7. TROPICAL CYCLONE SUPPORT SUMMARY

7.1 TROPICAL CYCLONE FORECASTER'S REFERENCE GUIDE

C.R. Sampson and J.-H. Chu
Naval Research Laboratory, Marine Meteorology Division, Monterey, CA

The Tropical Cyclone Forecasters Reference Guide consists of seven chapters. Chapters 1,2,3 and 5 have been published as four Naval Research Laboratory Publications since 1992. The remaining chapters, entitled tropical cyclone motion, intensity and structure, will be published in 1995.

There will also be a CD-ROM version of the guide. The paper version of the guide will be revised and put in an electronic format for browsing.

7.2 AUTOMATED TROPICAL CYCLONE FORECASTING SYSTEM (ATCF) 3.0

T.L. Tsui, A.J. Scrader and C.R. Sampson
Naval Research Laboratory, Marine Meteorology Division, Monterey, CA

The ATCF has been used operationally at JTWC since 1988. The current system runs on an IBM-DOS operating system. NRL, Monterey is adapting the ATCF to the UNIX operating system. The new system will become a part of the Tactical Environmental Support System (TESS) and is expected at JTWC in June of 1996.

7.3 PROTOTYPE AUTOMATED TROPICAL CYCLONE HANDBOOK (PATCH)

C.R. Sampson and R.A. Jeffries
Naval Research Laboratory, Marine Meteorology Division, Monterey, CA

PATCH is an expert system designed to provide tropical cyclone forecast and training guidance for the western North Pacific Ocean to JTWC. The scope of the project has expanded to include expertise pertaining to tropical cyclone formation, motion, intensification and dissipation, and structure and structure change. The expert system is an integral part of the ATCF upgrade. Initially PATCH will be in a basic stand-alone mode. Ultimately, it will be interactive with the ATCF.

7.4 NEW TROPICAL CYCLONE RELATED WIND DATA SETS

Jeff Hawkins and Chris Velden
Naval Research Laboratory, Marine Meteorology Division, Monterey, CA

Earth Remote-Sensing Satellite (ERS)-1 scatterometer data during the 1994 season proved valuable, although untimely (delayed 8-24 hours) . The 500 km swath highlighted the feast or famine nature of this narrow swath sensor. Excellent depiction of tropical cyclone circulation is possible when TC overflights occur and are especially relevant to TC wind radii warnings and thus TC numerical model bogus vortexes. ERS-2 (just launched) and more importantly the NASA Scatterometer (NSCAT) sensor (1200 km swath) on (Japanese) Advanced Earth Observing Satellite (ADEOS) (1996) will dramatically increase the coverage of this surface wind vector data set (note: scatterometer winds are typically valid up to a limit of 20-25 m/sec) .

Water vapor tracked winds from consecutive geostationary water vapor channel images are now under development by the University of Wisconsin (Velden) to supply upper-level winds. The advantages are 1) clouds need not be present and 2) Winds are produced from 200-

400 mb and thus fill a substantial data void. Accurate upper-level winds are sorely needed both by NOGAPS and by analysts trying to ascertain the synoptic pattern and it's impact of track motion and intensity.

GMS-5 completes a near global coverage of water vapor imagery when combined with the existing data sets from GOES-7/8 and METEOSAT. TC applications for real time will be coming online with automated tracking algorithms within the next 9-12 months.

7.5 SATELLITE IMAGERY ANALYSIS UPGRADES

Jeff Hawkins and Chris Velden
Naval Research Laboratory, Marine
Meteorology Division, Monterey, CA

Current Dvorak method results indicate distinct problems when applied to tropical cyclones (TC) falling within certain categories. Midget TC's forming within monsoon gyres, landfalling TC's and those that rapidly change intensity are difficult to adequately handle using the present rules. These intensity problems can be attributed to the fact these cases were not adequately covered in the original data set used to develop the method, difficulty in applying the method consistently and the generic limitations inherent in using visible and/or infrared digital data.

This effort will focus on studying a large sample of digital GMS visible/infrared images that will specifically include numerous examples from the problem cases noted above. Operational centers are being surveyed to list TC's which caused problems using the Dvorak technique. Particular attention will be placed on those storms that contain any validation data (aircraft, island, buoys, etc) that will assist in our evaluating the impact of any upgrades. This task will attempt to identify specific deficiencies in the current methods and test proposed modifications and/or new techniques aimed at improving the results and automating them to the extent possible.

