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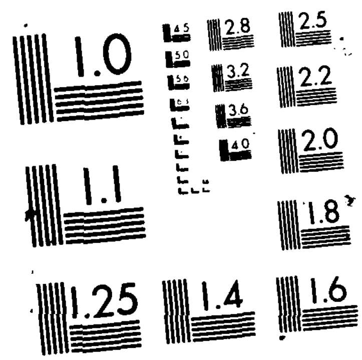
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NPS-63-87-007

NAVAL POSTGRADUATE SCHOOL

Monterey, California

INTERIM REVIEW OF

THE POSSIBILITIES AND OPPORTUNITIES FOR THE

ONR TROPICAL CYCLONE MOTION RESEARCH INITIATIVE

RUSSELL L. ELSBERRY

SEPTEMBER 1987

Interim Report for Period October 1986-September 1987

Prepared for:
Chief of Naval Research (Code 1122MM)
Arlington, VA 22217

NAVAL POSTGRADUATE SCHOOL
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The work reported herein was supported in part by the Office of Naval Research (Marine Meteorology) with funds provided by the Chief of Naval Research.

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Wisconsin, satellite-derived fields were already being studied Thus, it was concluded that a need exists for additional data sets, perhaps through deployment of recently developed dropwindsondes or of an array of wind profilers and the exploitation of satellite microwave imagers and sounders. Concerns regarding the feasibility of such a field experiment are related to lack of operational reconnaissance, availability of aircraft platforms for deploying the dropwindsondes and the need for international cooperation. The recommendation of the review group was to pursue further the possibilities for a reduced, but highly focused, field experiment. If the above concerns cannot be satisfactorily resolved within the budget limitations, expand the scope of the theoretical, numerical modelling and observational studies to exploit those opportunities to the fullest extent possible. The recommended mechanism to facilitate progress would be to establish a center for tropical cyclone motion studies.

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1. Introduction

The U. S. Office of Naval Research (ONR) has funded a five-year Accelerated Research Initiative on Tropical Cyclone Motion that began on 1 October 1986. This basic research program to improve understanding of tropical cyclone motion includes two components (theoretical studies and observational analyses based on existing data sets) that are to precede a field experiment in the western North Pacific during the 1989 or 1990 typhoon seasons. Some issues related to the theory of tropical cyclone motion that arose during a planning meeting during July 1986 are described in Elsberry (1986). Potential observing systems for tropical cyclone motion studies were explored at a workshop sponsored jointly by the Hurricane Research Division (HRD) of the National Oceanographic and Atmospheric Administration (NOAA) and ONR (Elsberry, 1987a).

One of the basic assumptions in funding the research initiative was that a limited amount of instrumentation would be necessary to supplement the existing observational system. However, the U. S. Air Force has discontinued aircraft reconnaissance in the western North Pacific tropical cyclones as of August 1987. This decision has removed a prime component of the observational system that is essential to describe the current position, intensity and low-level wind structure in the inner core during the field experiment. Consequently, this decision requires a re-thinking of the possible options for a reduced field experiment component. Alternatively, Dr. R. F. Abbey, Jr., Director of the Marine Meteorology Research Program of ONR, framed the basic premise as: Given no field experiment, what would be the best strategy to achieve the goal of improved understanding of tropical cyclone motion?

The participants (see list in Appendix A) included operational representatives from the U. S. Naval Oceanography Command Center (Guam), the Joint Typhoon Warning Center (Guam), 1st Weather Wing (USAF) and Headquarters, Air Weather Service. In addition to basic researchers in the theory and observational analysis of tropical cyclones, representatives of the Navy and Air Force groups that transition basic research to operational applications were present. The attendance of researchers from other U.S. agencies and from Australia and Hong Kong (unfortunately an invitee from Japan could not attend) was much appreciated as they broadened the perspective of the review.

CAPT Carl Hoffman (USN) provided the motivation from an operational viewpoint. He stated that the variability of tropical cyclone tracks is not presently predicted by any of the available objective aids. Thus, the typhoon duty officer at JTWC needs an improved understanding of cyclone motion as well as aids that will reliably and consistently predict the variability in the track.

