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Quantitative Precipitation Forecast in the Caspian Sea/Alburz Mountain Region: MM5 Verification

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Abstract: This study presents verification of QPF of a Mesoscale Modelling system (Pennsylvania State University/NCAR Fifth generation MM5) in the region bounded by southern shores of Caspian Sea and northern slopes of the Alburz Mountains in Iran, against the selected observation site's rainfall data for the 59 day period on September and October 2004. The choice of MM5 parameterization schemes follows the results of a previous sensitivity test in the region. The MM5 forecasts of light and moderate precipitation thresholds are more accurate than the heavy precipitation threshold. Analysis of the bias scores shows that MM5 has a tendency to forecast higher number of rainy events in lower rain thresholds at the selected observation points. Equitable treat scores show that except for some isolated points in the light rain threshold the 9 km domain produces better forecasts than the 27 km domain. The nearest grid point approximation in most cases produced better precipitation forecasts than the Cressman weighted average interpolation.

Key words: Mesoscale, QPF, MM5, Caspian, Alburz, verification, bias, ETS

INTRODUCTION

This is the second paper in a series examining Pennsylvania State University-National Center for Atmospheric Research (PSU-NCAR) fifth-generation Mesoscale Modelling System (MM5) Quantitative Precipitation Forecasts (QPF) over the Caspian Sea/Alburz Mountains region in Southwest Asia. The first part of this series (Oskouian *et al*., unpublished data) examined two rainfall events at 7 September and 13 October 2004 by performing sensitivity tests of MM5 24 h forecasts against the raingauge data of Iranian Meteorological Organization (IMO) selected stations in the Caspian/Alburz region. According to findings of the first part a 3 domain 81, 27 and 9 km model with Anthes-Kuo, Grell and Kain-Fritsch cumulus parameterizations respectively and with warm rain explicit moisture scheme in the warm season and Reisner mixed-phase scheme in the cold season gives better predictions for the rainfall intensity at point locations. On the other hand performing a FDDA run and increasing the resolution to 3 km showed no clear advantage over the previous runs. We use the results of those sensitivity tests for verification of the 24 h MM5 forecasts in a 59 days period in the Caspian/Alburz region.

The PSU/NCAR MM5 is a limited-area nonhydrostatic model that uses a terrain-following vertical coordinate system (Dudhia, 1993; Grell *et al*., 1994). It has 2-way nesting capabilities and flexible physics options. We compiled version 3.6 using intel suite of compilers on a Redhat 9 Linux box using 3.6 GHz CPU and 1 MB RAM.

MM5 has been extensively used for case studies of mesoscale orographic rainfalls (Litta *et al*., 2007; Juneng *et al*., 2007; Chiao *et al*., 2004; Lin *et al*., 2001; Hayes *et al*., 2002; Lou *et al*., 2001; Paolucci *et al*., 1999; Chen *et al*., 1998), simulation of mesoscale convective systems (Zhang *et al*., 2000, 2003), investigation of topography effects on the formation and intensification of convective systems (Peng *et al*., 2001; Lin and Chen, 2002) and the verification of QPFs (Colle *et al*., 2000; Chien *et al*., 2002).

We defined three domains at the site with dimensions 81, 27 and 9 km, respectively (Fig. 1) and ran 24 h simulations of MM5 for the 23 vertical sigma levels in these domains and for two months of September and October 2004 initialized by NCEP Global Tropospheric Analysis 6 hourly 1×1 resolution dataset and using NCEP Real Time Global Sea Surface high resolution daily Temperatures.

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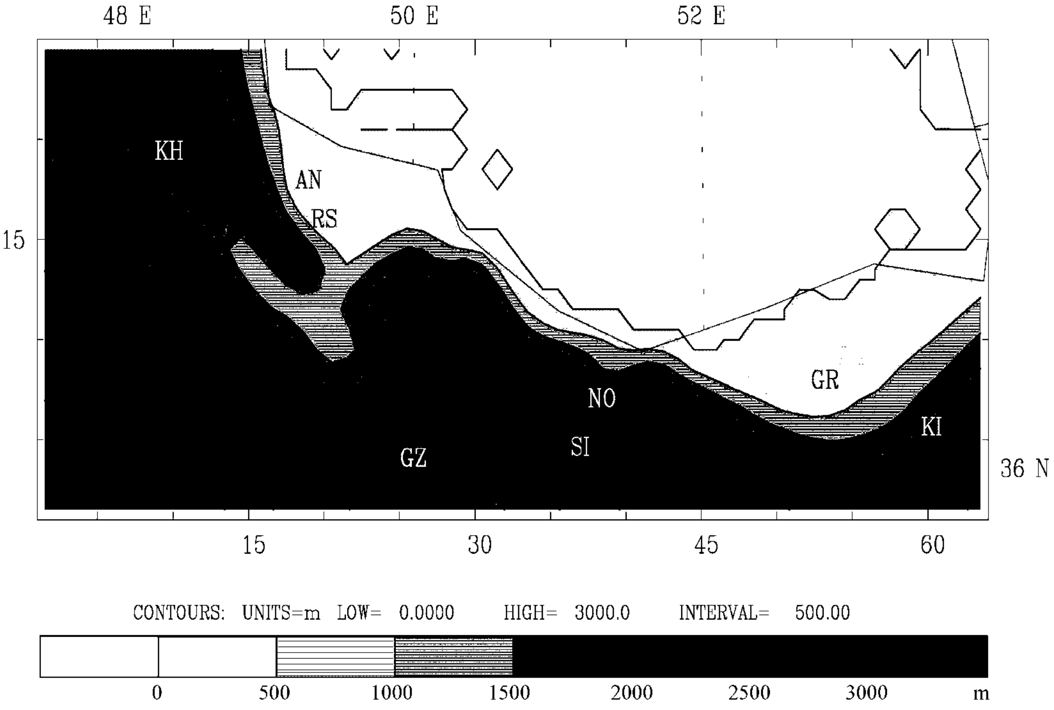

