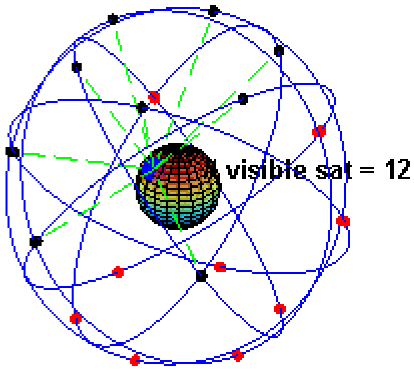
Ground Based GPS Receivers Network to Study the North American Monsoon

Christopher L. Castro[1]
Carlos Manuel Minjarez Sosa[1,2]

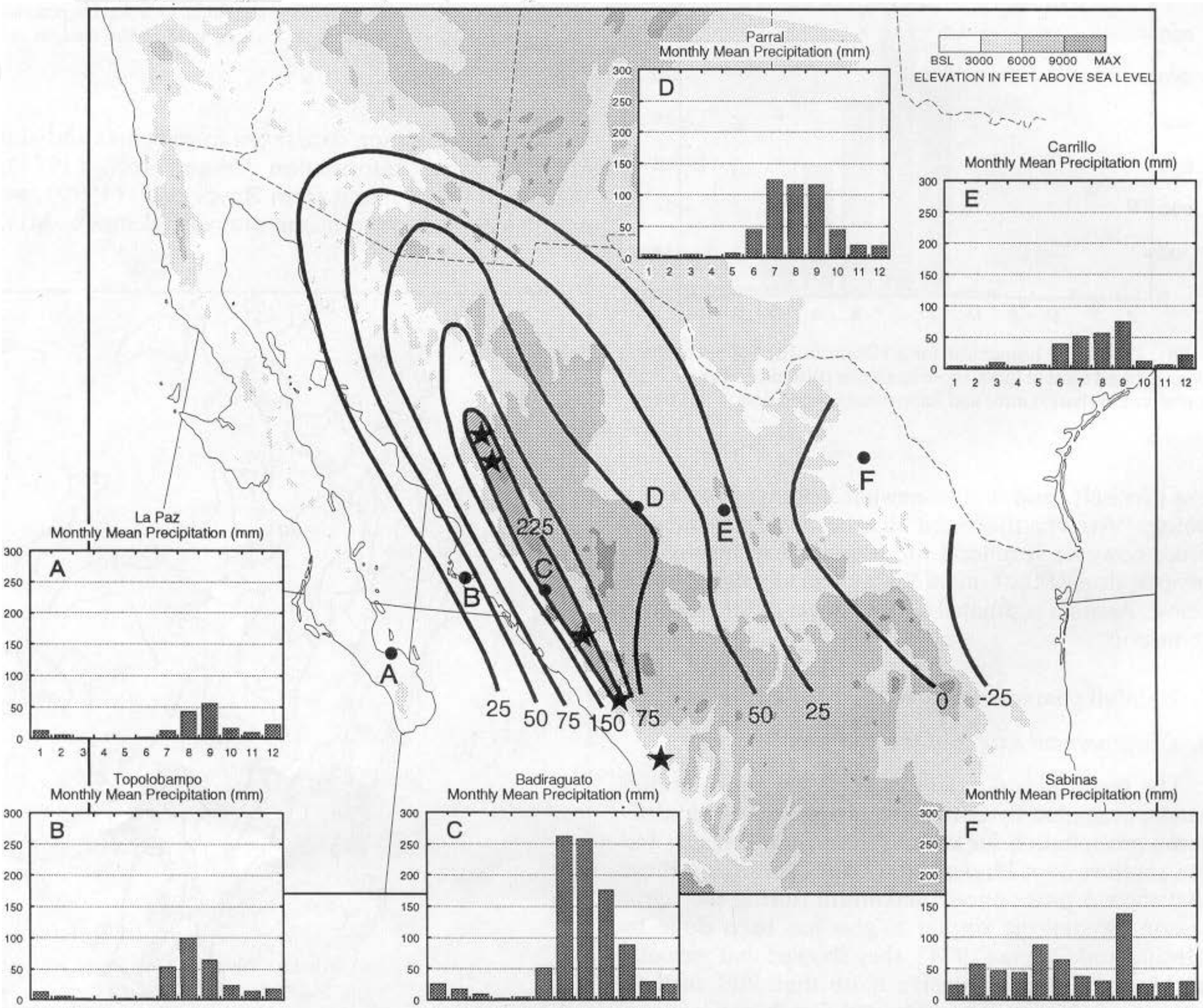
[1]University of Arizona, Department of Atmospheric Sciences
[2]Univesidad de Sonora, Departamento de Física.

Overview



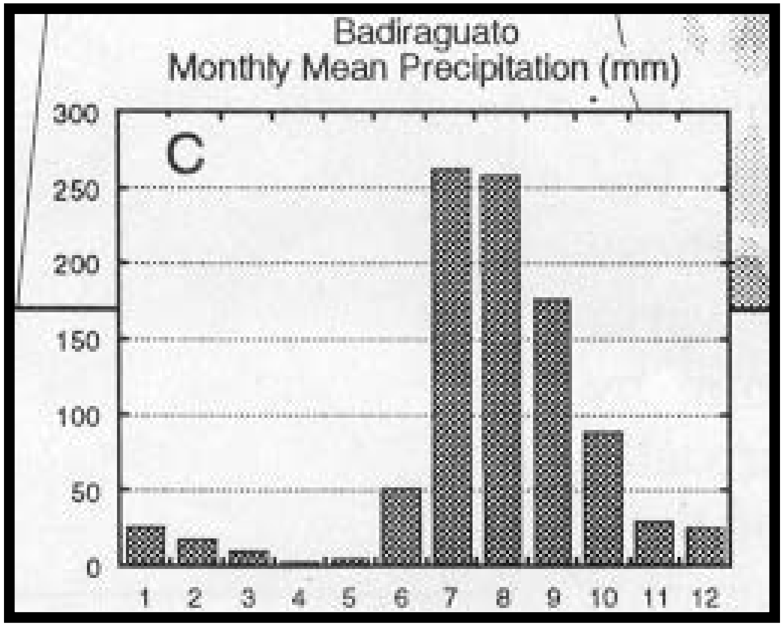
1. Weaknesses in North American Monsoon Understanding
2. Observing the monsoon via GPS sensors
3. Applications of GPS data in WRF monsoon modeling
4. Future Research proposal?

Monthly Average Precipitation in Core Monsoon Region

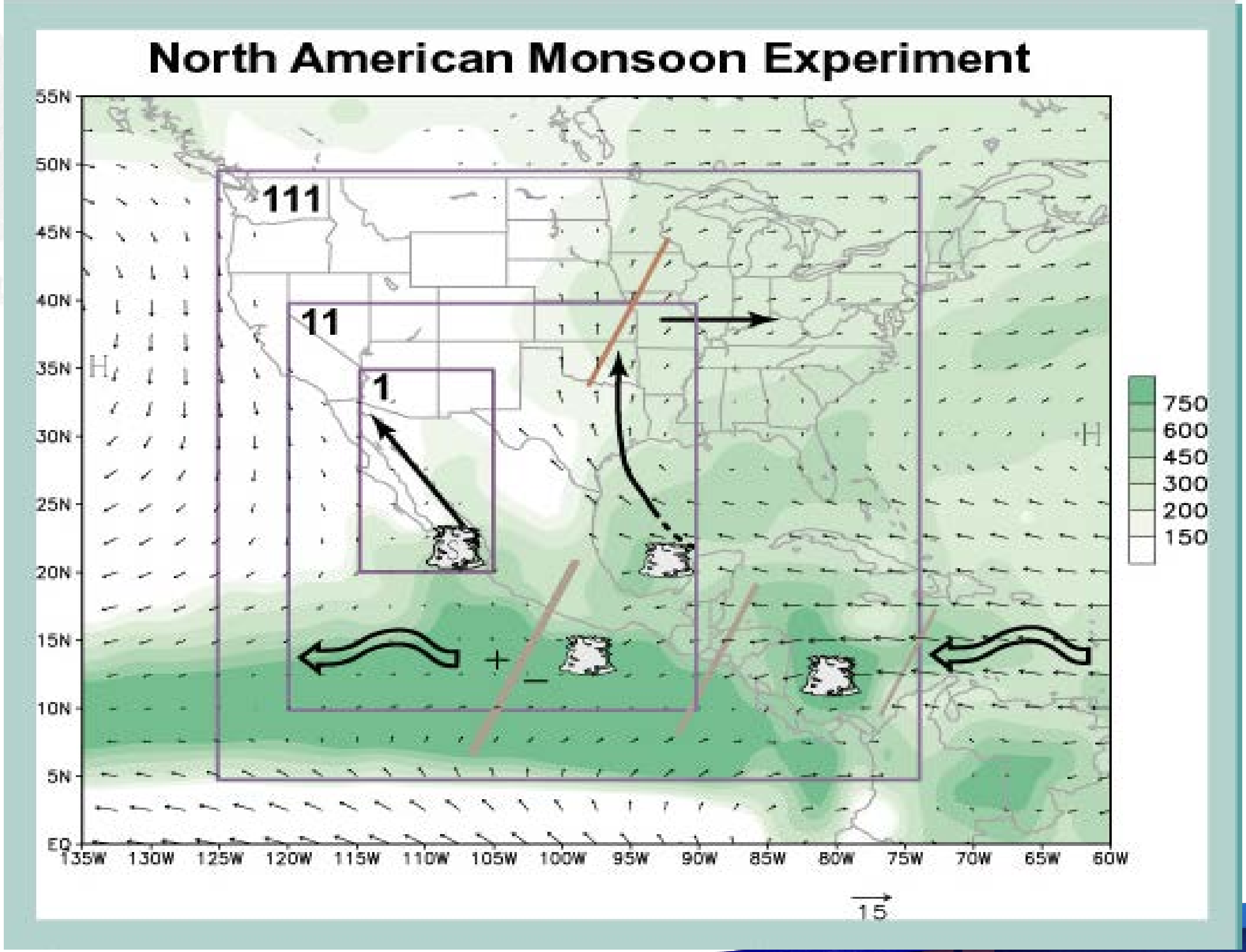


Douglas et al. 1993

Most monsoon rainfall is where the convection originates along the crest of the Sierra Madres—so characterization of moisture is critical there!

