ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 3, Issue 3, September 2013

An Approach to Predict Cyclogenesis using Radio Occultation Observations

Neerja Sharma, M. M. Ali
National Remote Sensing Centre, Indian Space Research Organization (ISRO), Hyderabad 500037 (India)

Abstract*— The accurate and timely identification of cyclogenesis has been one of the major issues in cyclone prediction. Due to the lack of in situ observations, model simulations, which are generally different from real conditions, are used to address this challenging problem. Since model derived parameters perform poorly in predicting cyclogenesis, we developed a neural network approach to identify cyclogenesis using the data obtained from Global Positioning System Radio Occultation (GPSRO) technique. For this purpose, we used 1-dimensional variational analysis temperature and pressure profiles and atmospheric stability and moisture indices, derived from this temperature and pressure profiles using GPSRO Constellation Observing System for Meteorology Ionosphere and Climate (COSMIC) mission over North Indian Ocean as predictors for cyclogenesis. Out of the 8686 COSMIC tangent points, during May 2006 - December 2010, 118 profiles are selected after applying thresholds to different parameters at different levels. Using these 118 profiles, a neural network model is developed to predict the cyclogenesis and non-cyclogenesis locations. Out of the 118 cases, the model could accurately predict 112 non-cyclogenesis and 5 cyclogenesis points. Though the model failed to predict one cyclogenesis case, there are no false alarms.

***Index Terms*—Artificial Neural Network, Atmospheric stability, Cyclogenesis prediction, One-dimensional variational analysis, Radio occultation observations.**

I. INTRODUCTION

Cyclones have a life cycle of genesis to dissipation. Besides sudden intensity changes of the tropical cyclones, identification of cyclogenesis locations has been a difficult problem. So far, tropical cyclogenesis predictions are obtained from numerical model simulations using low resolution atmospheric [1], [2], [3] and atmosphere ocean coupled models [4], [5]. Since model simulations could be significantly different from the actual observations, forecasting skills using output from the models for cyclogenesis predictions are usually poor [6].

Earlier studies suggested different precursor factors for cyclogensis formation: Palmen et al. [7] show that sea surface temperature (SST) of above 26°C is necessary for tropical cyclone formation. In a study of western Pacific typhoons, Riehl et al. [8] concluded that storm formation can be inhibited by the vertical shear of the horizontal wind. Gray [9] defines a tropical cyclone genesis condition as the product of thermodynamic and dynamical terms where, SST and middle level moisture affects are included as the thermodynamic terms and vertical shear and low level vorticity affects as the dynamical terms. Climatologically values of this product are well correlated with the global tropical cyclone formation regions [10]. Finally, Gray [9], [11] considered six potential precursor environmental conditions favorable for cyclogenesis.

Hennon et al. [12] suggested using in-situ observations for cyclogenesis prediction. Till the recent years this suggestion could not be implemented due to the limitations of the in situ radiosonde observations, particularly, over the oceans. However, Global Positioning System (GPS) Radio Occultation (RO), henceforth GPSRO, technique has been providing accurate and high resolution vertical profiles of temperature, humidity and pressure over a larger spatial and temporal scales [13], [14]. Presently operating GPSRO Constellation Observing System for Meteorology Ionosphere and Climate (COSMIC) mission (operating since May 2006) can track 90% of all rising and setting occultation soundings to within one kilometer of the earth's surface. The accuracies of COSMIC observations are similar to those of radiosonde with global mean temperature bias of -0.09K and a standard deviation (SD) of 1.72K [15] with the added advantage of availability over the oceans, where cylogenesis generally occurs. This mission provided a good amount of 1-dimensional variational (1-DVAR) temperature and pressure profiles from which a few precursor parameters required for cyclogenesis prediction could be estimated. Studies show that cyclone track and intensity forecasts have improved by incorporating GPSRO data into the model [16], [17]. However, these data have not been used so far for the prediction of cyclone formation. Thus for the first time we propose a methodology to predict cyclogenesis over the North Indian Ocean using COSMIC observations.

II. DATA

We used 1-DVAR temperature and pressure profiles from GPSRO COSMIC mission (http://cosmic-io.cosmic.ucar.edu) in the North Indian Ocean (5°N-25°N, 60°E-100°E) from May 2006 to December 2010 (Figure 1). The cyclogenesis locations are taken from best track data of Joint Typhoon Warning Center (JTWC) (http://www.usno.navy.mil/NOOC/nmfc-ph/RSS/jtwc/best tracks/ioindex.html).