A draft version of a report by Sandgathe (1987), which describes the operationally interesting motion prediction problems in the western North Pacific region was distributed to all participants. This report lists seven scenarios for which the forecaster in the western North Pacific needs improved understanding and guidance: 1. Cyclone-cyclone interaction; 2. Cyclone-midlatitude trough interaction; 3. Cyclone-subtropical ridge interaction; 4. Extratropical transition; 5. Terrain interaction; 6. Monsoon surge interaction; 7. Tropical Upper Atmospheric Trough (TUTT) or upper low interaction. This study provides a description and short-term climatology of these significant track prediction problems in the western North Pacific region.

Mr. Frank Wells presented a brief summary of a proposed operational development plan at JTWC during 1988-89. The goal of that plan (see Appendix B) is to improve the U.S. Pacific Command warning service by applying new and existing observational systems, such as the microwave sounder/imager and multispectral imager in the Defense Military Satellite Program or the drifting buoys being deployed in the Philippine Sea.

This proposal includes improved data handling techniques and forecast technique development.

The meeting was partitioned into a series of discussions on theory, numerical modelling, observational analysis and experimental plans, which were moderated by Roger Smith, Yoshio Kurihara, Greg Holland and Russell Elsberry, respectively. Reporting these discussions in detail would not be appropriate. Rather, the purpose of this report is to summarize briefly the highlights of the discussion and some of the plans for the future.

2. Theory

As indicated above, six theoretical issues had previously been identified in a planning meeting (Elsberry, 1986): 1. Definitions of vortex, basic current and nonlinear interaction effects; 2. Effect of vortex structure on the beta-effect; 3. Track differences due to the form of the vortex; 4. Role of physical processes; 5. Environmental structure effects on motion; and 6. Cyclone-cyclone interaction.

A new model by Willoughby (1987) describes large-scale, counter-rotating gyres that arise from the nonlinear interaction of the vortex and the basic current (Issue 1, above). Fiorino and Elsberry (1987) found that the orientation and strength of the "ventilation flow" between these gyres is closely related to the motion of the vortex in a non-divergent, barotropic model. Greg Holland reported difficulties in the "disection" into the three-component (vortex, basic current plus nonlinear interaction effects) system with wind analyses from the Australian Mesoscale Experiment (AMEX). Perhaps more complete analyses of these preliminary data will be able to detect the 1-3 m/s circulation features due to the nonlinearities. Bill Gray of Colorado State University is using reconnaissance and rawinsonde data sets from the western North Pacific to separate the winds into these three components.

Much of the theory of tropical cyclone motion has been based on barotropic models, especially for studies of the beta-effect (Issue 2, above). Recently, Chan and Williams (1987) have used such a model to clarify the role of the outer wind profile (rather than central intensity) in determining the track relative to the environmental flow. This confirms a study by DeMaria (1985), who demonstrated sensitivity to the vortex wind profile when beta forcing is applied. DeMaria and Baik (1987) demonstrated that the vortex displacement is poleward (equatorward) if the net relative angular momentum of the wind profile is cyclonic (anticyclonic). Fiorino and Elsberry (1987) also show a strong sensitivity in the vortex track to changes in the wind profile within the 300-800 km annulus. Mathur

(1987) showed that profiles of the bogus vortex inserted into multi-level, baroclinic models also affect the predicted track. Consequently, the various efforts to extend further these results and understand the implications of zero relative angular momentum profiles on motion seem quite justified.

Research is also needed to discover whether other physical processes that have been ignored in the present conceptual and analytical models are equally as important as the beta-effect. One of the motivations for the new model by Willoughby (1987) was to treat the effect of rotating convective cells on cyclone motion. He finds a resonance effect when the cells rotate at the same speed as the wind. At this "critical radius", the response is quite large in this linear model. This leads to an oscillatory motion along the path that is similar to the observed trochoidal motion. Willoughby shows the effect of divergence in a one-layer model (4 km depth) is quite small. However, this may not be true in multi-level models with strong physical process forcing.

Robert Merrill suggested that some of the difficulty of casting the observations in the framework of the present theory is that tropical cyclones have vertical and horizontal structures and physical processes that are more complex than the simple models used thus far. A more useful approach may be to determine the minimum amount of structure in the models to represent adequately the real tropical cyclone.

It does seem that extensions to baroclinic models are a necessary and highly desirable goal for advances in the theory of cyclone motion. Vertical and horizontal shear effects need to be considered (Issue 5, above). DeMaria reported that environmental vertical shear contributed to vertical tilt of the vortex and affected the motion to about the same order of magnitude as the beta-effect.

