SYSTEMATIC APPROACH TO TROPICAL CYCLONE TRACK FORECASTING

Lester E. Carr III
Department of Meteorology, MR/Cr
Naval Postgraduate School
589 Dyer Rd., Room 254
Monterey, CA 93943-5114
E-mail: carrle@nps.navy.mil
Telephone: (408) 656-2374
FAX: (408) 656-3061

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LONG-TERM GOALS:

The long-term goals of this project, which is being pursued in collaboration with R. L. Elsberry and M. A. Boothe, are to improve not only the quantitative accuracy of official tropical cyclone (TC) track forecasts, but also the qualitative meteorological utility of those forecasts. Needed improve- ments in the accuracy of official TC track forecasts include: (i) reducing the severity and frequency of major track forecast "busts" for which the track forecast error at a particular time exceeds seasonal averages by a factor of two or more; (ii) widening the margin by which on average the official TC track forecast improves upon available numerical and other objective TC track forecast guidance; and (iii) better temporal consistency (i.e., watch-to-watch) of official TC track forecasts.

Meteorological utility refers to the interpretative usefulness imparted (value added) to the official forecast track by the TC forecaster's formulation and articulation in narrative form of the meteorological reasoning behind the forecast, and should include a situation-specific assessment of the likely uncertainty in the forecast, and the range/probability of alternate scenarios that may be realized. Such reasoning often critically influences recommendations and decisions made by meteorologists and authorities responsible for TC-threatened areas. The long-term goal in this regard is to equip TC forecasters with the conceptual tools necessary to impart a high degree of meteorological utility to each forecast within the constraints of the current state of the science.

OBJECTIVES:

The specific objectives of this project are to conduct basic research to:

(i) develop a process by which TC forecaster can make an effective real-time application of availa- ble and emerging knowledge about TC motion, both in reality and in numerical TC forecast models, to formulate a comprehensive, dynamically-based picture of any particular TC forecast situation;
(ii) investigate the performance of numerical TC track forecast models and other forms of objective track forecast guidance in recurring meteorological situations to identify systematic traits that can be exploited by the forecaster when formulating the official TC track forecast; and
(iii) identify deficiencies in basic understanding of TC motion and numerical prediction of TC motion that are of practical importance to the TC forecaster, and communicate those deficiencies back to research community for subsequent study.

APPROACH:

(i) Develop an organized meteorological knowledge base that consists of a set of TC-environment conceptual models by which a forecaster may form a comprehensive meteorological picture of the influences contributing to the past/predicted motion of the TC. Key components of this picture are: (1) the motion-relevant structure of the TC; (2) recurring patterns of environment structure that

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produce characteristic directions of the environmental steering flow that is usually the primary impetus for TC motion; and (3) a set of mechanisms by which the environment structure, and thus the associated steering flow, is induced to change or "transition." Included in the transitional mechanisms are a number of modes of interaction between the TC circulation and the environment that are termed TC-environment transformations, and thus depend on the presence and structure of the TC being forecast. Herein lies the integrated aspect of the systematic approach, whereby the impact of TC structure on TC motion (and vice versa) is accounted for.

(ii) Evaluate and improve the effectiveness of the meteorological knowledge base for explaining TC motion by: (1) maintaining an up-to-date climatological database of classifications of TC structure, environment structure, transitions in environment structure to account for the observed motion of all TCs in a basin, making special note of those cases for which the knowledge base may be providing an unsatisfactory or marginal explanation; and (2) periodically obtaining feedback from forecasters on the effectiveness of the meteorological knowledge base.

(iii) Develop a knowledge base of the traits of numerical and other objective TC track forecast models available to the TC forecaster. The approach to this development will be guided by the frequency of occurrence of various TC-environment scenarios identified during the development of the meteorological database, and will proceed from the more common situations to the less common. Where database size and predictability considerations permit, traits will be characterized using standard statistical tools and measures. In other situations, only qualitative, but dynamically- based, guidelines or "rules of thumb" will be developed.

(iv) Evaluate the effectiveness of the numerical model and objective aid traits knowledge base. As with approach step (ii) above, initially introduce the model traits knowledge base to TC forecasters for testing, obtain feedback, and refine the knowledge base as appropriate.

(v) Develop a logical and methodical procedural framework, that is, "a systematic approach," that enables the forecaster to employ effectively the knowledge bases outlined in (i) and (iii) above to formulate an official TC track forecast that: (1) ensures a consistent and thorough application of available knowledge; (2) accounts for expected situation-dependent biases or failures in the track forecast guidance provided by numerical models or other objective guidance; and (3) includes a situation-dependent assessment of the uncertainty of the track forecast.

