The North American Monsoon in the Southwestern CONUS

A meteorological overview

What is a monsoon?

Regularly occurring seasonal shift in winds, typically accompanied by large changes in temperature, humidity, and rainfall.

Derived from Arabic mausim, which means season.

Fundamentally caused by a thermally direct circulation. The concept is key to understanding the large-scale circulation and how individual monsoon storms form.

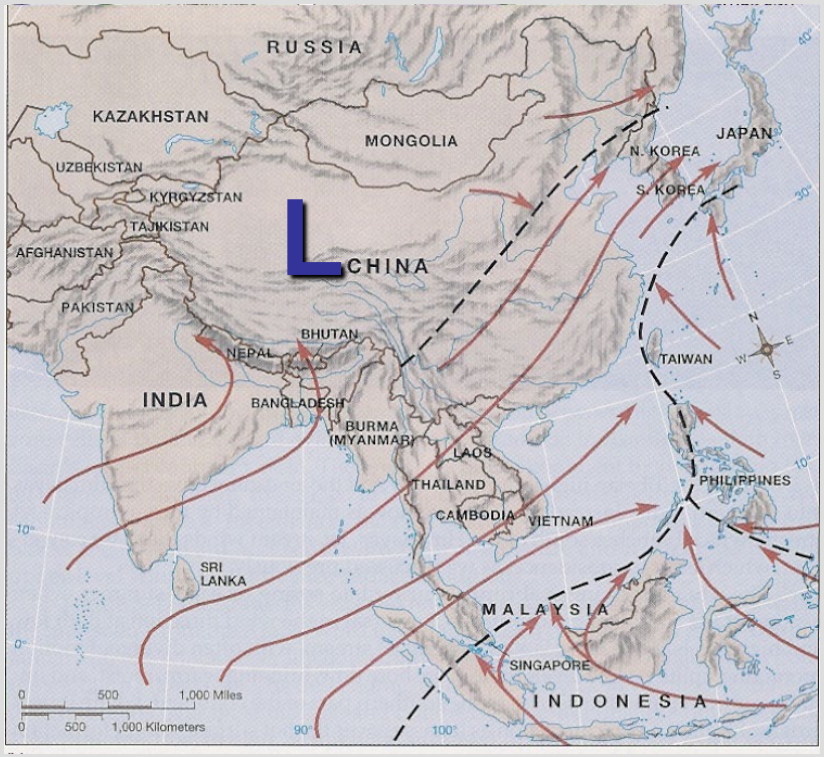
Why is the strongest monsoon in India?

To the north of India is the Himalaya Mountains and the Plateau of Tibet, with an average elevation of over 15,000 ft. and a horizontal extent of more than 1000 miles.

Contrast between the elevated plateau and the surrounding bodies of water south of India sets up a giant thermally direct circulation.

Indian Monsoon: Summer Wet Season

SUMMER LOW LEVEL CIRCULATION



(Aguado and Burt)

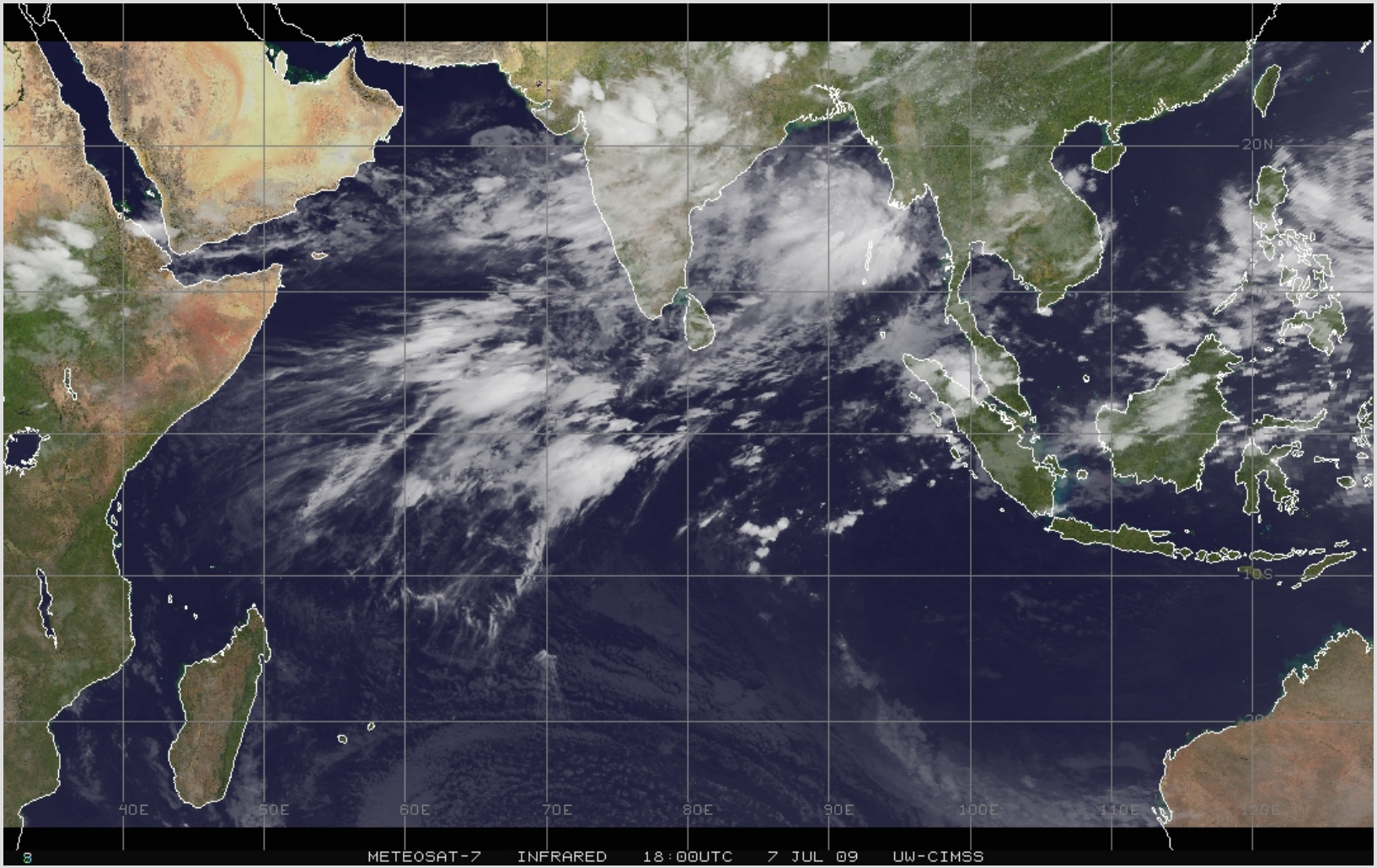
Tibetan Plateau is relatively warmer than the surrounding ocean off Asia

Warm air over the Tibetan Plateau is relatively less dense

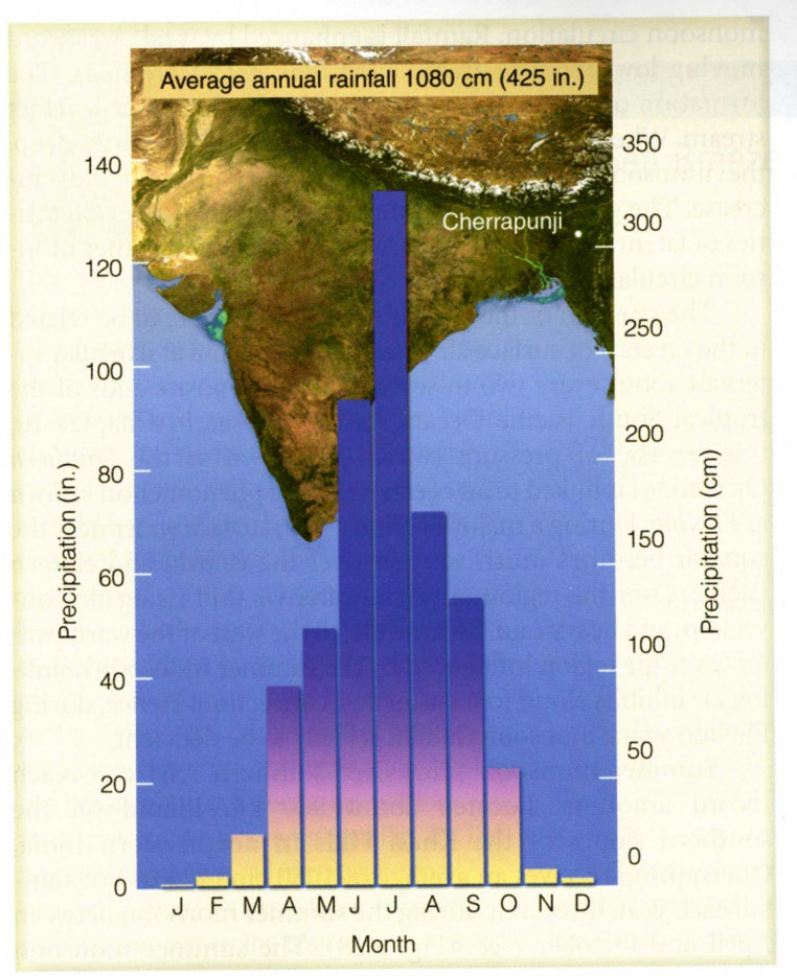
Wind flows from the ocean to the Tibetan Plateau.

Onshore flow transports moisture to the interior of Asia.

Indian Monsoon: July 7, 2009
Infrared satellite image



Monthly rainfall
Cherrapunji, India



ONE OF THE WETTEST SPOTS ON EARTH

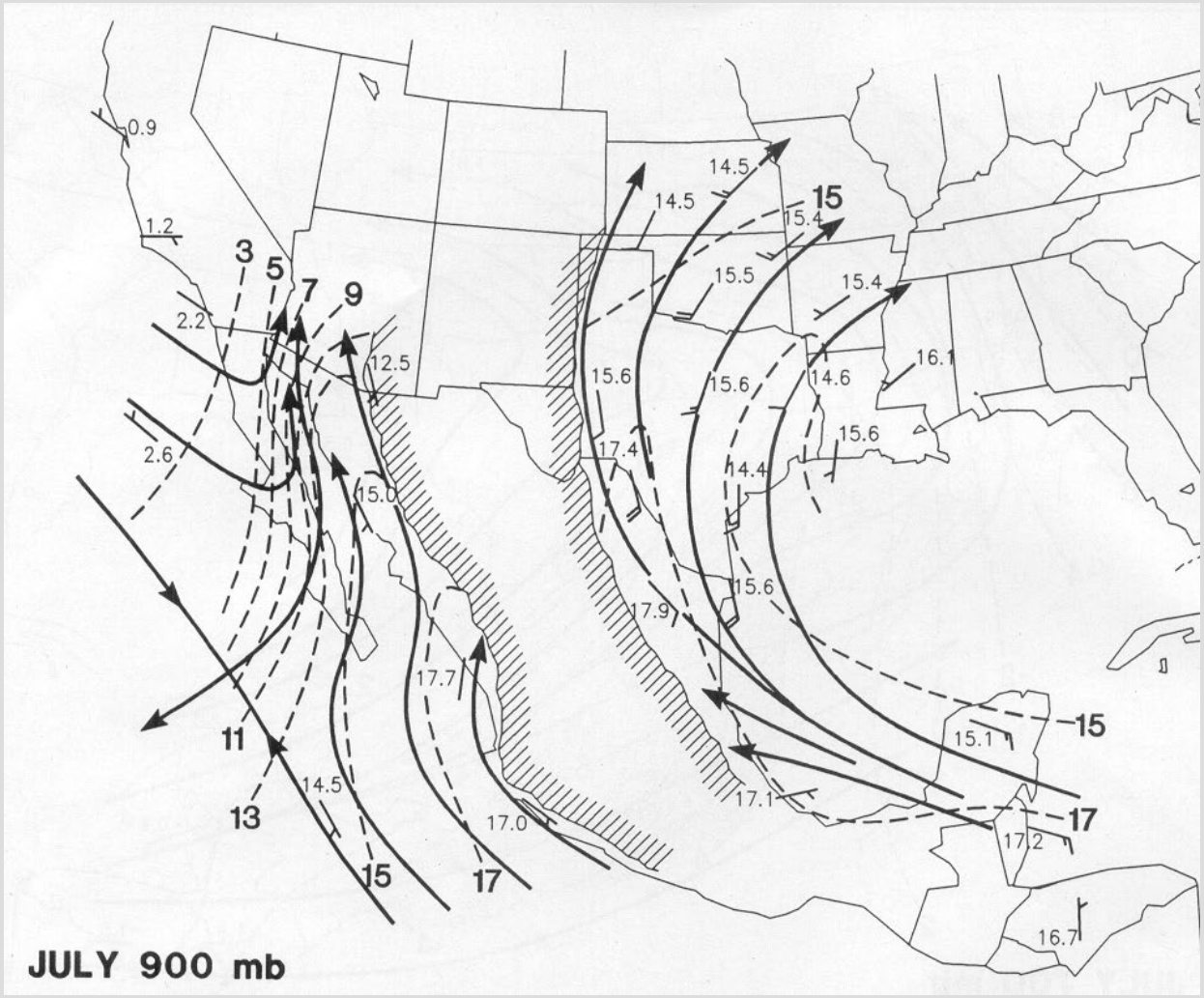
Why a North American Monsoon?

