Simulations of 1992 Flood in River Jhelum using High Resolution Regional Climate Model, PRECIS to Study the Underlying Physical Processes Involved in the Extreme Precipitation Event

SAJJAD SAEED[1], MUHAMMAD MUNIR SHEIKH[2], SYED FAISAL SAEED[3]

Pakistan Meteorological Department/Global change Impact Studies Centre[1, 3]
Global Change Impact Studies centre[2]

Abstract:

South Asia is a region with complex topography, land surface conditions and coastlines. The region is generally dominated by the monsoon climate in summer with large contribution from mesoscale phenomena, such as monsoon lows and depressions. A highly resolved regional climate model is required to study the regional climate in such a region. The PRECIS climate model is an atmospheric and land surface model of limited area and high resolution. The distinct features of this model include the description of dynamic flow, the atmospheric sulphur cycle, clouds and precipitation, radiative processes, the land surface and the deep soil.

This study is conducted to understand the underlying physical processes responsible for the extreme precipitation event of September, 1992 that caused severe flooding in River Jhelum, the worst one since 1959. Reanalysis data ERA15 of European Centre for Medium Range Weather Forecasts (ECMWF), which is available at 06-h intervals with a resolution of 2.5° × 2.5°, and 17 pressure levels, is used to drive the model as both the initial and lateral boundary conditions. The performance of the model is demonstrated by integrating it from December 01, 1991 to October 31, 1992 with a resolution of 0.44° × 0.44° and 0.22° × 0.22° covering the whole South Asia domain. CRU data together with real time observational precipitation and temperature data from meteorological stations representating the Jhelum River basin is used to compare and verify the model outputs. The model simulated realistically the temporal pattern of the area averaged precipitation, monthly mean precipitation spatial pattern and the daily precipitation intensity distribution. The model not only captured the fluctuations in the daily Maximum and Minimum temperature but also reproduced well the large scale monsoon circulations responsible for the moisture convergence in the catchment areas resulting in heavy precipitation. The extremely heavy precipitation occurred due to the interaction of intense monsoon depression with an active westerly wave passing over the area. At higher resolution i.e. 0.22° × 0.22°, the model suitably resolved the complex topography and land-sea contrast, and hence the simulated results are found very close to the observations.

Key words – Simulations, 1992 Flood, Jhelum River, Physical Conditions.

1. Introduction:

Pakistan has a long history of flooding from Indus River and its tributaries. Floods in Pakistan are mainly caused by heavy rainfall in the catchments during the summer monsoon season (JAS) which is augmented by snowmelt flows. Rainfall during the period occurs due to the monsoonal systems (Lows or depressions) coming either from the Arabian Sea or from the Bay of Bengal. The frequency of monsoon depressions formed in Bay of Bengal is about 80% of the total number of depressions formed in the South Asia monsoon region (G.B Pant & K.Rupa Kumar, 1997). Relatively few monsoon depressions form in the east Arabian Sea and over land in monsoon trough region. The average annual frequency of monsoon depression is seven, of which one occurs in June and two each in July, August and September. The monsoon depression normally takes a west-northwesterly course during the peak monsoon months of July and August, while they move in a northwesterly direction during the transition period in early June and late September (G.B Pant & K.Rupa Kumar, 1997). The depression generally weaken after crossing the central parts of India, owing to the cut-off in the moisture supply, the move further northwest and merge in the seasonal low over west Rajasthan and adjoining Pakistan. Sikka (1977) found that one third of the depressions fill up on crossing 85°E and nearly half on crossing 80°E. When the depressions are fed by fresh moisture supply from the Arabian Sea branch of the monsoon, the depression may retain their intensity and take a westerly course to reach Gujrat state of India, causing very heavy rains in the region. On some occasions the westerly wave passing over the north of Pakistan may take the depression under its grip and it may move in the north ward direction, causing heavy rains in the upper areas of Punjab and adjoining areas of NWFP and Kashmir.

Regional climate models are an appropriate tool for assessing the climate of a particular region with great details, especially in the regions where forcing due to complex topographical effect or coastlines, or both, regulate the regional distribution of climate variables (Giorgi 1990; Jones et al.1995; Wang et al.2000). The South Asia regional climate is governed not only by the large scale monsoon circulation but also by the mesoscale physical processes as well as a non linear interaction between the large scale and small scale environments. Previous studies have shown the capability of regional climate models in reproducing interannual variability when driven by good quality driving fields (Houghton et al. 2001; Wang et al. 2002). The PRECIS regional climate model developed at the Hadley Centre is based on the atmospheric component of HadCM3 (Gordon et al. 2000) with substantial modifications to the model physics. It is an atmospheric and land surface model of limited area with high resolution. Dynamic flow, the atmospheric sulpher cycle, clouds and precipitation, radiative processes, the land surface and deep soil are in the model. PRECIS assumes the atmosphere to be in a state of hydrostatic equilibrium and hence vertical motions are diagnosed separately from the equations of state. It has a complete representation of the coriolis force and employed a regular latitude-longitude grid in the horizontal and a hybrid vertical coordinate. There are 19 vertical levels, the lowest at ~50m and the highest at 0.5hpa (Cullen 1993) with terrain following σ-coordinates used for the bottom four levels, purely pressure coordinates for the top three levels and a combination in between (Simmons and Burridge 1981). The model equations are solved in the spherical polar coordinates and the latitude-longitude grid is rotated so that the equator lies inside the region of interest in order to obtain quasi-uniform grid box area throughout the region. The horizontal resolution is 0.44° x 0.44° and 0.22° x 0.22°, which gives a minimum resolution of ~50 km and ~25km at the equator of the rotated grid. Convective clouds and large scale clouds are treated separately in their formation, precipitation and radiative effects. A mass flux penetrative convective scheme (Gregory and Rowntree, 1990) is used with an explicit downdraught (Greogory and Allen, 1991) and including the direct impact of vertical convection on momentum. Mixing of convective parcels with environmental air, forced entrainment and detrainment are also considered in PRECIS regional climate model. This study is aimed at understanding the physical processes involved in the extreme precipitation event and to demonstrate the ability of the regional climate model PRECIS in simulating severe precipitation event over South Asia. The next section briefly describes the severe precipitation event of 1992 over Pakistan. Design of the numerical experiment is given in section 3. The simulation results of the extreme precipitation event and the associated circulation is discussed in section 4. Concluding remarks are presented in the last section.

2. An overview of 1992 severe precipitation event over Pakistan

During the summer monsoon season in 1992 heavy rainfall occurred over the Jhelum River basin (Fig.1) in the month of September which caused severe flooding in the Jhelum River. This was the worst event recorded since 1959 and brought in its wake large economic losses and infrastructure damage in Pakistan. This severe flooding event was induced by the severe precipitation event associated with the summer monsoon depression traveling from Bay of Bengal through India to upper parts of Punjab and adjoining areas of Kashmir and North West Frontier Province of Pakistan.

The observed distribution of monthly mean daily rainfall during the summer monsoon season i.e.; from June to September 1992 over the South Asia region is shown in Fig 2. During the month of June rainfall over Pakistan occurred due to the passage of westerly wave in the north of Pakistan. A trough developed in the upper air at 500hpa in north of Pakistan and moderate rainfall occurred on two occasions in the northern divisions. Moderate to heavy rainfall also occurred in Bangladesh, eastern coast and western Ghatts of India. During July, the weather activities over Pakistan were mainly due to the presence of a trough in the north of Pakistan at 500hpa. There were three spells in this month. The first spell was weak. It caused rainfall of light to moderate intensity where as the last two spells gave moderate to heavy rainfall over almost all catchment areas of the rivers. Moderate to heavy rainfall occurred over Bangladesh, south east Nepal and along the monsoon trough including eastern coast and western Ghatts of India. In August the rainfall over Pakistan occurred due to active westerly wave moving across northern areas of Pakistan. A deep incursion of monsoon current accentuated the weather phenomena. Four spells of rainfall occurred during the month. The first three spells were very active and gave moderate to heavy rainfall over the region, but the last two spells were less active and gave light to moderate rainfall. Central parts of India also observed moderate to heavy rainfall. Pakistan has experienced record breaking heavy rainfall in northern Punjab and adjoining areas of Kashmir and North West Province of Pakistan during the month of September. The abnormal monsoon rainfall was related to the interaction of monsoon depression with an intense westerly passing over north of Pakistan. In particular, the 05-day long lasted heavy rainfall event occurring over the Jhelum catchments from 07-11 September, 1992 brought a huge devastating flood of about

1,090,000 cusecs at Mangle. This was the worst flood after 1959 when a flood of 1,045,000 cusecs was recorded at the dam in July 1959. It was the most active spell of the season. It gave very heavy rainfall in almost all the divisions of NWFP, Northern areas of Punjab and Kashmir. Heavy rain fall also occurred in Bangladesh. South eastern Nepal, while moderate to heavy rainfall occurred over central and eastern parts of India.

