The North American Monsoon: It's What Makes Summer Weather Interesting in Arizona!

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Biosphere 2 Science Saturdays
October 10, 2009

ATMOSPHERIC SCIENCES
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Today’s presentation

What is a monsoon and why do we have one in Arizona?

How do monsoon storms form?

Monsoon severe weather hazards

Is it predictable?

Ongoing research at the Department of Atmospheric Sciences

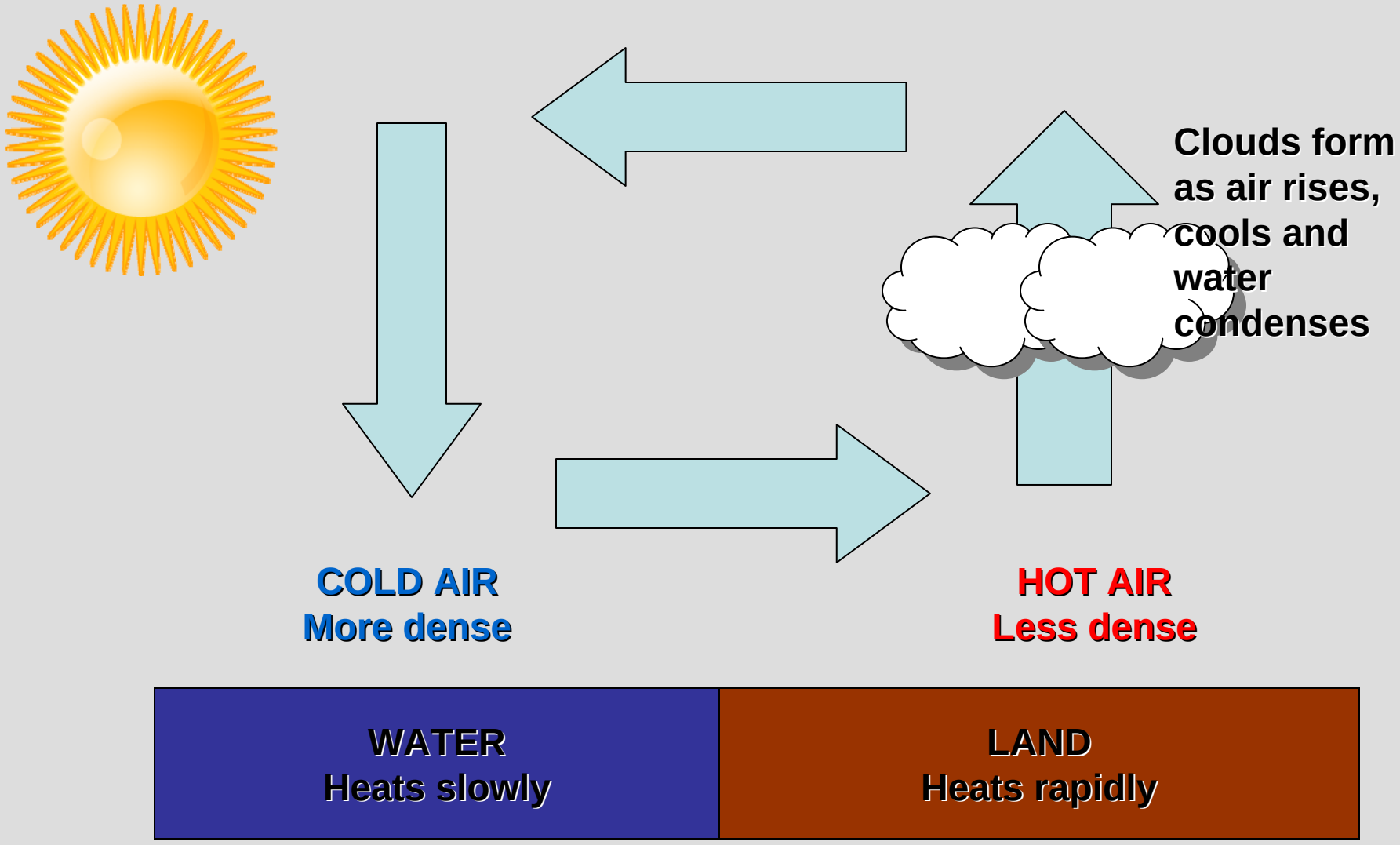
What is a monsoon?

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

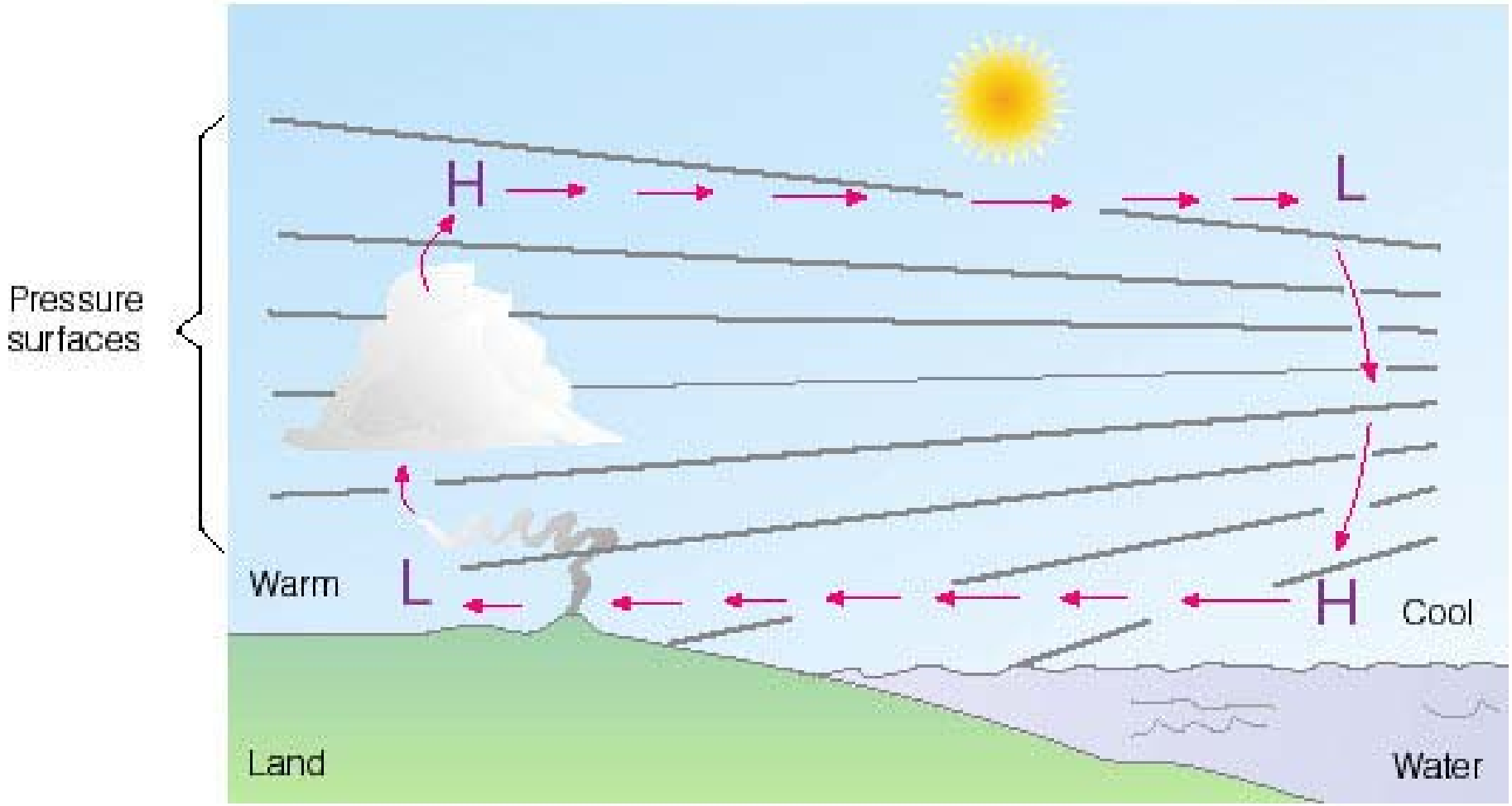
Derived from Arabic mausim, which means season.

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

Thermally direct circulation

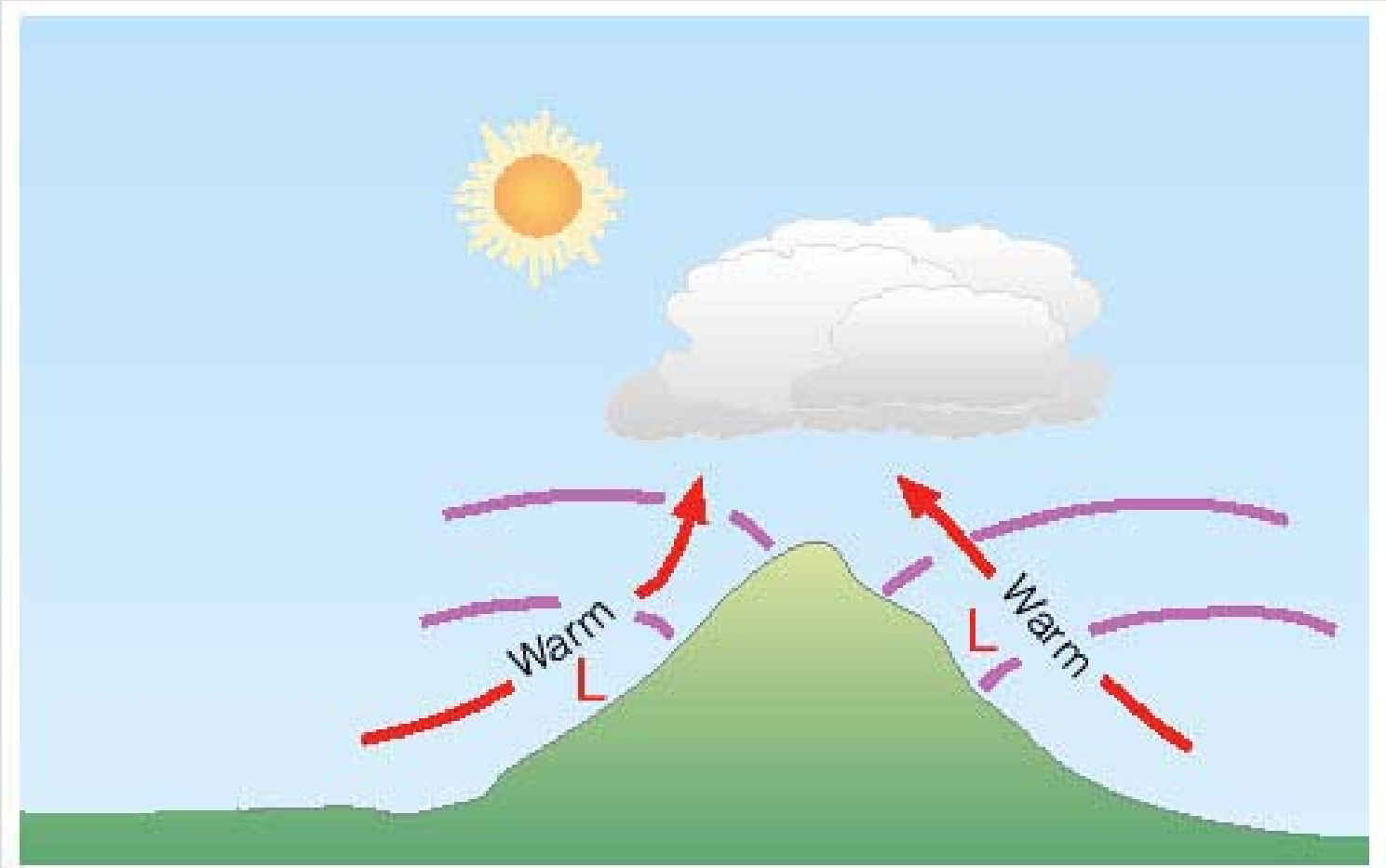


Sea Breeze



(a) Sea breeze

Mountain-Valley circulation



Valley Breeze

A monsoon is like a combination of a sea breeze and mountain-valley circulation, except on a continental scale.

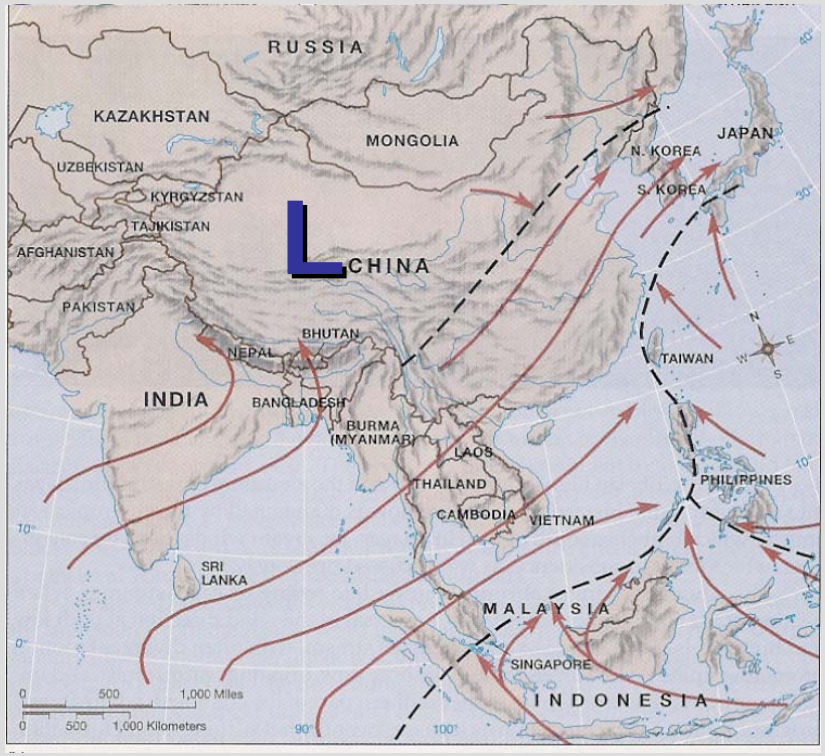
Why is the strongest monsoon in India?

