JAST, Vol. 4, No. 2, pp 33–42
○ Iranian Aerospace Society, June 2007

JAST Journal of Aerospace Science and Technology

Sensitivity Analysis of Different Convection Schemes and Domain Centers for Numerical Simulation of Winter Precipitation Over Iran

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This paper qualifies the impact of different convection schemes and domain centers on the simulation of two dry and wet winter precipitations of 1997 and 2000 over Iran using RegCM3 numerical climate model. The model uses a compressible, finite difference with hydrostatic equilibrium in sigma coordinate and a semi-implicit algorithm for reduction of horizontal diffusion. In this study, sensitivity of the RegCM3 regional climate model has been analyzed using different convection schemes, including Grell-AS, Grell- FC, Emanuel and Kuo schemes and different domain center locations including Himalaya, Mediterranean sea, Iran and Indian ocean (near Pakistan southern border). NNRP1 data with a 5-degree resolution,as well as GLCC and GTOPO dataset are used as initial and boundary conditions, land use and topography data, respectively.

We found that the performance of the Model strongly depends on the location of the domain center, for example when the center of the domain is located over Himalaya then the results for the precipitation are reasonably better especially when a Siberian high pressure develops over Iran. With Kuo scheme,the minimum of bias and MAE are -0.7mm and 0.6mm for dry year of 2000, but with Grell scheme the error is found to be a minimum compared to other configurations of the model both in dry and wet seasons. In all experiments the precipitation amounts are underestimated when compared to corresponding observations. The largest difference occurred in Himalaya experiment. Moreover, we found that there is an eastward shift in Caspian Sea precipitation pattern in all experiments.

It is also found that CRU reanalysis data cannot be considered as a reference for calibration of RegCM3 over Iran.

INTRODUCTION

Iran has a variable climate. In the northwest, winters are cold with heavy snowfall and freezing temperatures during December and January. Spring and fall are relatively mild, while summers are dry and hot. In the south, winter is mild and the summers are very hot, having average daily temperatures exceeding 38°C in July. On the Khuzestan plain, summer heat is accompanied by high humidity. In general, Iran has an arid climate in which most of annual precipitation falls between October through April. In most of the country, yearly precipitation average is about 250 millimeters or less. The major exceptions are the higher mountain valleys of the Zagros and the Caspian coastal plain, where the precipitation average is at least 500 millimeters annually. In the western part of the Caspian sea, rainfall exceeds 1000 millimeters per year and is distributed almost evenly throughout the year. This contrasts with the precipitation amount in some basins of the central plateau, which receive so only 100 millimeters or less precipitation annually [5].

Numerical climate modeling of Iran is a challeng-

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ing and complicated task due to its different climate and complex topography. Regional climate models such as RegCM3 are capable of predicting and simulating different climatic phenomena for calibrating seasonal forecasts and understanding deviations of model outputs on the basis of real climate. In this regard, sensitivity analysis of different numerical schemes including physical and computational processes used in the model is essential. RegCM3 is one of the widely used numerical regional climate models; it was first released as MM4, a short-term numerical weather prediction developed at Pennsylvania State University [13]. The dynamical core of RegCM3 is originated from that of MM4 which is compressible, finite difference with hydrostatic equilibrium in sigma coordinate. A semi-implicit algorithm has been added to the model for reduction of horizontal diffusion [19]. Physics of the model consists of radiation, surface layer, planetary boundary layer, convective precipitation, large-scale precipitation, oceanic flux, pressure gradient and tracer schemes [7, 12].

Batts et al., 1995 have shown that cold season precipitations of RegCM3 are very close to two-year observation pattern over the United States, but there is a 10 percent overestimation in warm season simulations [6]. Giorgi et al., (1997) have shown that small domains would render better results in a warm season precipitation simulation. Wang et al., (2003) have studied heavy precipitation during 1998 over China using RegCM3. Integration was done from 26 April up to 31 August with 0.5 degree resolution in the area bounded from 5 to 45 in the North and 90 to 140 in the East. They succeeded to model both mean monthly and daily amount of precipitation [19]. Azadi and Singh (2003) have studied the impact of SST on the modeling of spring rainfall over Middle East using RegCM3. They found that simulated rainfall was mostly overestimated. The model has shown remarkable ability to positively simulate the effect of SST on land-sea contrast [3]. Ahmadi et al., (2004) has studied the effect of BATS subgrid scale scheme on regional climate modeling over Iran using RegCM3 [1]. Their results were highly sensitive to choice of closure parameters. Fransisco et al. (2003) have studied impacts of biomass burning over Southeast Asia using RegCM3 modeling. The results have shown that the model can capture the transport and removal process, decrease of shortwave radiation reaching the surface; cooling of surface, tropospheric warming effect of absorbing aerosol [10]. Kwon W.T. used a regional climate change scenario over East Asia for providing reasonable future regional climate information for impact assessment studies with combination of dynamic downscaling (RegCM3) and statistical adjustment [18].

In this paper, sensitivity of RegCM3 regional climate model has been analyzed using different convection schemes and locations for domain center. Domain center of the model has been displaced toward large scale weather systems affecting Iran and other neighboring countries [4].

CONVECTION SCHEMES IN REGCM3

Convective precipitation can be computed using one of the three schemes of Grell , Modified-Kuo and Emanuel scheme. In addition, the Grell parameterization is implemented using one of two closure assumptions: (1) the Arakawa and Schubert and (2) the Fritsch and Chappell, hereafter referred to as AS74 and FC80, respectively.

