P3.17 USING AMSU DATA TO FORECAST PRECIPITATION FROM LANDFALLING HURRICANES

Stanley Q. Kidder* **and John A. Knaff**
CIRA, Colorado State University, Fort Collins, Colorado

Sheldon J. Kusselson
NOAA/NESDIS/Satellite Services Division, Camp Springs, Maryland

1. INTRODUCTION

Heavy rainfall from landfalling tropical cyclones is a major threat to life and property. Rappaport (2000) found that in the contiguous United States during the period 1970–1999, freshwater floods accounted for more than half of the 600 deaths directly associated with tropical cyclones.

Forecasting rainfall from landfalling tropical cyclones is a difficult task. While the storm is offshore, few rainfall observations are possible, and initializing NWP models with sufficient details of the storm so that accurate rainfall forecasts can be made is extremely difficult. Radar observations of storm rain rate and rain area are valuable, but only when the storm is within radar range of the coast.

Satellite-borne microwave radiometers can measure instantaneous rain rates through the entire cloud area of tropical cyclones (Kidder et al. 2000). This paper explores how these rain rates can be used to forecast potential tropical cyclone rainfall accumulations.

2. HISTORY

Over the years the observational aspects of tropical cyclone rainfall have been studied resulting in several empirical relationships that should be acknowledged. The well known rule of thumb for predicting the maximum rainfall in inches is 100 divided by the speed of the storm in knots. The rain rate of the tropical cyclone generally decreases logarithmically with distance from the center (Simpson and Riehl 1981). So, very simple rainfall estimates can be created using logarithmically decreasing rain rates and the speed of the storm. A similar method, that uses satellite-derived estimates of spatial rain rates for the particular tropical disturbance, allows for a potentially more accurate method.

Since 1992, the Satellite Services Division (SSD) of the National Environmental Satellite, Data and Information Service (NESDIS) has experimentally used the operational Defense Meteorological Satellite Program (DMSP) Special Sensor Microwave Imager (SSM/I) rain rate product to produce a rainfall potential for tropical disturbances expected to make landfall within 24 hours. The launch in 1998 of the first Advanced Microwave Sounding Unit (AMSU) on the NOAA 15 satellite provides an additional rainfall data source.

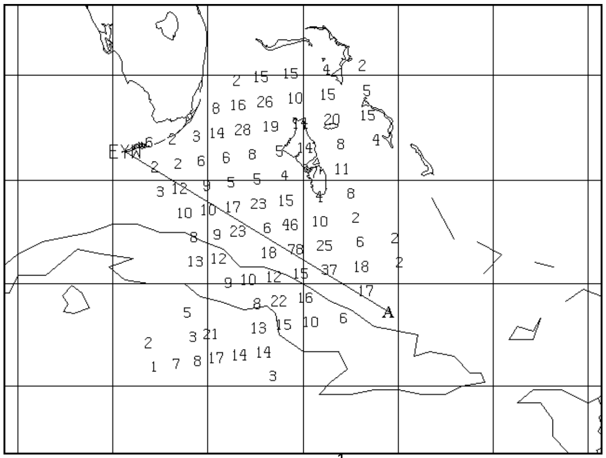

Figure 1. Rainfall rate (in h^{-1} x 100) retrieved from AMSU data for Hurricane Georges at 0023 UTC 25 September 1998.

The experimental product, known as the Tropical Rainfall Potential (TRaP), is produced manually by a satellite analyst. The process is illustrated in Fig. 1. First, the analyst displays the instantaneous rain rates retrieved from microwave measurements. Either operational SSM/I 14x16 km (Ferraro et. al. 1998) or the AMSU 48 km resolution rain rates (Grody et al. 1999) can be used. (Soon, 16 km AMSU-B rain rates will be available.) Second, a line is drawn across the storm's rain area in the direction of storm motion. One attempts to draw the line through the most intense rain so that the "maximum potential" of the storm can be analyzed. Third, the diameter (D) of the storm's rain area and the average rain rate (R_{av}) along the line are calculated. Finally, the analyst applies a rainfall potential formula

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**Corresponding author address:* Stanley Q. Kidder, CIRA, Colorado State University, Fort Collins, CO 80523-1375; tel: (970) 491-8367, e-mail: kidder@cira.colostate.edu.

$$\mathrm{TRaP} = R_{\mathrm{av}} D V^{-1}, \qquad (1)$$

where V is the speed of the storm. This is a simplified form of the rainfall potential formula used in the infrared-based NESDIS Operational Tropical Cyclone Precipitation Estimation Technique (Spayd and Scofield 1984).

