GPM Combined Algorithm Status

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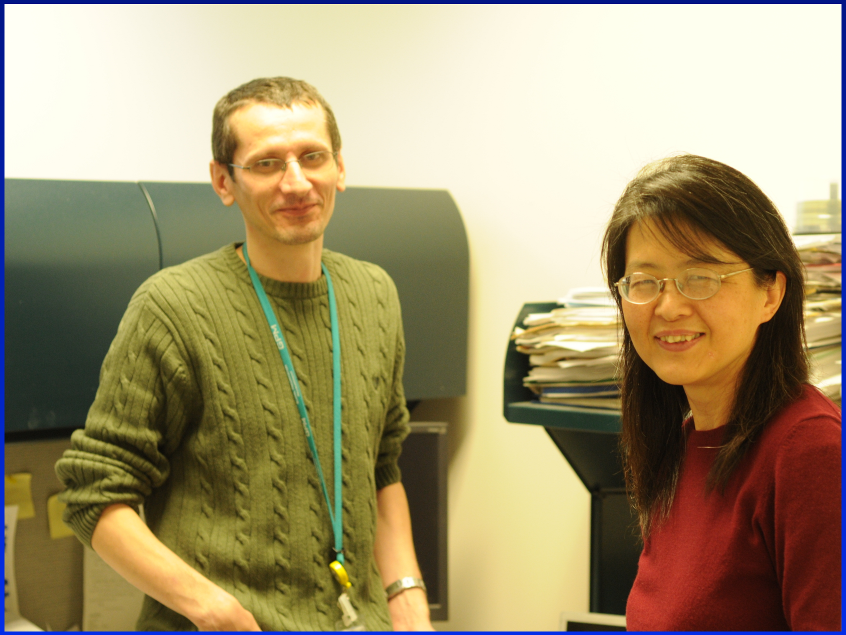
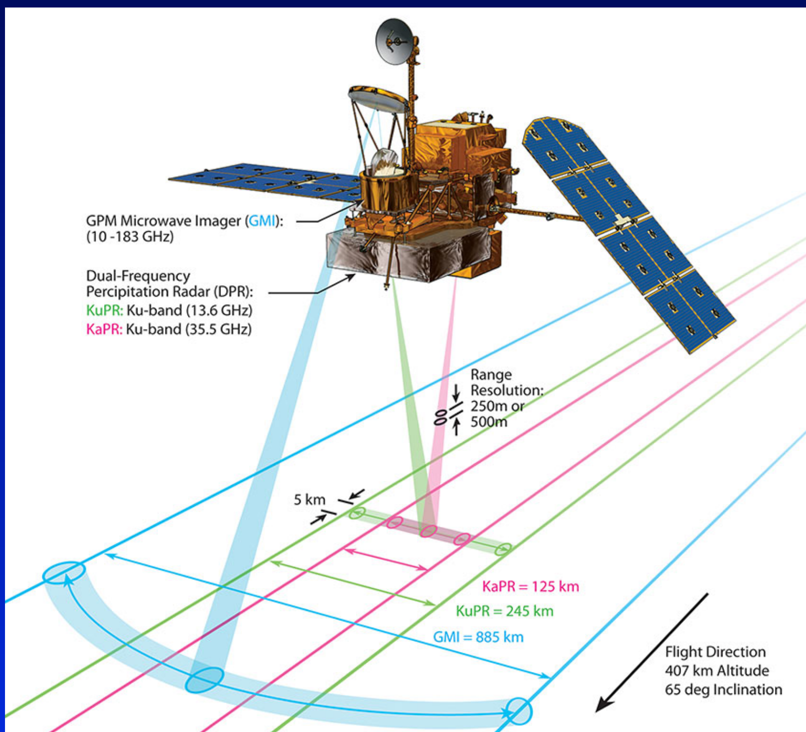
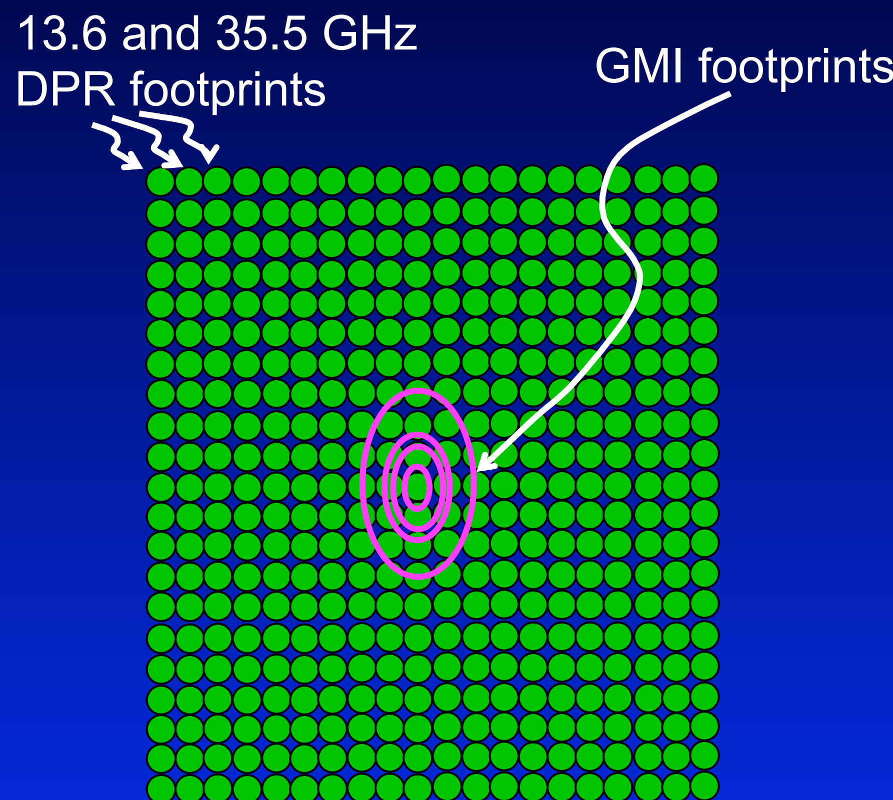
Joint Algorithm Teams
&
Working Group Contributors



Combined Radar-Radiometer Algorithm Input

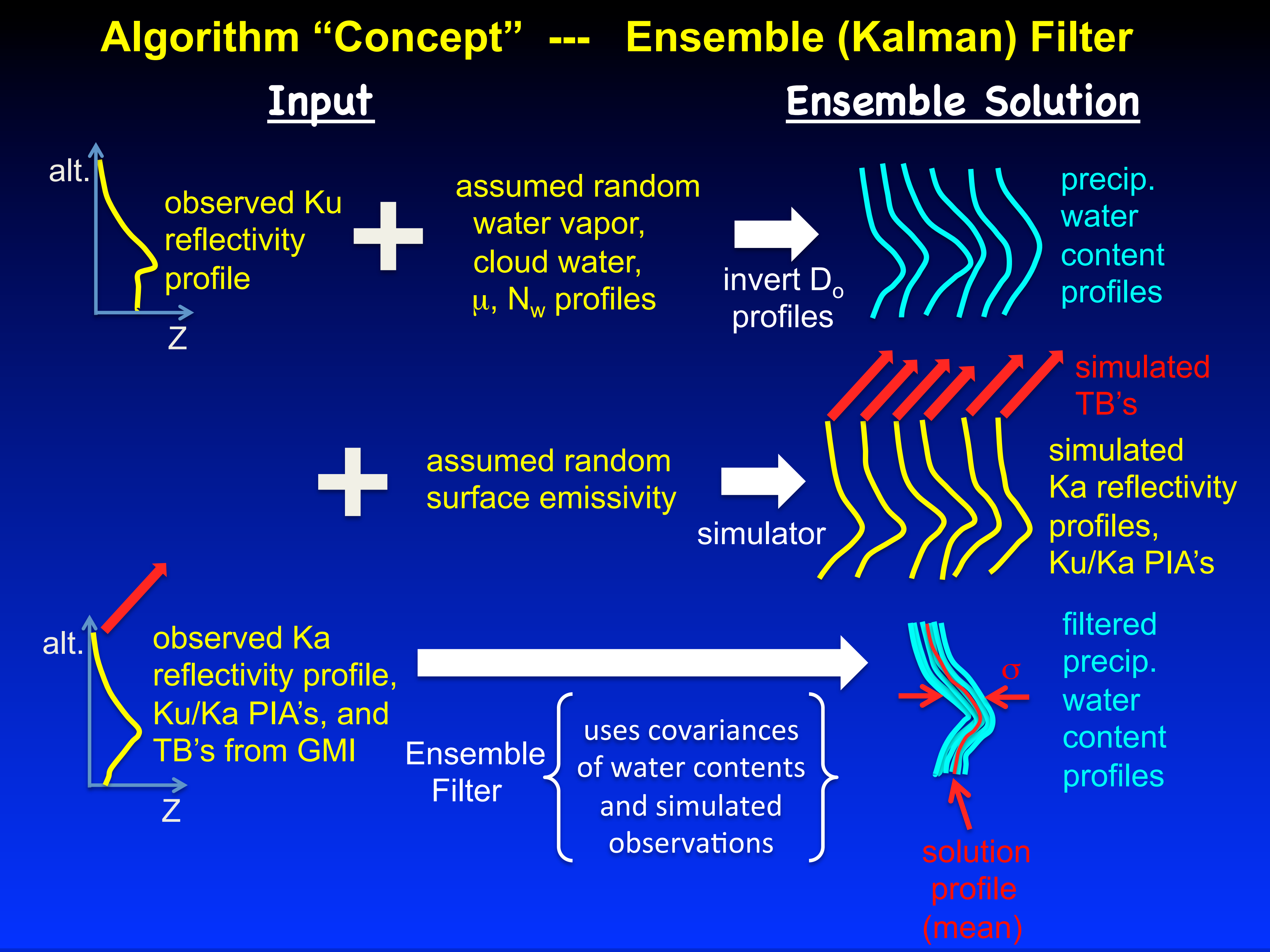
DPR / GMI Sampling and Resolution





DPR swath section

freq. 10.7, 18.7, 23.8, 36.5, 89.0, 165.5, 183.3±7, 183.3±3 GHz
resol. 26, 15, 12, 11, 6, 6, 6, 6 km


Algorithm "Concept" --- Ensemble (Kalman) Filter
Input
Ensemble Solution
alt.
Z
observed Ku reflectivity profile
+
assumed random water vapor, cloud water, μ, N_w profiles
invert D_o profiles
precip. water content profiles
simulated TB's
+
assumed random surface emissivity
simulator
simulated Ka reflectivity profiles, Ku/Ka PIA's
alt.
Z
observed Ka reflectivity profile, Ku/Ka PIA's, and TB's from GMI
Ensemble Filter
uses covariances of water contents and simulated observations
σ
filtered precip. water content profiles
solution profile (mean)

Algorithm Development --- Main Progress/Activities

- introduced simultaneous, rather than sequential, Ensemble Filter update using all Z-Ka, PIA, and TB observations associated with given solution profile at each DPR footprint.

- land emissivity (Aires) atlas introduced; TB's over land now included.

- nuts and bolts of interfacing with Level 1 and Level 2 inputs, and ancillary environmental data finished; modifications for parallel processing in PPS environment completed.

- V3 algorithm delivered to PPS December, 2012; updated V3b version (completed interfacing), now running at PPS, delivered to the team February, 2013.

- testing of algorithm sensitivity to sensor and environmental data information content, scattering tables, emissivity representation, initial ensemble assumptions, ongoing.

Algorithm Testing Plan – 4 components

(1) applications to TRMM data; validate with GV; McLaughlin.

(2) applications to one member of initial ensemble; Olson, Grecu, Munchak, Haddad.
- synth. profiles are consistent with Ku from TRMM.
- not really independent; alternative physics not feasible.

(3) applications to CRM-generated data; Grecu, Matsui, Olson.
- synth. data independent; alternative physics possible.
- data are relatively limited (a few CRM domains).

(4) field campaign studies; Johnson, Olson, Tian, Kuo, ongoing.

Want < 50% error for 50 km-res. estimates at 1 mm h^{-1}
< 25% error for 50 km-res. estimates at 10 mm h^{-1}

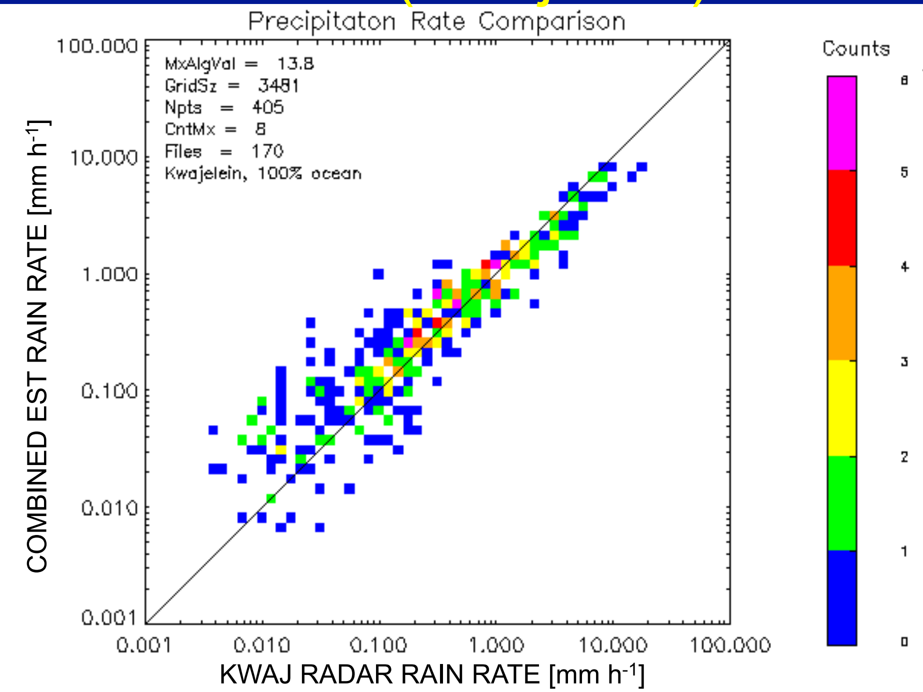
Test Plan Outline

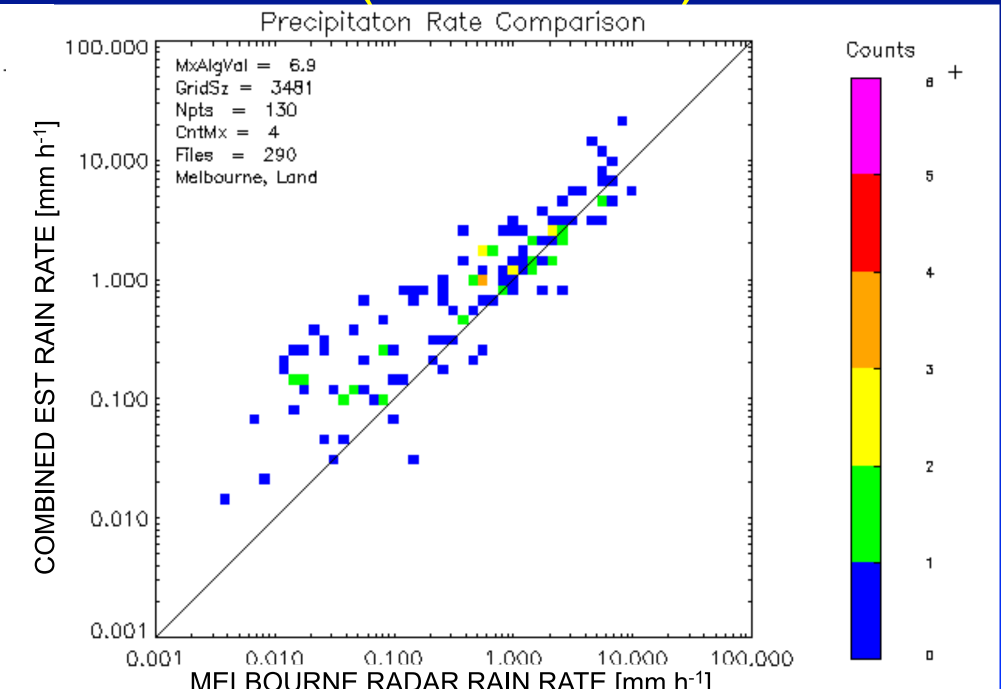
(1) Applications to TRMM Data

Data: TRMM PR and TMI data.
GV radar (Kwaj/Melbourne); NMQ & PMM GV product

Tests: Apply GPM Combined algorithm to TRMM observations and compare estimates to ground-based data.

Ocean (Kwajalein) @ 50 km Land (Melbourne)

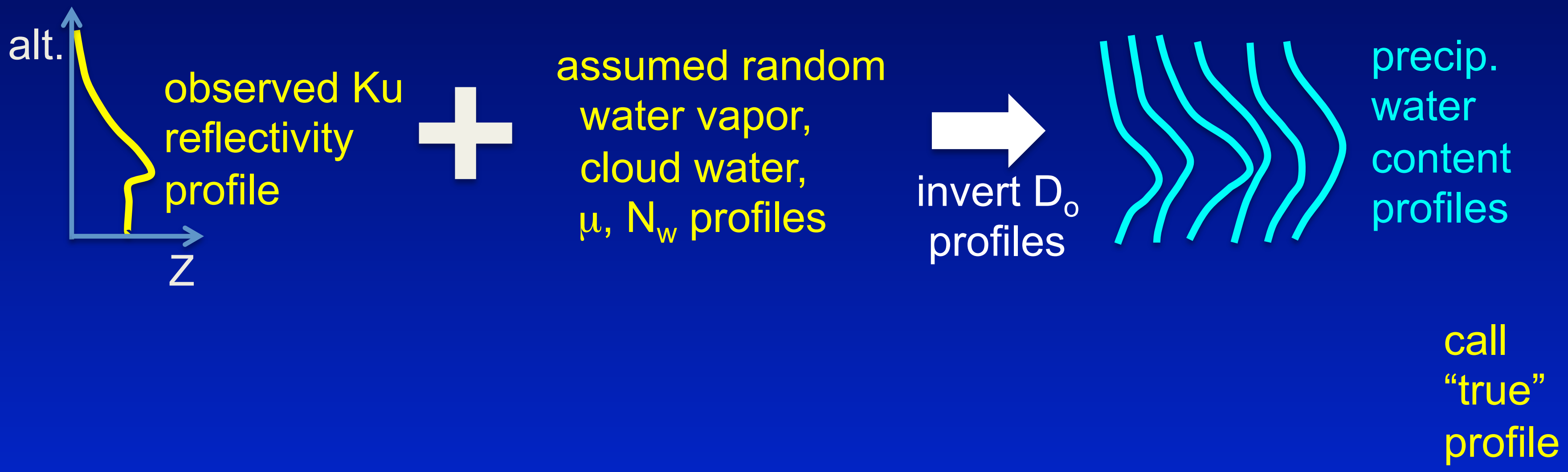




Test Plan Outline

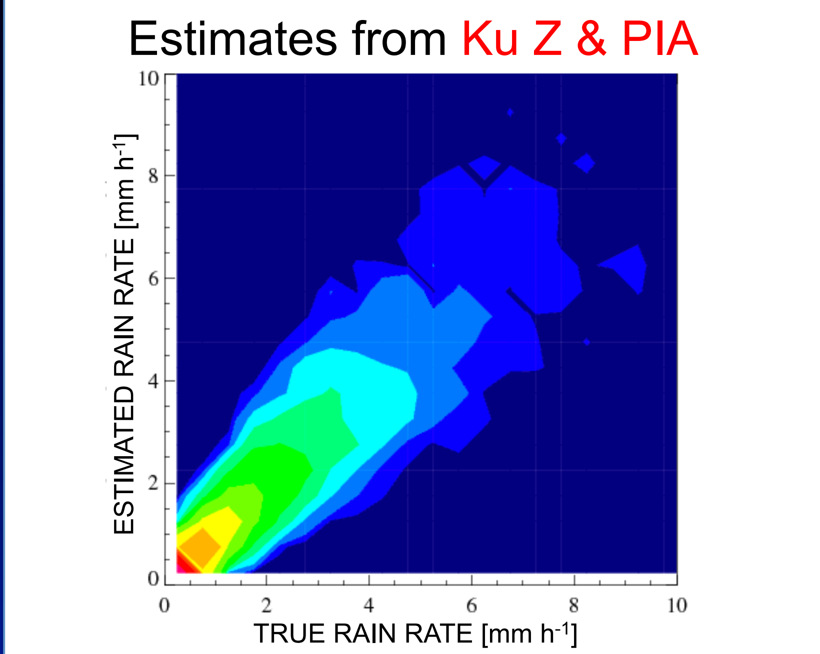
(2) "Internal" Synthetic Retrieval Tests

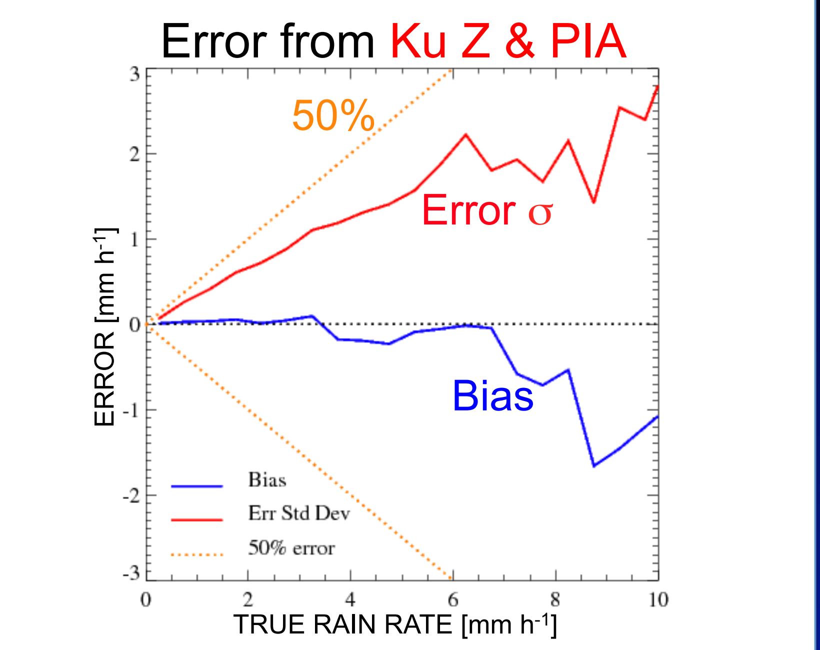
Data: use TRMM PR to synthesize DPR & GMI observations.

