# Hydrometeorology, HYD 513
# Department of Earth and Environmental Science
# New Mexico Tech

## Lecture 17:

### *1. North American Monsoon System*

Geographic Extent and Climatology

The North American Monsoon (NAM) is a regional circulation system that expresses itself annually during the northern summer.

NAM has received much attention by the scientific community, but still little is known about the detailed ocean-atmosphere-surface interactions that create, sustain and vary the monsoon from year to year.

Various names have been attributed to the North American Monsoon:

(1) Arizona Monsoon
(2) Mexican Monsoon
(3) Southwest Monsoon

The geographic region most affected by the monsoon includes: Arizona and New Mexico (in the US) and Sinaloa, Sonora, Chihuahua, Coahuila (in Mexico). Impacts are felt as well in the surrounding areas with lesser degrees of influence.

A long-standing controversy on the origin of the NAM circulation patterns and moisture sources has existed, in part due to sparse observations in northwest Mexico. We will discuss the current state of knowledge of NAM.

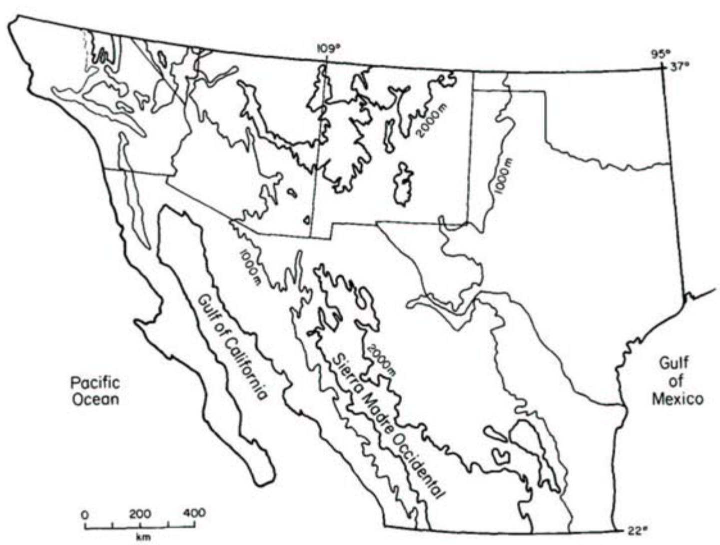


**Figure 1.** Geographic location of the North American Monsoon region showing topographic contours and moisture sources.

