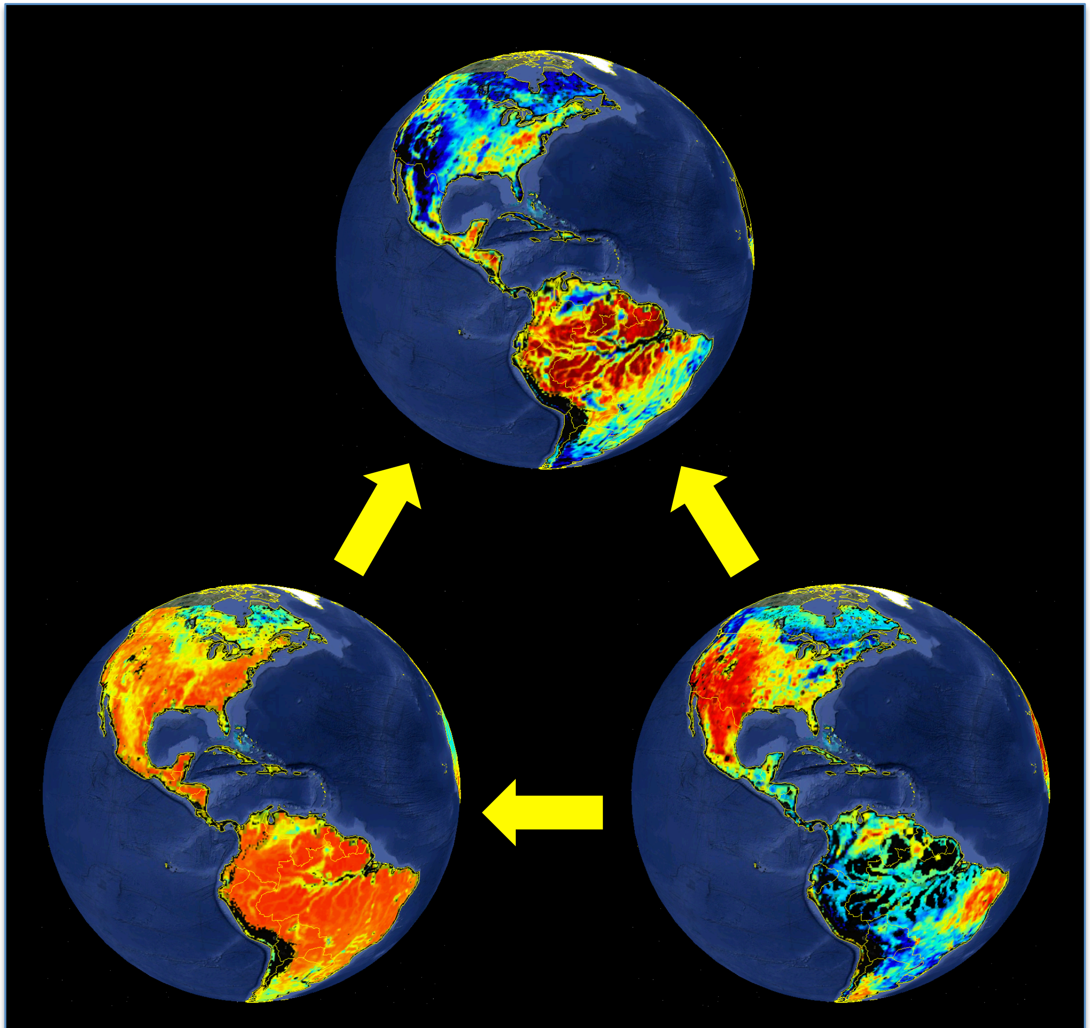
A Physically Consistent Structure of Microwave Surface Emissivity Means and Covariances from 10 years of WindSat and TRMM Data



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Precipitation Measuring Missions Science Team Meeting
18-21 March 2013, Annapolis, Maryland

Government sponsorship acknowledged

Rationale

The variable nature of the underlying surface emissivity (and radar backscatter cross section) are limiting factors for improved microwave precipitation products over the range of Earth land surfaces

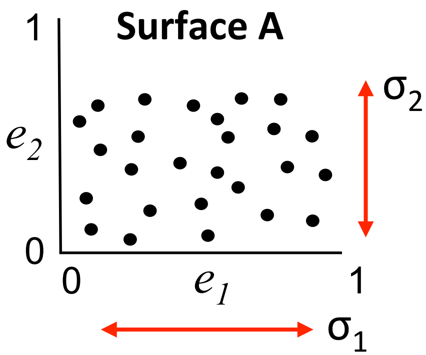
Analyze the physical factors that control emissivity, so they can be used to select appropriate candidate precipitation profiles

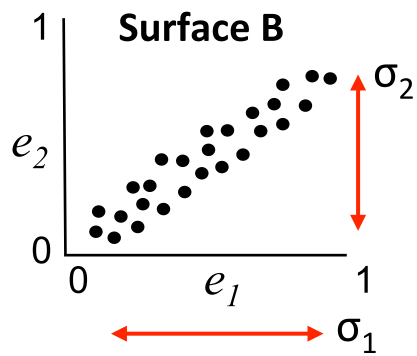
Use observationally-based physical zero-order model originally developed for NASA (AMSR-E, future SMAP) and Navy (WindSat) soil moisture missions

Brief presentation of activities, status and future projects of the Land Surface Working Group

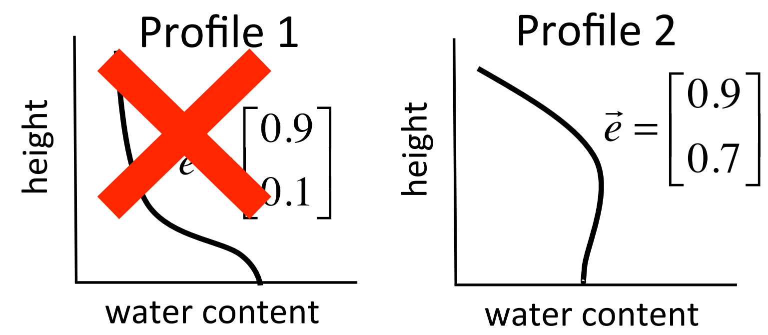
Simple Example

Assume a 2-channel radiometer observation $\vec{T}_B^{obs} = \begin{bmatrix} T_1 \\ T_2 \end{bmatrix}$





$\vec{T}_B^{sim} = \begin{bmatrix} T_1 \\ T_2 \end{bmatrix}$ Both agree with $\vec{T}_B^{obs}$



Simulated candidate solutions

$\vec{e} = \begin{bmatrix} e_1 \\ e_2 \end{bmatrix}$ Emissivity means and variance are the same for each surface. If I only know the means, I would vary e_2 independently of e_1, the same for both cases

Now extend this to the observational space for GPM:

$\vec{e} = \begin{bmatrix} e_{10H} \\ e_{10V} \\ \cdots\cdots \\ e_{85H} \end{bmatrix}$

Radiometer

9 TMI-like channels on GMI (36 unique covariance elements)

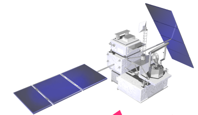
What physical properties determine the covariance structure?

$\vec{e} = \begin{bmatrix} e_{10H} \\ e_{10V} \\ \cdots\cdots \\ e_{85H} \\ \sigma_0^{Ku} \\ \sigma_0^{Ka} \end{bmatrix}$

Combined

9+2 (Ku and Ka-band surface backscatter cross sections)= 55 covariance elements (per DPR scan position)

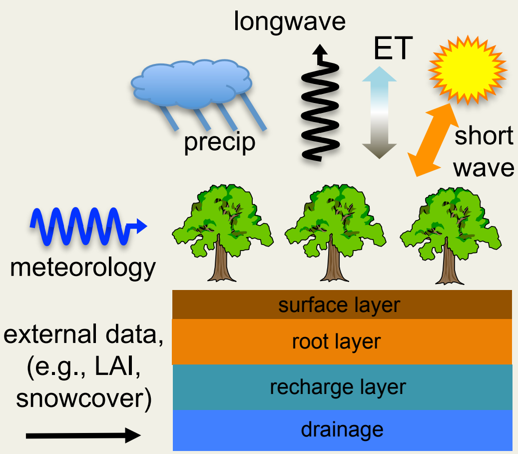
Difference Between S2, S1 and Physical Surface Model



S2

Diverse dynamic land model carrying many surface, subsurface and near-surface parameters that are fed to forward simulations

Forward simulator for any sensor supported in CRTM, CMEM



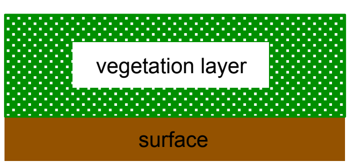
oversimplified and non-complete

Physical

Carries key physical parameters that control land emissivity (vegetation water content, soil moisture)

By design the retrieval statistically agrees with TB observations

Adjust physical parameters to bring simulated and observed TB (10, 19, 37 GHz) into simultaneous accord



Two-layer, zero-order model

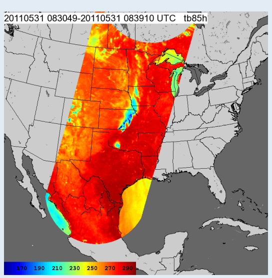
$$\text{vegetation} = f(\tau, \omega)$$

S1

Perform monthly classification on multi-year dataset of mean emissivities (current TELSEM correlations are fixed for each class)

Uniquely retrieve emissivity to match each observed TB

Clear-scene temperature & moisture profile, surface temperature



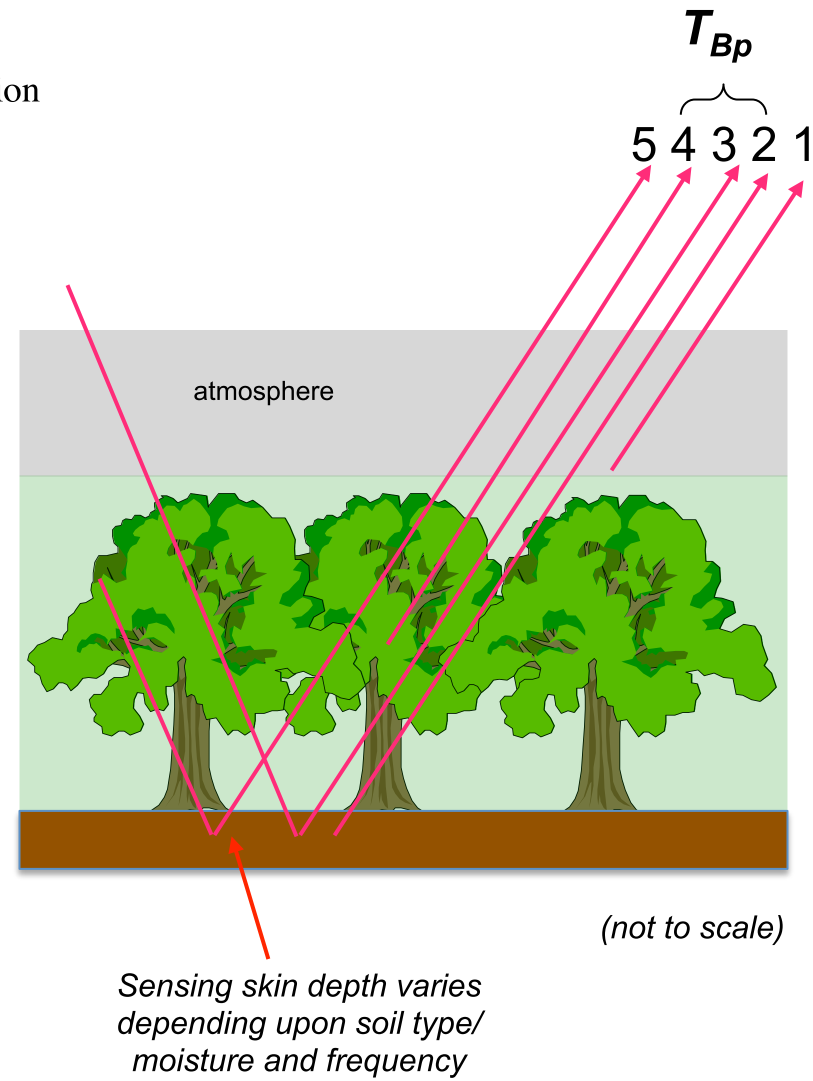
Many years of PMW sensor obs, any type, polarization

SSMI, SSMIS, AMSR-E, TMI AMSU, MHS, ATMS, etc.

Parameterized Radiative Transfer and Land Retrievals

$$T_{Bp} = T_u + e^{-\tau_a}\left[\left\{T_d r_{sp} e^{-2\tau_c}\right\} + T_e\left\{\left(1-r_{sp}\right)e^{-\tau_c} + \left(1-\omega_p\right)\left(1-e^{-\tau_c}\right)\left(1+r_{sp}e^{-\tau_c}\right)\right\}\right]$$

p denotes polarization
T_u and T_d are the upwelling and downwelling atmospheric emission
τ_a and τ_c is the atmospheric and vegetation opacity
T_e is the effective land surface/vegetation temperature
r_{sp} is the soil reflectivity
ω_p is the vegetation single scattering albedo



Soil reflectivity surface roughness model (*Wang and Choudhury, 1981*):

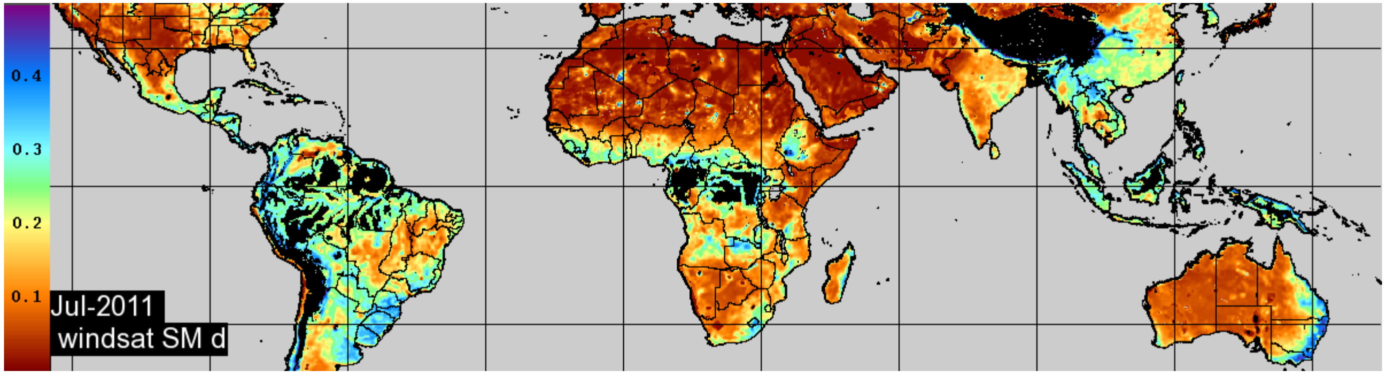
$$r_{sp} = e^{-h}[(1-Q)r_{op} + Q_{oq}]$$

r_{op} is the flat surface reflectivity and related to the soil dielectric constant ε by the Fresnel equations

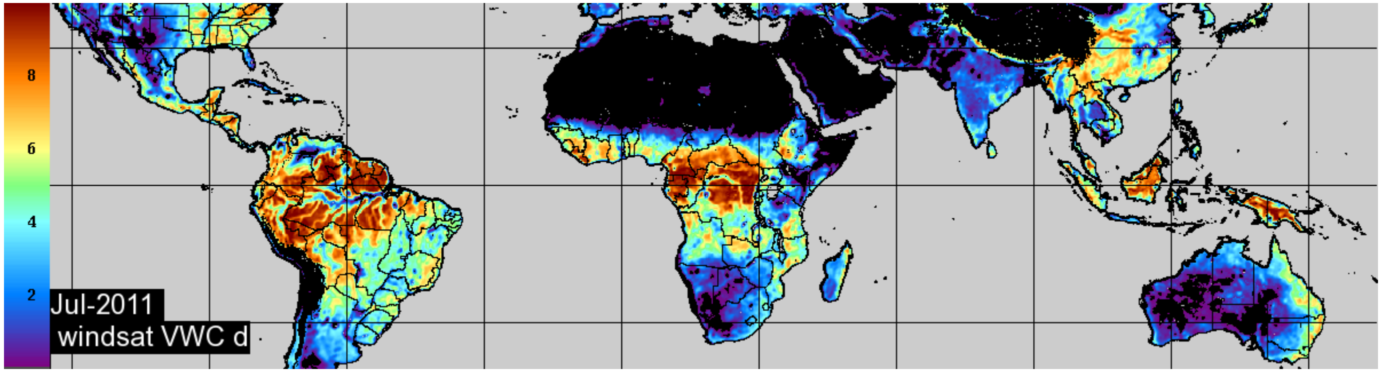
Physical Retrieval:

