12A.2 EVALUATION OF MICROWAVE IMAGERY IN THE LIFE CYCLE OF TROPICAL CYCLONES

Roger T. Edson, Anteon Corporation, U. of Guam (WERI), Mangilao, Guam and Mark A. Lander,
U. of Guam (WERI), Mangilao, Guam

1. INTRODUCTION

This paper examines the life cycle of tropical cyclones (TCs) as depicted in satellite-based microwave imagery (MI). MI has the ability to see rain and ice particle patterns in TCs that are normally blocked by mid- to upper-level clouds in infrared (IR) and visual (VIS) imagery. Although IR and VIS patterns have been used successfully in Dvorak's (1984) intensity analysis technique, there are several known weaknesses. One particular handicap is its dependency on knowing the precise location of the low level center. MI offers the ability to observe hidden rain band features allowing for a better diagnosis of the TC structure and structure change, as well as better knowledge of the low level center location. Intensity analysis methods and intensity prediction schemes using microwave imagery at 85 GHz have been tried in the past with limited success (Cocks et al., 1999; May et al., 1997; and Bankert et al, 2000). The Special Sensor Microwave Imager (SSM/I) on the Defense Meteorological Satellite Program (DMSP) satellites has been available to TC forecasters for almost 15 years, however the low resolution (15km at 85 GHz), the lack of continuous coverage, and difficulties in analyzing the low level cloud and moisture field in 85 GHz imagery have all made it difficult to improve upon the Dvorak technique. Since late 1997, additional microwave coverage has been provided by the Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI). The TMI offers 2-4 additional overhead passes in a 24 hour period because of its unique 38S to 38N orbit. Its lower orbit not only offers a higher resolution at 85 GHz (7km) but also gives sufficient resolution at 37 GHz (15km) to be effective at depicting lower rain band characteristics that were not visible in the 85 GHz due to either moisture saturation in the lower troposphere or obscuration due to ice particles in the upper troposphere (Lee et al., 2001). TMI (85 GHz and 37 GHz) and SSM/I (85 GHz) imagery are examined over the past 4 years in all basins. Five stages in a TC life cycle as viewed in MI are described here: (1) TC Genesis, (2) Early Intensification and Development, (3) Continued Intensification and Mature Stage, (4) Peaking and Initial Weakening, and (5) Dissipation and/or Extratropical Transition.

2. TC LIFE CYCLE AS SEEN IN THE MI

The first three stages described in this paper contain many similarities and some important differences to the patterns described in Dvorak (Fig. 1).

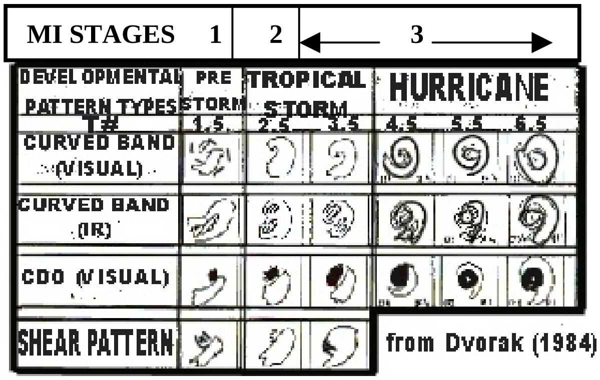

Fig. 1. Developmental patterns in Dvorak as compared with the first 3 Stages of MI development.

1. TC Genesis Stage. This is equivalent to the Dvorak Pre-Storm stage T#1.5 (or earlier). In this stage a low level circulation begins to form but still needs to consolidate. Convection is not well organized although it can be loosely associated with one of the Developmental Patterns shown in Fig 1. In the MI, extended curved bands and CDO-type convection are rarely seen at this stage (they may occur later). Instead, the primary patterns are a circular or elliptical area of increased low level moisture, and the initiation of organized shallow rain band activity (deeper convection may or may not be associated with this development).

a) 85 GHz: look for the development of a circular or elliptical low level moisture field as depicted by warmer temperatures over the MI-cool ocean surface. Deep convection is disorganized.

b) 37 GHz (and also the low level enhancement curve in SSM/I 85 GHz): look for evidence of isolated but curved rain bands within the moisture field. The center is often in a dry, rain-free area. Some heavier convection may exist within the weaker bands.

