MiRS: An all-surfaces, all-parameters physical retrieval algorithm for the GPM constellation

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1. Introduction

The Global Precipitation Mission (GPM) will continue and expand the global observing system with a focus on the hydrological cycle. The broad range of observations will improve the understanding of precipitation processes with meaningful impact on climate applications, short-term forecasting, and both global and regional Numerical Weather Prediction (NWP). Here we present a subset of efforts in support of GPM within NOAA/STAR and NOAA/EMC. Section 2 will introduce the Microwave Integrated Retrieval System, a 1DVAR physical retrieval algorithm and assimilation system applicable to all GPM passive microwave sensors. Section 3 will detail MiRS GPM status and results. Section 4 will present efforts to utilize GPM data within regional data assimilation systems, including the use of the MiRS 1DVAR as a preprocessor to the GSI 3DVAR/EnKF, and assimilation of Rainfall Rate with a focus on extreme precipitation cases (e.g. tropical cyclones) and forecast impacts in the HWRF model. Section 5 will detail future work and proposed synergy with the GPROF algorithm.

2. Description of the MiRS Algorithm

The MiRS algorithm is based on an iterative 1DVAR approach using the CRTM for its forward and jacobian operators. As such, the retrieval is valid in all cases the CRTM is valid in, including all weather conditions and over all surface types. The state vector supports the retrieval of temperature, water vapor, and hydrometeor profiles, along with surface emissivity and skin temperature depending on the information content of the sensor data being applied. A post-processor then derives products from the core-retrieval, such as TPW or Rainfall Rate. MiRS is applicable to the following microwave sensors in the GPM constellation: TRMM TMI, GPM GMI, GCOMW AMSR2, Megha-Tropiques SAPHIR/MADRAS, NPP/JPSS ATMS.

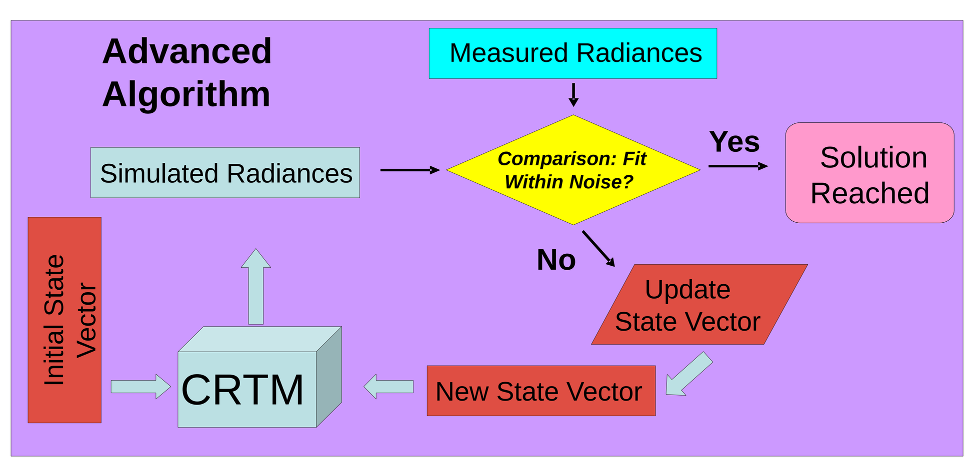


Figure 1. Schematic of the MiRS retrieval algorithm iterative process. The initial state vector is a regression algorithm applied on the observed brightness temperatures, but could also come from a climatological background or NWP model (assimilation mode).

To reach the iterative solution, the algorithm seeks to minimize the cost function

$$J(X)=\left[\frac{1}{2}(X-X_0)^T\times B^{-1}\times(X-X_0)\right]+\left[\frac{1}{2}(Y^m-Y(X))^T\times E^{-1}\times(Y^m-Y(X))\right]$$

where X in the 1st term on the right is the retrieved state vector, and the term itself represents the penalty for departing from the background X_0, weighted by the error covariance matrix B. The 2nd term represents the penalty for the simulated radiances Y departing from the observed radiances Y^m, weighted by instrument and modeling errors E. This leads to the iterative solution

$$\Delta X_{n+1}=\left\{BK_n^T\left(K_nBK_n^T+E\right)^{-1}\right\}\left[\left(Y^m-Y(X_n)\right)+K_n\Delta X_n\right],$$

where ΔX is the updated state vector at iteration n+1, and K is the matrix of Jacobians which contain the sensitivity of X (parameters to retrieve) to the radiances.