For the 0023 UTC 25 September 1998 *NOAA 15* AMSU observation of Hurricane Georges, the SSD analyst drew a line *A* through the digital rain rate image (Fig. 1) in the direction of motion of the storm. Line *A* resulted in an average rain rate (R_{av}) of 0.224 in h^{-1}; the diameter (D) along line A of the storm's rain area was 6.0º latitude (360 n mi); and the speed (V) of the storm was 12 kt. The resultant TRaP was 6.72 in. The observed rainfall in Key West (EYW) was 8.38 in.

The assumptions in the TRaP technique are:

A. The satellite rain rates are correct and do not change either in magnitude or area.
B. The raining area moves with the storm in a constant direction at a constant speed.
C. There are no outside influences on the storm, such as frontal interactions or terrain interactions, that can increase rain rates, or dry air intrusion or shear, that can decrease rain rates.

Studies at SSD indicate that the method is accurate as long as the assumptions are reasonably well satisfied. Quantitative accuracy assessments are in progress.

3. THE AREAL TRaP TECHNIQUE

The work reported in this paper aims at improving the TRaP technique in three ways. First, we wish to automate the technique for two reasons, (1) so that it does not have to be performed manually by an analyst and (2) so that it can be performed throughout the life cycle of the storm. Second, we would like to improve upon the assumption that the storm will move in a constant direction at a constant speed by using the Tropical Prediction Center (TPC) official track forecast. Third, we want to create graphical product-maps of accumulated rainfall that can be quickly analyzed and can serve as guidance for forecasters who issue public forecasts. To emphasize this third goal, we call the technique Areal TRaP to distinguish it from the manual TRaP which produces only a point estimate of accumulated rainfall.

The Areal TRaP technique starts with a satellite-based observation of rain rate. The Cooperative Institute for Research in the Atmosphere (CIRA) uses rain rates from the AMSU instrument produced by the Microwave Sensing Group of NESDIS. SSD also uses the technique with rain rates from the DMSP SSM/I and the operational NESDIS Autoestimator (Vicente et al. 1998).

To make the technique work properly, the time of observation of the storm must be known. CIRA uses the TPC track forecast together with the observed storm positions and the satellite ephemeris calculated from the orbital elements to precisely calculate the time when the satellite observed the center of the storm. Next, a cubic spline interpolation of the position of the storm center every 15 min throughout the 24 h forecast period is calculated as well as the cubic spline position of storm at the time of satellite observation. At every point in the output image, the rainfall is calculated as

$$\text{accumulated rainfall} = \int_{t_1}^{t_2} R(t)\,dt \qquad (2)$$

$R(t)$ is calculated by assuming that everything in the rain rate image moves with the storm center and by picking out in the rain rate image the point which will be over the station at time t. All calculations are performed on a Mercator map grid with 8 km resolution at the equator. Since everything moves with the storm, the calculation boils down to applying a set of *x-y* offsets for each 15 min time period.

The Areal TRaP calculation has been entirely automated at CIRA. Triggered by receipt of a track forecast, the AMSU rain rate data are accessed, and the Areal TRaP forecasts are made.

The assumptions for the Areal TRaP technique are essentially the same as for the manual TRaP, except assumption B becomes::

B'. The raining area moves with the storm center along the forecast track, which is assumed to be correct.

4. RESULTS

We have applied the Areal TRaP technique to several tropical cyclones. Two examples are presented. In both of these examples, the TPC Best Track was used in place of the forecast track.

Figure 2 shows the AMSU-observed rain rate, the 24 h Areal TRaP, and the corresponding 24 h gauge-observed rain accumulations for Hurricane Dennis (1999). The maximum AMSU rain rate was 0.93 in h^{-1}, which is probably realistic considering that it is an average over the 48 km footprint of the AMSU-A instrument. The gray areas along the coast are caused by the fact that the AMSU-A rain rate algorithm has a land algorithm and an ocean algorithm. Neither can be applied at the coastline, so no rain rate is calculated there (and zero is assumed in the Areal TRaP calculation). At this time Dennis was moving at 8.3 kt at 316º, approximately perpendicular to the coast.

