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Development Of An Expert System Based On The Systematic Approach To Tropical Cyclone Track Forecasting

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LONG-TERM GOALS

The long-term goals of this project are to improve the quantitative accuracy and interpretative utility of official tropical cyclone (TC) track forecasts by enabling forecasters to successfully recognize and skillfully compensate for periods when numerical TC track forecast models are likely to be making highly erroneous track forecasts. The conceptual methodology for accomplishing these goals is the Systematic Approach to Tropical Cyclone Track Forecasting (hereafter Systematic Approach) conceived by Carr and Elsberry (1994).

OBJECTIVES

The specific objectives of this project are to: (i) develop a prototype expert system based on the Systematic Approach; and (ii) demonstrate the feasibility of such an expert system for improving the accuracy and meteorological utility of official tropical cyclone track forecasts. It is emphasized that the purpose of the expert system is not to replace the human forecaster, but to proactively lead the forecaster through a methodical process of numerical guidance evaluation and forecast formulation that produces consistently skillful official track forecasts.

APPROACH

Figure 1 shows the procedural framework of the Systematic Approach, including the principal tasks that must be accomplished in each phase. The basic approach to create a Systematic Approach expert system is to develop a series of inter-linked software modules that assist the forecaster to accomplish each task. The formulation of an accurate TC forecast represents a highly complex information management problem that poses challenges with regard to timely *access*, effective *display*, and

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SYSTEMATIC APPROACH FRAMEWORK

Phase I: Numerical Guidance Evaluation
Phase IA: Classify Actual Meteorological Situation
Task 1: Classify TC Structure
Task 2: Classify Environment Structure/Transitions
Phase IB: Classify Model-depicted Meteorological Situation(s)
Task 1: Classify TC Structure
Task 2: Classify Environment Structure
Task 3: Assess Numerical Guidance Accuracy
Phase II: Objective Technique Evaluation
Task 1: Identify Track Guidance Groups
Task 2: Select Guidance Group for Official Forecast
Phase III: Official Track Forecast Formulation
Task 1: Construct Primary/Alternate Envelopes
Task 2: Construct Official Track Forecast
Task 3: Assign Confidence/Alternate Scenario

Figure 1. Listing of the three phases that comprise the Systematic Approach procedural framework, and the major tasks that must be accomplished in each phase.

informed *interpretation* of various information resources available to the forecaster. In developing the expert system modules, careful consideration is given to such things as: (i) identification of the key information (e.g., numerical fields, imagery, data, etc.); (ii) development of effective graphical user interfaces; and (iii) development and application of knowledge bases and algorithms to assist the forecaster to interpret correctly the displayed information, particularly with regard to successful assessment of the accuracy of the available numerical model forecasts of TC motion. Other considerations that affect how the expert system modules are developed include: (i) varying degrees of proactivity depending on the nature and difficulty of each task being accomplished; (ii) flexible design so that modules may be separately tested, revised, and re-tested; and (iii) a *HELP* function, in which a user can stop the decision process and review that aspect of the knowledge base relevant to accomplishing a particular task.

WORK COMPLETED

Development and documentation of an initial Model Traits knowledge base for the two numerical TC track forecast models (NOGAPS and GFDN) and the four NOGAPS-dependent objective techniques available to forecasters at the JTWC for the western North Pacific has been completed (Carr and Elsberry 1999).

Development of an expert system prototype that enables the forecaster to accomplish Phases I and II of the Systematic Approach concept (Fig. 1) was completed in July. The expert system prototype was installed and readied for real-time utilization and evaluation at both the Naval Postgraduate School (NPS) and the JTWC in August. For ease of reference, NPS and JTWC agreed to give the expert system prototype the name: Systematic Approach Forecasting Aid (SAFA).

A parallel real-time test of the SAFA prototype by an experimental forecast team at NPS and the JTWC forecasters (as permitted by operational workload) was conducted from 23 August to 30 September to evaluate the effectiveness of SAFA with regard to: (i) display of forecast track and field information needed to assess model accuracy; and (ii) formulation of selective consensus (SCON) track forecasts that are more accurate than a simple numerical consensus (NCON) of all available numerical model forecast tracks. Because of anomalous TC activity in the western North Pacific (i.e., disproportionate number of weak and/or short-lived systems), it was decided that the NPS component of the test would continue at least to the end of calendar year 1999 to provide a more statistically significant sample of SCON and NCON forecasts.

