Physical Modeling of Microwave Surface Emissivity from Passive Microwave Satellite Observations

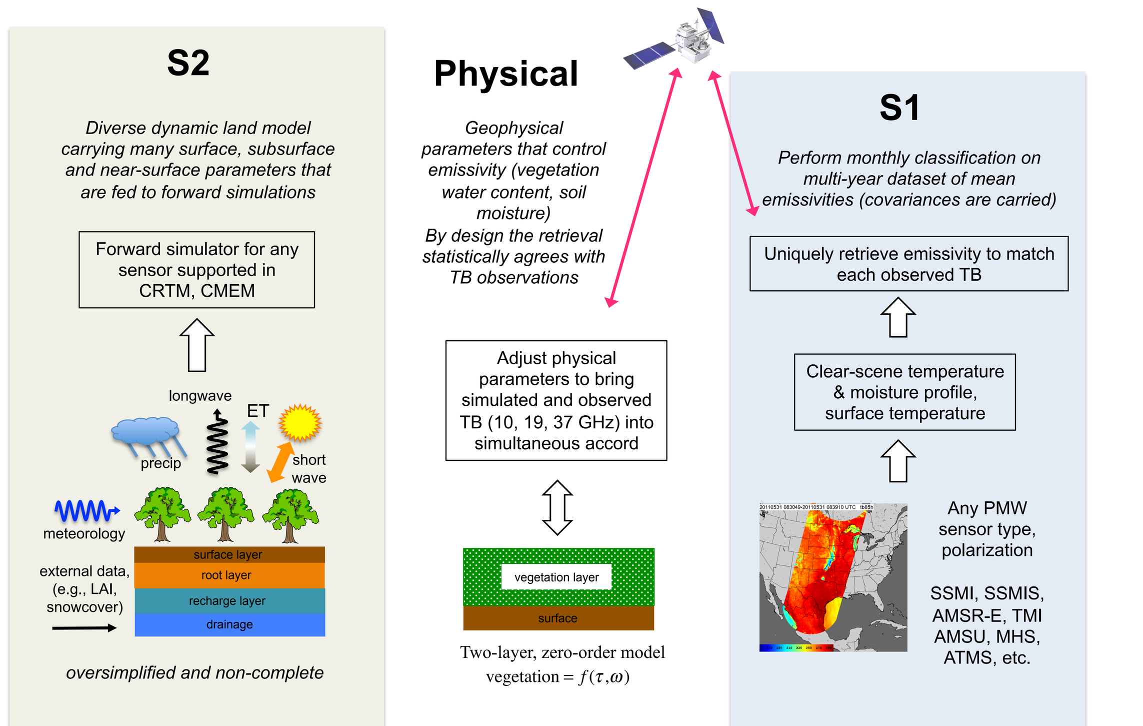
F. Joseph Turk, Li Li[2], Ziad S. Haddad[1], Yalei You[3]
[1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA
[2] Naval Research Laboratory, Washington, DC
[3]Florida State University, Tallahassee, FL

NASA PMM Science Team Meeting, 18-21 March 2013, Annapolis, Maryland

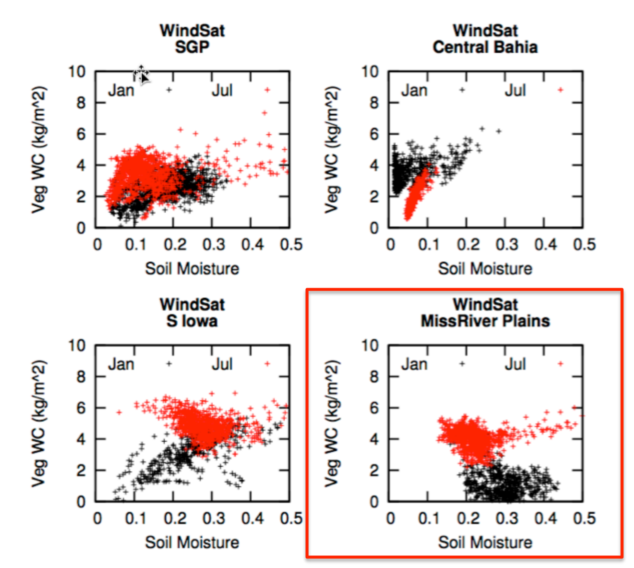
The authors acknowledge support from the NASA Precipitation Measuring Missions (PMM) program through Dr. Ramesh Kakar. TRMM data were provided through the Precipitation Processing System (PPS) at NASA Goddard Space Flight Center. This work was performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