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)

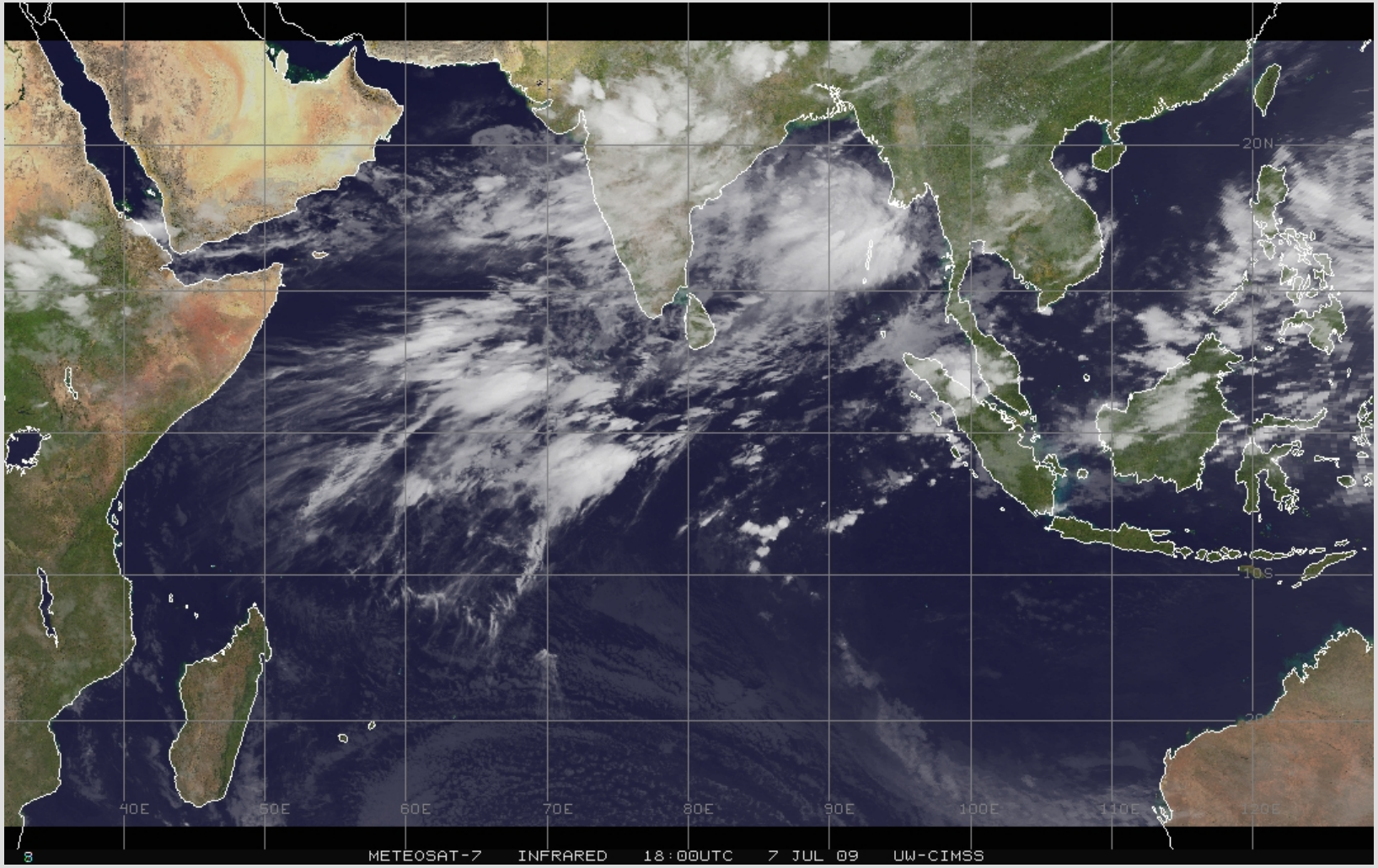
Tibetan Plateau is relatively warmer than the surrounding ocean off Asia

Warm air over the Tibetan Plateau is relatively less dense

Wind flows from the ocean to the Tibetan Plateau.

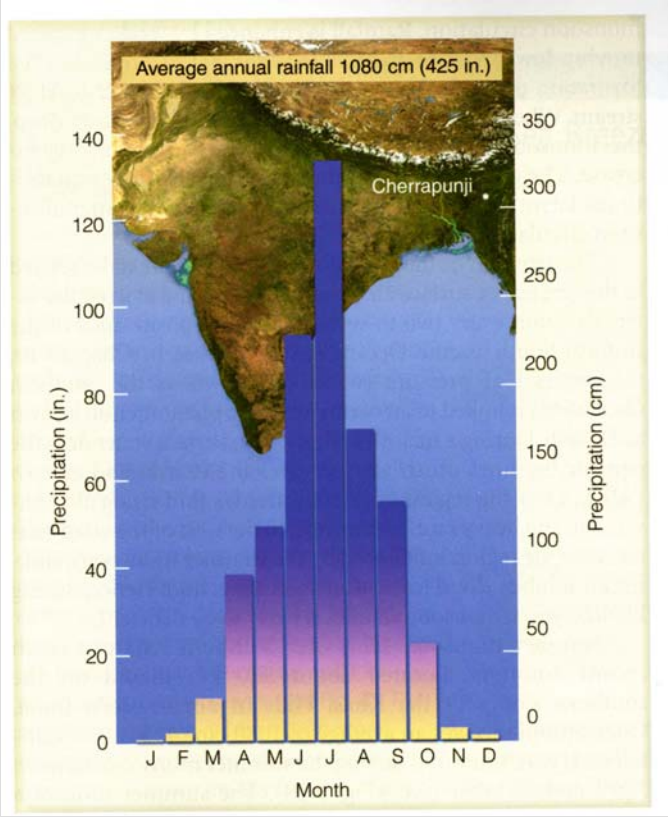
Onshore flow transports moisture to the interior of Asia.

Indian Monsoon: July 7, 2009
Infrared satellite image



The monsoon in India is REALLY WET!

Monthly rainfall
Cherrapunji, India



ONE OF THE WETTEST SPOTS ON EARTH!

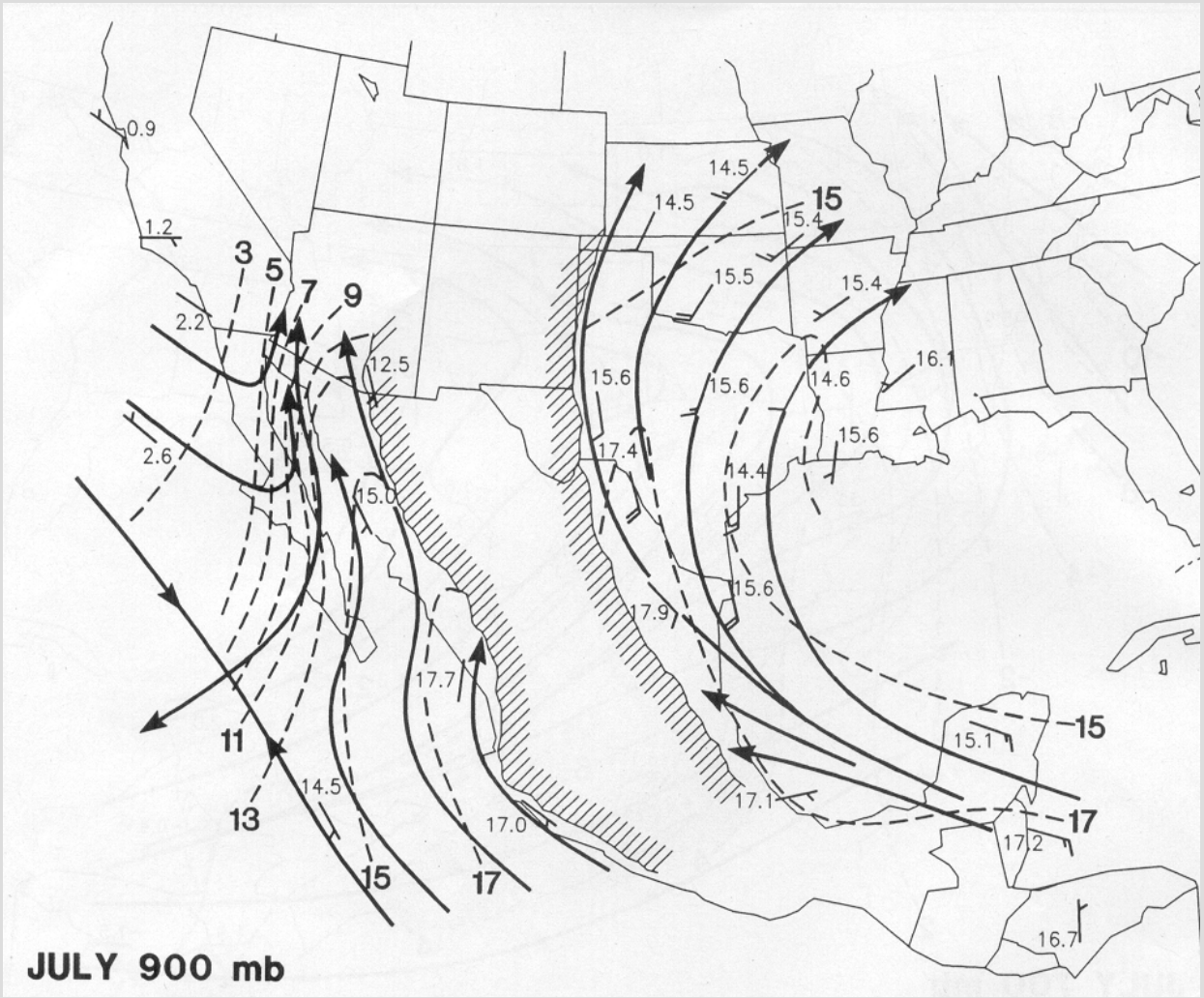
Why a North American Monsoon?

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



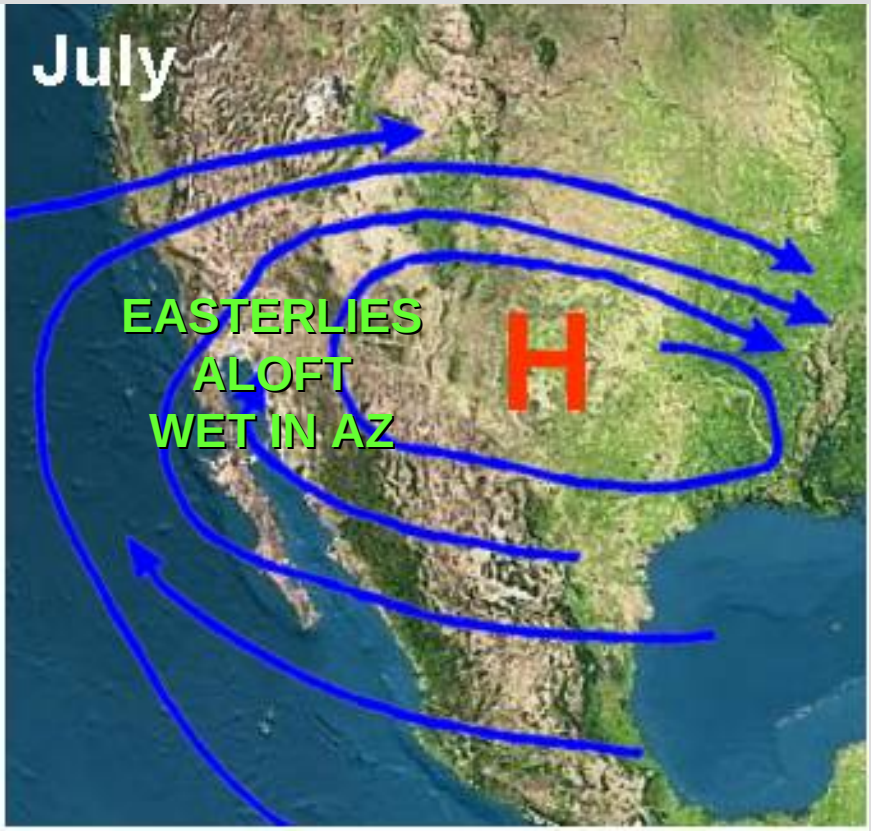
(Douglas et al. 1993)

