	1976	64
1965	-43	2011	63
1972	-42	1992	57
1968	-40	1978	55
1966	-39	1973	39
1974	-36	1983	36
2004	-35	2003	36
1991	-33	1961	33
1969	-30	1975	32
1971	-30	2012	31

Table 2: Country & provincial seasonal and monthly 2012 actual & normal rainfall (mm)

Region	Season			July			August			September		
	rainfall (mm)		%	rainfall (mm)		%	rainfall (mm)		%	rainfall (mm)		%
	nor	act	dep	nor	act	dep	nor	act	dep	nor	act	dep
Pakistan	141	185	31	63	37	-42	56	55	-3	21	93	337
Azad Kashmir	294	324	10	130	84	-36	114	146	28	50	94	88
Balochistan	59	88	50	30	21	-29	22	26	17	6	40	545
Gilgit-Baltistan	42	61	46	14	2	-84	17	17	-3	11	42	299
Khyber-Pakhtunkhwa	289	329	14	121	70	-42	117	139	19	51	119	133
Punjab	231	318	38	104	74	-29	93	92	-1	35	152	339
Sindh	134	172	28	60	8	-86	54	16	-70	20	147	640

Table 3: Stations received extreme seasonal rainfall

S.N.	Stations	Jul			Aug			Sep			Monsoon		
		act	nor	dep	act	nor	dep	act	nor	dep	act	nor	dep
1	Muzaffarabad	200	359	-159	482	227	255	214	108	106	896	695	201
2	Murree	129	364	-235	469	336	133	281	143	138	879	843	36
3	Islamabad	162	354	-192	283	335	-52	356	123	233	801	812	-11
4	Balakot	118	378	-259	332	277	55	319	115	204	769	769	0
5	Islamabad AP	145	309	-164	410	342	68	182	112	70	737	762	-25
6	Kotli	263	286	-22	319	298	21	128	92	36	710	676	35
7	Mandi-Bahu-Din	111	---	---	404	---	---	173	---	---	688	---	---
8	Kakul	146	264	-117	300	267	33	173	104	69	619	634	-15
9	Mangla	121	---	---	307	---	---	118	---	---	546	---	---
10	Jhelum	216	263	-48	266	252	14	59	75	-15	541	589	-49
11	Rawalakot	166	---	---	133	---	---	218	---	---	516	---	---
12	Gujranwala	158	---	---	239	---	---	115	---	---	513	---	---
13	Sialkot AP	159	---	---	261	---	---	87	---	---	507	---	---
14	Sialkot Cantt	255	304	-50	191	321	-129	51	91	-40	496	716	-219
15	Jacobabad	0	43	-43	0	35	-35	479	11	468	479	89	390
16	Sahiwal	99	---	---	134	---	---	226	---	---	459	---	---
17	Malam Jabba	104	---	---	165	---	---	185	---	---	453	---	---
18	Lahore PBO	38	212	-174	197	195	3	199	64	136	434	470	-36
19	Parachinar	120	99	21	221	97	124	69	55	14	410	252	158
20	Lahore AP	53	218	-165	176	198	-22	178	75	103	407	491	-84

Table 4: Monthly and seasonal rainfall (actual, normal & % departure)