- Maximum Likelihood Estimation using dual-polarization at three frequencies (10, 18, and 37 GHz) simultaneously.
- Simultaneous retrievals of soil moisture, vegetation water content (VWC), and Ts

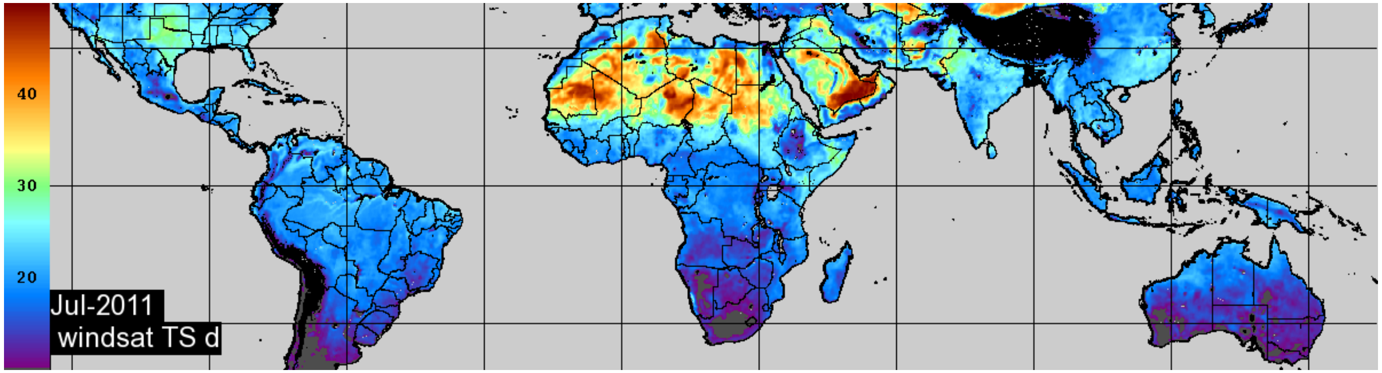
Example: WindSat-retrieved composited for July 2011



soil moisture
(red=dry blue=wet)

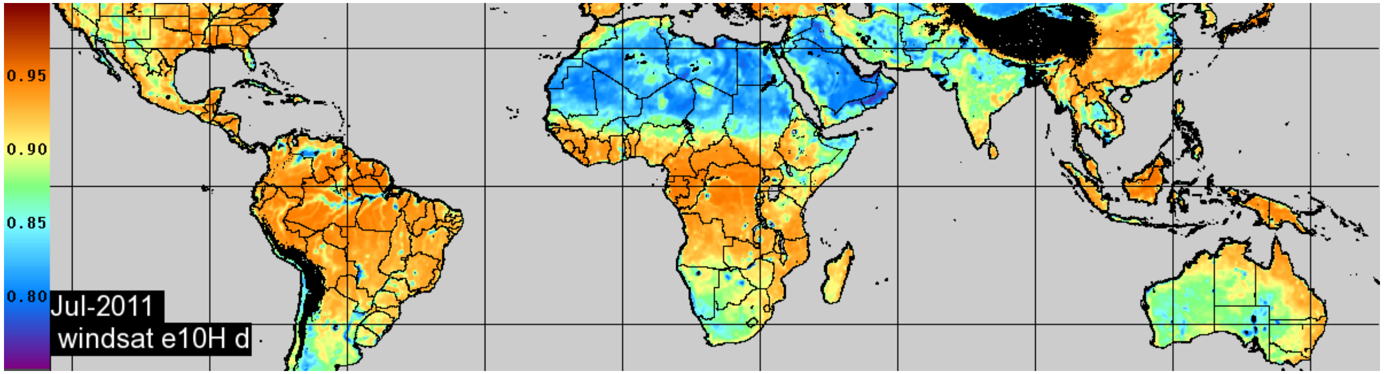


veg water content
(red=heavy, blue=light)

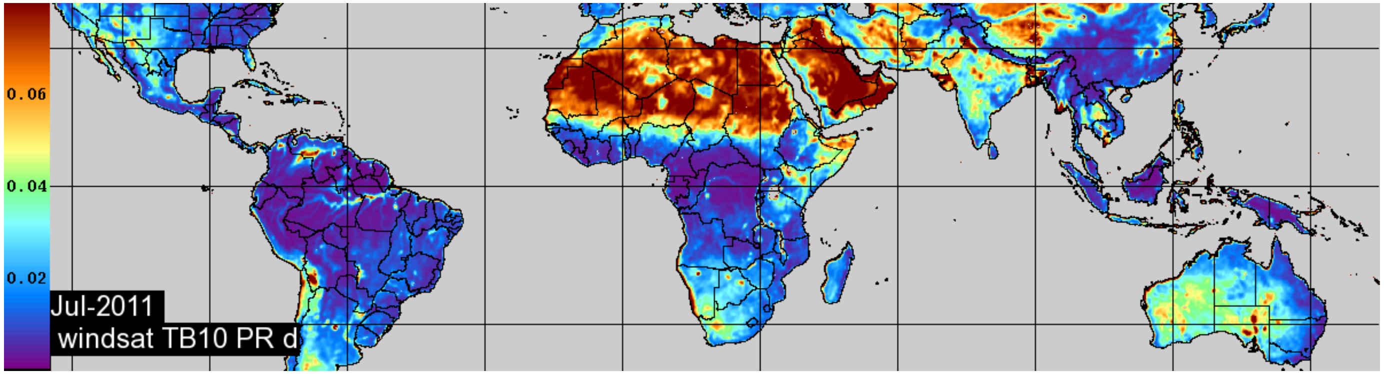


surface temperature
(red=hot, blue=cold)

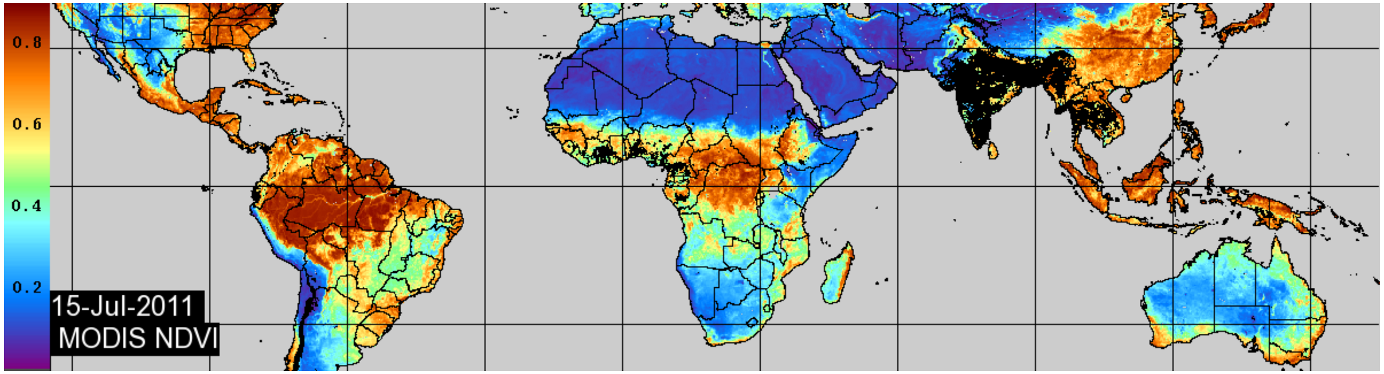
Example: WindSat-retrieved composited for July 2011



emissivity 10H
(red=high blue=low)



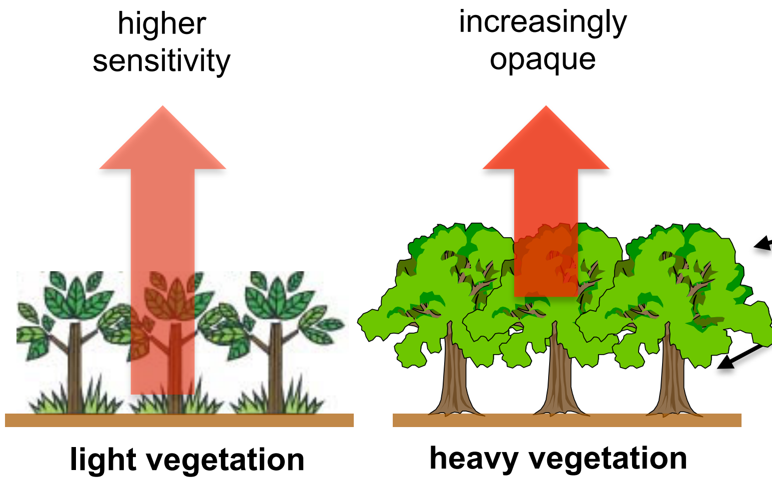
polarization ratio
10 GHz
(red=high, blue=low)



MODIS NDVI
(red=high, blue=low)

Relationship between optical & near-IR indices and VWC

X-band passive



$$\tau = b \cdot VWC \cdot \sec\theta$$

b term changes for vegetation and frequency

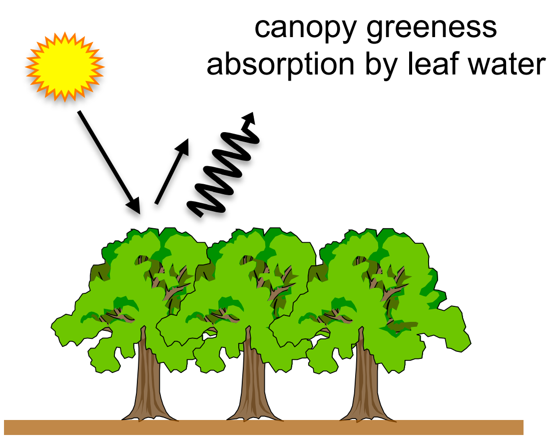
Vegetation Water Content (VWC) =
leaf water content +
water in crop stems or tree branches

VWC is not routinely measured and is typically estimated by combinations of optical (NDVI) or foliar indices (e.g., NDII)

NDVI is not responsive to full range of canopy water content, and stem mass is estimated indirectly

However there is extensive heritage and data for these indices, so it is important to understand the conditions that relate to VWC

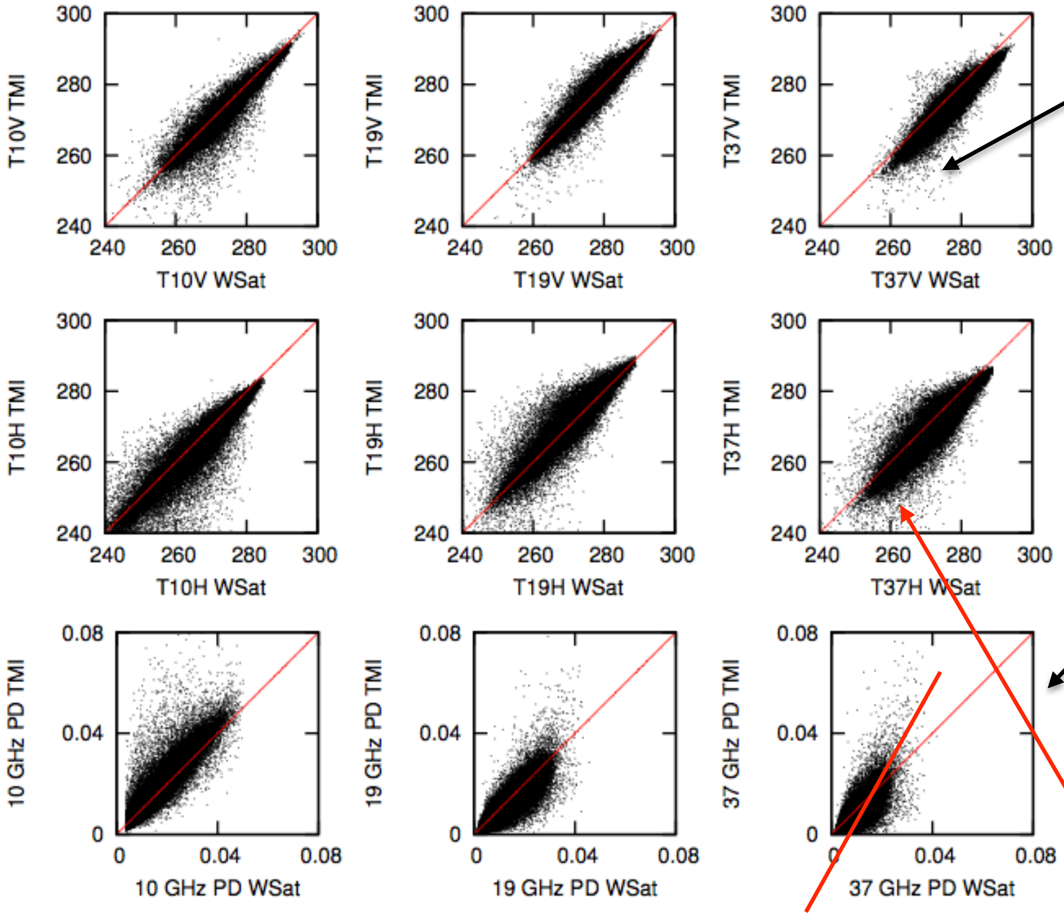
Optical, NIR, SW



$$NDVI = (R_{0.85} - R_{0.6}) / (R_{0.85} + R_{0.6}) \quad \text{MODIS channels 1,2}$$

$$NDII = (R_{0.85} - R_{1.65}) / (R_{0.85} + R_{1.65}) \quad \text{MODIS channels 2,6}$$

WindSat-TMI 1B11 Vers 7 5-minute matchups MJJA 2003-2011 Observations



37V (TMI) < 37V (WindSat)

$PR=(TB^V-TB^H)/(TB^V+TB^H)$

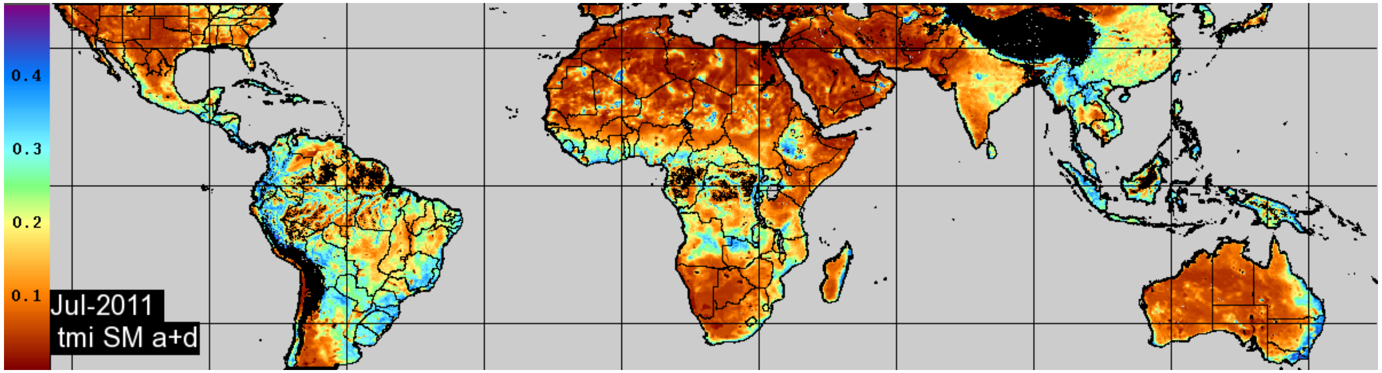
A few K can have a big effect on polarization ratio, most noted here at 37 GHz

Wilheit et. al. IGARSS-2011 Table 1 shows TMI too cold

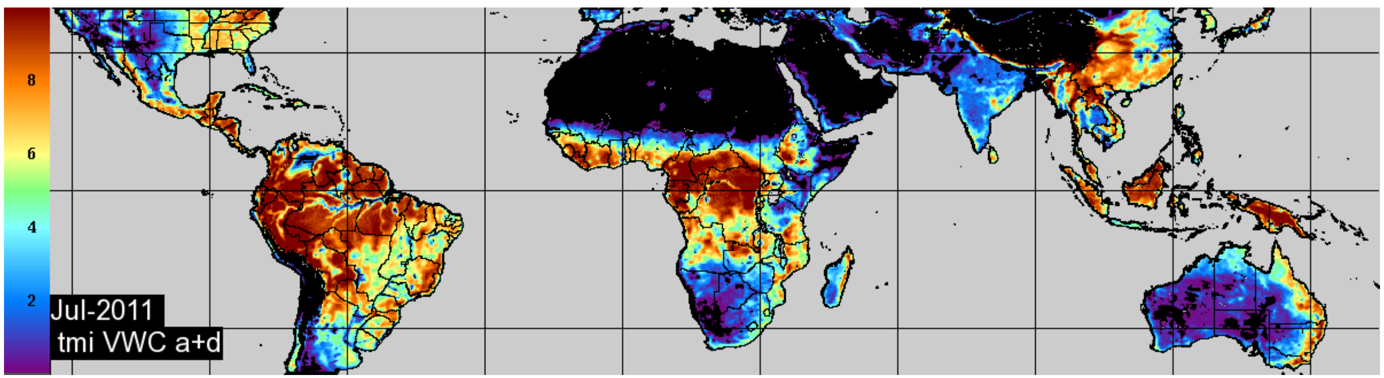
Table 1
DIFFERENCES BETWEEN TMI AND WINDSAT

