The Shallow-to-Deep Convective Transition: A Modeling Challenge

David K. Adams
CCA/UNAM
(on Sabbatical at Rutgers. Host Ben Lintner)

In Collaboration with Colleagues from
U.S. (UArizona, ASU, UCSD, UCD, UCLA, UW, NCAR, USDA-ARS)
Mexico (UNAM, UNISON, UACJ, ITSON)
Brazil (USP, UEA, UFPA, INPA/LBA)



Structure of Presentation

- Shallow-to-Deep Convection Transition

  A Serious Difficulty for Models

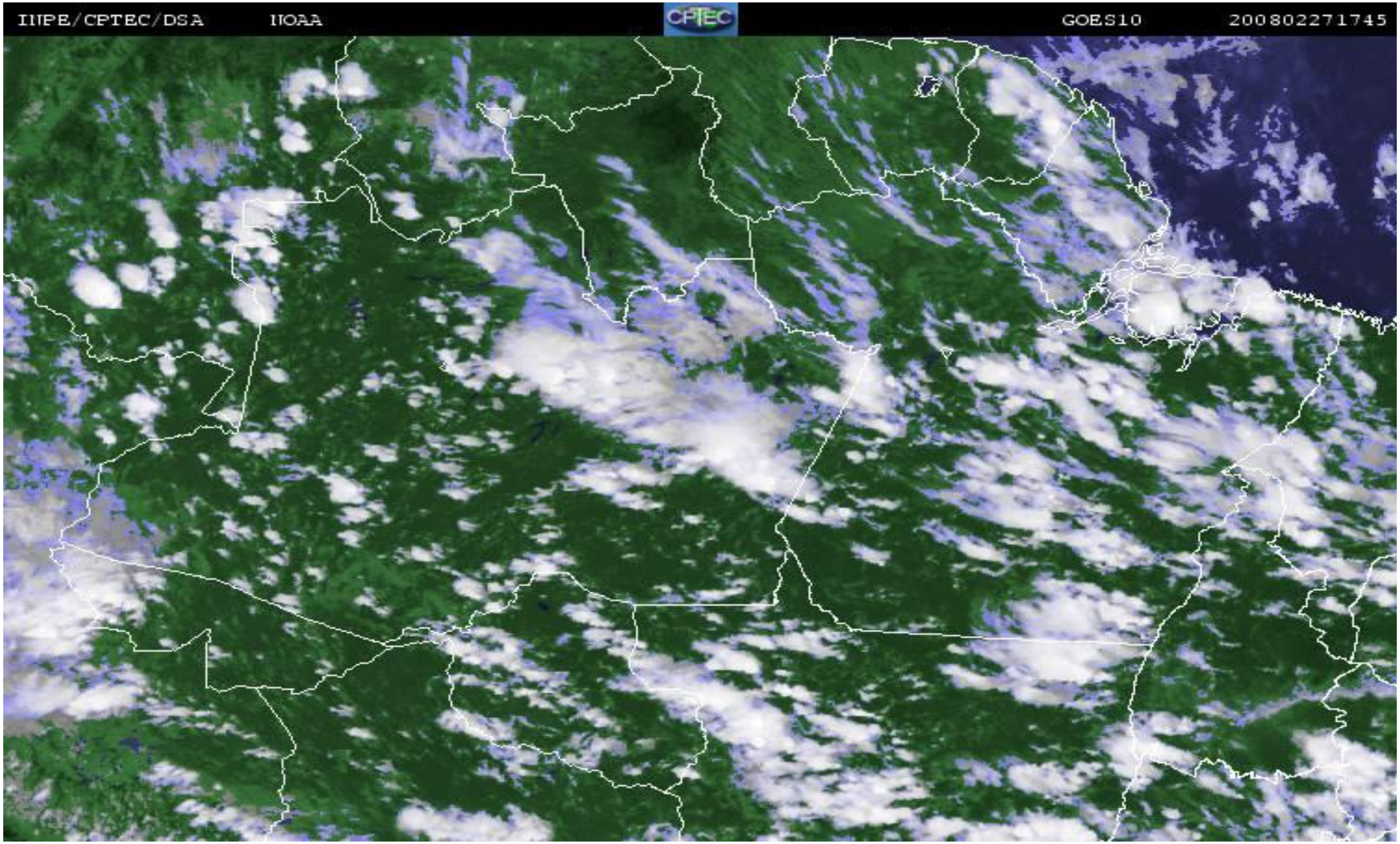
- Possible Mechanisms still Being Debated
- GPSmet Observations and Metrics

  for Model Validation from

  --Amazon Dense Network

  --NW Mexico GPS Hydromet Network

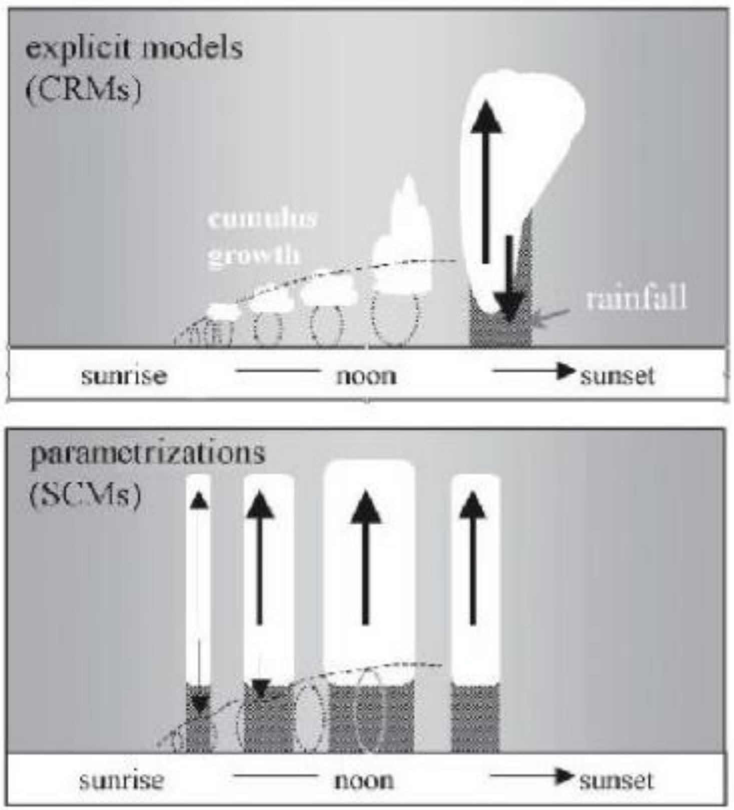
- Future Work



Convection covers Immense Time and Space Scales as well as Physical Processes
(e.g., turbulence to microphysics)
The Shallow-to-Deep Transition is Emblematic

Shallow-to-Deep Convective Transition in Tropics

Models do not replicate well, often skip shallow-to-deep transition entirely (e.g., Betts and Jakob 2002a,b) (A major theme from the LBA Experiment)



Kuang and Bretherton (2006) Dry mid-troposphere impedes transition to deep convection, must have moist mid-troposphere