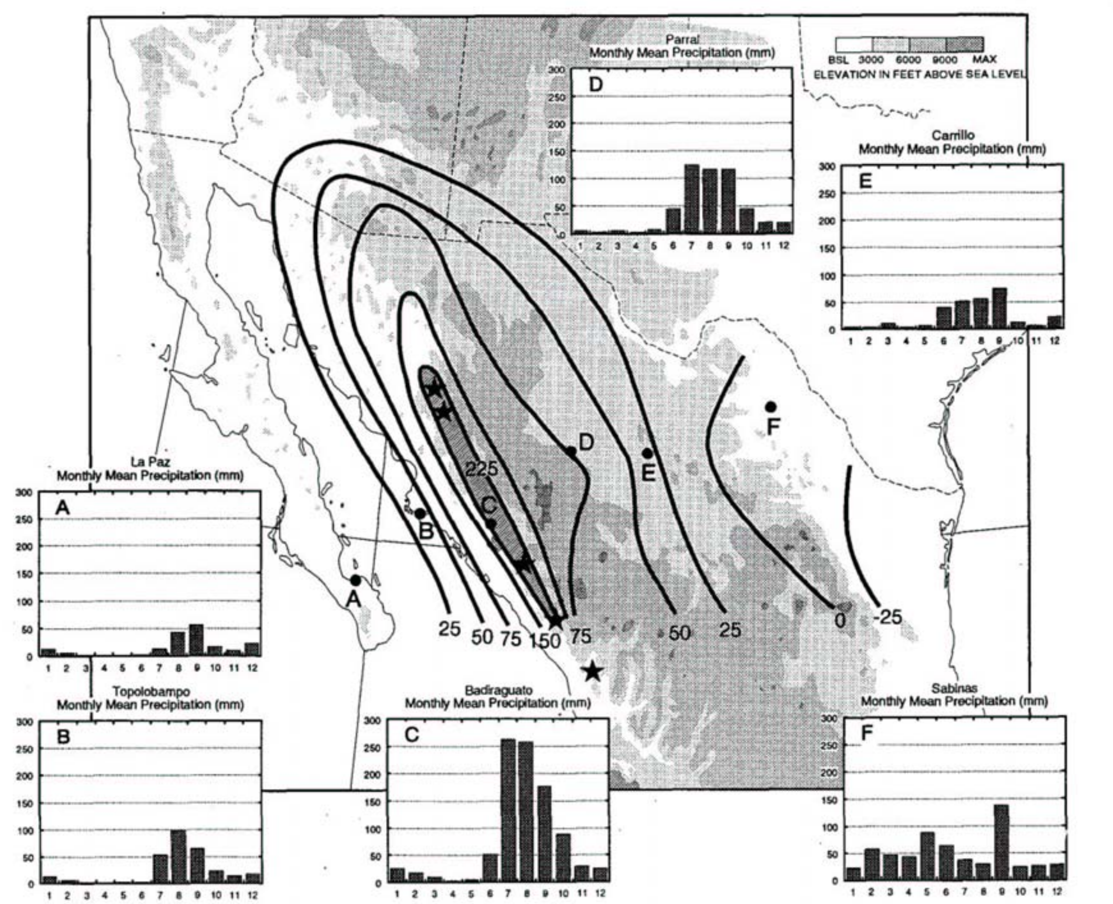


**Figure 2.** Contour plot of the difference between July and June rainfall in the core monsoon region along a transect across the Sierra Madre Occidental. Along with monthly histograms for several stations (from Douglas et al. 1993).

One important reason why the North American Monsoon exists are contrasts between the high elevation (mountains, high plateaus) along the western US and the low lying coastal zones and shallow seas (Gulf of California and Gulf of Mexico).

(1) Thermal heating in the high desert regions (e.g. Great Basin)
(2) Monsoon circulation set up between thermal low and high pressure centers located over Gulf of California.
(3) Low-level moisture transport through gulf surges into southwestern US.
(4) Orographic uplift leads to convection in mountain fronts.

Rainfall distributions from the NAM region illustrate the contribution of summer rainfall to the annual precipitation at locations within the semiarid US and Mexico:

**Figure 2** shows the large contribution of summer rainfall across the Sierra Madre Occidental (SMO) from La Paz (Baja California) to Sabinas (Nuevo Leon). It also illustrates the difference between June and July. Monsoon onset varies from mid-June closer to the core region to mid-to-late July far from the core region.

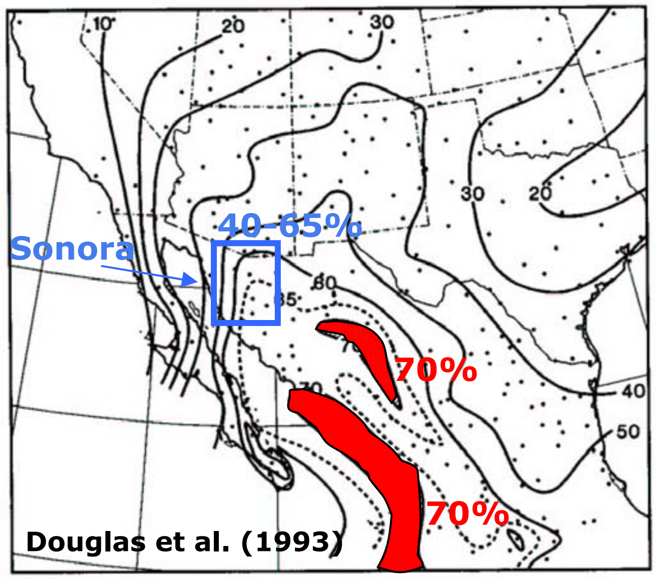


**Figure 3.** Percent of annual rainfall attributed to the NAM summer accumulations in July, August and September (from Douglas et al., 2003).

Notice the strong influence of the summer monsoon on the rainfall climatology of the region shown in Figure 3. There are two regions with greater than 70% contribution:

(1) Low-lying coastal valleys in Sonora and Sinaloa.
(2) High elevation mountain regions in the interior SMO over Chihuahua.

For Sonora and Baja California, sharp gradients in summer contribution are observed. In Sonora, variations from 40-65% are found within the western slopes of the SMO.

Sonora experiences a strong monsoon season and high rainfall contributions, in particular over complex terrain.

