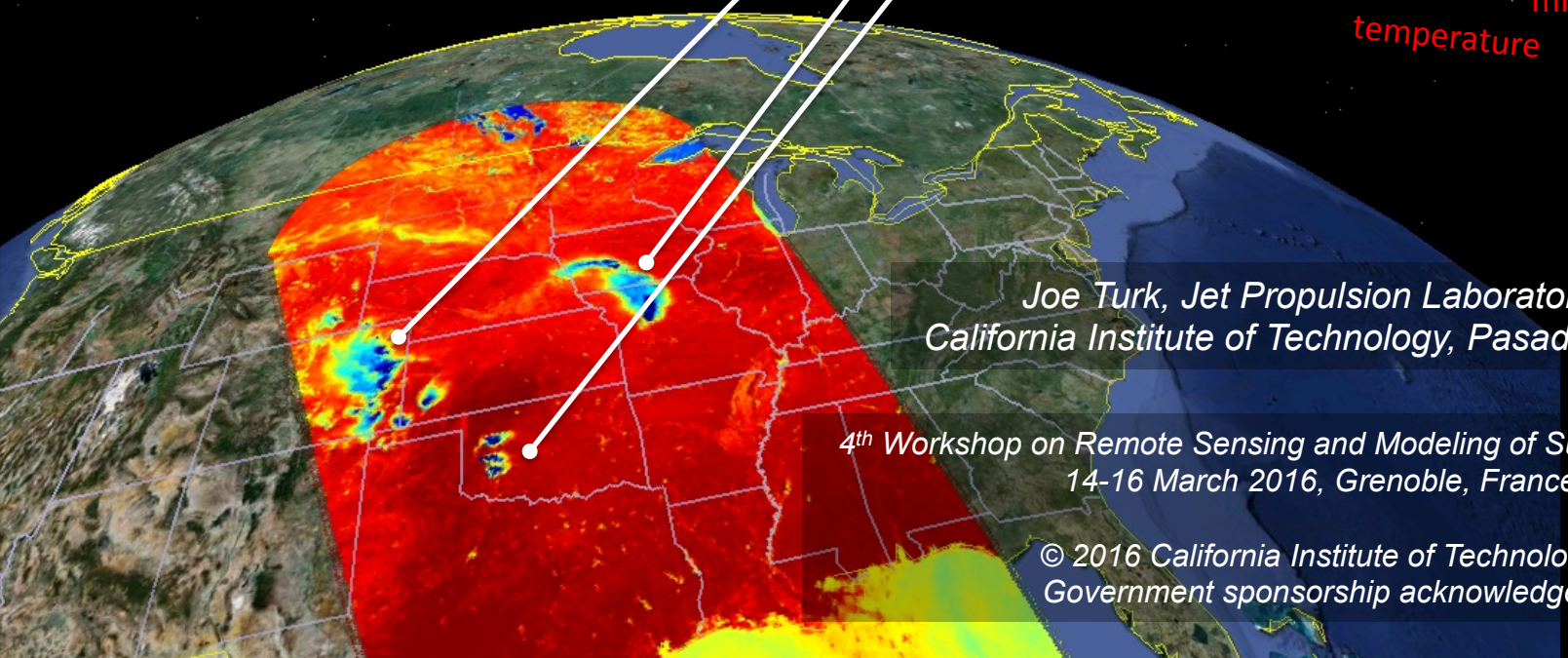
Estimating Non-Raining Surface Parameters to Assist GPM Constellation Radiometer Precipitation Products

≈ a dozen brightness temperatures, not independent

orientation
coast
crystals
deep
cloud
shape
size
graupel
shallow
snow
precipitation
profile
dry
moisture
rain
freezing level
surface
mixed phase
temperature
environment



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California Institute of Technology, Pasadena, CA

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14-16 March 2016, Grenoble, France

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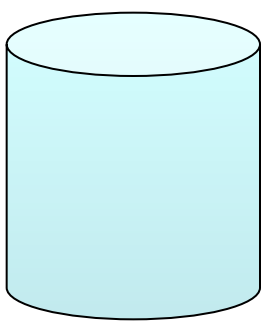
Why is this work needed?

- A-priori databases for current constellation radiometer-based precipitation are empirically generated from (mostly) ground-based radar precipitation observations.

- Future databases are envisioned to be physically generated, in order to apply common physics across all platforms/sensors

- Therefore the emissivity vector needs to be specified for each sensor type

- And some way of "connecting" to the land properties used for creating each database profile, when carrying out the retrieval



$$\bar{T}_B^1, \bar{e}^1, \bar{R}^1$$
$$\bar{T}_B^2, \bar{e}^2, \bar{R}^2$$
$$\ldots\ldots$$
$$\bar{T}_B^N, \bar{e}^N, \bar{R}^N$$

$$\longleftrightarrow \quad \bar{T}_B^{obs}$$

A-priori ***Observations***

"connect" surface and environmental conditions at the time of the retrieval, to corresponding conditions within the database

Current GPM-GPROF does this thru a "classification index"

Outline

- Summary of 2015 updated TMI physical emissivity modeling and 1998-2014 daily gridded dataset

- Adaptation of observationally-based emissivity specification from Turk et. al. 2014 approach, using current 14 months of GMI/DPR

- Variability in the (non-raining) joint Ku-band radar backscatter cross section and emissivity, as a function of previous rainfall accumulations (“wet surface” effect)

Contributions from P. Kirstetter, L. Li, Z. Haddad, J. Munchak, S. Durden, S. Ringerud, Y. Tian, and the PMM Land Surface Working Group

Matched GMI/DPR Data

Much of the time it is not raining, and the emissivity can be studied from the non-rain observations.

Use DPR NS, MS and HS scans to globally collect “no-cloud” GMI scenes, relative to the sensitivity at Ku/Ka-band (…not a cloud radar….)

Modifications to Turk et al. 2014 approach:

1) S1 (10-89 GHz) channel emissivities are retrieved from these observations, and the emissivity principal components are estimated by *nonlinear* TB combinations (one-time process).

2) Discriminant analysis to best separate PC’s of the “no-cloud” and “cloudy” scenes (one-time process)

3) For subsequent observations, the emissivity vector reconstruction is simply two matrix multiplications (and a third for the discriminant)

Historical Context: Grody's 1991 Scattering Index (SI)

Uses the 22V SSMI observations to estimate the non-scattering contribution to the 85V observations

$$SI = F - TB_{85V}$$

$$F = a_0 + a_1 TB_{19V} + a_2 TB_{22V} + a_3 TB_{22V}^2$$

$$SI > 10 \quad \rightarrow scattering\ materials$$

Various multispectral tests for discriminating snow, ice, desert, precipitation

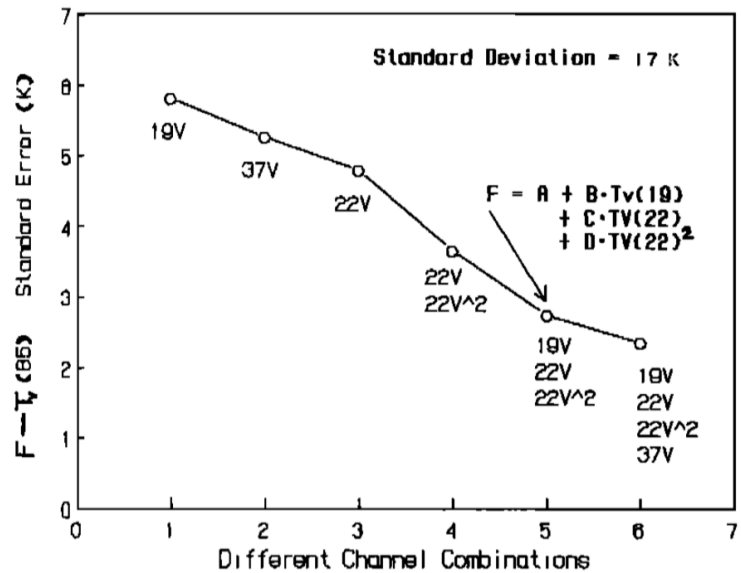


Fig. 3. Standard error of the estimated 85-GHz vertically polarized measurement, F, as derived using different combinations of the lower-frequency SSMI channels. The plot shows the errors relative to the actual measurements, $F - T_v(85)$, for different channel combinations. Results are based on a global data set of nonscattering materials over land and ocean.

Grody, N.C. (1991), Classification of snow cover and precipitation using the Special Sensor Microwave Imager. J. Geophys. Res., *96*, 7423-7435.

Today: Matched GMI/DPR Data

DPR Ku/Ka-band radar available to collect globally spectral signatures of the “no-cloud” GMI scenes, relative to the low-end sensitivity at Ka-band (….not a cloud radar….)

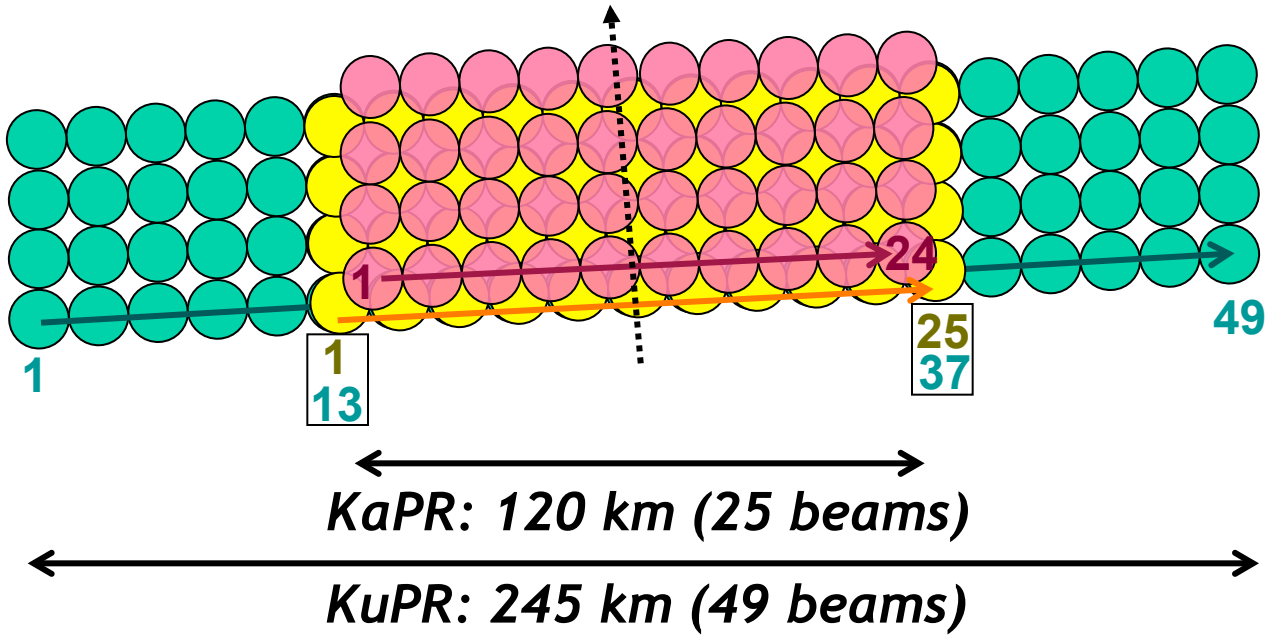
From these scenes, modern-era model analyses (….with their own characteristics....) available to estimate emissivities at GMI channel centers

Emissivities are known to be correlated, and related in a non-linear way to the underlying surface properties

Concept of the DPR antenna scan

Courtesy T. Iguchi, NICT

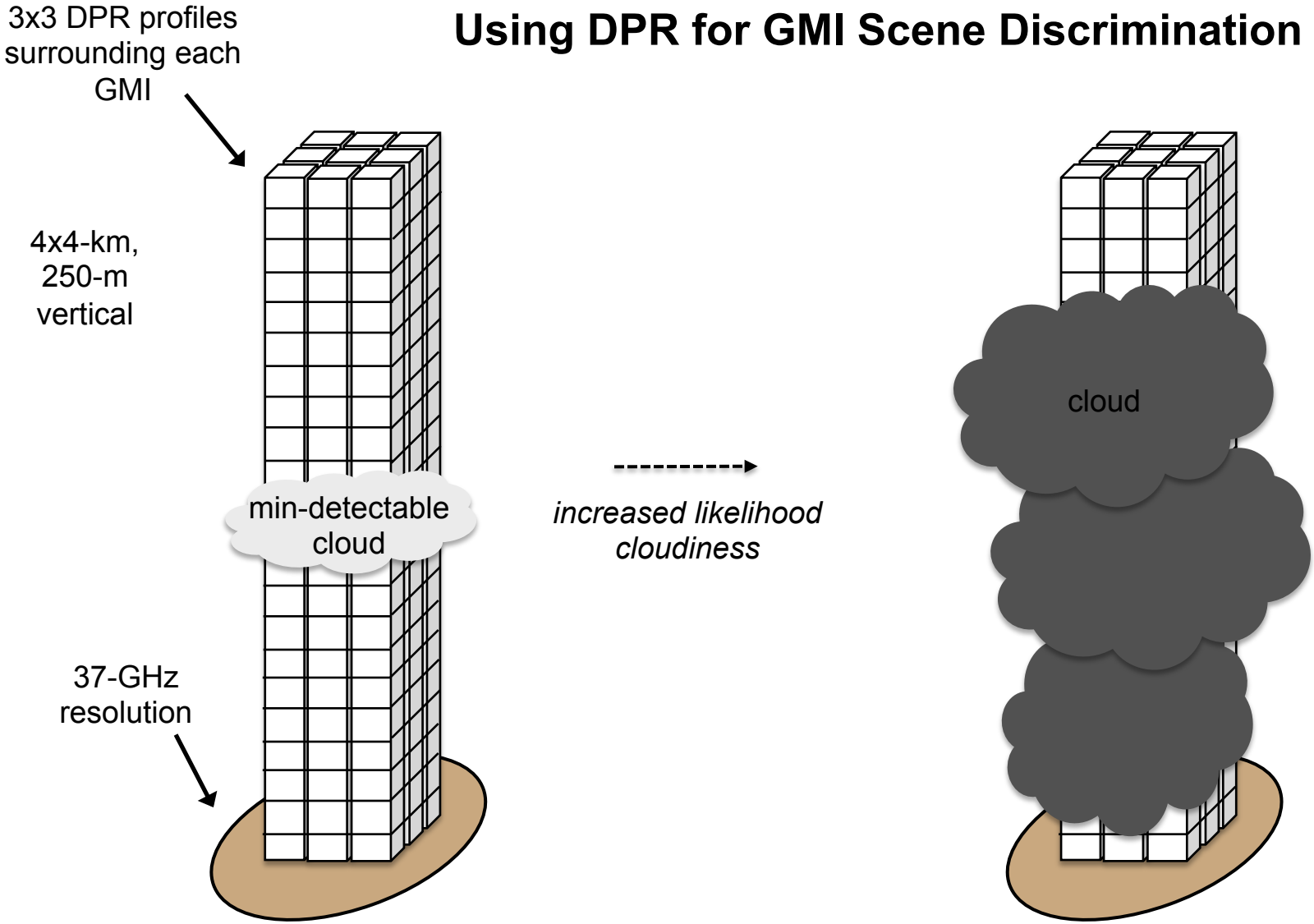
- *Ku-PR footprint (Normal scan, NS)* : *Δz = 250 m*
- *Ka-PR footprint (Matched-scan with Ku, MS)* : *Δz = 250 m*
- *Ka-PR footprint (High-sensitivity beam, HS)* : *Δz = **500 m***



In the interlacing scan area (●), the KaPR can measure snow and light rain in a high-sensitivity mode with a double pulse width.

