SIMULATION OF WINTER-2000 RAINFALL OVER PAKISTAN USING TWO DIFFERENT DOMAINS WITH REGCM3

Ata Hussain*, Muhammad Afzaal*

Abstract:

After monsoon season (July-Sept), the winter season (Jan-March) is the second highest with respect to the occurrence of rainfall in Pakistan. Rainfall in this season is important for Rabi crops (especially wheat) of the country. In this study, Regional Climate Model of the third generation (RegCM3) has been experimentally used in seasonal simulation of Rainfall in Pakistan using ERA-40 reanalysis of European Centre for Medium-Range Weather Forecasts (ECMWF) as initial and lateral boundary conditions for driving the RegCM3. The performance of RegCM3 (Feb-2005 version) is examined through experiments to simulate the amount of winter-2000 precipitation in Pakistan with model resolution of 60km. Winter-2000 is the part of history's worst drought conditions that occurred during 1998-2001 over Pakistan and the country received 47.5% below normal rainfall during the season. Simulations are performed using two different model domains. The purpose is to see up to what extent the model is capable of capturing the drought conditions over Pakistan during the season and also to ascertain the suitable model domain for the winter season. The model outputs are compared with the observational grid data of Climatic Research Unit (CRU) and real time data of Pakistan Meteorological Department (PMD). It is found that the simulation of winter rainfall over Pakistan is reasonably well captured by the model and the simulation of seasonal precipitation is affected by the domain size. The amount of simulated winter rainfall with Smaller Domain (SD) is found to be comparatively higher than that with Larger Domain (LD) over Pakistan. As compared to the amount of simulated rainfall with LD, the rainfall with SD is also found to be in close approximation with Climatic Research Unit (CRU) data and the real time data of PMD. However, the area weighted rainfall as simulated with SD is just 0.2% above to what calculated from Climatic Research Unit (CRU) data and almost 12% less than the real time data of PMD.

Key Words: Regional Climate Model, Simulation, Precipitation, Winter, Large Domain, Small Domain

Introduction:

Regional climate models are increasingly being used for downscaling climate scenarios and for seasonal climate studies in many parts of the world. In this paper, we present a simple sensitivity study of model domain choice for winter season of Pakistan.

* Pakistan Meteorological Department.

Geographically, Pakistan is situated in South Asia between longitudes 61º & 76º E and latitudes 24º & 37º N. The country possesses quite complicated physiographical features that include the northern high mountain ranges (the Himalayas, the Karakoram and the Hindukush), the western bordering highlands and the Indus plains. The country receives its winter (Jan-March) rainfall from the frontal systems (locally called western disturbances) that come from west along the westerly waves and move across the country. Although the area weighted rainfall received over Pakistan during winter is about half of the respective rainfall of monsoon season (July-Sept), yet the amount is the second highest contributor (after monsoonal rainfall) to the total annual rainfall over Pakistan. It has also significance due to the fact that variations in winter rainfall (along with other factors) can have serious impact on the yield of Rabi crops (especially wheat) of Pakistan.

In this study, precipitation in the winter-2000 has been simulated with the help of regional climate model (RegCM3, February-2005 version) using two different domains. The winter-2000 is chosen because it is part of the period 1998-2001 which saw history's worst drought conditions over Pakistan. Provinces of Sindh, Balochistan and southeaster parts of Punjab(southern half of the country) were the areas mostly affected by this drought (Chaudhry, Q. Z., 2001 & Chaudhry, Q. Z., 2002). During winter-2000 Pakistan received just 37.0 mm (area weighted rainfall) which is about 47.5% below normal (70.5 mm). Purpose of this study is to compare the model simulations of both domains with CRU and real time observations and to distinguish the suitable model domain for the winter season and also ascertain the extent up to which the model is successful in simulating the drought conditions over Pakistan during winter-2000. It is extremely important to improve the model-based seasonal precipitation prediction. Based on the advantages of regional climate models possibly to be applied to seasonal climate prediction, the RegCM3 is used to simulate seasonal precipitation regime of Pakistan for understanding the ability of the model to capture the winter precipitation pattern over the country. The methodology presented here provides a quantitative basis for evaluating domain choice in future studies.

Experimental Design:

Regional Climate Model (RegCM3):

The regional climate model used in this experiment is the latest version of The Abdus Salam International Centre for Theoretical Physics (ICTP) regional climate model (RegCM3) (Giorgi et al., 1993a, b). A brief description is provided here with emphasis on the new elements in RegCM3. It contains numerous options for different applications. The idea of Regional Climate Model (RCM) was based on the concept that large scale meteorological fields from General Circulation Model (GCM) runs can provide initial and time-dependent meteorological lateral boundary conditions for high resolution Regional Climate Model (RCM) simulations (Giorgi, F. 1990).

- RegCM3 is a primitive equation, hydrostatic, compressible, sigma-coordinate regional climate model based on NCAR's mesoescale meteorological model, MM4 (Anthes et al., 1987). The model's vertical resolution is 18 levels with 7 levels below 800hpa.

- Physics in RegCM3: The radiation patrameterization used is the CCM3 radiation package of Kiehl et al, (1996).
- Exchange of energy, moisture and momentum between the land surface and the atmosphere are computed using BATS1E land surface model (Dickinson et al, 1993)
- RegCM3 uses a medium-resolution planetary boundary scheme developed by (Holtslag et al, 1990).
- Different convective precipitation schemes are available in the model. Kuo-Anthes scheme (Anthes, 1977), Grell scheme (Grell 1993) with Fritsch & Chappell closure assumption (FC-80) or Arakawa & Schubert closure assumption (AS-80), Emanuel scheme.
- New features in RegCM3 include the surface flux scheme over the oceans of Zeng et al. (1998) and a subgrid explicit moisture scheme (SUBEX) of Pal et al. (2000). The surface flux scheme corrects the tendency of BATS1E to overestimate latent heat over the oceans in both weak and strong wind conditions and in general results in decreased precipitation over the oceans. SUBEX is a physically based parameterization that includes variation at the subgrid scale of clouds, cloud water accretion and evaporation of rain. Resolvable precipitation processes are treated with SUBEX.
- The whole released RegCM3 modeling software system is composed by four components: Terrain, ICBC, RegCM, and Postprocessor. Terrain and ICBC are the two components of RegCM preprocessor. Terrestrial variables include elevation, landuse and sea surface temperature and three-dimensional isobaric meteorological data are horizontally interpolated from a latitude-longitude mesh to a high-resolution domain on either a Rotated (or Normal) Mercator, Lambert Conformal, or Polar Stereographic projection (RegCM Version 3.0 User Guide, 2004).

Model Configuration and Data

In the present study, two different domains each of 60km resolution on Rotated Mercator projection are used to simulate the winter-2000 rainfall.

Large Domain has 32 N and 59 E as central latitude and longitude with 66 grid points in y-direction (about 15 N to 48 N) and 83 grid points in x-direction (38 E to 81 E). While the Small Domain has 31 N and 59 E as central latitude and longitude with 45 grid points in y-direction (about 20 N to 42 N) and 69 grid points in x-direction (41 E to 78 E) as shown in Figures1 & 2.

GTOPO30 Terrain, GLCC Landuse, OISST sea surface temperature and European Centre for Medium-Range Weather Forecasts (ECMWF) reanalysis ERA40 datasets were used as Terrain and ICBC input data.

Grell convective scheme (FC closure assumption) is used in the experiment. Although the choice of a convective scheme generally does not matter for the simulation of winter rainfall which occur due to the western disturbances weather producing systems that are mostly non-convective in nature.