Air flow at about 20 thousand feet

Before monsoon

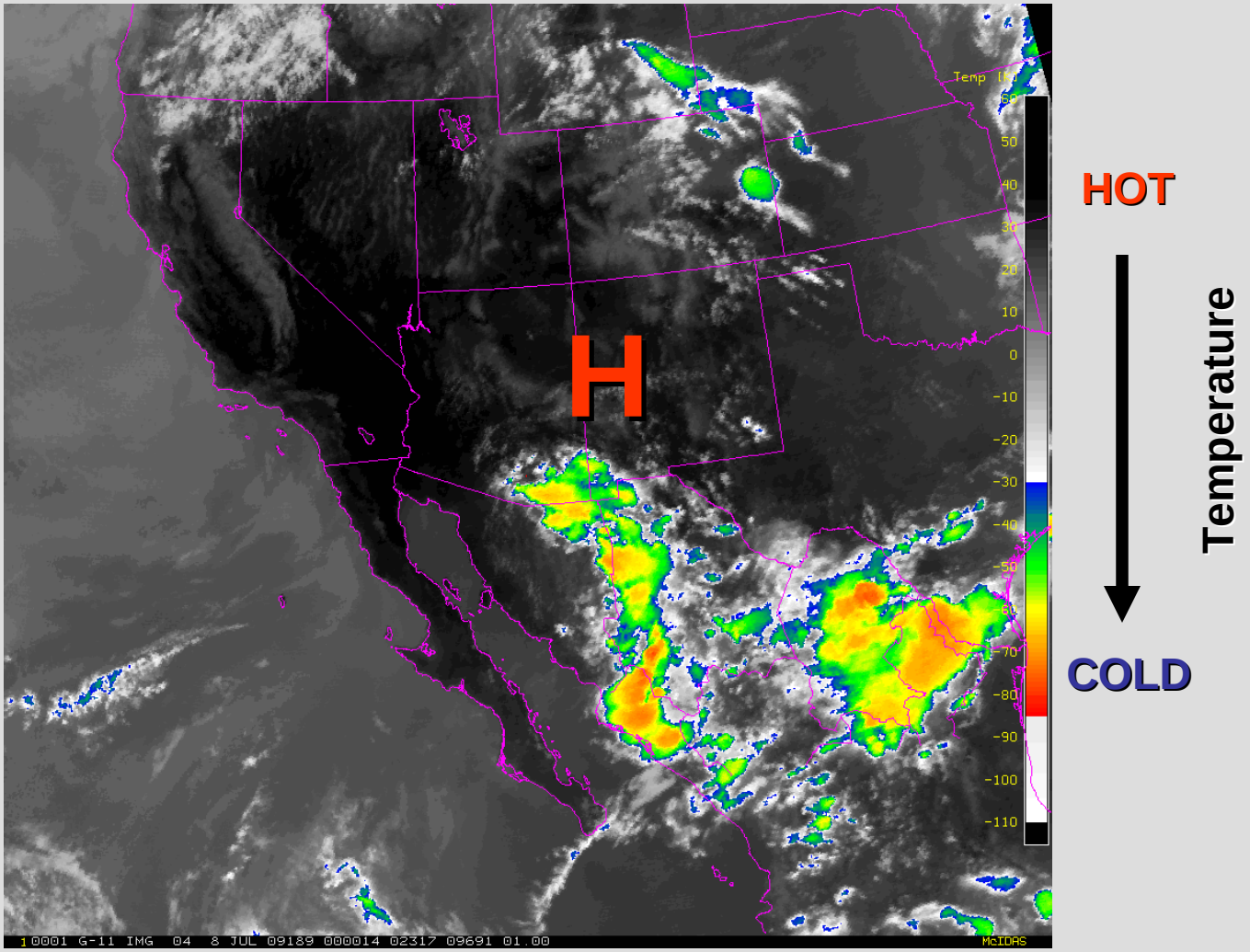
Westerlies aloft.
High pressure ridge to the south.
Little moisture at upper levels.

During Monsoon



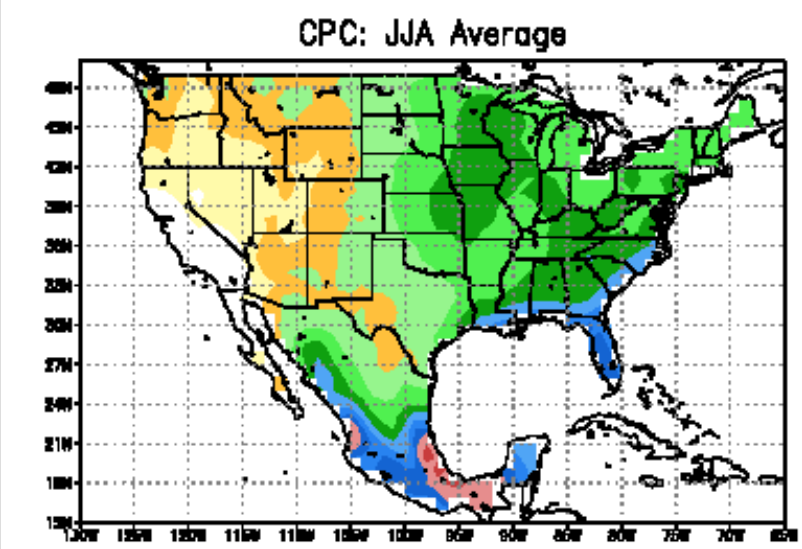
Easterlies aloft.
High pressure ridge to north (and east)
Moisture transport from Gulf of Mexico

Monsoon storms on July 7, 2009
Enhanced Infrared Satellite Image

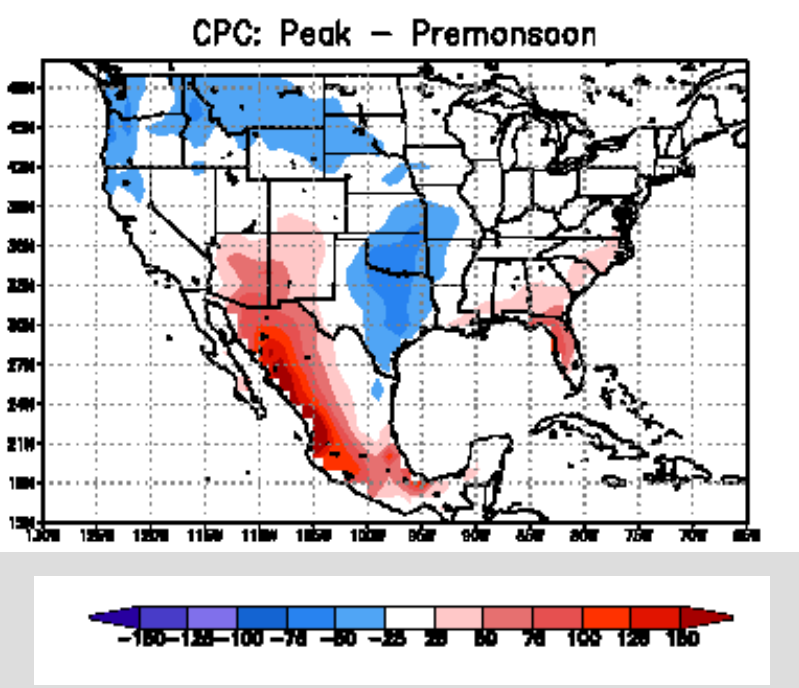


Continental Scale Shift in Rainfall (mm)

Summer Average Rainfall



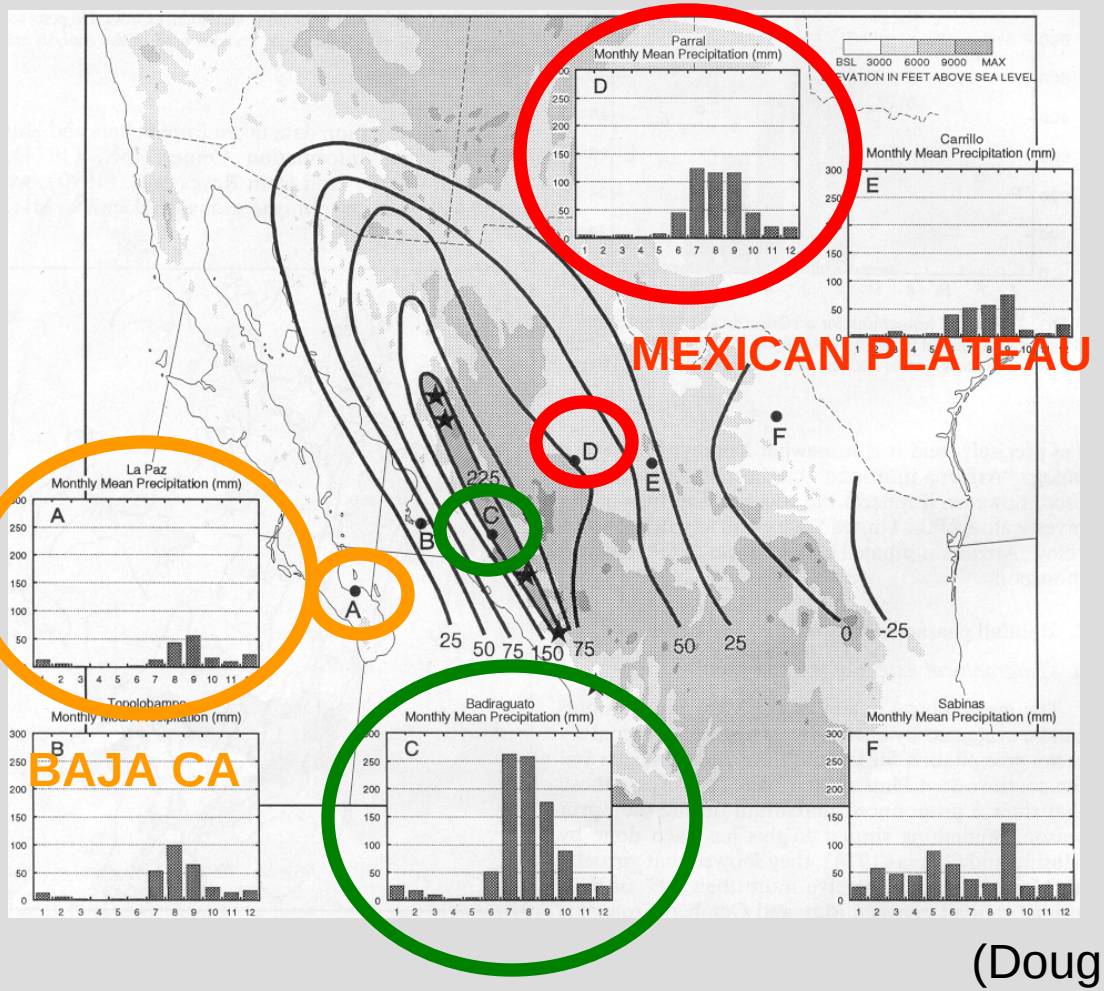
During monsoon – before monsoon



(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



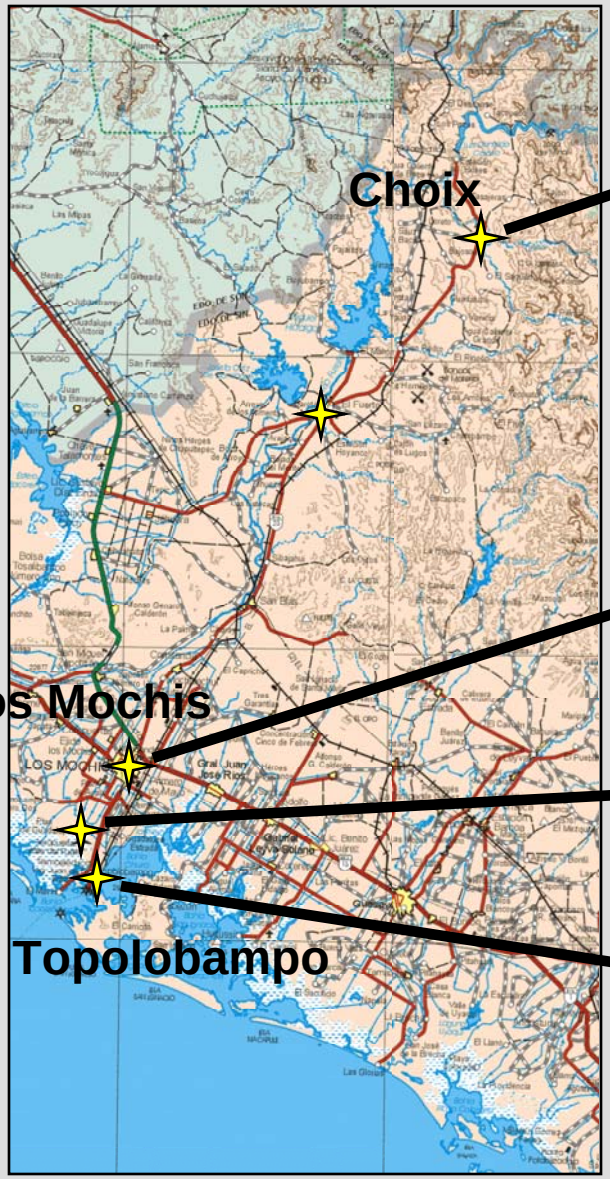
The core of the North American monsoon is in Mexico, not Arizona

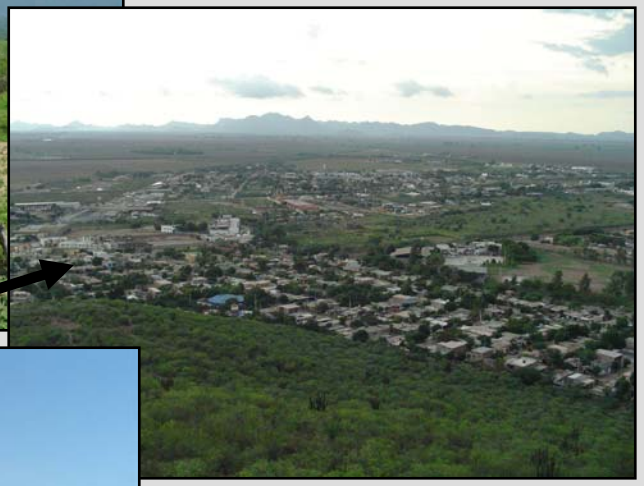
It accounts for about 60-70% of the rainfall there.