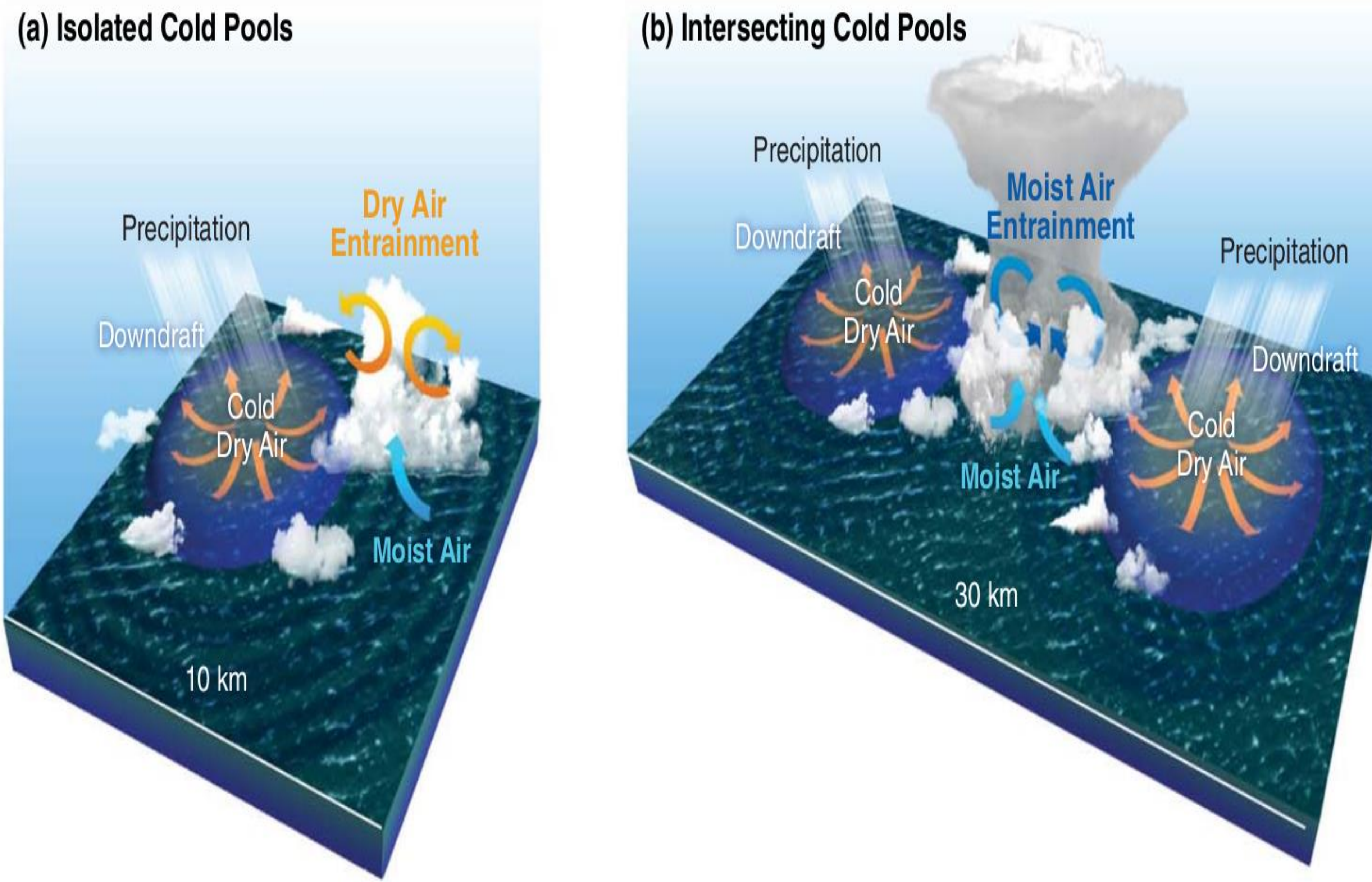
Chaboreau et al. (2004) and Waite and Khouider (2010) (Shallow Cumulus must moisten above boundary layer for STD Transition)

Khairoutdinov and Randall (2006); Make clouds larger decreasing entrainment effects. Congestus cold pools create convergence zone leading to deeper convection and so on…

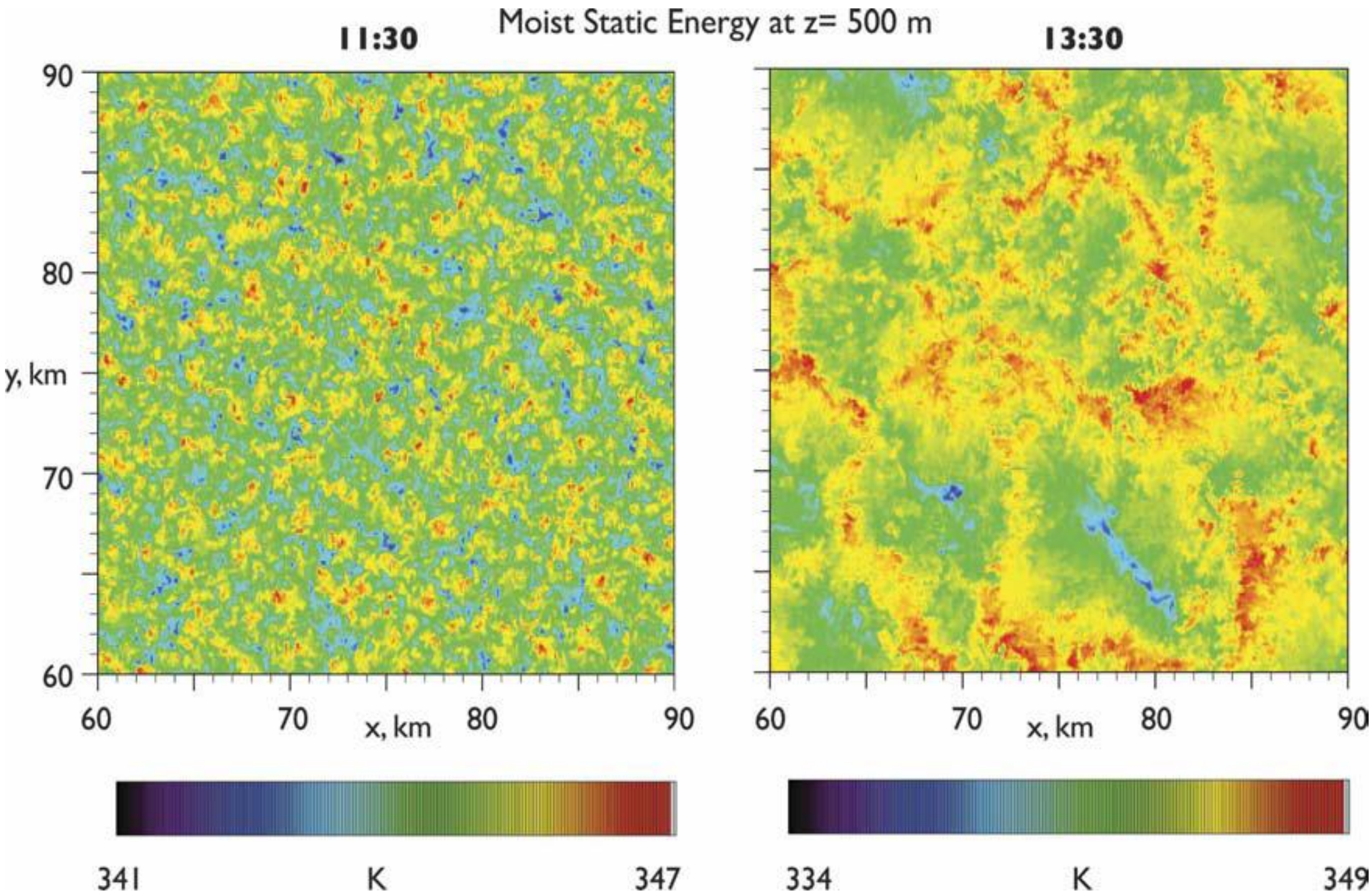
Wu et al. (2009) Critical lapse rate above boundary layer needed for transition to deep convection to occur