The synchronized matched beam (●) is necessary for the dual-frequency algorithm.

Using DPR for GMI Scene Discrimination

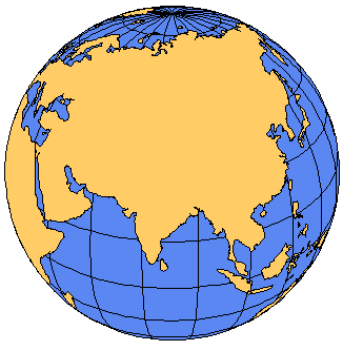


Z(Ku) < 15 dB and
Z(Ka) < 15 dB and
Z(Ka-HS) < 15 dB
(all bins) ➔ "no cloud"

N bins where Z(Ku) > 20 dB as a proxy for increased level of cloudiness and precipitation
N > 20 ➔ "low probability"
N > 50 ➔ "medium probability"
N > 100 ➔ "high probability"

Analysis Matched GMI/DPR Data

Extensive, diverse collection from 1+ year of DPR "no-cloud" emissivity vectors everywhere within ±65 degree latitude, without regard to the surface type



$$\begin{bmatrix} TB_{10V} \\ TB_{10H} \\ \dots \\ TB_{89H} \\ TB_{166V} \\ TB_{166H} \end{bmatrix} \begin{bmatrix} e_{10V} \\ e_{10H} \\ \dots \\ e_{89H} \\ T_{sfc} \\ TWV \end{bmatrix}$$

Principal component analysis :

$$\vec{u} = \left[E \right]^T \vec{e}$$

$$\left[\Lambda \right] = \left[E \right]^{-1} \left[S_x \right] \left[E \right]$$

$$\vec{e} \equiv \left[E \right] \vec{u}$$

$$\vec{e} \cong \left[E \right] \hat{u}$$

If there was some way to estimate each principal component from the observations, then the emissivity vector could be *approximately* reconstructed from the TB observations

Assume nonlinear TB combinations and polarization ratios "carry" the information on the surface properties

$$u_i = a_0 + \sum_{j=1}^{N} a_j TB_j + \sum_{j=1}^{N} \sum_{k=j}^{N} b_{jk} TB_j TB_k + \sum_{j=1}^{3} c_j PR_j \qquad i = 1,9$$

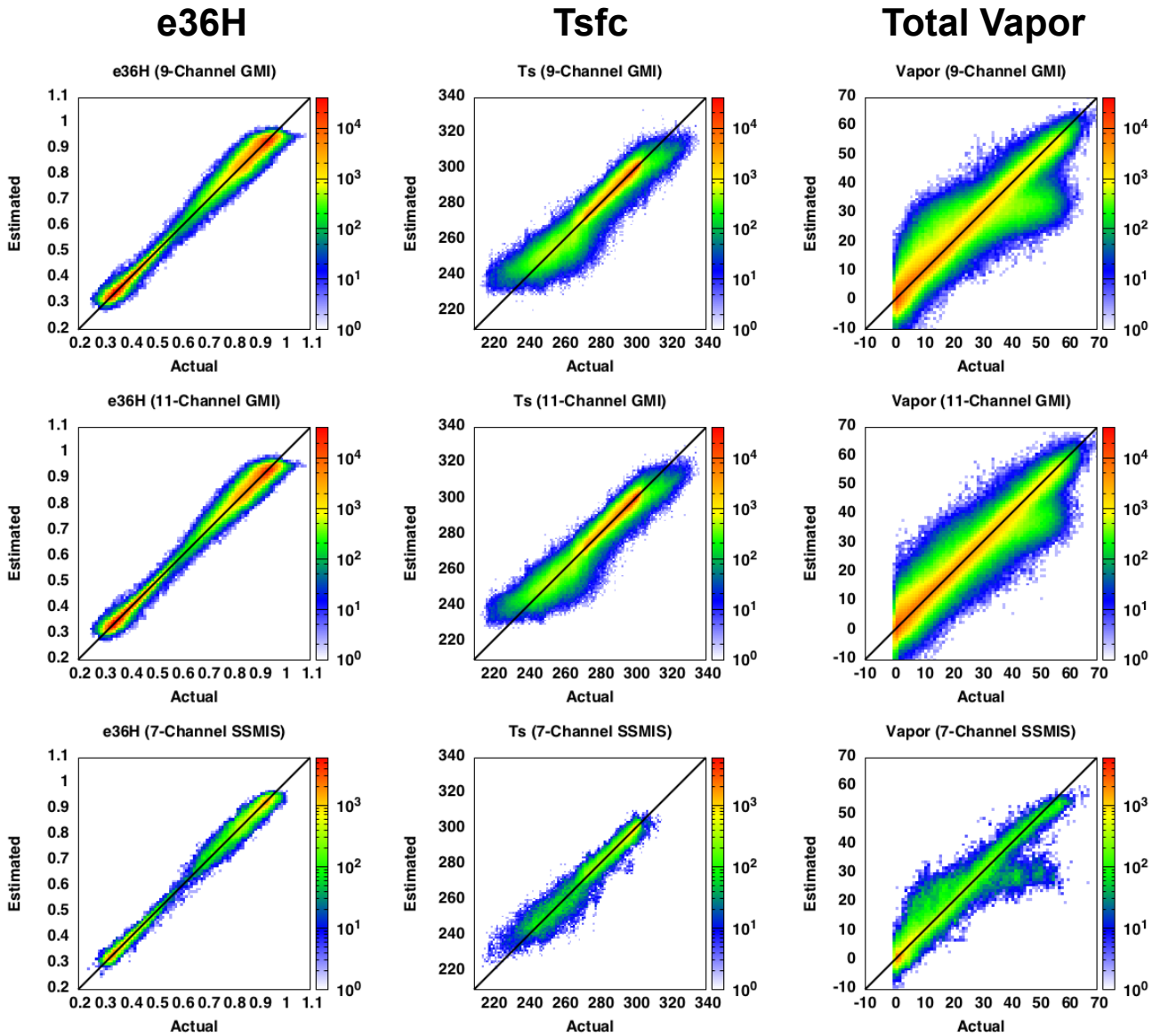
$$PR_j = (TB_j^V - TB_j^H) / (TB_j^V + TB_j^H) \quad j = 1,3$$

TB-Reconstructed Emissivity State Vector

N=9 (10-89 GHz)
High water vapor over land underestimated

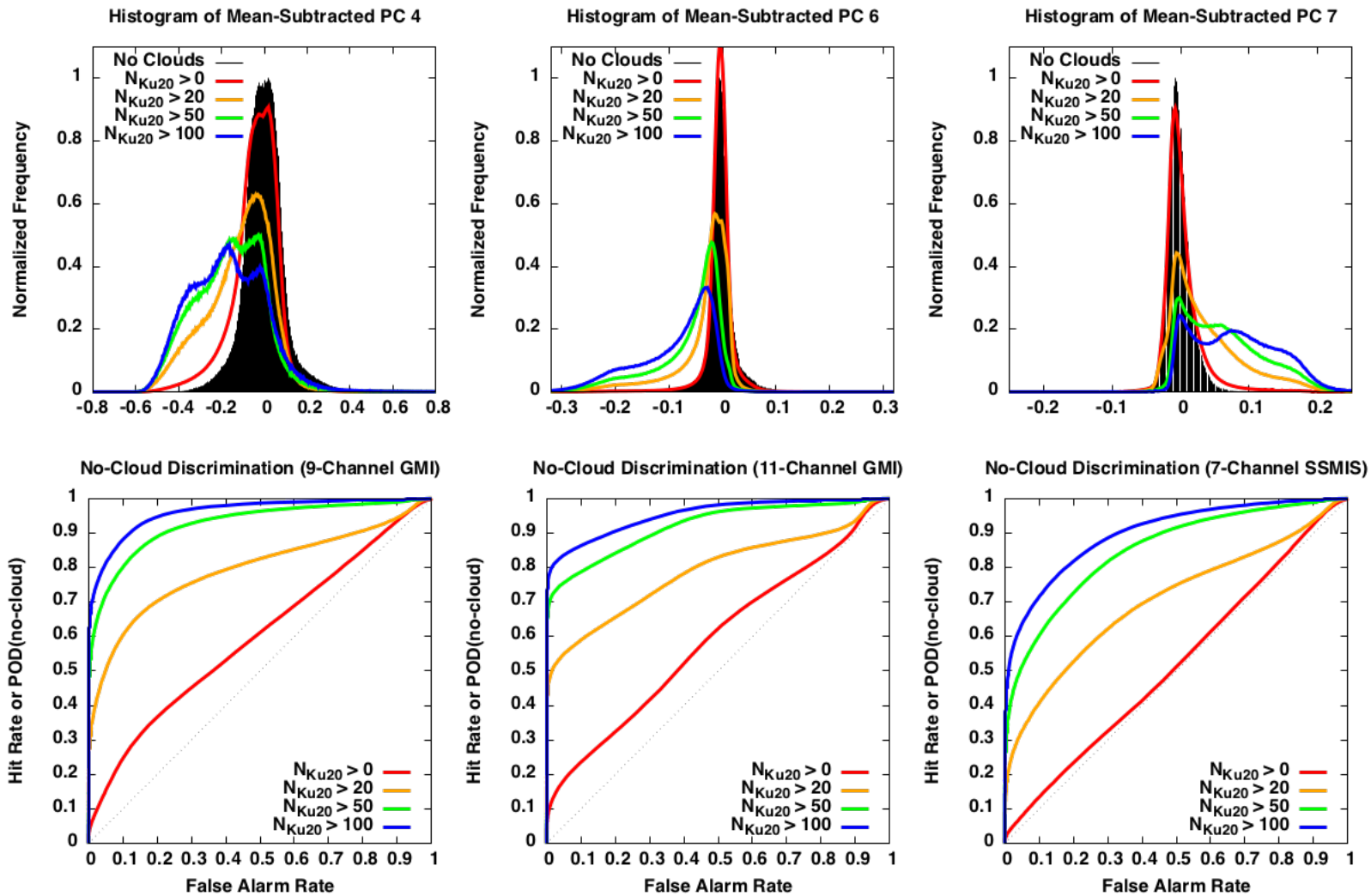
N=11 (10-166 GHz)
Improvement in over-land total vapor with inclusion of 166 GHz channels

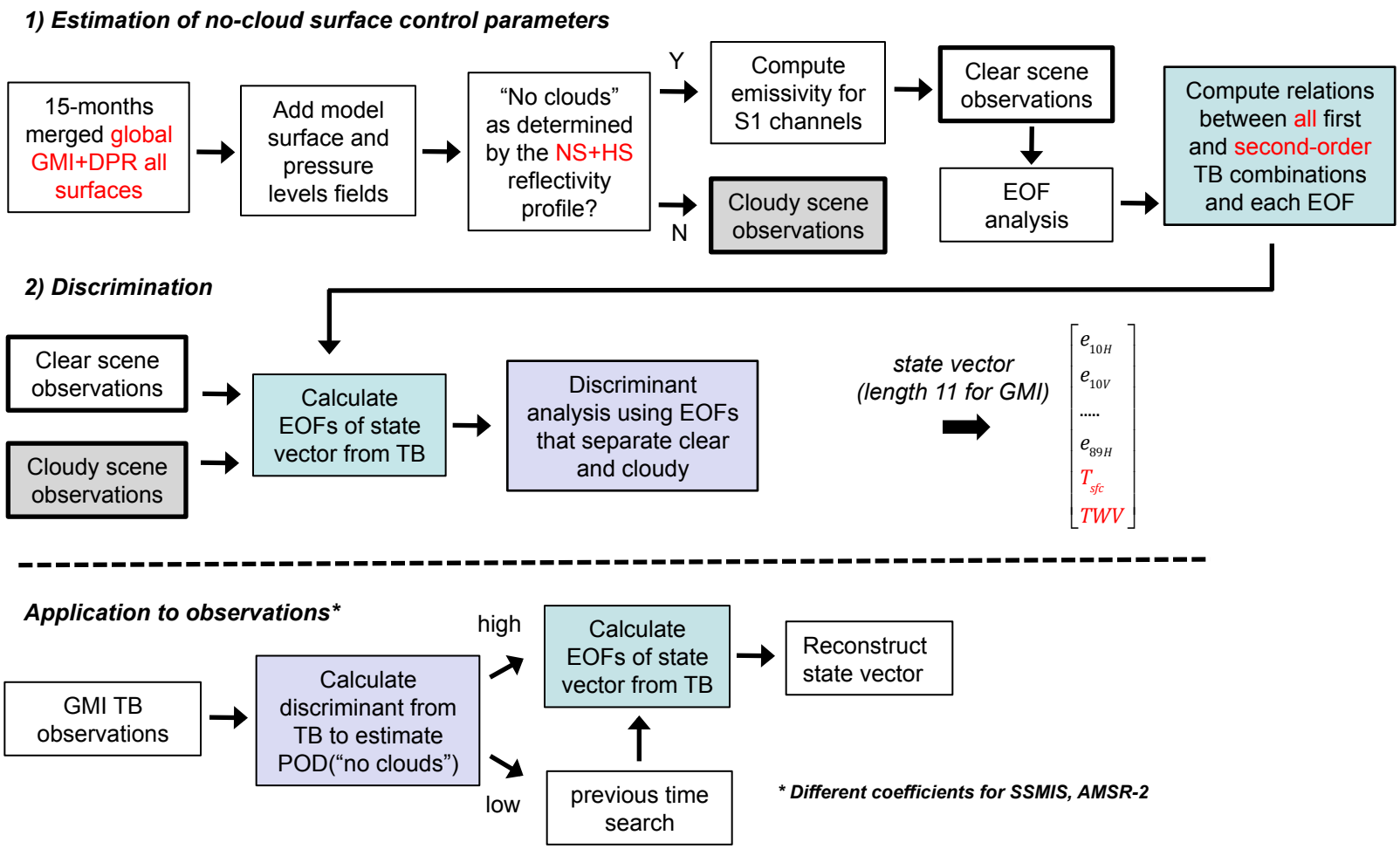
N=7 (19-85 GHz SSMIS)
SSMIS (no 10 GHz) dataset from 1-year of F17-GPM 15-min coincidences