(Douglas et al. 1993)

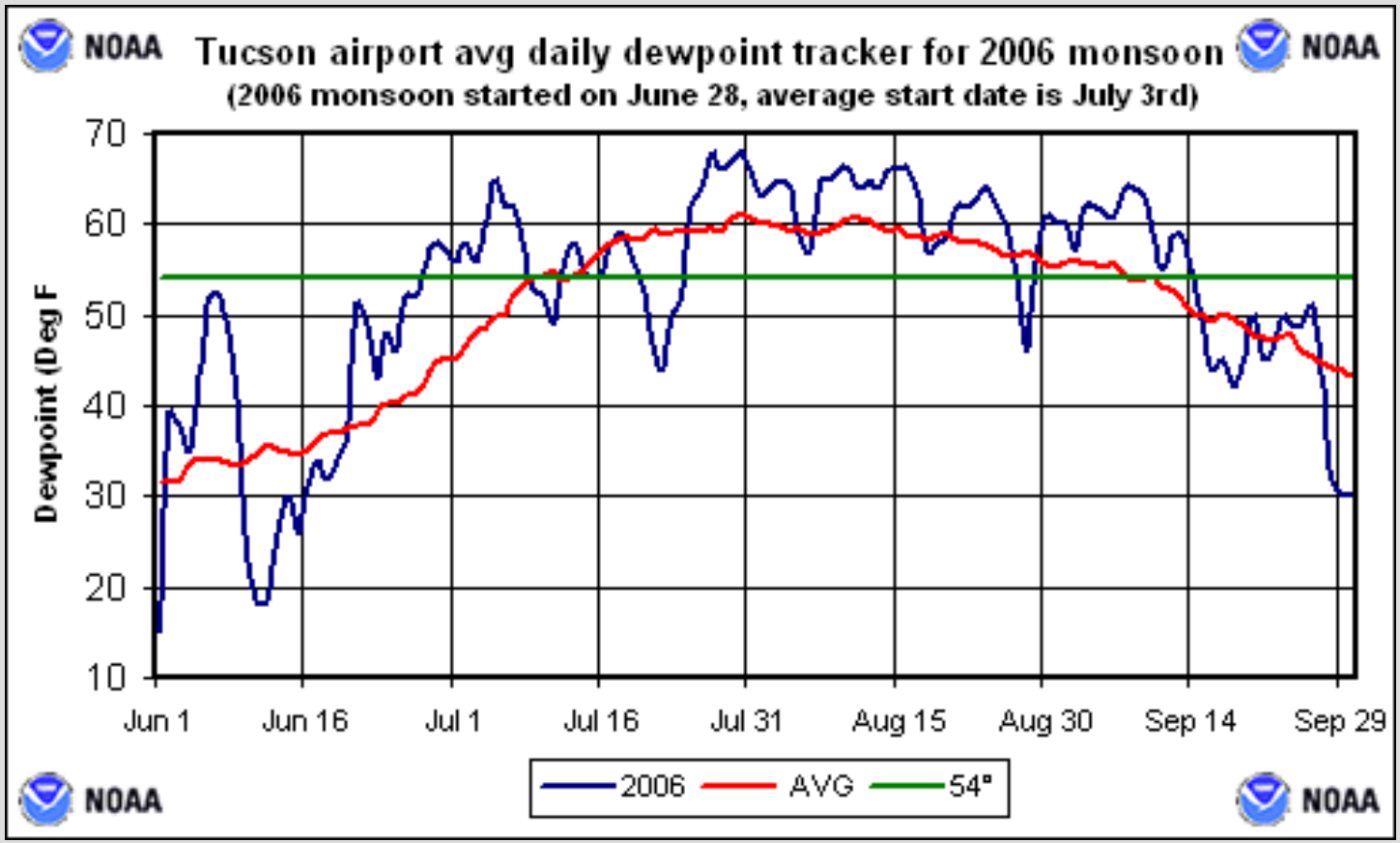
SIERRA MADRE OCCIDENTAL

From Los Mochis to Choix



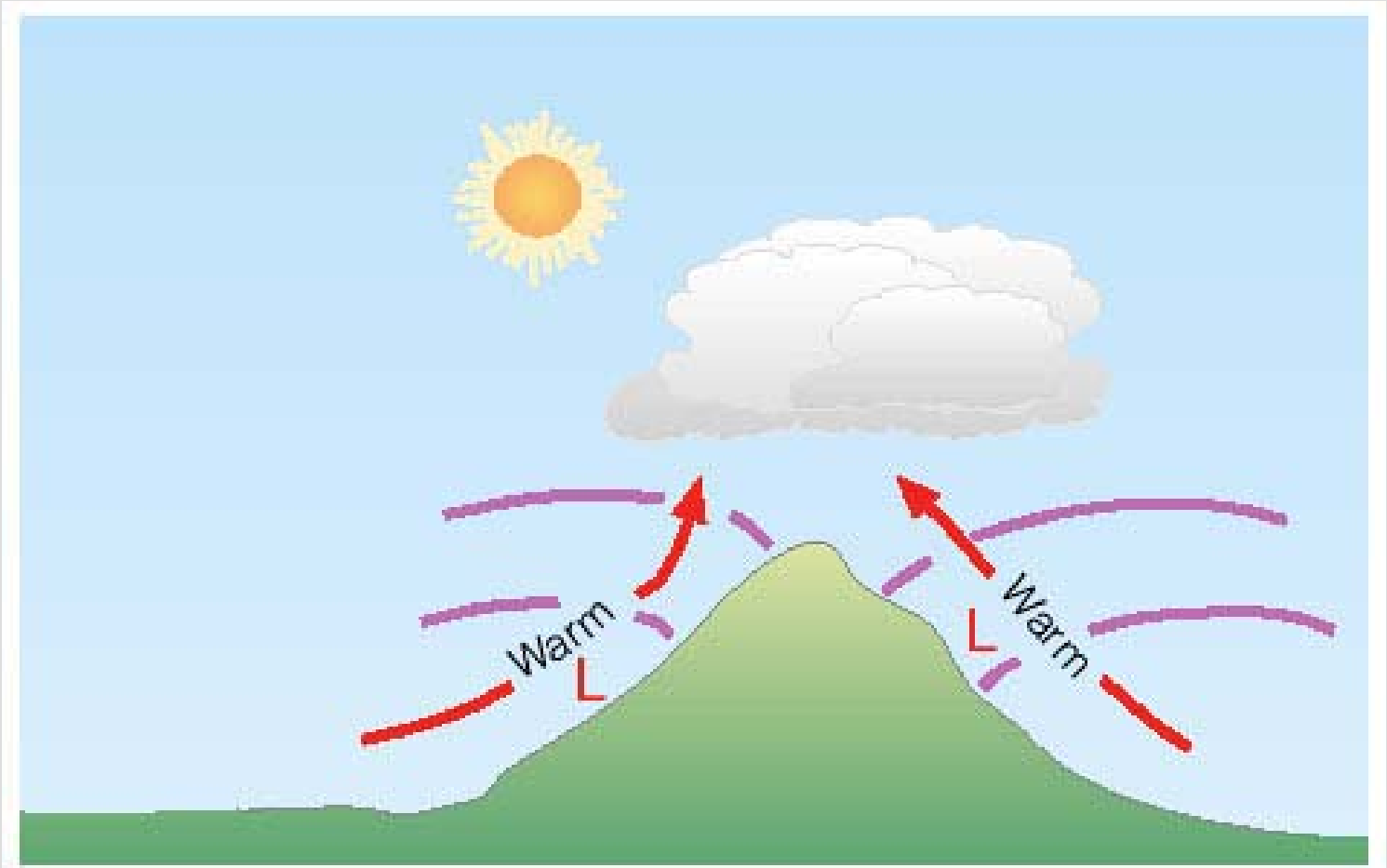


Monsoon in Tucson



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

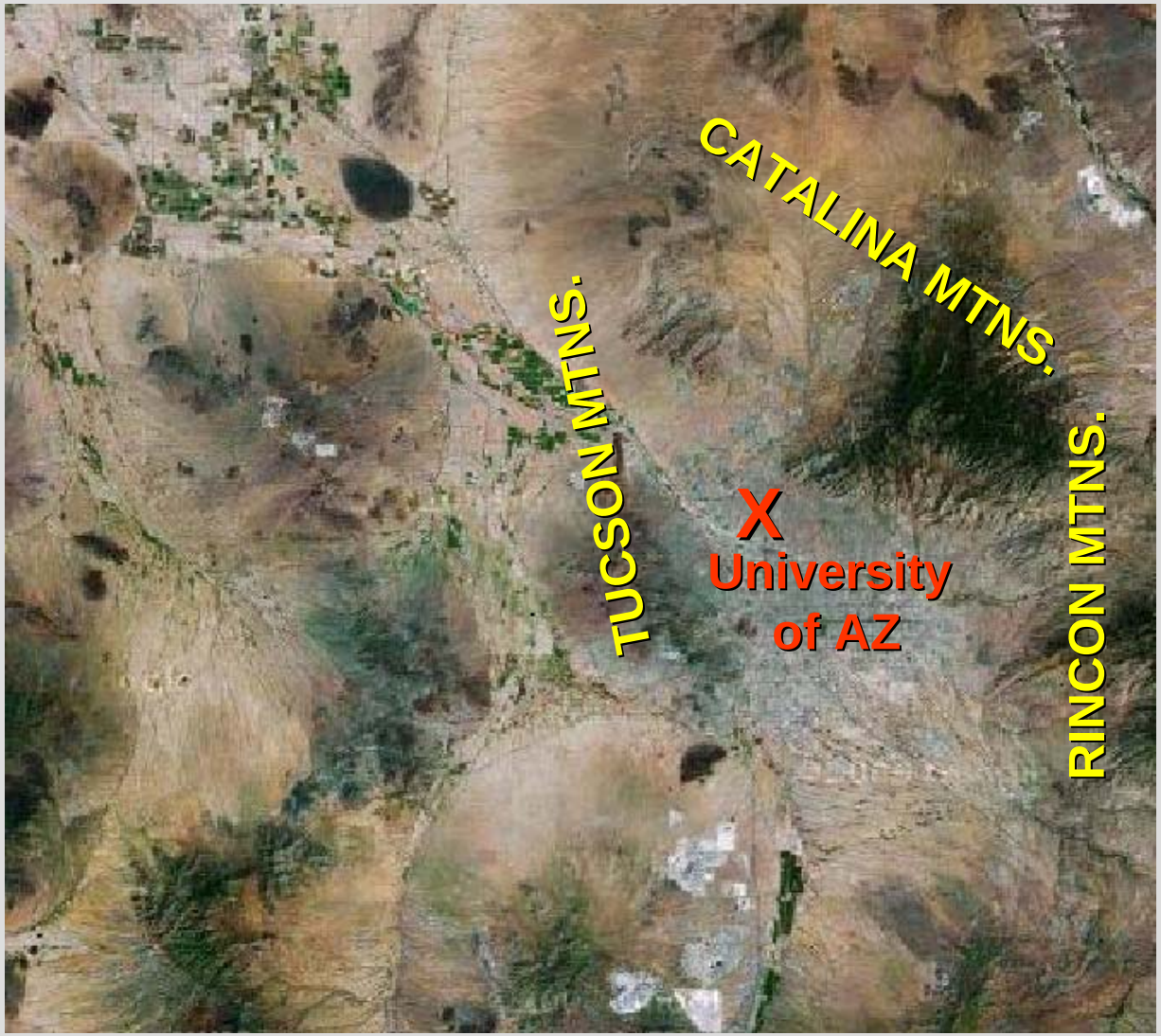
Mountain-valley circulations: What triggers monsoon storms!