Comparing parts (b) and (c) of the figure, it can be seen that the Areal TRaP did a good job of forecasting the area that actually received rain from Dennis during this 24 h period. Quantitatively, the maximum TRaP was 10.84 in, the maximum gauge-observed amount was 5.20 in, and the rule-of-thumb estimate for a storm moving at 8.3 kt is 12 in. For several reasons it is always difficult to compare gauge amounts with remotely sensed amounts. In this case the TRaP was high in comparison to gauges, but the rule-of-thumb estimate was even higher.

Figure 3 shows the results for Hurricane Irene. The maximum AMSU-estimated rain rate was 1.18 in h^{-1}. At this time, the storm was moving at 8.2 kt at 12º. The maximum off-shore TRaP was 20.86 in; the on-shore TRaPs were in the 1-2 in range with a band of 2-4 in TRaPs across Florida. Gauge-observed 24 h rain accumulations were all in this range. The maximum gauge-observed amount was 3.51 in. Because the speed of the two storms was essentially the same, the rule-of-thumb estimate of maximum 24 h rainfall for Irene is the same as for Dennis, 12 in. Since Irene never made landfall, maximum precipitation amounts cannot be verified.

5. DISCUSSION AND CONCLUSIONS

It is interesting to note that the rule-of-thumb estimate of the maximum 24 h rainfall from Irene is much less than the maximum Areal TRaP estimate, whereas the rule-of-thumb estimate for Dennis was greater than the Areal TRaP estimate. The reason for this variance can be understood by referring to Equation (1). The rule of thumb assumes that the product $R_{av}D$ is a constant 100 kt in. In reality, both D and R_{av} vary. Satellite microwave measurements can reveal both D and R_{av}, thus making improved rainfall estimates possible.

It is encouraging that in the case of a direct hit (Dennis) and a near miss (Irene), the Areal TRaP techinque was capable of estimating the 24 h on-shore rainfall. Of course many more cases will need to be examined before the accuracy of the technique can be determined.

Areal TRaPs are being produced automatically in real time at both CIRA and SSD for the 2000 hurricane season. Work continues on verification of these forecasts and those made after the fact for the 1999 hurricane season. Soon we will begin making Areal TRaP forecasts using 16 km AMSU-B rain rates.

We conclude that the Areal TRaP technique is a substantial improvement on both the manual TRaP technique and rule-of-thumb technique and it promises to provide additional guidance for forecasters to further improve the forecasts for the areal distribution and amount of rainfall from landfalling tropical cyclones.

Acknowledgments

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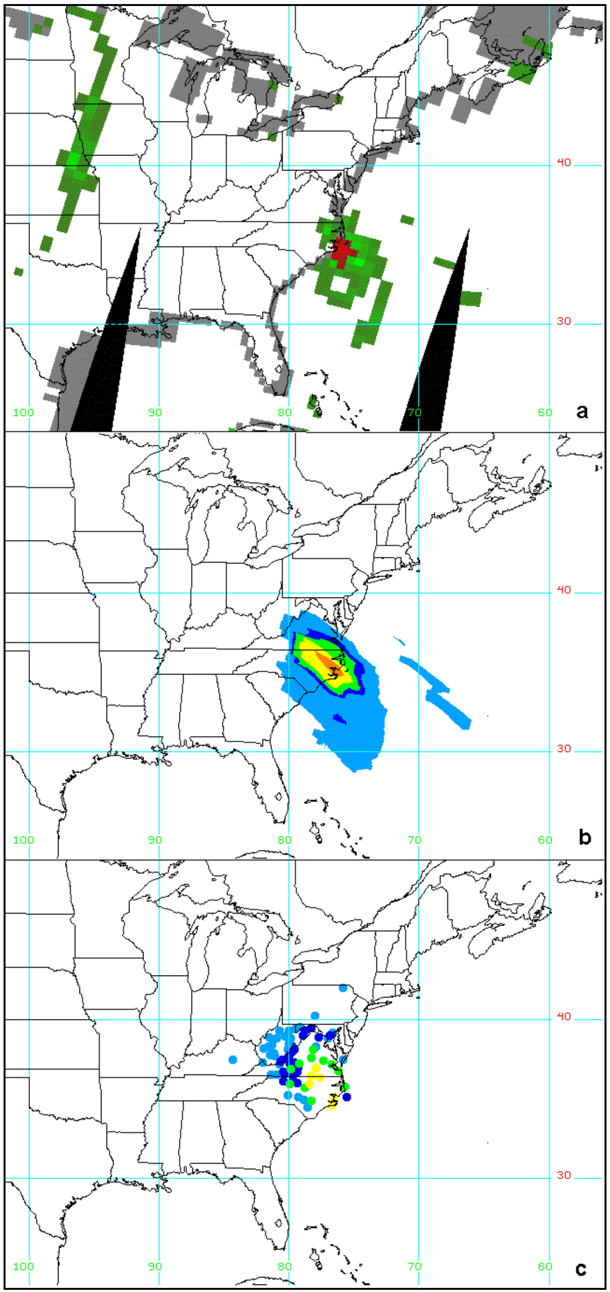