Similar to Asia, North America has a giant elevated plateau in the western U.S. and Mexico.

However, in our case, the Mexican plateau is only about 4000-7000 ft. in elevation, depending on where you are.

Though it is not as high as Tibet, it IS high enough that there is a regular seasonal reversal of circulation.

Average Flow Near Surface: July



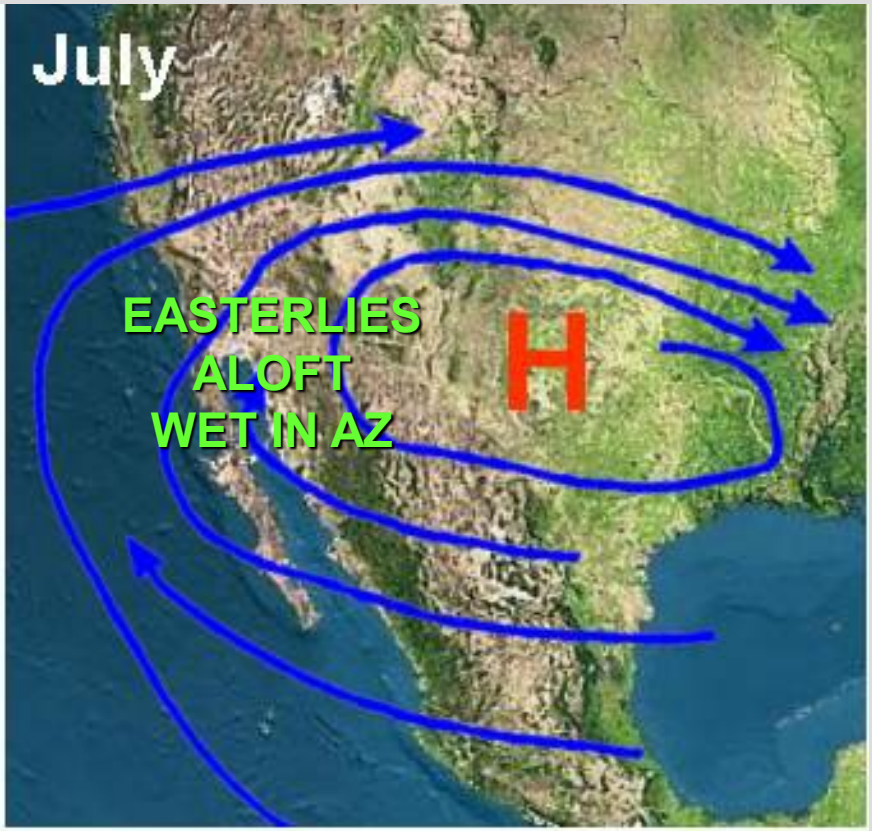
(Douglas et al. 1993)

Monsoon ridge in 500-mb pattern

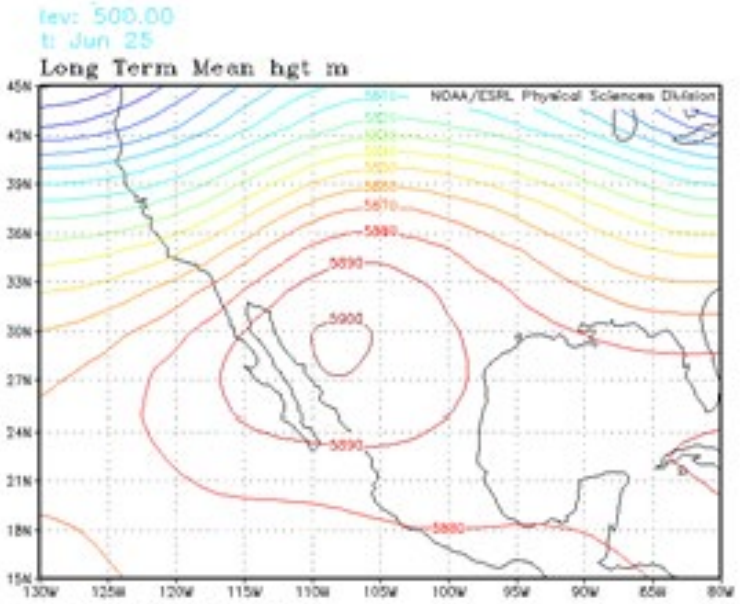
Before monsoon

Westerlies aloft.
High pressure ridge to the south.
Little moisture at upper levels.

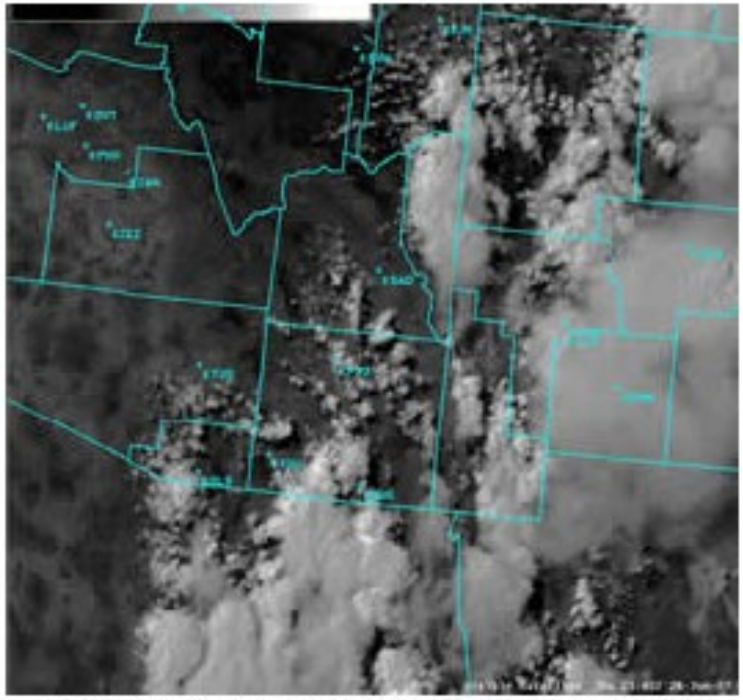
During Monsoon



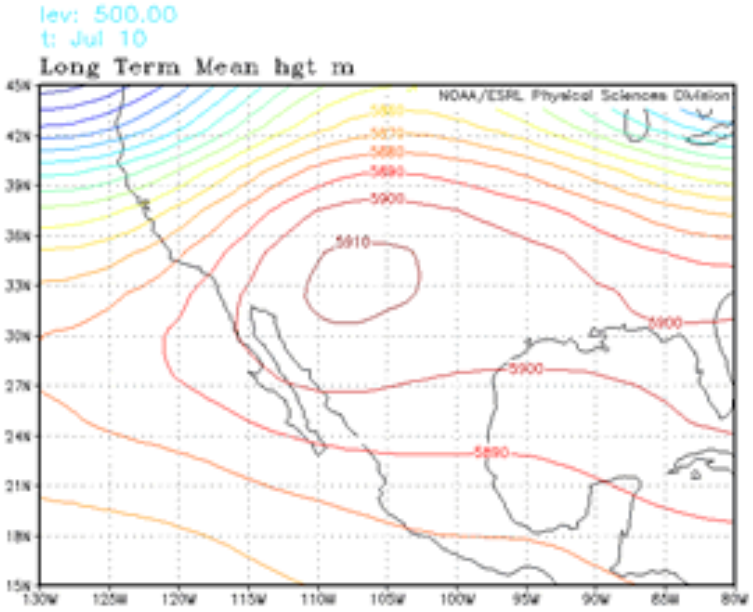
Easterlies aloft.
High pressure ridge to north (and east)
Moisture transport from Gulf of Mexico



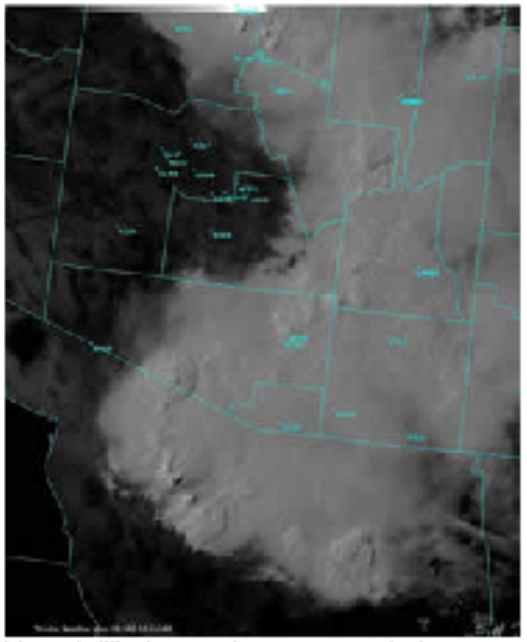
Mean 500mb heights, June 25 (monsoon ramp up)



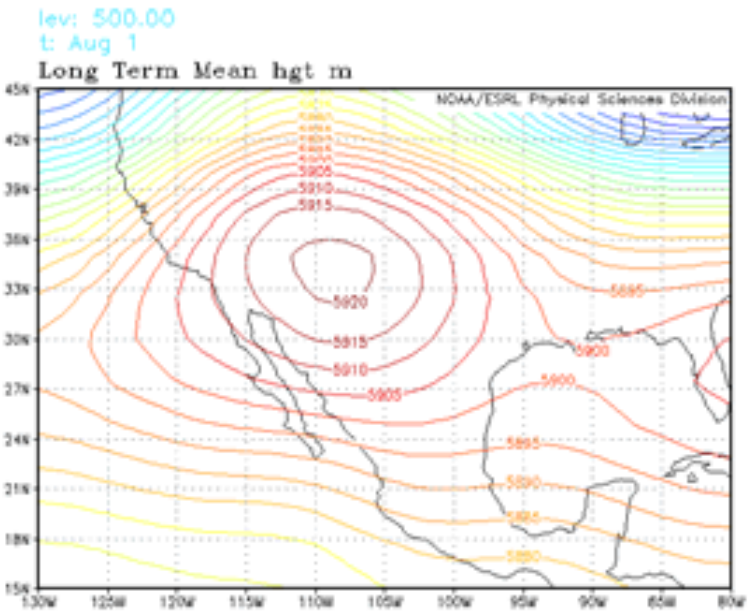
Visible satellite image of isolated thunderstorms during monsoon ramp-up, June 28, 2007