The model was run twice; Firstly with Large Domain and secondly with Small Domain for the months of January, February and March 2000.

In post processing step, the precipitation amount has been averaged for individual months January, February and March by running the postproc script and the precipitation for winter season was determined by adding up the rainfall of the individual months.

Simulated amount of rainfall for individual meteorological stations in Pakistan are determined with the help of station latitude & longitude and area weighted rainfall for those stations was calculated using their area factors and compared with Pakistan Metrological Department observational rainfall data. Data plot has been obtained using MS Excel software.

The modal output data and Climatic Research Unit (CRU) observational data have been displayed graphically by using GrADS (the visualization software).

Maps of winter seasonal and monthly rainfall was generated with the help of software Surfer version 8 using Real Time precipitation data of meteorological observatories of Pakistan Meteorological Department.

Simulated rainfall is also compared with real time data on some selected days of the period in order to see in which domain the individual precipitation event is better captured by the model.

Results and Discussion:

The model configuration (domain, resolution, and etc.) is an important issue for regional climate modeling and the domain of a regional climate model must be carefully selected for its specific application (Seth & Giorgi, (1998), Giorgi, (2004)). For Pakistan, a number of studies have begun to evaluate the performance of regional models for their ability to simulate the regional climate in retrospective studies. However, the effect of domain choice on the simulations of rainfall (especially of winter season) is not discussed explicitly. For the mid-latitudes, several studies have found that a larger domain reduces the constraints of the lateral boundary conditions, thereby permitting more internal model freedom (Jones et al., 1995; Seth and Giorgi, 1998; Vannitsem and Chom´e, 2005).

The amounts of precipitation reproduced by the model using two different domains are compared with CRU and real time data. Fig. 3 represents the total amount of precipitation of winter-2000 reproduced by the model using Large Domain. The amount of precipitation in northern and central parts of Punjab, central Parts of Balochistan and southern & central parts of North Western Frontier Province (NWFP) is in deficit when compared with the CRU data. CRU data plots are shown in Fig. 5. The amount of simulated rainfall is in excess over northern areas as compared to the CRU observations. The simulations are, however, quite good for southern parts of the country.

When compared with the real time Observations, the simulated amount of precipitation in northern and eastern parts of Punjab and southern & central parts of NWFP is in deficit. The real time data plots are shown in Fig. 6. The amount of simulated rainfall is again in excess over northern areas as compared to the real time observations but this

anomaly is less as that of when compared with the CRU data as mentioned in the above paragraph. In this case also, the simulations are quite good for southern parts of the country.

Fig. 4 represents the winter-2000 precipitation generated by the model using Small Domain. The simulated amount of precipitation in the eastern parts of Punjab and central parts of Balochistan is, however, in deficit when compared with the real time observational data.

When the patterns of simulated winter rainfall with both the domains are compared with the CRU and real time observations pattern, the pattern of simulated winter rainfall with Small Domain has good resemblance to the CRU and real time observations pattern. The simulations are, however, quite good for southern parts of the country.

The pattern of simulated rainfall in individual months (i.e. January, February and March) of the winter season with both the domains are also compared with the CRU and real time observations pattern (Fig.9 to 20). The patterns of simulated winter rainfall with Small Domain have good resemblance to the CRU and real time observations patterns. The simulated rainfall, however, is embellished in some northern parts of the country.

During winter-2000, the heaviest spell of rainfall was observed on 11th January, 2000. The real time data of rainfall of some meteorological stations is shown in the Table given below.

This individual event of precipitation is also comparatively captured well in Small Domain than in Large Domain. However, the rainfall observed on the same day over southwestern Sindh (see data of Karachi & Hyderabad in the table) was not captured in either of the domains by the model (Fig.21 & 22).

STATION	Longitude	Latitude	Total Rainfall (in mm) on 11/1/2000
CHITRAL	71.83	35.85	19.5
DALBANDIN	64.4	28.88	2
FAISALABAD	73.1	31.43	6
GILGIT	74.33	35.92	0.4
HYDERABAD	68.42	25.38	0
ISLAMABAD	73.1	33.62	31
JHELUM	73.72	32.93	25.9
KARACHI	67.13	24.9	19
LAHORE	74.4	31.52	19.1
PARACHINAR	70.08	33.87	9
QUETTA	66.88	30.25	7
SAIDU SHARIF	72.35	34.73	50.6

The comparison of real time total area weighted (AWT) rainfall over Pakistan in the winter-2000 with the total area weighted rainfall calculated using simulated rainfall with

large as well as small domain and CRU data is shown in Fig. 8. Normal area weighted rainfall for the winter season is also given. It can be seen that total area weighted rainfall simulated with Small Domain is very close to both real time (RT) and CRU area weighted rainfall. The area weighted simulated rainfall with Small Domain is just 0.2% above than the area weighted rainfall calculated from CRU data and 12.1 % less than the real time area weighted rainfall over Pakistan for winter 2000. While the area weighted rainfall with Large Domain is 36.9 % less than the corresponding rainfall from CRU data and 44.7 % less than the real time area weighted rainfall.

Conclusion:

The Regional Climate Model (RegCM3) at 60 km resolution is able to simulate the winter rainfall over Pakistan reasonably well and it is found that the simulation of seasonal precipitation is affected by the domain size. Inter-comparison of simulated rainfall over Pakistan suggests that the rainfall pattern simulated by RegCM3 using small domain is in good resemblance to the rainfall patterns of both CRU and real time observations. The model is also found to be capable of simulating drought conditions over the region especially in the southern half of the country. The Small Domain seems to be more appropriate for simulations of winter rainfall over Pakistan. However, some more experiments should be done using this Small Domain for winter seasons of different years with varying winter rainfall amounts (normal, below normal and above normal) and performance of the model should be evaluated by doing experiments with different resolutions.

References:

Chaudhry, Q. Z. (2001). History's Worst Drought Hit Pakistan. Farming Outlook. July-September, 2001. Soil, Agriculture, Fertilizer & Environment (SAFE) Foundation, Pakistan.

Chaudhry, Q. Z. (2002). Drought Monitoring and Early Warning System. Proceedings of the SAARC Workshop on Drought and Water Management Strategies (September 16-18, 2002 Lahore-Pakistan). Pakistan Council of Research in Water Resources, Islamabad, Pakistan.

Anthes R.A. (1977). A Cumulus Parameterization Scheme Utilizing a One-Dimensional Cloud Model, Monthly Weather Review, 105, pp 270-286.

Anthes R.A., E.Y Hsie and Y.H Kuo (1987). Description of the Penn State / NCAR Mesoscale Model Version4 (MM4), NCAR Technical Note, NCAR / TN-282+STR, pp 66 (Available from the National Center for Atmospheric Research, P.O. Box 3000, Boulder, CO 80307)

Dickinson, R.E., A Henderson-Sellers and P.J Kennedy (1993) Biosphere-Atmosphere Transfer Scheme, BATS: Version 1E as coupled to the NCAR Community Climate Model. NCAR Technical Note No NCAR/TN-387+STR, pp72 (Available from the National Center for Atmospheric Research, P.O. Box 3000, Boulder, CO 80307)

Giorgi, F. (1990). Simulation of regional climate using a limited area model nested in a general circulation model, Journal of Climate, vol. 3, Issue 9, pp 941-964.

Giorgi, F., M.R. Marinucci, G. deCanio, and G. T. Bates (1993a). Development of a Second Generation Regional Climate Model (RegCM2), Cumulus Cloud and Assimilation of Lateral Boundary Conditions, Monthly Weather Review, 121, pp2814-2832.

