Microwave Integrated Retrieval System (MiRS): Recent Science Improvements and Applications

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1. Background

MiRS (Microwave Integrated Retrieval System) is a One-Dimensional Variational inversion scheme (1DVAR) (Boukabara et al. 2011, 2013) that employs the Community Radiative Transfer Model (CRTM) as the forward and adjoint operators. It simultaneously solves for surface (Tskin, emissivity), and atmospheric parameters (temperature, water vapor, non-precipitating cloud and hydrometeor profiles). MiRS is currently being run operationally at NOAA for Suomi-NPP/ATMS, POES N18/N19, Metop-A, Metop-B, DMSP-F17/F18, and Megha-Tropiques/SAPHIR. The 1DVAR algorithm uses an iterative approach in which a solution is sought that best fits the observed satellite radiances, subject to other constraints.

In addition, once the core parameters of the state vector are retrieved in the 1DVAR minimization step, and additional post-processing is done in which a number of derived parameters are retrieved, based on inputs from the core 1DVAR retrieval. These include: surface rain rate, as well as cryospheric parameters such as snow pack properties, sea ice concentration and sea ice age.

In this poster, we report on important changes incorporated into the latest version of MiRS (v11.1) which has recently been released and transitioned to operations at NOAA. These changes have led to improved performance for many of the retrieval products.

2. MiRS 1DVar Algorithm

The 1DVAR algorithm uses an iterative approach in which a solution is sought which "best fits" the observed satellite radiances, subject to other constraints. 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 the radiances to changes in X (parameters to retrieve). This is then followed by the post-processing step which uses as inputs the elements of the state vector X. Figure 1 summarizes the MiRS processing components.

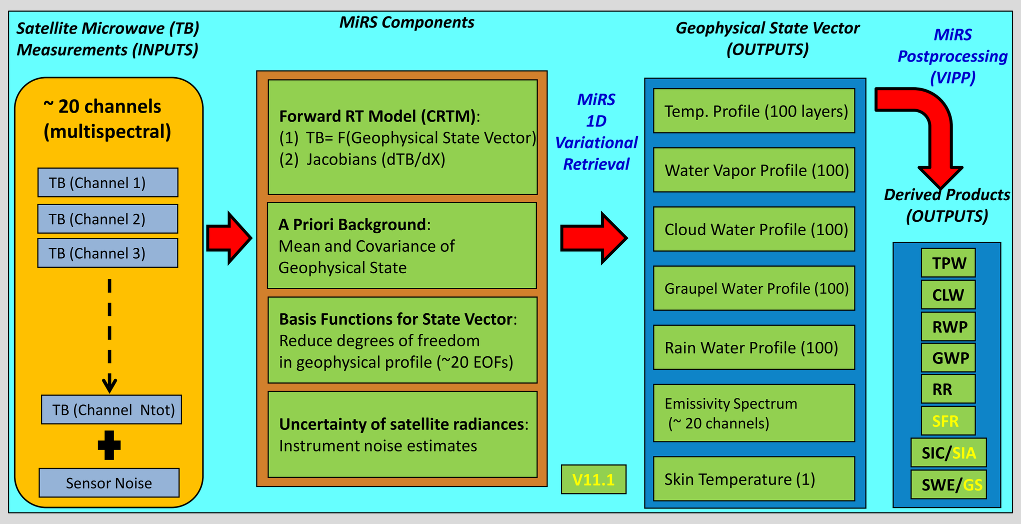


Figure 1. MiRS core retrieval and post-processing (VIPP) components. Core products are retrieved simultaneously as part of the state vector. VIPP products are derived through vertical integration (hydrometeors), catalogs (SIC, SWE), or fast regressions (Rain Rate). New retrieval products added in v11.1 are indicated in yellow: Snowfall Rate, Sea Ice Age, and Snow Grain Size.

In September 2015, a completely updated version of MiRS (version 11.1) was released publicly and transitioned to operations at NOAA. It was also integrated into an updated version of the Community Satellite Processing Package (CSPP), developed at the University of Wisconsin/SSEC for users with access to direct broadcast (DB) data (CSPP_MIRS_V2.0). Version 11.1 replaces the previous operational version of MiRS (V9.2), and contains a number of significant changes that have generally led to atmospheric and surface parameter retrievals with higher quality. The most significant changes are summarized in Table 1.