Fig. 1: The MM5 9 km domain over Caspian/Alburz region in Iran showing synoptic station locations and their approximate elevations. The selected stations (exact elevation in meters above mean sea level) are: ANzali (-26), NOeshahr (-21), RaSht (-7), GaRakhil (+15), KIasar (+1294), SIabisheh (+2165)

In this study MM5 was implemented with a) the MRF PBL parameterization scheme (Hong and Pan, 1996), b) the Rapid Radiative Transfer Model (RRTM) radiation scheme (Malwer *et al.*, 1997), c) the Warm Rain explicit moisture parameterization scheme for the September runs and the Reisner Mixed-Phase scheme (Reisner *et al.*, 1998) for the October runs and d) the following Cumulus Parameterizations: Anthes-Kuo scheme for 81 km domain, the Grell Cumulus scheme for the 27 km domain (Grell *et al.*, 1994), the Kain-Fritsch 2 scheme for the 9 km domain (Kain and Fritsch, 1993; Kain, 2002) according to the results presented in Oskouian *et al.* (unpublished data).

MATERIALS AND METHODS

Site description: The region in south west Asia roughly between 30°N to 45°N and 40°E to 60°E (Fig. 2) is the main area and the narrow strip between the Alburz mountain range and the Caspian Sea in Iran is the focus of this study. The Alburz range is an east-west wall of mountains with broad areas above 2500 m elevation and some isolated peaks reaching up to 5600 m. The Caspian Sea (technically a lake) extends from 36°N to 47°N (~1200 km) with an average width of 300 km and it's surface lies more than 20 m below mean sea level. We call this narrow coastal strip between the inland sea and the mountains here the Caspian/Alburz region. Moisture from the Caspian Sea and the orographic lift of the Alburz wall is considered a main factor to produce the highest rainfall rate in Iran for this region, creating a wet (1300-2000 mm/year) zone in the otherwise dry (~500 mm/year) plateau of Iran (Wikipedia, 2006). We used high temporal resolution rainfall data from selected synoptic stations (Fig. 2) in this area for the months September and October 2004 to verify the MM5 modelling system 24 h precipitation forecasts.

Methodology: As the observing network resolution in the Caspian/Alburz region is considerably lower than the model resolution (Fig. 2), we use an inverse distance Cressman method (Cressman, 1959; Stephens and Stitt, 1970) to interpolate the precipitation from the model grid to each observation site:

