14D.7 LOCALIZED UPPER TROPOSPHERIC WARMING DURING TROPICAL DEPRESSION AND STORM FORMATION REVEALED BY THE NOAA-15 AMSU

Roy W. Spencer *
NASA Marshall Space Flight Center
Global Hydrology and Climate Center
Huntsville, Alabama

William D. Braswell
Nichols Research Corporation
Global Hydrology and Climate Center
Huntsville, Alabama

1.0 INTRODUCTION

The warm core of hurricanes as measured by microwave temperature sounders has been related to various azimuthally averaged measures of hurricane strength by several researchers (e.g. Kidder et al., 1978; Grody et al., 1979; Kidder et al., 1980; Velden and Smith,1983). Unfortunately, the use of these instruments (e.g. the Microwave Sounding Units, MSU) for the routine monitoring of tropical cyclone genesis and intensity has been hampered by poor resolution.

The recent launch of the NOAA-15 AMSU represents a significant advance in our ability to monitor subtle atmospheric temperature variations (0.1-0.2 deg. C) at relatively high spatial resolution (50km) in the presence of clouds. Of particular interest is the possible capability of the AMSU to observe the slight warming associated with depression formation, and the relationship of the spatial characteristics of the warming to the surface pressure and wind field, without azimuthal averaging.

In order to present the AMSU data as imagery, we have developed a method for precise limb-correction of all 15 AMSU channels. Through a linear combination of several neighboring channels, we can very closely match the nadir weighting functions of a given AMSU sounding channel with the non-nadir data (Spencer et al., 1999).

It is found that there is discernible, localized upper tropospheric warming associated with depression formation in the Atlantic basin during the 1998 hurricane season. Also, it is found that uncertainty in positioning of tropical cyclone circulation centers can be reduced, as in the example of Hurricane Georges as it approached Cuba (results presented at the conference).

Finally, to explore the potential utility of a future high-resolution microwave temperature sounder, we present an analysis of the relationship between the modeled surface wind field and simulated high-resolution AMSU-type measurements, based upon cloud resolving model simulations of hurricane Andrew in 1992.

*Corresponding author address: Roy W. Spencer, NASA/MSFC/GHCC, 977 Explorer Blvd, Huntsville, Alabama 35806; roy.spencer@msfc.nasa.gov

2.0 AMSU INSTRUMENT CHARACTERISTICS

The AMSU-A package is a fifteen channel temperature sounder operating at frequencies from 23.8 to 89.0 GHz. The AMSU-A unit has three separate antenna systems designed to provide nearly the same spatial resolution (50 km, as opposed to 110 km for the MSU) at all frequencies. It scans cross-track and samples 30 footprints (as opposed to the MSUs' 11), and successive scan lines are separated by 50 km (as opposed to 150 km for the MSU). The AMSU-A has the instrument characteristics listed in Table 1. The temperature sensitivities (noise values) are averages of laboratory measured values of three copies of the instrument.

TABLE 1. AMSU-A characteristics

Chan. No.	Frequency (GHz)	Noise (deg. C)	Wgt. Fn. Peak
1	23.8	0.17	Surface
2	31.4	0.23	Surface
3	50.3	0.25	Surface
4	52.8	0.15	900 hPa
5	53.596	0.15	600 hPa
6	54.4	0.14	400 hPa
7	54.94	0.14	250 hPa
8	55.5	0.15	150 hPa
9	v_1=57.290344	0.17	90 hPa
10	v_1 +/- 0.217	0.22	50 hPa
11	v_1 +/- 0.3222 +/- 0.048	0.24	25 hPa
12	v_1 +/- 0.3222 +/- 0.022	0.36	10 hPa
13	v_1+/- 0.3222 +/- 0.010	0.48	5 hPa
14	v_1+/- 0.3222 +/- 0.0045	0.80	2.5 hPa
15	89.0	0.15	surface

3.0 MIDDLE AND UPPER TROPOSPHERIC TEMPERATURE KERNELS

Through examination of daily AMSU imagery during the 1998 hurricane season, we have found that AMSU channels 6, 7, and 8 have the greatest sensitivity to localized warming in the tropical middle and upper troposphere. While other channels provide additional information regarding tropical cyclone conditions (e.g. channel 1 at 23.8 GHz would be useful for a simultaneous estimate of rainfall distributions), here we will emphasize only air temperature measures.