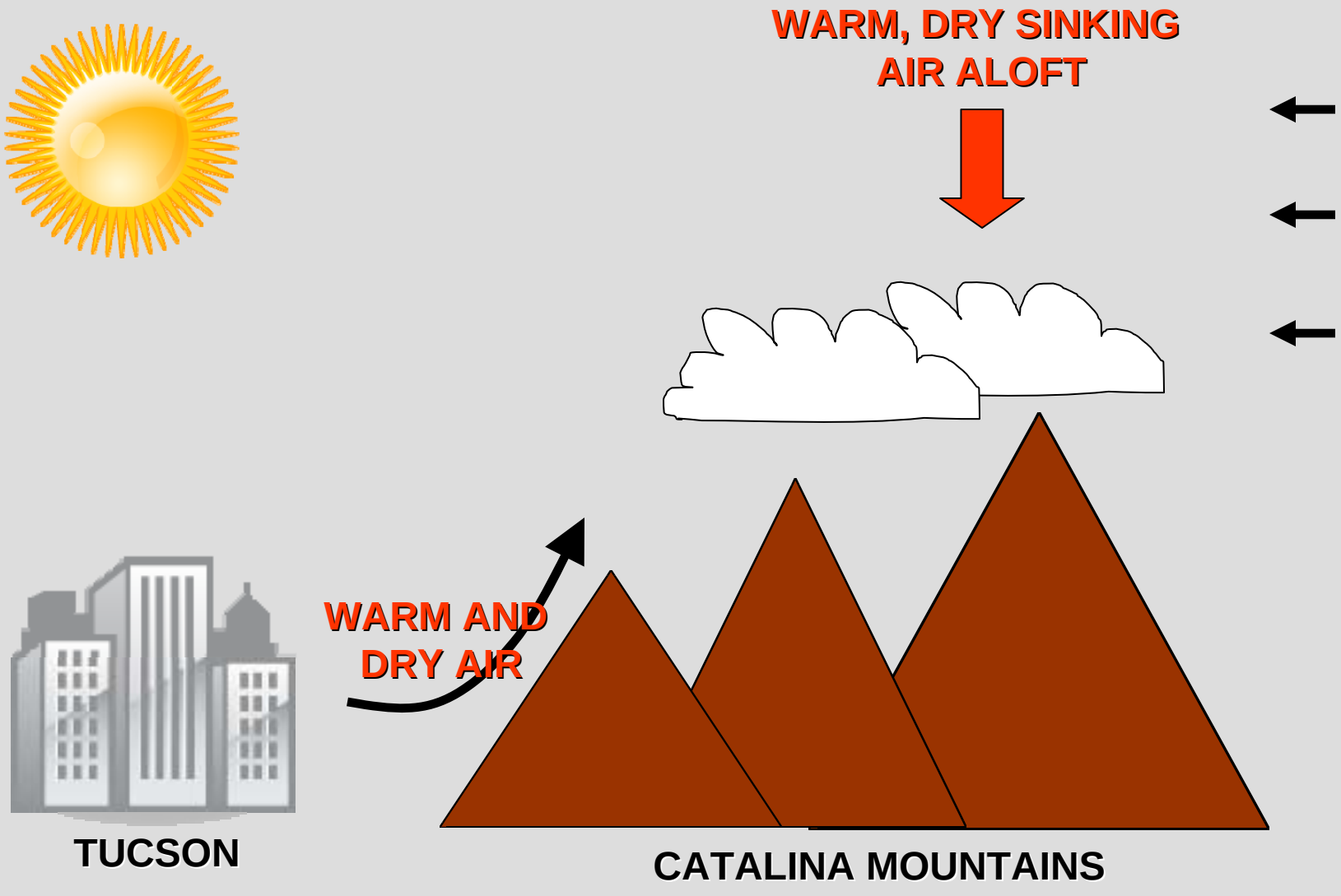
Valley Breeze

Local Topography of Tucson, AZ

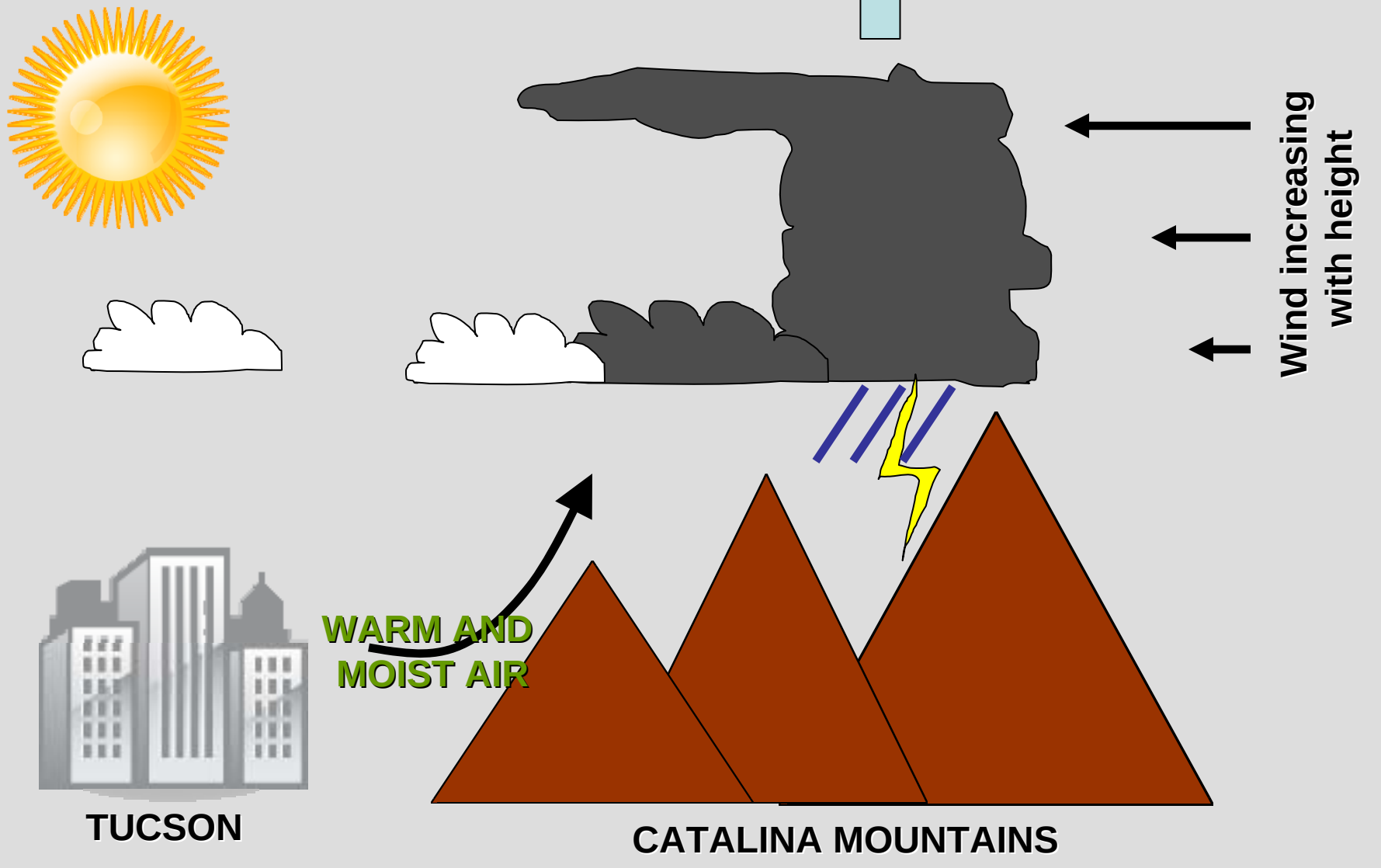
We're surrounded by mountains on three sides, so mountain valley circulations play a BIG role in our weather—especially during the monsoon!



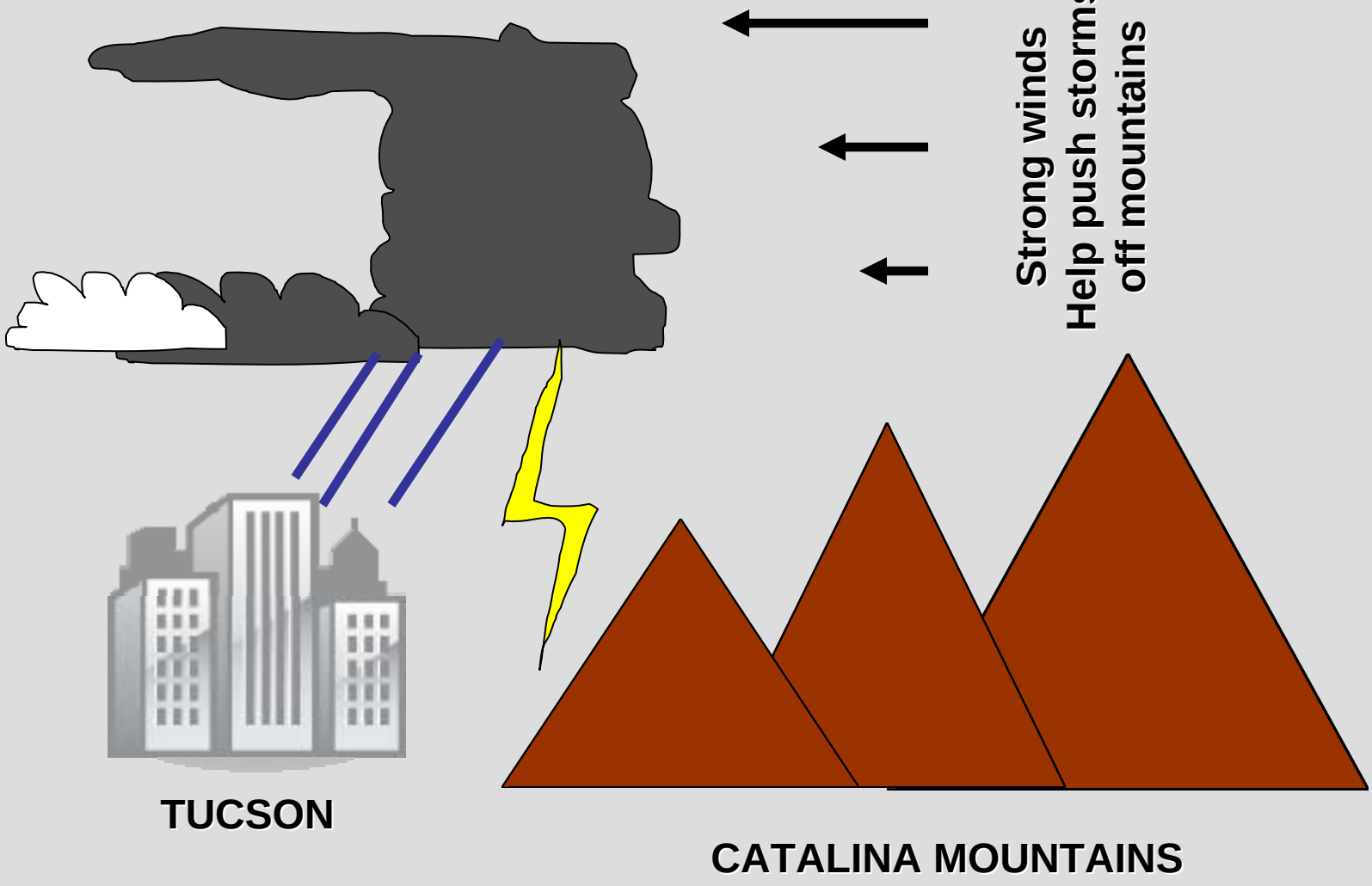
When the clouds just hang out over the mountains…and it's just hot and sunny in Tucson.



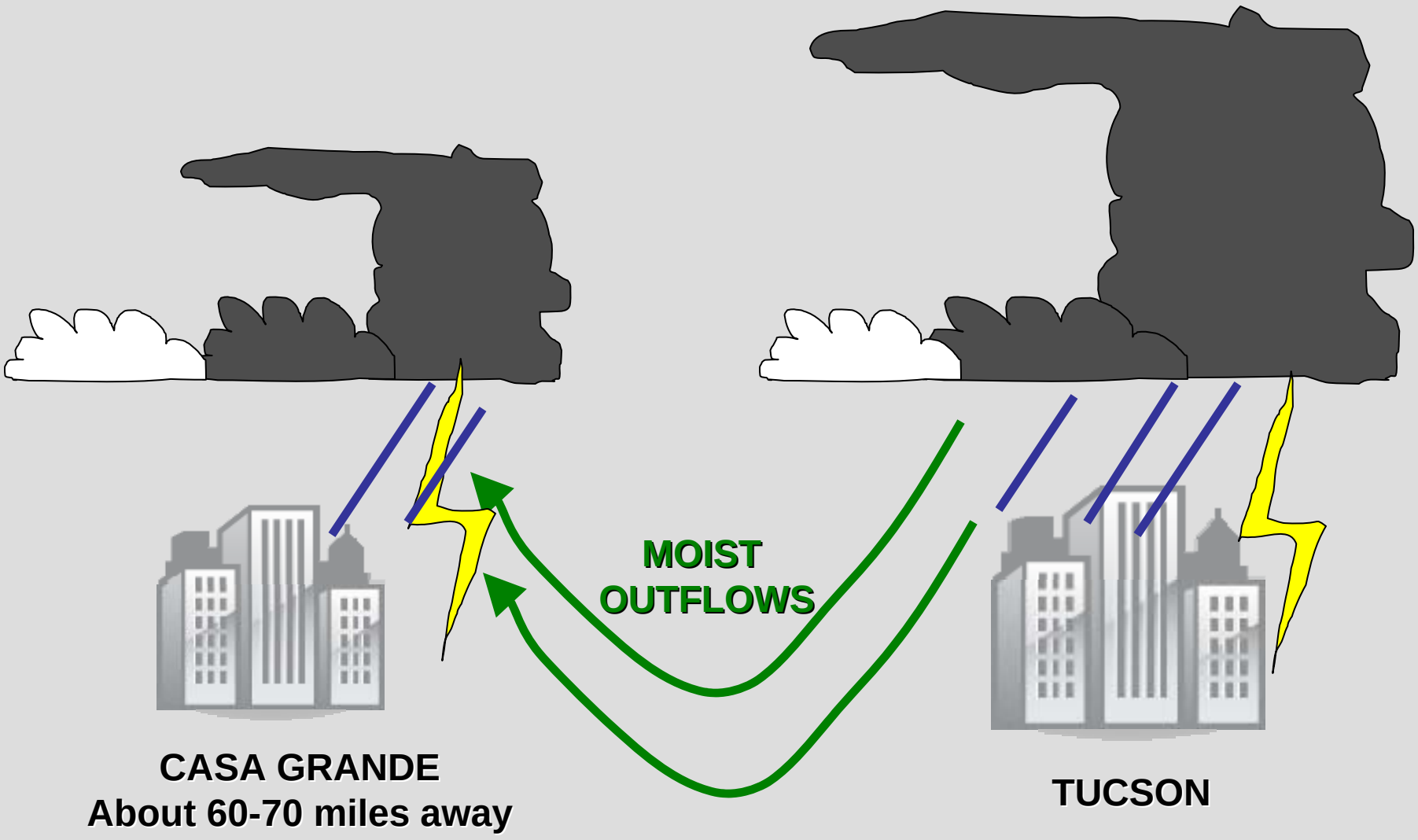
Beginnings of a stormy day in early afternoon…