3. Experimental Design

The Hadley Center's high resolution regional climate model, PRECIS, was used to simulate the severe precipitation event of 1992 over Pakistan to evaluate the performance of the model as well as to understand the underlying physical processes responsible for the extreme precipitation event. Reanalysis data ERA15 of European Centre for Medium Range Weather Forecasts (ECMWF), available at 06-h intervals with a horizontal resolution of $2.5° \times 2.5°$, and 17 pressure levels were used to drive the model as both the initial and lateral boundary conditions. The model was initialized from 0000 UTC on 01 December, 1991 and integrated continuously up to 31 October, 1992 with a horizontal resolution of $0.44° \times 0.44°$ and $0.22° \times 0.22°$ covering whole of South Asia domain (Fig.1) including 76×97 grid points. In this study a spin-up of five months was given to the model to allow the atmospheric and land surface processes to adjust and reach a mutual equilibrium state. Number of grid points used in the relaxation zone are 8. The time step in this case is 5 minutes by default. High resolution (10') topographic global dataset was used to obtain the model topography. The performance of the model is demonstrated by comparing the model simulated results with the CRU observational data sets and the independent station data from the meteorological stations representating the catchments of Jhelum River. The comparison between CRU data and PRECIS (50km and 25km) outputs is done on the same spatial grid. The different aspects of the model performance such as model bias from observations and the spatial correlation coefficient between the model's simulated and observed precipitation were investigated.

4. Results and Discussions:

The simulated monthly mean rainfalls in the 4 months from June to September 1992 are given in Fig 3. By comparing Fig. 2 and Fig.3, it is evident that model has simulated the overall spatial distributions of monthly mean rainfall. In June (Figs.2a & 3a) the model reasonably simulated the monthly mean precipitation over Pakistan, Bangladesh, most parts of India and western parts of Nepal except an underestimation over Southern parts of India. In July (Figs.2b & 3c), the model overestimated the precipitation over most parts of Pakistan and central parts of India. In August (Figs.2c & 3e), the model successfully reproduces the extensive precipitation over central parts of India except a little shift in the heavy precipitation towards eastern side and slight overestimation in the southern parts of Pakistan. In September (Figs.2d & 3g) the model successfully reproduced the extensive severe precipitation in the Jhelum River basin except a slight southeast extension of heavy precipitation. In September the model also less estimated the precipitation over the central parts of India and Bangladesh. The heavy precipitation observed over Bangladesh in July and September is shifted South ward (Figs.3c&3f) in the Bay of Bengal. Fig. 3(b, d, f, h) gives the model simulated precipitation at 25km resolution. At higher resolution the model suitably resolved the complex topography and hence realistically captured the extreme precipitation. In addition to simulation of the spatial distribution of monthly mean precipitation discussed above, the model also realistically simulated the temporal variation of precipitation. Time series of area averaged daily precipitation over the Jhelum River basin region are shown in Fig 4. Station observed precipitation data from meteorological stations representating the Jhelum River basin is used for comparison.The model reproduced reasonably the trends and fluctuations of precipitation over the above region, except for an overestimation of daily precipitation in the later June and early July and an underestimation in the mid July, early August and September. These underestimations and overestimations are responsible for the biases in the monthly mean daily precipitation. It can be seen that the extreme daily precipitation is captured well by the model at higher resolution because the topography is best resolved at higher resolution. In order to realistically simulate the monthly mean precipitation, the model should be able to simulate reasonably the individual precipitation events. Thus the performance of the regional climate model PRECIS in the simulation of precipitation was further evaluated by calculating the BIAS, spatial correlation coefficient between the observed and model simulated precipitation in the 4 months over the Jhelum River basin region (Table 1).

At 25km horizontal resolution the model overestimated (positive bias) the area averaged monthly mean precipitation in the 4 months over the Jhelum River basin while at 50km horizontal resolution the model underestimated (negative bias) the monthly mean precipitation in June, July and August. The maximum bias is in June and these reduced in the later months, probably because the land surface processes and the associated forcings are better resolved in the later months. The spatial correlation coefficient between the observed and model simulated precipitation is found to be relatively lower in June and July compared to August and September. In September 94% was achieved over the Jhelum River basin. The observed and model simulated surface air temperature variation at 50km horizontal resolution in the 4 months over the Jhelum River basin is shown in Fig. 5. The trends and fluctuations in the surface air temperature simulated by the model at 25km resolution resemble to that of the 50km resolution and hence the results are not shown here. We calculated the area averaged daily maximum and minimum surface air temperature in the 4 months over the Jhelum River basin region. In general PRECIS captured the trends and fluctuations in the daily maximum and minimum surface air temperature over the Jhelum River basin except for a warm bias (less then 2°C) in the daily maximum temperature in June and minimum temperature in June and August and a cold bias (0.8°C-3.5°C) in both maximum and minimum temperature in the later months. The biases between the observed and model simulated maximum and minimum temperature during the 4 months are shown in Table 2.

In order to examine the model capability of simulating the extreme precipitation and the associated circulation, Fig.6 shows the daily precipitation intensity distribution at 25km horizontal resolution over Jhelum river basin from 07-12 September, 1992. At higher resolution the model reasonably resolved the complex topography and the land-sea contrast and hence realistically simulated the daily precipitation intensity distribution. The heavy precipitation in the month of September that caused an extreme flooding in the Jhelum River resulted from the interaction of the intense monsoon depression with an active westerly wave passing over the north of Pakistan. The model simulated 500hpa wind vectors and Geo-potential heights at 50km horizontal resolution are shown in Fig.7. In Fig 7a the monsoon depression is located in the eastern coast of India, at the same time a very strong westerly wave can be seen in the northwest of Afghanistan. The monsoon depression initially moved in the North West direction (Figs.7b & 7c), but the westerly influenced the direction of motion of depression and hence the depression recurved in the north easterly direction, as a result the westward movement of the depression was completely stopped. The depression remained almost static over the Rajistan on 6th and 7th September. During this period, it became accentuated after getting the moisture from the Arabian Sea component. The north ward movement of depression was quite rapid and after entering into Pakistan the interaction of this monsoon depression with an active westerly passing over the north of Pakistan gave heavy rainfall in the Jhelum River basin region.

The model simulated the monsoon flow quite realistically. The ridge of the upper air high pressure is dominant over the South Asia region (Fig.7). This high pressure has played an important role in the moisture transportation from Bay of Bangal right upto the upper catchments of the rivers. The model also captured the track of the monsoon depression. The observed and model simulated tracks of the monsoon depression are shown in Fig.8. At 25 km horizontal resolution the model simulated track resembles closely to that of the observed track. The observed and simulated mean sea level pressure (MSLP) in September 1992 over the Jhelum River basin (Fig. 9a) also show a significant decrease during 09-10 September,1992. The Relative Humidity curves at different pressure levels (Fig.9b) also show sufficient moisture in the air up to 250 hpa. This abundant moisture together with a favorable circulation and orographic uplifting also played an important role in intensifying the rain spell over the catchments areas of Jhelum River.

