Mountain Precipitation and Hydrology in the Middle East

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1. Introduction

Like the Alps in Europe, the massive Zagros, Tauros and other mountain ranges in the Middle East exert a dominant control over the hydrology of the region. Perhaps, in a relative sense, the role of terrain is even more striking in the Middle East because of the surrounding dry climates of the Mediterranean zone, and deserts of Saudi Arabia and Central Asia. In both Europe and southwest Asia, elevated terrains have higher precipitation rates and slower evaporation rates than lower elevations, causing excess water to run off the land into streams and rivers. In the cold season, water is stored in the frozen state until the spring thaw, delaying and smoothing out the river discharge profile.

Conversely, the mountains may also be partly responsible for the surrounding dry climates. An important aspect of orographic precipitation is the rain shadow effect. Recent studies have tried to quantify this effect on Alpine terrain [Smith et al. 2003a]. In the Middle East, there are several important water sources including the Black, Caspian, Red and Mediterranean Seas and the Persian Gulf. Understanding vapor transport and loss away from these various source regions is essential for regional hydrology. For example, do the Black or Caspian Seas in the north and east, contribute to precipitation in the Tigris and Euphrates watersheds? And, does the coastal range along the Mediterranean trap precipitation that would otherwise moisten the steppes and deserts of Syria and Iraq?

Figure 1. Middle East geography and the Tigris and Euphrates watersheds.

Mountains also have an indirect effect on precipitation. Mostly through elevated heating, they generate atmospheric subsidence that warms and dries the surrounding areas [Broccoli and Manabe, 1992]. Evans et al. [2003] have shown that summer subsidence forced by the Iranian Plateau adds extra warming and drying to Mesopotamia. A simple model of this is the response to heating in a steady stratified stream [Smith and Lin, 1982]. The upstream tilt of heat-generated waves produces descent and zonal acceleration. The resulting increase of the Coriolis force deflects the air over Mesopotamia to the right (southward), opposite to the deflection expected from the mechanical lifting. The acceleration and turning may assist the strong northwesterly Shamal wind.

2. Orographic Precipitation

Mountains exert a strong influence on precipitation patterns in the region. Recent statistical analysis [Evans et al, 2003] indicates that compared to climate indices such as storminess and moist instability, an "upslope index" $UI = \vec{U} \cdot \nabla h(x, y)$ has more predictive power for seasonal and inter-annual precipitation. There are five dominant regions of orographic precipitation.

- The Mediterannean coastal range including the hills of Lebanon
- The Tauros mountains of Turkey,
- The Zagros mountains of Iran
- The Pontic range by the Black Sea
- The Elburz range by the Caspian Sea

The first three of these areas have a winter/spring maximum in precipitation associated with upslope winds in baroclinic weather systems. The Mediterranean coastal orography has a width of only 50km, so global and many regional models fail to reproduce observations. Smaller scale models may do a better job [Alpert and Shafir, 1991; Smith and Barstad, 2003].

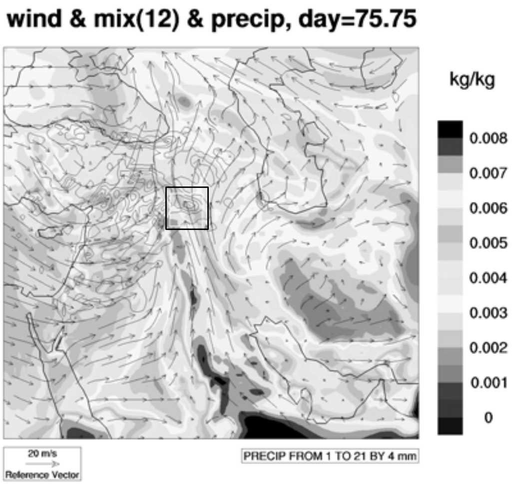

Figure 2. Wind vectors and water vapor mixing ratio (shaded) at 700hPa on February 16, 1990. Precipitation amounts are contoured. Data of from a RegCM2 simulation of a precipitation event on the Cilo-Sat Range (square box).

Precipitation patterns in the Tauros, Zagros, and the high Cilo-Sat ranges at their junction, are larger scale features and thus are captured more easily by coarse resolution models. Precipitation in the southern foothills of these mountains supports the rain-fed agriculture in the Fertile Crescent. Precipitation in the higher mountains feeds the southward flowing Tigris and Euphrates Rivers. Recent attempts to simulate precipitation in the Elburz region have failed, in part due to poor forecasting of regional wind seasonality and in part due to problems on the cloud physics parameterizations in current mesoscale models [Evans et al, 2003].

3. Water sources

An added geographical complexity is the relationship between mountain location and bodies of water that act as water sources. Elsewhere, good examples of this relationship include the Bay of Bengal supplying water to the Himalayas and the Ligurian Sea supplying water to the Alps.. Middle East hydrology includes many examples of this kind of source-mountain relationship. Source-mountain pairs include: Black Sea-Pontic Range, Mediterranean Sea - Levantine hills, Persian Gulf- Zagros Mountains., Caspian Sea-Elburz Mountains.

Some insight into source-mountain relationships can be gained with regional climate models. Recent work has shown that the upper reaches of the Tigris-Euphrates watershed in Turkey-Iran receive water vapor from both the Mediterranean Sea and the Persian Gulf [*Evans et al*, 2003]. An example is shown in Figure 2 for February 2, 1990. As a depression migrated eastward in mid-latitudes, distinct streams of moist air were drawn from the Mediterranean Sea and the Persian Gulf. These moist airstreams merged and were lifted by the high Cilo-Sat Ranges, including Mt. Ararat (5165m).