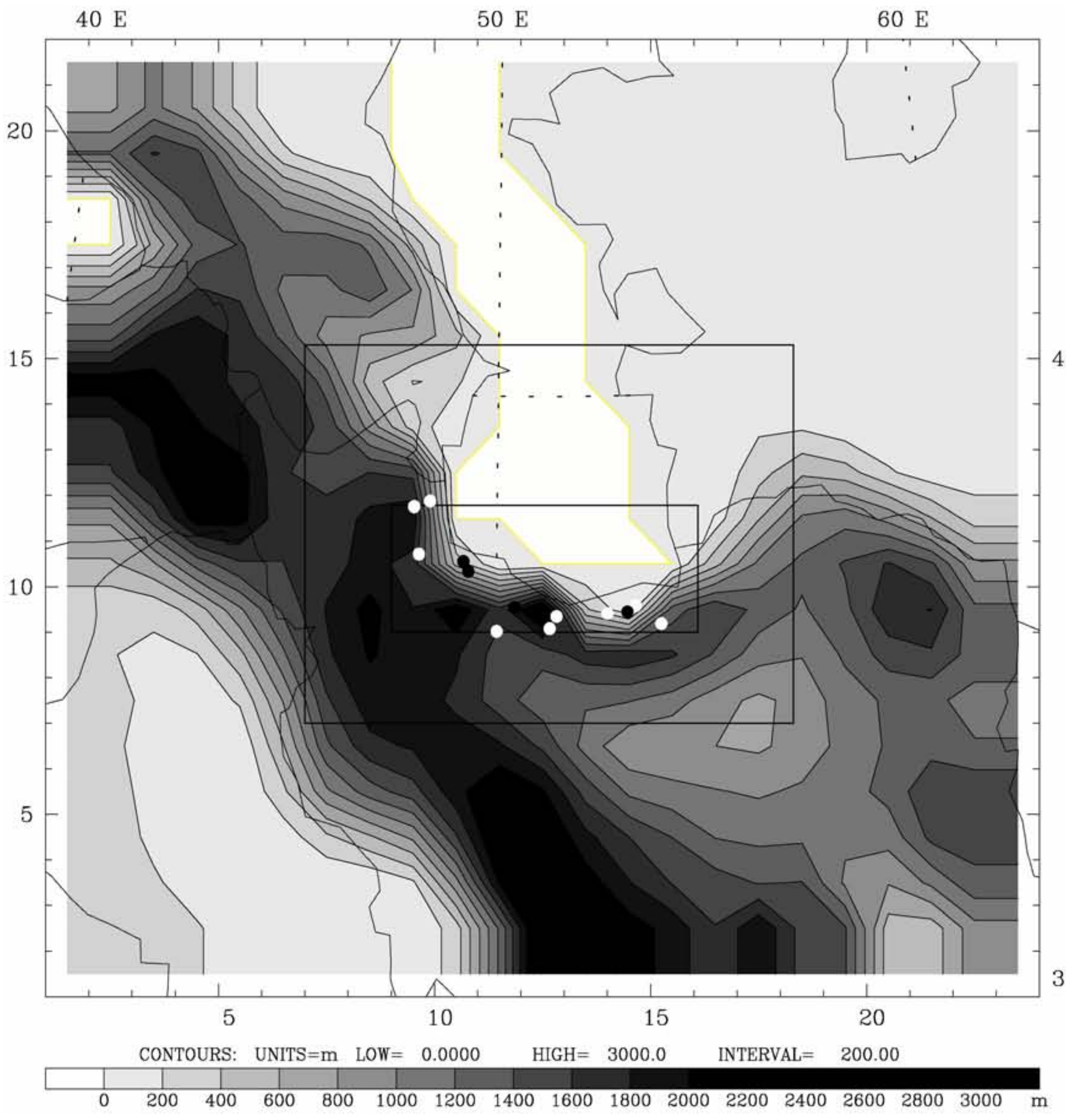

Fig. 2: The south west Asia region with three MM5 domains 81, 27, 9 km focusing on Caspian/Alburz region in Iran. Circles show synoptic stations of Iranian Meteorological Organization with available high temporal resolution rainfall data at the time of study

$$P = \frac{\sum W_n P_n}{\sum W_n}$$

where, P_n is the model precipitation at a number of adjacent grid points surrounding the observation. A parameter controls this number and depending on the location of observation inside the domain n is from 4 to 6. The weight W_n given to the surrounding grid point values is given by:

$$W_n = \frac{R^2 - D_n^2}{R^2 - D_n^2}$$

where, R is the model horizontal grid spacing and D is the horizontal distance from the model grid point to the observation. As a kind of smoothing of the model results in this approach is always expected, we also applied the nearest grid point value directly to the observation in the fine 9 km domain and in the figure legends labelled it n9 km in contrast to c9 km and 27 km for the Cressman values in the two respective domains.

We use contingency table approach following (Wilks, 1995). For a set of observations and dichotomous (yes/no) forecasts we may have a number of Hits (H), Misses (M), False Alarms (FA) and Correct Negatives (CN) and the sum of them all as Total (T) then a measure of Accuracy of the forecast is defined as:

$$\mathrm{Acc} = \frac{\mathrm{H + CN}}{\mathrm{T}}$$

Bias score measures the ratio of the frequency of forecasted to observed event and is defined as:

$$\mathrm{B} = \frac{\mathrm{H + FA}}{\mathrm{H + M}}$$

It reveals systematic over- (>1) or under- (<1) prediction by the model.

Equitable Treat Score measures the fraction of observed events that were correctly predicted, adjusted for the hits associated with random chance and is defined by:

$$\mathrm{ETS} = \frac{\mathrm{H - HR}}{\mathrm{H + M + FA - HR}}$$

where Random Hits (HR) is given by:

$$\mathrm{HR} = \frac{\mathrm{(H + M)\,(H + FA)}}{\mathrm{T}}$$

Heidke skill score measures the fraction of the correct forecasts after eliminating those forecasts which would be correct due purely to random chance and is defined by:

$$\mathrm{HSS} = \frac{\mathrm{(H + CN) - REC}}{\mathrm{T - REC}}$$

where Random Expected Correct is given by:

$$\mathrm{REC} = \frac{\mathrm{(H + M)\,(H + FA) + (CN + M)\,(CN + FA)}}{\mathrm{T}}$$

These scores are easily generalized for a multi-category forecast in which for instance the numerator of Bias score will be the number of forecasts at the observation stations with precipitation equal to or exceeding a given threshold amount and the denominator the number of occurrences in which the observations meet or exceed the threshold. In this study we setup a 4×4 contingency table with the categories being heavy (> 10 mm), moderate (>2.5 mm), light (>0.3 mm) and dry (<0.3 mm). Each MM5 run starts at 00.00 UTC and ends at 00.00 UTC of the next day. Rainfall accumulation period is 6 h and computed for lead times 12, 18 and 24.

RESULTS AND DISCUSSION

Figure 3 and 4 show bias scores for MM5 QPFs applied to observation sites mentioned in the titles using Cressman interpolation in the 27 km (27) and 9 km (c9) domains and nearest grid point method in 9 km (n9) domain for the September and October 2004 period. Accuracies for each domain and scheme are shown in the legends.