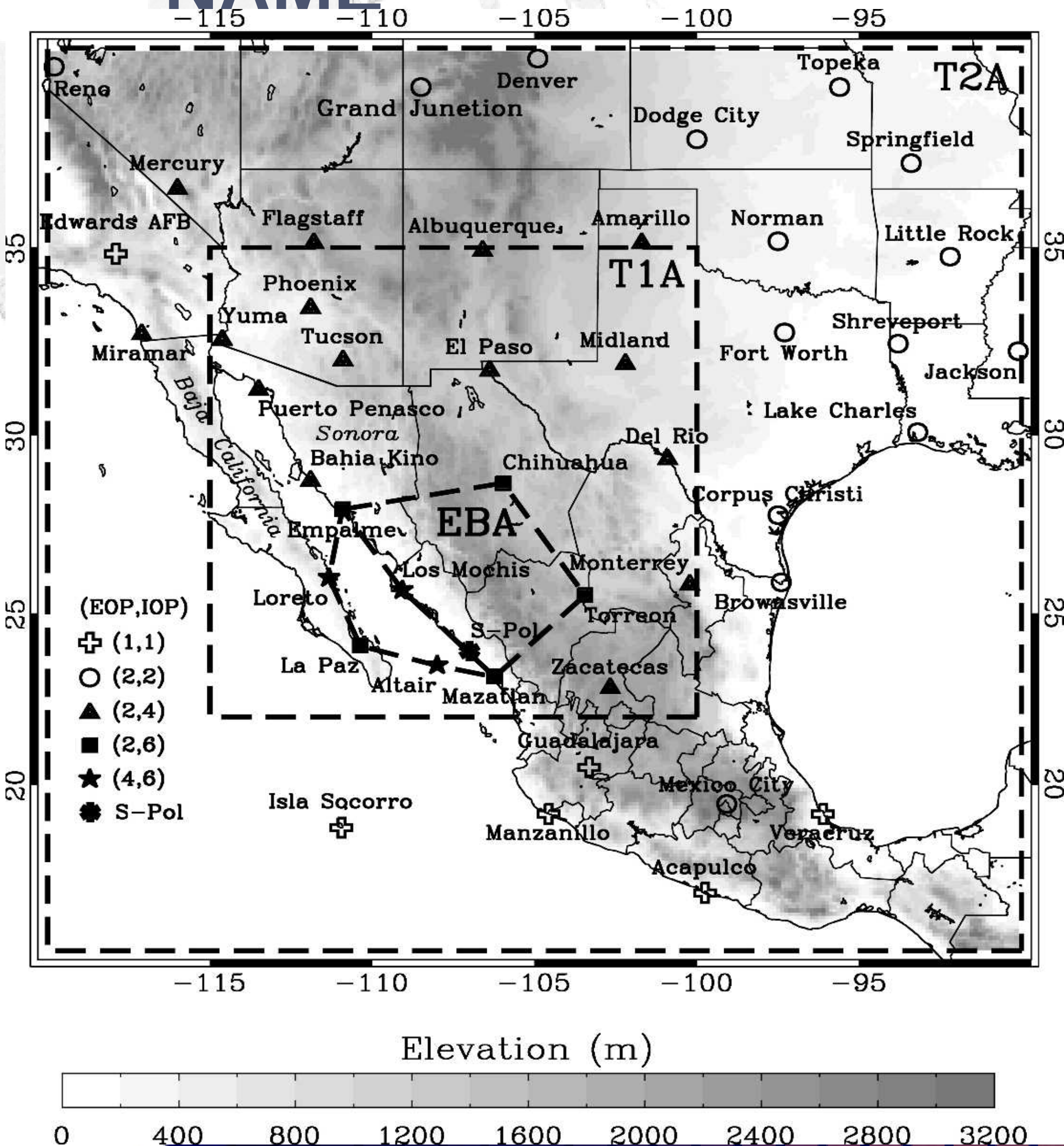


The North American Monsoon



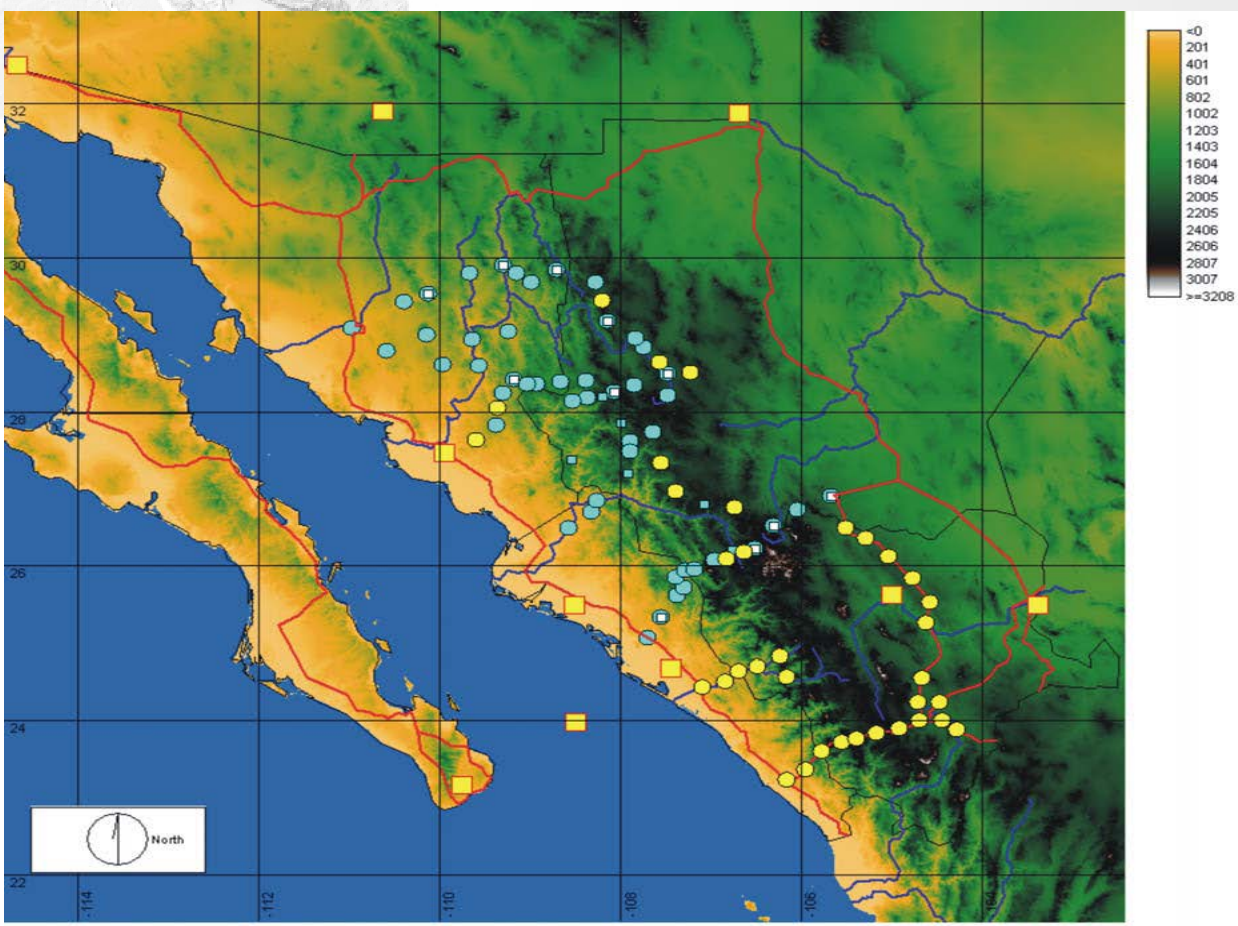
- Higgins et al. 2004

Upper Air Observation Network During NAME



- Most of the Upper Air Observations are Located either in lower terrain close to the gulf or in the eastern side of SMO.
- There are no Observations over the western side of SMO where most of the convection occurs during NAME

