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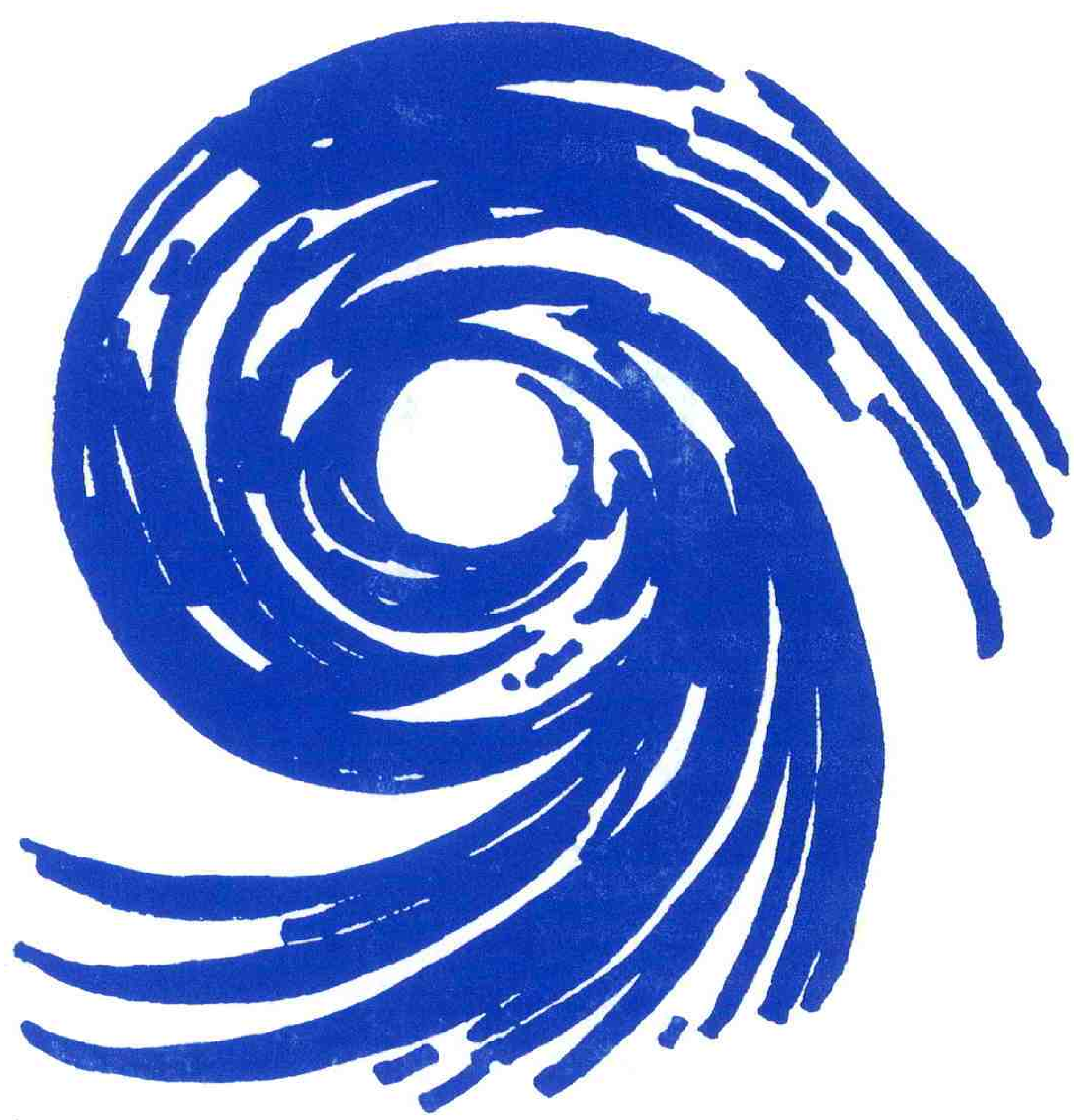
OFFICE OF THE FEDERAL COORDINATOR FOR
METEOROLOGICAL SERVICES AND SUPPORTING RESEARCH

National Plan For Tropical Cyclone Research



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FOREWORD

In Congressional hearings during the past several years, it has been reiterated that "a vigorous research program in tropical cyclone behavior and forecasting is important if the accuracy of prediction of tropical cyclones is to be significantly improved." Further, Congress has proposed that the Departments of Commerce and Defense establish a joint program to collect operational and reconnaissance data, conduct research, and analyze data on tropical cyclones. The Office of the Federal Coordinator for Meteorology (OFCM) is facilitating such a program through its interagency Ad Hoc Group for Tropical Cyclone Research.

This is the second edition of the National Plan for Tropical Cyclone Research. It addresses many of the issues raised in Congressional hearings, and provides a review of the research requirements of the government agencies concerned with tropical cyclone analyses and warnings. The plan also summarizes current relevant research at government and university laboratories and presents an assessment of additional work required. In this edition of the plan, Chapters 2, 3 and 4 were revised substantially, Chapter 6 was added and 2 new data set descriptions were added to Appendix B. It should also be noted that the priorities for two areas of research listed in Table 2.1 related to improving the surface wind description were increased from medium to high by the National Hurricane Center and the Central Pacific Hurricane Center.

It is hoped that this plan will continue to foster cooperative efforts among the various research groups, both within and outside of the government; and that the outcome will be long-term improvement in tropical cyclone analysis and warning services. Progress in these areas will be reported at the annual Interdepartmental Hurricane Conference as well as in updates to the plan.

James A. Almazan
Acting Federal Coordinator for
Meteorology

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NATIONAL PLAN FOR TROPICAL CYCLONE RESEARCH

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CHAPTER 1

INTRODUCTION

1.1 Ad-Hoc Group for Tropical Cyclone Research. The Ad-Hoc Group for Tropical Cyclone Research (AHG/TCR) is a subgroup of the Working Group for Hurricane and Winter Storms Operations of the Committee for Basic Services, which, in turn, is a subcommittee of the Interdepartmental Committee for Meteorological Services and Supporting Research (ICMSSR). This committee structure is under the Office of the Federal Coordinator for Meteorological Services and Supporting Research (hereafter referred to as the Federal Coordinator). AHG/TCR held its formation meeting in San Diego, California, on May 18, 1989, and has met periodically since then. Primary agency members are listed on the inside back cover. Each of the following organizations contributed to the development of the National Plan for Tropical Cyclone Research:

Air Force Global Weather Central
Central Pacific Hurricane Center
Environmental Group, United States Pacific Command
Fleet Numerical Oceanography Center
Hurricane Research Division (AOML)
Joint Typhoon Warning Center
National Hurricane Center
National Meteorological Center
Naval Postgraduate School

1.1.1 Background of AHG/TCR. The AHG/TCR was formed by or because of four actions:

a. The ICMSSR identified research on tropical cyclones, improvement of information on location and intensity of tropical cyclones, exchange of satellite data, and future of airborne reconnaissance as opportunities for increased interagency coordination at its meeting on November 15, 1988.

b. Mr. Robert L. Carnahan (then Federal Coordinator) charged the Interdepartmental Hurricane Conference Research Committee to explore the forecast and warning problems, identify research that can address those problems, and determine means of obtaining needed data when aerial weather reconnaissance as we now know it is no longer available.

c. Dr. Hal Gerrish, Chairman of the 1989 Research Committee, reported that the committee "strongly endorses appointment of an ad hoc committee of field people to develop a comprehensive plan for research on tropical cyclone meteorology at the earliest possible date." This recommendation was approved by the conference participants.

d. The ICMSSR approved the proposal to establish an Ad Hoc Group for Tropical Cyclone Research under the Working Group for Hurricane and Winter Storms Operations at the March 28, 1989 ICMSSR meeting.

1.1.2 Purpose of AHG/TCR. The Ad Hoc Group, at its first meeting, adopted the following purposes:

a. Obtain rank-ordered lists of the most pressing tropical cyclone forecast problems from the operational forecast centers and disseminate this information to the research community. Prepare for interdepartmental approval and subsequent action a comprehensive listing of these operational forecast and warning problems to guide research in tropical cyclone meteorology for the coming decade.

b. Review recent tropical cyclone research, including manpower and budget figures, for activities at government laboratories, universities and institutes. Identify those activities that are focused to improve the operational forecast and warning process. Recommend plans to facilitate transfer of this research to operational testing.

c. Periodically assess the developing sensors, technologies, and processing and display capabilities that may be adaptable to the tropical cyclone forecast and warning process. Identify promising items and plan interdepartmental cooperation to facilitate transfer of these developments to operations as rapidly as possible.

d. Coordinate the collection, compilation, and analyses of research data sets for improving tropical cyclone prediction. This activity will include blending of existing operational data with new directly or remotely sensed data (either research or operational). All available data sources should be included so that such data will be incorporated into real-time analyses for support of operational tropical cyclone warning and prediction. Determine optimal flow of such data into the operational forecast centers.

e. Publish a national plan containing sections on (1) pressing forecast and warning problems; (2) ongoing tropical cyclone research activities applicable to the forecast and warning problem; (3) developing sensors and technology transferable to operations in the near future; and (4) a compilation of research data sets available for research and analysis. Update the plan periodically.

CHAPTER 2

PRESSING FORECAST AND WARNING PROBLEMS

It was the committee's sense that attempts to improve the tropical cyclone warning system should be based on deficiencies in meeting national warning requirements. Following that reasoning, the first order of business was to identify the most pressing problems. This information was gathered by accepting lists representing the three U.S. tropical cyclone forecast centers: Joint Typhoon Warning Center (JTWC), National Hurricane Center (NHC) and Central Pacific Hurricane Center (CPHC).

Since such lists tend to reflect the thinking of the current authors and invariably omit some items, consolidation of the lists was deemed appropriate. Table 2-1 is the consolidated list categorized into fairly restricted topic areas, with a qualitative assessment of its importance to each of the centers entered next to each item. Because the missions of the three centers vary, their priority assessments also vary. The following paragraphs amplify the items listed in Table 2-1. Discussion of each item will include an appraisal of the type of research that is necessary. Where the deficiency arises from a lack of understanding, a program of basic research (commonly labelled 6.1 among Department of Defense agencies) is required. Exploratory research (6.2 category) is intended to convert basic research advancements at universities or research labs to prediction methods that will address forecast problems. Advanced development (6.3 category) efforts typically are applications to specific problems at the forecast center and are expected to be implemented operationally if validated with real-time data. Thus, specification of the required research category will indicate the appropriate funding agencies that are tasked to address research in these categories.

2.1 <u>Position and Motion</u>. The items related directly to track forecasting under the heading "position and motion" are given the highest ranking because other aspects of the tropical cyclone warning depend upon the track forecast. At the most elementary level, observational system improvements are required because better positioning and initial motion estimates are the foundation of the track forecast. Positioning also is critical in the determination of the post-analysis best track, which provides the standard for assessing official forecast and objective aid performance. At the most complex level, improvement in track forecasting may require the development of advanced dynamical or statistical- dynamical models. Although such models are intimately related to the synoptic environment specification, this topic is treated as a separate item (2.3) because the cyclone structure and other aspects of the warning also are dependent on this topic.

2.1.1 Positioning. All forecast centers rely upon satellite visible and infrared imagery to position the tropical cyclone. Because of the availability of aircraft reconnaissance in the Atlantic, this item is assigned a lower priority in Table 2-1 than in the western Pacific, where

Table 2-1 Consolidated Tropical Cyclone (TC) research items priority rating.

Research objectives	JTWC	CPHC	NHC
Improve position and motion (see paragraph 2.1)			
Positioning	med	med	med
Initial motion	med	high	high
Track forecasts	high	high	med
Improve surface wind description (see paragraph 2.2)			
Estimate of intensity (maximum winds or minimum sea level pressure (MSLP)	high	high	high
Intensity prediction	high	high	high
Wind structure	high	high	high
Synoptic environment (see paragraph 2.3)			
Tropical analysis			
Exploit existing data	med	low	med
Improve specification	med	med	high
Improve forecasting	med	high	med
Tropical cyclone genesis	med	low	med
Upgrade other models			
Monsoon	med	low	med
Trop Upper Tropospheric Trough (TUTT)	med	med	med
N. and S. Hemisphere twins	med	low	low
Hybrid or semitropical cyclones	med	low	med
Improve rainfall estimates and forecasts (see paragraph 2.4)			
TC-specific satellite rainfall estimates	low	low	high
TC rainfall forecasting techniques	low	low	high
Improve tornado understanding (see paragraph 2.5)	low	low	high
Improve storm surge prediction (see paragraph 2.6)	low	low	med
Improve sea state models (see paragraph 2.7)			
Estimation	med	med	med
Forecasting	med	high	med
Coastal effects	low	high	low
Information and data management (see paragraph 2.8)			
Data requirements	high	high	high
Damage assessment	low	low	low
Tropical cyclone typing	med	low	med
Objective aid design and performance	high	high	low
Global model evaluation	med	med	med
Non meteorological items (see paragraph 2.9)			
Presentation of information	high	med	high
Action motivation studies	med	low	high
Vertical refuge	low	low	high
Communications	high	low	high
Media interface	med	high	med

no aircraft reconnaissance is available. Research is needed to develop (6.2 category) or improve (6.3 category) satellite fix technologies, especially for weak and developing systems. If better, more reliable, satellite fixes were available (including intensity and close-in wind field information), the limited aircraft resources could be partially employed to collect synoptic and outer peripheral data. The Special Sensor Microwave/Imager (SSM/I), particularly the 85 GHz channel, may provide the high resolution needed for positioning. Some conceptual models of the precipitation signatures appearing on the SSM/I imagery would be useful to forecasters. Fix estimates from the 85 GHz channel should be assigned Position Code Numbers (PCN), and a study (6.3 category) that correlates these fixes with the best track positions should be done to calculate appropriate confidence values that should be ascribed to each PCN.

Animation of cloud targets from geostationary satellite imagery can reveal rotation and circulation centers in the wind field. Research (6.3 category) is needed to determine if methods based primarily on cloud signatures in single images from polar orbiters can discriminate actual low-level circulation centers from the geostationary imagery.

2.1.2 Initial Motion. Short-period track forecasting is critically dependent upon accurate initial motion estimates because most forecasting guidance is substantially weighted with persistence at the start. Exploratory research (6.2 category) is needed to improve initial motion forecasts from dynamical models. Where major track changes are taking place and persistence is not the dominant factor, a critical need exists for a measure of true motion from a sequence of fixes. The noisier the fixes, the more troublesome the dependency. Research (6.3 category) to develop an improved technique that would account for the noise inherent in the raw fixes would be an important contribution to this initial motion problem. Fundamentally, the longer the time average, the greater the dampening of fix noise, but the less representative will be the averaged motion of the current (and near future) motion. An optimum trade-off may exist, which may be situation-dependent. Thus, the product of the research might be this optimum time-averaging as a function of important variables, such as basin, latitude, intensity, track, and environment.

2.1.3 Track Forecasts. Without doubt, the track is the most important element to be forecast. After the implementation of NHC83 (later termed NHC90), which is a statistical dynamic model developed and tested over several years since 1983, the track forecasting problem became relatively less urgent in the Atlantic basin. However, it is still considered to be of highest priority in the central and western Pacific.

Comparisons between track forecasting errors and customer expectations raise questions. Basic research (6.1 category) is needed to specify the limits of predictability. Application of the NHC83 technique with best track positions and analyzed fields rather than predictions suggests that track errors could be reduced by a factor of two. Does chaos theory set fundamental limits to predictability that differ from the estimate based on the NHC83?

Interaction between tropical cyclones in multiple-storm situations complicates track forecasting. Improved understanding of the roles of cyclone size, strength, and intensity in this interaction will require basic research (6.1 category). In addition, the movement of the centroid between these systems in relation to the surrounding synoptic environment is not understood. This research also should address the interactions of tropical cyclones with other synoptic/subsynoptic circulations.

Bao (Ref Bao, 1981), Fett and Brand (Ref Fett and Brand, 1975) and Lajoie and Nicholas (Ref Lajoie and Nicholas, 1974) have developed empirical relationships between tropical cyclone motion changes and the cloud-system orientation. Although none of these methods can consistently demonstrate skill in the operational environment, each has something to offer. Weldon (Ref Weldon, 1979) and Dvorak (Ref Dvorak, 1984a) found signatures in the water vapor imagery that might be applied to track changes. Based on the above studies, advanced development (6.3 category) should be pursued with the goal of making the prognostic track information detectable in satellite imagery available to forecasters.

Over the past several years, Neumann and collaborators (for example, see Ref Neumann, 1979) have published statistical data about mean steering and the amount of variance explained by the flow at various levels and combinations of levels. The Colorado State University group under William Gray arrived at similar conclusions for Pacific tropical cyclones based on analysis of composite data. Basic research (6.1 category) is required to understand how tropical cyclone track deviations from mean steering depends on various parameters (e.g., size, strength, and vertical extent). This knowledge would permit the forecaster to fit the tropical cyclone into the most appropriate steering model. A subsequent effort (6.2 category) would be required to demonstrate operational skill in categorizing tropical cyclones to apply such a model.

Along-track or speed errors are the largest contributors to overall forecast track errors. Translation speed may be more related to the flow at the 700- or the 500-mb levels in different basins, synoptic situations, latitudes or seasons. The two components of track, direction and speed, are usually considered together in the forecasting process, but this approach is not necessarily optimum. For example, a forecast aid may be discounted by the forecaster because the direction is 45° off, when the prediction of its speed is accurate. A useful applied research (6.3 category) project might develop algorithms for speed that address such phenomena as stalling, major track changes, and erratic motion.