Description	Satellites/Sensors Affected	Benefit
Extension to high (MHS) resolution for AMSUA-MHS (LR=30 FOVs/scan, HR=90FOVs/scan)	N18, N19, MetopA/AMSUA-MHS, (MetopB, SNPP/ATMS already high-resolution)	Improved depiction of small-scale features: CLW, RR, WV, ice edge
Extension to high (ENV) resolution for SSMIS (LR=30 FOVs/scan, HR=90FOVs/scan)	F17 and F18/SSMIS	Better depiction of small-scale features: CLW, RR, WV, ice edge
Integration of CRTM 2.1.1	All: N18, N19, MetopA, MetopB/AMSUA-MHS, SNPP/ATMS, F17, F18/SSMIS (MT/SAPHIR already using CRTM 2.1.1)	Better sync with CRTM development cycle; more realistic ice water retrievals (Jacobians)
New radiometric bias corrections for all sensors	All	Needed for consistency with CRTM 2.1.1
Integration of new dynamic (varies spatially, temporally) a priori atmospheric background	All	Large improvement in T, WV sounding; reduction in average number of iterations; increase in convergence rate
Updated hydrometeor/rain rate relationships	All	Improved RR over land and ocean
Updated hydrometeor a priori background profiles	All	Improved RR over land and ocean; improved sounding products in rainy conditions
Updated surface type preclassifier	F17 and F18/SSMIS	Improved snow detection for conical scan instruments
New parameter: Snowfall Rate (SFR)	N18, N19, MetopA, MetopB/AMSUA-MHS (planned: SNPP/ATMS)	New product, supplements rain rate. At NOAA, separate OSPO/MSPPS processing can be turned off; potential for leveraging real-time MiRS retrieval products rather than GFS forecasts
Snow Water Equivalent (SWE) spatially-temporally variable climatology background	All: N18, N19, MetopA, MetopB/AMSUA-MHS, SNPP/ATMS, F17, F18/SSMIS	Better spatial and temporal constraint on SWE; also improved SGS retrieval
Snow Grain Size (SGS) and Sea Ice Age (SIA)	All: N18, N19, MetopA, MetopB/AMSUA-MHS, SNPP/ATMS, F17, F18/SSMIS	New product, satisfies operational user request
Updated all Snow Emissivity Catalogs: finer SGS discretization and larger physical ranges	All: N18, N19, MetopA, MetopB/AMSUA-MHS, SNPP/ATMS, F17, F18/SSMIS	Smoother distributions for SGS, SWE, larger dynamic range for SGS.
Miscellaneous changes to improve code efficiency, bug fixes	All	Matrix preparation time reduced from 40% to 5% of 1dvar computation time

Table 1. Summary of principal changes contained in MiRS V11.1 along with associated benefits.

3. Version 11.1 Retrievals

We present a number of examples comparing MiRS retrievals using V11.1 and V9.2 and, when available, use standard reference data for evaluating the differences. Retrieval parameters shown include: (1) temperature and water vapor profiles, (2) rain rate, (3) land surface emissivity, (4) snow water equivalent, and snow grain size, (6) sea ice concentration and sea ice age, and (7) 3-dimensional depiction of severe weather and tropical cyclone structure.

