Modeling the Climate of South West Asia

J.P Evans and R.B. Smith

Department of Geology and Geophysics, Yale University, USA.
(jason.evans@yale.edu)

Abstract The performance of a regional climate model (RegCM2) is examined for a region of southwest Asia including Syria, Iraq, Lebanon, Israel, Jordan and southeastern Turkey. Model output is verified against climatological monthly precipitation and temperature surfaces created by interpolating FAO/WMO station data using a CRESSMAN technique with a variable radius of influence, and snow cover extent in the Zagros and Tauros mountains as determined using 13 years of AVHRR composite data. The model performs well in terms of temperature but relatively poorly in terms of precipitation. The model is particularly sensitive to the presence (or absence) of a very narrow mountain range along the Mediterranean coast. It also tends to overestimate the snow cover extent in the mountains.

Key Words: regional climate, Middle East, RegCM2, modelling.

1 INTRODUCTION

South-West Asia (or the Middle-East), shown in Figure 1, is a relatively data sparse region of the world however it is interesting for several reasons. It is a region marked by political conflict. Rapid population growth and water scarcity are common throughout the area, rendering it sensitive to changes in climate. This emphasizes the importance of good meteorological and climatic knowledge to the region.

The region is interesting both meteorologically and climatically being a predominantly semi-arid to arid region surrounded by the Black and Caspian Seas in the north, the Mediterranean in the West and the Red Sea and Persian Gulf in the south, and crossed by the impressive Tauros and Zagros mountains. It includes the archeologically important *Fertile Crescent*, the birthplace of agriculture and civilization. This change from fertile then, to (semi-)arid now poses an interesting question about the paleo-climate evolution of the region, and the link between this evolution and the vegetation of the area.

This work occurs within the auspices of a larger project, the South-West Asia Project (SWAP), who's eventual aim it is to address various paleo-climatic and agricultural questions.

The sparsity of atmospheric data is accompanied by a corresponding sparsity in the meteorological and climatic literature. A general description of Near East climate is given by Taha et al. [1981]. Analysis of natural vegetation and climate can be found in Nahal [1981] and Zohary [1973], while various aspects of the regions meteorology have been studied in Eshel and Farrell [2000]; Eshel and Farrell [2001]; Reddaway and Bigg [1996]; Rodwell and Hoskins [1996]; Saaroni and Ziv [2000].

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. Given adequate reproduction of present climate by the model it will then be used, in conjunction with some paleo-climate GCM runs made using CCM3, to investigate the evolution of the paleo-climate and it's influence on the rise of agriculture and civilization.

In section 2 data sets with which to test the model are developed from ground and satellite based observational platforms. Section 3 provides a model description while section 4 specifies the experimental setup. The models performance is compared to the observational datasets in section 5 and this is followed by conclusions and future work.

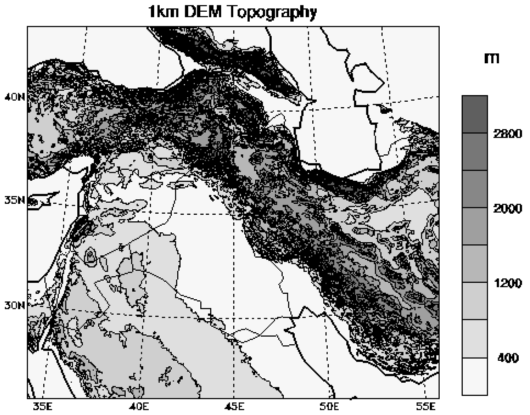

Figure 1: Topography of Southwest Asia.

2 OBSERVATIONS

The study area is shown in Figure 1, along with terrain height and country boundaries. The relative sparsity of these stations is clear. Data from these stations was used to create monthly temperature and precipitation climatologies. This data is interpolated to a 5km grid. In order to account for the large changes in inter-station distances a CRESSMAN technique using a variable radius of interest was used. The interpolation scheme includes a -5°*C/km* temperature lapse rate correction but no corresponding correction to precipitation. The spatial and seasonal distribution of precipitation shows a strong increase of precipitation northward and outward from the deserts of Saudi Arabia, eastern Jordan, western Iraq and southeastern Syria, toward the mountains and the Mediterranean and Caspian Seas.

