FORECASTING TROPICAL CYCLONE INTENSITY CHANGE USING TMI OBSERVATIONS

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1. INTRODUCTION

Forecasts of tropical cyclone (TC here onwards) movement have improved steadily over the last three decades, owing to a combination of better observations and much improved numerical models (DeMaria and Kaplan, 1997). By contrast, there has been comparatively little advance in predictions of intensity (as measured, for example, by maximum surface wind speed), in spite of the application of sophisticated numerical models (DeMaria and Kaplan, 1997). The best intensity forecasts today are based on a combination of climatology and persistence (DeMaria and Kaplan, 1994). An accurate intensity forecast is extremely important in the forecast advisory/warning process, primarily because emergency management decision-making is closely tied to the intensity of landfalling tropical cyclones. It has been realized by the forecasters that the process that lead to changes in intensity of a tropical cyclone is closely related to changes in structure, primarily of the inner core. However, such information has not been exploited to its full potential for prediction of TC intensity change. Since the observations of tropical cyclones are limited by their remote locations over the oceans, and observations from aircraft reconnaissance are not available over most of the global basins, the analysis of remotely sensed data is the only viable means for determining tropical cyclone structure, leading to the estimation and prediction of TC intensity. Although visible and infrared data from geostationary satellites provide continuous data for these storms, observations from microwave sensors onboard polar orbiting satellites are more directly related to the factors influencing TC intensification. These are precipitation and convection at the inner core, and surface level wind speed, water vapor and SST structures over the outer environment of a tropical cyclone. Rao and MacArthur (1994), and Rao and McCoy (1997) examined the precipitation features of a number of typhoons over western North Pacific ocean using SSM/I (Special Sensor Microwave/imager) data, and noticed that the inner core precipitation (within 2 deg from the TC center)
was more highly correlated to the 24-h future intensity than either the current intensity or intensity change during 24-hours. Rodgers and Pierce (1995) used 12-h change in inner core (within 1 deg from center) precipitation derived from 85 GHz channel of SSM/I and related them to the 12-h and 24-h intensity changes in the intensity of tropical depressions, tropical storms and typhoons over western North Pacific Ocean. Only the tropical storm sample yielded a usable correlation of 0.51. On the contrary, using a much smaller sample, Rodgers et al (1994) found that this correlation was much higher for the intensity change of western North Atlantic hurricanes (0.78) while correlations for tropical depressions and tropical storms were much lower. Using a large number of SSM/I observations of tropical cyclones over Atlantic, Eastern North Pacific, and Western North Pacific ocean, Cecil and Zipser (1999) analyzed the relationship between polarization corrected temperature (PCT) of 85 GHz channel and current and future TC intensity.

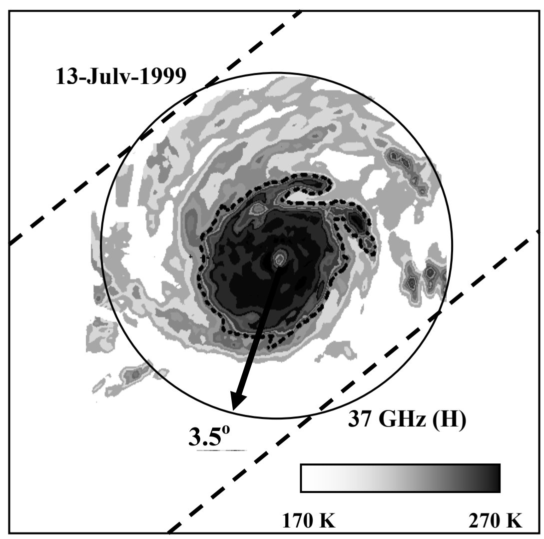

Fig. 1 : Distribution of 37 GHz(H) BT over a tropical cyclone. Circle denotes the region of analysis, dashed line shows the TM swath, and thick dotted line denotes the boundary of cloud-mask.

They noticed that even though the PCT features were strongly correlated with the 24-h future intensity of cyclones, in general the correlations between PCT and 24-h "intensity-change" were very low, with a large amount of scatter. Moreover, the PCT-intensity change correlations showed basin-dependency and usable

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correlations (> 0.6) were found only for Eastern North Pacific cyclones.

In the present paper, we have assessed how the information from brightness temperature (BT) and their spatial patterns from the observations from TRMM Microwave Imager (TMI) can be utilized for the prediction of 24-hour change in TC intensity. One common approach of using multi-layered information for making a decision is to use the decision tree, and predict the outcome for different combinations of available information. Another alternative is finding an empirical relationship between available information and desired outcome. In case of a complex process, simple empirical methods like linear regression may be inadequate to capture the maximum possible variability of the outcome, and one may require more rigorous data-fitting approaches that can translate the available information into a forecasting tool. In the present study we have explored the scope of one such approach to meet our objective of predicting 24-h intensity change of tropical cyclones using TMI data.