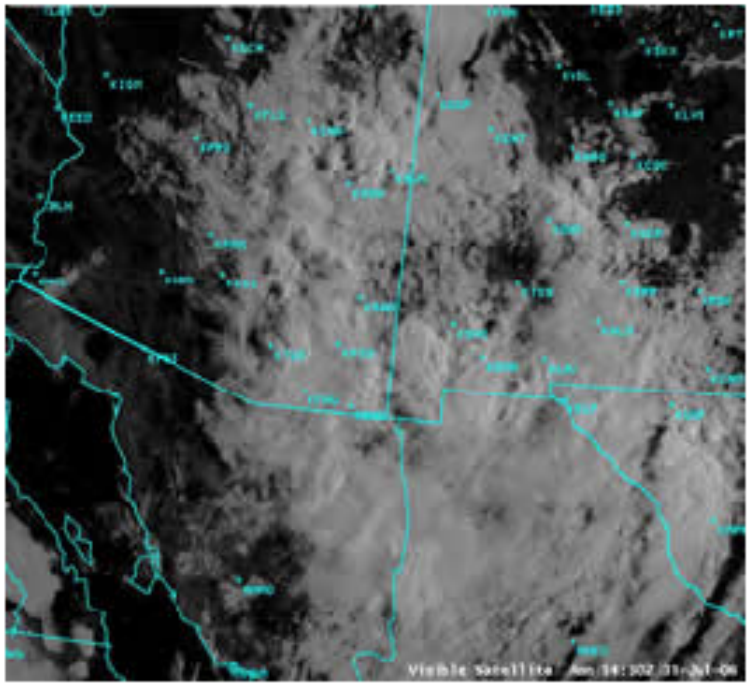
Mean 500mb heights, July 10 (monsoon onset)



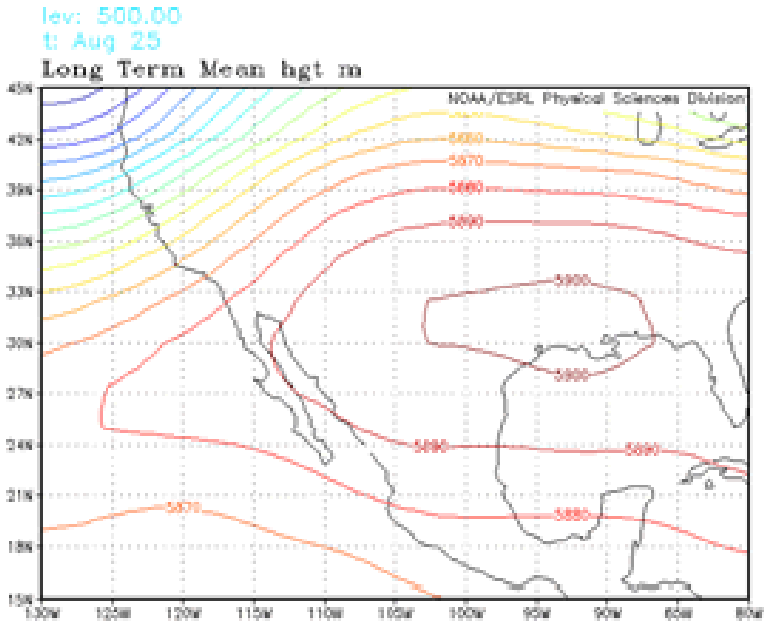
Visible satellite image from an onset phase severe thunderstorm outbreak over southeast Arizona, July 14, 2002.



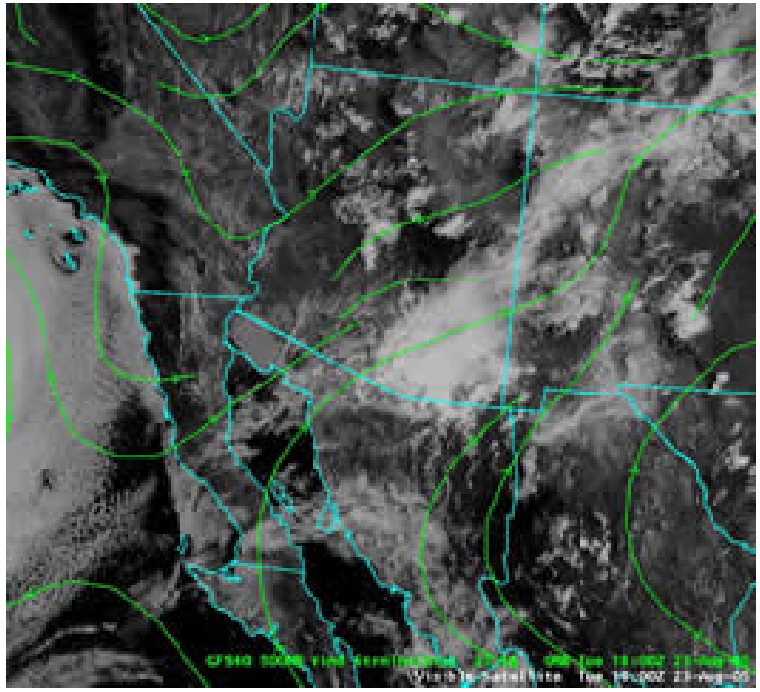
Mean 500mb height, August 1 (monsoon peak)



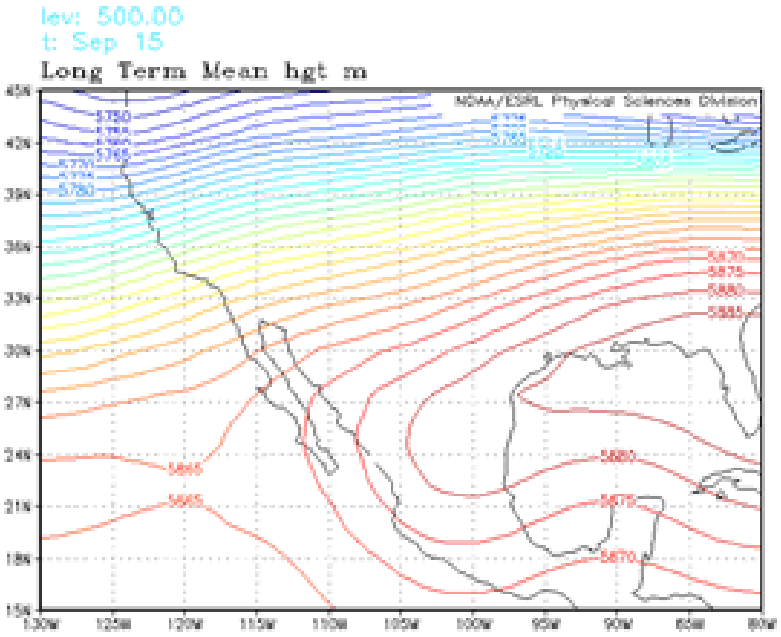
Visible satellite image from early morning thunderstorms, 0730 am MST July 31, 2006, during the peak of the 2006 monsoon. Many of these thunderstorms produced 1-2 inches of rain per hour.



Mean 500mb height, August 25 (late monsoon)



Visible satellite image from a late season severe thunderstorm and flash flood event, August 23, 2005. Note southwest flow aloft and weak trough near the lower Colorado River.



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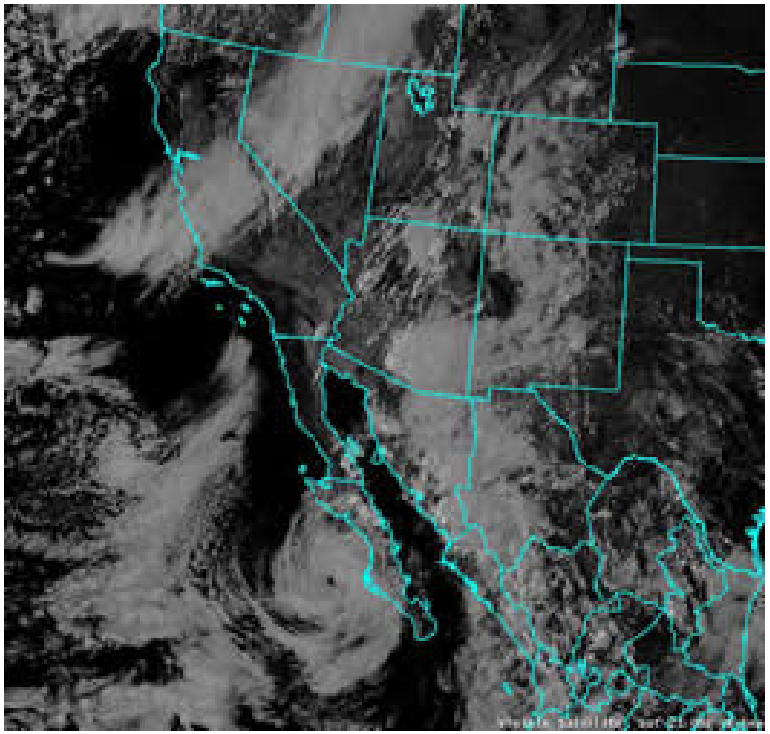
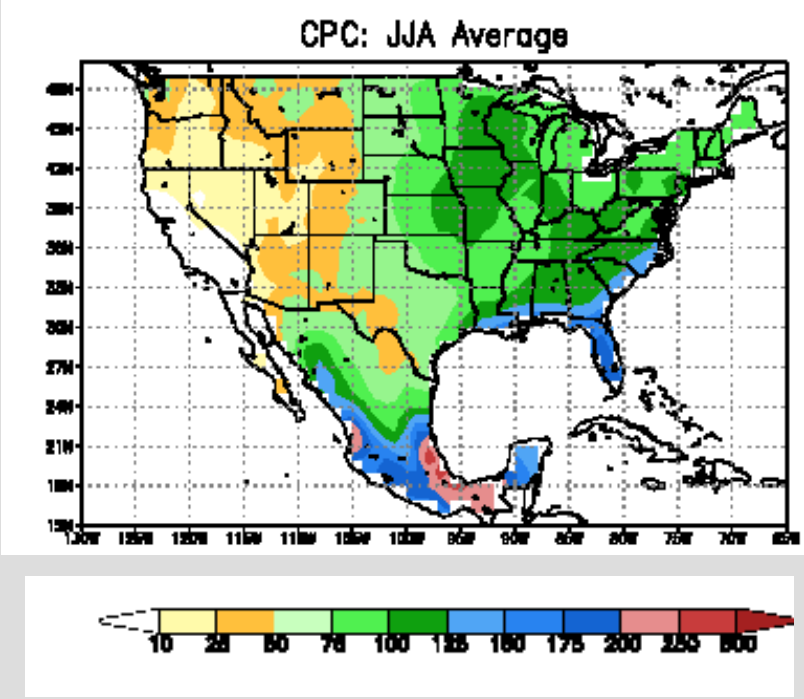


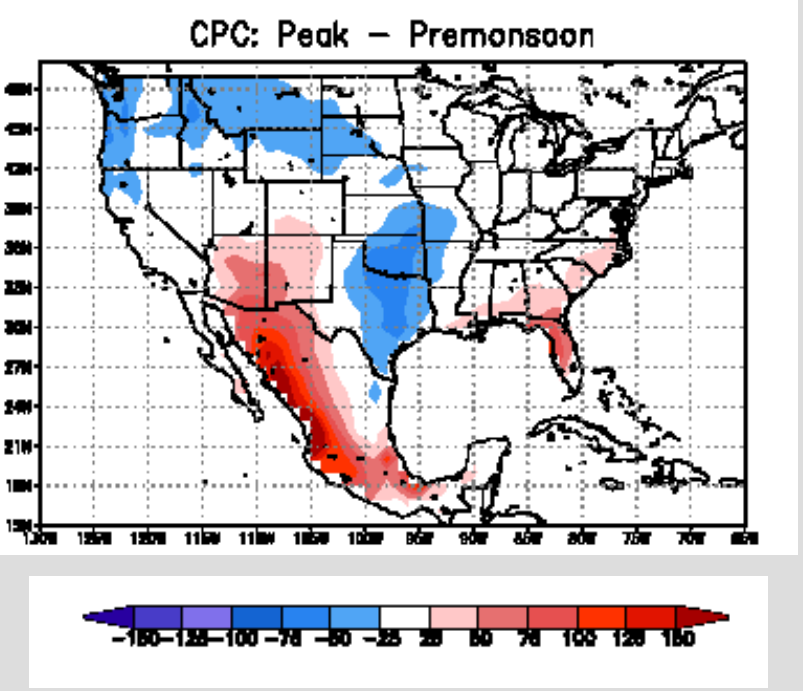
Visible satellite image from a late season severe thunderstorm and flash flood event, August 23, 2005. Note southwest flow aloft and weak trough near the lower Colorado River.