Figure 5 and 6 show equitable treat scores for MM5 QPFs applied to observation sites mentioned in the titles using Cressman interpolation (27 and c9) and nearest grid point (n9) for the same two months period. Heidke skill scores for each domain and scheme are shown in the legends. Six hours accumulated rain is computed for lead times shown in the titles of Fig. 3-6.

The exact numbers of all the scores of the figures are shown in the Table 1-6. Bias scores for the QPF lead times 12, 18 and 24 h are presented in Table 1-3, respectively. Equitable treat scores for the same QPF lead times are displayed in Table 4-6.

Accuracies: Figure 3f and c show more accurate n9 than c9 for Anzali and Siabisheh but Cressman method show more accurate in Gharakhil (Fig. 4d), Noeshahr (Fig. 4b) and Kiasar (Fig. 4e). This can be explained by existence of a more nearby grid point to the locations of Anzali and Siabisheh. All three schemes show drop in accuracy by increase in forecast lead times (Fig. 3, 4).

Bias scores

Light rain: Rainfall category 2 (0.3 to 2.5 mm) represents light rain. This category clearly over-predicted in almost all stations for all schemes (Fig. 3, 4) except unbiased n9 in Gharakhil (Fig. 4c, d). This over-prediction intensifies with lead time increase (Fig. 3). The n9 scheme exhibits weaker over-prediction in all stations (Fig. 3, 4) except in high-level Siabisheh which c9 have weakest over-prediction (Fig. 4f).

Moderate rain: Rainfall category 3 (2.5 to 10 mm) represents moderate rain. All three schemes show over-prediction in this category. Although n9 slightly reduces over-prediction but c9 and 27 schemes show more over-prediction with lead time (Fig. 3). We face slightly negative or slightly positive bias for all schemes in other stations (Fig. 4). This is the most unbiased category.