Inclusion of horizontal shear of the environment leads to two contributions to the motion (DeMaria, 1985). Given a meridional gradient in the zonal wind, an "effective-beta term" results. In addition, any meridional replacement will bring the storm into a different basic flow. These effects have to be treated numerically. DeMaria found that the tracks may be quite sensitive to the initial storm location within the sheared wind field.

As indicated in the introduction, cyclone-cyclone interaction (Issue 6, above) is considered to be one of the foremost operational problems in the western North Pacific region. Chang (1983) and DeMaria and Chan (1984) have recently modelled the rotation and attraction-repelling of two cyclones. However, Sandgathe states that several other forms of interaction between western North Pacific tropical cyclones have not been studied and need to be understood by the forecasters.

Roger Smith is considering the effects of asymmetrics in the vorticity field near the core. These asymmetries are not sustained and lead to only short-period (about 6 h) oscillations in the track. Smith is also exploring the contributions that numerical inaccuracies might make in distorting the vortex and leading to erroneous motion predictions. Effects of periodic and channel model boundary conditions are also being studied.

Finally, Greg Holland reported on some work by Klaus Fraederic, who is applying chaos theory to the question of predictability of tropical cyclone motion. Pairs of storms with similar initial tracks (as in analog-type models) are examined to see the rate at which the separation distances are doubled, etc. These will be compared with estimates by Neumann (1987), who used a statistical model to demonstrate that the present track forecast errors could be decreased by half. The outcomes of the predictability studies may include a determination of what factors limit forecast accuracy, or contribute to high variability in tracks with different synoptic conditions.

In summary, theoretical studies of tropical cyclone motion have recently become more frequent after a long hiatus (G. Holland). One of the goals of this research initiative is to build upon and extend this area of study. As indicated above, many opportunities exist for advances in theory.

3. **Numerical modelling possibilities**

This area of research in tropical cyclone motion was not covered extensively at the first planning meeting during July 1986. Consequently, it was very beneficial to have Y. Kurihara (Geophysical Fluid Dynamics Laboratory, NOAA) attend and present a comprehensive state-of-the-art review. Again, only some brief highlights will be given here to illustrate the opportunities in this topic area.

(i) Representation of physical processes. The parameterization issue (especially of convective heat release and the planetary boundary layer) is one of the central problems in understanding and improving prediction of tropical circulations. The early parameterization techniques, which were developed for tropical cyclone intensification studies, have been widely used in general circulation models and numerical weather prediction models. Similarly, the explicit representations of the moist processes, which parameterize only the microphysical processes, were also developed to study tropical cyclone intensification. The HRD group under Willoughby has been a leader in describing the role of mesoscale convection (including rainbands and concentric eyewalls) on hurricane structure and intensity. Given the new understanding in this area, the questions are: What effects do these processes have on the track? What are the appropriate representations of these physical processes for track prediction models?

(ii) Representation of environmental effects. Kurihara listed a number of scales of time variability in the tropics: decadal, quasi-biennial oscillation, seasonal, 30-50 day, episodic changes, 10-15 day, synoptic (3-5 day) and diurnal. He suggested that numerical models for the tropical cyclone track problem should be used to study the time changes on the last two scales, as well as the quasi-steadiness of the fields on longer scales. Unpublished studies by Bob Tuleya of the GFDL group using the First GARP Global Experiment (FGGE) data in the Atlantic, Pacific and Indian Ocean regions appear to indicate good results. The question is whether our understanding (and the data sources) of the western North Pacific environmental effects (see Sandgathe report mentioned above) is adequate. As Sandgathe indicates, none of the available objective aids provides the forecaster with consistent guidance. Specific tests of the adequacy of existing observational cases for tropical cyclone track prediction are proposed below.

(iii) Specification of initial conditions. This issue deals with our capability to incorporate a variety of spatially and temporally inhomogeneous data sources into an accurate analysis of the tropical cyclone and its environment. Tremendous advances have been made in this topic for midlatitude circulations. However, the problem is much more difficult in the tropics because of the ageostrophic nature of the circulation. The divergent wind components, which are not well treated by the successful midlatitude procedures, are much more important in the tropics. Furthermore, initialization of the moisture field is crucial because of the importance of convective heat release in tropical circulations. Specification of accurate initial conditions for tropical cyclones has become a concern for operational numerical prediction centers (e.g., Hall, 1987) because the grid size of the global models is now small enough to resolve tropical cyclone circulations. The problem may be separated into a specification of these circulations and their environment (4-D data assimilation, physical initialization, etc.) and specification of the inner region of the tropical cyclone. The GFDL group and Krishnamurti's group at Florida State University have been addressing these topics with sophisticated numerical models. Similarly, the Australian Bureau of Meteorology Research Centre is developing an initialization technique for their numerical model that relates the divergent components to a specified heating distribution estimated from cold cloud tops. The HRD group and the University of Wisconsin groups have been addressing the problem from the perspective of producing analyses from dropwindsondes and from satellite observations, respectively. Kurihara suggested that the recently developed "adjoint method" may have applicability to the tropical cyclone problem. A better assessment of the opportunities for improvements in this topic should be gained from a workshop during December 1987 sponsored by the National Meteorological Center and GFDL.