Rain Gauge Network



PHASE 1 Event Raingage

Isotope Collector

PHASE 2 Event Raingage

Existing or Proposed Radar Site

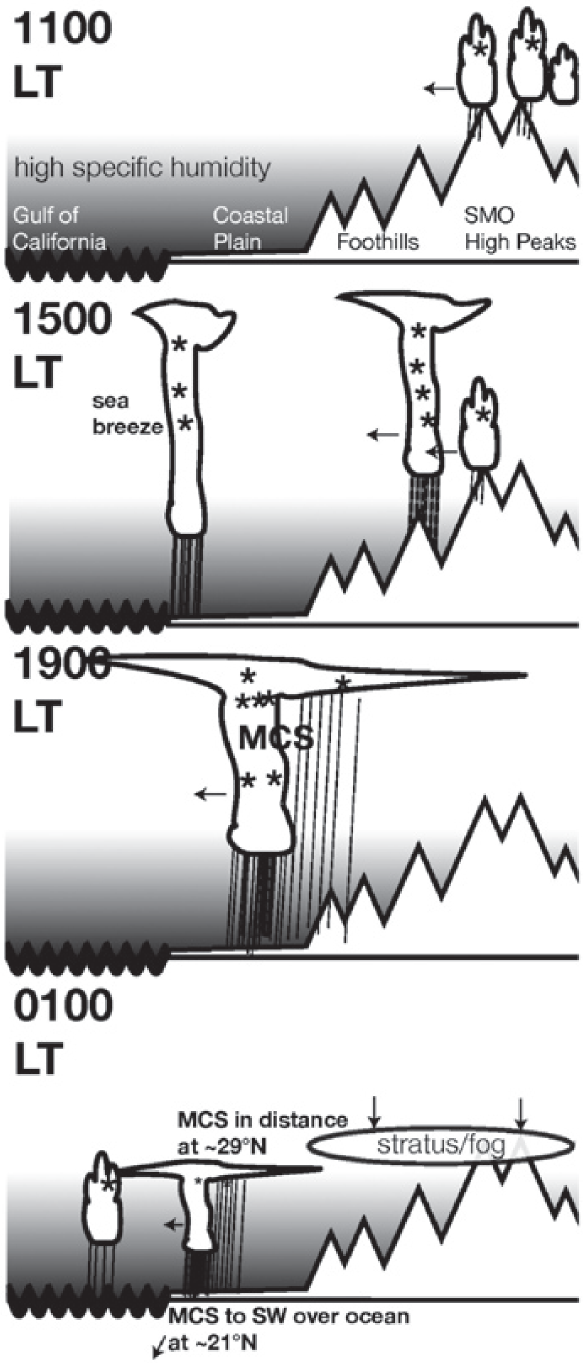
Diurnal cycle of convection

Convective clouds form over the mountains in the morning.

By afternoon and everning 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.

Nesbitt et al. 2008



Lack of NAME data in Sierra Madres

Most detailed understanding of upper air structure during NAME from Johnson et al. analyses from Colorado State.

They note a significant weakness is the lack of sounding data in the Sierra Madres and this affected their results.

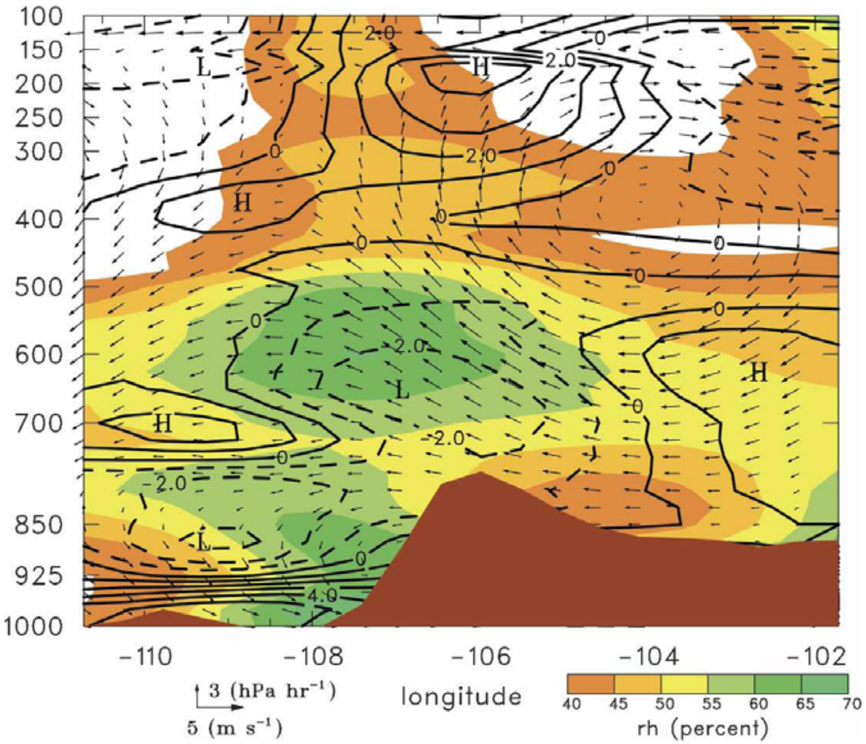
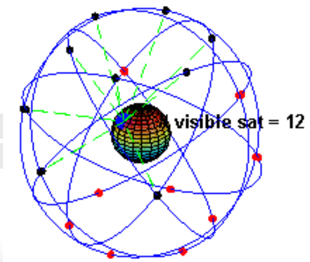


FIG. 14. Vertical cross section perpendicular to the GoC (position shown in Fig. 4a) of the wind component in the plane of the section, divergence (10^{-5} s^{-1}), and relative humidity averaged for the period 1 Jul–15 Aug 2004 based on two-times daily T2A analyses. Vertical axis is pressure (hPa).

