



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

**Christopher L. Castro
Assistant Professor
Department of Atmospheric Sciences
University of Arizona**

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**ATMOSPHERIC
SCIENCES**

UIASCIENCE

THE UNIVERSITY OF
ARIZONA
TUCSON ARIZONA

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

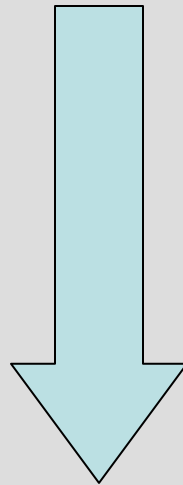
What is a monsoon?

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

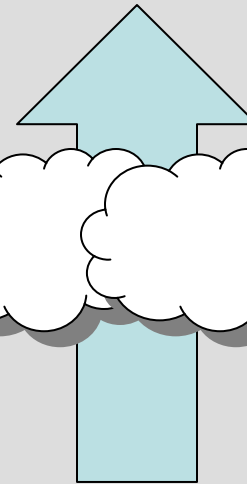
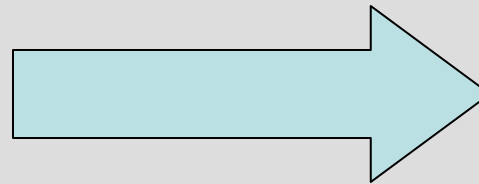
Derived from Arabic mausim, which means season.

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



COLD AIR
More dense



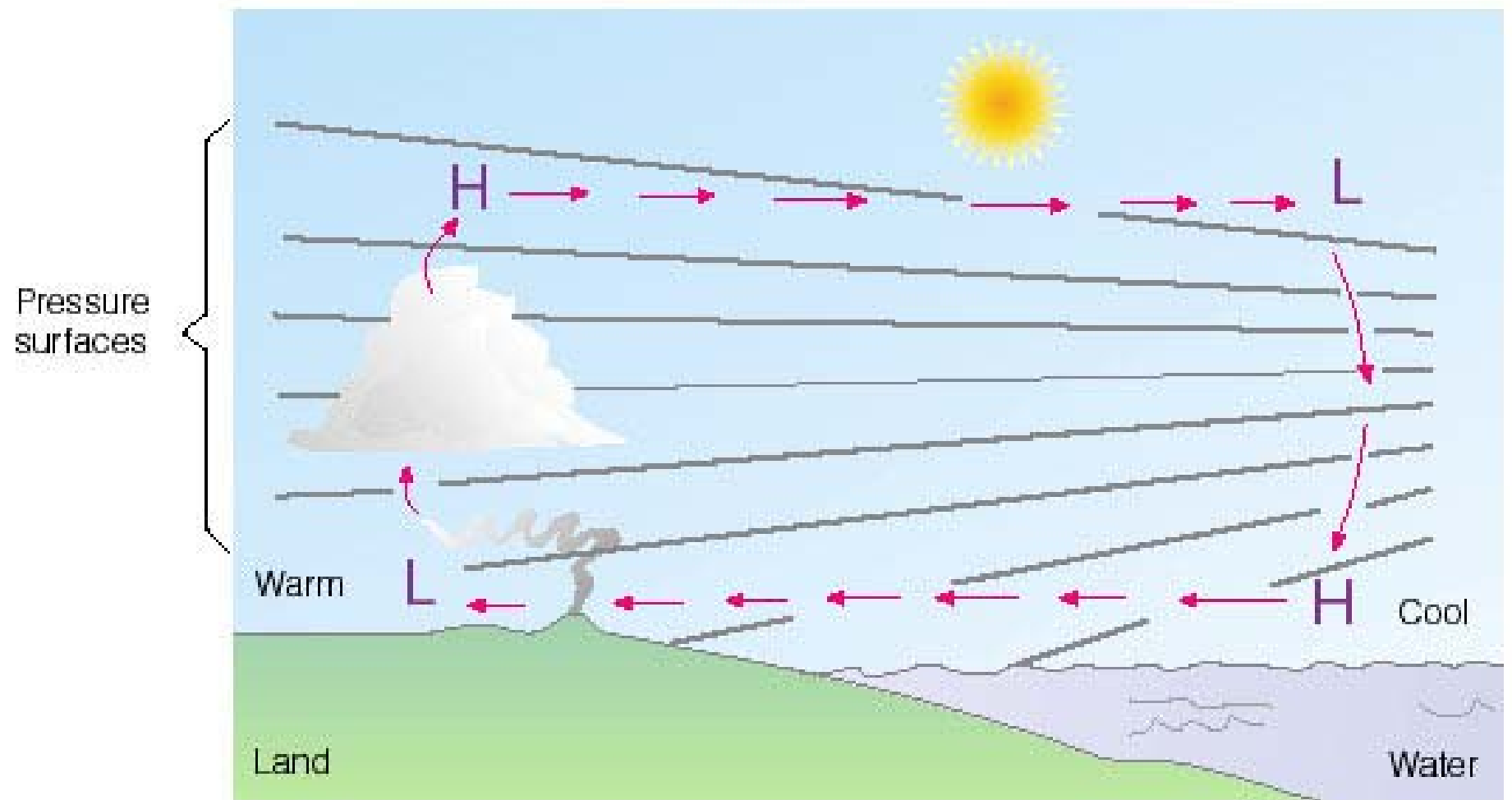
Clouds form
as air rises,
cools and
water
condenses

HOT AIR
Less dense

WATER
Heats slowly

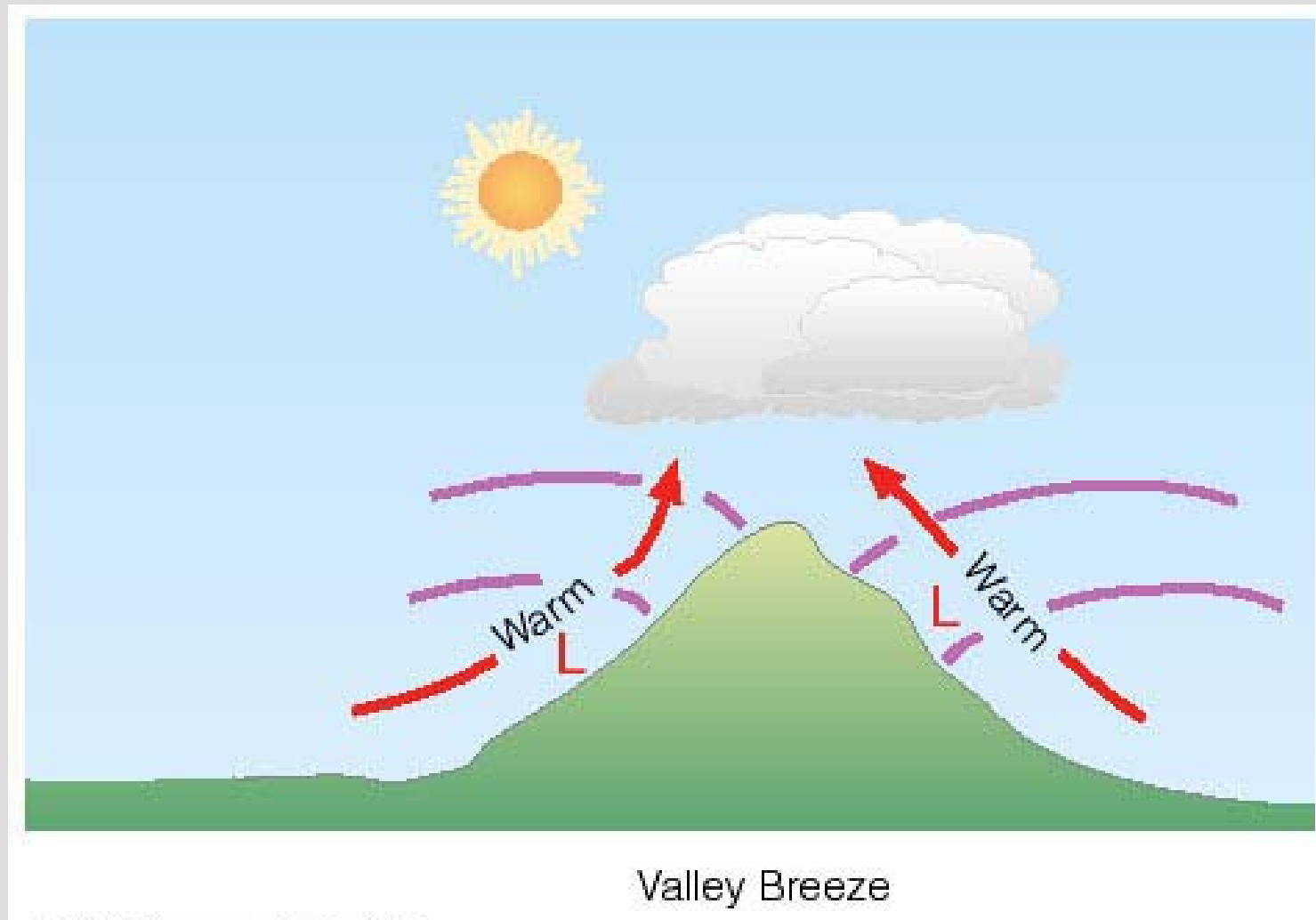
LAND
Heats rapidly

Sea Breeze



(a) Sea breeze

Mountain-Valley circulation



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?

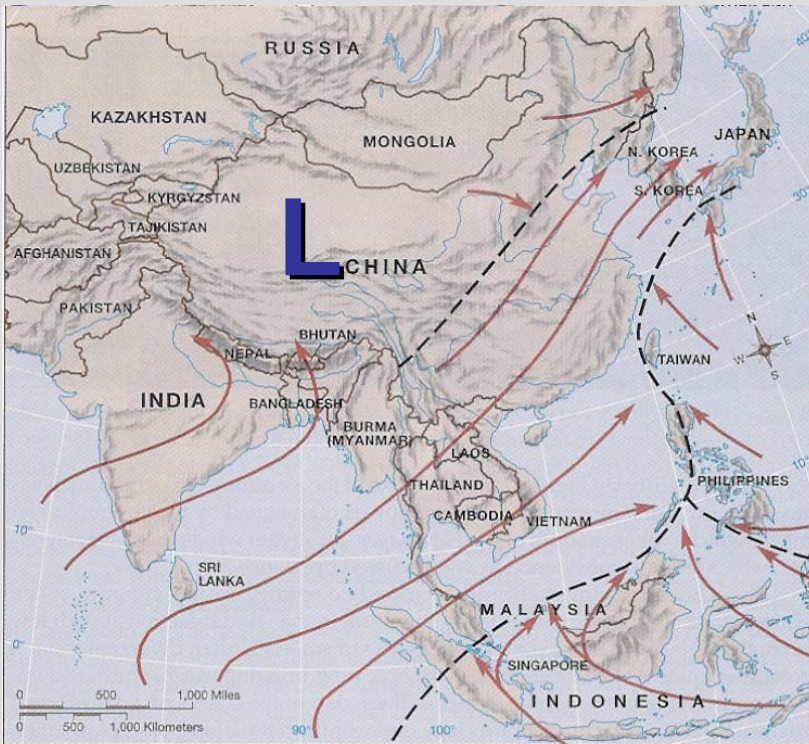


To the north of India is the Himalaya Mountains and the Plateau of Tibet, with an average elevation of over 15,000 ft. and a horizontal extent of more than 1000 miles.

