P3.2 TROPICAL CYCLONE ANALYSIS USING AMSU DATA

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1. INTRODUCTION

Scientific progress often comes about as a result of new instruments for making scientific observations. The Advanced Microwave Sounding Unit (AMSU) is one such new instrument. First flown on the *NOAA 15* satellite launched 13 May 1998, AMSU will fly on the *NOAA 16* and *NOAA 17* satellites as well.

AMSU is a 20-channel instrument designed to make temperature and moisture soundings through clouds. Geophysical parameters such as rain rate, column-integrated water vapor and column-integrated cloud liquid water can also be retrieved. The AMSU has significantly improved spatial resolution, radiometric accuracy, and number of channels over the Microwave Sounding Unit, which flew on *TIROS N* and the *NOAA 6* through *NOAA 14* satellites.

One of the most exciting capabilities of the AMSU is the observation of tropical cyclones. Since microwaves penetrate clouds, the AMSU can measure the above parameters even through the central dense overcast (CDO) which prevents visible and infrared satellite instruments from making these measurements.

2. RETRIEVED PARAMETERS

Retrieval of atmospheric temperatures from AMSU data has several steps, but is straightforward. First a correction for antenna side lobes is made (Mo 1999). A second correction adjusts the brightness temperatures from the 30 different view angles to appear to be nadir observations. This step is called limb adjustment and is based on Wark (1993). Atmospheric temperature is retrieved from the limb-adjusted brightness temperatures using regression analysis. The regression coefficients to estimate temperature between the surface and 10 hPa from AMSU observations were generated from collocated AMSU-A limb adjusted brightness temperatures and radiosonde temperature profiles. Above 10 hPa, the regression coefficients were generated from brightness temperatures simulated from a set of rocketsonde profiles. The root mean square (rms) differences between AMSU-A temperature retrievals and collocated radiosondes for the latitude range of 0º to 30º north are less than 2 K. Additional details on the temperature retrieval procedures and accuracies are given in Goldberg (1999).

Rain rate and column-integrated cloud liquid water and water vapor are retrieved semi-operationally by the NESDIS/Microwave Sensing Group using algorithms described in Grody et al. (1999). These algorithms are similar to those developed for the Special Sensor Microwave Imager (SSM/I) (Weng and Grody 1994; Grody 1991)

3. TROPICAL CYCLONE APPLICATIONS

Tropical cyclone analysis using microwave data has a long history, which is detailed in Kidder et al. (2000) Here we present five research and forecasting capabilities made possible by the AMSU.

3.1 *Upper Tropospheric Temperature Anomalies*

Figure 1 shows a vertical cross-section of AMSU-derived temperature anomalies (temperature minus environmental temperature at each level) of Hurricane Bonnie on 25 August 1998 at 1230 UTC. At this time the central location of Bonnie was near 29º North and 75º West. The cross-section clearly shows the warm core of the hurricane centered at an elevation of about 35,000 feet (10.7 km). It is remarkably similar to cross sections determined from aircraft penetrations (Hawkins and Rubsam 1968) including the extension of the warm anomaly down into the lower troposphere inside the eye. The negative temperature anomalies at lower levels are due to contamination by heavy precipitation.

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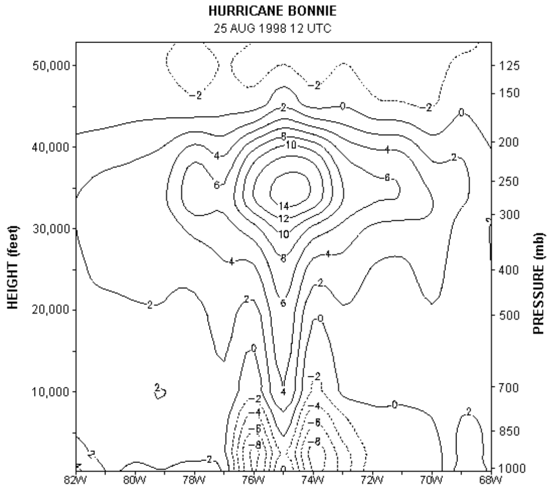

Figure 1. Temperature anomalies in Hurricane Bonnie retrieved from AMSU data.