2. Early Intensification and Development Stage. This is equivalent to the Dvorak (early) Tropical Storm stage, T#2.5. In this stage the low level circulation has become better organized, tighter and moister. Deeper convective rain bands exist (often only along portions of the low level rain bands and on one side of the circulation center), but are much less developed than in the IR or VIS Dvorak patterns. A pre-eyewall rain band may begin to encircle the rain-free center.

a) 85 GHz: Convective bands are not continuous but are in short segments in line with weaker rain bands. Rain bands may 'point' towards the center but do not wrap around it. A large convective area may exist but generally not close to the center. The warm moisture field is more sharply delineated and may contain cyclonically curved striations.

b) 37 GHz: Look for evidence of increased low level organization. Rain bands are seen completely

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**Corresponding author address:* Roger T. Edson *c/o* WERI, Univ. of Guam, Mangilao, Guam *96923;* email: redson@uog.edu

encircling the low level center and may be partially tucked under the heavier convection. The center is almost always found in a rain-free area. A pre-eyewall may exist.

3. Continued Intensification and Mature stage. This stage includes all categories above the Dvorak Strong Tropical Storm stage (T3.5) to the highest intensity that the TC reaches (greater than T3.5). During this stage, changes in the character of deep convective rain bands as seen in the 85 GHz are most closely related to intensity change. Patterns now look like either Dvorak IR curved bands or the MI patterns described in Cocks et al. (1999) as ‘hooks’, ‘claws’, ‘sixes’ and (for the more intense TCs) as ‘rings’ or ‘double rings’. Here, the MI can often give signs of rapid intensification, eyewall replacement cycles, and peaking.

a) 85 GHz: Used primarily in this stage. Look for an increase in organization (curvature and thickness) of the coldest rain band temperatures. Since rain bands must be associated with the system center prior to eye formation, use either a low level enhancement curve or 37 GHz to verify the system center.

b) 37 GHz: May be used to verify system center (but use a polarized correction enhancement (Lee and Edson, 2001) to aid positioning. Outside the deep convection as seen in the 85 GHz, the stronger (but lower) rain bands may help show the limits of the 50 and 35kt wind radii.

4. Peaking and Initial Weakening Stage. One of the weaknesses in Dvorak is the uncertainty of when a TC has reached its peak and begins to weaken. In Dvorak, there are no unique weakening patterns and the analyst is forced to move back down through the stages shown in Fig. 1. Confusion often exists as to whether the TC is weakening or just showing temporary fluctuations in structure or eye appearance. The MI offers the view of any changes to the eye wall or supporting rain bands. Comparisons should be made between the differences in organization and vigor of the deep convection versus the weaker rain bands.

a) 85 GHz: Changes of TC structure viewed in this frequency remain the most important. Look for signs that the coldest temperatures in the central rain bands no longer encircle the center (several breaks appear). Only slow (fluctuating) weakening occurs if the rain band temperatures are only slightly warmer. Sometimes, stronger outer rain bands move in to replace weaker inner bands similar to Stage 3, above. Quicker weakening occurs if the more intense (colder) rain bands disappear without any replacement. However, do not weaken too quickly if lower cloud bands (seen in either 85 or 37 GHz) still show good organization and vigor.

b) 37 GHz (or low level 85 GHz enhancement): Used to evaluate the vigor and organization of the less intense rain bands nearest to the system center. 37 GHz may still may be used to estimate outer wind radii.

5. Dissipating and Extratropical Transition. During this stage the TC is progressively disrupted through interaction with its environment. The low level center continues to separate from any remaining deep convection. Dissipation over water usually shows the circular rain and moisture field getting weaker with time. During extratropical transition, interaction with mid latitude features such as high shear or a frontal boundary manifest as asymmetries in rain bands and in distortions of the low level cloud field. After dissipation of most deep convection, strong winds at the surface may still be present in regions of well organized shallow convective rain bands. These are best seen in 37 GHz imagery (or in the SSM/I low level enhancements).

a) 85 GHz: Deeper convection continues to dissipate and move away from the center. Look for the shrinking of the warm-appearing moisture field due to subsidence and dry air encroachment.

b) 37 GHz: Look for dissipation of the remaining low level rain bands.

3. FUTURE WORK AND REMARKS

This study has made an attempt to identify important TC features that are primarily seen in the MI that may help diagnose structure and intensity during the TC life cycle. Future work will continue to stratify and quantify these results. Methods will then be developed to either replace or (more likely) supplement the current Dvorak procedure. Examples of all features described in this extended abstract will be shown during the conference oral presentation.

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