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

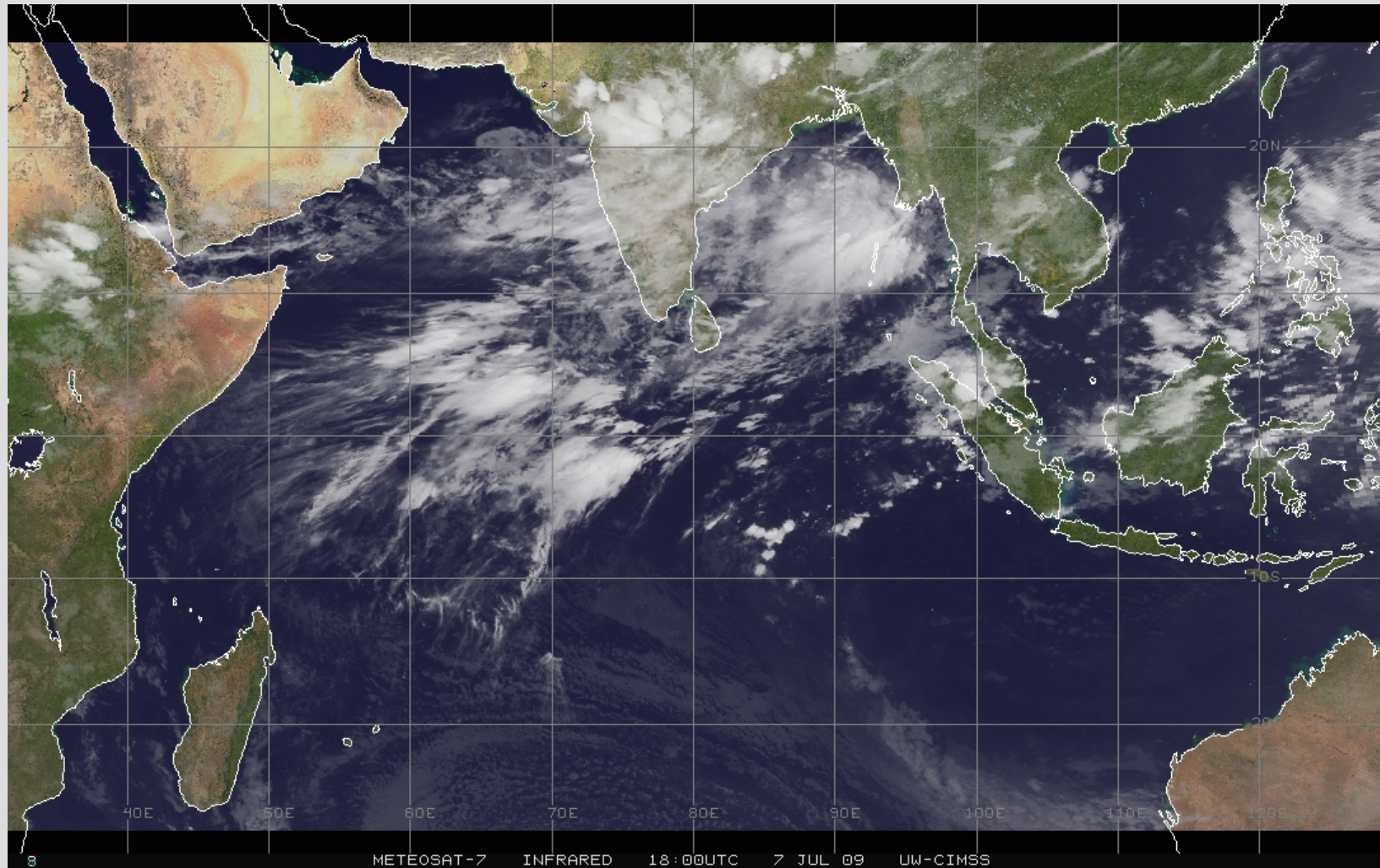
Warm air over the Tibetan Plateau is relatively less dense

Wind flows from the ocean to the Tibetan Plateau.

Onshore flow transports moisture to the interior of Asia.

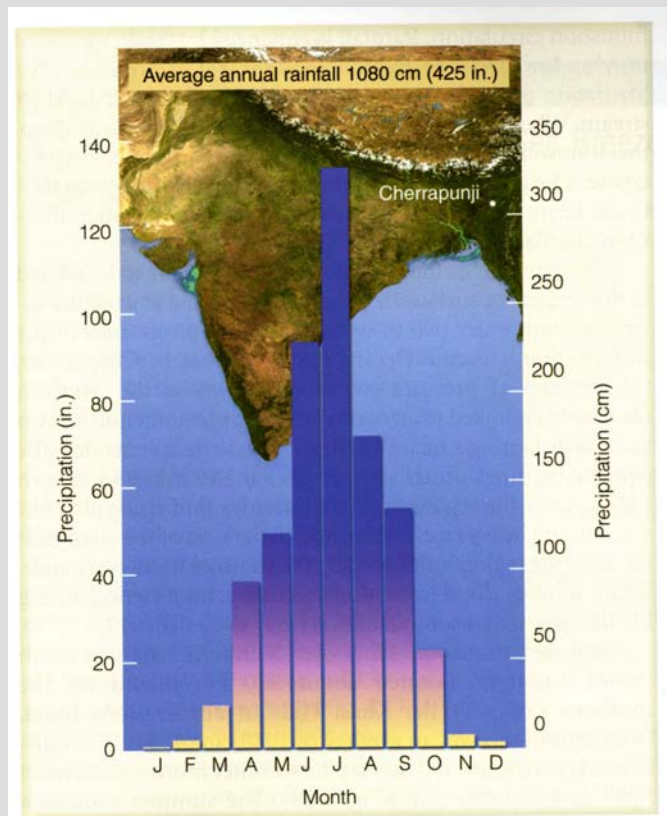
Indian Monsoon: July 7, 2009

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?

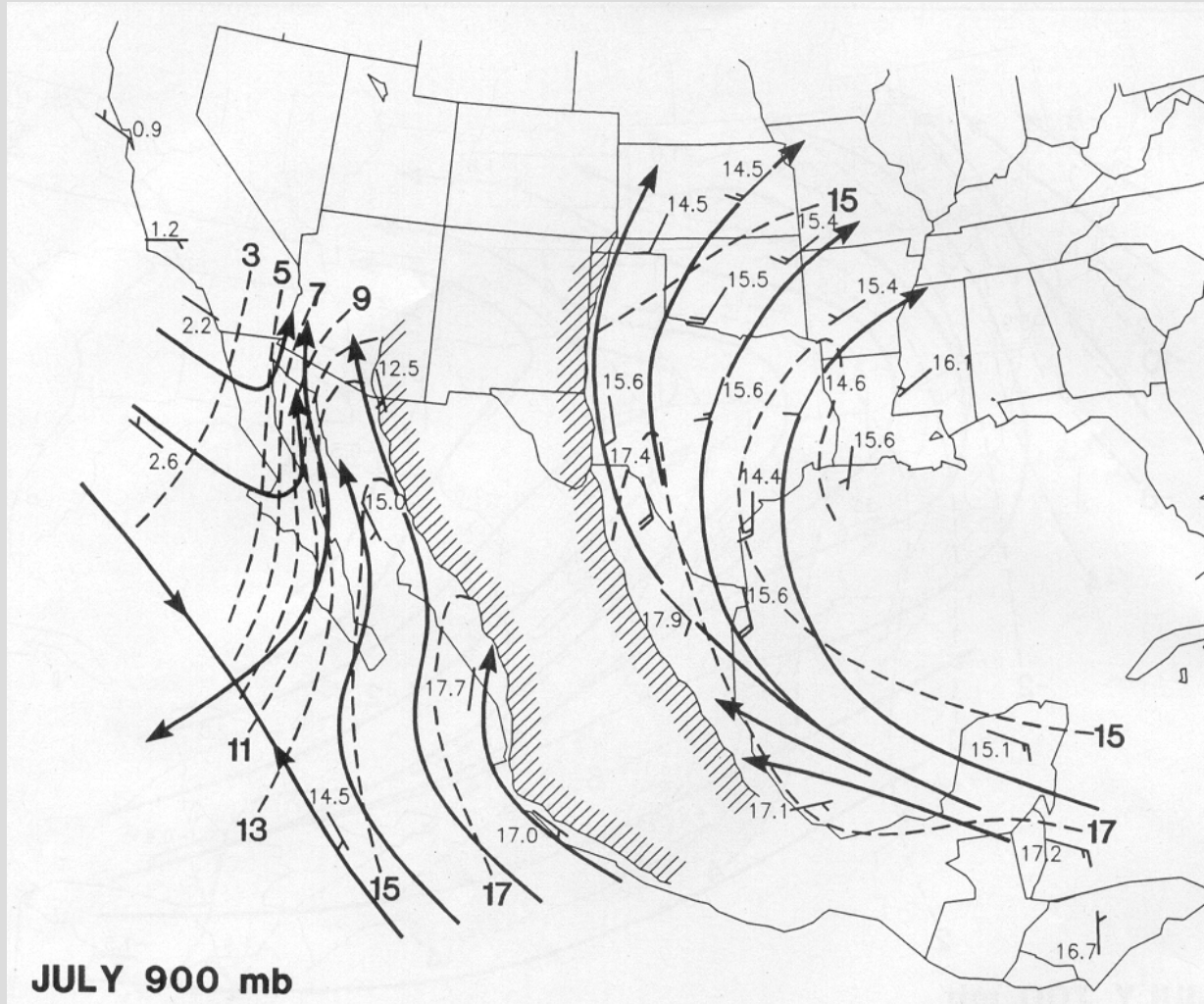


Similar to Asia, North America has a giant elevated plateau in the western U.S. and Mexico.

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)