4. Temperature and Water Vapor Sounding

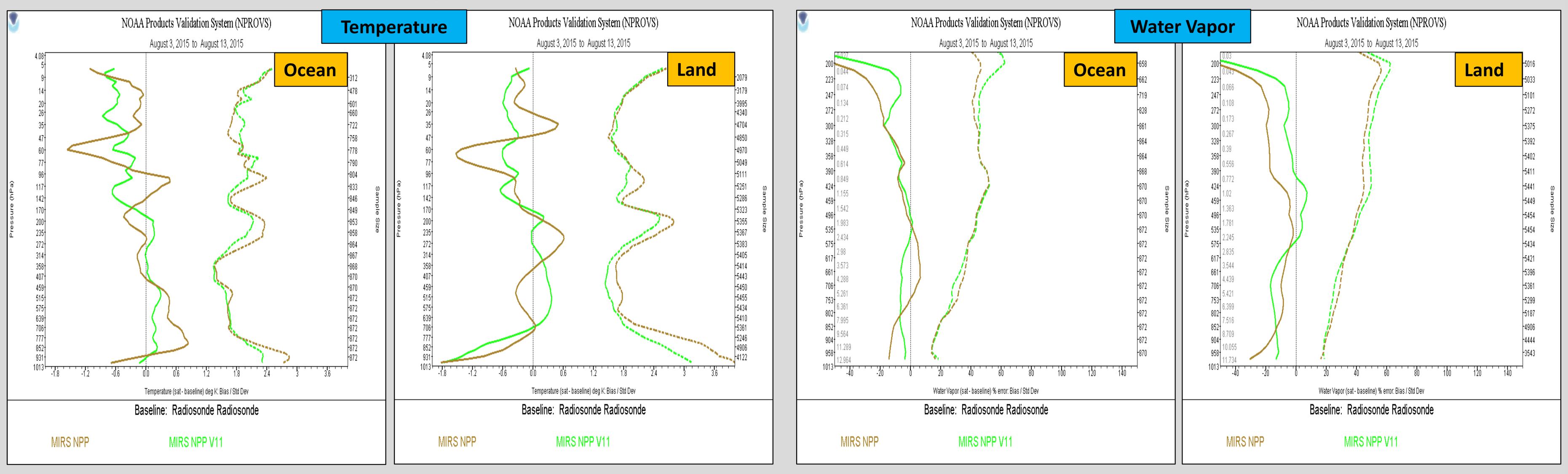


Figure 2. Sounding performance of MiRS V11.1 (green) and V9.2 (brown) based on radiosonde matchups for the period 3-13 August 2015. In general, bias and standard deviation are reduced or unchanged in V11.1 over both land and ocean.

5. Rain Rate

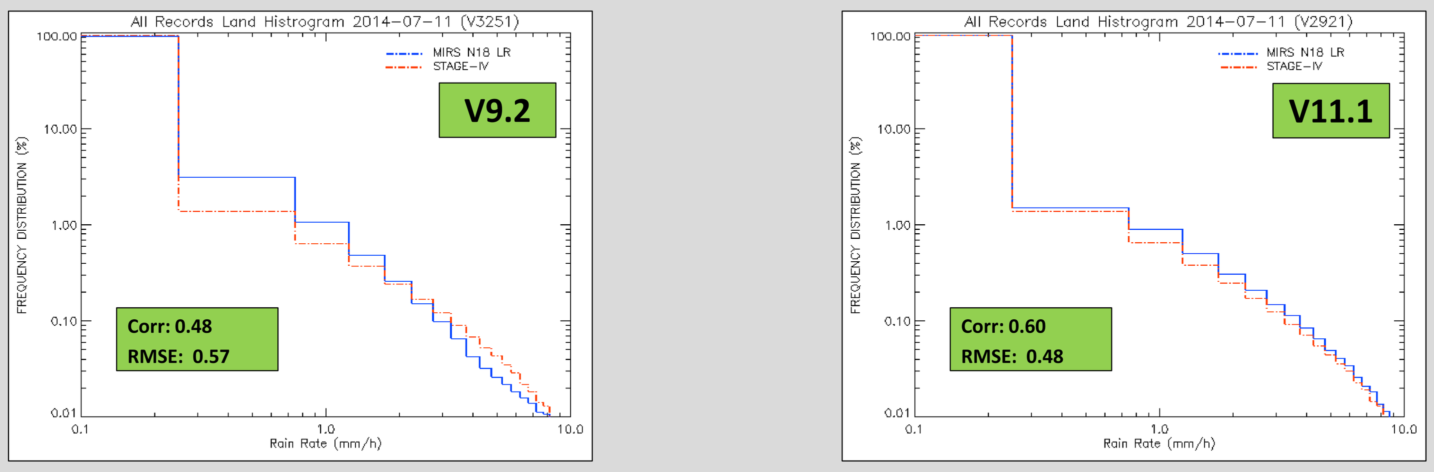


Figure 3. MiRS N18/AMSU-MHS rain rate (blue) assessment versus Stage IV radar-gauge composite (red) for the period 2009-2014. Histograms are shown for V9.2 (left) and V11.1 (right). Results show that V11.1 matches Stage IV better over the entire range of observed rain rates, as well as has better agreement in terms of correlation and RMS differences.