Giorgi, F., M. Marinucci and G. T. Bates (1993b) Development of a Second-generation Regional Climate Model (RegCM2). Part II: Convective Processes and Assimilation of Lateral Boundary Conditions. Monthly Weather Review, 121, pp 2814-2832

Grell, G. A. (1993). Prognostic Evaluation of Assumptions Used by Cumulus Parametrization, Monthly Weather Review, 121, pp.764-787.

Holtslag A., E. de Bruijn and H.L. Pan (1990). A High Resolution Air Mass Transformation Model For Short-Range Weather Forecasting. Monthly Weather Review, 118, pp1561-1575

Jones R.G., J.M. Murphy and M. Noguer (1995). Simulations of Climate Change over Europe using a Nested Regional Climate Model. I: Assessment of Control Climate, Including Sensitivity to Location of Lateral Boundaries. Quarterly Journal of Royal Meteorological Society, 121, 14131449.

Kiehl, J.T., G.B. Bonan, B.A. Boville, B.P. Briegleb, D.L. Williamson and P.J. Rasch (1996). Description of the NCAR Community Climate Model (CCM3). NCAR Technical Note NCAR TN-420 + STR, pp 152 (Available from the National Center for Atmospheric Research, P.O. Box 3000, Boulder, CO 80307)

Pal, J., E. Small and E. Eltahir (2000). Simulation of Regional-Scale Water and Energy Budgets: Representation of Subgrid Cloud and Precipitation Processes within RegCM, Journal of Geophysical Research-Atmospheres, Volume 105, Issue D24, pp 29579-29594.

RegCM Version 3.0 User's Guide (June 2004). Physics of Weather and Climate Group, The Abdus Salam International Centre for Theoretical Physics, Trieste, Italy, pp 5.

Seth, A. and F. Giorgi (1998). The Effects of Domain Choice on Summer Precipitation Simulation and Sensitivity in a Regional Climate Model, Journal of Climate, vol.11, Issue 10, pp.2698-2712

Vannitsem S., F. Chom´e (2005). One-way Nested Regional Climate Simulations and Domain Size. Journal of Climate, 18, pp.229-233

Zeng, X., M. Zhao and R.E. Dickinson (1998). Inter Comparison of Bulk Aerodynamic Algorithms for the Computation of Sea Surface Fluxes using TOGA COARE and TAO Data, Journal of Climate, 11, pp 2628-2644.

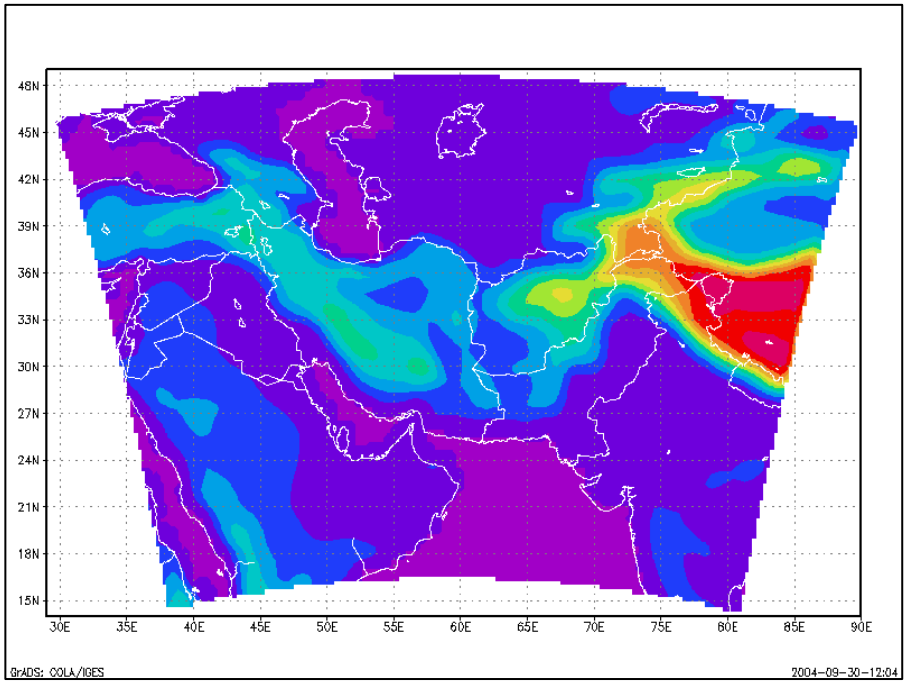

Fig. 1: Large Domain (LD)

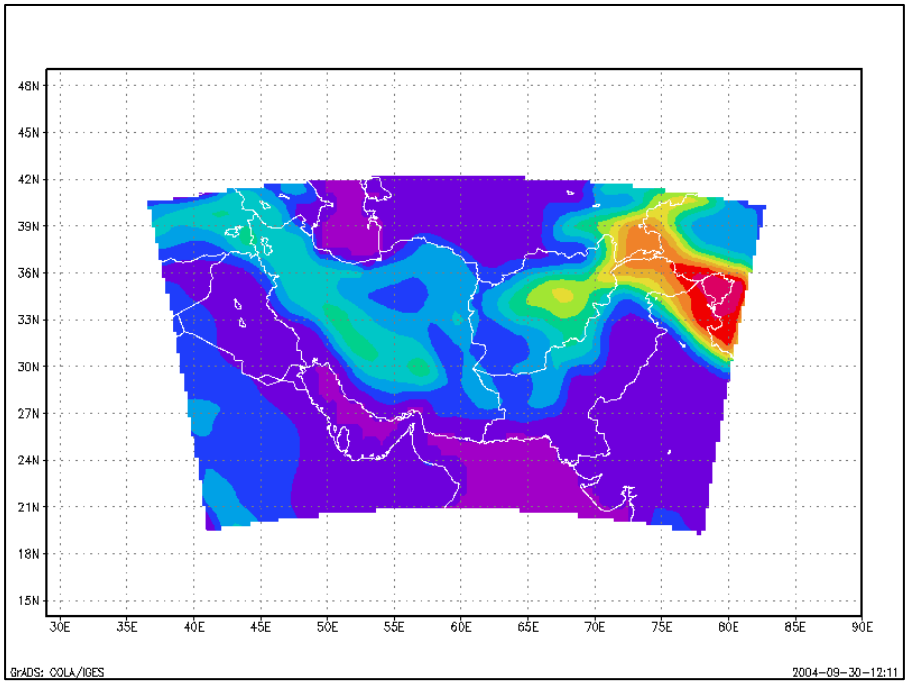

Fig. 2: Small Domain (SD)

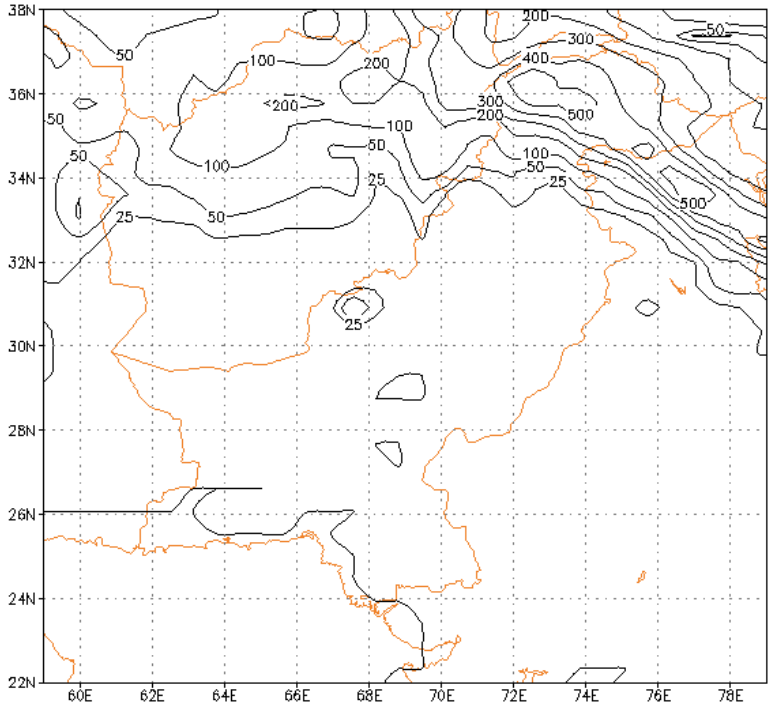

Fig. 3: Winter-2000 rainfall as simulated by RegCM3 with Large Domain (LD)