Of these three, channels 6 and 7 have sensitivity to scattering by precipitation-size ice hydrometeors. These ice particles can cause localized Tb cooling wherever deep convection exists (e.g. Grody, 1983; Spencer et al., 1989), partly or completely masking the cyclone warmth. We have found empirically that a weighted linear difference of channels 6 and 7 with the next lower channel can cancel out the average ice scattering effects on the Tb. The averaging kernels that correct for ice scattering are computed with

$$T6c = 1.5\,T6 - 0.5\,T5 \quad \text{and} \tag{1}$$

$$T7c = 1.4\,T7 - 0.4\,T6. \tag{2}$$

where T5, T6, and T7 are the limb corrected Tb for channels 5, 6, and 7. The weighting functions corresponding to these averaging kernels are shown in Fig. 1. This is the same general procedure that allows deconvolution of overlapping weighting functions to enhance vertical resolution (Conrath, 1972). Upper tropospheric warming in channel 8 requires damping of stratospheric contributions, which can be achieved with

$$T8c = 1.5\,T8 - 0.5\,T9 \tag{3}$$

Eqs. 1-3 are the three channel kernels we believe contain information on tropical cyclone warm structures in the middle and upper troposphere.

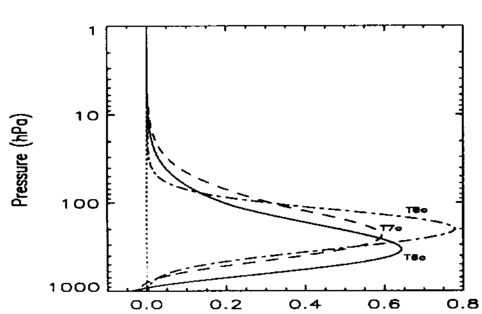

Fig. 1 Averaging kernel weighting functions ($\delta\tau/\delta \ln p$) corresponding to ice scattering-corrected AMSU channels 6, 7, and 8.

4.0 AMSU DATA INTEPRETATION

AMSU imagery of tropical systems will be presented at the conference.

Along-track Tb measured by the AMSU through Hurricane Georges at various stages in its development is shown in Fig. 2 for channel 7c. The Tb gradient near the warm core is well related to the maximum winds reported by NHC. Specifically, the average T7c gradient next to the core reveals an average gradient of 0.1 deg. C per 50 km for every 10 knots of maximum wind speed.

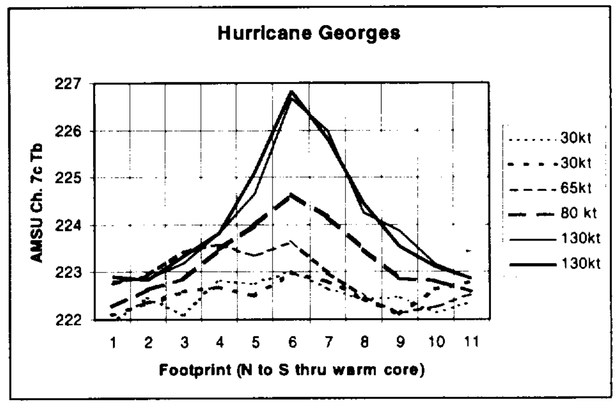

Fig. 2 North to south channel 7 Tc traces through the warmest footprint in Georges at various stages times. The footprint spacing is 50 km.

The warming associated with the several Atlantic tropical *depressions* that occurred before this paper was written had the following characteristics:

1) warming of 0.2 to 0.4 deg. C in channel T7c, with warmest T7c usually near the circulation center. The spatial scale of cyclone-scale warmth seemed to correspond to the breadth of the cyclonic circulation.
2) Warming in the next higher channel, T8c, was somewhat weaker than in T7c, or non-existent
3) No obvious warming in T6c.

Warming associated with Atlantic tropical *storms* suggested:

1) warming of 0.3 to 0.8 deg. C in T7c, and nearly comparable warming in T8c.
2) weak warming of 0.5 deg C in T6c

Those storms that strengthened into hurricanes had well defined warm cores of about equal magnitudes in T6c, T7c and T8c.