Hohenegger and Stevens (2013) Dispel Above PBL Moistening and argue for timescale analysis when considering mechanisms

Kurowski et al. (2018) Start with Assumption of Cold Pool control and argue LES land-surface interaction is critical


(a) Isolated Cold Pools
Precipitation
Dry Air
Entrainment
Downdraft
Cold
Dry Air
Moist Air
10 km
(b) Intersecting Cold Pools
Precipitation
Moist Air
Entrainment
Downdraft
Cold
Dry Air
Precipitation
Downdraft
Cold
Dry Air
Moist Air
30 km

Cold Pools may play a dominant role in organization of convection in the central Amazon (Khairoutdinov and Randall 2006)



Which argument is correct? Difficult to say given lack of observations.
One way to tackle this difficulty is through timescale analysis (Hohenegger and Stevens 2013).

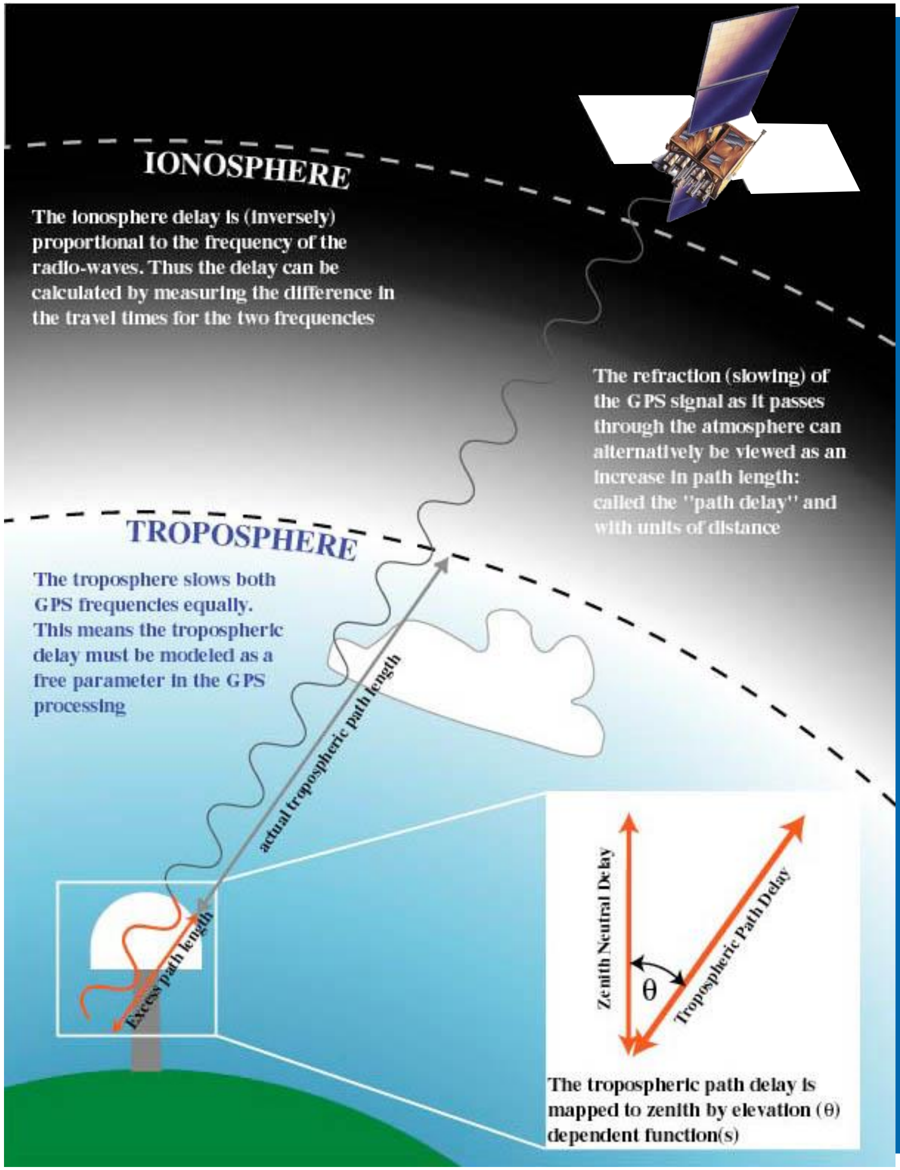
- Physical processes responsible for convective activity must have the proper time scale to jibe with observations

- **BUT**, these above and nearly all other studies are ***Modeling Studies*** and subject to all of their uncertainties in representing deep convection

- We need long-term, high-spatial/temporal resolution**, all-weather** observations to carry out time scale analysis