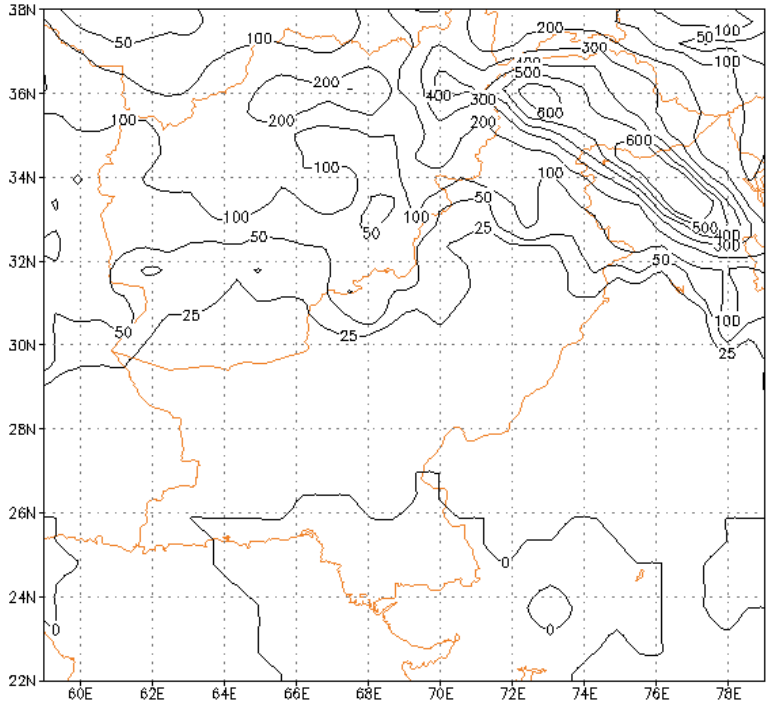

Fig. 4: Winter-2000 rainfall as simulated by RegCM3 with Small Domain (SD)

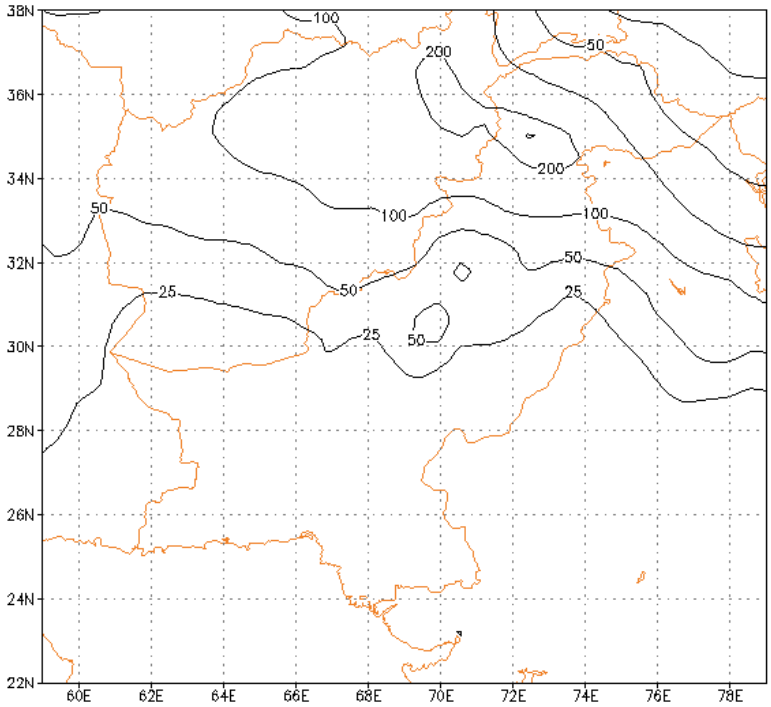

Fig. 5: Winter-2000 rainfall pattern over Pakistan according to Climatic Research Unit (CRU) observational data

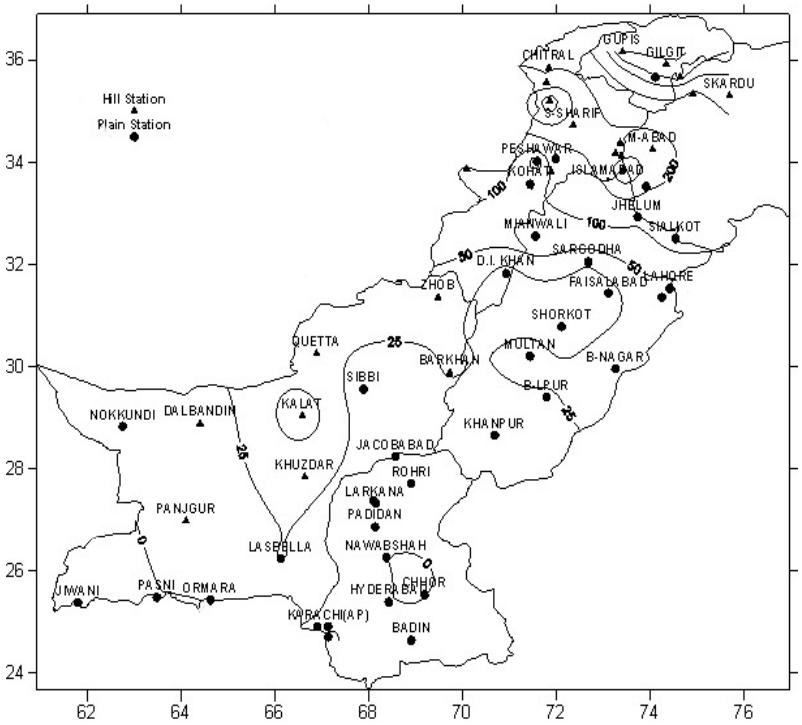

Fig. 6: Winter-2000 rainfall over Pakistan according to real time data of meteorological observatories of PMD.