5. Summary

In this study regional climate model PRECIS developed at the Hadley Centre was used to simulate the severe precipitation event of 1992 over Jhelum River basin in order to evaluate the performance of the model in simulating the regional climates as well as to understand the physical processes responsible for this extreme precipitation event. PRECIS simulated successfully the sever precipitation over Jhelum River basin during the summer monsoon season of 1992. The simulated results show that model reproduced well the temporal pattern of area averaged precipitation, the monthly mean precipitation spatial pattern and the daily precipitation intensity distribution. The model also realistically simulated the trends and fluctuations in the area averaged daily maximum and minimum temperature. However, there exit a warm bias in daily maximum temperature in June and minimum temperature in June and August and a cold bias in both maximum and minimum temperature in the later months. The model not only reproduced the large scale monsoon circulation over the South Asia that was responsible for the moisture transport from Arabian sea and Bay of Bengal to the catchments of the rivers but also captured the track of the monsoon depression that interacted with an intense westerly wave passing over the north of Pakistan resulting in the heavy precipitation in the catchments areas of Jhelum river. The higher level of moisture contents in the air together with a favorable circulation and orographic uplifting also played a significant role in the intensification of the rainfall over the Jhelum River basin region. At higher resolution i.e. 022° × 022°, the model reasonably resolved the complex topography and land-sea contrast and hence the model results were found very close to the observations.

Acknowledgments

The authors would like to pay thanks to Dr Wilfran Moufouma-Okia, Regional Climate Modelling Scientist, Hadley Centre for Climate Prediction and Research, Met Office, U.K, for his comments and suggestions on the above paper.

References

Dickinson, R.E., R. M. Errico, F.Giorgi, and G. T. Bates, 1989: “A regional climate model for western U.S.”, Climate Chang, 15, 383-422.

Giorgi, F., 1990: “Simulation of regional climate using a limited area model nested in a general circulation model”, J. Climate, 3, 941-963.

Grong, W., and W.C. Wang, 2000: “A regional model simulation of the 1991 severe precipitation event over the Yangtze-Huai river Valley. Part II: Model bias”, J.Climate, 13, 93-108.

Houghton, J. T., Y. Ding, D. J. Griggs, M. Noguer, P. J. van der Linden, X. Dai, K. Maskell, and C. A. Johnson, Eds., 2001:Climate Change 2001: The Scientific Basis. Cambridge University Press, 881 pp.

Jones, R., D. Hassel, D. Hudson, S. Wilson, G. Jenkins and J. Mitchell, 2003: “Workbook on generating high resolution climate change scenarios using PRECIS”, ed. Met Office, UK, 32p.

Johns, T. C., R. E., Carnell, J.F.,Crossley, J. M. Gregory, j. F. B. Mitchell, C. A Senior, S. F. B Tett, and R. A. Wood, 1997: “The Second Hadley Centre coupled ocean – atmosphere GCM: model description, spinup and validation”, Climate Dyn., 13, 103-134.

Lee, D.-K, and M.-S. Suh, 2000: “Ten-year Asian Summer monsoon simulation using a regional climate model(RegCM2)”, J.Geo-phys, Res.,105, 29 565-29 577.

Lui, Y.-Q., F. Giorgi, and W.M Washington, 1994: “Simulation of summer monsoon climate over East Asia with an NCAR regional climate model”, Mon. Wea. Rev., 122, 2331-2348.

Leung, L. R., S. J. Ghan, Z. –C. Zhao, Y. Luo, W.-C.Wang, and H. L. Wei, 1999: “Intercomparison of regional climate simulations the 1991 summer monsoon in eastern Asia”, J. Geophys. Res., 104, 6425-6454.

Lee, D.-K., H.-R. Kim, and S.-Y. Hong, 1998: "Heavy precipitation over Korea during 1980-1990", Koean J. Atmos. Sci., 1, 32-50.

Pant, G.B., and R. K. Kolli, Eds., 1997: Characteristics features of South Asian summer monsoon, Climates of South Asia, John Willy & sons Ltd. Press, 17p.

Majeed. A., 1992: "Flood report 1992", ed. Pakistan Meteorological Department, 10-25p.
Walsh, K., and J. L. McGregor, 1995: "January and July climate simulations over the Australian region using a limited-area model", J. Climate, 8, 2387-2403.

Wang, Y., O. L. Sen, and B. Wang, 2003: "A highly resolved regional climate model (IPRC-RegCM) and its simulation of the 1998 severe precipitation event over China. Part I: model description and verification of simulation", J. Climate, 16, 1721-1738.
Wang, B., and LinHo,2002: "Rainy season of Asian- Pacific summer monsoon", J. Climate, 15, 386-398.

Wang, W.-C., W. Grong, and H. Wei, 2000: "A regional model simulation of the 1991 severe precipitation event over the Yangtze-Huai river Valley. Part I: Precipitation and circulation statistic". J.Climate, 13, 74-92.

Wilson S., D. Hassel, D. Hein, R. Jones and R. Taylor, 2004: "Installing and using the Hadley Centre regional modeling system – PRECIS version 1.1", ed. Met Office, UK, 10-126p.

TABLE 1. Monthly mean statistics of observed and simulated precipitation (mm) over the Jhelum River basin in 4 months

Month	Observed	Simulated 50 km	BIAS	SC	Observed	Simulated 25km	BIAS	SC
June	1.38	3.74	2.36	0.74	1.38	3.76	2.38	0.77
July	9.53	8.97	-0.56	0.74	9.53	11.56	2.03	0.65
Aug	8.31	7.72	-0.59	0.82	8.31	9.75	1.44	0.91
Sep	11.18	9.28	-1.9	0.94	11.18	11.85	0.67	0.94

TABLE 2. Monthly mean maximum and minimum observed and simulated temperature (°C) over the Jhelum River basin in 4 months

Month	Observed Maximum (°C)	Simulated Maximum (°C)	BIAS (°C)	Observed Minimum (°C)	Simulated Minimum (°C)	BIAS (°C)
Jun	36.4	38.3	1.9	22.9	24.2	1.3
Jul	32.0	30.6	-1.4	23.2	19.7	-3.5
Aug	30.9	29.9	-1.0	23.3	23.5	0.2
Sep	30.3	27.7	-2.6	20.7	19.9	-0.8

List of Figures:

Fig 1. Model topography in meters with contour interval 500m.

Fig.2. Distribution of observed monthly mean rainfall at 50km horizontal resolution over South Asia in the 4 months from Jun to Sep in 1992. Contours are shown at 0,2,4,8,12,16,20,24,28,32,36 and 40 mm day^{-1}

Fig.3. Distribution of model-simulated monthly mean rainfall at 50km figs.3(a,c,e,g) and 25km figs.3(b,d,f,h) horizontal resolution in the 4 months over the South Asia region from June to September 1992. Contours are shown at 0, 5, 10, 15,20,25,30,35,40,45 and 50 mm day^{-1}.

Fig.4. The observed (solid) and model simulated (dashed) areal averaged daily precipitation in the 4 months in the Jhelum River basin region

Fig. 5. The observed (solid) and model simulated (dashed) at 50km horizontal resolution daily minimum (lowers curves in each panel) and daily maximum (upper curves in each panel) in the 4 months over Jhelum River basin region.

Fig.6. Model simulated daily precipitation intensity distribution at 25km horizontal resolution from 07-12 September, 1992.

Fig.7. The model simulated (50km) wind vectors and Geo-potential heights at 500 hpa from 01-10 September, 1992.

Fig.8. Observed and model simulated positions of the monsoon depression from 01-10 September, 1992

Fig..9 (a) - The observed (solid) and simulated (dashed) MSLP (hpa),
(b) - Simulated Relative Humidity (%) at 850hpa, 700hpa ,500hpa and 250hpa pressure levels, in Jhelum River basin during September 1992.

