FIFTH INTERNATIONAL WORKSHOP on TROPICAL CYCLONES

Topic: 0.2 Tropical Cyclone Intensity Estimation Using NOAA-KLM Series Advanced Microwave Sounding Unit (AMSU) Warm Core Observations

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Abstract:

Introduction

Satellite-based passive microwave radiometers are uniquely capable of measuring the three-dimensional structure of tropical cyclone warm cores by virtue of their ability to sense tropospheric thermal structure in the presence of non-precipitating, upper-tropospheric clouds. Dense cirrus cloud canopies often mask important structure and structure change features that can provide forecasters and analysts vital clues on tropical cyclone position, axisymmetry, intensity and intensity change. This report summarizes a four-year, multi-institutional (UW-CIMSS, USAF Academy, Naval Research Laboratory) effort to develop a satellite-based passive microwave tropical cyclone intensity estimation technique using NOAA-KLM Advanced Microwave Sounding Unit temperature (AMSU-A) and moisture (AMSU-B) sounder radiance data. Research results are quite promising and generally support the value of routine evaluation and/or incorporation of AMSU-based tropical cyclone intensity estimates into the overall analysis, forecast and warning process. Furthermore, the ability of near real-time AMSU-A and AMSU-B observational data to provide valuable quantitative information on tropical cyclone position, structure, intensity and intensity change is noteworthy and deserves recognition. This presentation will briefly discuss historical work, the current AMSU algorithm, independent testing and lastly ongoing efforts to transition capabilities into operations under the US Weather Research Program (UWSRP) Joint Hurricane Testbed (JHT) initiative.

Background

The ability to remotely observe and characterize the three-dimensional structure of tropical cyclone warm cores has *improved dramatically* since IWTC-IV. The May 1998 launch of the first AMSU instrument on NOAA-K (NOAA-15) marked the 20th consecutive year of passive microwave tropical cyclone warm core observations and heralded a new era of higher resolution (horizontal and vertical) observations. Kidder et al. (1978) first identified the utility of 55GHz-region passive microwave observations in detecting and monitoring upper tropospheric warm anomalies accompanying tropical cyclones using the Scanning Microwave Spectrometer (SCAMS) on NIMBUS 6. Subsequently, many authors (Kidder et al., 1978, Velden, 1983, Velden et al., 1989, 1991, Kidder et al., 2000, Spencer and Braswell, 2001, Brueske and Velden, 2002) have contributed substantially to our understanding of the overall utility -- and limitations -- of satellite-based passive microwave tropical cyclone warm core observations and intensity techniques. However, it has only been possible within the past four years to remotely characterize the three-dimensional warm core structure (Fig. 1) by virtue of improved AMSU-A horizontal (48km near nadir) and vertical resolution (15 channels ranging from 23.8 - 89.0GHz) and reductions in instrument noise.

