Assimilation of Satellite Microwave Observations over the Rainbands of Tropical Cyclones

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Summary

We propose a novel Bayesian Monte Carlo Integration (BMCI) technique to retrieve the profiles of temperature, water vapor, and cloud liquid/ice water content from microwave cloudy measurements in the presence of tropical cyclones (TCs). These retrievals then can either be directly used by meteorologists to analyze the structure of TCs or be assimilated to provide accurate initial conditions for the NWP models. The technique is applied to the data from the Advanced Technology Microwave Sounder (ATMS) onboard Suomi National Polar-orbiting Partnership (NPP) and Global Precipitation Measurement (GPM) Microwave Imager (GMI).

The BMCI Technique

The BMCI technique can be summarized in three steps:

- generation of a retrieval database of atmospheric state and cloud variables using a-priori information. The database should also include extreme cases as the extrapolation is not allowed.
- the atmospheric state and cloud variables are fed into the RT model to generate the synthetic observations. In addition to the state variables such as temperature, water vapor, and cloud profiles, cloud microphysics and parameterization such as particles' shape and size distribution are also utilized as input.
- real measurements along with the generated database are given to the retrieval package, then the retrieval package will select the cases which are close to the real measurements and integrate them according to the Bayes' theorem to give the estimate of the mean and uncertainty of the state and cloud variables.

Starting from Bayes' theorem:

$$p_{post}(\vec{x}|\vec{y}) = \frac{p_f(\vec{y}|\vec{x})p_p(\vec{x})}{\int p_f(\vec{y}|\vec{x})p_p(\vec{x})d\vec{x'}} \Rightarrow Posterior = \frac{Likelihood \times Prior}{Marginal\ Likelihood}$$

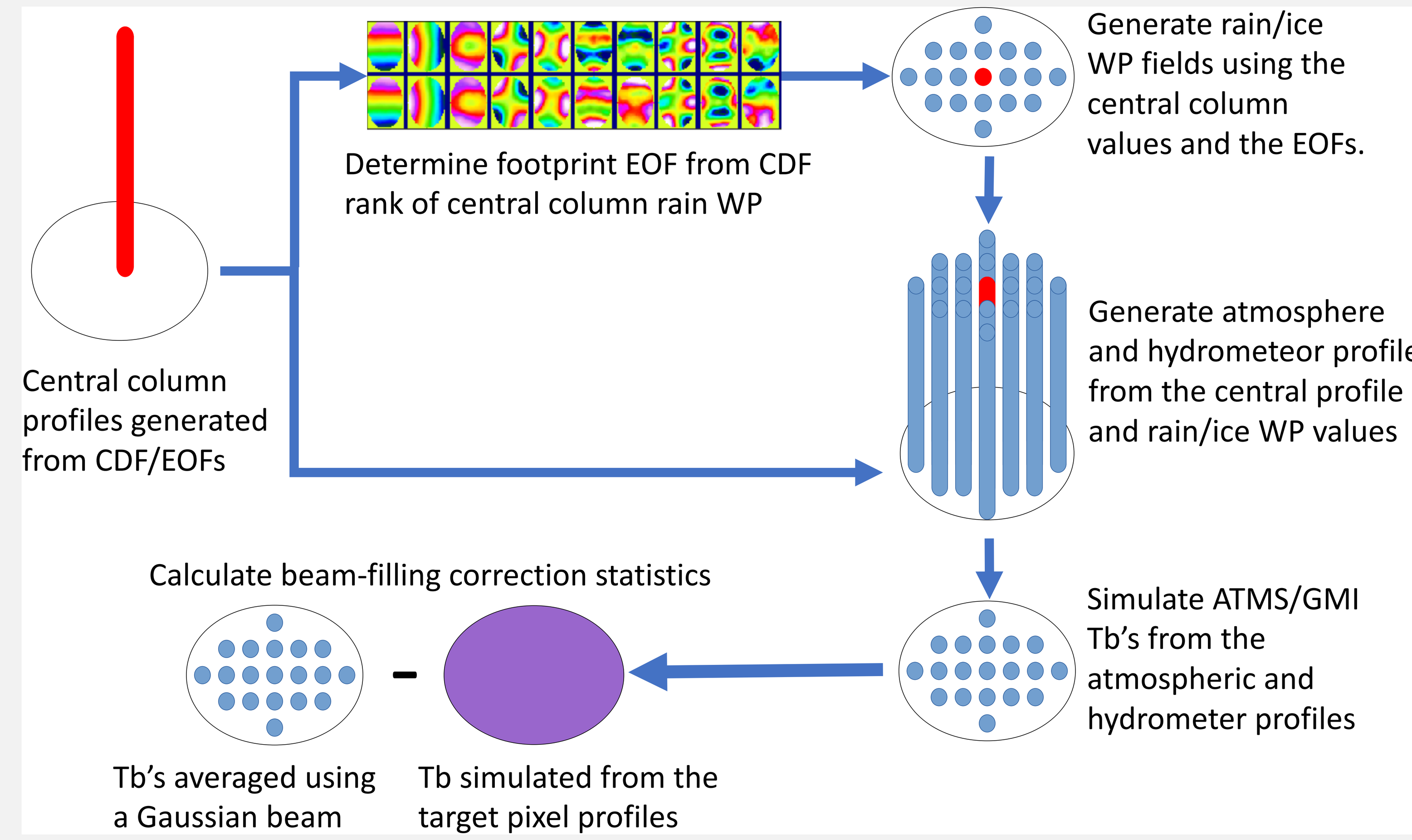
ending with ...