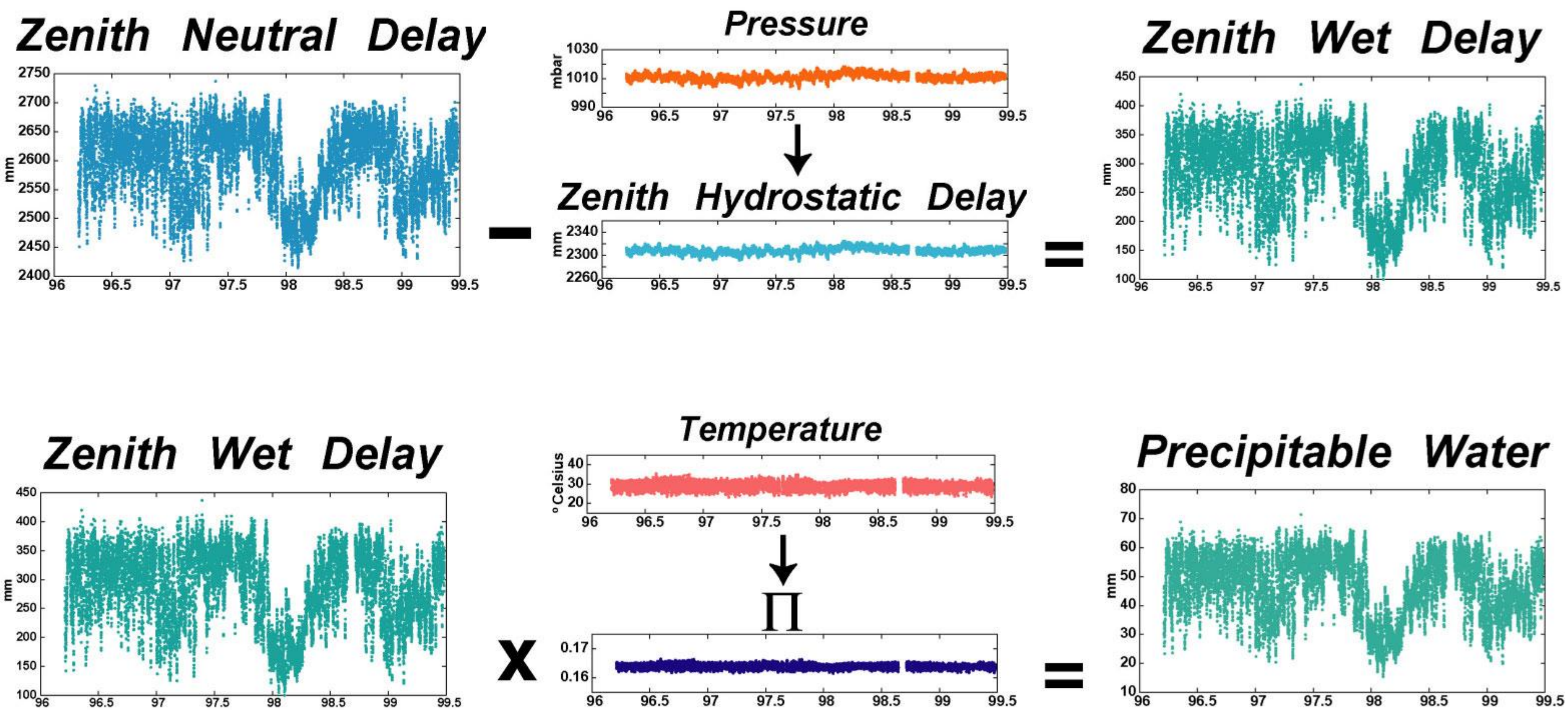
- GNSS/GPS Meteorology can help

GPS-IPW Measurements



- Signal delays caused by the neutral atmosphere have a wet and dry component.
- The dry delay is caused by the mass of the atmosphere, and can be estimated with high accuracy from a surface pressure measurement.
- The wet delay is simply the difference between the total delay and the dry delay.
- The ratio of the wet delay to the dry delay is the integrated mixing ratio.
- The wet signal delay is nearly proportional to the total quantity of precipitable water vapor in the atmosphere directly above the GPS site.

Transformations of GPS Meteorology



Our Approach for Process Oriented Studies: Water Conservation Equation (Adams et al. 2013)

$$\frac{\partial}{\partial t}(IWV) + \frac{\partial}{\partial t}\int q_c \frac{dp}{g} + \nabla \cdot \int q\vec{V}\frac{dp}{g} = E - P.$$

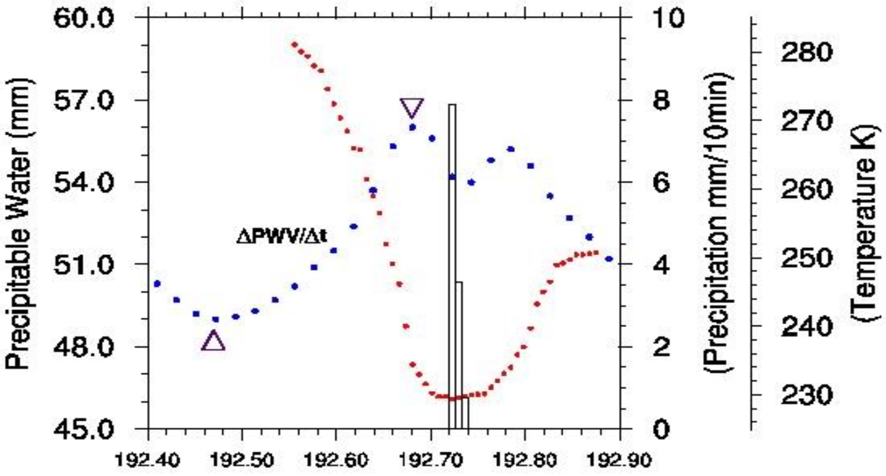
Precipitable Water Vapor is Integrated (or Column) Water Vapor divided by the density of water

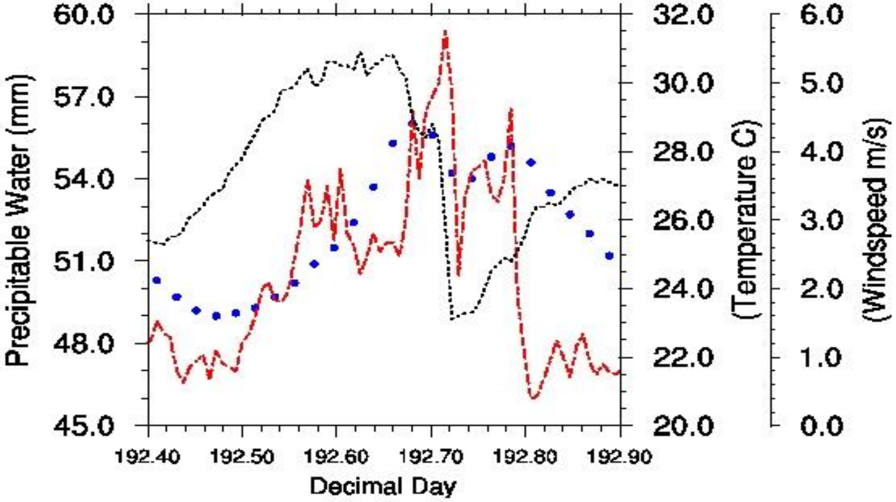
$$PWV = \frac{1}{\rho_w}\int q\frac{dp}{g} = \frac{IWV}{\rho_w}$$

To first order, the time-rate-of-change of PWV is simply moisture flux convergence:

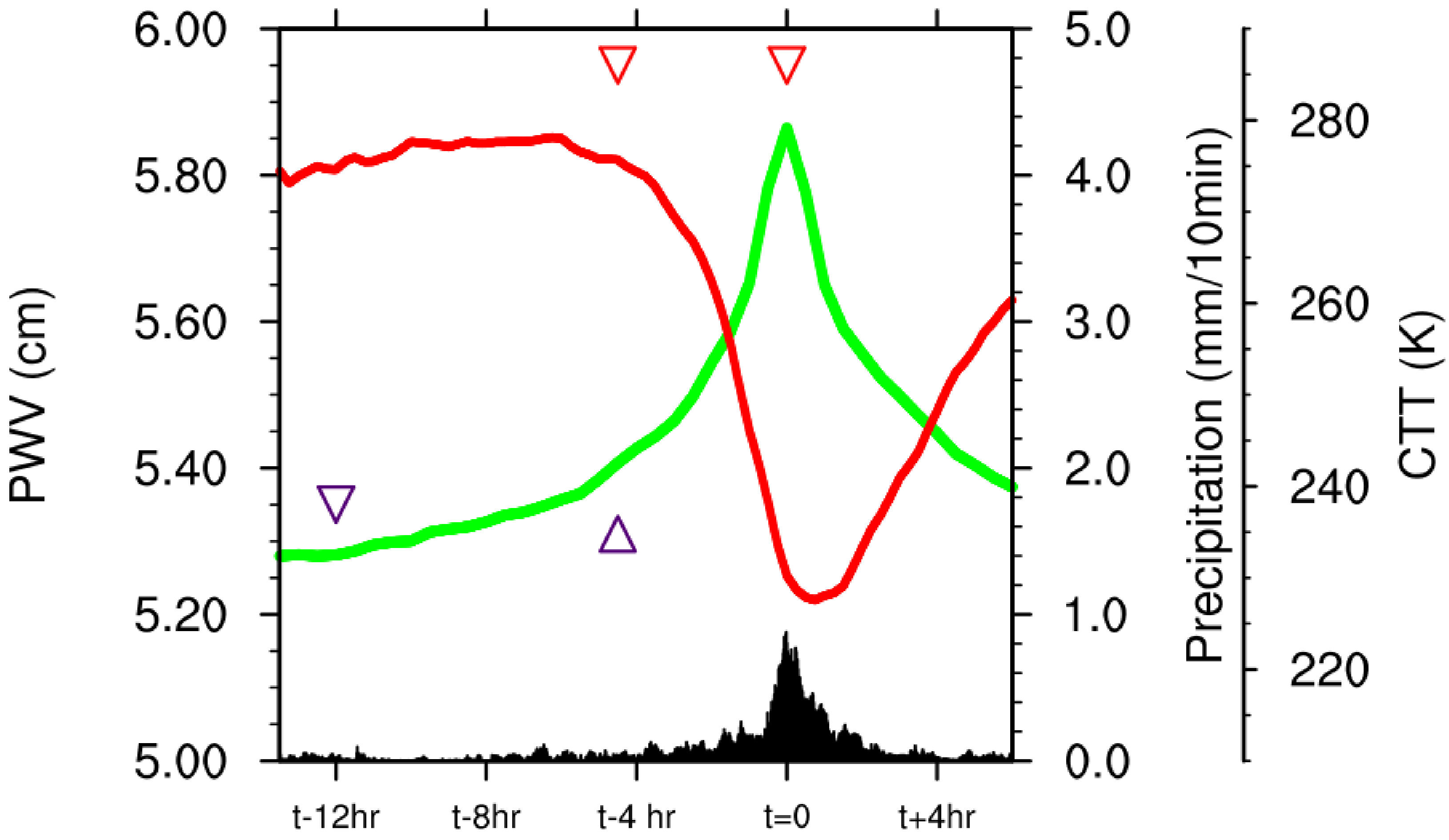
$$|\frac{\partial}{\partial t}(PWV)| \sim |\nabla \cdot \frac{1}{\rho_w}\int q\vec{V}\frac{dp}{g}|$$

Real-Time GPS Meteorology Station (*INPA/LBA*, Manaus, Central Amazon 2008-12)

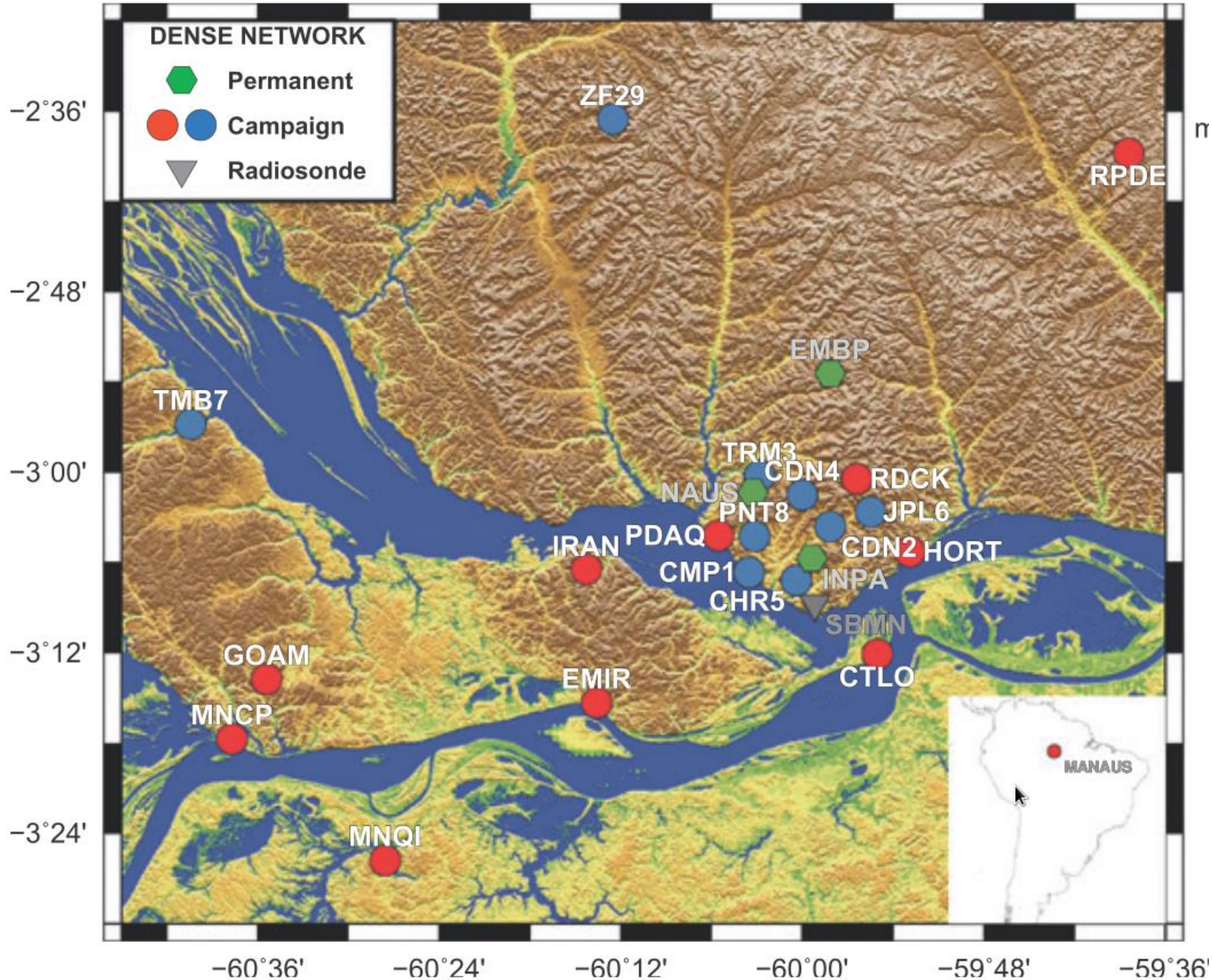




Timescale Analysis for the Shallow-to-Deep Transition
Composite of 320 Convective Events
~4 WV Convergence Timescale
(*Adams et al. 2013 GRL*)