A parallel effort will be designed to analyze whether SSM/I brightness temperature images can be evaluated by themselves or in tandem with visible/infrared imagery. Eighty-five GHz imagery depicts the rainband features of TCs extremely well and often include detail not evident in visible/infrared data. A cursory analysis indicates promise for this task, but this effort will need to examine hundreds of available SSM/I images.

7.6 SATELLITE MULTI-SENSOR STRUCTURE AND INTENSITY APPLICATIONS

Jeff Hawkins, Kim Richardson, Joe Turk,
Doug May, Nita Chase, Glenn Sandlin,
Gene Poe and Chris Velden
Naval Research Laboratory, Marine
Meteorology Division, Monterey, CA

No single satellite channel or sensor is capable of measuring all the features and parameters required by operational centers to accurately locate and specify the structure and intensity of tropical cyclones (TC). Thus, a multispectral multi-sensor combination that takes advantage of the inherent benefits of each can likely lead to improved satellite analysis results. This study will include digital data from imagery (visible, infrared and passive microwave), sounders (SSM/T1 & SSM/T2 and the MSU) and scatterometer sensors.

The SSM/I will be the initial focus of this study since it measures parameters ideally suited in depicting the TC and its surrounding environment (e.g., surface wind speed, rainrate, total precipitable water and cloud liquid water). Earlier efforts have shown that individual brightness temperatures (Tbs) and derived parameters are correlated with TC intensity and can help in TC positioning.

Our initial results reveal that remapping SSM/I data to the OLS infrared resolutions can be successfully done using the method of Poe (1990). Direct comparisons with OLS data not only show a one-to-one correlation with rain-band features, but also indicate detail not available in either infrared or visible data. In addition, we have found that multi-channel combinations of SSM/I channels using normalized differences highlights features and brings out more storm structure. Information on rain structure, maturity, and phase (ice, liquid) can be extracted and potentially help in understanding current intensity.

Initial work on intensity correlation has been positive, but additional cases involving a wider variety of TC types and environmental conditions are required before definitive accuracies can be determined. Thus, a data base with hundreds of SSM/I TC cases is being created with coincident OLS infrared data. In addition to regression type correlations, a neural network approach is being applied to the SSM/I data sets. All SSM/I Tbs will be put into a training data set and then applied to an independent data set for accuracy analysis. This automated approach could augment and/or provide increased confidence in Dvorak-type estimates.

Microwave sounder data has proven reliable by Velden (1991) in depicting upper-level warm anomalies that are highly correlated with storm intensity. We are working on methods to incorporate this automated technique operationally so that the TDO has this additional tool in real time. The multi-sensor task will also review how to bring this important piece of upper-level atmospheric information into the broader picture of a unified intensity estimate.

7.7 DEVELOPMENT OF THE SYSTEMATIC APPROACH TO TROPICAL CYCLONE TRACK FORECASTING

L.E. Carr, III and R.L. Elsberry
Naval Postgraduate School
Monterey, California

A Systematic and Integrated Approach to Tropical Cyclone Track Forecasting (hereafter the Systematic Approach) is being developed that helps forecasters to more insightfully and consistently: (i) interpret the TC motion ramifications of evolving global model fields; and (ii) anticipate errors in the tropical cyclone (TC) forecast tracks provided by the global model and by other objective track forecast aids that depend on the numerical model. The Systematic Approach is based on the premise that under certain circumstances forecasters can formulate TC track forecasts that improve upon numerical model and objective aid forecasts, if the forecasters are equipped with two key knowledge bases. The first knowledge base is a set of TC-Environmental conceptual models that may be used to associate a wide variety of TC motion patterns with a relatively few recurring combinations of TC structure, environment structure, and interactions between the TC and its environment. The second knowledge base is a set of TC track forecast traits for the numerical model and associated objective aids that is organized around the meteorological knowledge base. Development of the overall framework of the Systematic Approach and the TC-Environment conceptual models knowledge base has been completed (Carr and Elsberry 1994).