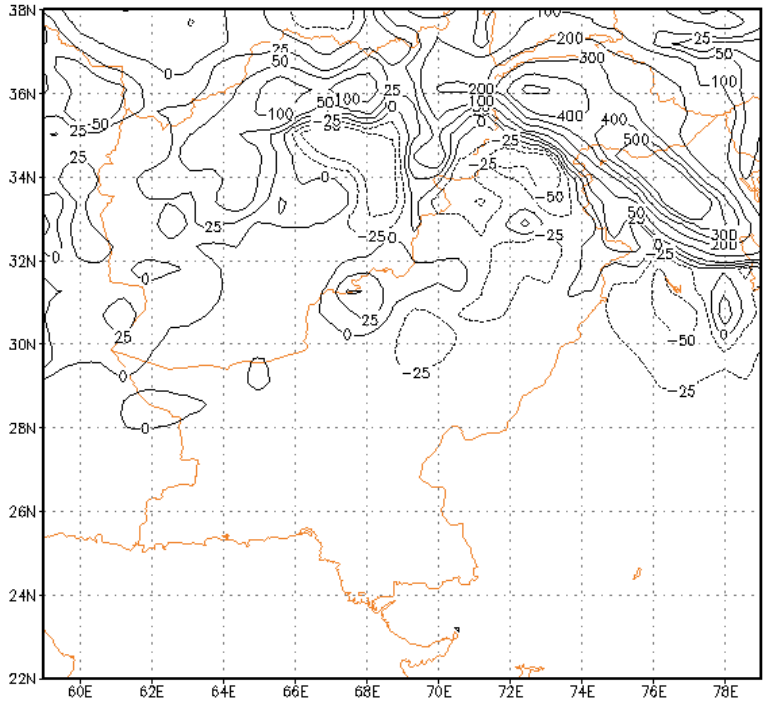

Fig. 7: Difference of RegCM3 simulated rainfall data with SD and CRU data.

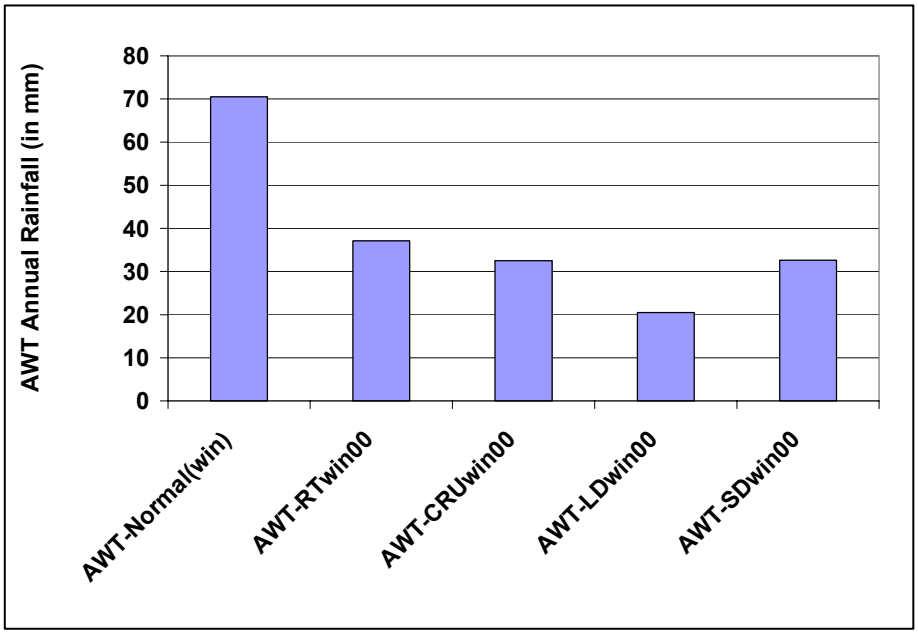

Fig. 8: Area Weighted (AWT) rainfall using Real Time (RT), CRU, and model simulated data with LD and SD. Normal area weighted winter rainfall is also shown for comparison.

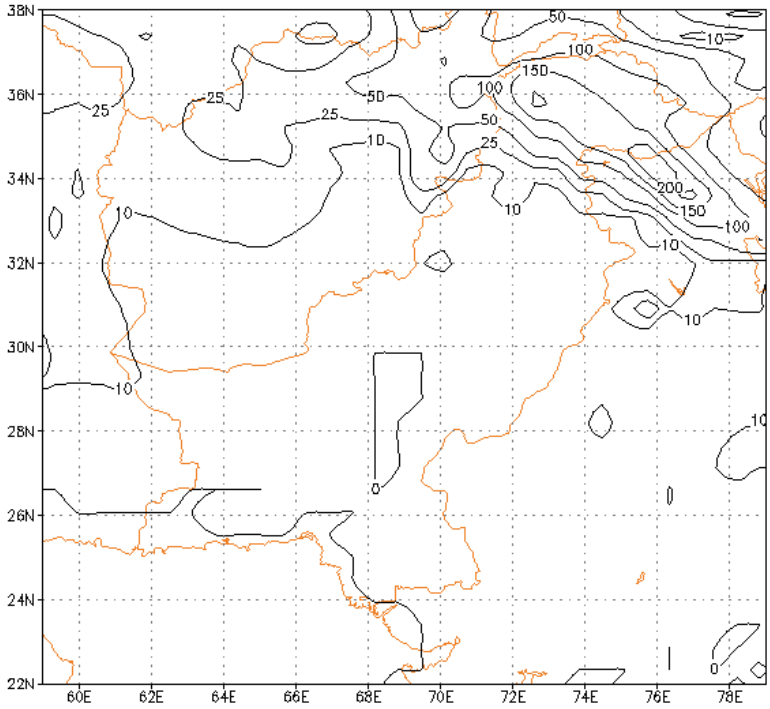

Fig. 9: January-2000 rainfall as simulated by RegCM3 with Large Domain (LD)

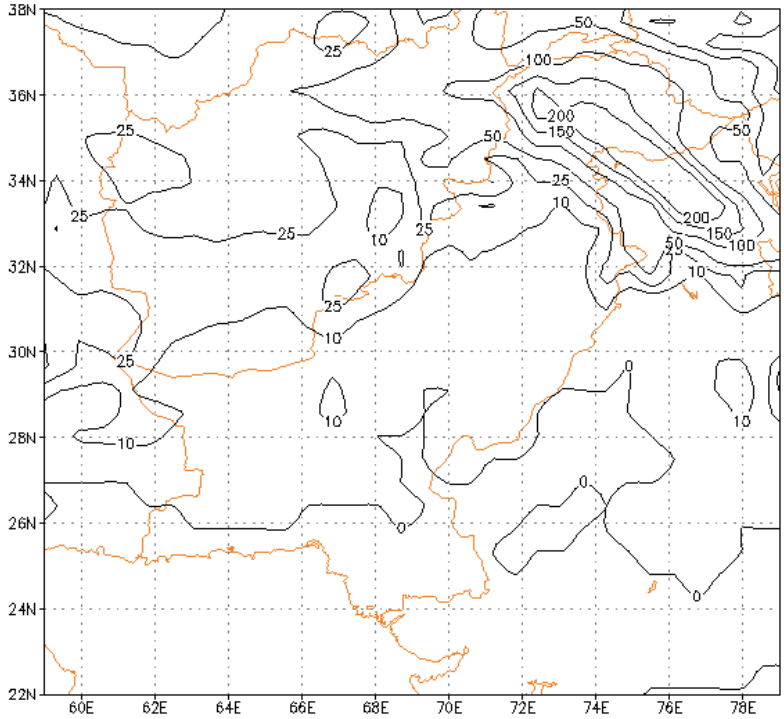

Fig. 10: January-2000 rainfall as simulated by RegCM3 with Small Domain (SD)