Continental Scale Shift in Rainfall (mm)

Summer Average Rainfall



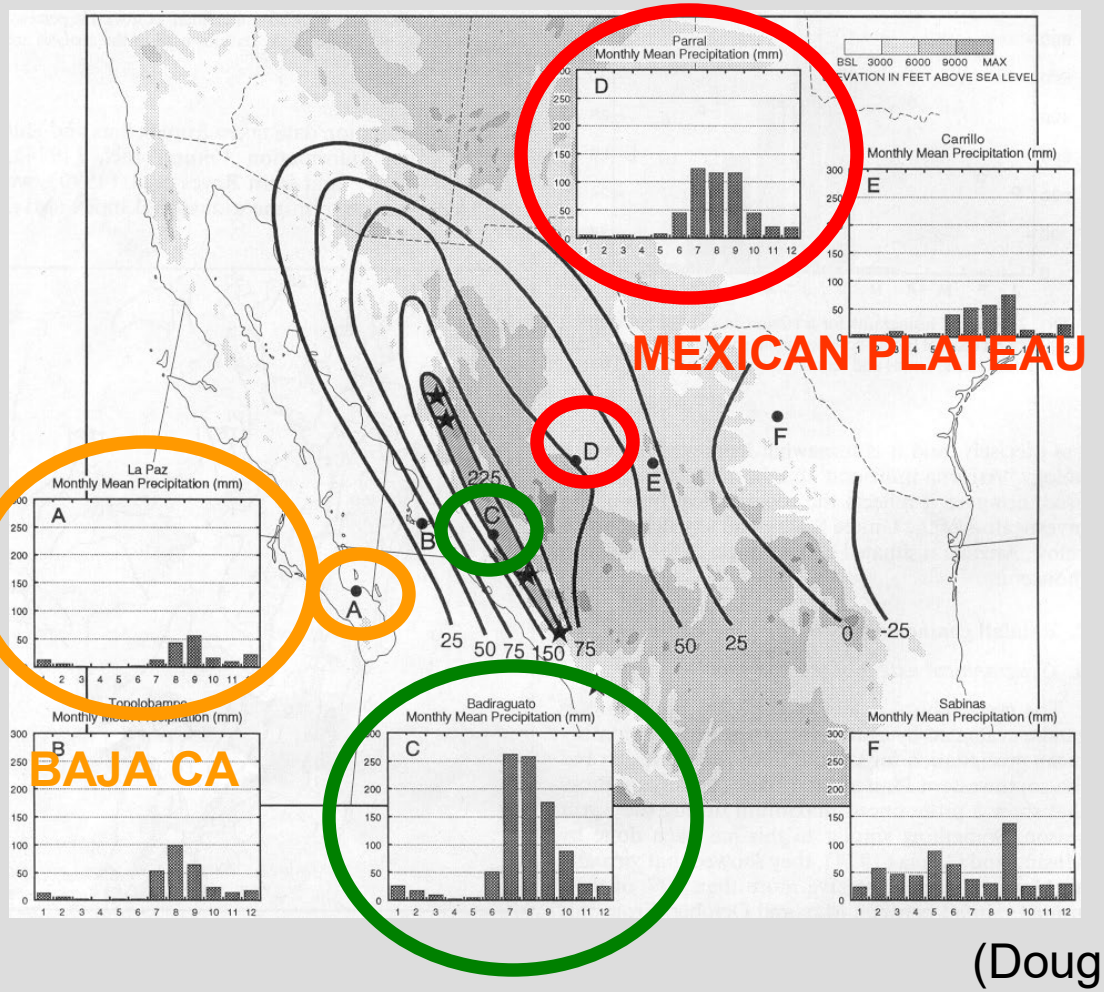
During monsoon – before monsoon



(Castro et al. 2007)

As the Southwest U.S. and western Mexico get wet, it dries out in the central U.S.

Monthly rainfall in western Mexico

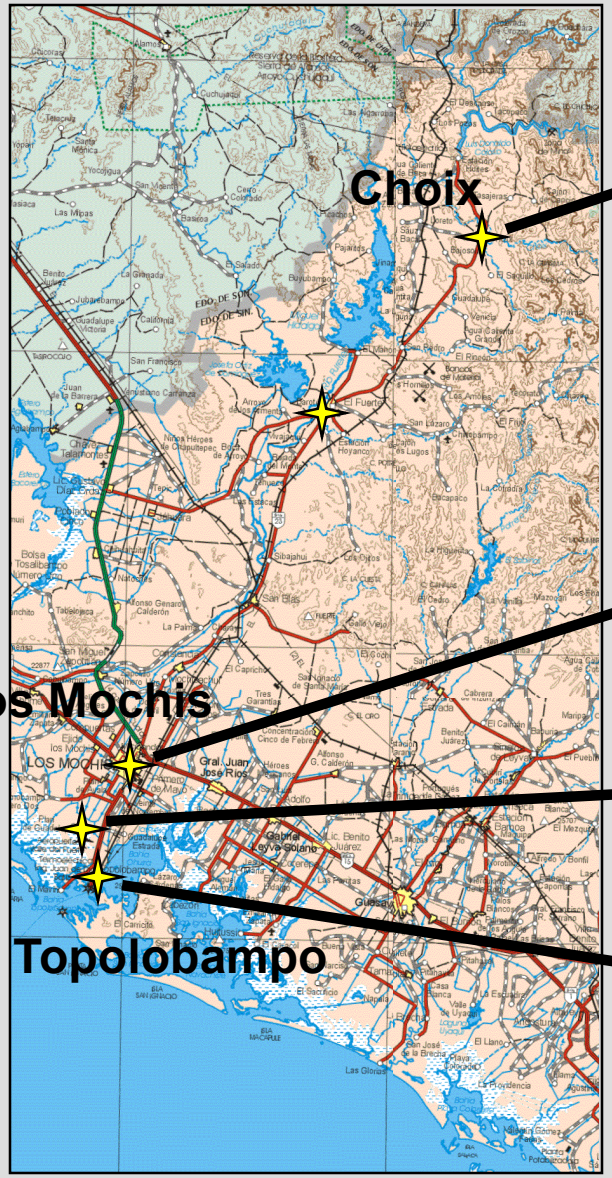


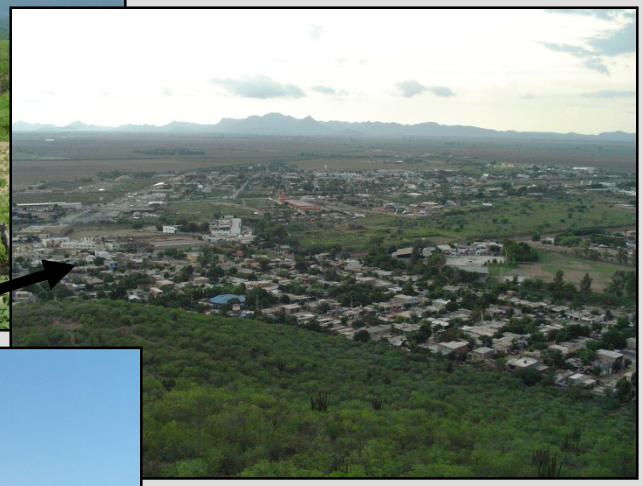
The core of the North American monsoon is in Mexico, not the Southwest U.S.

It accounts for about 60-70% of the rainfall there.

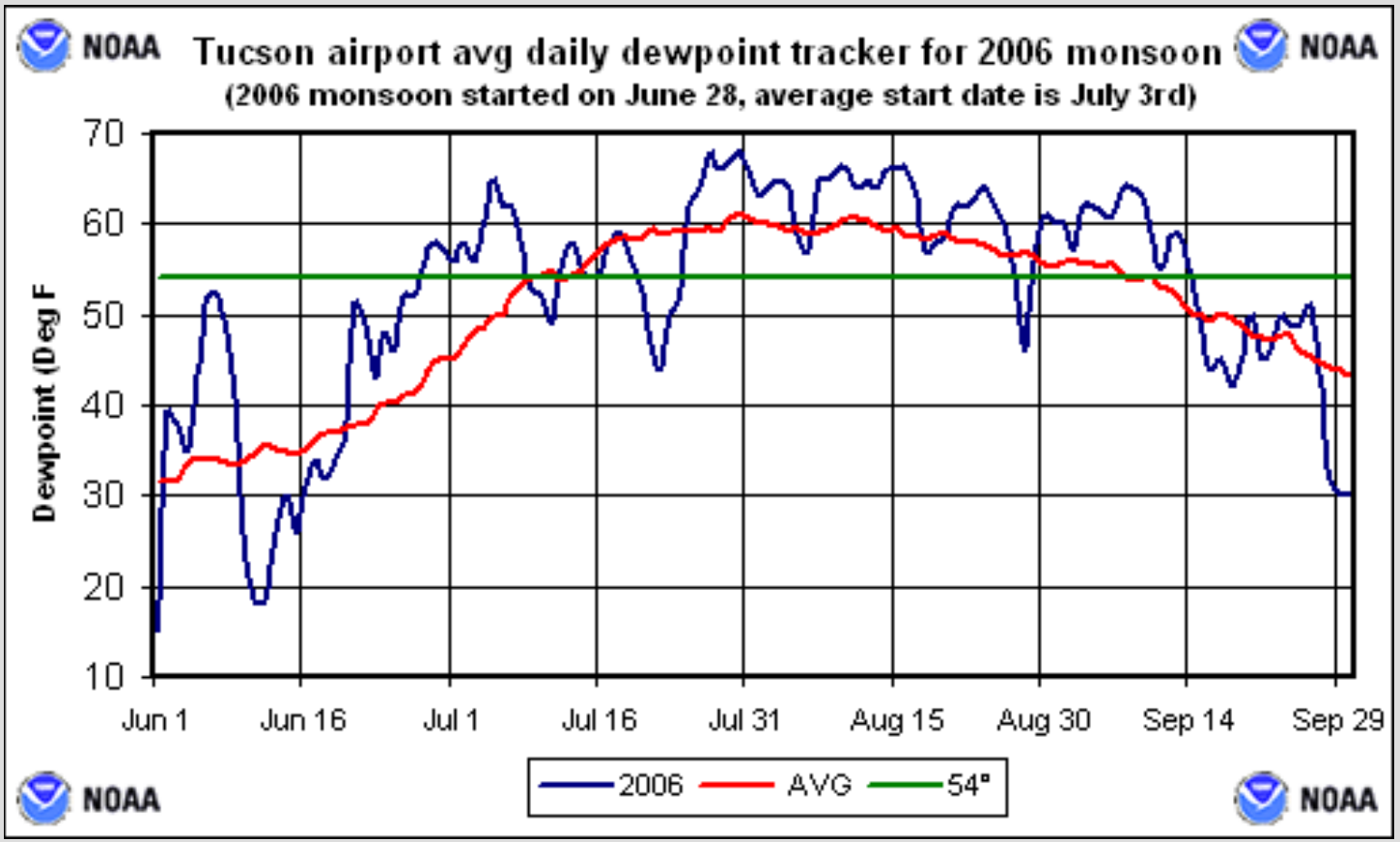
(Douglas et al. 1993)

