Precipitation processes in the Middle East

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Abstract: A regional climate model, RegCM2, is used to investigate the relative importance of storm tracks and topography in generating precipitation in the Middle East. The model is run for five years (1990 thru 1994) at 25km horizontal resolution forced at the boundaries by the ECMWF-TOGA analysis. Six sub-regions that exhibit precipitation regimes disparate from one-another are identified and examined. The models ability to reproduce these precipitation regimes was tested with mixed results. RegCM2 is better able to capture the scale of the interannual variability than the ECMWF analysis. In order to assess the hypothesis that precipitation is controlled by both storm-track location and the presence of topography, we performed multi-variate regressions between monthly precipitation and relevant indices. Results indicate that the storm track indices are best correlated with the seasonal cycle of precipitation. The topographic indicator is better correlated with precipitation anomalies suggesting that the number and intensity of storms is less important in explaining interannual variations than whether they produce upslope flow, i.e. the storm location.

Keywords: *Precipitation; Middle East; Regional Climate Modelling*

1. INTRODUCTION

While much of the Middle East region has a Mediterranean climate type, Csa in the widely used Koeppen classification (Oliver and Hidore, 1984) with wet winters and dry summers, the spatial gradients in climate are far sharper than in the broad prototype Csa region to the west. For example, along the 40N meridian, the northward transition from desert (BWh) through steppe (BSh) to cool highland climate (H) occurs within 400km. Elsewhere in the region, numerous coastlines and mountain ranges modify the local climates. The coasts of the Black and Caspian Seas in the north, the Mediterranean in the west and the Red Sea and Persian Gulf in the south, experience a reduced winter-summer temperature range due to maritime thermal inertia and, where winds are onshore, increased precipitation occurs. Orographic precipitation in the landlocked Taurus and Zagros mountains supplies the flow of the Euphrates and Tigris Rivers, which in turn supply the Mesopotamia region with needed water. The mountainous southern coasts of the Black and Caspian Sea, and eastern coast of the Mediterranean Sea, experience upslope seasonal precipitation. The Red Sea and Persian Gulf, while acting as powerful sources of water vapour, trigger little precipitation locally due to descending air in the Hadley cell. The interior steppe and deserts of Syria, Iraq, Jordan and Saudi Arabia, which would be dry anyway because of their latitudinal position, are made still dryer by the surrounding mountain ranges. This complex relationship between landscape and climate poses a challenge for climate modellers.

Here, we use a regional climate model developed at the National Center for Atmospheric Research (NCAR) USA, RegCM2, to numerically model the climate for the region. Model results are then analysed with a view to establishing the dominant controls over precipitation in various regions.

2. MODEL EXPERIMENT

RegCM2 (Giorgi, et al., 1993a & b) was implemented using a 25km grid centred at 35N 45E and covering a total area of almost 8,000,000 km^2. The model time step was 90 seconds. The topography and land use are interpolated to the model grid points from a global 10-minute dataset. The initial and boundary conditions are extracted from the ECMWF TOGA analysis (ECMWF, 2001), covering 5 years beginning in January 1990.

Since the region in question is quite complex with many climate zones and precipitation regimes present, we have divided the domain into subregions for further analysis (Figure 1). These regions consist of the southeast Black sea coast, the south-west Caspian sea coast, the eastern Mediterranean coast, eastern part of the Fertile Crescent (essentially the headwaters of the Tigris river), the southern Zagros Mountains and the

Saudi desert. Each of these areas demonstrate substantial climatological differences and thus provide quite a strong test of the regional models abilities.

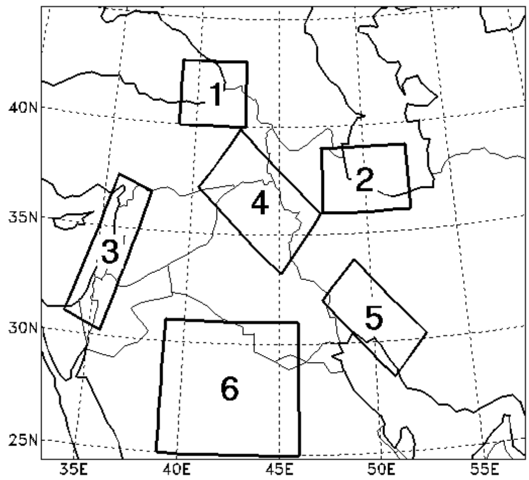

Figure 1: Study domain showing the focus subregions. 1. South-East Black Sea coast, 2. South-West Caspian Sea coast, 3. Eastern Mediterranean coast, 4. Fertile Crescent (headwaters of Tigris river), 5. Zagros Mountains and 6. Saudi desert.