4. Interannual variability of snow-pack and river discharge

The interannual variability of river discharge in the Tigris and Euphrates Rivers are associated both with precipitation and temperature fluctuations. The influence of temperature fluctuation is felt both through evaporation and snow pack storage changes. An overview of the snow pack variability in January is seen in Figure 3. Not surprisingly, the highest terrain near Lake Van and Mt. Ararat have snow in every year, while vast areas of mid-altitude terrain are variable in this respect. It can be shown that the interannual differences in snow area correlate with monthly temperature anomalies, but the exact spatial patterns are more difficult to predict.

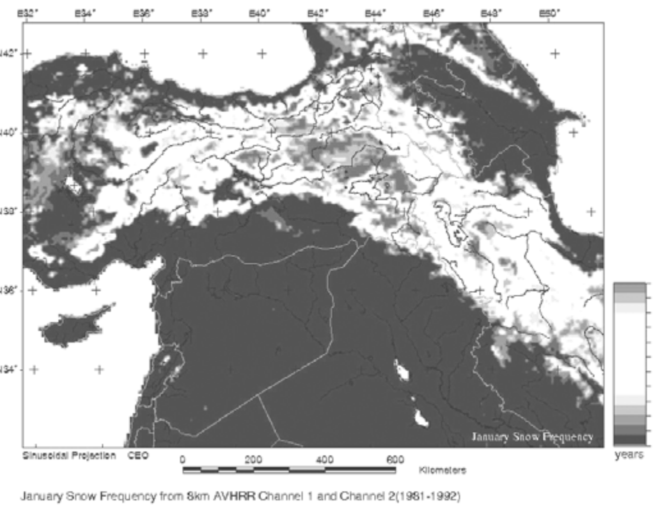

Figure 3. The frequency of snow cover in the Mountains of Turkey and Iran over the period 1983-1994, derived from AVHRR data [Smith et al, 2003a].

The impact of climate variability on snow pack and discharge can be estimated using a simple spatially distributed bucket hydrology model [Smith et al. 2003a]. In this model, the monthly precipitation, evaporation, soil moisture, snowpack and runoff from each 5-km pixel in the Middle East are computed. The model assumes that the maximum storage capacity of the soil is 100mm of column water. The model is driven by the observed monthly climatology for the region from the period 1950 to 1975. The runoff from each pixel is aggregated for each watershed. One result from the model, the monthly discharge in the Euphrates, is shown in Figure 4.

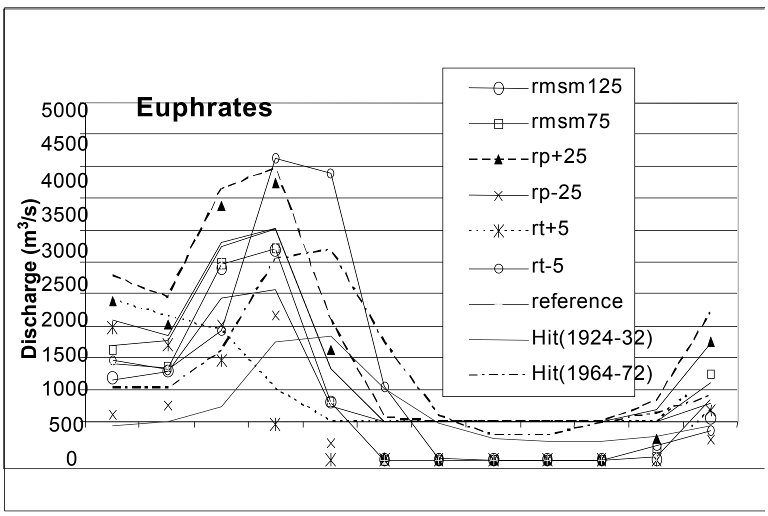

Figure 4. Monthly Euphrates river discharge. Record begins in the month of November.

The reader should first examine the reference run and the two curves showing observed discharge at Hit, a gauging station near Bahgdad. Note that the reference run is obscured by two nearly identical curves with altered maximum soil moisture (MSM). The reference model discharge peaks in February at 3000 cubic meters per second. For the earlier climate period, the peak discharge values are lower than predicted (1800 m3/s) but for the more relevant later period, the agreement is satisfactory. In comparison with both periods, the computed peak is too early, due to a lack of storage delays in the model.

To test the sensitivity of discharge to climate, the input monthly climate values can be altered systematically. When the precipitation is increased or decreased by 25% everywhere, the discharge reacts qualitatively as expected. The quantitative response is strong however. The annual discharge increases by about 40%, nearly twice as large as the imposed precipitation change. The amplification is due to the fact that discharge is a “threshold” phenomena. Only precipitation above the evaporation amount will run off the land.

In the second climate sensitivity test, the temperature in each month is increased or decreased by 5ºC. The watershed response to this change is profound. For the cooler case, the peak discharge increases to 4300 m^3/s due to reduced evaporation. Furthermore, the peak is delayed by one month due to the later snow-pack melt. In the warmer case, the peak discharge is less than 2000 m^3/s and occurs in December, generally tracking the precipitation time series. Little snow-pack storage effect is seen.

5. Conclusions

The hydrology of the Middle East is strongly controlled by its distribution of mountains and seas, and is susceptible to significant interannual variation. The region is generally data poor, and little regional climate modeling has occurred. Our recent model studies, using both linear models, GCMs, full regional climate models and simple hydrology models reveal some of the special characteristics of the region. The critical physical processes in the region are orographic precipitation on different scales, water vapor sources, rain shadow, heat-induced descent, and snow-pack storage of water.

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