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 3, Issue 3, September 2013

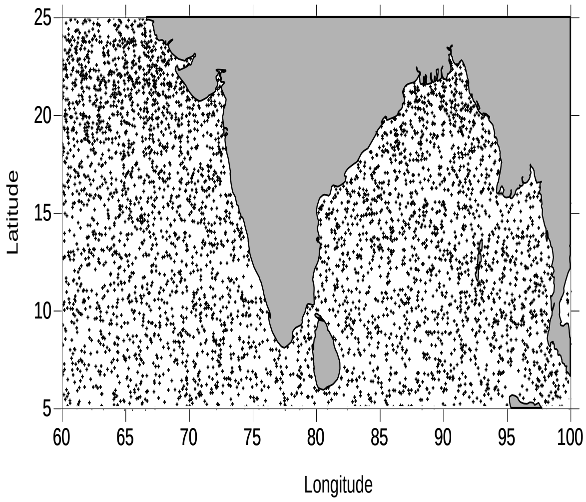

Fig 1. Tangent point locations of COSMIC observations during May 2006 to Dec 2010

III. APPROACH

Average refractive index (RI), relative humidity (RH) and total perceptible water (TPW) respectively represent the atmospheric instability, likelihood of precipitation and the total latent heat available in the atmospheric column [18]. Hence, these parameters are calculated using 1-DVAR temperature and pressure profiles. RI and TPW are calculated at five levels (from available lowest surface - 800 hap, 800-600 hPa, 600-400 hPa, 400-200 hPa and 200-100 hPa). Since cyclogenesis process is affected by the vertical thermodynamic condition of the troposphere, we also calculated the temperature and RH at 9 levels (850, 700, 500, 400, 300, 250, 200, 150 and 100 hPa). Thus, in total 28 observations (RI and TPW at 5 levels and RH and temperature at 9 levels) are calculated at all the 8686 COSMIC locations available during May 2006- December 2010.

Since all the values of 28 observations need not be conducive for cyclogenesis, applied thresholds to these values. For this purpose, we first collocated the cyclogenesis locations with the COSMIC observations falling within 1° spatial and 24 hour temporal domines before the formation of cyclone. During the study period 21 cyclones and 12 tropical depressions (TD) occurred, out of which 4 cyclones (Bijli-2009, Nargis-2008, Rashmi-2008 and Khai-Muk-2008) and 2 TDs (August-2008 and December-2008) locations coincided with the COSMIC observations satisfying the above criteria. The dates and locations of cyclogenesis and occultation's are given in Table-1. The thresholds applied for various parameters are shown in Figure 2. The y-axis represents the threshold for each of the predictor (say, T100, RI400-200, RH200, TPW800-600). T, RI, RH and TPW are for temperature, refractive index, relative humidity and total precipitable water respectively. The numbers with these abbreviations correspond to the pressure level of each parameter.

Table 1: List of collocated cyclogenesis locations with COSMIC occultations

S. No	Cyclone name	Actual cyclogenesis date	Actual cyclogenesis location	Occultation date	Occultation location
1	Bijli	14April 2009	12.6°N 87.7° E	13April 2009	12.2°N 86.2°E
2	Nargis	27April 2008	10.5°N 90.3°E	25April 2008	10.8°N 89.9°E
3	TD	9 Aug 2008	20°N 83°E	8 Aug 2008	20.1°N 84°E
4	Rashm i	24Oct 2008	16°N 85°E	23Oct 2008	16.7°N 86°E
5	Khai muk	13Nov 2008	10.5°N 85°E	11Nov 2008	9.1°N 84.6°E
6	TD	4Dec 2008	5.9°N 91.3°E	3 Dec 2008	5.9°N 91.1°E

From these six collocations, the minimum values of each of the 28 computed parameters are considered as thresholds (Figure 2).

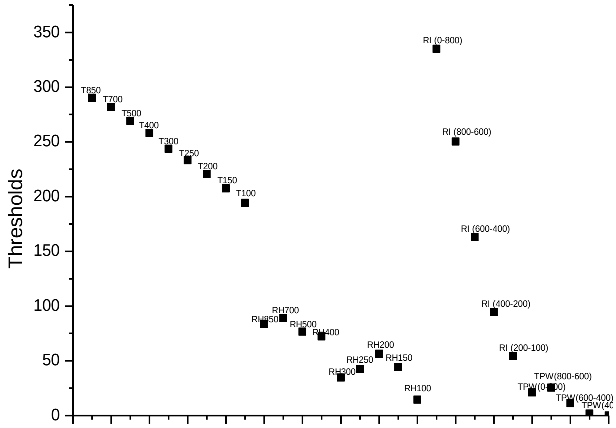

Fig.2 Thresholds applied to 28 predictors. The numbers with the abbreviations correspond to the pressure level of each parameter.