Mountain snow plays a significant role in water storage and release making it a relevant basis for detecting the influence of interannual climate fluctuations. Using 13-years of 8*km* AVHRR composites, the monthly snow cover was determined based on a combination of the reflectance of visible radiation (channel #1) and the emission of thermal infrared radiation (channel #2). This data shows that the snow cover changes considerably from year to year. In 1985 the maximum snow cover was only 180,000 km^2 while in 1993 the snow cover reached 330,000 km^2.

3 MODEL DESCRIPTION

The second generation NCAR Regional climate model (RegCM2) is based on the National Center for Atmospheric Research-Pennsylvania State University Mesoscale Model version MM4, an atmospheric circulation model. Several of the MM4's physics parameterizations were modified to adapt it to long-term climate simulations. Key modifications include detailed representations of radiative transfer [Briegleb, 1992], surface physics-soil hydrology processes [Dickinson et al., 1993], the model planetary boundary layer [Holtslag et al., 1990] and convective precipitation schemes [Giorgi, 1991]. Much of the development of RegCM2 can be found in Giorgi et al. [1993a,b].

The dynamical component of RegCM2 is essentially the same as that of the standard MM4 [Anthes et al., 1987, Anthes and Warner, 1978]. The MM4 is a hydrostatic, compressible, primitive equation, terrain following σ vertical coordinate model, where $\sigma = (p - p_{top}) / (p_s - p_{top})$, p is pressure, p_{top} is the pressure specified to be the model top, and p_s is the prognostic surface pressure. RegCM2 has been used in many climate studies [Bates et al., 1995, Giorgi et al., 1994, Hostetler and Giorgi, 1992].

4 EXPERIMENTAL SETUP

Two RegCM2 runs have been performed over the SWAP region. First RegCM2 was implemented using a 45km grid centered at 35N 45E and covering a total area of almost 8,000,000 km^2. The model time step was 150 seconds. The topography and landuse 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 3 years beginning in December 1989.

Another run was performed using a grid spacing of 25km and time step of 90 seconds. This increase in resolution causes a significant increase in the detail of the topography as can be seen in Figure2 below. Note particularly the presence of a coastal mountain range along the northern end of the eastern Mediterranean in both the 1km DEM (Figure 1) and the high resolution (HR) run (Figure 2b) but it's absence in the low resolution (LR) run (Figure 2a). Note also that the area modeled greatly exceeds the SWAP area shown in Figure 1.

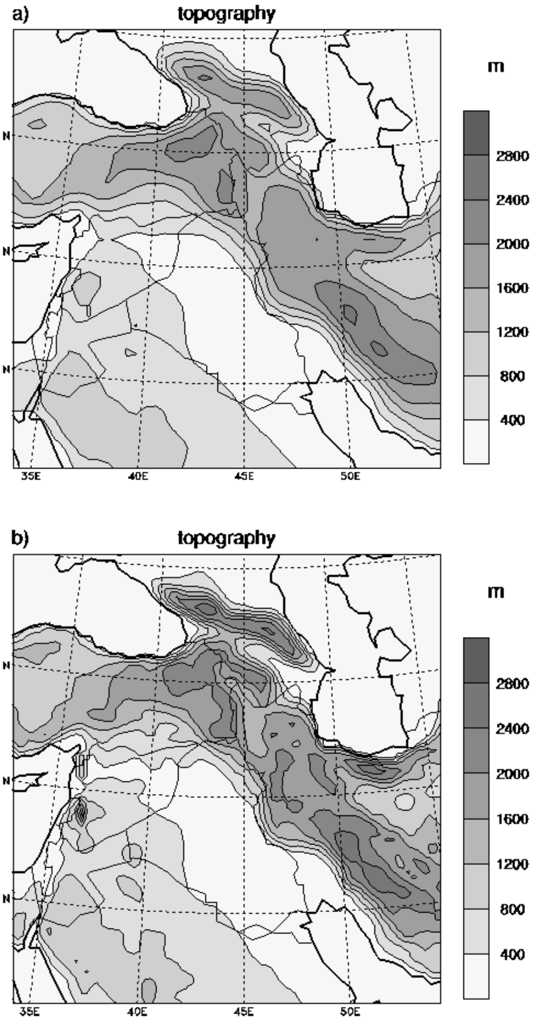

Figure 2: Topography of the model runs. a) LR (45km grid); b) HR (25km grid)

5 MODEL VALIDATION

Here we compare model results with the observational data sets that have been created. Figure 3 presents the mean annual temperatures for the region. The LR and HR runs generally agree well with each other and with the observations. One point to note is the presence of low temperatures observed along the Mediterranean coast, particularly the mountains in Lebanon. This cooler area is seen much more clearly in the HR run than the LR run.