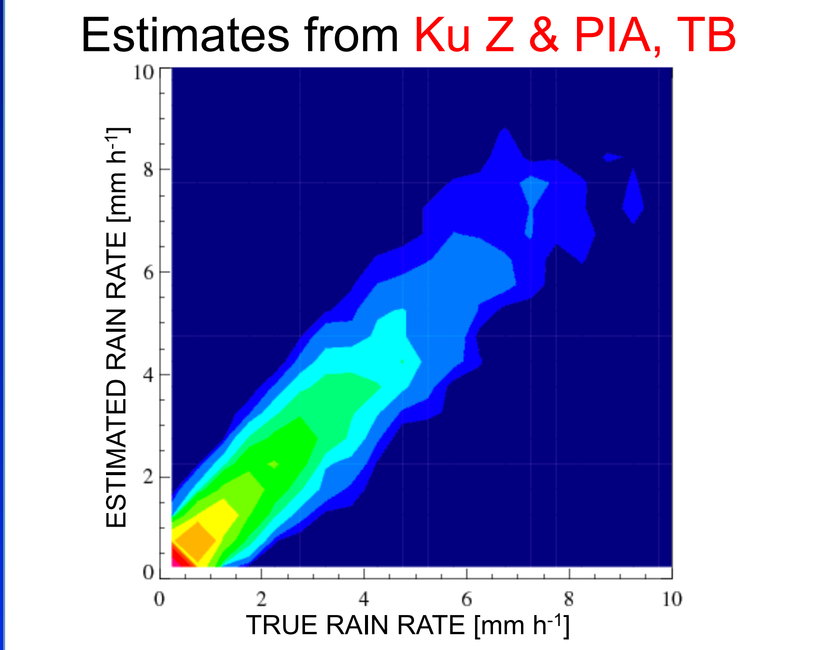


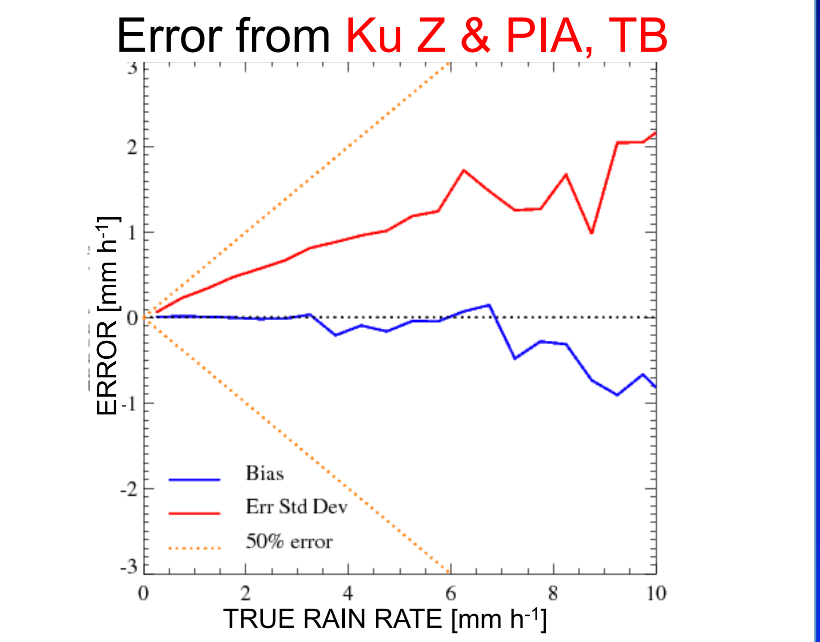
Tests: e.g., sensitivity to sensor/environment information, *a priori* assumptions.

Test Plan Outline – 1 week of TRMM ocean data; 50 km res.



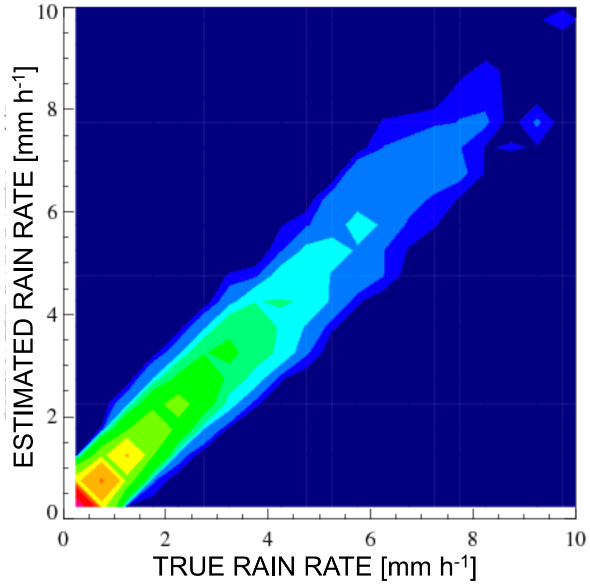




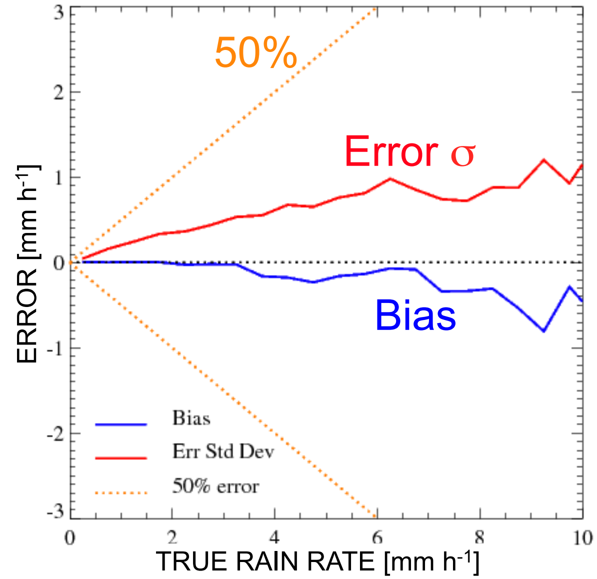


Test Plan Outline – 1 week of TRMM ocean data; 50 km res.

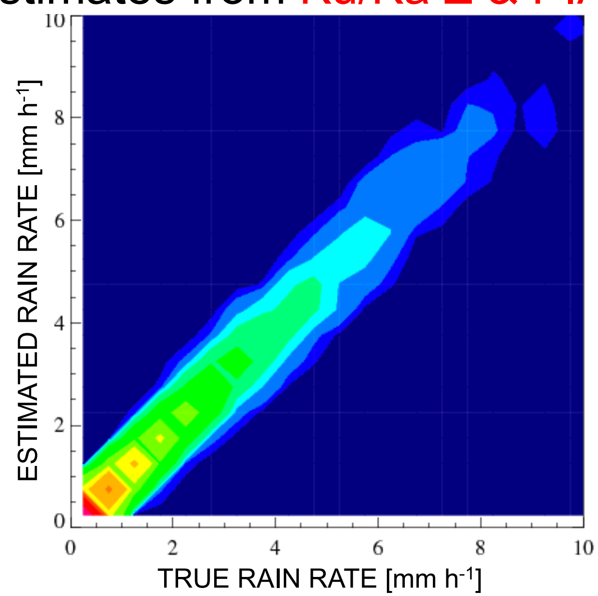
Estimates from Ku/Ka Z & PIA



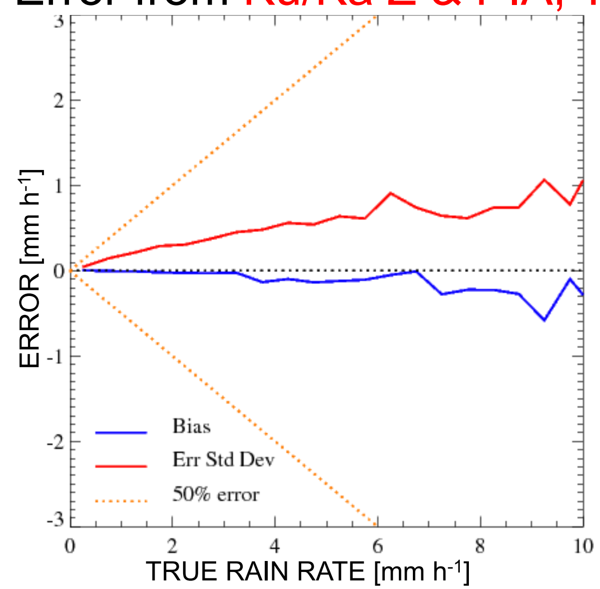
Error from Ku/Ka Z & PIA



Estimates from Ku/Ka Z & PIA, TB

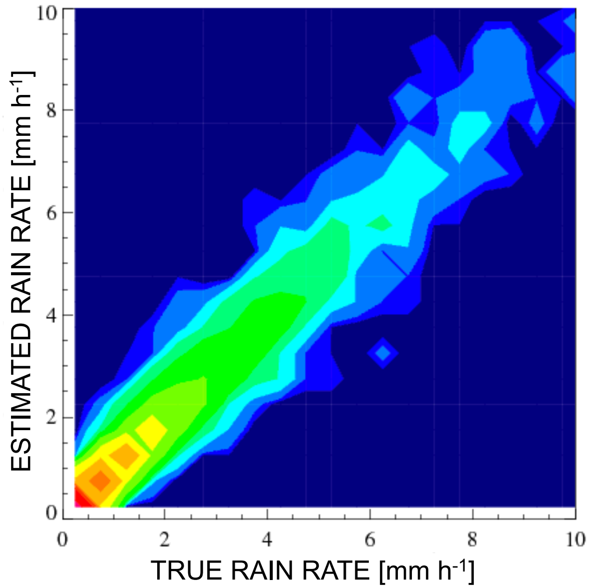


Error from Ku/Ka Z & PIA, TB

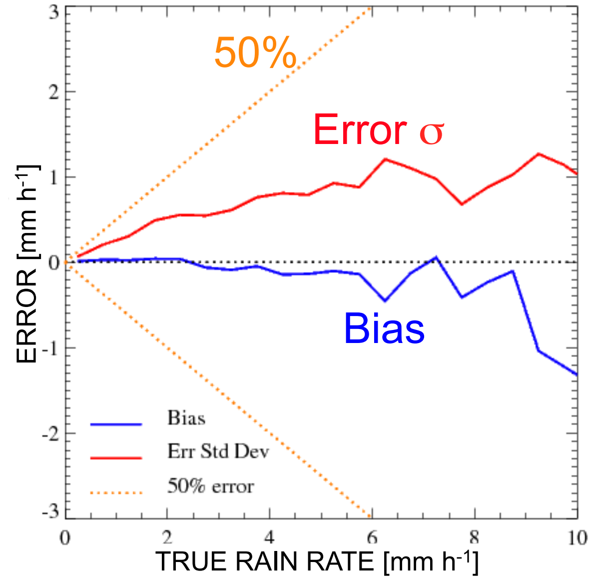


Test Plan Outline – 1 week of TRMM land data; 50 km res.

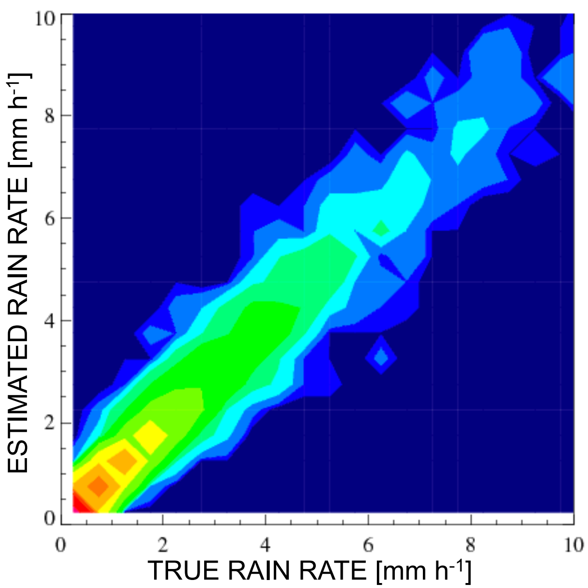
Estimates from Ku/Ka Z & PIA



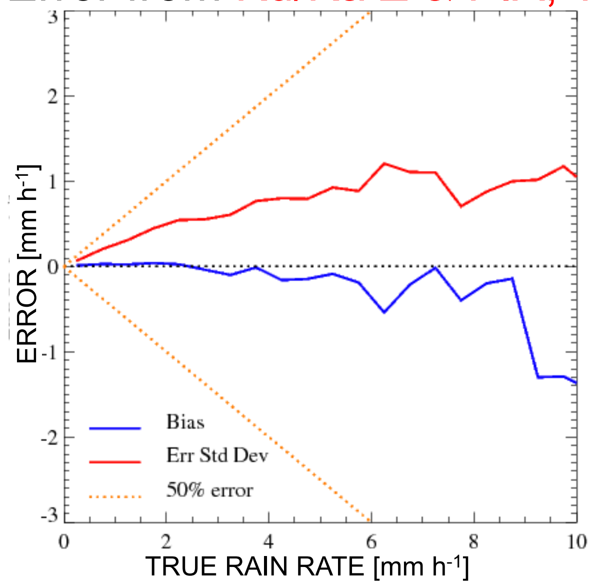
Error from Ku/Ka Z & PIA



Estimates from Ku/Ka Z & PIA, TB



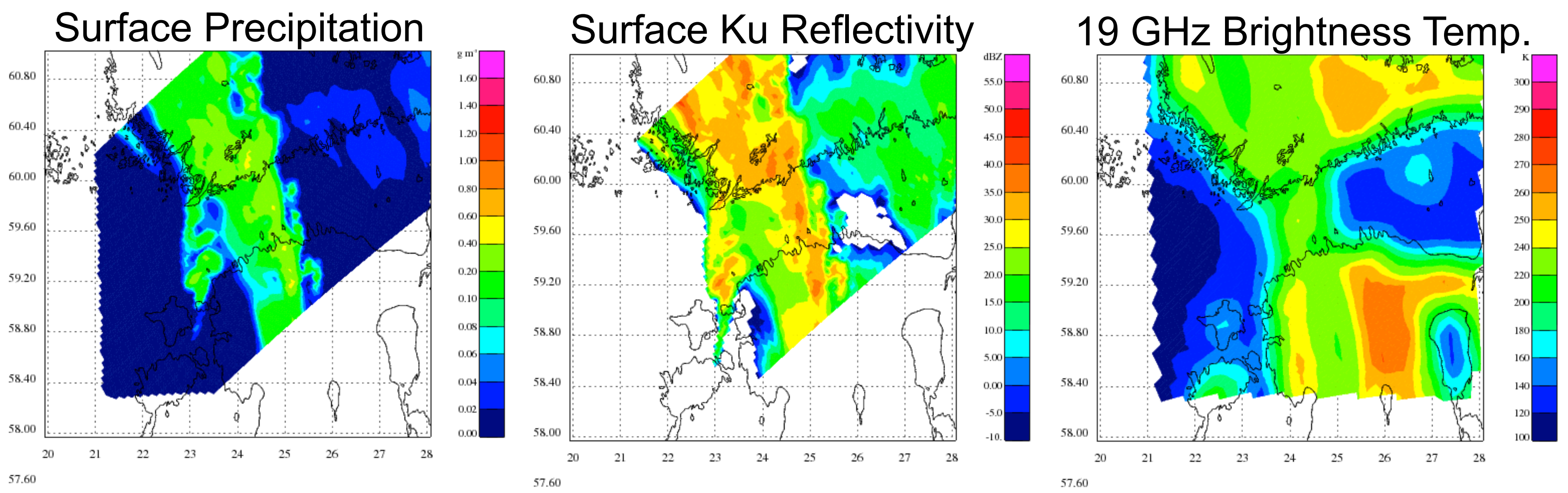
Error from Ku/Ka Z & PIA, TB



Test Plan Outline

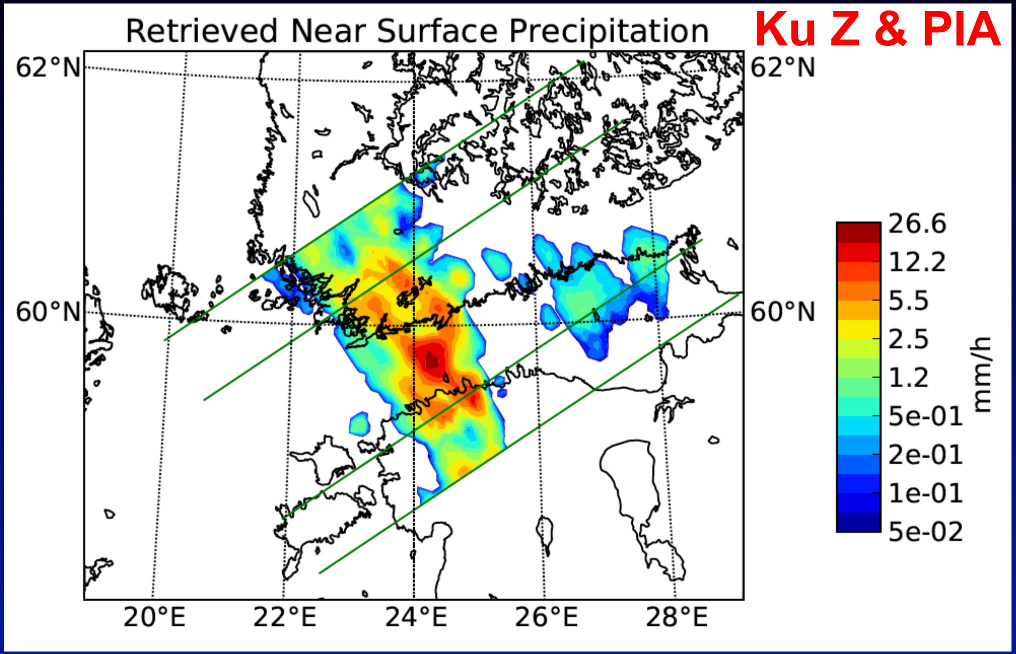
(3) CRM-based Synthetic Retrieval Tests

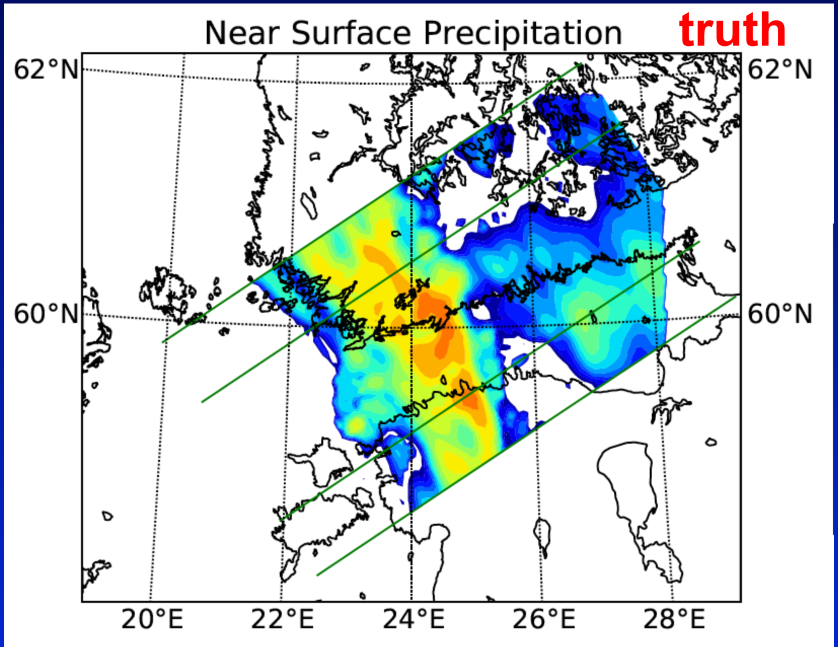
Data: use WRF Model (Matsui) to synthesize DPR and GMI observations; e.g. LPVEx on 9/21/10

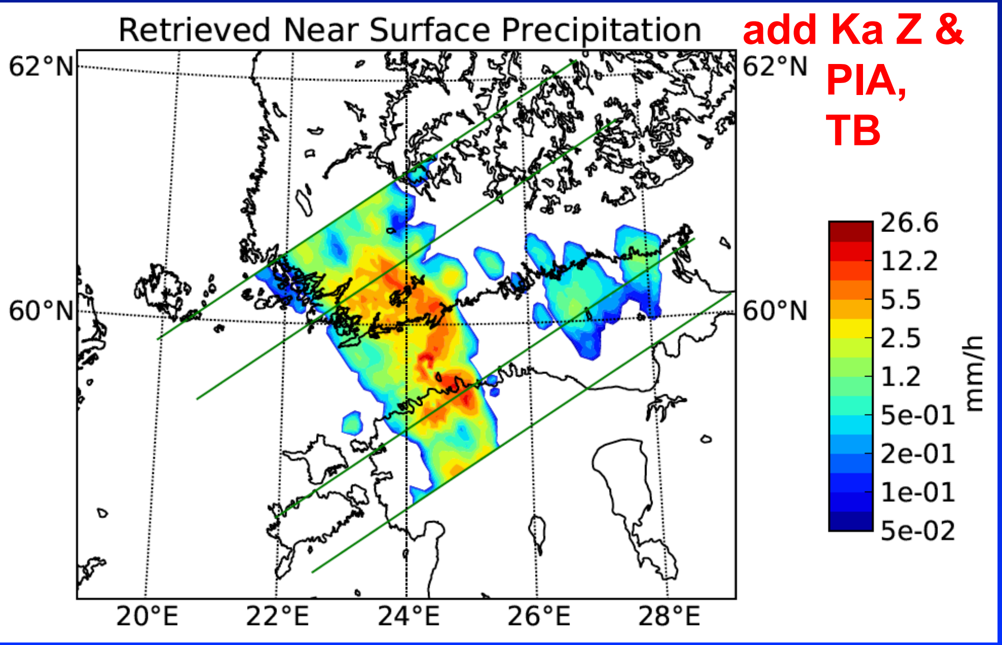


Tests: e.g., sensitivity to sensor/environment information, scattering assumptions, emissivity assumptions, PSD representation, beamfilling uncertainties.

