Precipitation Variability Across Satellite Field-of-Views Derived from Ground-based Polarimetric Scanning Radar Observations

Christopher R. Williams[(1)], Walter Petersen[(2)], David Wolff[(3)], and V. Chandrasekar[(4)]

(1) University of Colorado Boulder and NOAA Earth System Research Laboratory, (2) NASA Marshall Space Flight Center, (3) NASA Wallops Space Flight Center, (4) Colorado State University

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1. Motivation

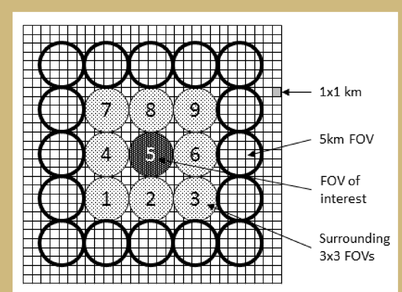
Without prior parameterization, satellite retrieval algorithms assume uniform precipitation across the satellite sensor's field-of-view (FOV). Deviations from uniform is called: Non-Uniform Beam Filling (NUBF).

The NASA / JAXA Tropical Rainfall Measuring Mission (TRMM) and Global Precipitation Mission (GPM) rainfall retrieval algorithms use the coefficient of variation (COV, also known as normalized standard deviation defined as standard deviation / mean, $\gamma = \sigma/\mu$) to parameterize NUBF (i.e., Iguchi et al. 2000). As COV approaches zero, the precipitation becomes more uniform across the FOV which reduces the impact of NUBF affects.

Since the satellite observations cannot resolve sub-FOV variability, Kozu & Iguchi (1999) used downscaling arguments to infer sub-FOV variability from variability observed over the neighboring 3x3 FOVs.

Science Question: Using GPM field campaign ground-based scanning radar observations, are there relationships between precipitation variability over 3x3 neighboring observations with sub-FOV precipitation variability?

2. Downscaling Methodology



Sub-FOV Variability:
The sub-FOV variability of some quantity x (e.g,. reflectivity or rain rate) over the ith FOV is given by:

Mean of x: $$\hat{\mu}_{x,i}^{FOV} = \frac{1}{\sum_j^n w_j}\sum_j^n w_j x_j$$

where w_j is a Gaussian antenna beam weighting and j indicates one of n individual 1x1 km radar observations.

Sample standard deviation of x: $$\hat{\sigma}_{x,i}^{FOV} = \left[\frac{1}{\sum_j^n w_j}\sum_j^n w_j\left(x_j^{FOV} - \hat{\mu}_{x,i}^{FOV}\right)^2\right]^{1/2}$$

Sample coefficient of variation (COV) of x: $$\hat{\gamma}_{x,i}^{FOV} = \frac{\hat{\sigma}_{x,i}^{FOV}}{\hat{\mu}_{x,i}^{FOV}}$$

3x3 Neighborhood Variability:
The 3x3 variability of some quantity x is given by:

Mean of x: $$\hat{\mu}_{x,i}^{3x3} = \frac{1}{9}\sum_k^9 \hat{\mu}_{x,k}^{FOV}$$

where k represents one of nine members of the 3x3 domain and in the diagram above, $i = 5$.

Sample standard deviation of x: $$\hat{\sigma}_{x,i}^{3x3} = \left[\frac{1}{9}\sum_k^9\left(x_k^{FOV} - \hat{\mu}_{x,i}^{3x3}\right)^2\right]^{1/2}$$

Sample coefficient of variation (COV) of x: $$\hat{\gamma}_{x,i}^{3x3} = \frac{\hat{\sigma}_{x,i}^{3x3}}{\hat{\mu}_{x,i}^{3x3}}$$

Research Objective:
As discussed in Kozu & Iguchi (1999), assuming a linear relationship between FOV and 3x3 domain variability, we seek to find c_x such that

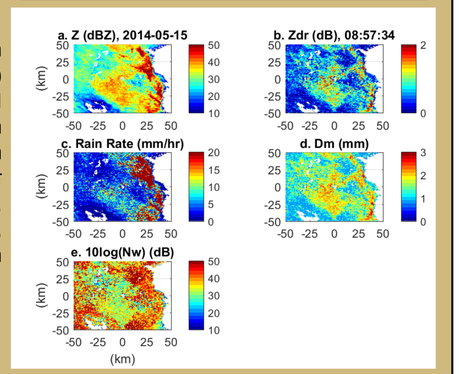
$$\hat{\gamma}_{x,i}^{FOV} = c_x \hat{\gamma}_{x,i}^{3x3}$$

3. Radar Observations – PPI Scans

Surface Scanning Radar:
This study uses NASA S-band Polarimetric scanning radar (NPOL) observations from the Integrated Precipitation and Hydrology Experiment (IPHEx) held in the southern Appalachian Mountains in the eastern United States in May-June 2014.

Example: 15-May-2014, 08:57 UTC

Grid to 1x1 km resolution:
Reflectivity at horizontal polarization (Z_h) and differential reflectivity (Z_{dr}) from constant 2 degree elevation PPI scans with 125 m range resolution are gridded into a uniform 1x1 km grid. Using surface disdrometer derived relationships, rain rate (R), mean mass-weighted diameter (D_m), and normalized number concentration (N_w) were derived from Z_h and Z_{dr}.