2. DATA AND METHODOLOGY

A detailed description of TMI sensor package is provided by Kummerow et al (1998). TMI has some advantages compared to SSM/I. Due to lower altitude of TRMM satellite, even low frequency channels of TMI provide higher spatial resolution that can lead to extraction of information from a narrow but active segment such as core and eye-wall region of a TC. Moreover, 10 GHz channel of TMI is sensitive to intense rainfall, normally associated with intense TCs, as well as the SST patterns in the outer regions of a TC where cloud liquid water is low. A total of 146 TMI scenes were selected belonging to a number of TCs that occurred over the North Atlantic (NATL), North-East Pacific (NEPAC) and Indian Ocean (IO) basins during 1998-2002. We have tried to include only those TMI scenes that display all the major features of a TC e.g. inner-core and bands. All the scenes within 100 km distance from the land were excluded from the analysis. Maximum Sustained Wind (MSW) has been considered as the measure of TC intensity. Best-track analyses from Tropical Prediction Center (TPC), Washington, were used to determine the TC intensity for all the cases, and TC position for some cases. For most of the scenes, we determined the TC center position using 37 GHz images using the distinguished and unambiguous patterns leading to center-fixation (Hawkins et al, 2001). In case of some ambiguity regarding such patterns, 85 GHz images were used, and if still there was a doubt about the center, 6-hourly TPC analysis of best track position was interpolated to the time of the TMI scene. Tropical cyclones in all the basins have been treated alike in the present analysis. Data within 3.5-degree radius from the center of the cyclone has been analyzed.

3. RESULTS

Our analysis indicates that the nature and the magnitude of the information that TMI channels provide about the 24-hour intensity change (C-24 here onwards) critically depend upon the present intensity of the cyclone. A simple correlation analysis indicates that for TCs with MSW < 60 Kts, the most useful signals about C-24 come from 10 GHz (V), 19 GHz(V), and minimum PCT (PCT_{min}) respectively. Fig. 2(a) shows these correlations for different values of the upper limit of MSW. This figure indicates that even though low frequency channels provide extremely good signals about the intensification of tropical depressions (MSW ~ 30 kt), the correlations rapidly become unusable as the cyclones grow in intensity, and PCT_{min} remains the only useful indicator of C-24. PCT_{min} v/s C-24 correlation is similar to that reported in earlier studies (Cecil and Zipser, 1999).

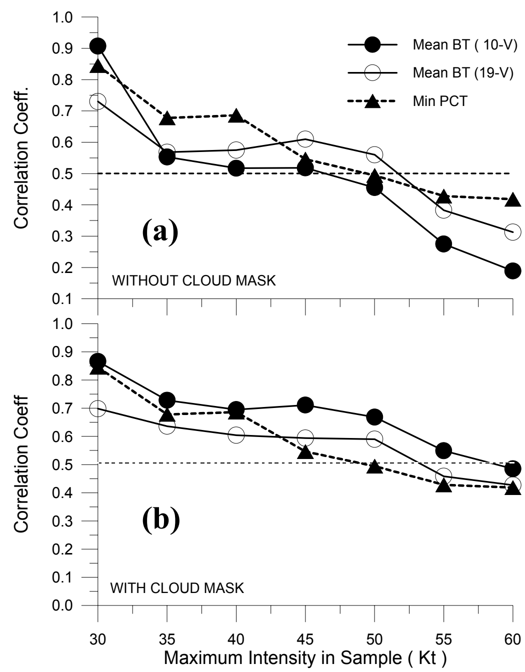

Fig. 2: Magnitude of correlation of area mean (0-3.5°) BT of 10 GHz(V), 19GHz(V) and Minimum PCT with C-24 (a) Without cloud-mask (b) With cloud mask.

However, the information content of low frequency channels (particularly 10 GHz) increases if we use a 'cloud-mask' to exclude the observations from the regions with high cloud-liquid water (CLW) content.

Brightness temperatures at 37 GHz are excellent indicators of lower tropospheric cloud liquid water. A preliminary analysis using the available data indicates that BT (37-H) > 200 K serves as a good 'cloud-mask' and we excluded this region for the computation of the averages of BTs from low-frequency channels (Fig. 1). Increase in the correlations of low frequency channels with C-24 outside this cloud-mask is interesting and it indicates that the intensity-change information is arriving from surface wind and sea surface temperature (SST) outside the main core of the cyclone since these channels are sensitive to wind and SST particularly in low rain-rate and low CLW environment.

