JPSS GOESS Proving Ground/Risk Reduction Summit- College Park, MD - 24 – 28 February, 2020

Preliminary Development and Assessment of the NOAA Microwave Integrated Retrieval System for Tropical Cyclones (MiRS-TC): A Passive Satellite Microwave Retrieval Algorithm Optimized for Tropical Cyclones

Christopher Grassotti[1], Shuyan Liu[2], Yong-Keun Lee[1], and Quanhua Liu[3]

1.University of Maryland, Cooperative Institute for Satellite Earth System Studies and NOAA/NESDIS/STAR (christopher.grassotti@noaa.gov) 2. Colorado State University/CIRA and NOAA/NESDIS/STAR 3. NOAA/NESDIS/STAR

Abstract

Tropical Cyclones (TCs) represent a significant threat to human life and property relating to multiple hazards including high winds, heavy rainfall, and storm surge fooding. TCs occur in multiple ocean basins including the western Atlantic, eastern and western Pacific, and Indian Oceans. TC formation and intensification occurs over oceans, and can often take place in remote regions making frequent direct in situ observations by instrumented aircraft more challenging. Satellite observations, particularly from cloud-penetrating microwave measurements, can provide a critical component of the global observing system and can supplement traditional observations. In fact, NOAA operational algorithms in place (e.g. HISA, Hurricane Intensity and Structure Algorithm (Chirokova et al., 2018)) utilize microwave retrievals of the temperature and moisture structure from the operational MiRS algorithm to estimate current cyclone intensity.

We present recent work with the operational NOAA Microwave Integrated Retrieval System (MiRS) the goal of which is to develop a version that is optimized for performance in TC environmental conditions (MiRS-TC). The work is motivated by the fact that in the current operational version of MiRS several key components of the retrieval system are designed to optimize retrieval accuracy and precision in a globally-averaged sense, not for the unique conditions present in the vicinity of TCs. For example, a priori constraints on the temperature and water vapor profiles in terms of means and covariances, EOF basis functions for temperature and water vapor, and channel selection are all based on global data and validation results. Here we will present results based on a set of TC case studies in the Atlantics Basin (i.e. Hurricanes Florence in 2018, and Dorian in 2019) showing that, by adjusting the various critical components of the retrieval system, a TC-specific version of MiRS can produce retrievals that are consistently more accurate than the baseline operational global version. In particular, we examine the ability to retrieve the temperature warm core anomaly structure and its horizontal and vertical dependence, which is known to be a strong indicator of TC intensity.

1. Background

MiRS (Microwave Integrated Retrieval System) is a One-Dimensional Variational inversion scheme (1DVAR) (Boukabara et al. 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, Megha-Tropiques/SAPHIR, and GPM/GMI. In June 2018, an updated version (v11.3) was delivered to NOAA operations, extending processing capability to NOAA-20/ATMS measurements. This has subsequently been updated to v11.4 in operations in July 2019. Processing of Metop-C non-operationally in NOAA/STAR has been underway since shortly after launch in November 2018, and operational implementation is expected in 2020. The algorithm which is based on a one-dimensional variational approach uses the CRTM forward model to simulate radiances and to determine the atmospheric state which best fits the observed radiometric measurements, subject to other a priori constraints. To reach the iterative solution, the algorithm seeks to minimize a cost function which in effect balances a fit of the simulated to observed radiances with the departure of the solution from an a priori climatology. Figure 1 summarizes the MiRS processing components. The core 1DVAR retrieval consists of vertical profiles of atmospheric temperature, water vapor, non-precipitating clouds, precipitation size rain and ice particles, surface skin temperature and surface emissivity. Further post-processing is used to estimate, where appropriate, surface rain rate (Liu et al. 2017, Iturbide-Sanchez et al. 2011), snowfall rate, sea ice concentration and ice age, as well as snow water equivalent and snow grain size.