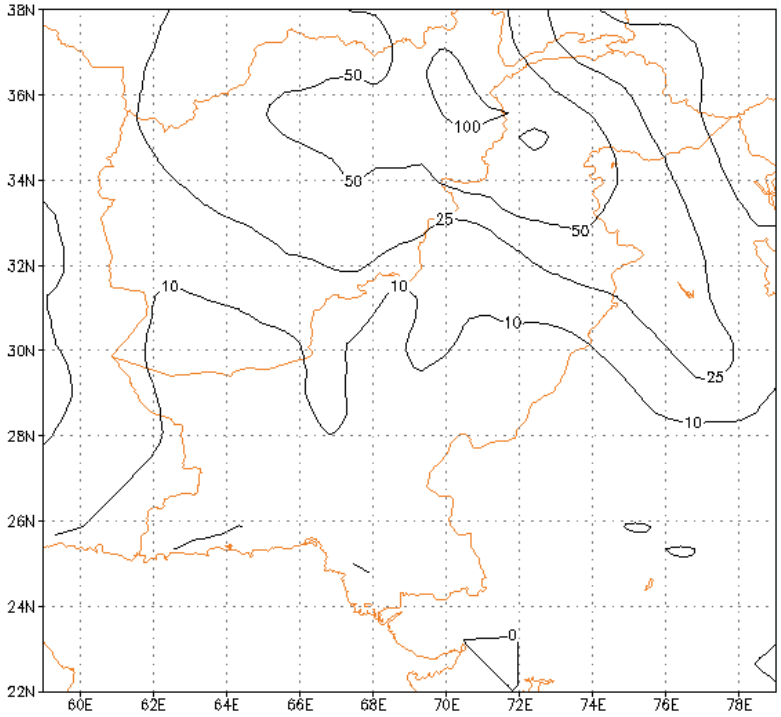

Fig. 11: January-2000 rainfall pattern over Pakistan according to Climatic Research Unit (CRU) observational data

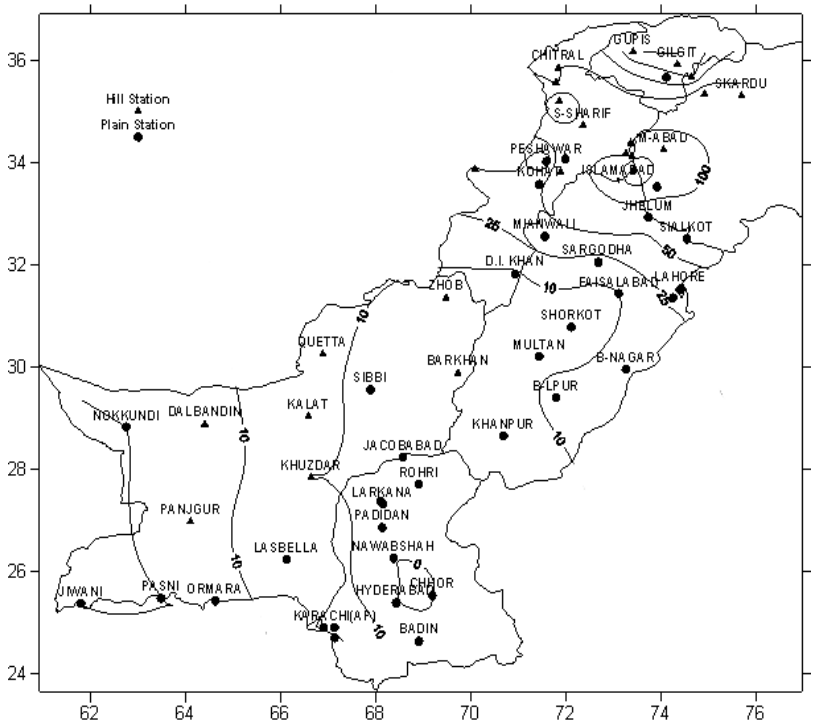

Fig. 12: January-2000 rainfall over Pakistan according to real time data of meteorological observatories of PMD.

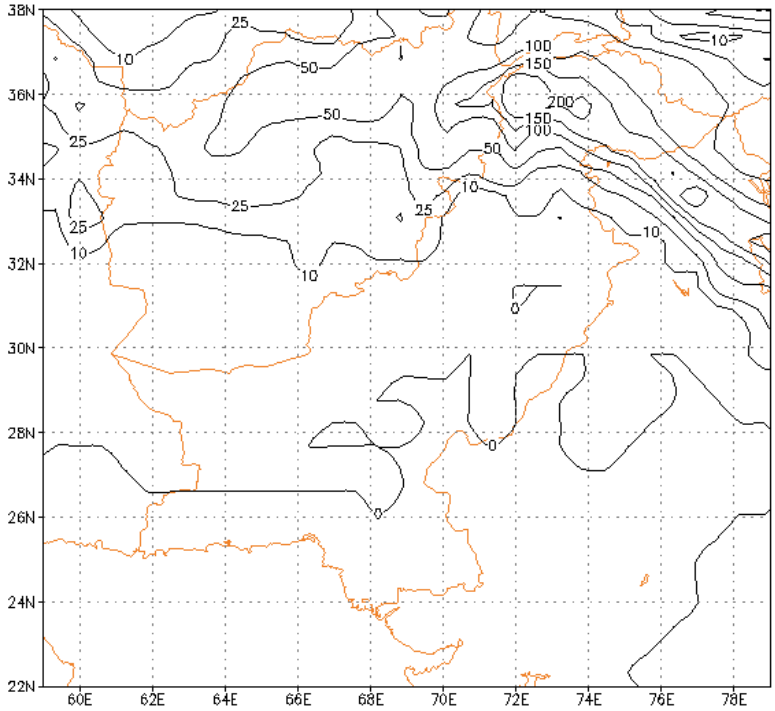

Fig. 13: February-2000 rainfall as simulated by RegCM3 with Large Domain (LD)

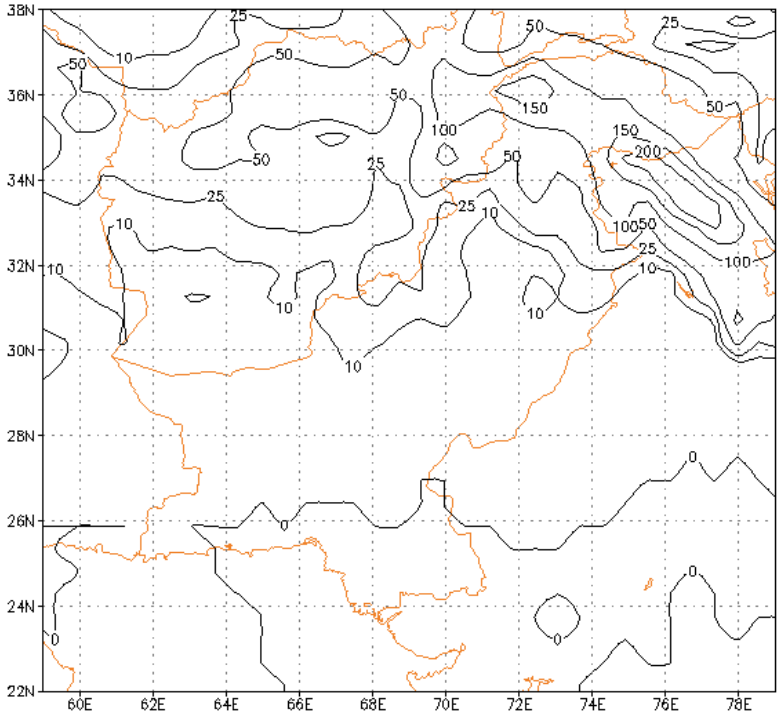

Fig. 14: February-2000 rainfall as simulated by RegCM3 with Small Domain (SD)