The microwave brightness temperature is a radiative transfer process of soil surface-vegetation interaction, driven by atmospheric conditions. Surface properties such as microwave emissivity are controlled by physical properties of the medium, such as dielectric constant, vegetation, roughness and horizontal correlation length. Since the same physical properties that affect a TB at one channel affect the TB at other channels, it is reasonable to specify or modify the emissivity at all channels jointly. Physical modeling provides a means to examine the emissivity covariance structure under a range of surface and vegetative conditions, which does not depend upon pre-determined surface classifications, and is self-consistent with the observed TB structure.

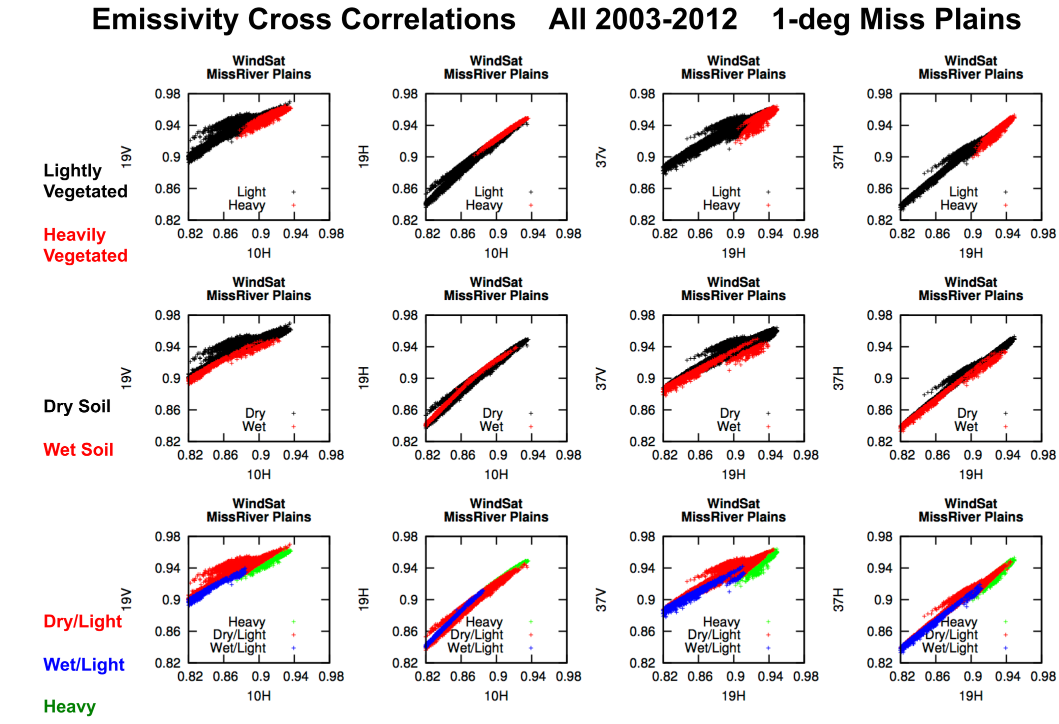
Difference & Similarity Between S2, S1 and Physical Model



(RIGHT) From the maps shown on the left, all points within a 1-degree region surrounding the Mississippi River alluvial flood plains were extracted and plotted on the right, separated by different soil moisture (SM) and VWC states. This region has both wetlands and cultivated regions and exhibits different SM and VWC depending upon season. Other regions show different joint variability throughout the year (below).