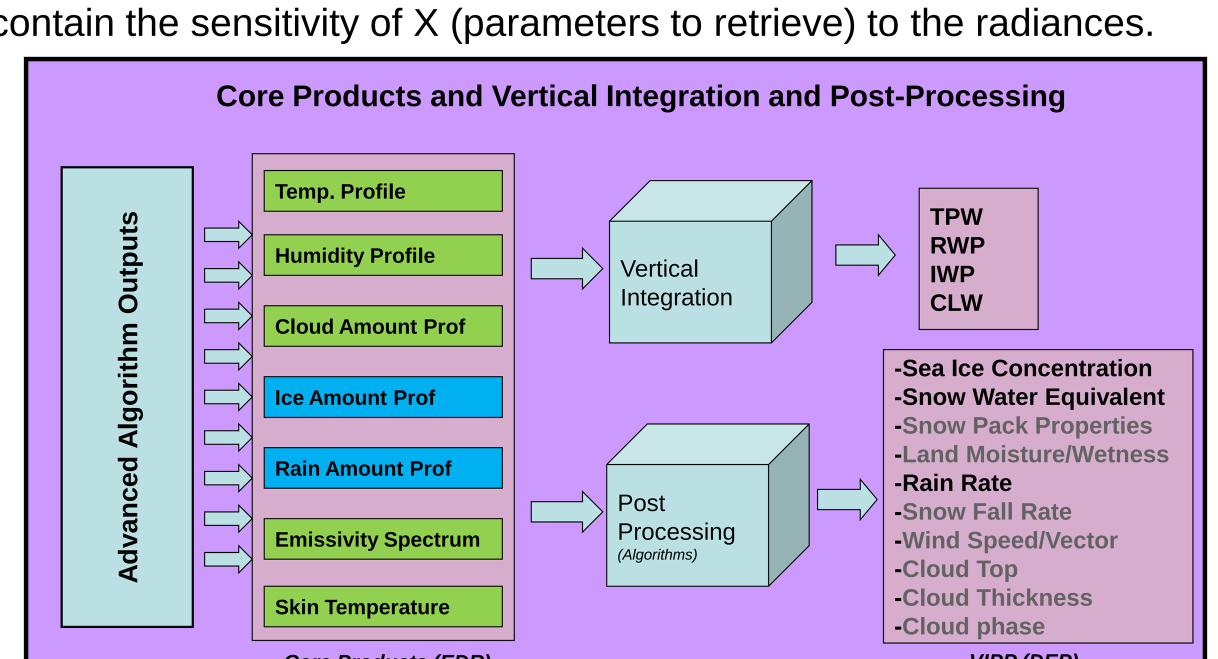


Figure 2. MiRS core and post-processing products. Core products are retrieved simultaneously as part of the state vector. Ice and Rain amount are retrieved in a 2nd retrieval attempt, if the 1st attempt (no scattering assumed) fails to reach a solution that fits the radiances.

A post processing algorithm derives the instantaneous rainfall rate through a fast regression that relates the rainfall rate to the retrieved integrated amounts of hydrometeors. The regression is trained using WRF model simulations for various precipitating regimes and is formulated as:

$$RR = a_0 + a_1CLWP + a_2RWP + a_3IWP$$

Where CLWP, RWP and IWP are the retrieved integrated amounts of cloud, rain and ice, and a_0, a_1, a_2, and a_3 are the regression coefficients.

3. Status and Results

Ongoing Assessments/Validation

Previous efforts in support of GPM include extension of the MiRS to TRMM TMI and simulated GPM GMI. TRMM TMI 1B11 data is processed on a daily basis, and MiRS rainfall rate compared to TRMM 2A12 rainfall rate, along with intercomparisons of the two Rainfall Rate products to NCEP Stage IV.