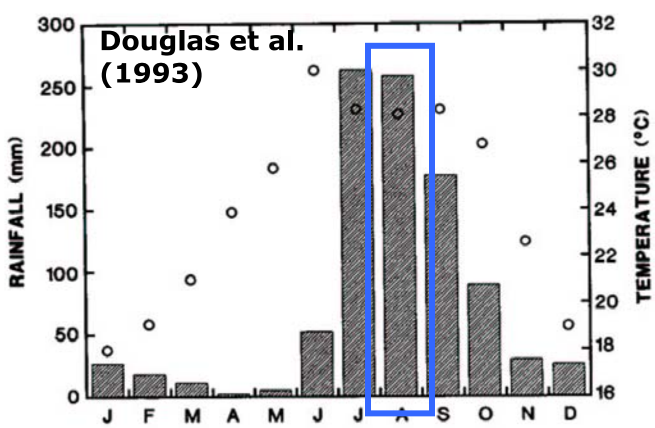


**Figure 4.** Long term mean monthly precipitation and temperature for a station in Sonora, Mexico. Note the peak temperature occurring during June before the monsoon onset.

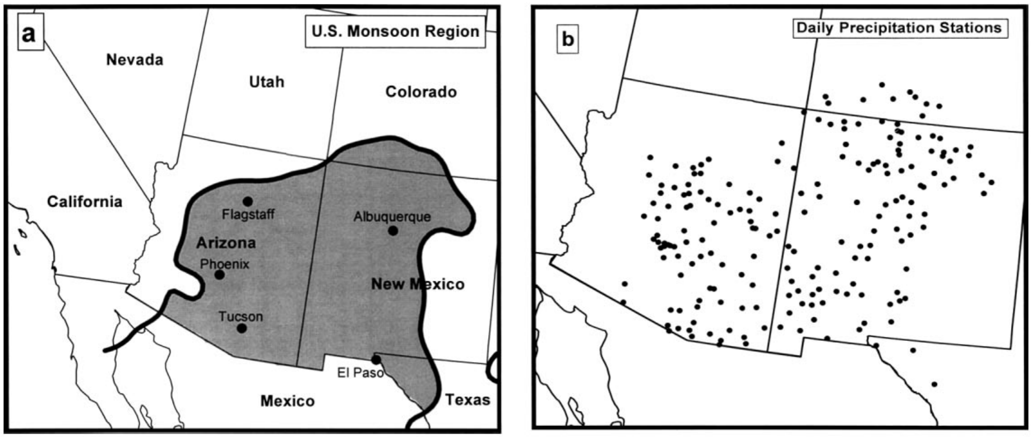


**Figure 5.** Climatological definition of monsoon region (shaded area) in Southwestern United States based on rain gauge records and Principal Component Analysis (PCA).

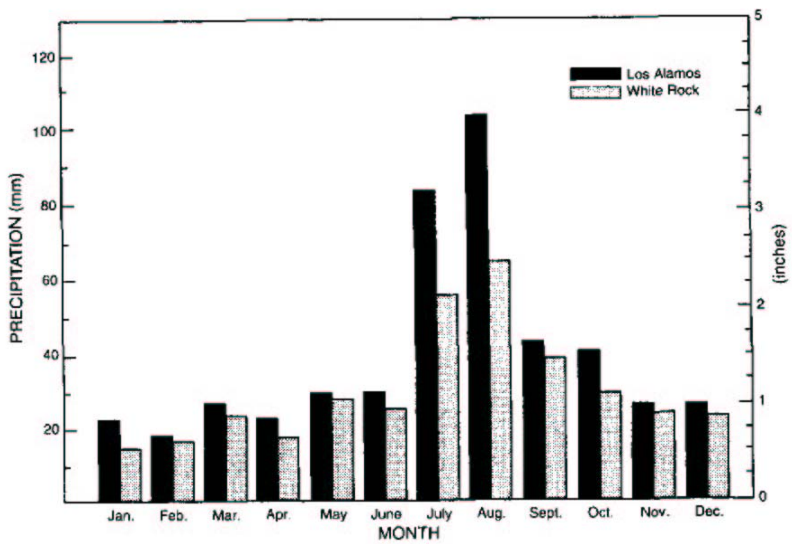


**Figure 6.** Monthly rainfall (mm) over 30 and 25 year periods ending in 1990 for Los Alamos and White Rock, NM. (from Bowen 1996).

In New Mexico, NAM monsoon rainfall is also a significant component of the annual precipitation, although the relative amounts is smaller than in the core monsoon region.

For example, Bower (1996) presents the monthly climatology at Los Alamos and White Rock, NM on the Pajarito Plateau.

(1) Los Alamos, at a higher elevation, receives proportionally larger orographic effect during July and August as compared to other months.
(2) White Rock, at a lower elevation, does not have as a significant monsoon effect, although rainfall in JJA is greater than for other months.
(3) Moderate precipitation amounts are also observed fro September and October from late-summer monsoon storms and fall frontal activity.