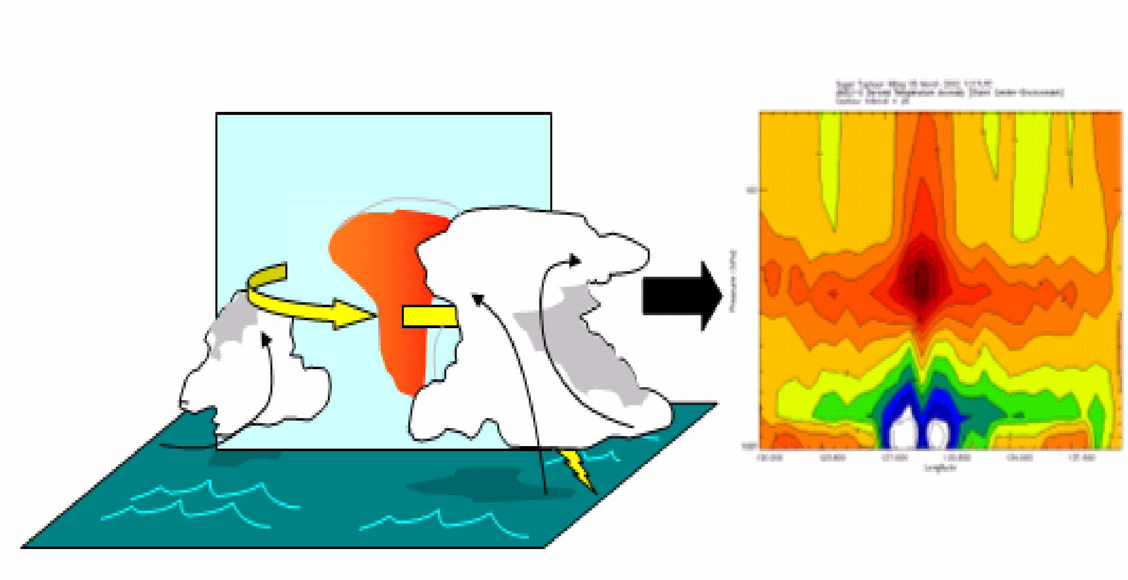

Figure 1. A schematic diagram of a tropical cyclone (left) depicting a mature vortex and warm core and the vertical cross-section of an actual warm core (right) derived from AMSU-A radiance data for Super Typhoon Mitag (western North Pacific), 1017UTC 5 March 2002. An AMSU-A derived upper tropospheric warm anomaly of ΔT = 16°C exists near 250hPa while strong cooling in the lower troposphere (ΔT = -10°C) reflects strong hydrometeor scattering associated with intense convection in the inner

Despite improvements in AMSU-A resolution and radiometric accuracy, hydrometeor scattering effects on 55GHz-region radiance measurements continue to limit our ability to precisely determine both peak upper tropospheric warming anomaly (UTWA) strength and the structure of the inner core region. Left untreated, lower tropospheric hydrometeor scattering effects are particularly troublesome as they often mask the low-to-mid tropospheric warm core and can occasionally reduce the magnitude of the UTWA owing to individual AMSU-A channel weighting function overlap. The former issue complicates attempts to determine minimum sea level pressure (MSLP) hydrostatically while the latter issue challenges attempts to statistically relate UTWA strength to tropical cyclone intensity. The need to account for tropical cyclone UTWA strength and variability was noted very early by Jordan (1961) who found that low-to-mid tropospheric inner core region warming could only account for 15-20% of the observed MSLP variance. As a result, most authors (Velden, 1989, 1991, Spencer and Braswell, 2001) focused on statistical, single-channel passive microwave tropical cyclone intensity estimation techniques based on the apparent governing dominance of the UTWA combined with formidable hydrometeor scattering effects.

Retrieval of Tropical Cyclone Intensity Using AMSU Warm Core Observations

In addition to hydrometeor scattering issues, Merrill (1995) demonstrated that a passive microwave radiometer's UTWA ***effective measurement accuracy*** is a complex function of several factors including (1) storm position within the radiometer scan swath (ϕ), (2) position of the UTWA within a radiometer's instantaneous earth field of view (θ) and (3) UTWA horizontal scale (Fig. 2). Merrill proposed and developed the 'EXperimental Tropical Cyclone Retrieval' (XTCR) to explicitly model and remove tropical cyclone UTWA scan geometry-related effects using a novel, modified form of the Rodgers (1976) maximum