3. ANNUAL CYCLE OF PRECIPITATION

Annual cycles of precipitation for each subregion are shown in Figure 2. Both models are able to reproduce the cycles for the fertile crescent and Zagros mountains quite well though the winter maximum in the Zagros mountains is overestimated. The models do not successfully simulate the observed precipitation cycles in the Black and Caspian sea zones. While the annual precipitation totals are in reasonable agreement with observations, the timing of the maximum precipitation is as much as six months out of phase. Clearly much of this timing problem is passed on to RegCM2 from the ECMWF lateral boundary conditions. RegCM2's precipitation timing in the Black Sea region follows that of ECMWF quite closely while reducing the magnitude of the maximums predicted by the ECMWF model. The Caspian Sea coast is somewhat more complicated with RegCM2 following the ECMWF model closely in autumn and winter but deviating substantially in spring and summer. This spring/summer overestimation by RegCM2 is due to the production of mountain waves as the westerly wind blows off the mountain plateau down to the Caspian Sea. These mountain waves cause ascending air aloft while the near surface air is descending. This causes cloud and rain formation aloft, and this rain must then pass through a drier descending air mass before reaching the ground. The vast majority, if not all, of this rain would evaporate before reaching the surface. In RegCM2 however this evaporative process is not modelled and the rain does reach the ground.

RegCM2 simulates the summer minimum but fails to simulate the large winter precipitation maximum observed along the eastern Mediterranean coast. This lack of winter precipitation is related to the lack of coastal mountains which trigger the precipitation. This coastal mountain range extends almost the entire length of the eastern Mediterranean coast with peaks well over a kilometre in height. Except for the Lebanon area, the range is little more than 25km wide. Not wide enough to be resolved by RegCM2 run with a 25km spacing but large enough to cause a significant climatological divide, wet to the west of the range, dry to the east. Here model resolution, in particular the lack of resolved topography, is a primary impediment to model performance. The ECMWF model topography contains broad elevated terrain along the entire length of the Eastern Mediterranean coast. This terrain captures neither the low coastal zone nor the narrow mountain ranges however it does allow the ECMWF model to capture this winter maximum despite it predicting only half the precipitation observed in the early part of the year.

Over the Saudi desert RegCM2 significantly overestimates the precipitation in spring and autumn. The observational network is particularly sparse in this region and hence is likely to miss precipitation from convective systems with limited spatial extent. RegCM2 simulates convective precipitation maxima in April and October when enough energy is present to trigger local convection but before the descending arm of the Hadley cell begins to dominate the area in summer. While it seems unlikely that such a sparse observational network would capture the precipitation in a convectively dominated system, it appears that much of RegCM2's overestimation is due to the model ignoring the evaporation of rain as it falls. These convective storms appear in a region where relative humidity is usually less than 40% and hence a significant proportion of the falling rain would evaporate.