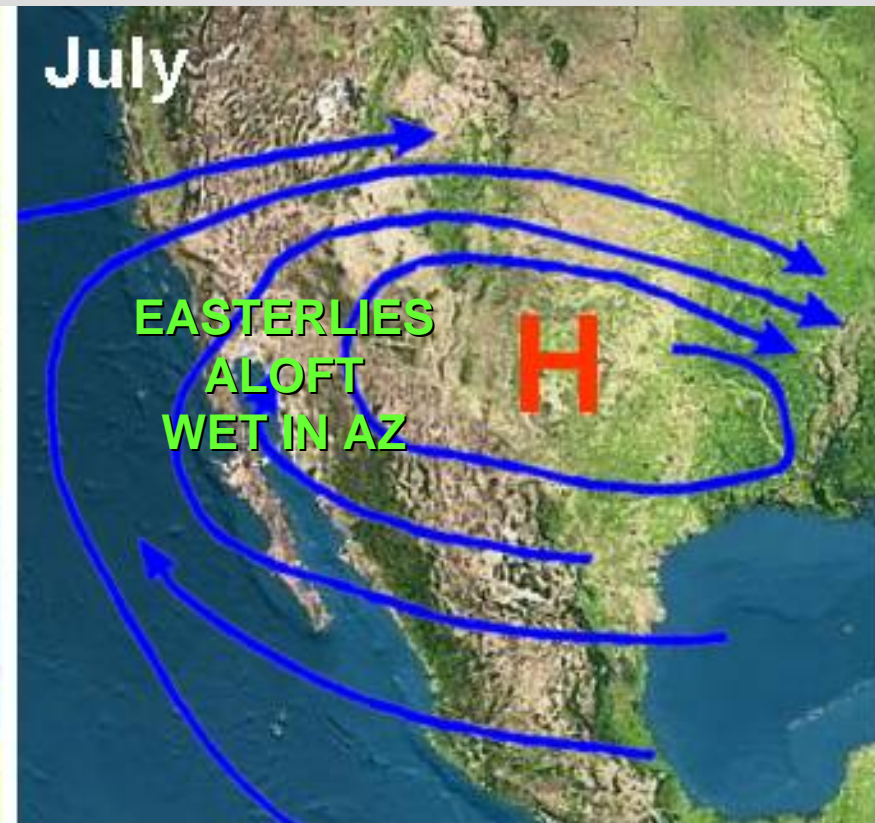
Air flow at about 20 thousand feet

Before monsoon



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

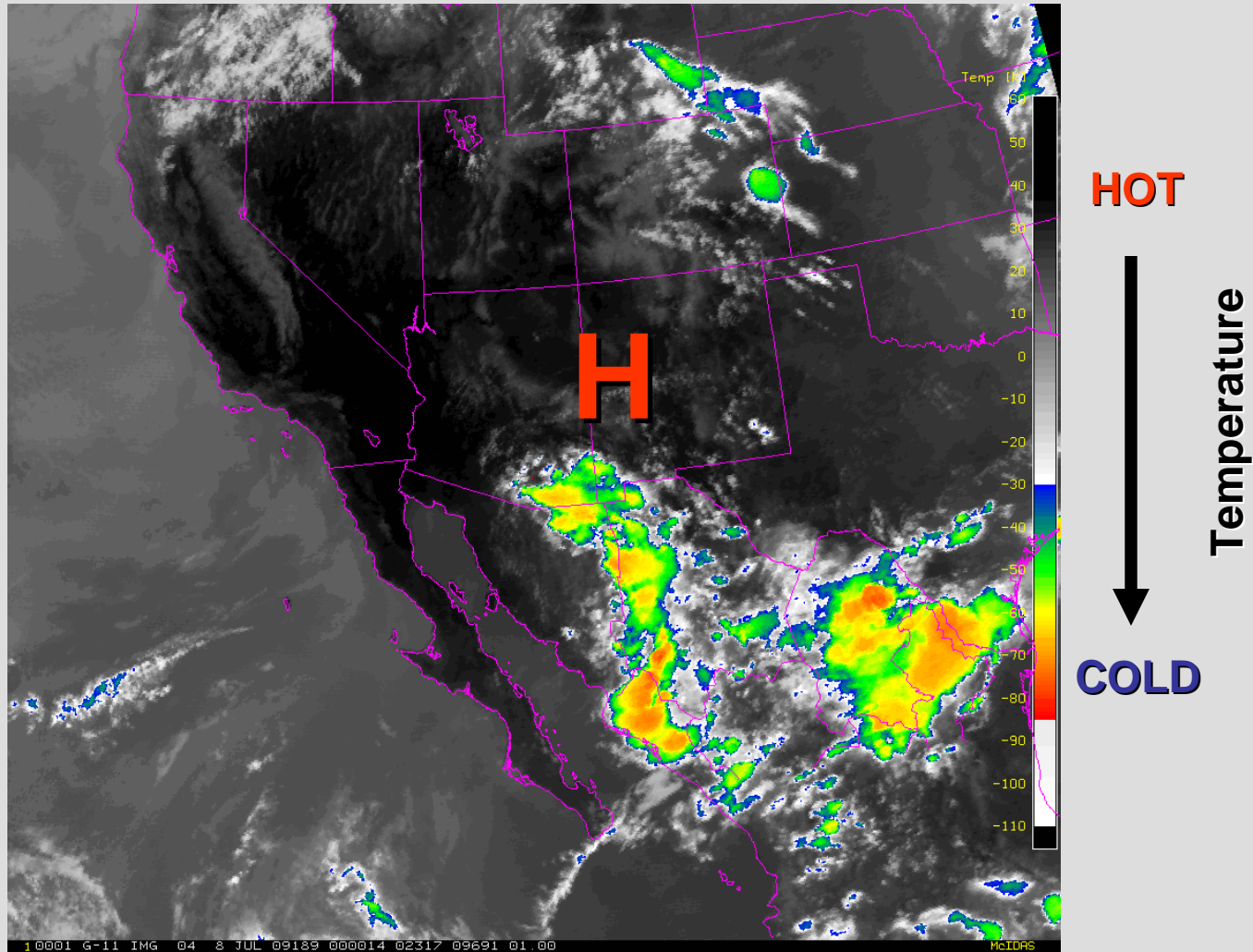
During Monsoon



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

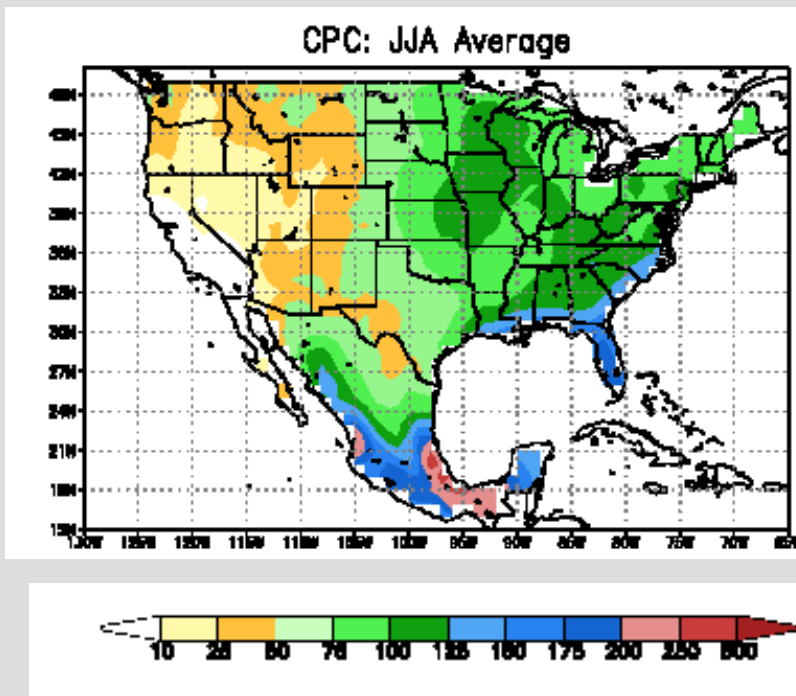
Monsoon storms on July 7, 2009

Enhanced Infrared Satellite Image

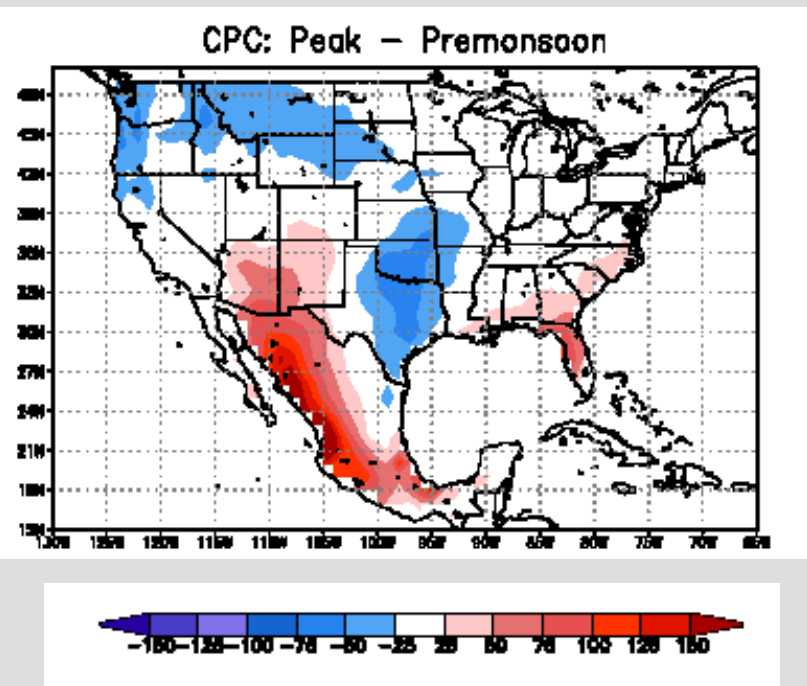


Continental Scale Shift in Rainfall (mm)

Summer Average Rainfall



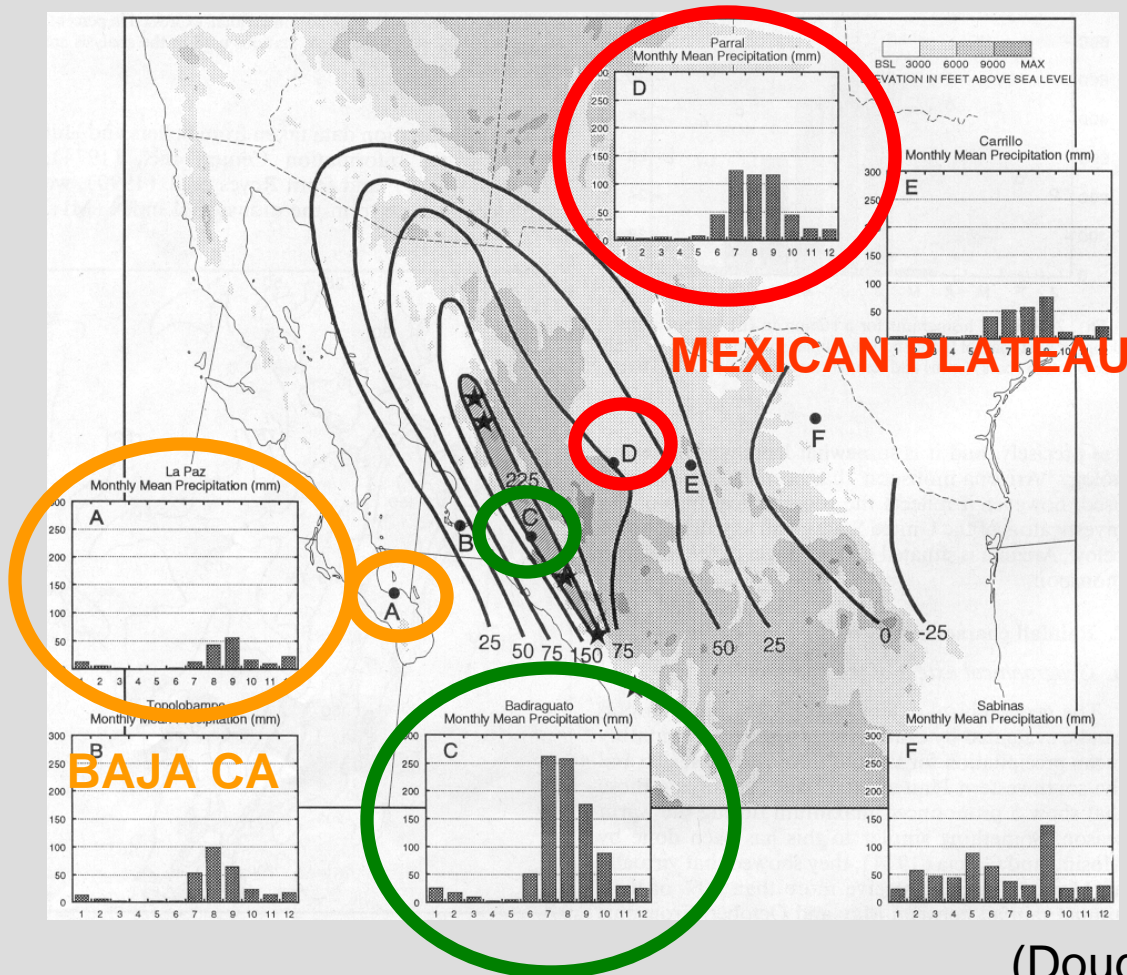
During monsoon – before monsoon



(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



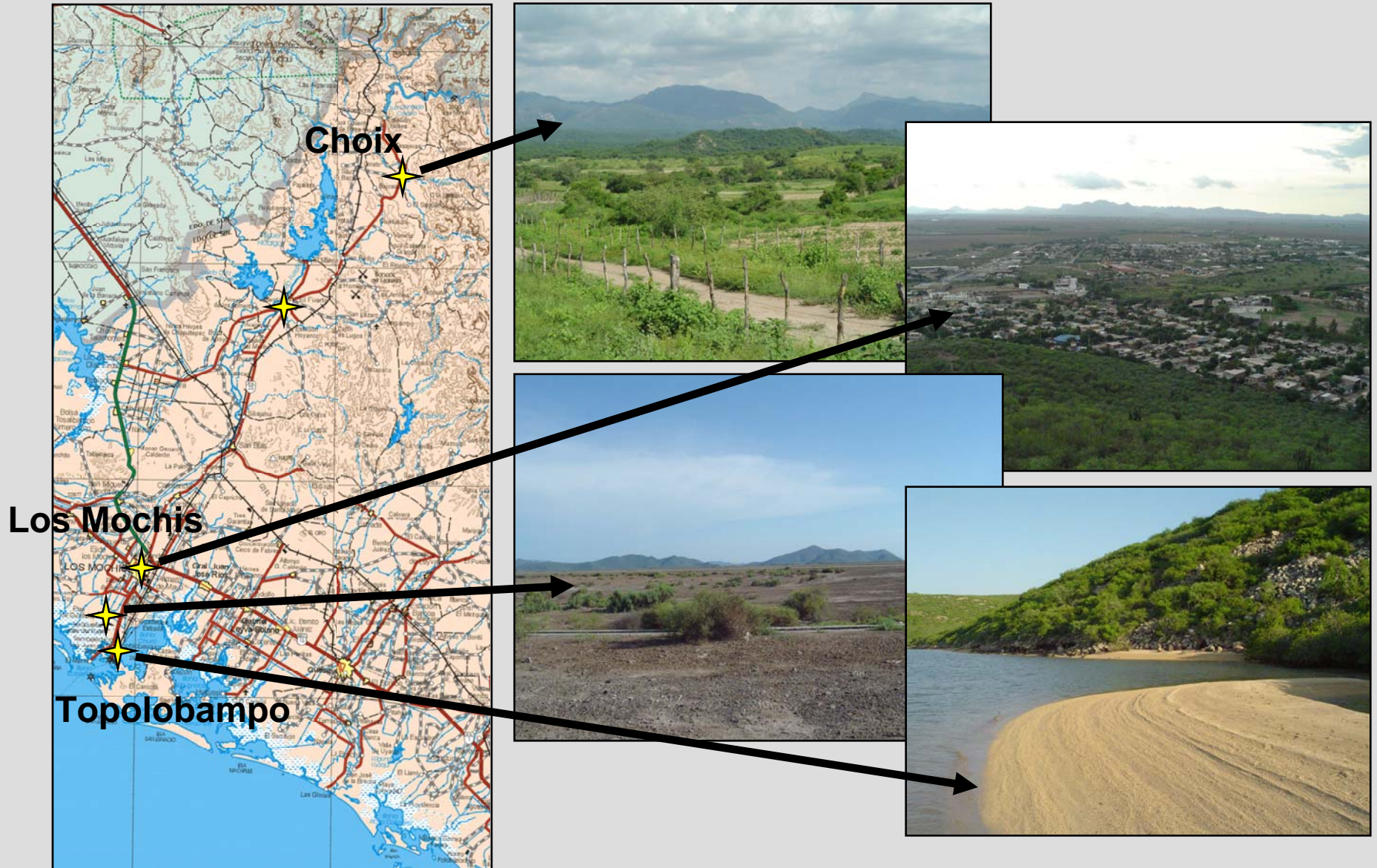
The core of the North American monsoon is in Mexico, not Arizona