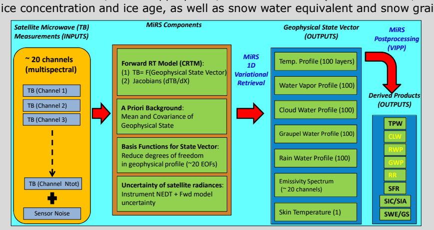


Figure 1. MiRS core retrieval and post-processing (VIPP) components. Core products are retrieved simultaneously as part of the state vector. VIPP products are derived through vertical integration (hydrometeors), catalogs (SIC, SWE), or fast regressions (Rain Rate). Hydrometeor retrieval products are indicated in yellow: Rain Rate, Graupel Water Path, Rain Water Path and Cloud Liquid Water.

2. Atmospheric Covariance Structure Variability

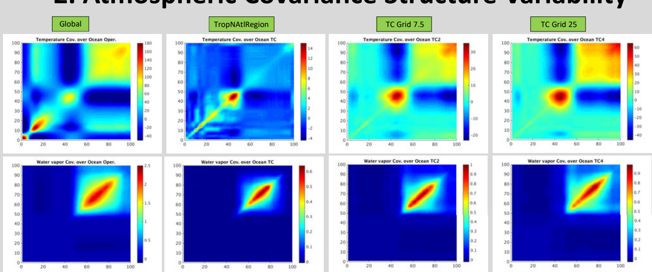


Figure 2. Examples of atmospheric temperature (top row), and water vapor (bottom row) covariances based on different temporal and spatial sampling of ECMWF operational analyses. From left to right: Global is used operationally in MiRS and is based on the ECMWF60 data set, a global set of atmospheric profiles sampled from a wide range of climate conditions and seasons. The remaining statistics were obtained from time periods corresponding to Hurricanes Dorian (2019-08-25 to 2019-09-10), Florence (2018-08-31 to 2018-09-17) and Michael (2018-10-07 to 2018-10-20). TropNAtlantic is for the region defined by 0 to 35 degrees N latitude and 80 to 50 degrees W longitude. TC Grid 7.5 and TC Grid 25 were based on sampling of grids within ±7.5 and ±25 degrees latitude/longitude, respectively, of the corresponding TC center location. Layer indices 1 and 100 correspond to the top and bottom atmospheric layers, respectively.

Changing the sampling of the model atmosphere results in significant differences in the corresponding atmospheric covariances, both in structure and magnitude. As expected, the more restrictive the sampling is in space and time, the smaller are the resulting covariances. It is logical to assume that an a priori covariance structure more consistent with tropical or TC conditions may result in better retrievals since the variational retrieval has significant dependence on the a priori constraints. And since the domain of application of a TC-specific retrieval algorithm would be more limited, smaller covariances would likely restrict the retrieval solutions to those consistent with TCs, assuming the background mean variables are also corrrectly specified.

3. MiRS-TC Development

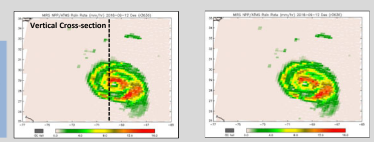
Development of a version of MiRS adapted to the TC environment (MiRS-TC) has focused on a number of components of the retrieval algorithm: (1) the retrieval methodology itself (i.e. 2-attempt vs. a multi-attempt framework, (2) simultaneous vs. sequential retrievals, (3) channel selection, (4) vertical basis functions (Empirical Orthogonal Functions, EOFs) used to represent the temperature and water vapor profiles, and (5) specification of the a priori background mean and covariance for temperature and water vapor used as constraints in the 1DVAR retrieval. Retrieval experiments have been conducted on a number of TCs occurring in the Atlantic Basin: Dorian (2019), Florence (2018), Harvey (2017), Matthew (2016), Joaquin (2015), and Edouard (2014). The table below summarizes the two configurations that have been used for our most recent tests: operational (OPER) and multi-attempt (multi_02). Text highlighted in red indicates features that were changed with respect to the operational version of MiRS.