S.N.	Stations	July 2012			August 2012			September 2012			MONSOON 2012		
		actual	normal	departure	actual	normal	departure	actual	normal	departure	actual	normal	departure
	AZAD KASHMIR												
1	Astore	10.2	25.7	-15.5	18.2	28.6	-10.4	78.2	21.6	56.6	106.6	75.9	30.7
2	Bunii	4.8	18.9	-14.1	9.7	21.5	-11.8	75.8	10.7	65.1	90.3	51.1	39.2
3	Garhi Dopatta	57.0	265.6	-	138.0	235.8	-97.8	184.0	104.3	79.7	379.0	605.7	-226.7
4	Kotli	263.4	285.8	-22.4	319.0	297.6	21.4	128.0	92.1	35.9	710.4	675.5	34.9
5	Muzaffarabad	200.4	359.4	-	481.9	227.4	254.5	213.6	108.1	105.5	895.9	694.9	201.0
6	Rawalakot	165.5	---	---	133.0	---	---	217.5	---	---	516.0	---	---
7	Skardu	1.4	11.3	-9.9	10.1	14.7	-4.6	30.8	8.7	22.1	42.3	34.7	7.6
	BALOCHISTAN												
8	Barkhan	138.1	109.3	28.8	30.2	87.7	-57.5	46.0	44.5	1.5	52.0	241.5	-27.2
9	Dalbandin	0.0	2.6	-2.6	0.0	1.0	-1.0	0.0	0.2	-0.2	0.0	3.8	-3.8
10	Gawadar	0.0	---	---	0.0	---	---	0.0	---	---	0.0	---	---
11	Jiwani	0.0	8.6	-8.6	0.0	2.1	-2.1	0.0	0.3	-0.3	0.0	11.0	-11.0
12	Kalat	0.0	20.2	-20.2	0.0	9.1	-9.1	7.0	2.1	4.9	16.0	31.4	-24.4
13	Khuzdar	5.2	58.5	-53.3	51.0	58.2	-7.2	54.2	7.9	46.3	54.2	124.6	-14.2
14	Lasbela	4.0	32.9	-28.9	0.0	31.5	-31.5	21.2	30.8	-9.6	21.2	95.2	-70.0
15	Nokkundi	0.0	2.0	-2.0	0.0	0.4	-0.4	0.0	0.0	0.0	0.0	2.4	-2.4
16	Panjgur	5.0	21.2	-16.2	0.0	7.4	-7.4	0.0	2.5	-2.5	0.0	31.1	-26.1
17	Pasni	0.0	5.0	-5.0	0.0	11.5	-11.5	0.0	1.3	-1.3	0.0	17.8	-17.8
18	Quetta	0.0	16.3	-16.3	0.0	13.2	-13.2	4.0	2.5	1.5	4.0	32.0	-28.0
19	Sibbi	42.6	37.4	5.2	106.0	37.2	68.8	112.0	9.0	103.0	112.0	83.6	177.0
20	Turbat	0.0	---	---	0.0	---	---	0.0	---	---	0.0	---	---
21	Ormara	0.0	10.7	-10.7	0.0	4.5	-4.5	0.0	0.0	0.0	0.0	15.2	-15.2
22	Zhob	42.1	61.3	-19.2	57.0	49.7	7.3	28.0	11.5	16.5	28.0	122.5	4.6
	GILGIT- BALTISTAN												
23	Chilas	0.6	14.1	-13.5	16.6	16.9	-0.3	33.9	7.8	26.1	51.1	38.8	12.3
24	Gilgit	1.1	16.2	-15.1	11.3	17.0	-5.7	49.0	8.5	40.5	61.4	41.7	19.7
25	Gupis	5.0	14.0	-9.0	43.0	23.8	19.2	27.0	11.8	15.2	75.0	49.6	25.4
26	Hunza	2.7	---	---	20.8	---	---	40.1	---	---	63.6	---	---
	KHYBER PAKHTUNKHWA												
27	Balakot	118.4	377.8	-	331.8	276.7	55.1	319.0	114.8	204.2	769.2	769.3	-0.1
28	Bannu	30.4	---	---	99.0	---	---	44.8	---	---	174.2	---	---
29	Cherat	4.0	93.4	-89.4	105.0	96.4	8.6	135.0	34.5	100.5	244.0	224.3	19.7
30	Chitral	0.0	5.5	-5.5	0.0	6.6	-6.6	44.6	13.4	31.2	44.6	25.5	19.1
31	D.I.Khan	100.5	60.3	40.2	75.0	60.7	14.3	95.0	24.4	70.6	270.5	145.4	125.1
32	Dir	27.9	154.1	-	64.9	156.9	-92.0	152.6	90.6	62.0	245.4	401.6	-156.2
33	Lower Dir	75.0	---	---	150.0	---	---	107.0	---	---	332.0	---	---
34	Drosh	28.1	22.1	6.0	20.0	20.1	-0.1	23.7	21.8	1.9	71.8	64.0	7.8
35	Kakul	146.4	263.6	-	299.8	266.5	33.3	173.0	104.3	68.7	619.2	634.4	-15.2
36	Kalam	6.7	---	---	42.5	---	---	98.7	---	---	147.9	---	---
37	Kohat	38.0	75.3	-37.3	83.0	115.6	-32.6	74.0	42.2	31.8	195.0	233.1	-38.1
38	Malam Jabba	103.5	---	---	164.5	---	---	184.5	---	---	452.5	---	---
39	Mirkhani	4.1	---	---	3.0	---	---	10.0	---	---	17.1	---	---