The TC-Environment knowledge base enabled the forecaster to develop a comprehensive mental picture of the TC-Environmental situation. This picture consists of conceptual models of Environment structure, TC structure, and TC-Environment transformations by which the structure of the environment and/or the TC may be changed as they interact. The structure of the environment surrounding the TC is assigned to one of four Synoptic Patterns, which are comprised of one or more smaller areas called Synoptic Regions. A Pattern and Region specification together characterizes the contribution of environmental steering to TC motion.

The wind field structure of the TC is characterized in terms of an Intensity and a Size. The Intensity categories (Exposed Low-level, Tropical Depression/Storm, Typhoon, Intense Typhoon) serve primarily to determine the best steering level at which to make the Pattern and Region characterization of environment structure. The Size categories (Midget, Small, Average, and Large) are assigned according to the maximum B-effect propagation (BEP) speed that would be exhibited by an equivalent size vortex in a nonlinear barotropic model integration. To facilitate such a determination of BEP speed, a TC tangential wind distribution model based on angular momentum conservation is developed, and techniques for adjusting parameters of this model to be consistent with the wind distribution of the actual TC are provided.

A key aspect of the TC-Environment conceptual model knowledge base is that various combinations of Environment structure and TC structure may initiate certain TC-Environment transformations, which include:

- Beta Effect Propagation (BEP);
- Vertical Wind Shear (VWS);
- Ridge Modification by Large TC (RMT);
- Monsoon Gyre-TC Interaction (MTI); and
- Multiple Tropical Cyclone Interactions (TCIs).

The TCIs transformation model represents a significant departure from the conventional practice of attributing most centroid-relative rotations between two TCs as arising from the Fujiwhara effect, i.e., the mutual advection by the cyclonic circulations of the two TCs. Rather, a set of six distinct modes of binary TC interactions, which include both direct and indirect influences, are defined and illustrated via case studies (Carr and Elsberry 1994).

The result of the TC-Environment transformations is to cause various motion-affecting alterations to the Environment Structure and/or TC Structure combination that initiated the transformation. The impact on TC Structure is a rather straightforward change in Intensity (which affects steering level) and Size. In terms of the effect on Environmental Structure, the transformations function as "traditional mechanisms" that cause the environment of the TC to transition either from one Synoptic Region to another within a persistent Synoptic Pattern, or from one Pattern/Region combination to another. It is this second type of transition that usually results in late changes in TC track that may not be well forecast by numerical models or other objective track forecast techniques.

7.8 DEVELOPMENT OF A HIGH CONFIDENCE TROPICAL CYCLONE INTENSITY DATA BASE

C. P. Guard and M. A. Lander
University of Guam
Mangilao, Guam

A close investigation of the tropical cyclone intensity data bases of JTWC reveals that the quality of the data bases may not be sufficient for tropical cyclone intensity studies and validation. A "high confidence" intensity data base is being developed that reevaluates the raw data, makes changes to the intensity data base where warranted, then places a confidence level on the intensity depending on the quality of the raw data on which the near-surface intensity was based. Weighting values are developed for the confidence levels. An important input to the reevaluation is the maximum intensity from land falling tropical cyclones. These data are not routinely available to warning centers outside the country of occurrence. In conjunction with this initiative is a proposal to the WMO for the sharing of landfall data among tropical cyclone warning centers and a proposal to include the peak gust and its time of occurrence into the synoptic code.

7.9 AN INVESTIGATION OF THE RELATIONSHIPS BETWEEN CYCLONIC CELLS IN THE TUTT AND THE INTENSITY CHANGE OF TROPICAL CYCLONES.

C. P. Guard
University of Guam
Mangilao, Guam

Tropical cyclone intensity change is correlated with the relative proximity of the TUTT and cyclonic cells within it. Synoptic models are developed that indicate the most favorable patterns for tropical cyclone intensification, rapid intensification, and explosive deepening. Favorable locations, movements, and separation distances are identified. Thumb rules for forecasters are developed from the synoptic models, and the synoptic models will also be shared with modelers to try to better understand the dynamics that occur during the identified relationships between the tropical cyclone and the TUTT.