Emissivity Cross Correlations All 2003-2012 1-deg Miss Plains

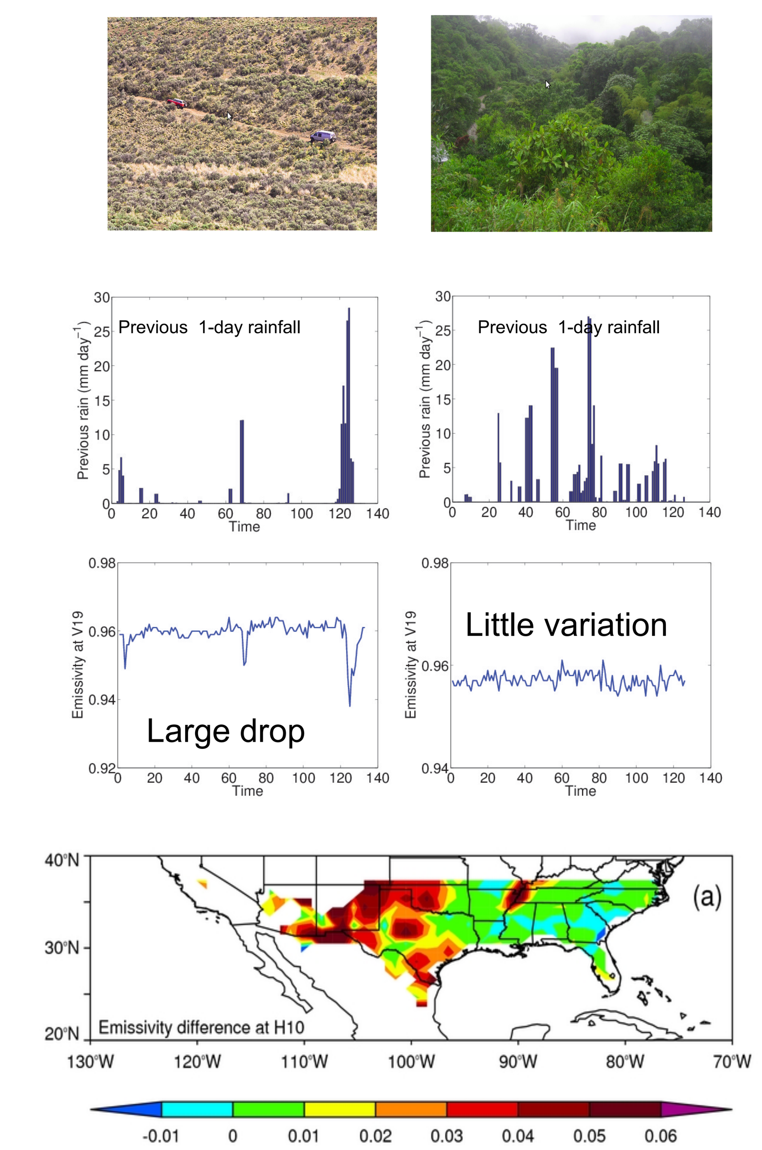


The plots above (all months between 2003-2012) show that in this region, the microwave emissivity is highly correlated between channels, with larger variability under wet (summer) conditions and lightly vegetated conditions. The physical modeling provides details on how much to vary each emissivity to capture the range experienced by changing SM and VWC conditions, and if a good correlation exists, also how to **jointly** vary all emissivities together.

How rainfall affects emissivity

Typically, emissivity is estimated under clear sky conditions. However, for physically estimating rainfall using passive microwave radiometers, what really matters is the emissivity under raining conditions. Therefore, understanding how rainfall impacts emissivity and how this impact differs for different surface types are of importance.