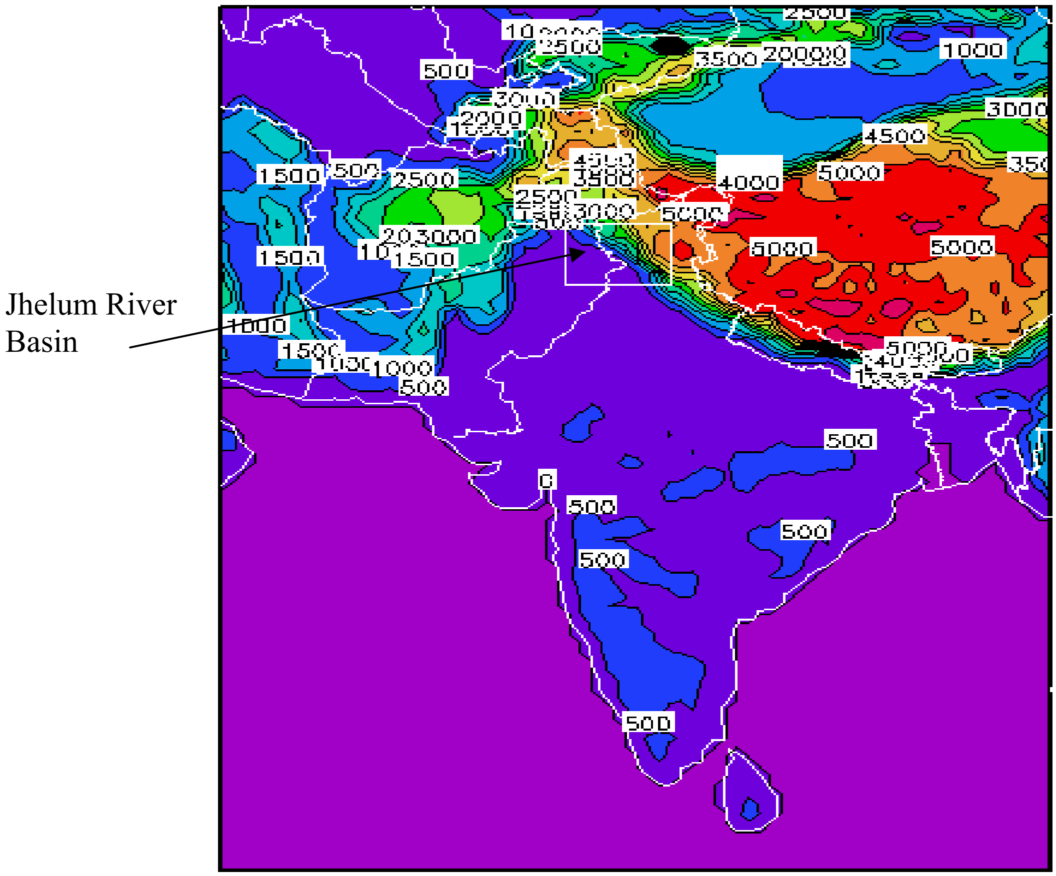
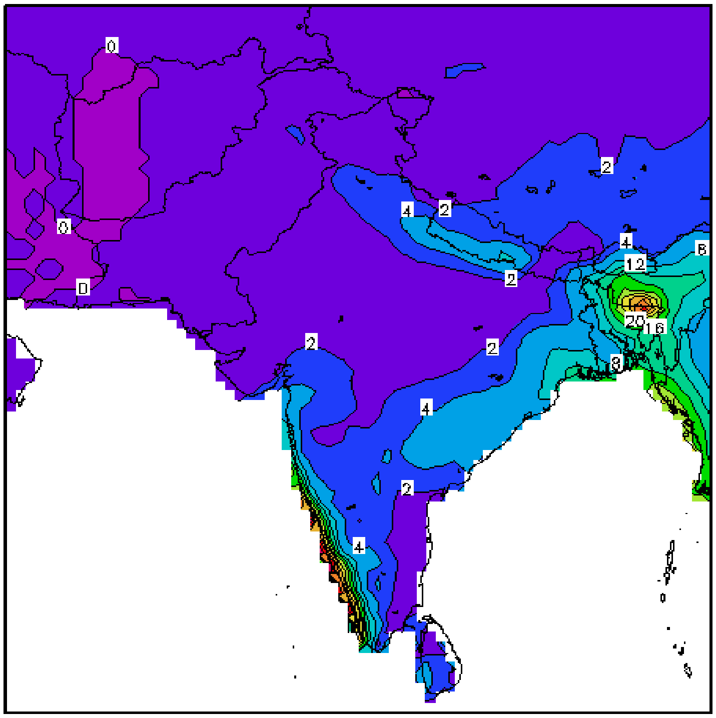
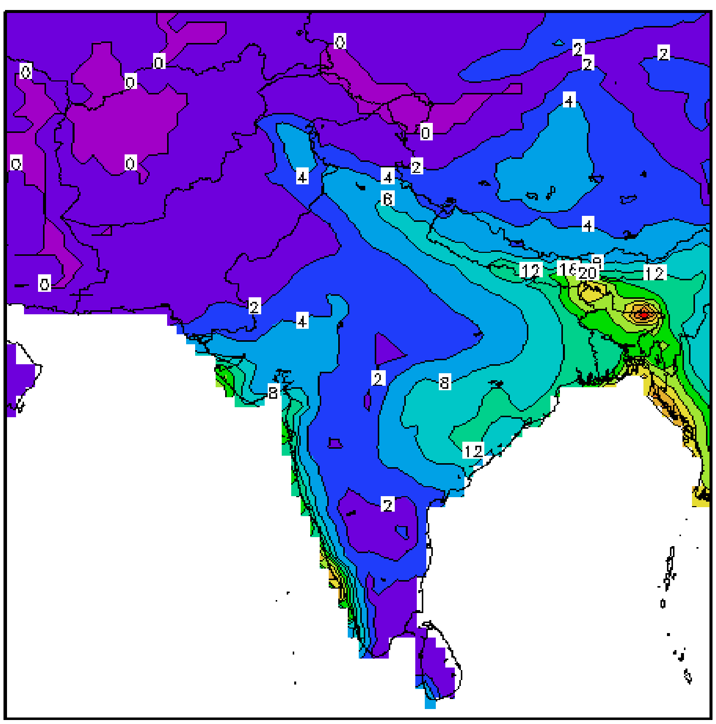


Fig 1. Model topography in meters with contour interval 500m.