Test Plan Outline







Test Plan Outline

(4) Field Campaign Physics/Statistics Studies (ongoing)

Data: airborne radar Ku/Ka Z's, PIA's
airborne microwave radiometer TB's
in situ microphysics probe
2D video disdrometer, polarimetric radar, profiler
soundings

e.g., Wakasa Bay, LPVEx, MC3E, GCPEx data.

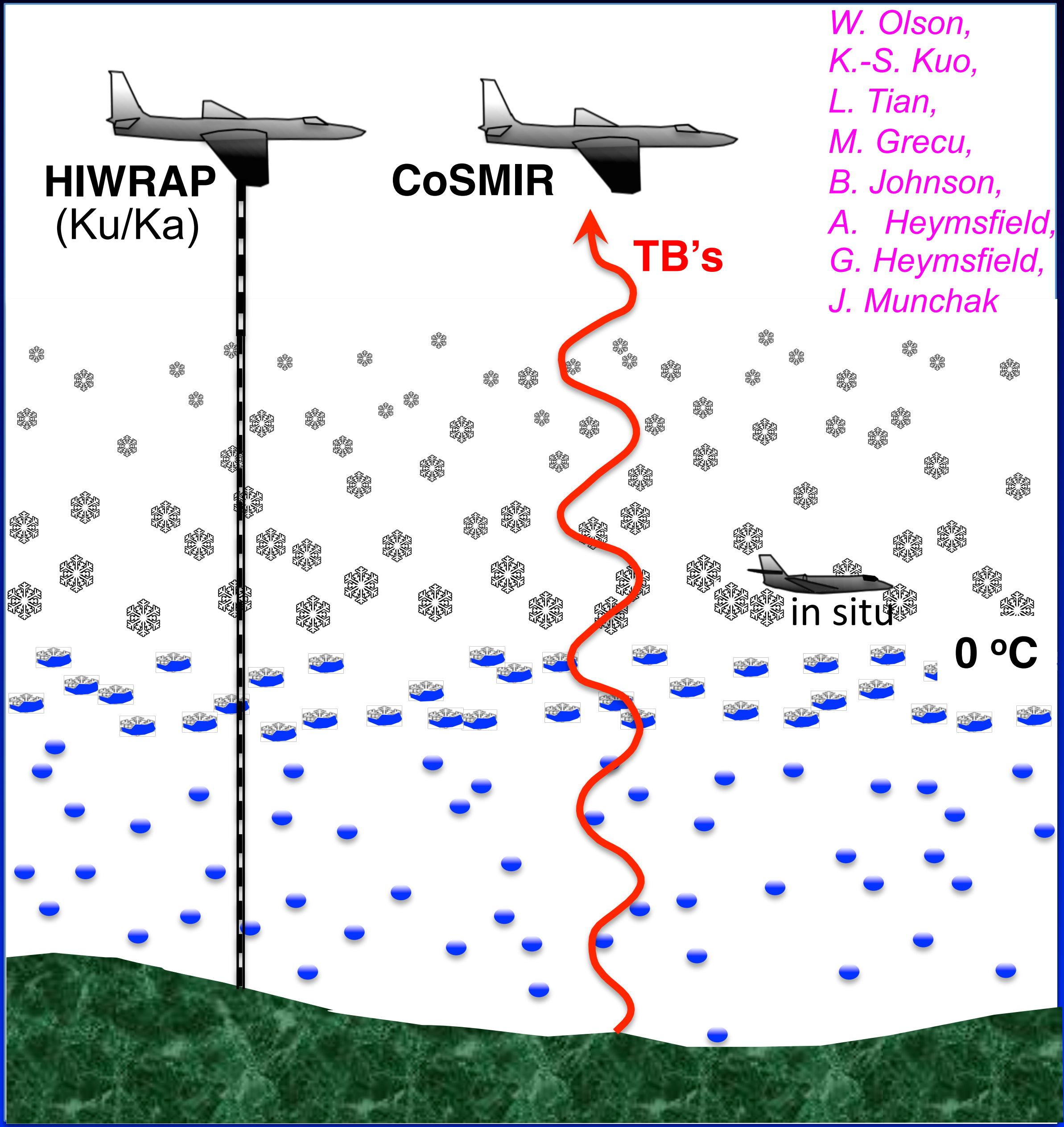
Tests: e.g., test consistency of physical models with simultaneous observations using algorithm framework; update "scattering tables".

e.g., measurement of precipitation size distribution parameter properties; update "scattering tables".

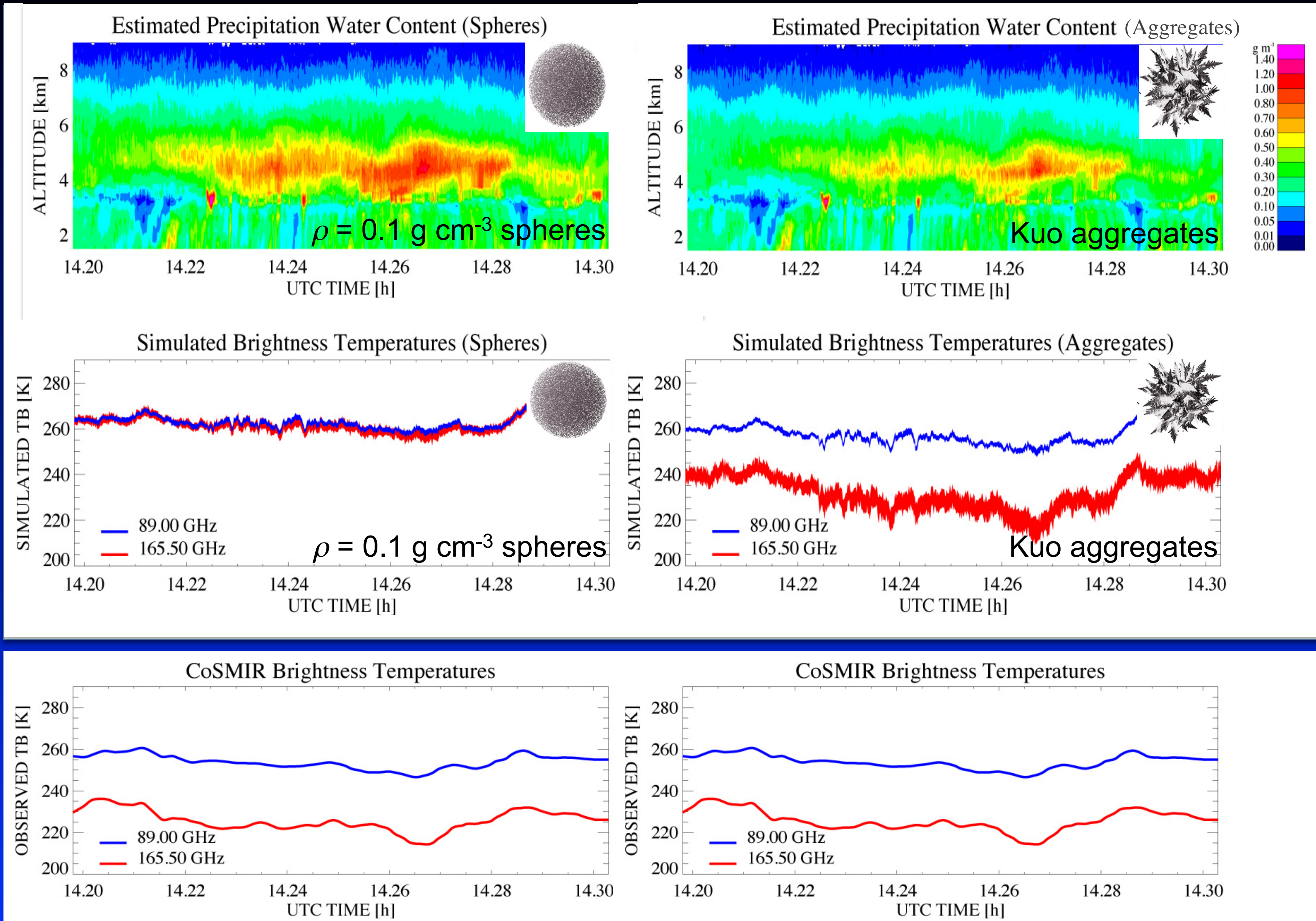
Evaluating Snow Physics Using HIWRAP and CoSMIR in MC3E

- Assign scattering model.
- Retrieve precip profile (PSD's) using HIWRAP.
- Compute consistent microwave scattering properties in profile.
- Simulate upwelling brightness temperatures at 89, 165.5 GHz.
- Compare to CoSMIR obs.

Note: brightness temps aren't sensitive to variations of surface emission and liquid precip if light rain is present => scattering signatures discriminate snow particle models.

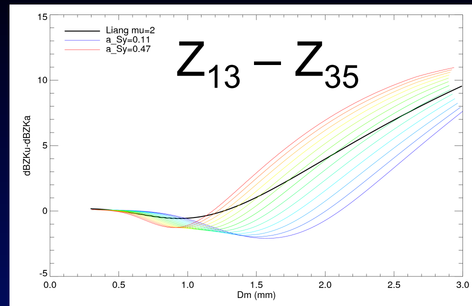


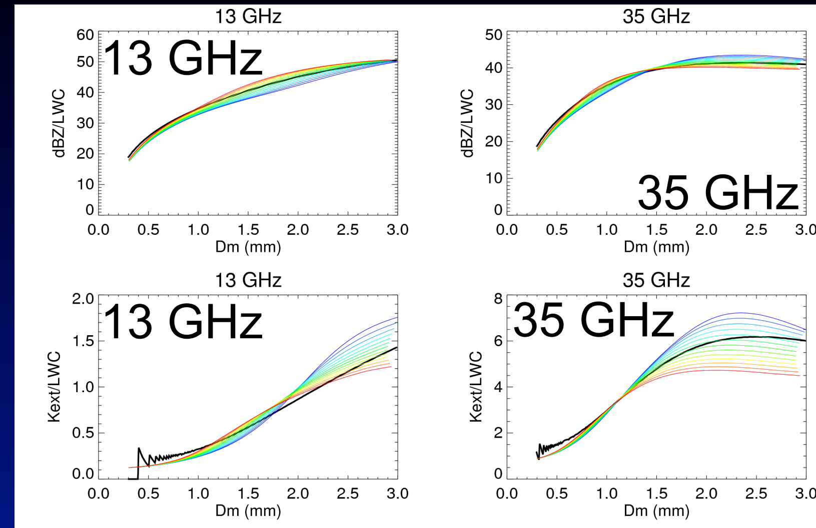
Radar Retrieval and Simulation of TB's Using Spherical/Aggregate Ice



Precipitation Size Distribution μ-D_m Relations in Tables

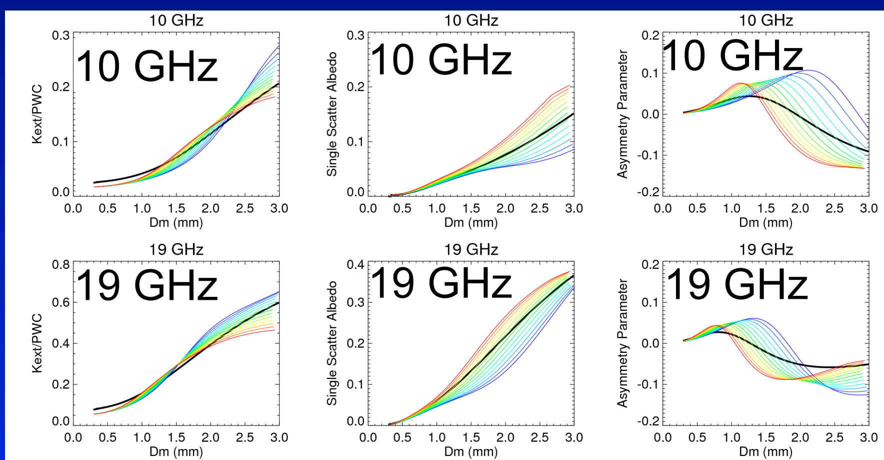
- for DPR:

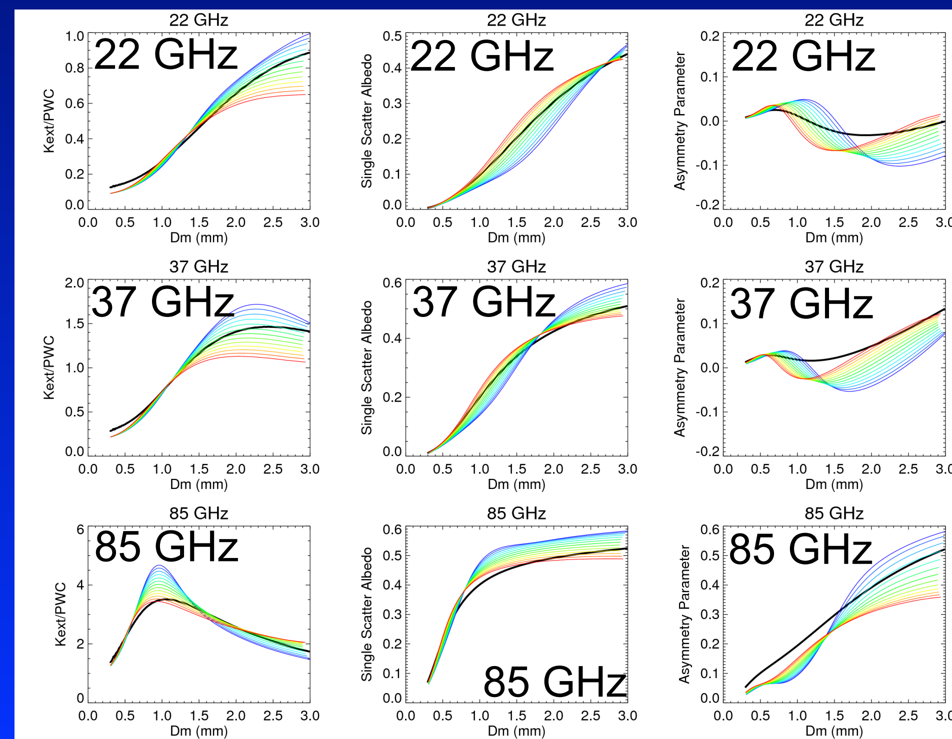




- for radiometer:

DSD group, Ziad Haddad, Joe Munchak





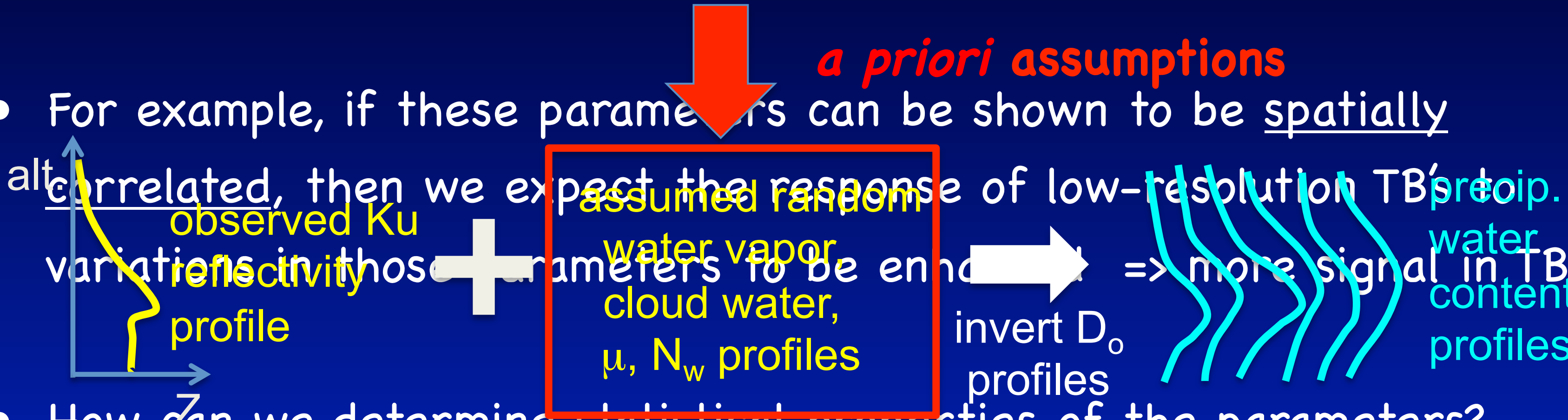
μ = 2 (black line)

various values of σ_y within 3 standard deviations (colors)

How do we get more impact from GMI brightness temps?

- Generally, to enhance impact of TB's, need more specific information on N_w, RH, cloud water, land surface emissivity.

- For example, if these parameters can be shown to be spatially correlated, then we expect the response of low-resolution TB's to variations in those parameters to be enhanced => more signal in TB's.



- How can we determine statistical properties of the parameters?

  - ➡ field campaign data as guide, e.g., PSD's from dual-pol, profiler.
  - ➡ post launch algorithm "bootstrapping", e.g., N_w.

- Same principle can be applied to constrain PSD parameters in outer swath using statistics derived from accurate inner swath PSD's.

At Launch Code for Sept. 2013

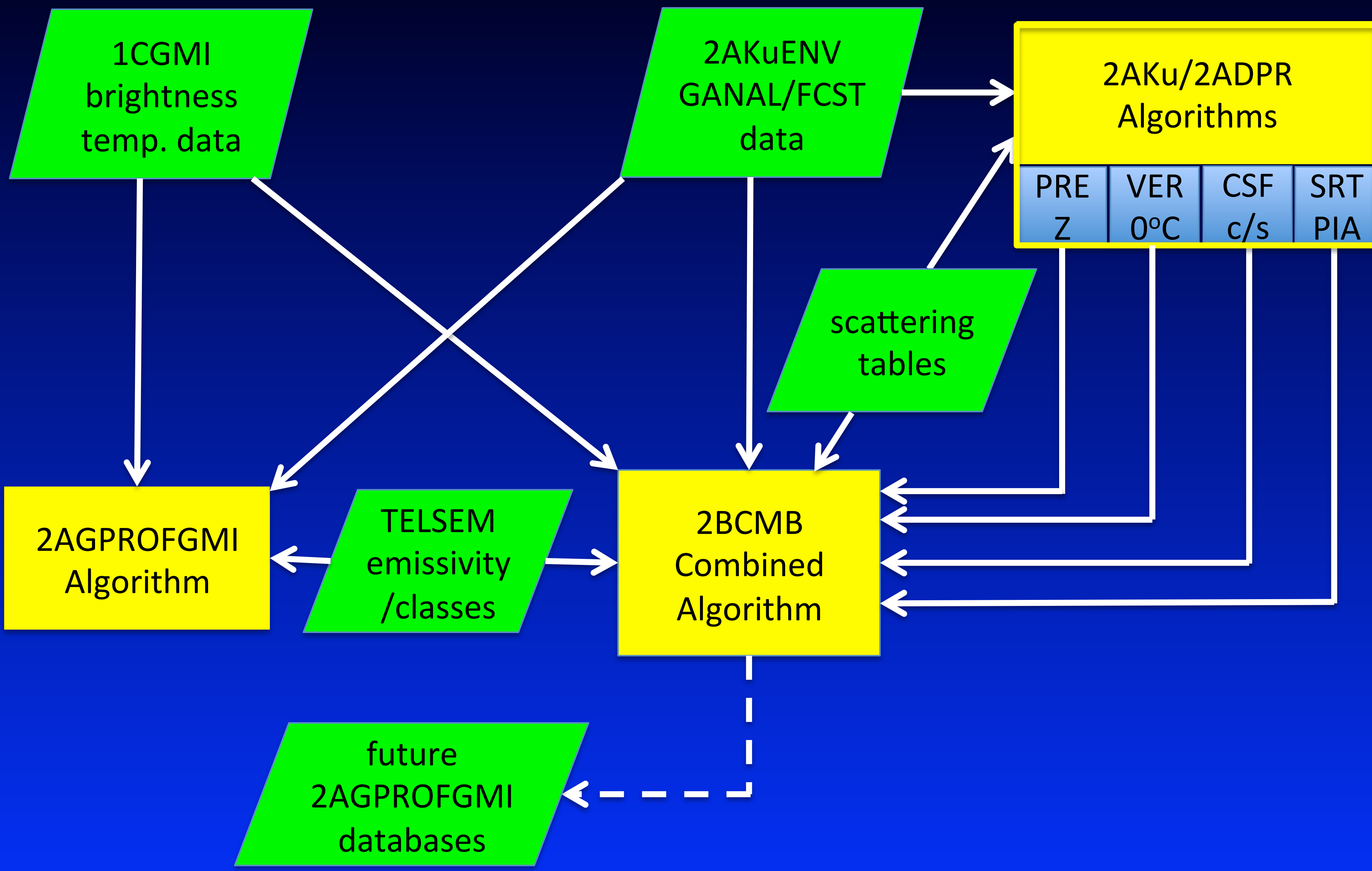
- Ensure compatibility with DPR L2 PRE, VER, CSF, and SRT inputs.
- Include GMI high-frequency data; snow scattering tables.
- Select final precipitation scattering tables; D_m vs. μ constraint.
- Generalize *a priori* atmospheric environmental state -> higher lats.
- Select final land emissivity representation; interchannel covariances.
- Test of full satellite algorithm, including TRMM- and CRM-generated synthetic data.