Channel	Δ TB	@ TB	Δ TB	@ TB
10V	0.31K	163K	-0.76K	281K
10H	-1.66	85	-0.92	280
19V	-0.61	188	-1.20	285
19H	-3.20	109	-1.43	284
21V	-1.89	200	-3.37	284
37V	-3.24	206	-3.17	281
37H	-2.41	135	-3.16	281

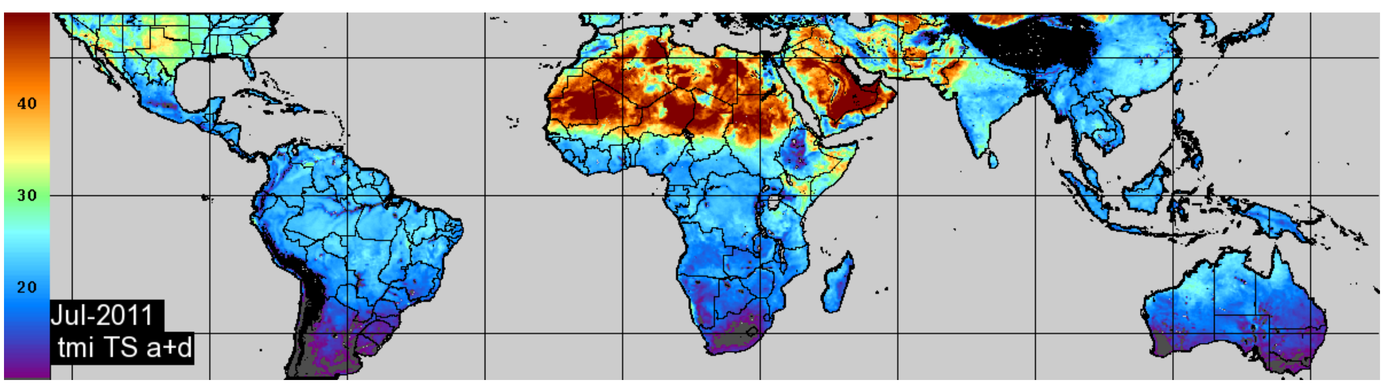
Example: TMI-retrieved composited for July 2011



soil moisture
(red=dry blue=wet)



veg water content
(red=heavy, blue=light)

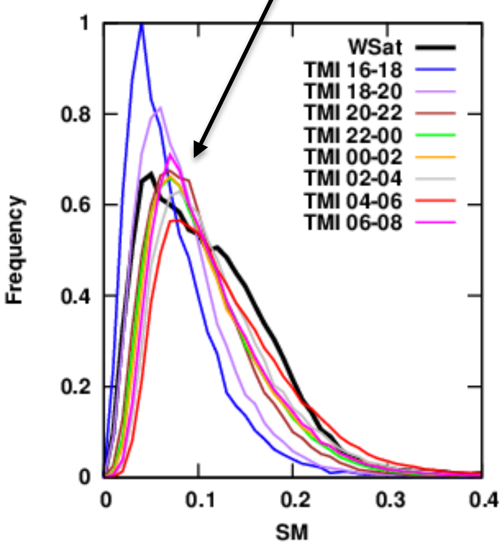


surface temperature
(red=hot, blue=cold)

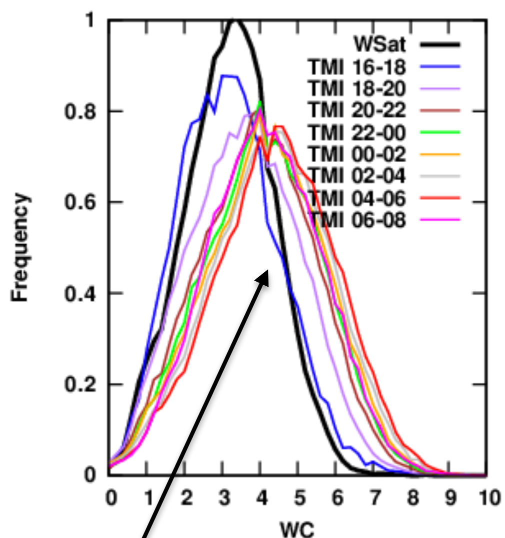
WindSat-TMI 1B11 Vers 7   Binned by TMI local time   MJJA 2003-2011

TMI (various colors indicate the local time bin) SM histograms best align with WindSat (black color, always 6 AM local time) for early morning hours (04-08 local time)

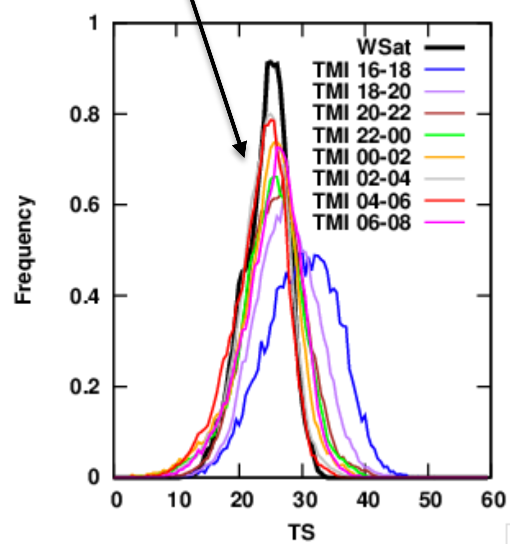
TMI Ts histograms best align with WindSat for early morning hours (04-08 local time)



soil moisture



vegetation WC

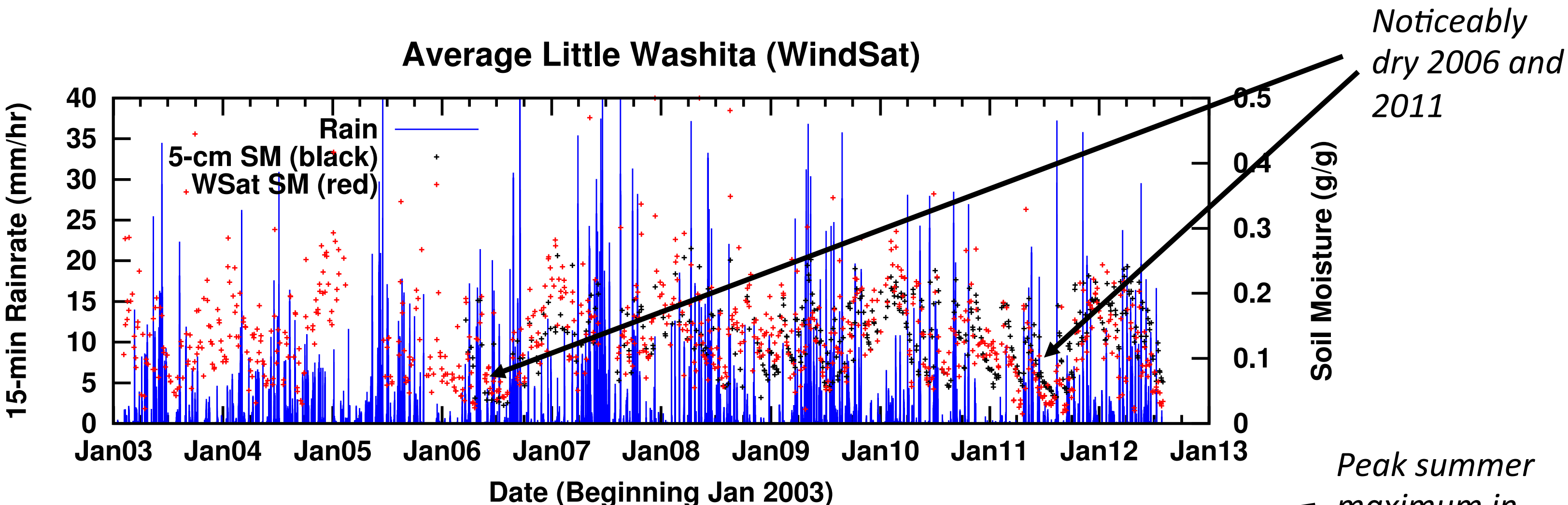


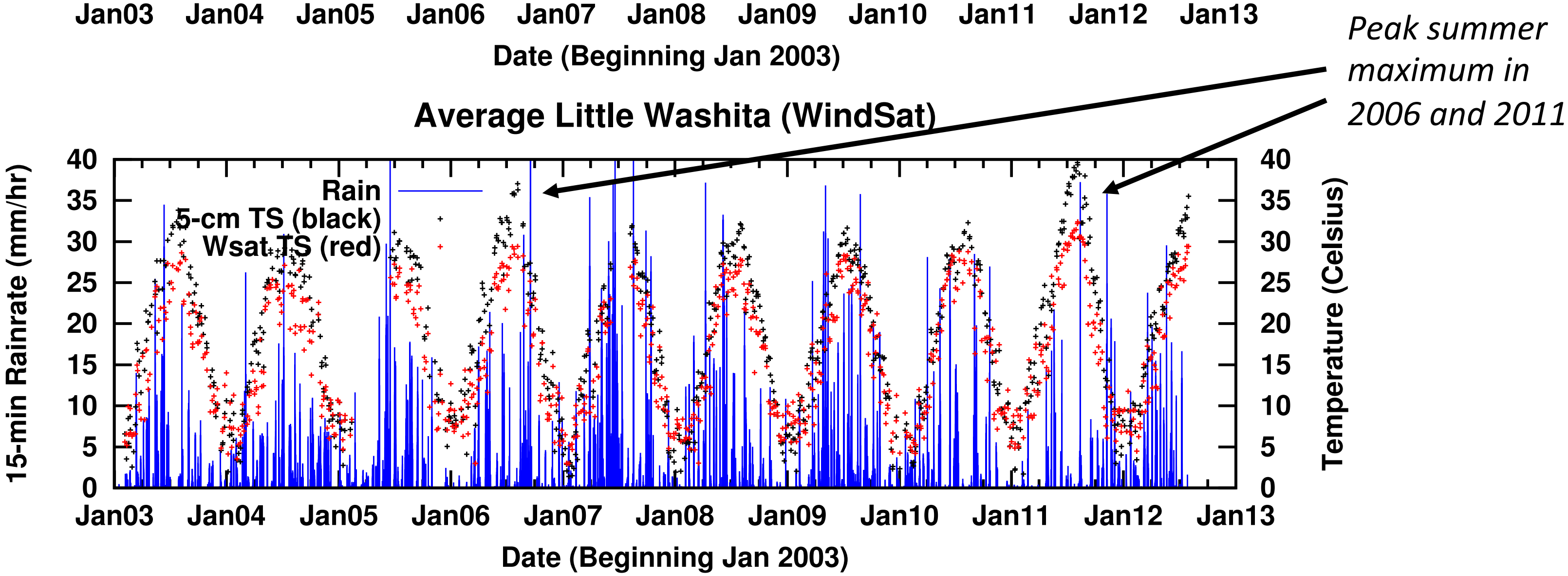
surface temperature

Still issues with TMI VWC to be addressed in this year’s reprocessing

WindSat vs In-Situ Stations Instantaneous Comparisons 2003-2012, Oklahoma

Satellite overpass times matched to nearest 15-minute ARS station data
5-cm Soil Moisture (top)   5-cm Temperature (bottom)



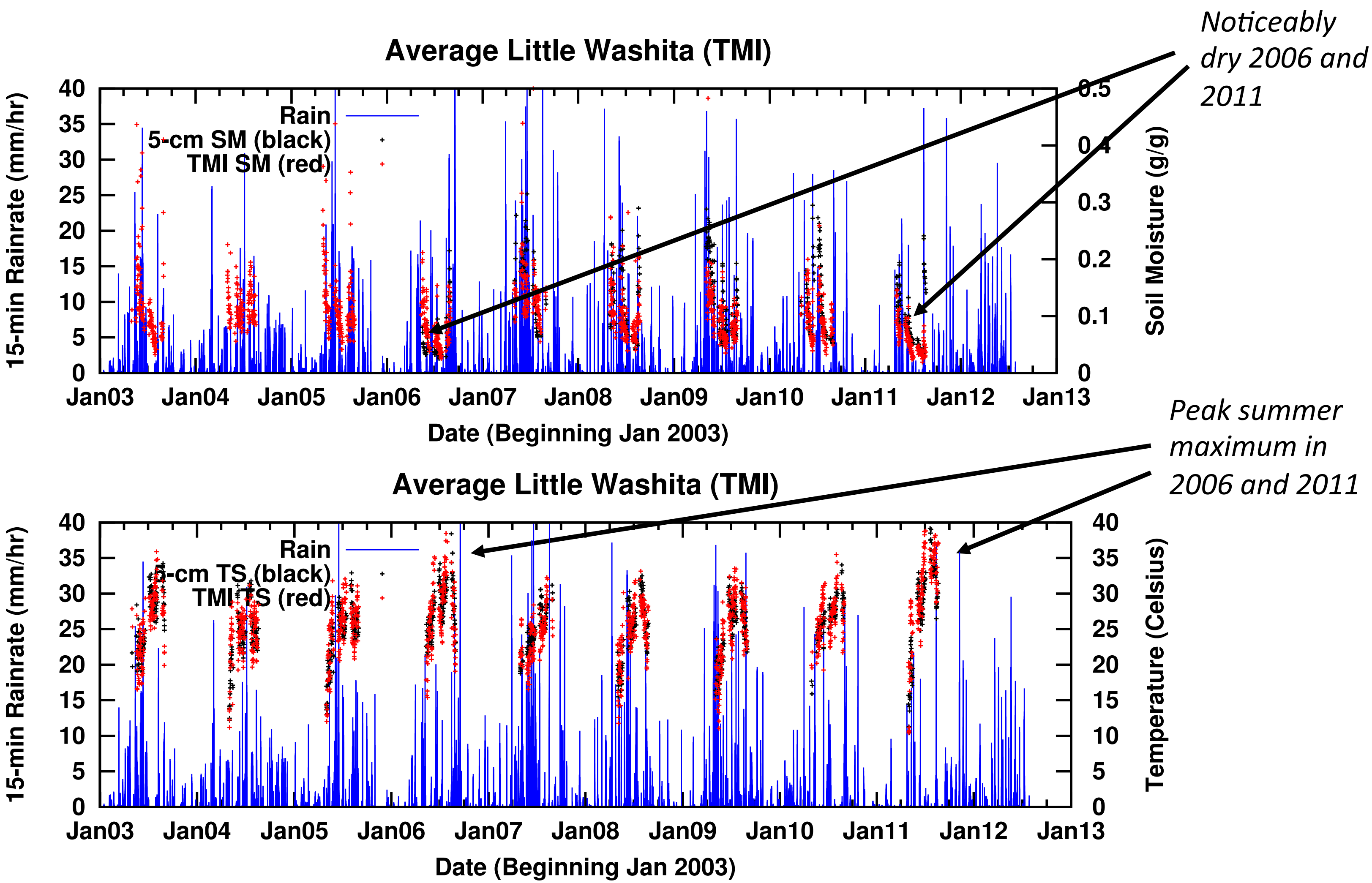


Average Little Washita (TMI)

TMI 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)