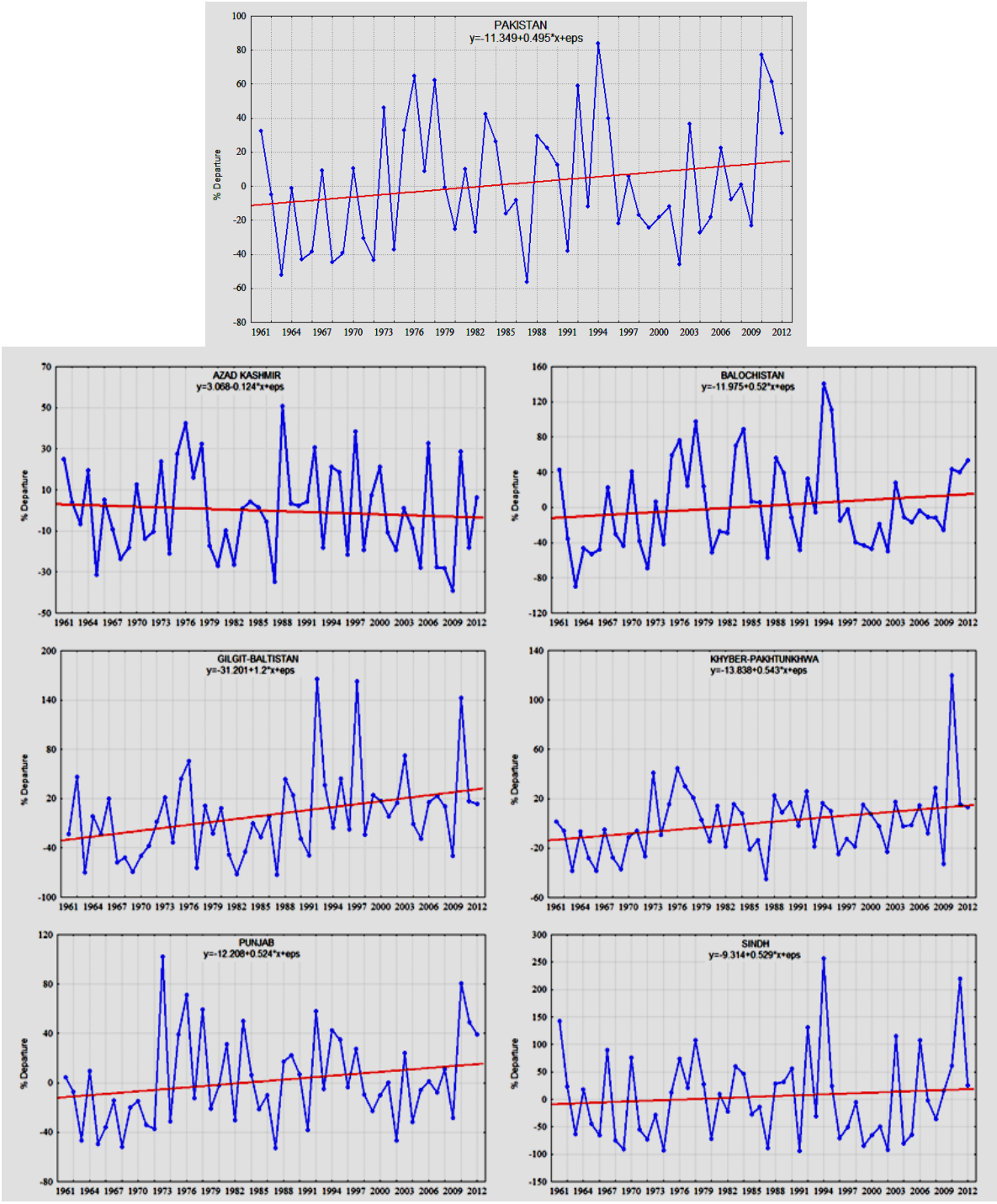

Figure 1: Pakistan and provinces Rainfall (percentage departure) time series (1961-2012) and trends.