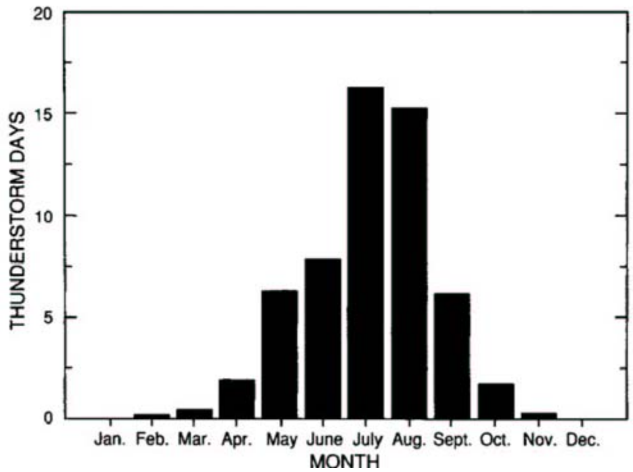

**Figure 7.** Mean monthly thunderstorm days in Los Alamos (from Bowen 1996).

Associated with the NAM are other important climate characteristics:

(1) Elevated levels of relative humidity
(2) Thunderstorm activity, lightning, hail and high winds

The convective activity in the summer monsoon originates from a combination of:

(A) High thermal heating in particular over mountain ranges.
(B) Upper level moisture availability from monsoon sources

The convective environment within a particular region will determine the most prominent period of the day during which rainfall will occur. It is important to note that this will vary with location in the monsoon domain and proximity to mountain ranges. For Los Alamos, an hourly analysis of rainfall illustrated that the early afternoon (noon to 4 pm) has a higher frequency of rainfall.

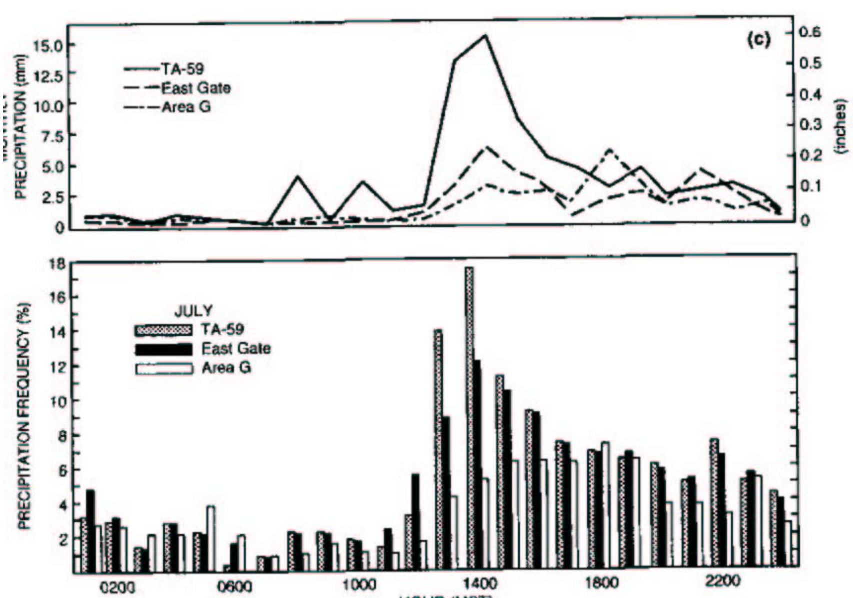

**Figure 8.** Mean hourly rainfall at three sites in Los Alamos for June (1981- 1989)

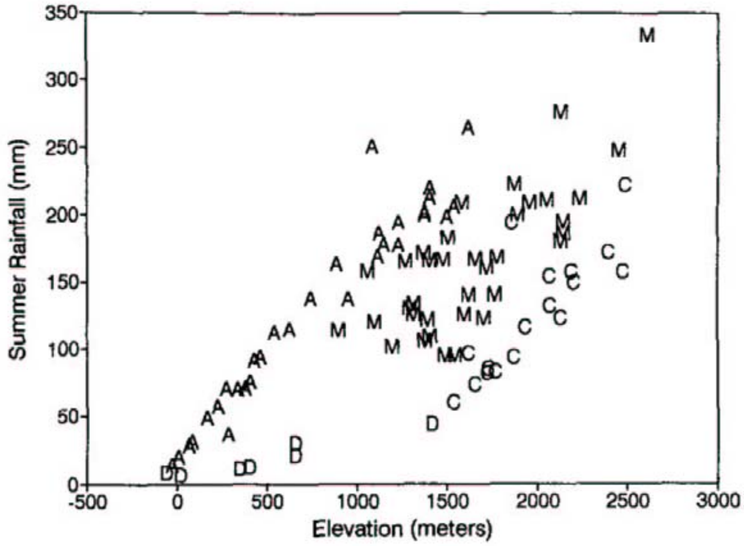


**Figure 9.** Mean summer rainfall (mm) versus elevation (m) for the period 1915-1974 by Michaud et al. (1995) classified into A = southwestern Arizona, C = Colorado Plateau, D = California and Nevada deserts and M = central mountains in Arizona and New Mexico.