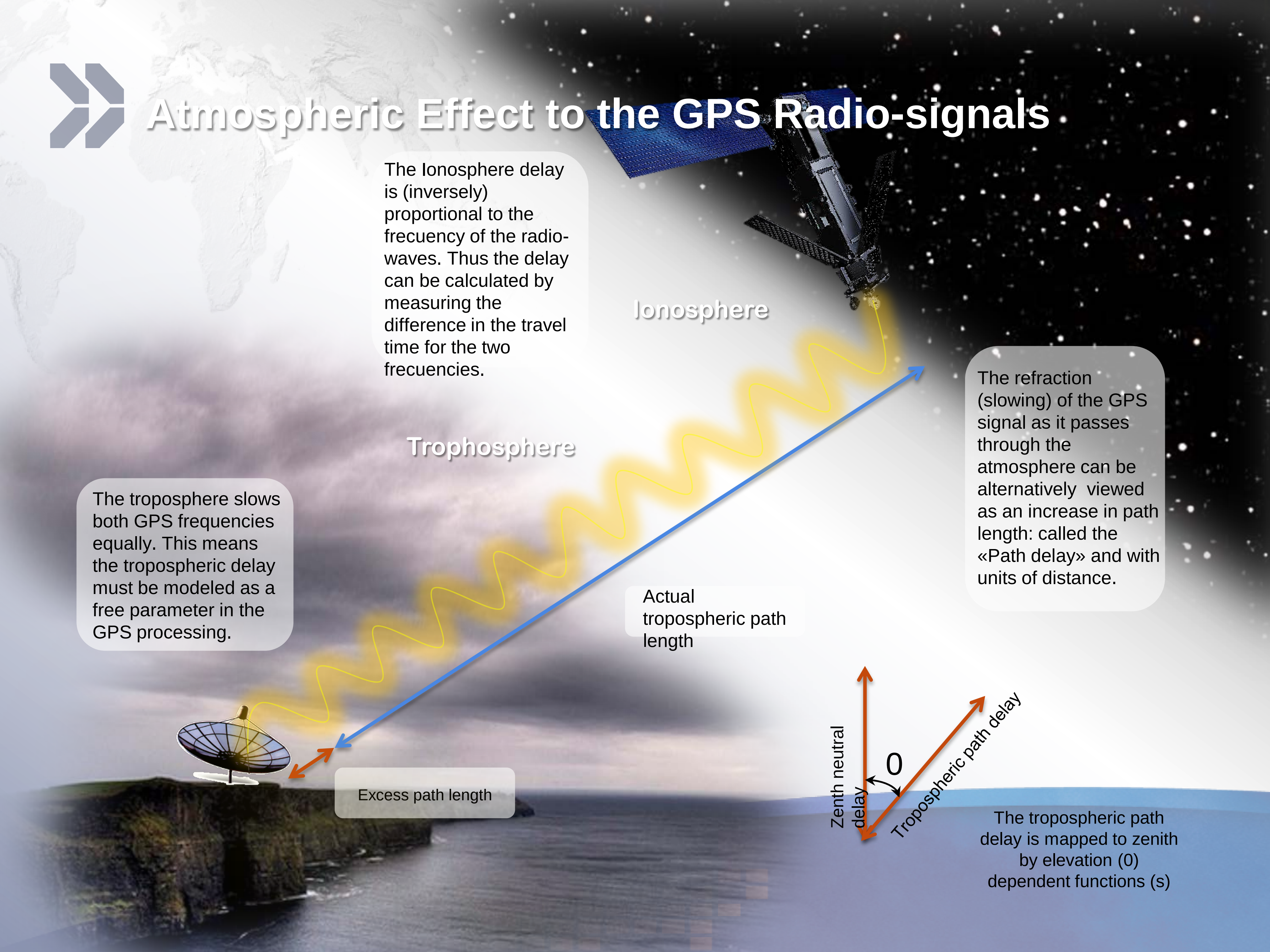
Johnson et al. 2007

GPS Constellation

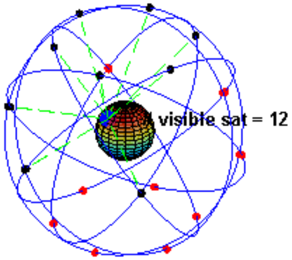


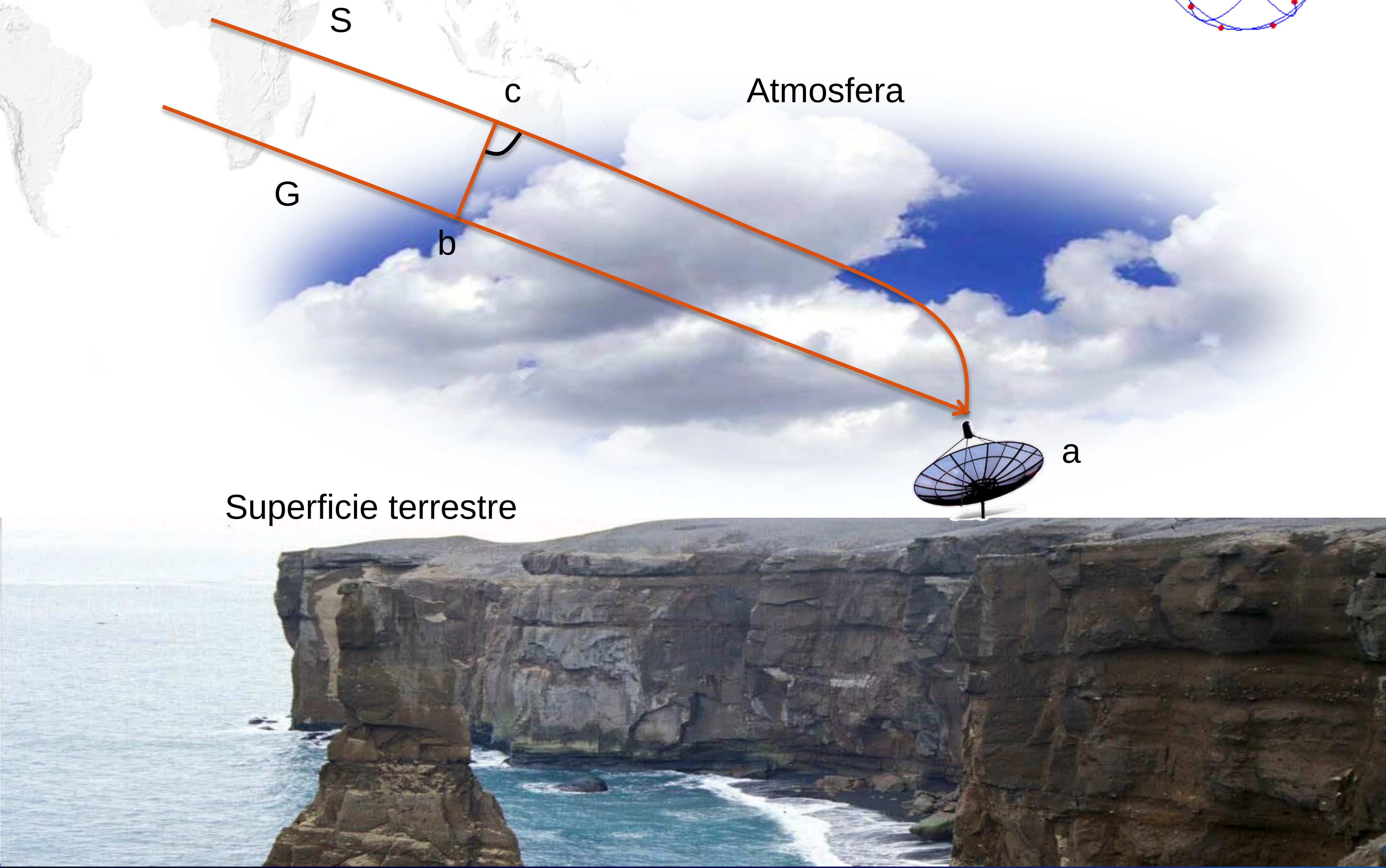
24 satellites encircle the planet in 6 orbits.

- GPS illuminates the atmosphere with L1 y L2 (~1.2 y 1.6 GHz) microwaves.
- Upper and lower atmosphere induce delays that can be estimated with high precision (sub-millimeters).

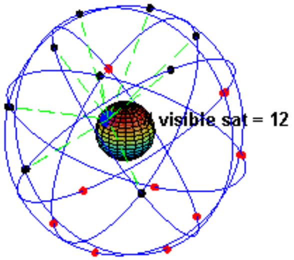

Atmospheric Effect to the GPS Radio-signals
The Ionosphere delay is (inversely) proportional to the frecuency of the radio-waves. Thus the delay can be calculated by measuring the difference in the travel time for the two frecuencies.
Ionosphere
Trophosphere
The refraction (slowing) of the GPS signal as it passes through the atmosphere can be alternatively viewed as an increase in path length: called the «Path delay» and with units of distance.
The troposphere slows both GPS frequencies equally. This means the tropospheric delay must be modeled as a free parameter in the GPS processing.
Actual tropospheric path length
Excess path length
Zenth neutral delay
0
Tropospheric path delay
The tropospheric path delay is mapped to zenith by elevation (0) dependent functions (s)

Atmospheric Delay Geometry





Atmospheric Delay Estimation



- The extra path can be written by:

$$\Delta L = \int_{s} n(s)ds - G$$

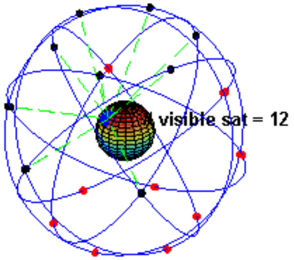
$$N = 10^{6}(n-1)$$

$$\Delta L = 10^{-6}\int_{s} N(s)ds$$

- Where N is given as:

$$N = k_1 \frac{P_d}{T} Z_d^{-1} + k_2 \frac{e}{T} Z_w^{-1} + k_3 \frac{e}{T^2} Z_w^{-1}$$

Atmospheric Delay Estimation



$$\Delta L^0 \approx 10^{-6}\left[k_1 \frac{R^*}{m_d}\frac{P_{antenna}}{g} + \int_o^\infty \left(k_2' \frac{e}{T} Z_w^{-1} + k_3 \frac{e}{T^2} Z_w^{-1}\right) dz\right]$$