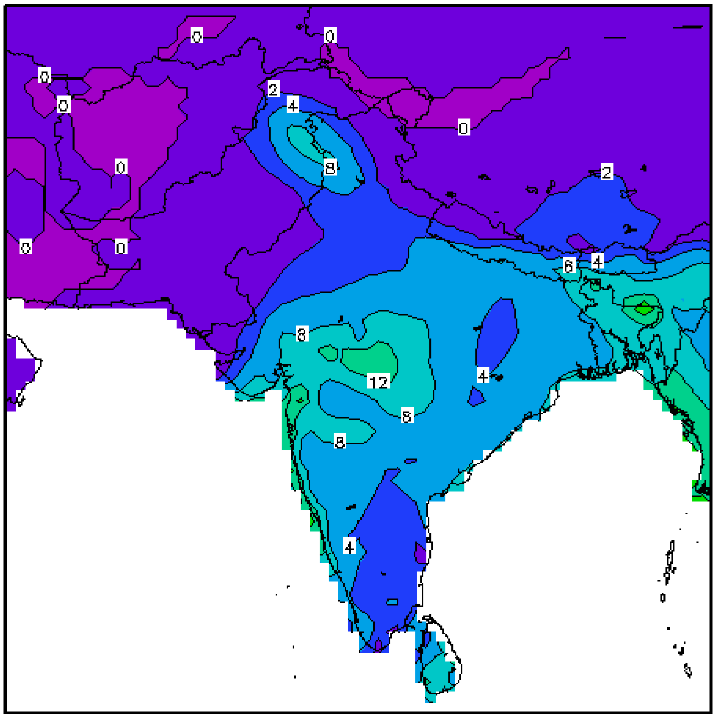
(a) Mean daily rainfall in JUN



(b) Mean daily rainfall in JUL



(c) Mean daily rainfall in AUG



(d) Mean daily rainfall in SEP

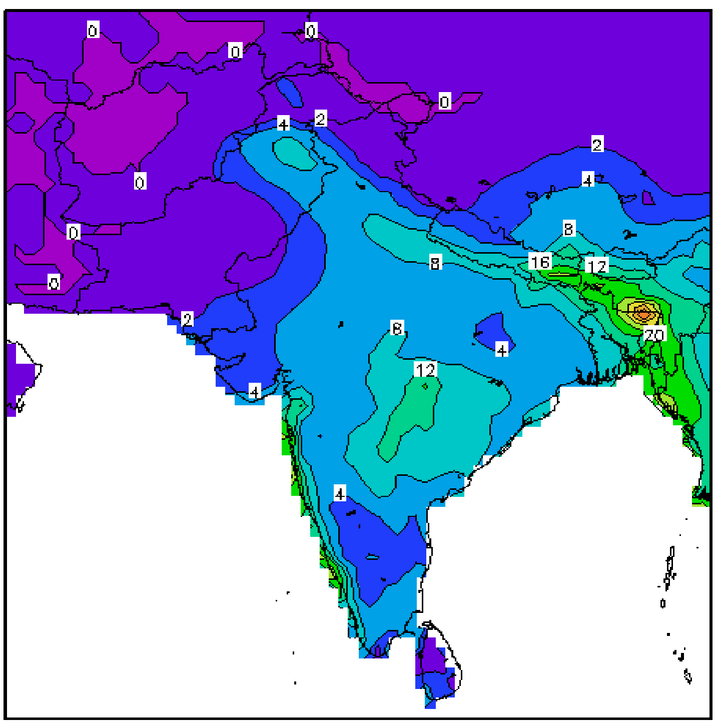
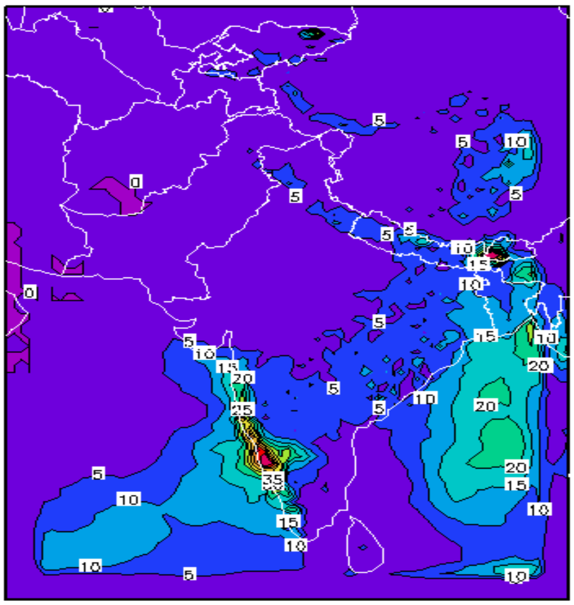


Fig.2(a-d). Distribution of observed monthly mean rainfall at 50km horizontal resolution over South Asia in the 4 months from Jun to Sep in 1992. Contours are shown at 0,2,4,8,12,16,20,24,28,32,36 and 40 mm day^{-1}