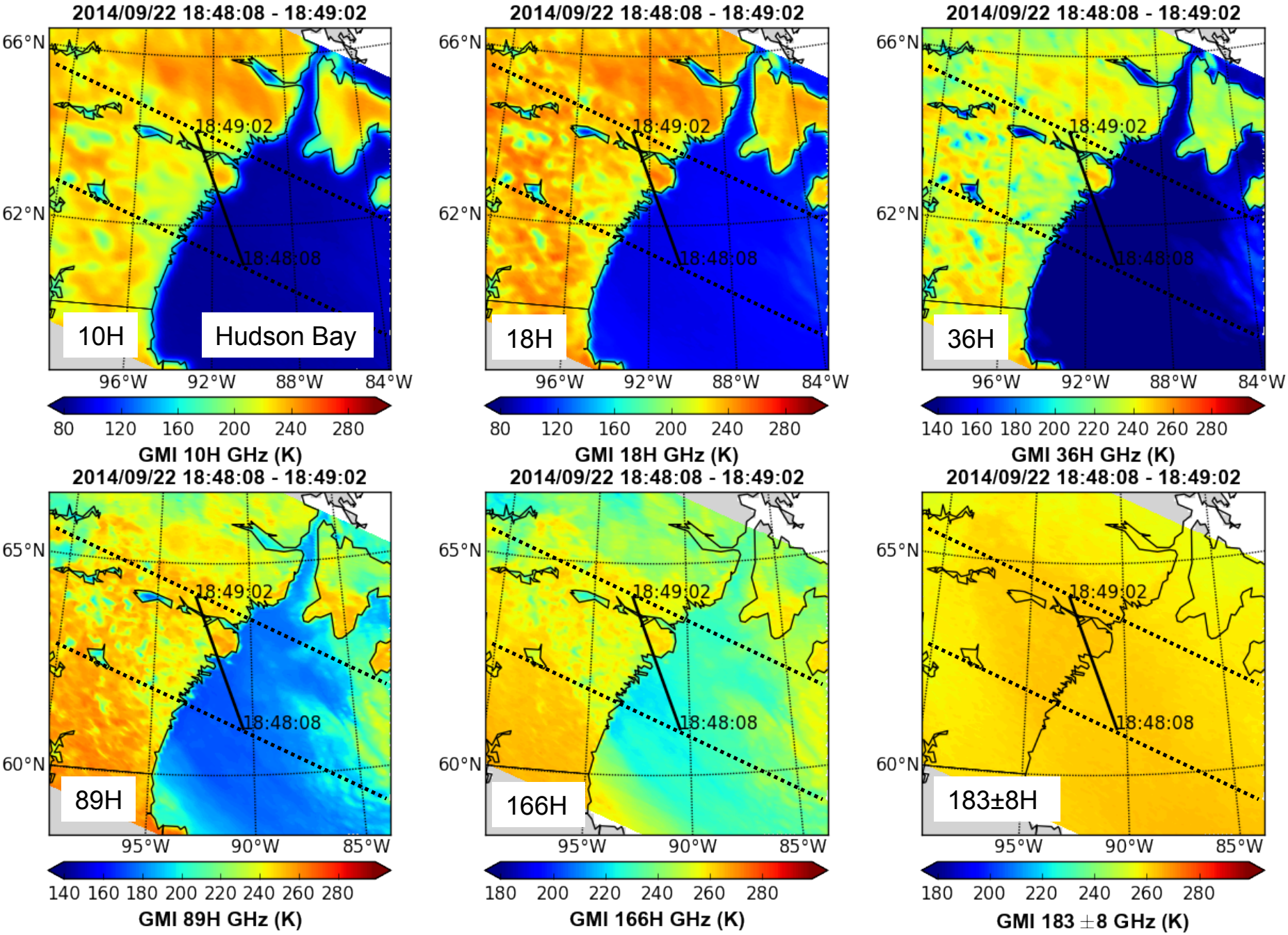


Discrimination Performance
N(Ku) > 20 dB in column
N>0 N>20 N>50 N>100

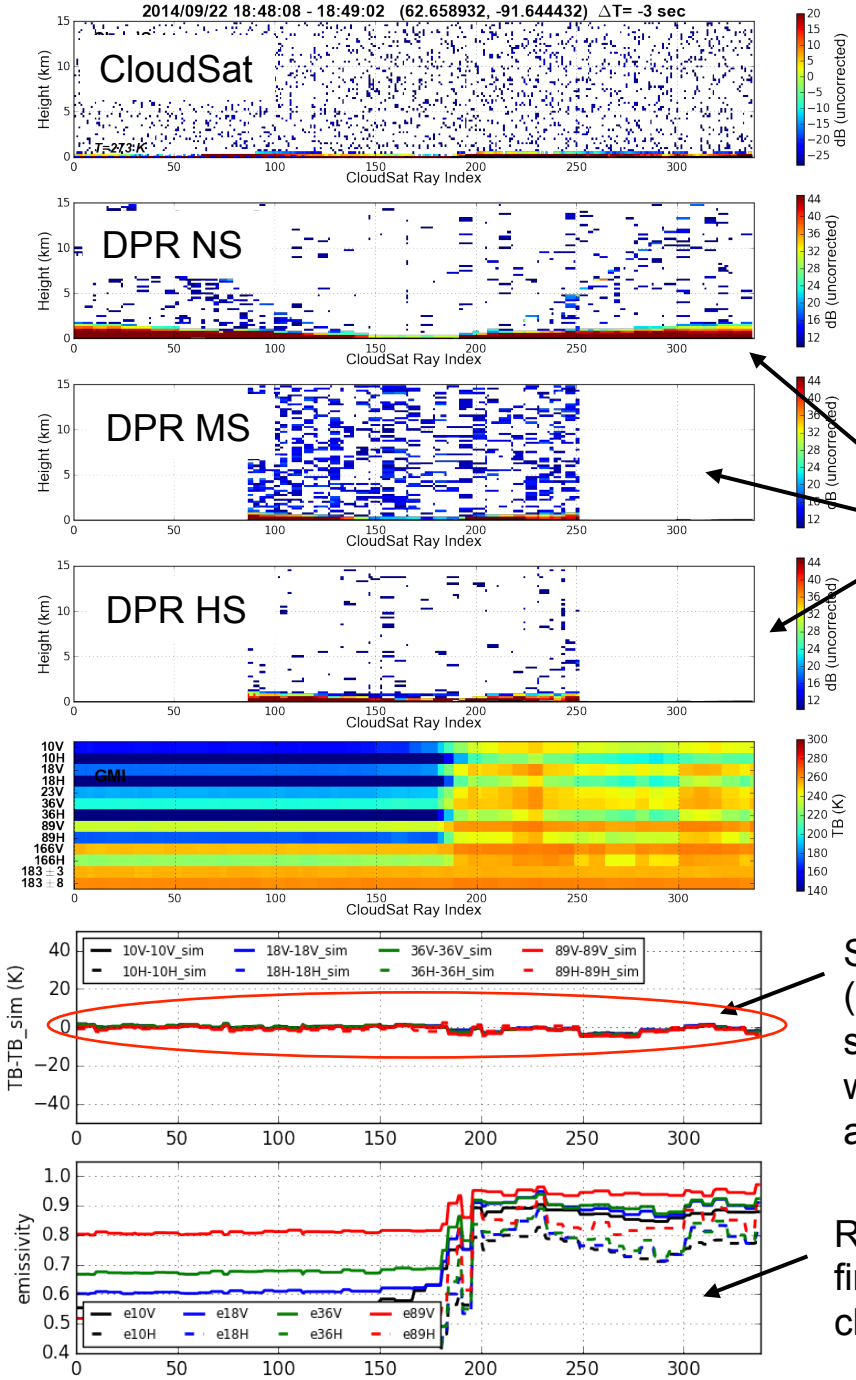
3 PC-based discriminant, using 9-channels in the regression, is a good compromise, also since S2 (166, 183 GHz) channels not always available




1) Estimation of no-cloud surface control parameters
15-months merged global GMI+DPR all surfaces
Add model surface and pressure levels fields
"No clouds" as determined by the NS+HS reflectivity profile?
Y
N
Compute emissivity for S1 channels
Cloudy scene observations
Clear scene observations
EOF analysis
Compute relations between all first and second-order TB combinations and each EOF
2) Discrimination
Clear scene observations
Cloudy scene observations
Calculate EOFs of state vector from TB
Discriminant analysis using EOFs that separate clear and cloudy
state vector (length 11 for GMI)
e_{10H}
e_{10V}
.....
e_{89H}
T_{sfc}
TWV
Application to observations*
GMI TB observations
Calculate discriminant from TB to estimate POD("no clouds")
high
low
Calculate EOFs of state vector from TB
previous time search
Reconstruct state vector
* Different coefficients for SSMIS, AMSR-2


2014/09/22 18:48:08 - 18:49:02
66°N
62°N
18:49:02
18:48:08
10H
Hudson Bay
96°W
92°W
88°W
84°W
80 120 160 200 240 280
GMI 10H GHz (K)
2014/09/22 18:48:08 - 18:49:02
18H
80 120 160 200 240 280
GMI 18H GHz (K)
2014/09/22 18:48:08 - 18:49:02
36H
140 160 180 200 220 240 260 280
GMI 36H GHz (K)
2014/09/22 18:48:08 - 18:49:02
65°N
60°N
89H
95°W
90°W
85°W
140 160 180 200 220 240 260 280
GMI 89H GHz (K)
2014/09/22 18:48:08 - 18:49:02
166H
180 200 220 240 260 280
GMI 166H GHz (K)
2014/09/22 18:48:08 - 18:49:02
183±8H
180 200 220 240 260 280
GMI 183 ±8 GHz (K)

22 September 2014
Hudson Bay Land-Water

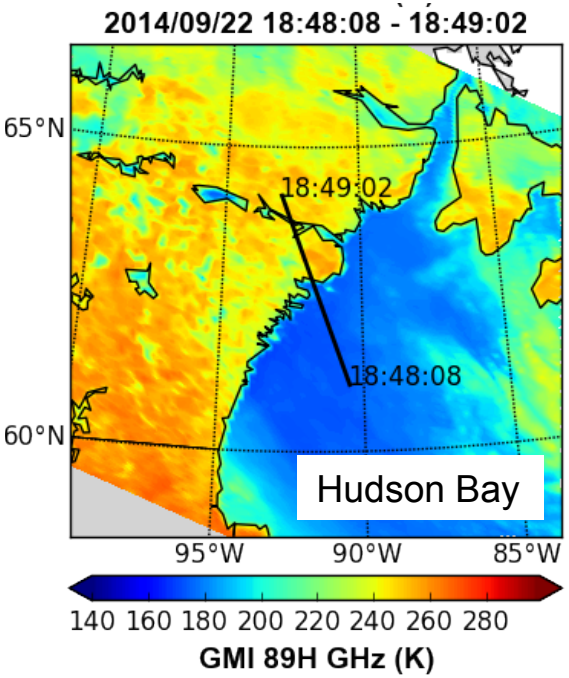


No clouds evident in all three DPR scans

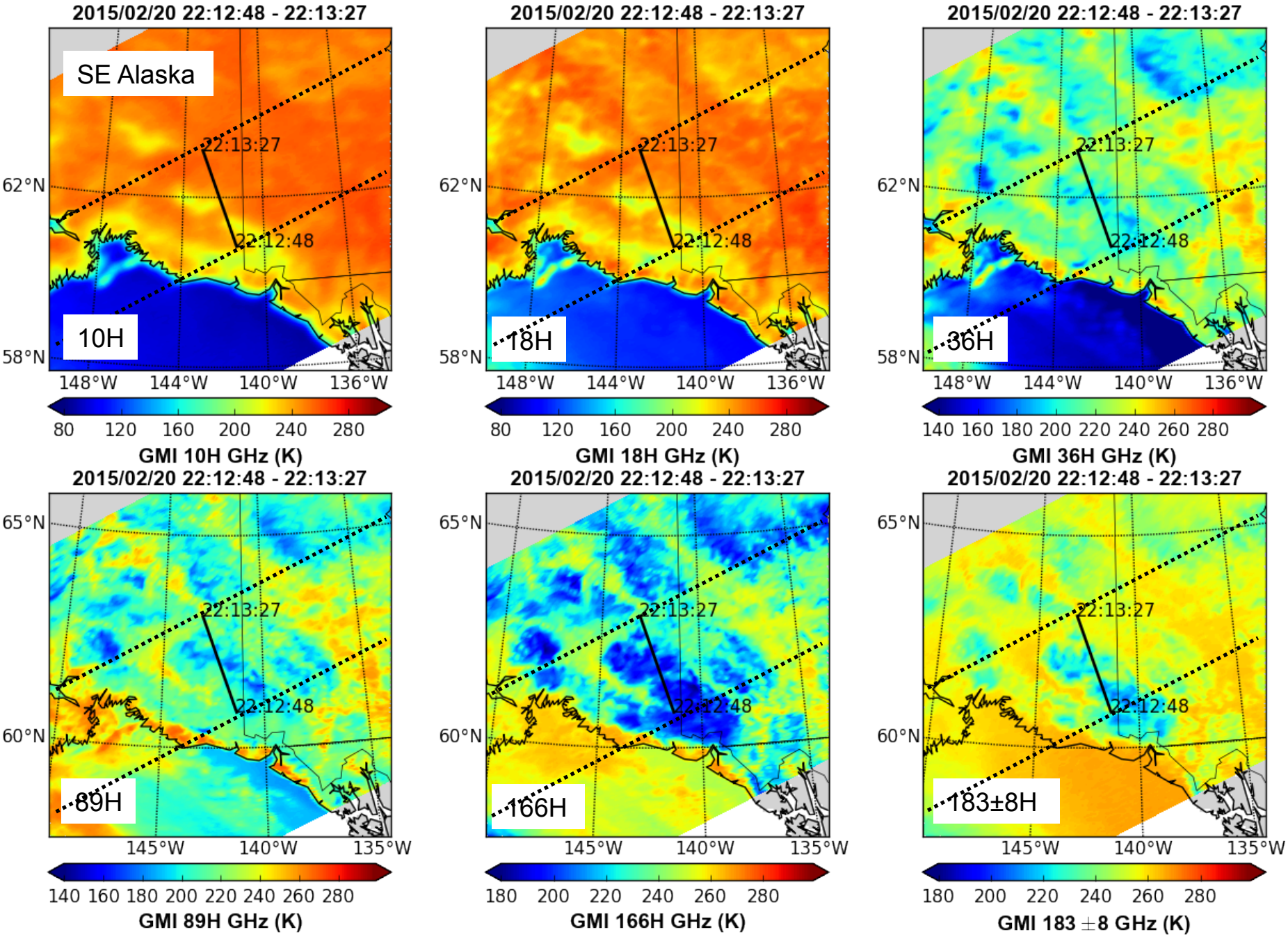
Trace of all 13 GMI channels

Simulated TB difference (using ECMWF) Near seamless land-coast-water transition across all 9 GMI (S1) channels

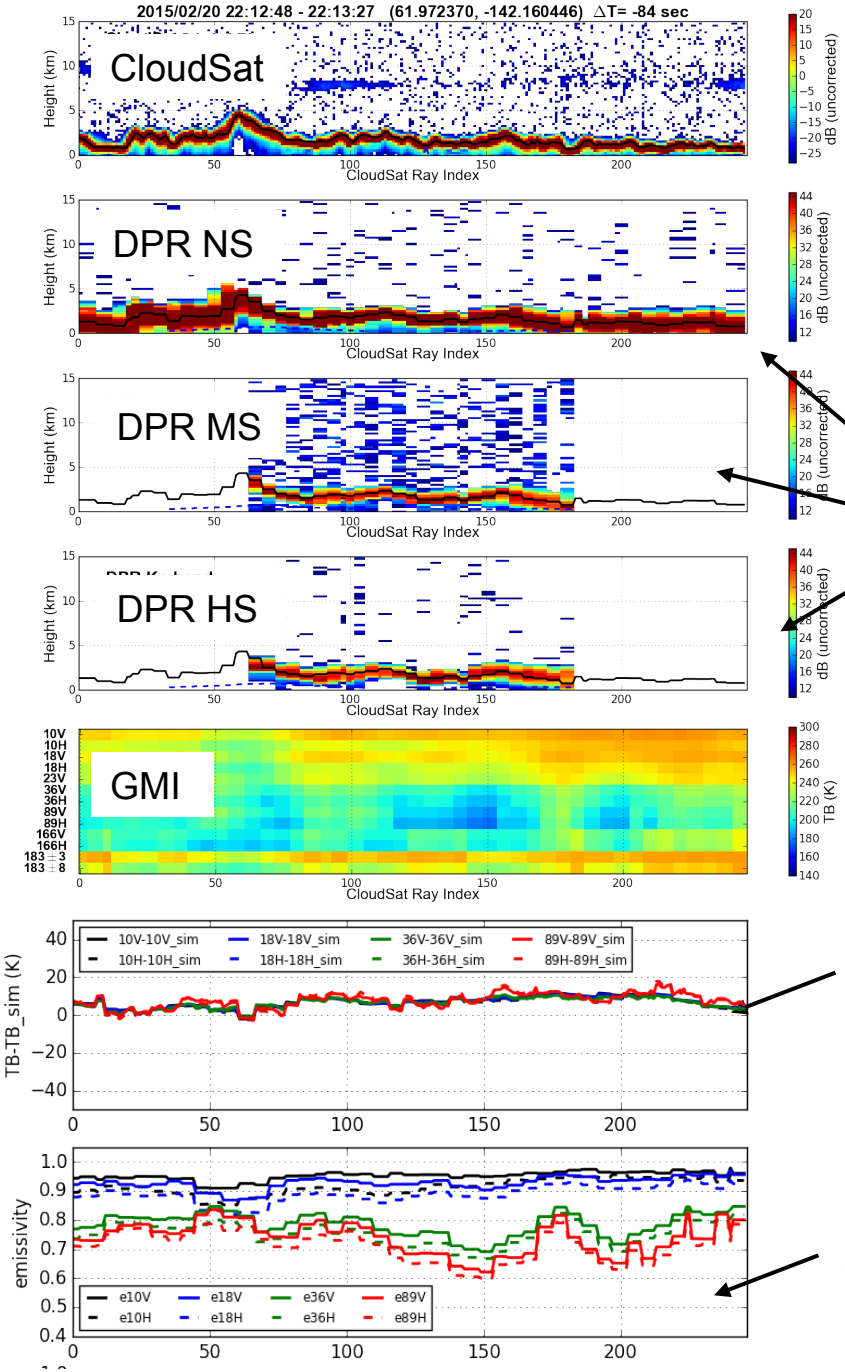
Resultant emissivity at first 9 GMI (S1) channels