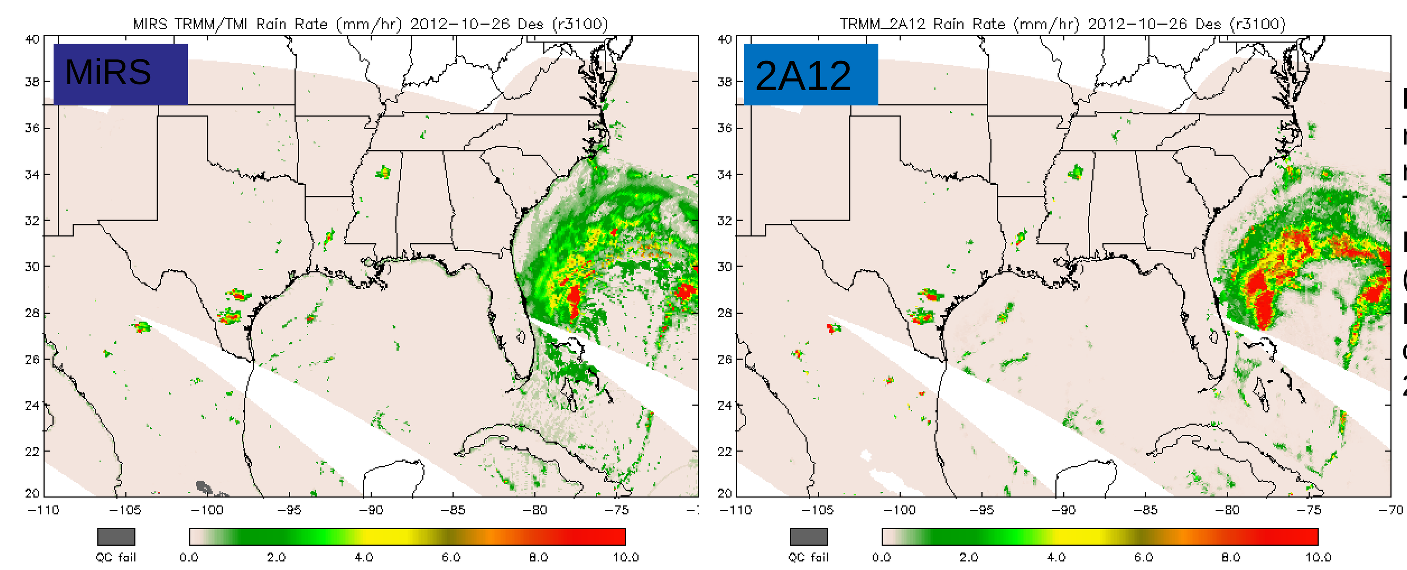


Figure 3. MiRS retrieved rainfall rate (left) and TRMM 2A12 Rainfall Rate (right) over Hurricane Sandy on October 26, 2012.