Grell Scheme

Grell scheme considers clouds as two steady-state circulations: an updraft and a downdraft [16]. No direct mixing occurs between cloudy air and environmental air except at the top and bottom of the circulations. The mass flux is uniform in the upward direction and no entrainment or detrainment occurs along the cloud edges. The originating levels of the updraft and downdraft are given by the levels of maximum and minimum moist static energy, respectively. The Grell scheme is activated when a lifted parcel attains moist convection. Condensation in the updraft is calculated by lifting a saturated parcel. The downdraft mass flux (m_0) depends on the updraft mass flux (m_b) according to the following relation:

$$m_0 = \frac{\beta I_1}{I_2} m_b \tag{1}$$

where I_1 is the normalized updraft condensation, I_2 is the normalized downdraft evaporation, and β is the fraction of updraft condensation that re-evaporates in the downdraft. β depends on the wind shear and typically varies between 0.3 and 0.5. Rainfall is given by

$$P^{CU} = I_1 m_b (1 - \beta) \tag{2}$$

Heating and moistening in Grell scheme are determined both by the mass flux and the detrainment at top and bottom of the cloud. In addition, the cooling effect of moist downdrafts is included. Due to the simplistic nature of the Grell scheme, several closure assumptions can be adopted. RegCM3's default version directly implements the quasi-equilibrium assumption of AS74. It assumes that convective clouds stabilize the environment as fast as non-convective processes destabilize it [11, 17].

Kuo Scheme

Convective activity in the Kuo scheme is initiated when the moisture convergence M in a column exceeds a given threshold and the vertical sounding is convectively unstable [2]. A fraction of the moisture convergence β moistens the column and the rest is converted into rainfall P^{CU} as per the following relation:

$$P^{CU} = M(1-\beta) \tag{3}$$

β is a function of the average relative humidity $\overline{RH}$ of the sounding as follows:

$$\beta = \begin{cases} 2(1-\overline{RH}) & \overline{RH} \geq 0.5 \\ 1.0 & \text{Otherwise} \end{cases} \tag{4}$$

Moisture convergence term includes only the advective tendencies for water vapor. The latent heat resulting from condensation is distributed between the cloud top and bottom by a function that allocates the maximum heating to the upper portion of the cloud layer. To eliminate numerical point storms, a horizontal diffusion term and a time release constant are included so that the redistributions of moisture and the latent heat release do not happen instantaneously [14, 15].

Emanuel scheme

The newest cumulus convection option for the Regional Climate Model version 3 (RegCM3) is the Massachusetts Institute of Technology (MIT) scheme. More detailed descriptions can be found in Emanuel (1991) and Emanuel and Zivkovic-Rothman (1999) [8, 9]. The scheme assumes that the mixing in clouds is highly episodic and inhomogeneous (as opposed to a continuous entraining plume) and considers convective fluxes based on an idealized model of sub-cloud-scale updrafts and downdrafts. Convection is triggered when the level of neutral buoyancy is greater than the cloud base level. Between these two levels, air is lifted and a fraction of the condensed moisture forms precipitation while the remaining fraction forms the cloud. The cloud is assumed to mix with the air from the environment according to a uniform spectrum of mixtures that ascend or descend to their respective levels of neutral buoyancy. The mixing entrainment and detrainment rates are functions of the vertical gradients of buoyancy in clouds. The fraction of the total cloud base mass flux that mixes with its environment at each level is proportional to the undiluted buoyancy rate of change with altitude. The cloud base upward mass flux is relaxed towards the sub-cloud layer quasi equilibrium.

DATA, REGION AND PERIOD OF STUDY

Iran Plateau has a complex topography with two main mountain chains of Alborz located in the north and Zagros chain near the western border There are large forest areas over the northern region, and two great deserts in the central regions of Iran. Our domain of study is bounded inside a region of ($10°W$, $15°N$) and ($80°E$, $55°N$). Domain covers the entire Middleast and parts of India, Russia and Eastern Europe. All the evaluations and sensitivity analyses have been done for Iran only. Winter seasons of 1997 and 2000 were selected as dry and wet seasons for sensitivity analysis and evaluation skill forecast of RegCM3 over Iran. Seasonal distribution of precipitation in the winters of 1997 and 2000 are shown in Figure 1 and 2.

There are two main maxima in the 1997 winter precipitation,one over the Caspian Sea costal area with the value of 260 mm and the other over the western part of Iran with 300 mm. The winter precipitation pattern during 2000 is almost the same as 1997, as can be seen in Figure 2. We have used 151 synoptic stations and CRU data for the evaluation of model output. CRU datasets with 0.5 degree resolution for 1901-2000, are provided by Mitchell and Tyndall at the University of East Anglia at the Climatic Research Unit. They are available in the categories of temperature; precipitation and other climatic parameters in