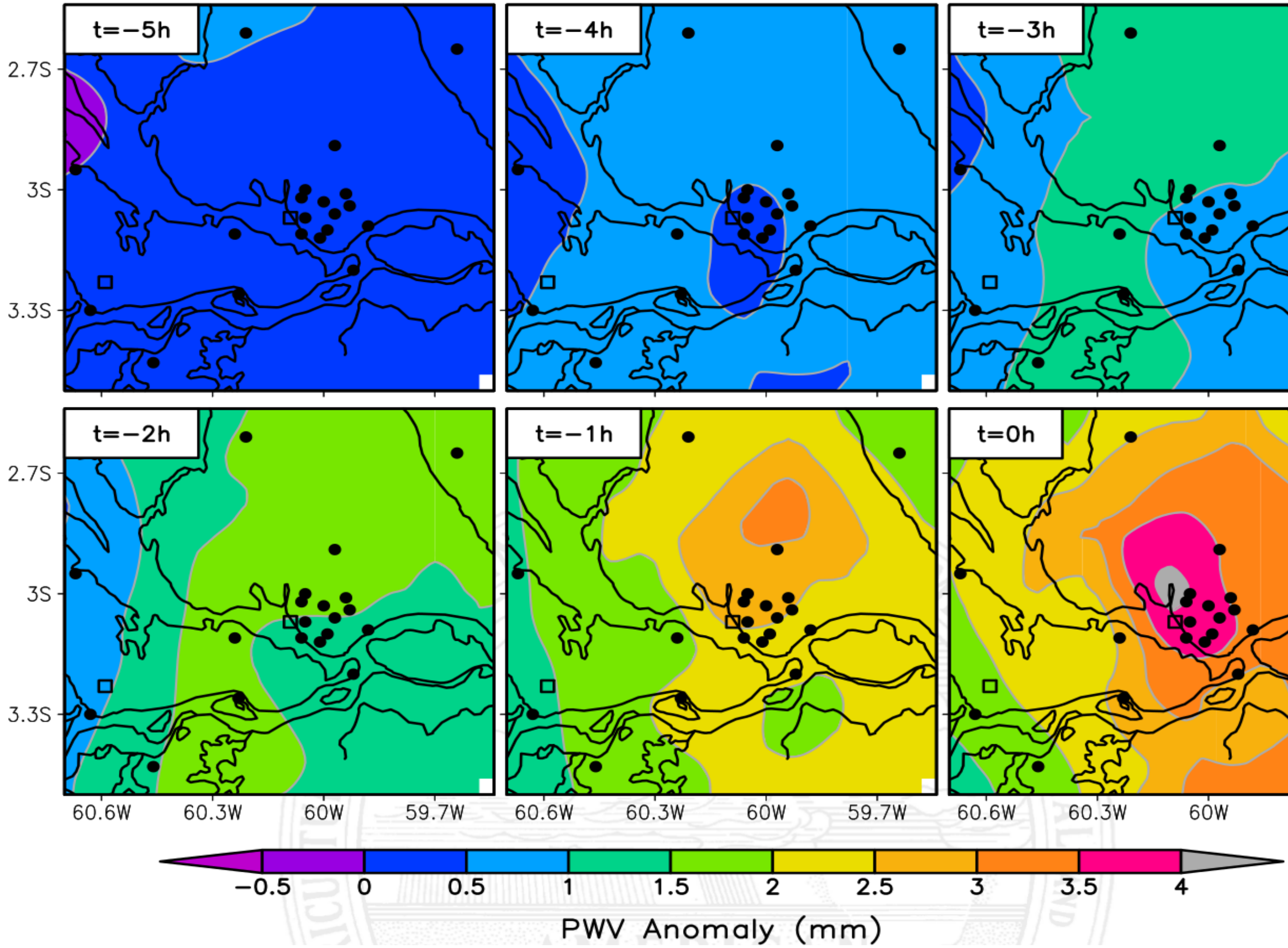


GNSS/GPS Dense Meteorological Network Manaus (2011-2012)
Adams et al. 2015 (BAMS)



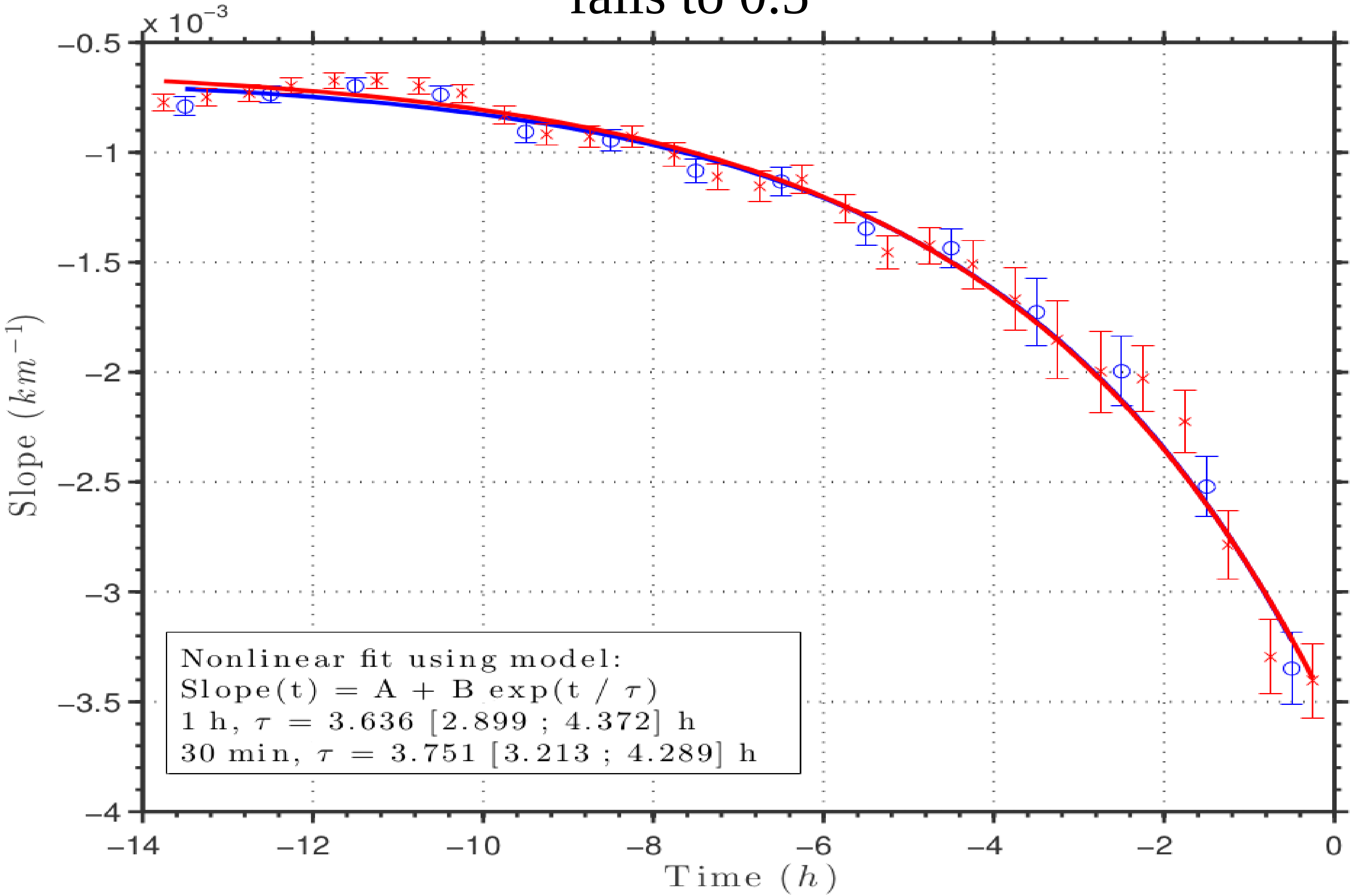
But what spatial scale of CWV should we expect during the STD Transition? Adams et al. 2017 (MWR)