(iv) Interaction with terrain. Kurihara reported on the progress that his GFDL group has made in numerically simulating the interaction of a tropical cyclone with mountainous island terrain (Bender et al., 1987). The GFDL model has much higher horizontal resolution than existing operational models. Given these encouraging simulations, the GFDL group is attempting real-data forecasts, which will involve the adequacy of the observational data base and initialization procedures discussed above. Hopefully, these efforts will lead to improvements in this topic area, which is a significant problem for western North Pacific forecasters.

(v) Interface condition problems. Given the small horizontal scales involved in tropical cyclones, it is generally necessary to "nest" finer scale grids within a coarser resolution grid. For example, the GFDL model includes three grids with successively finer resolution as the center is approached. Kurihara feels that considerable progress has been made in treating the flow at and near the interfaces between the grids. Vic Ooyama of HRD has been developing a technique that accurately represents the wave propagation across the interface. Besides the nesting problem, a regional model requires specification of lateral boundary conditions for the entire domain. A recent paper by Tatsumi (1986) of Japan describes a method for specifying the time-dependent boundary conditions for a regional spectral model. Another method suitable for a grid model is being developed at GFDL. Consequently, this important topic area seems to be well in hand for possible tropical cyclone applications.

(vi) Model intercomparison studies. Greg Holland proposed a series of model intercomparison studies using the AMEX analyses. Numerical predictions are in progress with the Australian tropical model and the European Centre for Medium-range Weather Forecasts model. The AMEX analyses will be made available to other groups for model intercomparison studies. The purpose of these studies is to understand the present capabilities/limitations of the models. Given successful predictions, the relative importance of physical processes might also be studied by selectively withholding each process.

In summary, a number of fruitful areas of numerical modelling research on tropical cyclone motion should be pursued. Since much of the past research has been related to Atlantic hurricanes, more numerical studies involving environmental conditions related to the western North Pacific are clearly needed. Careful diagnostic interpretations of the model fields from cases of successful numerical predictions may also contribute to basic insights into tropical cyclone motion.

4. Observational analyses

This section examines the opportunities for research with existing data sets. Greg Holland listed the following sets:

(i) Western North Pacific reconnaissance and rawinsonde sets being analyzed by Bill Gray at Colorado State University;

(ii) Four cases of Omega dropwindsonde surveys from 400 mb to the surface are being analyzed by HRD (two of these analyses have been completed and are available for use by other groups; two sets for Gloria during

1985 and Josephine during 1984 are presently being analyzed);

(iii) Satellite-based sets (about five) in the Atlantic and eastern North Pacific derived by the University of Wisconsin and available for use (may overlap with the HRD cases);

(iv) Two cases obtained during AMEX that are being analyzed by Greg Holland and others in Australia; and,

(v) Operationally analyzed fields in the western North Pacific from Fleet Numerical Oceanography Center that the Naval Postgraduate School has analyzed.

These data sets are not complete in that some contain external data without corresponding interior data. That is, "the complete data set" does not exist. The only sets of single-day fields that have coverage over a large region and could be used for detailed diagnostic testing of hypotheses are the HRD and AMEX sets. Neither of these sets is in the Pacific and thus the environmental conditions are quite different; e.g., absence of monsoonal influences, TUTT influences, etc. Although it seems quite likely that the inner core physics are similar regardless of the basin, this region of the storm is not important for determination of the long-term track (e.g., Chan and Williams, 1987). That is, inner core physics experiments could be done in any basin, but the motion experiments need to be done in the environment of the basin of interest, namely the western North Pacific.