$$\hat{x} = \frac{\sum_i w_i \vec{x_i}}{\sum_i w_i} \qquad w_i = \exp(-\frac{1}{2}\chi^2)$$

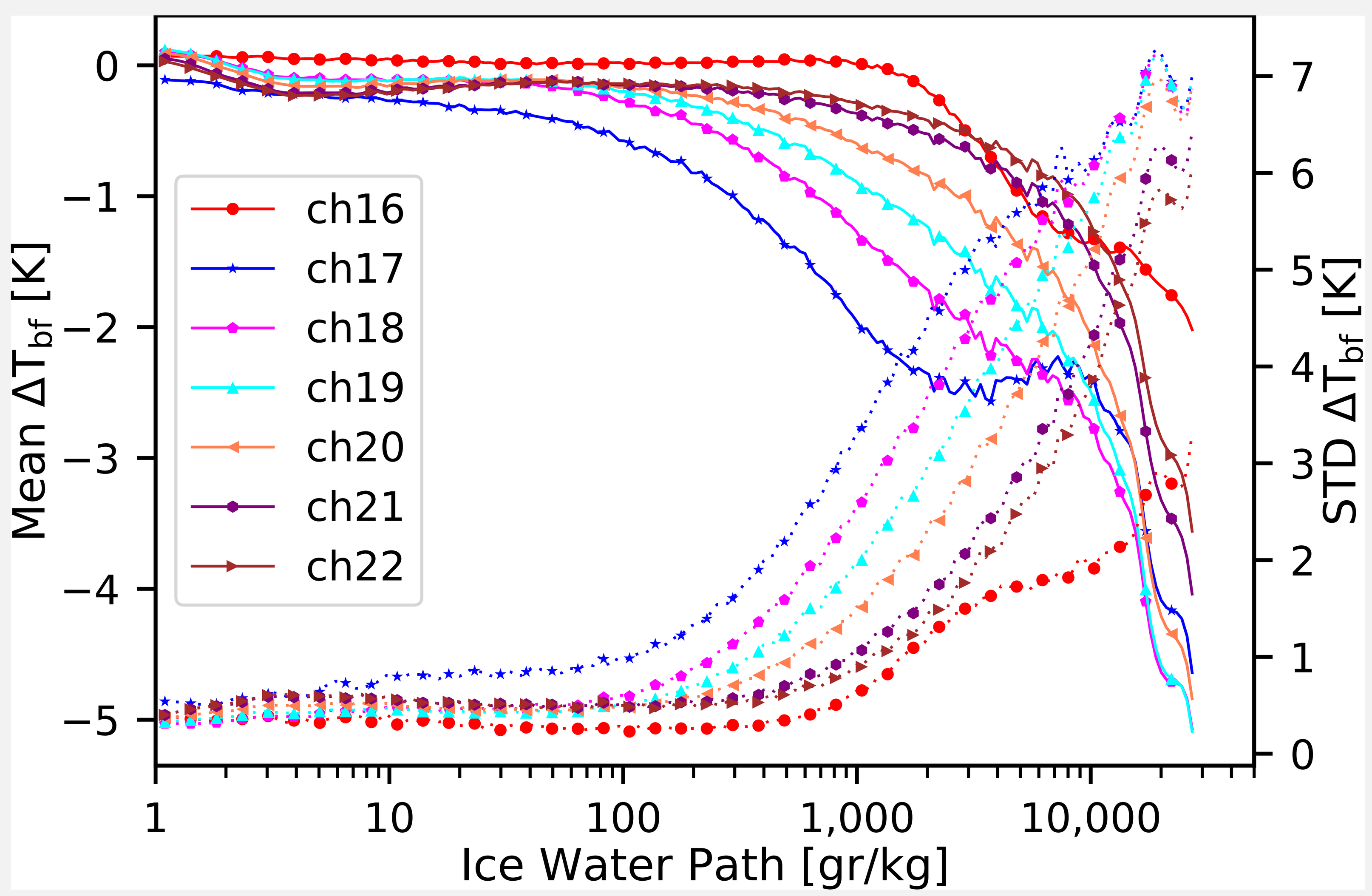
$$\chi^2 = \sum_{j=1}^{M} \frac{[\vec{y_j} - H_j(\vec{x})]^2}{\sigma_j^2}$$

σ is the noise in the measurements.