With this method, the emissivity vector is estimated directly from the TBs (nothing else needed), along with a probabilistic confidence measure


2015/02/20 22:12:48 - 22:13:27
SE Alaska
22:13:27
22:12:48
10H
62°N
58°N
148°W
144°W
140°W
136°W
80 120 160 200 240 280
GMI 10H GHz (K)
2015/02/20 22:12:48 - 22:13:27
22:13:27
22:12:48
18H
62°N
58°N
148°W
144°W
140°W
136°W
80 120 160 200 240 280
GMI 18H GHz (K)
2015/02/20 22:12:48 - 22:13:27
22:13:27
22:12:48
36H
62°N
58°N
148°W
144°W
140°W
136°W
140 160 180 200 220 240 260 280
GMI 36H GHz (K)
2015/02/20 22:12:48 - 22:13:27
22:13:27
22:12:48
89H
65°N
60°N
145°W
140°W
135°W
140 160 180 200 220 240 260 280
GMI 89H GHz (K)
2015/02/20 22:12:48 - 22:13:27
22:13:27
22:12:48
166H
65°N
60°N
145°W
140°W
135°W
180 200 220 240 260 280
GMI 166H GHz (K)
2015/02/20 22:12:48 - 22:13:27
22:13:27
22:12:48
183±8H
65°N
60°N
145°W
140°W
135°W
180 200 220 240 260 280
GMI 183 ±8 GHz (K)

20 February 2015
Alaska winter mountainous terrain

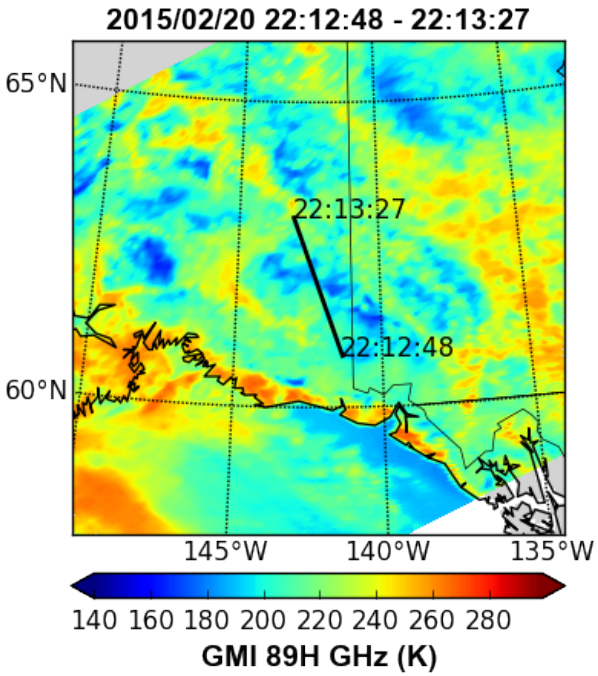


No clouds evident in all three DPR scans

Trace of all 13 GMI channels

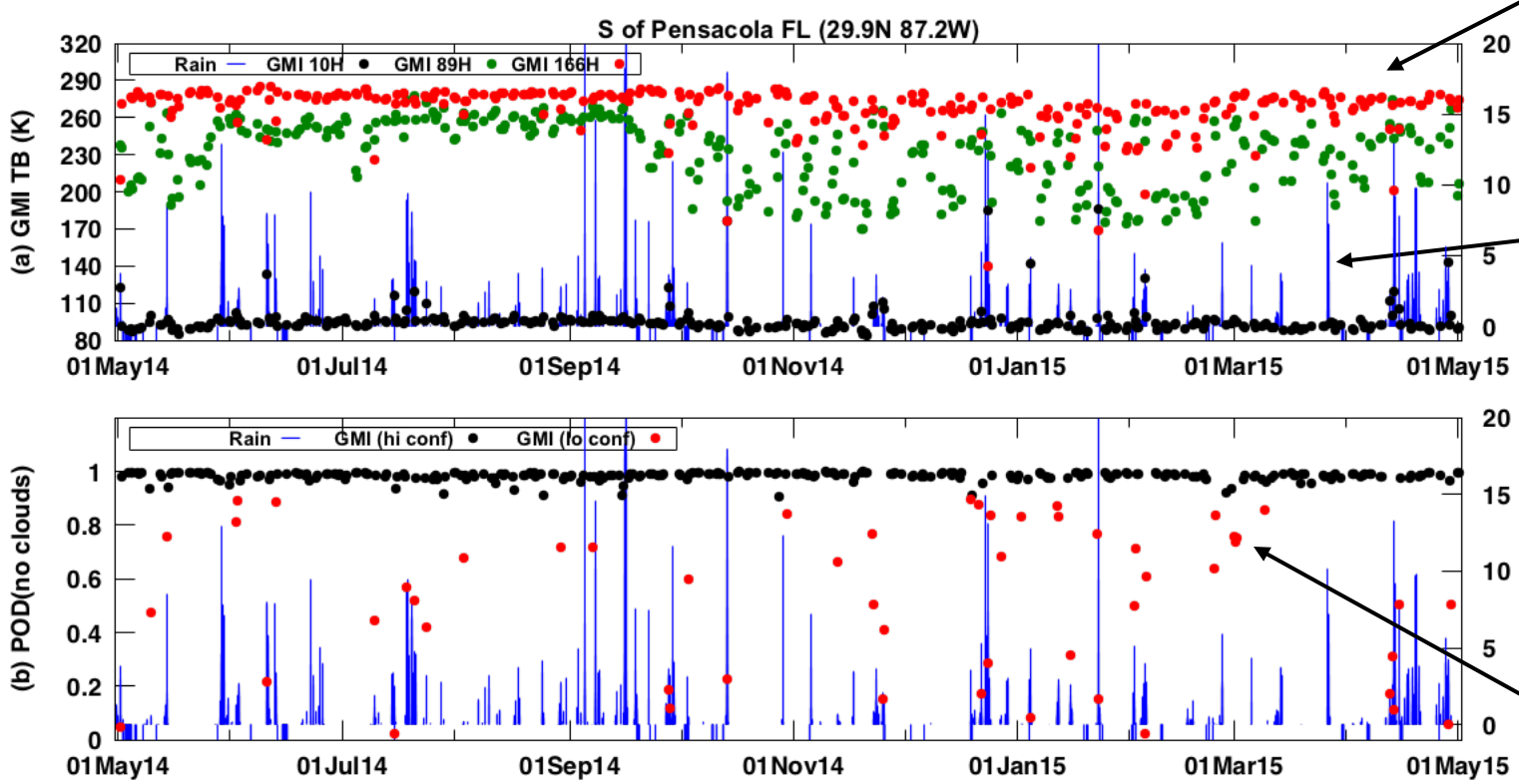
Simulated TB difference (using ECMWF) within 10K across all 9 GMI (S1) channels