Extras

Synopsis

- Revised "At-Launch" algorithm, and ATBD, for PPS will be produced this month (March 2013).
- On track to deliver final At-Launch algorithm by Sept. 2013.
- Primary activity in 2013 will be the testing of different options within the algorithm architecture that has been established.
- To optimize impact of all GPM channels, need to ensure physical parameterizations and statistics of initial ensembles are realistic.
  => continued FC studies & 1-D testing; algorithm bootstrapping.

Combined Algorithm Links to Other Algorithms/Datasets



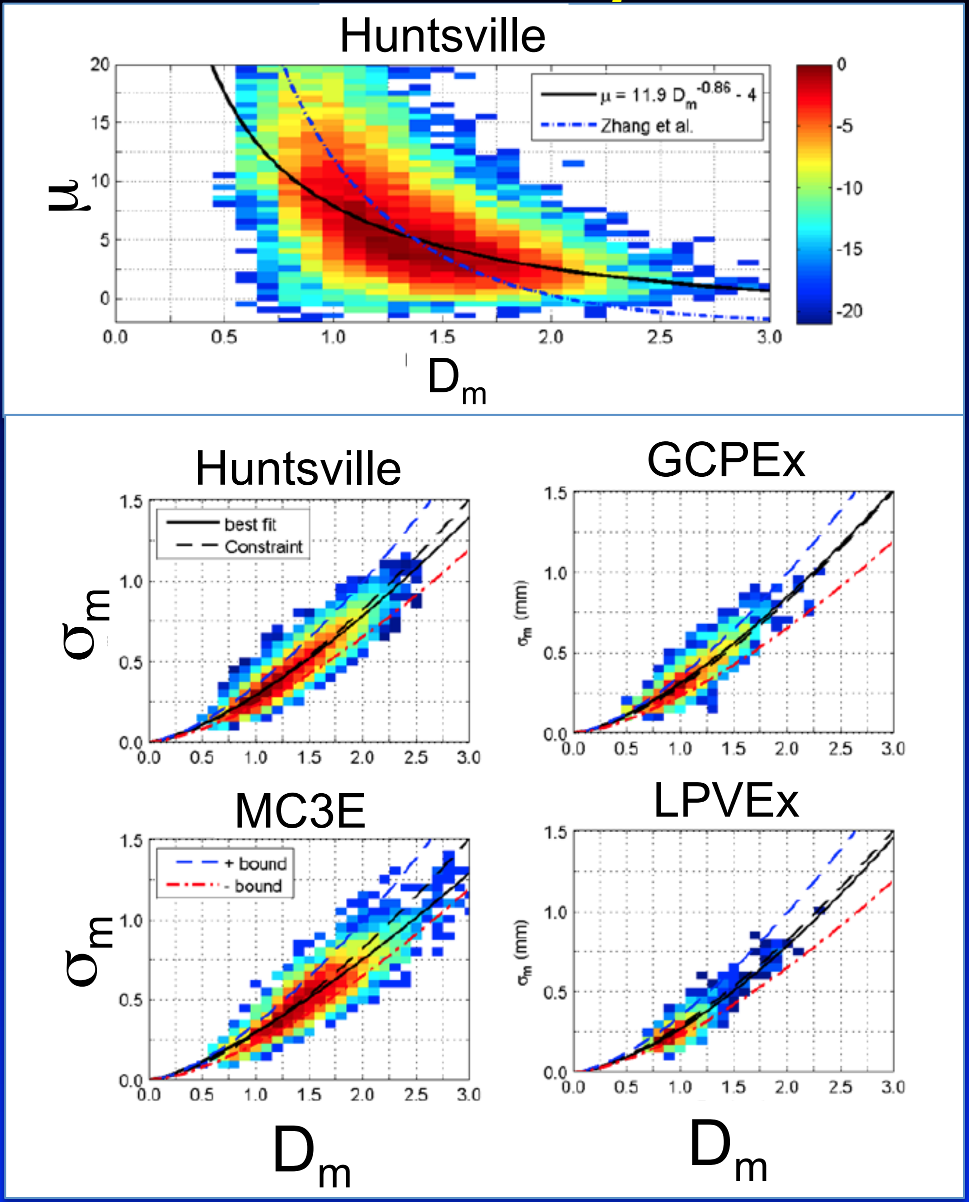
Precipitation Size Distribution Statistical Properties

- DPR yields 2 reflectivities per gate. Therefore seek 2 precipitation PSD params.
- Usually μ is fixed and N_w, D_m retrieved, but μ is anticorrelated with D_m!
- However, field campaigns show:

$$\sigma_m = \sigma_y D_m^{1.42}$$

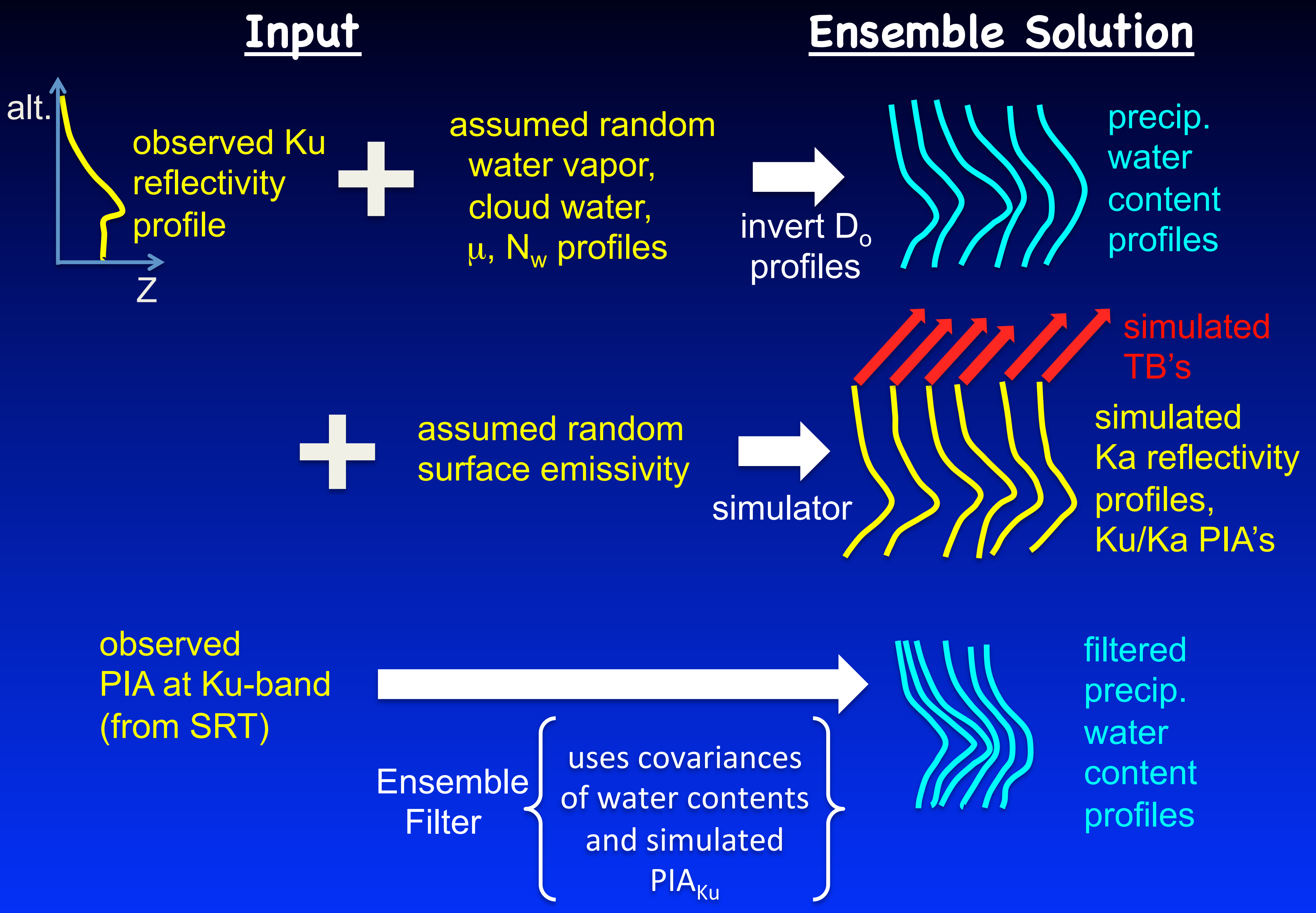
- Combine with:

$$\sigma_m^2 = D_m^2 / (4 + \mu)$$



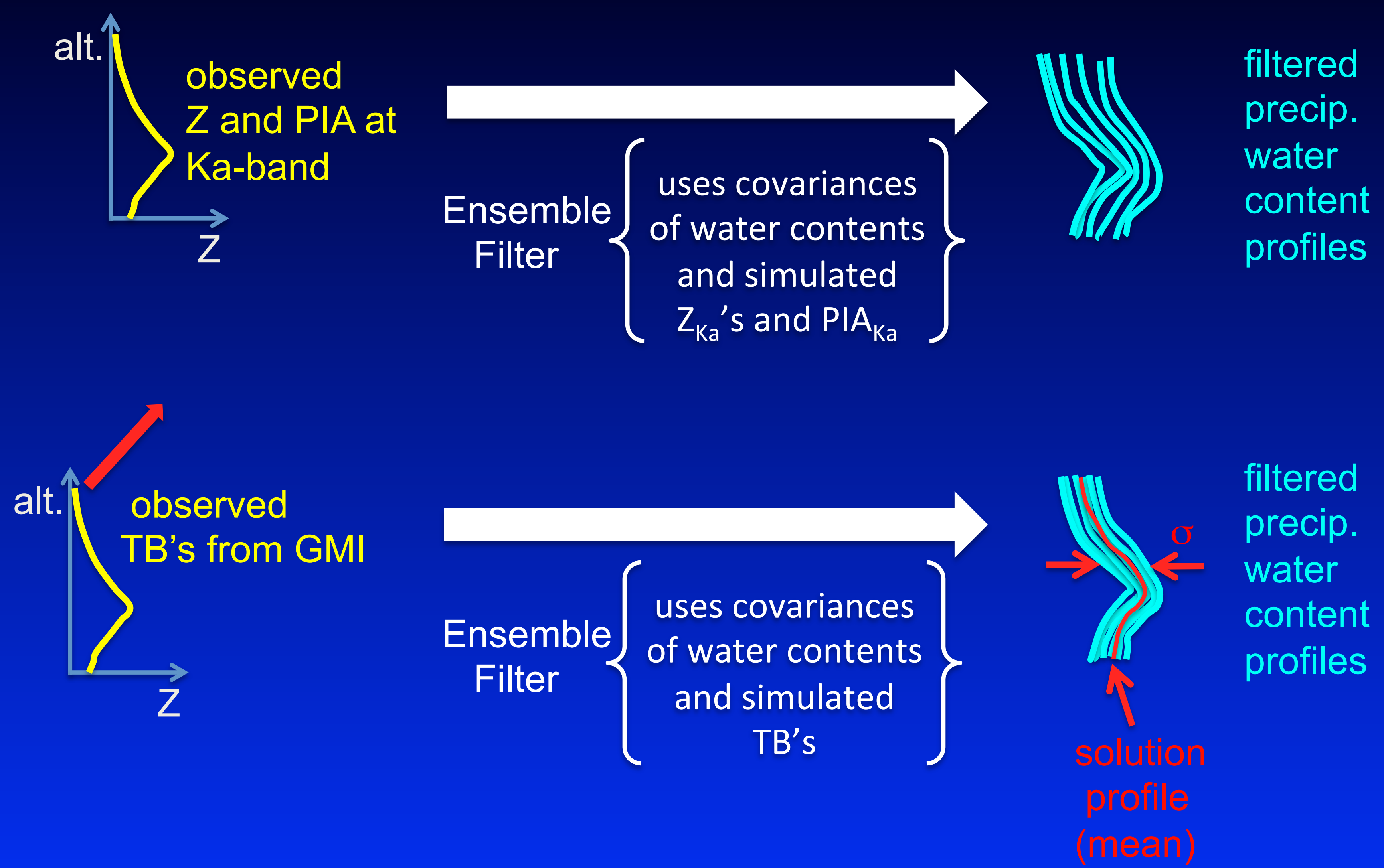
to obtain D_m vs μ relation in scattering tables.

Algorithm "Concept" --- Ensemble (Kalman) Filter



Algorithm "Concept" --- Ensemble (Kalman) Filter

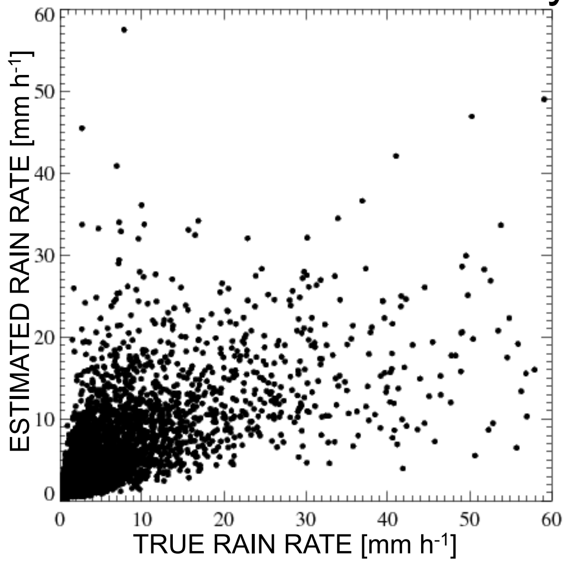
Input | **Ensemble Solution**



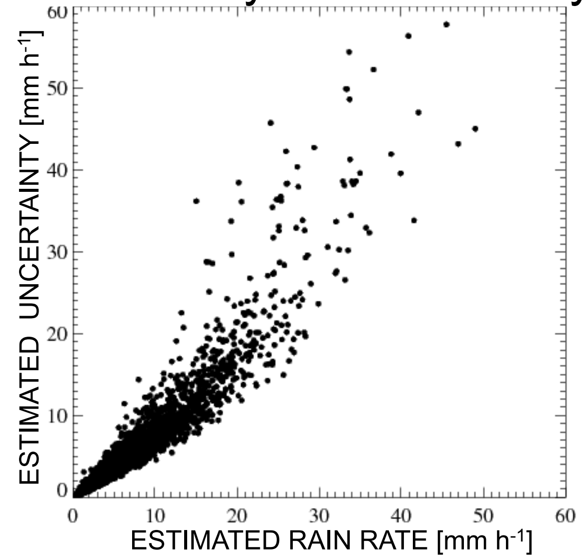
Test Plan Outline

Based on TRMM Orbit 77612 – Footprint Scale

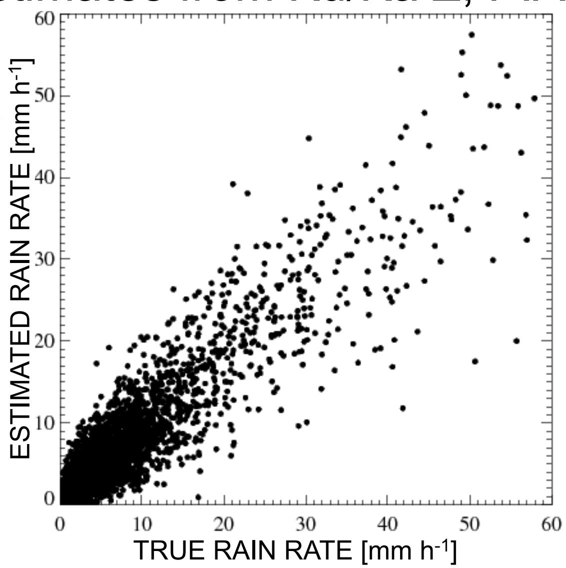
Estimates from Ku Z only



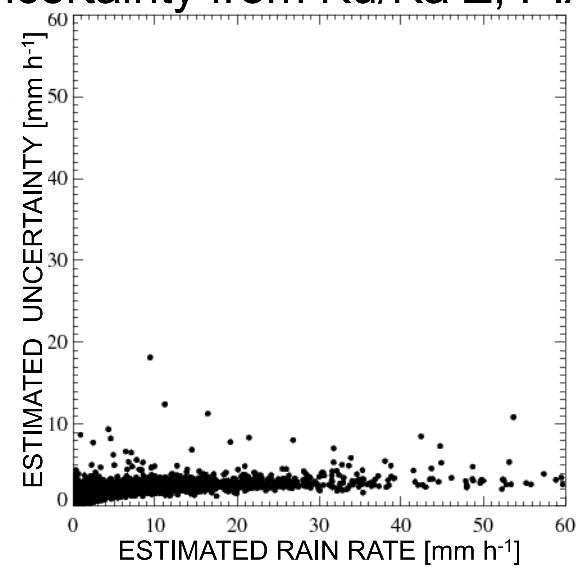
Uncertainty from Ku Z only



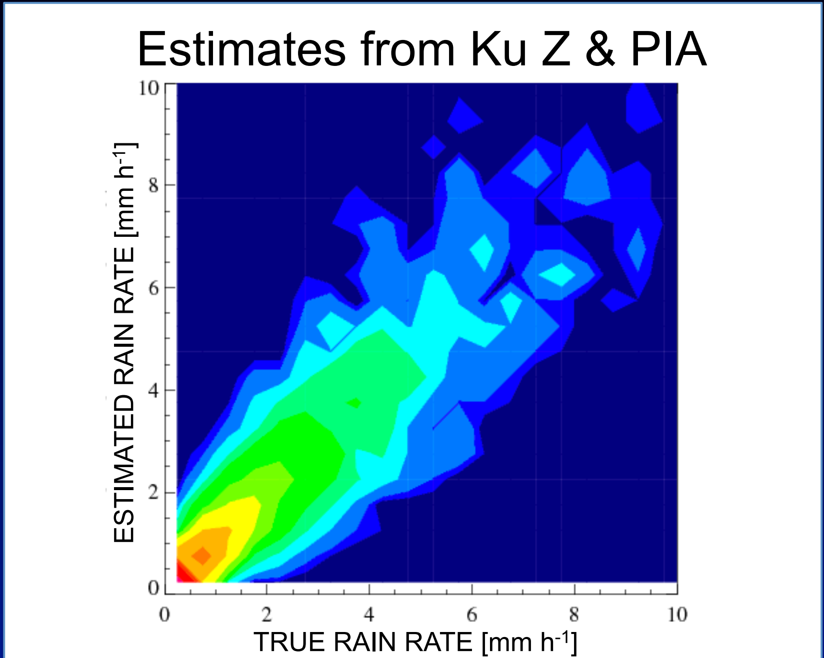
Estimates from Ku/Ka Z, PIA, TB

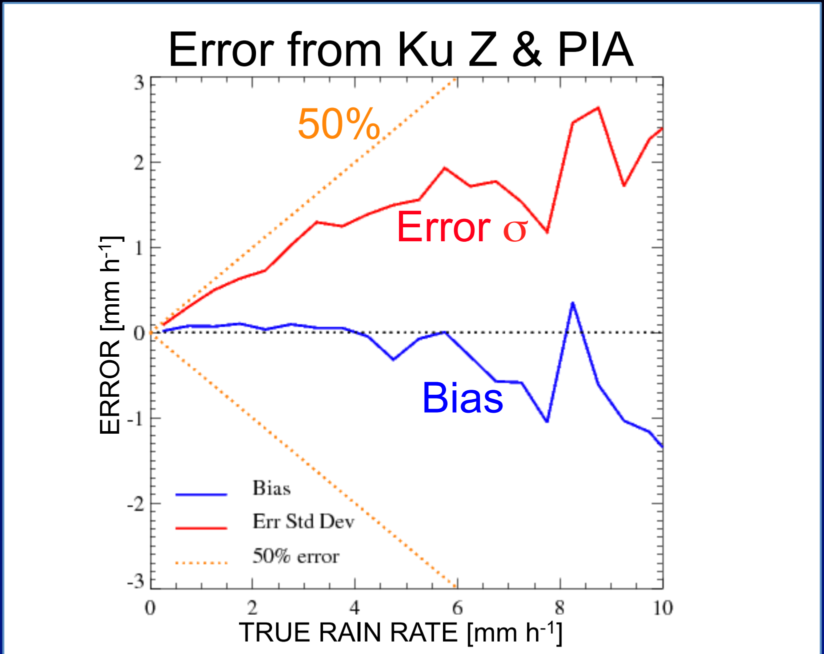


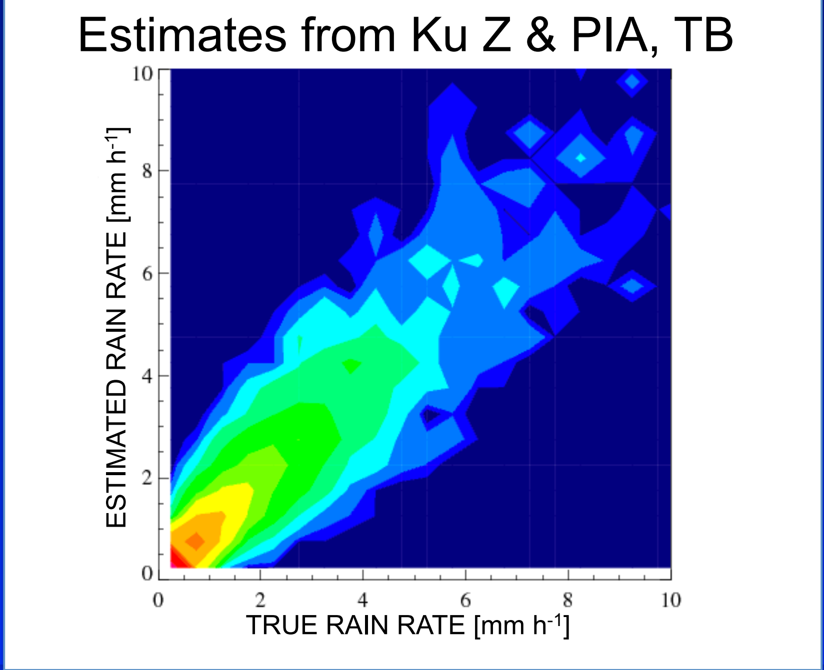
Uncertainty from Ku/Ka Z, PIA, TB

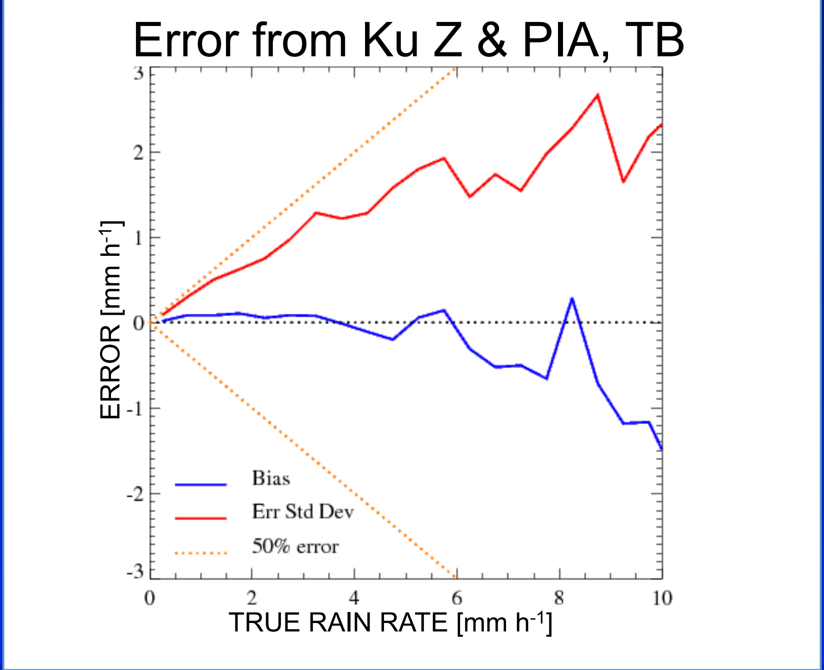


Test Plan Outline – 1 week of TRMM land data; 50 km res.