6. Land Surface Emissivity

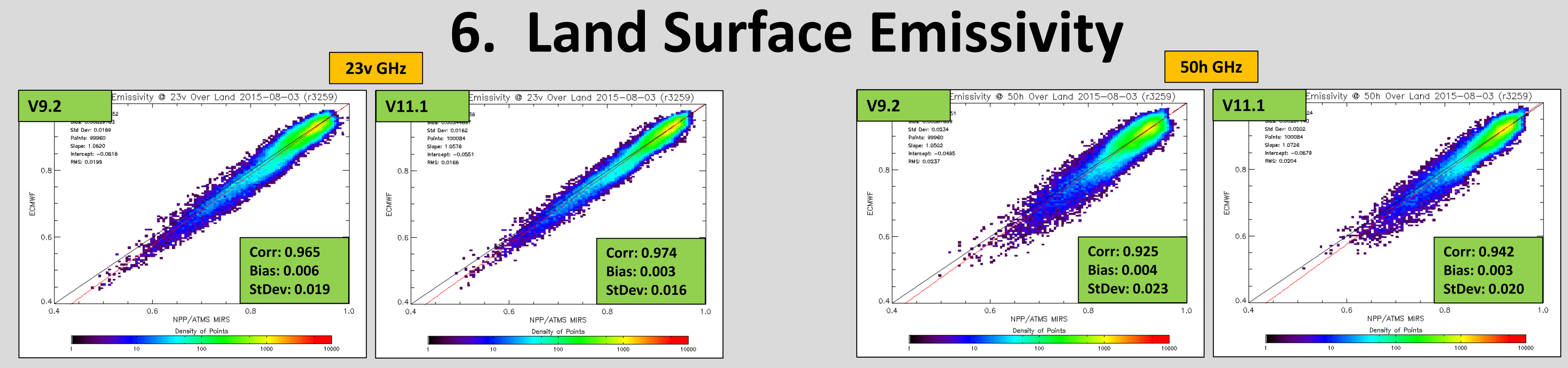


Figure 4. MiRS S-NPP/ATMS retrievals of global land surface emissivity at 23 (left) and 50 GHz (right) on 3 August 2015 compared with so-called "analytic" emissivity computed from observed brightness temperatures combined with ECMWF analyses of Tskin, temperature and water vapor along with CRTM-simulated estimates of upwelling and downwelling radiance. Results show that MiRS V11.1 emissivity has higher correlation and lower errors than V9.2. Accurate surface emissivity retrievals are an important component of monitoring changes related to vegetation and/or surface moisture