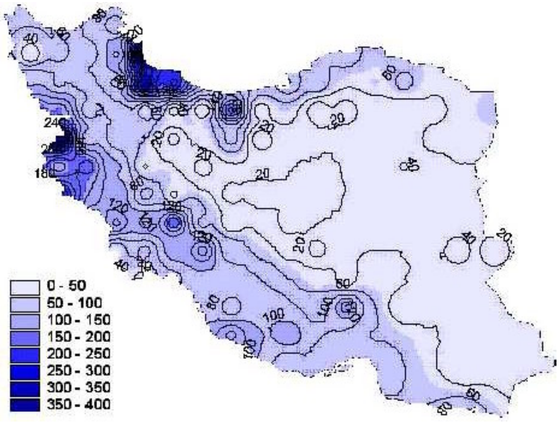


Figure 1. Distribution of 1997 (as a dry season) winter precipitation over Iran

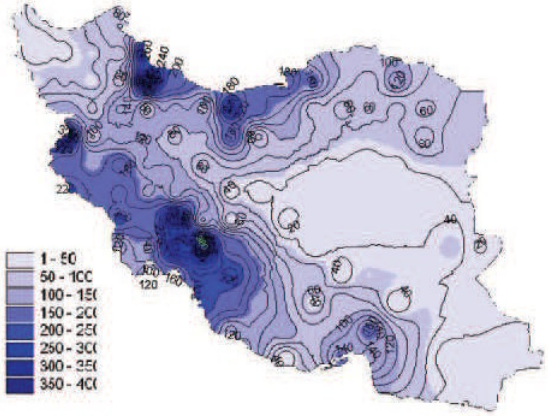


Figure 2. Same as Fig 1, but for winter 2000 (as a wet season)

indices. Some of these can be accessed on the CRU website at www.cru.uea.ac.uk. Total precipitations of Iran are shown in the figures 3 and 4 using the CRU data.

NNRP1 (NCEP/NCAR Reanalysis Project version 1) dataset with a 2.5 degree horizontal resolution have been obtained from NOAA and are used as initial and boundary conditions in the model. GLCC and GTOPO datasets are used as land use and topography in the model. OISST dataset has been used as sea surface temperature (SST) data in the model.

EXPERIMENTS

Two series of experiments are conducted in this research. They are listed in Table 1. In all experiments the grid space and time step of the model are selected to be 75 km and 150 s, respectively.

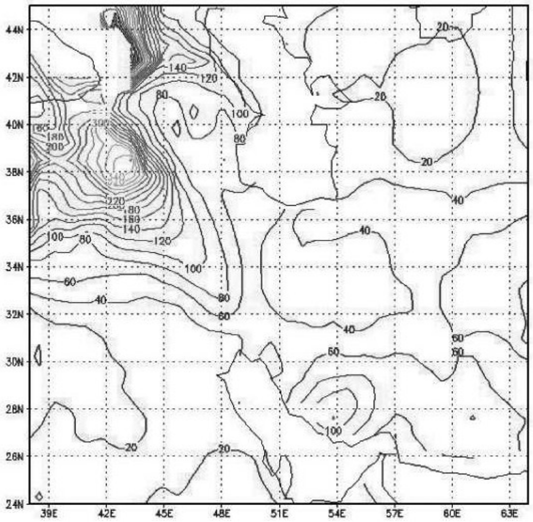


Figure 3. Total precipitation over Iran using CRU data for winter 1997

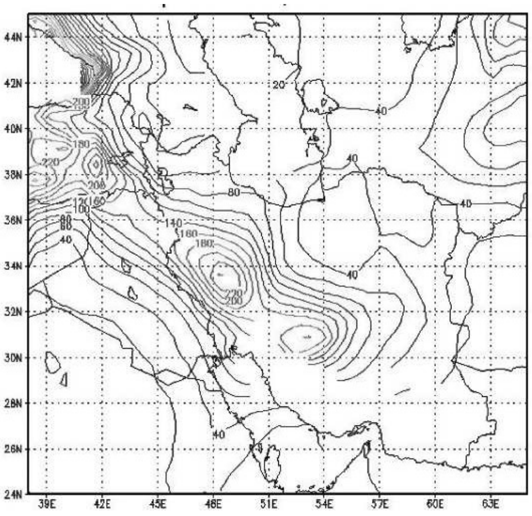


Figure 4. Same as Fig 3, but for 2000

In the first series of experiments with different convection schemes, the center of the model domain is located over Iran at (53°E, 33°N). RegCM3 has four different options for convection schemes: Kuo, Grell-FC, Grell-AS and Emanuel. In the second series of experiments, the Grell-FC option is selected as the convection scheme but location of the model domain center is varying over the Mediterranean Sea, India and Himalaya region. COFC experiment has the same convection and domain centre as the DOIR experiment (table 1).

SIMULATIONS AND DISCUSSION

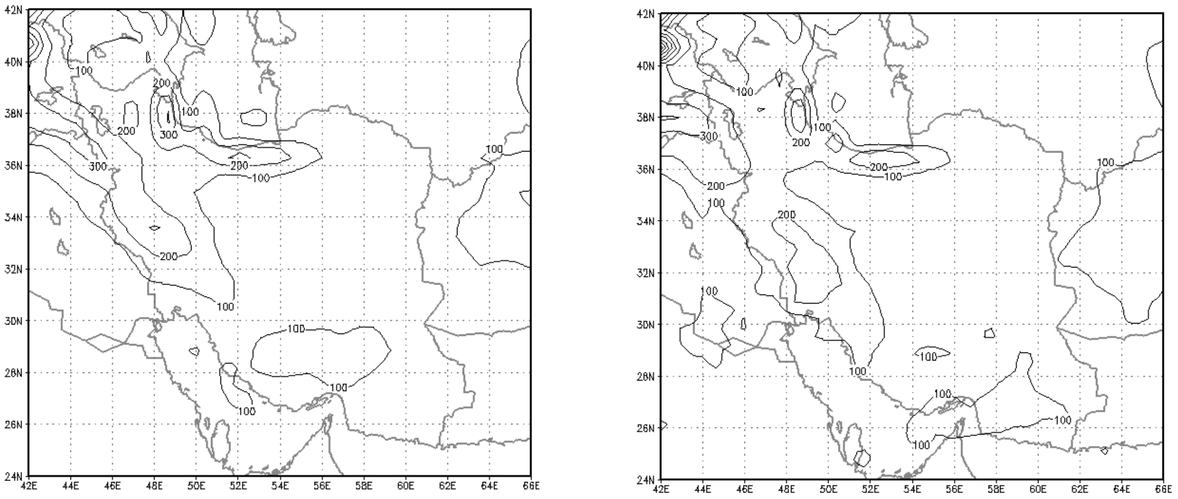
As mentioned earlier, two kinds of experiments have been conducted on sensitivity analysis of the RegCM3: convection schemes and location of the model domain center. In the following, we describe details of these two series of experiments.