Resultant emissivity at first 9 GMI (S1) channels



Extension to 166 GHz being examined for very dry cold scenes

Rain/Emissivity State Timeseries near a point: S of Pensacola, FL



Observations
TB 10H
TB 89H
TB 166H

MRMS
1-hr rain

Discrimination
POD("no-cloud")
90% High
Confidence

< 90%=Reduced
Confidence

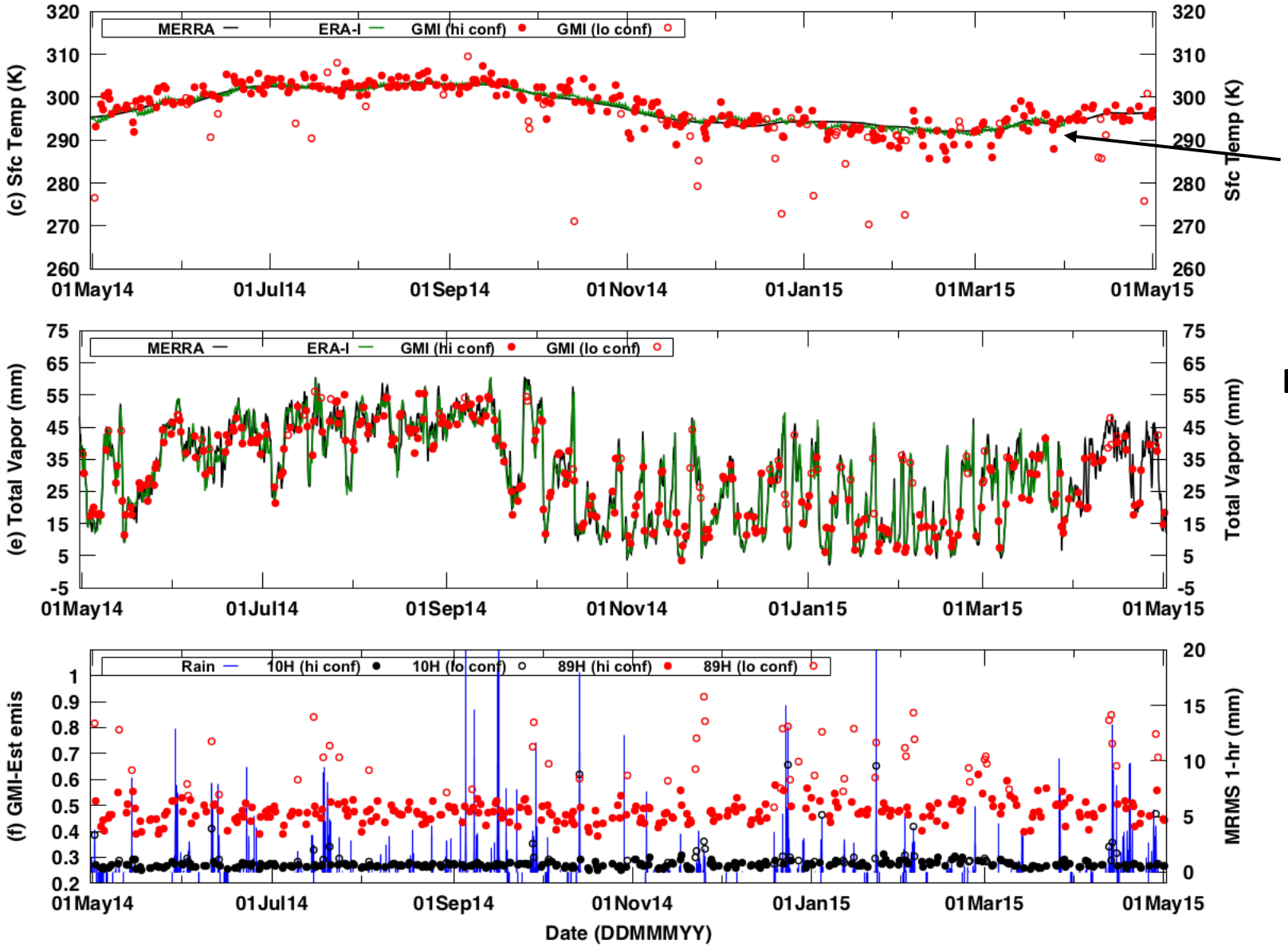
12 months

1 May 2014 – 1 May 2015

Mid-Latitude, Over-Water, No Coastal/Mixed Pixel Conditions

Rain/Emissivity State Timeseries near a point: S of Pensacola, FL

Closed Circles= High Confidence, Open Circles= Reduced Confidence



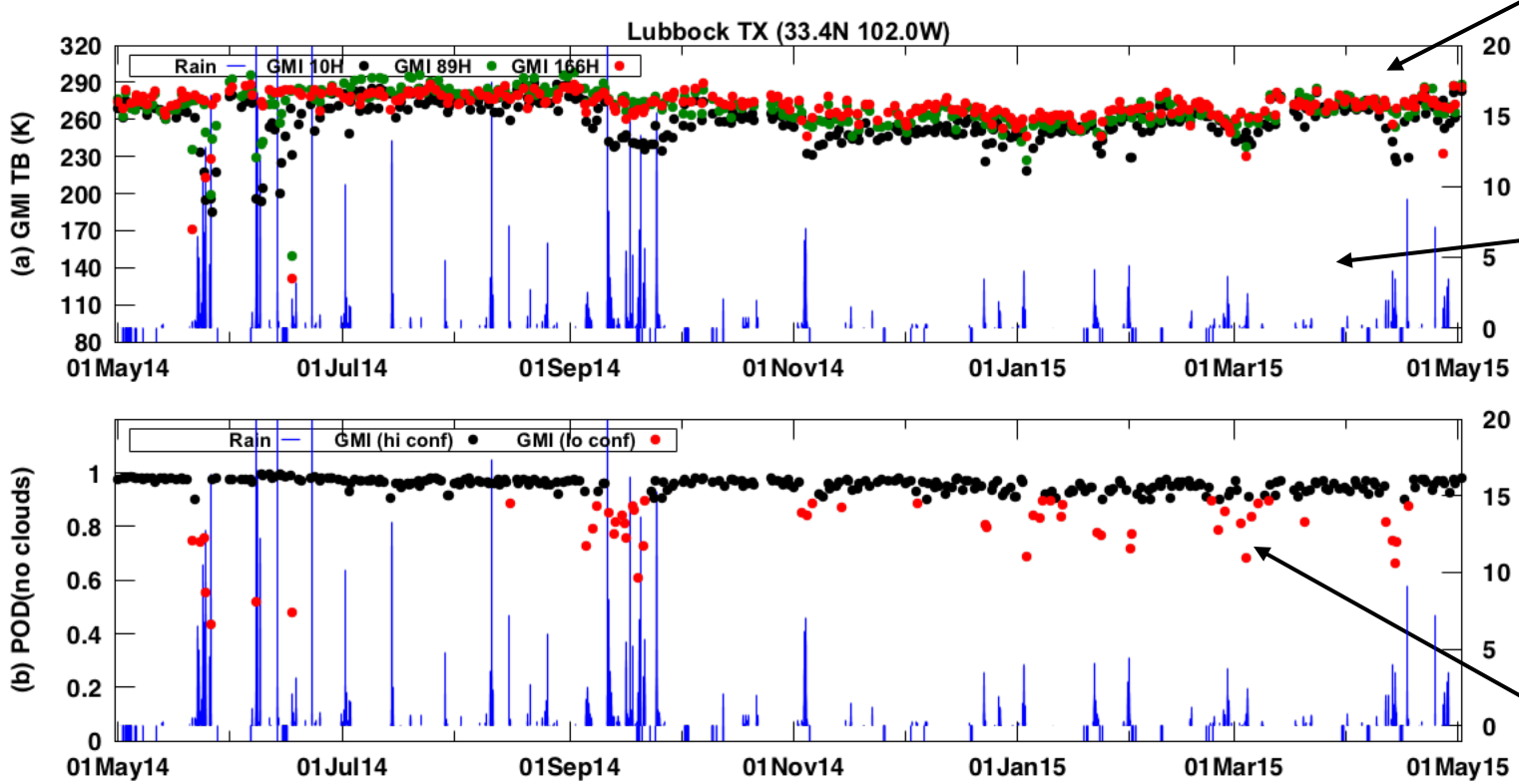
MERRA Ts
ERA-I Ts
Est. Ts

MERRA Tvap
ERA-I Tvap
Est. Tvap

Est. e10H
Est. e89H

MRMS
1-hr rain

Rain/Emissivity State Timeseries near a point: West of Lubbock, TX



Observations
TB 10H
TB 89H
TB 166H

MRMS
1-hr rain

Discrimination
("no-cloud")
90% High
Confidence

Reduced
Confidence

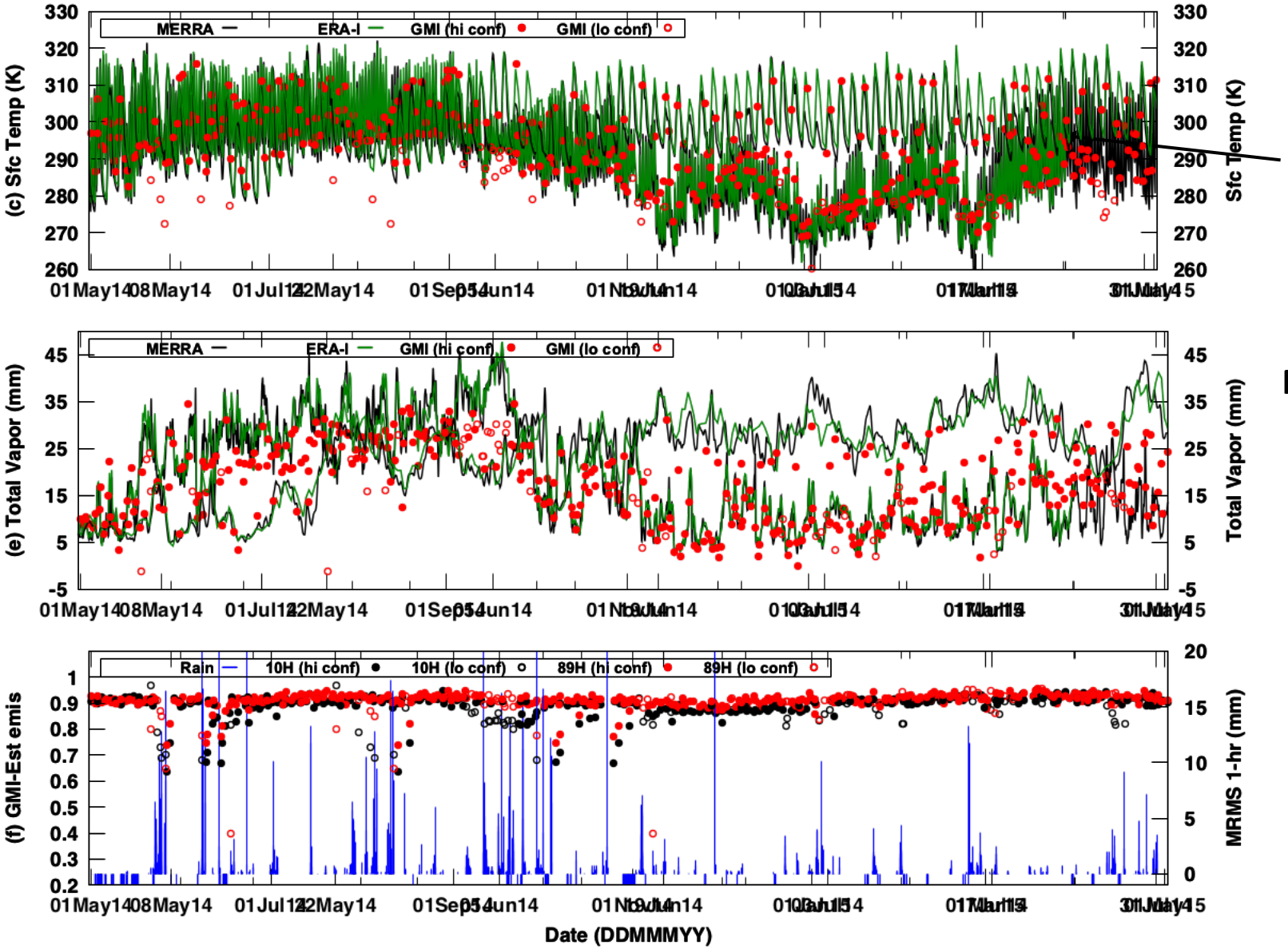
12 months

1 May 2014 – 1 May 2015

Soil type and scrub-like vegetation exhibit rapid rain response and dry-down

Rain/Emissivity State Timeseries near a point: West of Lubbock, TX

Closed Circles= High Confidence, Open Circles= Reduced Confidence



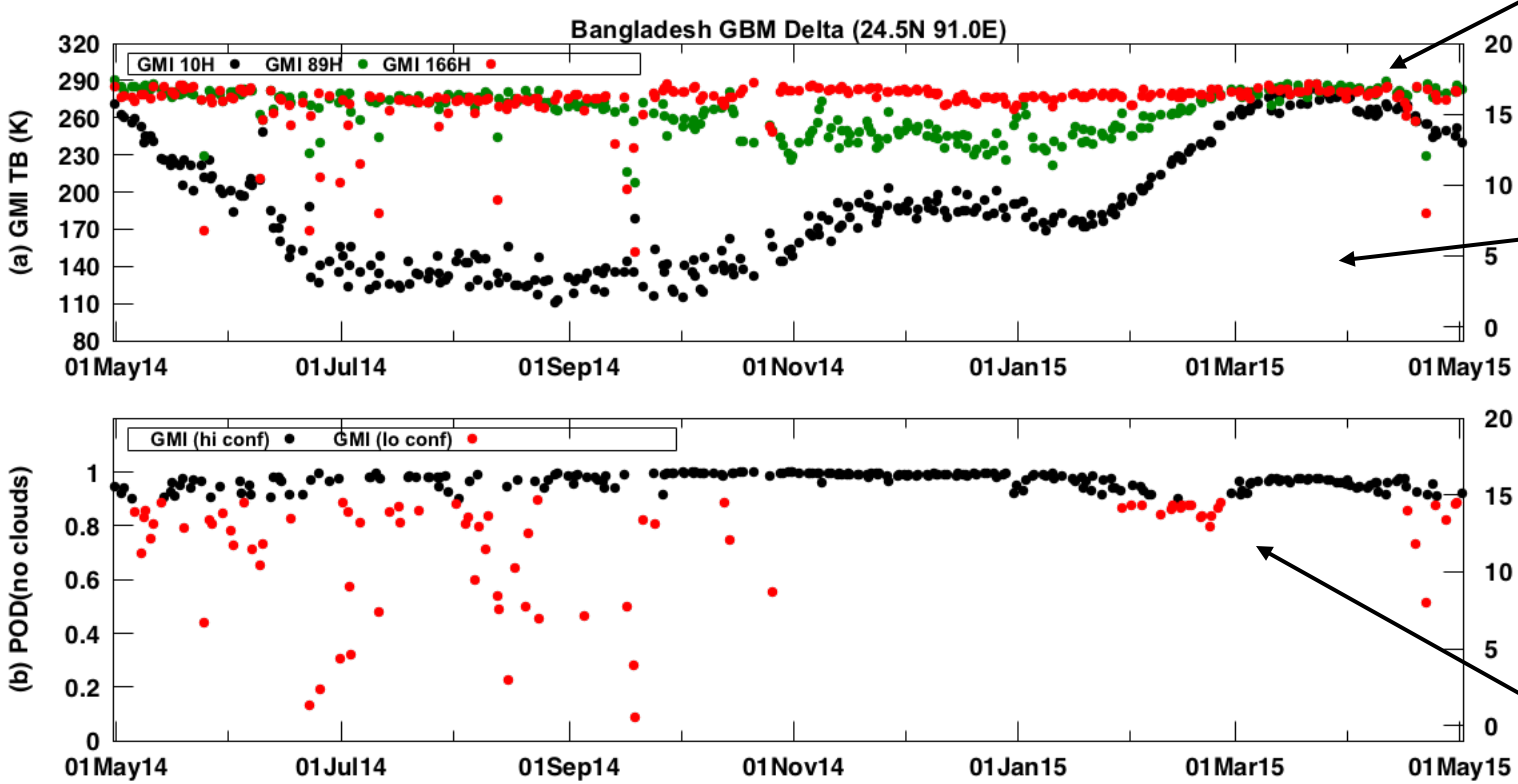
MERRA Ts
ERA-I Ts
Est. Ts

MERRA Tvap
ERA-I Tvap
Est. Tvap

Est. e10H
Est. e89H

MRMS
1-hr rain

Meghna River Seasonal Wetland ("Haor")



Observations

TB 10H

TB 89H

TB 166H

MRMS 1-hr rain

Discrimination ("no-cloud") 90% High Confidence

Reduced Confidence

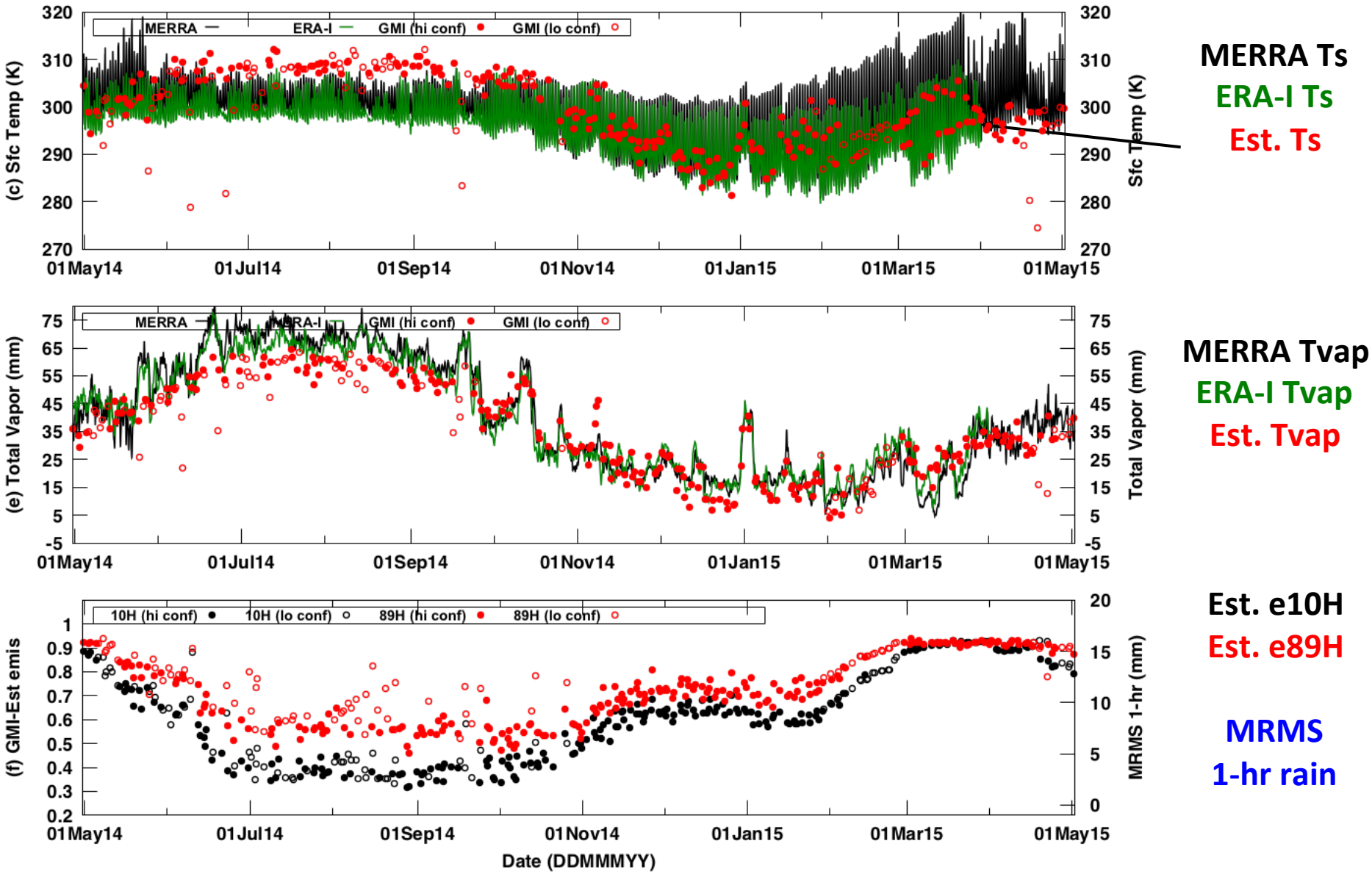
12 months

1 May 2014 – 1 May 2015

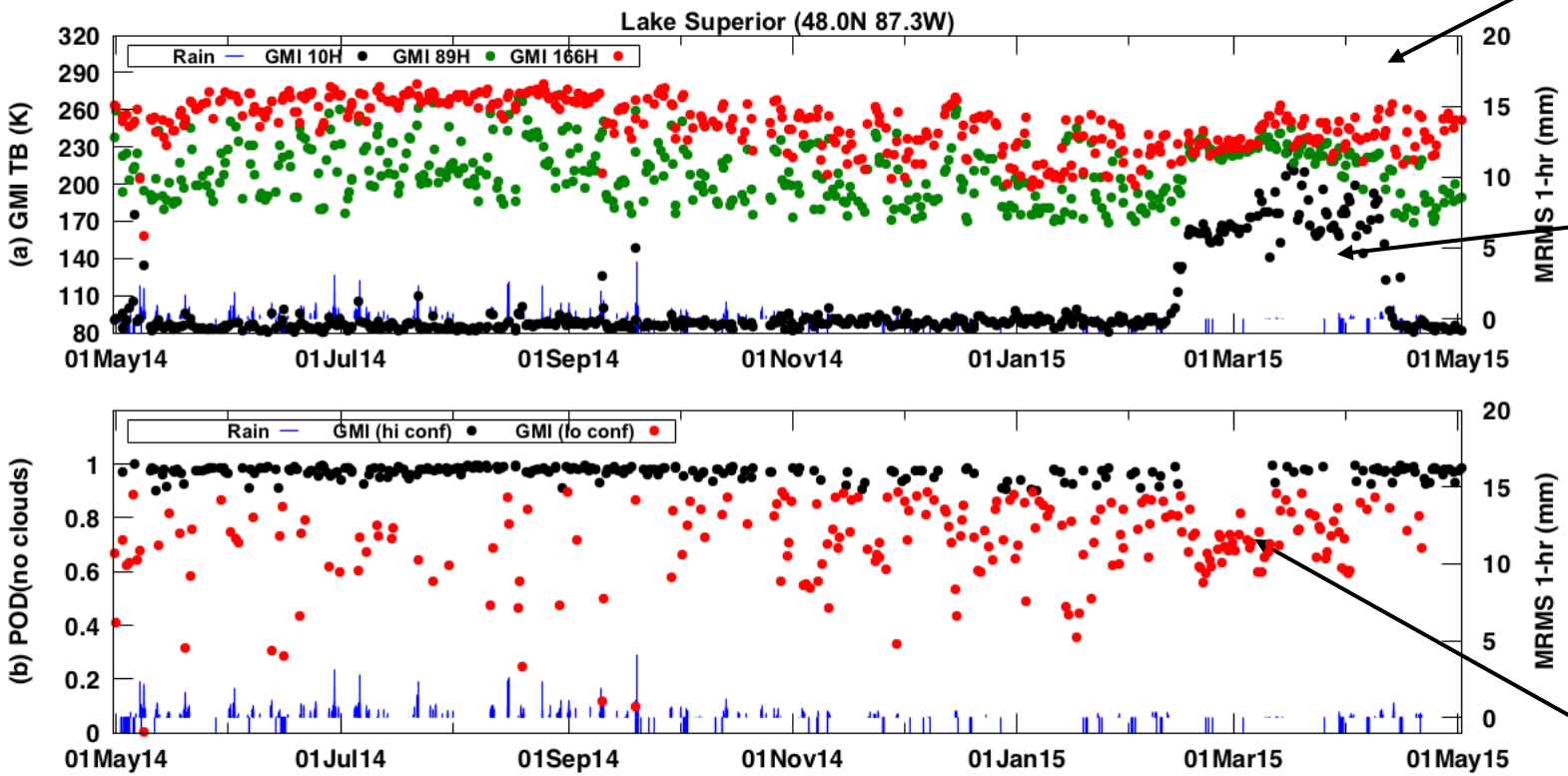
Can also experience rapid emissivity change across inundated areas