Long-wave patterns have an effect on the longitudes or areas for recurvature. For some forecasting purposes, tropical cyclones are categorized as straight runners or recurvers. However, a class of tropical cyclones with northward-oriented tracks does not fall conveniently into these categories. An exploratory research (6.2 category) project to categorize tracks relative to long-wave patterns may be fruitful.

Dynamical track predictions have become available from barotropic, limited-area and global baroclinic models. In addition, so-called beta and advection models, in which the advective component calculated from global model steering is modified for deviations due to the earth vorticity gradient (beta), also provide dynamical guidance. Standard procedures for communicating tropical cyclone warning positions and other structure characteristics have been achieved recently. This information will allow the numerical forecast centers to bogus the tropical cyclone vortex in a systematic manner. Archives of the resulting track forecasts need to be established so that a research project (6.2 category) to evaluate the dynamical track predictions can be accomplished. The track errors should be evaluated as a function of storm characteristics such as intensity and size, and for various synoptic regimes and seasons. The time of receipt of the dynamical track prediction by the forecaster must be considered in the intercomparison with other objective aids.

2.2 Surface Wind Description. 'Surface wind description' includes wind specification, measurement, vertical analysis and forecasting. It also includes coastal effects, relationships between sea-level pressure and maximum winds, and improvements in the forecast of tropical cyclone development. The terms "intensity", "maximum winds", and "minimum sea level pressure (MSLP)" are used interchangeably in the following discussion, as they are in operational practice.

In recent years, three factors have brought new emphasis to the problem of describing tropical cyclone surface winds: (i) loss of aircraft reconnaissance, which has forced greater reliance on satellite data; (ii) critical role of storm surge prediction in emergency planning and the equally important role of prediction of surface wind forcing; and (iii) extent of gale-force surface winds, which is becoming a key element in the timing of emergency actions.

It is difficult to measure the distribution of winds, especially at the surface. With the possible exception of tropical cyclones transitioning to extratropical storms there is little understanding or empirical guidance to aid in the forecast. Improvement of maximum wind estimates is another item that has taken on a new importance with the loss of aircraft reconnaissance. The standard error of estimation in Dvorak satellite wind estimates is about one category on the Saffir-Simpson scale. In some major metropolitan areas, this could be a difference of hundreds of thousands of people unnecessarily evacuated, or not evacuated and left vulnerable to storm surge inundation or in unsafe structures.

2.2.1 Intensity (Maximum Winds/MSLP) Diagnosis. Intensity estimation with the Dvorak (Ref Dvorak, 1984b) technique is used at all forecast centers. A research project (6.3 category) to evaluate, and upgrade where necessary, this technique is needed. For example, the appropriateness of the model 0-, 6-, 12-, 18-, or 24-h delay during weakening (or movement over land or over cold water) needs to be resolved. Winter tropical cyclones can exhibit higher intensity than that estimated by the Dvorak technique (e.g., Tropical Storm Winona in January 1989). Colder than normal cloud tops are suspected in the western North Pacific basin, particularly during the off-season months. Colder values result in higher estimates of intensity. Since there is a high correlation between maximum winds on the advisory, peripheral winds and Enhanced InfraRed (EIR) satellite estimates, attention to the question of basin or seasonal bias in the EIR technique is warranted. In addition, adjustments to the Dvorak technique to account for different storm translational speeds should be the subject of further study.

Large fluctuations in inner core convection occur on diurnal time scales. Systematic procedures for detecting these fluctuations and normalizing the intensity estimates, especially in the early stages of the life cycle, should be developed in a research (6.3 category) study.

Microwave techniques that relate the warm core aloft or the pattern of high rain-rate features to the present intensity should be the subject of a research (6.3 category) project.

2.2.2 Intensity prediction. Better conceptual models for intensification are needed. Although the synoptic-statistical technique by Dvorak performs well for steadily developing cases, the dynamics of the process are missing. Empiricism is useful, but the answers to the "why's" of the dynamics of growth and decay of the tropical cyclone need to be understood via a basic research (6.1 category) study. The absence of conceptual model guidance to forecast intensity promotes reliance on persistence, climatological and statistical models, none of which are capable of identifying the unusual and dangerous rapid change situations.

While several investigators have developed general relationships between synoptic events and tropical cyclone intensification, none has quantified these relationships. A better understanding of these relationships needs to be developed in a basic research (6.1 category) study.

A statistical approach based on the environment, synoptic typing, and predictors from the numerical prognosis fields could provide insight to the important processes. Satellite cloud signatures, as precursors to rapid or explosive deepening and the peaking day, have not been identified adequately. A hypothesis by Chan (Ref Chan, 1982) that increases in cloud-top vorticity are precursors to "spin up" and subsequent intensification of the tropical cyclone, is an idea that should be pursued. Research (6.2 category) should address these items and their application to intensity forecasts.

2.2.3 Wind Structure. The requirement to improve tropical cyclone wind forecasts presents a range of problems, from inadequacies in horizontal wind models and deficiencies in models of the vertical distribution of horizontal winds to orographic influences on the wind field.

2.2.3.1 Better Surface Wind Models. A basic research (6.1 category) project to gain a better understanding of surface wind distribution is the first step to development of better surface wind prediction methods. There is a need to understand why some storms have cyclonic winds extending to large distances and others are very compact, and how such structural characteristics change in time. The various types of tropical cyclones, such as partially tropical, semitropical (sometimes referred to as subtropical or hybrid) and the extratropical transition must be understood. Given these distinctions, it must be understood how the cloud patterns and wind distributions are correlated; e.g., will the gales be near the center or displaced far from the center? There is a need to understand what processes create and sustain the wind distribution asymmetries. Finally, it is necessary to know the effect on intensification due to cold air penetrating to the eye wall region; how long the occasionally large, but apparently short-lived, intensification or weakening will last; and how such changes can be forecast during extratropical transition.

A separate research (6.2 category) effort is required to develop airborne and satellite remote sensing techniques to observe the surface wind distribution, including asymmetries. Microwave instruments, such as the airborne stepped frequency microwave radiometer, the airborne and satellite based scatterometer (C-SCAT or ERS-1) and the SSM/I, can detect outer wind structure, but improved techniques are required to remove contamination due to rain rate features.

2.2.3.2 Relationship of High-level Winds to Surface Winds. Vertical reduction of aircraft flight-level winds is an item that is clearly of interest in the Atlantic and central Pacific where aircraft are still available for reconnaissance. It is also of interest in the western North Pacific where archived aircraft data are used for model development and validation. The general topic is also of importance in reducing winds at elevations from different platforms (such as oil rigs and C-MAN stations) or from new systems (such as radar wind profilers or Doppler radars) to the surface. The same technology will be required to specify wind loading on upper portions of high rise structures. Although many studies are available, a research (6.3 category) program to collate and validate this information, and to put it in a convenient form for the forecasters, is required.

2.2.3.3 Nonstandard Wind Averaging Times. The measurement duration for winds needs to be clearly defined and relationships between winds measured over different durations in the tropical cyclone environment need to be established. Whereas most countries consider a 10-min average wind speed as a sustained wind, all U.S. T.C. warnings are specified for 1 min. Other implied averaging periods have been used, such as the "fastest mile", and winds measured from moving platforms (e.g., aircraft) averaged over a set distance. It is not possible to convert a measurement that is based on one standard to another standard. However, algorithms can be developed to determine maximum short period wind averages over some larger time period, given some knowledge of the frequency distribution of the wind. For example the method of Durst (Ref Durst, 1960) can be used to estimate the highest 1 minute wind over a 10 minute period. This work has been conducted by HRD (See Ref Powell et al, 1991), but little data are available to validate these techniques; additional research (6.3 category) is required.

2.2.3.4 Orographic Effects. Reduction of surface winds due to orography is a topic of importance in all tropical cyclone basins. Even when surface winds over open water are known, the actual surface winds inland and along shore can be substantially different. Forecasts of wind gusts are important because gust-loading on structures can be particularly destructive. Better understanding and modeling of these inland and coastal influences via a basic research (6.1 category) program would be a first step. A research (6.2 category) effort to utilize new observing technology such as Doppler radars and radar wind profilers in observing coastal and orographic effects would be helpful in validating the models and providing guidance to the forecaster.

2.3 Synoptic Environment.

2.3.1 Tropical Analysis. Numerical objective analysis in the tropics leaves much to be desired. Tropical waves, for example, are rarely depicted and tropical cyclone vortices are frequently misplaced. Clearly, a good analysis is required to produce a consistently good prognosis. A poor initial analysis is the most frequent cause for poor performance of the statistical-dynamic model NHC83.

2.3.1.1 Existing Data. The challenge is to provide better, more reliable data to support an improved analysis. Because of the insufficient number and spatial distribution of direct measurement platforms, techniques for exploiting observations of remote-sensing platforms must be developed via advanced development (6.3 category) programs. Real-time surface wind estimates from SSM/I or scatterometer data should be improved for operational use and technique development at the centers. Soundings from the TIROS-N Operational Vertical Sounder (TOVS) and the Special Sensor Microwave/Temperature (SSM/T) should be evaluated to determine if warming in the upper troposphere, thickness, and other factors can be applied to the tropical cyclone analysis and forecasting problem.

Automated surface observation systems, (e.g., drifting buoys, moored buoys, and land stations) that report regularly via satellite, are providing new measurements that are especially valuable in data-sparse regions; and a quantitative anchor to satellite-derived measurements. For example, JTWC is utilizing automatic surface weather observing stations and meteorological buoys. A network of approximately 100 moored buoys and automated fixed coastal stations operated by the National Data Buoy Center (NDBC), is an important supplement to tropical analysis around the U.S. mainland. Advanced development (6.3 category) studies to incorporate these new observations directly, and to use them to anchor the satellite-derived measurements, are required to improve tropical analyses.

2.3.1.2 Improve Specification. Many of the synoptically important features of the tropics have horizontal scales that are not resolved by the observation network but are detected in the satellite imagery. In the absence of a good three-dimensional conceptual model of these features, satellite-derived winds at only the gradient and cirrus levels are inadequate to resolve the vertical structure of these features. Exploratory development (6.2 category) research is required to develop a man-machine technology whereby the conceptual analysis of an experienced tropical analyst can be replicated by numerical analysis.

2.3.2 Improve Forecasting. Global models seem to provide a reasonable forecast in the tropics when they have a good initial analysis. Thus, improved forecasts of the environment around tropical cyclones would result from an advanced development (6.3 category) effort to improve techniques for inserting bogus/synthetic observation information, satellite winds, and reconnaissance data in such a way as to insure that the data assimilation technique will accept and utilize these inputs.

2.3.3 Tropical Cyclone Genesis. The "where, when, why, and how" of tropical cyclone genesis is little understood. Until such understanding exists, a practical technique is required to assess the potential for genesis. Because the genesis is believed to be controlled by the environmental conditions, a better tropical analysis is an essential step. Exploratory research (6.2 category) to relate cyclone genesis and intensification to the environmental patterns analyzed by the global models may provide a useful tool for the forecaster.

2.3.4 Upgrade Other Models.

2.3.4.1 Monsoon Models. The development and structure of the monsoon circulations over the Asian continent and the adjacent Pacific Ocean are critical features in western North Pacific tropical cyclone formation and movement. Recent studies have documented northward shifts in the monsoon trough to 25°N. Intraseasonal fluctuations in the 700 mb wind fields have been related to persistent periods of straight-moving or recurving track types (Ref Harr and Elsberry, 1991). Additional basic research (6.1 category) is required to improve understanding of the interaction between the monsoon circulation and tropical cyclone formation and motion. Present numerical models do not correctly predict deep southwesterly flow that may be brought upward through 200 mb by deep persistent convection. This may be partially a horizontal or vertical resolution problem. Alternately, it may be a data problem, and improved observations of the momentum field in the monsoon may need to be obtained using remote sensing techniques. These topics are appropriate for exploratory research (6.2 category) studies.

2.3.4.2 TUTT Model. The Tropical Upper Tropospheric Trough (TUTT) is little understood. Upper cold lows in the TUTT may have a profound influence on tropical cyclone genesis, motion and intensity. For example, Sadler (Ref Sadler, 1978) has described sympathetic tropical cyclone genesis in the trade wind regime from the TUTT lows. The TUTT may also influence the subtropical ridge beneath it, and thus, indirectly affect the steering of the tropical cyclone. The direct or indirect coupling of the TUTT to monsoon surges that affect tropical cyclone formation is also poorly understood. Thus, basic research (6.1 category) is required to understand the TUTT and its effect on the surrounding environment and, in particular, tropical cyclones. Because the TUTT is poorly handled by numerical models, tropical cyclone dynamic forecast guidance may be degraded. Exploratory research (6.2 category) to improve the representation of the TUTT in the initial conditions of numerical models is required.

2.3.4.3 Twin Cyclones. Genesis of twin tropical cyclones in low latitudes and opposite hemispheres is a process that has been little documented in the literature. This is an important topic because a surprising number of these twins reach supertyphoon intensity. Better conceptual models and understanding of the role of the equatorial westerlies, sympathetic intensification of the twin cyclones, the subsequent movement, and possible teleconnections need to be developed via basic research (6.1 category).

Mechanisms for the regulation of tropical deep convection are poorly understood. Cross-equatorial interactions between the winter and summer hemispheres can affect tropical cyclone genesis and intensification in low latitudes. Low-level surges across tropical low latitudes from the winter hemisphere can cause major readjustments in the area/extent and strength of the convection in the summer hemisphere. Basic knowledge of various tropical wave types is severely limited. Some sample topics for a basic research (6.1 category) initiative might include: (i) the role of equatorial waves in twin tropical cyclone formation; (ii) role of the 40-to 50-day intraseasonal cycles in formation and movement; (iii) modulation of large- and small-scale convective areas by these waves and cycles; and (iv) predictability of these waves and associated convective areas on time scales pertinent to operational forecasting.

2.3.4.4 Hybrid Storm Systems. The detection and prediction of hybrid or semitropical cyclones is a major forecast concern because of the potential transition to tropical cyclones. Hebert and Poteat (Ref Herbert and Poteat, 1975) provide a good basis, but we lack an understanding of the physical processes that create and sustain these systems. Thus, some basic research (6.1 category) is required. Until this understanding is achieved, exploratory research (6.2 category) is required to refine the satellite analysis techniques. Monsoon depressions, that may be coded at 25-35 kt using the Dvorak technique with a shear-type pattern, may have 40-70 kt winds displaced 150 n mi or more from the light and variable wind center. It may be necessary to address these questions by individual basins because the environmental conditions may differ.

2.4 <u>Rainfall</u>. This item is important because rainfall and associated flooding are the greatest causes of tropical cyclone deaths in inland areas away from the immediate coast.

2.4.1 Tropical Cyclone-specific Satellite Rainfall Estimates. Although remote sensing techniques for rainfall estimation have proven fairly accurate in the subtropics and midlatitudes, these techniques do not work well in the tropics. An advanced development (6.3 category) effort to refine these techniques is required to reduce the large errors that are frequently present in tropical cyclone situations.

2.4.2 Tropical Cyclone Rainfall Forecasting Techniques. The distribution and amount of rainfall associated with tropical cyclones can vary considerably. Effects of terrain and translation speed on precipitation distribution and rainfall accumulations are understood only in a general way. We do not understand why some cyclones produce substantially heavier rainfall than others under apparently identical circumstances. This lack of understanding of the fundamental processes involved indicates a need for basic research (6.1 category).

2.5 <u>Tornadoes</u>. Most observations of tornado activity associated with tropical cyclones have been with landfall. Some general information is available about where to expect tornadoes relative to the center. We do not know the specific conditions that lead to tornado genesis, or greater or less tornado activity than usual. As advances in understanding tornado genesis are made, these need to be applied to tropical cyclones in an exploratory research (6.2 category) study. It would be particularly useful to forecasters if a satellite cloud signature could be found to indicate the specific area to expect tornadoes.

2.6 <u>Storm Surge</u>. In the Atlantic and for the coast of the continental United States, storm surge models have been advanced beyond the accuracy of the cyclone characteristics (track, intensity) that are required inputs. Therefore, better storm surge forecasts in the Atlantic require improved cyclone forecasts. Most of the items discussed above would contribute to improved meteorological inputs. An advanced development (6.3 category) effort to apply the storm surge models should be initiated for selected storm-surge prone areas of U. S. interest in the Pacific basin.

2.7 <u>Sea State</u>. Marine advisories for hurricanes and bulletins for typhoons require specification of the radius of 12-ft seas. In some cases, wave run-up is an important contributor to water level and is usually measured as storm surge. The centers have little skill in specifying or predicting sea state.

2.7.1 Estimation. In the absence of observations, the centers must estimate the radius of 12-ft seas on the basis of tropical cyclone characteristics. At NHC, this type of estimation usually means accepting the radius of 34-kt winds as the radius of 12-ft seas. The skill of such a forecast is unknown, but is generally conceded to be low. An advanced development (6.3 category) study that would do a post-analysis of the sea state for several storms could form the basis for an improved parameterization. Application (6.3 category) of techniques for remote sensing of the sea state around tropical cyclones is needed as a solution to this initialization problem.

2.7.2 Forecasting. At NHC, the time in the forecast cycle is so short that only a fast parametric model would be of practical use. Any model in the forecast mode will be ultimately limited by the inaccuracies of the track and wind forcing. As forecasts of these inputs are improved, an exploratory development (6.2 category) effort to apply spectral wave models to the tropical cyclone problem should be pursued.

2.7.3 Coastal Effects. Surf, shoaling and wave run-up are often important contributors to water level. Exploratory research (6.2 category) efforts are required to include these effects in the current storm surge models.