Convection

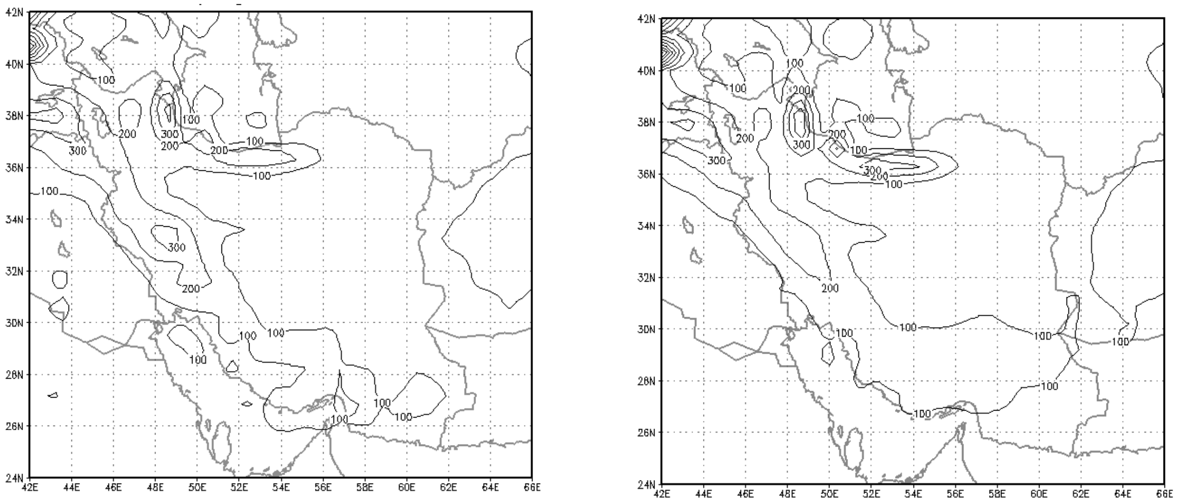
RegCM3 uses four different schemes for convective precipitation, including: Grell-FC, Grell-AS, modified Kuo and Emanuel. RegCM3 simulations for 1997 and 2000 wintertime precipitations are shown in Figure 5 and 6. In convection experiments, Grell-FC has well modeled the precipitation of 1997 in southern parts of the Caspian Sea, but this scheme can not model the precipitations of the south-western part of Iran, including Khuzestan and Ilam provinces. Computed bias and mean absolute error of 1997 winter precipitation are shown in Table 2. Minimum MAE and bias belong to Grell-AS scheme with 21% and -47 mm. It seems that the main error of 1997 winter simulation is because of the weakness of the model for simulation of northwest precipitation. There were three maximum precipitation patterns over Iran, namely Fars, west of the Caspian Sea and west of Iran. It is not recommended to use Emanuel and Kuo convection scheme for modeling the south west and south east precipitation of Iran. Grell-FC and Grell-AS schemes are acceptable for modeling the Caspian Sea winter precipitation. Table 3 has indicated the computed

Table 1. Experiments designed for sensitivity analysis of RegCM3 over Iran

Category	Exp.	Convection Scheme	Domain Name	Center (lat. & lon.)
	COKU	KUO	Iran	53°E, 33°N
Convection	COFC	Grell-FC	Iran	53°E, 33°N
	COAS	Grell-As	Iran	53°E, 33°N
	COEM	Emanuel	Iran	53°E, 33°N
Center Domain	DOHY	Grell-FC	Himalaya	63°E,40°N
	DOMD	Grell-FC	Mediterranean	35°E, 35°N
	DOIN	Grell-FC	India	70°E, 25°N
	DOIR	Grell-FC	Iran	53°E, 33°N