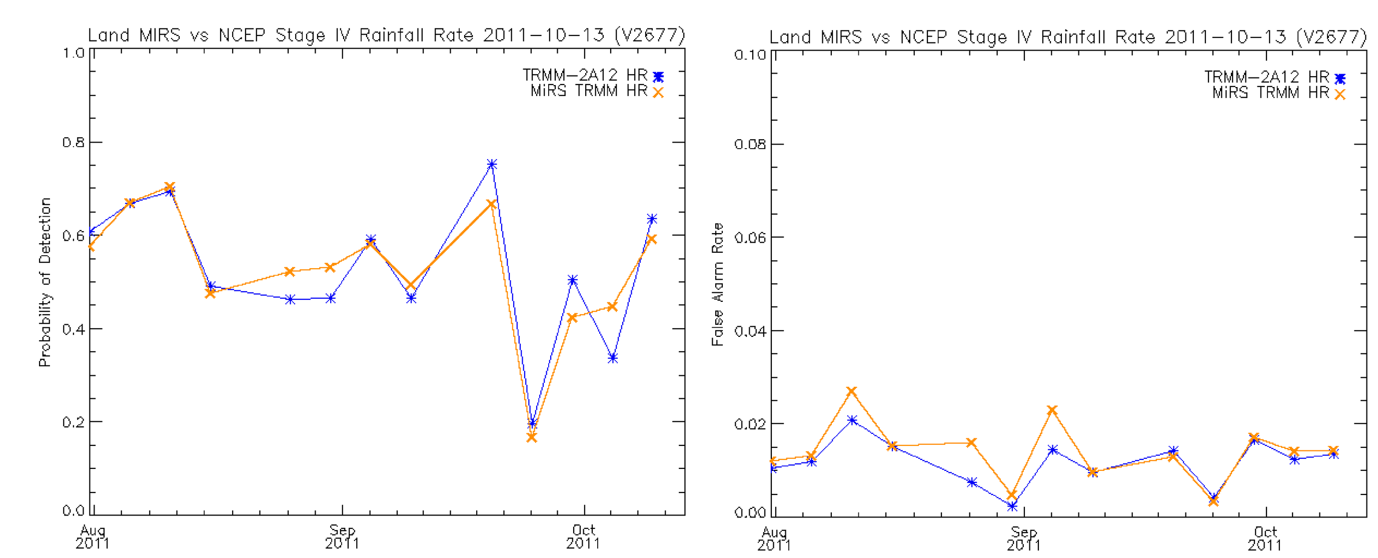
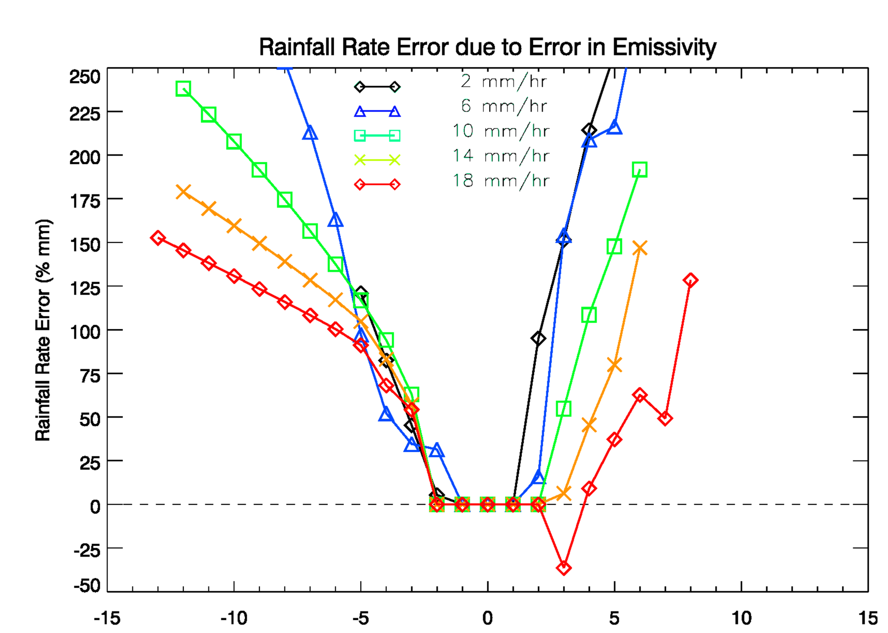


Figure 4. MiRS and TRMM 2A12 Rainfall Rate Probability of Detection (left) and False Alarm Rate (right) versus NCEP Stage IV sampled Aug. – Oct. 2011.

Surface Emissivity Sensitivity/Error Analysis

In the past it has been demonstrated that even in moderately intense precipitation, low frequency (10-20 GHz) brightness temperatures observed from satellites still contain surface signals. The MiRS retrieves surface emissivity to better isolate signal from precipitation and clouds and reduce errors in retrieved Rainfall Rate.



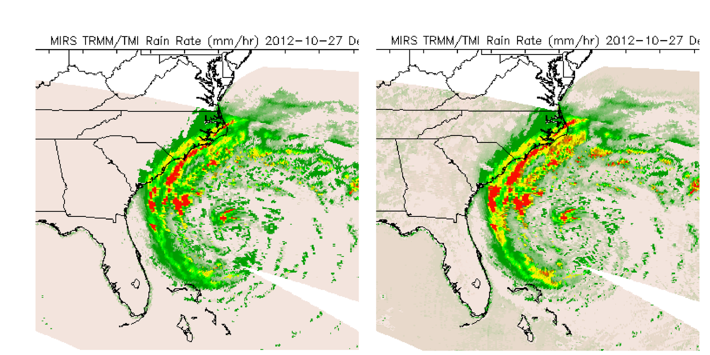


Figure 5. Rainfall Rate error as a function of emissivity error for varying intensities. Simulatoins were performed over land surfaces (left). MiRS Rainfall Rate over Hurricane Sandy with emissivity retrieval turned on (middle) and fixed ocean-background emissivity (right).