RESULTS

A summary of the error mechanism analysis results documented in Carr and Elsberry (1999) is shown in Table 1, and includes some significant changes compared to the preliminary result shown in last year's report. An important and encouraging result is that in 1997 only six error mechanisms account for 84% of the poor NOGAPS track forecasts (Table 1; red/bold entries in NOGAPS column) and only three error mechanisms account for 68% of the poor GFDN track forecasts (Table 1; red/bold entries in GFDN column). The practical benefits of these result are twofold. First, during the numerical model evaluation process (Fig. 1) the forecaster can justifiably direct the initial effort to identifying indications of a comparatively small number of frequently occurring error mechanisms, and only consider the less frequently occurring error mechanisms if no indications of the more frequent error

CAUSES OF NOGAPS OR GFDN 72-H FORECAST TRACK ERRORS GREATER THAN 300 N MI		NUMBER OF FORECASTS	
Phenomenon Name	Acronym	NOGAPS	GFDN
Direct Cyclone Interaction	**DCI**	**39-0**	**31-0**
Semi-direct Cyclone Interaction	SCI		
SCI on Western TC	SCIW	0-0	0-0
SCI on Eastern TC	SCIE	3-0	1-0
Indirect Cyclone Interaction	ICI		
ICI on Eastern TC	ICIE	0-0	3-0
ICI on Western TC	ICIW	0-0	0-1
Ridge Modification by TC	**RMT**	**12-0**	2-1
Reverse Trough Formation	**RTF**	**10-0**	2-0
Response to Vertical wind Shear	**RVS**	**10-0**	1-3
Baroclinic Cyclone Interaction	**BCI**	**8-12**	**11-2**
Midlatitude System Evolutions	MSE		
Midlatitude CycloGenesis	**MCG**	0-0	**19-0**
Midlatitude CycloLysis	MCL	0-0	0-0
Midlatitude AnticycloGenesis	MAG	3-0	0-0
Midlatitude AnticycloLysis	MAL	0-4	0-2
Tropical Cyclone Initialization Size	TCS	5-0	9-0
Not discernable or explainable		2	2
Fields not available		0	9
All causes		108	99

Table 1. Number of forecasts for which various meteorological phenomena were responsible for large (>300 n mi) 72-h forecast track errors (FTEs) in NOGAPS and GFDN in 1997. When two numbers are shown, the first (second) number indicates that phenomenon occurred in the model to an excessive (insufficient) degree. The rows that are in bold/red identify the comparatively frequent error mechanisms.

mechanisms can be found. Second, this research result will help model developers and researchers at FNMOC, NRL Monterey, and GFDL focus their efforts to improve the TC track forecasting accuracy of NOGAPS and GFDN. Another pivotal result shown in Table 1 is that, with the exception of Baroclinic Cyclone Interaction (BCI) that can occur to both an excessive and insufficient degree, all the other error mechanisms involve only excessive processes in NOGAPS and GFDN. The practical benefit of this result is that when such one-sided error mechanisms appear to be present in one or more numerical models, the models with tracks that appear to be least affected are likely to have the most accurate track forecasts.

The SAFA prototype completed during this year has all of the essential functions described under the Approach section above, including: (i) highly structured, but non-binding procedural guidance with selectable levels of detail; (ii) cluster-based objective assignment of most probable error mechanism options to focus the model evaluation process; (iii) an error mechanism HELP feature that includes track graphics and field animations that illustrate the key indications of the frequently occurring error mechanisms; (iv) a highly sophisticated model tracks and fields display and animation capability; (v) an interactive error mechanism assignment capability that instantly lets the forecaster see the impact of rejecting certain model tracks(s) on the SCON track; and (vi) an interactive Summary Sheet feature that records objective ensemble spread and cluster analysis data, objective and subjective error mechanism assignment, and forecaster comments to facilitate shift-to-shift information flow.

The objectives of the real-time parallel test of SAFA by NPS and JTWC included: (i) evaluating the effectiveness of the various information display components under operational time constraints; (ii) validating the error mechanism frequencies suggested by the previous research (Table 1); (iii) determining whether error mechanisms could be correctly identified without the benefit of hindsight; (iv) determining the circumstances under which SCON track forecasts may be produced that are significantly more accurate than a simple NCON track forecast. Because the parallel test occurred at the end of FY99, and the NPS component of the real-time test will continue to the end of calendar year 1999, conclusions concerning objectives (i)-(vi) above based on a thorough evaluation of the results of the SAFA test are not yet available. However, a number of tentative conclusions can be made at this time. With regard to objective (i) above, JTWC personnel were extremely impressed with the information display capabilities of the SAFA prototype (Deputy Director, JTWC, personal communication), made many valuable suggestions for further refining that aspect of SAFA, and expressed eagerness to have a version of SAFA that provides track and field display through their entire Area Of Responsibility as soon as possible. Despite the small sample of SAFA forecasts thus far, the NPS forecast team found that excessive direct cyclone interaction (E-DCI) was, as expected, the most frequent error mechanism, affecting one or more models for significant periods during four of the seven TCs since the start of the test. This result validates objective (ii) for E-DCI, and it is expected that similar results will be found for the other frequently occurring error mechanisms in Table 1 as the number of SAFA forecasts grows. In addition, NPS forecast team found that cases of E-DCI sufficient to cause a 72-h track forecast error exceeding 300 n mi were readily identifiable, thus providing a preliminary validation of objective (iii). Finally, as shown in Fig. 2, the NPS forecast team found that when only frequently occurring error mechanisms were occurring (E-DCI and E-RTF thus far during the test), it is possible to create SCON track forecasts that are much more accurate than NCON forecasts. However, in situations where infrequent error mechanisms were the primary source of model error, or compensating and different error mechanisms were occurring in different models, it was not possible to consistently identify the erroneous models and thus make SCON more accurate than NCON.