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

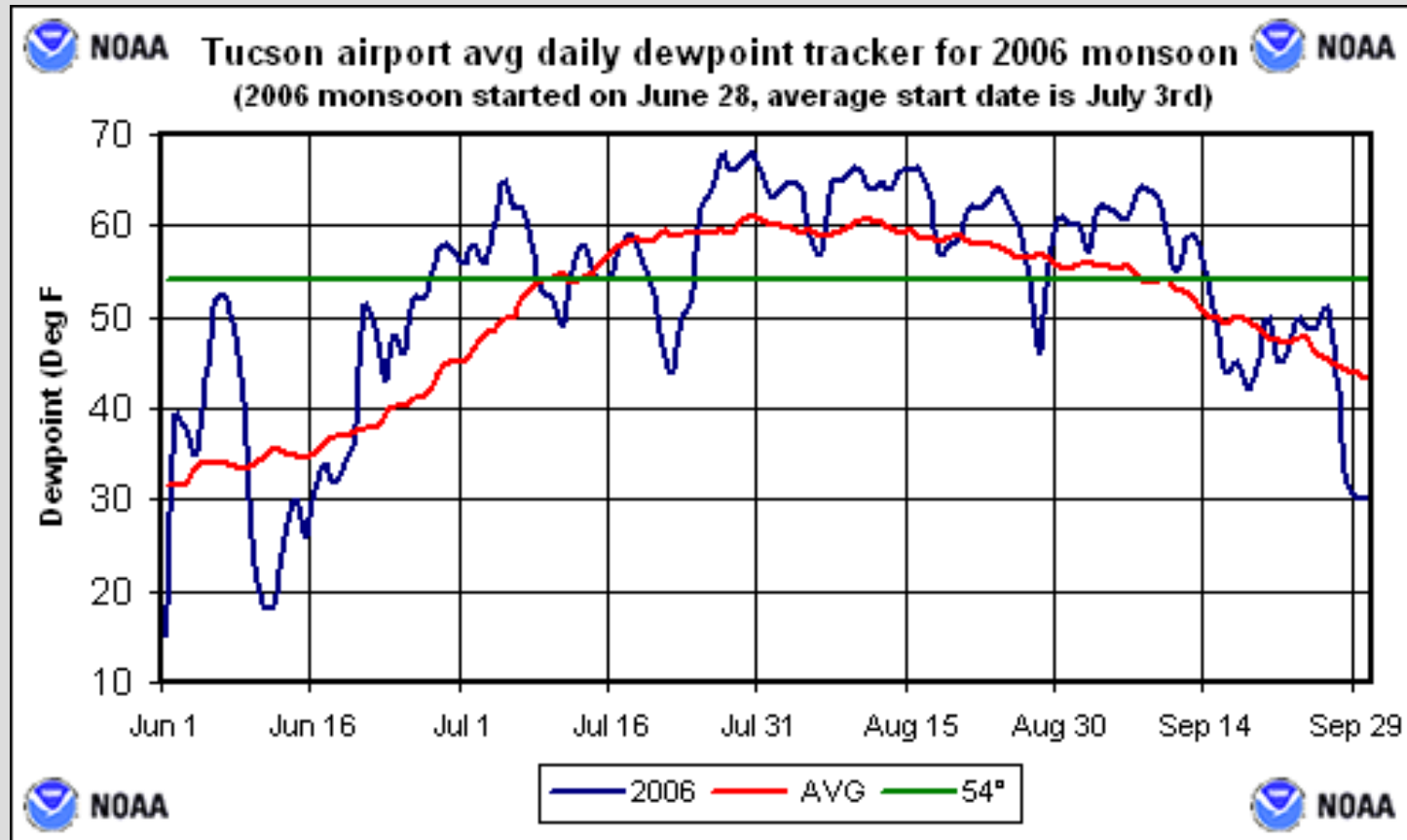
(Douglas et al. 1993)

SIERRA MADRE OCCIDENTAL

From Los Mochis to Choix

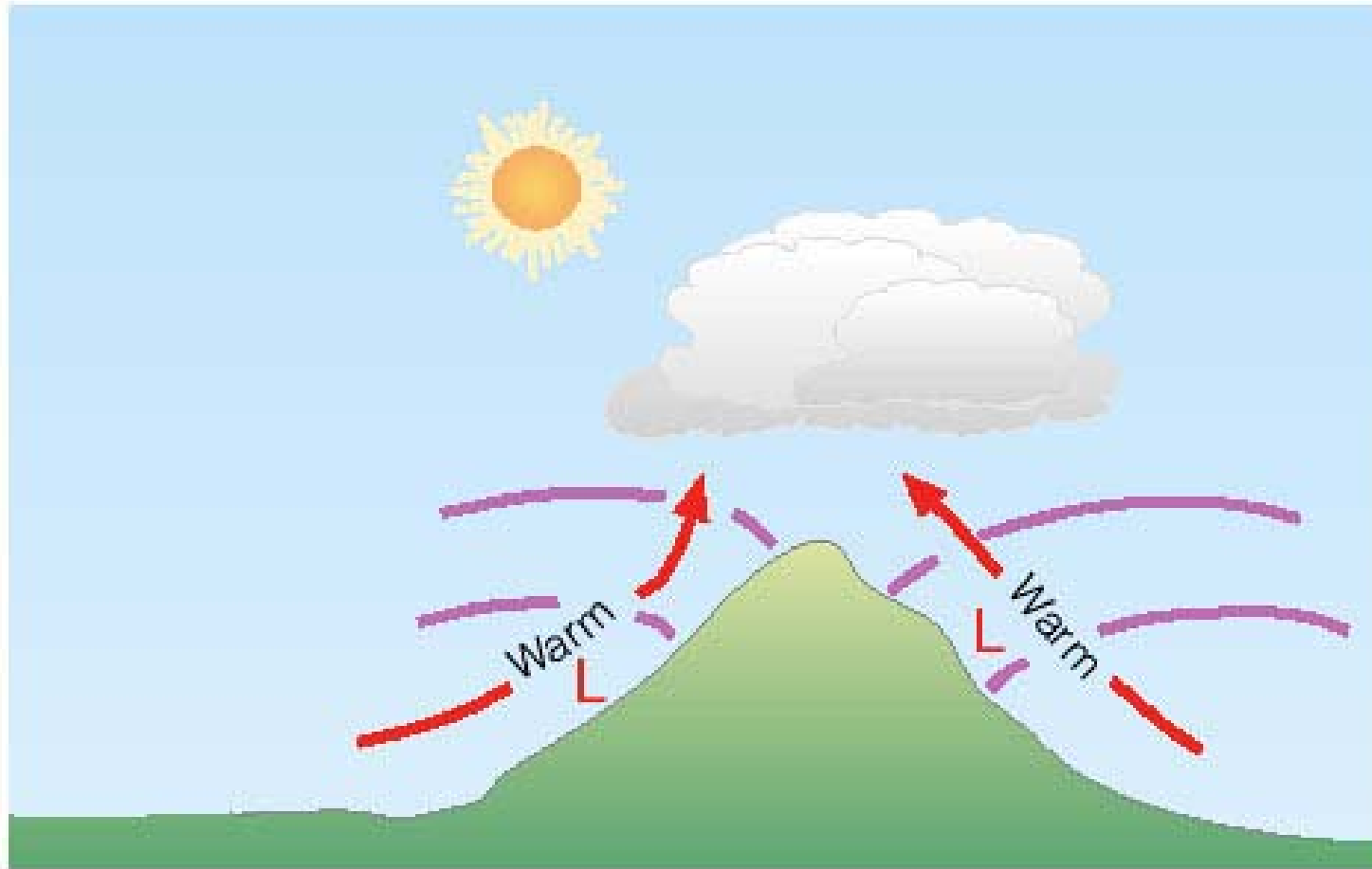


Monsoon in Tucson



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

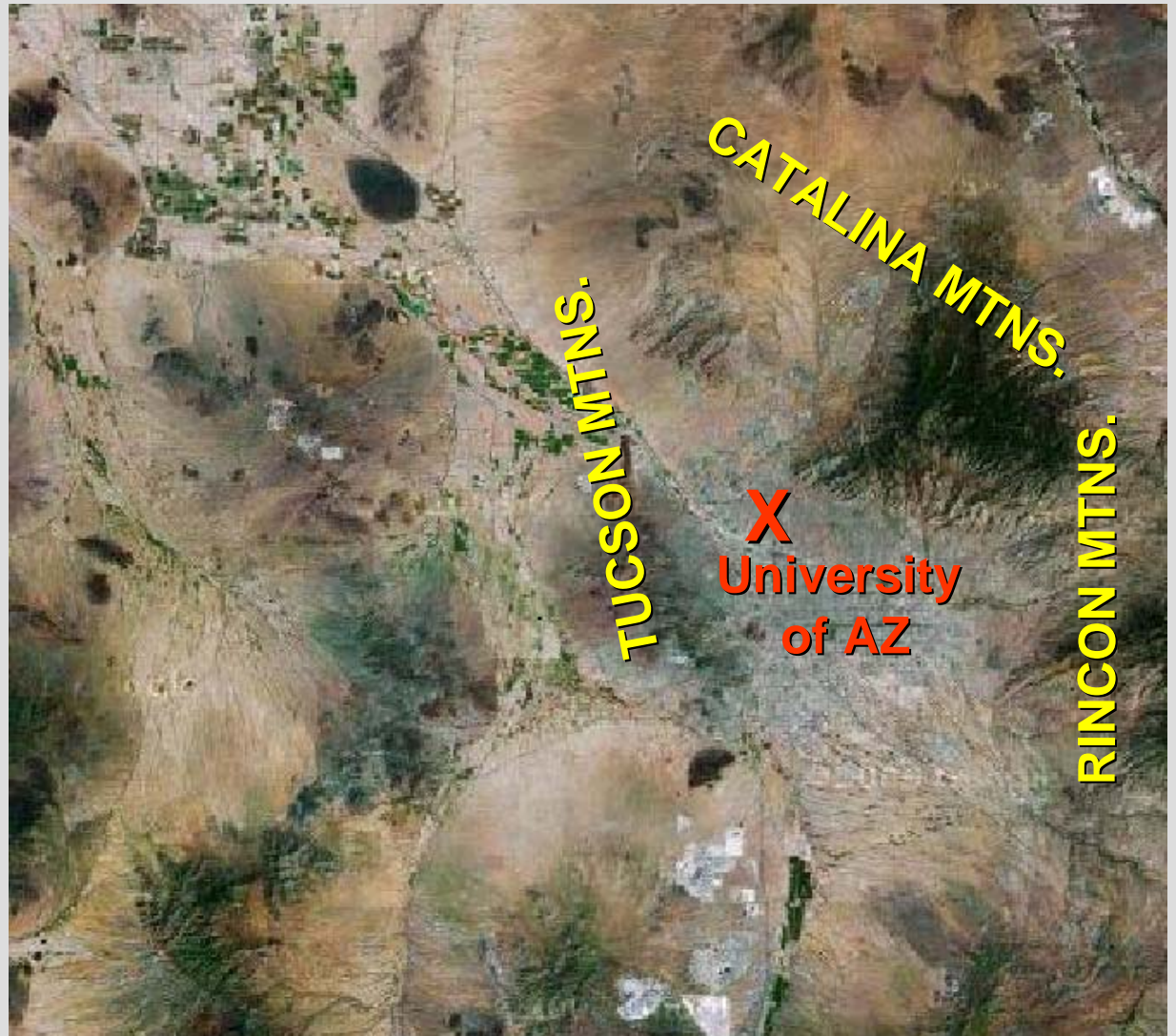
Mountain-valley circulations: What triggers monsoon storms!



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!

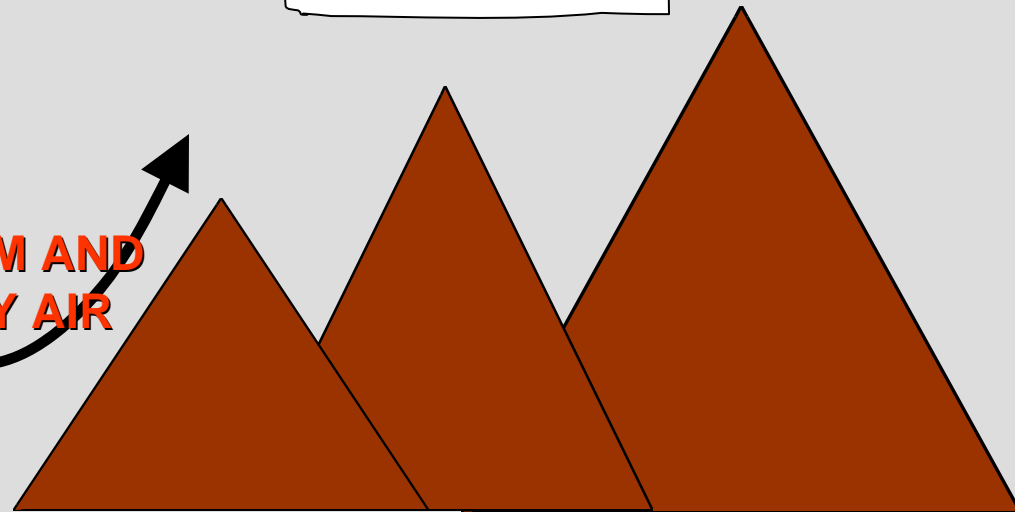


When the clouds just hang out over the mountains...and it's just hot and sunny in Tucson.



