A Physically-based Rainfall Rate Algorithm for All Surfaces: Applicability to All Microwave Sensors Including TRMM & GPM

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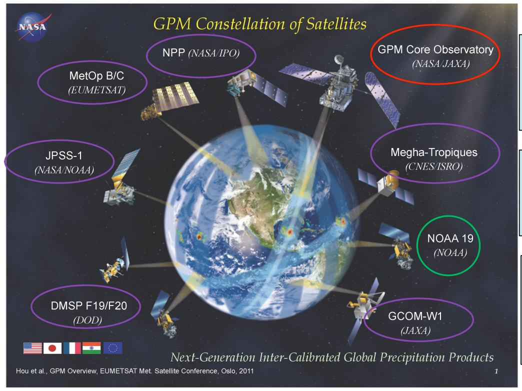
1. Introduction

The Microwave Integrated Retrieval System (MiRS) algorithm has been applied successfully in the past, and its modular design allows for a timely and efficient extension to the GPM and future sensors. MiRS is currently being applied operationally at NOAA to NOAA-18, 19, Metop-A, DMSP-F16 SSMIS, TRMM, and experimentally for AMSR-E (i.e a daily processing is in place but not in real-time). MiRS also runs for NPP/ATMS and GPM using proxy data. MiRS will expand to include other sensors in the GPM constellation.



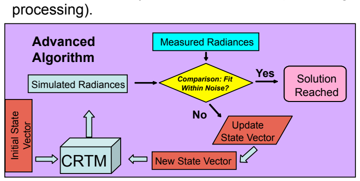
Applied Operationally
- POES N18/N19
- MeteopA AMSU/MHS
- DMSP SSMI/S F16/F18

Applied in Research Mode
- GPM
- TRMM TMI
- AMSR-E

Planned for Operational
- Megha-Tropiq.
- NPP
- MetOp B/C
- JPSS-1
- DMSP F19/F20
- GCOM-W1

2. Description of the Algorithm

NOAA/NESDIS/STAR has developed MiRS, a flexible, physical algorithm:
- Can be applied to multiple microwave imagers and sounders.
- 1DVAR approach using CRTM as forward and jacobian operator.
- Retrieves sounding and surface parameters simultaneously, including hydrometeor profiles, rainfall rate, and surface emissivity.
- Applicable over all surfaces and in all-weather conditions.
- Run operationally at NOAA OSDPD (and integrated at NDE for NPP/JPSS future processing).



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.

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 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.

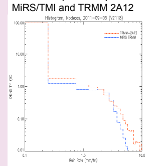
Two retrieval attempts are possible for each scene. The first attempt assumes a clear or cloudy scene (radiometric signal is due to atmospheric emission). If the attempt is non-convergent (Y^m not fit by Y), precipitation is assumed, scattering is turned on and rain and ice water profiles are retrieved along with sounding and surface products.

3. Direct Assessment of Rain Rate

Comparisons to TRMM 2A12

Improvements implemented to Rain Rate agorithm:
- Tightening of RTM uncertainties at high frequencies in first attempt (to detect more rain)
- Relax RTM uncertainty in 2nd attempt to account for RTM inaccuracies in rainy conditions
- Increase minimum threshold of RWP and IWP to start producing rain (lack of WV sounding channels means these thresholds are higher than the ones in MHS and SSMIS)
- Turn OFF Channel 2 (10.65 GHz, Hpol) that have large footprints–contamination by land in coastal areas.
- Make second attempt without hydrometeors when 10.65 GHz, Hpol&Vpol residuals are high and 37.0 GHz, Hpol residuals are low – to reduce coastal false alarm rain.
- Include Ice Field in the second attempt's first guess.

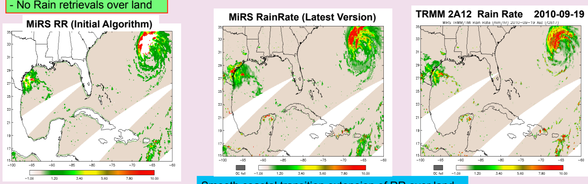
Point –to – point comparison MiRS/TMI and TRMM 2A12



* Non-convergence in heavy rain
* Lack of light rain detection

- No Rain retrievals over land

Full detection of rain structures (from light to heavy precipitation) over Land and Ocean



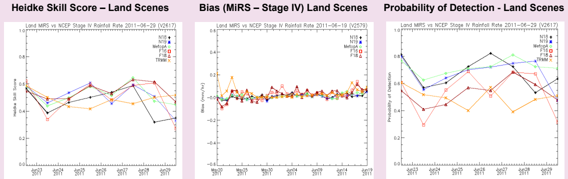
-Coastal false alarm signal

Smooth coastal transition extension of RR over land
Coast false alarm RR greatly reduced

Comparisons to NWP Stage IV Radar Data

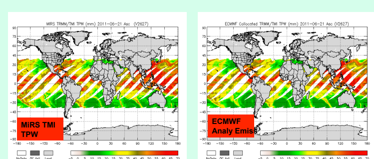
- MiRS TRMM has statistics similar to other microwave detectors.
- Probability of Detection is highly dependent on coverage

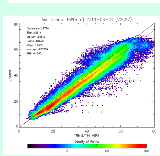
Time series of Bias: MiRS RR – NCEP Stage IV, May 2011 – June 2011.