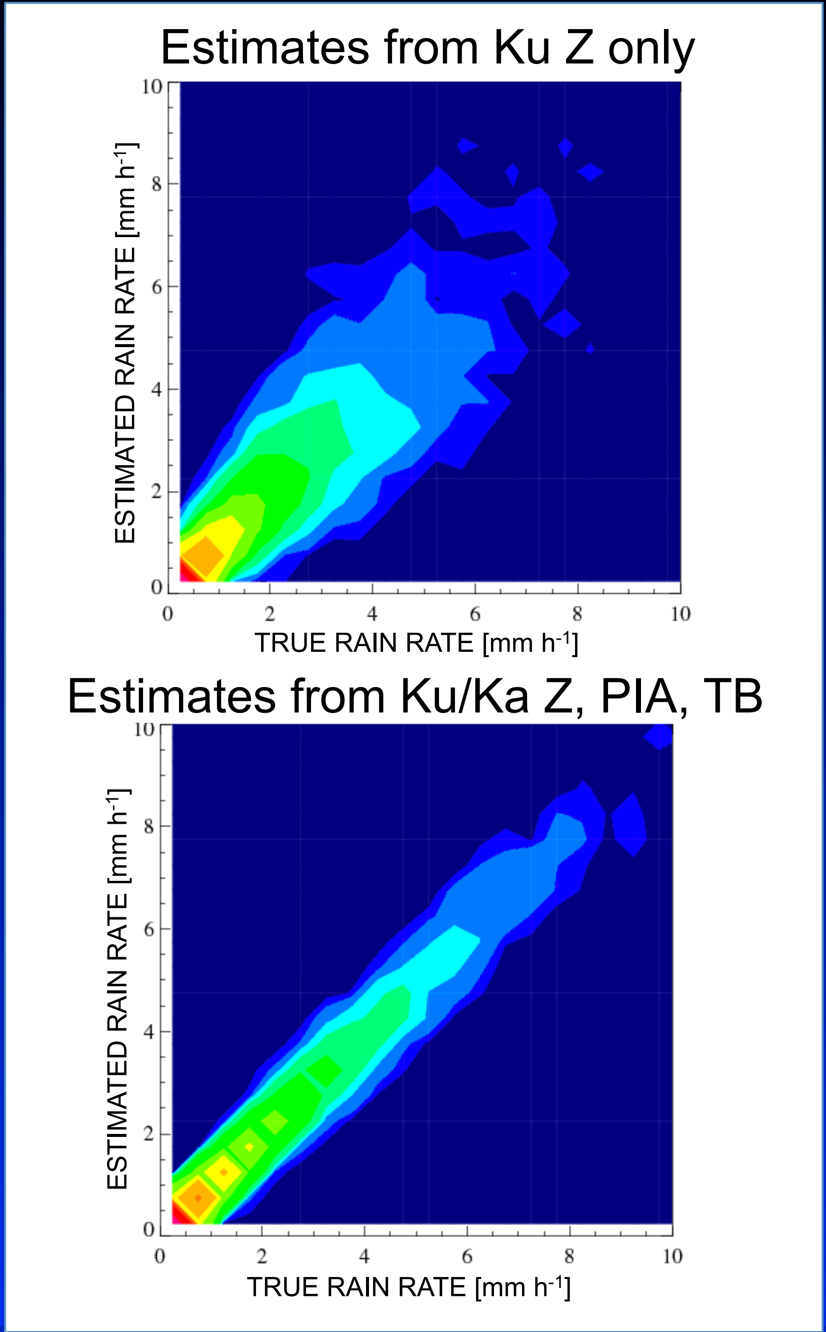


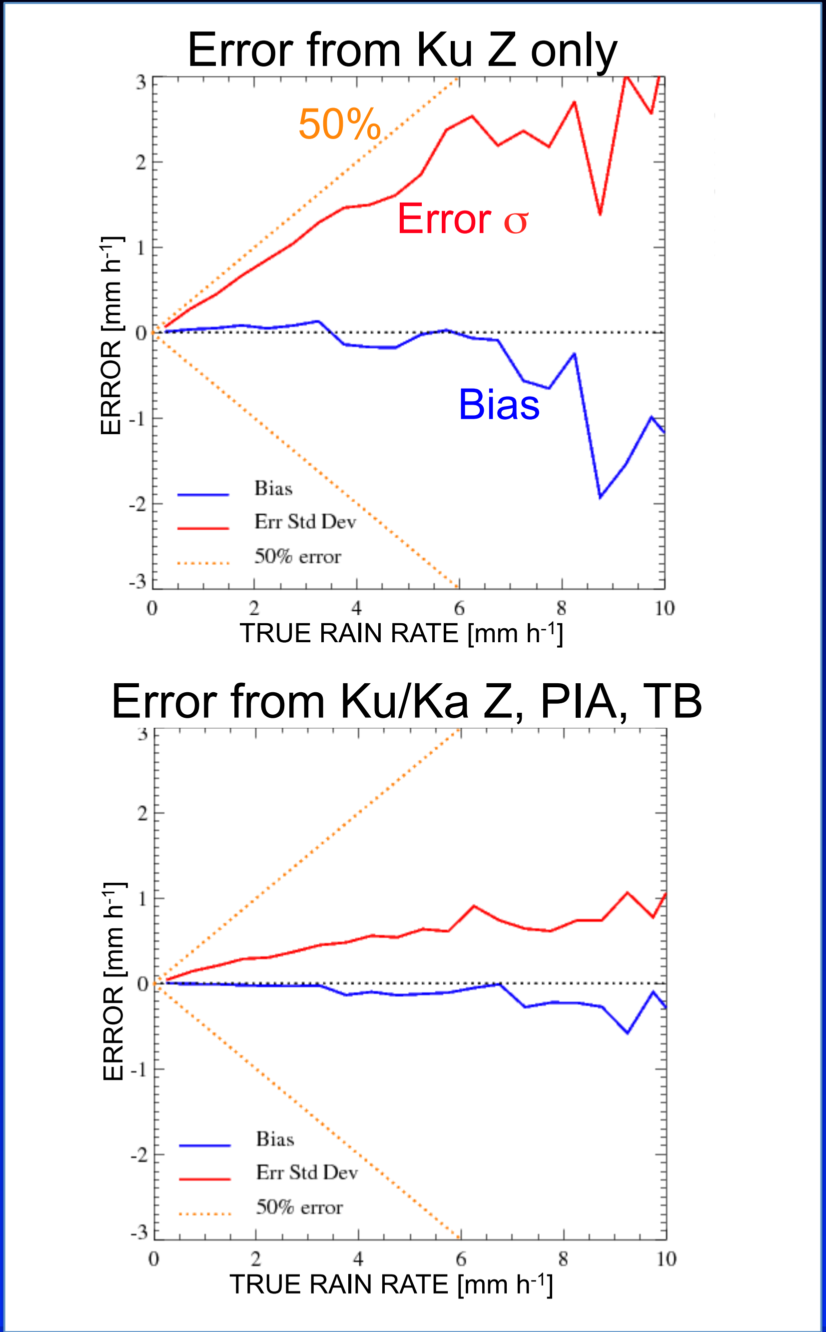




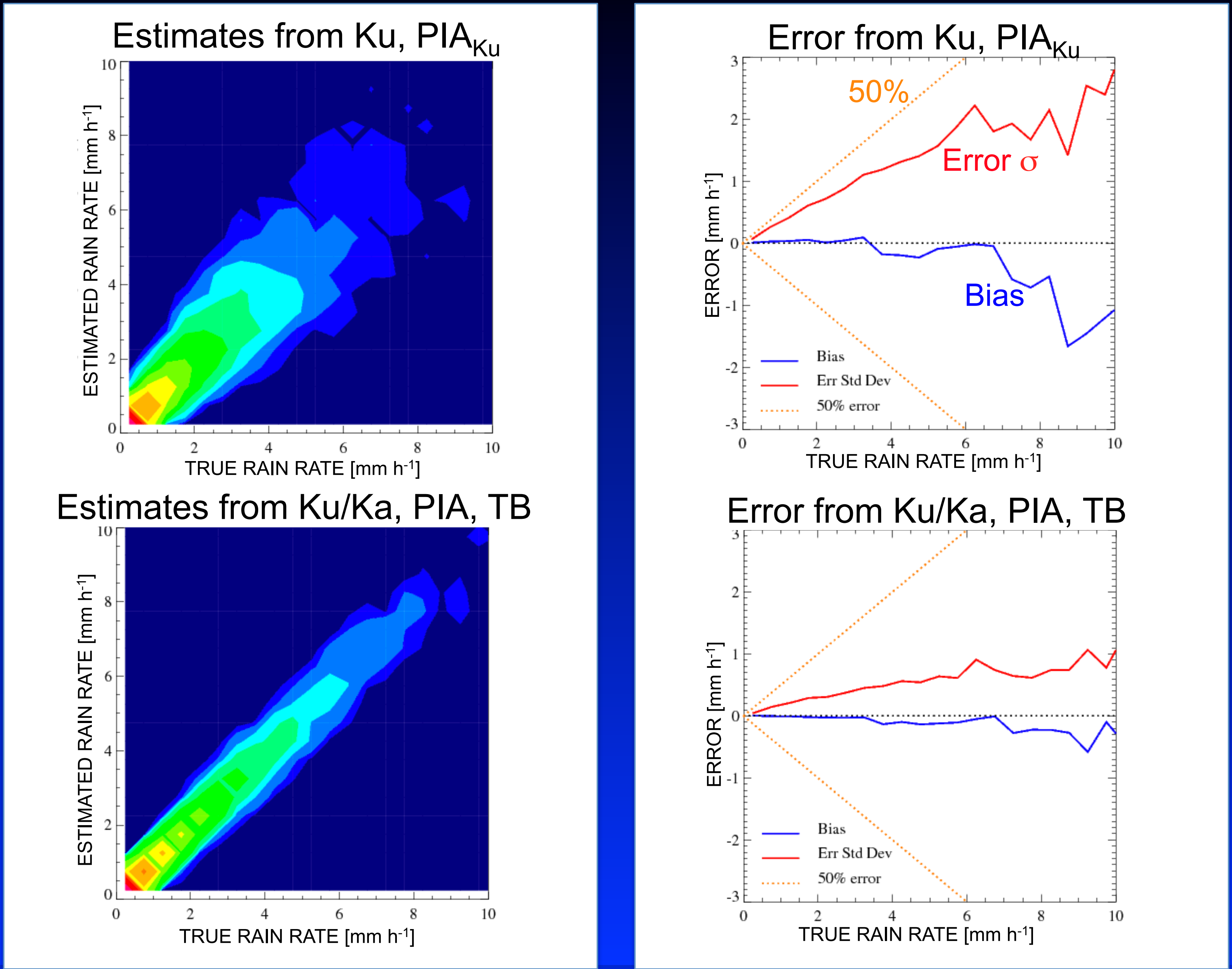


Test Plan Outline – 1 week of TRMM ocean data; 50 km res.

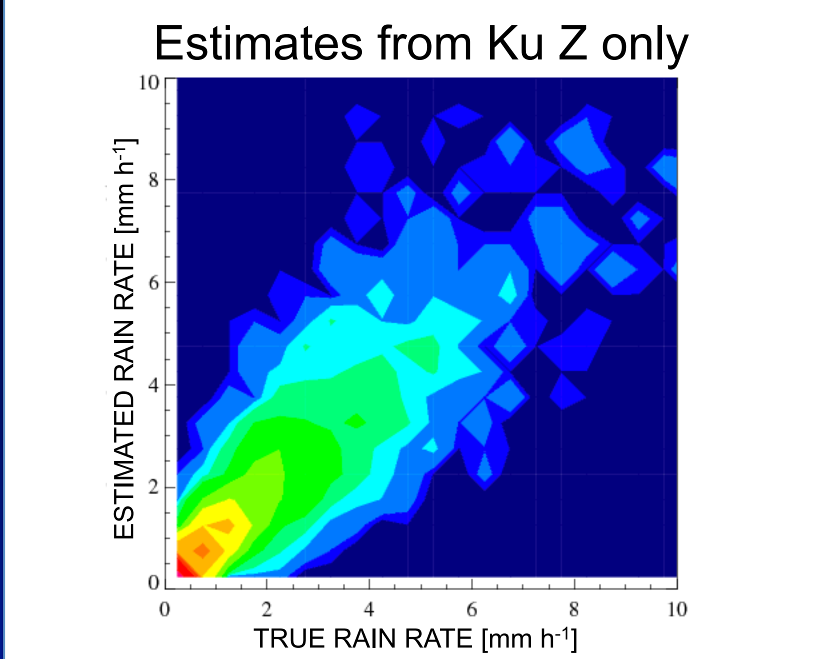


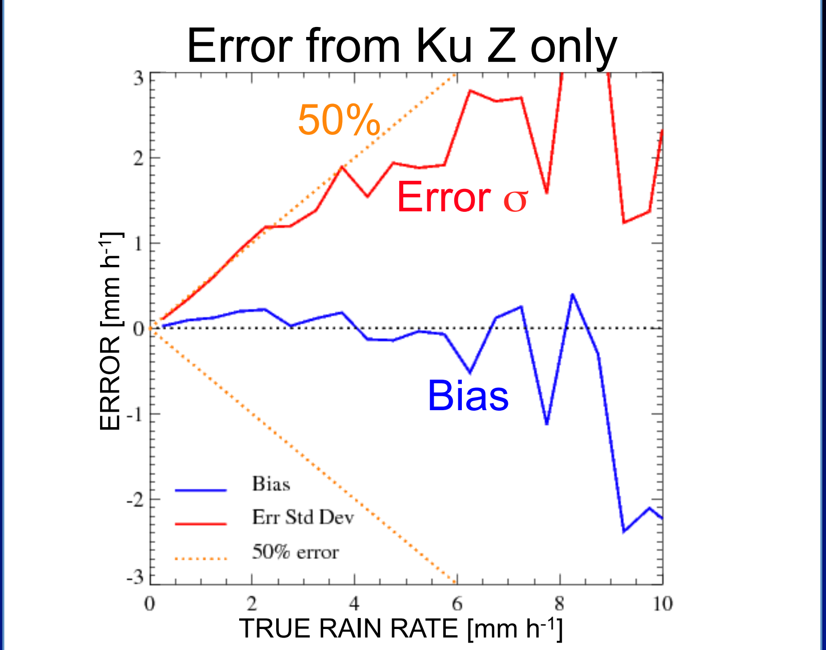


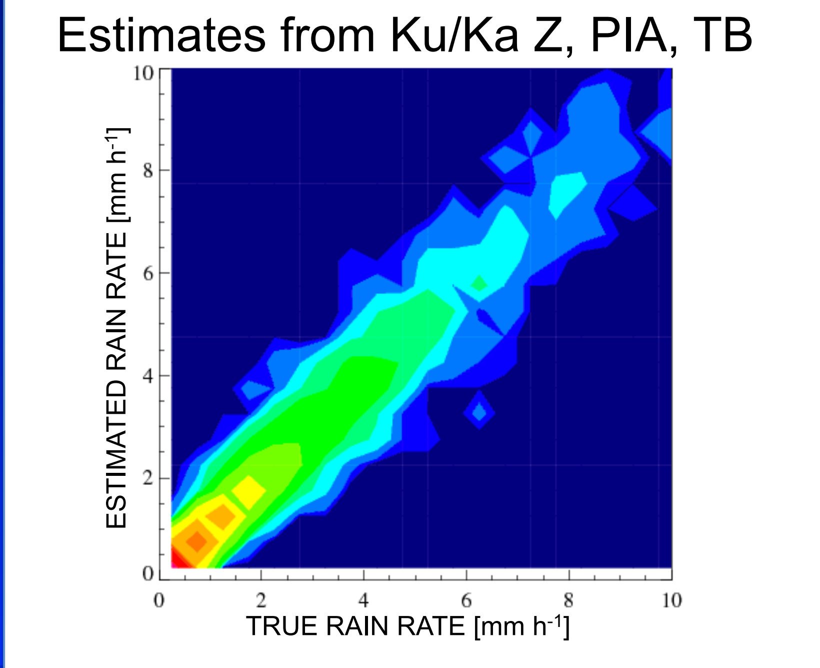
Test Plan Outline – 1 week of TRMM ocean data; 50 km res.

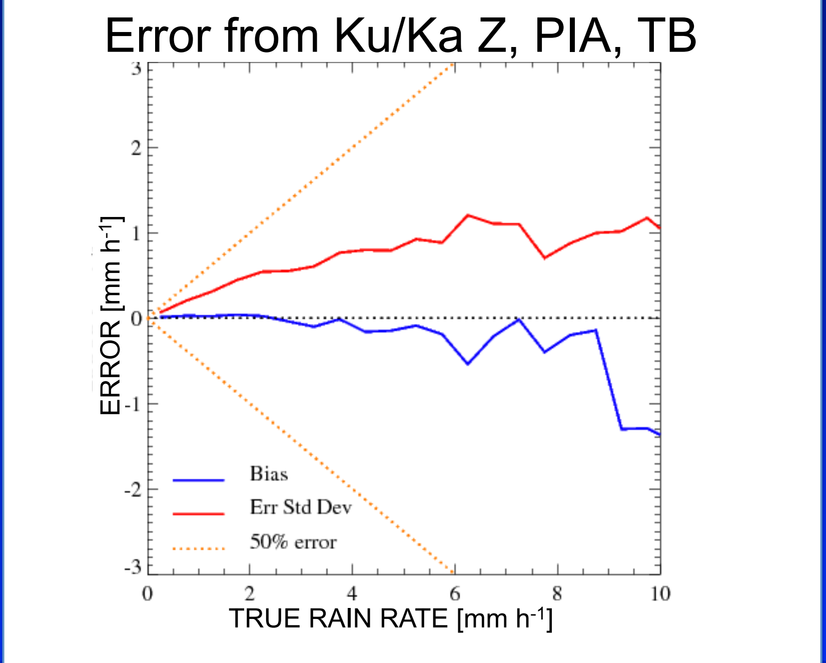


Test Plan Outline – 1 week of TRMM land data; 50 km res.