TUCSON

**WARM AND
DRY AIR**



CATALINA MOUNTAINS

**WARM, DRY SINKING
AIR ALOFT**

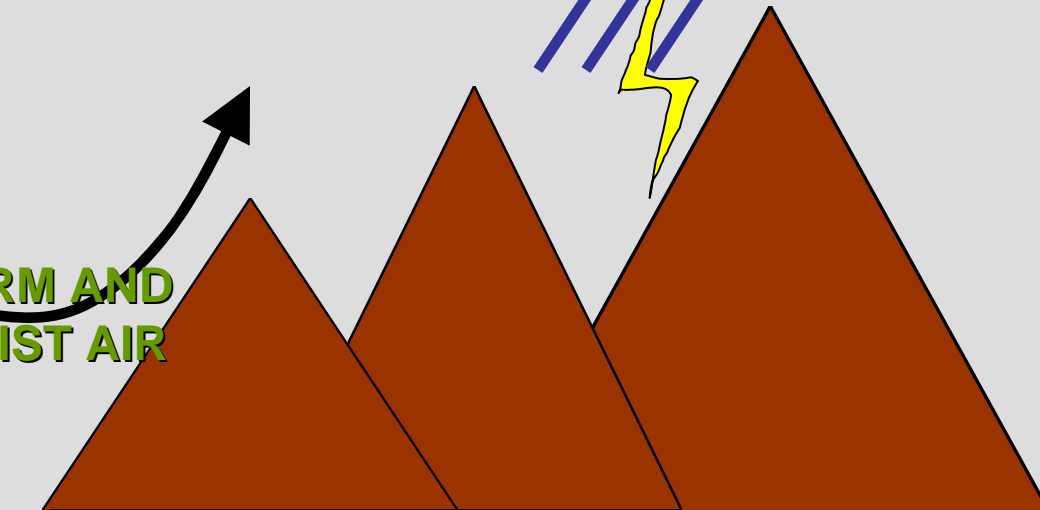


**Beginnings of a
stormy day in
early afternoon...**



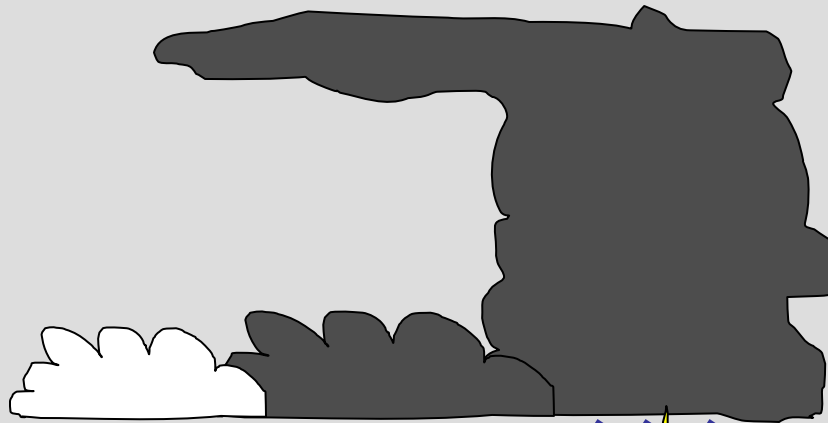
TUCSON

**WARM AND
MOIST AIR**

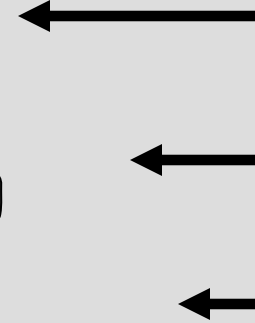


CATALINA MOUNTAINS

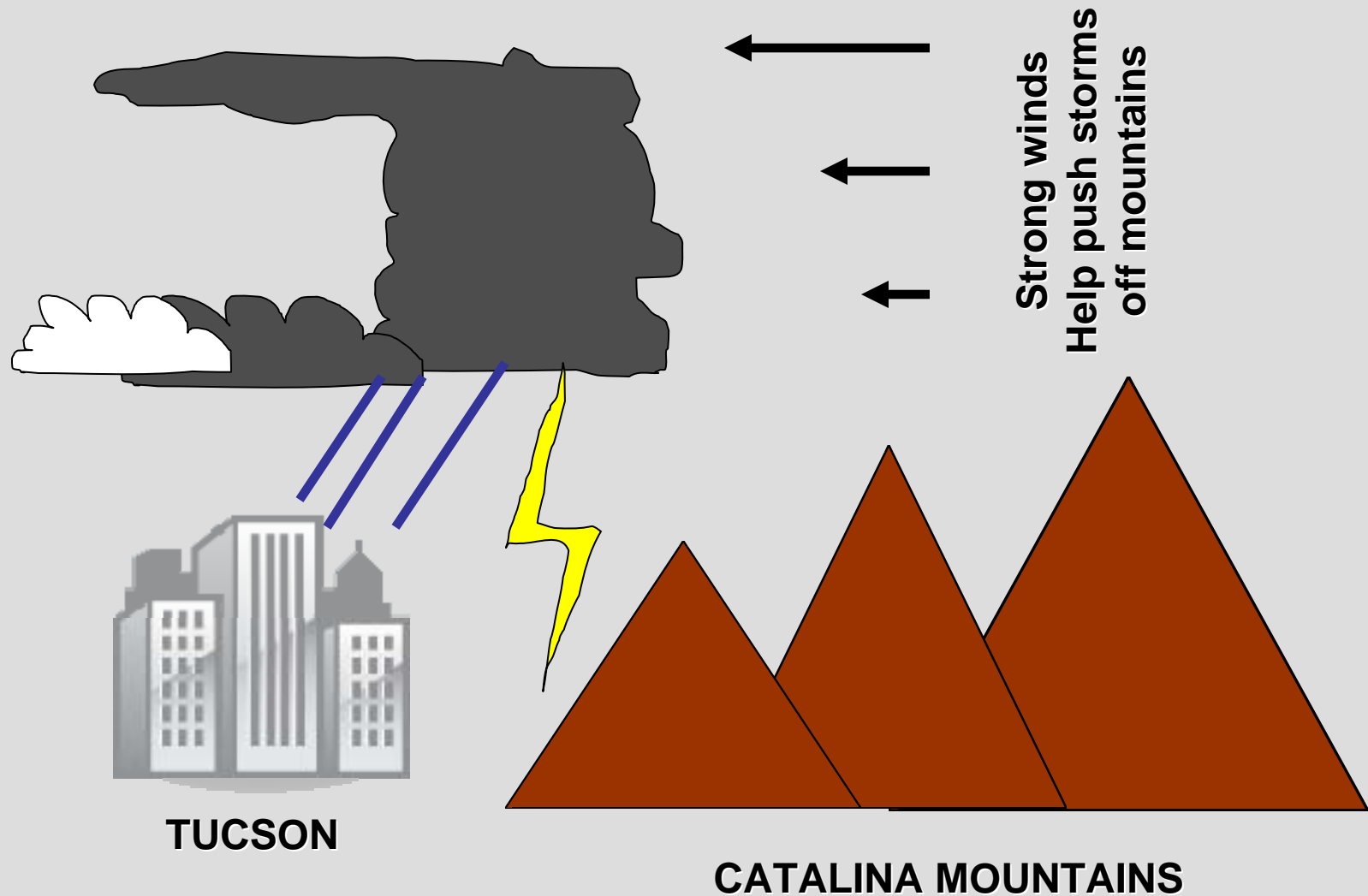
**COLD AND MOIST RISING
AIR ALOFT**



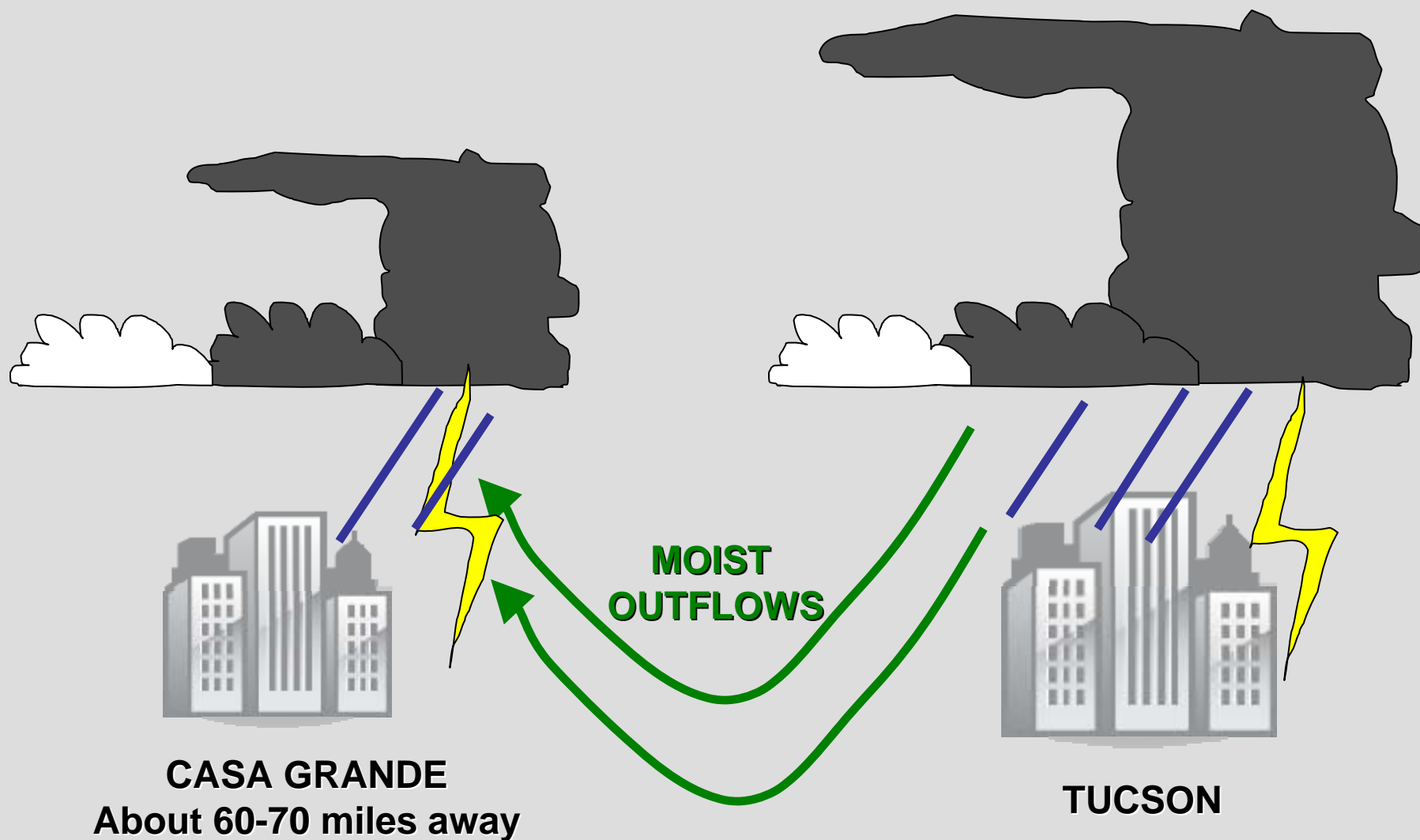
**Wind increasing
with height**