a) Kuo b) Grell-FC

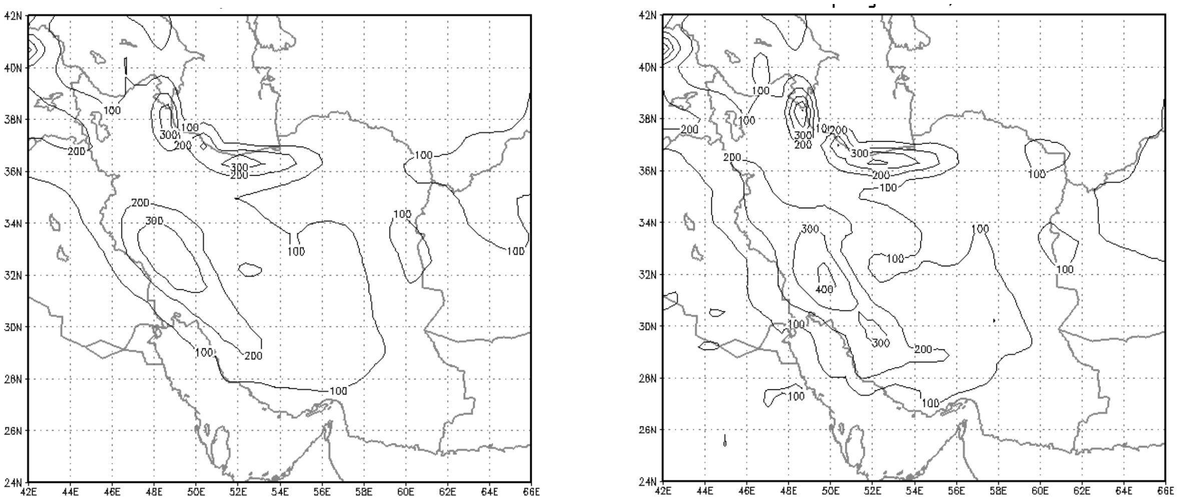


c) Grell-AS d) Emanuel

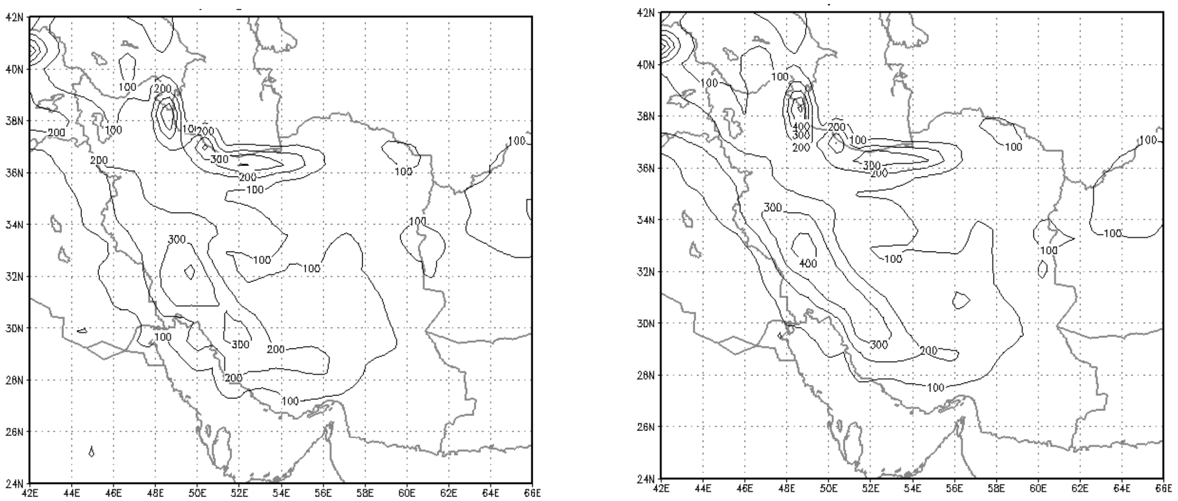
Figure 5. RegCM3 simulations for 1997 winter precipitation using different convection schemes.

Table 2. Bias and mean absolute error estimated for 1997 winter precipitation with domain center fixed over Iran

Experiment (1997- dry)		**No.**	Amount of precipitation (mm)							**Average**	**MAE**	**Bias**
			Southwest of Caspian Sea	**Northwest**	**West**	**Khuzestan**	Center	Northeast	Southeast			
Convection scheme	**Kuo**	**CU-1**	240	160	260	100	40	40	60	128.57	41.9	-92.85
	Grell-FC	**CU-2**	300	160	**200**	200	60	55	90	152.14	31.28	-69.28
	Grell-AS	**CU-3**	320	120	**220**	180	70	50	70	174.28	21.28	-47.14
	Emanuel	**CU-4**	340	180	240	140	60	70	100	161.42	27.09	-60
CRU			60	80	100	60	40	40	60	62.85	71.61	-158.57
Observation			240	800	300	80	40	40	50	221.42		



a) Kuo b) Grell-FC



c) Grell-AS d) Emanuel

Figure 6. Same as Figure 3 but for year 2000

Table 3. Bias and mean absolute error estimated for 2000 winter precipitation with domain center fixed over Iran

Experiment (2000-wet)		**No.**	Amount of precipitation (mm)							**Average**	**MAE**	**Bias**
			Southwest of Caspian Sea	**Northwest**	**West**	**Khuzestan**	Center	Northeast	Southeast			
Convection scheme	**Kuo**	**CU-1**	170	120	180	120	140	80	40	121.42	0.58	-0.72
	Grell-FC	**CU-2**	140	120	**190**	140	120	80	35	117.85	3.51	-4.29
	Grell-AS	**CU-3**	300	120	**200**	200	201	80	40	151.42	23.97	29.28
	Emanuel	**CU-4**	270	150	230	170	110	90	45	152.14	24.56	30
CRU			80	70	160	80	60	40	20	72.85	40.35	-49.29
Observation			250	60	240	140	50	60	55	122.14		

bias and MAE of 2000 winter precipitation. Grell-FC scheme has correctly modeled the precipitation of central parts of Iran. Kuo experiment has a minimum bias of -0.7 mm over the winter precipitation of 2000. Finally minimum average error for the two seasons under this study was found in Grell-FC scheme.