Storms roll off mountains and into the Tucson basin by early evening

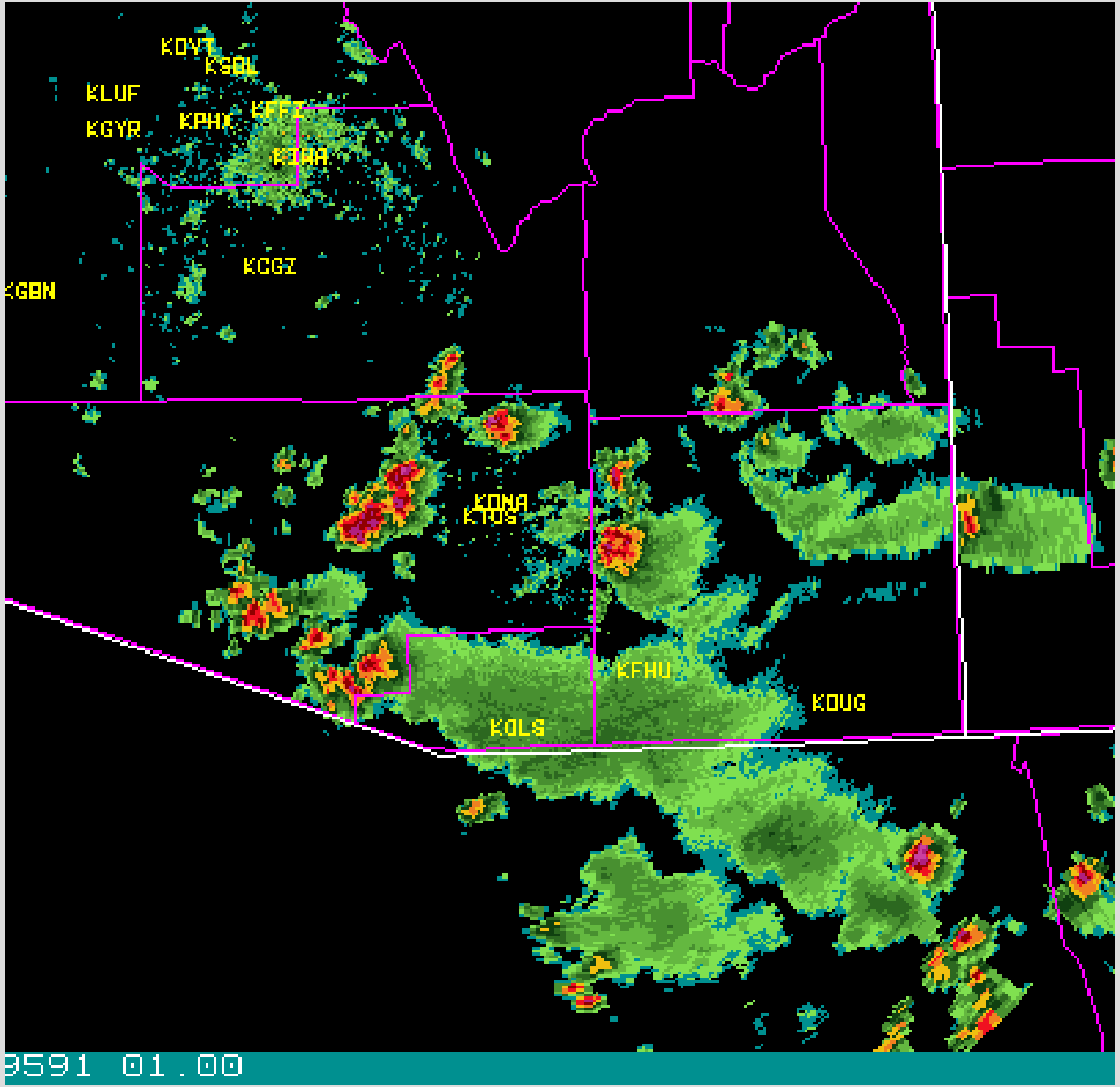


On a REALLY good monsoon day…
Outflows may trigger new thunderstorms farther west, away from mountains.



Radar reflectivity

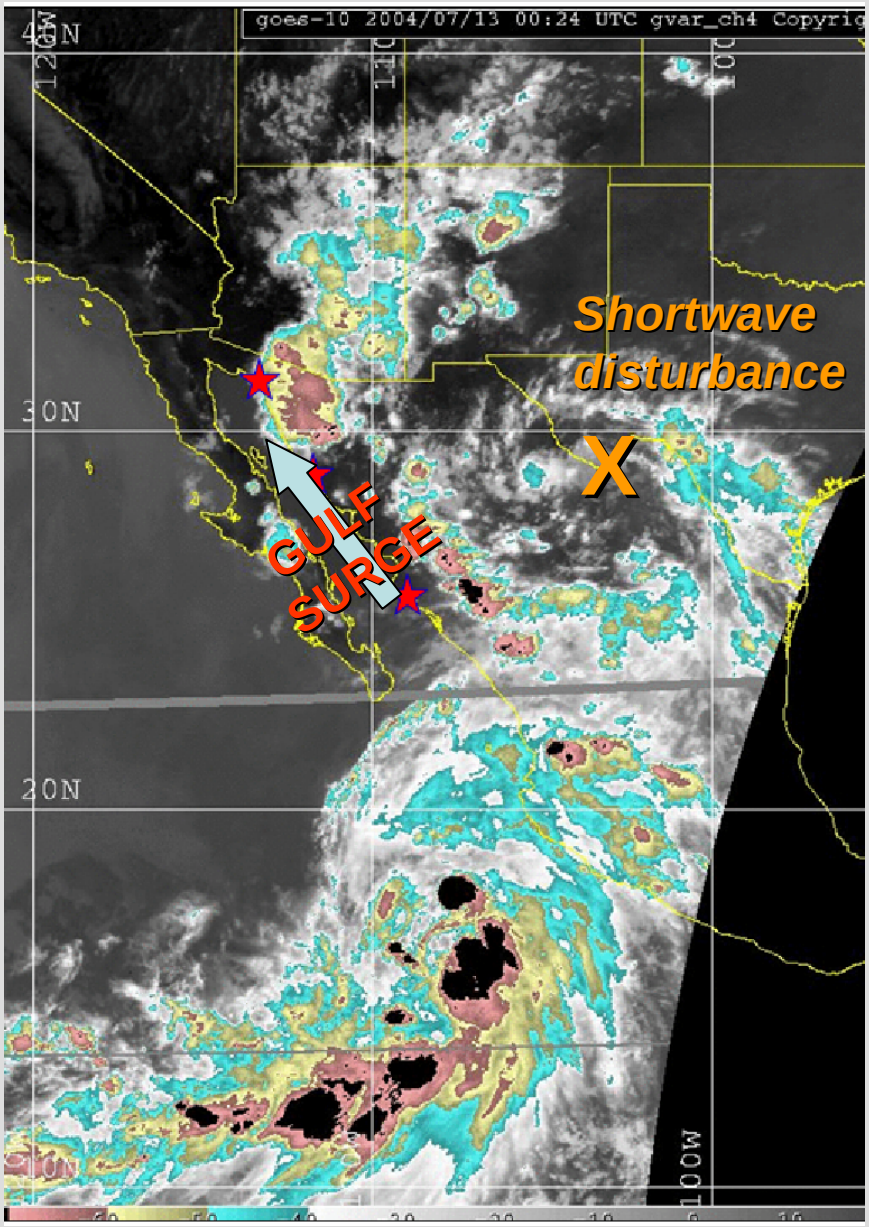
July 7, 2009
Late afternoon



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

July 7, 2009

July 21, 2007



Conditions for enhanced monsoon thunderstorms

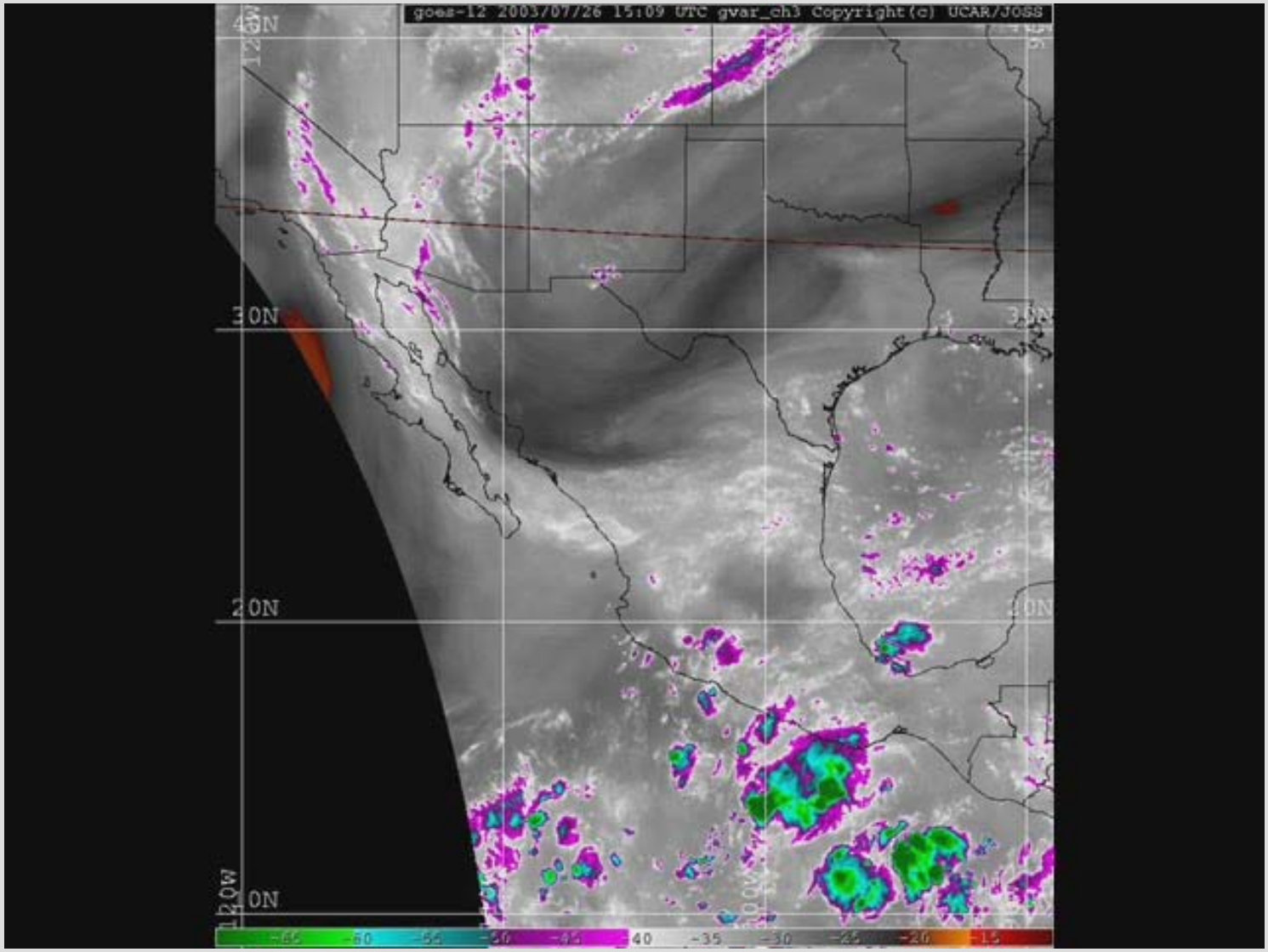
An upper-level disturbance (X) traveling around the monsoon ridge.

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…

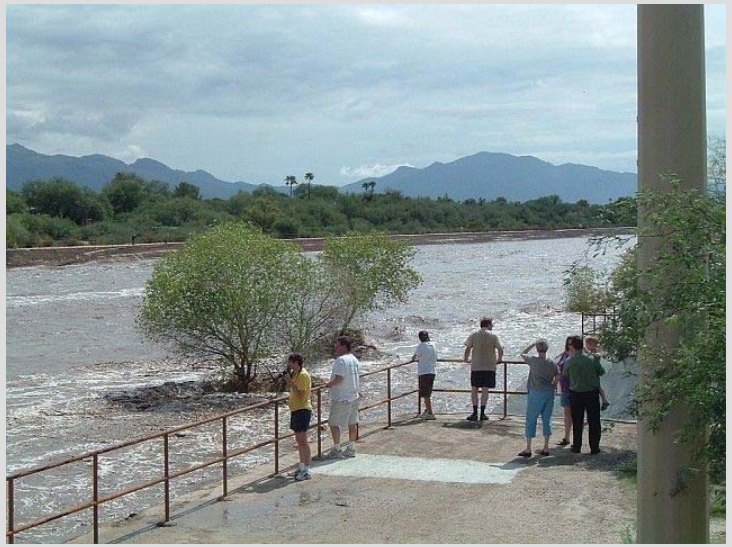


Monsoon Severe Weather Hazards

Flash Flooding

ARROYOS

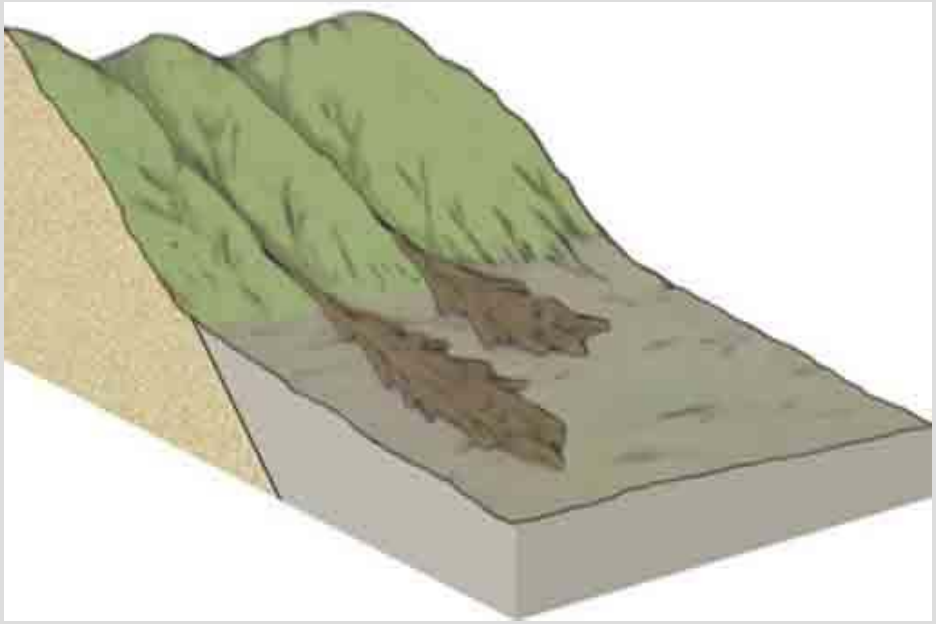
CANYONS AND DRY RIVERBEDS



WHEN THE STREETS OR ARROYOS FLOOD, DON'T TRY TO CROSS THEM!!