2.8 <u>Information and Data Management</u>.

2.8.1 Data Requirements. Most of the sensors that provide data critical for tropical cyclone tracking and monitoring were developed for other purposes and adapted to the present use. Some systems, such as the Improved Weather Reconnaissance System (IWRS) are highly tailored to this very specialized job. Rather than decide, a priori, that a new generation of aircraft and spacecraft is needed, it is essential to systematically validate the measurements required to provide an acceptable level of service, then develop the optimum mix of remote and in-situ systems which would complement each other to satisfy data requirements. The current reconnaissance aircraft capability will likely need to be replaced within a decade. Therefore, defining the requirements and initiating procurement of new aircraft are already behind schedule. That process should be started as soon as possible.

2.8.2 Damage Assessment. The Saffir-Simpson (Ref Simpson, 1974) Hurricane Scale was developed for the Atlantic basin. A modified version has been developed that keys on vegetation and structural damage in the data-sparse western Pacific Ocean. The modified version may also be applicale to the Caribbean Islands.

2.8.3 Tropical Cyclone Characteristics Typing. A requirement exists to better define the departures of a specific cyclone from the average tropical cyclone. Categories should be defined by classifications based upon the unique differences. Typing might consider depth, areal extent and asymmetries of the outflow and inflow layers, steering levels, environmental influences, teleconnections, multiple cyclone interaction, adjacent monsoon flow, TUTT, relative position of upper cold lows, vertical wind shear, vorticity gradients, cloudiness, and sea-surface temperature. These data might be handled in a correlation matrix so anomalous features could be identified more readily and analogs more specifically identified.

2.8.4 Objective Aid Design and Performance. As aids are designed, software is engineered, developed and implemented into the operational forecast system. Unfortunately, the forecaster must make a precise forecast based on guidance provided by an aid that may be inappropriate to the case at hand. The forecaster needs to know the assumptions of the designer and programmer. In addition, he needs to know under what conditions the system performs well or poorly, and if specific biases exist.

2.8.5 Global Model Evaluation. Equally as important as the performance of various objective guidance models is the performance of the global models that drive the objective models. Frequently, the objective guidance will be wrong because the supporting global model is wrong. Thus, the forecaster needs to be aware of systematic errors in the global models and situations wherein these models perform either abnormally well or abnormally poorly. In the latter case, the forecaster must know the nature of the weakness.

2.9 Nonmeteorological Items. Improved public awareness and communication have contributed greatly to the reduced loss of life from tropical cyclones in recent years. Some nonmeteorological problems must be resolved or improved upon if we are to continue to hold the line on tropical cyclone-related casualties.

2.9.1 Presentation of Information. The satellite and WSR-88D radar threaten to inundate tropical cyclone warning services with data. Only a small fraction of these data will be processed and an even smaller amount presented to the customer. However, much of the mesoscale information could be useful to the general public, and to emergency management officials in particular. Innovative ways to extract and present detailed information in a timely and clear manner could be an appropriate topic for an advanced development (6.3 category) effort.

2.9.2 Action Motivation Studies. The words we use and the graphics we show are intended to motivate people to follow a desired course of action. There is little scientific evidence to indicate the extent to which we are successful. Systematic studies (6.3 category) are needed to guide how best to motivate a nonhomogeneous population at risk to follow various courses of action.

2.9.3 Vertical Refuge. Evacuation of many coastal communities will require more than 24 hours. Some situations such as an unexpected track change or explosive deepening may make it impossible to give enough advance notice to permit total clearance, and some people may be trapped in automobiles or in unsafe shelters. To alleviate this situation, the possibility of emergency vertical refuge in high-rise buildings needs to be evaluated. This would require a study (6.3 category) of the limitations of designating both public and private buildings for such purposes. Consideration needs to be given to physical safety and legal liability, as well as other social issues.

2.9.4 Communications. Communications are the life blood of the tropical cyclone warning service. The possibilities are almost limitless as to the combinations of communication resources, message content and message release times. The present communications systems evolved over many years and there is little assurance that they are near optimum. An end-to-end communications study (6.3 category) is needed to evaluate how well the system is performing. Such a study would consider the electronic and physical aspects of the current system, the use of languages, the message syntax, the message context, and the timing of various releases, on a regional and cultural basis.

2.9.5 Media Interface. Communications are designed to convey information. The mass media (radio, television, newspapers) employ individuals who are experts at disseminating information. The understanding of these individuals can be crucial to the impact of the warning message on the public. Training sessions or seminars have been organized to enhance their understanding of the warning process and hazards of tropical storms. Are there more effective ways to educate and motivate these people?

2.10 Summary. For the convenience of the readers and agencies involved, the suggested research topics are summarized in Tables 2-2, 2-3 and 2-4 according to the three categories. Although the topics follow the general rankings in Table 2-1, the order within these subheadings does not indicate any ranking. Finally, the differences between categories 6.1, 6.2 and 6.3 are sometimes not precise. A general progression from basic research to applications is the intended goal of this listing.

Table 2-2 Summary of suggested basic research (6.1) topics

Paragraph	**Topic**
	Position and Motion
2.1.3	Specify limits of predictability of track forecasting from chaos theory
2.1.3	Understand multiple-storm interaction effects on motion
2.1.3	Understand track deviations from steering as function of cyclone and environment characteristics
	Surface Wind Description
2.2.2	Understand the basic dynamics of growth and decay of tropical cyclones
2.2.3.1	Understand the dynamics of wind structure and structure change during formation, mature and extratropical transition stages.
2.2.3.4	Use dynamical models to understand coastal and orographic effects on the wind distribution
	Synoptic Environment
2.3.4.2	Understand the TUTT and its effect on the surrounding environment and, in particular, tropical cyclones.
2.3.4.3	Understand environmental effects on the formation of twin cyclone and subsequent tracks
2.3.4.3	Understand basic dynamics and predictability of deep convection areas in relation to tropical waves, cyclone formation and intraseasonal oscillations
2.3.4.4	Understand physical processes that create and sustain hybrid storm systems
	Rainfall
2.4.2	Understand fundamental processes that lead to different precipitation distributions and accumulations in tropical cyclones

Table 2-3 **Summary of suggested exploratory research (6.2) topics**

Paragraph	Topic
	Position and Motion
2.1.1	Develop new remote sensing techniques for positioning
2.1.2	Develop technique to improve initial motion estimates in dynamical track prediction models
2.1.3	Develop cyclone/environment typing scheme to apply model of track deviations from steering
2.1.3	Develop technique to categorize track types relative to long-wave patterns
2.1.3	Evaluate new dynamical track predictions as function of cyclone characteristics and environmental conditions
	Surface Wind Distribution
2.2.2	Develop a statistical technique for intensity estimation based on environmental conditions and cyclone characteristics
2.2.3.1	Develop remote sensing techniques to observe the surface wind distribution
2.2.3.4	Utilize new technology such as Doppler radars and radar wind profilers to observe coastal and orographic effects
	Synoptic Environment
2.3.1.2	Develop man-machine technology to specify 3-d structure of tropical circulations based on conceptual models
2.3.3	Develop techniques to relate cyclone genesis and intensification to environmental patterns from global models
2.3.4.1	Improve numerical model analyses and predictions of the monsoon circulations
2.3.4.2	Improve representation of Tropical Upper Tropospheric Trough cells in the numerical forecast models
2.3.4.4	Improve satellite analysis techniques for specifying conditions during hybrid storm development

Table 2-3 Summary of suggested exploratory research (6.2) topics (continued)

	<u>Tornadoes</u>
2.5	Improve satellite interpretation of tornado genesis in tropical cyclones
	<u>Sea State</u>
2.7.2	Apply spectral wave models to the tropical cyclone
2.7.3	Upgrade storm surge model to include surf, shoaling and wave run-up effects

Table 2-4 Summary of suggested advanced development (6.3) topics

Paragraph	Topic
	Position and Motion
2.1.1	Improve existing remote sensing techniques for positioning
2.1.1	Calculate PCN confidence values for positioning with 85 GHz channel
2.1.2	Develop optimum time-averaging technique for initial motion estimation
2.1.3	Develop satellite techniques to forecast future motion changes
2.1.3	Develop algorithm for improved translation speed forecasts
	Surface Wind Description
2.2.1	Upgrade Dvorak technique for intensity diagnosis
2.2.1	Develop procedures for treating diurnal convection variability in intensity estimates during early stages
2.2.1	Develop intensity estimation technique based on satellite microwave observations
2.2.3.2	Collate and validate specifications of surface wind from upper-level wind observations of various types
2.2.3.3	Develop algorithms to convert from and to nonstandard wind averaging times
	Synoptic Environment
2.3.1.1	Develop remote sensing techniques for improved observations in the tropics
2.3.1.1	Develop techniques for utilizing new observations such as drifting buoys in tropical analyses
2.3.2	Improve global model data assimilation and forecasts by insertion of bogus/synthetic observation information, satellite winds, etc.

Table 2-4 Summary of suggested advanced development (6.3) topics (continued)

Paragraph	Topic
	Rainfall
2.4.1	Improve satellite techniques for tropical cyclone rainfall estimation
	Storm Surge
2.6	Apply storm surge models in selected Pacific areas
	Sea State
2.7.1	Improve sea state specification via post-analysis for prior storms
	Non-meteorological Items
2.9.1	Improve communication of meteorological information from new observational systems in a form appropriate to general public or emergency management officials
2.9.2	Improve techniques to motivate population to respond to warnings
2.9.3	Study feasibility of vertical refuge in high-rise buildings
2.9.4	Evaluate effectiveness of communication systems for tropical cyclone warning service

CHAPTER 3

REVIEW OF TROPICAL CYCLONE FORECASTING RESEARCH

There is considerable tropical cyclone research at various government laboratories and in universities. In this section, the tropical cyclone research that may have operational application is reviewed. Only current research projects and work completed in the past year or two are included. This review is a compilation of summaries prepared by numerous authors. Because of the large amount of information, descriptions of individual research efforts are as brief as possible, although manpower and budget figures have been included when available. The research (technique development) at government agencies is summarized first, followed by university research.

The agencies that provided input for this research summary are:

A. Government Operational Agencies and Laboratories

1. Air Force Global Weather Central (AFGWC), Omaha, NE
2. Fleet Numerical Oceanography Center (FNOC), Monterey, CA
3. Geophysical Fluid Dynamics Laboratory (GFDL), Princeton, NJ
4. Phillips Laboratory, Geophysics Directorate (PL/GPA), Hanscom AFB, MA
5. Hurricane Research Division (HRD), Miami, FL
6. Joint Typhoon Warning Center (JTWC), Nimitz Hill, Guam
7. National Hurricane Center (NHC), Miami, FL
8. National Meteorological Center (NMC), Washington, DC
9. NASA/Goddard Space Flight Center (GSFC), Greenbelt, MD
10. National Environmental Satellite, Data and Information Service (NESDIS), Washington, DC and Ft. Collins, CO
11. Naval Research Laboratory (NRL) Marine Meteorology Division (Formerly NOARL West and NEPRF), Monterey, CA
12. Naval Research Laboratory (NRL), Washington, DC

B. Universities

1. Colorado State University (CSU), Ft. Collins, CO
2. Florida State University (FSU), Tallahassee, FL
3. Massachusetts Institute of Technology (MIT), Cambridge, MA
4. Naval Postgraduate School (NPS), Monterey, CA
5. North Carolina State University (NCSU), Raleigh, NC
6. Pennsylvania State University (PSU), University Park, PA
7. State University of New York at Albany (SUNYA)

8. University of Guam (UG), Mangilao Guam
9. University of Hawaii (UH), Honolulu, HI
10. University of Massachusetts (UMASS)
11. University of Wisconsin (UWISC), Madison, WI

3.1 Air Force Global Weather Central.

3.1.1 Special Sensor Microwave Imager (SSM/I) Data. SSM/I data from the Defense Meteorological Satellite Program (DMSP) are being used to identify tropical cyclone center positions, 30 kt wind radius perimeter extent, and improved center positioning impact on non-eye infrared intensity estimates. This project is led by LtCol. Charles Holliday.

3.1.2 Satellite Data Handling System (SDHS). SSM/I data are being examined with co-located DMSP Operational Line Scan (OLS) Visual (Vis) and Infrared (IR) data on AFGWC's SDHS network. This operational satellite imagery processing and multiple monitor display system allows multispectral analysis of individual pass swath data with animation and RGB color-gun display features.

3.2 Fleet Numerical Oceanography Center.

3.2.1 Bogussing Technique for a Global Prediction Model. Techniques have been developed that incorporate bogus tropical cyclone circulations into the data assimilation process for the Navy Operational Global Atmospheric Prediction System (NOGAPS). Techniques are being developed to track tropical cyclone vortices in the NOGAPS forecast output. The personnel involved in this project are Charles Mauck and Harry Hamilton.

3.3 Geophysical Fluid Dynamics Laboratory.

3.3.1 Forecast Studies of Tropical Cyclones. Real data cases during genesis, intensification and decay stages of tropical cyclones continue to be studied on a global basis. Objective data sets that have been used as initial conditions were provided by First GARP Global Experiment (FGGE), Australian Monsoon Experiment (AMEX), NMC and HRD. Extensive use of Tropical Cyclone Motion Experiment 1990 (TCM-90) data sets is anticipated. Experiments have used both nested and uniform horizontal resolution, as well as 11 and 18 level versions of the GFDL Tropical Cyclone model.

3.3.2 Model Development. Improvements and additions to various physical packages are being developed. Areas of interest are land surface processes including vegetation, radiation, and bogus vortex specification. Also being developed is a coupled air-sea model to investigate the interactive effects of the ocean and atmosphere in the hurricane environment. Project personnel include Yoshio Kurihara, Robert Tuleya, Morris Bender, Rebecca Ross and Isaac Ginis.

3.4 Phillips Laboratory, Geophysics Directorate (formerly, AFGL).

3.4.1 Hurricane Algorithms for Next Generation Weather Radars (NEXRAD). Composite hurricane wind data are used to develop hurricane monitoring algorithms for NEXRAD. The annual budget for this work is 2.5 staff years. The project manager is Ken Glover.

3.4.2 Satellite Observations of Tropical Cyclones. Techniques for estimating storm position and intensity based on SSM/I and Operational Line Scanner (OLS) Infrared (IR) imagery are being developed. These data are also being used to study the response of the microwave channels to conditions at the center of tropical cyclones. Methods for improving the display of microwave imagery to identify storm features are also being studied. The personnel involved in this project are Morton Glass and Gerald Felde.

3.5 Hurricane Research Division.

3.5.1 Synoptic-flow Experiments. Omega dropwindsonde observations are collected within about 1,000 km from the center of tropical cyclones to investigate the vortex steering flow. Thirteen cases have been obtained since 1982. The personnel involved in this project are Robert Burpee and James Franklin.

3.5.2 Dynamics of the Hurricane Core. Observational and theoretical studies of the evolution of the eyewall circulation are being carried out. Real-time aircraft data are analyzed to determine current intensity and short term intensity changes. Methods for objective track determination using spline-fitting techniques are also being tested in real-time. The personnel involved in this project are Hugh Willoughby, William Barry and Ed Rahn.

3.5.3 Vortex Motion and Dynamics. Two-dimensional (barotropic) and simple three-dimensional models are used to increase the understanding of vortex/environmental interaction. The personnel involved in this project are Lloyd Shapiro and Hugh Willoughby.

3.5.4 Boundary Layer Studies. Stepped-frequency Microwave Radiometer (SFRM) and C-band Scattermometer (C-SCAT) data from the NOAA WP-3D aircraft are being used to estimate the surface wind speed in tropical cyclones. Aircraft and buoy data are also being used to determine the relationships between flight-level and surface winds in hurricane boundary layers. Techniques are being developed to combine numerous data types using a spline-fitting technique to produce real-time surface wind analyses. The personnel involved in this project are Peter Black, Mark Powell and Sam Houston.

3.5.5 Development of a Nested Spectral Hurricane Forecast Model. Aircraft, satellite and conventional synoptic data are analyzed in real-time by fitting cubic B-splines to the observations on nested domains. This analysis is used to initialize a barotropic track forecast model. The personnel involved in this project are Mark DeMaria, K. Vic Ooyama and Sim Aberson.

3.5.6 Land-Falling Hurricane Structure. The evolution of the wind and precipitation structure of tropical cyclones during landfall is being studied using digitized National Weather Service (NWS) radar data. The personnel involved in this project are Peter Dodge, Michael Black, Mark Powell and Sam Houston.

3.5.7 Large-Scale Influences on Tropical Cyclone Intensity Change. An archive of wind and height analyses in the regions surrounding Atlantic tropical cyclones is being developed to study the effect of environment forcing on tropical cyclone intensity change. Statistical techniques are being used to develop a hurricane intensity prediction scheme that can be run in real-time. The personnel involved in this project are Mark DeMaria and John Kaplan.

3.6 Joint Typhoon Warning Center.

3.6.1 Position Estimation Techniques. Position estimation techniques are being improved by enhancing the resolution of the cold end of the temperature scale of geostationary infrared satellite imagery. This allows for easier identification of the curvature of convective elements which improves the position estimates. Techniques for enhancing the warm end of the temperature scale are also being developed to improve the position estimates of sheared systems where the low-level center is partially or completely exposed. This procedure also helps to identify land areas for gridding purposes. These techniques are especially useful at night. This project is led by Capt. Robert Hudson and is funded by the U.S. Air Force.