Beam-filling modification



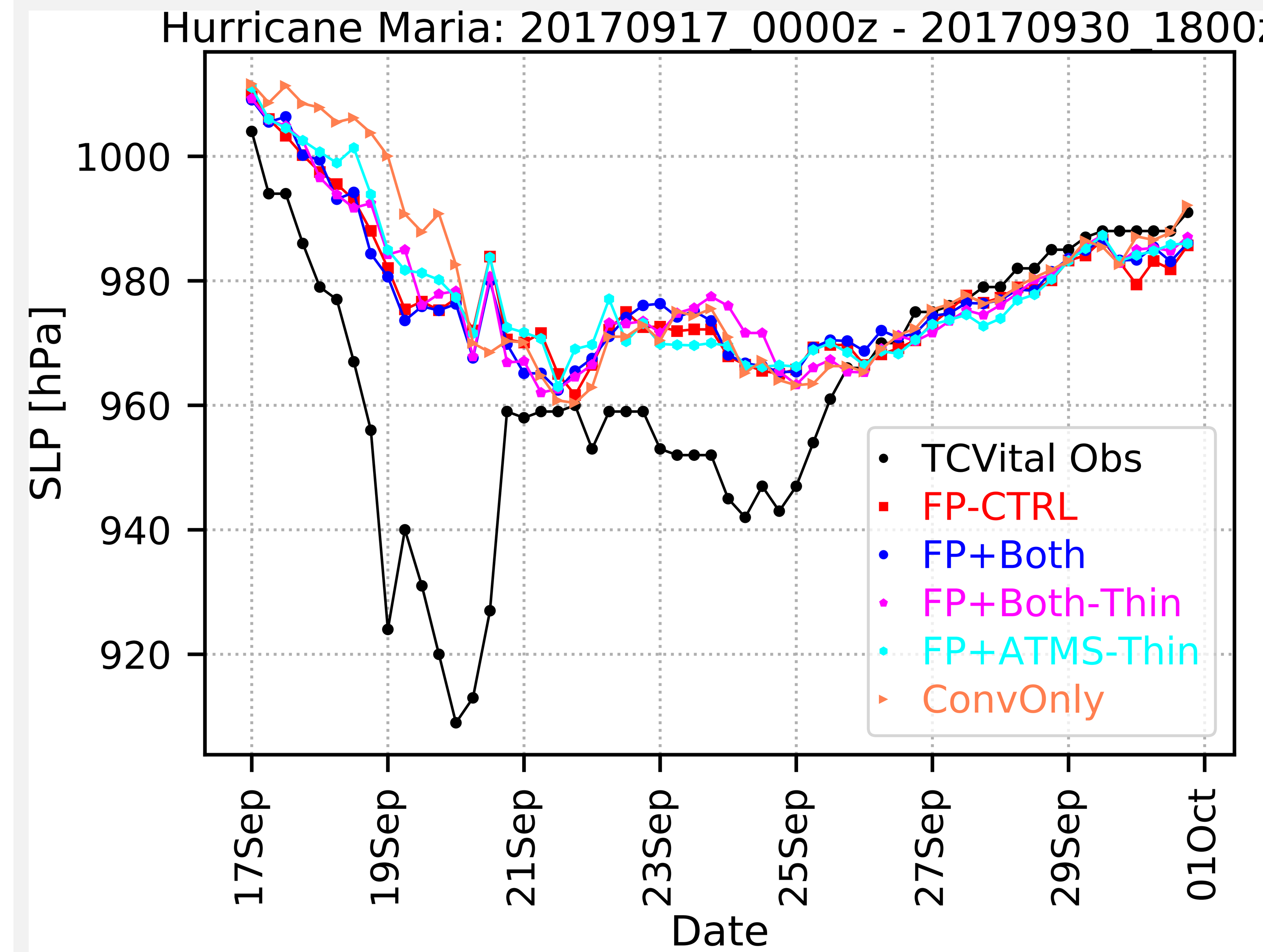
A flowchart of the procedure used to generate stochastic 3D fields of atmospheric profiles in radiometer footprints, and the use of these footprint fields to calculate beam-filling corrections to the brightness temperatures.