Holland also summarized the potential analysis techniques that might be utilized. The widely used "compositing" technique will have to be used in those sets in which single-period observations are not adequate to perform an analysis. Advantages and disadvantages of this technique are well known (e.g., Elsberry, 1987b). Case study analysis is desirable, but the data are normally lacking for detailed diagnostic (i.e., budget) studies necessary to verify specific hypotheses. Some recent studies have intercompared diagnoses of numerical model fields with corresponding analyses that were based on limited observations. Since the numerical fields are "model-dependent", the conclusions of such studies must eventually be tested with real data from a field experiment.

Holland discussed the problem of "disection" of the analyzed field into a vortex, the basic flow and nonlinearities (see Section 2) as an example of the type of diagnosis that might be done. In the "single-wind" representation of a deep-layer mean steering current, all observations in the domain are averaged both vertically and horizontally. It has been shown (Neumann, 1979) that such a steering current can explain about 80% of the variance in tropical cyclone tracks. An alternative is to subtract out only the symmetric (azimuthally averaged) vortex, which leaves a horizontal field that contains both the background flow and any nonlinearities. Another alternative is to remove the cyclone-scale component by filtering or by Fourier spectral decomposition. If the cyclone is embedded in a cyclonic shear zone associated with the monsoonal trough, there may not be a clear distinction between cyclone and environment, as there usually is in an isolated vortex embedded in nearly uniform trade wind flow.

In the case of the AMEX analyses described above, Holland subtracted a symmetric vortex plus the mean wind averaged over the domain. The remaining circulation contains the environmental vorticity associated with the nonlinearities (no inner region data were available to resolve any asymmetric vorticity associated with the vortex). Based only on preliminary analyses, Holland finds somewhat noisy fields, and no clear indication of a protected inner core region discussed by Willoughby (1987). Rather, the cyclones appear to be well ventilated by a relative flow from front to back as in the model study by Fiorino and Elsberry (1987).

Of the above data sets, the one that is not presently being exploited fully for motion studies is the University of Wisconsin satellite-derived fields.

According to Robert Merrill, they have the capability of generating additional data sets for Atlantic and eastern North Pacific hurricanes. It was mentioned above that model intercomparison studies are planned for the AMEX analyses. Similar studies could be done with other sets, such as the HRD and University of Wisconsin data sets.

5. Field experiments

The first consideration is whether a field experiment is even needed. Based on the above review of existing data sets, the participants agreed that a field experiment is indeed desirable. Available data sets lack either inner region or outer region data, or were obtained in environmental settings that are not applicable to the primary forecast problems in the western North Pacific (Sandgathe, 1987).

What might be the nature of such a field experiment? One suggestion is to explore the applicability of new technology to the tropical cyclone recurvature problem in the western North Pacific. For example, LORAN or Global Positioning Satellite (GPS) dropwindsonde surveys could be made in the crucial environmental regions that determine whether the tropical cyclone is going to recurve into the westerlies, or resume a westward track. The potential accuracies of these dropwindsondes are discussed in

Elsberry (1987a). The GPS sonde is expected to be very accurate and could be dropped from jet aircraft levels in a rapid sequence (provided GPS signals are available, which depends on the Space Shuttle launches of satellites). The LORAN sonde is being tested in December 1987 and will be used in the Experiment on Rapidly Intensifying Cyclones over the Atlantic (ERICA) during December 1988-January 1989.

Another new technology is the "clear-air radar" wind profiler that provides nearly continuous vertical profiles of wind speed and direction (Elsberry, 1987a). Penn State University will be bringing such a profiler to the western North Pacific to demonstrate its capability in the tropical maritime environment. Additional profilers might be obtained from the Naval Postgraduate School or the Wave Propagation Laboratory (NOAA). A "picket fence" of these profilers along a line north of the typhoon could provide a unique data set for understanding tropical cyclone recurvature and interactions with the subtropical ridge.

Another source of new data is the microwave imagers and sounders being deployed. The algorithms for applying these satellite-based observations need to be tested and refined in regions of accurate "ground truth". A field experiment in the western North Pacific would provide an excellent test-bed for such an algorithm refinement in a region that must now rely more and more on remotely-sensed data.

In summary, a "demonstration of new technology" field experiment in support of the highly relevant tropical cyclone recurvature problem is desirable. However, the question is whether such an experiment is <u>feasible</u> in view of the constraints: (i) lack of operational reconnaissance of the storm position and inner core structure; (ii) availability of aircraft platforms for deploying the dropwindsondes; and (iii) international cooperation that has not been assured. Each of these will be discussed below.