Current Status

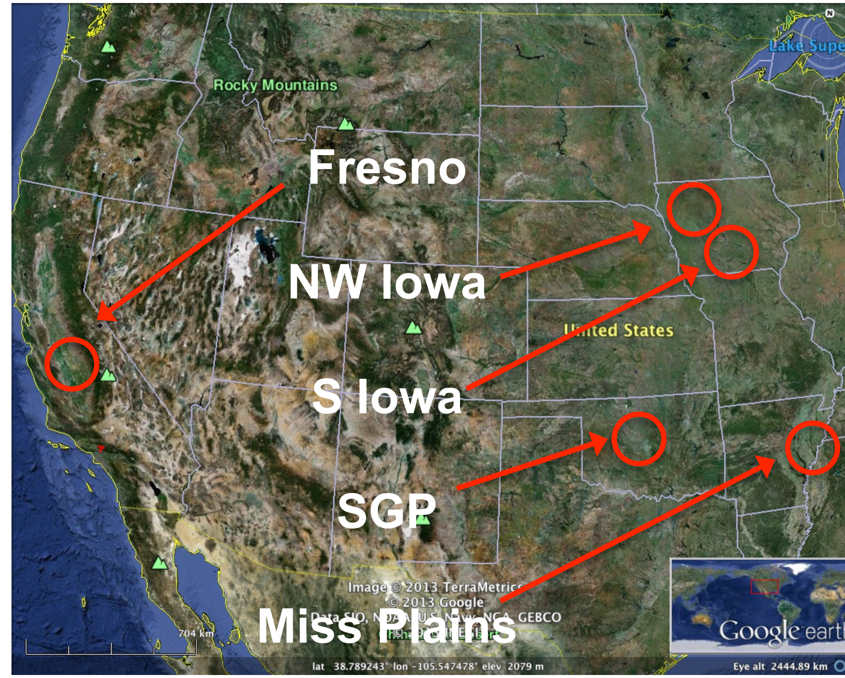
Processing and testing of WindSat physical retrievals is complete through July 2012, and four months of each of 2002-2011 (May-August) of TMI was completed for cross-comparison

Current plans are to apply recent X-Cal adjustments to TMI and reprocess entire TRMM mission

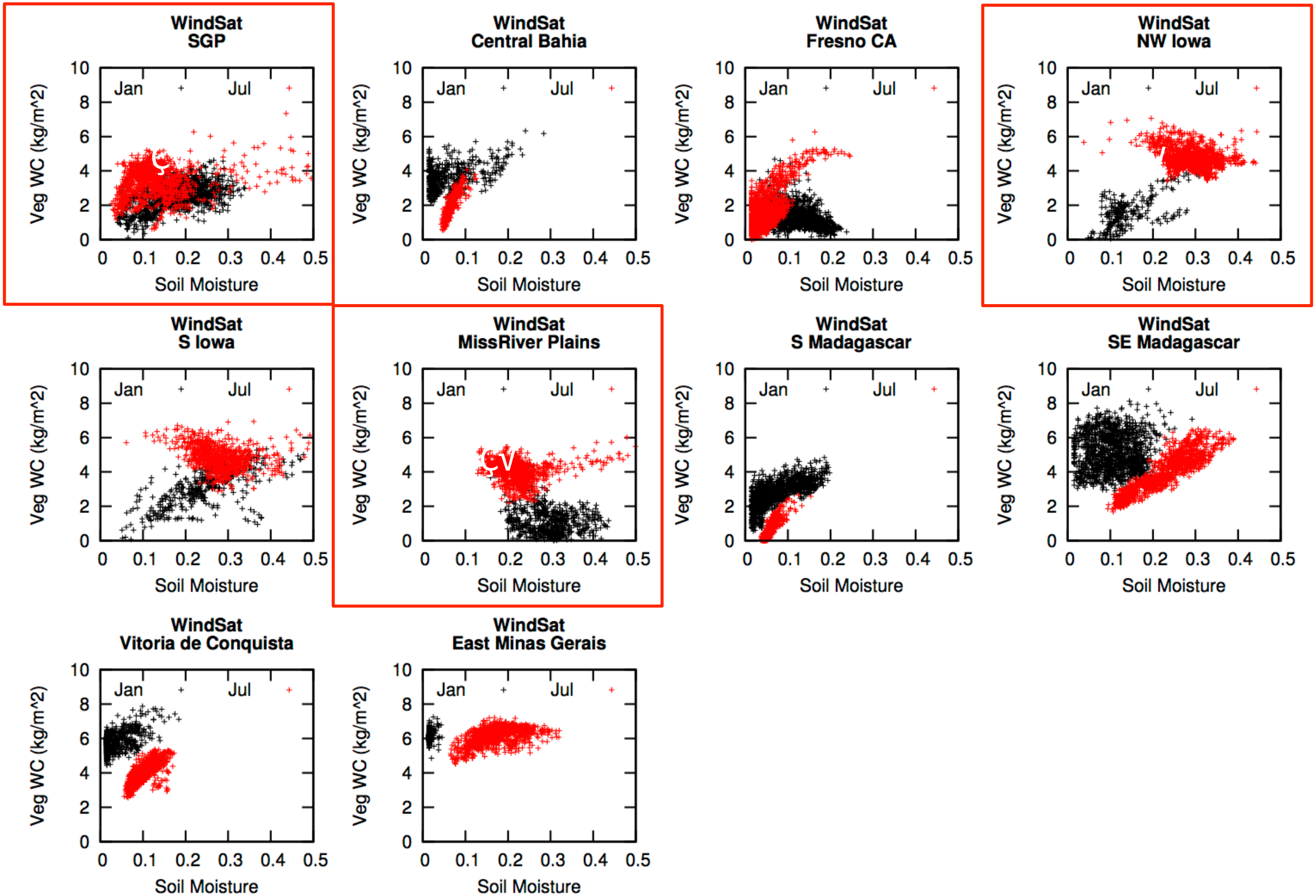
Datasets packaged in daily netCDF files (separate ascending and descending for TRMM), on same 25-km EASE grid (586x1383) used for AMSR-E land products: latitude, longitude, date, soil moisture, vegetation WC, surface temperature, emissivity*6, TB*6, IGBP class, NDVI and EVI interpolated from 16-day MODIS

Have had initial discussions to host dataset at PPS

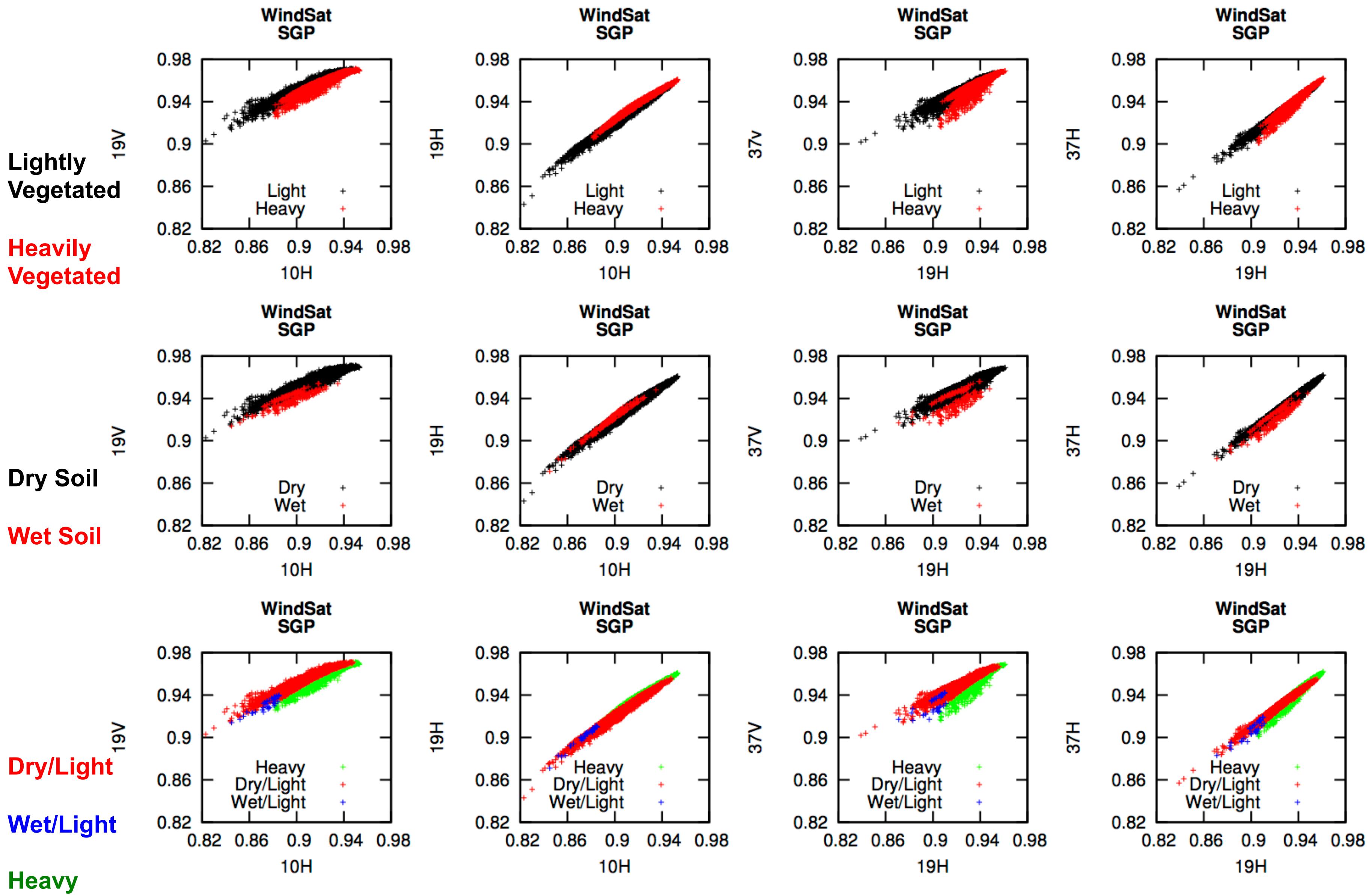
Selected 1-degree Regions



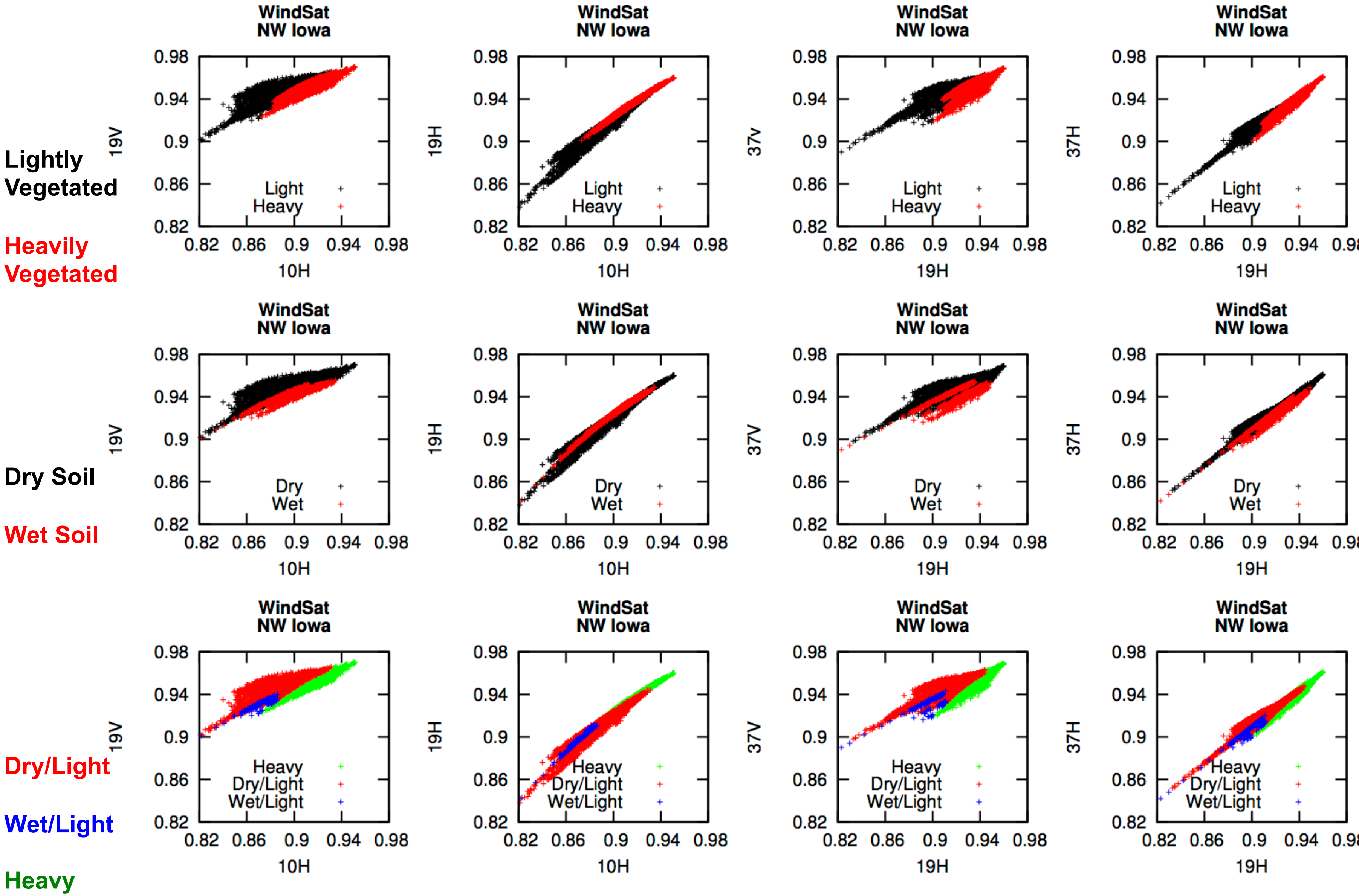
1-deg Regions All 2003-2012 Black=January Red=July



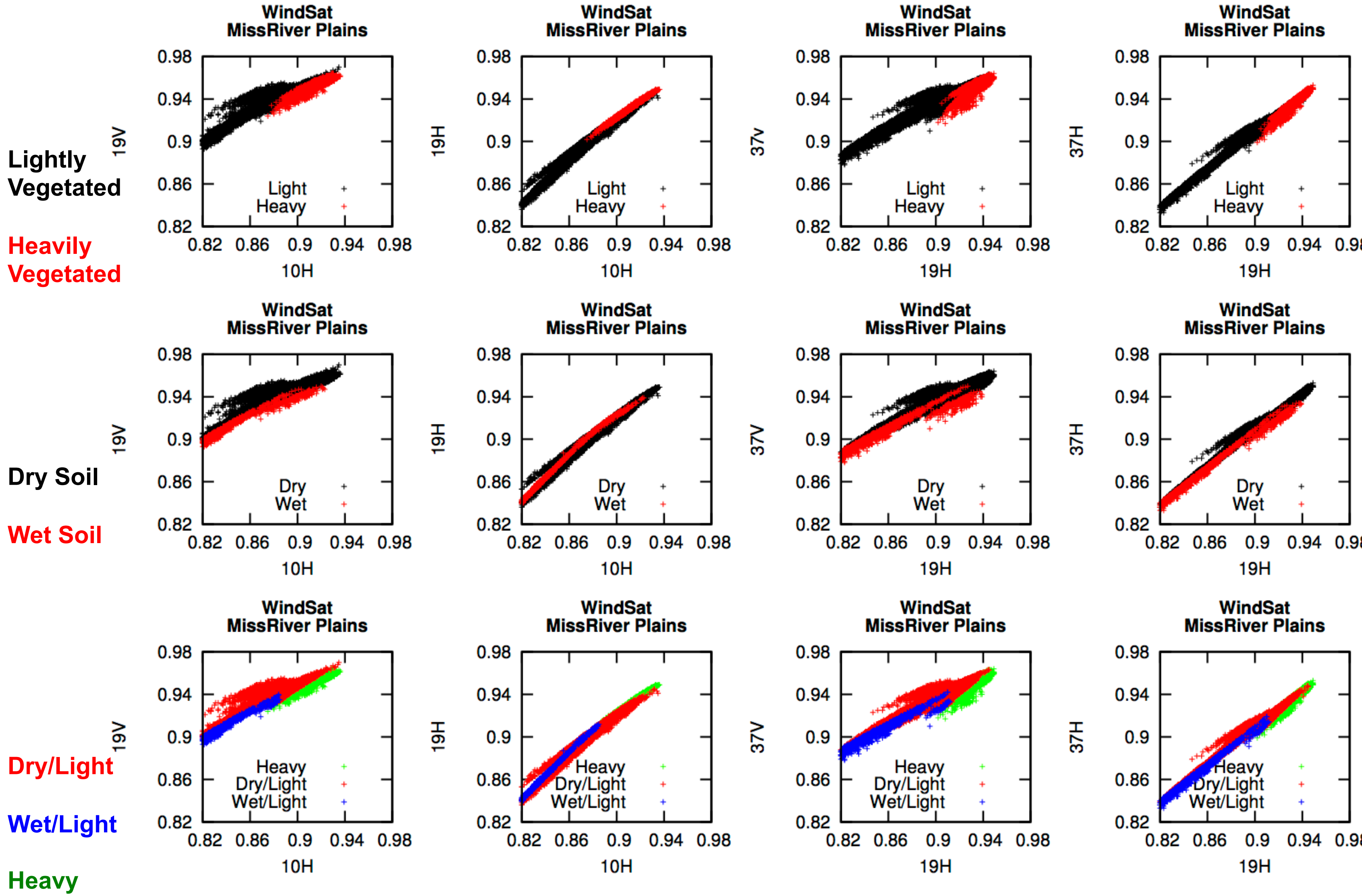
Emissivity Cross Correlations   All 2003-2012   1-deg SGP