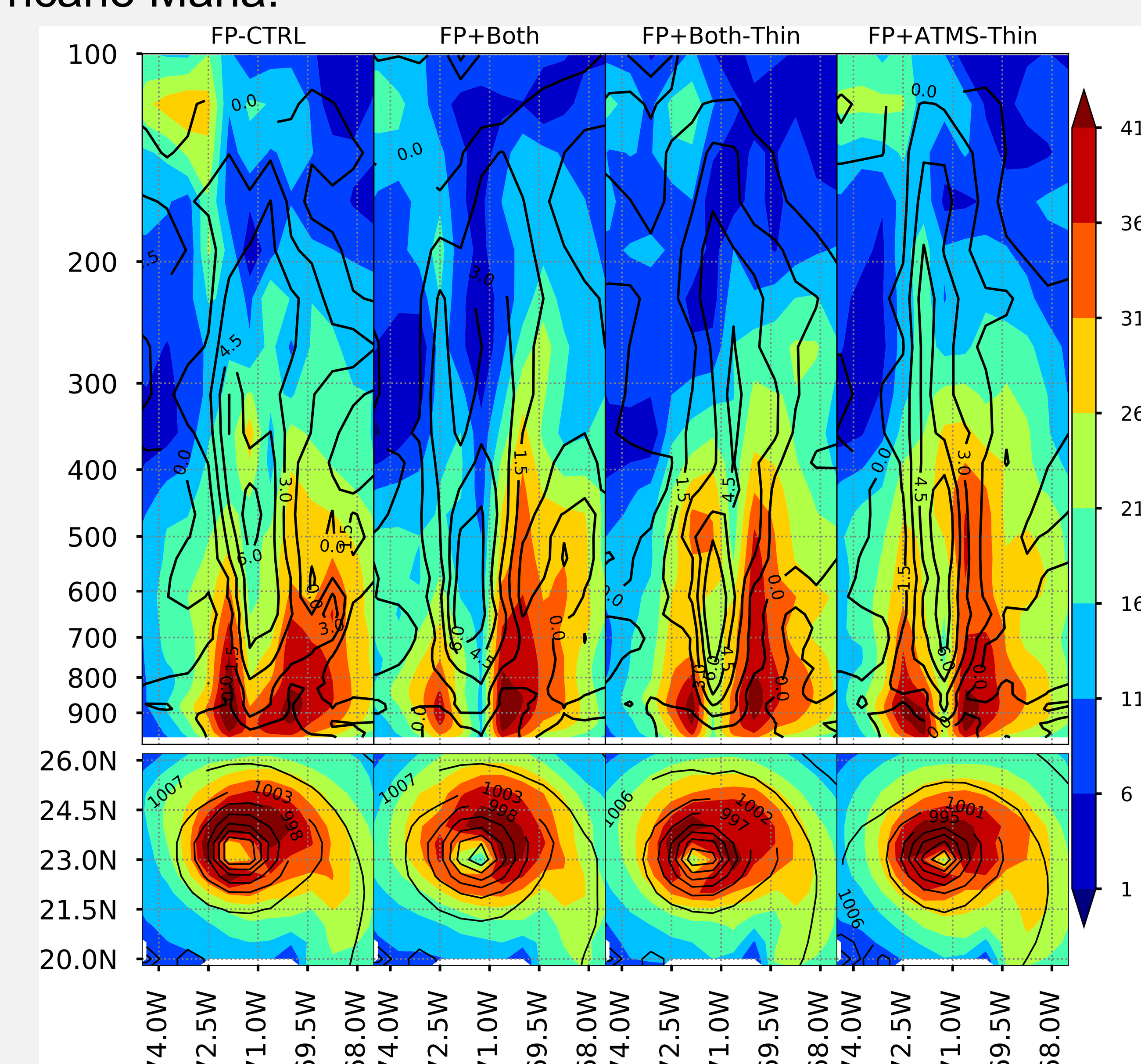
The beam-filling impact on (top) GMI and (bottom) ATMS lower frequency channels sensitive to liquid (left) and higher frequency channels sensitive to ice particles (right). The solid lines are for bias and the dashed lines for standard deviation.

Reference: Moradi et al., MWR 2020:
https://doi.org/10.1175/MWR-D-19-0341.1

Data Assimilation



Minimum sea-level pressure in the GEOS analysis for Hurricane Maria.



Vertical cross section of wind magnitude in meters per second (top shaded) and temperature anomaly in Kelvin (top contours) as well as 850 hPa wind speed (bottom shaded) and sea surface pressure in hPa (bottom contours). The depicts are for the cycle 21z, September 22, 2017.

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