5.0 AMSU Simulations of Hurricane Andrew

To explore how well surface wind speeds might potentially be related to the middle and upper tropospheric warming associated with tropical cyclones, we computed AMSU Tb from MM5 simulations of Hurricane Andrew (Liu et al., 1997). These MM5 simulations included explicit convection. Spatial gradients of the Tb, at a nominal spatial resolution of approximately 5 km, were correlated to the surface wind speeds at the same resolution. Precipitation effects on the Tb were ignored. For 17 model times between 00 UTC 21 August to 12 UTC 28 August 1998, the highest correlations were found between surface wind and the gradients in T8 (0.84). (Future work will address the gradient wind relationship for improved performance). The surface wind field from the MM5 simulation for 00 UTC 24 August, just before Andrew struck Florida, is shown in Fig. 3. Also shown is a linear-regression derived diagnosis of the surface wind speed based upon the spatial gradients in the average of AMSU channels 6 through 8 (T6+T7+T8)/3. While there is general similarity between the two fields, there is considerable difference in the details. Much further work on this will be required to come to a better understanding of the relationships that might exist between the thermal and surface wind fields at high spatial resolution.

6.0 DISCUSSION AND CONCLUSIONS

These preliminary results suggest that the AMSU-A can discern the weak upper tropospheric warming associated with tropical depression formation, assuming high-quality limb corrections are performed. Larger cyclonic circulation systems are associated with larger warm patterns, suggesting some utility for quantifying the spatial extent of the surface circulation. It is not yet obvious that the spatial gradients can be well related to surface wind speed distribution in different sectors of the cyclone. Thus, AMSU-diagnosed winds might have to be restricted to estimates of the usual indicies such as maximum sustained winds or the average radius of different wind speeds.

We have also noticed that care must be taken to not mistake the upper tropospheric warming associated with subtropical baroclinic systems for a tropical system. In these cases, well defined upper tropospheric warm cores were associated with weak cool pools of air revealed by channel T5. As discussed by Spencer et al. (1995), these warm cores in baroclinic systems are associated with vorticity maxima. These baroclinic systems will complicate attempts to automatically classify tropical cyclones.

Finally, these (admittedly limited) results suggest that a geostationary microwave temperature sounder would be a valuable tool for tropical cyclone monitoring, assuming sufficient spatial resolution could be attained from geostationary orbit. Alternatively, a fleet of low-Earth orbit 55 GHz sensors with, say, 15 km resolution would probably provide a very useful tropical cyclone monitoring tool.

7.0 ACKNOWLEDGMENTS

We thank Da-Lin Zhang for his generous provision of the Andrew simulation fields

8.0 REFERENCES

Grody, N.C., C.M. Hayden, C.C. Shen, P.W. Rosenkranz, and D.H. Staelin, 1979: Typhoon June winds estimated from scanning microwave spectrometer measurements at 55.45 GHz. *J. Geophys. Res.*, **84**, 3689-3695.

Grody, N.C., 1983: Severe storm observations with the Microwave Sounding Unit. *J. Clim. Appl. Meteor.*, **22**, 609-625.

Kidder, S.Q., W.M. Gray, and T.H. VonderHaar, 1978: Estimating tropical cyclone central pressure and outer winds from satellite microwave data. *Mon. Wea. Rev.*, **106**, 1458-1464.

Kidder, S.Q., W.M. Gray, and T.H. VonderHaar, 1980: Tropical cyclone surface winds derived from satellite microwave sounder data. *Mon. Wea. Rev.*, **108**, 144-152.

Liu, Y., D.-L. Zhang, and M.K. Yau, 1997: A multiscale numerical study of Hurricane Andrew (1992),Part I: Explicit simulation and verification. *Mon Wea. Rev.*, **125**, 3073-3093.

Spencer, R.W., W. M. Lapenta, and F. R. Robertson, 1995: Vorticity and vertical motions diagnosed from satellite deep layer temperatures. *Mon. Wea. Rev.*, **123**,1800-1810.

Spencer, R.W., H.M. Goodman, and R.E. Hood, 1989: Precipitation retrieval over land and ocean with the SSM/I: identification and characteristics of the scattering signal. *J. Atmos. Oceanic Tech.*, **6**, 254-273.

Spencer, R.W., W.D. Braswell, and J.R. Christy, 1999. A new era in global temperature monitoring with the Advanced Microwave Sounding Unit (AMSU). *Preprints, 10^{th} Symposium on Global Change Studies*, Dallas.

Velden, C.S., and W.L. Smith, 1983: Monitoring tropical cyclone evolution with NOAA satellite microwave observations. *J. Clim. Appl. Meteor.*, **22**, 714-724.