For intensity change estimation of low-intensity cyclones we considered the mean of low frequency channels (10,19,22, and 37 GHz channels) outside the cloud mask, mean and minimum PCT , mean of 10 GHz(V) BT inside the cloud -mask, and 12-hour intensity change prior to the TMI scene.

For higher intensity cyclones (MSW > 60 kt), the correlations of TMI derived parameters and C-24 is generally low. The parameter having highest correlation with C-24 is PCT-MIN (r ~ -0.45), the correlations with low frequency channels are significant but unusable if one tries to use them in a linear model for the prediction of C-24. However, in a non-linear data fitting approach, correlations of individual parameters may not be a prohibitive factor for the development of a prediction tool, because the non-linear combinations of different variables may be used to retrieve sufficient information about the desired quantity. After a close examination of several TMI scenes, we selected a number of variables depending upon the multi-channel brightness temperature and their spatial patterns to develop an algorithm for the prediction of C-24. These parameters are

(1) Convective Mass ($\sum$CM, where CM=MAX ((230 K -PCT)$^{1.1}$, 0.0) for $0 < r < 1.3^o$, r being the radial distance from the center of TC.

(2) Convective Mass for $1.3^o \leq r < 2.5^o$

(3) Isotropy Index (an index to determine if the convection, defined by population of pixels with PCT < 240 K, is circularly distributed or confined to a few angular sectors) for $0 < r < 1.3^o$

(4) Isotropy Index for $1.3^o \leq r < 2.5^o$

(5) *Convective Shear* : Angular shift between the region with maximum pixels with high BT in 37 GHz, and maximum pixels with low PCT in 85 GHz images. Convective shear is measured only for $0^o \leq r < 2.0^o$

(6) Mean PCT for $0 < r < 1.3^o$

(7) Minimum PCT for $0 < r < 1.3^o$

(8) Mean of 10 GHz (V) BT outside the cloud-mask.

(9) Day of the year.

(10) Local time of the TMI scene (expressed as a sine function).

(11) Intensity change during 12 hours prior to the TMI scene.

Separate algorithms were developed for TCs with MSW < 60 Kt, and for MSW ≥ 60 kt. For both the cases, we used a non-linear data fitting approach known as ‘genetic-algorithm’ based on the Darwin’s laws of natural selection, and “survival of the fittest”. A detailed description of the Genetic Algorithm can be found in the works of Szpiro (1997), and Alvarez et al (2001). Alvarez et al (2000) and Kishtawal et al (2003) showed the potential of Genetic Algorithm for the prediction of geophysical processes like SST and seasonal rainfall. A genetic algorithm is programmed to approximate the equation, in symbolic form, that best describes the relationship between independent and dependent parameters. Due to the shortage of space, it is not possible to provide the details of this technique here. An ideal non-linear approximation can possibly simulate a decision-tree approach through the combination of dependent parameters. 122 cases were used to train the algorithm while 24 cases were selected for verification. The summary of results is as follows. The training data set yielded a correlation of 0.85 between estimated and observed 24-h TC intensity change, with an r.m.s. error of 7.43 kt. For validation data set these figures were 0.82 and 7.17 kt respectively. From the combined data set (training + validation) of 146 scenes, the difference between actual and estimated C-24 was larger than 100% (of observed values) for 37 cases. For 123 cases the algorithm captured the correct sign of 24-hour intensity change, while for 23 scenes, the estimated quantity showed false sign. Fig. 3 shows the comparison of actual and estimated values of 24-h TC intensity change for training and validation data sets. Attempts to reduce the false alarm and to further improve the accuracy of prediction are ongoing. A detailed description of the methodology and results will be reported to a scientific journal in near future.

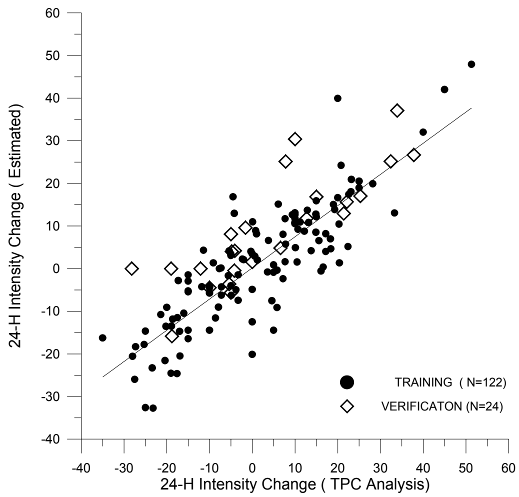

Fig. 3: A comparison of estimated and actual values of 24-hour TC intensity change for training (dark dots) and validation (open diamonds) data sets. Actual values are based on TPC analysis.

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