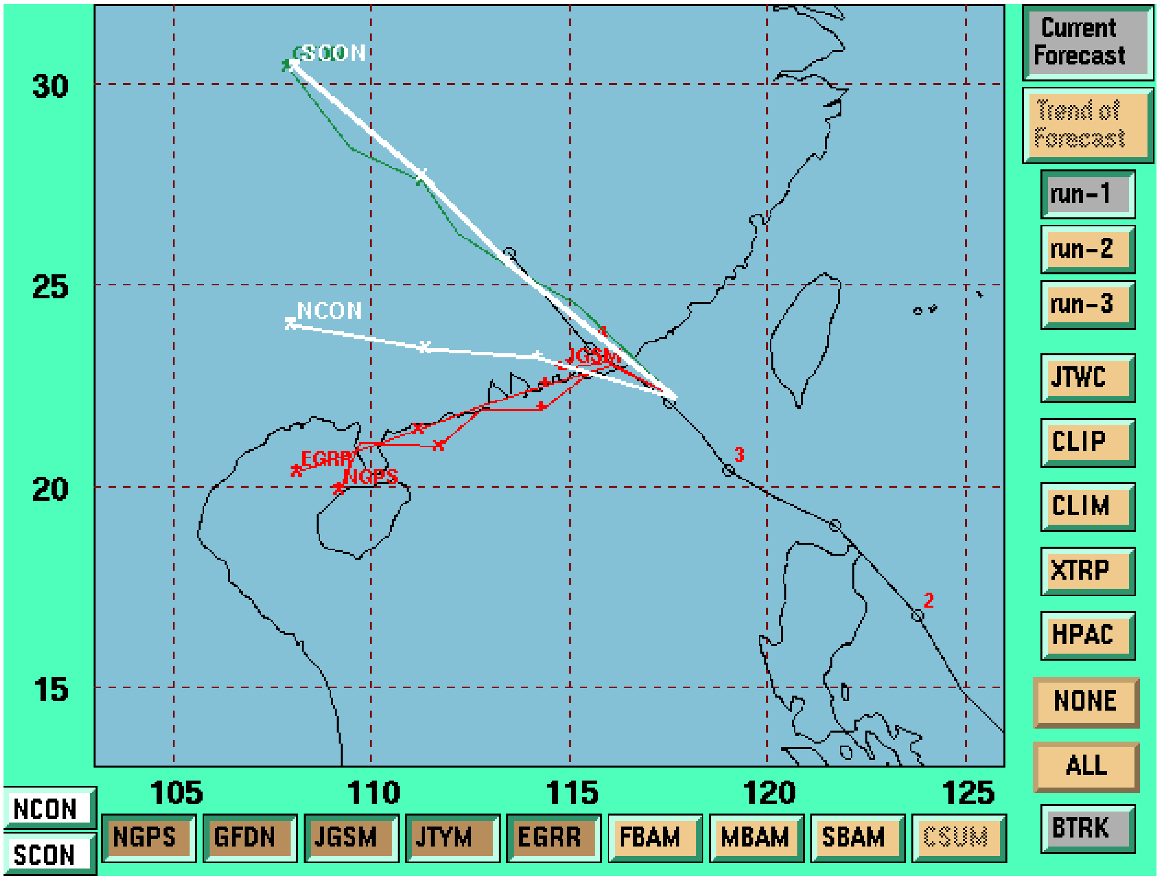

Figure 2. Example of the track display portion of the SAFA screen at 1200 UTC 03 September 1999 for Tropical Storm Wendy, except that the subsequent track of the TC has been added for the purpose of verification. Notice the difference between the inaccurate numerical consensus track (NCON), which is comprised of all available numerical models, and the selective consensus (SCON) track, which in this case is based only on the track of GFDN (green) because the tracks of the other three numerical models (NGPS, EGRR, and JGSM in red) were correctly rejected due to indication of excessive direct cyclone interaction (E-DCI).

IMPACT/APPLICATION

A thorough analysis of the results of the SAFA prototype test is still pending and subject to endorsement by JTWC. However, it is anticipated that the feasibility of using SAFA to help the forecaster successfully identify situations in which the official track forecast should be based on a selective consensus of the available numerical TC track forecast models (as in Fig. 2) as opposed to an indiscriminate numerical consensus will be demonstrated, thus warranting further development of the SAFA prototype into a fully operational system.

RELATED PROJECTS

This project is a follow-on to, and utilizes the results of, the project entitled SYSTEMATIC APPROACH TO TROPICAL CYCLONE TRACK FORECASTING by Lester E. Carr III and collaborators, which appeared in the FY97 annual report.

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