LAS VEGAS FLOOD, July 1999

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.

Hail

Formed in the strongest thunderstorms with highest cloud tops.

Allows for extended growth of ice particles.

Large hail is relatively rare in Arizona, typically pea size or less.

Lightning

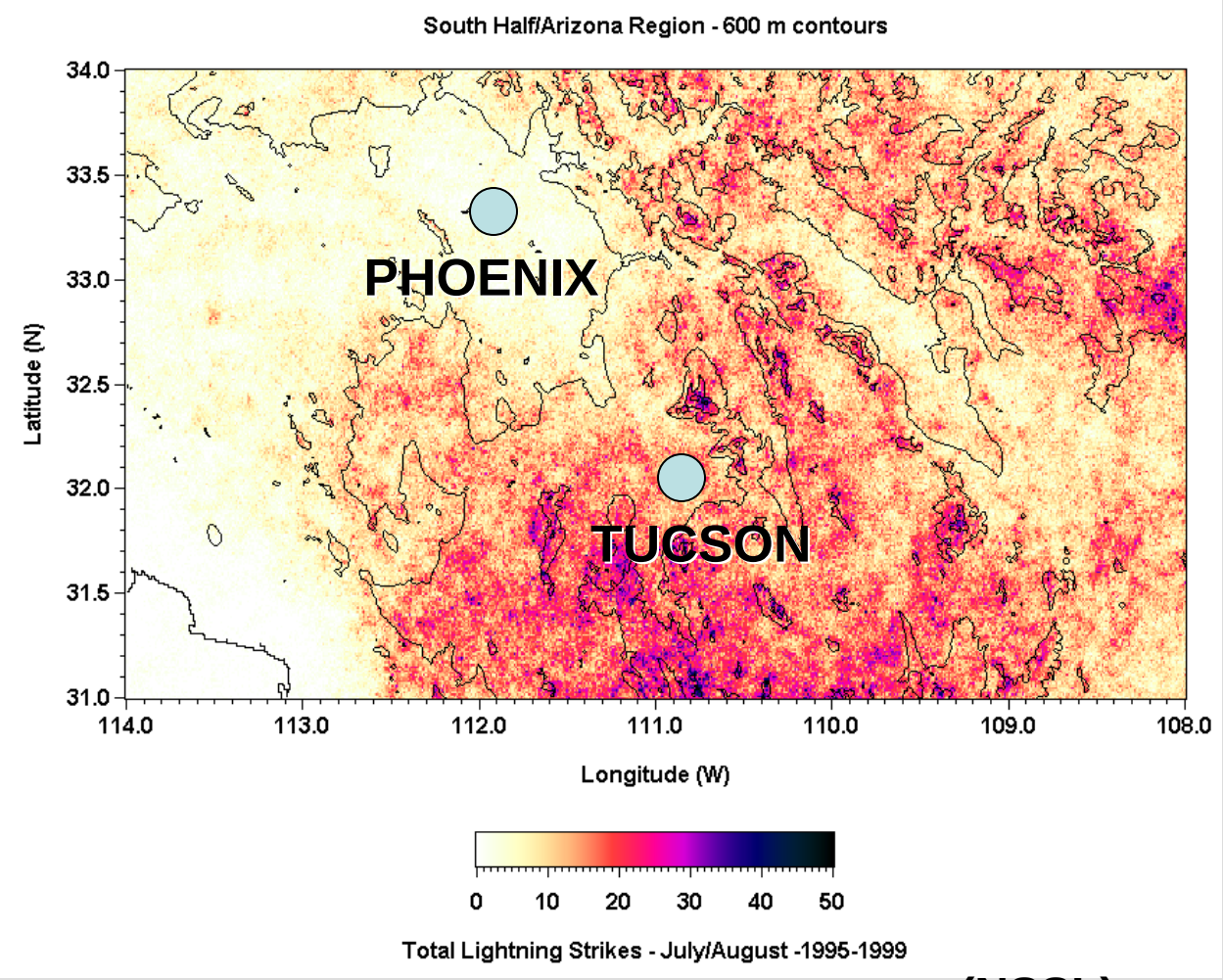
Discharge of electricity, or spark that usually occurs in thunderstorms.

Only about 20% actually are cloud-to-ground.

TEMPERATURE WITHIN THE BOLT = 30,000°C
(5X HOTTER THAN SUN)

Extreme slow motion animation of cloud-to-ground lightning strike

Tucson Lightning Distribution
Southern Arizona



(NSSL)

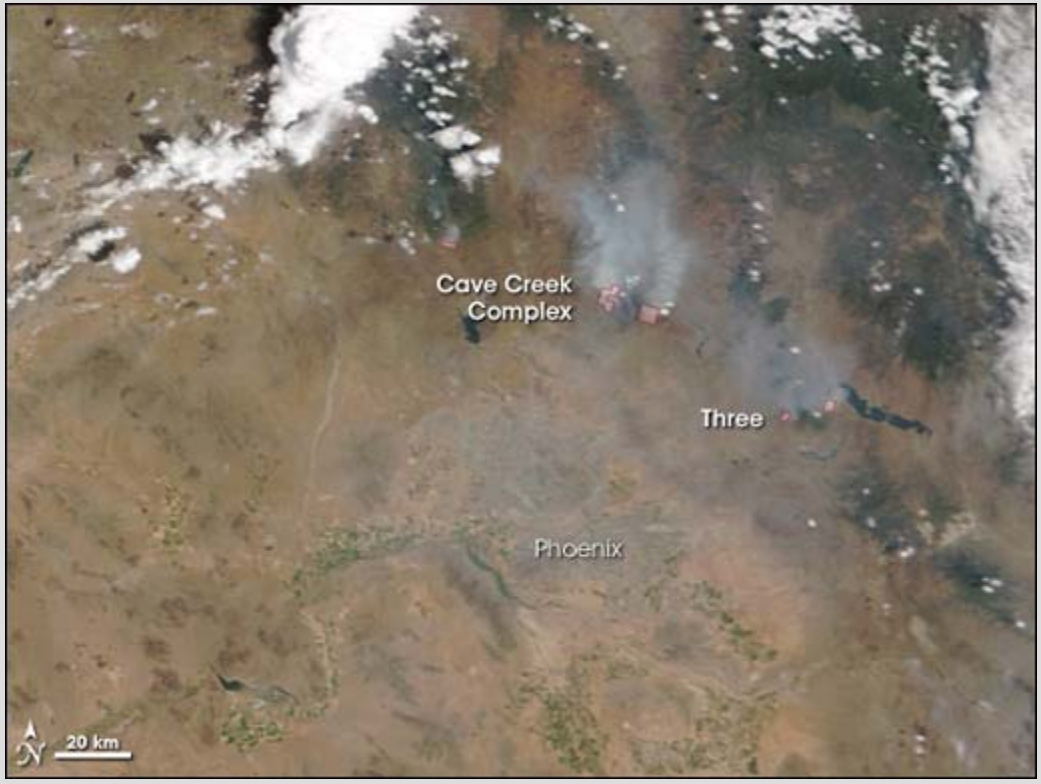
<u>Why more here?</u>

HIGHER ELEVATION

CLOSER TO MTNS.

MORE RAINFALL

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.

Is the monsoon predictable?

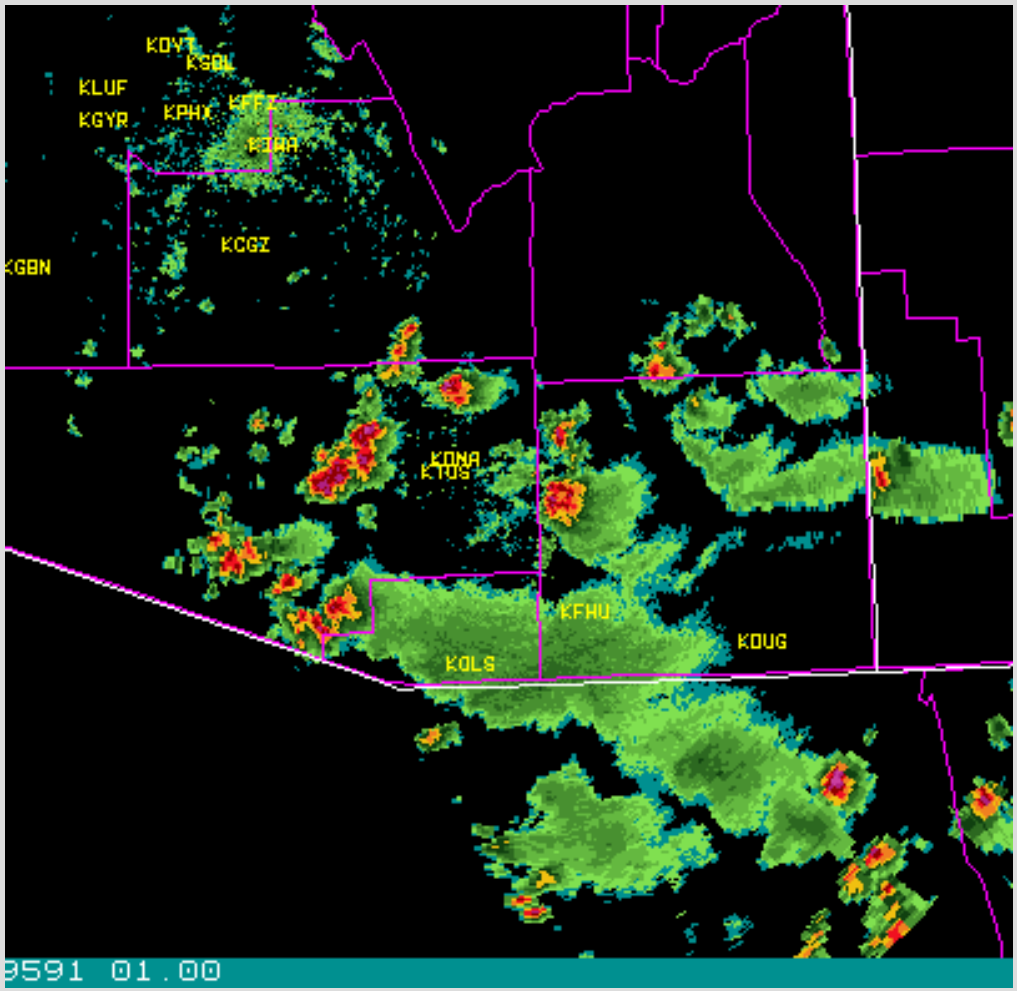
A Meteorologist's Answer:

It Depends…

Can we forecast monsoon storms perfectly exact every day?

ANSWER: NO

Even the most sophisticated and resolved atmospheric models cannot predict the timing, location, and intensity of monsoon storms with absolute certainty.



Can we forecast the timing and intensity of the monsoon in Arizona?

ANSWER: MAYBE

The circulation features that govern the timing and strength of the monsoon are related to conditions in the Pacific Ocean, like El Niño, and perhaps the Atlantic too.