Several options are available for aircraft for reconnaissance or deploying dropwindsondes. The status of the USAF aircraft that were removed from Guam is uncertain at this time. Assuming that the eight Improved Weather Reconnaissance Systems (IWRS) will be procured and installed on the remaining USAF C-130 aircraft as planned, a considerable reserve exists to cover all the Atlantic hurricane reconnaissance needs. One of the possibilities to be explored is whether 2-3 of these (or other) USAF planes could be stationed in the western Pacific for approximately a month during a field experiment during 1990. This would provide an opportunity for efficiently training the flight crews in any Pacific tropical cyclones in preparation for Atlantic hurricanes. Tests of the IWRS and other new technology under severe tropical cyclone conditions could also be carried out efficiently. Not all of the aircraft would be needed for penetrations to the eye, because the dropwindsonde deployment flights would be in the environment of the storm.

The question regarding the availability of the NOAA WWP-3D research aircraft during the same period as Atlantic hurricanes might occur has not been resolved. These aircraft (if available at reasonable cost) might be considered as a replacement for the USAF planes in the inner region. As indicated above, the HRD could very efficiently complete an entire season of their research experiments in approximately a month of flights in the western North Pacific because of the large number of storms (Sandgathe,1987).

Although considerable negotiations are necessary to resolve such aircraft issues, the point is that opportunities do exist. However, all U.S. reconnaissance assets are now under the ultimate control of the National Hurricane Center (NHC). Approval for any of these aircraft to be away from Miami during the hurricane season must be obtained from the Director, NHC.

Time for arranging international participation is growing short. One of the realities is that cooperation with some agencies/nations is made more difficult because of the sponsorship by the ONR, and thus an involvement with the Department of Defense. Consequently, a two-pronged approach is proposed. First, a suggestion would be made to the Asian nations Typhoon Committee that they plan a Typhoon Operational Experiment (TOPEX) at the same time as the ONR field experiment. This coincident (but separate) TOPEX would be patterned after the 1983 TOPEX, in which all the nations made a special effort to collect and transmit all possible rawinsonde data to an experimental forecast center manned by forecasters from throughout the Asian region. They would also have available the additional ONR field experiment data, which could be used for improving their operational forecasts, or in later studies to demonstrate the impact of these enhanced data sources.

A separate approach could be made to selected nations or individual scientists to encourage direct participation in the field experiment. In addition to extra rawinsondes/stations and radar observations, special sites will be necessary for the wind profiler installations. Satellite data processing and archiving needs to be addressed. Several of the nations have research ships that are (or can be) equipped with rawinsonde launchers. Other nations might provide scientists or other resources (such as analysis routines, etc.) to contribute to achieving the goals of the experiment.

The over-riding concern of the workshop participants was the limited amount of funds to carry out the field experiment in view of the termination of operational tropical cyclone reconnaissance. Adequate resources must be acquired by voluntary participation of agencies or nations as indicated above, or by tapping other funding sources. Several of the participants agreed to explore these possibilities.

The theoretical, numerical and observational analyses provide a scientific basis for a field experiment in the western North Pacific area. A successful field experiment would produce the best set of observations ever collected for tropical cyclone motion studies in the western North Pacific. In view of the desirability of a field experiment, all possibilities should be explored. It is recognized that additional funding and resources will be required to execute such an experiment. A number of opportunities exist for acquiring the resources. Given the constraints and uncertainties involved in the field experiment, it is important to emphasize that additional opportunities for theoretical, numerical modelling and observational studies are clearly available. As indicated above, these opportunities should be exploited to the fullest extent if the probability of a successful field experiment is severely constrained.

6. Proposed cooperative analysis center

Regardless of whether a field experiment will be planned, the participants expressed strong support for the type of interaction between scientists that took place at this and previous meetings. Now that the theoretical and observational studies are bearing fruit, it is highly desirable that cooperative studies and interaction take place. The participants endorsed preparation of a plan for facilitating visits to a central site for periods ranging from two weeks to six months. Greg Holland volunteered to prepare a draft of a plan.

Acknowledgements. The success of this review is attributed to the lively and candid exchange of views among the ONR project scientists, their colleagues from other agencies and from other countries, and the representatives of the operational forces. All participants are sincerely thanked for their contributions. The author's participation and preparation for this report were funded by the Marine Meteorology Research Program of the Office of Naval Research (Program Element 61153N; Project No.RR033-03-01). Mrs. Penny Jones skillfully prepared the manuscript.