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

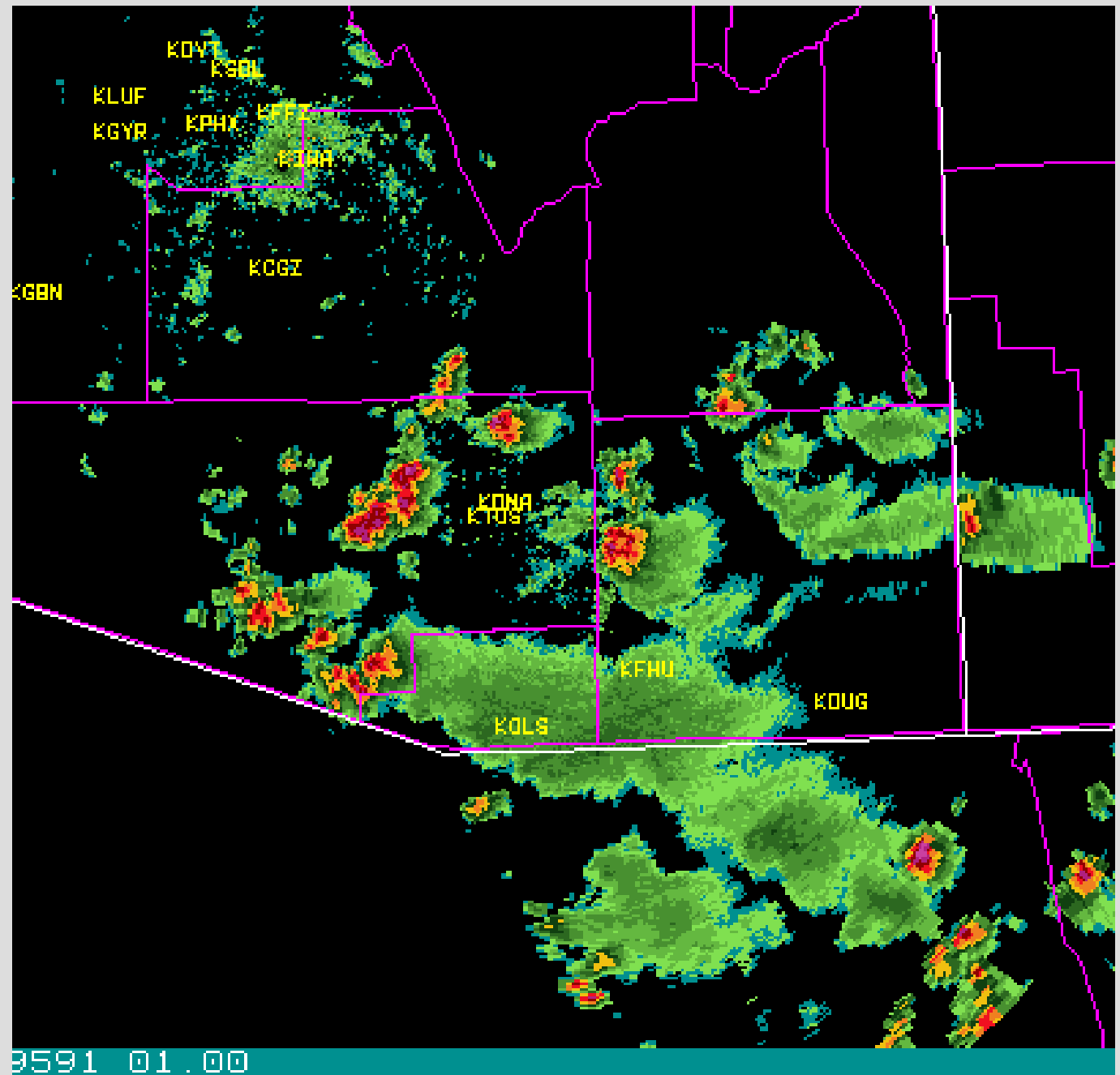


**On a REALLY good monsoon day...
Outflows may trigger new thunderstorms
farther west, away from mountains.**



Radar reflectivity

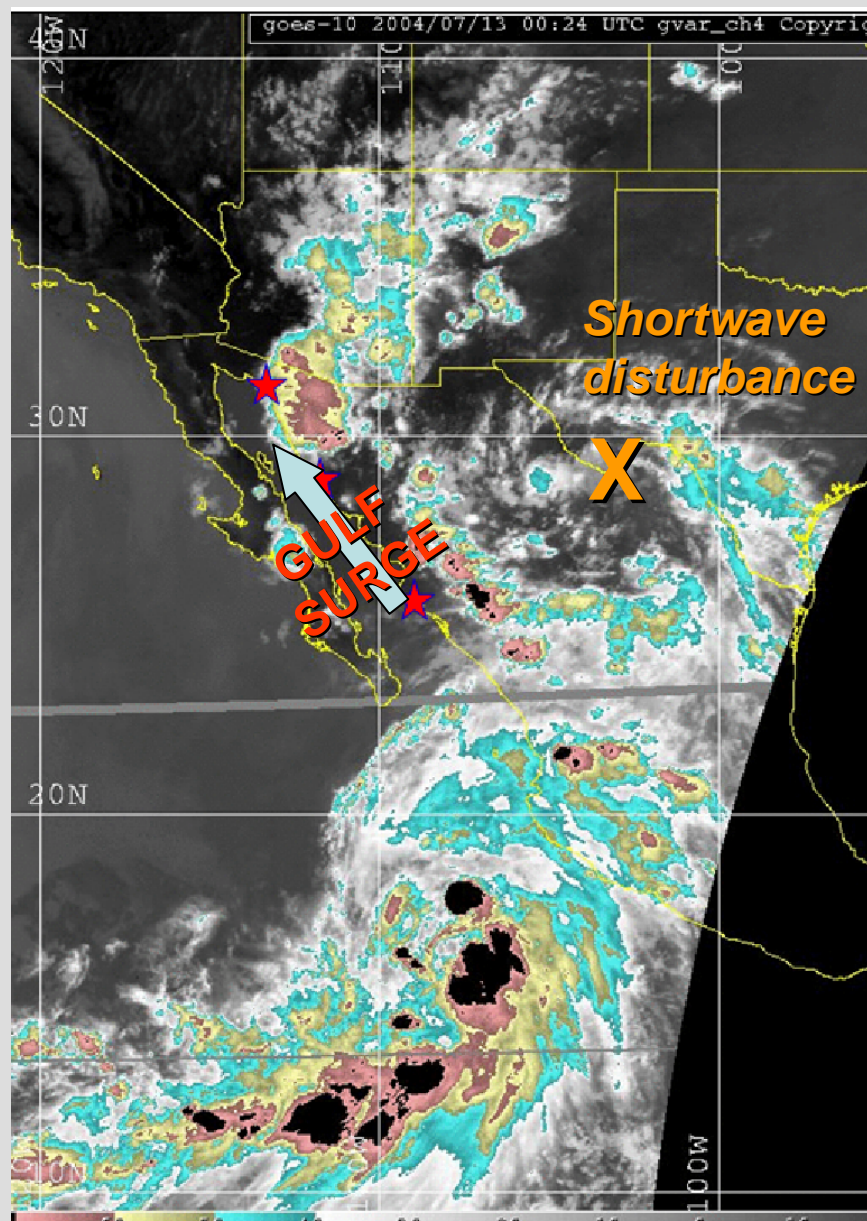
July 7, 2009
Late
afternoon



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

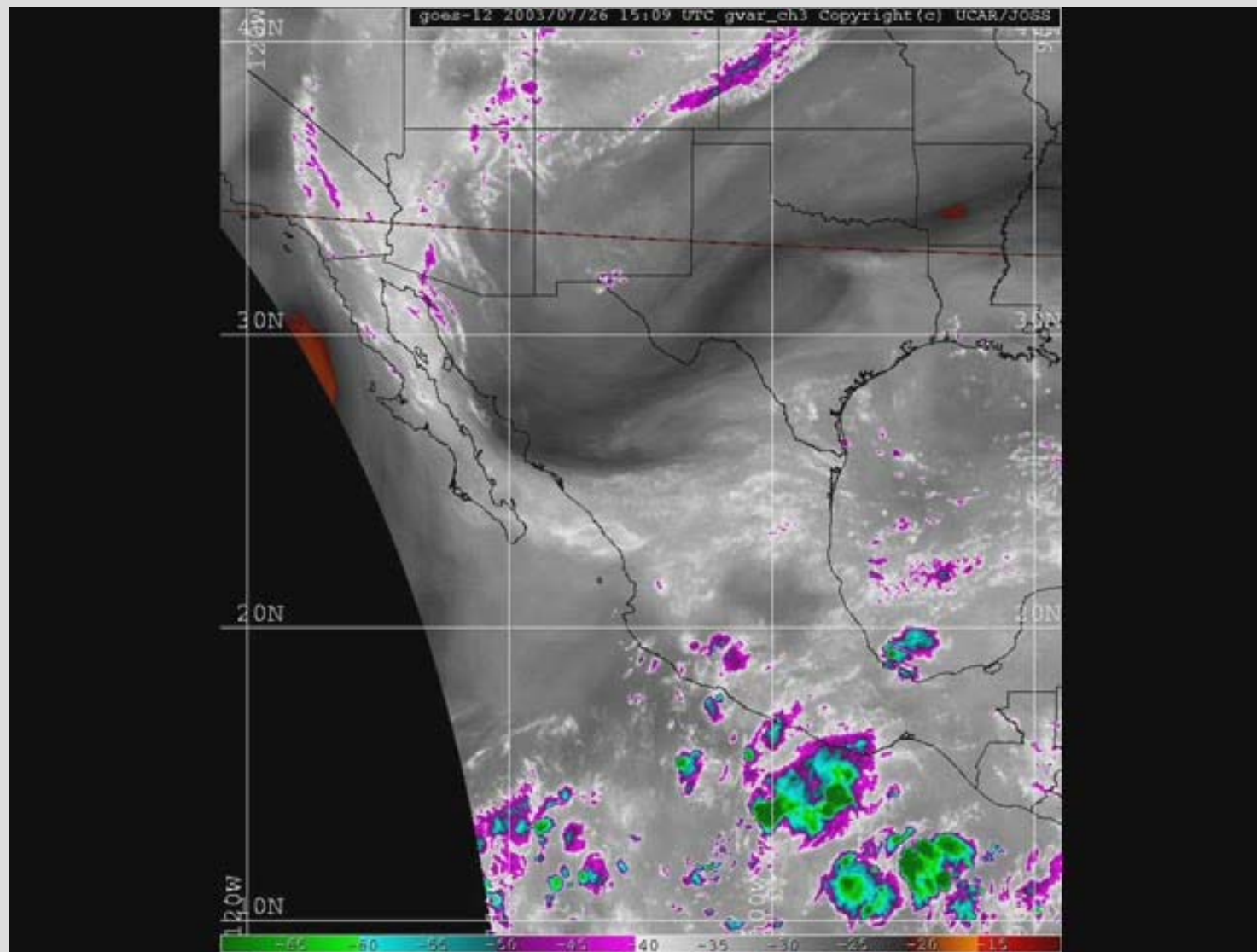
An upper-level disturbance (X) traveling around the monsoon ridge.

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...