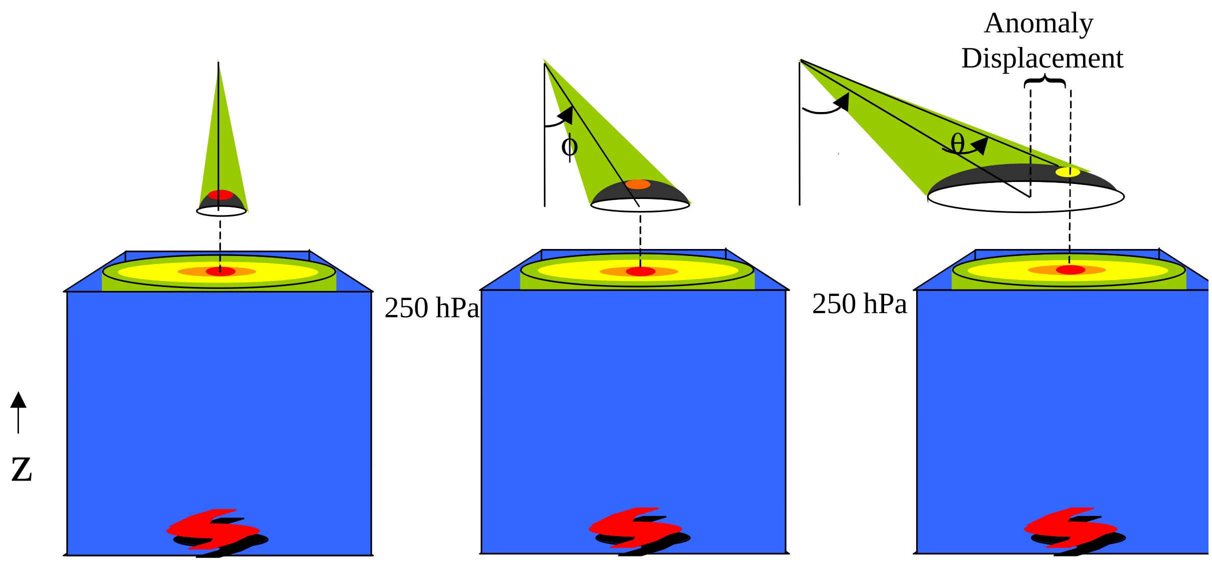

Figure 2. Schematic diagram of a mature tropical cyclone with a UTWA at approximately 250hPa. The degree of UTWA sub sampling depends on several factors including scan angle φ and off-axis scan angle θ. As scan angle φ increases to a maximum of 48°, AMSU-A resolution decreases from 48km (nadir) to over 100km (limb) . A non-zero off-axis scan angle θ between the UTWA position and AMSU-A FOV center will also contribute to a reduced UTWA magnitude through principles of diffraction. The magnitude of these scan-geometry related effects (φ,θ) depends on tropical cyclone UTWA horizontal

likelihood regression technique commonly used to retrieve vertical temperature profiles from satellite based tropospheric radiance observations. While Merrill's XTCR algorithm offered early indications of promise, it proved to be highly sensitive to accurate a priori specification of the UTWA horizontal scale – information largely unavailable at that time (ex. Defense Meteorological Satellite Program (DMSP) Special Sensor Microwave Imager (SSM/I) 85GHz radiance data, commonly known to provide detailed tropical cyclone structure information, was not available for evaluation in near real-time in the early 1990s).

Brueske and Velden (2002) modified XTCR for use with AMSU-A including the use of hydrometeor-scatter induced cooling in AMSU-B 89GHz moisture sounder radiances as a proxy for UTWA horizontal scale (Fig. 3). Dependent test raw and retrieved AMSU-A 54.9GHz UTWA regression coefficients (based on limb corrected brightness temperatures) were developed using near coincident AMSU-A and aircraft reconnaissance MSLP observations in 1998/1999 (Table 1) and were subsequently applied to predict tropical cyclone MSLP in 2000 using a completely automated, fully objective processing scheme. Independent test results were very encouraging; however, several unusually small and intense tropical cyclones in 2001 cast doubt on the new algorithm's ability to adequately quantify UTWA horizontal scale using AMSU-B 89GHz (16km at nadir) radiance data. Based on the disappointing 2001 results, the authors investigated use of Automated Tropical Cyclone Forecast (ATCF) radius

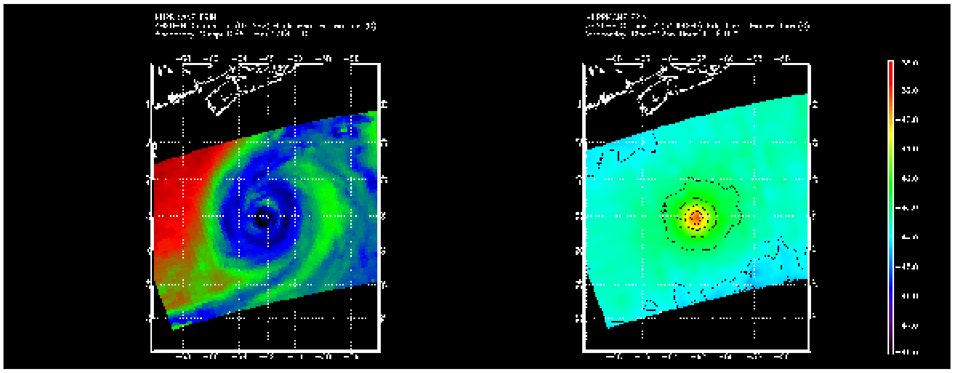

Figure 3. Color enhanced AMSU-B 89GHz (left) and AMSU-A 54.9GHz imagery (right) for Hurricane Erin, 1718UTC 12 September 2001. The horizontal scale and peak UTWA warming is effectively constrained by strong inertial stability within the eye wall region.