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APPENDIX A

List of Participants

R. F. Abbey (Chairman)	Office of Naval Research
B. Altenhof	Air Weather Service (1st Wea. Wing)
J. C.-L. Chan	Royal Observatory, Hong Kong
M. DeMaria	Hurricane Research Division (NOAA)
R. L. Elsberry	Naval Postgraduate School
M. Glass	Air Force Geophysical Laboratory
C. Guard	Air Weather Service Headquarters
C. Hoffman	Naval Oceanography Command Center (Guam)
G. Holland	Bureau of Meteorology (Australia)
Y. Kurihara	Geophysical Fluid Dynamics Laboratory (NOAA)
R. Merrill	Cooperative Institute for Meteorological Satellite Studies (Wisconsin)
B. Morton	Monash University (Australia)
W. Schubert	Colorado State University
R. Smith	Monash University
T. Tsui	Naval Environmental Prediction Research Facility
F. Wells	Joint Typhoon Warning Center (Guam)

APPENDIX B

The enclosed copies of the transparencies summarize the presentation by Frank Wells of the Joint Typhoon Warning Center (Guam), who attended as a representative of LtC Dan McMorrow, Director.

TROPICAL CYCLONE OPERATIONAL EXPERIMENT

(TCOPE) 1988-89

LTC DAN MCMORROW

AUGUST 87

OVERVIEW

* Goals and Objectives
* Why a Field Experiment at JTWC?
* Methodology
* Data Network
* Summary

EXPERIMENTAL GOALS

Obtain a clearer understanding of synoptic scale influences on tropical cyclone genesis, development and movement in the Western Pacific with a view toward improving the U.S. Pacific Command Tropical Cyclone Warning System

RESEARCH OBJECTIVES

* DETERMINE THE IMPACT OF THE ENVIRONMENT ON TROPICAL CYCLONE INTENSIFICATION/MOVEMENT -- LOCATION AND STRENGTH OF THE LOWER/MID LEVEL TROPOSPHERIC SUBTROPICAL RIDGE, INFLUENCE OF THE TROPICAL UPPER-TROPOSPHERIC TROUGH AND EFFECT OF SURGES IN THE MONSOON

* IMPROVE FORECASTS OF TROPICAL CYCLONE DEVELOPMENT IN THE MONSOONAL TROUGH

* UNDERSTAND THERMODYNAMIC PROCESSES IN TROPICAL CYCLONE DEVELOPMENT ON THE SYNOPTIC AND SUBSYNOPTIC LEVEL

* DEVELOP AN EXPERIMENTAL DATA BASE FOR FOLLOW-ON RESEARCH

* APPLY REMOTE SENSING TO INITIALIZATION OF DATA FIELDS

OPERATIONAL OBJECTIVES

* EVALUATE THE USE OF REAL TIME OR NEAR REAL TIME MICROWAVE SOUNDER AND IMAGER, AND MULTISPECTRAL IMAGER DATA AT JTWC FOR FORECASTING CYCLONE DEVELOPMENT AND MOVEMENT

* DETERMINE IF A HIGH RESOLUTION INTERACTIVE GRAPHICS CAPABILITY AT JTWC WILL SIGNIFICANTLY IMPROVE TYPHOON WARNINGS IN THE PACIFIC

* DEFINE ADDITIONAL IMAGERY SIGNATURES THAT ARE KEYS IN TROPICAL CYCLONE EVOLUTION AND MOTION

* DETERMINE UTILITY OF DRIFTING BUOYS TO FILL DATA VOIDS IN TROPICAL CYCLONE GENERATION AREAS

* DETERMINE THE RELATIONSHIP BETWEEN CLOUD VORTICITY CENTERS AND LOW LEVEL WIND CENTERS AS IT APPLIES TO CYCLONE POSITIONING

* ASSESS IMPORTANCE OF ADDITIONAL DATA SOURCES IN IMPROVING TROPICAL CYCLONE FORECASTING

WHY A FIELD EXPERIMENT AT JTWC?

* PROVIDE A REAL TIME LABORATORY TO TEST HYPOTHESES. UNDERSTANDING GAINED AT THIS LABORATORY WILL BENEFIT THE INTERNATIONAL COMMUNITY.