3.2 *Tropical Cyclone Intensity Estimates*

Using data from previous microwave instruments several investigators have examined the relationship between temperature anomalies and the surface wind speed and central pressure of tropical cyclones (e.g., Kidder et al. 1978, 1980; Velden and Smith 1983; Velden 1989; Velden et al. 1991). Temperature retrievals for 61 time periods from Hurricanes Bonnie, Georges, and Mitch, and Super Typhoon Zeb were made, and the maximum temperature anomaly was calculated. We related the maximum temperature anomaly near the center of the storm to storm intensity (maximum 1 min average wind speed at 10 m) and central pressure obtained from operational track data (Fig. 2). In general, the temperature anomalies closely follow both the wind speeds and the pressures. Gaps in the data are caused by the storm being located between orbital swaths or by missing AMSU data. Correlating intensity versus maximum temperature anomaly yields a correlation coefficient of 0.84 and a standard error of 19 kt. Correlating central pressure versus maximum temperature yields a correlation coefficient of 0.86 and a standard error of 12 hPa.

One of the reasons for the scatter in the data is that the AMSU-A resolution of 48 km—though much better than previous microwave sounders— is still not small in comparison with the size of a tropical cyclones central core or eye. Based on earlier work by Merrill (1995) using data from the MSU, this has two effects. First, the storm center may fall “between” sensor beam positions or footprints. Second, at the limb, the footprints become large, which compounds the first problem. As Merrill (1995) shows, the “bracketing effect” (storm eye falling in between adjacent half-power footprints) decreases the effective accuracy of the warm anomaly measurements. Work is underway (Velden and Brueske 1999, 2000) to develop a method to better estimate the warm anomaly from the AMSU raw radiance information.

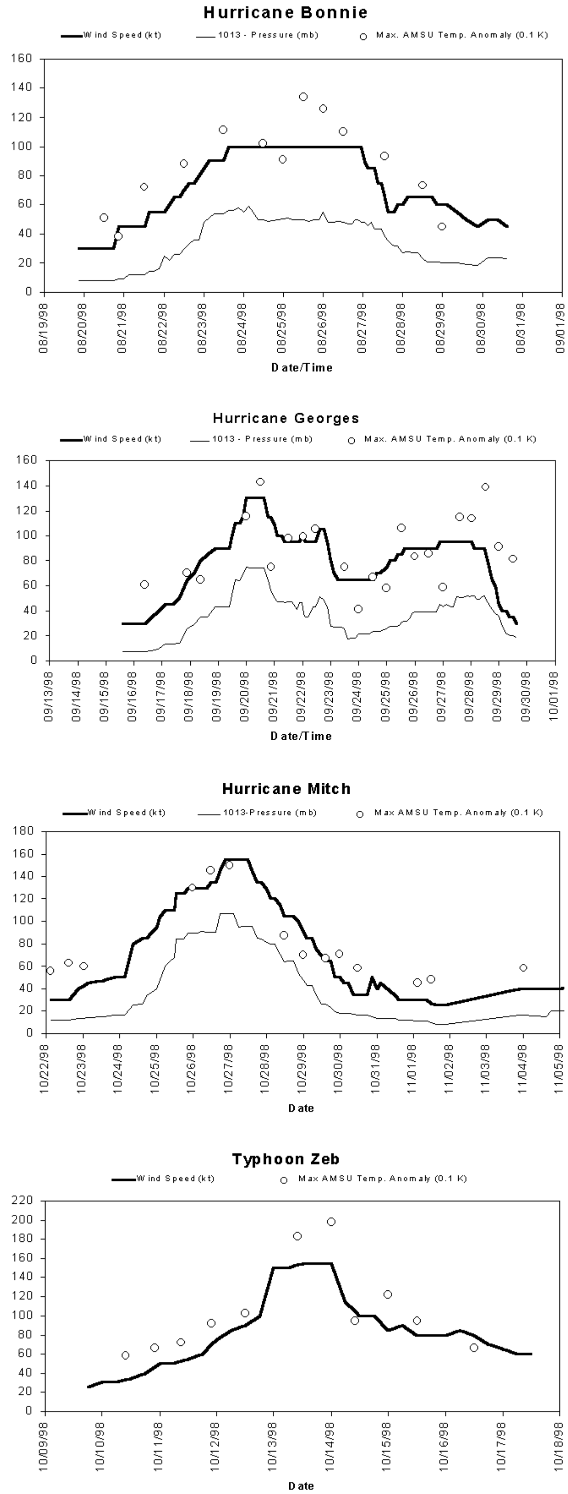

Figure 2. Maximum temperature anomalies retrieved from AMSU data compared with storm intensity and central pressure.