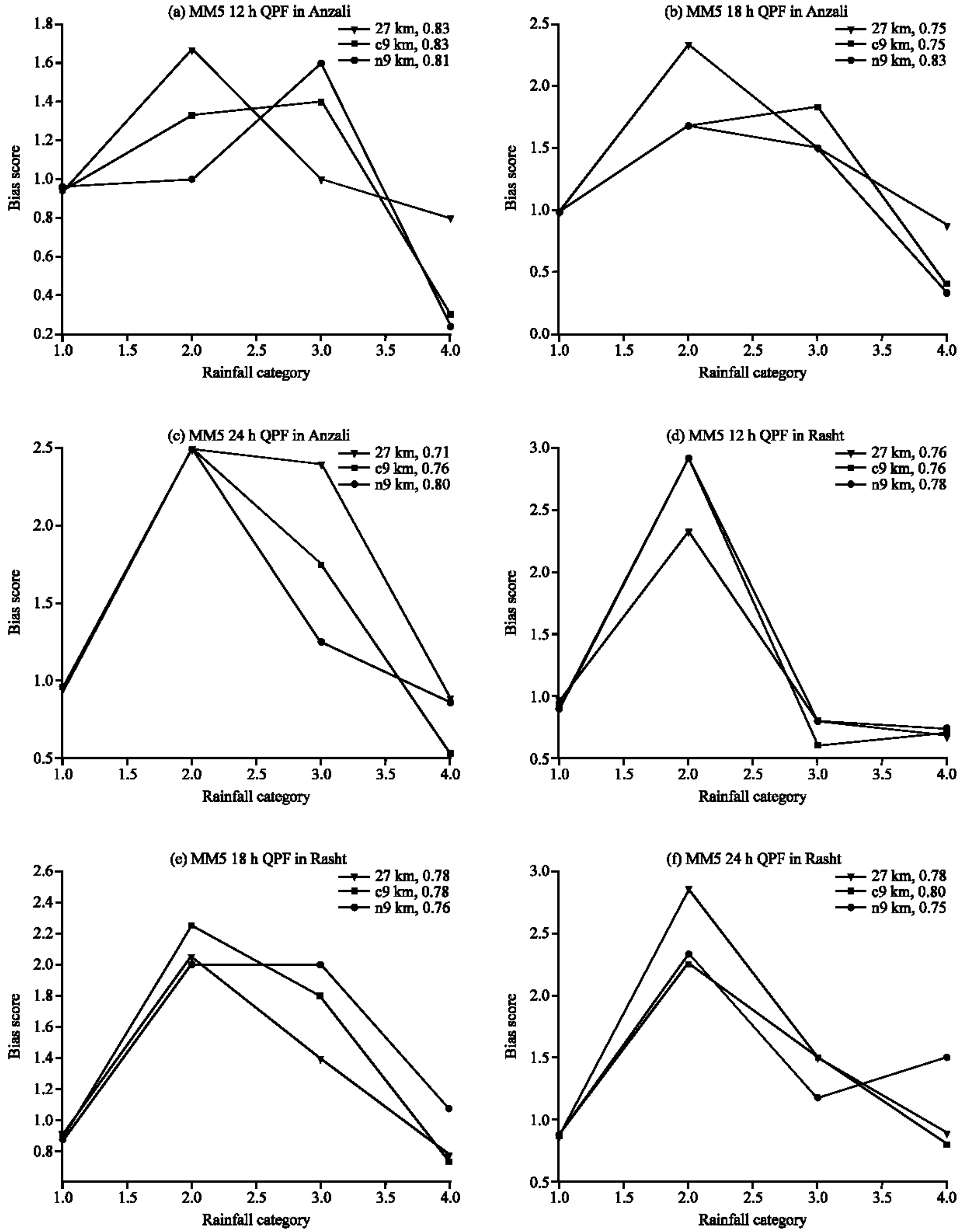

Fig. 3: Bias scores for MM5 QPFs applied to observation sites Anzali and Rasht using Cressman interpolation in the domains 27 and 9 km and nearest grid point method in 9 km domain for the September and October 2004 period. Six hour accumulated rain is computed for lead times shown on the titles. Accuracies are shown in the legends