Domain center

In the experiments with different domain centers, the convection scheme used in the model is selected to be Grell-FC for studying the impact of the location of model domain center. Four different domain centers are chosen for the investigation of error inflow into the model domain, which are located over Iran, Mediterranean Sea, Himalaya and North-west of the Indian Ocean. In these experiments, there were no changes in the physical parameterization or computational schemes of the model. Results of the model runs are shown in Fig. 7 and 8.

In this experiment, it was found that when domain center is located over the Himalaya, the model is capable of simulating the 1997 and 2000 winter precipitation better as compared to other mentioned locations for domain center including Iran, Mediterranean Sea and Indian Ocean. Minimum error of -4.3 mm was found when using Iran as domain center for simulating the precipitation of winter 2000. Bias and MAE of winter precipitation of 1997 and 2000 are shown in Tables 4 and 5.

CONCLUSION

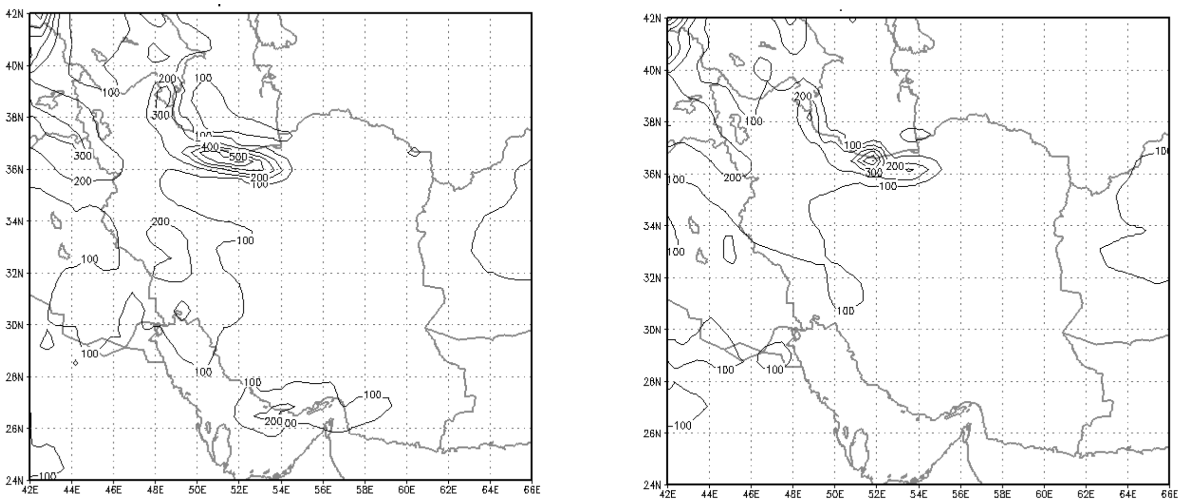
In this study the winter time precipitation of the years 1997 and 2000 called dry and wet winters was simulated using RegCM3 numerical climate model, and the results were compared with the corresponding CRU reanalysis data and observed precipitation in 151 synoptic stations over Iran. RegCM3 simulations have been done by different convective schemes and different locations for model domain center. Results show that there is a relationship between the model and the dominant synoptic patterns for the month of simulation such that, for a month with dominant Siberian high pressure over Iran, model results improve if the model domain center is located around the Siberian high pressure near north-east boundaries of Iran or near the Himalaya mountain range. In the case of Mediterranean low pressure, the domain center is better to be near the Mediterranean Sea. Other findings of this research are as follows:

- In all the experiments conducted for this work, precipitation pattern modeled by RegCM3 has an eastward shift over the Caspian Sea.
- In the experiments with different convection schemes, Grell-FC scheme has well modeled the precipitation of winter 1997 in the southern part of the Caspian Sea; however, it fails to model the precipitation of the southwestern part of Iran including Khuzestan and Ilam provinces.
- With Kuo and Emanuel schemes, the model is not successful in simulating the precipitation pattern over southwest and southeast of Iran, though Emanuel scheme have acceptable results over southeastern part of Iran,
- With Grell convection scheme, the model is capable of simulating winter precipitation over the coast line of the Caspian Sea.
- In the experiments with Kuo as the convection scheme the minimum bias for winter precipitation error during the year 2000 is -0.7 mm, though on average, with Grell-FC the error in both dry and wet seasons was at a minimum.
- With Himalaya as the location of the domain center, the model can simulate winter precipitation better as opposed to other locations of the model domain center, both in 1997 and 2000.

Finally for decreasing the errors, synoptic climatology of large-scale weather systems suggests that the

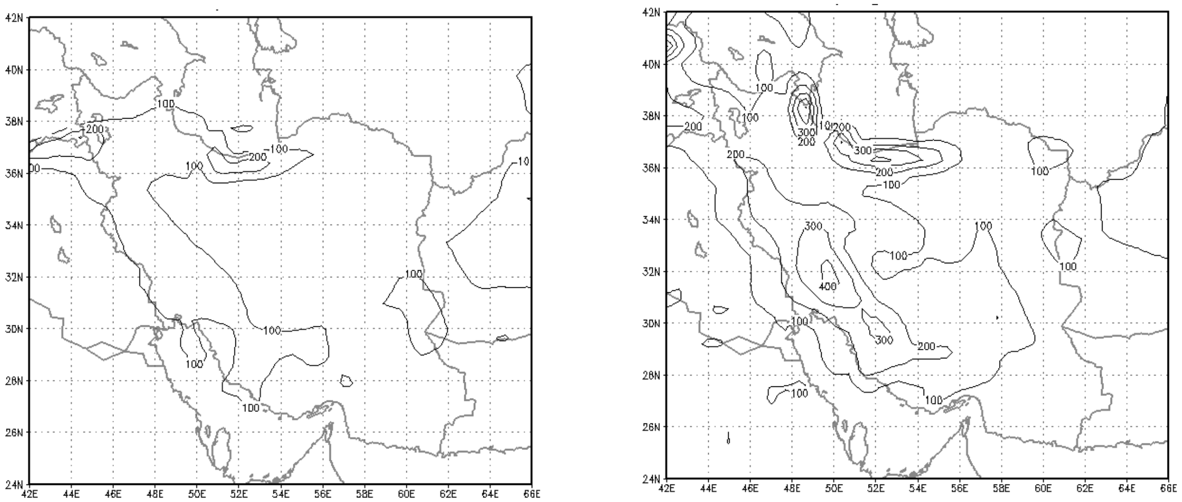
Table 4. Bias and MAE estimated for 1997 winter precipitation with different domain centers