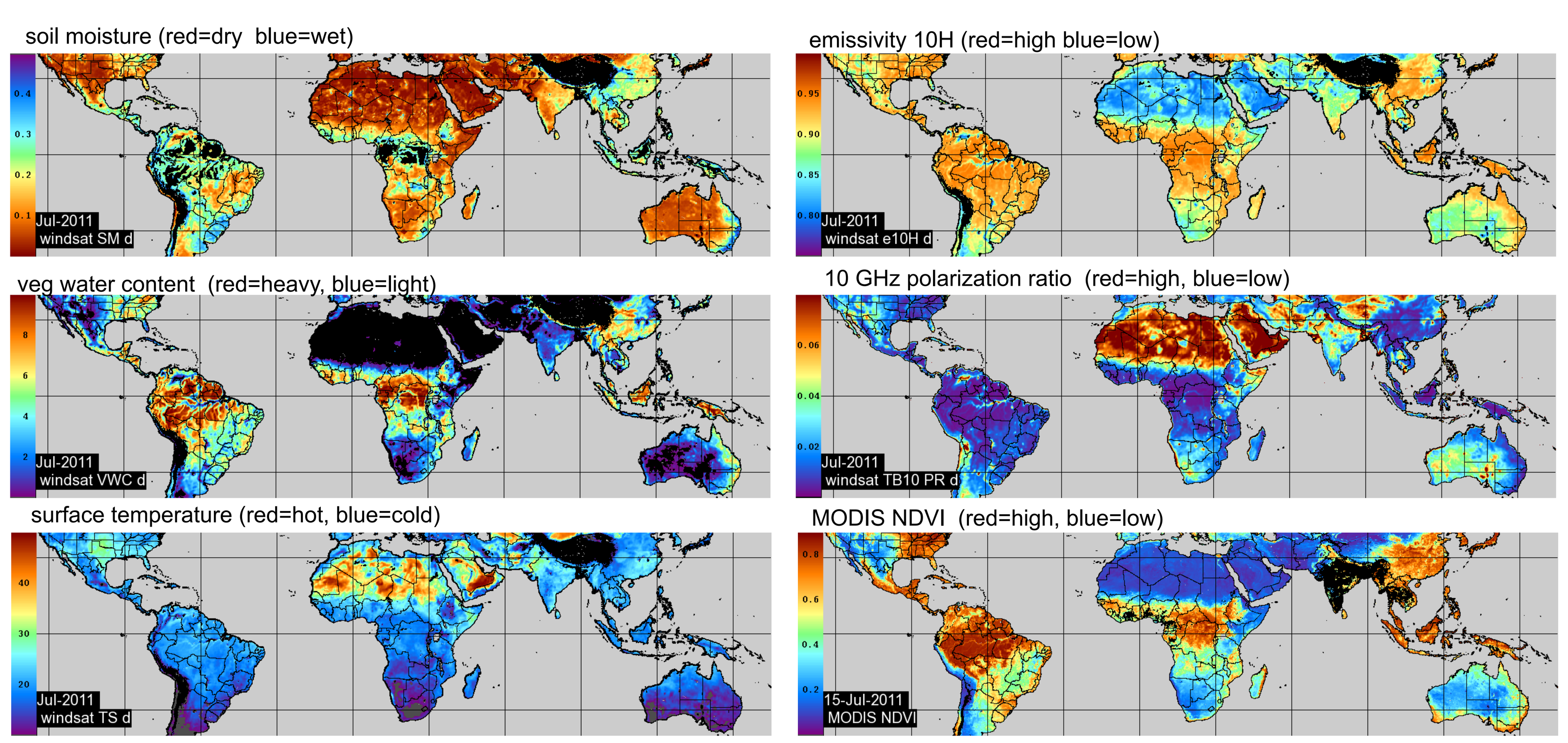
This case shows: previous rainfall cause large drop over closed-shrub land, while little change is observed over forest.



The color figure shows the H10 emissivity difference between cases where the previous 1-day showed no-rain, and rain greater than 20 mm.