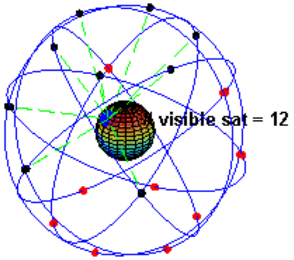
Zenith Hydrostatic Delay

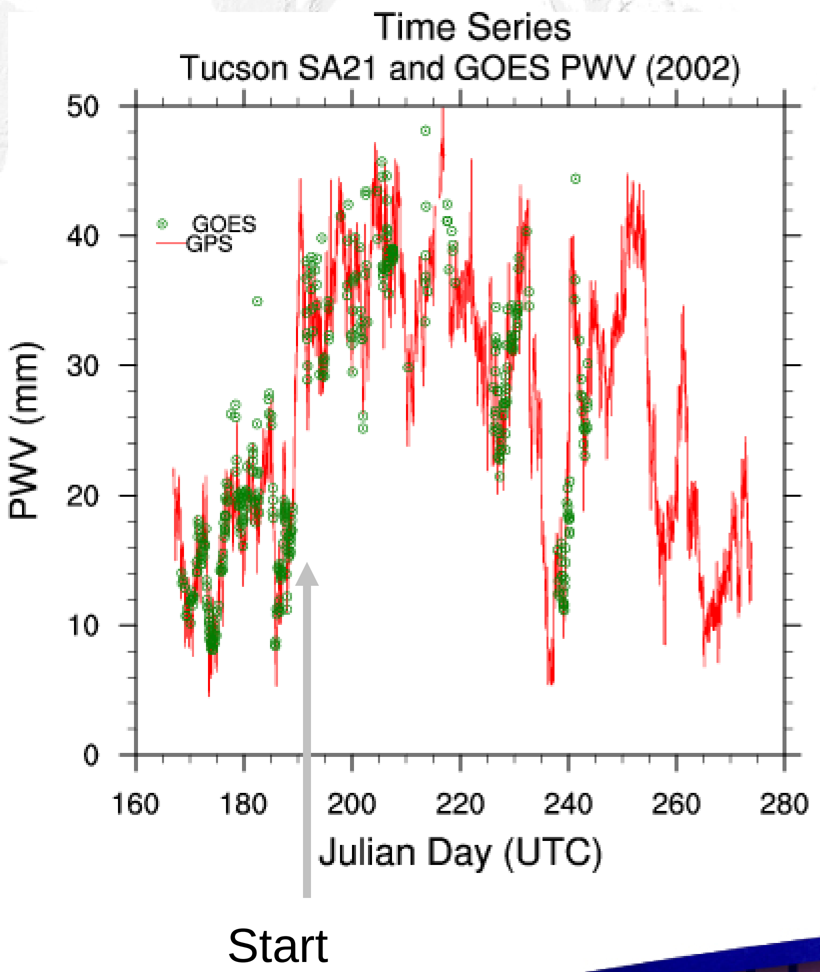
Zenith Wet Delay

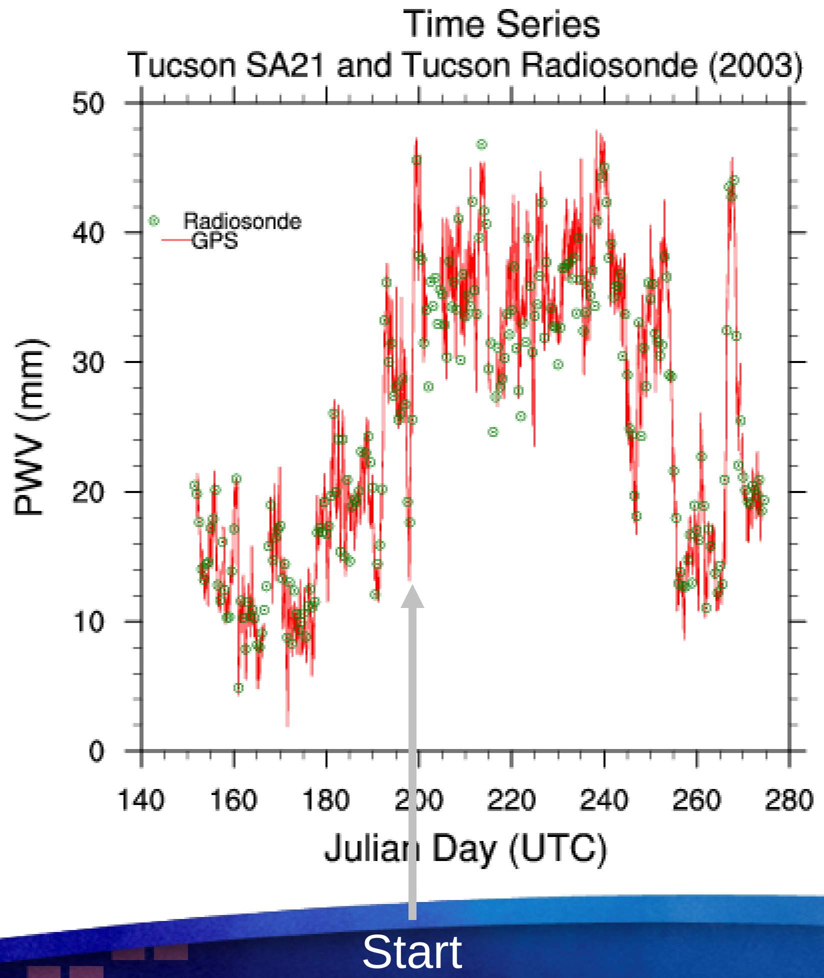
Finally PWV is given by:

$$PWV = \pi \times \Delta L_w^0$$

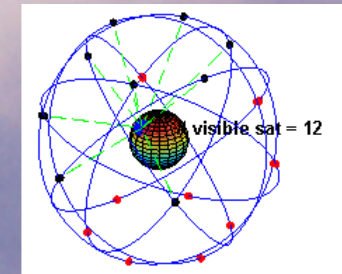
Series de Tiempo de VAP







PS and the detection of Convective vents



ta

- S PWV data from the FSL ecasting Lab .
- minutes time resolution

ations:

- A46 (Tucson, Arizona)
- 27 (Hermosillo, Sonora, xico)
- face data from WXT510 sala)