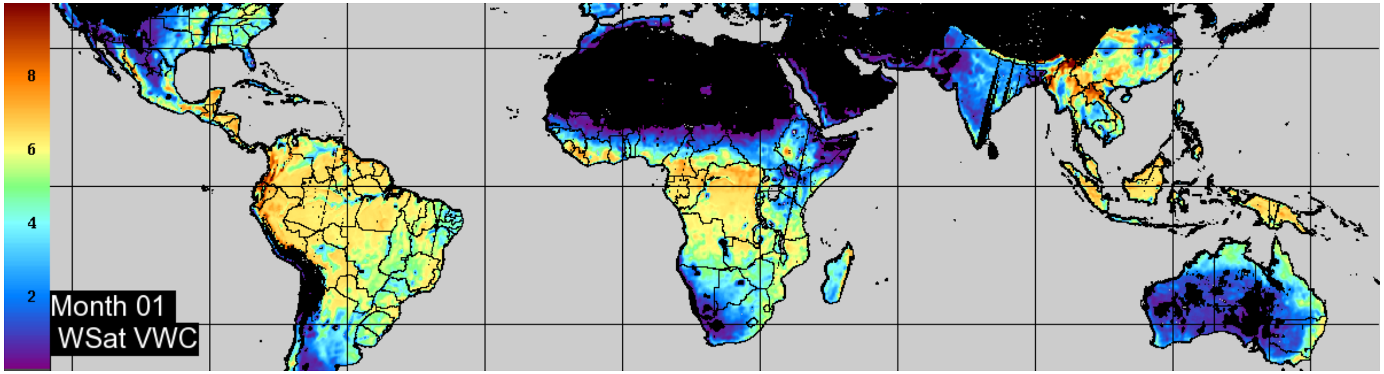
Emissivity Cross Correlations All 2003-2012 1-deg NW Iowa



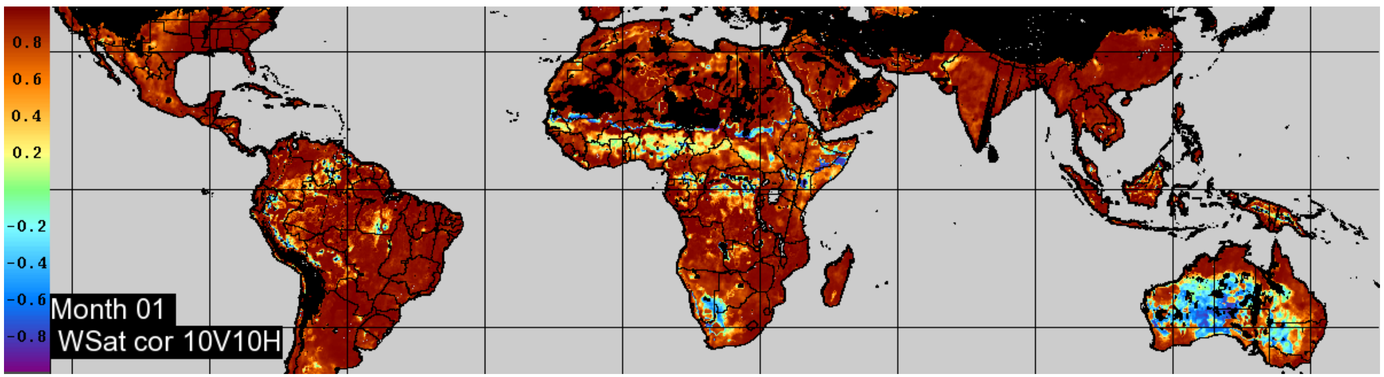
Emissivity Cross Correlations   All 2003-2012   1-deg Miss Plains



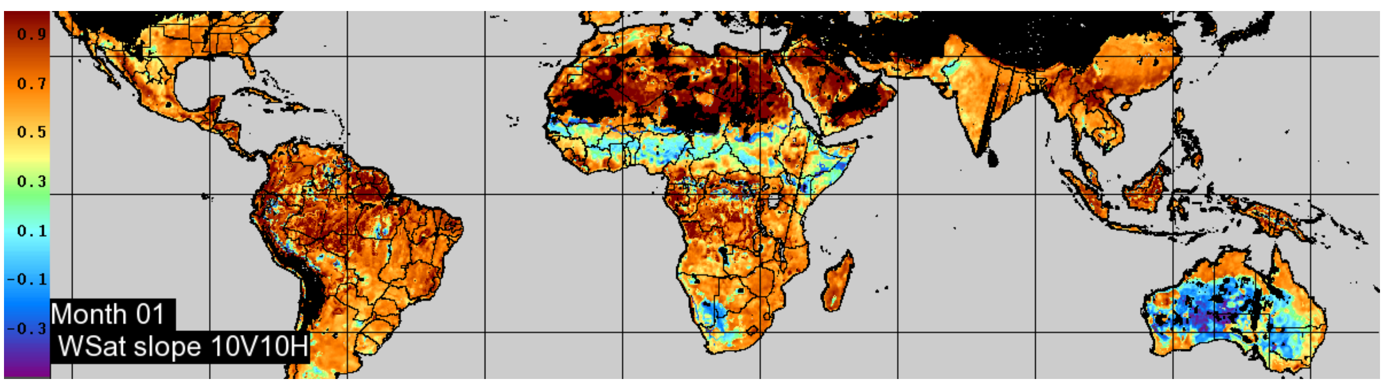
Emissivity Cross Correlations & Slopes 2003-2012 January



Veg Water Content
(red=heavier)

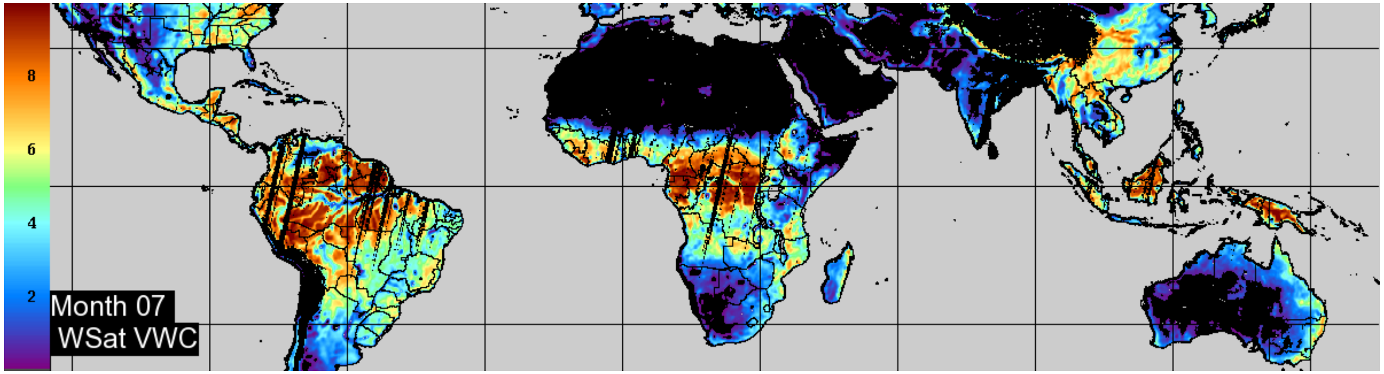


Correlation 10V/10H
(red=near unity)

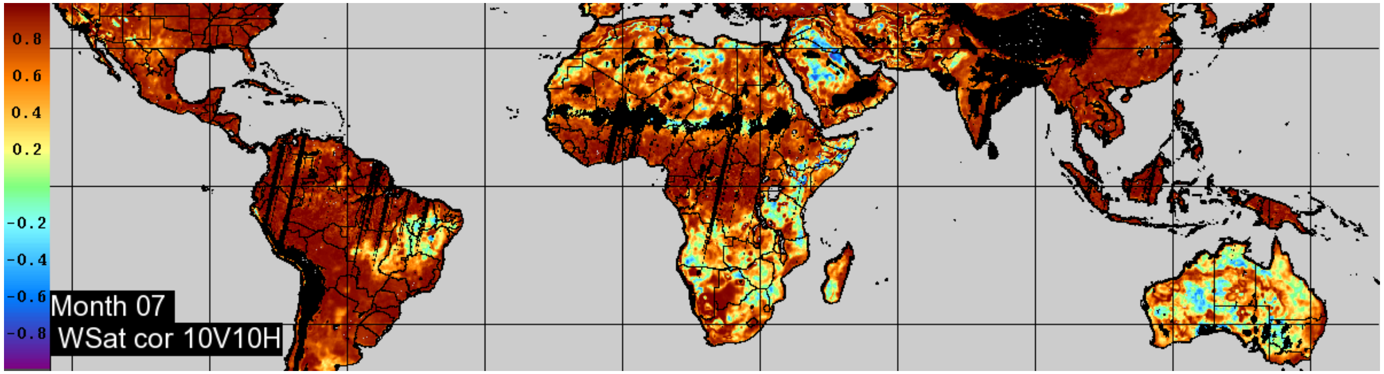


Slope 10V/10H
(red=positive,
blue=negative)

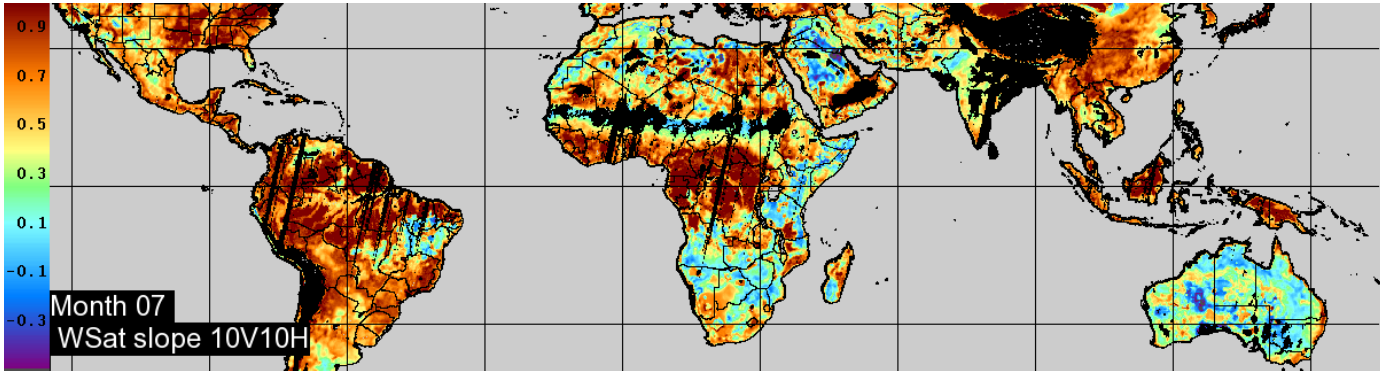
Emissivity Cross Correlations & Slopes   2003-2012   July



Veg Water Content
(red=heavier)



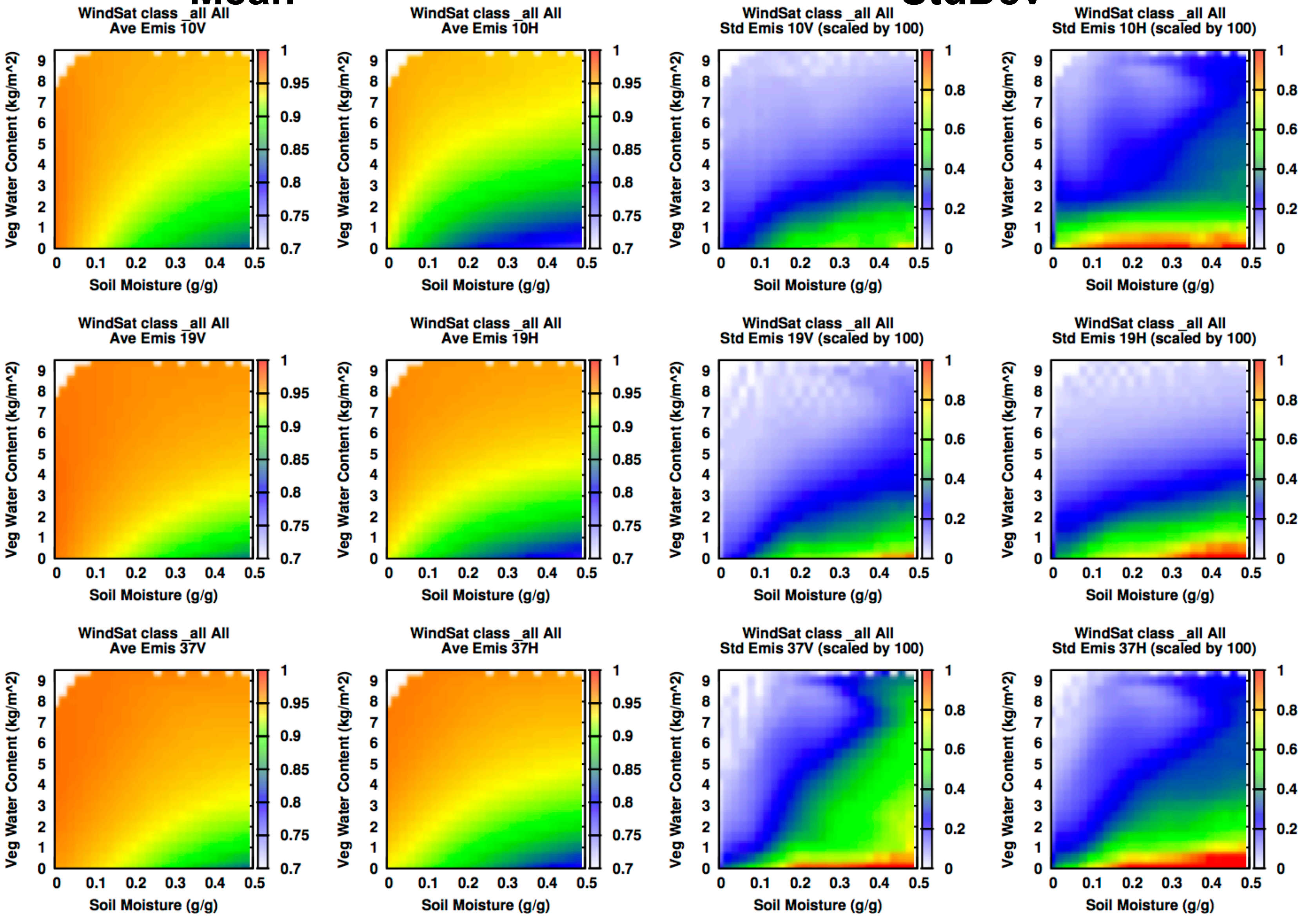
Correlation 10V/10H
(red=near unity)



Slope 10V/10H
(red=positive,
blue=negative)