From Los Mochis to Choix



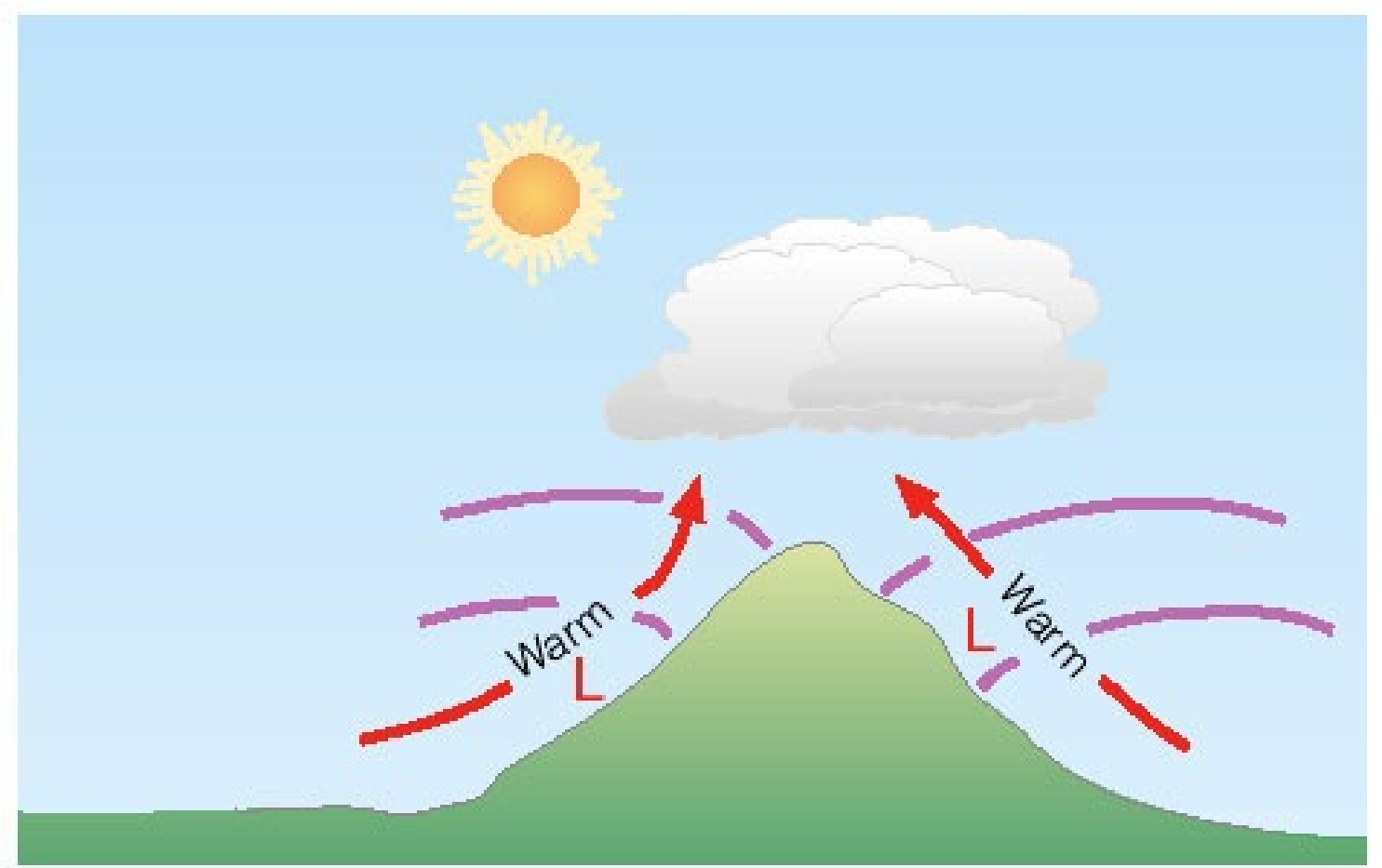


Monsoon in Tucson



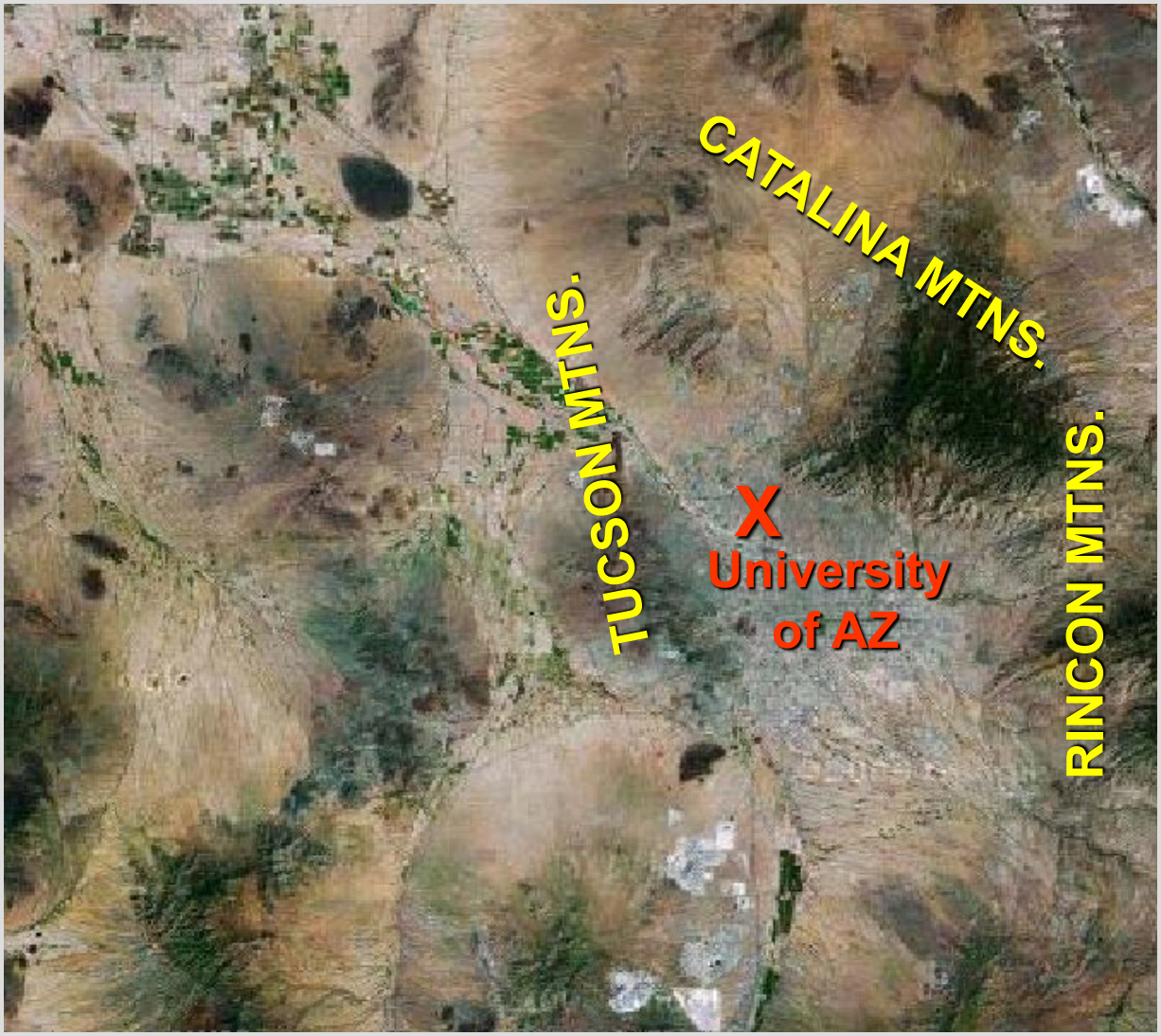
Old definition: monsoon onset defined as when dew point exceeds 54°F for three consecutive days.

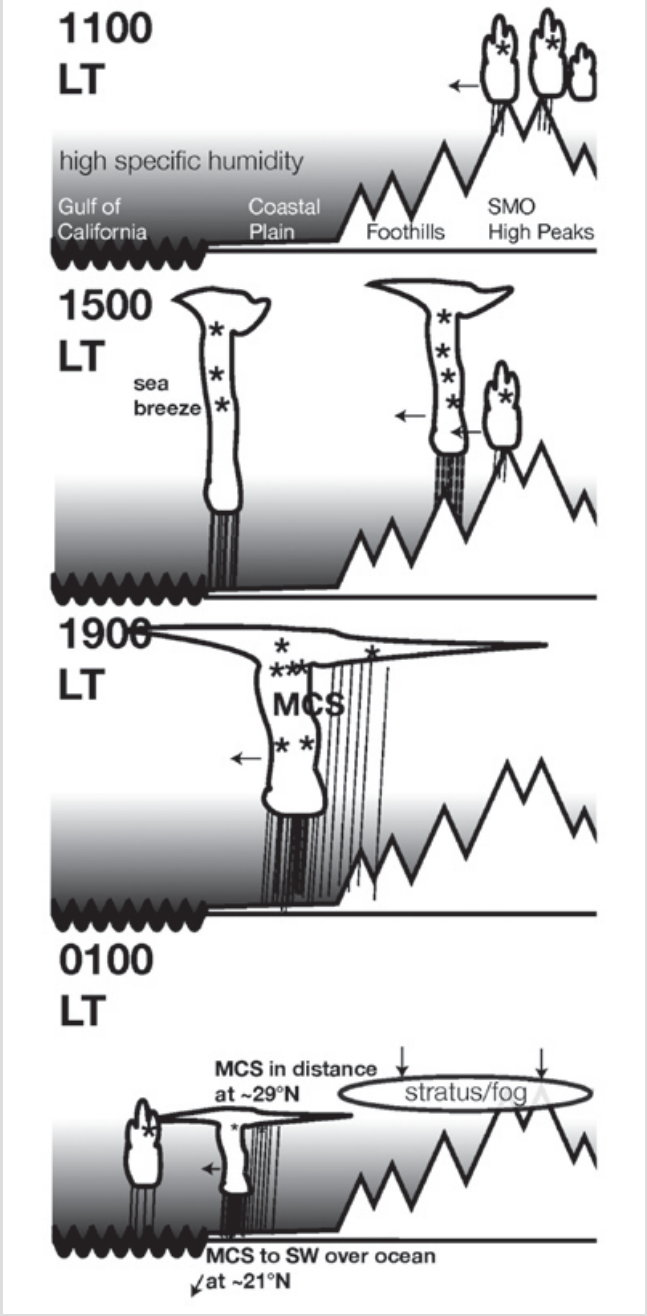
Mountain-valley circulations: What triggers monsoon storms!



Local Topography of Tucson, AZ

We're surrounded by mountains on three sides, so mountain valley circulations play a BIG role in our weather—especially during the monsoon!





Nesbitt et al. (2008)

Convective organization and propagation

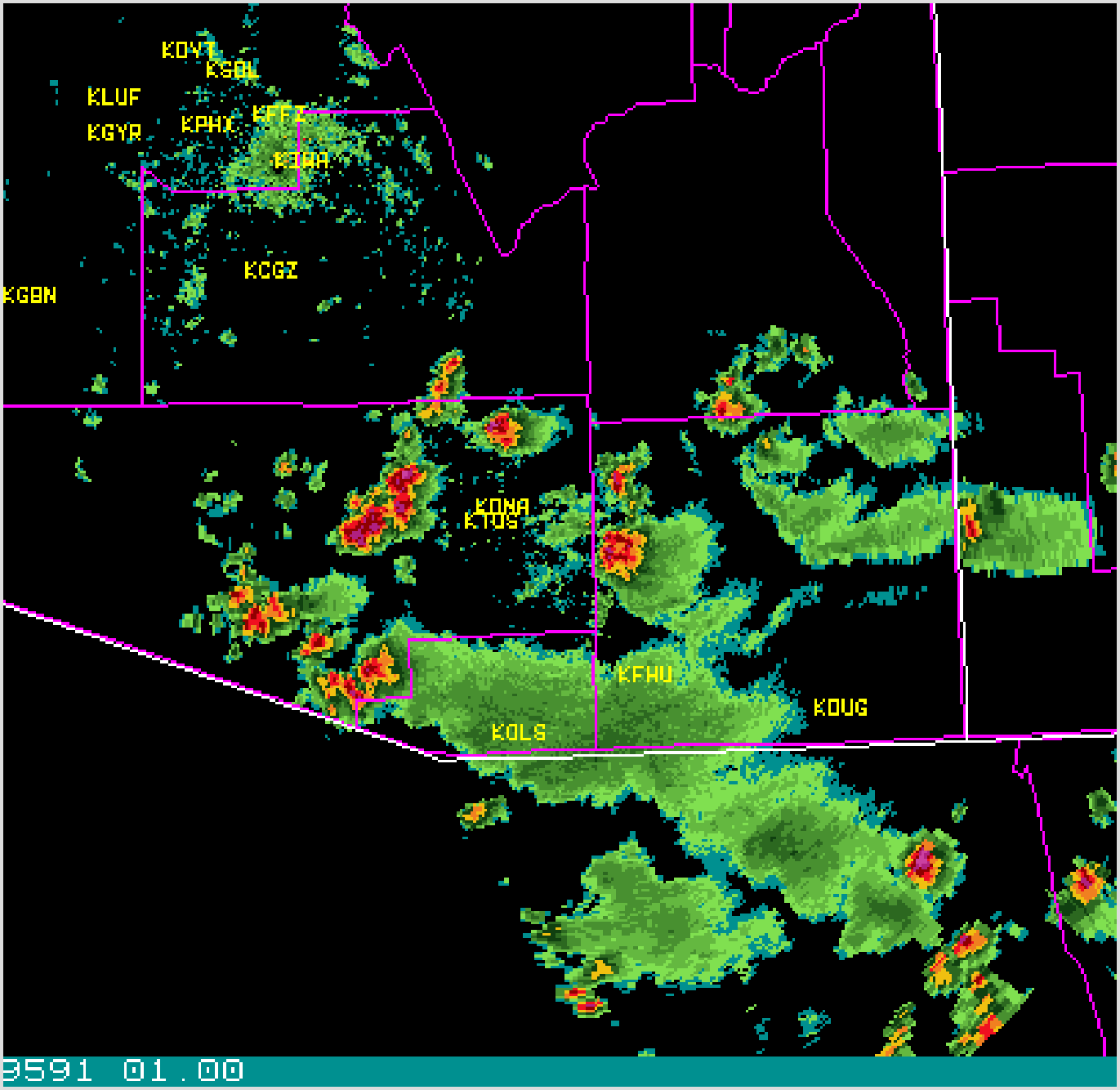
Convective clouds form over the mountains in the morning.