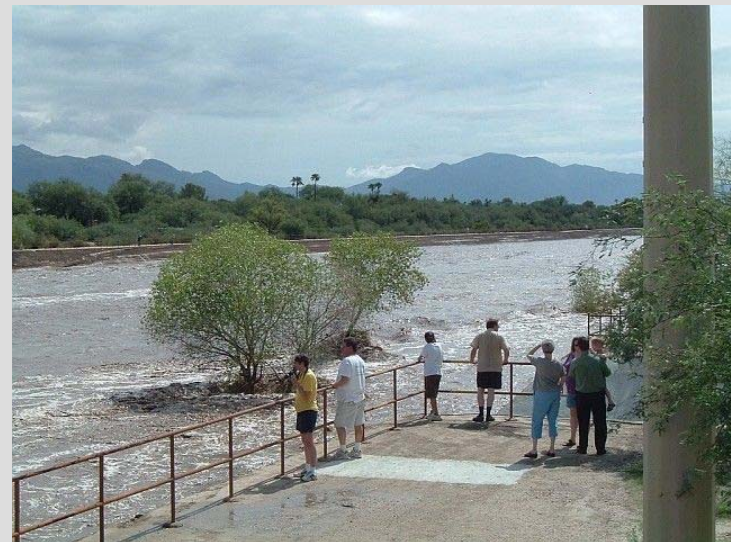
Monsoon Severe Weather Hazards

Flash Flooding

ARROYOS



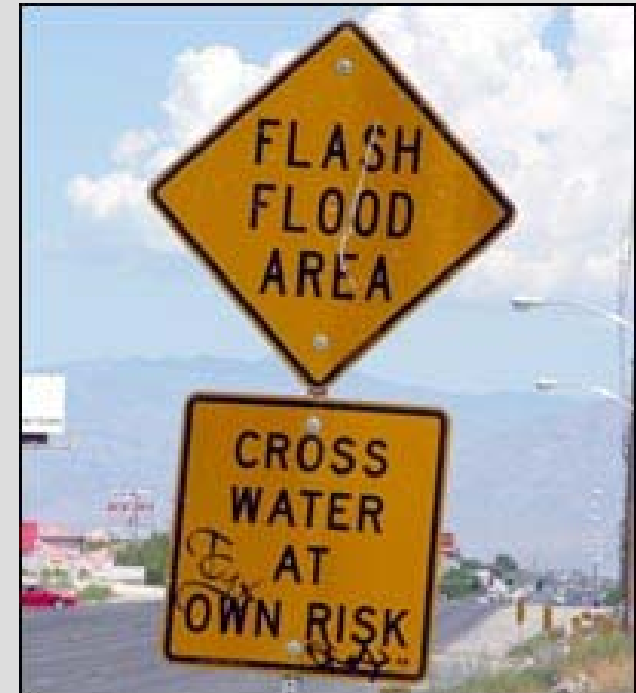
CANYONS AND DRY RIVERBEDS



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



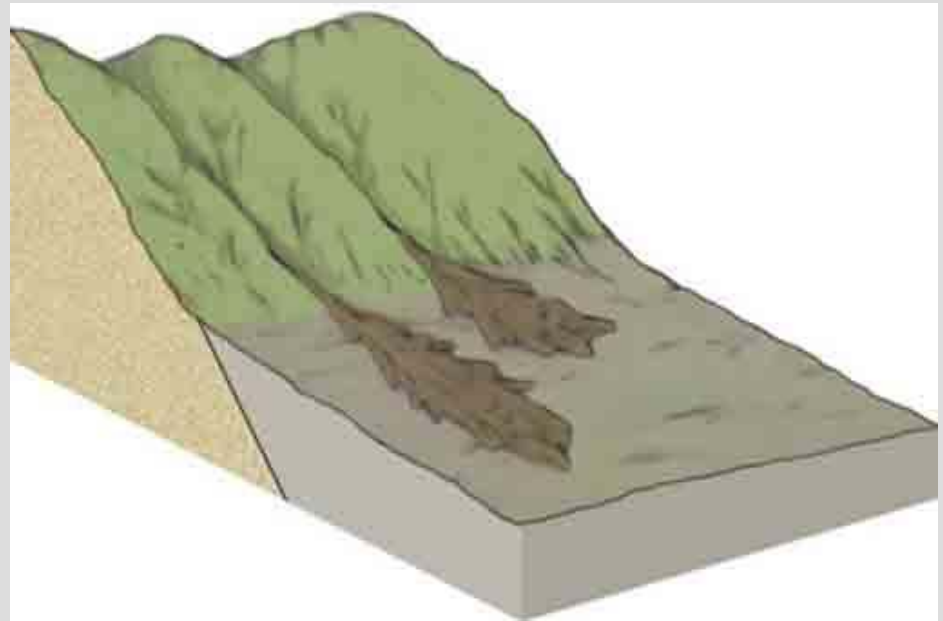
LAS VEGAS FLOOD, July 1999



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



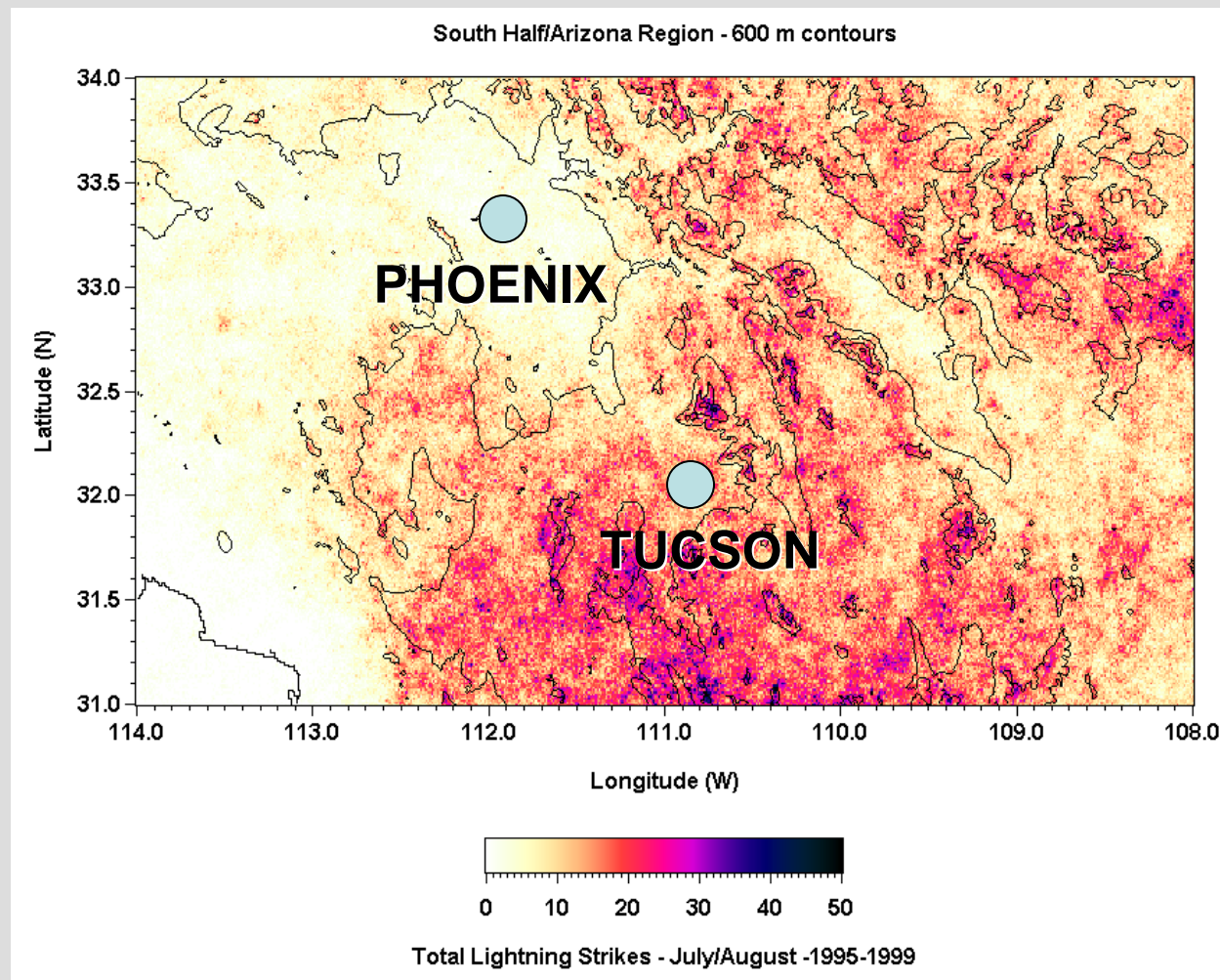
Discharge of electricity, or spark that usually occurs in thunderstorms.

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



Why more here?

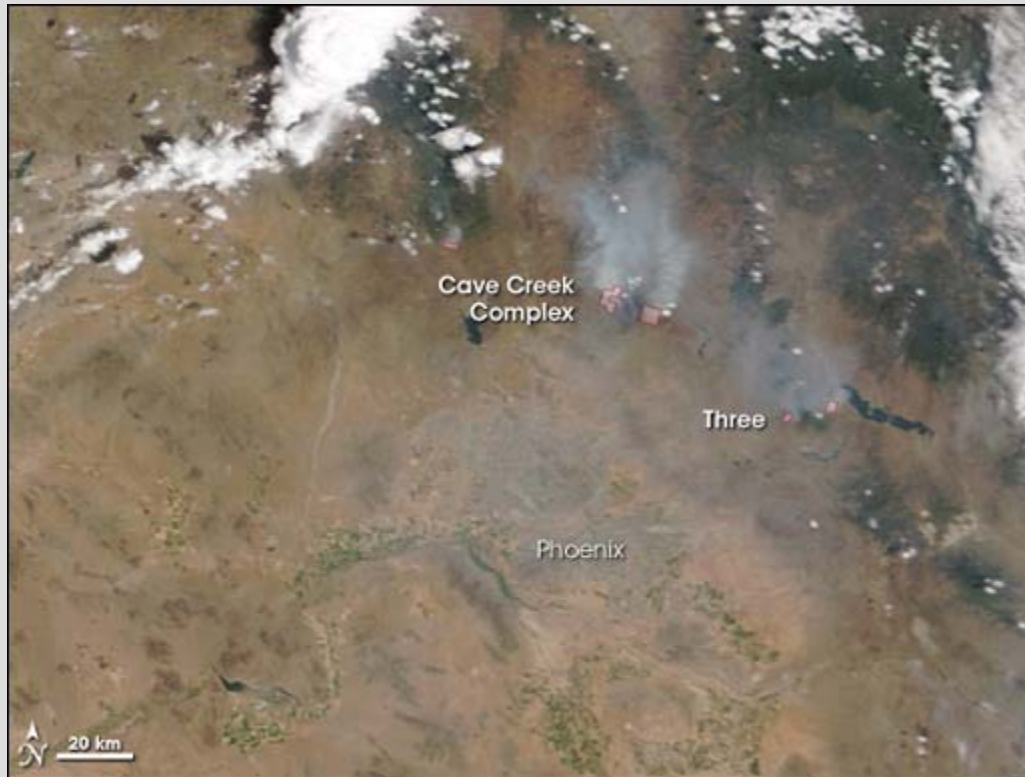
HIGHER ELEVATION

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.

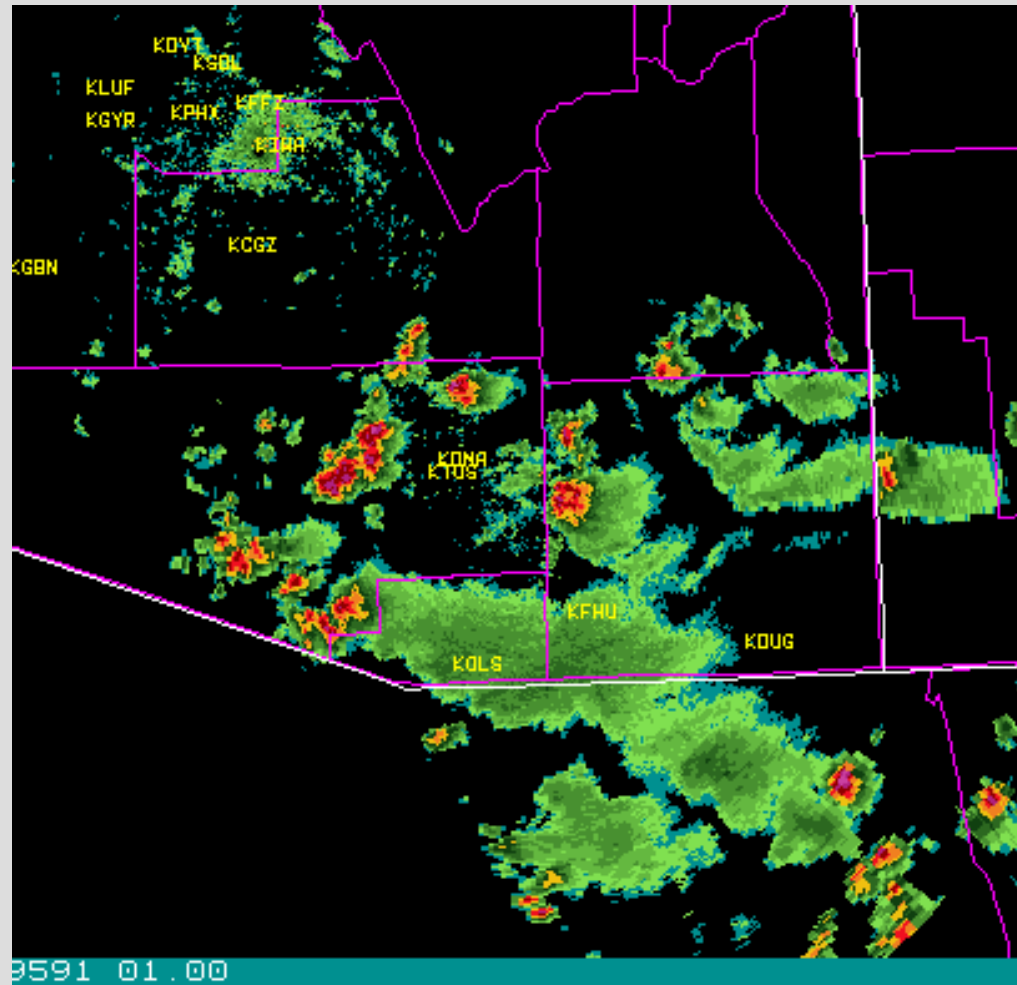
Is the monsoon predictable?

**A Meteorologist's Answer:
It Depends...**

Can we forecast monsoon storms perfectly exact every day?

ANSWER: NO

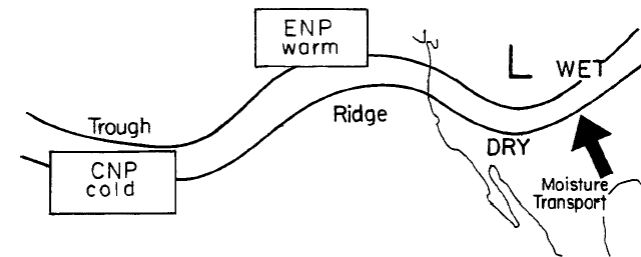
Even the most sophisticated and resolved atmospheric models cannot predict the timing, location, and intensity of monsoon storms with absolute certainty.