4. Indirect Assessment of Rain Rate through TPW, Tskin (not shown), Emissivity

TPW Assessment : MiRS vs. ECMWF

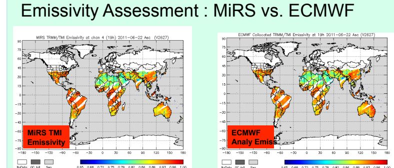


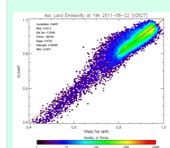


- Performances (3.5 mm std deviation) are similar to F16 SSMIS (noisy sensor) but less than those of F18 or N18, Metop (global coverage).

This could be due to:
- Lack of WV sounding channels or more noisiness in sensor
- Limited coverage (should be tropics only)
- Might indicate that bias needs fine tuning

Emissivity Assessment : MiRS vs. ECMWF



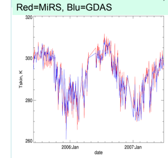


- Performances (2.4% standard deviation) are lower than SSMIS (around 1.6%).
- Could be due to higher differences in MiRS/TMI Tskin (due to penetration depth issues at 10. 65 GHz)

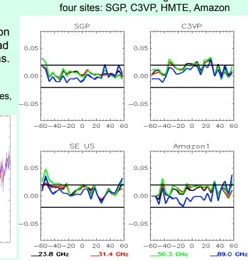
Emissivity MiRS vs. GDAS at a number of sites

- At the DOE ARM site Southern Great Plains (SGP), differences were generally within 2% over 2 year period.
- Ocean scenes had the least bias (not shown).
- High latitude Canadian Cloudsat CALIPSO Validation (C3VP) and Finland sites had a positive (MiRS-GDAS) bias.

NOAA 18 AMSU/A TskinTimeSeries, Red=MiRS, Blu=GDAS

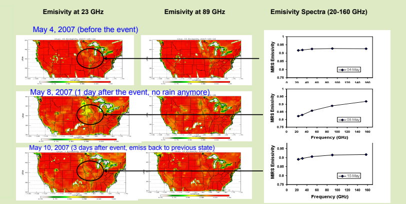


Emissivity Differences (MiRS – GDAS) as a function of view angle four sites: SGP, C3VP, HMTE, Amazon

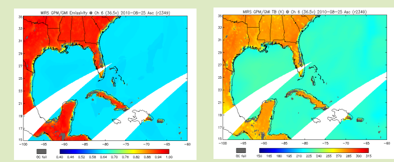


5. Current and Future Work

Emissivities under Rainy Conditions
- MiRS responds to surface wetness variations: before, right after the storm and later. Note the emissivity depression at 21 GHz and the inverted emissivity spectra on May 8, 2007.
- Physically-consistent behavior noticed in the emissivity variation

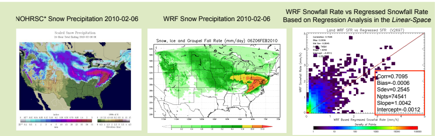


Simulated GPM GMI
- Shown are 36.5 GHz V. Surface emissivity and Brightness temparature.
- MiRS is ready to ingest GPM GMI data.



Snowfall Rate Calculations (ongoing work).

Maps of WRF snowfall rates correspond well with snow reports.
Regressions of WRF snow precipitation are made against RWP, IWP.



6. Summary

- MiRS TRMM is being processed on a daily basis at 9 km resolution near the Southeast US and Gulf of Mexico region and globally at 70 km resolution.
- Direct assessments of MiRS TMI Rain Rates and indirect assessments by way of Surface Emissivity, TPW, and Tskin show good agreement, and improvements continue to be made.
- MiRS emissivity retrievals are shown to be possible under rainy conditions, with a dynamic response to rain events.
- GPM GMI simulated data are being generated using European Centre for Medium-Range Weather Forecasts (ECMWF) fields collocated with the TRMM TMI, and used to produced MiRS GMI products daily over same region and resolution.