3.6.2 Storm Motion and Intensity Forecasting Improvements. A new tropical cyclone climatology is being developed to improve storm motion and intensity forecasting. The climatology can be accessed interactively on a desktop computer. The system can be used operationally to display the tracks of storms that are similar to the current storm of interest. This climatology can also be used to determine intensity trends. This project is led by Capt. Daniel Shoemaker and is funded by the U.S. Air Force.

3.6.3 Development of Meteorological Imagery, Data Display, and Analysis System (MIDDAS). NASA GSFC has developed a state of the art satellite processing and display system for tropical cyclone satellite reconnaissance at JTWC. This system is similar to McIdas and is tailored for the Pacific and Indian Ocean regions. The system incorporates data from geostationary and polar orbiting satellites. Among its capabilities will be pixel averaging techniques that will enable JTWC to develop techniques for improving the Dvorak method, for forecasting rapid deepening, and for estimating the 35-knot wind radius from infrared data. NASA Project Officer is Mr. Fran Stetina and the Air Force Project Officer is LtCol. Clifford Matsumoto. Implementation, evaluation, and operational software design are being handled by Capt. Dan Shoemaker, Capt. Bob Hudson, and MSgt. Charlie Bonini of the Air Force, and staff and contractors of NASA GSFC.

3.6.4 Objective Forecast Aid Verification. A study of objective forecast aids is underway to determine whether the performance of the aids depends on the synoptic conditions. The goal is to build an interactive data base which can be used to provide forecasters with a quantitative estimate of the confidence of the aids in a given situation. This project is a combined effort of the JTWC staff and is funded by the U.S. Navy.

3.6.5 Wind Estimation. A technique is being developed to estimate the outer wind structure from the Dvorak intensity estimate and a size parameter determined from infrared satellite imagery. Microwave imager and conventional data will also be used. Enhancement of the low-level temperatures from geostationary infrared satellite data is being used to infer areas of strong subsidence. This information is also used to determine changes in storm motion due to changes in position of pressure ridges. This project is led by Capt. Daniel Shoemaker and is funded by the U.S. Air Force.

3.7 National Hurricane Center.

3.7.1 Data Processing. Winds and heights from NMC analyses and forecast models are archived. Software for microcomputers is being developed to display data fields as well as storm tracks, warning areas, strike probabilities, and estimated wind distributions. The personnel involved in this project are Colin McAdie and Edward Rappaport.

3.7.2 Forecast Techniques. The statistical-dynamical track forecast model (NHC90) and the program for predicting the probabilities of a hurricane strike are being improved. The Automated Tropical Cyclone Forecast System (ATCF) developed by NRL is being adapted for use at NHC. Beta and Advection Model (BAM) track forecasts using a shallow, medium, deep layer horizontal winds are being compared. The personnel involved in this project are Jerry Jarrell, Colin McAdie, Edward Rappaport, James Gross, and Ray Fagen.

3.7.3 Satellite studies. Software is being developed for real-time display of rainfall and surface wind speed estimates from SSM/I data. Estimates of tropical cyclone intensities from satellites and aircraft are being compared. This project is lead by Edward Rappaport.

3.7.4 Storm Surge. Work is continuing in the preparation of a storm surge atlas for the U.S. coastline. The personnel involved in this project are Brian Jarvinen and Victor Wiggert.

3.8 National Meteorological Center.

3.8.1 Steering Current in a Track Forecast Model. A method is being developed to initialize a numerical model so the initial motion of the model storm matches the observed motion. This project is led by Makut Mathur.

3.8.2 Bogussing Technique for the Medium Range Forecast Model. A method to include the storm circulation in the Medium Range Forecast model is being developed. Commonly, the vortex is missing in the analysis or the vortex center and/or model precipitation fields are displaced from the observed locations. This project is led by Stephen Lord.

3.8.3 Initial Vortex Specification. A method to determine a bogus vortex that is dynamically consistent with the physics and large-scale features of a numerical model is being developed. This project is led by Stephen Lord.

3.9 NASA/Goddard Space Flight Center.

3.9.1 Remote Sensing of Precipitation in Tropical Cyclones. Techniques are being developed to estimate precipitation in the vicinity of tropical cyclones using passive microwave and infrared sensors. Efforts are being made to combine the infrared approach (which has greater temporal resolution) with the passive microwave technique (which has greater accuracy but is available less often). This research effort directed by Edward Rodgers and supports one-half person for 1 year.

3.9.2 Stratospheric Response to Tropical Cyclone Intensity Change. Upper-tropospheric/stratospheric exchange processes within and surrounding tropical cyclones will be examined numerically and observationally during the period of intensity change. These studies may provide information concerning the mutual response of the upper-troposphere/lower-stratosphere and tropical cyclones during intensification or weakening. This research effort is directed by Edward Rodgers and supports one person for 3 years.

3.9.3 Tropical cyclone precipitation response to intensity and motion change and environmental influence. This numerical and observational study will look at the relationship between the spatial and temporal change in tropical cyclone precipitation characteristics and tropical cyclone intensity and motion change. The study will also examine the relationship between the spatial and temporal changes in tropical cyclone precipitation and environmental forcing. The research effort is directed by Edward Rodgers and supports one person for 3 years.

3.9.4 Numerical Simulation of Tropical Cyclones. A 4-D data assimilation of satellite-derived precipitation rates in the simulation of Hurricane Florence (1988) is being carried out with the use of a mesoscale model. The model-based diagnostics from these simulations will be used to study the precipitation processes and dynamics of intensifying tropical cyclones. This research effort is led by V. Mohan Karyampudi and supports one and a half persons for 3 years.

3.10 National Environmental Satellite, Data, and Information Service.

3.10.1 Diurnal Variations of Tropical Cyclones. The diurnal variations of convective clouds in tropical cyclones were studied using infrared cloud-top temperature thresholds. The amplitude and phase of the oscillation depend strongly on the temperature threshold used, with more variation for colder temperatures. There is an early morning (near sunrise) maximum of cold (<65°C) IR cloud area, associated with convectively active tropical cyclones over the open ocean. The project leader is Raymond Zehr.

3.10.2 Objective Techniques to Estimate Tropical Cyclone Intensity. Improvements to the Dvorak technique of estimating tropical cyclone intensity from infrared (IR) imagery are being developed. Emphasis is on very intense storms and early stage systems. Multi-radius computation and time averaging techniques are being developed. Raymond Zehr is the project leader.

3.10.3 Outer Wind Estimates from Objective IR Techniques. Techniques are being developed to estimate the radius of 30-and 50-kt winds from IR imagery. Raymond Zehr leads this project.

3.10.4 Tropical Cyclone Genesis. Research is under way to improve understanding and enhance forecasting of the development of tropical cyclones from weak tropical weather systems. This project is lead by Raymond Zehr.

3.10.5 Cloud-track Wind Data Sets. Cloud-track winds are combined with radiosonde winds to produce tropical wind analyses. These analyses are being used to study the hurricane outflow layer. The project leader is Gary Ellrod, Satellite Applications Laboratory.

3.10.6 Water Vapor Image Techniques. 6.7-micrometer water vapor image techniques are under development to aid in forecasting tropical cyclone recurvature or non-recurvature. The project leader is Mike Mogil, Satellite Applications Laboratory.

3.10.7 New Cooperative Institute for Research in the Atmosphere (CIRA) Work-station Capabilities and New Satellite Data Types. A new Wide Word Workstation has been installed at CIRA, awaiting installation of a high speed data line. Improved capability for tropical cyclone forecast product development is anticipated. Special emphasis will be on techniques which utilize new satellite data types, such as the SSM/I on DMSP, and the Advanced Microwave Sounding Unit (AMSU) on NOAA satellites. The project personnel involved in this project are Raymond Zehr, Jim Purdom, NESDIS, Fort Collins, Co; and Debra Lubich CIRA, Fort Collins, CO.

3.11 Naval Research Laboratory, Marine Meterology Division (formerly NOARL WEST and NEPRF).

3.11.1 Tropical Cyclone Forecasters Handbook. Forecasters' experiences are being compiled in a handbook. This project is led by LT Rich Jefferies.

3.11.2 Tropical Cyclone Artificial Intelligence Project. Tropical cyclone forecasting knowledge is being assembled into a rule-based expert system in parallel with the development of the forecasters handbook. This project is led by Mr. Buck Sampson.

3.11.3 Navy Operational Global Atmospheric Prediction System (NOGAPS) tropical cyclone forecast verification. The NOGAPS model is being verified to assess how well it forecasts motion, genesis, and intensity, and rules of thumb will be developed for use of the model. This project is led by Dr. Jim Goerss.

3.12 Naval Research Laboratory.

3.12.1 Numerical Modeling of Tropical Cyclones. A modeling effort is ongoing to understand the dynamic and thermodynamic structure changes in tropical cyclones in interaction with their environments. The environmental forcing under study includes sea surface temperature, large-scale wind shear, upper-troposhperic troughs, landfall and dry air intrusion. The effect of assimilation of various remote sensing data on the model forecast capability is also being examined. A coupled air-sea interacting model is also being constructed jointly with NRL Atmospheric Division to study the air-sea interaction problem. The personnel involved at NRL are Simon Chang, one Post Doctoral Fellow, one Ph.D. and one M.S. student. This effort is supported by NRL, Office of Naval Research (ONR) and NASA.

3.13 Colorado State University.

3.13.1 Tropical Cyclone Genesis Versus Prominent Tropical Disturbance Non-genesis. The personnel involved in this project are William Gray, Raymond Zehr (NOAA) and one Ph.D. student. This work is supported by the Phillips Laboratory.

3.13.2 Tropical Cyclone Motion as Related to Steering Flow and Recurvature. The personnel involved in this project are William Gray and two M.S. students. This work is funded by the ONR.

3.13.3 Tropical Cyclone Intensity: Factors That Best Tip Off Rapid Deepening Versus Non-deepening. The personnel involved in this project are William Gray, Raymond Zehr (NOAA) and one M.S. student. This work is supported by the Phillips Laboratory.

3.13.4 Seasonal Tropical Cyclone Frequency and Intensity Prediction in the Atlantic and Western North Pacific. The leader of this project is William Gray. This work is supported by the National Science Foundation (NSF).

3.14 Florida State University.

3.14.1 Numerical Prediction of Tropical Cyclones. Numerical prediction of tropical cyclones is being studied using two models. One is a high-resolution global spectral model with a triangular truncation of 170 (T170). The other is a mesoscale regional model with a horizontal resolution of about 50 km. The focus of the work is on the recurvature problem with the global model and on the landfall problem with the regional model. The sensitivity to enhanced vertical resolution near the tropopause (outflow) level and the importance of the divergent component of the wind are being studied with the global model. The regional model is being used to develop parameterizations of land surface processes, including ground wetness. Satellite and surface based data sets are used with the regional model to develop the parameterizations. The personnel involved in this project are T.N. Krishnamurti, D. Oosterhof, K.S. Yap and Jack Beven. This work is funded by the NSF and the ONR.

3.14.2 Mechanisms of Hurricane Formation and Intensification. The effect of eddy heat and momentum fluxes on tropical cyclone genesis and intensification is being studied using theoretical and numerical modeling approaches. The personnel involved in this project are Richard Pfeffer and Malakondayya Challa. This work is funded by NOAA.

3.15 Massachusetts Institute of Technology.

3.15.1 Finite-amplitude Nature of Tropical Cyclogenesis. A theoretical analysis is being performed to understand why a finite-amplitude "starter" is needed to initiate tropical cyclone intensification. The personnel involved in this project are Mark Handel and Kerry Emanuel. This work is supported by the NSF.

3.15.2 Interaction of Tropical Cyclones with the Ocean. The negative feedback of sea surface temperature decreases on tropical cyclone intensity is being studied using coupled air-sea models. An observational study is also being performed to relate reduced cyclone intensity to the depth of the oceanic mixed layer and the size and speed of motion of tropical cyclones. The personnel involved in this work are Kerry Emanuel, R. Rotunno, P. Gallacher and Lars Schade. This work is supported by the NSF.

3.15.3 The Role of Upper Troposphere Potential Vorticity Anomalies in Tropical Cyclogenesis. An observational study is being performed to determine the relationship between the transformation of weak disturbances into tropical cyclones and the approach of upper-tropospheric potential vorticity anomalies. The personnel involved in this project are Kerry Emanuel and Daniel Reilly. This work is supported by the NSF.

3.15.4 Large-scale Vertical Wind Shear. The effect of large-scale vertical wind shear on the steering of tropical cyclones (a theoretical study) is being performed to understand the effect of vertical wind shear on the interaction of upper- and lower-tropospheric potential vorticity anomalies associated with tropical cyclones. The personnel involved in this project are Kerry Emanuel and Chun-Chieh Wu. This work is supported by the NSF.

3.16 Naval Postgraduate School.

3.16.1 Basic Research Studies. Two of the basic research projects are in support of the ONR tropical cyclone motion initiative. The primary focus of the group under R. L. Elsberry is the interaction between the tropical cyclone and the adjacent synoptic features that lead to changes in the track. Observational studies using the NASA DC-8 flight-level observations and dropwindsondes and the NPS radar wind profiler at Okinawa are in progress. The control of tropical cyclone track types (recurvers versus straight-movers) by large-scale circulations that vary on intraseasonal time scales is being addressed. A group led by R. T. Williams is using analytical and numerical models to understand the dynamics of tropical cyclone motion. The effects of environmental wind shear and of the vortex wind structure on tropical cyclone motion are being studied. These two projects are funded by ONR and the NPS Direct Research fund and involve four faculty members, two Ph.D. students and two M.S. students.

Another basic research project led by C.-P. Chang and R. T. Williams has begun. It is an observational and numerical model study of the effect of the Taiwan orography on the pressure, wind and precipitation distributions associated with typhoons. This NSF-funded project also involves two adjunct professors.

3.16.2 Applied Research Studies. The applied research studies are in support of the JTWC. Evaluation of the objective aids for such characteristics as time consistency is an example of these studies. An empirical orthogonal function representation of the vorticity field has been proposed as a forecast tool. This representation is also being tested as a tool for forecasting recurvature and the time-to-recurvature. Two faculty members and two M.S. students are being funded by the NPS Direct Research Fund for these studies.

3.17 North Carolina State University.

3.17.1 Rainfall Prediction of Landfalling Hurricanes. A statistical method is being developed to predict the rainfall from landfalling tropical cyclones. Surface observations from about 20 storms that struck the Atlantic coast during the period 1950-1989 are being used to relate rainfall patterns to storm and climatological characteristics. A study of gulf coast storms is also planned. The personnel involved in this study are Jerry Davis, Debbie Dutcher and Julie Enman.

3.18 Pennsylvania State University.

3.18.1 Participation in the ONR Tropical Cyclone Motion Experiment. Two wind profilers and a variety of other ground-based remote sensing devices were taken to the western North Pacific region during July-September 1990 for the ONR experiment. The PSU work will focus on the principal rainbands that pass over the instrumented site and on upper level outflow jets. The personnel involved in this work are William Frank and Dennis Thomson in collaboration with Greg Holland of The Bureau of Meteorology Research Center, Australia.

3.18.2 Numerical Modeling of Tropical Cyclogenesis. Three-dimensional model simulations are used to study mesoscale vortex formation in convective systems. It will be determined whether the vortices that form in the middle levels in convective systems over land will extend downward to the surface and become coupled with the warm oceanic energy source in a maritime environment. The personnel involved in this work are William Frank and Shuyi Chen. This work is funded by the NSF.

3.19 State University of New York at Albany.

3.19.1 Generation of Outer Wind Maxima in Incipient Tropical Cyclones. Reconnaissance data are used to describe the response of developing tropical cyclones to interactions with their environment. The goal is to understand the processes by which upper tropospheric vorticity maxima interact with the inner core of incipient hurricanes, particularly with regard to development of contracting wind maxima. Personnel involved are John Molinari and David Vollaro. The work is funded by NOAA.

3.19.2 External Influences on Tropical Cyclones. The role of upper tropospheric potential vorticity maxima in both the development and reintensification of tropical cyclones is examined. Emphasis is placed on past storms which showed unusual intensification rates. Personnel are John Molinari, David Vollaro, and Frank Alsheimer. This work is supported by the NSF.

3.19.3 Tropical Cyclone Formation from Baroclinic Systems. Tropical storm formation in a baroclinic environment seems to occur in roughly 5% of all storm development cases. These types of developments are being studied using an observational approach. The typical development scenario is the formation of a wave cyclone along an old decaying frontal boundary from higher latitudes. Spin up to tropical storm stage is possible if a potential vorticity (PV) anomaly aloft begins to approach the incipient low-level disturbance and mid-levels are sufficiently moistened and destabilized. Surface sensible and latent heat fluxes are important in the destabilization process. This project is led by Lance Bosart.

3.20 University of Guam.

3.20.1 Influence of Multi-Vortex Interactions on Tropical Cyclone Motion. Observational and theoretical studies on the interaction of tropical cyclones with environmental vortices including other tropical cyclones are being carried out by M. A. Lander in collaboration with G. H. Holland of the Bureau of Meteorology Research Center in Australia.

3.20.2 The Wind Structure of Tropical and Sub-Tropical Cyclones. Observational and theoretical studies on the wind structure of tropical cyclones, monsoon depressions, and sub-tropical cyclones are in progress with JTWC. This project is led by M. A. Lander, and funding is provided by ONR.

3.20.3 The Structure and Mechanics of an Active Monsoonal Trough. Observational and theoretical studies are underway with JTWC to study the structure and mechanics of active monsoonal troughs, monsoon surges, and monsoon depressions with respect to tropical cyclone genesis, motion, intensification, and wind structure. This project is led by M. A. Lander, and funding is provided by ONR.