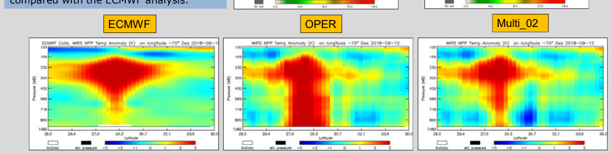
	Retrieval Configurations to Date	
	OPER (operational configuration)	**Multi_02 (TC configuration)**
Number of Retrieval Attempts	Two "Attempts": 1st attempt assumes no hydrometor scattering and stops with retrieved atmospheric and surface parameters if convergence criteria met. Otherwise 2nd attempt assumes hydrometeor scattering (~5% of cases globally) and retrieves all atmospheric and surface parameters with relaxed radiance fitting criteria in most channels.	Flexible number of "Attempts": In practice, 3 attempts. 1st attempt assumes no hydrometor scattering and stops with retrieved atmospheric and surface parameters if convergence criteria met. Otherwise 2nd attempt retrieves T, WV and hydrometeor profiles, but high frequency channels (ATMS 16-22) are turned off, allowing less interference of hydrometeors in the T and WV profiles. 3rd Attempt turns on high frequency channels in order to obtain more accurate hydrometeors, but fixes the T and WV profiles to the 2nd attempt values.
Channel Selection	All ATMS channels used in both attempts.	Channel selection dependent on attempt number. Channels selected to optimize retrieval parameters of interest in each attempt.
Simultaneous or Sequential Retrieval	Simultaneous retrieval: all atmospheric and surface parameters retrieved at same time.	Sequential retrieval: selected atmospheric and surface parameters are targeted in 2nd and 3rd attempts. T and WV in 2nd attempt are held fixed in the 3rd attempt in which the final rain rates are retrieved.
A priori background T and WV Profile	First Guess/Background T and WV from "dynamic climatology" which varies with lat/lon, and time.	First Guess/Background T from "dynamic climatology" which varies with lat/lon, and time. WV profile from a TC-specific climatology derived from COSMIC data. WV climatology varies with radial distance from TC center location.
A priori background T and WV Covariances and EOF Basis Functions	• Background covariances: single matrix derived from analysis of global profiles of T and WV from multiple seasons and weather regimes. Stratified by surface type. • EOF basis functions: derived from the global covariances above.	• Background covariances: single matrix derived from analysis of global profiles of T and WV from multiple seasons and weather regimes. Stratified by surface type. • EOF basis functions: derived from the global covariances above. Number of EOFs adjusted.

4. Retrieved Rain Rate and Vertical Cross-Sections

Florence: 2018-09-12

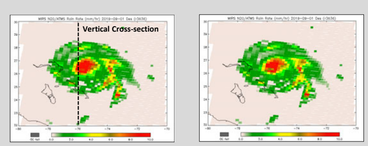
Figure 3. MiRS NPP/ATMS retrieved rain rate and temperature anomaly cross-sections for the case of Hurricane Florence on 12 September 2018. Cross-sections show that the MiRS-TC (multi_02) version has a more accurate depiction of the hurricane temperature structure when compared with the ECMWF analysis.

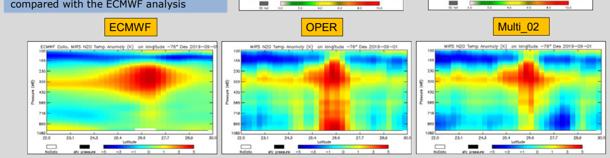




Dorian: 2019-09-01

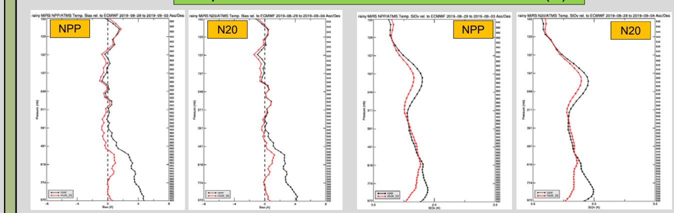
Figure 4. MiRS NOAA-20/ATMS retrieved rain rate and temperature anomaly cross-sections for the case of Hurricane Dorian on 1 September 2019. Cross-sections show that the MiRS-TC (multi_02) version has a more accurate depiction of the hurricane temperature structure when compared with the ECMWF analysis