Experiment (1997- dry)		**No.**	Amount of precipitation (mm)							**Average**	**MAE**	**Bias**
			Southwest of Caspian Sea	**Northwest**	**West**	**Khuzestan**	Center	Northeast	Southeast			
center domain	**Iran**	**Cen-1**	300	160	200	200	60	55	90	152.14	31.28	-69.28
	Mediterranean	**Cen-2**	280	120	**160**	160	50	60	60	135.71	38.7	-85.71
	Himalaya	**Cen-3**	160	160	**140**	130	60	35	55	105.71	52.25	-115.71
	Indian Ocean	**Cen-4**	260	120	200	80	30	40	40	110	50.32	-11.42
CRU			60	80	100	60	40	40	60	62.85	71.61	-158.57
Observation			240	800	300	80	40	40	50	221.42		



a) Mediterranean sea

b) Himalaya



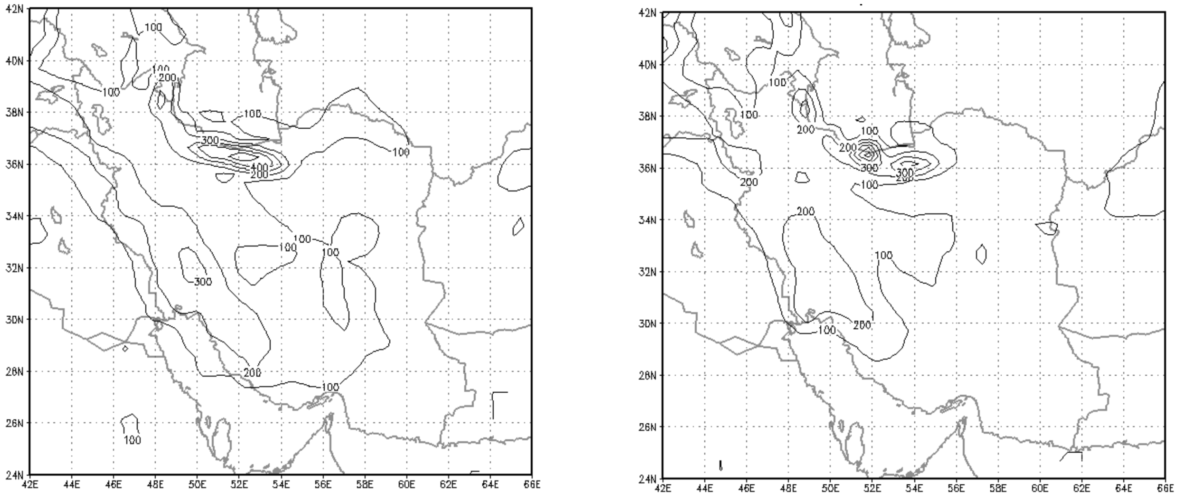
c) Indian Ocean

d) Iran

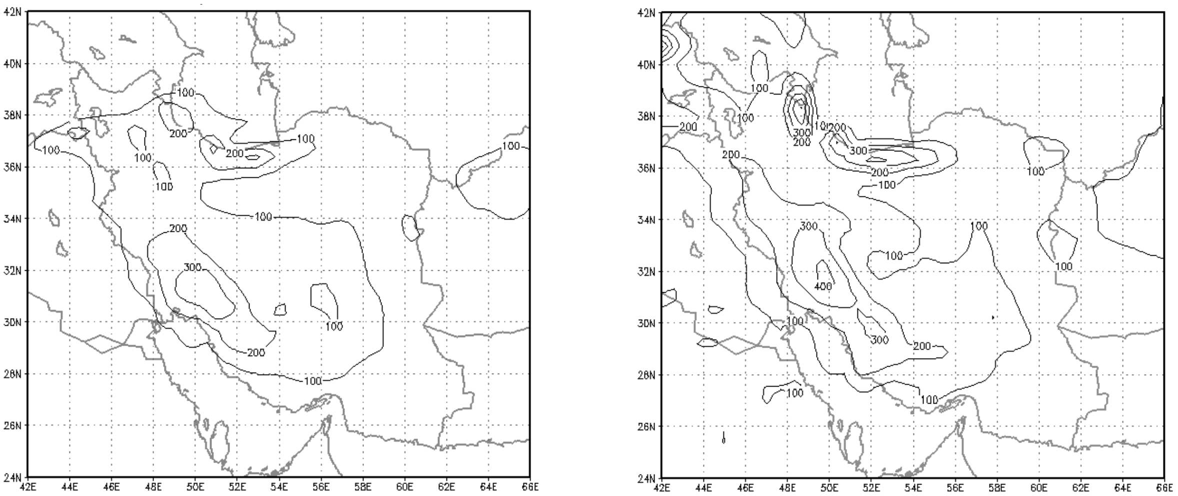
Figure 7. RegCM3 simulations for 1997 winter precipitation using different center of domain