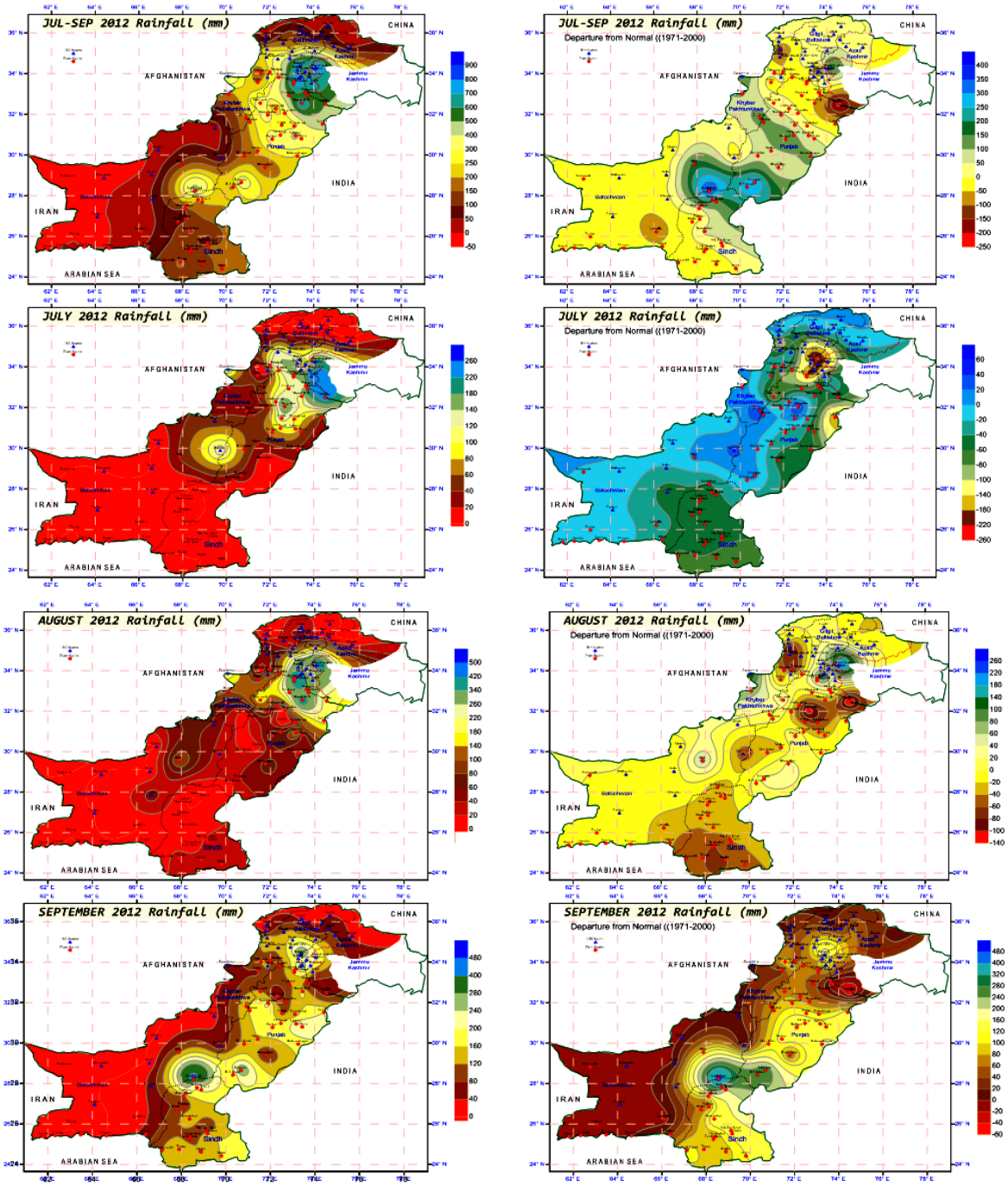

Figure 2: Spatial pattern of seasonal season and monthly rainfall actual & departure (mm)