7.10 THE NATURAL VARIATION IN THE RELATIONSHIP BETWEEN MAXIMUM WIND AND MINIMUM CENTRAL PRESSURE IN TROPICAL CYCLONES.

M. A. Lander and C. P. Guard
University of Guam
Mangilao, Guam

A three-year investigation of the relationships between maximum wind and minimum central pressure in tropical cyclones is culminating in the development of a set of universal wind-pressure relationships that are basin independent. The study reveals the physical parameters that contribute to the relationship, and weights the importance of the various parameters. The radius of maximum winds (RMW) (basically eye size) and the rate of "fall-off" of the winds between the RMW and the outside of the circulation (basically storm size) are found to be the most important. The natural variability between observed maximum wind speed and minimum central pressure is explained in terms of the identified parameters.

7.11 A STUDY OF THE CHARACTERISTICS OF VERY SMALL (MIDGET) TROPICAL CYCLONES.

C. P. Guard and M. A. Lander
University of Guam
Mangilao, Guam

A special case of the study of the relationship between maximum wind and minimum central pressure in tropical cyclones addresses the very small or "midget" tropical cyclone in which the central pressure is frequently observed to be 20 hPa higher for a specific maximum wind than it is in larger tropical cyclones. The study identifies the unique characteristics of these cyclones and presents some proposed mechanisms for their development and rapid intensification at minimal tropical storm intensity. A basin-independent wind-pressure relationship is derived for midget tropical cyclones.

7.12 A SAFFIR-SIMPSON-LIKE HURRICANE SCALE FOR THE TROPICAL WESTERN PACIFIC.

C. P. Guard and M. A. Lander
University of Guam
Mangilao, Guam

The Saffir-Simpson Hurricane Scale (Simpson 1974) has been adapted for use in the tropical western Pacific. After five years of modification and testing, the scale has been fine-tuned and implemented for use in the western North Pacific. The Scale incorporates the basic Saffir-Simpson Scale, but modifies it for tropical building materials, building practices, considers the detrimental effects of termites, wood rot, and sea salt spray, integrates the damage to tropical vegetation and agricultural products, and factors in the affects of coral reefs on storm surge and inundation. The Scale should be applicable in the global tropics.

7.13 NOGAPS TROPICAL CYCLONE FORECAST PERFORMANCE

J.S. Goerss
Naval Research Laboratory
Monterey, California

The tropical cyclone forecast performance of the NOGAPS T159 global spectral model in the North Pacific for July-September 1994 was examined and compared with that for the NOGAPS T79 forecast model. The impact of the assimilation of synthetic tropical cyclone observations upon the NOGAPS T79 analyses and forecasts for the North Pacific was determined along with the impact of incorporating storm motion information into the synthetic observations. The results of this research were presented at the 1995 U.S. PACOM Tropical Cyclone Conference and appear in the conference proceeding report. A paper on the impact of the assimilation of the synthetic observations was presented at the 21st Conference on Hurricanes and Tropical Meteorology. The incorporation of storm motion information into the synthetic tropical cyclone observations was made operational at FNMOC in March 1995.

BIBLIOGRAPHY

Atkinson, G. D. and C. R. Holliday, 1977: Tropical cyclone minimum sea-level pressure and maximum sustained wind relationship for the western North Pacific. *Mon.Wea. Rev.*, **105**, pp 421-427 (also Fleet Weather Central/JTWC Technical Note 75-1).

Brand, S., 1970: Interaction of binary tropical cyclones in the western North Pacific Ocean. *J. Appl. Meteor.*, **9**, pp 433-441.

Brand, S., 1972: Very Large and Very Small Typhoons of the Western North Pacific Ocean. *J. Meteor. Soc. Japan*, **50**, pp 332-341.

Carr, L.E., and R.L. Elsberry, 1994: Monsoonal interactions leading to sudden tropical cyclone track changes. *Mon. Wea. Rev.*, **123**, pp 265-289.

Carr, L.E., and R.L. Elsberry, 1994: Systematic and integrated approach to tropical cyclone track forecasting, Part I: description of basic approach. Naval Postgraduate School publication NPS-MR-002. Naval Postgraduate School, Monterey, CA 93943. 65 pp. plus figs. and append.

Climate Analysis Center, 1994: Climate Diagnostics Bulletin. Dept of Commerce, Washington, D.C. month by bulletins.

Diercks, J. M., R. C. Weir and M. K. Kopper, 1982: Forecast Verification and Reconnaissance Data for Southern Hemisphere Tropical Cyclones (July 1980 through June 1982). NOCC/JTWC Technical Note 82-1, 77 pp.