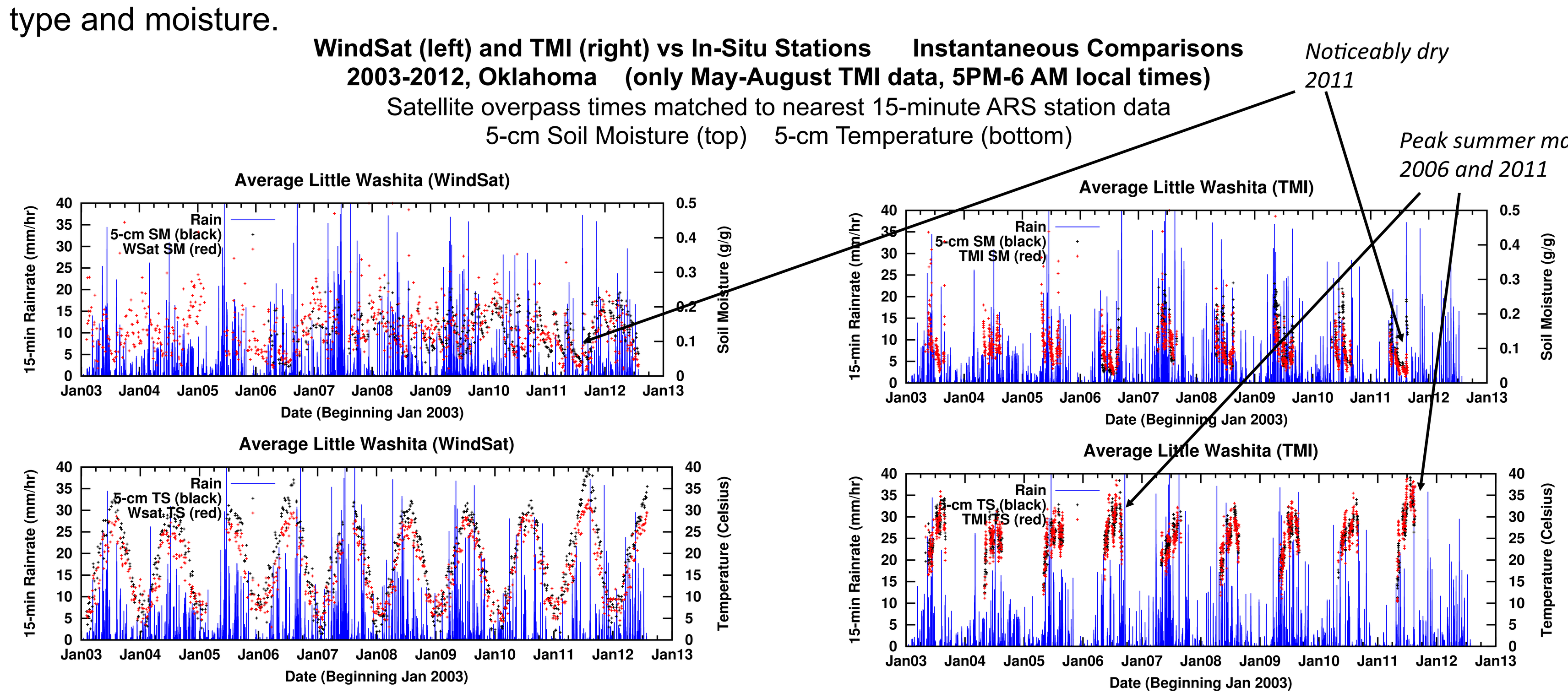
There is a large response over the Southern Great Plains and a small area over central U.S, where crop land shrub land dominates. Also a high correlation (not shown) between previous 1-day rainfall and emissivity at H10 over both regions.

