NOAA Technical Report NESDIS 11

Tropical Cyclone Intensity Analysis Using Satellite Data

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Washington, D.C.
September 1984

U.S. DEPARTMENT OF COMMERCE
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National Oceanic and Atmospheric Administration
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National Environmental Satellite, Data, and Information Service
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ABSTRACT. New and improved techniques for determining tropical cyclone intensity from satellite data have been developed over the past several years. This paper contains descriptions of methods designed to be used with visible, enhanced infrared and digital infrared data. The analysis techniques all use cloud feature measurements and rules based on a model of tropical cyclone development to arrive at the current and future intensity of a tropical cyclone. The model describes tropical cyclone development in terms of day by day changes in the cloud pattern of the storm and its environment. It contains cloud pattern descriptions at each stage of development and information on how they change with time. The VIS and IR techniques differ mainly in the cloud features that are used in the analysis and the way in which they are measured. The procedures and rules are the same for both methods.

The enhanced and digital infrared techniques, when applied to storms of hurricane strength, rely almost entirely on measurements of the "eye" temperature and the temperature of the clouds around the eye for the intensity determination. The enhanced infrared technique requires the use of a new concept to deal with the common occurrence of a sudden spreading of cold clouds over the central features of the disturbance. This central cold cover (CCC), when it persists, is used in the technique to signal an interruption in the development of the storm.

When visual pictures, or infrared pictures of weaker disturbances, are used for the intensity analysis the cloud feature measurements are usually more subjective and more complex. The analysis involves the appearance of the clouds forming the cloud system center and those encircling the center as well as measurements of these features. This results in more reliance on rules and modeling principles then is necessary with the enhanced or digital infrared technique.

Methods used to forecast tropical cyclone development and weakening are also described in the paper. These include a recently developed technique that uses cloud feature indications of changes in the westerly jet stream to forecast changes in tropical cyclone intensity.

I. INTRODUCTION

Tropical meteorologists have been using satellite pictures for monitoring tropical storms for almost 25 years. One of the most important applications of the pictures is in determining the intensity of the storms. The first methods developed for this purpose were used operationally in the early 1960's when only one satellite picture a day of a tropical cyclone was available for the analysis (Timchalk et al., 1965; Fett, 1964). At that time, the intensity estimation was made from the appearance of a storm's eye, its banding, and the size of the cloud pattern. These methods were useful for approximating the intensity of tropical storms in most cases, but they had serious shortcomings when the cloud pattern of a storm was either unclear or when it was undergoing extreme short-period change.

By the late 1960's, meteorologists had observed many tropical cyclones during their entire life cycles using good quality satellite pictures. Nighttime views and short-interval daytime pictures were also coming into use at that time with the advent of infrared (IR) sensors and geostationary satellites. Experience with these data shed new light on the relationship between tropical cyclone development and the cloud patterns observed in satellite pictures. One of the most important observations made during these years was that the cloud patterns of tropical cyclones evolve through recognizable stages as the intensity of the cyclone changed. The cloud patterns in general showed that the dense (cold) clouds of the disturbance formed around the storm center in the shape of a curved band in the early stages of development. The band was observed to curve halfway around the center at the weak tropical storm stage and completely around the center forming an "eye" at the weak hurricane stage. Further intensification was indicated by increasing dense (cold) clouds around the eye or by the eye becoming more well-defined (warmer). The difficulty with following this pattern evolution, however, was that the form and clarity of the pattern often varied with time. Periods of cloud pattern distortion, cloud dissipation, or of the development of an obscuring central overcast made it difficult to follow the evolution of the curved band pattern.

Movies made in subsequent years with pictures taken at short intervals showed that the cloud pattern did not evolve continuously from stage to stage but appeared to form in surges. The center as defined by the cloud features would appear well-defined and easy to interpret during a surge of pattern growth; but following the surge, the cloud features often became poorly defined and difficult to understand. The variability in the cyclone's cloud pattern appeared to result from several causes. Some of the variability was due to short-period convective-scale activity, some was related to diurnal influences, while other longer period distortions were due to the effects of adjacent circulations impinging on the storm. Much of the difficulty with intensity analysis during the 1960's arose when the only picture available for analysis was taken during a period when the cloud pattern was undergoing considerable variability. It was becoming apparent through these years that analysis procedures and rules would be needed along with additional cloud pattern signatures to derive consistently reliable intensity estimates from satellite pictures.

Other important observations made during the late 1960's concerned the initial development, future development, and the weakening of tropical cyclones as viewed in satellite pictures. It was found that cloud patterns normally showed indications of cyclogenesis 36 hours before the storm reached tropical storm intensity. Indications of whether or not a storm would continue to develop once the developmental process was initiated were also observed in the cloud features of both the storm and its environment. And when a storm started weakening, the indications of weakening in the cloud features were observed to precede the weakening shown in central pressure measurements of the storm. These observations suggested the possibility of using the pictures to make intensity forecasts.

The recognition of these and other factors led to a new technique for intensity analysis and forecasting using satellite pictures (Dvorak, 1972 and 1975). The technique came into operational use early in the 1970's and has been gradually improved over the years. During recent years, methods using enhanced IR and digital IR data have been added to the technique. By providing temperature measurements that are used in place of subjective judgments, these data make the analysis simpler and more objective than it is when visible pictures are used. The concepts underlying the technique are explained in this paper. A detailed description of the technique for use with visible or enhanced infrared imagery is given in the appendix.

II. TROPICAL CYCLONE ANALYSIS IN GENERAL

It is the pattern formed by the clouds of a tropical cyclone that is related to the cyclone's intensity and not the amount of clouds in the pattern.* Certain characteristics or features of the pattern such as those which form the storm center and the overcast around the center have been used for years to estimate tropical cyclone intensity. When the features are clear-cut and when they evolve in a systematic manner, they can be used to obtain reliable intensity estimates. But these essential features do not always appear clear-cut and may take on a variety of appearances at each level of cyclone intensity. There are also periods in the life cycle of storms such as the pre-storm stage and the weakening stage when some cloud patterns are known to be unrepresentative of the intensity of the storm. The analysis technique deals with this complexity through the use of systematic procedures, cloud pattern descriptions, and rules. The cloud pattern descriptions include measurable features used for quantitative analysis as well as drawings of cloud patterns to be used for qualitative comparisons. The descriptions show the cloud features that are related to storm intensity on each successive day of storm development to help the analyst recognize the essential elements in patterns of considerable complexity. The rules of the technique are designed to guide the use of the cloud pattern descriptions when the cloud pattern being analyzed is unclear or is known to be unrepresentative of the storm's intensity.

*Arnold (1977) could find no significant difference in the amount of convective cloudiness between stages of tropical cyclone development.