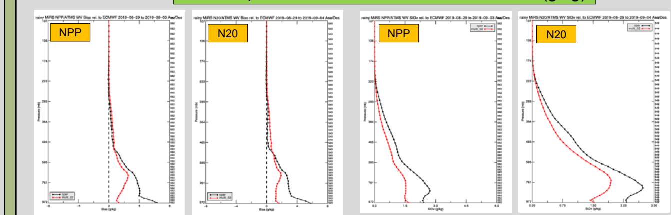


5. Retrieval Error Statistics for Hurricane Dorian

Temperature Error Bias and Standard Deviation (K)



Water Vapor Error Bias and Standard Deviation (g/kg)



Water Vapor Error Bias and Standard Deviation (%)

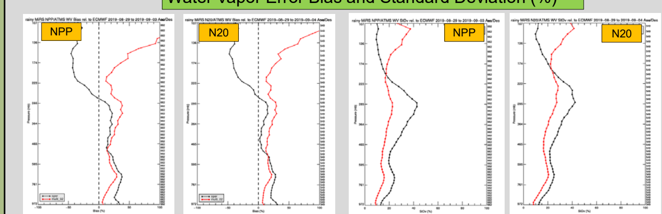


Figure 5. MiRS NPP and NOAA-20/ATMS retrieval error statistics (with respect to ECMWF analyses) for the case of Hurricane Dorian for rainy scenes only that were within 100 km of the hurricane center. Two experiments are shown: operational MiRS (oper, black), and MiRS-TC (multi_02, red). Statistics shown are averaged temperature error bias and standard deviation (K, top row), averaged water vapor bias and standard deviation (g/kg, middle row), and averaged water vapor bias and standard deviation (%, bottom row). Results are based on the period 29 August – 4 September 2019.

The results shown clearly demonstrate that the experimental MiRS-TC significantly reduces the retrieval bias and error standard deviation in the mid to lower troposphere when compared with the operational version of MiRS. Both temperature and water vapor retrievals are improved in MiRS-TC.

6. Summary

An experimental version of MiRS optimized for tropical cyclone conditions (MiRS-TC) is under development. Features of the current version of MiRS-TC include:

- Flexible number of attempts with retrievals performed sequentially. Each stage is designed to handle specific atmospheric conditions with different retrieved variables in each attempt.
- Radiometric channels are selected in each attempt to optimize retrieval of the parameters in question.
- An a priori background mean water vapor profile derived from COSMIC soundings in TC conditions.
- Initial validation results show that both MiRS-TC temperature and water vapor retrievals are significantly improved relative to the operational MiRS.

Future Work:

- Development and testing of new mean temperature and water vapor background and covariances specific to TC conditions. A larger number of TCs and ocean basins will be sampled.
- Extend validation activities to include dropsonde data.
- Collaboration with CIRA to assess the impact of the MiRS-TC retrievals on the TC intensity estimates from HISA.

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

7. Acknowledgements

This work was supported by NOAA Grant NA14NES4320003 (Cooperative Institute for Climate and Satellites - CICS) at the University of Maryland/Earth System Science Interdisciplinary Center (ESSIC). The COSMIC-derived backround profiles were provided by the Cooperative Institute for Research in the Atmosphere (CIRA).

8. References

Boukabara et al., 2013: A Physical Approach for a Simultaneous Retrieval of Sounding, Surface, Hydrometeor, and Cryospheric Parameters from SNPP/ATMS. J. Geophys. Res. Atmos., 118, 12,600–12,619, doi: 10.1002/2013JD020448.

Iturbide-Sanchez et al., 2013: Assessment of a Variational Inversion System for Rainfall Rate over Land and Water Surfaces. IEEE Trans. Geosci. and Remote Sens. 49, 3311-3333, doi: 10.1109/tgrs.2011.2119375.

Liu et al., 2017: GPM Products from the Microwave Integrated Retrieval System. IEEE J. Sel. Topics Appl. Earth Observ., 10, 2565-2574, doi: 10.1109/JSTARS.2017.2716356.

Chirokova et al., 2018: Hurricane Intensity and Wind Structure Estimation: from AMSU to TROPICS. 33rd Conf. on Hurricanes and Tropical Meteorology, 16-20 April 2018, Ponte Vedra, FL.