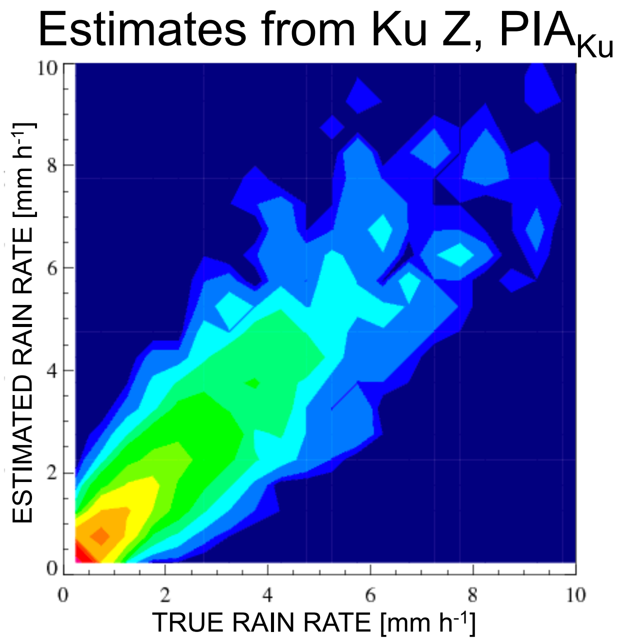


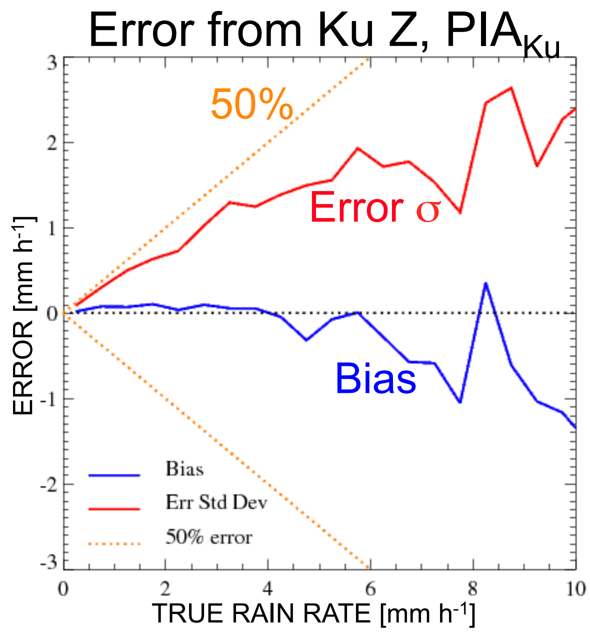


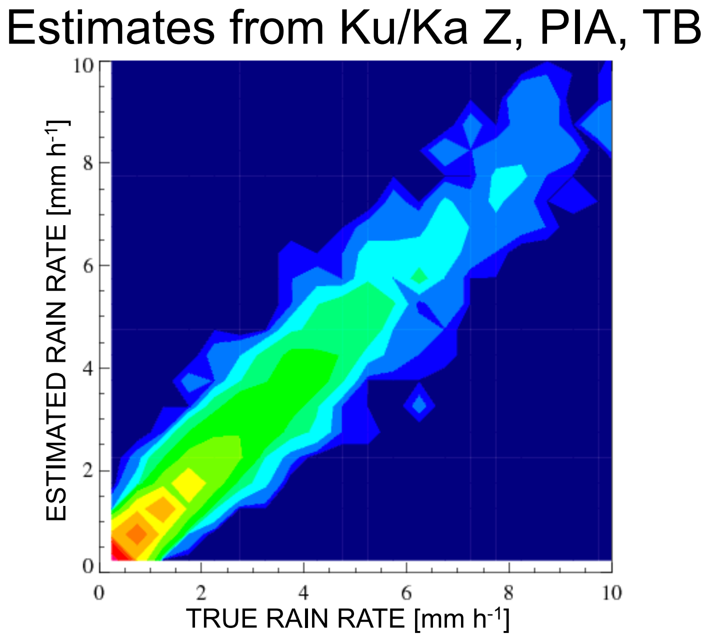


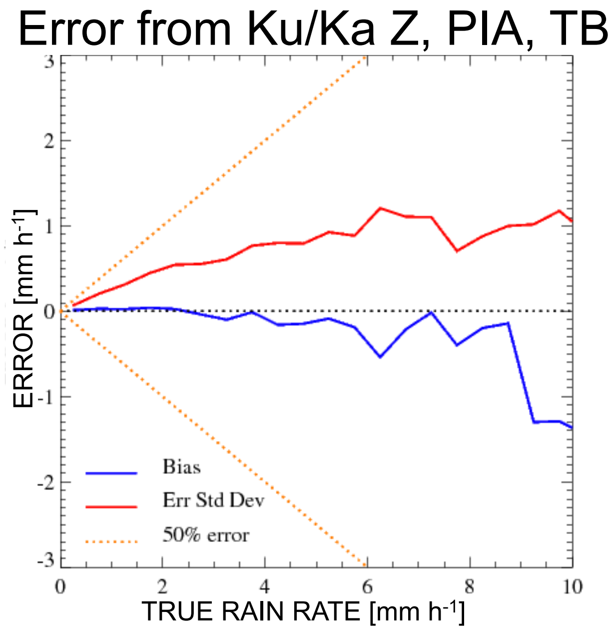


Test Plan Outline – 1 week of TRMM land data; 50 km res.



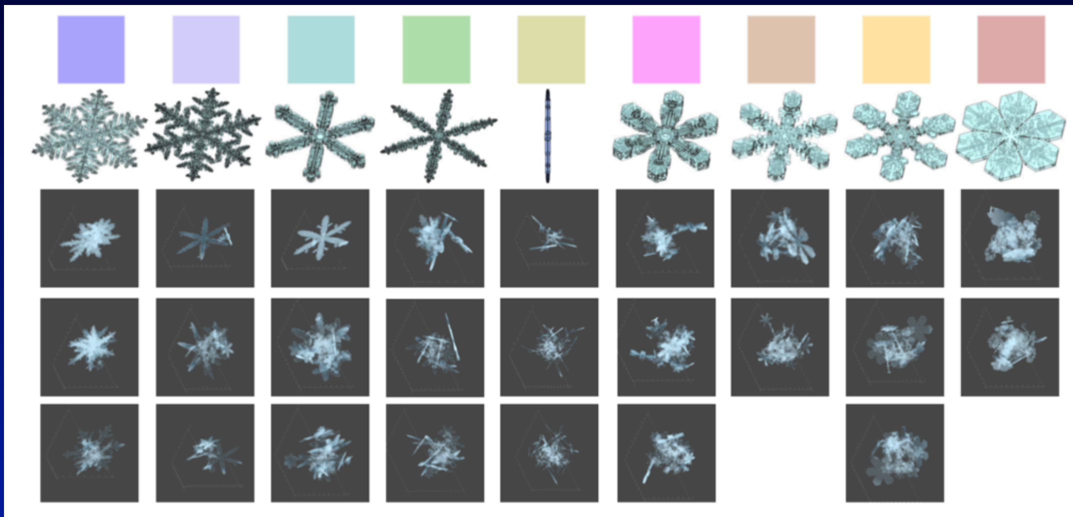




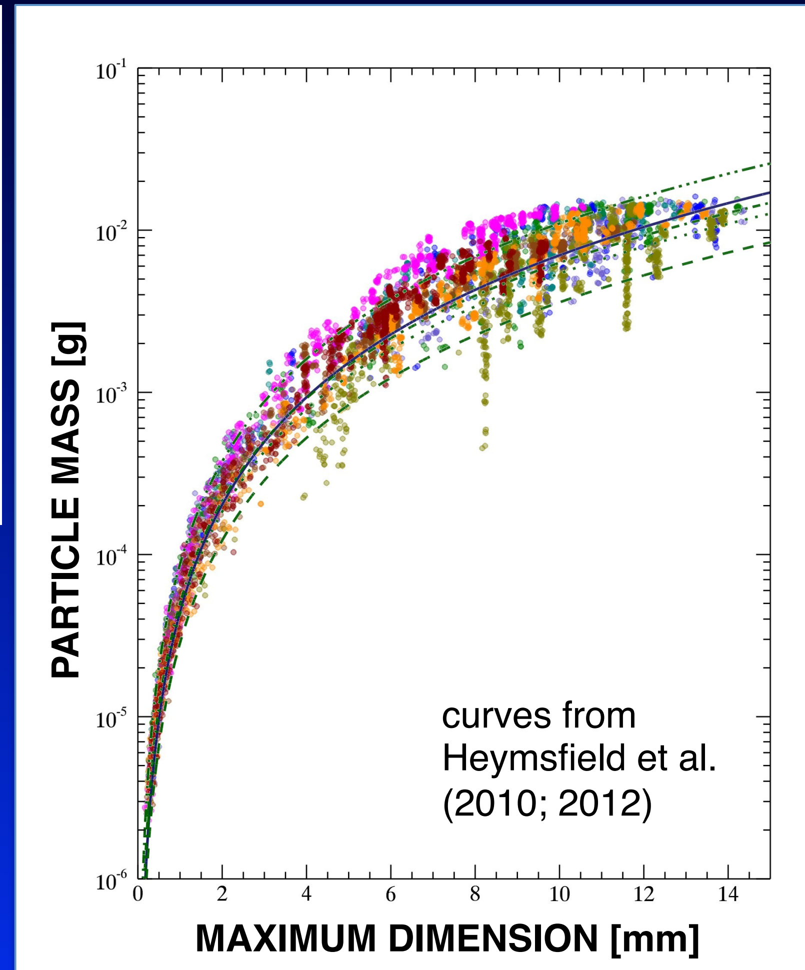


Simulation of Ice-Phase Precipitation in Stratiform Regions

Simulated Aggregates



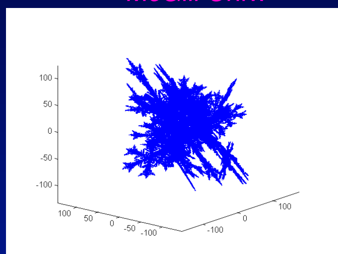
Mass vs. Size

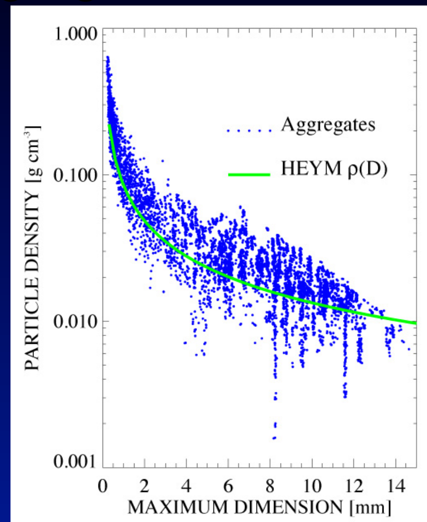


- Note that aggregates are composed of only one pristine crystal type, indicated by the colors.
- Mass vs. size fairly consistent with airborne *in situ* observations.

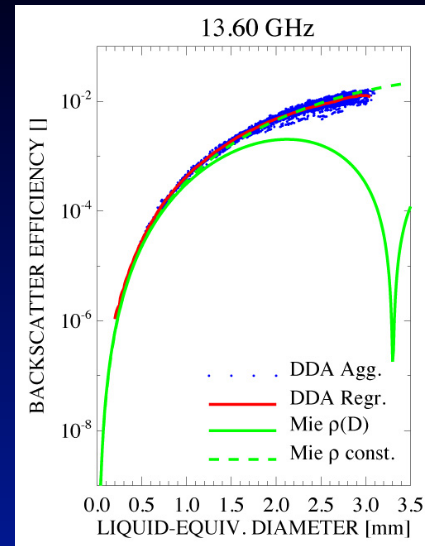
Single-Scattering Calculations for Spherical and Aggregate Ice Particles

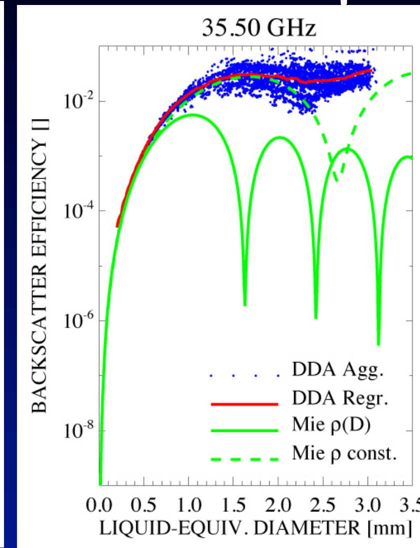
Simulated Aggregate Particles



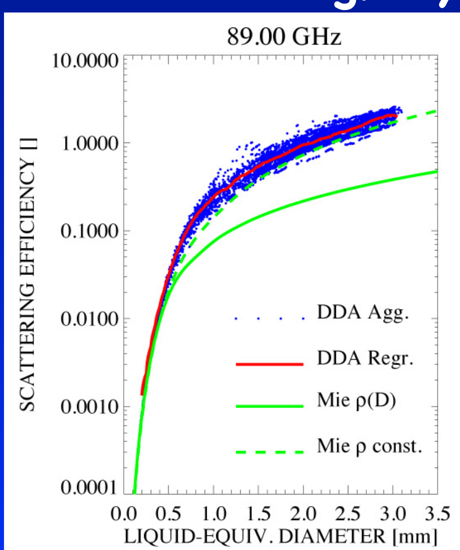


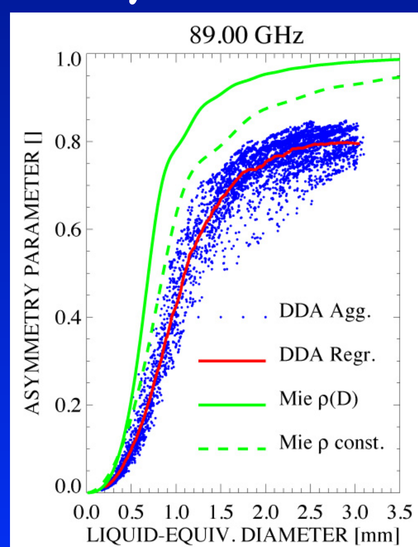
Backscatter at 13 and 35 GHz Frequencies

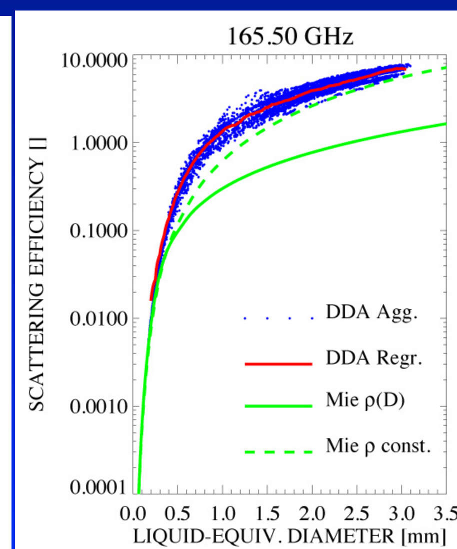


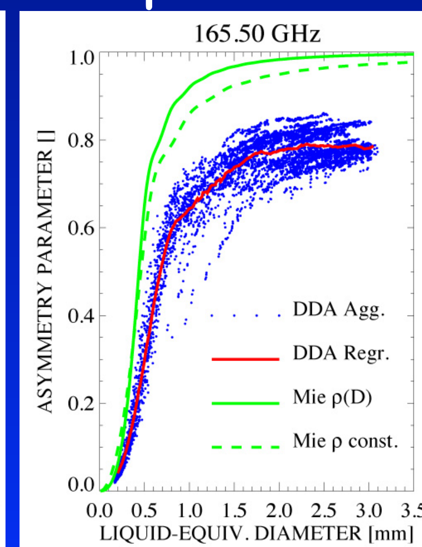


Scattering/Asymmetry at 89 GHz and 165 GHz Channel Frequencies



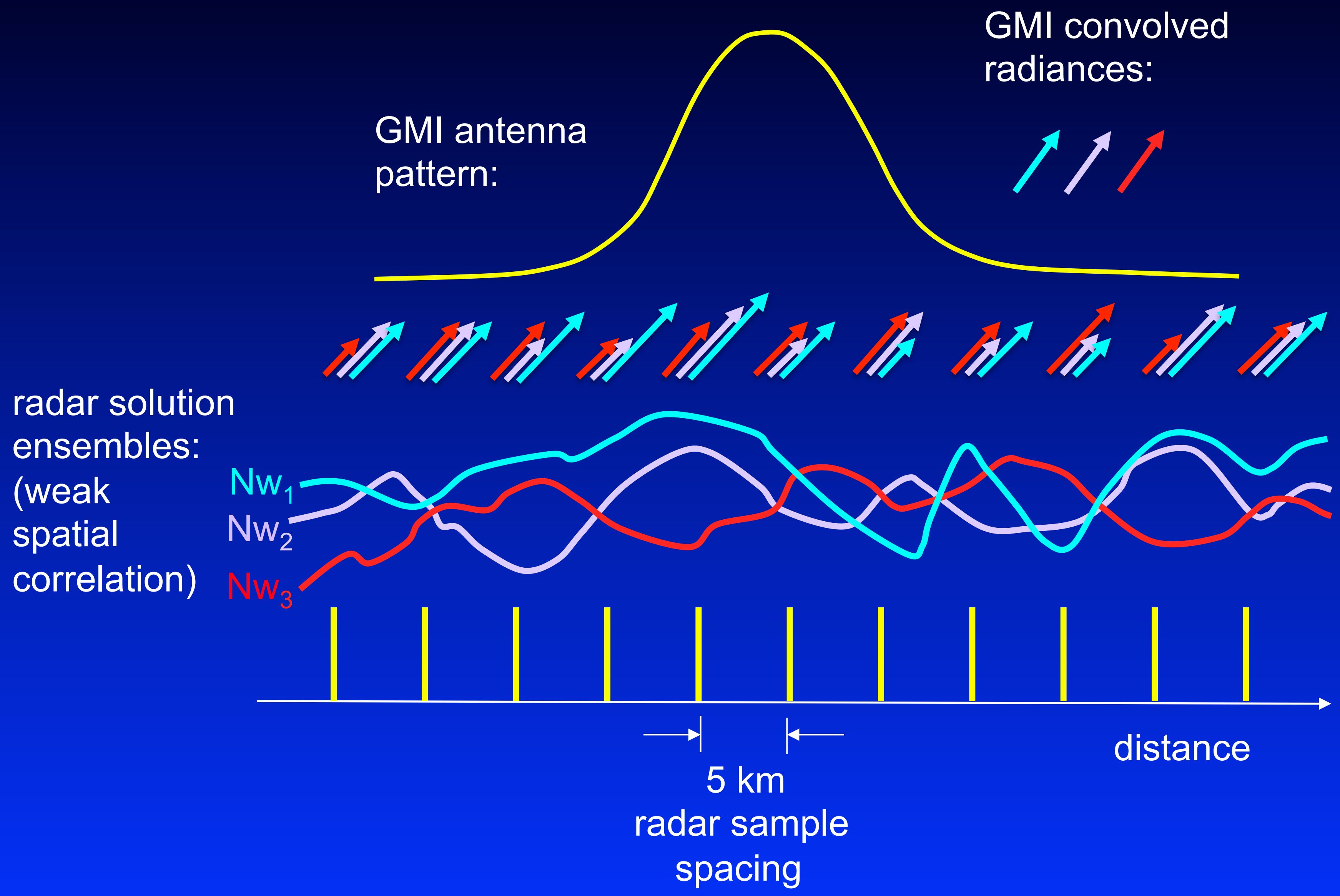






These sphere/aggregate calculations are introduced into dual-λ radar algorithm

Algorithm Theoretical Basis



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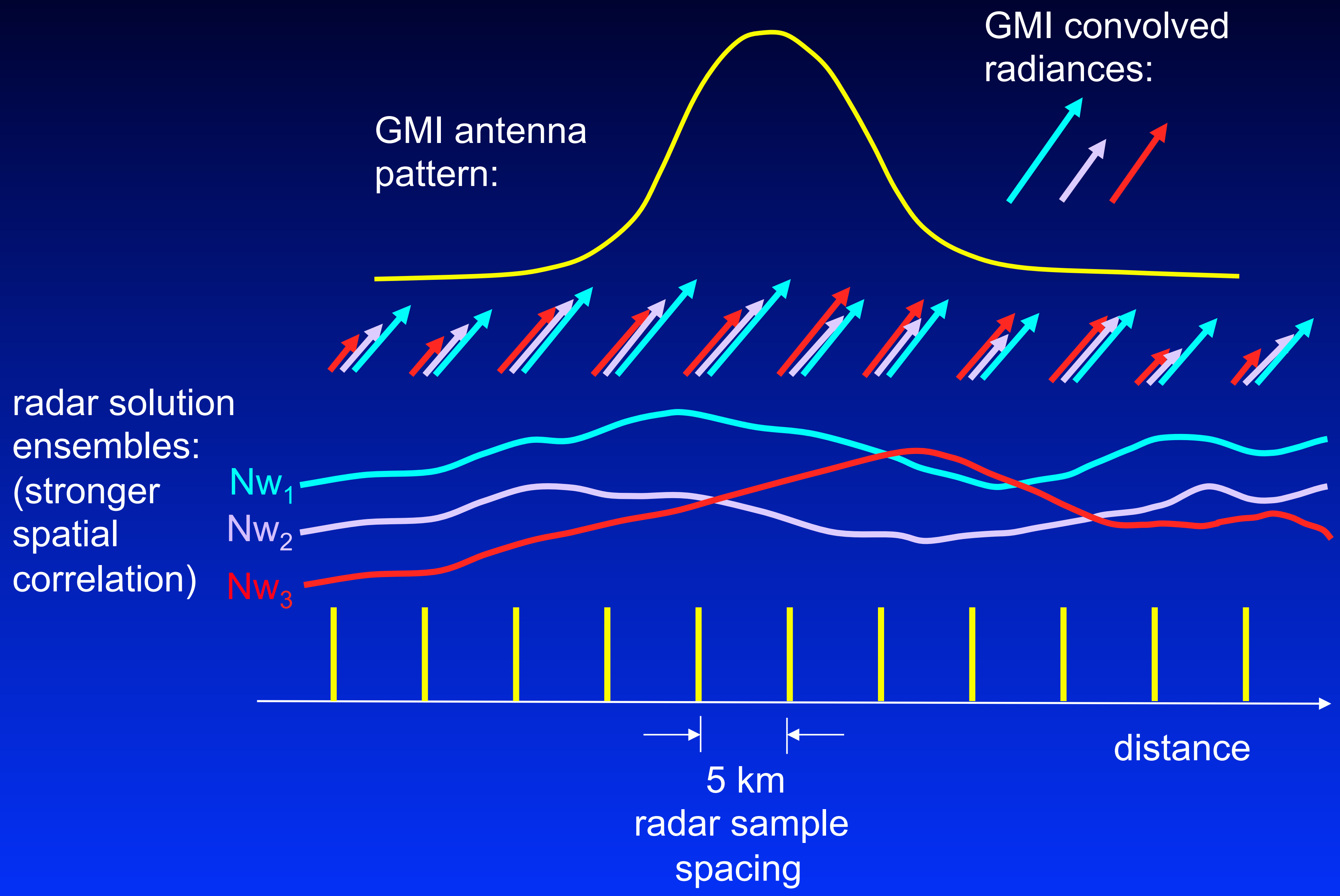


Test Plan Outline

Pre-Launch "Validation" Studies (beginning winter 2012)

- Data: TRMM Observations

  CRM-generated GPM Observations
  (e.g., tropical MCS, midlatitude squall line,
  synoptic-scale snow, lake effect snow,
  high-latitude shallow stratiform).