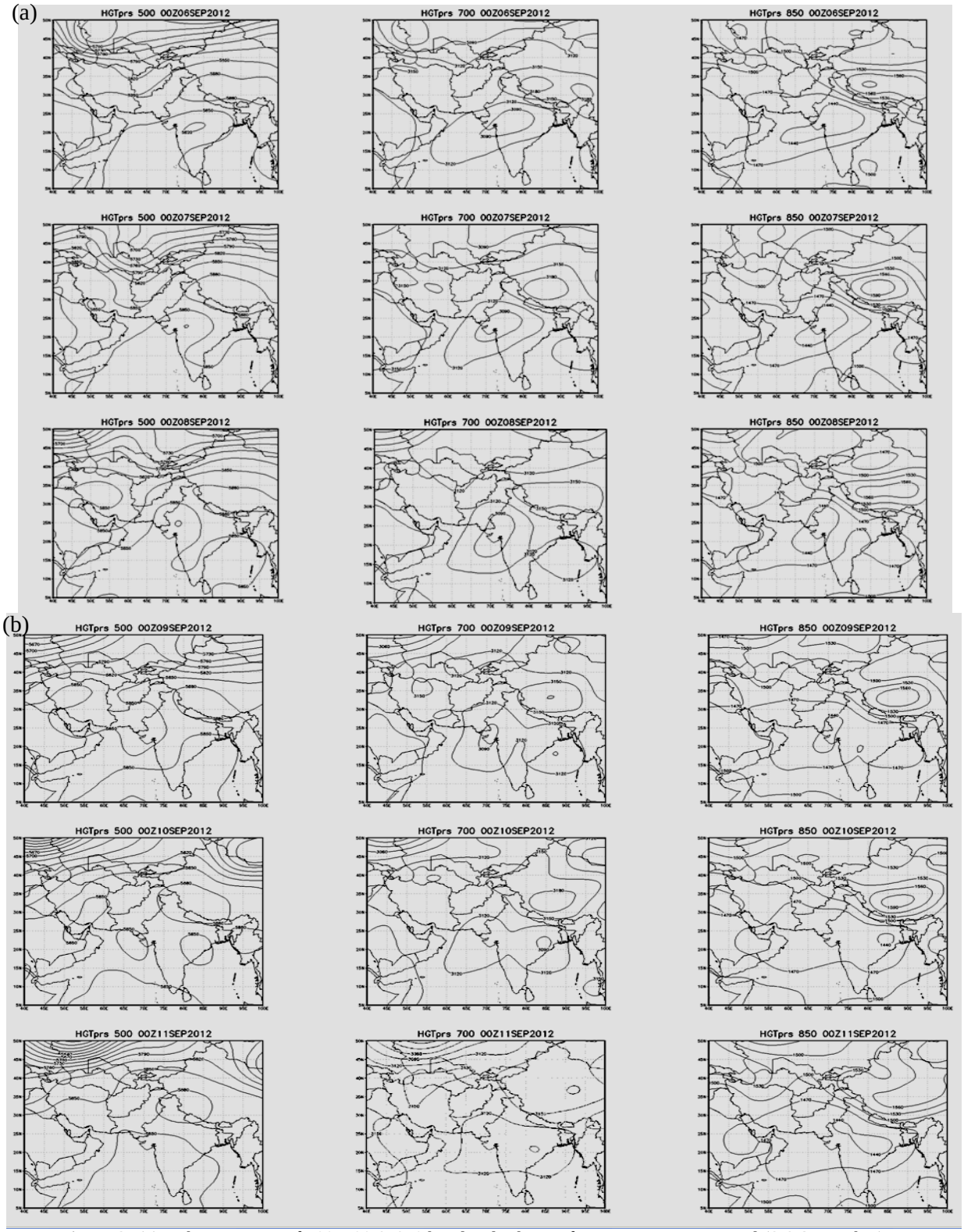

Figure 3: (a) Isobaric pattern of 500, 700 & 850 hPa levels charts of intense monsoon period (6-8 September). [Source NCEP, NOAA, USA] **(b):** Isobaric pattern of 500, 700 & 850 hPa levels charts of intense monsoon period (9-11September)). [Source NCEP, NOAA, USA]