(vi) Focus this development process initially in the western North Pacific where there is high Department of Defense (DoD) interest and the Joint Typhoon Warning Center (JTWC) produces TC warnings. Extend the development to other basins as appropriate based on the status of development progress in the western North Pacific and level of DoD interest.

WORK COMPLETED:

With regard to approach element (i), synthesis of available basic understanding (based on primarily barotropic dynamics at present) of TC motion into a comprehensive meteorological knowledge base that provides credible physically-based explanations for essentially all observed patterns of TC motion in the western North Pacific has been completed. The set of conceptual models that comprise the knowledge base incorporate the accomplishment of many research groups over the last several decades. Carr and Elsberry (1997a) and Carr et al. (1997a) document original research results from the members of this project that form the basis for several of the conceptual models in the knowledge base.

The development of the meteorological knowledge base has been periodically documented via technical reports and journal articles that appropriately provide detailed justifications and explanations of the knowledge base components and include copious citations and summarizations of the work of others on which the knowledge base has been built. However, documentation in this form is not conducive to real-time utilization by the operational forecaster. Furthermore, some of the conceptual models and terminology developed in earlier publications have been superseded or modified by later publications as the meteorological knowledge base has been developed and refined. To address these concerns, a condensed and updated version of the knowledge base has been developed (Carr et al. 1997c), and was made available in draft technical report form to JTWC forecasters in July for evaluation during 1997 western North Pacific typhoon season, and subsequent feedback. The report methodically presents the components of the knowledge base using a text/graphics layout designed to help the forecaster rapidly find and assimilation desired information. A "soft" version of the essentially the same text/graphics format will be the foundation of the HELP function of the expert system (summarized elsewhere in this report) that is being designed to enable full operational implementation of the systematic approach concept.

Pursuant to project approach element (ii) above, the western North Pacific climatological database of environment structure classifications (i.e., pattern, region, and transitional mechanisms), based on evaluation of Navy Operational Global Atmospheric Prediction System (NOGAPS) analyses, the JTWC final best track of each TC, and satellite imagery, has been extended to eight years with the addition of the TCs forming in 1996. In addition, the accuracy of the knowledge base with regard to occurrence of various mode of TC interaction (TCI) was evaluated using the objective TCI detection criteria developed by Carr and Elsberry (1997b). These criteria are based on an extensive analysis of the actual motion, relative rotation, and direction of orientation of TC pairs, and thus are not susceptible to analysis errors in NOGAPS.

As a result of this evaluation, the database records for a small number of TCs were modified to the reflect concurrence by the systematic approach developers that periods of TCI had been missed during the original classification process. Most of these cases involved weak TCs that were not well-analyzed by NOGAPS, and the indirect TC interaction (ITI) phenomenon that: (i) occurs at larger separation distances (up to 30^{o} lat. of separation): (ii) exhibits slower, and thus more subtle, rotation rates; and (iii) involves an intervening anticyclone that depends on a proper representation of the western TC. Thus, this basic research project has resulted in an objective criteria that has improved the existing climatological database, but also promises to be useful tool to assist forecasters in detecting periods of ITI during operational forecasting.

Pursuant to project approach elements (iii and (iv) above, the larger eight-year climatological database has permitted a more detailed and comprehensive analysis of situation-specific track forecast traits of NOGAPS, as well as the various objective techniques employed by JTWC. A brief summary of some of these results appears in Carr et al. (1997b), and more complete trait compilation has been provided to the forecasters at JTWC for evaluation and feedback. The compilation includes NOGAPS and objective technique traits for: (i) a number of persistent environment structures: (ii) frequently occurring environment structure transitions associated with significant westward-to-poleward and poleward-to-westward TC tracks changes; and (iii) individual case studies that identify different modes of false or erroneous TC-vortex interaction that occasionally occur in NOGAPS and other numerical models that depend on proper representation of the TC and nearby vortices.

Pursuant to project approach element (v) above, significant progress has been in transforming the systematic approach concept into a detailed step-by-step procedural framework. Because the procedural framework finds immediate application in an expert system based on the systematic approach concept, the details of the procedural framework development are included in the summary of the prototype expert system project summarized elsewhere in this report.

TRANSITIONS:

Transition of the major results of this project (meteorological knowledge base, model traits knowledge base, systematic approach process) into a workstation-based expert system was in progress throughout FY97. A summary of progress on the development of the expert system is located elsewhere in this report.

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DEVELOPMENT OF AN EXPERT SYSTEM BASED ON THE SYSTEMATIC APPROACH TO TROPICAL CYCLONE TRACK FORECASTING