Figure 4 presents the annual range in temperature. This is calculated as the mean of the maximum daily temperatures in July minus the mean of the minimum daily temperatures in Jan. The observations show the coastal regions (of both the Mediterranean and Caspian Seas) to have much lower temperature ranges than the rest of the region. These coastal regions are observed to have annual ranges of between 20 and 30ºC. Both the LR and HR runs are able to reproduce this range along the Caspian Sea coast, however along the Mediterranean coast the LR run very quickly reaches ranges of 35ºC plus, while the HR run is better able to create a coastal zone like that observed. In general the models simulate an annual range of temperatures which is larger than the observed by 4-5ºC. The difference comes from both overestimating the maximum slightly and underestimating the minimum slightly.

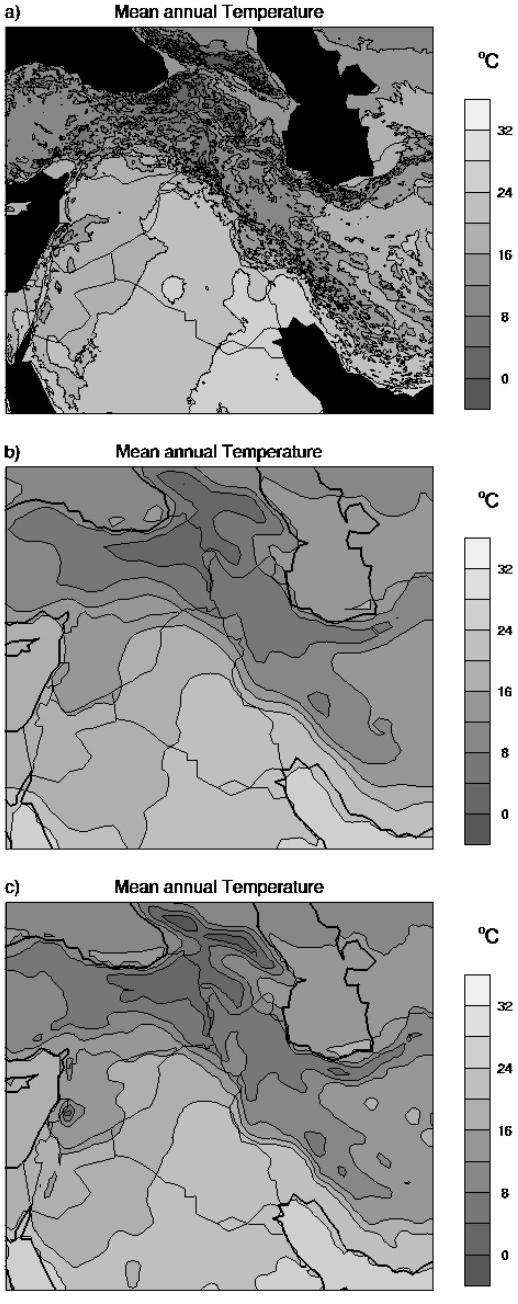

Figure 3: Mean annual temperature given by a) observations, b) LR run and c) HR run