Table 5. Bias and MAE estimated for 2000 winter precipitation with different domain centers

Experiment (2000- wet)		**No.**	Amount of precipitation (mm)							**Average**	**MAE**	**Bias**
			Southwest of Caspian Sea	**Northwest**	**West**	**Khuzestan**	Center	Northeast	Southeast			
center domain	**Iran**	**Cen-1**	140	120	190	140	120	80	35	117.85	3.51	-4.29
	Mediterranean	**Cen-2**	240	120	**210**	240	120	100	50	154.28	26.31	32.14
	Himalaya	**Cen-3**	200	120	**150**	180	130	80	40	128.57	5.26	6.34
	Indian Ocean	**Cen-4**	220	100	190	230	90	60	25	130.71	7.01	8.57
CRU			80	70	160	80	60	40	20	72.85	40.35	-49.29
Observation			250	60	240	140	50	60	55	122.14		



a) Mediterranean sea b) Himalaya



c) Indian Ocean d) Iran

Figure 8. Same as Fig 5, but for 2000

center domain must be near a dominant large-scale weather system. In this regard, in December and February, the center domain should be located near the northeast of Iran and the Mediterranean region, respectively.

ACKNOWLEDGMENT

This paper has been extracted from a project supported by Iranian Meteorological Organization and Climatological Research Institute entitled "Modeling 1997 and 2000 Winter Precipitation over Iran using RegCM3". We would like to thank Dr. M. Azadi for his valuable comments and insights.

REFERENCES

1. Ahmadi Givi, F., et.all, "Effect of mountains and land use on regional climate modelling of Iran: effect of BATS subgrid scale scheme on RegCM modeling", *proceeding of Iranian meeting on Numerical Weather Prediction*, Tehran, Iran, (2004).
2. Anthes, R. A., "A cumulus parameterization scheme utilizing a one-dimensional cloud model", *Monthly Weather Review*, **105**, PP 270–286(1977).
3. Azadi, M., Singh, G.P., "Impact of SST in RegCM on the spring Rainfall over Middle East", *ICTP Workshop on The Theory and use of Regional Climate Model*, Trieste, Italy, (2003).
4. Babaeian, I. et al, "Modeling of 1997 and 2000 winter simulations over Iran using RegCM3", *technical report of CRI*, PP 92-185(2005).

5. Badripour, H., “Country Pasture/Forage Resource Profiles”, *website http://www.fao.org/.*
6. Bates, G. T., Hostetler, S. W. Giorgi, F., “Two-Year Simulation of Great Lake Region with a Coupled Modeling System”, *Monthly Weather Review*, PP 1505-1522(1995).
7. Elguindi, N. et al., “RegCM Version 3.0 User’s Guide”, *Physics of Weather and Climate Group, International Center for Theoretical Physics*, (2003).
8. Emanuel, K. A., “A scheme for representing cumulus convection in large-scale models”, *J. Atmos. Sci.*, **48(**21**)**, PP 2313–2335(1991).
9. Emanuel, K. A., and M. Zivkovic-Rothman, “Development and evaluation of a convection scheme for use in climate models”, *J. Atmos. Sci.*, **56**, PP 1766–1782(1999).
10. Fransisco, R., “Regional Climate Modeling The Philippine Experience”, *ICTP Workshop on The Theory and use of Regional Climate Model*, Trieste, Italy, (2003).
11. Fritsch, J. M., and C. F. Chappell, “Numerical prediction of convectively driven mesoscale pressure systems. Part I: Convective parameterization”, *J. Atmos. Sci.*, **37**, PP 1722–1733(1980).
12. ICTP/RegCM3 Homepage: `http://www.ictp.trieste.it/~pubregcm/`, .
13. Giorgi, F., “Two-dimensional simulations of possible mesoscale effects of nuclear war fires”, *Journal of Geophysical Research*, PP 1127-1144(1989).
14. Giorgi, F., and G. T. Bates, “The climatological skill of a regional model over complex terrain”, *Monthly Weather Review*, **117**, PP 2325–2347(1989).
15. Giorgi, F., and M. R. Marinucci, “Validation of a regional atmospheric model over europe: Sensitivity of wintertime and summertime simulations to selected physics parameterizations and lower boundary conditions”, *Quart. J. Roy. Meteor. Soc.*, **117**, PP 1171–1206(1991).
16. Grell, G. A., J. Dudhia, and D. R. Stauffer, “Description of the fifth generation Penn State/NCAR Mesoscale Model (MM5)”, *Tech. Rep. TN-398+STR*, NCAR, Boulder, Colorado, PP 121(1994).
17. Grell, G., “Prognostic evaluation of assumptions used by cumulus parameterizations”, *Monthly Weather Review*, **121**, PP 764–787(1993).
18. Kwon, W.T, “Regional Climate Change Scenarios over East Asia”, *ICTP Workshop on The Theory and use of Regional Climate Model*, Trieste, Italy, (2003).
19. Wang, Y., Sen, O. L., Wang, B, “A Highly Resolved Regional Climate Model (IPRC-RegCM) and It’s Simulation of the 1998 Severe Precipitation Event over China Part I: Model Description and Verification of Simulation”, *Journal of Climate*, PP 1721-1738(2003).