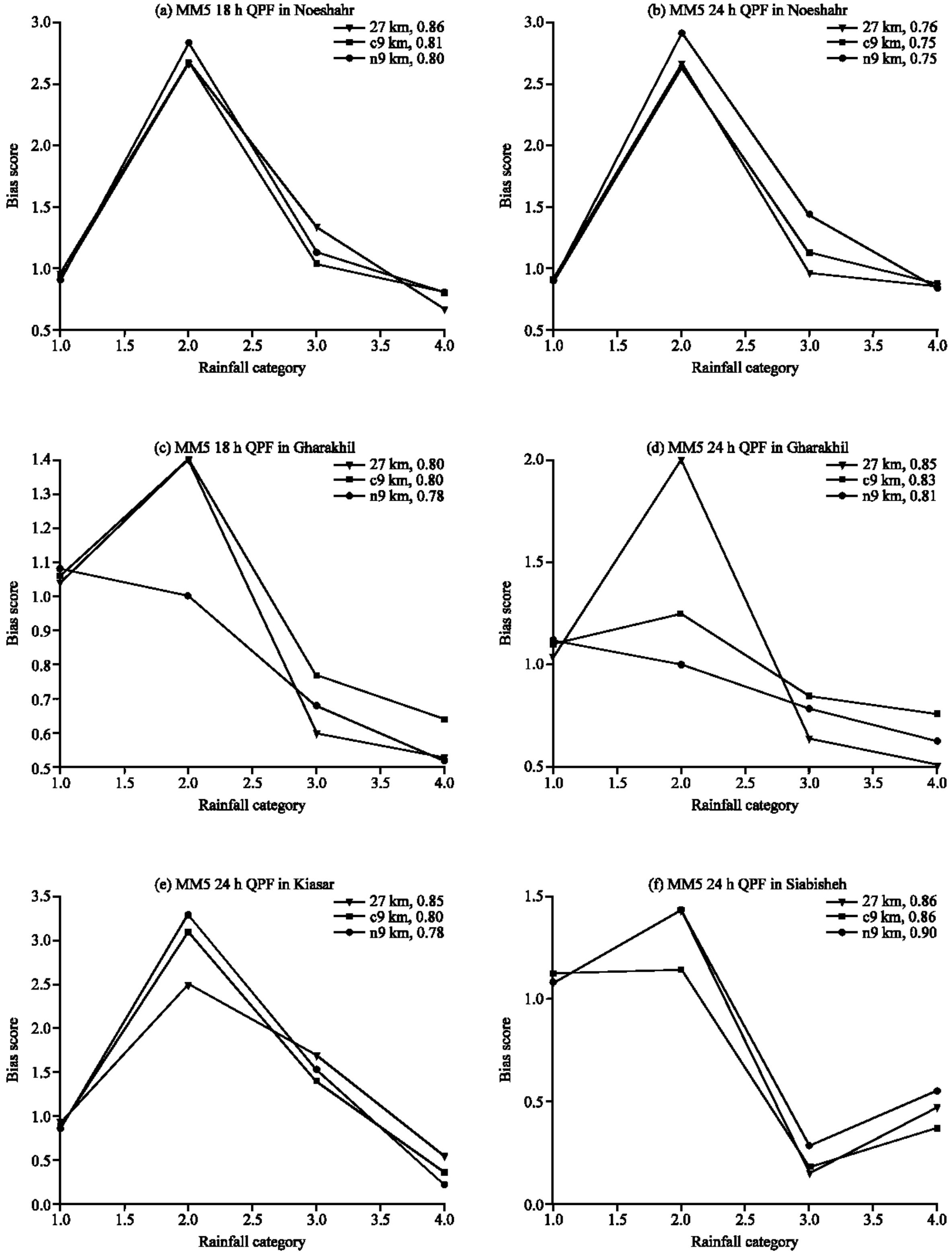

Fig. 4: Same as Fig. 3 but for other observation sites mentioned on the titles

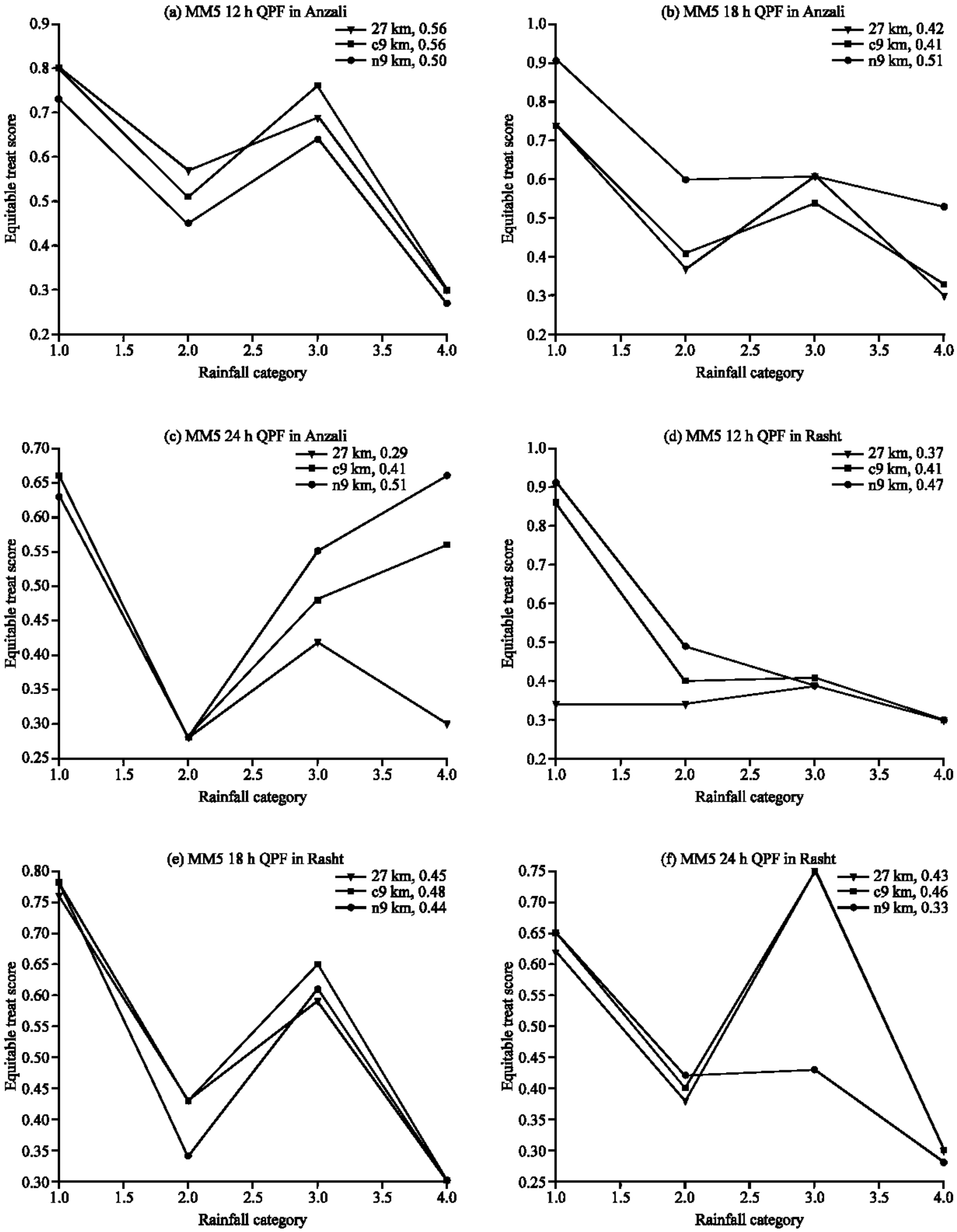

Fig. 5: Equitable treat scores for MM5 QPFs applied to observation sites Anzali and Rasht using Cressman interpolation in the domains 27 and 9 km and nearest grid point method in 9 km domain for the September and October 2004 period. Six hour accumulated rain is computed for lead times shown on the titles. Heidke skill scores are shown in the legends