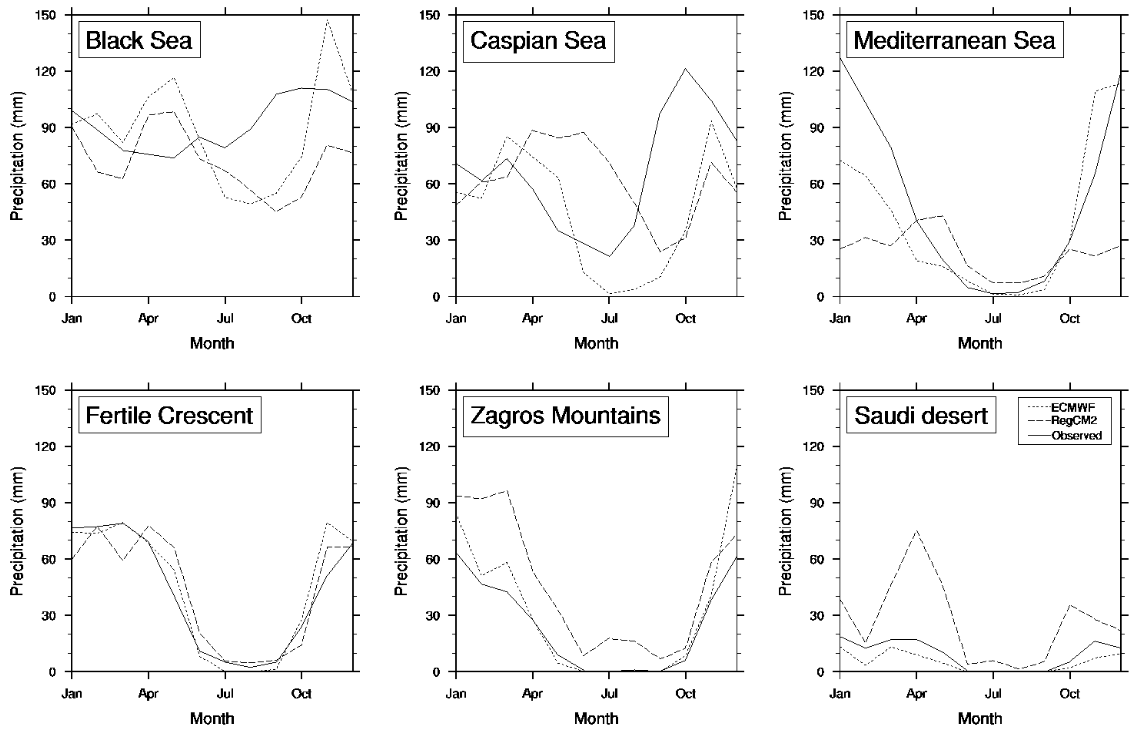

Figure 2: Monthly averaged precipitation for each subregion. Observations are from the FAO dataset.

4. INTERANNUAL VARIABILITY OF PRECIPITATION

The magnitude of interannual variability simulated by the models and present in the CPC observations is shown in Figure 3. Mean values of the seasonal precipitation are also shown. Much of the interannual variability in the RegCM2 simulation is passed in through the boundary conditions as large scale forcing from the ECMWF model. Significant differences in interannual variability between the models demonstrate the impact of the regional effects modelled by RegCM2. Over the entire domain the ECMWF model simulates twice as much interannual variability in winter and spring than is present in the CPC observations. RegCM2 is better able to capture this variability in all seasons except summer when it underestimates this interannual variability despite overestimating the mean.

In the Black Sea region both models generally underestimate the standard deviation with neither model able to capture the seasonal cycle in variability. In the Caspian Sea region the ECMWF model tends to overestimate while RegCM2 tends to underestimate the variability. A similar situation exists in the Mediterranean Sea region though here RegCM2 significantly underestimates the variability in winter when the lack of a coastal mountain range causes a severe underestimation of precipitation.

The remaining three regions contain very sparse observational networks so that significant uncertainty is associated with the observations themselves. In the Fertile Crescent region, both models tend to overestimate the variability in winter. RegCM2 is able to capture the scale of variability through the rest of the year while the ECMWF model significantly overestimates in spring and autumn as well. In the Zagros mountains region, both models tend to overestimate the variability though the correct seasonal cycle is present. In the Saudi desert region the ECMWF model tends to underestimate the variability, particularly in the spring and autumn while RegCM2 is better able to capture the magnitude of variability through the seasons.

5. MONTHLY INDICATORS

Here we test the extent to which storm track location and topography explain the modelled precipitation. To identify the location of storm tracks two proxies are defined on a monthly basis. The first is simply the standard deviation of the daily 500hPa geopotential height (*sdgp*), the second is the standard deviation of the daily