of maximum wind (RMW) information as a proxy for tropical cyclone UTWA horizontal scale. Reanalysis of 2001 cases using ATCF RMW information led to improved results with retrieved tropical cyclone MSLP superior to MSLP estimates generated using raw AMSU-A 54.9GHz data. Furthermore, Kabat et al. (2002) found that in approximately 30% of historical cases in which AMSU-A tropical cyclone UTWA observations were available (N=817), peak warming occurred at an altitude (AMSU-A 55.3 GHz (Ch.8) or ~150hPa) above that used by the retrieval (AMSU-A 54.9GHz (Ch. 7) or ~250hPa). Finally, the reanalysis results emphasized the known dependence of the retrieval on accurate a priori UTWA horizontal scale information, the ability of the retrieval to improve tropical cyclone MSLP estimate accuracy, and the emerging need for a multi-channel AMSU-A approach.

Year	Error (hPa)	Raw	Ret (AMSU-B)	Ret (ATCF)	Dvorak	N
2000	Mean	7.5	5.5	N/A	7.8	31
	Std Dev	9.9	7.2		7.6	
2001	Mean	10.4	11.5	8.6	4.8	63
	Std Dev	11.1	12.3	7.1	4.1	

Table 1. Independent test results for the Atlantic Basin during 2000 and 2001. (A) ‘Raw’ indicates tropical cyclone MSLP estimates generated using AMSU-A 54.9GHz raw brightness temperature (T_b) anomalies and regression coefficients, (B) ‘Ret (AMSU-B)’ indicates MSLP estimates generated using AMSU-A 54.9GHz retrieved T_b anomalies, regression coefficients and AMSU-B 89GHz-derived UTWA horizontal scale parameter, (C) same as (B) with the exception that ATCF RMW values were used to specify UTWA horizontal scale, (D) ‘Dvorak’ are Dvorak-generated MSLP-equivalent values.

Future Work

Based on four-years worth of AMSU-A warm core observations and in-depth analysis of retrieval algorithm performance, a modified form of the Brueske and Velden (2002) AMSU tropical cyclone intensity estimation retrieval is being employed in 2002. The new retrieval incorporates (1) ATCF RMW information as a proxy for tropical cyclone UTWA horizontal scale, (2) uses multiple AMSU-A channels (54.9GHz and 55.3GHz), regression coefficients and logic to accommodate for upper- tropospheric warm core variability, (3) and uses latitude and RMW thresholds to prohibit retrieval application for unusually small and intense ‘pin-hole’ systems or for systems undergoing extratropical transition in which baroclinic modification of the UTWA structure makes application of the retrieval unwarranted. Additionally, AMSU-generated tropical cyclone intensity (MSLP) estimates are now routinely sent to the NOAA Tropical Prediction Center/National Hurricane Center (TPC/NHC) for analysis and review by forecasters under the US Weather Research Program-funded Joint Hurricane Testbed program.

Concerning the issues of hydrometeor scattering and scan geometry-related effects, work is underway to model and explicitly treat tropical cyclone hydrometeor scattering effects and their impact on passive microwave observations of inner core region warming and structure. Furthermore, the next-generation of converged National Polar Orbiting Environmental Satellite System (NPOESS) satellite conical scanning passive microwave radiometers will greatly reduce the impact of UTWA sub sampling by virtue of their near constant horizontal resolution and improved radiometric accuracy. While conical scan geometry will likely ameliorate scan-angle dependent tropical cyclone UTWA sub sampling for all but a small percentage of unusually small tropical cyclones with extremely compact warm cores, it is likely that diffraction effects for non-FOV centered UTWA will remain.

Summary

Passive microwave observations of tropical cyclone warm cores continue to offer a viable means to estimate tropical cyclone intensity in a manner wholly independent of other satellite-based intensity estimation schemes most notably the Dvorak (1975) technique. The author, through the assistance and success of multi-agency cooperative research, has demonstrated the efficacy of a passive microwave-based technique using the latest generation NOAA polar orbiting AMSU instruments. It is important to recognize that in order for AMSU-generated tropical cyclone intensity estimates to be operationally relevant, not only must intensity estimate accuracy be competitive with other satellite-based techniques, but they also must be available in a timely manner to facilitate their evaluation and use. Both factors – accuracy and timeliness -- dictate the use of a technique capable of treating storm scan/storm scale geometry interaction and the entire AMSU scan swath. It is these factors that motivate, and will continue to motivate, the use and refinement of the aforementioned methodology until the next generation of improved, constant horizontal resolution passive microwave radiometers makes its use largely obsolete.

Acknowledgments

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