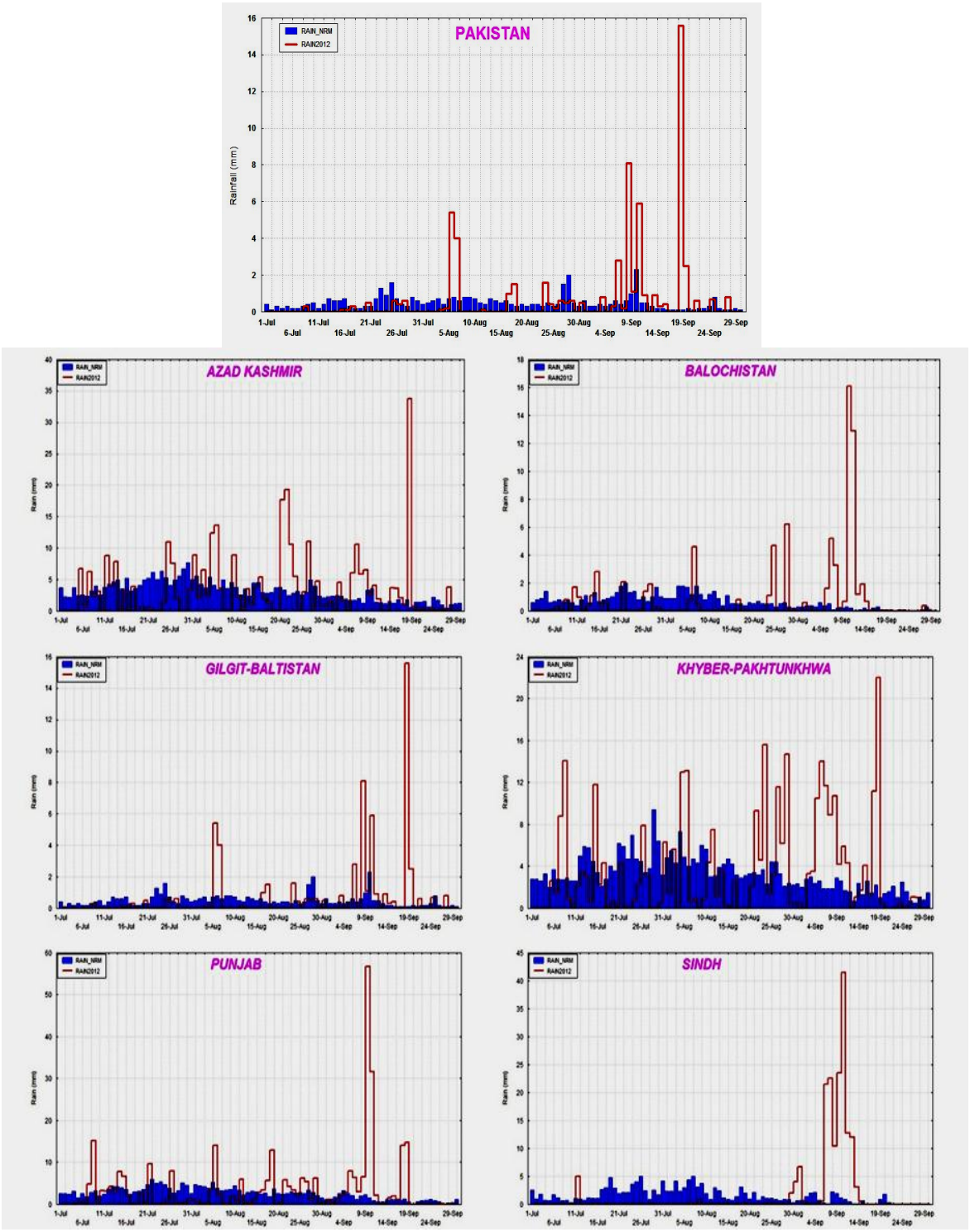

Figure 4: Comparisons of daily (area weighted) rainfall of actual & normal values