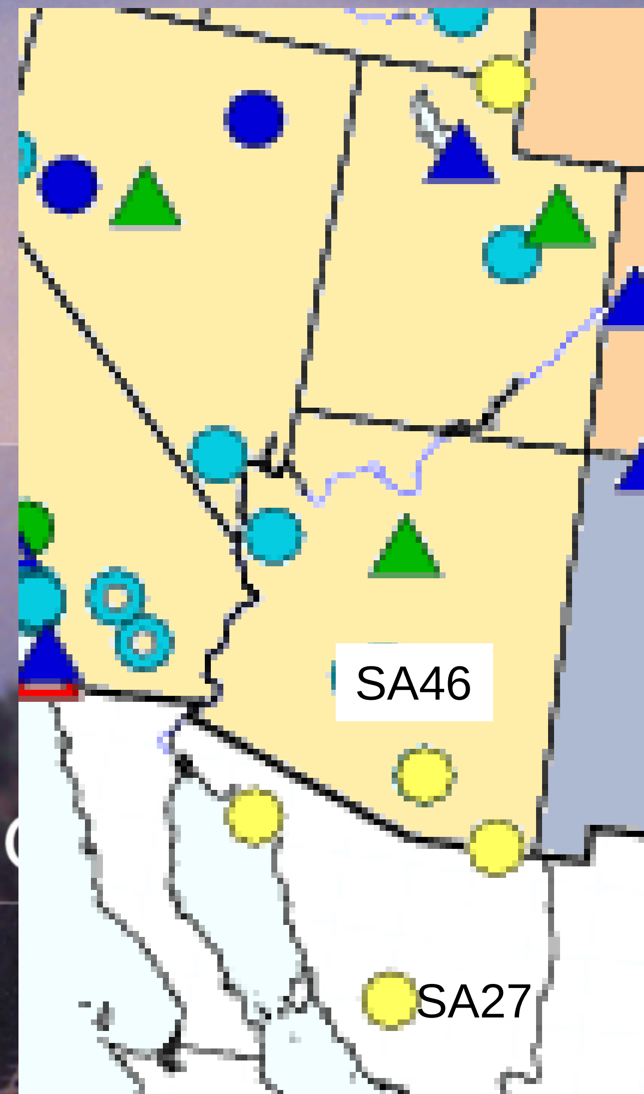
Down Draft

ethodology

Gust Front

wv/dt > 5 mm and

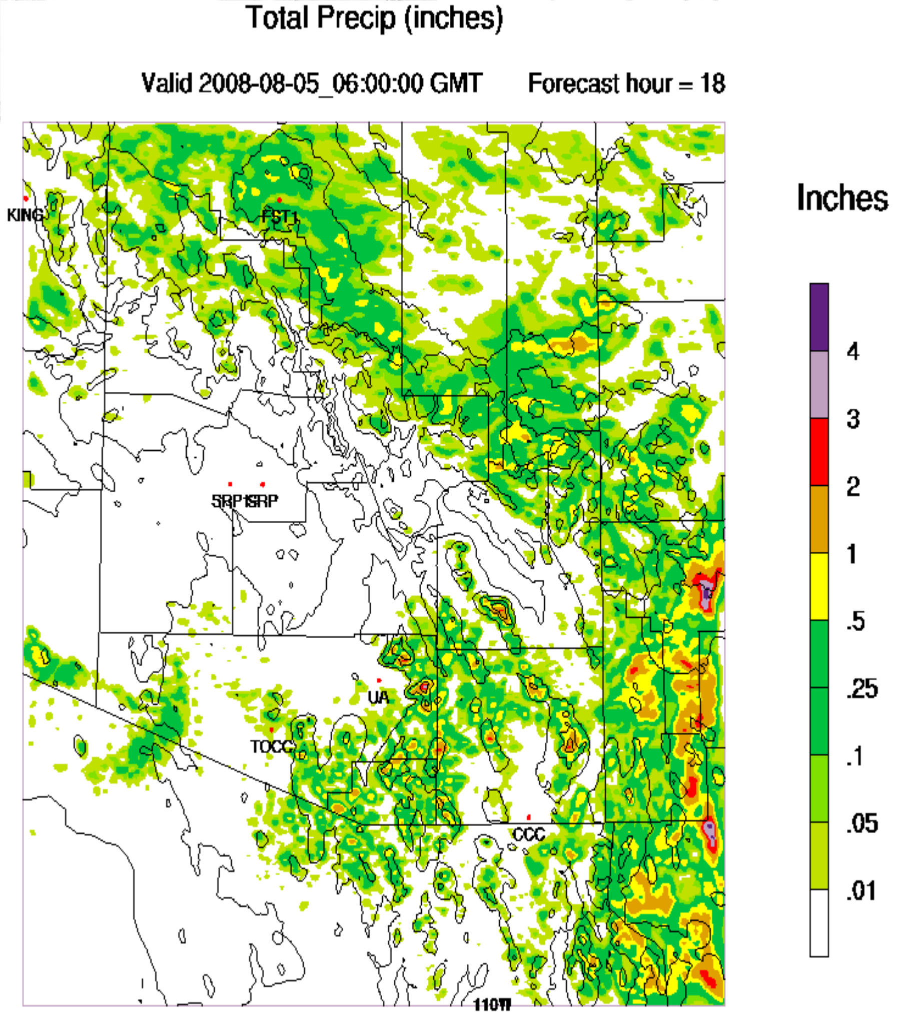
/dt > 8 C over 3 hours iods



Incorporation of GPS data in UA monsoon forecasts

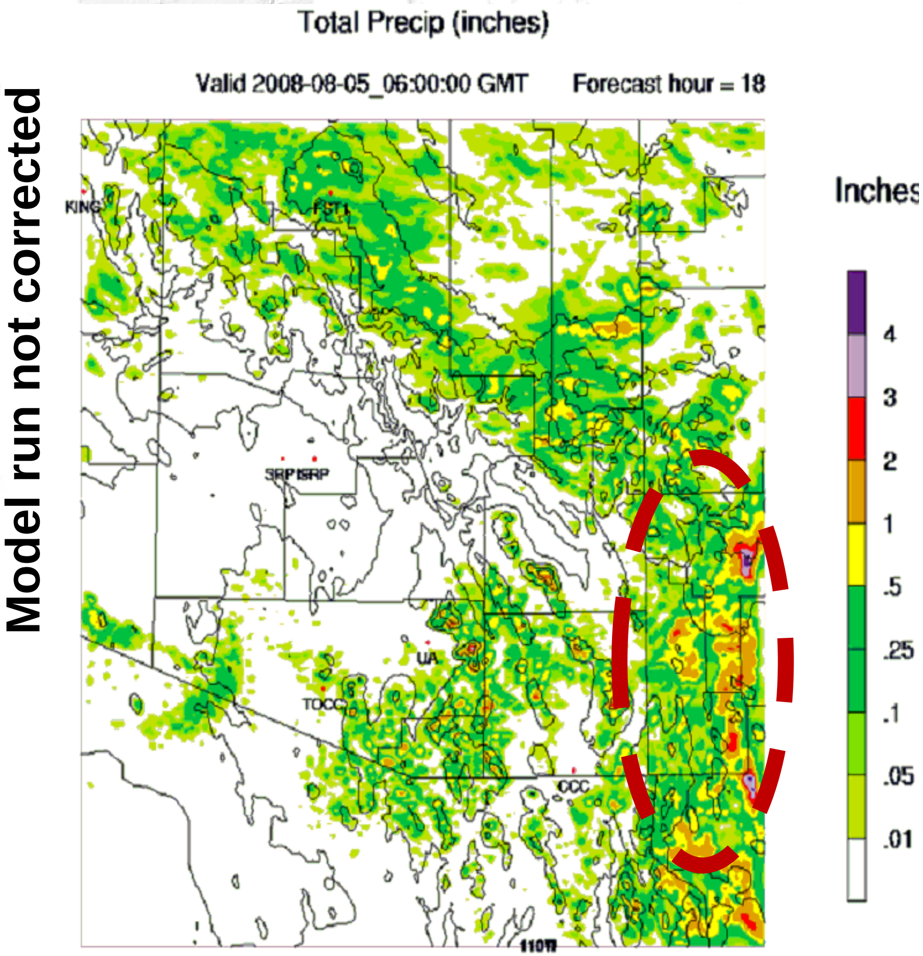
- GPS PWV data to adjust the analysis from GFS PWV used in initialization of WRF operational simulations
- 7.2 Km grid on outer mesh and 1.8 grid on inner domain
- Initialized using 0.5 degree GFS analysis data
- Explicit Convection on Both Domains (no cumulus parameterization scheme)
- WRF single-Moment 5 class microphysics
- Mellor-Yamada-Janjic TKE PBL scheme with NOAH Surface Model classes

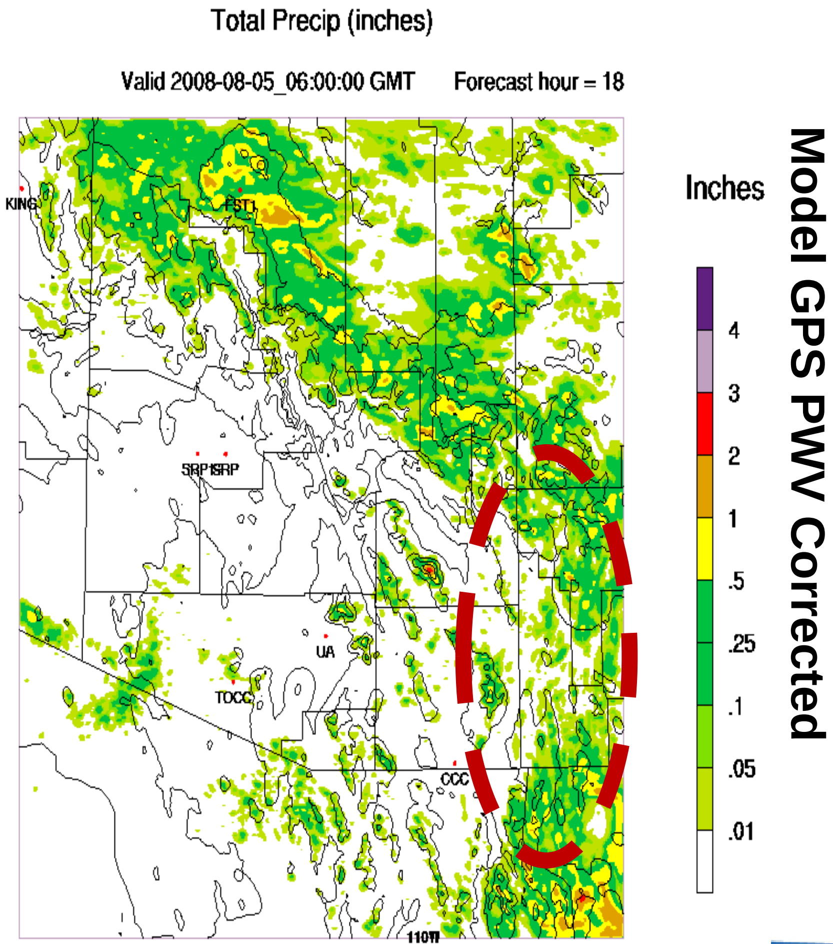
Difference Observation and Model (no corrected).



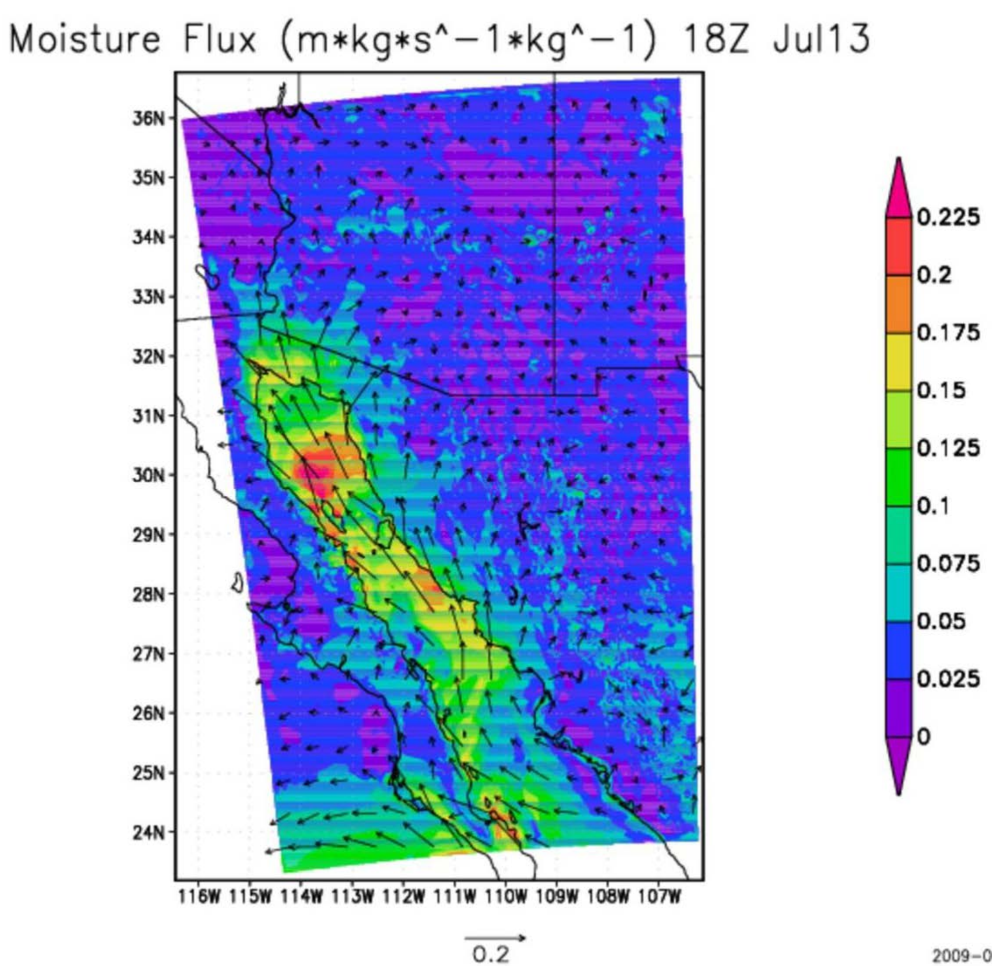
- GFS PWV is compared to the GPS PWV.
- A simple distance weighted difference (percentage) is used to adjust PWV on the outer and inner domains.
- Figure Shows the difference field (outer domain) for 1200 UTC July 19, 2006.
- This difference is used to adjust specific humidity from surface about 700 mb.