WindSat-retrieved composited for July 2011



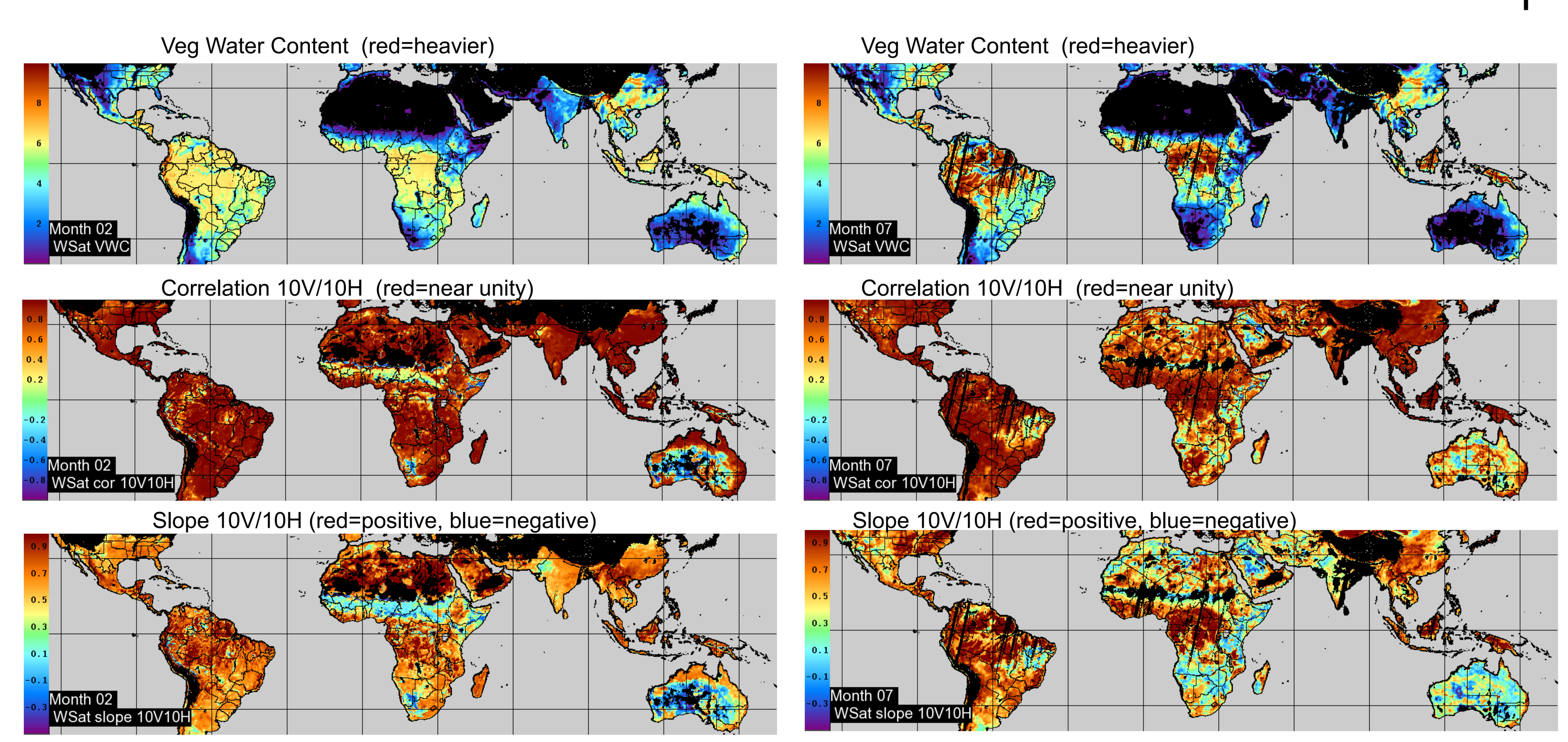
(ABOVE) The WindSat/TMI-based approach uses six channels (10H/V, 19H/V, 37H/V) to simultaneously estimate the vegetation water content (VWC), soil moisture, and surface temperature. The soil dielectric model provides the 6-channel emissivity (channel 10H shown above). Since VWC is not routinely measured, it is typically estimated from other satellite observations, such as the Normalized Difference Vegetation Index (NDVI) or Normalized Difference Infrared Index (NDII), which rely upon relations between the stem mass and leaf mass which vary with vegetation type. The Microwave Polarization Difference Index (MPDI) is a microwaved-based analogy to these indices, which generally decreases as vegetation increases, but it is also sensitive to vegetation type, soil type and moisture.

WindSat (left) and TMI (right) vs In-Situ Stations Instantaneous Comparisons
2003-2012, Oklahoma (only May-August TMI data, 5PM-6 AM local times)
Satellite overpass times matched to nearest 15-minute ARS station data
5-cm Soil Moisture (top) 5-cm Temperature (bottom)