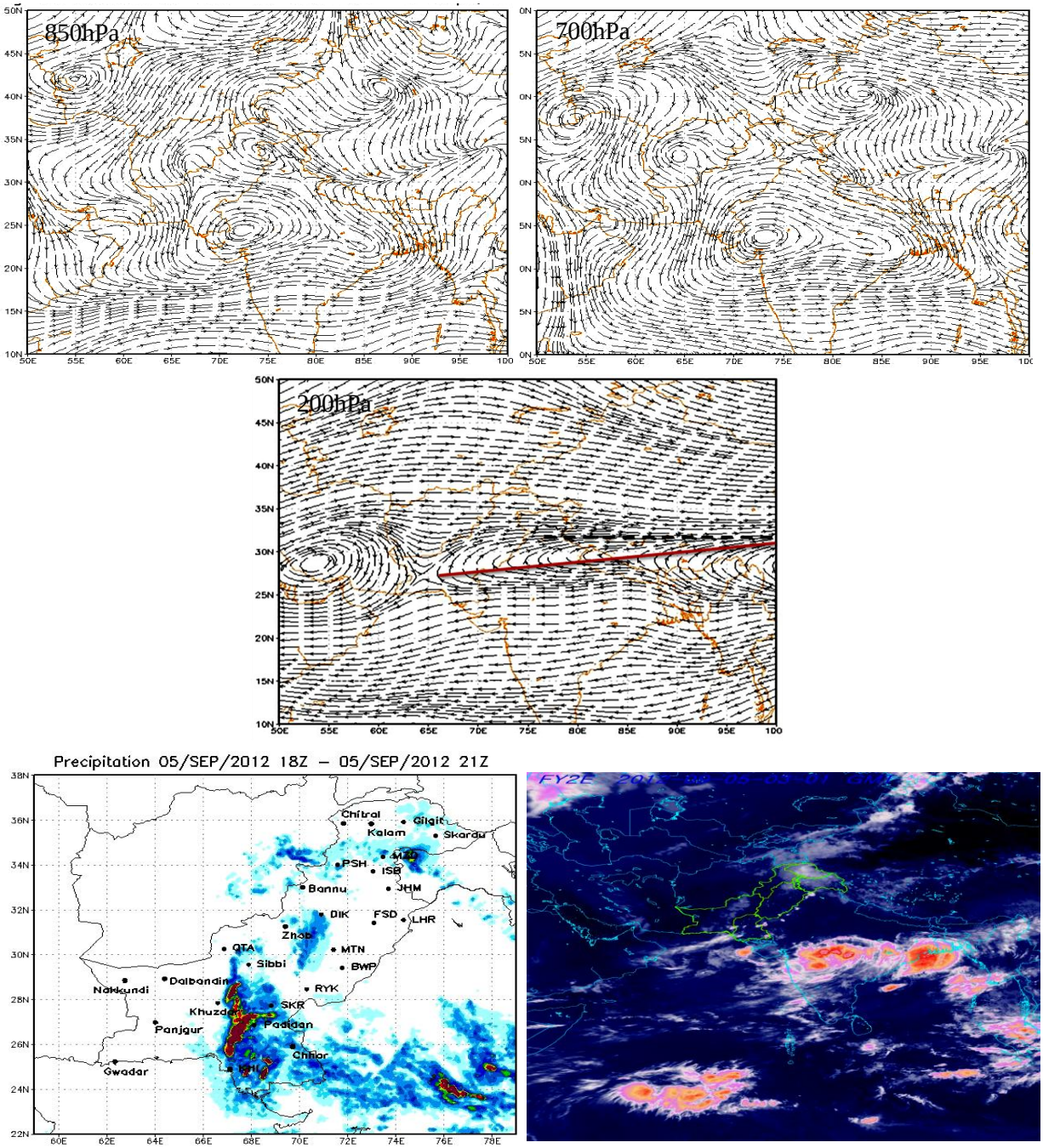

Figure 5: Average Streamlines pattern from 01-11 September 2012 at 850 hPa, 700 hPa, 200 hPa (dotted line is the actual position of Tibetan High & solid line is the position of TH in 2012) and images of High Resolution Model (HRM) along with satellite images respectively.