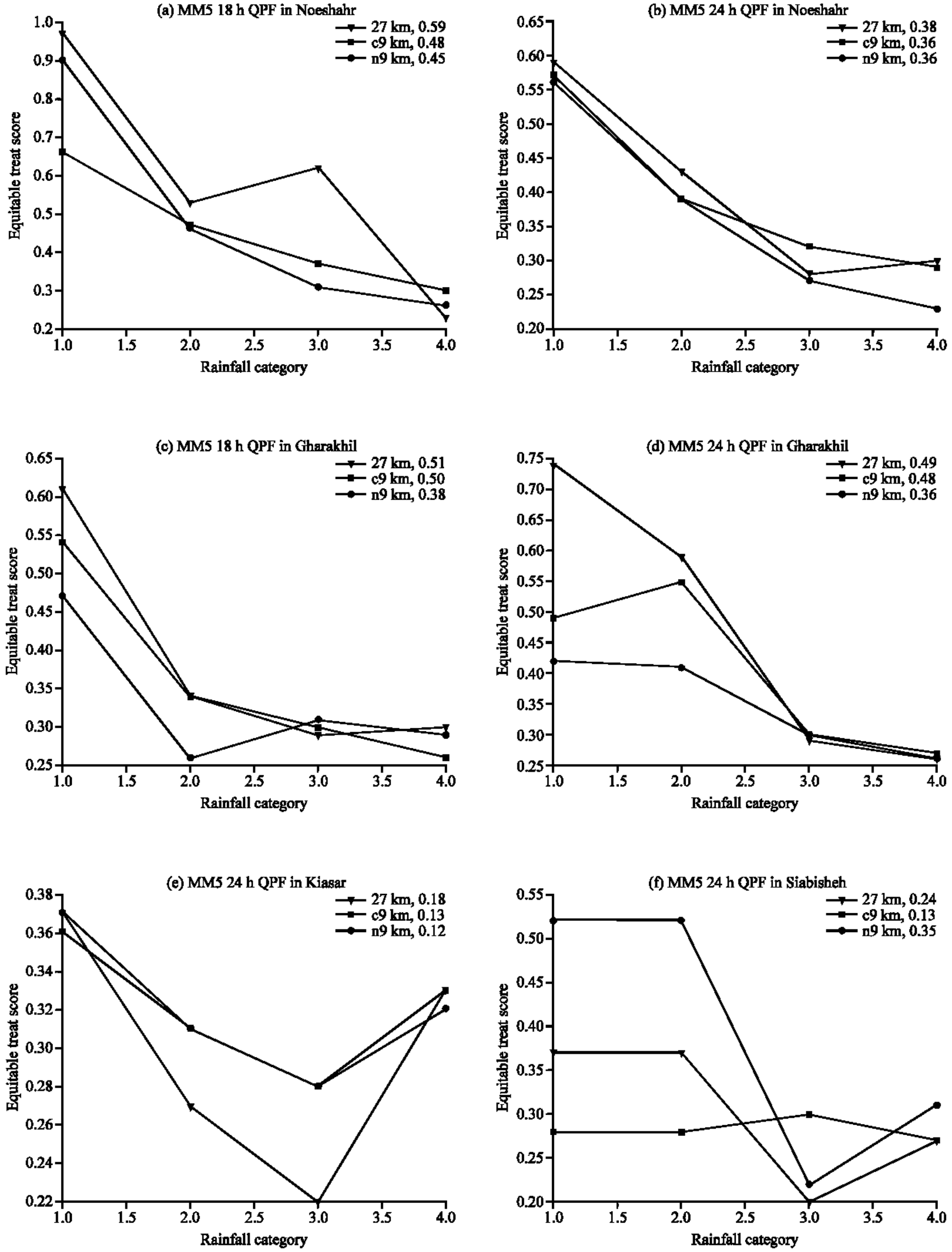

Fig. 6: Same as Fig. 5 but for other observation sites mentioned on the titles

Table 1: Twelve hours QPF Bias scores in rainfall categories dry, light, moderate and heavy and for different MM5 schemes in selected stations in Caspian-Alburz region

	Dry	Light	Mod	Heavy
Anzali				
27	0.94	1.67	1.00	0.80
c9	0.94	1.33	1.40	0.30
n9	0.96	1.00	1.60	0.24
Rasht				
27	0.96	2.33	0.80	0.67
c9	0.91	2.92	0.60	0.70
n9	0.89	2.92	0.80	0.73

Table 2: Eighteen hours QPF bias scores in rainfall categories dry, light, moderate and heavy and for different MM5 schemes in selected stations in Caspian-Alburz region

	Dry	Light	Mod	Heavy
Anzali				
27	0.98	2.33	1.50	0.87
c9	0.98	1.67	1.83	0.40
n9	0.98	1.67	1.50	0.33
Rasht				
27	0.91	2.05	1.40	0.77
c9	0.87	2.25	1.80	0.73
n9	0.87	2.00	2.00	1.07
Gharakhil				
27	1.04	1.40	0.60	0.53
c9	1.06	1.40	0.77	0.64
n9	1.08	1.00	0.68	0.52
Noeshahr				
27	0.96	2.67	1.33	0.67
c9	0.92	2.67	1.03	0.80
n9	0.90	2.83	1.13	0.80

Table 3: Twenty four hours QPF bias scores in rainfall categories dry, light, moderate and heavy and for different MM5 schemes in selected stations in Caspian-Alburz region

	Dry	Light	Mod	Heavy
Anzali				
27	0.96	2.50	2.40	0.89
c9	0.96	2.50	1.75	0.53
n9	0.93	2.50	1.25	0.86
Rasht				
27	0.86	2.85	1.50	0.89
c9	0.88	2.25	1.50	0.80
n9	0.88	2.33	1.17	1.50
Gharakhil				
27	1.04	2.00	0.64	0.51
c9	1.10	1.25	0.85	0.76
n9	1.12	1.00	0.79	0.63
Noeshahr				
27	0.92	2.67	0.97	0.85
c9	0.90	2.63	1.13	0.88
n9	0.90	2.92	1.44	0.84
Siabisheh				
27	1.08	1.43	0.15	0.47
c9	1.12	1.14	0.18	0.37
n9	1.08	1.43	0.28	0.55
Kiasar				
27	0.93	2.50	1.70	0.55
c9	0.88	3.10	1.40	0.36
n9	0.86	3.30	1.53	0.22

Table 4: Twelve hours QPF ETS scores in rainfall categories dry, light, moderate and heavy and for different MM5 schemes in selected stations in Caspian-Alburz region