A spatial decorrelation timescale was calculated for 67 convective events



Decorrelation Timescale of 3.5 hours during Shallow-to-Deep Convective Transition

At Max. Station separation distance of 150km CWV correlation falls to 0.5



GPSmet for Land-Atmosphere Interactions

The North American Monsoon GPS Hydromet Network 2017

Adams and many Co-authors (in Preparation)

Linking Surface Water Vapor Flux to PWV
North American Monsoon Region

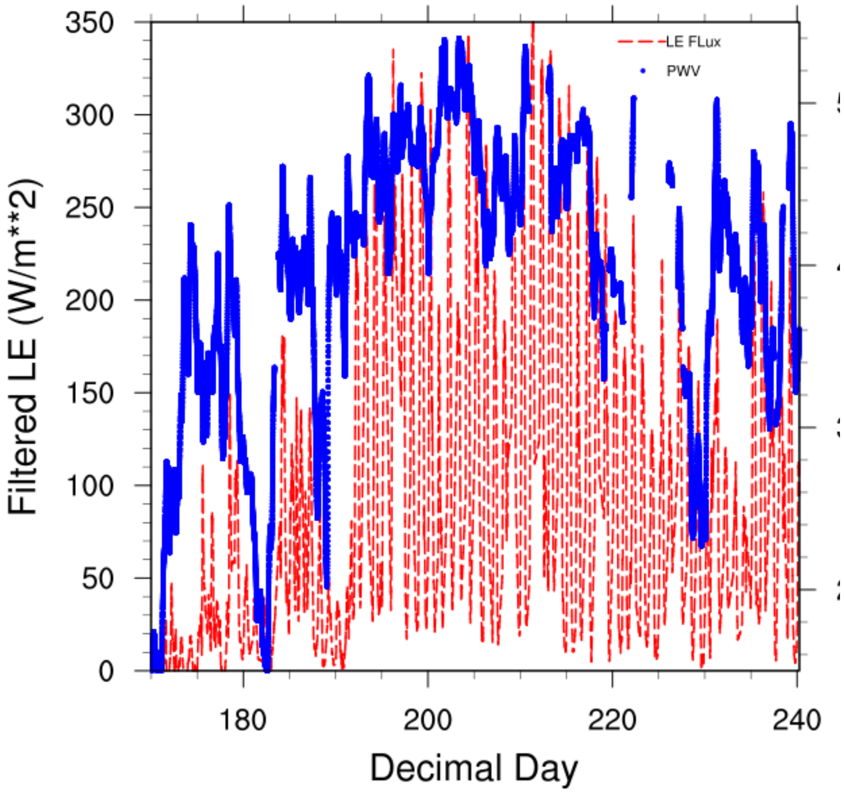
Mesquite Trees in Valley Bottom

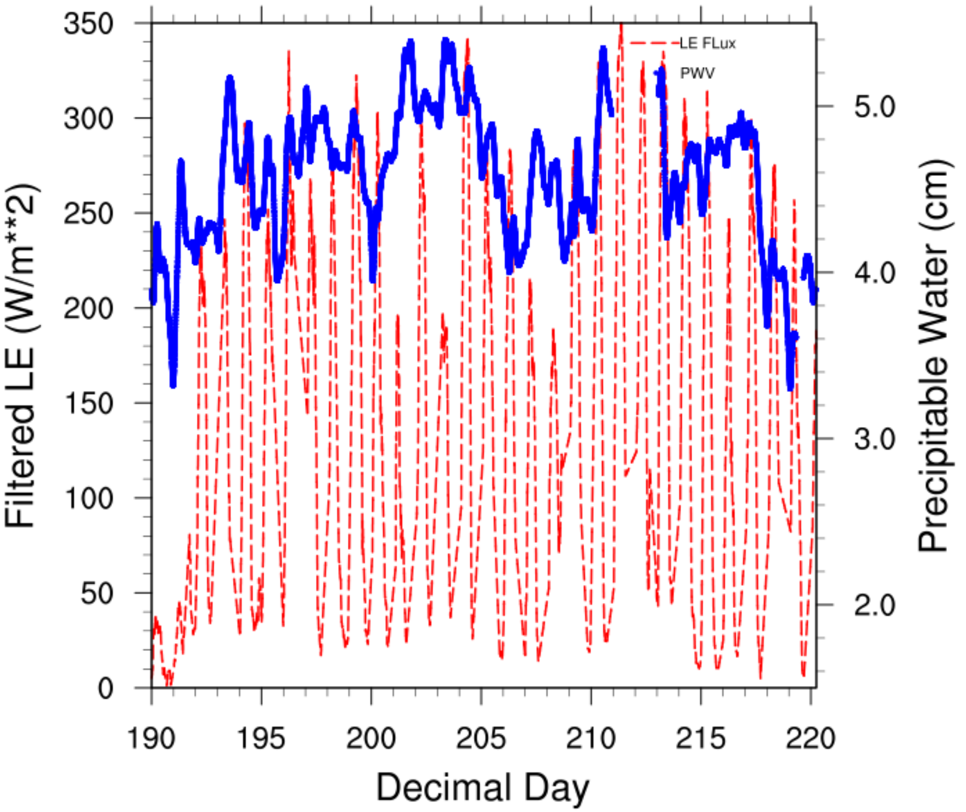
Oak Savanna at Mountain Top

Subtropical Scrubland in Alluvial Fan

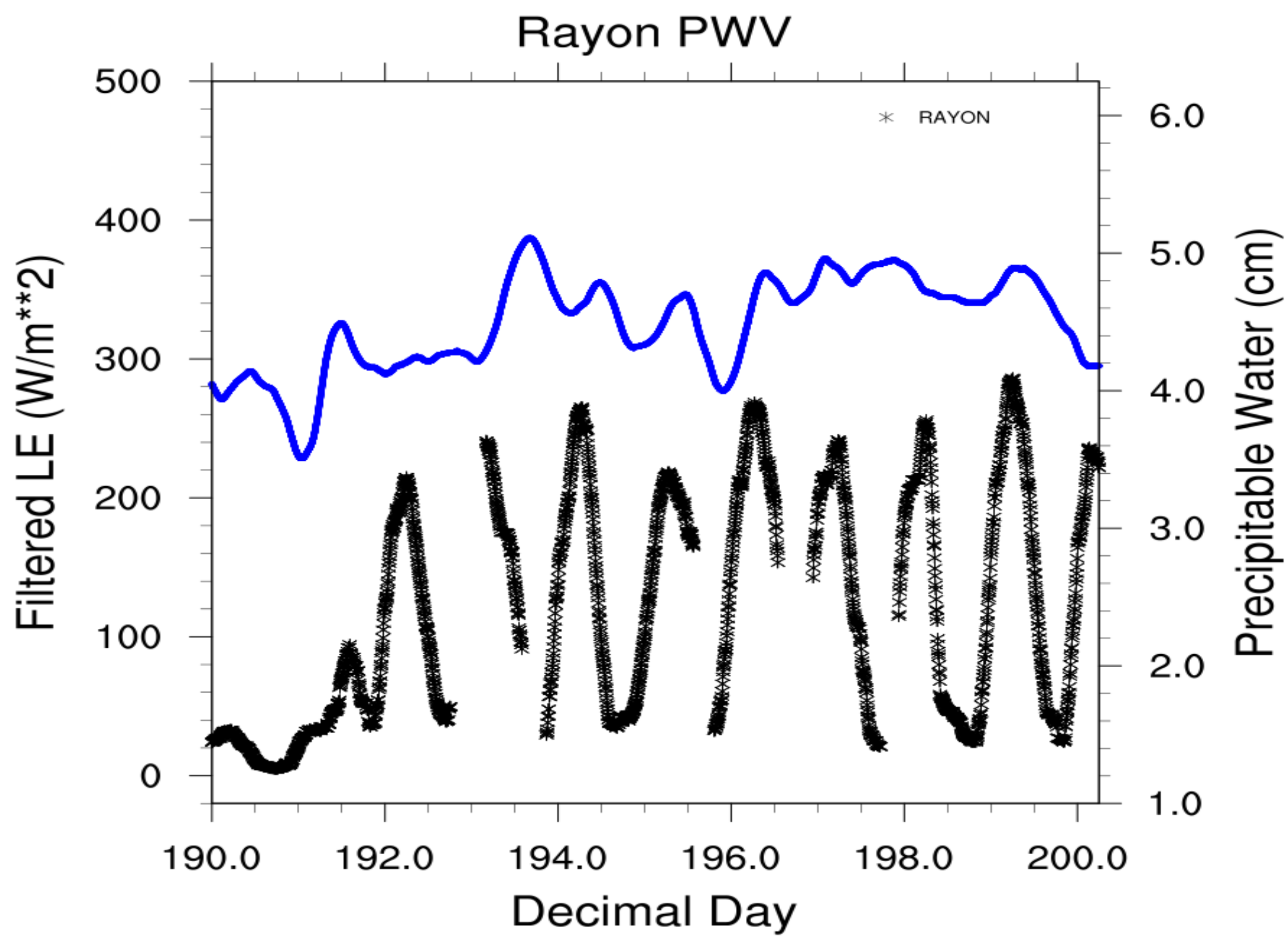
<u>Collocated GPSmet and Flux Measurements in Different Ecosystems</u>

Latent Heat Fluxes vs Colloated GPS CWV During Campaign Rayón Sonora (5 minute LH Flux and CWV)

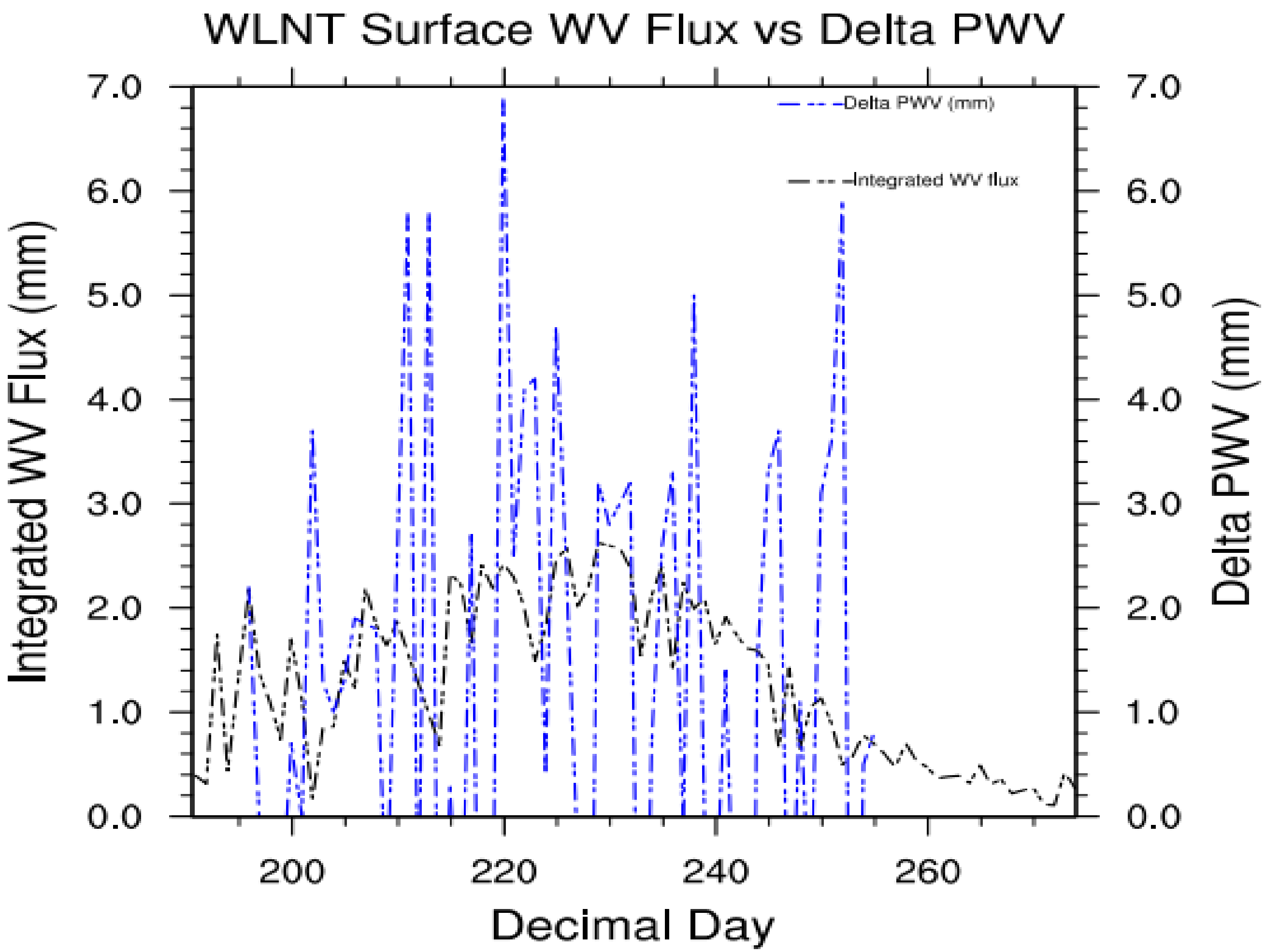




(At Diurnal/Sub-Diurnal Timescales
LH Fluxes and PWV Relationship Weak)
Ravón. Sonora



Directly Linking Surface WV Flux Contribution to PWV -Little Relationship, Advection Dominates.



Summary/Conclusions

- STD Transition Modeling Argues Different Mechanisms.
- Regardless of Mechanism, Timescale Analysis Shows STD Transition A robust 4 hours for Tropical Continental Convection
- Model Observations and Metrics should be non-complex, easily available, preferably inexpensive. GPSmet fits the bill
-

Current/Future Work

- Land Surface Influence on Moisture Recycling and Convective Precipitation for NAM Region (NAM GPS Hydromet Network)
- OTREC provides GPSmet Data from Costa Rica and Colombia (e.g., STD Sea-Breeze Regime)
- Work w Giuseppe Torri and Henrique Barbosa with LES Model Employing GPS Dense Network and GOAmazon Data

Thank you to MAC-MAQ and Saulo Freitas

dave.k.adams@gmail.com