Hydrometeor PSD Sensitivity/Error Analysis

The implementation of CRTM 2.1 in MiRS has allowed for increased flexibility for hydrometeor particle size distribution (PSD) assumptions. Current studies are focusing on the sensitivity of Rainfall Rate retrievals to these parameterizations, which may lead to a more dynamic selection of PSD on a scene-by-scene basis in the future.

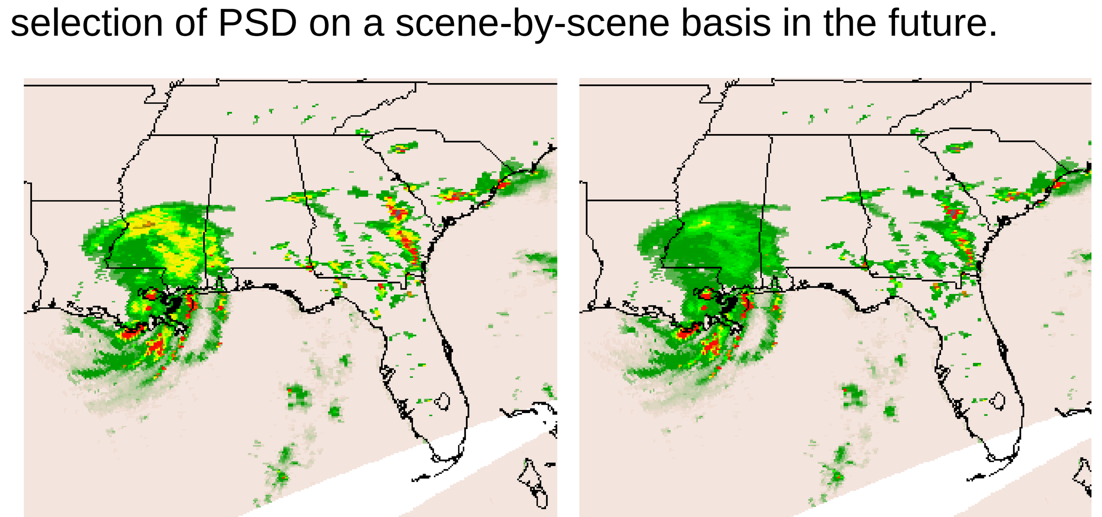


Figure 6. MiRS TRMM TMI Rainfall Rate retrieved in simulation assuming true graupel and rain PSD (left), and Rainfall Rate retrieved with a 100% increase in assumed graupel effective radius (right).

4. Application to Regional Data Assimilation

This work will involve GPM data impact assessment experiments using GPM data or proxy data in the NOAA operational Hurricane Weather Research and Forecast (HWRF) model. Specifically, the extension of the control variables to account for hydrometeors and rainfall rate in these models will be supported, with a focus on hurricane track and intensity forecast impacts. The integration of a 1DVAR preprocessor (MiRS) in the GSI data assimilation will allow for Rainfall Rate information and improved surface characterization from GPM data.

HWRF Model Overview

- The atmosphere-ocean coupled Hurricane modeling system has been NCEP's operational hurricane forecast system since the 2007 hurricane season, and is based on WRF NMM dynamical core with vortex following high-resolution telescopic nests and advanced physical parameterization schemes specific to the hurricane problem.
- An advanced vortex initialization and cycling technique provides initial representation of storm structure.
- Data assimilation system based on GSI 3DVAR/EnKF Hybrid system.
- Triple-nest capability that includes a cloud-resolving inner most grid operating at 3 km horizontal resolution.