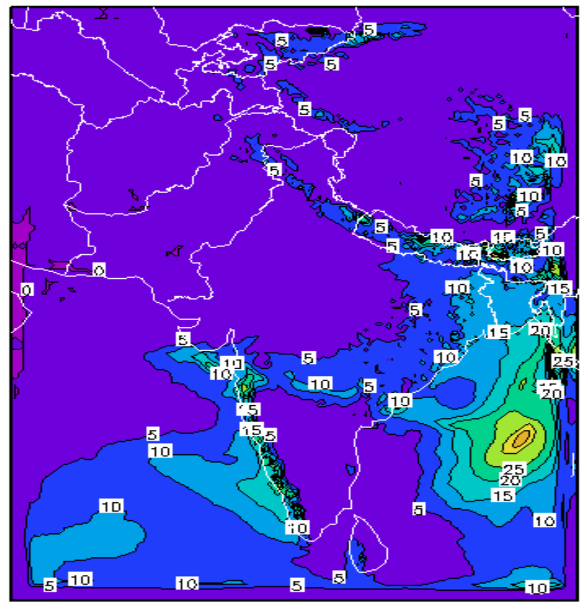
50 km

25km

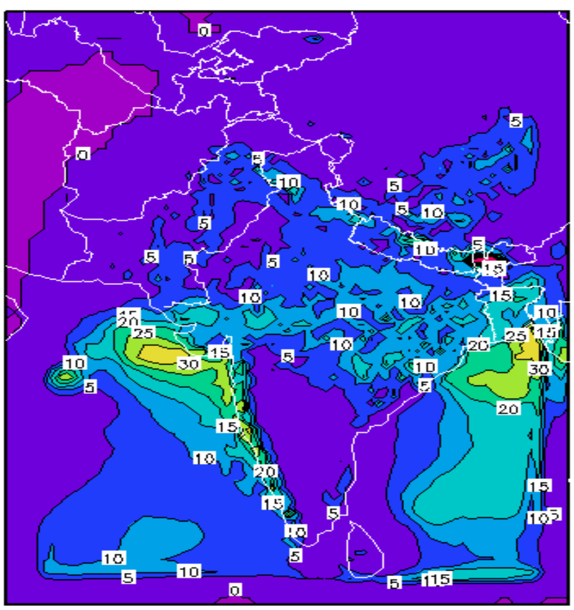
(a) June 1992



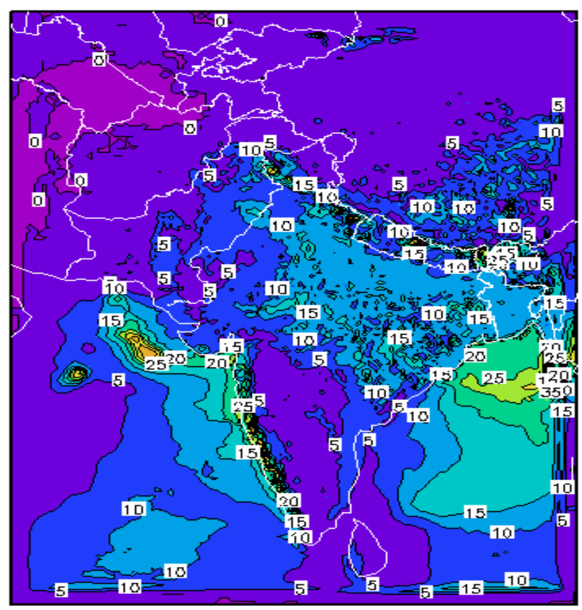
(b) June 1992



(c) July 1992



(d) July 1992



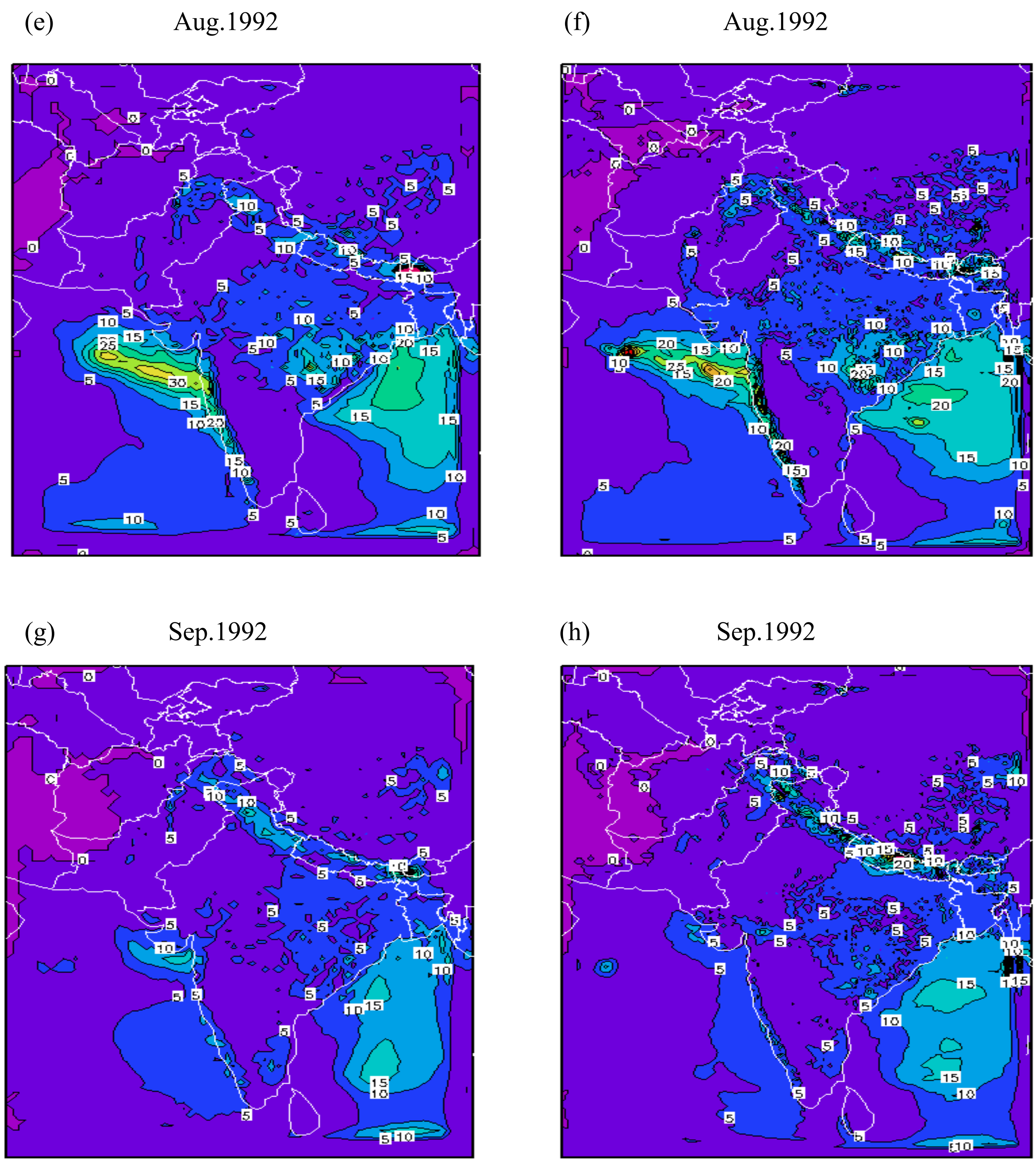


Fig.3. Distribution of model-simulated monthly mean rainfall at 50km (a,c,e,g) and 25km (b,d,f,h) horizontal resolution in the 4 months over the South Asia region from June to September 1992. Contours are shown at 0, 5, 10, 15,20,25,30,35,40,45 and 50 mm day^{-1}.

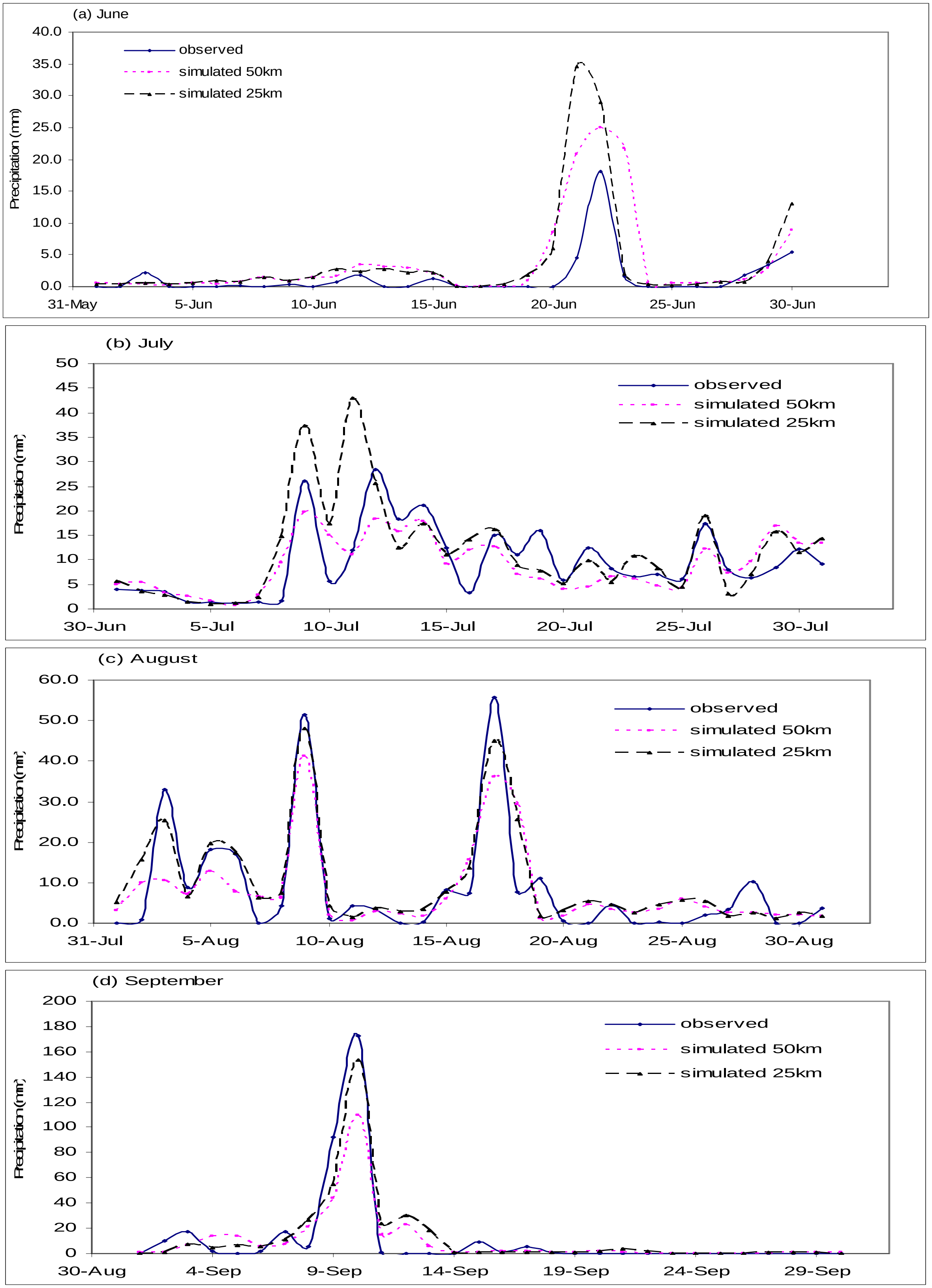


Fig.4. The observed (solid) and model simulated (dashed) areal averaged daily precipitation in the 4 months in the Jhelum River basin region.