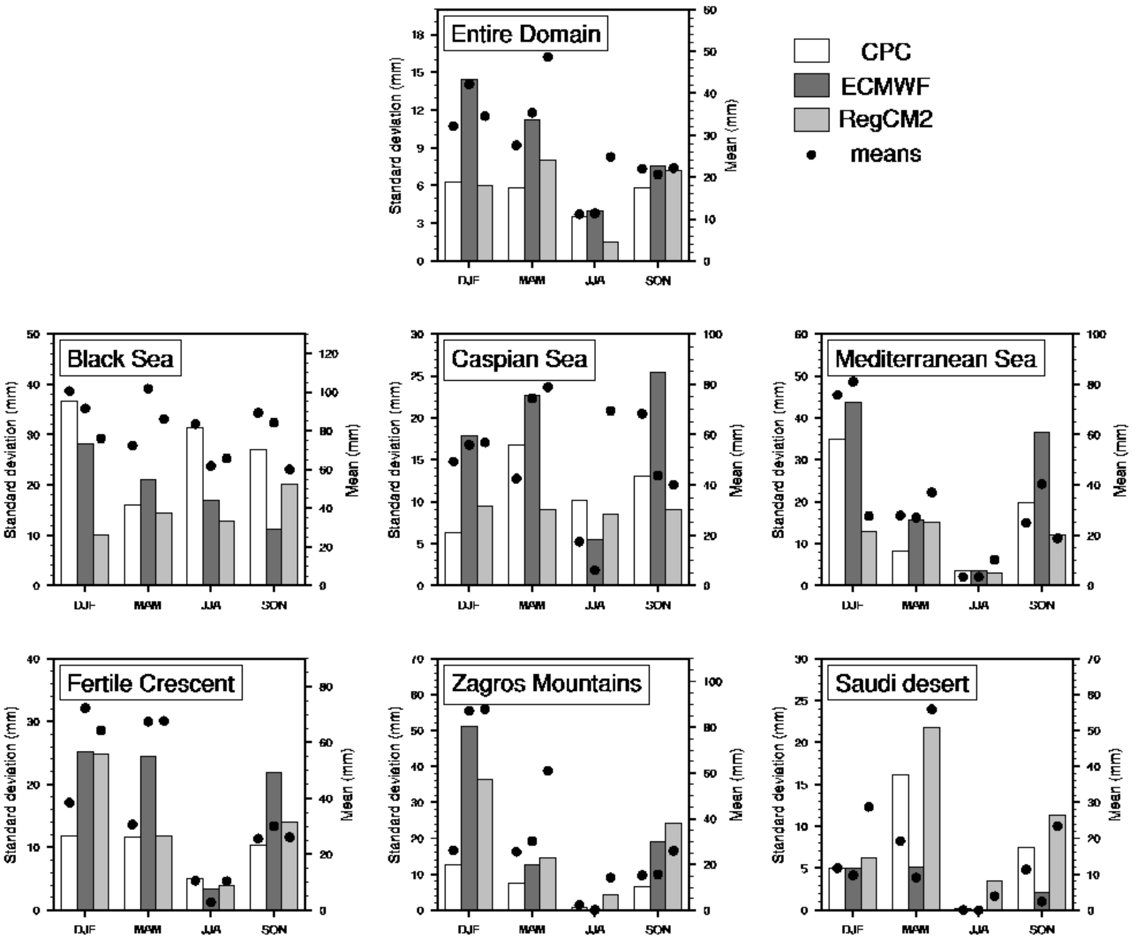

Figure 3: Standard deviation and mean of the seasonal precipitation associated with interannual variations for 1990 thru 1994.

500hPa kinetic energy (*sdke*). The kinetic energy present is obtained through the magnitude of the horizontal wind field (KE = ½ mv^2) and its standard deviation is also known as the eddy kinetic energy. To identify the influence of topography we define a topographic index, ψ, as

$$\psi = \vec{\phi}_{wv}.\nabla h \qquad (1)$$

where $\vec{\phi}_{wv}$ is the flux of water vapour and h is the topographic elevation. This index then provides a measure of the flux of water vapour moving upslope. All indicators are calculated as a mean value for the specified region.

Table 1 presents the correlations between monthly precipitation and the storm track and topographic indicators averaged over the entire domain as well as the focus subregions defined earlier. Over the entire domain, similar correlations are obtained between each of the three indicators and precipitation however, when focusing on the subregions the correlations can change substantially. The correlations associated with the two storm track indicators are quite similar in all subregions except the Saudi desert where sdgp produces a much better correlation than the sdke. ψ actually produces negative correlations in the Caspian Sea and Saudi desert regions indicating that precipitation occurs despite the monthly mean water vapour flux being down-slope. This indicates the importance of events occurring on a much shorter time scale than monthly when investigating precipitation phenomena and hence a limitation in the utility of these monthly mean indicators. Nevertheless relatively high correlations exist for all three indicators for the Fertile Crescent and Zagros Mountains regions. It should be noted that the storm track indices display strong seasonal cycles, as does the precipitation in most subregions. Thus high correlations in Table 1 indicate, to a large extent, similar seasonal cycles. This precludes a simple cause and effect relationship from being inferred as other seasonally varying variables may be involved.