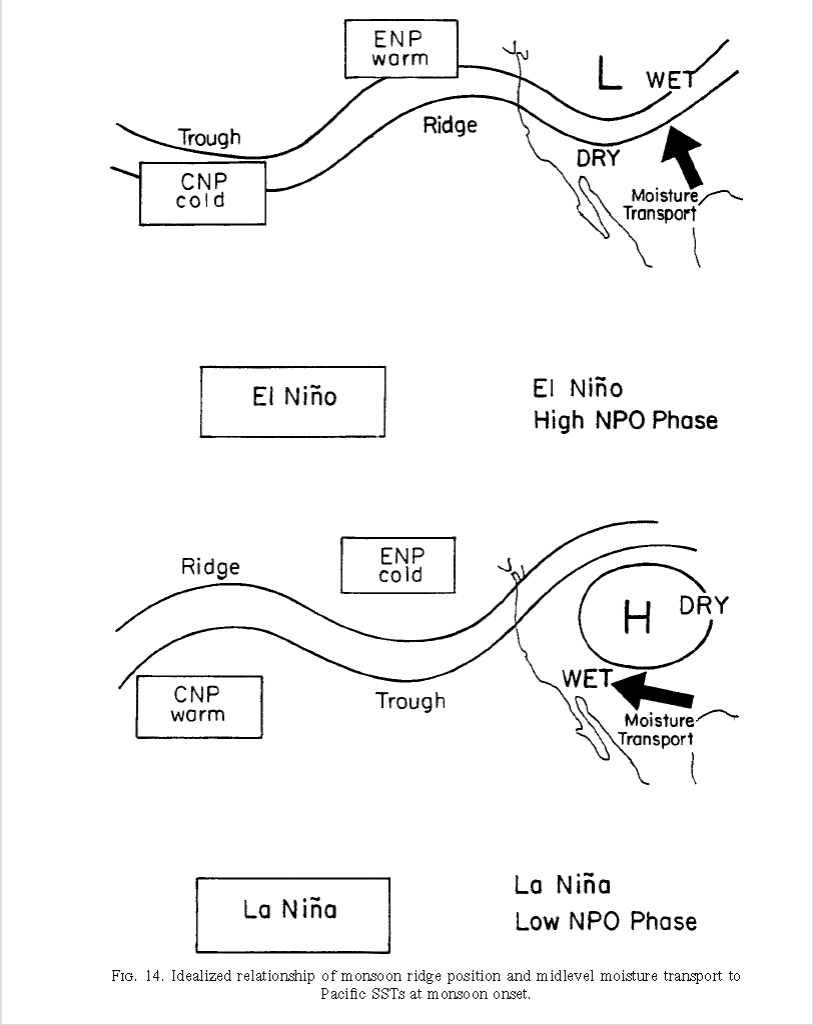
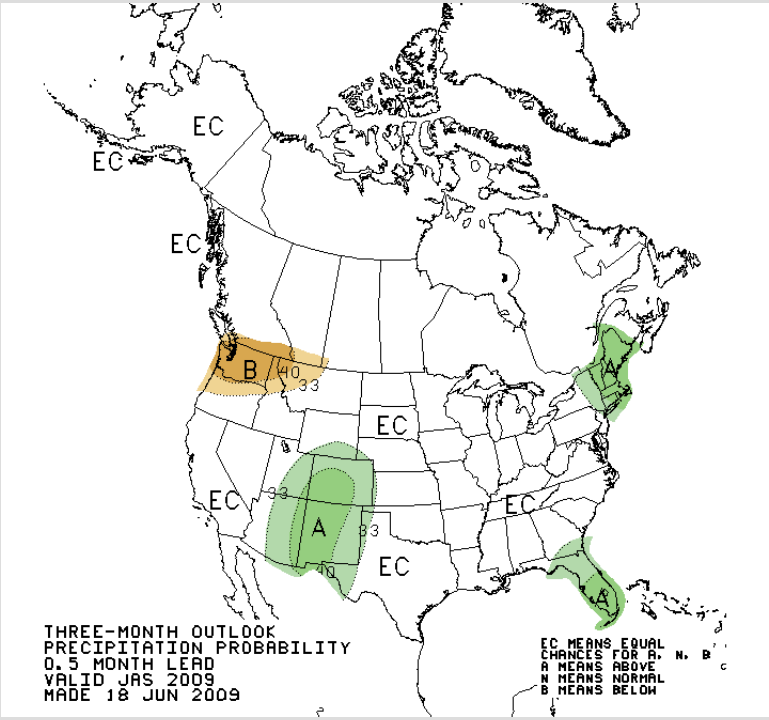


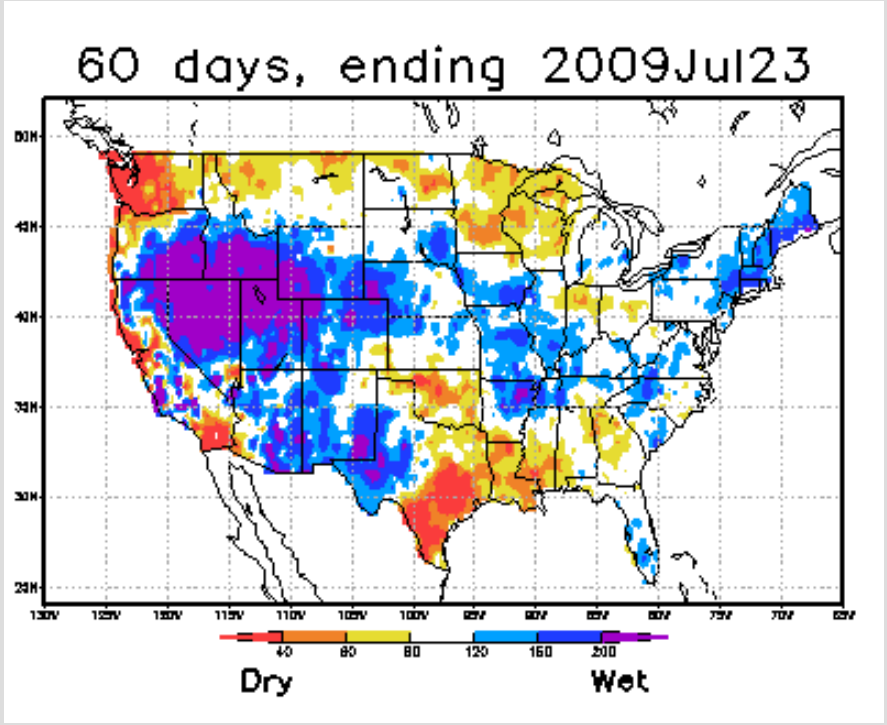
FIG. 14. Idealized relationship of monsoon ridge position and midlevel moisture transport to Pacific SSTs at monsoon onset.

Climate Prediction Center Precipitation Forecast for this year's monsoon vs. truth (About mid-way through…)

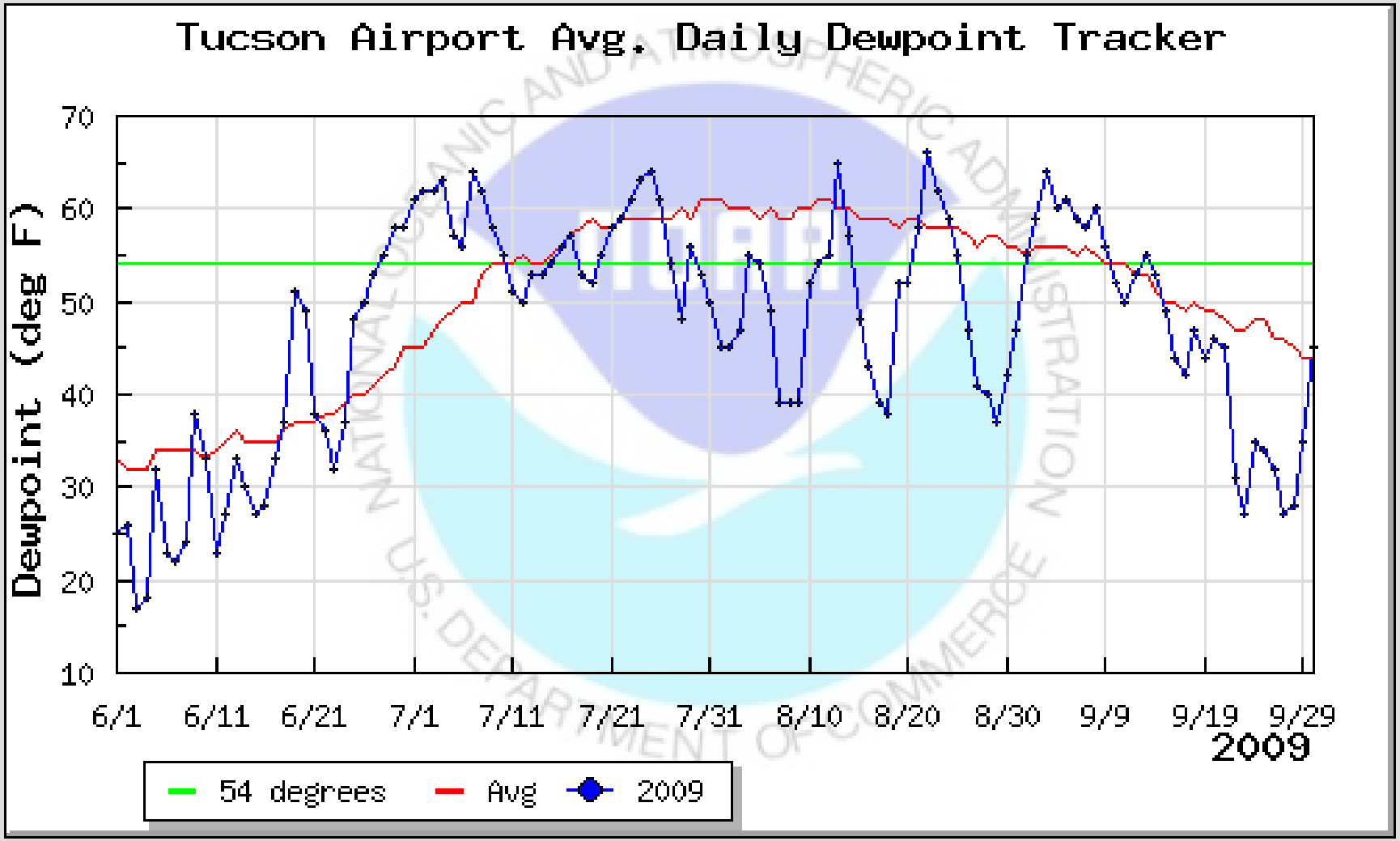
FORECAST

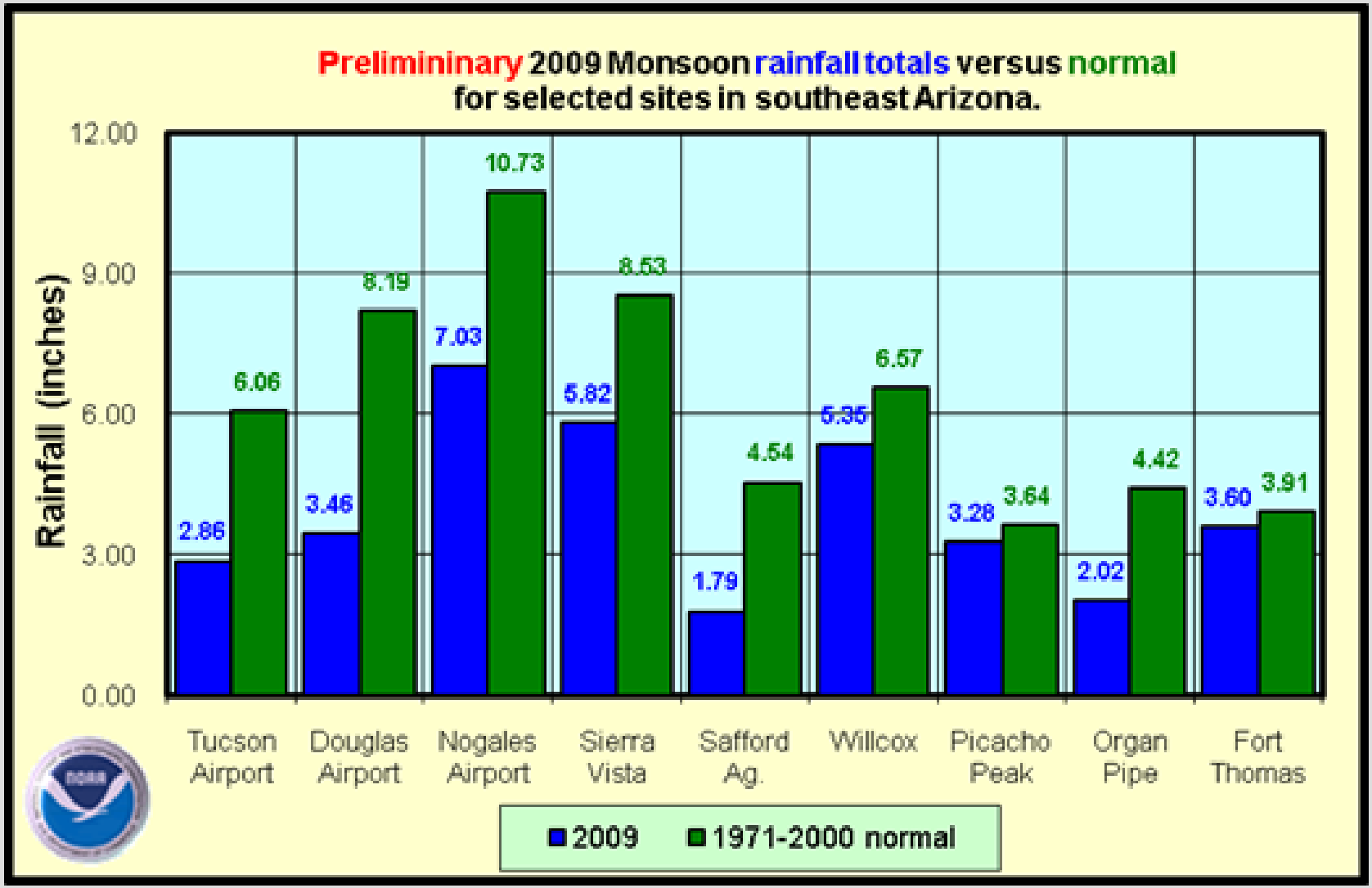


MOTHER NATURE



Percent of precipitation above normal


Tucson Airport Avg. Daily Dewpoint Tracker
Dewpoint (deg F)
70
60
50
40
30
20
10
6/1
6/11
6/21
7/1
7/11
7/21
7/31
8/10
8/20
8/30
9/9
9/19
9/29
2009
54 degrees
Avg
2009


Preliminary 2009 Monsoon rainfall totals versus normal
for selected sites in southeast Arizona.
Rainfall (inches)
12.00
9.00
6.00
3.00
0.00
2.86
6.06
3.46
8.19
7.03
10.73
5.82
8.53
1.79
4.54
5.35
6.57
3.28
3.64
2.02
4.42
3.60
3.91
Tucson Airport
Douglas Airport
Nogales Airport
Sierra Vista
Safford Ag.
Willcox
Picacho Peak
Organ Pipe
Fort Thomas
2009
1971-2000 normal

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


THANK YOU!
Questions?