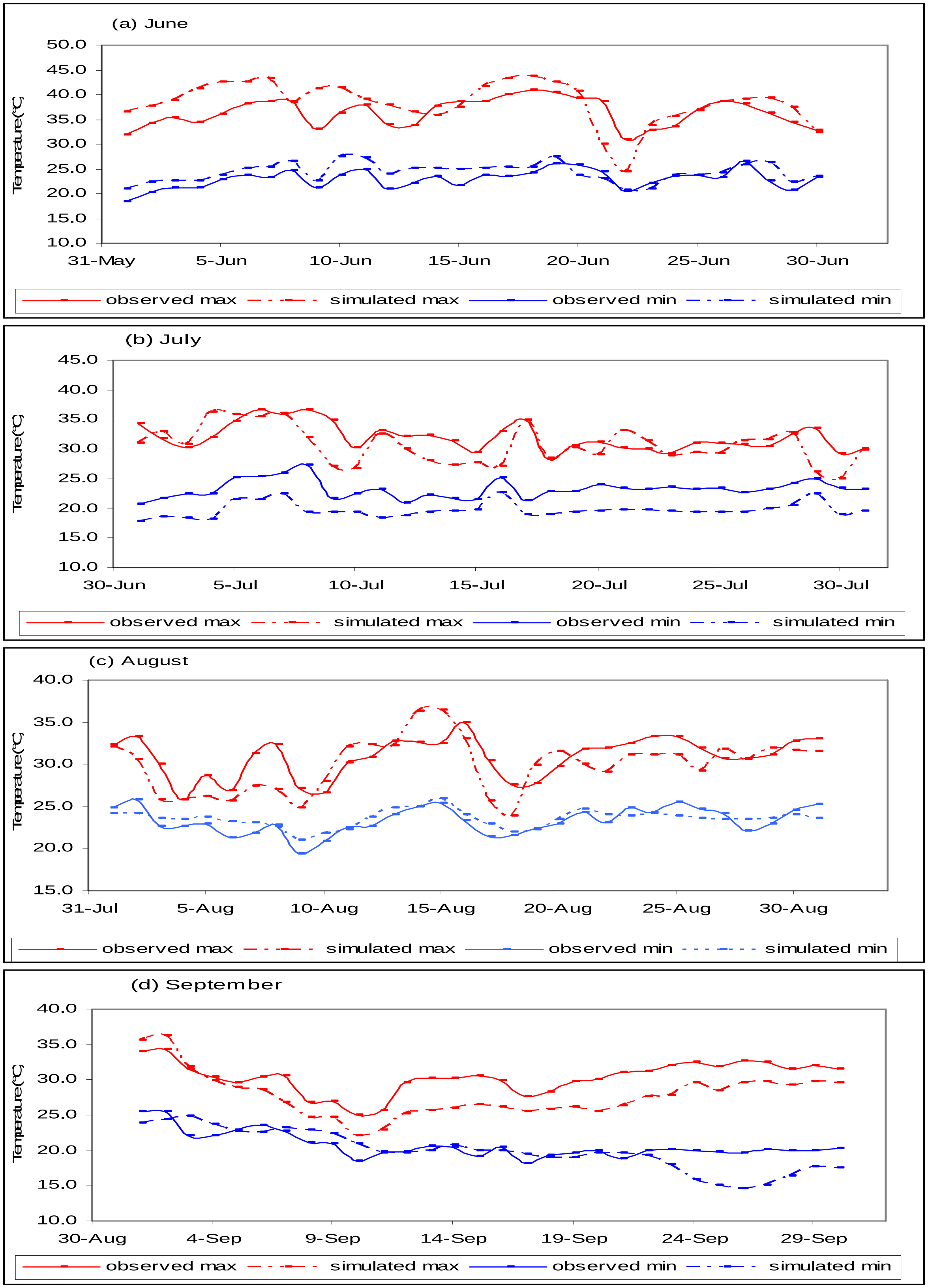


Fig. 5. The observed (solid) and model simulated (dashed) at 50km horizontal resolution daily minimum (lowers curves in each panel) and daily maximum (upper curves in each panel) in the 4 months over Jhelum River basin region.

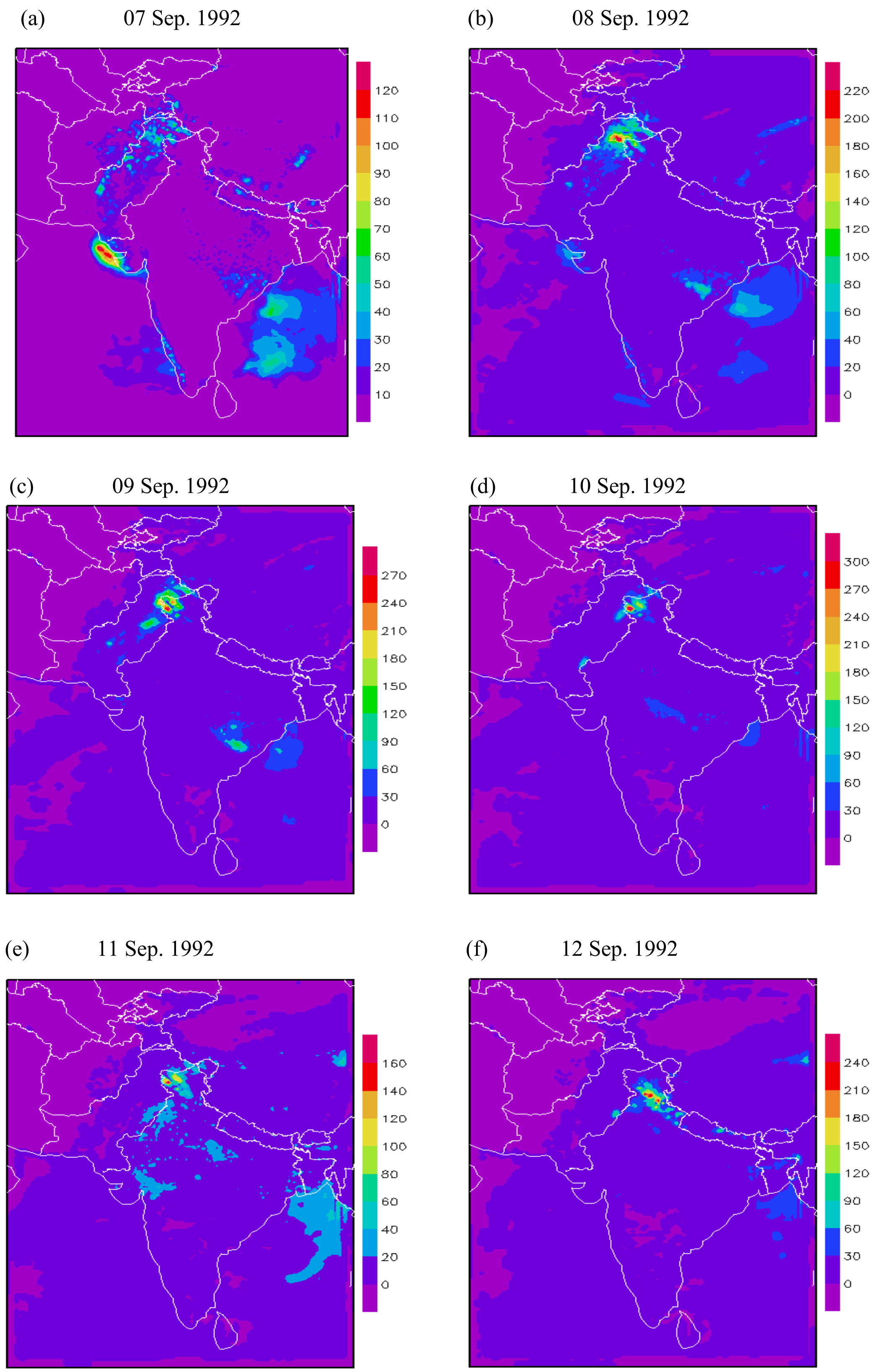


Fig.6. Model simulated daily precipitation intensity distribution at 25km horizontal resolution from 07-12, September 1992.

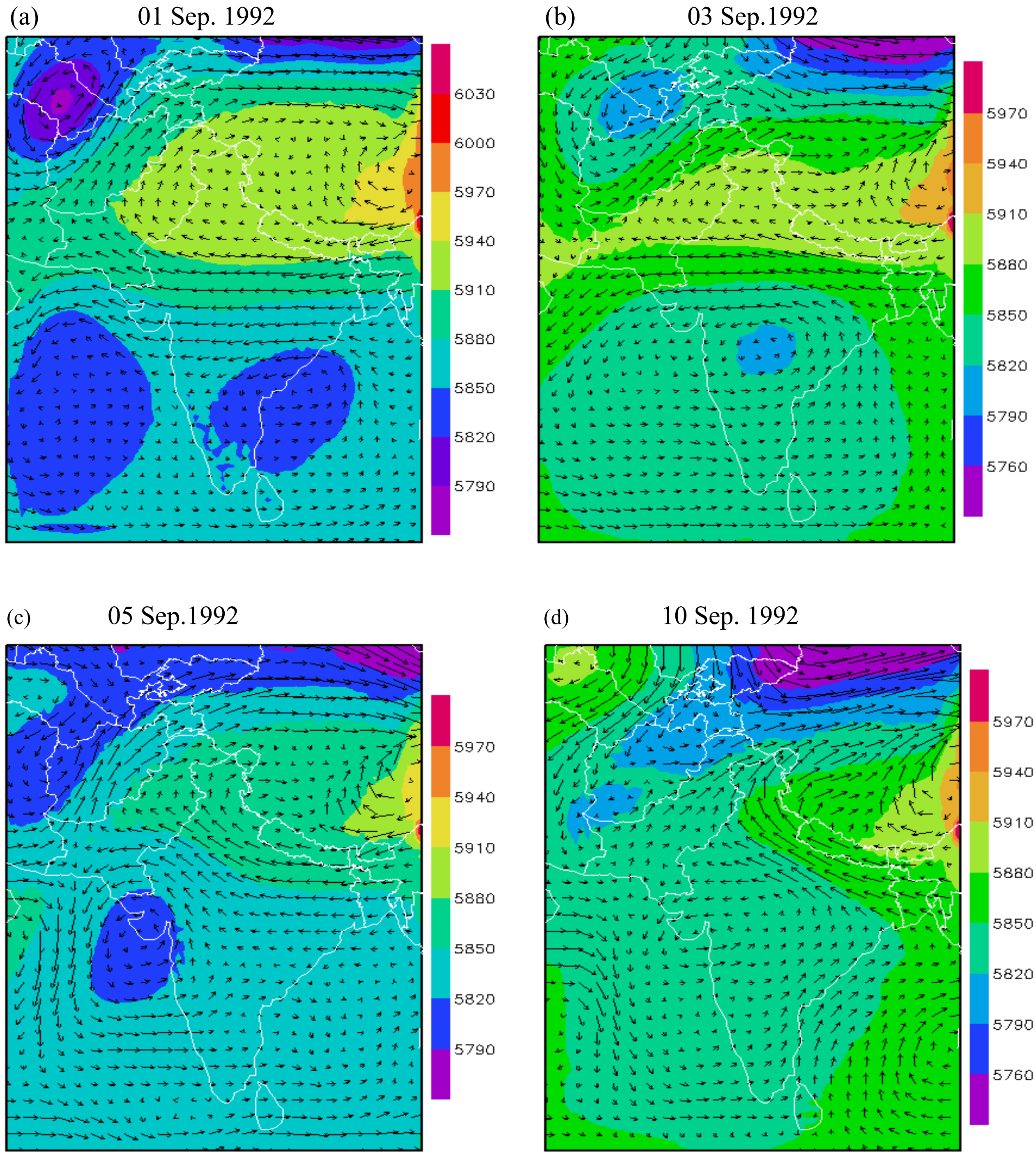


Fig.7. The model simulated (50km) wind vectors and Geo-potential heights at 500 hpa from 01-10, September 1992.