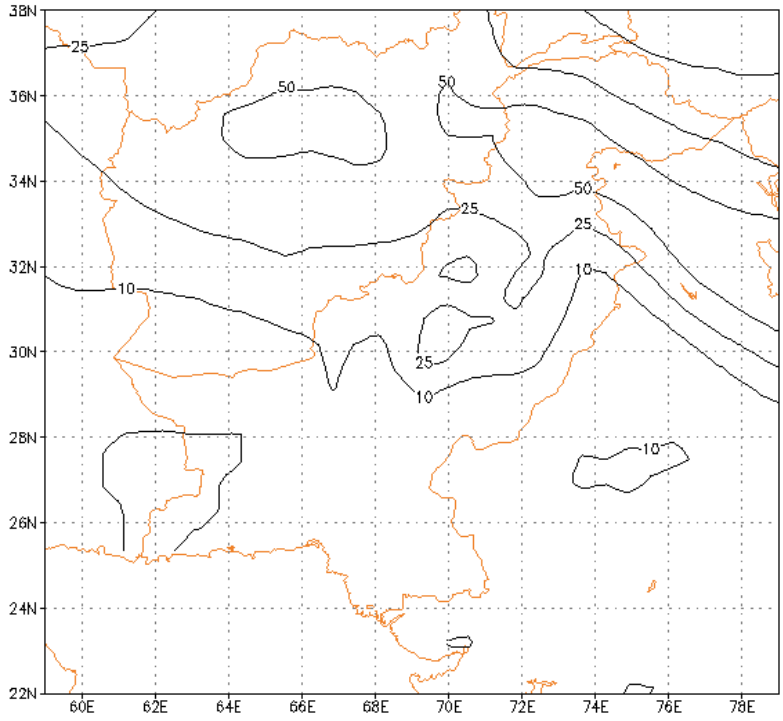

Fig. 15: February-2000 rainfall pattern over Pakistan according to Climatic Research Unit (CRU) observational data

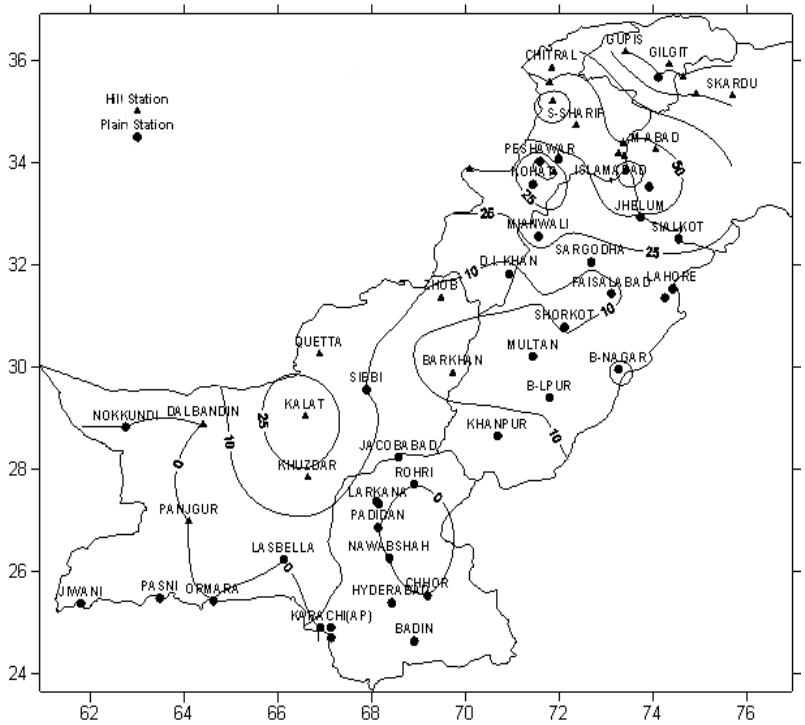

Fig. 16: February-2000 rainfall over Pakistan according to real time data of meteorological observatories of PMD.

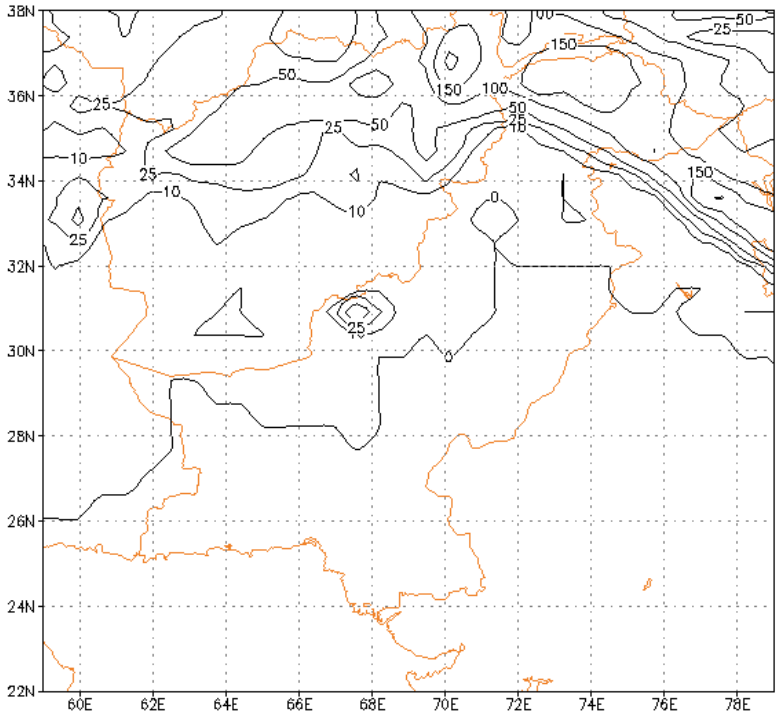

Fig. 17: March-2000 rainfall as simulated by RegCM3 with Large Domain (LD)

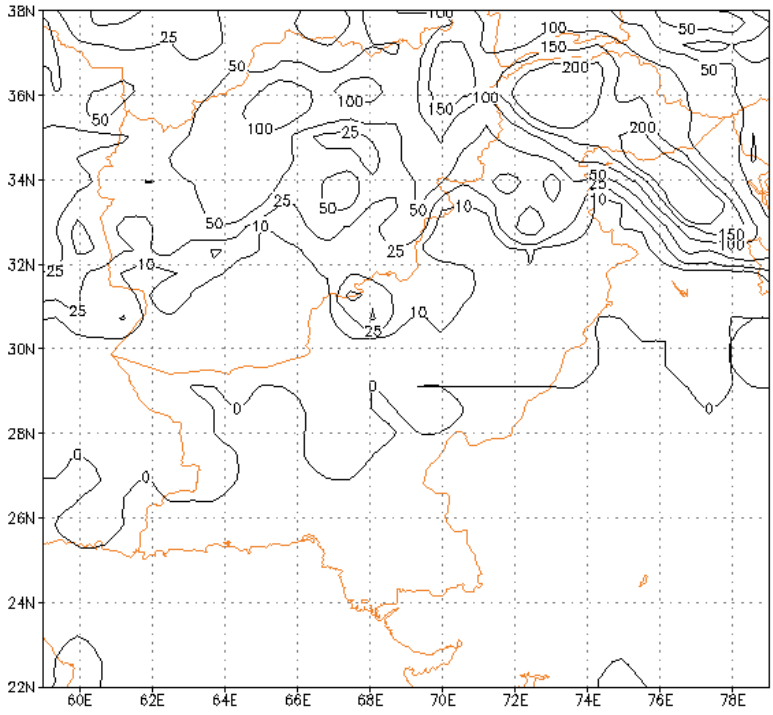

Fig. 18: March -2000 rainfall as simulated by RegCM3 with Small Domain (SD)