By afternoon and evening storms propagate to the west towards the Gulf of California where they can organize into mesoscale convective systems if there is sufficient moisture and instability.

It's likely that a resolution less than 5 km is necessary to represent this process correctly in regional models. Global models pretty much fail.

Radar reflectivity

July 7, 2009
Late afternoon



Cloud movies
From top of Gould-Simpson Building
University of Arizona
Looking NE towards Catalina Mountains

July 7, 2009

July 21, 2007

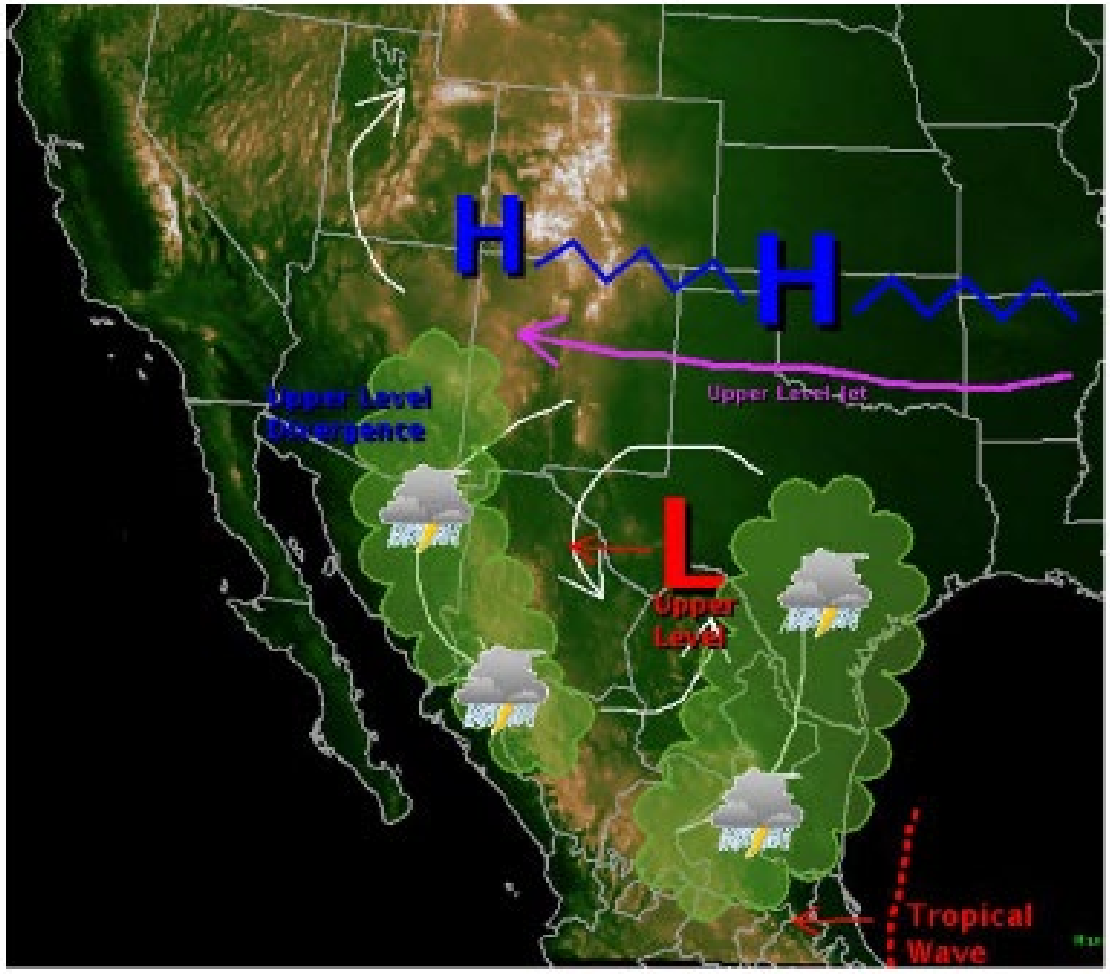


Figure 2: Conceptual hypothesis of a subtropical upper tropospheric low moving west into the North American Monsoon regime. From Pytlak, et al. 2005.

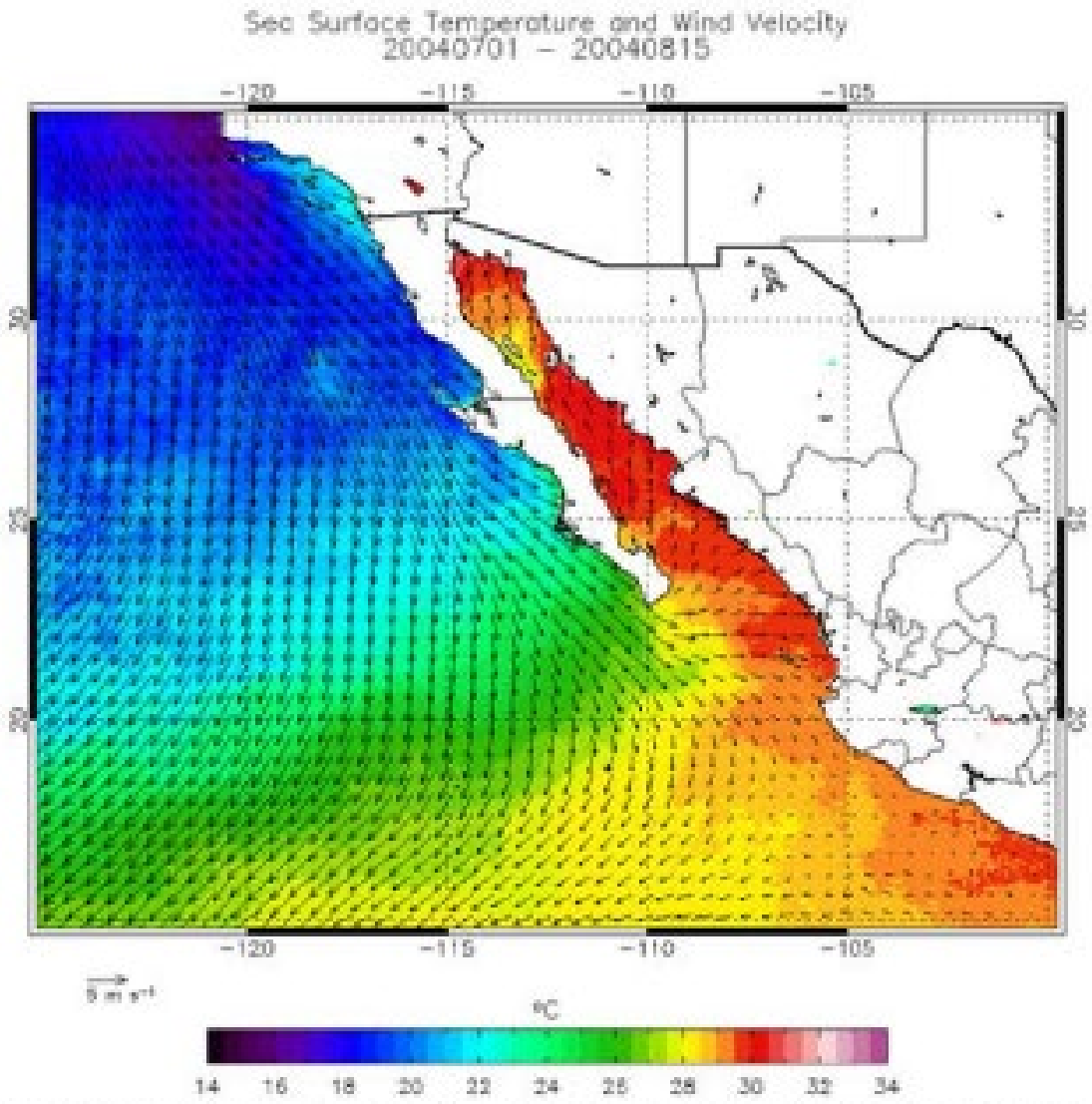


Figure 1: Mean sea surface temperatures (color) and mean surface wind, 1 July-15 August 2004. From Johnson, et al.