Emissivity Cross Correlations 2003-2012 February

Emissivity Cross Correlations 2003-2012 July

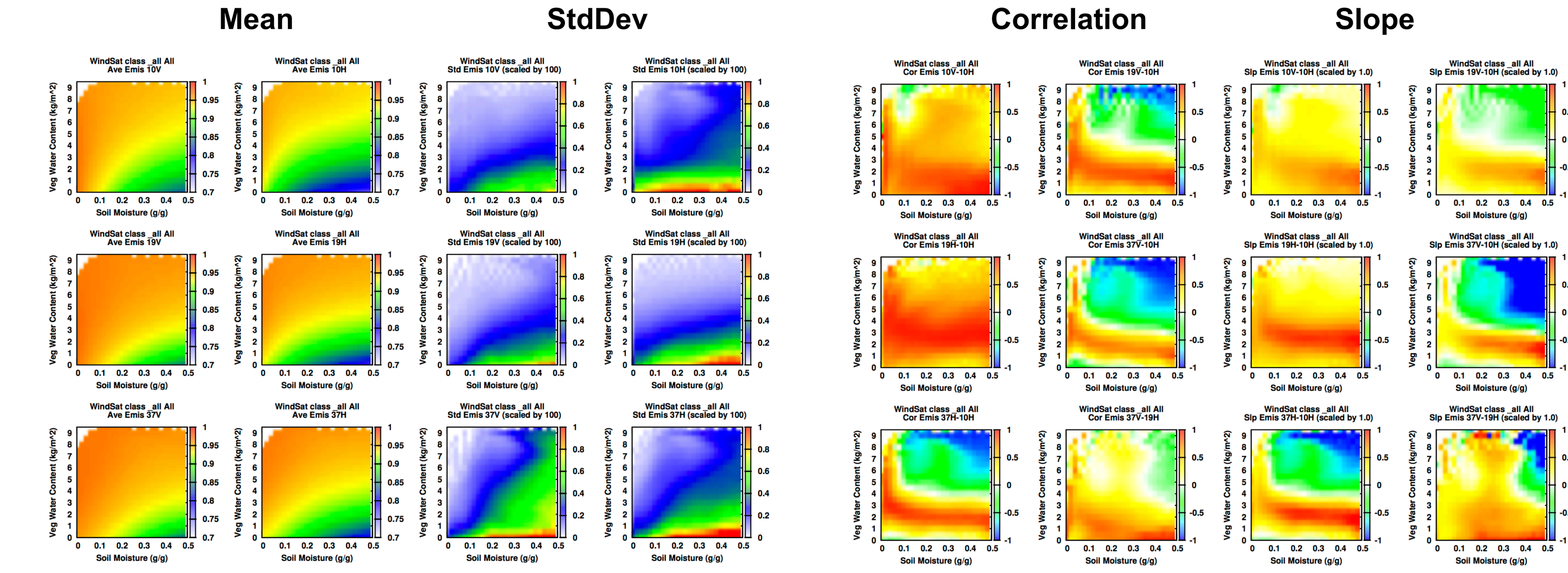


(ABOVE) Global maps of the correlation between 10V and 10H emissivity, and the associated slope of the line. In general, the correlation is strongest over lightly vegetated regions with moderate soil moisture variations. Close-up inspection of this figure reveals a fine-scale variability for unique land conditions, most notably in drier regions (e.g., southeast Brazil, parts of Africa below the equator).

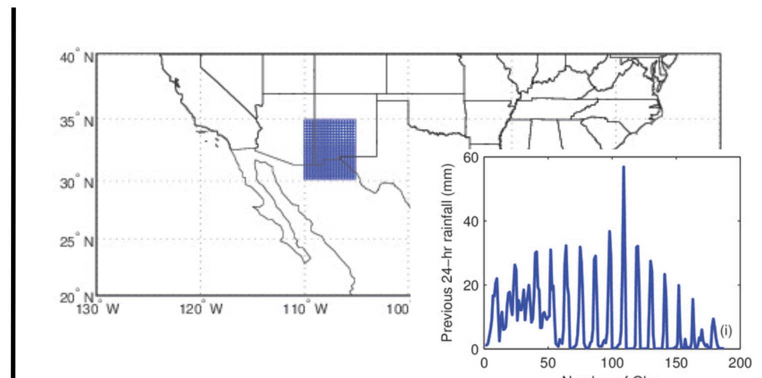
(BELOW) Phase diagrams (VWC vs. SM) for the 10H/V, 19H/V, and 37H/V emissivity mean and std deviation (**left panels**) and the cross-channel correlation and slope for six different channel combinations (**right panels**). The H-H correlations remain large across a wider range of SM and VWC variability relative to the cross-polarization (V-H). Past VWC > 5 kg m^{-2} or so, there is little variability in the emissivity.