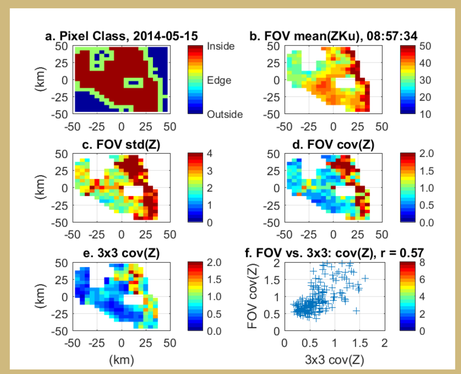
Simulating Reflectivity and Specific Attenuation at Ku-band:
Assuming Gamma shaped raindrop size distributions with a shape factor and maximum diameter dependent on D_m (Williams et al. 2014 and Carey & Petersen 2015), intrinsic reflectivity (non-attenuated reflectivity) factor $Z(Ku)$ and specific attenuation $k(Ku)$ were estimate at Ku-band (13.8 GHz).

Example: 15-May-2014, 08:57 UTC

Reflectivity: Z(Ku)

FOV statistics

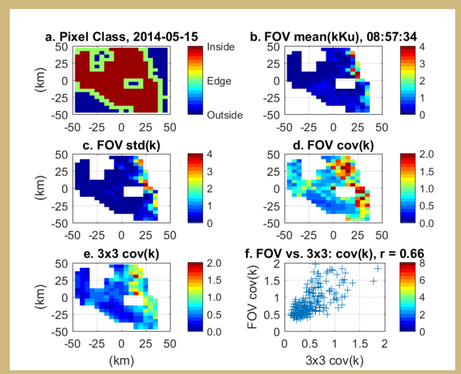
3x3 statistics



Specific Attenuation: k(Ku)

FOV statistics

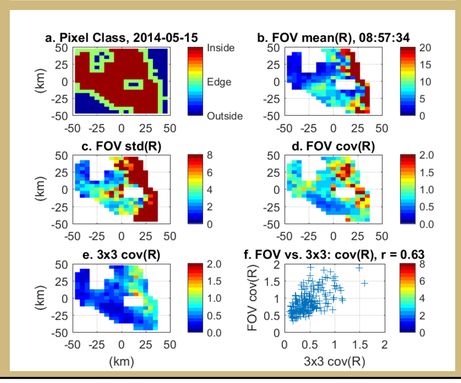
3x3 statistics



Rain Rate: R

FOV statistics

3x3 statistics



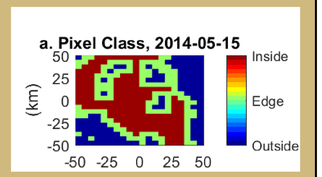
4. Edge and Inside FOVs

Edge and Inside FOVs:
To avoid complications due to partially illuminated 3x3 FOVs, each FOV is defined as either an *Outside*, *Edge*, or *Inside* FOV.

Outside FOVs have reflectivity less than 20 dBZ.

Edge FOVs are missing one of their 3x3 neighbors.

Inside FOVs have all nine 3x3 neighbors and are used in this analysis.



5. Multiple PPI Scans

15-May-2014 Rain Event:
On 15 May 2014, a precipitation event passed over the IPHEx domain and over 12,500 Inside FOVs were analyzed.

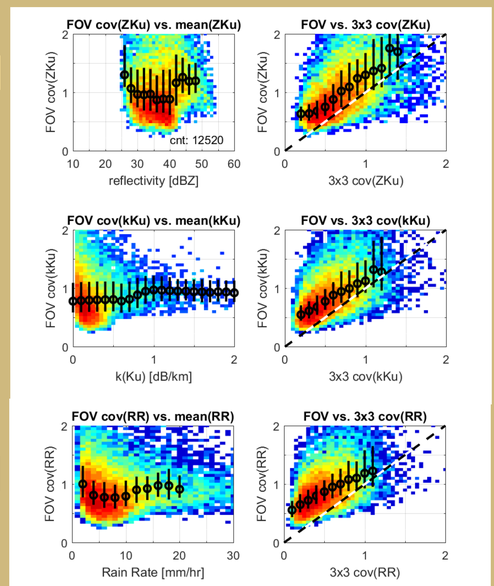
Scatter plots show sub-FOV variability (COV) as a function of FOV mean and as a function of 3x3 COV.

FOV COV vs. mean | **COV FOV vs. 3x3**

Reflectivity: Z(Ku)

Specific Attenuation: k(Ku)

Rain Rate: R



6. Concluding Remarks

Using high spatial resolution scanning radar observations, this work shows:

- Sub-FOV precipitation variability is linearly related to 3x3 FOV variability
- Correlation was only approximately 0.6
- NUBF parameter could be used as a *statistical constraint* in probabilistic algorithms, but not in *determinsitc algorithms*
- Actual performance depends on algorithm logic and cost minimization procedure

7. References

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