	Dry	Light	Mod	Heavy
Anzali				
27	0.80	0.57	0.69	0.30
c9	0.80	0.51	0.76	0.30
n9	0.73	0.45	0.64	0.27
Rasht				
27	0.34	0.34	0.39	0.30
c9	0.86	0.40	0.41	0.30
n9	0.91	0.49	0.39	0.30

Table 5: Eighteen hours QPF ETS scores in rainfall categories dry, light, moderate and heavy and for different MM5 schemes in selected stations in Caspian-Alburz region

	Dry	Light	Mod	Heavy
Anzali				
27	0.74	0.37	0.61	0.30
c9	0.74	0.41	0.54	0.33
n9	0.91	0.60	0.61	0.53
Rasht				
27	0.76	0.43	0.59	0.30
c9	0.78	0.43	0.65	0.30
n9	0.78	0.34	0.61	0.30
Gharakhil				
27	0.61	0.34	0.29	0.30
c9	0.54	0.34	0.30	0.26
n9	0.47	0.26	0.31	0.29
Noeshahr				
27	0.97	0.53	0.62	0.23
c9	0.66	0.47	0.37	0.30
n9	0.90	0.46	0.31	0.26

Table 6: Twenty four hours QPF ETS scores in rainfall categories dry, light, moderate and heavy and for different MM5 schemes in selected stations in Caspian-Alburz region

	Dry	Light	Mod	Heavy
Anzali				
27	0.66	0.28	0.42	0.30
c9	0.66	0.28	0.48	0.56
n9	0.63	0.28	0.55	0.66
Rasht				
27	0.62	0.38	0.75	0.30
c9	0.65	0.40	0.75	0.30
n9	0.65	0.42	0.43	0.28
Gharakhil				
27	0.74	0.59	0.29	0.26
c9	0.49	0.55	0.30	0.27
n9	0.42	0.41	0.30	0.26
Noeshahr				
27	0.59	0.43	0.28	0.30
c9	0.57	0.39	0.32	0.29
n9	0.56	0.39	0.27	0.23
Siabisheh				
27	0.37	0.37	0.20	0.27
c9	0.28	0.28	0.30	0.27
n9	0.52	0.52	0.22	0.31
Kiasar				
27	0.37	0.27	0.22	0.33
c9	0.36	0.31	0.28	0.33
n9	0.37	0.31	0.28	0.32

Heavy rain: Rainfall category 4 (> 10 mm) represents heavy rain. This category is under-predicted at all lead times and for all schemes (Fig. 3, 4). It does not change with lead time in 27 km scheme (Fig. 3) but we experience weaker under-prediction (0.8 to 0.3 in n9) with lead time in c9 and n9 to the extent that in Rasht (Fig. 3d, e) we see the only over-prediction (1.4) in n9. High level stations like Siabisheh (Fig. 4f) show intense under-prediction of heavy rain.

Heidke skill scores: The Heidke skill score show a higher skill for n9 in Anzali (Fig. 5c) and Siabisheh (Fig. 6f) by the same reasoning mentioned in accuracy section. Cressman method gives similar higher skills for Rasht (Fig. 5f), Noeshahr (Fig. 6b) and Gharakhil (Fig. 6d). In Kiasar we have more skill for 27 km (Fig. 6d) which it's highly elevated (+1294 m) and steep slope mountainous location may explain this higher skill. All three schemes show decrease in Heidke skill score with increase in forecast lead time in Noeshahr (Fig. 6a, b) and Gharakhil (Fig. 6c, d) and a slight decrease in Rasht specially from 18-24 h (Fig. 5d-f) and decrease or no change in Anzali (Fig. 5c).

Equitable Treat Scores (ETS)

Light rain: Cressman method has higher ETS values for 27 km (Fig. 6b, d) and for c9 (Fig. 5c, f, e). n9 only dominates Cressman in the high-level station Siabisheh (Fig. 6f). ETS generally reduces with lead time increase (Fig. 5a-c).

Moderate rain: ETS reduces with lead time in most of the stations (Fig. 5a-c, 6a, b). Cressman method shows good performance in almost all stations except in Anzali (Fig. 5c). c9 generally gets higher ETS values (Fig. 6b, e, f).

Heavy rain: This category has clearly the lowest ETS values relative to moderate and light rain categories (Fig. 5, 6). ETS does not show considerable change with lead time except an increase with lead time in Anzali (Fig. 5a-c). n9 shows clear advantage over Cressman method in Anzali and Siabisheh (Fig. 5c, 6f) but c9 has slightly better performance in almost all other stations.

CONCLUSION

The bias scores are closer to one for higher rain thresholds so the model seems to forecast a higher number of rainy events than observed events for lower rain thresholds. The MM5 forecasts of light and moderate thresholds of precipitation are more accurate than the heavy thresholds. The 9 km domain generally produces better QPFs. However for light rain threshold in some stations 27 km gives better forecasts which may be explained by double penalty problem (Bougeault, 2003). In most cases the nearest grid point approximation produces better forecasts for isolated points than a weighted average interpolation like Cressman method.

This verification can be used as a background analysis for further verification of mesoscale models against higher resolution observations in the Caspian/Alburz region.

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