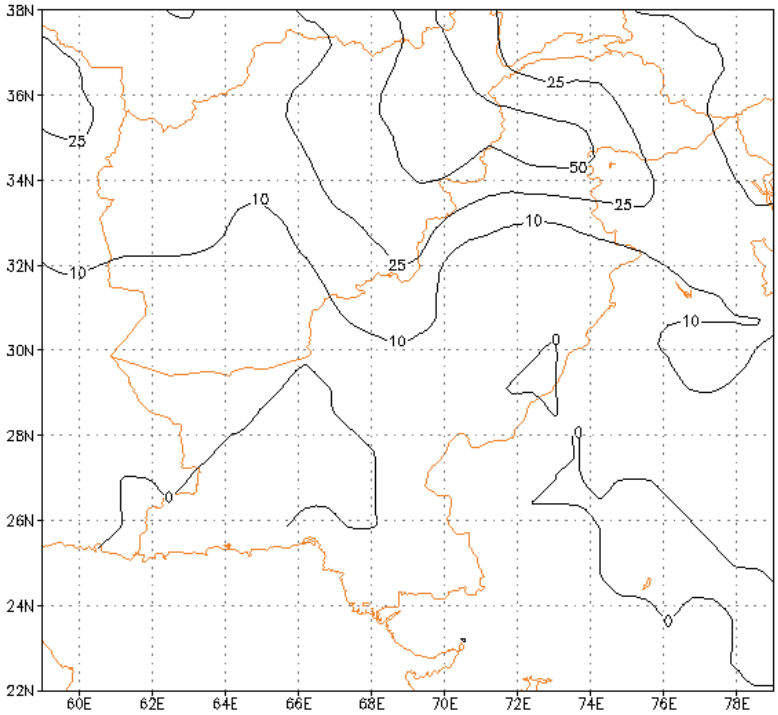

Fig. 19: March -2000 rainfall pattern over Pakistan according to Climatic Research Unit (CRU) observational data

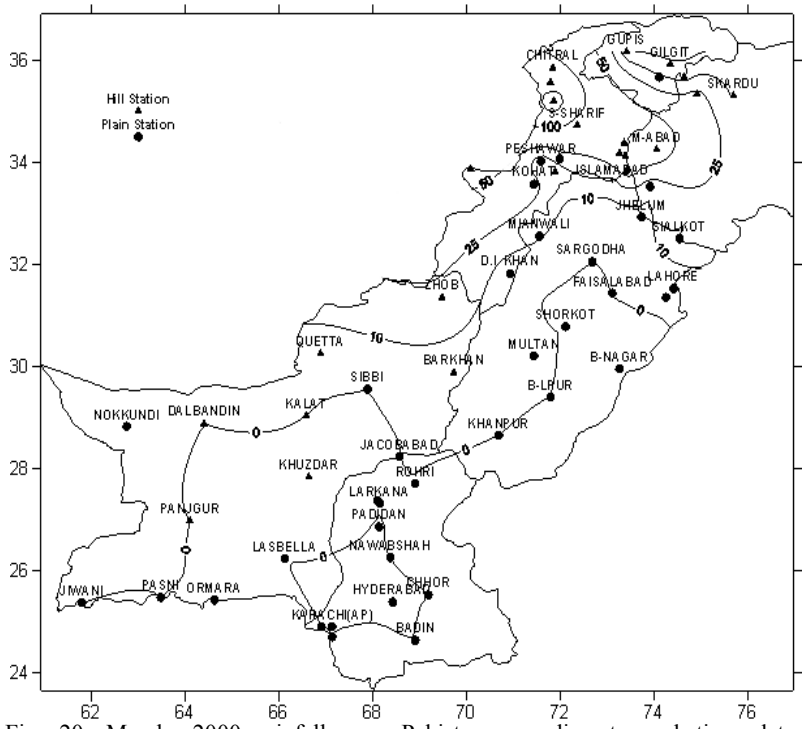

Fig. 20: March -2000 rainfall over Pakistan according to real time data of meteorological observatories of PMD.

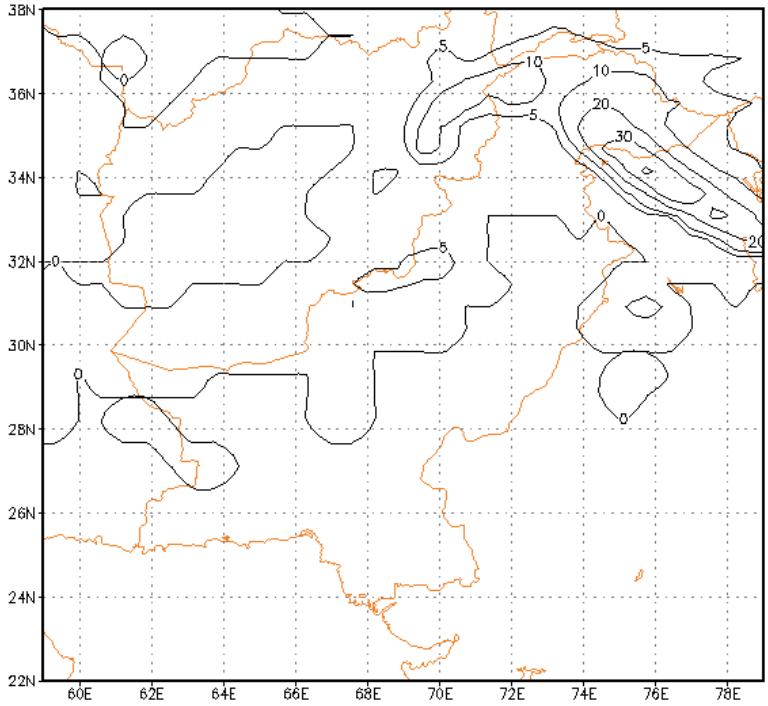

Fig. 21: Rainfall on 11-01-2000 as simulated by RegCM3 with Large Domain (LD)

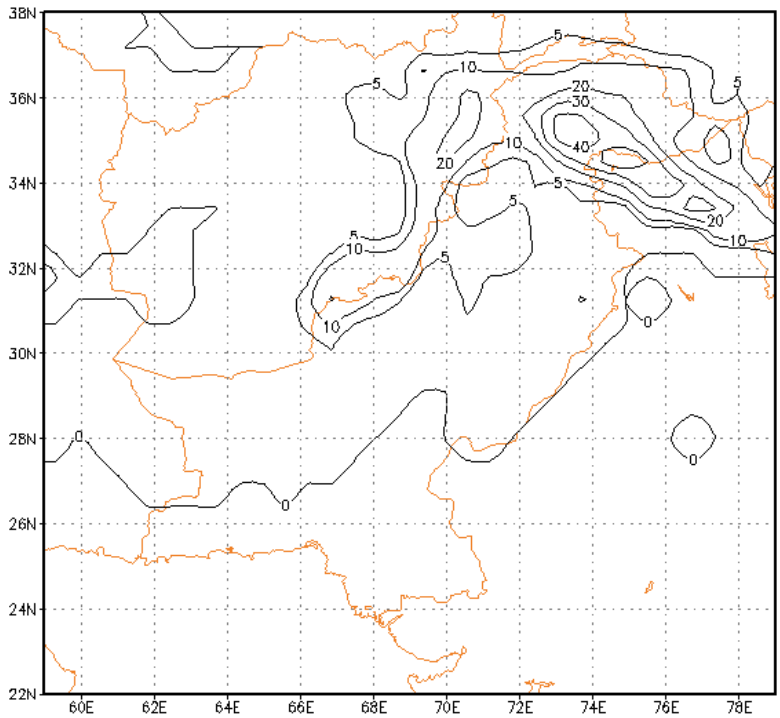

Fig. 22: Rainfall on 11-01-2000 as simulated by RegCM3 with Small Domain (SD)