2003-2011 WindSat All Months VWC & Soil Moisture

Mean StdDev Correlation Slope

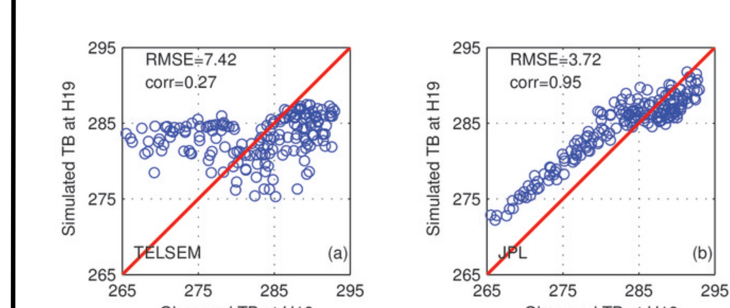


How instantaneous and climatological emissivity differ



Case Study: 8/12/2012, heavy rain occurred in previous 24 hours for this case.

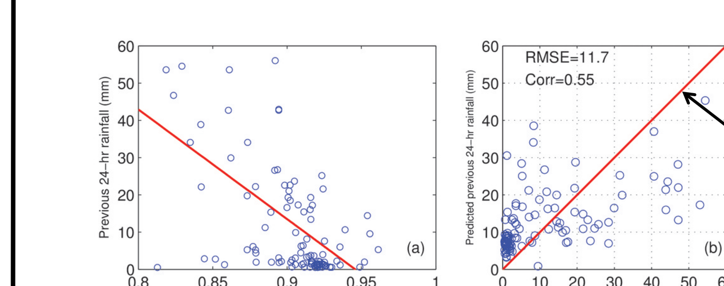
Simulated TBs using a principal component-based (PC-based) scheme emissivity (Turk et. al, 2013, in revision) agree much better with actual TB observations, while using TELSEM gives an almost horizontal line.



Simulations over whole studied regions (not shown) confirms that the PC-based instantaneous emissivity works better, especially over wet surface, compared with TELSEM.

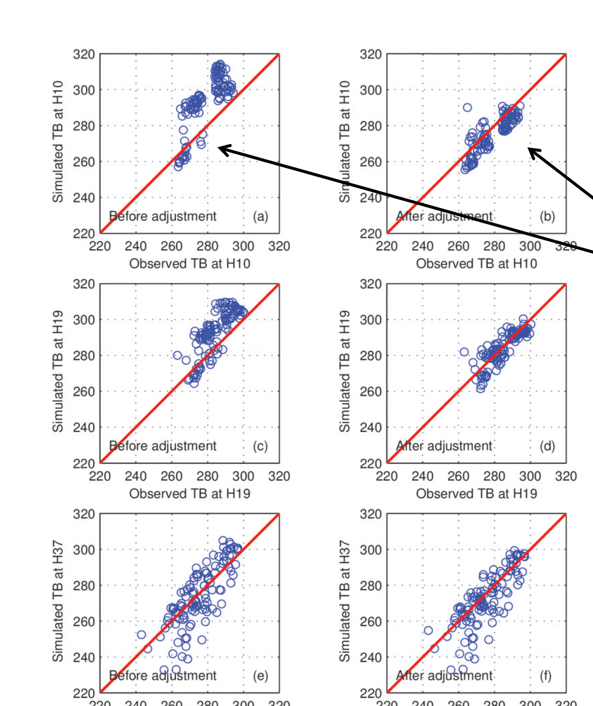
Two potential applications of instantaneous emissivity

(1) Use of clear-sky emissivity to retrieve previous rainfall, over where emissivity is fairly well correlated with previous rainfall, (e.g. Southern Great Plains).



Case study over 31°N to 32°N, 99° to 100°W showed that retrieved rainfall largely agrees with observations.

(2) Adjusting clear-sky emissivity to obtain emissivity under raining scenes. The underlying assumption for this adjustment is that, regardless of clear sky or raining condition, the relationship between PCs and surface wetness is similar.



Only PC1, PC3 and PC4 are adjusted, until difference between simulated and observed TB less than 10K. All emissivities at nine channels therefore obtained simultaneously.

Without adjustment, positively biased. Large improvement after adjustment.