3.3 *AMSU, AVHRR, and GOES* Imagery

Because microwaves penetrate clouds, the AMSU provides views of the structure inside tropical cyclones that are not observable with visible and infrared sensors. The temperature anomalies discussed above are one such example. Another is the ability of window channels to sense precipitation-sized particles through the CDO (Fig. 3). With weaker storms, the eye is often cloud covered or poorly defined. In those situations, the IR and visible images are not useful in determining eye size or location, but the 89 GHz images from the AMSU may make eye size and location estimates possible.

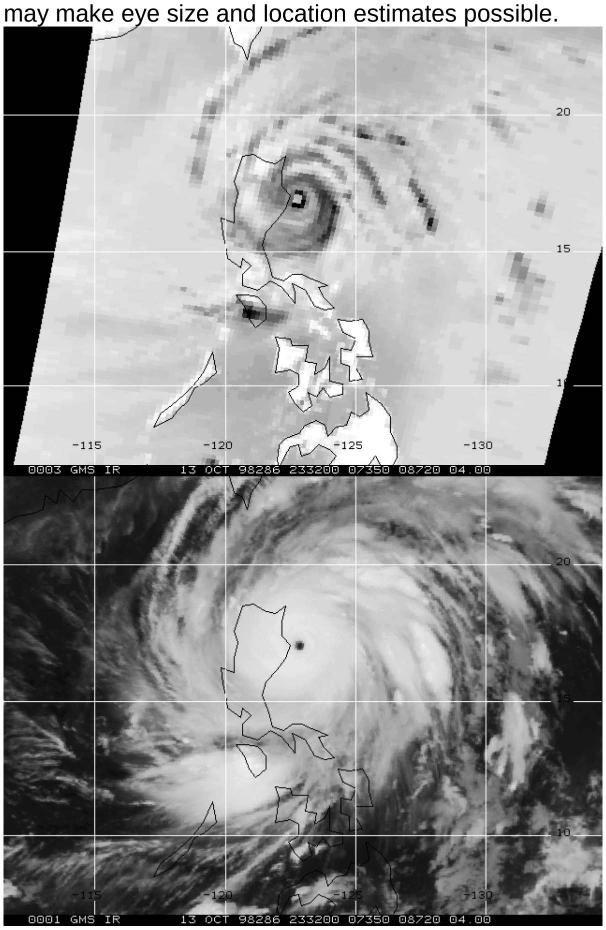

Figure 3. (Top) AMSU-B 16 km resolution 89 GHz image of Typhoon Zeb. (Bottom) The coincident 4 km resolution infrared image of Zeb.

It is always desirable to compare two or more observations of storms. Twice daily AMSU observations are augmented by much more frequent geostationary observations, and 16 or 48 km resolution AMSU observations are augmented by 1.1 km observations from the Advanced Very High Resolution Radiometer (AVHRR) which flies with AMSU on the NOAA satellites.

3.4 *Gradient Wind Retrieval*

AMSU temperature soundings from Hurricane Bonnie on 25 August 1998 near 12 UTC were retrieved at 40 vertical levels from 0.1 to 1000 hPa. Because the 1000 hPa level could be below the surface near the center of the storm, the temperature data at this level were not used. AMSU temperature data at 22 levels from 920 to 50 hPa were used in the calculation. The retrieved temperatures were interpolated to a radial grid centered on the National Hurricane Center's best track location and azimuthally averaged. A constant surface temperature—equal to the sea surface temperature (SST) near the storm center minus 1 K—was assumed. The surface pressure at the outer radius of the radial grid (500 km) was estimated from the initial analysis for the NCEP global forecast model. The hydrostatic equation was integrated at this outer radius up to the 50 hPa level, and it was assumed that the height of the 50 hPa level was constant for all radii. The hydrostatic equation was applied again at all radial grid points, starting at the 50 hPa level to determine the height of the vertical grid points and the surface pressure. The final step was to use the radial pressure gradients to calculate the tangential wind speeds at all levels assuming gradient balance. The cold anomalies caused by rain contamination were removed by setting to zero any negative temperature anomalies below 500 hPa. The tangential wind distribution calculated for Hurricane Bonnie is shown in Fig. 4.