3.21 University of Hawaii.

3.21.1 Observational and Theoretical Aspects of Tropical Cyclone Motion. Tropical cyclone motion is being studied using observational studies, numerical modeling of specific cases and idealized cases, and the development of a nonlinear theoretical model. The emphasis of this work is on western North Pacific typhoons. The personnel involved in this work are T.A. Schroeder and B. Wang.

3.21.2 Tropical Cyclone Outflow Layer. Theoretical and numerical studies of the instability of the outflow layer are being carried out. The leader of this project is D.E. Stevens.

3.22 University of Massachusetts.

3.22.1 Microwave Remote-Sensing Measurements of Ocean Surface Winds in Hurricanes. A C-Band Stepped-Frequency Microwave Radiometer (SFMR) and a C-band Scatterometer (C-SCAT) on the NOAA WP-3D aircraft are being used to remotely measure surface wind speeds and rain rates in hurricanes. The SFMR project is led by Calvin Swift and is funded by NOAA. The C-SCAT project is lead by Robert McIntosh and is funded by NASA.

3.23 University of Wisconsin.

3.23.1 Evaluation of Visible Infrared Spin-scan Radiometer Atmospheric Sounder (VAS) Data. The quality and utility of VAS data are being evaluated in tropical analyses using dropwindsonde data as verification. Water vapor imagery is being investigated as a way to provide midtropospheric wind information. A method is also being developed to estimate sea-surface temperatures from the VAS data. The leader of these projects is Chris Velden.

3.23.2 Effect of Satellite-derived Winds on Hurricane Track Forecasts. The effect of high-density satellite-derived winds in the tropical cyclone environment is being evaluated with a barotropic hurricane track forecast model. The leader of these projects is Chris Velden.

3.23.3 Hurricane Intensity Estimation from TIROS Microwave Data. Passive microwave observations from the NOAA polar-orbiting satellites are used to estimate the surface pressure in tropical cyclones. A model has been developed for Atlantic storms and a western North Pacific typhoon study is under way. Project participants are Bob Merrill and Chris Velden.

3.23.4 Observation of Tropical Cyclones from Microwave Data. The SSM/I has been used to determine center fixes of tropical cyclones and a model is under development for tropical cylone rainfall estimation. Chris Velden and Bill Olson are the project leaders.

3.23.5 Tropical Cyclone Motion Studies. The relationship between tropical cyclone motion, the depth of the environmental flow and intensity are being investigated with a barotropic track forecast model. A study in the Australian area has been completed, with a comparable study over the Atlantic underway. This project is supported by ONR and the investigator is Chris Velden.

3.23.6 Typhoon Motion Experiment Participation. Satellite data were collected, archived, postprocessed and disseminated during the 1990 ONR tropical cyclone motion experiment (TCM-90) in the western North Pacific. Currently, high density cloud motion wind sets are being produced. Chris Velden and Bob Merrill are the personnel involved and this project is supported with funds from the ONR.

3.23.7 Investigation of Tropical Cylcone Outflow Layer. Outflow layer structure will be analyzed in isentropic coordinates from several cases during TCM-90 to further understanding of the vertical structure and its interaction with the tropospheric and stratospheric environment, which may be important to tropical cyclone intensity. This project is funded by NSF. Bob Merrill is principal investigator and Chris Velden is co-investigator.

CHAPTER 4

REQUIREMENTS COMPARED WITH ONGOING RESEARCH

In this national plan, it was deemed appropriate to compare the ongoing research presented in Chapter 3 with pressing forecast problems described in Chapter 2. The comparison was made by the Ad Hoc Group and in subsequent correspondence and discussions with the research community. The purpose was to highlight important areas that are not being researched or that are receiving disproportionate research attention. The expectation is that researchers would tend to gravitate toward problems not being addressed by other investigators and that funding agencies would more readily fund projects that are high-ranked on the list of pressing problems and not overworked by other groups. There is a tendency here to stress applied research, because the process started with a list of operational requirements from the field; however, the value of basic research is recognized and in many cases ongoing basic research is cited, which may now, or in the future, be applicable to stated problems.

The format of this section follows that of Chapter 2 in that the same topics are considered in the same order; however, the emphasis is on the known research that relates to the topics. Table 4.1 lists the pressing research items, in the same format as Table 2.1, and also shows the organizations that have research activity in those areas. Several of the "research activities" are, in fact, operational centers and in those cases the activity is best described as "technique development."

4.1 Position and Motion.

4.1.1 Positioning. The Hurricane Research Division of the Atlantic Oceanographic and Meteorological Laboratory (AOML) is heavily involved in positioning studies through the use of aircraft data. The Phillips Laboratory (U.S. Air Force) participates in this topic through its Special Sensor Microwave/Imager (SSM/I) related research. The University of Wisconsin (UWISC) is also involved in research in this area as it relates to satellite position estimates in general. The Joint Typhoon Warning Center (JTWC) is active in this area through its satellite data enhancement studies.

4.1.2 Initial Motion. This area was arbitrarily restricted to obtaining motion estimates independent of indicated fix-to-fix movement. All known, pertinent, research deals with estimation of the future basic motion from deep-layer mean fields and initiation of forecast models. A closely related topic is filtering the vortex (either bogus or natural) in the large-scale steering fields. The filtering problem research results should constitute an important approach to the initial motion problem. Estimating tropical cyclone motion from satellite data has been attempted by many groups and abandoned because the quantitative satellite data are too inaccurate for tropical regions and the qualitative information is not precise.

Table 4.1 Research Problems Versus Research Activities

Research objectives	Research Activities
Improve position and motion (see paragraph 4.1)	
Positioning	HRD, PL, UWISC, JTWC
Initial motion	NMC, NRL, FNOC
Track forecasts	Several
Improve surface wind description (see paragraph 4.2)	
Est. of intensity (max winds or MSLP)	Several
Intensity prediction	NESDIS, CSU, JTWC, HRD, GFDL
Wind structure	Several
Synoptic environment (see paragraph 4.3)	
Tropical analysis	HRD, FSU, NMC, UH
Exploit existing data	NRL, UWISC, NHC
Improve specification	Operational Centers
Improve forecasting	NMC, FNOC, HRD, GFDL
Tropical cyclone genesis	CSU, JTWC, GFDL, FSU, MIT
Upgrade other models	
Monsoon	FSU, ST LOU U, NPS
Trop upper tropospheric trough	NASA, UH
N. and S. Hemisphere twins	UG
Hybrid or semitropical cyclones	MIT, UG
Improve rainfall estimates and forecasts (see paragraph 4.4)	
TC-specific remotely sensed rainfall estimate	NASA, PL
TC rainfall forecasting techniques	NASA, HRD, UMASS, NCSU
Improve tornado understanding (see paragraph 4.5)	NSSL, PL, UOK
Improve storm surge prediction (see paragraph 4.6)	NHC, TDL, HRD
Improve sea state models (see paragraph 4.7)	
Estimation	AOML, FNOC
Forecasting	FNOC
Coastal effects	Unknown
Information and data management (see paragraph 4.8)	
Data requirements	NASA, NMC, HRD
Damage assessment	UCHI
Quantify and adjust satellite data for diurnel effects	JTWC, NESDIS
Tropical cyclone typing	Unknown
Objective aid design and performance	NRL, FNOC, JTWC, NHC, NMC
Evaluation of global models (see paragraph 4.9)	NMC, FNOC, NPS
Nonmeteorological items (see paragraph 4.10)	
Presentation of information	NASA
Action motivation studies	Unknown
Vertical refuge	TEXAS A&M
Communication	Unknown
Media interface	Unknown

4.1.3 Track Forecasts. Virtually all research activities with tropical cyclone programs have some effort in the track forecasting area. Currently, various organizations are studying this problem using data from Tropical Cyclone Motion experiment 1990 (TCM 90).

4.2 Surface Wind Description. Surface Wind description is widely recognized as the next major tropical cyclone forecast challenge after track forecasting. Here, also, there are many players and the variety can be partially attributed to available sensor data. There is a dearth of good surface truth data. For this reason, work at the University of Massachusetts (UMASS) on developing remote wind measuring equipment takes on a high level of importance. Hurricane Research Division (HRD), with NOAA's Aircraft Operations Center, has been heavily involved in validating that equipment. Colorado State University (CSU) has a history of using rawinsonde and archived aircraft data to examine various aspects of the tropical cyclone wind field. NASA/Goddard Space Flight Center (GSFC) has an involvement in trying to exploit current remote sensors and encourage development of advanced sensors. The National Environmental Satellite Data and Information Service (NESDIS) has been a leader in acquiring cloud drift winds ever closer to the tropical cyclone and improving pattern recognition techniques, which are in use worldwide to estimate intensities. The WSR-88D radars promise to offer some opportunities for near-coast and overland wind studies. Phillips Laboratory (PL) is developing Doppler radar hurricane algorithms.

4.2.1 Intensity (Maximum Winds/MSLP) Diagnosis. HRD is the leader in intensity diagnosis through use of measurements of surface winds. However, since aircraft are only available in the Atlantic and central Pacific, satellite-based intensity estimates will continue to be the mainstay. NESDIS and JTWC are the clear leaders in the development and improvement of satellite applications.

4.2.2 Intensity Prediction. Research on better prediction of intensity has been hampered to some extent by the quality of surface truth data. The real problem is that the emphasis simply has not been on intensity forecasting. The JTWC has a serious effort to develop intensity forecast techniques and there is some effort in this direction at NESDIS, CSU, and HRD. This is an area that is both important and not overloaded with investigators.

4.2.3 Wind Structure. This is an area where there are many players with little or no duplication of effort, because the problem is complex and probably does not have a single solution. The Environmental Group, U.S. Pacific Command, has endorsed a major Department of Defense (DOD) basic research initiative to study this problem.

4.2.3.1 Better Surface Wind Models. To our knowledge, no one is working on the problem of categorizing tropical cyclones by type as a preliminary to wind structure studies, except, JTWC with a minor effort and CSU with only an expressed interest in the topic. The UMASS Stepped-Frequency Microwave Radiometer (SFMR) study expects to improve the quality of wind field estimates.

4.2.3.2 Vertical Variability of Winds. Vertical reduction of aircraft flight-level winds is clearly an important part of the HRD research effort. Indirectly, these findings can apply to the more general problem of adjustment of winds to a standard reference level.

4.2.3.3 Nonstandard Wind-averaging Times HRD, in dealing with the variety of wind measurements, has had to resolve the issue of nonstandard wind averaging times. The solution to this problem may be a simple stability-dependent application of algorithms developed in the course of research.

4.2.3.4 Orographic Effects. Orographic effects relate to the other wind structure problems in that much of the available data suffer from orographic influence. Naval Research Laboratory (NRL) and Geophysics Fliud Dynamics Laboratory (GFDL) are investigating Tropical Cyclone (TC) interactions with various surfaces. Florida State University (FSU) is investigating landfall processes for the purpose of parameterization.

4.2.3.5 Surface Wind Depiction. The horizontal description of surface winds is related to the above topic of models of surface winds around tropical cyclones. To some extent, all centers dealing with surface winds are using and improving surface wind models (or perhaps more appropriately, parameterizations). There is no known research effort to improve tropical cyclone surface wind models.

4.2.3.6 Maximum Winds. In areas that have aircraft, the maximum winds problem will benefit directly from the HRD measurement efforts. NESDIS has a continuous project to improve the Dvorak-type pattern recognition scheme. JTWC has a similar project for the Eastern Hemisphere.

4.2.3.7 Minimum Sea-level Pressure. In areas that have aircraft, minimum sea-level pressure (MSLP) is not a problem because current measurements (or even extrapolations) are accurate enough for operational purposes. The reliability of MSLP estimates from satellites leaves much to be desired and, indeed, there is no known effort to develop a capability to directly measure surface pressure. Indirectly, an improvement in the Dvorak-type technique would also improve the estimation of MSLP.

4.3 Synoptic Environment.

4.3.1 Tropical Analysis. The operational numerical centers are constantly striving to improve the numerical objective analyses throughout the globe with generally less emphasis on the tropics. In recent years, this lack of emphasis on the tropics may have changed. National Meteorological Center (NMC), for example, has a strong program in place to cooperate with National Hurricane Center (NHC) in improving its tropical analysis. The problems are no longer just data problems. As more data have become available, largely in the form of cloud-drift winds, it has become apparent that the objective analyses are less sensitive to data than desired, and even the most common tropical features are not always depicted. Tropical waves, for example, are rarely depicted and tropical cyclone vortices are frequently misplaced.

4.3.1.1 Existing Data. Much of the ongoing effort at NMC, and at such places as the UWISC, is to exploit the existing data, primarily satellite winds. The former has concentrated on model mechanics that tend to exclude data in areas of large change, while the latter has stressed maximum use of the available data to support a vertically consistent three-dimensional analysis. The University of Hawaii (UH), FSU, HRD, and NRL Atmospheric Division have active programs in this area. The NHC is committed to maintaining a quality analysis as part of its World Meteorological Organization (WMO), Regional Specialized Meteorological Center (RSMC) responsibilities and for its own internal use.

4.3.1.2 Improve Specification. Two NHC objectives are to portray the synoptically important features of the tropics and to create data files that will cause the NMC analysis to do likewise. It is expected that attainment of these goals will require an experienced tropical analyst to interact with the NMC computers. The operational centers are concurrently improving their objective analysis models.

4.3.2 Improve Forecasting. There is ongoing work at NMC, FNOC, HRD, and GFDL to improve aspects of the global models. New, large and fast computers will permit fine resolution models. There should be some improvement as smaller scales are resolved.

4.3.3 Tropical Cyclone Genesis. There is ongoing work in tropical cyclone genesis at CSU, JTWC, GFDL, MIT, and FSU.

4.3.4 Upgrade Other models.

4.3.4.1 Monsoon Models. Monsoons are being studied at FSU, St. Louis University (ST LOU U) and the Naval Postgraduate School (NPS). While details are unknown, this work appears to be aimed at increasing basic understanding of the phenomena.

4.3.4.2 Tropical Upper Tropospheric Trough (TUTT) Model. The TUTT has been, and continues to be, an ongoing project at the UH. GSFC also has an ongoing research project on the TUTT.

4.3.4.3 Twin Cyclones. The UG has an interest in twin cyclones; however, the extent of their research program is unknown.

4.3.4.4 Hybrid Storm Systems. Massachusetts Institute of Technology (MIT) and UG have an interest in hybrid storm systems; however, the extent of their research program is unknown.

4.4 Rainfall. GSFC and PL/GPA have ongoing tropical rainfall remote-sensing programs. NCSU is developing a statistical rainfall prediction scheme for landfalling storms.

4.5 Tornadoes. The National Severe Storms Laboratory (NSSL), PL, and the University of Oklahoma (UOk) have research programs that include studies of tornadoes around tropical cyclones.

4.6 Storm Surge. The NHC, the National Weather Service (NWS) Techniques Development Laboratory, and HRD have programs to improve storm surge prediction.

4.7 Sea State. The sea state has been researched primarily at AOML and at NRL working with FNOC.

4.7.1 Estimation. Historically, AOML has researched the improvement of tropical-cyclone-related sea-state specification, but is not currently studying this problem. In the absence of observations, the centers must estimate the radius of 12-ft seas on the basis of tropical cyclone characteristics. A parametric model developed several years ago at AOML (Duncan Ross model) satisfies this requirement; however, it should be tested operationally.

4.7.2 Forecasting. The Navy has progressed considerably in forecasting sea states. A very good model, developed by Cardone (Oceanweather, Inc.), resides at FNOC. It is unclear whether this model would satisfy the operational requirements of the tropical cyclone forecast centers.

4.7.3 Coastal Effects. There is no known program in support of tropical-cyclone-related coastal effects problems (see paragraph 2.7.3).

4.8 Information and Data Management.

4.8.1 Data Requirements. NASA has a program to specify data requirements as related to future satellite design. NMC has an effort to determine the utility of various data types in model initialization. HRD has been in the forefront of applying new airborne measurement techniques. There is no known program to specify data requirements based on reducing uncertainty in tropical cyclone impact forecasts.

4.8.2 Damage Assessment. The University of Chicago (UCHI), under T.T. Fujita, has a program of damage assessment. It is not known to what extent this program could address the damage assessment concerns expressed in paragraph 2.8.2.

4.8.3 Quantify and Adjust Satellite Data for Diurnal Effects. The JTWC and NESDIS (under Zehr,) have projects to quantify and adjust satellite data for diurnal effects.

4.8.4 Tropical Cyclone Characteristics Typing. Tropical cyclone characteristics typing was considered by the ad-hoc group to be a novel and worthwhile project; however, there is no known program using this approach.

4.8.5 Objective Aid Design and Performance. NRL Marine Meteorology Division, FNOC and JTWC have projects in the area of objective aid design and performance. Since there is very little continuity between the aids in different basins, the work that is primarily targeted to the western North Pacific will have little application in other areas. NHC and NMC are studying the performance and improving the design of aids for the Atlantic basin.

4.9 Global Model Evaluation. NMC, FNOC, NPS, and other universities and operational centers have programs to evaluate operational global models. NHC and JTWC have supported short-term trouble-shooting projects when erratic or poor performance by a usually reliable model suggests a flaw in an underlying global or regional model.

4.10 Nonmeteorological Items. Research on nonmeteorological items has not been conducted by labs or universities in connection with meteorology research programs. FSU (Geography Department) and the University of Minnesota (UMINN) have had programs in these areas.

4.10.1 Presentation of information. NASA is studying the problem of information dissemination in a general sense; and there probably are many universities and private companies also pursuing this topic. Nevertheless, there is an obvious opening for studies on how to present specific TC information to the public to maximize understanding.