  } -> PPS GPM formats

- Tests: compatibility with PPS
  fitting of physical model to data.
  retrieved parameters within realistic ranges?
  is attenuation correction of Z data reasonable?
  how well are rain rates and DSD's estimated?
  (data sensitivity, e.g. Ku vs. Ku + Ka, ancillary data source.
  state sensitivity, e.g. land vs. ocean, high vs. low latitude.)

- TRMM Validation: Primary Validation Sites (Kwajalein, Melbourne)
  GPM Validation Network (VN Z's and NMQ rain rates)

Post-Launch Validation Studies (beginning 2014)

- **Data:** GPM Z_{Ku}, Z_{Ka}, PIA's, TB's.

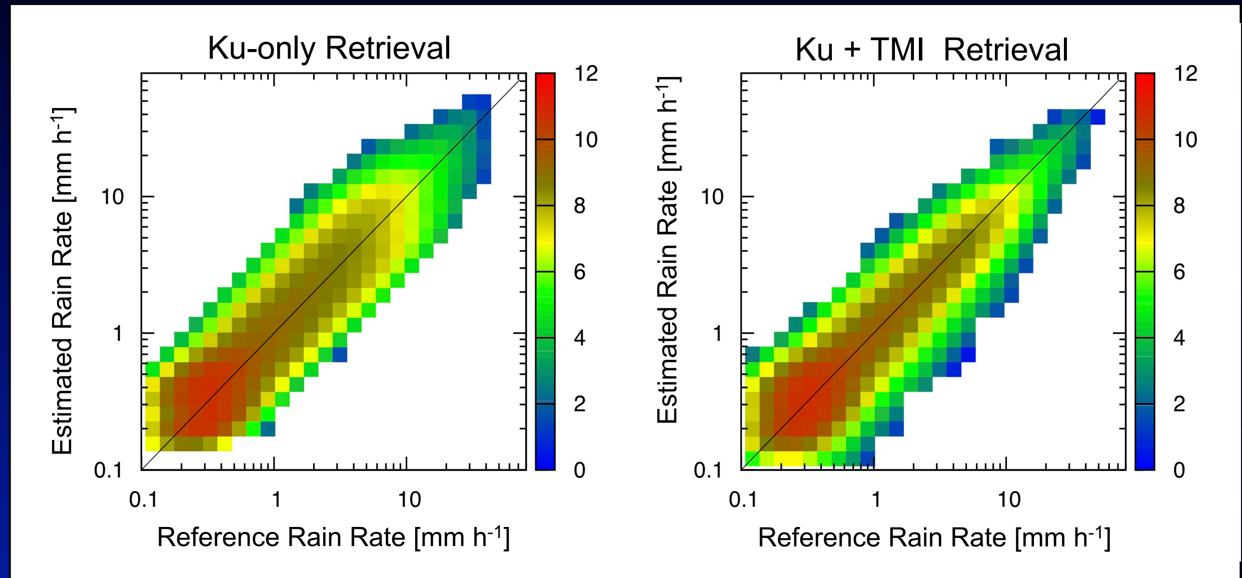
- **Tests/Validation: see above; extend to GV in other regimes.**