* OPPORTUNITY TO BRIDGE THE GAP BETWEEN "BASIC RESEARCHERS" AND OPERATIONAL FORECASTERS IN AREA OF TROPICAL CYCLONES AND TO PRODUCE OPERATIONAL TECHNIQUES THAT ARE VALUABLE TO THE TROPICAL CYCLONE WARNING SYSTEM

METHODOLOGY

* CONDUCT A FIELD EXPERIMENT AT THE JTWC DURING THE WESTERN NORTH PACIFIC TROPICAL CYCLONE SEASON. THE FIELD PORTION OF THE EXPERIMENT WILL EXTEND FROM JULY THROUGH OCTOBER IN 1988 AND 1989.

* EXPERIMENT WOULD BE SIMILAR TO THE JOINT DOPPLER OPERATIONAL PROJECT (JDOP) RUN BY DOD AND DOC TO EVALUATE THE OPERATIONAL VALUE OF SINGLE DOPPLER WEATHER RADAR FOR SEVERE STORM FORECASTING.
  - .. JDOP WAS CONDUCTED AT NSSL, NORMAN, OK IN 1977/78
  - .. JDOP WAS A CRITICAL STEP IN DEVELOPING THE NEXRAD PROGRAM

* TCOPE WILL USE ALL AVAILABLE CAPABILITIES (HARDWARE AND SOFTWARE) AT JTWC IN EARLY FY 88, PLUS LEASED/BORROWED ADDITIONAL ITEMS AS NEEDED

* ACCESS TO MAINFRAME COMPUTERS (INCLUDING A SUPERCOMPUTER) VIA A DIRECT LINE TO FNOC FROM JTWC

* BACKUP SUPPORT FROM NEPRF, AFGWC AND AFGL

JTWC - DET 1 CAPABILITIES

* JTWC AUTOMATION (SUMMER 88)

.. INTERNETTED MICROCOMPUTERS

.. ATCF SYSTEM

* LOW RESOLUTION LOOPER .. ALDEN 3000

* NAVAL SATELLITE DISPLAY SYSTEM (NSDS) (SPRING 88)

.. LOOPING OF HIGH RESOLUTION (1 KM) STORED POLAR ORBITER IMAGERY (VISUAL AND INFRARED)

* SSM/I DATA - SDRS (25 KM) AND EDRS (50 KM) (AUGUST 87)

.. DIRECT READOUT (SUMMER 88)

* SSM/T DATA

.. DIRECT READOUT (SUMMER 88)

* MEDIUM DATA UTILIZATION STATION (MDUS) UPGRADE (SPRING 88)

.. ONE HOUR STRETCHED VISSR (DIGITAL) GMS DATA

.. LOOPING OF IMAGERY

.. INCREASED GREY SHADES (VISUAL, 64 VICE 32; IR 256 VICE 32)

.. HIGH RESOLUTION VISUAL IMAGERY (1.25 KM VICE 2.5 KM; IR STILL AT 5 KM)

UNIQUE DATA NETWORK

* Buoy Network

.. Deploy and expand drifting buoy network in FY 88 similar to experiment in 1987

.. Modify new buoys to include wind direction

.. Establish an island/atoll network of moored buoys or automated weather stations from the Marianas through Bonin Islands

.. Real time readout via NOAA satellites with Automated Weather Network (AWN) backup

* Conventional Data Network

.. AWN

.. GTS

.. Airfield Fixed Telecommunications Network (AFTN)

.. Defense Data Network (DDN)

.. Automatic weather stations (ie. HANDAR)

.. PIBAL/RAWIN stations

* Satellite data

  .. Visual/IR high resolution polar orbiter (NOAA, DMSP) via Mark III

  .. One hour digital GMS data via MDUS upgrade

  .. high resolution products via NSDS

  .. SSM/I and SSM/T data via a direct readout at JTWC via Mark III modification

  .. High speed data link for visible, infrared, SSM/I, SSM/T, from FNOC/AFGWC/Western Pacific DMSP sites

  .. DDN link with weather centrals

* Aircraft data

  .. Additional AIREPS from Navy P3 and transiting MAC flights

* Radar data

  .. Direct dial access to digital radars at Kadena and Guam

  .. Potential for Doppler radar

SUMMARY

* Unique opportunity in 1988/89 to couple basic research and operational goals with a tropical cyclone operational experiment at Guam

* JTWC capabilities can support a significant research effort beginning in 1988

* Laboratory to test hypotheses in the world's most active tropical cyclone region

* Extensive data base

* Challenging opportunity to contribute to the understanding of the tropical cyclone and its environment

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