Figure 2. Hurricane Dennis. (a) AMSU-estimated rain rates at 1314 UTC 4 September 1999. (b) 24 h Areal TRaP for the period ending 1200 UTC 5 September 1999. (c) Gauge-observed 24 h rainfall for the period ending 1200 UTC 5 September 1999.

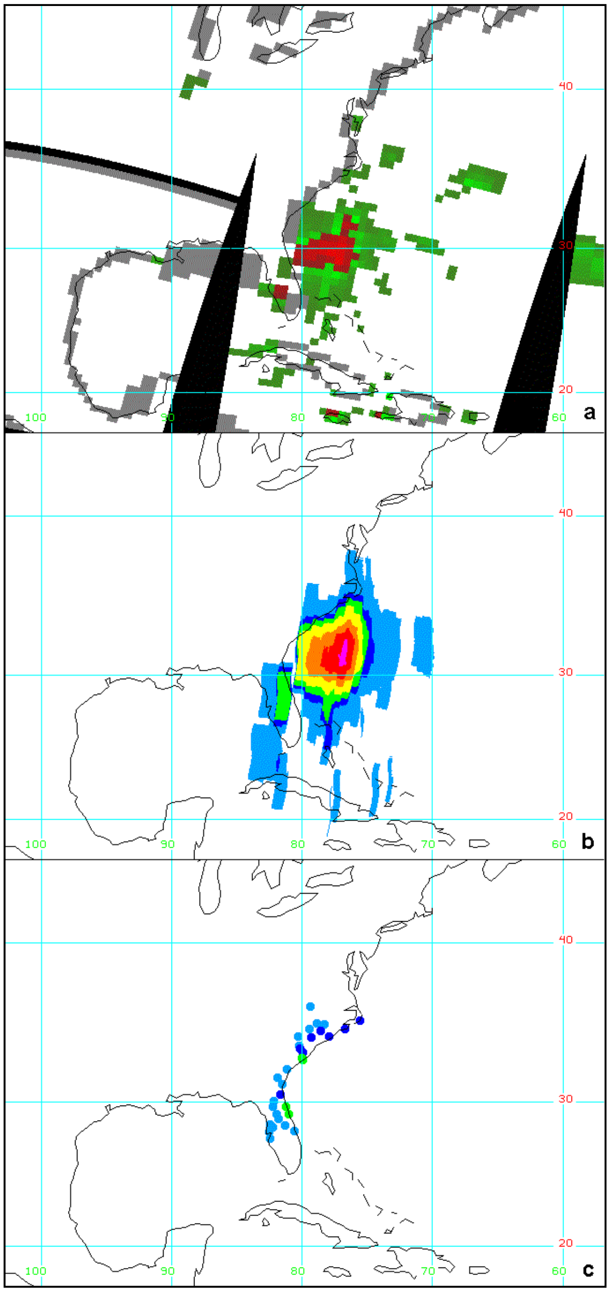

Figure 3. Hurricane Irene. (a) AMSU-estimated rain rates at 1244 UTC 16 October 1999. (b) 24 h Areal TRaP for the period ending 1200 UTC 17 October 1999. (c) Gauge-observed 24 h rainfall for the period ending 1200 UTC 17 October 1999.