Effect of GPS data in sample WRF simulation





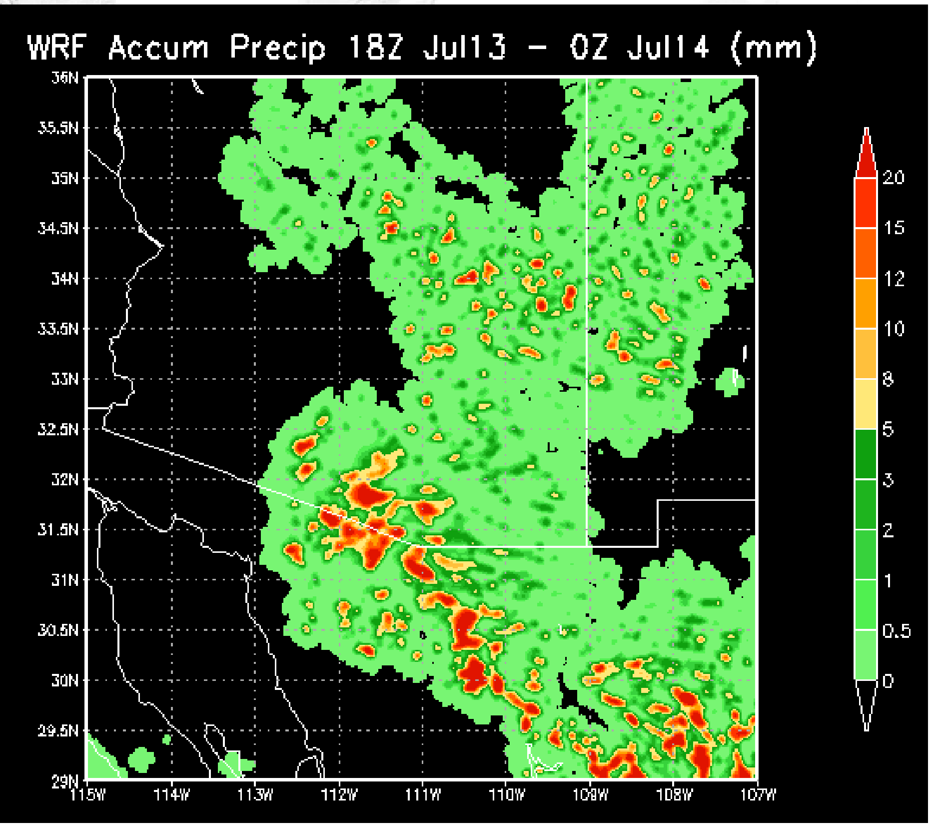
Highlights of WRF high resolution simulation (2.5 km) results for NAME IOP 2

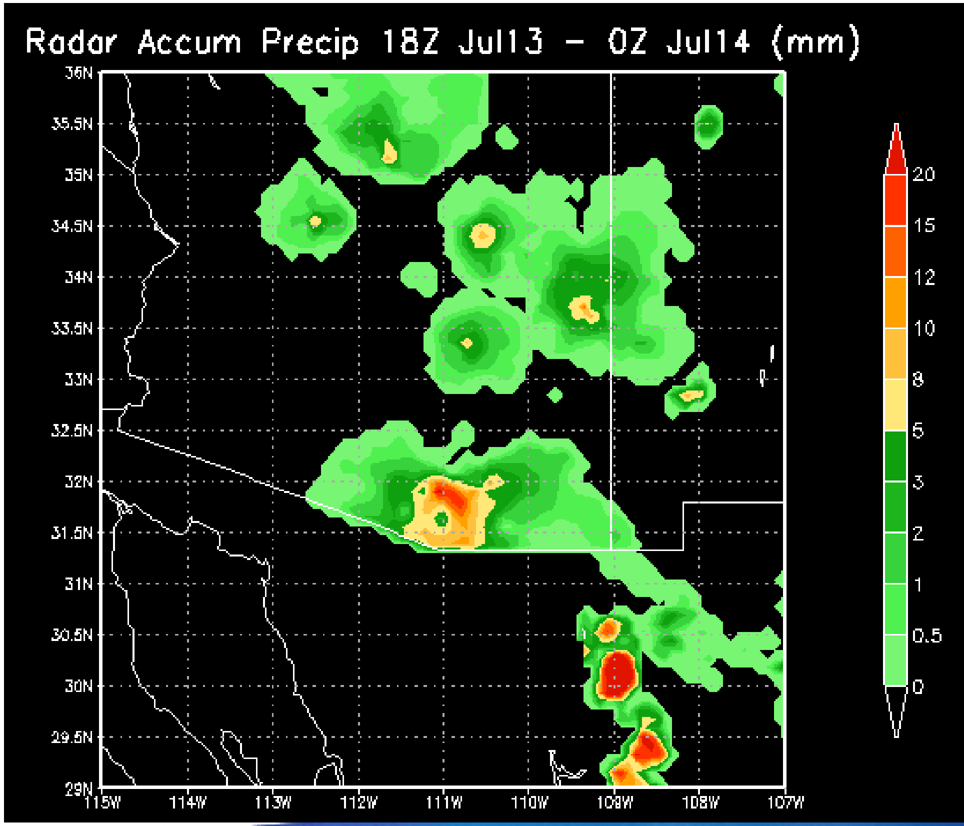


Clear gulf surge signature in Northern Gulf of California with distinct wavefront.

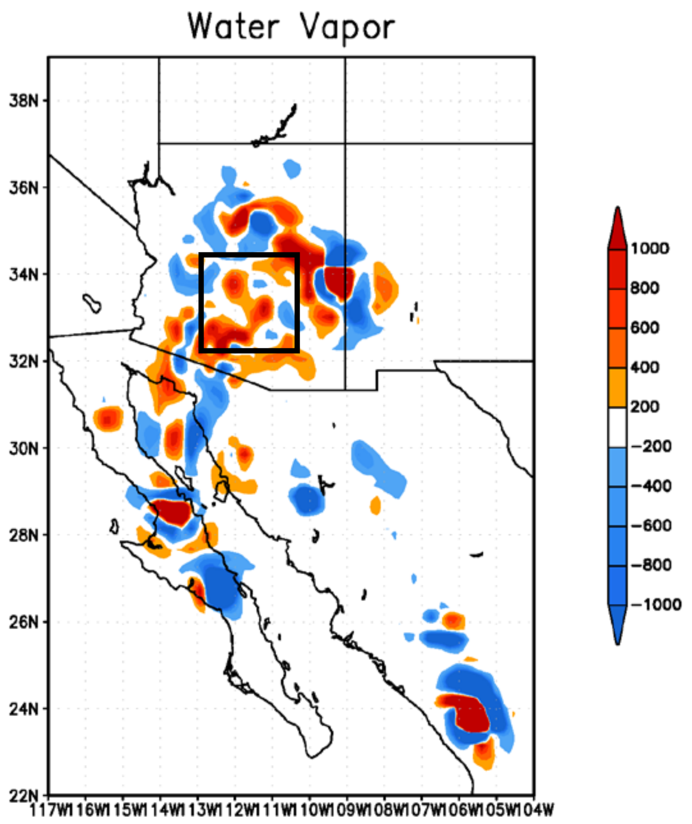
Winds oriented parallel to the Gulf.

Highlights of WRF high resolution simulation (2.5 km) results for NAME IOP 2





Use of WRF adjoint technique to determine "hot spots" for forecast sensitivity in significant events. Tells us where best to place GPS sensors!