7. Snow Water and Grain Size

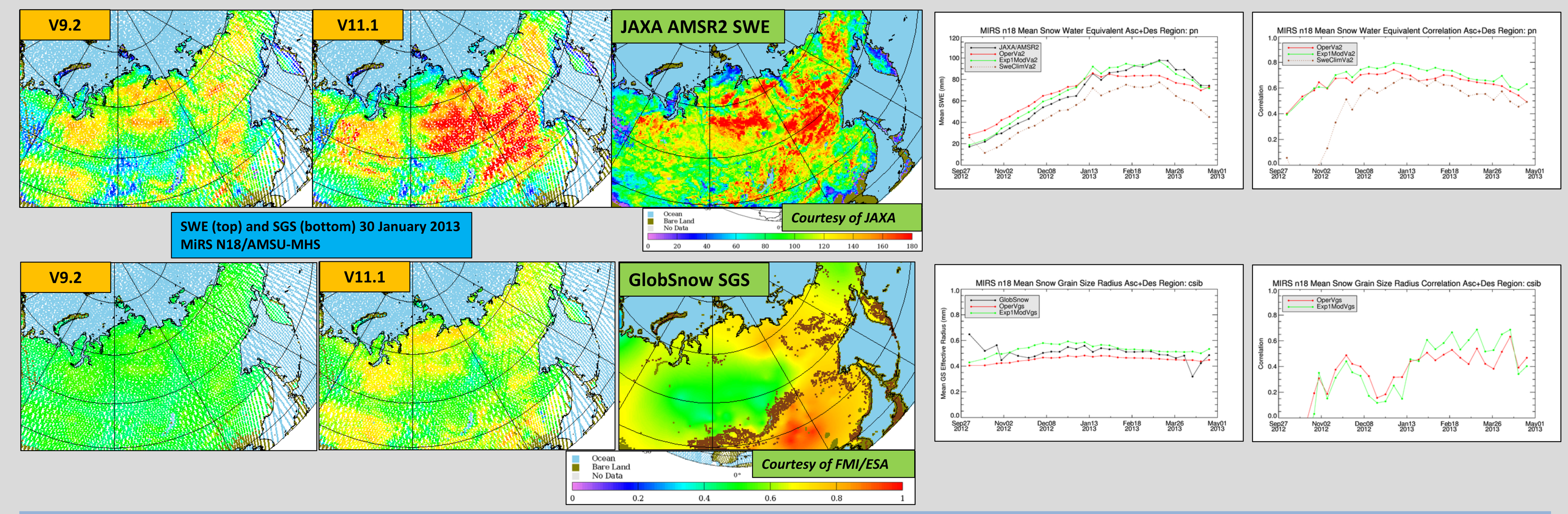


Figure 5. Top: MiRS SWE retrievals (mm) from N18/AMSU-MHS, compared with the official AMSR2 SWE product from JAXA. Time series at right show global performance (mean and correlation) for the period October 2012-April 2013 for V9.2 (red), V11.1 (green), and climatology (brown). Bottom: MiRS N18 AMSU-MHS SGS retrievals (mm) compared with the European GlobSnow analysis. Time series at right show performance over Central Siberia for the period October 2012-April 2013 for V9.2 (red), V11.1 (green).

8. Sea Ice Concentration and Ice Age

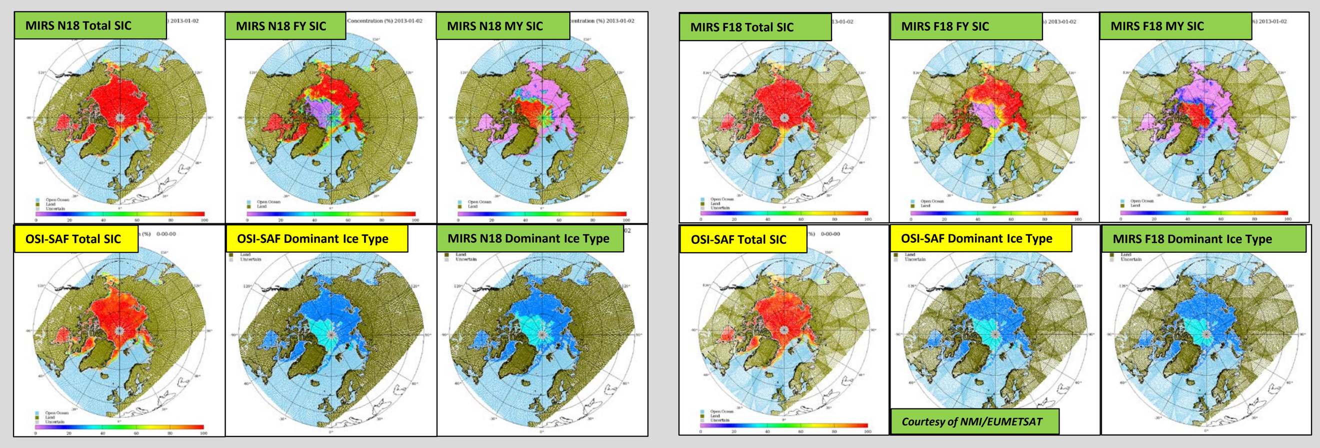
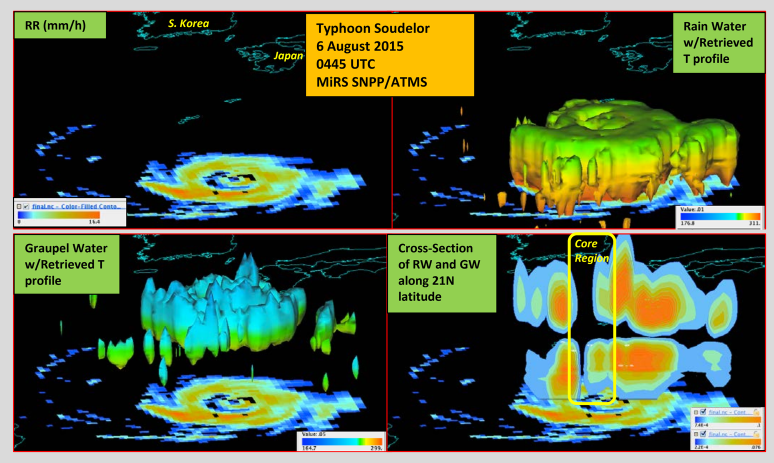


Figure 6. Left: MiRS V11.1 Sea Ice Concentration and Ice Age retrieved from N18/AMSU-MHS on 02 January 2013 compared with the EUMETSAT Ocean and Sea Ice Satellite Application Facility (OSI-SAF) operational analysis. Right: MiRS F18/SSMIS sea ice retrievals on the same day.

MiRS retrievals of both total and dominant ice type agree well with the OSI-SAF analyses. Moreover, there is high consistency between the retrievals from AMSU-MHS and SSMIS. MiRS retrievals of first year and multiyear ice concentration are converted to dominant ice type for comparison with OSI-SAF.