2003-2011 WindSat All Months All Classes VWC & Soil Moisture

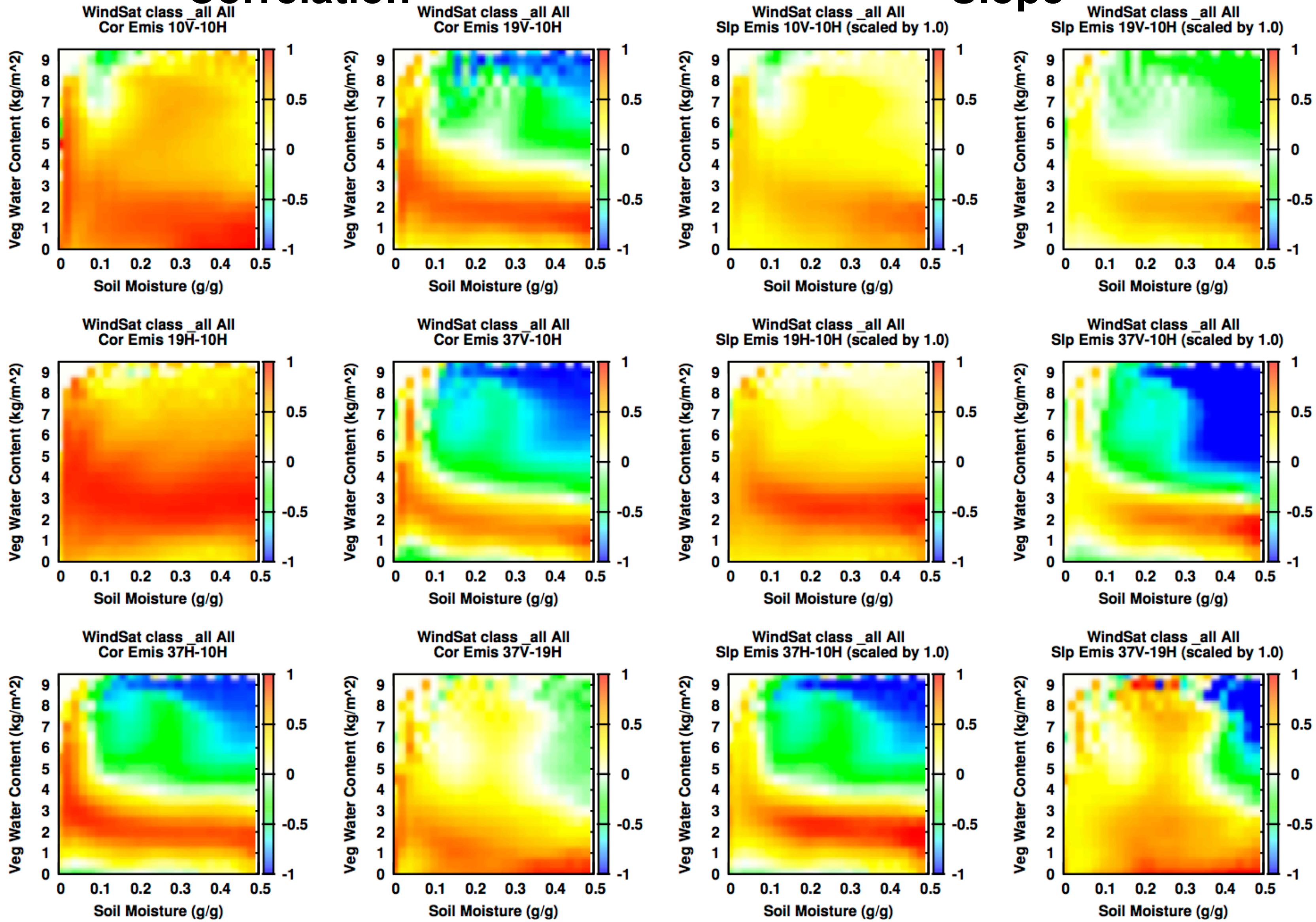
Mean StdDev



2003-2011 WindSat All Months All Classes VWC & Soil Moisture

Correlation

Slope



Summary

Physical modeling is useful to complement the rigorous land models and the clustering-based classification models

Self-consistent with the TB observations, and does not depend upon pre-determined land classifications (within limits of the 2-layer model)

Does not work everywhere (heavy vegetation, cold surface, snow, rain)

Synergistic handling of VWC (e.g., microwave-based retrieval of VWC, SM and precipitation), which is otherwise indirectly estimated

Tracks locations and seasons where/when emissivity correlation structure lines up (or breaks down), and how to jointly vary emissivities

May be more useful for 1-d var approaches rather than Bayesian

Addendum

GV-Centric Focused Land Study Areas

(From Tuesday night land group meeting)
J. Turk, C. Peters-Lidard, Co-Chairs

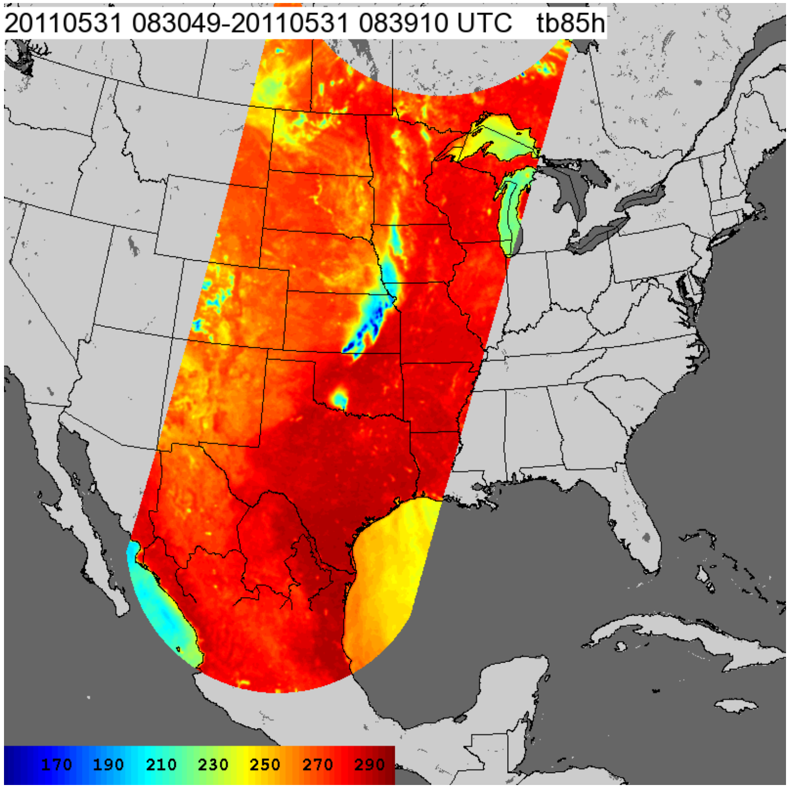
PMM Land Surface Working Group meets via telecall approximately every month to discuss selected research topics and address GPM action items. jturk@jpl.nasa.gov for details.

SSMIS data courtesy of the FCDR effort from Wes Berg, CSU
NMQ data courtesy of Pierre-Emmanuel Kirstetter, OU/CIMMS

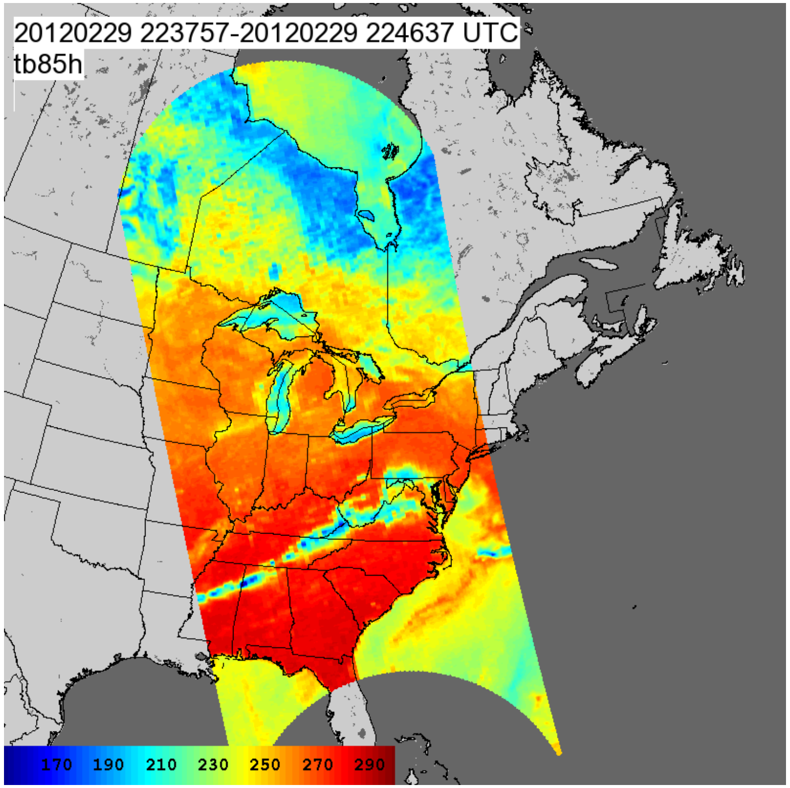
Satellite Overpasses Over MC3E and GCPEx Field Experiment Domains

LSWG Field Experiment Based Study Areas
Joe Turk, 30 Jan 2013

MC3E
22 April-6 June 2011



GCPEx
17 Jan-29 Feb 2012



For GCPEx, 186 SSMIS overpasses from F-16, F-17 and F-18 located that passed within 700-km of the D3R radar site (1700-km SSMIS swath)

For MC3E, 49 AMSR-E overpasses from Aqua located passing within 700-km of the D3R site in Oklahoma

For each, an 8-9 minute overpass segment was extracted

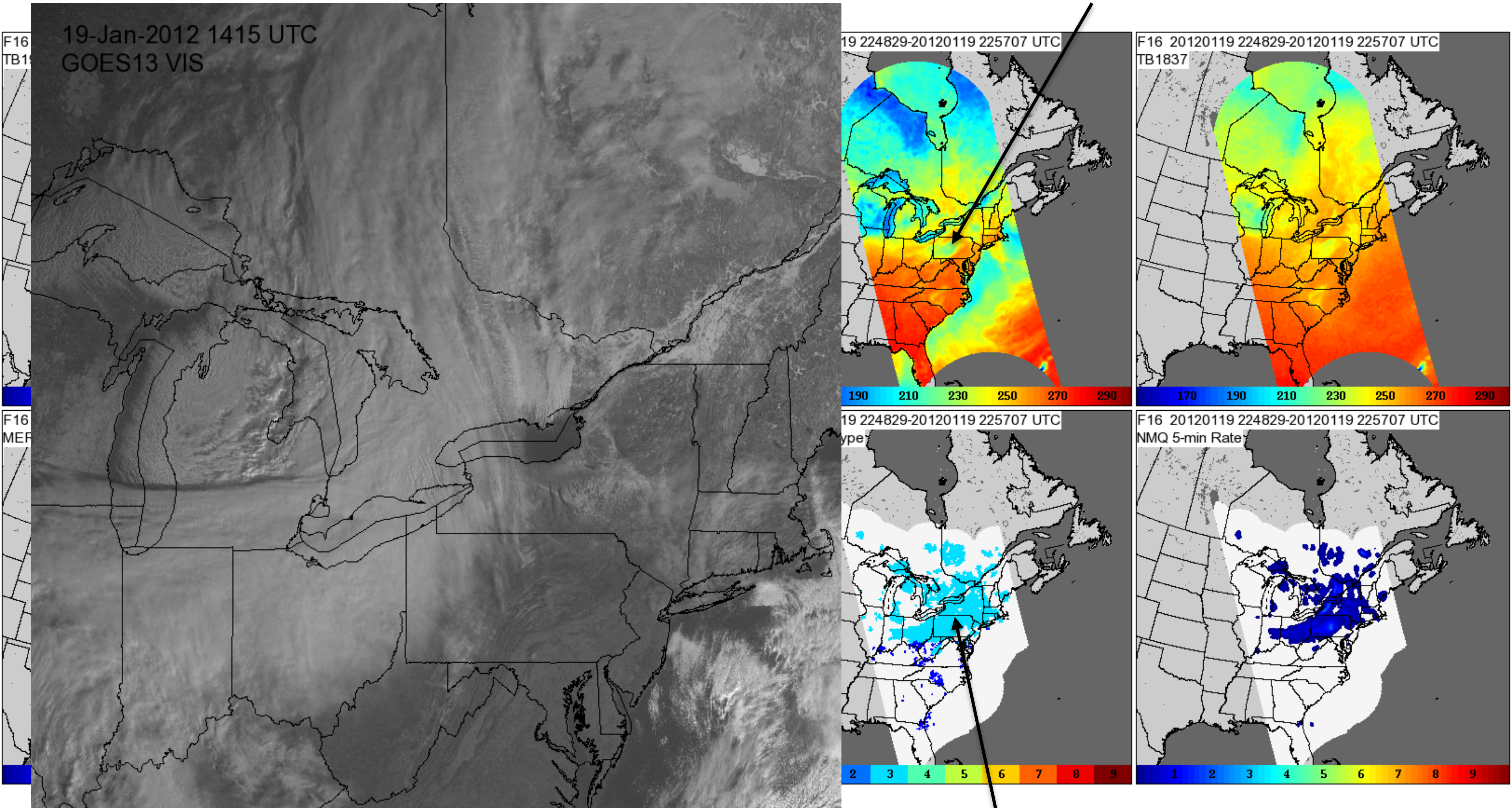
Ancillary fields provided alongside TB: 10-day IMS snowcover flag; 2-m T; 10-m T; sfc T; nearest 5-min NMQ rainrate and raintype; 1, 3, 6, 12, 24-hr NMQ accumulations; total column vapor; 42-level MERRA T/q/p profile (sufficient for clear-scene radiative transfer)

Available at the GV ftp at NSSTC. The data, documentation and quicklook images can be found at:
ftp://gpm.nsstc.nasa.gov/gpm_validation/gcpex/overpasses_composite/
ftp://gpm.nsstc.nasa.gov/gpm_validation/mc3e/overpasses_composite/

Have suggested that select cases be included for GPROF algorithm testing (TBD during group meetings this week).

GCPEx Case Studies: 19 January 2012 2248 UTC SSMIS F16
Eastern US light snow falling along the snowcover boundary

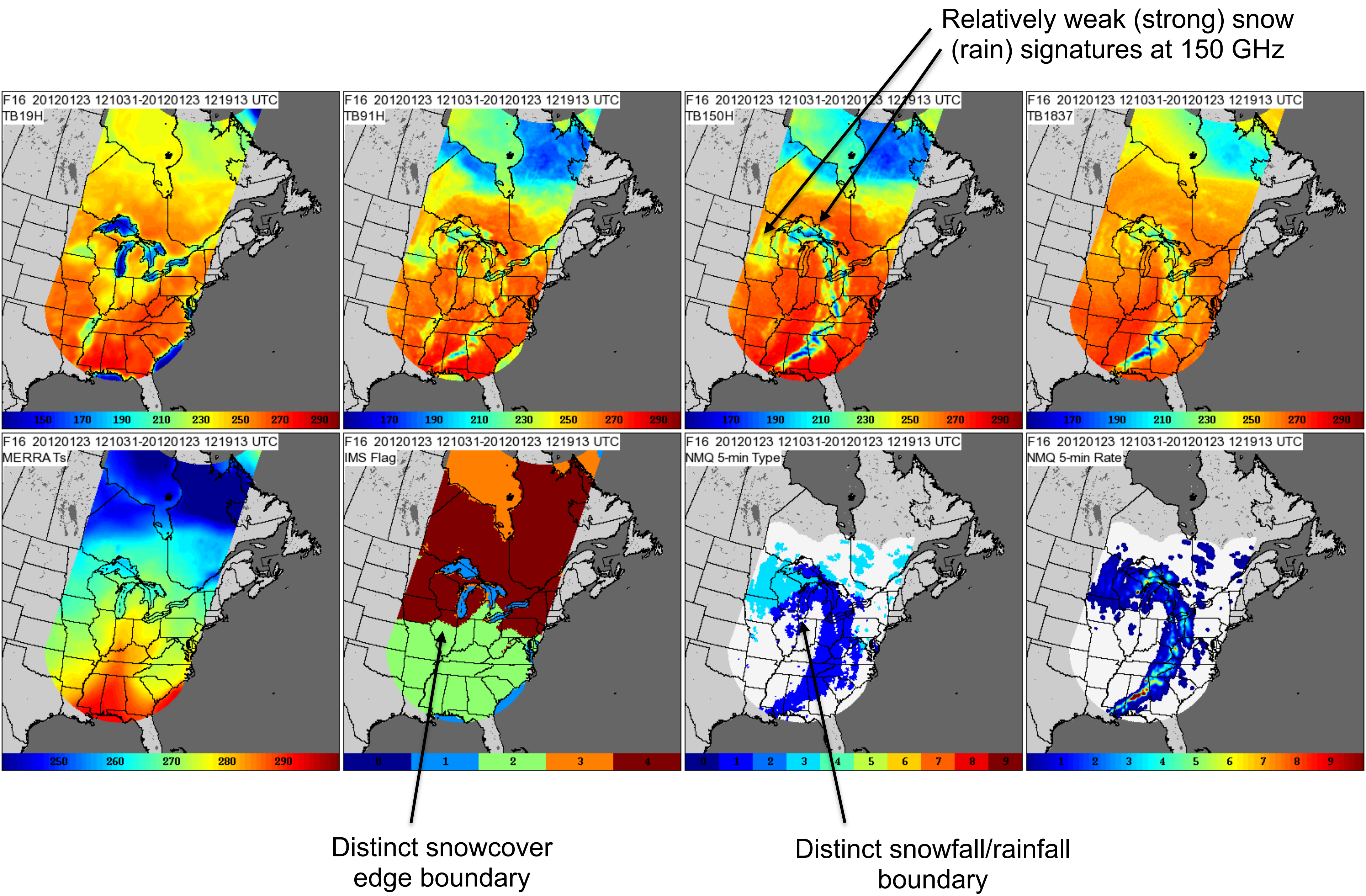
Snowband had moved over eastern US at overpass time