Testing - Application to Simulated TRMM Data

TMI simulated from Ku

Ku-only 5% bias; 35% rms

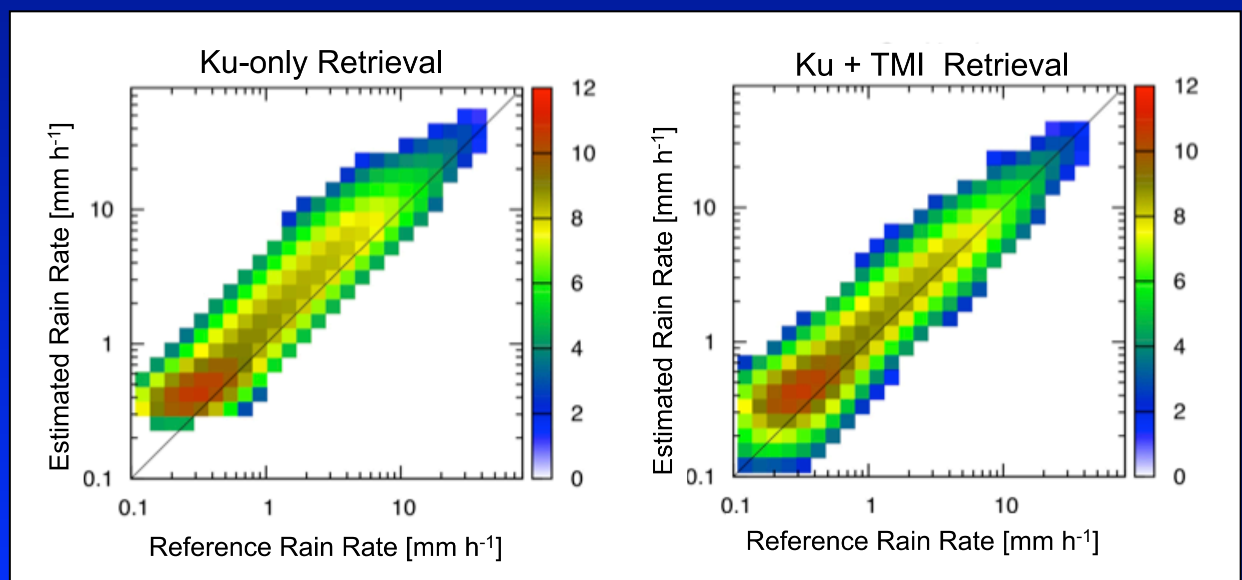
Ku+TMI -2% bias; 15% rms



w/positive bias in initial N_w

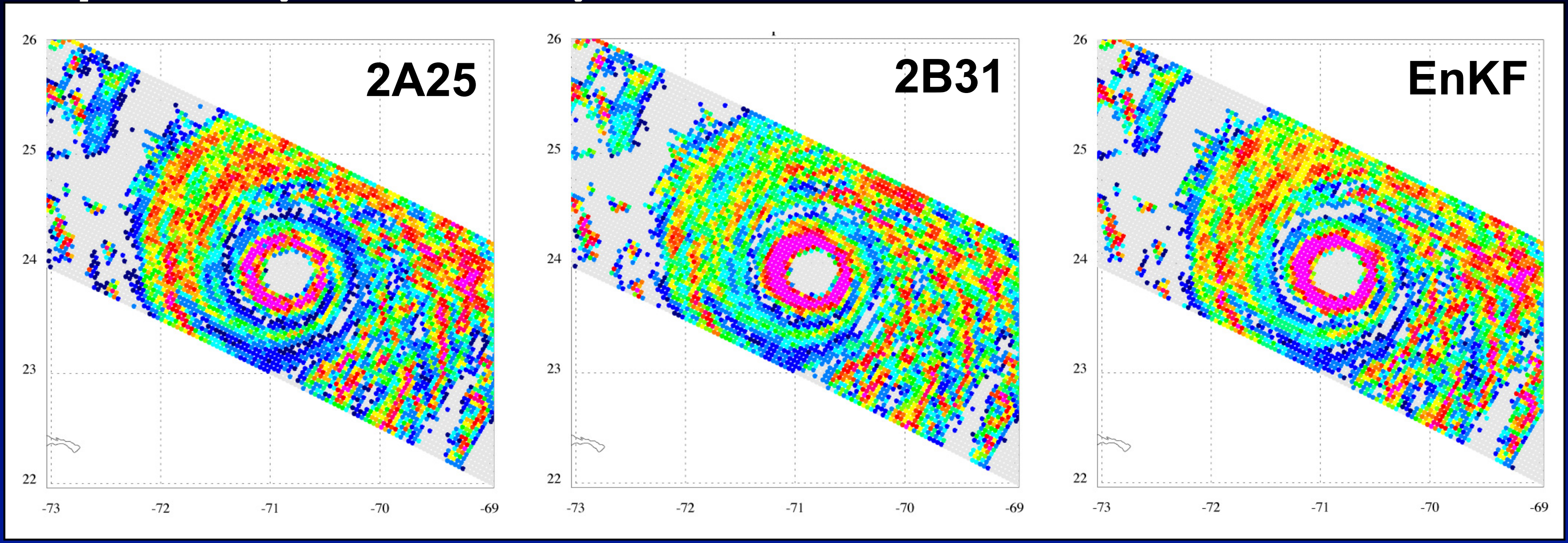
Ku-only 43% bias; 41% rms

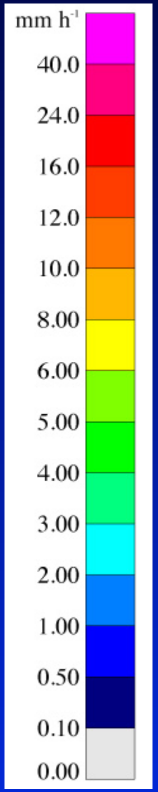
Ku+TMI 18% bias; 14% rms



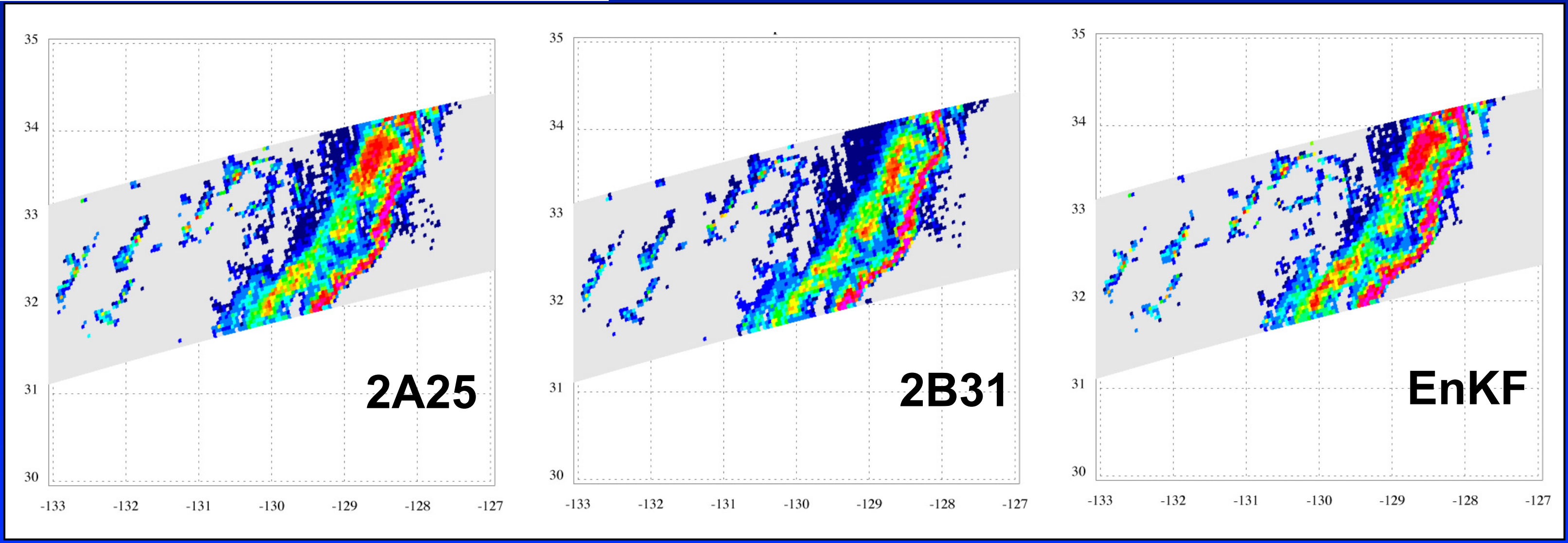
Testing - Application to TRMM Data

Tropical Cyclone Floyd

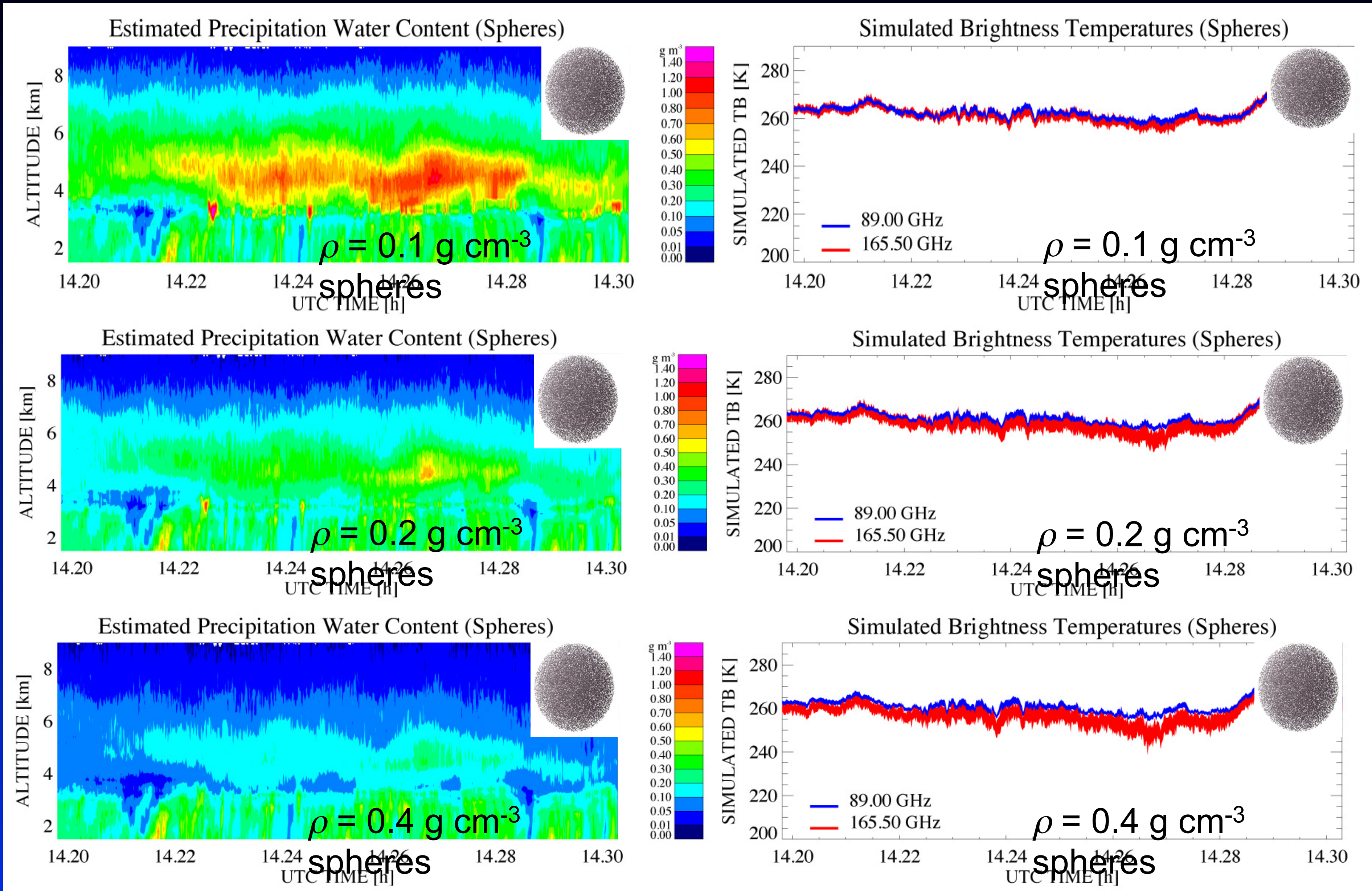




Pacific Winter Storm

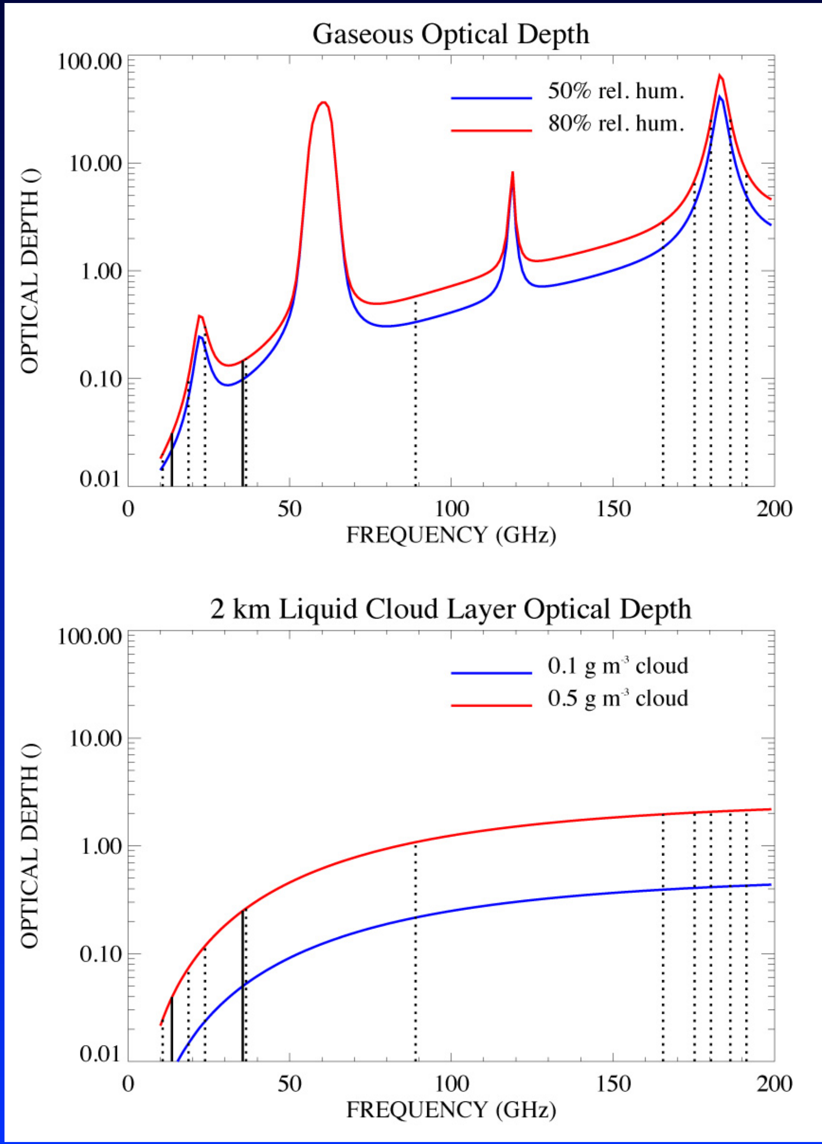


Sensitivity of Sphere-Based Retrievals/Simulations to Ice Density



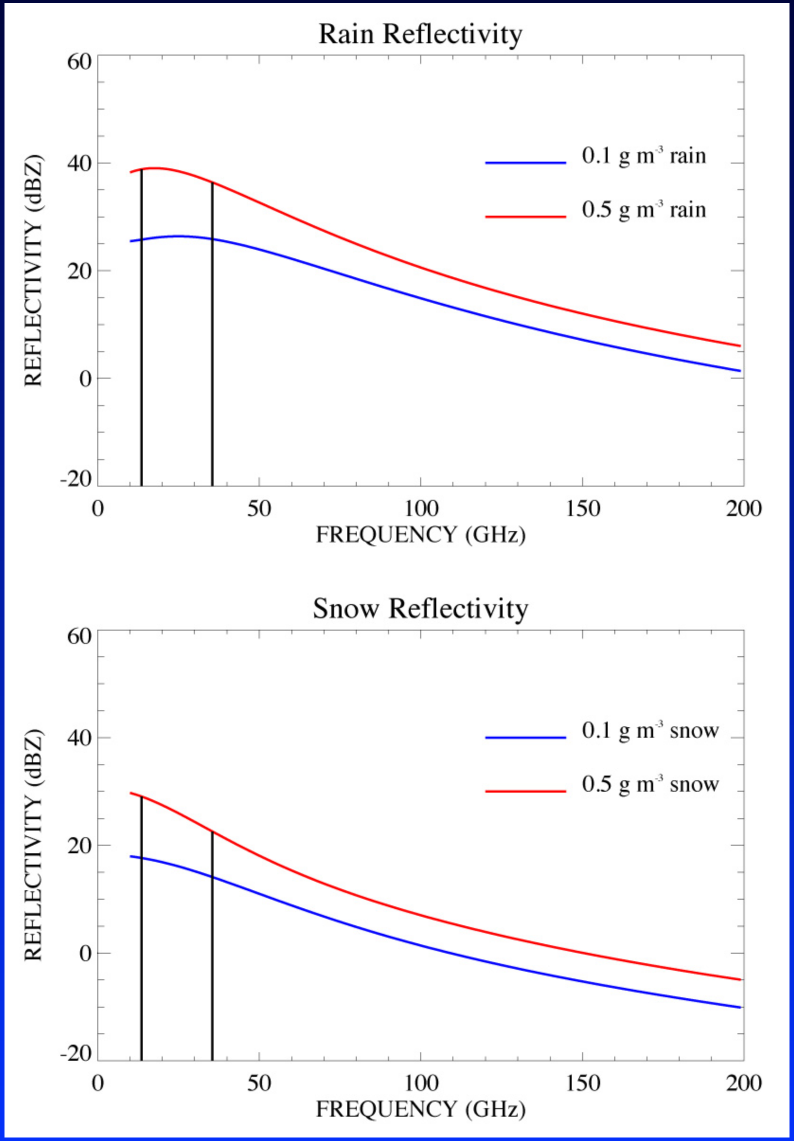
Physics of DPR/GMI Channels

Gaseous and Cloud Absorption

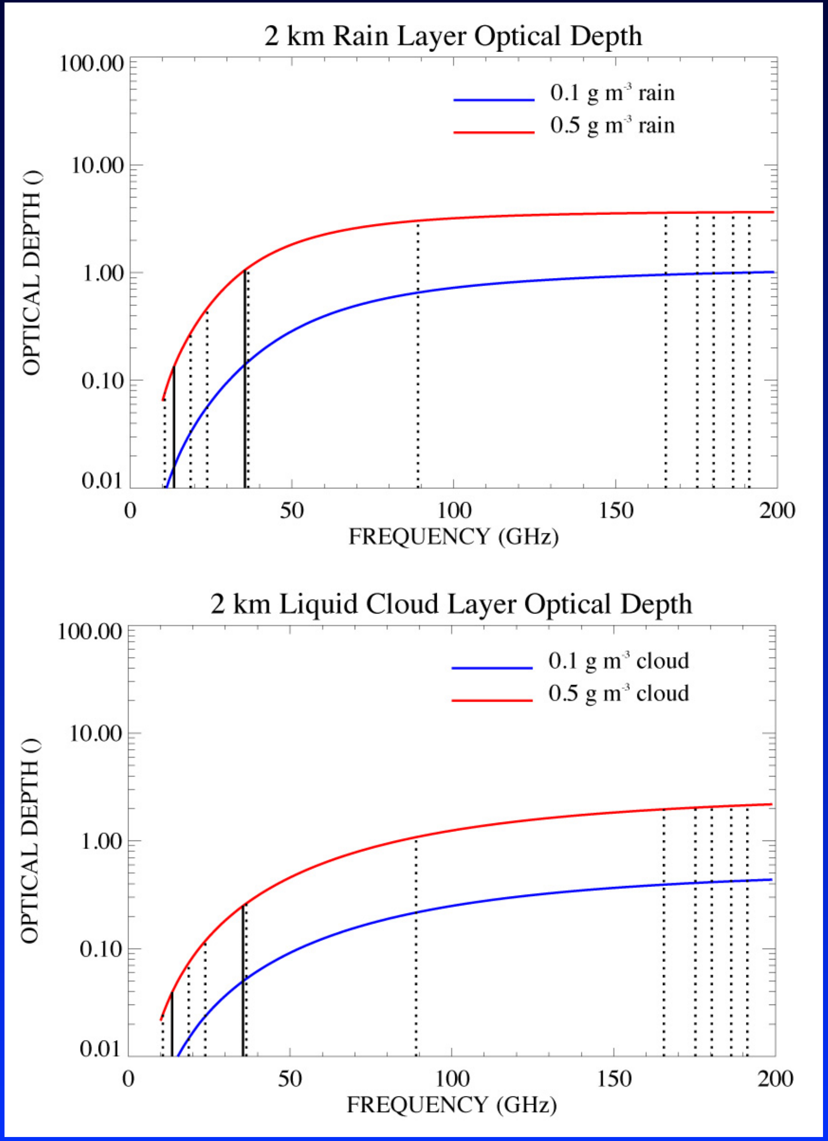


Physics of DPR/GMI Channels

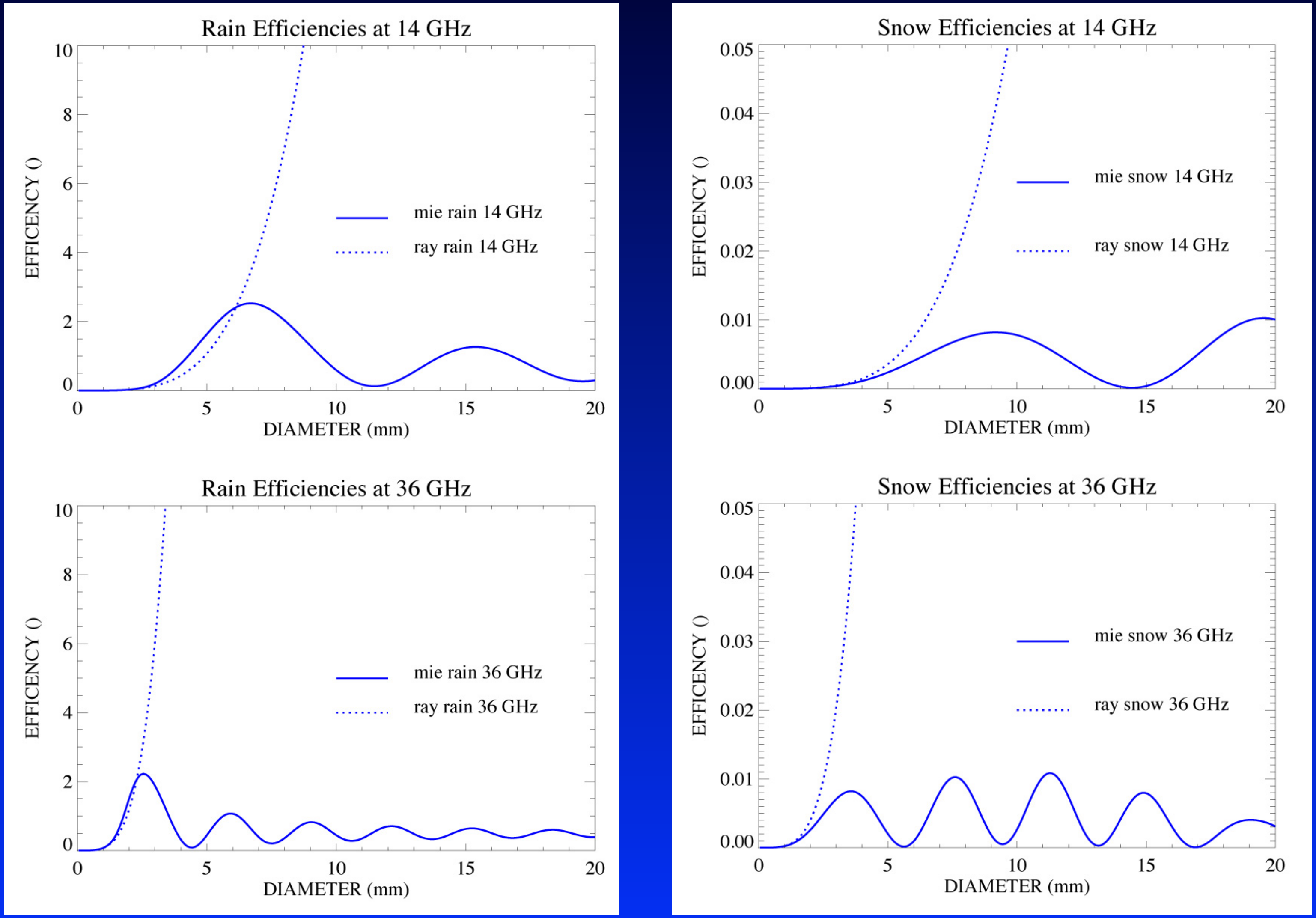
Reflectivities



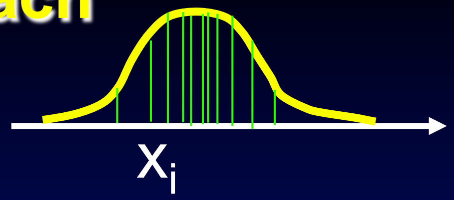
Attenuation



Rain/Snow Backscatter Efficiencies



Ensemble Kalman Filtering Approach



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Ensemble Kalman Filtering Approach

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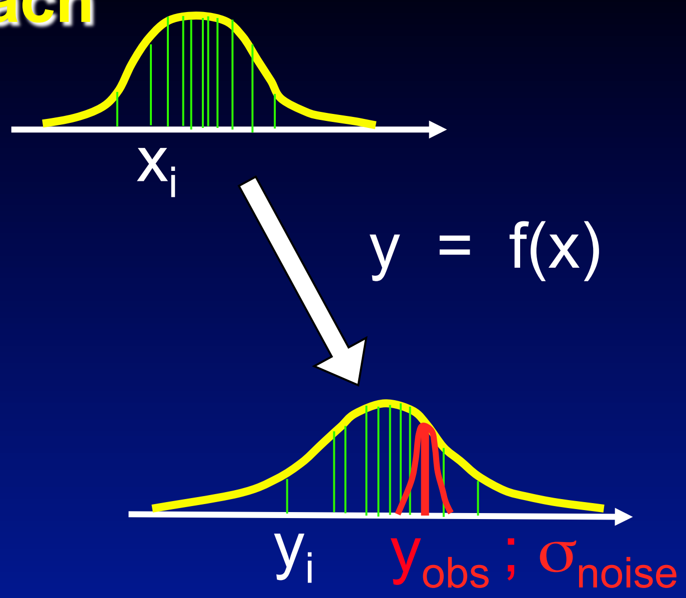
- Use forward model $y = f(x)$ to simulate observable y_i for each x_i.



Ensemble Kalman Filtering Approach

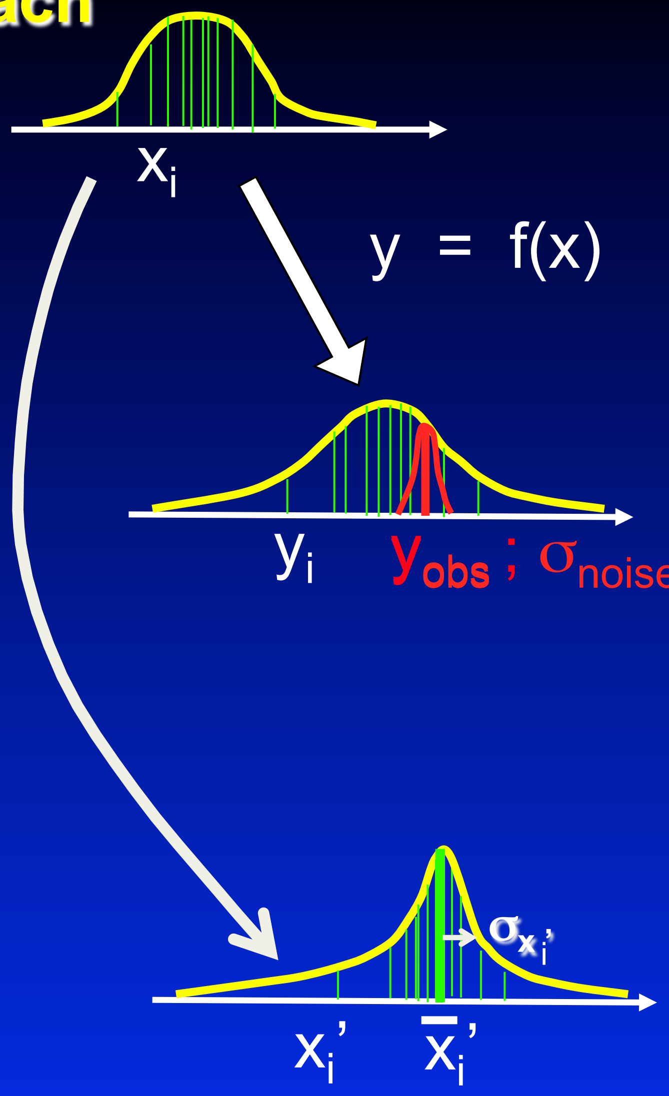
- Assume *a priori* ensemble, x_i, of desired parameter, x.

- Use forward model $y = f(x)$ to simulate observable y_i for each x_i.

- Update x_i using y_{obs} and covariance σ_{xy} of x_i and y_i :

$$x_i' = x_i + \sigma_{xy} / (\sigma_{yy} + \sigma^2_{noise}) \cdot (y_{obs} - y_i)$$

- take mean of x_i (solution) and standard deviation of x_i (uncertainty).



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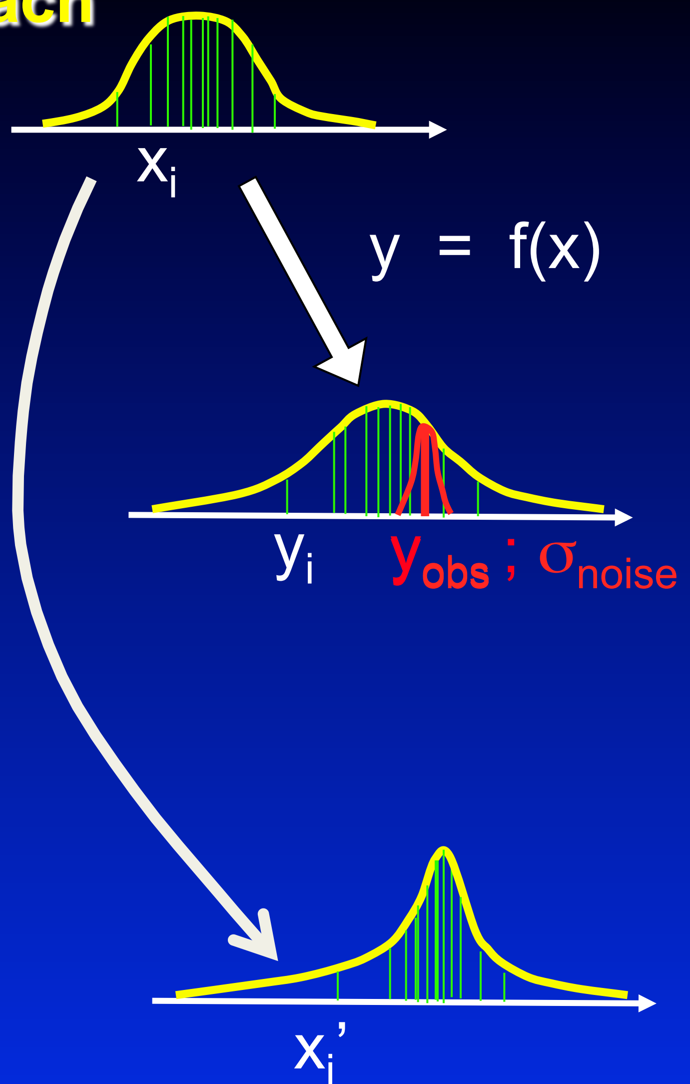

Simple Examples

- Take a simple 1D example:

$y_{obs} = 4$, with noise $\sigma_{noise} = 0.5$

& try to fit model $y(x) = x^2$

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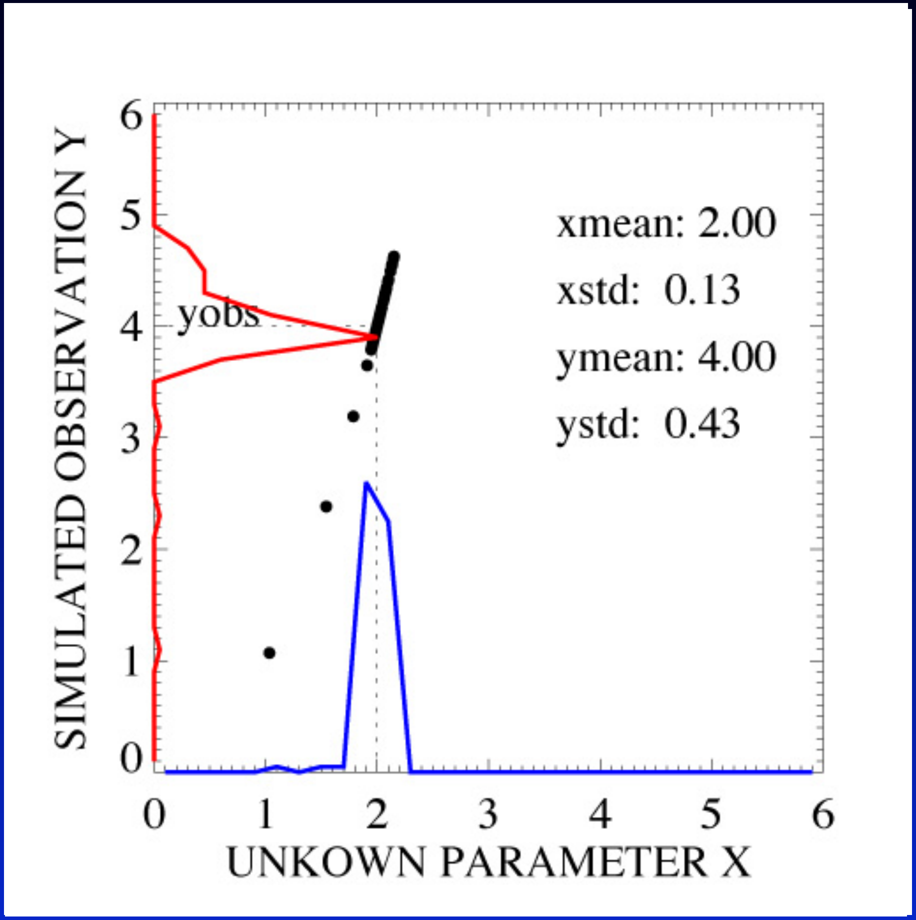
Ensemble Filtering approach:

<u>update</u> *a priori* distribution, x_i, using

$y_i = y(x_i)$ and then

$$x_i' - x_i = \sigma_{xy} / (\sigma_{yy} + \sigma^2_{noise}) \cdot (y_{obs} - y_i)$$



Algorithm Theoretical Basis

Generalized Hitschfeld-Bordan Method (applied to Ku-band data only)

- original Hitschfeld-Bordan fast, but reqs. $k = \alpha Z^{\beta}$.

$$Z(r) = \frac{Z_{Ku}(r)}{\left[1 - q\int_0^r \alpha(s) Z_{Ku}^{\beta}(s)\, ds\right]^{1/\beta}}, \quad q \equiv 0.2\,\beta \ln(10)$$

- iterative techniques typically slow.

- alternative interative procedure, assuming $N_o(r)$ and approximate approximate β from k-Z relation:

$$Z(r) = \frac{Z_{Ku}(r)}{\left[1 - q\int_0^r Z_{Ku}^{\beta}(s) \frac{k(Z(s))}{Z^{\beta}(s)}\, ds\right]^{1/\beta}}$$

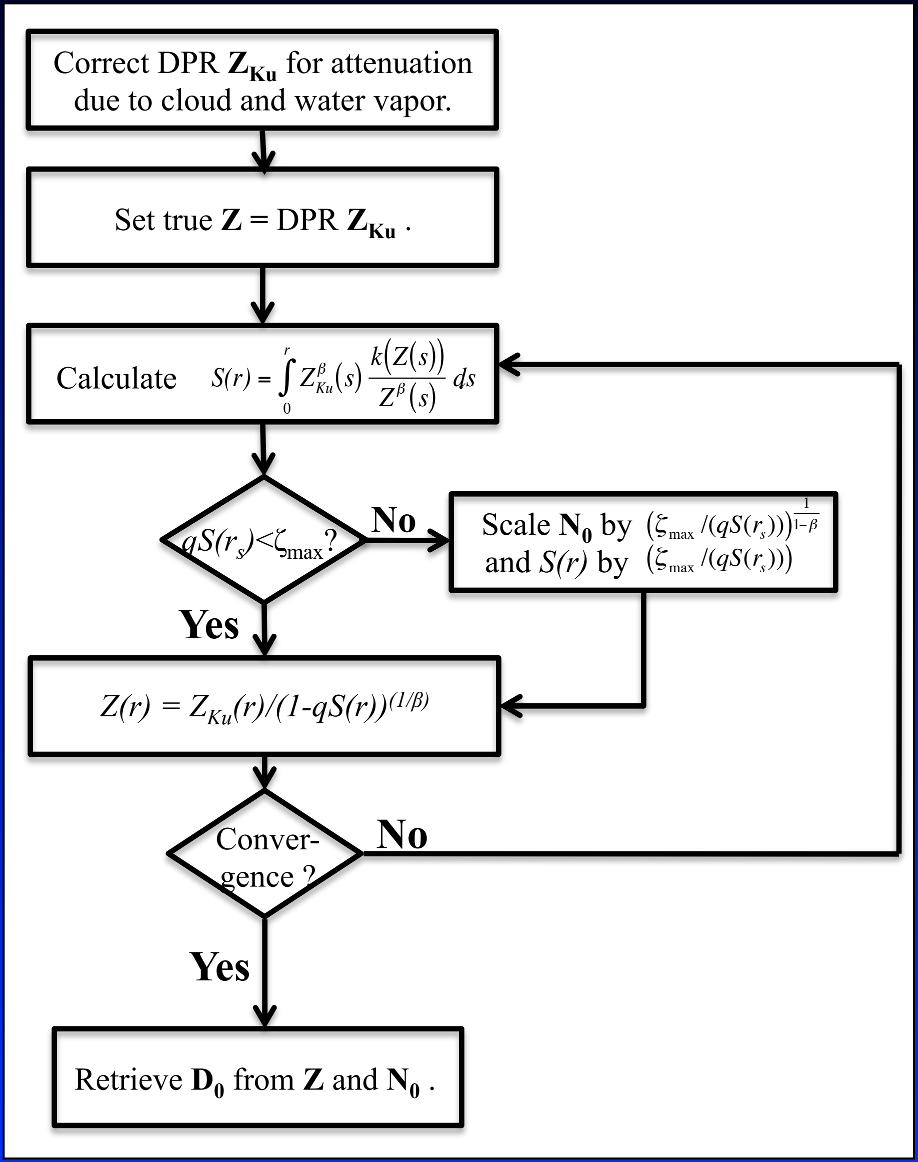
Algorithm Theoretical Basis

Generalized Hitschfeld-Bordan Method

- procedure is fast because iterative equation is a close approx. to H-B solution.

- note procedure avoids instability by rescaling $N_o(r)$, if needed.

- yields $D_o(r)$, given $N_o(r)$, μ, and Z_{Ku} .



Post-Launch

- Adapt to post-launch modifications of Level 1 or Level 2 input data.
- Begin statistical validation of GPM combined estimates against GV radar.

★ To enhance impact of brightness temperatures, need more information on *a priori* spatial correlations of N_w, RH, cloud water, surface emissivity.

→ field campaign data as guide, e.g., PSD's from dual-pol, profiler.

→ algorithm "bootstrapping", e.g., N_w.

- Similarly, significant cross-correlations of different variables can help to limit the degrees of freedom in the retrieval problem.
- Continue to test physical and statistical parameterizations with field campaign data.