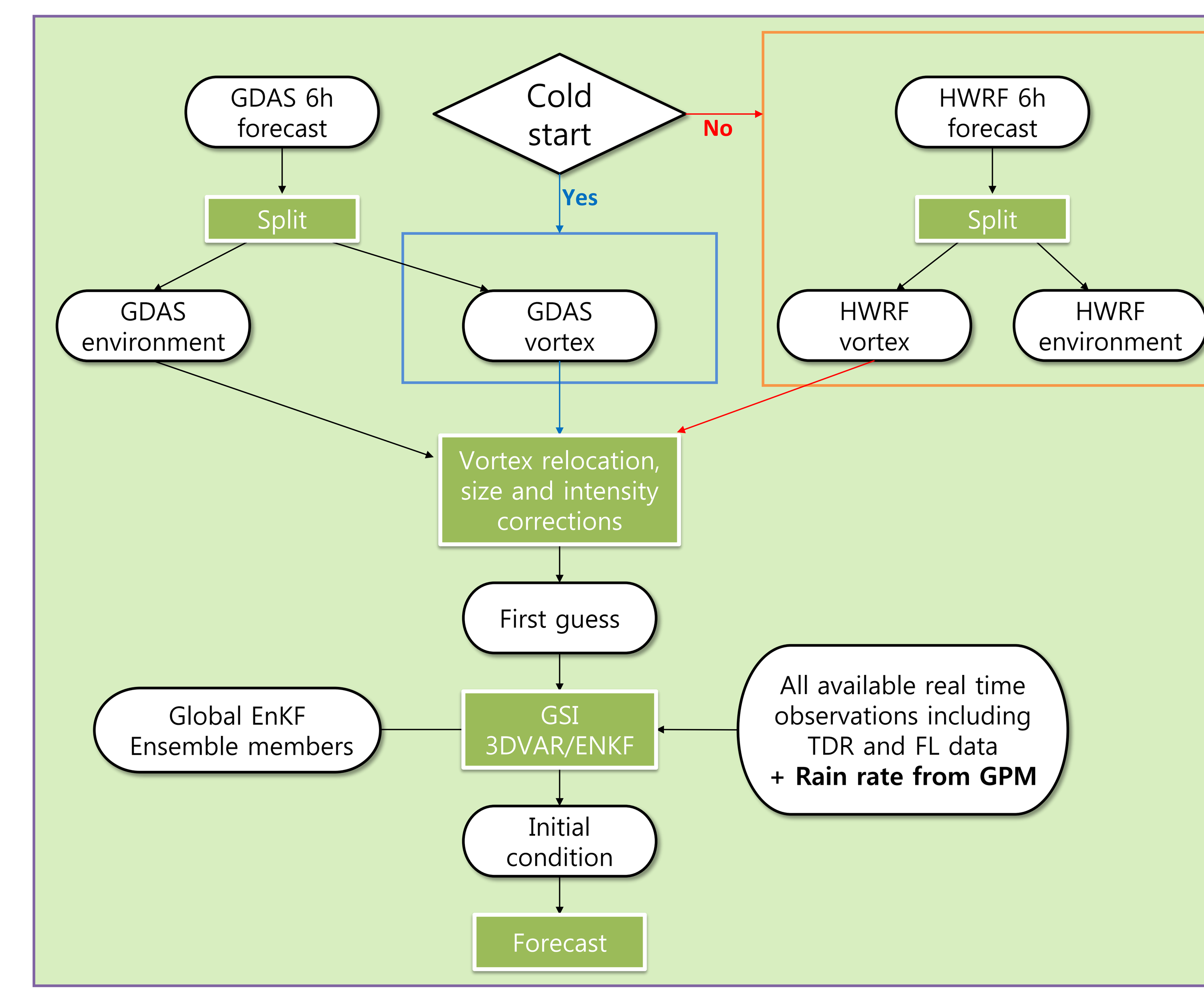


Figure 7. Flow chart of HWRF vortex initialization and data assimilation for the HWRF initial condition.

5 . Future Work

MiRS Algorithm

- Investigate synergy with the GPROF algorithm
  - Use hydrometeor profiles derived from GPROF to constrain the MiRS 1DVAR hydrometeor retrieval
  - Use MiRS surface emissivity within the GPROF to constrain Rainfall Rate.
  - Create an ensemble approach for Rainfall Rate retrieval using MiRS and GPROF
- Optimize hydrometeor assumptions within the CRTM including dynamic retrieval of cloud, rain and ice effective size.

Data Assimilation

- Direct assimilation of Rainfall Rates retrieved by the MiRS algorithm using GSI GPM datasets for HWRF model diagnostics to improve precipitation physics, especially for heavy rain around hurricane convective cloud bands.
- Quality control techniques for GMI-like imagers will be assessed through their impact on the quality and accuracy of forecasts at regional scales.