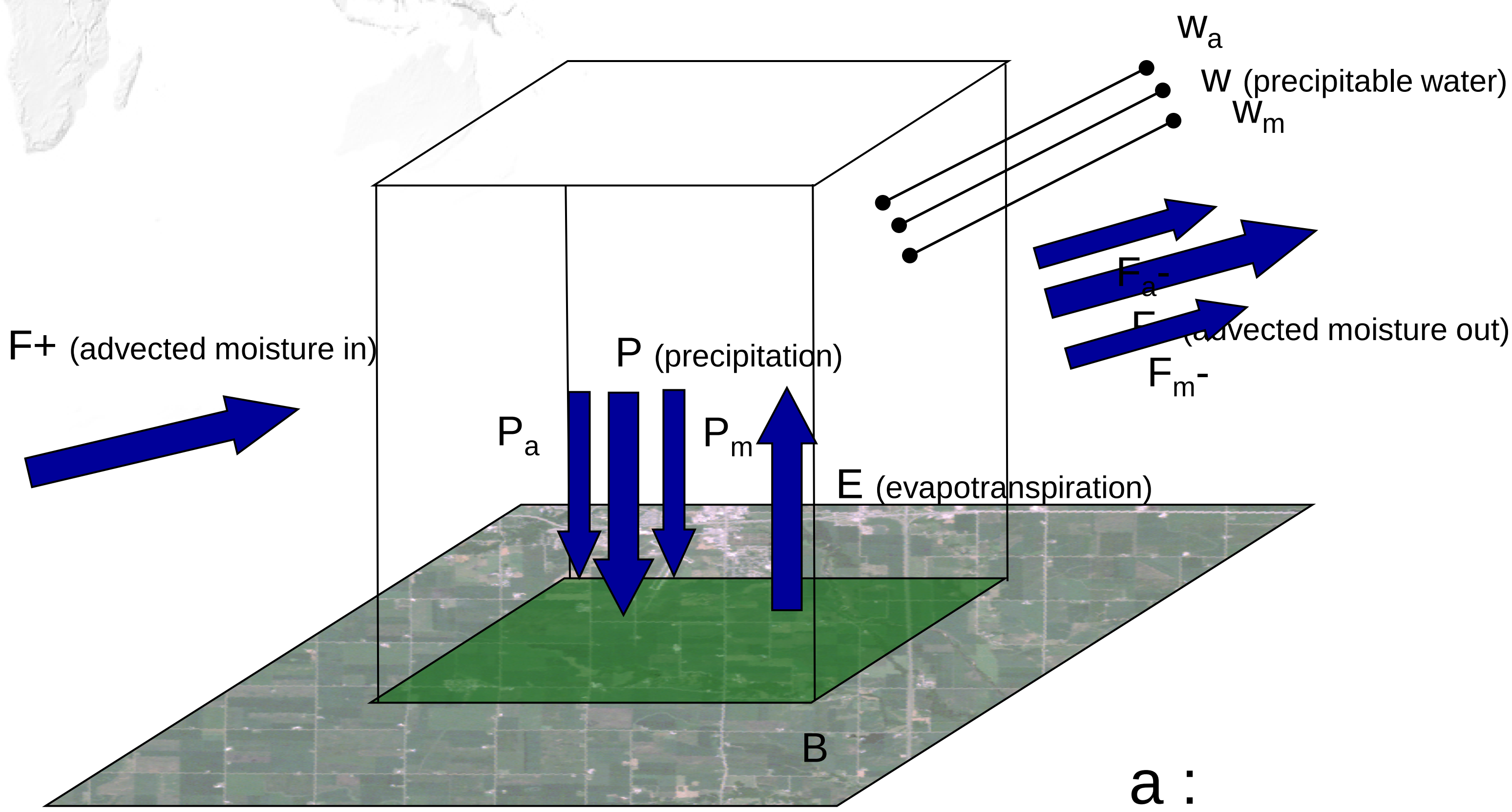


Sensitivity of WRF forecast low-level winds in the Phoenix area (box) to the initial low-level water vapor in a 24h simulation.

Event was for a severe thunderstorm case in the Phoenix area in August 2005, related in part to a Gulf surge.

Units: $m^2\ s^{-2}\ kg\ kg^{-1}$

Recycled precipitation is the precipitation originating from evapotranspiration within a region.

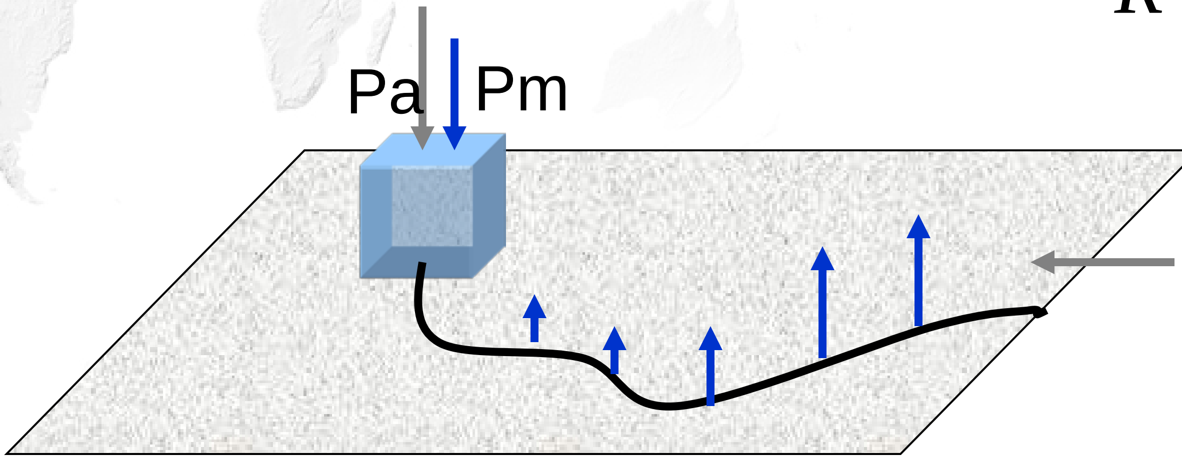


a : advected

m : recycled

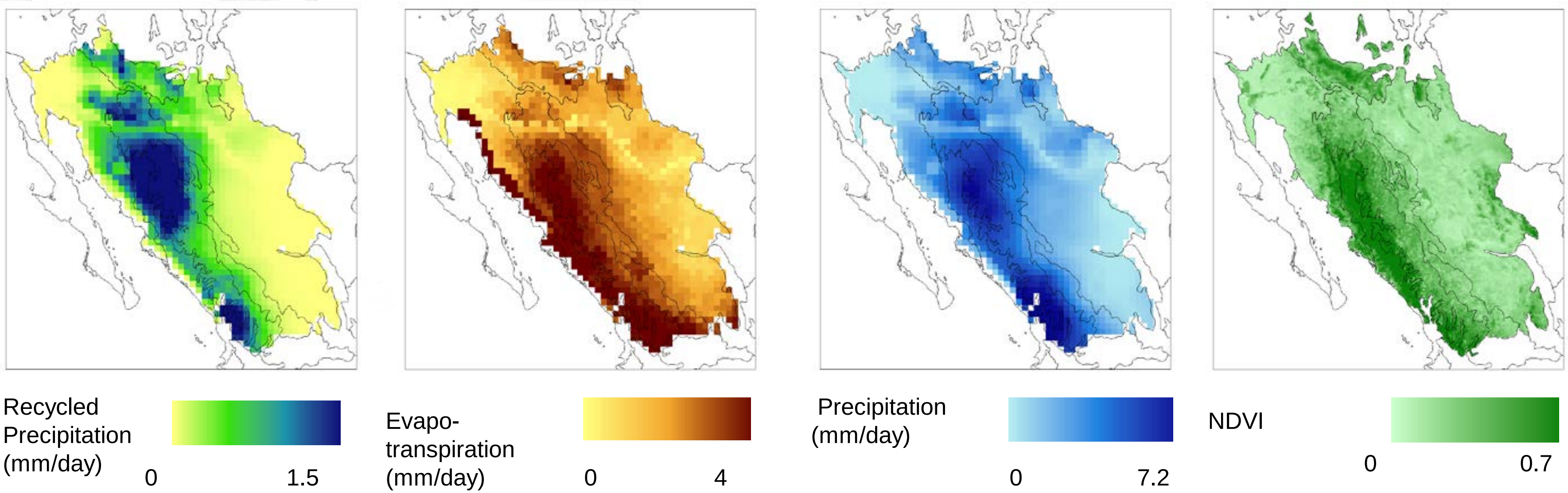
We have developed an analytic model that quantifies the precipitation of recycled origin.

$$R = 1 - \exp\left[-\int_0^{\tau} \frac{\varepsilon}{\omega} d\tau' \right]$$



The model requires information about the winds, humidity, precipitation and evapotranspiration.

Precipitation, evapotranspiration and vegetation greenness is higher in the southwest of the region



Average daily precipitation of recycled origin, evapotranspiration, precipitation and NDVI for the period of Aug 1 - Aug 15 of 1986 (long monsoon).

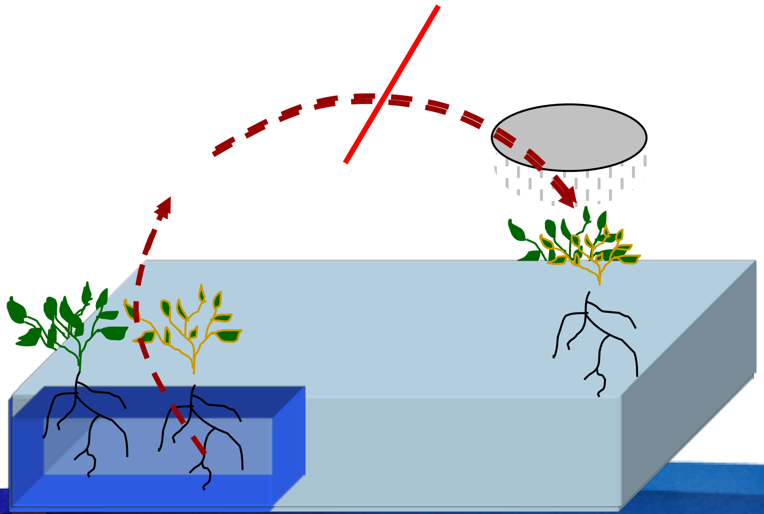
Evapotranspiration is transported north and east where it falls as precipitation of recycled origin.

Dominguez et al. J. Climate 2008

While this analysis has been done with NARR data, we know there are serious deficiencies of NARR in Mexico. We would like to use the WRF model as forcing.

Assimilation of *GPS-derived water vapor and soil moisture data into WRF* will allow us to have realistic estimates of these variables, and high resolution simulations to address the questions related to precipitation recycling.

If a moisture abundant ecosystem is degraded, what would be the consequence for downwind regions?



Assimilation of GPS data into high resolution WRF simulations. A possible research proposal?

- Use high resolution Mexican GPS data to assimilate into WRF regional atmospheric model simulations for a very high resolution domain that covers NAME tier I region.
- High resolution simulations can explicitly resolve convection and dramatically improve storm propagation and organization.
- Would build on existing real time GPS data assimilation and use recently developed WRF data assimilation capabilities.
- Possible collaborative proposal that would involve data assimilation, remote sensing, regional modeling.

Thanks for Your Atention

Any Questions??