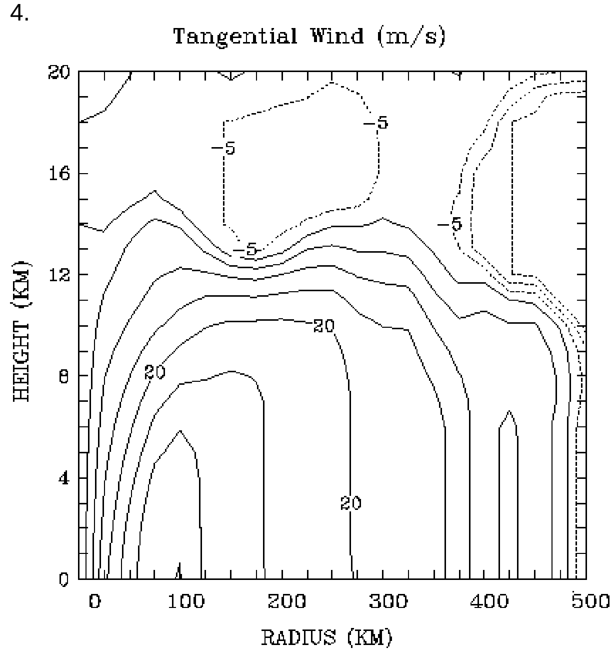

Figure 4. Tangential wind profile of Hurricane Bonnie calculated from AMSU data.

Aircraft reconnaissance data shows that the radius of maximum wind was quite large (about 100 km), consistent with the AMSU gradient winds. The average difference between the aircraft and AMSU winds (out to 250 km) was 4.6 m/s. This technique is further discussed in DeMaria et al. (2000).

3.5 *Tropical Cyclone Precipitation Potential*

Since 1992, the Satellite Analysis Branch (SAB) of NESDIS has experimentally used SSM/I data to produce a rainfall potential for tropical disturbances expected to make landfall within the next 24 hours. The launch in 1998 of the first AMSU now provides us with an additional way to calculate rainfall potential from tropical disturbances worldwide.

In determining the Tropical Rainfall Potential (TRaP), the analyst applies a rainfall potential formula

$$\text{TRaP} = R_{av} D V^{-1} \quad (1)$$

that is simplified from the NESDIS Operational Tropical Rainfall Estimation Technique (Spayd and Scofield 1984). R_{av} is the average rain rate along a line in the direction of motion of the cyclone. D is the distance of that line across the rain area of the storm in its direction of motion. V is the actual speed of the tropical cyclone.

For the 0023 UTC 25 September 1998 *NOAA 15* AMSU observation of Hurricane Georges, the SAB analyst drew a line *A* through the digital rain rate image (Fig. 5) in the direction of motion of the storm. Line *A* resulted in an average rain rate (R_{av}) of 0.224 in/hr (5.69 mm/hr); the distance (D) of the line was 6.0º latitude (667 km); and the speed (V) of the storm was 12 kt (22.2 km/hr). The resultant TRaP was 6.72 inches (171 mm) . The observed rainfall in Key West (EYW) was 8.38 inches (213 mm).

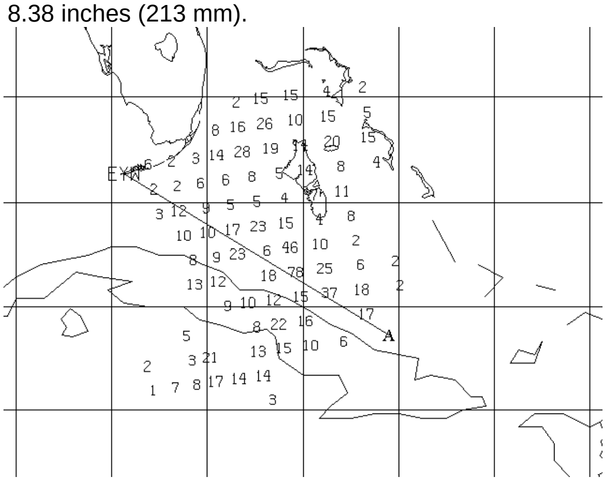

Figure 5. Rainfall rate (inches/hour x 100) retrieved from AMSU data for Hurricane Georges at 0023 UTC 25 September 1998.

4. SUMMARY AND CONCLUSIONS

The Advance Microwave Sounding Unit flying on the *NOAA 15* satellite is the first of a series of microwave imager/sounders which can sense atmospheric temperature, moisture, and precipitation through clouds. In this paper, we have examined how the AMSU data can be applied to tropical cyclone analysis and forecasting. We conclude that the AMSU is extremely promising for improving our knowledge of tropical cyclones

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