4.10.2 Action Motivation Studies. The UMINN, FSU, and the Hazards Management Group (a private company) have been involved in action motivation studies. Such efforts have influenced almost every aspect of the warning process and should be continued.

4.10.3 Vertical Refuge. Vertical refuge is important to several communities along the Atlantic and Gulf coasts, and to several legislatures. Research in this topic is underway at the College of Architecture, Texas A&M University. Until prototype legislative solutions are developed, this remains a fertile area for academic research.

4.10.4 Communications. There is no known research program in tropical cyclone communications.

4.10.5 Media Interface. There is no known research program in media interface with forecasting organizations.

CHAPTER 5

ASSESSMENT OF PROMISING TECHNOLOGY

Forecasters and numerical models continue to suffer from the lack of quantitative data over the tropics and sub-tropics. Therefore, analyses require manual interpretation of qualitative information. The next generation Geostationary Operational Environmental Satellite (GOES) series satellites, with the first satellite in the series planned for launch during 1993, is expected to provide more accurate and higher resolution "sounding" data than presently available from geosynchronous satellites. Similar improvements are expected from polar-orbiter satellite systems. However, much of the information available to the analyst will remain qualitative in nature. Therefore, it is expected that the best possible analysis for the tropical and sub-tropical regions will involve a man/computer interactive multiple level analysis scheme with an initial objective analysis modified by the analyst. Although quite difficult, the scheme should contain four-dimensional checks for dynamical consistency. Such a scheme is being pursued at NHC. These new sounding capabilities and this analysis approach should improve initial analyses and forecasts of the large scale flow patterns over the tropical and sub-tropical regions. However, it is likely that the accuracy of these analyses and forecasts will continue to lag those at mid-latitudes where more quantitative data are available.

5.1 Improved Models. Modelers indicate that improved initial data sets, in the tropical cyclone, its near environment, and over the general tropical and subtropical belt, will result in significant improvements in tropical cyclone track and intensity predictions. Any major improvements in longer range forecasts (36- to 72- hours) will likely only come through improved dynamical models. Global, hemispheric, and regional models have shown considerable promise in recent years for forecasting storm motion. Such models showed some excellent forecasts for Hugo, but they also suffered from a lack of consistency. These models are presently out-performed by statistical/dynamical models through 72-hour forecast periods, but have been closing the gap in recent years. In addition, these dynamic models often provide the best guidance available for difficult forecast situations.

5.1.1 Statistical/Dynamical Models. Statistical/dynamical models will likely continue to be the best performers for tropical cyclone track predictions, for the next several years, through forecast periods up to 36 hours or more. Results from improved versions of NHC83, (called NHC90) indicate that tropical cyclone forecast track errors might be reduced by as much as 10 to 20 percent through the use of these types of models over the next few years, depending upon the performance of the associated dynamical model.

5.1.2 Mesoscale Models. In addition to the models cited above, mesoscale models such as the new ETA coordinate system model, under development and testing at NMC, are showing great promise. Hopefully, these models and perhaps the regional and hemispheric dynamical models mentioned earlier will start to show some skill in the prediction of tropical cyclone formation and intensity. Such skill is sorely lacking at this time.

5.2 <u>Improved Observations</u>. Methods for observations in and around tropical cyclones continue to improve.

5.2.1 Satellite Observations. New satellite technology includes the Air Force Special Sensor Microwave/Imager (SSM/I) system aboard a polar orbiting satellite. This system shows promise for improved rainfall estimates and surface wind estimates outside of high rain rate areas where wind speeds are less than 30 to 50 knots . The microwave sensor also provides essentially a "smeared" radar image which can help in center locations of tropical cyclones.

5.2.2 Lightning Detection. Lightning detection systems are also coming into use for monitoring the convective activity in hurricanes well away from land. These systems have a potential for tracking movement of the convective bands and "eyewall" and perhaps to infer intensity changes.

5.2.3 Aircraft Observations. New aircraft capabilities include the Air Force Improved Weather Reconnaissance System (IWRS) capabilities using satellite data links which provide detailed wind fields in real time for operational use in storm surge calculations and damage potential warnings. Also these systems provide capabilities for improved tropical cyclone tracking using the mass field, a methodology that has shown potential for significant improvement in the 12- to 36-hour forecasts.

Present operational reconnaissance aircraft provide valuable data in the core of the hurricane. However, these data are generally limited to measurements taken along the flight path or to dropwindsonde data below it at infrequent intervals. These aircraft are also slow. Doppler radar capabilities are now an integral part of NOAA's research aircraft operations. These systems provide entire data fields within several miles of the path of the aircraft. Even though remote sensing technology continues to advance, the use of satellite-based sensors in the core of the hurricane is rather limited, partially due to the poor resolution provided from orbital altitudes of 400 miles or more. Perhaps these same sensors could be adapted for use on fast, high-altitude jet aircraft. The result could be a comprehensive data set provided by the aircraft flying through the storm and satellite surveillance of the storms environment. Also, single or orthogonal passes through the tropical cyclone could quickly provide entire data fields. This would permit more time for near-environment sampling for model use and assist in "calibration" of the coarse satellite data. Shorter response times for the faster aircraft would reduce the number of flights scheduled and subsequently canceled after deployments due to more recent data. The combination of all these factors would not only mean that data coverage would be greatly improved, but that perhaps four or five specially equipped aircraft could meet the

Atlantic basin operational data needs as compared to maintaining large reconnaissance squadrons with aging aircraft.

The possibility of long-range, high-altitude pilotless flights with multiple dropsonde capability is very exciting. This capability would provide the opportunity to enhance the observations of the synoptic scale environment surrounding a hurricane located over an oceanic data-sparse area and to, therefore, increase the accuracy of hurricane track and, possibly, intensity forecasting.

5.2.4 Radar Observations. The addition of doppler capabilities for the NWS Next Generation Weather Radars (NEXRAD) systems will add a new dimension to hurricane warning capabilities. These systems are scheduled for installation along the Gulf of Mexico and Atlantic coasts of the U.S. during the early and mid 1990's. The doppler capabilities will provide much needed information on tropical cyclone wind fields and their changes as they move inland (Ref Wood and Marks, 1989). These and other capabilities will permit more refined warnings during hurricane events. It is envisioned that there will be warnings within warnings. That is, hurricane warnings will be issued for a broad area of the coast, as they are today, to provide time for evacuations and other preparations, well in advance of the arrival of strong winds and heavy rains on that coast. The NEXRAD system will then be used by local NWS offices to provide short term warnings as rainbands, high winds, and possibly tornadoes move toward specific locations. This will permit incomplete emergency preparations to continue in safety until more extreme conditions approach.

In addition to the wind and storm surge problems normally associated with hurricanes as they approach the coast, heavy rains and flooding frequently occur over widespread areas extending well inland. The NEXRAD system should aid in improving rainfall forecasts and permit better warnings for inland river flooding such as that caused by hurricane Agnes in 1972. The remnants of Agnes caused major flooding from North Carolina through Pennsylvania and New York with the loss of 122 lives and $2 billion in damage.

5.3 <u>Improved Data Processing</u>. Improved observing systems and anticipated improvements in analysis, forecasting and warning programs require efficient accessing, processing and analyzing of large quantities of different types of data from numerous sources. These data also provide the opportunity for improved forecasts from numerical models.

5.3.1 National Meteorological Center Computer. The class VII computer scheduled for NMC at Suitland, MD will permit operational implementation of next generation hurricane prediction models.

5.3.2 Advanced Weather Interactive Processing Systems (AWIPS). Products must be provided to users which optimize desired responses. The AWIPS will be the primary tool for accomplishing this task. Critical meteorological information required by local, state and federal officials and private industry, can be displayed graphically and either accessed or transmitted to users. For example, warning areas, predictions of coastal flooding, expected rainfall, maps of probabilities, etc., would be generated and made accessible to users. Providing a uniform product for these users should then minimize chances of confusion and result in a more effective warning and evacuation process.

CHAPTER 6

TECHNOLOGY TRANSFER TO OPERATIONS

Several of the objectives adopted by the Ad Hoc Group for Tropical Cyclone Research (AHG/TCR) included the need to identify promising sensors, technologies or display/processing capabilities and plan interdepartmental cooperation to transfer these developments to operations. This is the first edition of the "National Plan" to include specific technology transfer candidates. The reason for the delay was that additional time was needed after the first edition was published to properly assess research progress and technology developments and coordinate plans for the transfer of promising technology or applications into tropical cyclone operations. The candidates listed below were coordinated and agreed upon by agency representatives at the January 1992 meeting of the AHG/TCR.

6.1 Candidate Research and Technology Developments for Transition to Tropical Cyclone Operations.

The format shown lists the title of the candidate followed by the primary point of contact (POC), the contact's organization, the transition period, and the action needed to complete the transition or operational testing of the candidate.

6.1.1. Automated Tropical Cyclone Forecast (ATCF) System for the Central Pacific Hurricane Center (CPHC).

- POC: Mr. Glenn Trapp, CPHC.
- Transition Period: FY92-93.
- Action Needed:
    - Adapting codes and software to CPHC.
    - Communication access to NMC/NHC/FNOC.

6.1.2. Martin - Holland Wind Distribution Technique.

- POC: LtCol. Charles Guard, JTWC.
- Transition Period: FY92-93.
- Action Needed:
    - Complete the documentation and crossfeed the technique for use in the central and eastern Pacific.

6.1.3. Saffir - Simpson Scale for the Pacific.

- POC: LtCol. Charles Guard, JTWC.
- Transition Period: FY93.
- Action Needed:
  - Complete the documentation and crossfeed the S-S scale for possible adaptation to the Caribbean.

6.1.4. Recurvature Index.

- POC: LT Jeffries, USN/NRL Monterey
- Transition Period: FY93.
- Action Needed:
  - Independent evaluation of the index.

6.1.5. Statistical Hurricane Intensity Prediction Scheme (SHIPS) Model.

- POC: Dr. Mark DeMaria, HRD.
- Transition Period: FY92-93.
- Action Needed:
  - Additional testing in the Atlantic (FY92)
  - Adapt for testing in the Pacific (FY93)

6.1.6. DMSP Sensor Data Applications.

- POC: LtCol. Ken Nash, AFGWC.
- Transition Period: FY92-93.
- Action Needed:
  - Investigate access to the DMSP data at NMC (FY92).
  - Adapt AFGWC applications techniques to NHC operations (FY93).

6.1.7. NESDIS Satellite Data Application Techniques.

- POC: Mr. Ray Zehr, NESDIS.
- Transition Period: FY92.
- Action Needed:
  - Investigate adaption of NESDIS satellite technique to NHC and NESDIS/SAB operations.

6.1.8. WP-3 Work Station Product Dissemination.

- POC: Dr. Bob Burpee, HRD.
- Transition Period: FY92-95.
- Action Needed:
  - Expand the availability of WP-3 Workstation products to NHC.

6.1.9. HRD Wind Analysis.

- POC: Dr. Mark Powell, HRD.
- Transition Period: FY93.
- Action Needed:
  - Enhance near real-time availability of the wind analysis.
  - Provide access to output for NHC operations.

6.1.10. Omega Dropwindsonde (ODW) Transition to Routine Operations.

- POC: Dr. Stephen Lord, NMC.
- Transition Period: FY94-95.
- Action Needed:
  - Program to fund the ODW transition, adapt the system to new sondes, and to upgrade the ODW system on NOAA WP-3s.

6.1.11. Stepped Frequency Microwave Radiometer (SFMR)

- POC: Dr. Peter Black, HRD and OFCM
- Transition Period: FY92-95.
- Action Needed:
  - Develop, test, evaluate and adapt the SFMR to WC-130 operations.

6.2 Future Activities

The AHG/TCR members and advisors will meet periodically to assess progress on the transfer of these candidate applications into tropical cyclone operations. They will also report such progress to the OFCM Working Groups for Hurricane and Winter Storm Operations and at the annual Interdepartment Hurricane Conferences. The AHG/TCR will also continue to identify additional sensor, technology or research candidates to coordinate and add to the Chapter 6 listings in subsequent years.

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APPENDIX A

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13. Simpson, R.H. "The hurricane disaster potential scale." *Weatherwise.* Vol 27 (1974), pp. 169-186.

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APPENDIX B

TROPICAL CYCLONE DATA SETS

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TROPICAL CYCLONE RESEARCH DATA SET

1. **DESCRIPTION OF DATA SET:**

   a. TITLE AND/OR STORM NAME: JOINT TYPHOON WARNING CENTER TRACK AND FIX DATA FOR TROPICAL CYCLONES
   b. DATA SET ID: Track and FIX
   c. START DATE: 1986
   d. STOP DATE: 1988
   e. PLATFORM AND SENSOR:
   f. GEOGRAPHIC COVERAGE: Western North Pacific, North Indian, South Indian, and South Pacific Oceans
   g. PRINCIPAL INVESTIGATOR: JTWC
   h. REMARKS: For Particulars Concerning Warning and Fix Data Prior 1986, Please contact the Joint Typhoon Warning Center (JTWC).

2. **PARAMETERS IN DATA SET:**

   a. FIX
      1) PARAMETER A: Satellite
      2) PARAMETER B: Aircraft (Dedicated Aircraft Recon Available until August 1987)
      3) PARAMETER C: Radar
      4) PARAMETER D: Synoptic
   b. TRACK
      1) PARAMETER E: Initial Warning (Position and Intensity)
      2) PARAMETER F: Best Track Position (Initial, Minus 12-and Minus 24-hour)
      3) PARAMETER G: Best Track Position (24-, 48- and 72-hour)
      4) PARAMETER H: JTWC Forecast (24-, 48- and 72-hour)
      5) REMARKS:

3. **STORAGE MEDIA:**

   a. MEDIUM: 5 1/4" Floppy Diskettes (IBM Compatible) or 3 1/2" (Macintosh Compatible)
   b. FILM SIZE: Contact JTWC
   c. FILE TAG: Track or Fix
   d. FORMAT: Contact JTWC
   e. REMARKS:

4. **HOW TO OBTAIN COPIES OF DATA SET:**

   a. INSTRUCTIONS: Please send data request to: NOCC/JTWC, COMNAVMAR Box 17, FPO San Francisco 96630-5000. Identify desired specifics, such as, year, area and include the appropriate number of disks.
   b. COST: None
   c. PAYABLE TO: N/A
   d. REMARKS:

5. **POINT OF CONTACT:**

   a. NAME: Frank H. Wells
   b. ADDRESS: NAVOCEANCOMCEN/JTWC
COMNAVMAR BOX 17
FPO San Francisco 96630-5000
   c. COMMERCIAL TELEPHONE: (671) 344-5240
   d. FTS: N/A
   e. AUTOVON: 344-5240 (GUAM)
   f. FACSIMILE TELEPHONE NUMBER: (671) 477-6186
   g. E-MAIL ADDRESS: N/A

TROPICAL CYCLONE RESEARCH DATA SET

1. DESCRIPTION OF DATA SET:

a.	TITLE AND/OR STORM NAME:	All Atlantic and East Pacific tropical cyclones
b.	DATA SET ID:	Digital geostationary (GOES) satellite data
c.	START DATE:	1981
d.	STOP DATE:	Present
e.	PLATFORM AND SENSOR:	GOES satellite
f.	GEOGRAPHIC COVERAGE:	Western Hemisphere
g.	PRINCIPAL INVESTIGATOR:	UW-Space Science and Engineering Center

h. REMARKS: Geographical coverage varies with satellite configuration (whether one or two satellites in operation)

2. PARAMETERS IN DATA SET:

a.	PARAMETER A:	Infrared imagery
b.	PARAMETER B:	Visible imagers
c.	PARAMETER C:'	Water vapor imagery
d.	PARAMETER D:	Multispectral VAS imagery
e.	PARAMETER F:	Navigation
f.	PARAMETER G:	

g. REMARKS: Digital data are in the form of brightness temperature
Nominally, IR and VIS, imagery is available at 30 min. intervals
Variable spatial and temporal coverage with water vapor and VAS data

3. STORAGE MEDIA:

a.	MEDIUM:	Computer compatible 9-track tapes (1600 or 6250 bpi)
b.	FILM SIZE:	Variable depending on geographic coverage
c.	FILE TAG: N/A	
d.	FORMAT:	Provided

e. REMARKS: Documentation on file structure and format is given in the first file of distributed tape. Videotapes (1/2" VAS) of selected satellite imagery from hurricanes Elena and Gloria (1985). Gilbert (1988) and Hugo (1989) are also available from Chris Velden ($20/tape, payable to the University of Wisconsin)

4. HOW TO OBTAIN COPIES OF DATA SET:

a.	INSTRUCTIONS:	Andy Horvitz Satellite Data Services Division. NOAA/NESDIS. Room 100. Princeton Executive Center Washington, DC 20233 (301) 763-8400
b.	COST:	$66/scene ($100 minimum)
c.	PAYABLE TO:	NOAA/NESDIS

d. REMARKS: payment in advance required; allow 4-6 weeks for delivery

5. POINT OF CONTACT:

a.	NAME:	Chris Velden or Robert Merrill
b.	ADDRESS:	University of Wisconsin - SSEC 1225 West Dayton Street Madison. WI 53706
c.	COMMERCIAL TELEPHONE:	(608) 262-9168 or 263-6842
d.	FTS:	364-5325
e.	AUTOVON: N/A	
f.	FACSIMILE TELEPHONE NUMBER:	(608) 262-5974
g.	E-MAIL ADDRESS:	R.FOX (OMNET) ATTN: C. Velden