Snowfall is along the snowcover edge

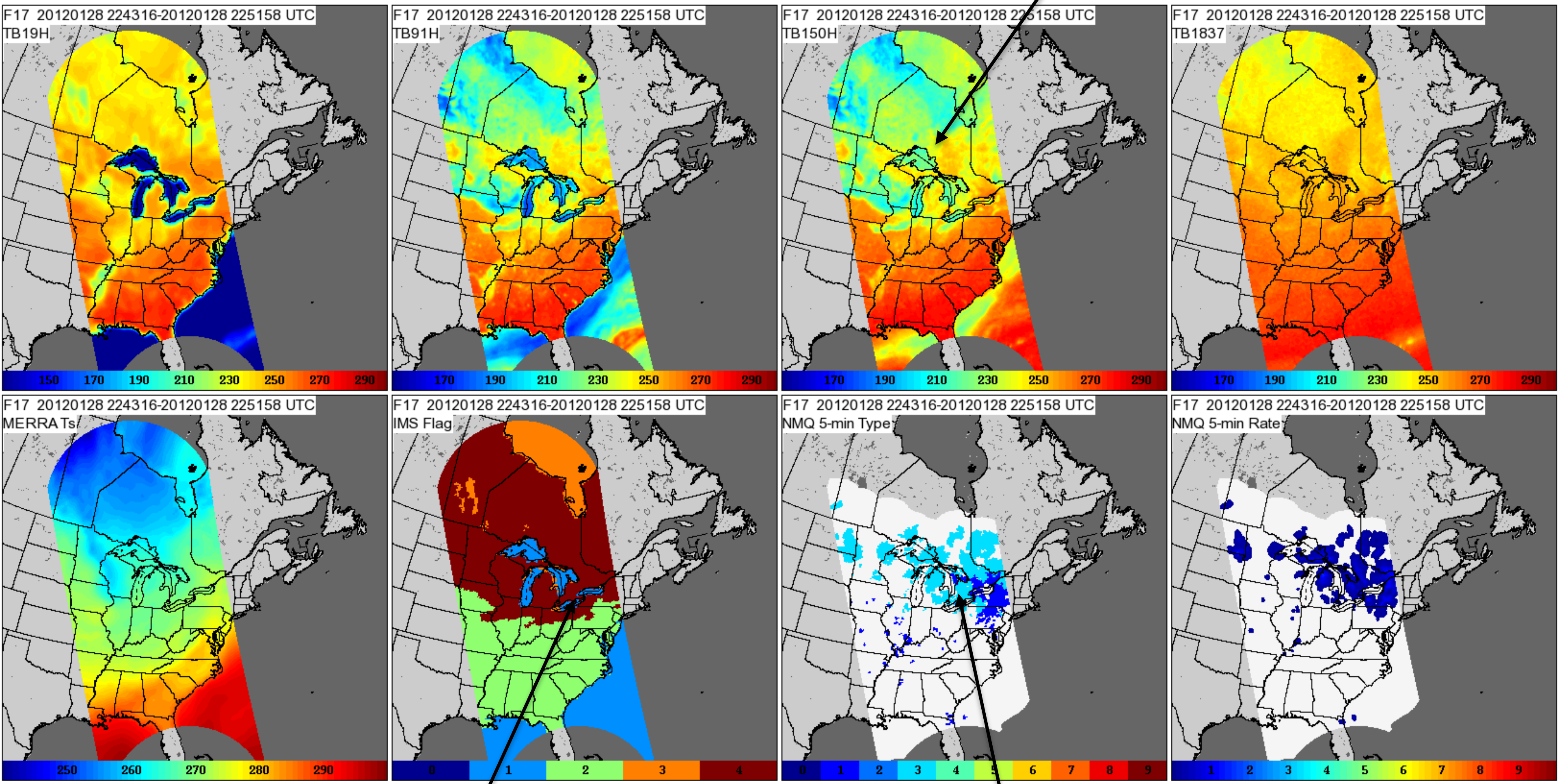
Nearly all frozen precipitation

GCPEx Case Studies: 23 January 2012 1210 UTC SSMIS F16
Snow/rain conditions over snow/no-snow cover, Great Lakes



GCPEx Case Studies: 28 January 2012 2247 UTC   SSMIS F17
Case from Gail's CoSMIR presentation on Tuesday

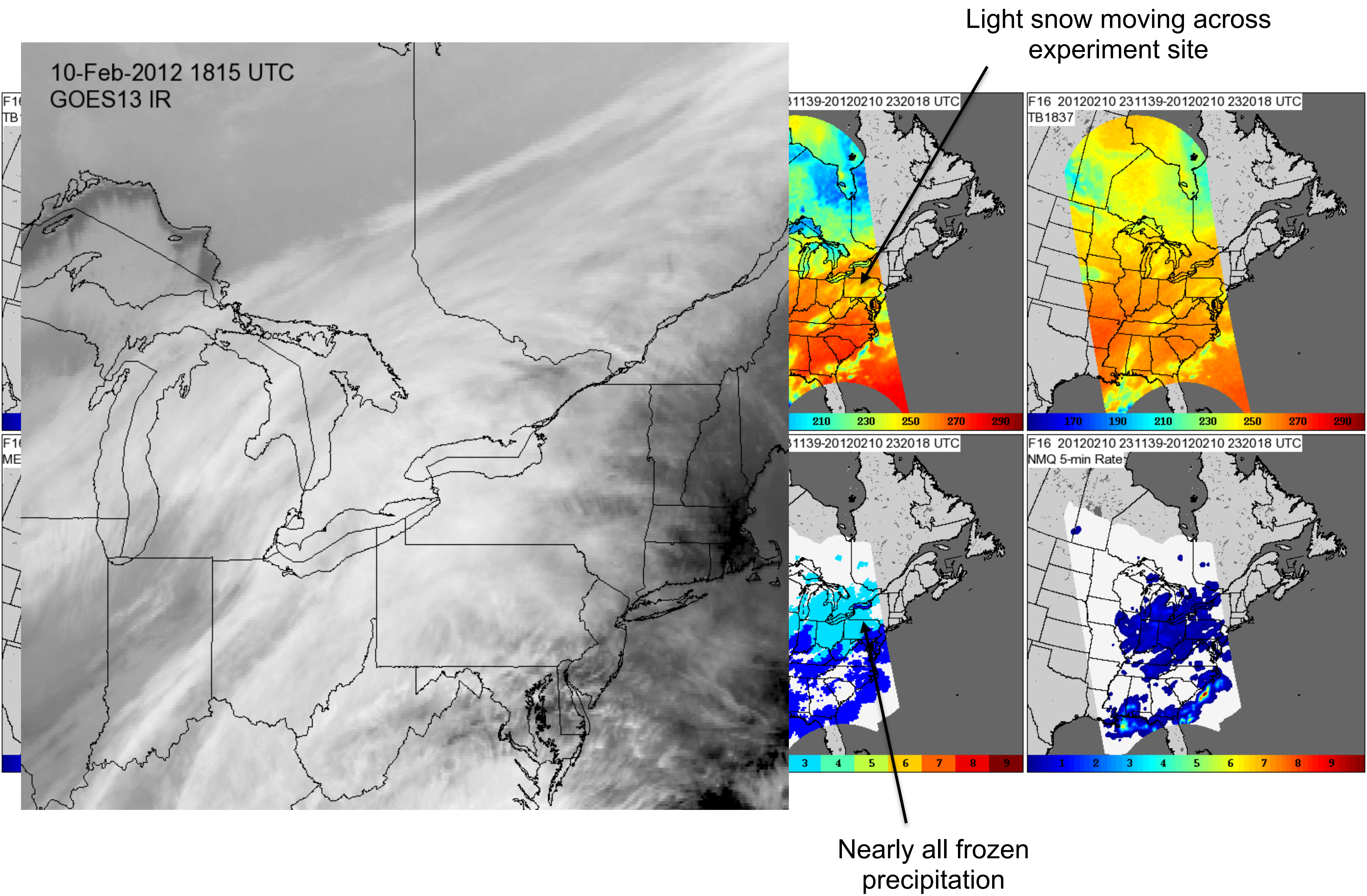
Relatively weak snow signatures
at 150 GHz



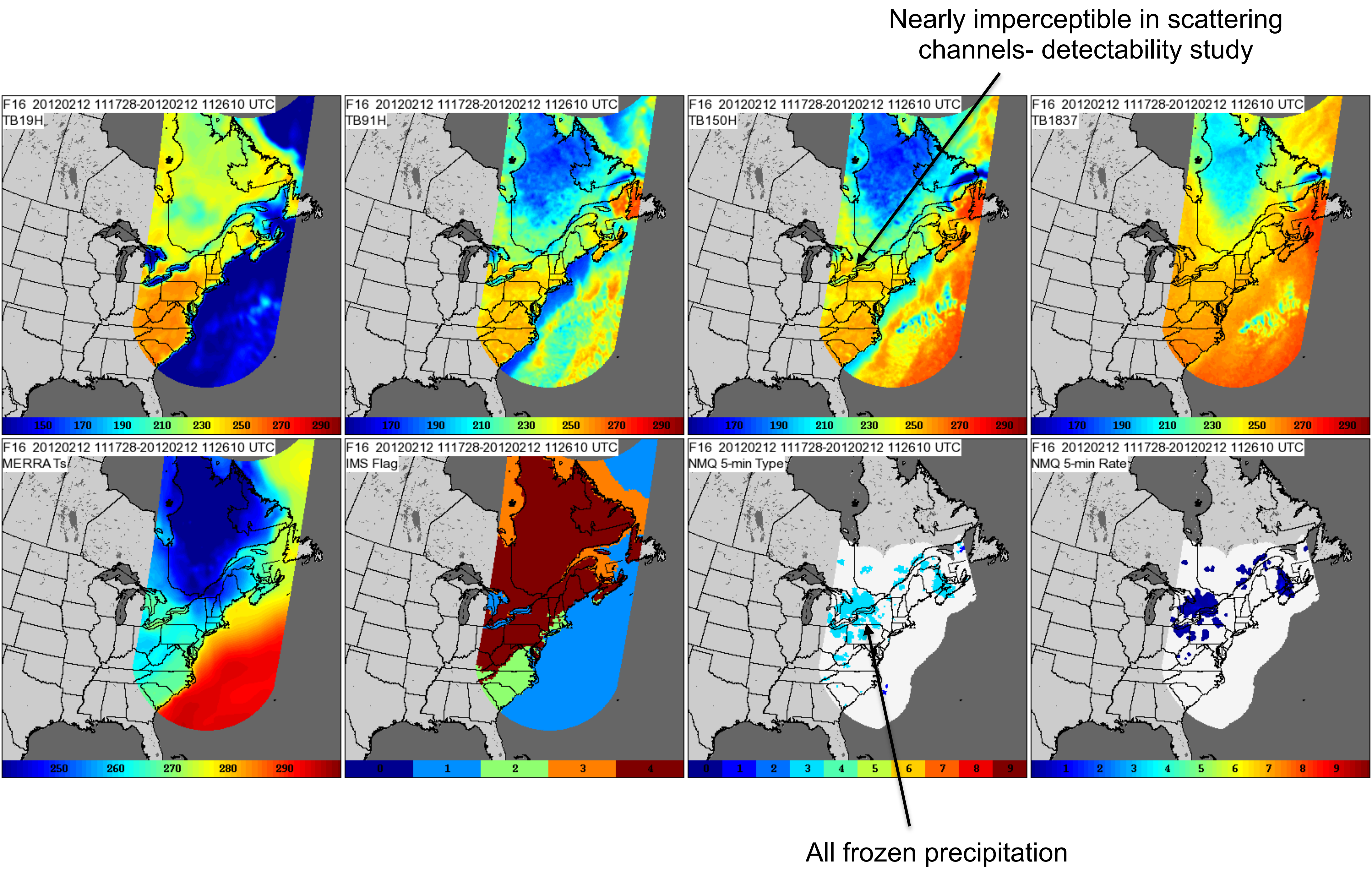
All snowcovered

Variable snow-rain
mixture

GCPEx Case Studies: 10 February 2012 2248 UTC SSMIS F16
Eastern US light snow falling along the snowcover boundary

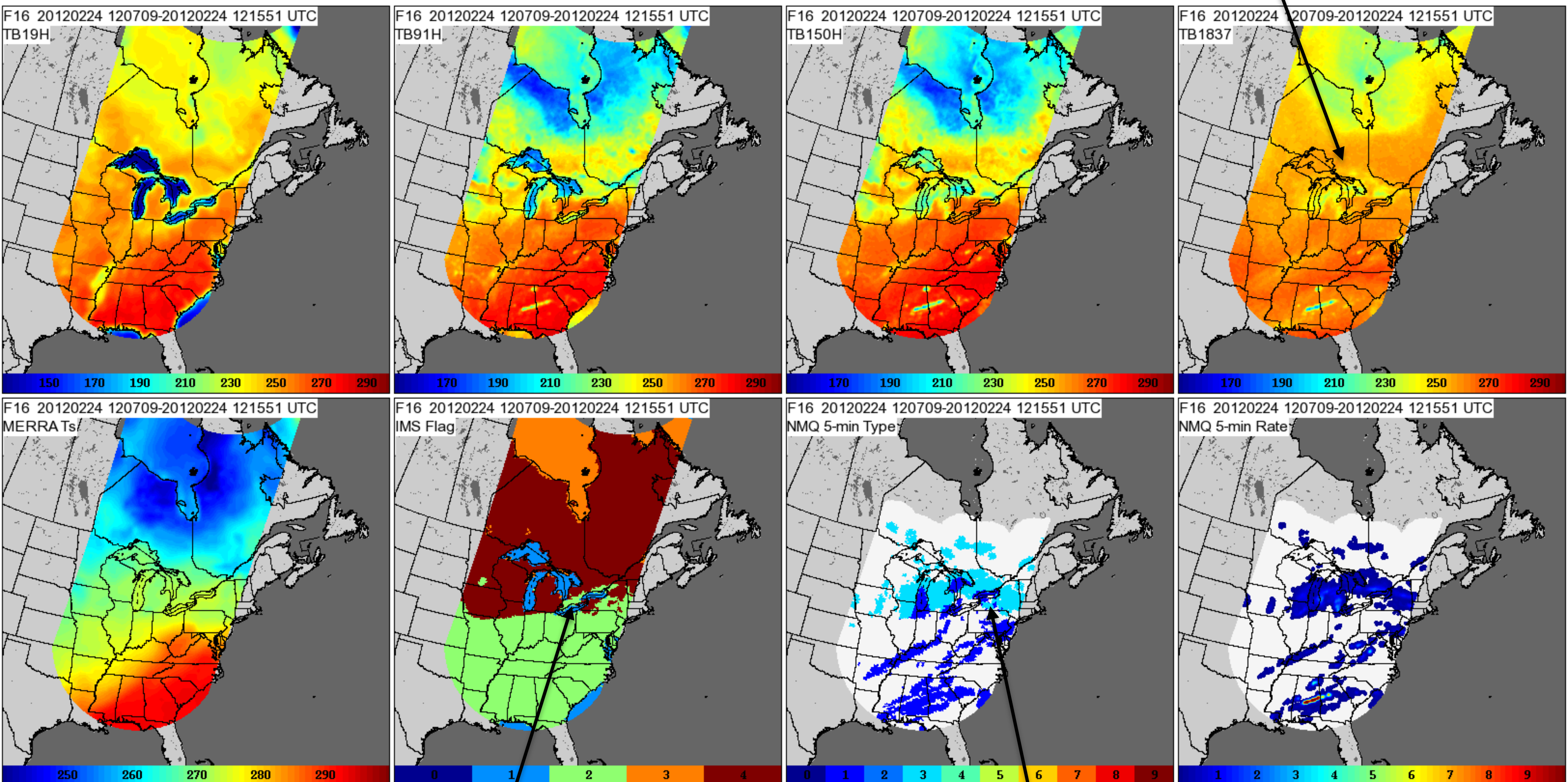


GCPEx Case Studies: 12 February 2012 1121 UTC   SSMIS F16
One of the 25 King radar "event" cases from Paul Joe's presentation on Tuesday



GCPEx Case Studies: 24 February 2012 1211 UTC   SSMIS F16
Case from Gail's presentation on Tuesday