Fig. 3 Model surface wind speed (top) and simulated AMSU channel wind speed diagnosed from the spatial gradients in Tb (bottom). Diagnosed winds are too high close to the cyclone center, suggesting the need for a gradient-type wind relationship. Note that the peak diagnosed winds are in a different quadrant than are the model winds.

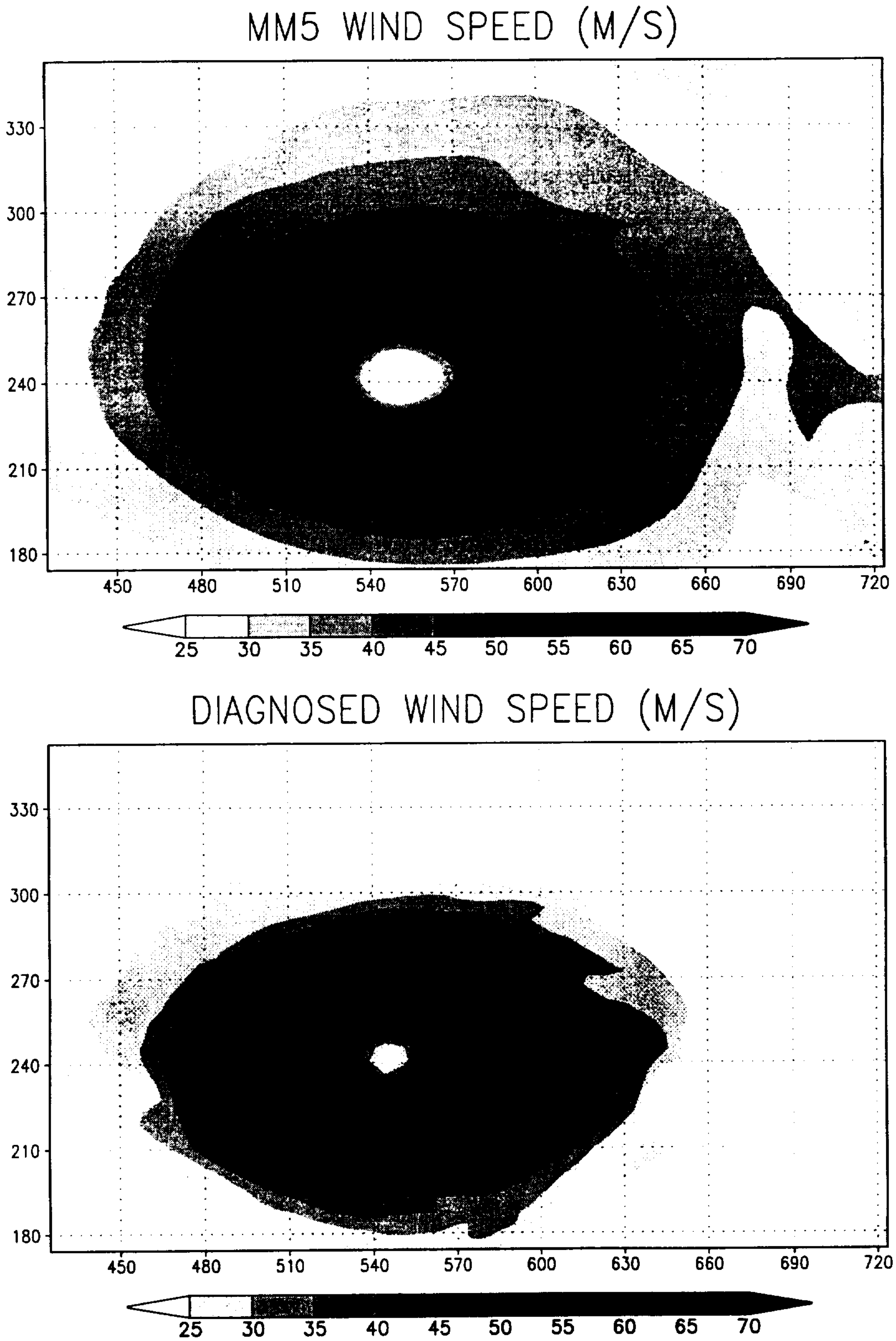

Fig. 3 Model surface wind speed (top) and simulated AMSU channel wind speed diagnosed from the spatial gradients in Tb (bottom). Diagnosed winds are too high close to the cyclone center, suggesting the need for a gradient-type wind relationship. Note that the peak diagnosed winds are in a different quadrant than are the model winds.