TROPICAL CYCLONE RESEARCH DATA SET

1. DESCRIPTION OF DATA SET:

a. TITLE AND/OR STORM NAME:	Selected Atlantic storms
b. DATA SET ID:	GOES satellite derived cloud drift and water vapor motion winds
c. START DATE:	1985
d. STOP DATE:	1989
e. PLATFORM AND SENSOR:	GOES
f. GEOGRAPHIC COVERAGE:	Western Atlantic, Caribbean, Gulf of Mexico
g. PRINCIPAL INVESTIGATOR:	N/A
h. REMARKS: Nominal availability at 00 and 12 UTC Selected cases only	

2. PARAMETERS IN DATA SET:

a. PARAMETER A:	Wind speed (m/sec)
b. PARAMETER B:	Wind direction
c. PARAMETER C:	Wind height
d. PARAMETER D:	Wind type (cloud drift or water vapor motion)
e. PARAMETER E.	Station ID
f. PARAMETER F:	Lat/Long
h. PARAMETER G:	N/A
i. REMARKS:	N/A

3. STORAGE MEDIA:

a. MEDIUM:	Computer compatible 9-track tape
b. FILM SIZE:	Variable
c. FILE TAG:	N/A
d. FORMAT:	EBCDIC fixed block
e. REMARKS: Documentation will be provided	

4. HOW TO OBTAIN COPIES OF DATA SET:

a. INSTRUCTIONS:	Contact Chris Velden or Robert Merrill
b. COST:	Negotiable
c. PAYABLE TO:	TBD
d. REMARKS: Cost depends on size request	

5. POINT OF CONTACT:

a. NAME:	Chris Velden or Robert Merrill
b. ADDRESS:	University of Wisconsin - SSEC 1225 West Dayton Street Madison, WI 53706
c. COMMERCIAL TELEPHONE:	(608) 262-9168 or 263-6842
d. FTS:	364-5325
e. AUTOVON: (608) 262-5974	
f. FACSIMILE TELEPHONE NUMBER:	(608) 262-5974
g. E-MAIL ADDRESS:	R. FOX (OMNET) ATTN: C. Velden

TROPICAL CYCLONE RESEARCH DATA SET

1. **DESCRIPTION OF DATA SET:**

a.	TITLE AND/OR STORM NAME:	Selected Atlantic storms
b.	DATA SET ID:	VAS satellite soundings
c.	START DATE:	1985
d.	STOP DATE:	1988
e.	PLATFORM AND SENSOR:	GOES VISSR Atmospheric Sounder
f.	GEOGRAPHIC COVERAGE:	Western Atlantic, Gulf of Mexico
g.	PRINCIPAL INVESTIGATOR:	N/A
h.	REMARKS: Sounding availability is variable Physical simultaneous retrieval method used	

2. **PARAMETERS IN DATA SET:**

a.	PARAMETER A:	Temperature
b.	PARAMETER B:	Dew point
c.	PARAMETER C:	Height
d.	PARAMETER D:	Derived gradient winds (variable availability)
e.	PARAMETER E:	MSLP
f.	PARAMETER F:	Station elevation (m)
g.	PARAMETER G:	Station identification
h.	PARAMETER H:	Lat/Long
i.	REMARKS: MANDATORY LEVEL T, Td, Z, U, V	

3. **STORAGE MEDIA:**

a.	MEDIUM:	Computer compatible 9-track tape
b.	FILM SIZE:	312 bytes per report x # reports (typically 300)
c.	FILE TAG:	N/A
d.	FORMAT:	Fixed block EBCDIC
e.	REMARKS: Documentation will be provided	

4. **HOW TO OBTAIN COPIES OF DATA SET:**

a.	INSTRUCTIONS:	Contact Chris Velden or Robert Merrill
b.	COST:	Negotiable
c.	PAYABLE TO:	TBD
d.	REMARKS: Cost depends on size of request	

5. **POINT OF CONTACT:**

a.	NAME:	Contact Chris Velden or Robert Merrill
b.	ADDRESS:	University of Wisconsin - SSEC 1225 West Dayton Street Madison, WI 53706
c.	COMMERCIAL TELEPHONE	(608) 262-9168 or 263-6842
d.	FTS:	364-5325
e.	AUTOVON: N/A	
f.	FACSIMILE TELEPHONE NUMBER:	(608) 262-5974
g.	E-MAIL ADDRESS:	R. FOX (OMNET) ATTN: C. Velden

TROPICAL CYCLONE RESEARCH DATA SET

1. **DESCRIPTION OF DATA SET:**

a. TITLE AND/OR STORM NAME:	Digital Satellite Images
b. DATA SET ID:	ISCCP B1 GMS
c. START DATE:	July, 1983
d. STOP DATE:	Present
e. PLATFORM AND SENSOR:	GMS series of geostationary satellite
f. GEOGRAPHIC COVERAGE:	Sub-point: Equator, 140 E
g. PRINCIPAL INVESTIGATOR:	N/A

h. REMARKS: 3-hourly full disk at 10-km resolution in both visible and IR. A portion of this disk set is available at CIRA/CSU. The entire data set is available at: NOAA/NESDIS/NCDS Satellite Data Services Division, Rm. 100 Princeton Executive Center, Washington, DC 20233
Contact: Andy Horvitz, 301-763-8400 (See Para 4)

2. **PARAMETERS IN DATA SET:**

a. PARAMETER A:	IR brightness (equivalent blackbody temperature, conventional infrared imagery)
b. PARAMETER B:	Visible brightness (conventional visible imagery)
c. PARAMETER C:	Navigation and calibration information
d PARAMETER D:	N/A
f. PARAMETER F:	N/A
h. PARAMETER G:	N/A
i. REMARKS:	

3. **STORAGE MEDIA:**

a. MEDIUM:	9-track magnetic tape (6250 PI)
b. FILM SIZE:	1100 X 1100 X 8-bit
c. FILE TAG:	N/A
d. FORMAT:	N/A
e. REMARKS:	

4. **HOW TO OBTAIN COPIES OF DATA SET:**

a. INSTRUCTIONS:	Small data requests may be available from CIRA/CSU, for the cost of magnetic tapes and shipping. We have most of the data for the 6-month period, July 1-Dec 31, for 1983 through 1986. Some "hard-copy" images may also be available. Large data requests must be handled by NESDIS Satellite Data Services Division (See Para 1h).
b. COST:	TBD
c. PAYABLE TO:	TBD
d. REMARKS:	

5. **POINT OF CONTACT:**

a. NAME:	Raymond Zehr, NOAA/NESDIS/Debra Lubich, CIRA
b. ADDRESS:	CIRA Bldg. Colorado State University Fort Collins, CO 80523
c. COMMERCIAL TELEPHONE:	303-491-8446
d. FTS:	323-1124
e. AUTOVON: N/A	
f. FACSIMILE TELEPHONE NUMBER:	N/A
g. E-MAIL ADDRESS:	N/A

TROPICAL CYCLONE RESEARCH DATA SET

1. DESCRIPTION OF DATA SET:

a. TITLE AND/OR STORM NAME: Digital Satellite Images
b. DATA SET ID: GOES
c. START DATE: July, 3, 1991
d. STOP DATE: October 9, 1991
e. PLATFORM AND SENSOR: Conventional visible and infrared image data
f. GEOGRAPHIC COVERAGE: Sub-point: 98 deg West longitude
g. PRINCIPAL INVESTIGATOR: N/A
h. REMARKS: Three-hourly IR, 16 X 8 km resolution sector covering approximately 35N to 5S and 55W to 125W; 30-min VIS for about a 6-hr period each day, 4 km resolution sector covering the eastern Pacific region July 3 - Aug. 12, and the Atlantic-Caribbean region from Aug. 31 - Oct. 9.

2. PARAMETERS IN DATA SET:

a. PARAMETER A: IR brightness (equivalent blackbody temperature, conventional infrared imagery)
b. PARAMETER B: Visible brightness (conventional visible imagery)
c. PARAMETER C: Navigation and calibration information
d PARAMETER D: N/A
f. PARAMETER F: N/A
h. PARAMETER G: N/A
i. REMARKS:

3. STORAGE MEDIA:

a. MEDIUM: 9-track magnetic tape or optical disk
b. FILM SIZE: N/A
c. FILE TAG: N/A
d. FORMAT: N/A
e. REMARKS:

4. HOW TO OBTAIN COPIES OF DATA SET:

a. INSTRUCTIONS: Small hard-copy data requests may be available. Data display and navigation software may be available for DEC Vax workstations.
b. COST: TBD
c. PAYABLE TO: TBD
d. REMARKS:

5. POINT OF CONTACT:

a. NAME: Raymond Zehr, NOAA/NESDIS/Debra Lubich, CIRA
b. ADDRESS: CIRA Bldg.
Colorado State University
Fort Collins, CO 80523
c. COMMERCIAL TELEPHONE: 303-491-8446
d. FTS: 323-1124
e. AUTOVON: N/A
f. FACSIMILE TELEPHONE NUMBER: N/A
g. E-MAIL ADDRESS: N/A

TROPICAL CYCLONE RESEARCH DATA SET

1. DESCRIPTION OF DATA SET: NOAA P-3 Flight Level Data

- a. TITLE AND/OR STORM NAME: Numerous Atlantic Tropical Cyclones
- b. DATA SET ID: N/A
- c. START DATE: 1977
- d. STOP DATE: Present
- e. PLATFORM AND SENSOR: NOAA WP-3D Aircraft
- f. GEOGRAPHIC COVERAGE: Typically 0-2 degrees from storm center
- g. PRINCIPAL INVESTIGATOR: Hurricane Research Division
- h. REMARKS: Several Eastern Pacific Storms may also be available

2. PARAMETERS IN DATA SET:

- a. PARAMETER A: Horizontal wind
- b. PARAMETER B: Vertical wind
- c. PARAMETER C: Temperature
- d. PARAMETER D: Dew Point Temperature
- e. PARAMETER E: Height
- f. PARAMETER F: Estimated Surface Pressure
- g. PARAMETER G: Pressure
- h. PARAMETER H: Radiometer data
- i. REMARKS: Numerous other aircraft parameters are also available

3. STORAGE MEDIA:

- a. MEDIUM: Magnetic Tape
- b. FILM SIZE: N/A
- c. FILE TAG: N/A
- d. FORMAT: See para 3e
- e. REMARKS: Format, etc depend on flight and year.

4. HOW TO OBTAIN COPIES OF DATA SET:

- a. INSTRUCTIONS: Depends on size of request, contact 5a for further information
- b. COST: Variable
- c. PAYABLE TO: TBD
- d. REMARKS:

5. POINT OF CONTACT:

- a. NAME: Howard A. Friedman
- b. ADDRESS: 4301 Rickenbacker Causeway
NOAA/AOML/HRD
Miami, FL 33149
- c. COMMERCIAL TELEPHONE: 305-361-4319
- d. FTS: 350-1319
- e. AUTOVON: N/A
- f. FACSIMILE TELEPHONE NUMBER: N/A
- g. E-MAIL ADDRESS: N/A

TROPICAL CYCLONE RESEARCH DATA SET

1. DESCRIPTION OF DATA SET: NOAA P-3 Omega Dropwindsonde Data

a. TITLE AND/OR STORM NAME: Eight Tropical Cyclones since 1982
b. DATA SET ID: N/A
c. START DATE: 1982
d. STOP DATE: Present
e. PLATFORM AND SENSOR: NOAA WP-3D Aircraft
f. GEOGRAPHIC COVERAGE: Typically 0-10 degrees from storm center
g. PRINCIPAL INVESTIGATOR: Hurricane Research Division
h. REMARKS:

2. PARAMETERS IN DATA SET:

a. PARAMETER A: Horizontal Wind
b. PARAMETER B: Temperature
c. PARAMETER C: Dew Point Temperature
d. PARAMETER D: Pressure
f. PARAMETER F: N/A
h. PARAMETER G: N/A
i. REMARKS: Processed data usually at 50 mb intervals from surface to 400mb.

3. STORAGE MEDIA:

a. MEDIUM: Magnetic Tape
b. FILM SIZE: N/A
c. FILE TAG: N/A
d. FORMAT: See para 3e.
e. REMARKS: Format, etc. depend on flight and year

4. HOW TO OBTAIN COPIES OF DATA SET:

a. INSTRUCTIONS: Depends on site of request, contact 5a for further information
b. COST: Variable
c. PAYABLE TO: TBD
d. REMARKS:

5. POINT OF CONTACT:

a. NAME: Howard A. Friedman
b. ADDRESS: 4301 Rickenbacker Causeway
NOAA/AOML/HRD
Miami, FL 33149
c. COMMERCIAL TELEPHONE: 305-361-4319
d. FTS: 350-1319
e. AUTOVON: N/A
f. FACSIMILE TELEPHONE NUMBER: N/A
g. E-MAIL ADDRESS: N/A

TROPICAL CYCLONE RESEARCH DATA SET

1.	**DESCRIPTION OF DATA SET:**	NOAA P-3 Airborne Radar Data
a.	TITLE AND/OR STORM NAME:	Numerous Atlantic Tropical Cyclones
b.	DATA SET ID:	N/A
c.	START DATE:	1977
d.	STOP DATE:	Present
e.	PLATFORM AND SENSOR:	NOAA WP-3D Aircraft
f.	GEOGRAPHIC COVERAGE:	Typically 0-1 degrees from Storm Center
g.	PRINCIPAL INVESTIGATOR:	Hurricane Research Division
h.	REMARKS:	
2.	**PARAMETERS IN DATA SET:**	
a.	PARAMETER A:	Doppler winds (Since 1982)
b.	PARAMETER B:	Reflectivity (Since 1977)
c.	PARAMETER C:	N/A
d.	PARAMETER D:	N/A
f.	PARAMETER F:	N/A
h.	PARAMETER G:	N/A
i.	REMARKS:	
3.	**STORAGE MEDIA:**	
a.	MEDIUM:	Magnetic Tape
b.	FILM SIZE:	N/A
c.	FILE TAG:	N/A
d.	FORMAT:	See para 3d.
e.	REMARKS: Format, etc. depend on flight and year.	
4.	**HOW TO OBTAIN COPIES OF DATA SET:**	
a.	INSTRUCTIONS:	Depends on site of request, contact 5a for further information
b.	COST:	Variable
c.	PAYABLE TO:	TBD
d.	REMARKS:	
5.	**POINT OF CONTACT:**	
a.	NAME:	Howard A. Friedman
b.	ADDRESS:	4301 Rickenbacker Causeway NOAA/AOML/HRD Miami, FL 33149
c.	COMMERCIAL TELEPHONE:	305-361-4319
d.	FTS:	350-1319
e.	AUTOVON: N/A	
f.	FACSIMILE TELEPHONE NUMBER:	N/A
g.	E-MAIL ADDRESS:	N/A

TROPICAL CYCLONE RESEARCH DATA SET

1. DESCRIPTION OF DATA SET:

a.	TITLE AND/OR STORM NAMES AND DATES:	
	HURRICANE GILBERT	Sept. 10 to Sept. 17, 1988
	T. S. BERYL	Aug. 8, 1988 00Z
	T. S. FLORENCE	Sept. 7, 1988 12Z
	HURRICANE FABIO	Aug. 2, 1988 to Aug. 5, 1988
	T. S. ALETTA	June 17, 1988 to June 17, 1988
	T. S. GILMA	Aug. 2, 1988
	HURRICANE ULEKI	Aug. 29, 1988 to Aug. 30, 1988
	T. S. KEITH	Nov. 21, 1988, 00Z
e.	PLATFORM AND SENSOR:	N/A
f.	GEOGRAPHIC COVERAGE:	Global
g.	PRINCIPAL INVESTIGATOR:	John Ward
h.	REMARKS:	

2. PARAMETERS IN DATA SET:

a.	PARAMETER A:	Temperature
b.	PARAMETER B:	Vorticity
c.	PARAMETER C:	Divergence
d.	PARAMETER D:	Specific Humidity
f.	PARAMETER F:	N/A
h.	PARAMETER G:	N/A

i. REMARKS: T80 spectral coefficients from NMC aviation run 16 levels of information in sequence for forecast hours 0, 6, 12, 18, 24, 30, 36, 42, 48, 54, 60, 66, & 72.

3. STORAGE MEDIA:

a.	MEDIUM:	6250 9-Track Tape
b.	FILM SIZE:	N/A
c.	FILE TAG:	AVNCOF
d.	FORMAT:	VS
e.	REMARKS:	

4. HOW TO OBTAIN COPIES OF DATA SET:

a.	INSTRUCTIONS:	Write to: Director National Meteorological Center W/NMC, WWB, Rm. 204 Washington, DC 20233
b.	COST:	TBD
c.	PAYABLE TO:	TBD
d.	REMARKS:	

5. POINT OF CONTACT:

a.	NAME:	Dr. John H. Ward
b.	ADDRESS:	NMC W/WMC22, WWB, Rm. 204 Washington, DC 20233
c.	COMMERCIAL TELEPHONE:	(301) 763-8056
d.	FTS:	763-8056
e.	AUTOVON: N/A	
f.	FACSIMILE TELEPHONE NUMBER:	N/A
g.	E-MAIL ADDRESS:	N/A

TROPICAL CYCLONE RESEARCH DATA SET

1.DESCRIPTION OF DATA SET:

a. TITLE AND/OR STORM NAMES AND DATES:

T. S. KEITH	Nov. 21, 1988, 00Z
T. S. KEITH	Nov. 22, 1988, 00Z
HURRICANE JOAN	Oct. 14, 1988, 12Z
HURRICANE JOAN	Oct. 12, 1988, 12Z
HURRICANE HELENE	Sept. 22, 1988, 00Z
HURRICANE HELENE	Sept. 24, 1988, 12Z
HURRICANE COSME	June 21, 1989, 12Z
T. S. ALLISON	June 25, 1989, 12Z
HURRICANE DALILA	July 17, 1989, 12Z
HURRICANE DALILA	July 18, 1989, 00Z

d. STOP DATE: N/A
e. PLATFORM AND SENSOR: N/A
f. GEOGRAPHIC COVERAGE: Global
g. PRINCIPAL INVESTIGATOR: Mukut Mathur
h. REMARKS:

2. PARAMETERS IN DATA SET:

a. PARAMETER A: Temperature
b. PARAMETER B: Vorticity
c. PARAMETER C: Divergence
d. PARAMETER D: Specific Humidity
f. PARAMETER F: N/A
h. PARAMETER G: N/A
i. REMARKS: T80 spectral coefficients from NMC aviation run; 18 levels information in sequence for forecast hours 0, 6, 12, 18, 24, 30 36, 42, 48, 54, 60, 66, & 72.