More notable in 183/7 compared to
Jan 28 case - detectability study



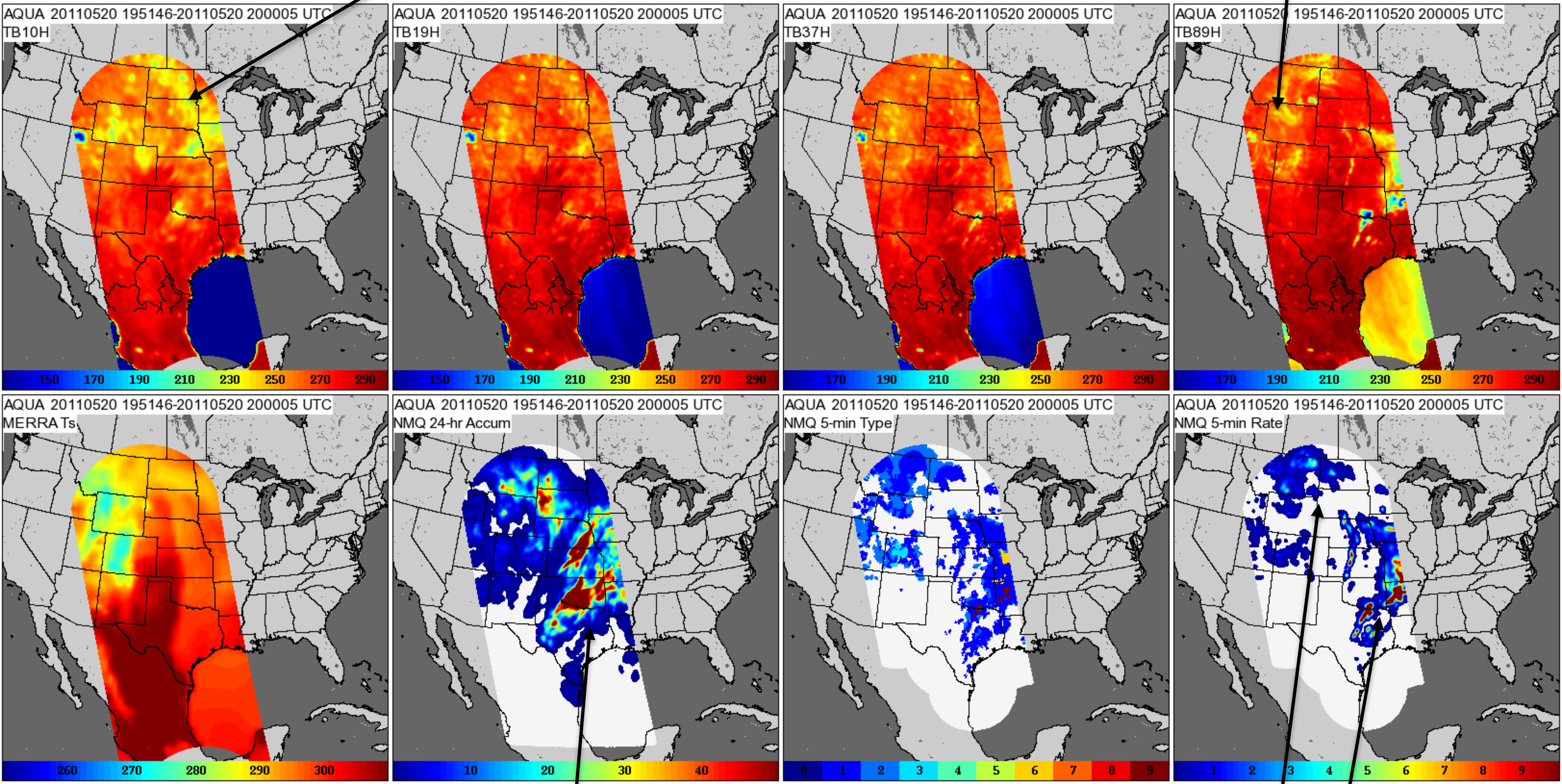
Snowcover, no snow, open Lake Erie

Snow-rain mix

MC3E Case Studies: 20 May 2011 1955 UTC Aqua AMSR-E
Case from Walt Peterson's presentation on Tuesday

Reduced emissivity land surfaces

Relatively weak TB signatures in 89 GHz over wet surfaces



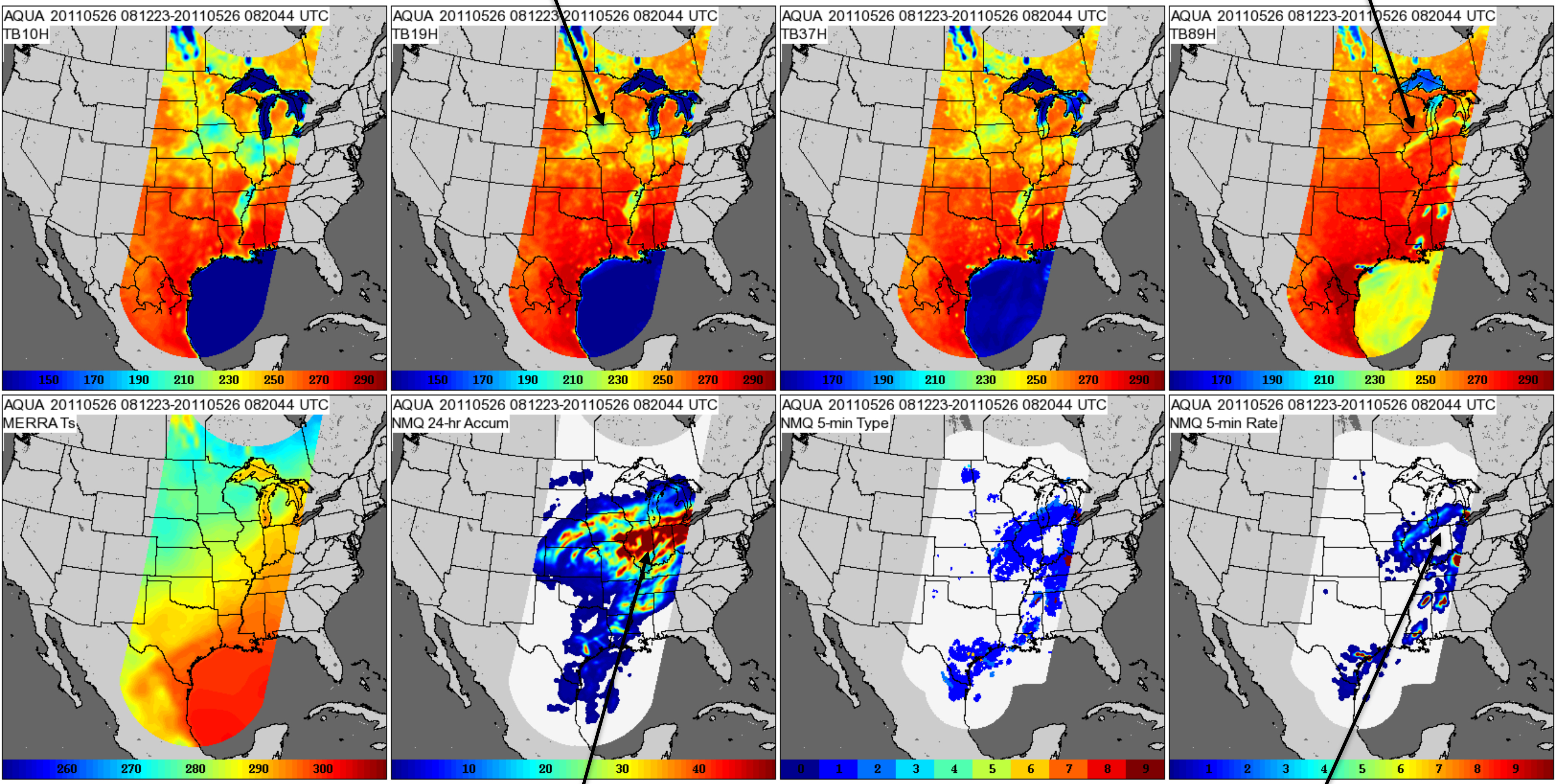
Ample rainfall during the 24-hrs prior to this overpass

Light and heavy precipitation in different regions

MC3E Case Studies: 26 May 2011 0812 UTC   Aqua AMSR-E
Some embedded convection, over wet land surfaces

Reduced emissivity land surfaces

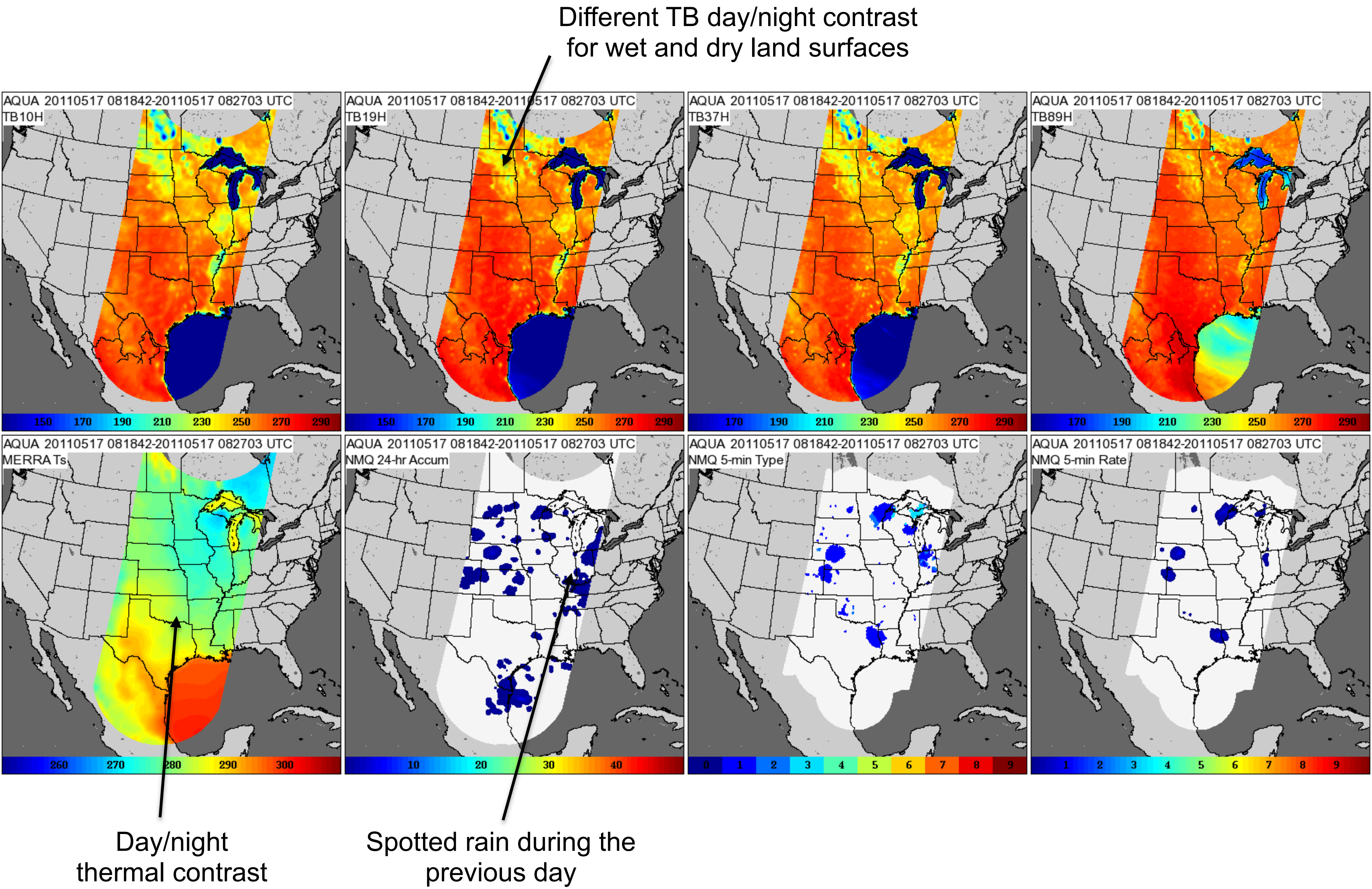
Relatively weak TB signatures in 89 GHz



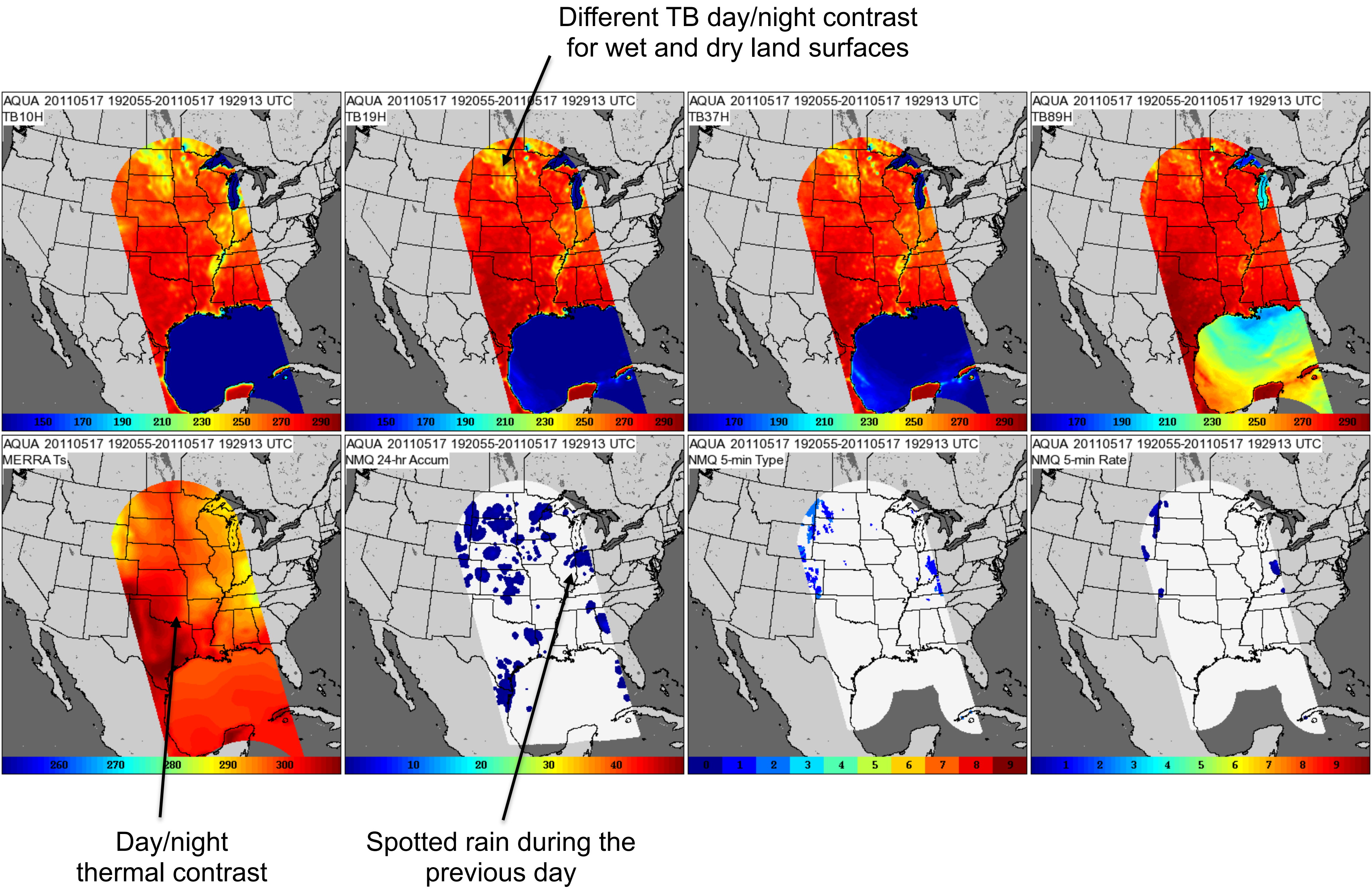
Ample rainfall during the 24-hrs prior to this overpass

Precipitation over wet surfaces and lakes

MC3E Case Studies: 17 May 2011 0818 UTC   Aqua AMSR-E
Night time, mostly clear skies



MC3E Case Studies: 17 May 2011 1929 UTC   Aqua AMSR-E
Day time 12 hours later, still mostly clear skies



Follow-on to the “point based” LSWG emissivity study (Ferraro et.al., 2013)

Compare simulated and observed TB scenes over clear regions (or precipitating regions, if possible)

Compare with surface state during this time, to relate poor algorithm performance or caveats to surface characteristics (snowcover, previous rain, day/night land temp differences, vegetation type/change, etc.)

PMM microphysics group have prepared a similar combined dataset of ground and aircraft observations over MC3E, but need surface details to simulate passive/active observations

Short-term goal is to have some results to show at the next GPM GV meeting in November; longer term publication would result

May provide possible entry into GPM wine cellar…….