Then, these thresholds are applied to all the 8686 profiles. After applying thresholds, only 118 locations remained with 112 non-cyclogenesis and 6 cyclogenesis cases. All these locations are categorized as 'Y' where cyclogenesis occurred and as 'N' where cyclogenesis did not occur. Then we developed an Artificial Neural Network (ANN) model to identify cyclogenesis and non-cyclogenesis locations with 28 observations as predictors and the categorical output (Y/N) as the predictant. Out of the 118 locations ANN randomly used 84 locations to train the model 17 for testing and 17 locations for validation. 3 cyclogenesis locations are in training data set,1 in selection and 2 are in validation set. A summary of the ANN approach is given in Sharma and Ali [19]. In short an ANN is the information processing paradigm that is inspired by the way biological nervous system, such as the brain, processes information. Performing an ANN analysis requires three sets of data under the categories training, verification (testing) and prediction (validation). The data set marked for training is used to train the neural

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 3, Issue 3, September 2013

network. Verification cases are used to check the model during training so that the model does not over-fit. Validation dataset is used to compare the model estimated values with the actual indepent data.

The ANN model correctly identified 117 locations out of the 118 locations. It failed in only one case where it could not identify one cyclogenesis (out of six) of training data set. 117 correct predictions out of 118 tries has an accuracy of 99.15%, with a 95% confidence interval of 95.37 to 99.98%. We have carried out a sensitivity test to see which parameters are more important in predicting cyclogenesis. The top 10 parameters which are more important are shown in Figure 3. Out of the 28 parameters, RH at 100 hPa is the most important parameter followed by that at 400 hPa, RI between 200-100 hPa and temperature at 700 hPa. From this figure it may be concluded that relative humidity and atmospheric stability at the upper levels and temperature at the lower layers are most important factors in the formation of cyclogenesis.

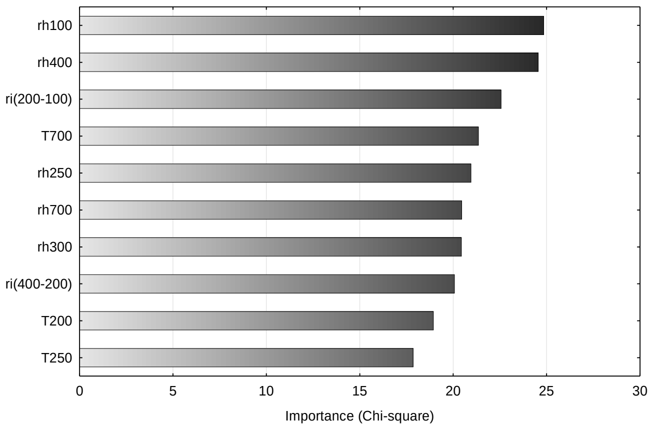

Fig 3: Top ten parameters which are important in predicting the cyclogenesis.

IV. CONCLUSION

We conclude that the observations of atmospheric parameters obtained from COSMIC 1-DVAR technique can play an important role in cyclogenesis identification. The vertical profiles of atmospheric stability, moisture indices and temperature can provide more actual status of atmosphere during cyclogenesis. The present approach is successful in identifying 117 cases out of 118. Though it could not identify one genesis case, there is no false alarm in this analysis i.e. Cyclogenesis is not predicted at non cyclogenesis location. Sensitivity analysis reveals that relative humidity at upper levels and temperature at the lower levels are important for cyclogenesis. Since the present occultations are not sufficient to co-locate the cyclogenesis of all 33 cases occurred during the study period, we recommend more RO sensors in future satellite missions for precise and timely prediction of cyclogenesis. Though the present study suggests a method to predict cyclogenesis in North Indian Ocean, the same procedure can be applied to other ocean basins to develop region specific algorithms.

ACKNOWLEDGMENT

We used the 1-dvar temperature and pressure profiles from the COSMIC website (http://cosmic-io.cosmic.ucar.edu). We acknowledge the facilities and encouragement provided at NRSC. We thank Dr. John Pezzullo for the discussion on the statistical analysis. We used the website http://StatPages.org/confint.html for computing the accuracy of our estimations.