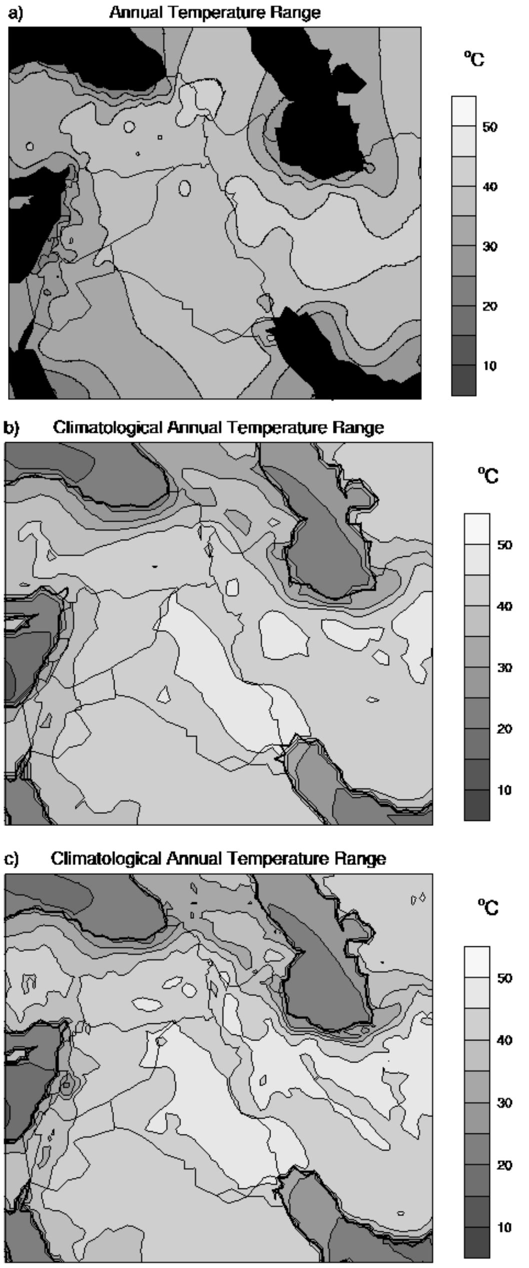

Figure 4: Mean annual temperature range given by a) observations, b) LR run and c) HR run

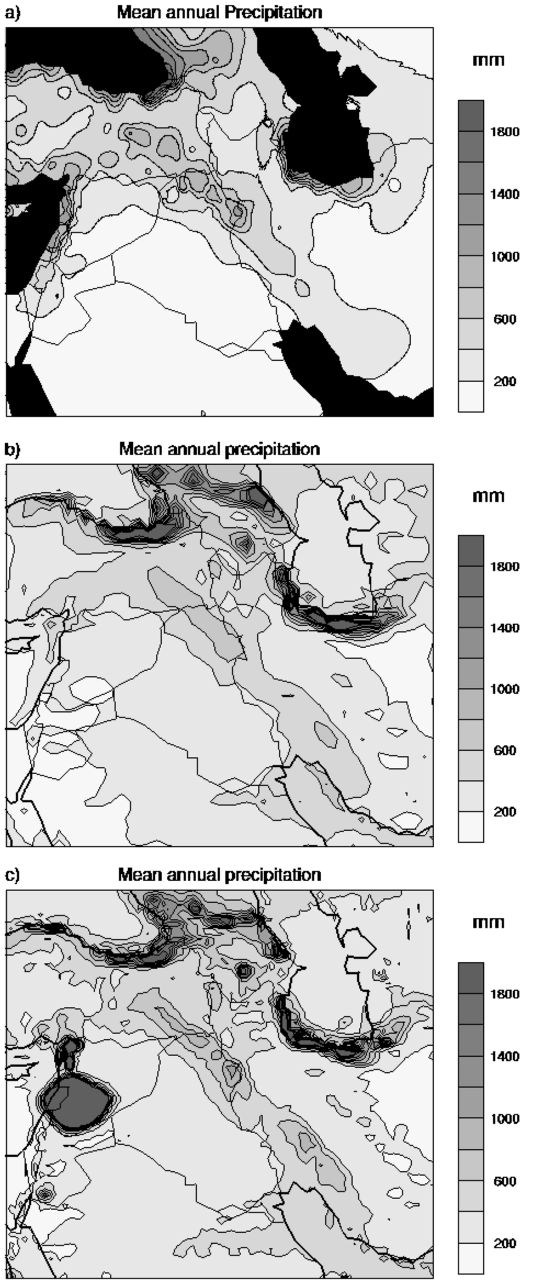

Figure 5: Mean annual precipitation given by a) observations, b) LR run and c) HR run

The annual precipitation fields are shown in Figure 5. From the observations three regions of precipitation maxima can be seen. These are the coastal regions of the Mediterranean and Caspian Seas as well as the mountainous region in south eastern Turkey and northern Iraq.

On an annual basis both the HR and the LR runs capture the Caspian coast maxima, however on a seasonal timescale the observations show much of this precipitation falling in September or October while the models simulate the precipitation to fall predominantly in April/May. The mountainous precipitation region is also captured by both models. Here the LR run simulates considerably less precipitation than is observed to fall by almost 10% while the HR run simulates amounts much closer to that observed, within 4%.