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

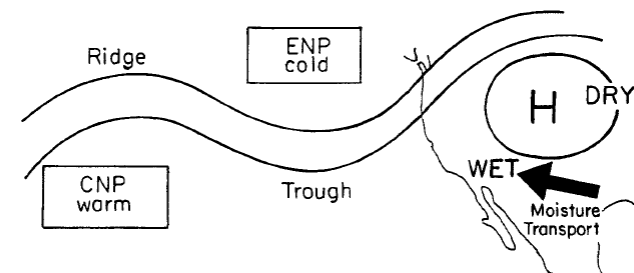
ANSWER: MAYBE

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.



El Niño

El Niño
High NPO Phase



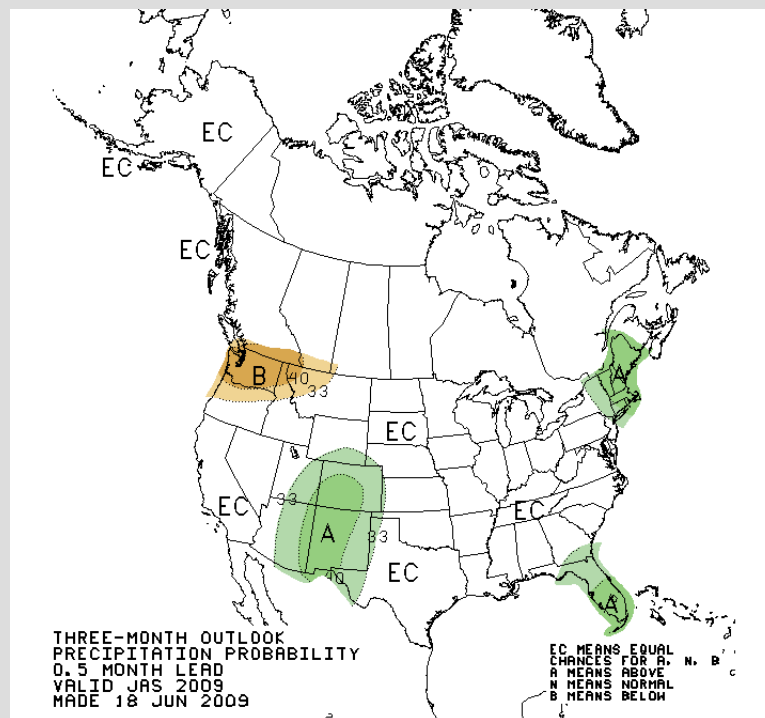
La Niña

La Niña
Low NPO Phase

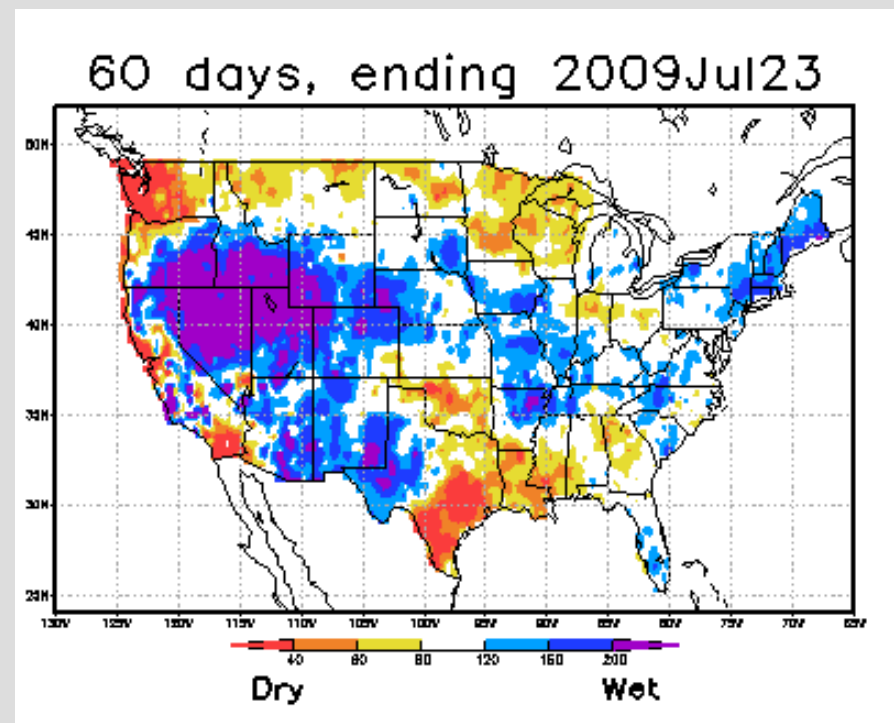
FIG. 14. Idealized relationship of monsoon ridge position and midlevel moisture transport to Pacific SSTs at monsoon onset.

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

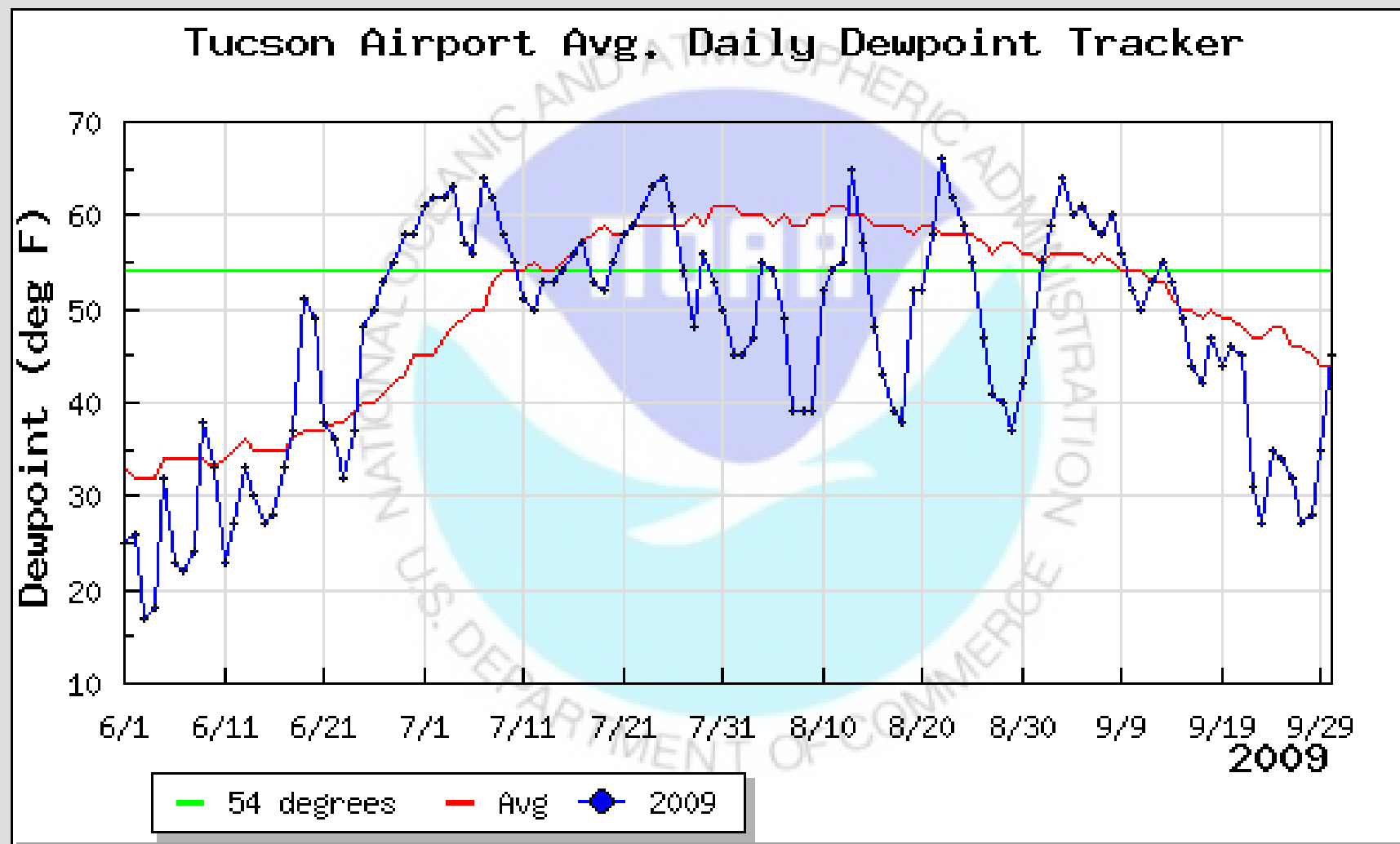
FORECAST



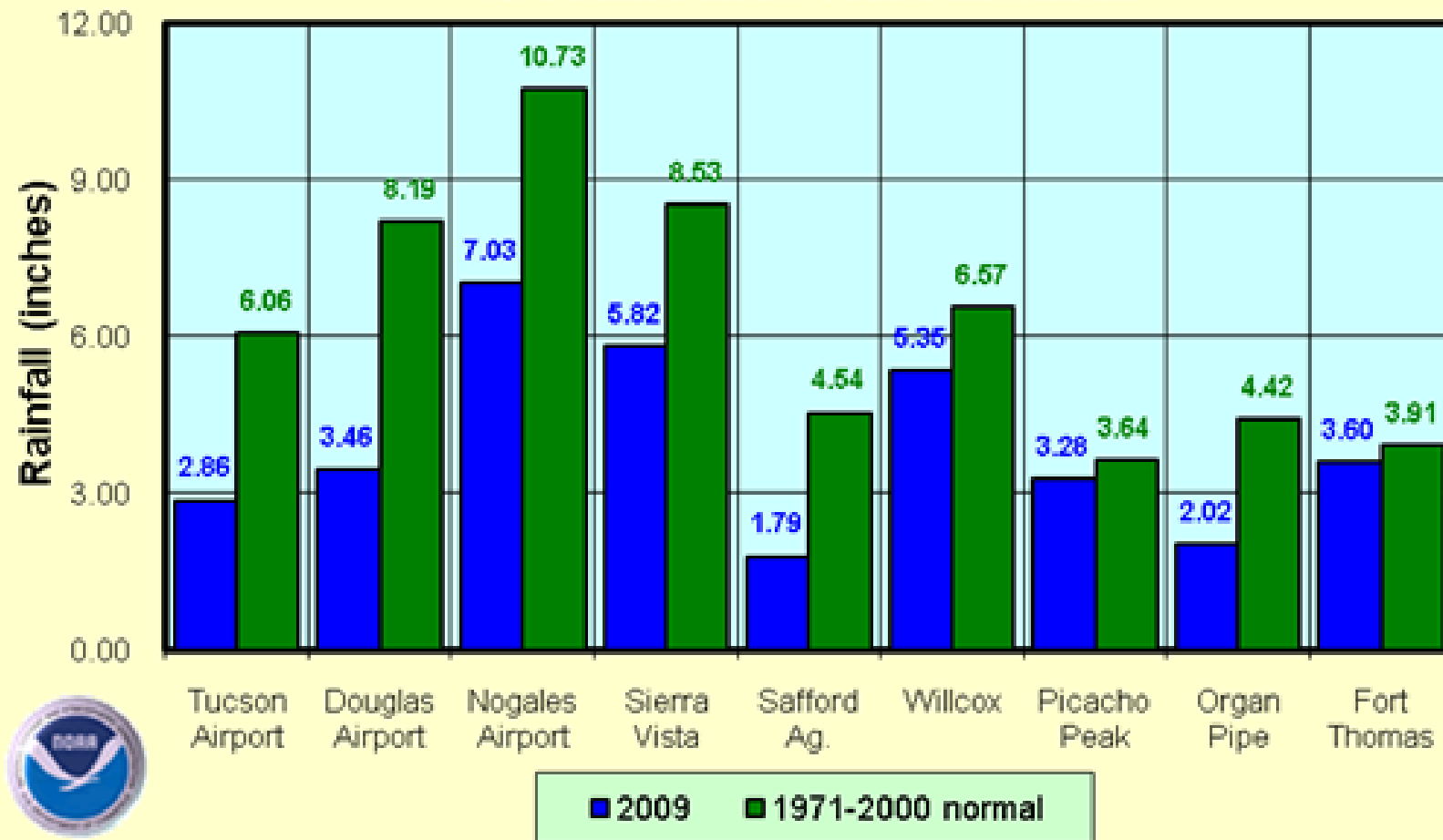
MOTHER NATURE



Percent of precipitation above normal



Preliminary 2009 Monsoon rainfall totals versus normal
for selected sites in southeast Arizona.



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?