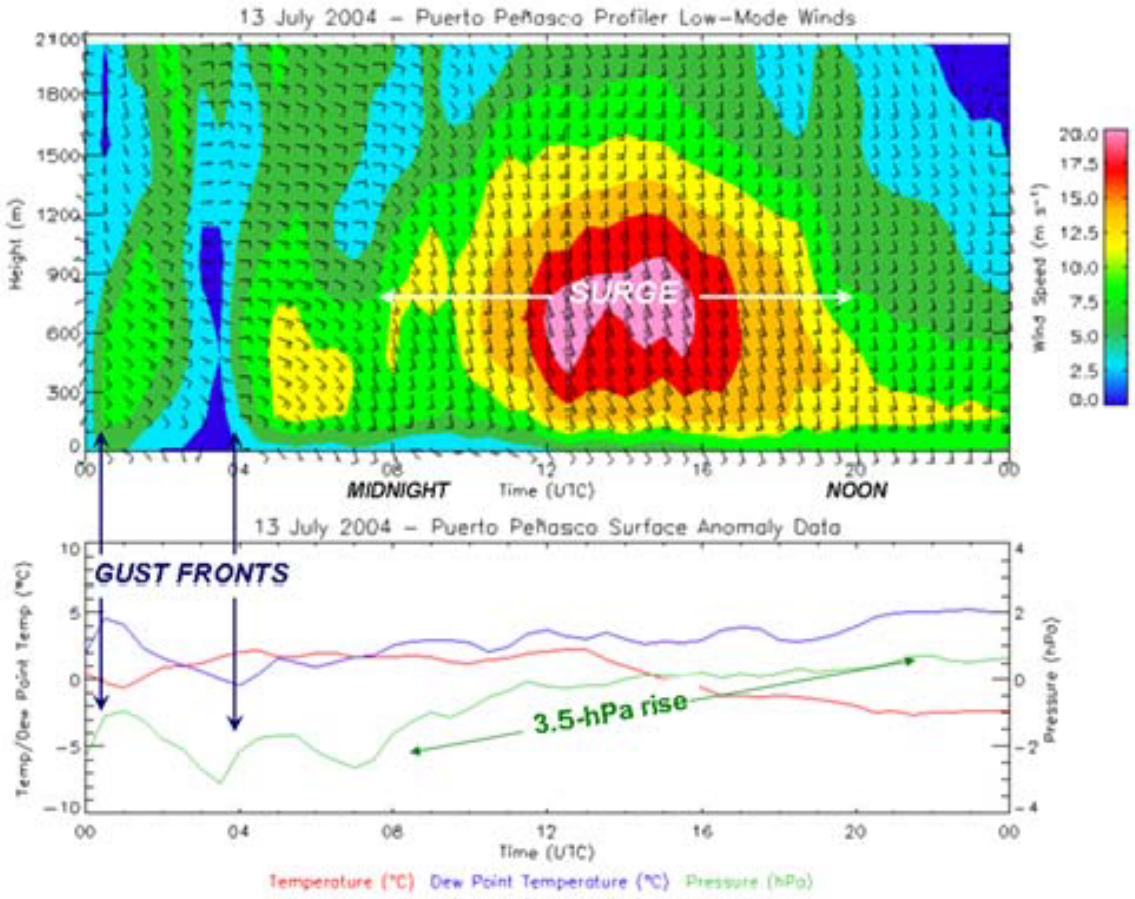
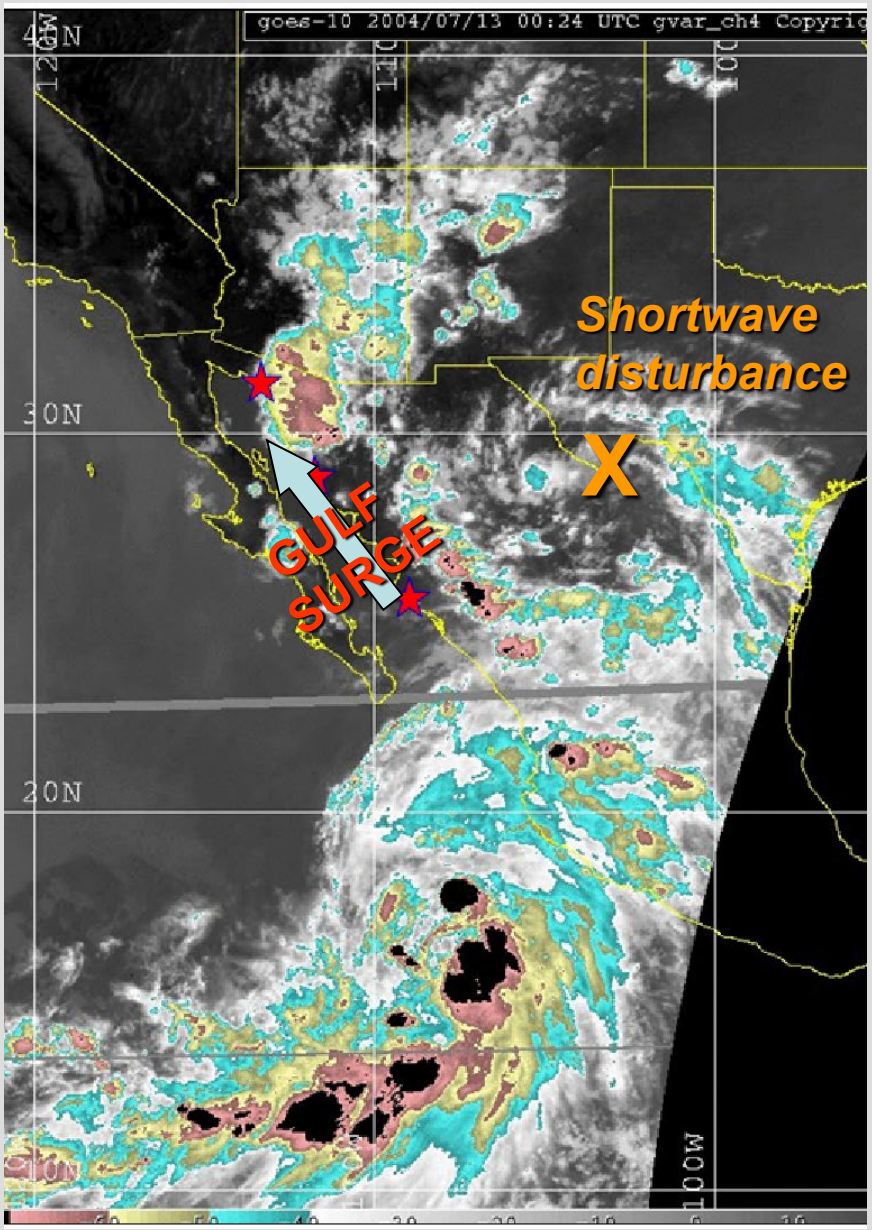


Figure 2: Weak outflow Gulf Surges are followed by a strong (gravity wave) Gulf Surge at Puerto Peñasco, Sonora, 13 July 2004. Note the 20 m/s (45mph winds) just above the surface between 12 UTC (5am MST) and 19 UTC (Noon MST). [NAME data repository on line at http://www.eol.ucar.edu/projects/name



Conditions for enhanced monsoon thunderstorms

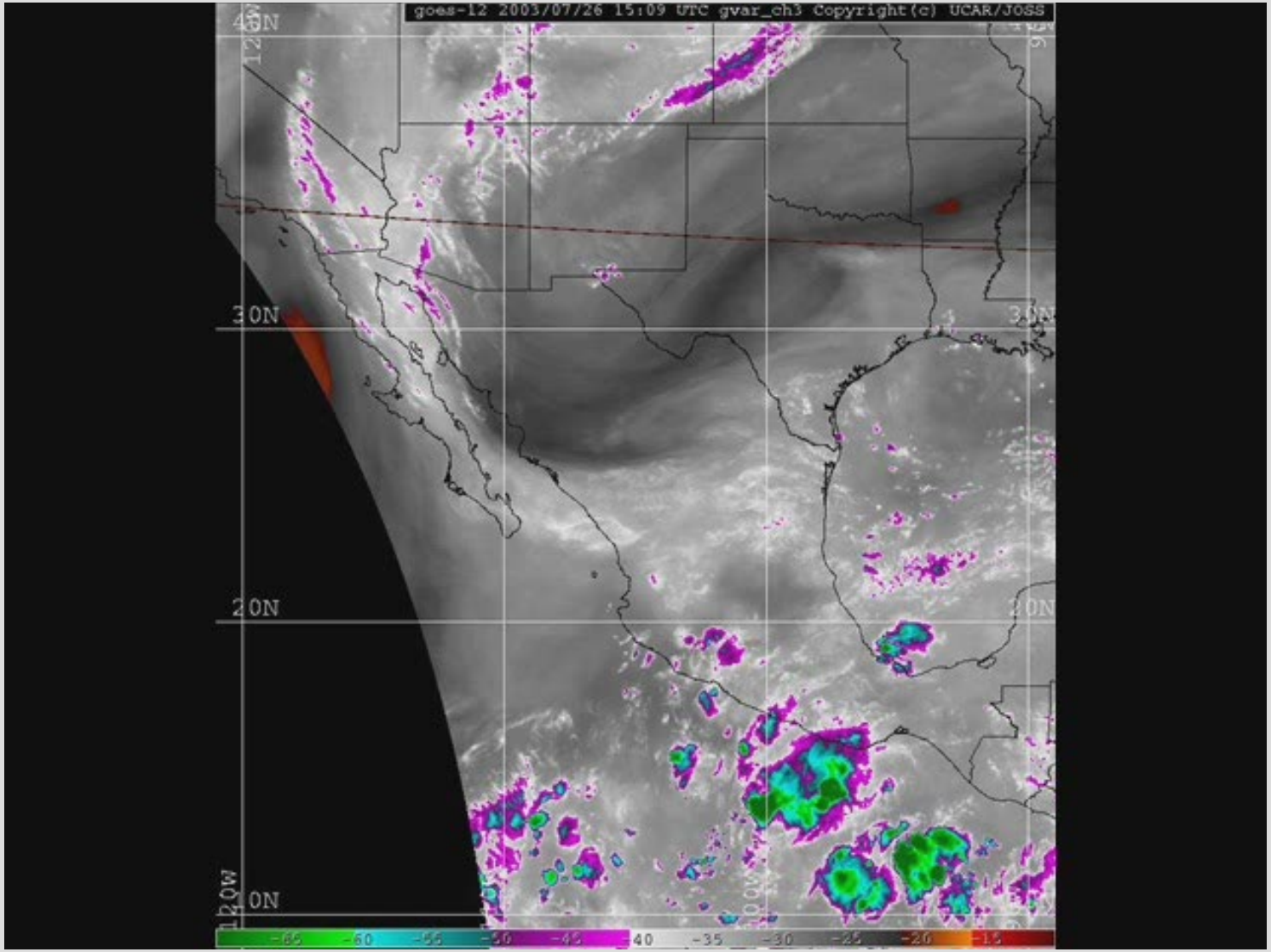
An upper-level disturbance (X) traveling around the monsoon ridge.

Low level-moisture surging up the Gulf of California

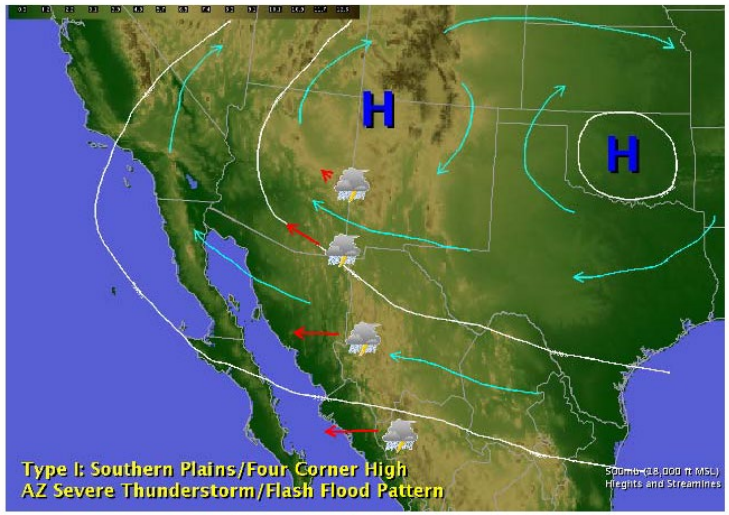
RESULT

Thunderstorms which originate on the Mogollon Rim intensify and move westward toward low deserts and the Colorado River Valley.