The major differences between the observations and modeled annual precipitation can seen along the Mediterranean coast. The LR run lacks any significant topography along this coast and as a result produces almost no precipitation response. The HR run on the other hand, produces a very large response to the coastal topography. In particular the mountains in the east of Lebanon produce a very large precipitation anomaly which is not confined to the coast as the observations are. There is some evidence that the steep terrain gradient in this region has caused some instability in the model.

The snow cover extent is compared in Figure 6. It should be noted here that the models output an equivalent depth of snow in mm of H_2O. This is an average value for each grid cell and hence the lower this value the less likely that an entire grid cell area is actually covered in snow but rather some fraction of the grid cell would be. Therefore as a simple comparison with the satellite derived data a cutoff is chosen above which it is assumed that the entire grid cell is snow covered and below which none of the grid cell is covered. In Figure 6, two such cutoffs are shown. The models in general produce a much larger extent for the snow cover than is observed.

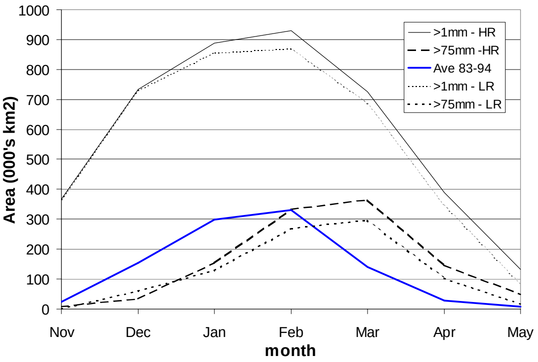

Figure 6: Snow cover extent

6 DISCUSSION AND CONCLUSIONS

As is often the case when working with numerical weather prediction models or regional climate models, the models tend to perform much better in terms of temperature than precipitation. This is evident for both the LR and the HR runs which do particularly well for annual mean temperature but relatively poorly for annual mean precipitation.

The impact of the higher resolution (especially the Mediterranean coastal mountains) is also much more evident in the precipitation then in the temperature data. While the simulated precipitation improved in the central mountainous region going from LR to HR, we also note the large precipitation maxima in southern Syria. This seems to be related to the model reacting strongly to the very large topographic gradient associated with the mountains in Lebanon. Further work to investigate the nature of this precipitation is under way.

The timing problem associated with the Caspian coast precipitation may be related to the development of a sea-breeze type circulation dependant on dominant wind direction at different times of the year. Also the SSTs used may not be representative of the Caspian Sea and the vegetation is forced into a seasonal cycle which peaks around April/May. Further work is required to elucidate the reasons for this anomaly.

The snow cover extent is quite important hydrologically and agriculturally. Figure 6 shows the model overestimating the snow cover. In order to approximate the observed snow cover extent a cutoff of around 75mm would need to be used with the model data. A realistic value would lie somewhere between this and the 1mm cutoff curve which is consistent with the models underestimating the minimum temperature values by some 2 or 3ºC. Thus much of this overestimation of snow cover can be attributed to the cold bias during winter. Essentially the 75mm model curves can be thought of as providing a measure of the extent of deep snow and the difference between this and the 1mm curve is the extent of shallow snow. During March the extent of shallow snow reduces considerably however the extent of deep snow continues to increase. This overestimation of snow may also be related to the use of simple microphysics in the model.

Thus we have demonstrated the use of a regional climate model in a data sparse area. In general we conclude that the model (particular HR) is able to reproduce the present climate of the region reasonably well. The largest problems occur in simulating precipitation along the Mediterranean coast and snow accumulation in the mountains.

7 FUTURE WORK

The immediate continuance of this work includes further experiments with the regional climate model such as including a more comprehensive microphysics parameterization and incorporating a two-way nest in order to have better definition of the mountains along the Mediterranean coast. Further examination of results with specific interest in water sources and transport, coastal effects, summer convection and the scale dependence of precipitation.

Experiments aimed at identifying the role of each of the major water bodies in the region will also be conducted along with increased CO_2 experiments. The eventual aim of this work being to conduct paleo-climate experiments. To identify regional impacts of changes in climate over the past several thousand years and their implications for agriculture and the rise of civilization.

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