Meghna River Seasonal Wetland ("Haor")

Closed Circles= High Confidence, Open Circles= Reduced Confidence



Middle of Lake Superior, US/Canada



Observations
TB 10H
TB 89H
TB 166H

MRMS
1-hr rain

Discrimination ("no-cloud") 90% High Confidence

Reduced Confidence

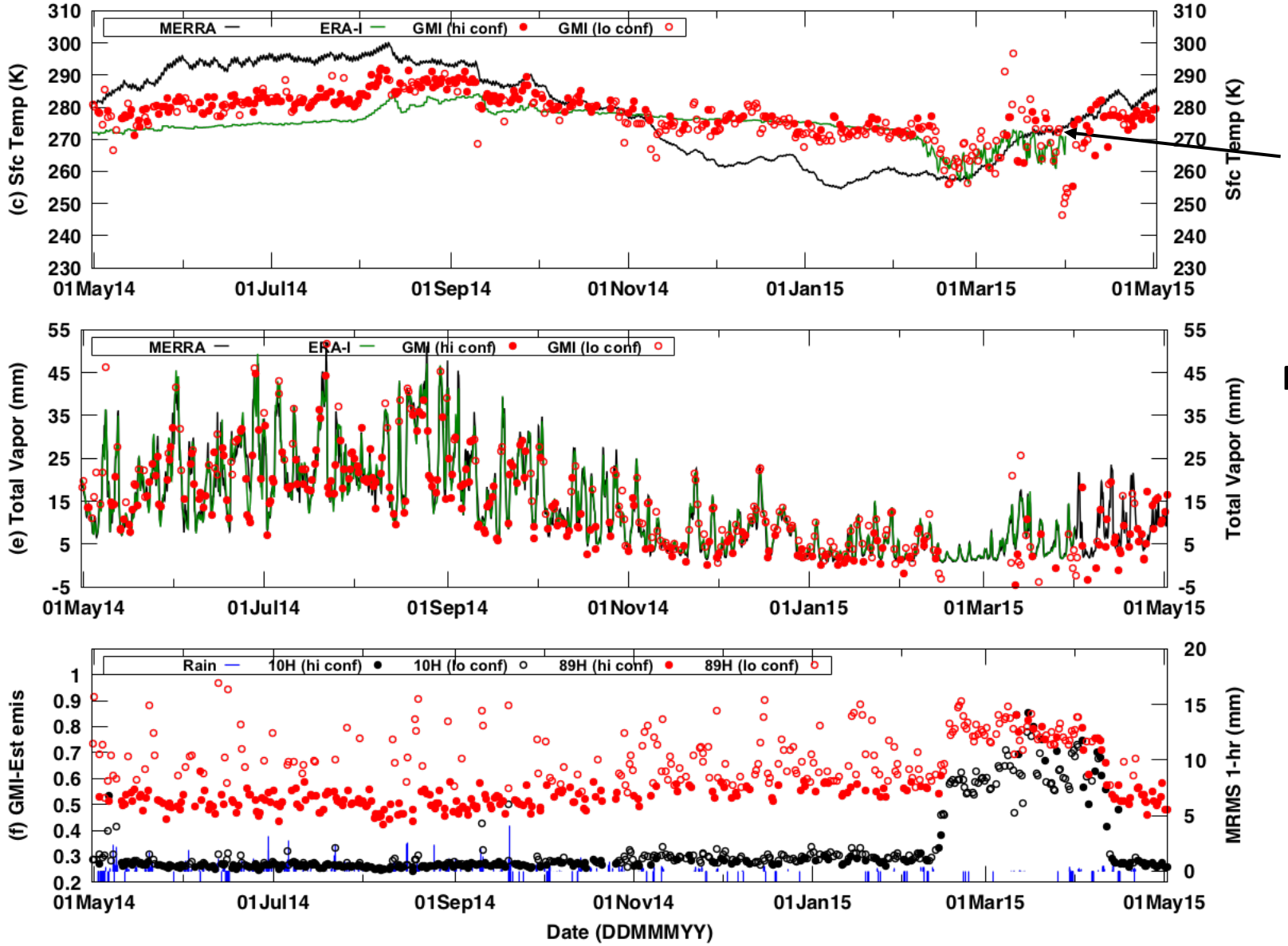
12 months

1 May 2014 – 1 May 2015

Can also experience rapid emissivity change across inundated areas

Middle of Lake Superior, US/Canada

Closed Circles= High Confidence, Open Circles= Reduced Confidence



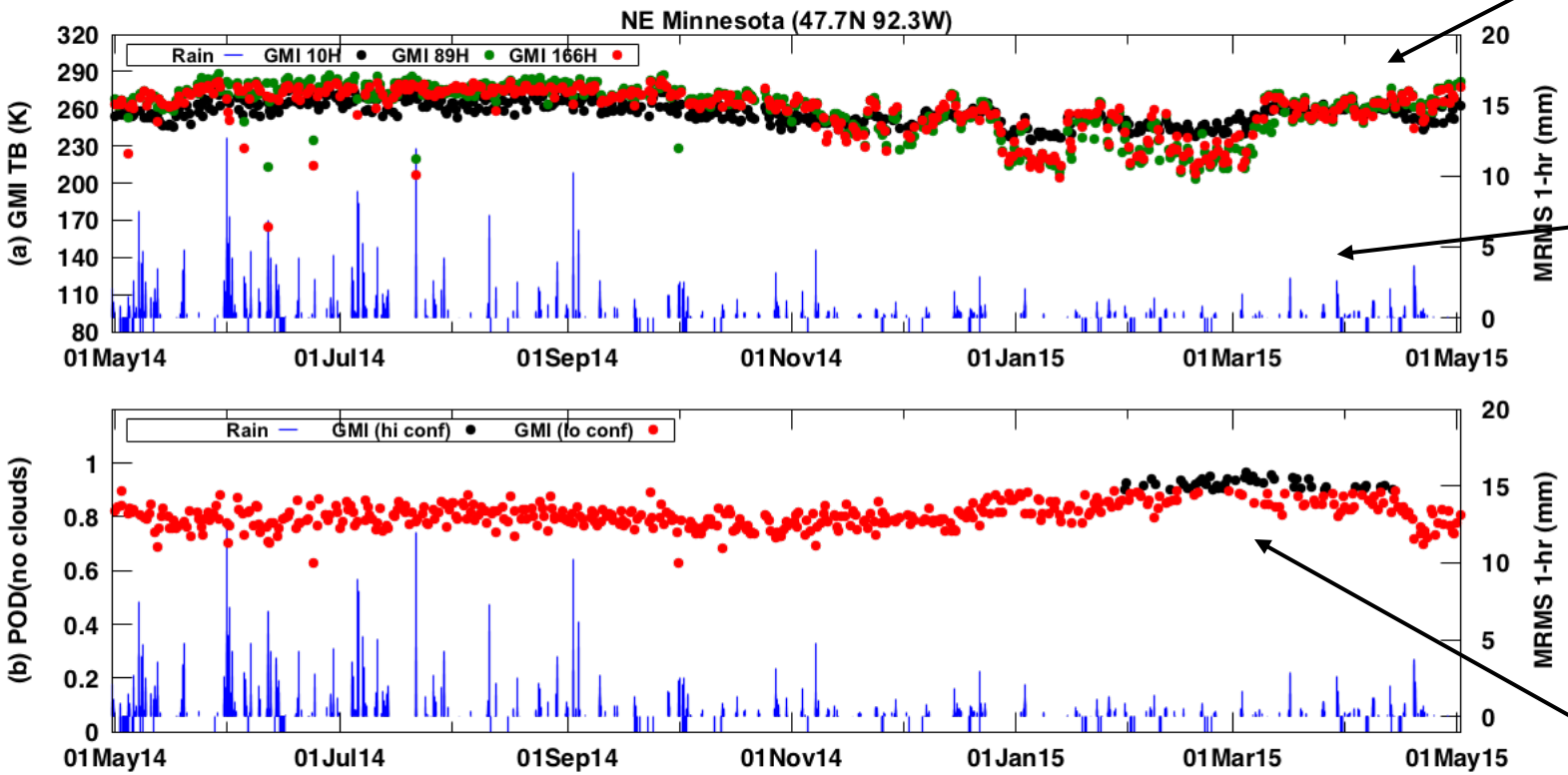
MERRA Ts
ERA-I Ts
Est. Ts

MERRA Tvap
ERA-I Tvap
Est. Tvap

Est. e10H
Est. e89H

MRMS
1-hr rain

Northern Minnesota, US



Observations
TB 10H
TB 89H
TB 166H

MRMS
1-hr rain

Discrimination ("no-cloud") 90% High Confidence

Reduced Confidence

12 months

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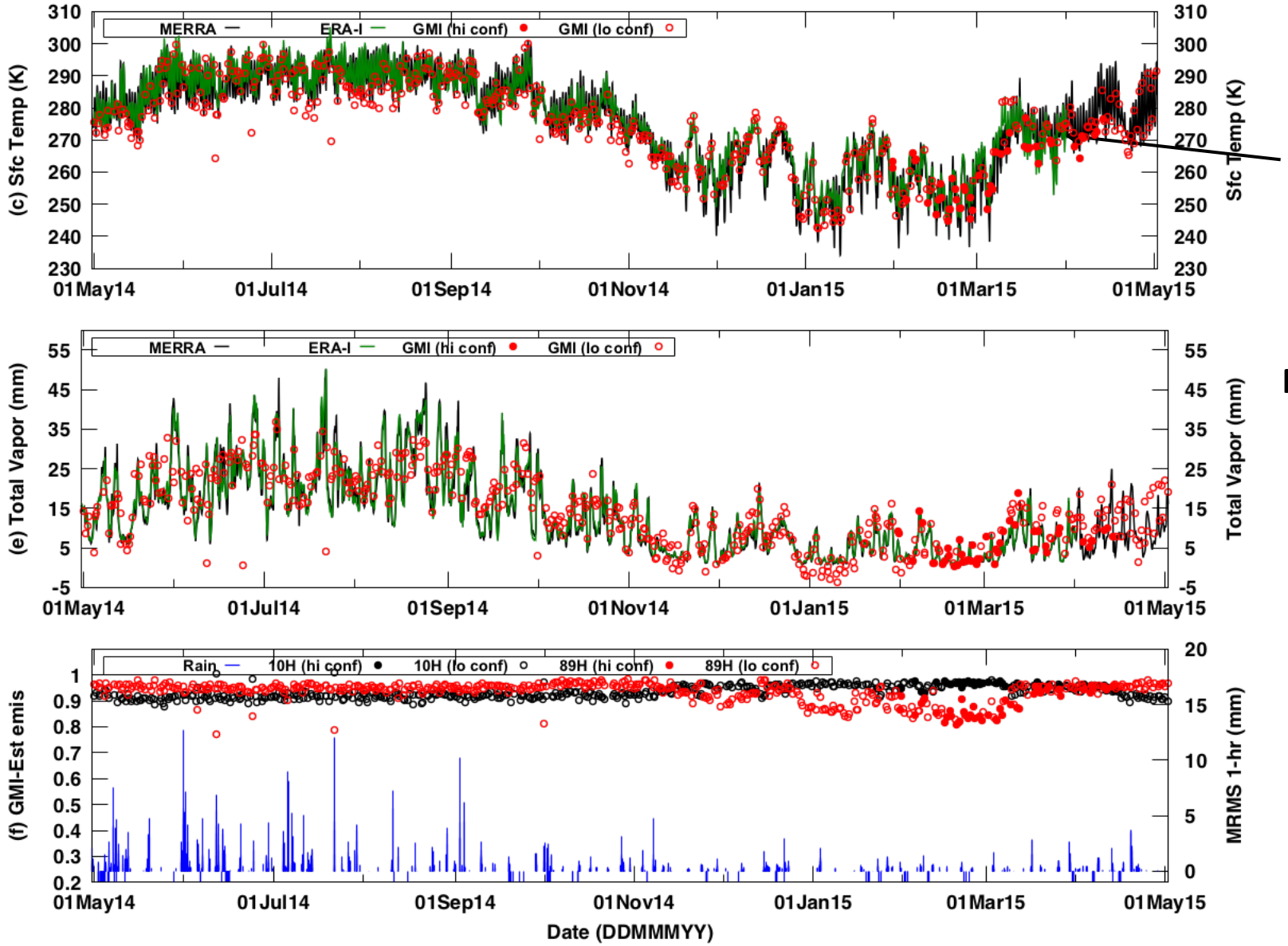
Can also experience rapid emissivity change across inundated areas