Dong, K. and C. J. Neumann, 1983: On the relative motion of binary tropical cyclones. *Mon. Wea. Rev.*, **111**, pp 945-953.

Dunnavan, G. M., 1981: Forecasting Intense Tropical Cyclones Using 700 mb Equivalent Potential Temperature and Central Sea-Level Pressure. NOCC/JTWC Technical Note 81-1, 12 pp.

Dvorak, V. F., 1975: TC Intensity Analysis and Forecasting from Satellite Imagery. *Mon. Wea. Rev.*, **103**, pp 420-430.

Dvorak, V. F., 1984: Tropical Cyclone Intensity Analysis Using Satellite Data. NOAA Technical Report NESDIS 11, 46 pp.

Fujiwhara, S., 1921: The natural tendency towards symmetry, etc. *Quart. J. Roy. Meteor. Soc.*, **47**, pp 287-293.

Fujiwhara, S., 1923: On the growth and decay of vortical systems. **Quart. J. Roy. Meteor. Soc., 49**, pp 75-104.

Fujiwhara, S., 1931: Short note on the behavior of two vortices. *Proc. Phys. Math. Soc. Japan*, Ser. 3, 13, pp 106-110.

Glass, M., and G.W. Felde, 1990: Tropical storm structure analysis using SSM/I and OLS data. 5th Intl. Conf. on Interactive and Info. Processing Systems for Meteor., Oceanogr. and Hydrol., Aneheim, CA, Amer. Meteor. Soc., 432-437.

Gray, W.M., 1968: Global view of the origin of tropical disturbances and storms. *Mon. Wea. Rev.*, **96**, pp 669-700.

Guard, C.P., 1983: A Study of Western North Pacific Tropical Storms and Typhoons that Intensify after Recurvature. First Weather Wing Technical Note-83/002, 28 pp.

Harr, P.A., and R.L. Elsberry, 1991: Tropical cyclone track characteristics as a function of large-scale circulation anomalies. *Mon. Wea. Rev.*, **119**, pp 1448-1468.

Harr, P.A., and R.L. Elsberry, 1995: Large-scale circulation variability over the tropical western North Pacific. Part I: Spatial patterns and tropical cyclone characteristics. *Mon. Wea. Rev.*, **123**, pp 1225-1246.

Hebert, P. H. and K. O. Poteat, 1975: A Satellite Classification Technique for Subtropical Cyclones. NOAA Technical Memorandum NWS SR-83, 25 pp.

Holland, G. J., 1980: An analytical model of wind and pressure profiles in hurricanes. *Mon.Wea. Rev.*, **108**, pp 1212-1218.

Holland, G.J., 1987: [Tropical cyclone] mature structure and structure change. A Global View of Tropical Cyclones. R.L. Elsberry, Ed. (Limited edition publication sponsored by the U.S. Navy, Office of Naval Research.)

Holliday, C. R. and A. H. Thompson, 1979: Climatological characteristics of rapidly intensifying typhoons. *Mon.Wea. Rev.*, **107**, pp 1022-1034.

Japan Meteorological Agency, 1976: Manual for Typhoons. (English Version), Japan Meteorological Agency, 1-3-4 Ote-machi, Chiyoda-ku, Tokyo, 277 pp.

Keen, R.A. 1982: The role of cross-equatorial tropical cyclone pairs in the Southern Oscillation. *Mon.Wea. Rev.*, **110**, pp 1405-1416.

Kepert, J.D., 1993: Research rapporteur report on oceanography and air-sea interaction. Annex to Topic Rapporteur Reports of the Third WMO/ICSU International Workshop on Tropical Cyclones (JTWC-III), Huatulco, Santa Cruz, Mexico, 22 November -1 December 1993. WMO/TD No. 573. Secretariat of the WMO, Geneva, Switzerland.

Kurihara, Y., 1992: Surface conditions in tropical cyclone models. In Modeling Severe Weather: Papers presented at the Fourth BMRC Modeling Workshop.Bureau of Meteorology Research Centre, Melbourne, Australia.

Lander, M. A., 1990: Evolution of the cloud pattern during the formation of tropical cyclone twins symmetrical with respect to the equator. *Mon. Wea. Rev.*, **118**, pp 1194-1202.