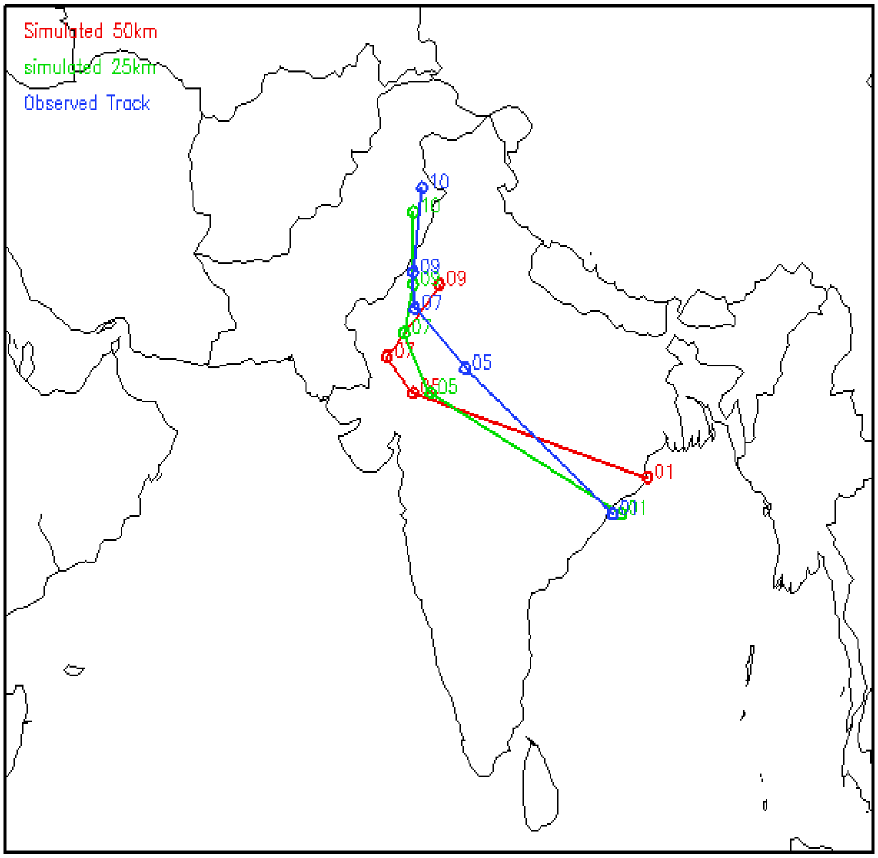
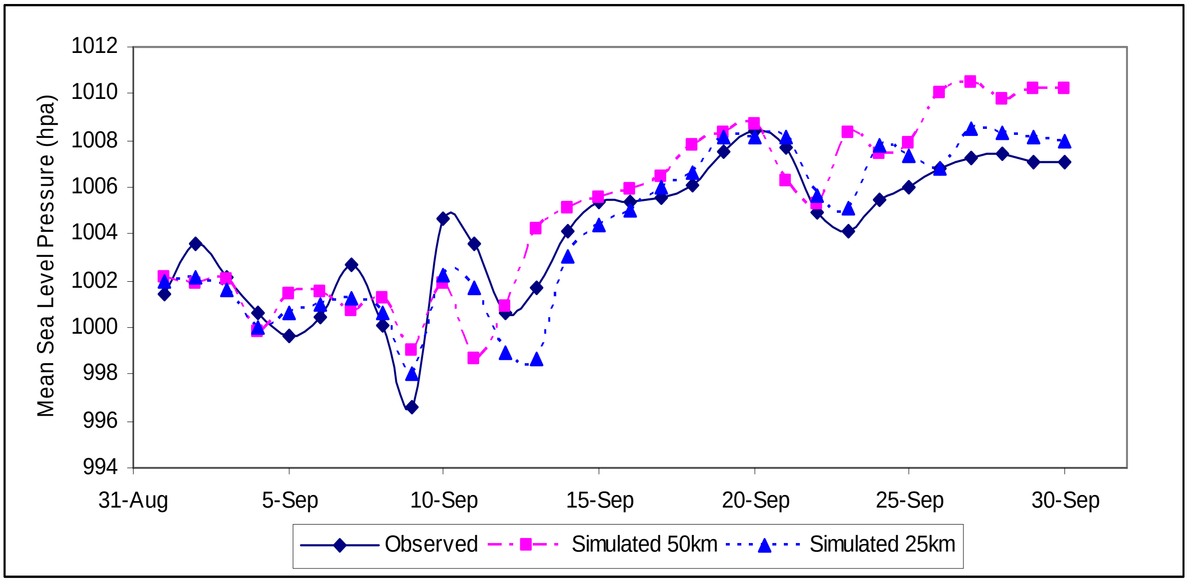


Fig.8. Observed and model simulated track of the monsoon depression from 01-10 September 1992.

(a)



(b)

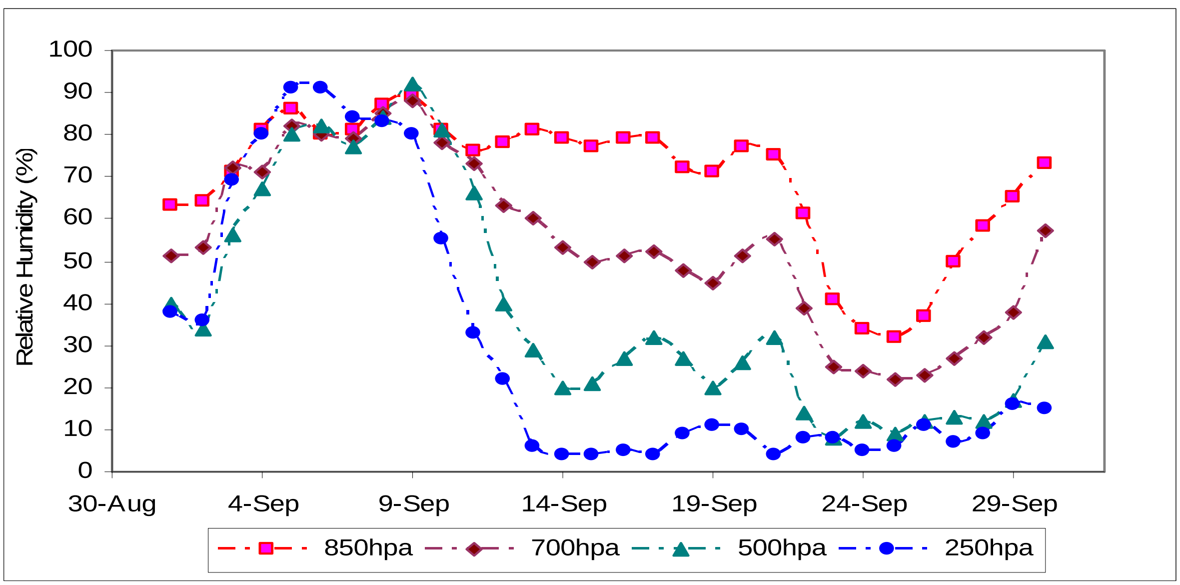


Fig.9 (a)- The observed (solid) and simulated (dashed) MSLP(hpa), (b) Simulated Relative Humidity (%) at 850hpa, 700hpa ,500hpa and 250hpa pressure levels, in Jhelum River basin during September 1992.