9. 3-Dimensional Hydrometeor Structure



Left: *MiRS algorithm simultaneously retrieves not only the atmospheric profiles of temperature and water vapor, but also atmospheric rain water, graupel and cloud, making it possible to reconstruct the 3-dimensional structure of the storm. The results show that the 3-dimensional structure of atmospheric rain and ice, as well as the surface rain rate are realistically retrieved, with maximum surface rain rates of 16 mm/h, and the storm core structure present in both rain and graupel fields.*
Right: *MiRS retrieval of hydrometeor structure shows complexity (GW vs. RW distribution in vertical cross-section), and surface rain rates align well with NEXRAD reflectivities.*

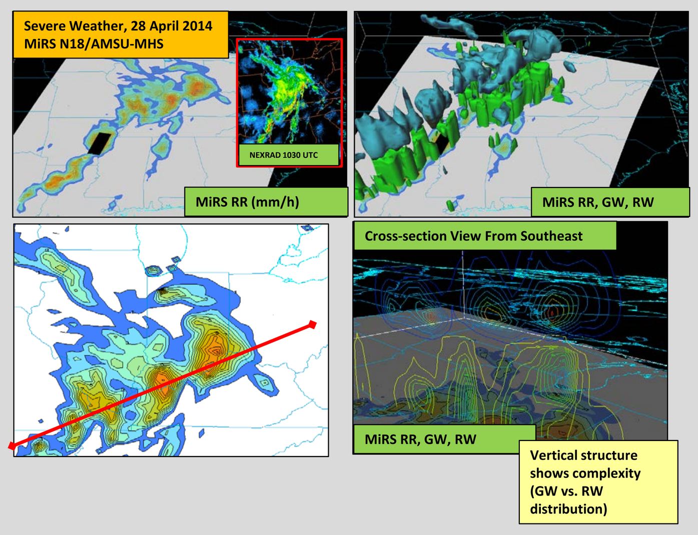


Figure 7. Left: MiRS V11.1 retrievals of hydrometeor and temperature structure around Typhoon Soudelor from Suomi-NPP/ATMS microwave observations at 0445 UTC on 6 August 2015. Panels show surface rain rate (top left), rain water 0.01 mm isosurface with temperature profile superimposed (top right), graupel water 0.05 mm isosurface with temperature profile superimposed (bottom left), and a vertical cross-section along 21 degrees north latitude of both rain and graupel water (bottom right). Right: MiRS N18 AMSU-MHS retrievals of hydrometeor structure through a severe weather outbreak on 28 April2014 at 1030 UTC.

10. Summary

A new version of the NOAA MiRS algorithm (V11.1) has been released and transitioned to operations at NOAA. It has also been integrated into a new version of the Community Satellite Processing Package (CSPP_MIRS_2.0). V11.1 contains a number of technical and scientific enhancements that have led to improved retrieval performance. Some of the improvements include:

- Reduction in temperature profile bias and standard deviation over both ocean and land surfaces
- Improvement in hourly rain rate in terms of correlation and RMS differences with collocated Stage IV gauge-adjusted radar estimates; a 4-year comparison shows improved rain rate distributions, especially for rain rates above 4 mm/h.
- Retrieval of land surface emissivity at 23 and 50 GHz with a reduced bias and standard deviation relative to a reference analytic emissivity.
- Snow water equivalent estimates show better agreement with JAXA AMSR2 snow water retrievals, both statistically, and in terms of spatial patterns; snow grain size retrievals from V11.1 also agree better with the GlobSnow grain size estimates.
- Total sea ice concentration and age (first year/multiyear) agree well with the operational products from OSI-SAF.
- Depiction of the 3-dimensional structure of hydrometeors, rain rate, and temperature in severe weather systems and tropical cyclones.

Future Work:
- Extension of MiRS operational capability to DMSP F-19/SSMIS and GPM/GMI in early 2016, and extension to upcoming JPSS-1/ATMS mission data by 2017.
- Possible extension to infrared sounder measurements, and to active (e.g. precipitation radar) sensors.

Access to MiRS data and software: (1) MiRS website at mirs.nesdis.noaa.gov, (2) NOAA CLASS archive at www.class.noaa.gov, (3) CSPP_MIRS_2.0 at cimss.ssec.wisc.edu/cspp

11. Acknowledgements

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12. References

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