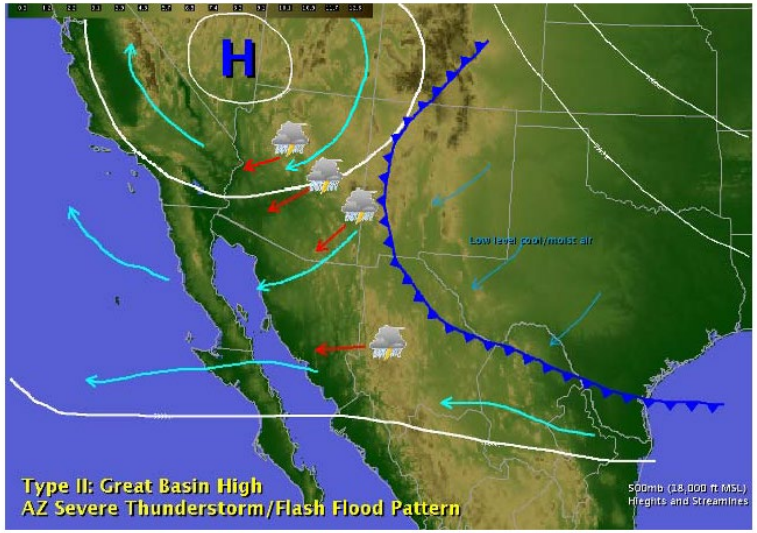
An active monsoon day…



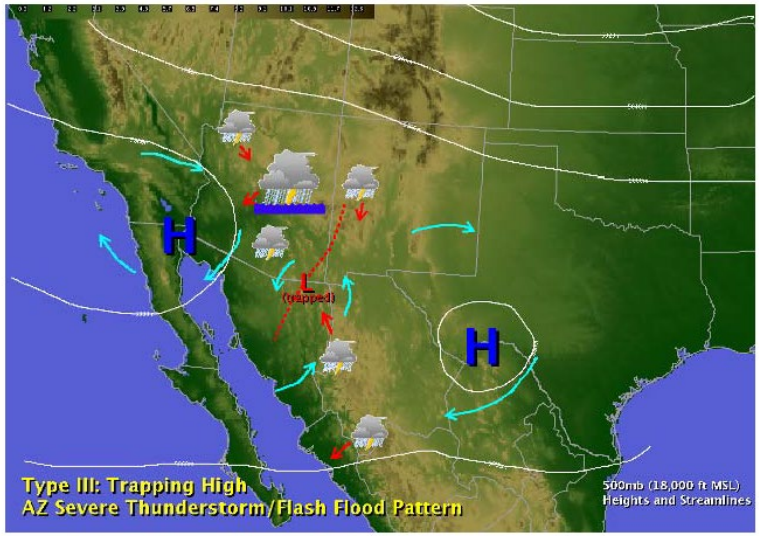
Maddox monsoon severe weather patterns



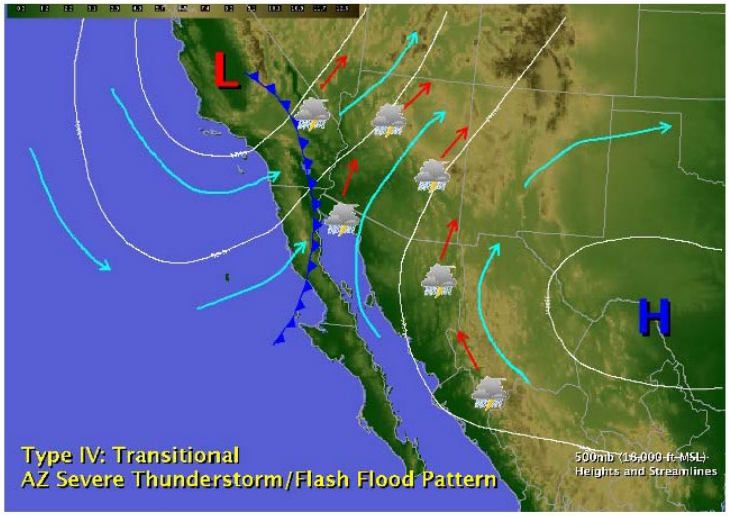
Type I: Southern Plains / Four Corner High



Type II: Great Basin High



Type III: Trapping High



Type IV: Transitional

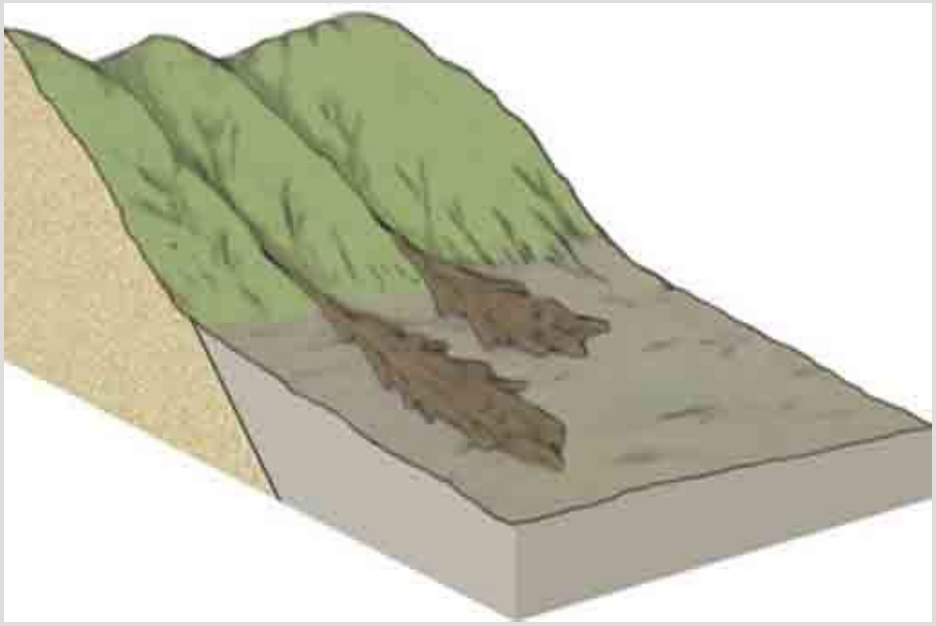
Monsoon Severe Weather Hazards

Flash Flooding

ARROYOS

CANYONS AND DRY RIVERBEDS

Debris Flows



Rapidly moving flows of mixed rock, mud, and water

Sabino Canyon 2006 was a classic example

Sabino Canyon Debris Flows

Microburst

Precipitation in the downdraft part of the thunderstorm evaporates (partially or fully) before it hits the ground.

Cooled air sinks rapidly toward the surface.

Dry microburst near Denver, CO.

Wet microburst on the west side of Tucson, near Ryan Field

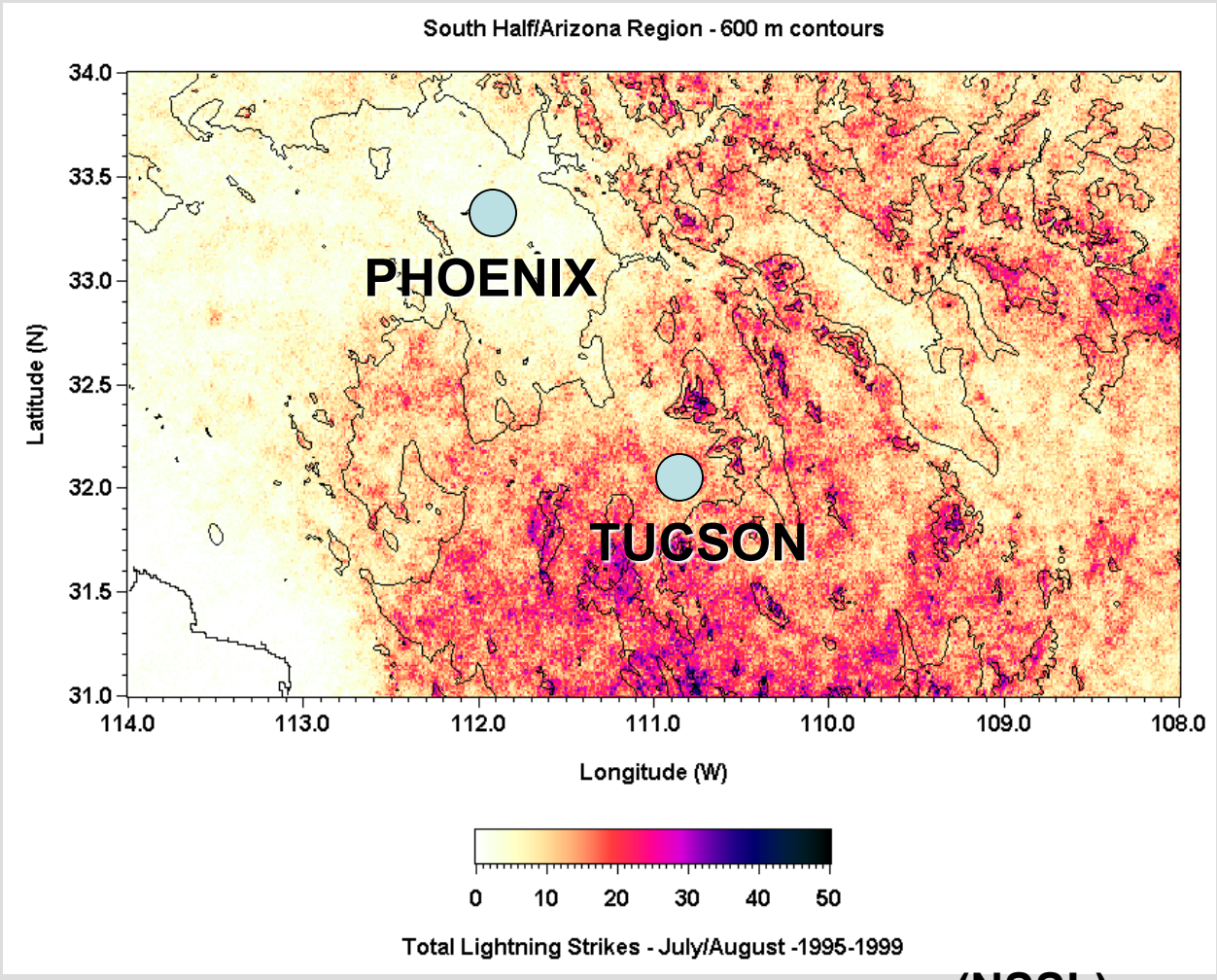
Haboob: Dust or sand storm

Phoenix, Arizona

Caused by rapid movement of air associated with a dry microburst.

Typical as the monsoon gets going in late June or early July.

Tucson Lightning Distribution
Southern Arizona



<u>Why more here?</u>

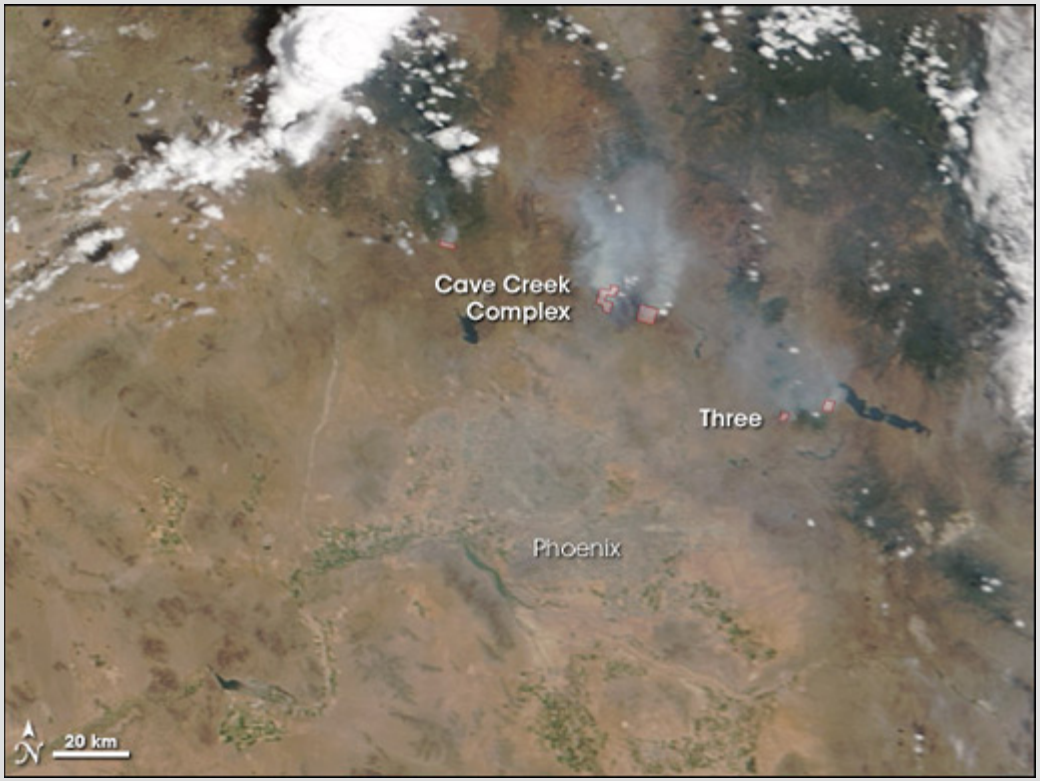
HIGHER ELEVATION

CLOSER TO MTNS.

MORE RAINFALL

(NSSL)

Lightning and Wildfire Danger in Arizona



NASA Image of Cave Creek fire in late June 2005

Lightning induced wildfire is a threat in Arizona, which is most acute right before the monsoon.

Factors:

Dry thunderstorms that produce lightning and wind but little or no rainfall.

Late spring and early summer before the monsoon is the driest and hottest part of the year.

Current monsoon research at UA Department of Atmospheric Sciences

High resolution real-time monsoon forecasts

Forecast sensitivity to specification of observed data

Sensitivity of monsoon storms to urbanization

High resolution seasonal forecasts and climate change projections

Hydrologic forecasting