Lander, M.A., and G.J. Holland, 1993: On the interaction of tropical-cyclone scale vortices. I: Observations. *Quart. J. Roy. Meteor. Soc.*, **119**, pp 1347 - 1361.

Lander, M.A., 1994a: Description of a monsoon gyre and its effects on the tropical cyclones in the western North Pacific during August 1991. *Weather and Forecasting*, **9**, pp 640-654.

Lander, M.A., 1994b: An exploration of the relationships between tropical storm formation in the Western North Pacific and ENSO, *Mon. Wea. Rev.*, **122**, pp 636-651.

Lander, M.A., 1995a: Specific tropical cyclone track types and unusual tropical cyclone motions associated with a reverse-oriented monsoon trough in the western North Pacific. (Submitted to Weather and Forecasting.)

Lander, M.A., 1995b: The merger of two tropical cyclones. *Mon. Wea. Rev.*, (July issue).

Luther, D.S., D.E. Harrison and R.A. Knox, 1983: Zonal winds in the Central Equatorial Pacific and El Nino. *Science*, **222**, pp 327-330.

Matsumoto, C. R., 1984: A statistical method for one- to three-day tropical cyclone track prediction. Colorado State University Department of Atmospheric Science, Paper 379, 201 pp.

Merrill, R.T., 1984: A comparison of large and small tropical cyclones. *Mon. Wea. Rev.*, **112**, pp 1408-1418.

Mundell, D.B., 1990: Prediction of Tropical Cyclone Rapid Intensification Events. Thesis for fulfillment of Master's degree submitted to Colorado State University, 186 pp.

OFCM, 1993: National Hurricane Operations Plan, U.S. Dept. of Commerce, Washington, D.C., p E-1.

Price, J.F., 1981: Upper ocean response to a hurricane. *J. Phys. Oceanogr.*, **11**, 153-175.

Ramage, C.S., 1986: El Nino. *Scientific American*, June Issue, pp 77-84

Sadler, J.C., 1967: The tropical upper tropospheric trough as a secondary source of typhoons and a primary source of trade wind disturbances. Final Report, contract No. AF 19(628)-3860, HIG Report 67-12, Hawaii Institute of Geophysics, University of Hawaii, Honolulu, HI, 44 pp.

Sadler, J.C., 1976: A role of the tropical upper tropospheric trough in early season typhoon development. *Mon. Wea. Rev.*, 104, pp 1266-1278.

Sadler, J.C., M.A. Lander, A.M. Hori, and L.K. Oda, 1987: Tropical marine climatic Atlas, Vol II, Pacific Ocean. UHMET 87-02, University of Hawaii, Department of Meteorology, 14 pp.

Sandgathe, S. A., 1987: Opportunities for tropical cyclone motion research in the Northwest Pacific region. Technical Report NPS 63-87-006, Naval Postgraduate School, Monterey, CA 93943, 36 pp.

Shoemaker, D.N., 1991: Characteristics of Tropical Cyclones Affecting the Philippine Islands. NOCC/JTWC Technical Note 91-01, 35 pp.

Simpson, R.H., 1974: The hurricane disaster potential scale. *Weatherwise*, 27, pp 169-186.

Weatherford, C.L. and W.M. Gray, 1985: Typhoon Structural Variability. Colorado State University Department of Atmospheric Science, Paper No. 391, 77 pp.

Weir, R. C., 1982: Predicting the Acceleration of Northward-moving Tropical Cyclones using Upper-Tropospheric Winds. NOCC/JTWC Technical Note 82-2, 40 pp.

Willoughby, H.E., J.A. Clos, and M.G., 1982: Concentric eye walls, secondary wind maxima, and the evolution of teh hurricane vortex. *J. Atmos. Sci.*, **39**, pp 395-411.

Willoughby, H.E., 1990: Temporal changes in the primary circulation in tropical cyclones. *J. Atmos. Sci.*, **47**, pp 242-264.

Wirfel, W. P. and S. A. Sandgathe, 1986: Forecast Verification and Reconnaissance Data for Southern Hemisphere Tropical Cyclones (July 1982 through June 1984). NOCC/JTWC Technical Note 86-1, 102 pp.

Xu, Y. and C. J. Neumann, 1985: A Statistical Model for the Prediction of Western North Pacific Tropical Cyclone Motion. NOAA Technical Memorandum NWS NHC 28, 30 pp.