<u>Orographic Effects</u>

The influence of complex topography is an important effect on convective monsoon rainfall leading to:

(1) Increasing rainfall with elevation at climatological time scales
(2) Creation of rain shadows on the lee ward side of mountains
(3) Preferential rainfall in mountain ranges oriented perpendicular to the monsoon moisture source.

Michaud et al. (1995) presents an analysis of the effect of topography on the monsoon rainfall for the southwestern US. They found:

(A) Orographic relationships varied between regions defined as: (1) Colorado Plateau, (2) southwester Arizona, (3) central mountainous Arizona and New Mexico and (4) California and Nevada deserts
(B) Good linear regressions were obtained by considering latitude and longitude (e.g. spatial location) in addition to elevation.

The authors developed a regression model of summer rainfall based solely on location and elevation (MSWR = Mean South West Rainfall). They used monthly rainfall from 190 stations in the region (divided into calibration and validation sets).

Michaud et al. (1995) present a rainfall climatology developed at 1 degree by 1 degree grids for the Southwest based on their algorithm. This method is a useful comparative case for other orographic interpolation techniques.

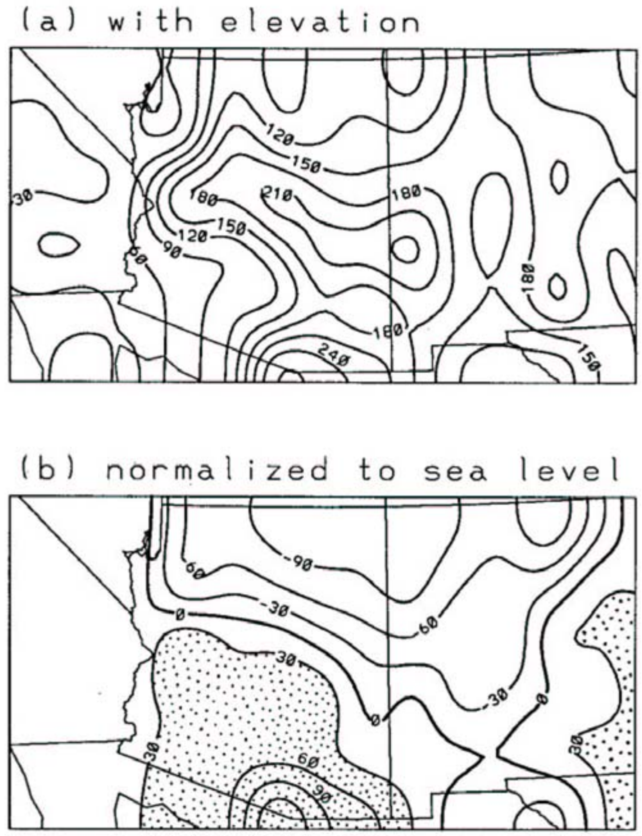


**Figure 10.** Mean summer rainfall with and without the effects of elevation (mm). Note the normalized to sea level plots are a good indicator of monsoon moisture sources.

Michaud et al. (1995) also describe the parameters of their regression model (B, C) which can vary with region and month.

An interesting development is the use of the intercept of the linear regression as a measure of the rainfall value at sea level. In other words, the authors remove the effects of elevation to obtain a sea level precipitation map.

Normalized Sea Level Rainfall helps illustrate the moisture sources of rainfall:

(1) Gulf of California – affecting Sonora, southern Arizona and southwest NM
(2) Gulf of Mexico – affecting Chihuahua and southeast NM

<u>Dual Moisture Source Theory:</u>

Using surface and upper air observations, remote sensing and numerical models, the accepted hypothesis about the NAM moisture source is a dual source:

(1) Low level moisture is transported from the Gulf of California over the low-lying coastal valleys in Sonora and Arizona.
(2) Upper level moisture is transported from the Gulf of Mexico over the higher terrain in northeastern Mexico (Sierra Madre Occidental and Oriental).
(3) Mixing of the two moisture sources due to mountain convection.