By calculating anomalies from the monthly climatology of each variable the seasonal cycle is removed and the degree to which these indicator anomalies can explain the interannual variations can be tested. Table 2 presents the correlation between monthly precipitation anomalies and indicator anomalies. Over the entire domain, ψ has a much higher correlation than either of the storm track indices. This implies that the number and strength of storms explains less of the interannual variability than their particular orientation, i.e. whether or not they produce upslope flow.

In order to find the combination of indicators that produces the best predictor of monthly precipitation anomalies a multi-variable stepwise linear regression with a 0.05 significance cut-off was performed for each region. The resulting best model can be found in Table 3 along with the corresponding correlation coefficient. Over the entire domain precipitation anomalies can best be predicted using ψ, while neither storm track indicator provides a significant contribution to this interannual variability.

Table 1: Correlation between monthly precipitation (1990 thru 1994) and storm track and topographic indicators.

Region	*sdgp*	*sdke*	ψ
Entire domain	0.60	0.49	0.54
Black Sea	0.30	0.26	0.24
Caspian Sea	0.28	0.20	-0.34
Mediterranean Sea	0.48	0.41	0.21
Fertile Crescent	0.74	0.70	0.59
Zagros Mountains	0.65	0.75	0.74
Saudi Desert	0.52	0.35	-0.65

Table 2: Correlation between monthly precipitation anomaly (1990 thru 1994) and storm track and topographic indicator anomalies.

Region	*sdgp*	*sdke*	ψ
Entire domain	0.29	0.19	0.49
Black Sea	0.18	0.16	0.21
Caspian Sea	0.18	-0.02	0.00
Mediterranean Sea	0.18	-0.08	0.12
Fertile Crescent	0.27	-0.04	0.37
Zagros Mountains	0.14	0.35	0.60
Saudi Desert	0.21	-0.08	-0.30

While they are able to explain much of the seasonal cycle in precipitation, none of these indicators is able to significantly explain any of the interannual variance in the Black Sea, Caspian Sea and Mediterranean Sea subregions.

In the Fertile Crescent subregion both *sdgp* and ψ were found to be significant predictors of precipitation anomaly. This suggests that the interannual variability is sensitive to the number and strength of low pressure systems as well as to whether they produce upslope flow.

Over the Zagros Mountains subregion only ψ is a significant predictor. Here the number and intensity of storm tracks is less important than whether they drive upslope flow.

In the Saudi desert only the topographic index is significant. Since the topography here is fairly benign, and much of the precipitation is convective in nature, minimal topographic influence is expected. Here it seems that ψ is acting more as a proxy for season through the presence of water vapour and wind rather then of upslope flow.

Table 3: The best multi-variable linear regression model between monthly precipitation anomalies and the three indicator anomalies determined using stepwise selection with a 0.05 significance cut-off, and the models associated correlation coefficient.

Region	*Best model*	*r*
Entire domain	$0.09 + 530.98\psi$	0.49
Black Sea	-	-
Caspian Sea	-	-
Mediterranean Sea	-	-
Fertile Crescent	$-1.31 + 0.40 sdgp + 126.54\psi$	0.45
Zagros Mountains	$-2.83 + 98.30\psi$	0.60
Saudi desert	$-1.00 – 150.61\psi$	0.30

6. CONCLUSIONS

In this paper a regional climate model, RegCM2, was used to investigate potential precipitation drivers in several subregions of the Middle East. The competing precipitation drivers used represent storm track (standard deviation of the daily 500hPa geopotential height (*sdgp*), and the standard deviation of the daily 500hPa kinetic energy (*sdke*)) and topographic (i.e. upslope flow of water vapour) influences.

On a monthly basis the precipitation time series tends to have a strong seasonal cycle. The storm track indices also have strong seasonal cycles hence correlate best with the precipitation time series. That is, much of the annual cycle can be attributed to the annual cycle in storm tracks.

Focusing on interannual variability (anomalies) reveals a significantly more important role for the topography in causing upslope flow of water vapour. While this orographically driven precipitation is less important than the storm tracks in explaining the annual cycle, it is more important in explaining the interannual variability in some subregions.

7. ACKNOWLEDGEMENTS

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