REFERENCES

[1] S.J. Camargo, A.G. Barnston and S.E. Zebiak, “A statistical assessment of tropical cyclones in atmospheric general circulation models,” Tellus, 57A, pp.589–604, 2005.

[2] S. Braun, “Reevaluating the Role of the Saharan Air Layer in Atlantic Tropical Cyclogenesis and Evolution,” Mon. Wea. Rev., vol.138 (6), pp. 2007-2037 10.1175/2009MWR3135.1, 2010.

[3] B, Shen, W. Tao, W. Lau and R. Atlas, “Predicting tropical cyclogenesis with a global mesoscale model: Hierarchical multiscale interactions during the formation of tropical cyclone Nargis (2008),” J. Geophys. Res., 115, D14102, doi 10.1029/2009JD01340, 2010.

[4] T, Matsuura, M. Yumoto and S. Iizuka, “A mechanism of interdecadal variability of tropical cyclone activity over the western North Pacific,” Clim. Dyn., vol. 21, pp.105–117, 2003.

[5] F. Vitart, “Seasonal forecasting of tropical storm frequency using a multi-model ensemble,” Q. J. R. Meteorol. Soc.,vol. 132, pp.647–666, 2006.

[6] J.L. Beven, “The bogus cane-A serious problem with the NCEP medium range forecast model in tropics. Preprints, 23d Conf. on. Hurricanes and Tropical Meteorology, Dallas, TX, Amer. Meteor. Soc., 845-848, 1999.

[7] E. Palmen, "On the formation and structure of tropical cyclones, Geophysics, 3, 26–38, 1948.

[8] R.J. Riehl, “On the formation of typhoons”. J.Meteor. 5, 247-264, 1948.

[9] W.M.Gray. “Global view of the origin of tropical disturbances and storms. Mon.wea. rev., 96, 669-700, 1968.

[10] J.L. McBride and R. Zehr, “Observational analysis of tropical cyclone formation. Part II: Comparison of non-developing versus developing systems. J. Atmos. Sci., 38, 1132-1151, 1981.

[11] W.M. Gray, “Hurricanes: Their formation, structure and likely role in the tropical circulation. Meteorology Over Tropical Oceans”. D. B. Shaw (Ed.), Roy. Meteor. Soc., James Glaisher House, Granville Place, Bracknell, Berkshire, RG12 1BX, 155-218, 1979.

[12] C.C. Hennon and J.S. Hobgood. “Forecasting tropical cyclogenesis over the Atlantic basin using large-scale data. Mon. Wea. Rev., 131, 2997-2940, 2003.

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 3, Issue 3, September 2013

[13] C. Rocken et al., “Analysis and validation of GPS/MET data in the neutral atmosphere,” J. Geophys Res., vol. 102, pp. 29849-29866, 1997.

[14] R.A. Anthes et al., “The COSMIC/FORMOSAT-3 mission early results,” Bull. Amer. Meteor., Soc., vol. 89, pp.313-333, 2008.

[15] B.-R.Wang et al., “Assessment of COSMIC radio occultation retrieval product using global radiosonde data,” Atmos. Meas. Tech. Discuss., 5, 8405–8434, 2012.

[16] C.Y. Haumg et al., Impact of GPS radio occultation data assimilation on regional weather prediction”. GPS Solut, 14:35–49, DOI 10.1007/s10291-009-0144-1, 2010.

[17] H.Liu, J. L. Anderson, and Y.-H. Kuo, “Improved analyses and forecast of Hurricane Ernesto genesis using radio occultation data in an ensemble filter assimilation system”, Mon. Wea. Rev., American Met. Soc. 140: 151-166, 2012.

[18] N. Sharma, D. Jagadheesha, P. C. Joshi and P. K. Pal, “Atmospheric Stability Estimation Using Radio Occultation Data Over India and Surrounding Regions,” IJRSP., vol. 38(6), pp.317-325, 2009.

[19] N. Sharma and M.M. Ali (2013). “A Neural Network Approach to Improve the Vertical Resolution of Atmospheric Temperature Profiles from Geostationary Satellites”, IEEE Geosciences and Remote Sensing Letters, Vol. 10, pp 34-37, DOI No. 10.1109/LGRS.2012.2191763.

AUTHOR BIOGRAPHY

First Author Dr. Neerja Sharma is a PhD in Ionosphere with research experience in atmospheric sciences using remote sensing observations.

Second Author Dr. M. M. Ali is a PhD in Meteorology with research experience in ocean-atmosphere interaction.