3. STORAGE MEDIA:

a. MEDIUM: 6250 Magnetic Tape
b. FILM SIZE: N/A
c. File TAG: AVNCOF
d. FORMAT: VS
e. REMARKS:

4. HOW TO OBTAIN COPIES OF DATA SET:

a. INSTRUCTIONS: Write to:
Director
National Meteorological Center
W/NMC, WWB, Rm. 101
Washington, DC 20233

b. COST: TBD
c. PAYABLE TO: TBD
d. REMARKS:

5. POINT OF CONTACT:

a. NAME: Mukut Mathur
b. ADDRESS: NMC, W/WMC22, WWB, Rm. 204
Washington, DC 20233
c. COMMERCIAL TELEPHONE: (301) 763-8161
d. FTS: 763-8161
e. AUTOVON: N/A
f. FACSIMILE TELEPHONE NUMBER: N/A
g. E-MAIL ADDRESS: N/A

TROPICAL CYCLONE RESEARCH DATA SET

1.	**DESCRIPTION OF DATA SET:**	
a.	TITLE AND/OR STORM NAME:	NMC Global Tropical Cyclone Archive
b.	DATA SET ID:	(YYMMDDHH), HH=0., 12. HH=O contains 00, 06 UTC and HH=12 contains 12, 18 UTC files.
c.	START DATE:	Gloria, 20 Sep 1985 00 UTC - 28 Sep 1985 UTC Emily, 21 Sep 1987 00 UTC - 27 Sep 1987 12 UTC Floyd, 08 Oct 1987 00 UTC - 14 Oct 1987 12 UTC. Future cases to be archived include Gilbert and Joan (1988). In 1989 and subsequent years, we will archive most Atlantic hurricane cases, and in 1990 and subsequent years, we will archive selected storms from the East Pacific and the western North Pacific.
d.	STOP DATE:	Same
e.	PLATFORM AND SENSOR:	All operational observations gathered and processed by NMC, including upper air, surface, satellite winds, TIROS thickness aircraft and reconnaissance data.
f.	GEOGRAPHIC COVERAGE:	Global
g.	PRINCIPAL INVESTIGATOR:	Dr. Stephen J. Lord NMC, W/NMC2 WWB Rm. 204 Washington, DC 20233 (301) 763-8301
h.	REMARKS: Special requests for data sets not already gathers may be forwarded to the principal investigator above.	
2.	**PARAMETERS IN DATA SET:**	**Several subsets of files exist as follows:**
a.	PARAMETER A:	Operational analyses of wind, geopotential height, moisture on mandatory pressure levels with a special representation of Rhomboidal 40 waves.
b.	PARAMETER B:	Operational analyses on sigma coordinate surfaces represented as Triangular 80 waves.
c.	PARAMETER C:	Operational 6 hour forecasts on sigma coordinate surfaces represented as Triangular 80 waves valid at the analysis time. These forecasts are used as a background field for the model analysis.
d.	PARAMETER D:	Global observations as described in 1e above.
f.	PARAMETER F:	N/A
h.	PARAMETER G:	N/A
3.	**STORAGE MEDIA:**	
a.	MEDIUM:	Data sets are recovered from optical disk and copied to magnetic tape.
b.	FILM SIZE:	Approximately 7 days of twice daily files will fit on one tape.
c.	File TAG:	N/A

d. FORMAT: The data format may be either of two types as listed below.

1. IBM internal binary (all observations currently available only in this format).
2. WMO gridded bineary (GRIB) In this case, FORTRAN 77 code is available for unpacking the GRIB records. Precision is the full 32 bit representation for all spectral coefficients.

e. REMARKS: Data may be obtained by writing or telephoning the Principal Investigator in 1g above.

4.	**HOW TO OBTAIN COPIES OF DATA SET:**	
a.	INSTRUCTIONS:	Write to: Director, National Meteorological Center W/NMC, WWB, Rm. 101 Washington, DC 20233
b.	COST:	TBD
c.	PAYABLE TO:	TBD
d.	REMARKS:	
5.	**POINT OF CONTACT:**	
a.	NAME:	Dr. Stephen J. Lord
b.	ADDRESS:	See 1g
c.	COMMERCIAL TELEPHONE:	See 1g
d.	FTS:	763-8161
e.	AUTOVON: N/A	

TROPICAL CYCLONE RESEARCH DATA SET

1. DESCRIPTION OF DATA SET:

a. TITLE OR STORM NAME:	Tropical Cyclone Data Base
b. DATA SET ID:	Best Track, Forecasts and Fixes
c. BEST TRACK:	6 hourly lat, long, max winds
d. FORECASTS:	JTWC 24, 48, 72 forecast lat, long Objective aid 24, 48, 72 forecast lat, long
e. FIXES:	Satellite, Aircraft, Radar, Synoptic fixes

2. PARAMETERS IN DATA SET:

Time/Area Coverage

Basin	Latitude	Longitude	Best Track	Forecasts	Fixes
Western North Pacific (WP)	EQ-60N	100E-180E	1945-1990	1966-1977 1978-1990	1966-1977 1979-1990
North Indian Ocean (IO)	EQ-60N	40-E-100E	1945-1990	1978-1990	1972-1990
Eastern North Pacific (EP)	EQ-60N	180W-80W	1945-1990	--------	1990
North Atlantic (AL)	EQ-60N	100W-10E	1945-1990	--------	1990
Southern Hemi-sphere (SH)	EQ-60S	20E-120W	1945-1990	1980-1990	1980-1990

(Note Southern Hemisphere storm years are July 1-June 30. For example, the first tropical cyclone on or after July 1, 1982 would be the first storm of the 1983 storm year).

3. STORAGE MEDIA:	Available on 5 1/4" floppy disk or magnetic tape. Data is ASCII and format will be sent with each data request.
4. HOW TO OBTAIN COPIES:	See para 5.

5. POINT OF CONTACT:

a. NAME:	Buck Sampson
b. ADDRESS:	Naval Research Laboratory Marine Meteorology Division Monterey, CA 93943-5006
c. COMMERCIAL TELEPHONE:	(408) 647-4714
d. FTS:	N/A
e. AUTOVON:	878-4714
f. FACSIMILE TELEPHONE NO:	N/A
g. E-MAIL ADDRESS:	SAMPSON @ NRLMRY.NAVY.MIL

TROPICAL CYCLONE RESEARCH DATA SET

1. DESCRIPTION OF DATA SET:

a.	TITLE AND/OR STORM NAME:	Office of Naval Research. Tropical Cyclone Motion Experiment (TCM-90)
b.	DATA SET ID:	Raw observation data set
c.	STATE DATE:	00 UTC 1 AUGUST 1990
d.	STOP DATE:	00 UTC 20 SEPTEMBER 1990
e.	PLATFORM AND SENSOR:	Rawinsondes, pilot balloons, dropwindsondes, aircraft reports, surface land reports, fixed ship and buoy reports, mobile ship reports, drifting buoy reports, satellite soundings, satellite cloud-tracked winds, radar wind profilers.
f.	GEOGRAPHIC COVERAGE:	60°E - 180°E, 10°S - 60°N
g.	PRINCIPAL INVESTIGATOR:	Prof. Russell L. Elsberry Dept. of Meteorology Code MR/Es Naval Postgraduate School Monterey, CA 93943-5000

h. REMARKS: This data set contains operational and special observations collected during the TCM-90 field experiment. Special observations include drifting buoy observations, ship observations, re-processed satellite cloud-tracked winds, radar wind profilers, and dropwindsondes plus flight-level data from aircraft missions around and through selected tropical cyclones. Observations are available at 6 h intervals during intensive observing periods (IOPs) and 12 h intervals during non-IOP times. The IOPs are specified as follows:

IOP-1 12 UTC 8 AUG - 00 UTC 10 AUG (TY WINONA)
IOP-2 12 UTC 15 AUG - 12 UTC 17 AUG (TY YANCY)
IOP-3 00 UTC 18 AUG - 00 UTC 20 AUG (TY YANCY/TY ZOLA)
IOP-4 12 UTC 5 SEP - 00 UTC 8 SEP (TY DOT)
IOP-5 00 UTC 13 SEP - 12 UTC 14 SEP (TY ED)
IOP-6 00 UTC 15 SEP - 12 UTC 16 SEP (TY ED/STY FLO)
IOP-7 00 UTC 17 SEP - 00 UTC 19 SEP (STY FLO)

2. PARAMETERS IN DATA SET: Several subsets of files are contained in the data set.

a.	PARAMETER A:	RAWINSONDES - includes mandatory and significant levels, heights, temperatures, dew points, winds.
b.	PARAMETER B:	PILOT BALLOONS - heights, winds.
c.	PARAMETER C:	DROPWINDSONDES - heights, temperatures, dew points, winds, at 10 mb intervals.
d.	PARAMETER D:	AIRCRAFT REPORTS - pressure, height, temperature, wind at flight level.
e.	PARAMETER E:	SURFACE LAND STATIONS - pressure, height, temperature, dew pt., wind.
f.	PARAMETER F:	FIXED SHIP OR BUOY REPORT - pressure, height, temperature, dew pt., wind.
g.	PARAMETER G:	MOBILE SHIP REPORT - pressure, height, temperature, dew pt., wind.
h.	PARAMETER H:	SATELLITE SOUNDINGS - thickness, precipitable water.
i.	PARAMETER I:	SATELLITE CLOUD-TRACKED WINDS - pressure, wind.
j.	PARAMETER J:	DRIFTING BUOYS - surface pressure, temperature, wind.
k.	PARAMETER K:	RADAR WIND PROFILERS - heights, winds.

3. STORAGE MEDIA:

a.	MEDIUM	Two 2400 foot magnetic tapes, 6250 bpi.
b.	FILM SIZE	N/A
c.	FILE TAG:	N/A
d.	FORMAT:	ASCII, FGGE-IIB
e.	REMARKS: Documentation is provided.	

4. HOW TO OBTAIN COPIES OF DATA SET:

a. INSTRUCTIONS:	Contact: Prof. Russell L. Elsberry Dept. of Meteorology Code MR/Es Naval Postgraduate School Monterey, CA 93943-5000
b. COST:	TBD
c. PAYABLE TO:	TBD
d. REMARKS:	

5. POINT OF CONTACT:

a. NAME:	Prof. Russell L. Elsberry
b. ADDRESS:	See 4a
c. COMMERCIAL PHONE:	408-646-2373
d. FTS:	N/A
e AUTOVON:	878-2373
f. FACSIMILE TELEPHONE NUMBER:	408-646-3061
g. E-MAIL ADDRESS:	(OMNET) NPS.MET ATTN: R. Elsberry

TROPICAL CYCLONE RESEARCH DATA SET

1. DESCRIPTION OF DATA SET:

a. TITLE AND/OR STORM NAME:	Weather Reconnaissance
b. DATA SET ID:	Weather Reconnaissance
c. START DATE:	Varied
d. STOP DATE:	Varied
e. PLATFORM AND SENSOR:	WC-130 Aircraft
f. GEOGRAPHIC COVERAGE:	Varied
g. PRINCIPAL INVESTIGATOR:	N/A
h. REMARKS:	

2. PARAMETERS IN DATA SET:

a. PARAMETER A:	N/A
b. PARAMETER B:	N/A
c. PARAMETER C:	N/A
d. PARAMETER D:	N/A
f. PARAMETER F:	N/A
h. PARAMETER G:	N/A
i. REMARKS:	

3. STORAGE MEDIA:

a. MEDIUM:	On paper
b. FILM SIZE: N/A	
c. FILE TAG:	N/A
d. FORMAT:	N/A
e. REMARKS: Stored at NCDC, Asheville, NC	

4. HOW TO OBTAIN COPIES OF DATA SET:

a. INSTRUCTIONS:	Contact Mr. John Walsh; See 5.a. and b.
b. COST:	TBD
c. PAYABLE TO:	TBD
d. REMARKS:	

5. POINT OF CONTACT:

a. NAME:	Mr. John Walsh
b. ADDRESS:	OL-A, USAFETAC Asheville, NC 28801-2723
c. COMMERCIAL TELEPHONE:	(704) 259-0218/0404
d. FTS:	N/A
e. AUTOVON:	697-8358
f. FACSIMILE TELEPHONE NUMBER:	N/A
g. E-MAIL ADDRESS:	N/A

APPENDIX C

ABBREVIATIONS

-A-

AFCRL	Air Force Cambridge Research Laboratory (see AFGL)
AFGL	Air Force Geophysics Laboratory (Formerly AFCRL)
AFGWC	Air Force Global Weather Central
AHG/TCR	Ad-Hoc Group for Tropical Cyclone Research
AMEX	Australian Monsoon Experiment
AMSU	Advanced Microwave Sounding Unit
AOML	Atlantic Oceanographic and Meteorological Laboratory
ATCF	Automated Tropical Cyclone Forecast System
AWIPS	Advanced Weather Interactive Processing Systems

-C-

CIRA	Cooperative Institute for Research in the Atmosphere
CSU	Colorado State University

-D-

DMSP	Defense Meteorological Satellite Program

-E-

EBCDIC	Extended Binary Coded Decimal Interchange Code
EIR	enhanced infrared
E-mail	Electronic main

-F-

FGGE	First Global GARP Experimen
FNOC	Fleet Numerical Oceanography Center
FSU	Florida State University

-G-

GFDL	Geophysical Fluid Dynamics Laboratory
GOES	Geostationary Operational Environmental Satellite
GRIB	gridded binary (data)
GSFC	Goddard Space Flight Center

-H-

HRD	Hurricane Research Division

-I-

ICMSSR	Meteorological Services and Supporting Research
IR	infrared
IWRS	Improved Weather Reconnaissance System

-J-

JTWC	Joint Typhoon Warning Center

-K-

kt	knot(s)

-M-

MIT	Massachusetts Institute of Technology
MSLP	minimum sea level pressure

-N-

NASA	National Aeronautics and Space Administration
NATCF	Navy Automated Tropical Cyclone Forecasting System
NCDC	National Climatic Data Center
NCSU	North Carolina State University
NDBC	National Data Buoy Center
NEPRF	Naval Environmental Prediction Research Facility

NESDIS	National Environmental Satellite, Data and Information Service
NEXRAD	Next Generation Weather Radar
NHC	National Hurricane Center
NHC83	an NHC statistical dynamic model for forecasting track of tropical storms
NMC	National Meteorological Center
NOAA	National Oceanic and Atmospheric Administration
NOARL	Naval Oceanographic and Atmospheric Research Laboratory
NOGAPS	Navy Operational Global Atmospheric Prediction System
NPS	Naval Postgraduate School
NRL	Naval Research Laboratory
NSF	National Science Foundation
NSFC	NASA/Goddard Space Flight Center
NSSL	National Severe Storms Laboratory
NWS	National Weather Service

-O-

OLS	Operational Line Scanner
ONR	Office of Naval Research

-P-

PCN	Position Code Numbers
PL/GPA	Phillips Laboratory Geophysics Directorate
PSU	Pennsylvania State University

-R-

RSMC	Regional Specialized Meteorological Center

-S-

SFRM	stepped-frequency microwave radiometer
SLP	sea level pressure
SSM/I	special sensor microwave imager
SSM/T	special sensor microwave/temperature
SSMR	scanning multichannel microwave radiometer
ST LOU U	St. Louis University
SUNYA	State University of New York at Albany

-T-

TBD	to be determined
TC	tropical cyclone
TCFS	Tropical Cyclone Forecast Simulation
TDL	Techniques Development Laboratory
TOVS	TIROS-N Operational Vertical Sounder
TUTT	tropical upper tropospheric trough

-U-

UCHI	University of Chicago
UG	University of Guam
UH	University of Hawaii
UMASS	University of Massachusetts
UMINN	University of Minnesota
UOK	University of Oklahoma
UWISC	University of Wisconsin

-V-

VAS	VISSR Atmospheric Sounder
VISSR	Visible and Infrared Spin-scan Radiometer

-W-

WMO	World Meteorological Organization
WWB	World Weather Building

APPENDIX D

DISTRIBUTION

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Director, AOML Hurricane Research Division 5

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and Coastal Zone Management 1
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HQ 403 AW/DO	1
815 AS/DO	1
815 WF	1
HQ AWS/XT	10
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Commander, Fifth Coast Guard District 1
Commander, (RE) Seventh Coast Guard District 1
Commander, Eight Coast Guard District 1
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Commander, Eleventh Coast Guard District 1
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Naval Postgraduate School 1
Pennsylvania State University 1
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U.S. Air Force Academy 1
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University of Massachusetts 1
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American Meteorological Society 1

* U.S. G.P.O.:1992-313-153:60492

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Office of the Federal Coordinator for Meterology
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