Northern Minnesota, US

Closed Circles= High Confidence, Open Circles= Reduced Confidence



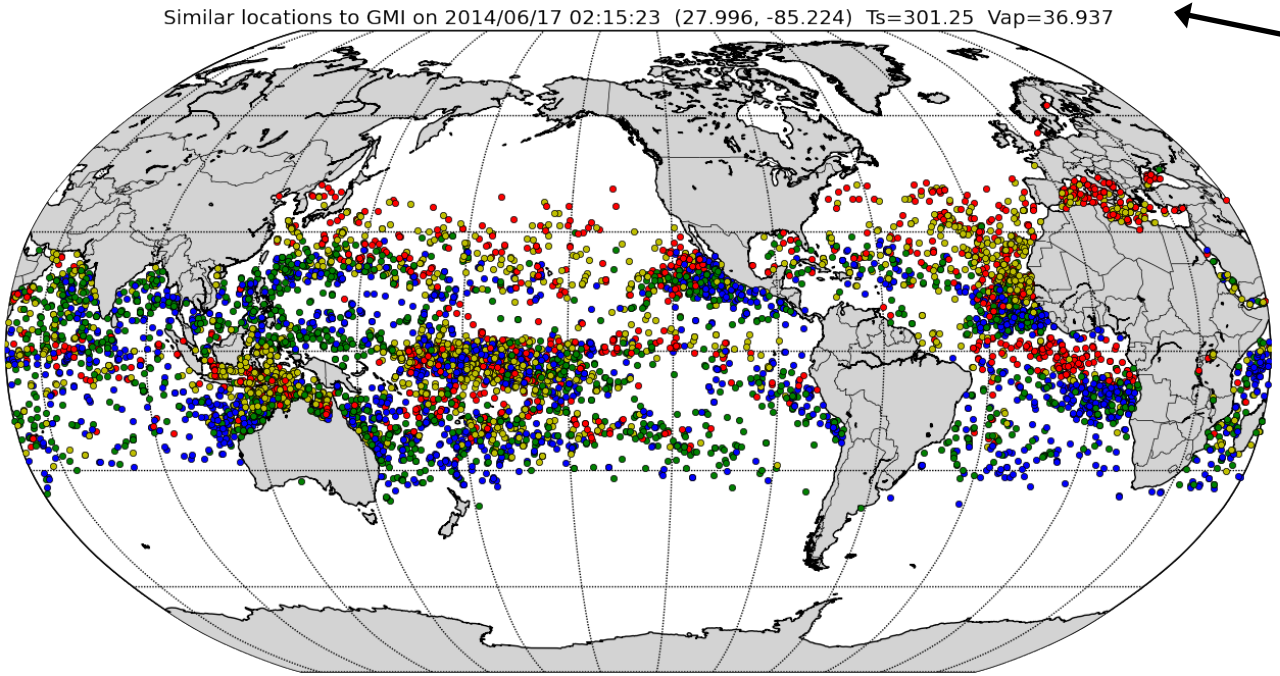
MERRA Ts
ERA-I Ts
Est. Ts

MERRA Tvap
ERA-I Tvap
Est. Tvap

Est. e10H
Est. e89H

MRMS
1-hr rain

Applicability to Database Search: Example from Over-Ocean Warm SST



Gulf of Mexico
17 June 2014

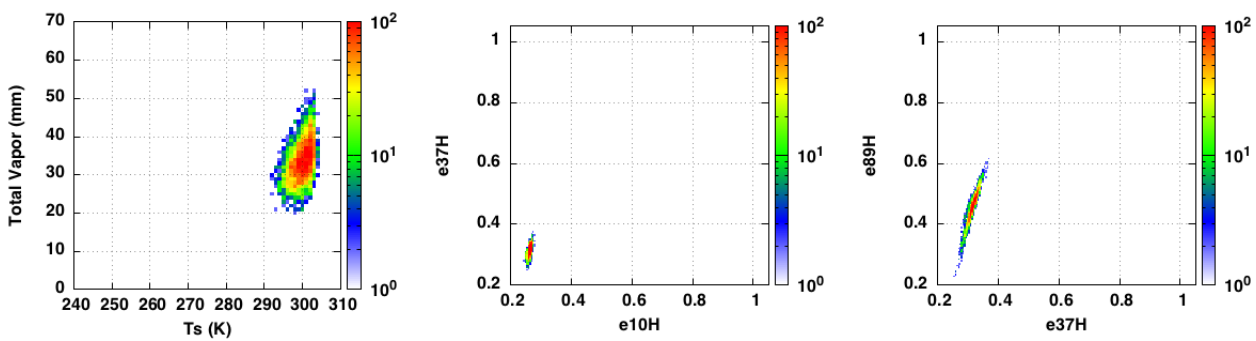
DJF MAM
JJA SON

Search for "nearby" entries in leading EOF-space:

$$r = \sqrt{\frac{1}{N}\sum[(u^{obs} - u_i^{sim})/\sigma_i]^2} \quad N = 3$$

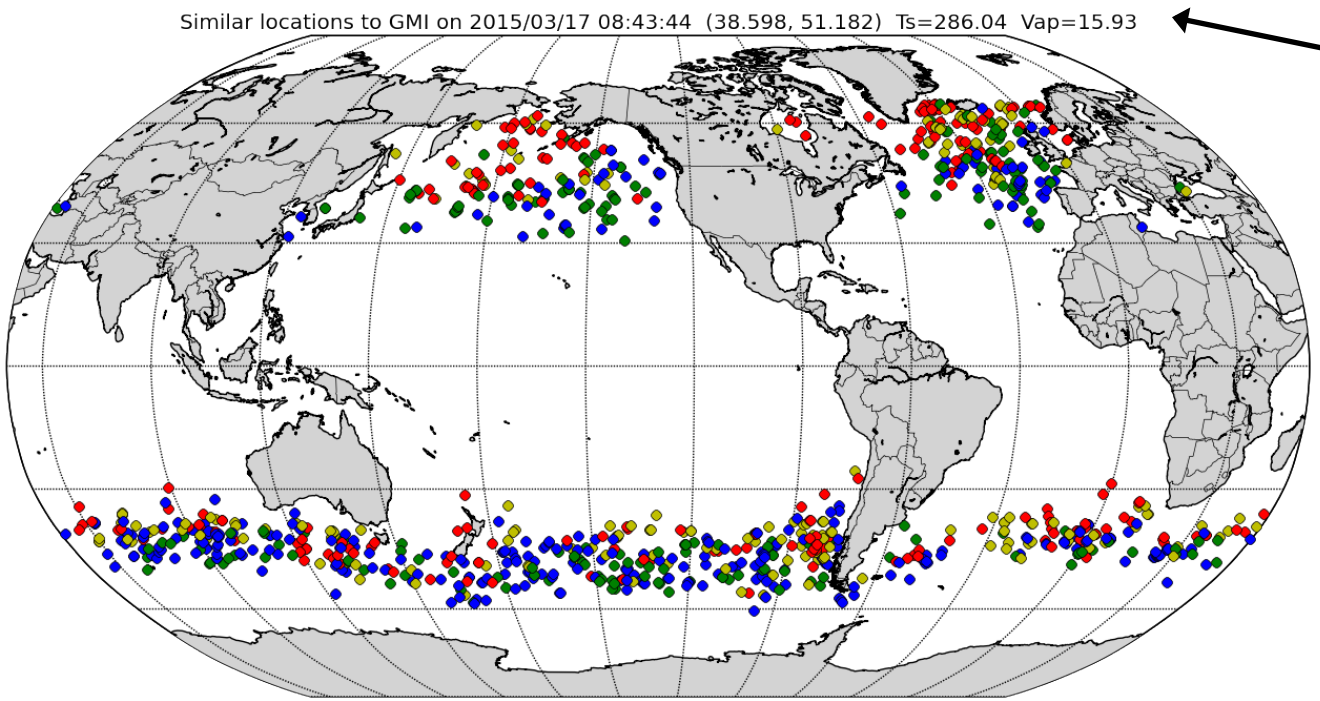
Throughout the process, the only time that latitude/longitude was ever consulted, was to plot the points on the map

Associated variability in surface and WV state variables



suggests possible alternate ways to index databases (transformation of variables)

Applicability to Database Search: Example from Midlatitude Inland Water



Center of the Caspian Sea 17 March 2015

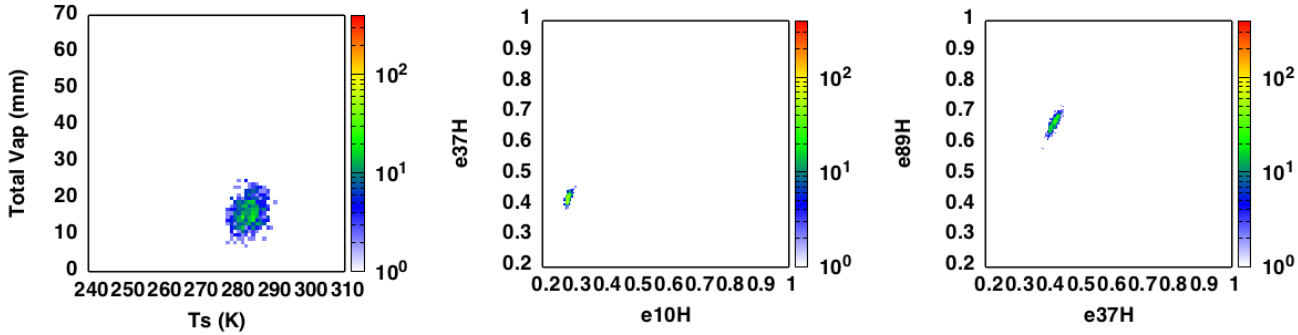
DJF MAM
JJA SON

Search for "nearby" entries in leading EOF-space:

$$r = \sqrt{\frac{1}{N}\sum[(u^{obs} - u_i^{sim})/\sigma_i]^2} \quad N = 3$$

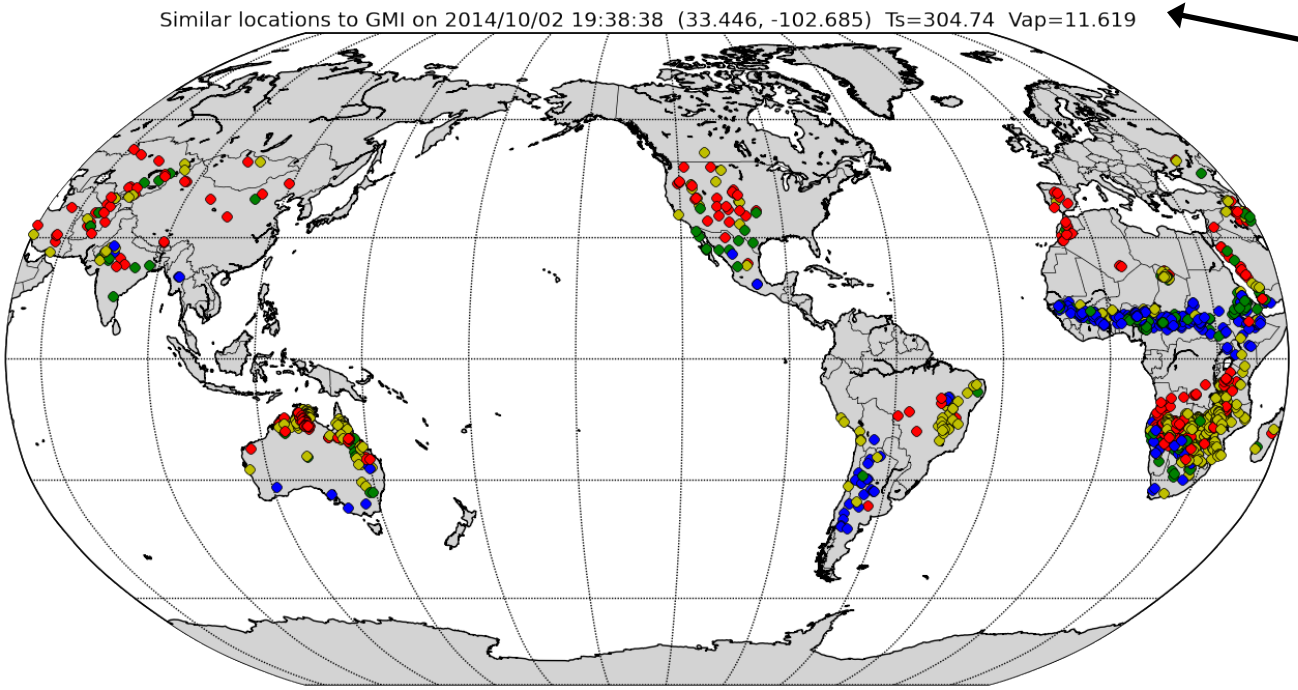
Throughout the process, the only time that latitude/longitude was ever consulted, was to plot the points on the map

Associated variability in surface and WV state variables



suggests possible alternate ways to index databases (transformation of variables)

Applicability to Database Search: Example from Bare Soil-Like, Daytime



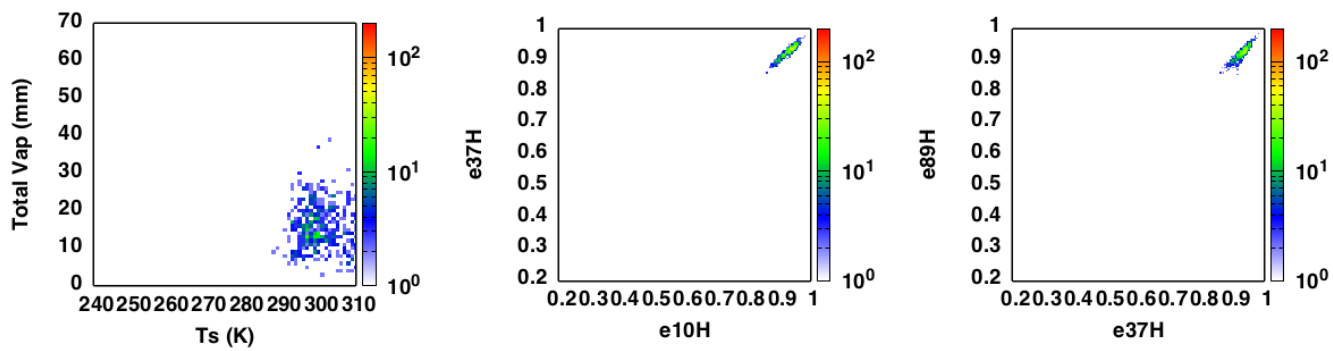
West Texas
2 October
2014

DJF MAM
JJA SON

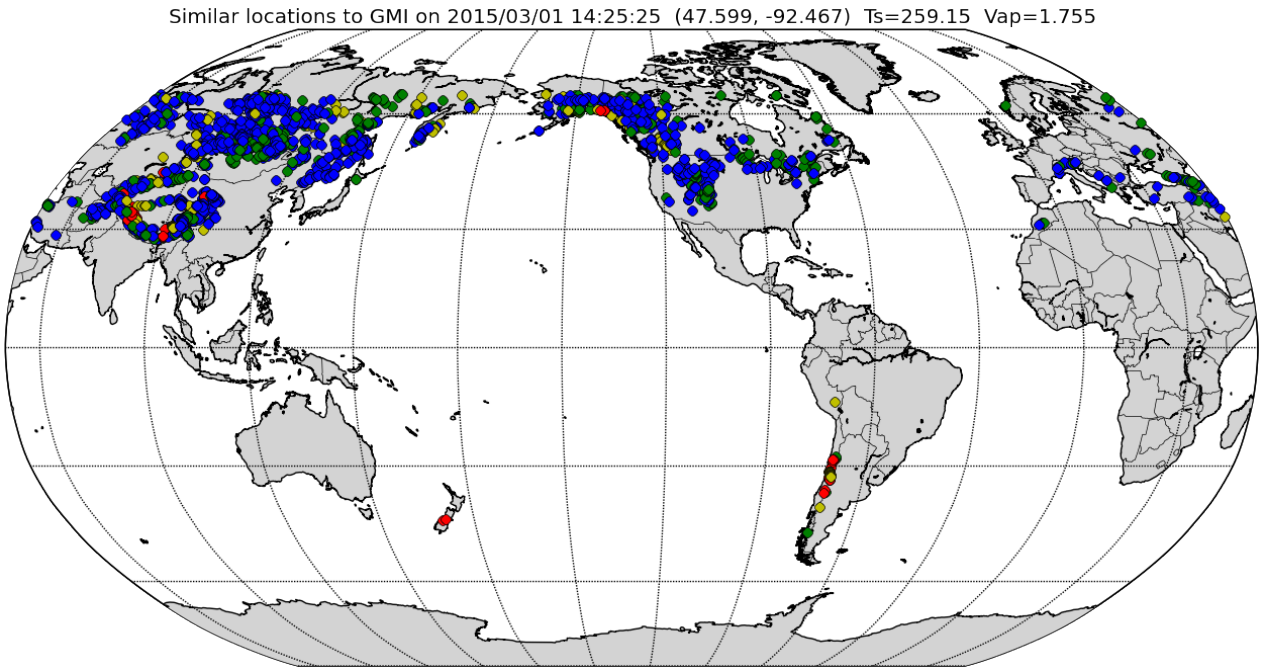
Search for "nearby" entries in leading EOF-space:

$$r = \sqrt{\frac{1}{N}\sum[(u^{obs} - u_i^{sim})/\sigma_i]^2} \quad N = 3$$

Associated variability in surface and WV state variables is carried



Applicability to Database Search: Snow Covered, Cold, Dry



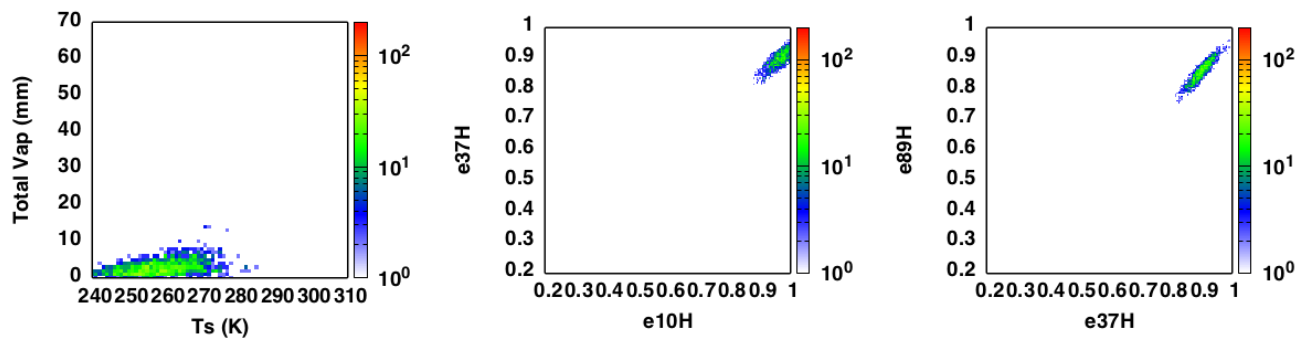
NE Minnesota, snow-covered 1 March 2015

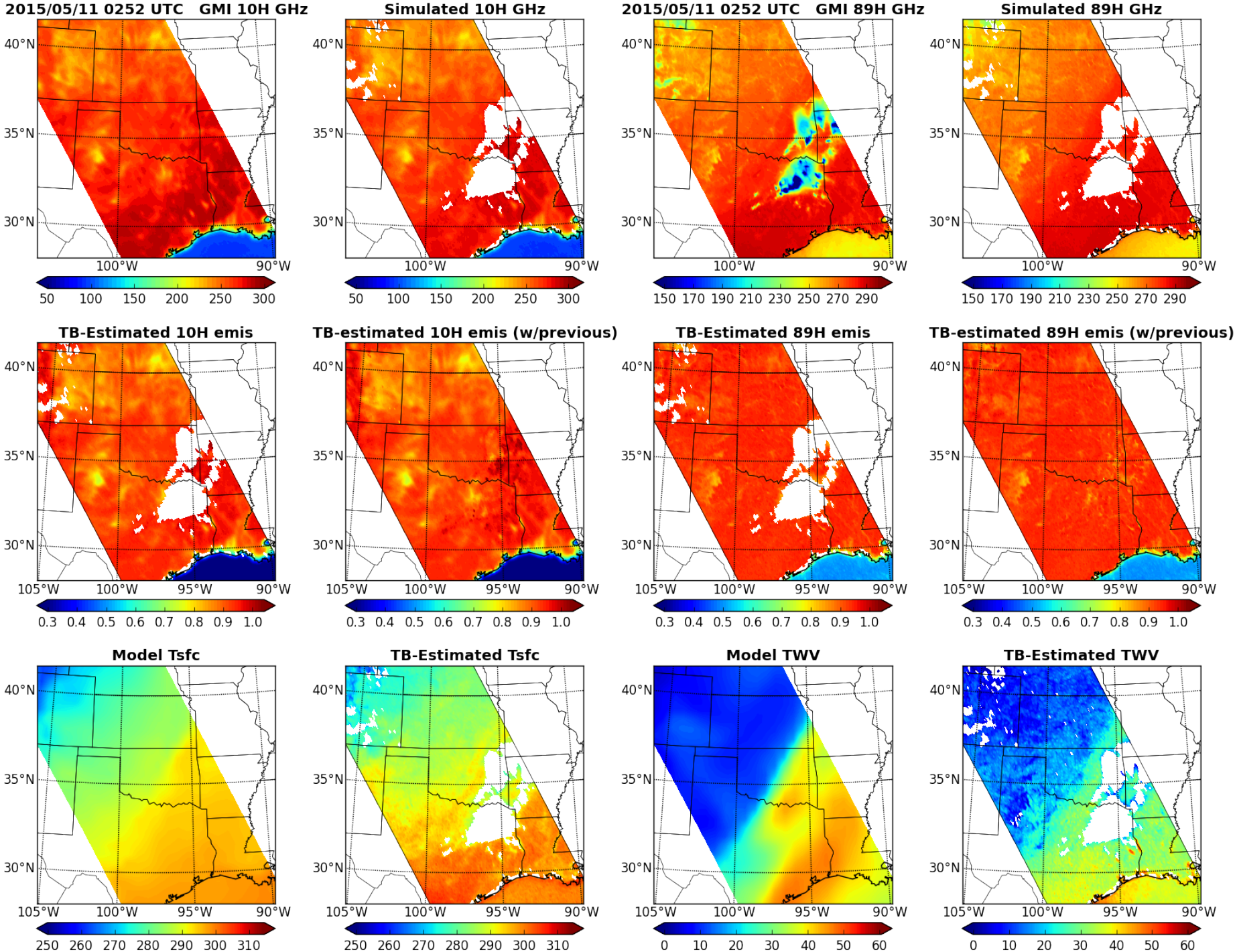
DJF MAM
JJA SON

Search for "nearby" entries in leading EOF-space:

$$r = \sqrt{\frac{1}{N}\sum[(u^{obs} - u_i^{sim})/\sigma_i]^2} \quad N = 3$$

Associated variability in surface and WV state variables




2015/05/11 0252 UTC GMI 10H GHz
Simulated 10H GHz
2015/05/11 0252 UTC GMI 89H GHz
Simulated 89H GHz
TB-Estimated 10H emis
TB-estimated 10H emis (w/previous)
TB-Estimated 89H emis
TB-estimated 89H emis (w/previous)
Model Tsfc
TB-Estimated Tsfc
Model TWV
TB-Estimated TWV
40°N
35°N
30°N
105°W
100°W
95°W
90°W
50 100 150 200 250 300
150 170 190 210 230 250 270 290
0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
250 260 270 280 290 300 310
0 10 20 30 40 50 60

Future Efforts

Evaluate emissivity vector formulation for existing GPM a-priori databases (transformation of variables)

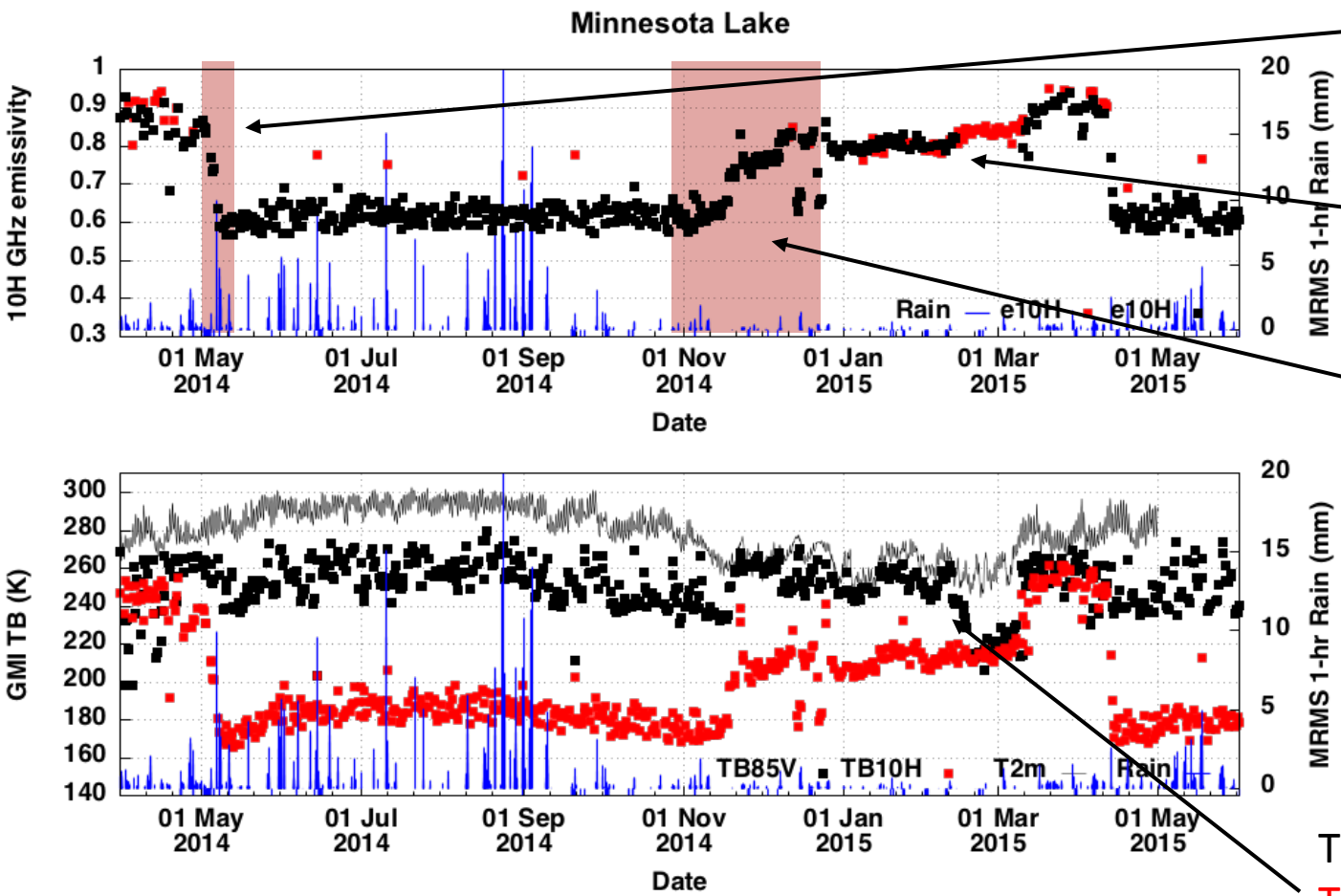
Replace search by (Tsfc, TotVap, class) with (u

Evaluate utility of HF channels for cold-season precipitation using GPM-CloudSat (W-band) coincidence dataset

Work with an offline version of GPROF-GPM to test and evaluate use of observationally-based emissivity vector in forward TB radiometer simulations.

Examine further extension to 166 GHz for very dry (< 10 mm column vapor) cold season scenes, to better guide GPM snowfall and light rain TB simulations

Minnesota Inland Lake (10H)



thaw period only a few days

Ice/snow-covered

More gradual freeze period

MRMS 1-hr accumulations (blue impulses)

TB 85V (black)

TB 10H (red)

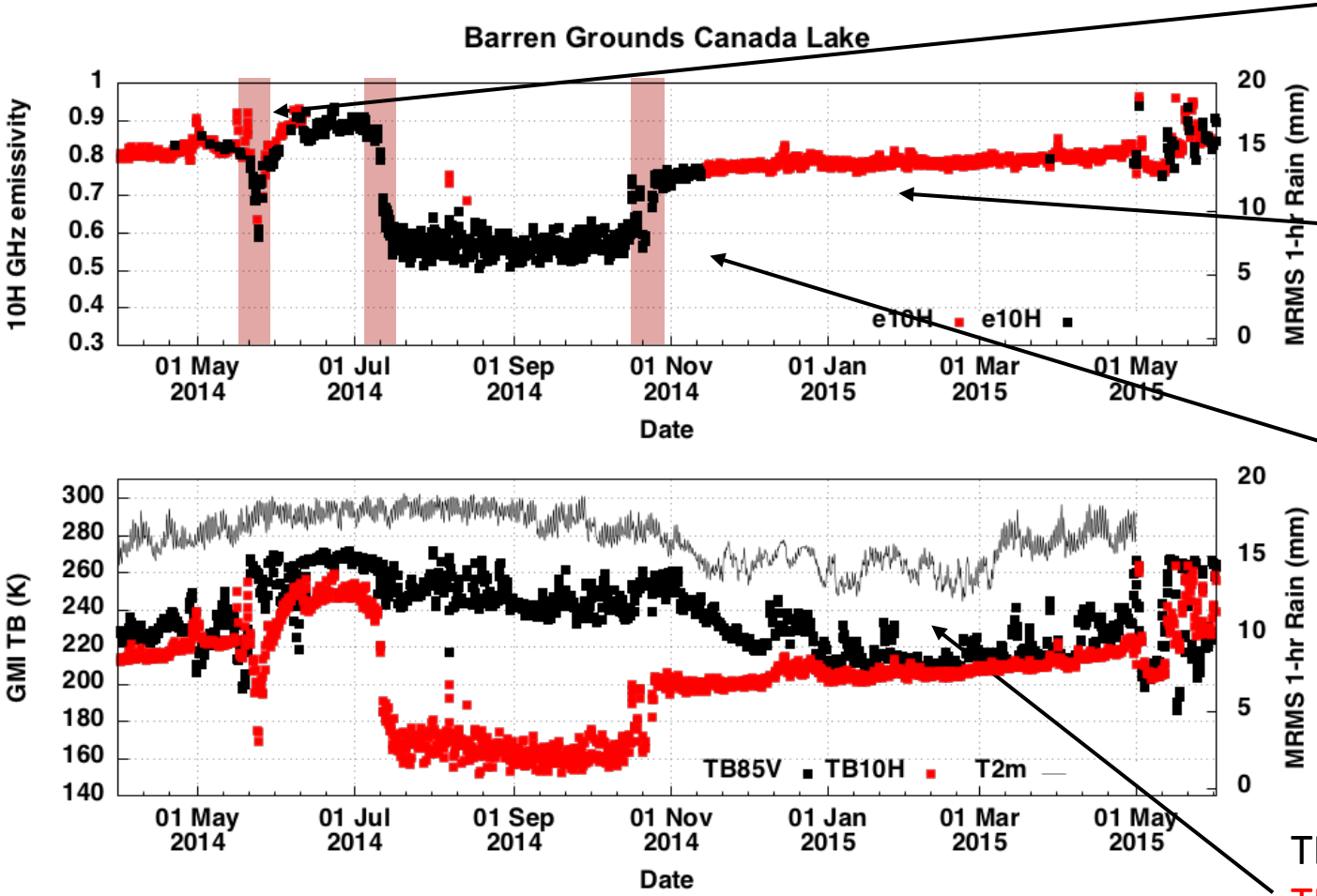
T2m (thin black line)

14 months

1 Apr 2014 – 1 Jun 2015

Rapid emissivity change from freeze-thaw cycles

Northern Canada Barren Grounds Lake (10H)



Exposed open water "leads", or rain-on-snow?

Slow change in snow cover as it ages

Much shorter freeze period

TB 85V (black)

TB 10H (red)

T2m (thin black line)

14 months

1 Apr 2014 – 1 Jun 2015

More rapid emissivity change from freeze-thaw cycle and snow morphology