JULE GREGORY CHARNEY
MC 184 BOX 16, F. 523

WEATHER BUREAU, U.S. DEPARTMENT of COMMERCE:
NATIONAL HURRICANE RESEARCH PROJECT,
1955-1961

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UNITED STATES DEPARTMENT OF COMMERCE
WEATHER BUREAU

NATIONAL HURRICANE RESEARCH PROJECT
AVIATION BUILDING, ROOM 517
3240 N.W. 27TH AVENUE
MIAMI 42, FLORIDA

March 7, 1961

Dr. Jule G. Charney, Director
Dynamical Weather Prediction Project
Department of Meteorology
Massachusetts Institute of Technology
Cambridge 39, Massachusetts

Dear Jule:

Many thanks for your kind note of February 27, 1961. We were almost afraid that your interest in hurricanes had been completely obliterated by snowfall. Needless to say, we are more than happy that you and Ogura are "calculating away like mad". We down here in the swamps were not aware of your commitment to visit Russia in June but it sounds like a marvelous development--certainly our invitation was not a mere formality issued in the knowledge that the results were a foregone conclusion. If it so happens that our international relations deteriorate, I recommend that we not jeopardize your security by exposing you to the obvious hazards involved, but propose that you come to the Conference and contribute from the floor.

Coming down to the more practical and immediate, is it possible that the work which you are currently doing might justify a short trip down here within the next month. If so, we would be more than happy to entertain the suggestion of such a trip for the purposes of presenting a seminar to our staff here, as well as consulting with various members as to the work they are doing. The Mai-Kai is still doing business at the old stand and my more degraded emissaries report that they have now replaced the bar attendants with Polynesian maidens (probably from Brooklyn), dressed in nonsanforized facsimiles of their native garb. Apparently these bronze aphrodites are threatening to become a local scandal and already represent a considerable deterent to eating.

More seriously, Jule, if the idea of a trip down in about three or four weeks appeals to you, I am quite sure that it could be arranged and feel that it would be most worthwhile from our point of view. I believe that any thing that you might present to a local audience before the Conference would be all that much more to the good. In any event, we are pleased to learn of your re-awakened interest and are looking forward to Dr. Ogura's presentation in June. If the matter of a visit seems too preposterous, there is certainly no need for an answer to this letter, and we certainly wish you the best on your Russian trip.

Yours sincerely,

Harry

Harry F. Hawkins, Acting Director
National Hurricane Research Project

February 27, 1961

Mr. Harry Hawkins
U.S. Weather Bureau
N.H.R.P., Aviation Bldg., Rm 517
3240 N.W. 27th Avenue
Miami 42, Florida

Dear Harry:

Thank you for your warm invitation to attend and participate in the Second Technical Conference on Hurricanes. I am still as interested in the hurricane problem as ever, and Ogura and I are calculating away like mad. Unfortunately, the Conference comes at a time when I expect to be in Russia (the month of June). While this is not yet certain, I must, under the circumstances, regretfully decline your invitation. However, Ogura expects to attend and will present any results we have at that time.

With best wishes for a second successful conference, I am,

Sincerely yours,

Jule Charney

jc:tb

MIAMI METEOROLOGICAL SOCIETY

Greater Miami Branch
of
American Meteorological Society

February 8, 1961

In reply, please address:
U.S. Weather Bureau
N.H.R.P., Aviation Bldg., Rm 517
3240 N.W. 27th Avenue
Miami 42, Florida

Dr. Jule G. Charney
Dynamical Weather Prediction Project
Department of Meteorology
Massachusetts Institute of Technology
Cambridge 39, Massachusetts

Dear Dr. Charney:

I trust that the fact we have not heard from you regarding the Second Technical Conference on Hurricanes (reference our letter of January 16, 1961) has not been due to lack of interest in the hurricane problem but rather to preoccupation with other affairs. If you plan to attend and to present a paper, it would be most helpful if we could hear from you in the near future. The program with title and abstract will have to be submitted to the AMS before the end of February so that title and abstract should be available here by February 22.

Needless to say, if you find it impossible to prepare a presentation in advance, we would be most happy to have you attend and make contributions from the floor.

In view of the rigors of winter, currently being experienced in the Boston area, it seems more than likely that a thorough warming of the bones would be highly desirable. Miami in late June should surely be able to promise at least that. While awaiting your reply, I remain,

Yours sincerely,

H. Hawkins

Harry F. Hawkins, Chairman
Program Committee

MIAMI METEOROLOGICAL SOCIETY

Greater Miami Branch
of
American Meteorological Society

January 16, 1961

In reply, please address:
U.S. Weather Bureau
N.H.R.P., Aviation Bldg., Rm 517
3240 N.W. 27th Avenue
Miami 42, Florida

Dr. Jule G. Charney
Dynamical Weather Prediction Project
Department of Meteorology
Massachusetts Institute of Technology
Cambridge 39, Massachusetts

Dear Dr. Charney:

On behalf of the Program Committee, it is my sincere pleasure to extend a warm invitation to you to attend and participate in the coming Second Technical Conference on Hurricanes. As you may be aware, these sessions are scheduled for June 27 through 30, 1961, on Miami Beach. It is our desire that you participate in these proceedings to the fullest possible extent, and our hope that you may have pertinent research results available for presentation at this time.

I trust that you recall with some pleasure the First Technical Conference whose success you contributed to in no small part. I distinctly remember your masterful presentation on that occasion and recall it as one of those delightful experiences when a research report was combined with charm and sophistry. I turst that the manifest response from the audience was compensating gratification for your efforts. Needless to say, we would like this particular brand of lightning to strike twice. On that occasion I felt that you thoroughly enjoyed the meetings in general, and seemed stimulated by the exchange of ideas and information. We have every hope that the coming Technical Conference will be just as successful as the first, and trust that you will be on hand to contribute to and enjoy the proceedings.

While awaiting your reply, I remain,

Yours sincerely,

H. F. Hawkins

Harry F. Hawkins, Chairman
Program Committee

CC: Mr. Kenneth S. Spengler
Executive Secretary, AMS, Boston

UNITED STATES DEPARTMENT OF COMMERCE
WEATHER BUREAU

RESEARCH OPERATIONS BASE
WEST PALM BEACH, FLA.

P.O. Box 271
April 13, 1959

AIRMAIL

Professor Jule G. Charney
Department of Meteorology
Massachusetts Institute of Technology
Cambridge 39, Massachusetts

Dear Jule:

We are forwarding under separate cover Preprint Report No. 27 of the National Hurricane Research Project. This contains the "Proceedings of the Board of Review and Conference on Research Progress" of the Hurricane Technical Conference meetings held at Miami Beach last November.

This report was considered too lengthy for publication by the American Meteorological Society and was therefore reproduced in this form, in order that it could be made available in its entirety to the research workers on hurricanes and to the people who attended the Conference.

These Minutes are at the present time being condensed for publication by the American Meteorological Society. As soon as this condensation is completed it will be forwarded to you for review before submission to the Editor.

Let me again express our appreciation for your participation in the Meetings and for your cooperation in getting these Minutes edited and prepared for publication.

With best wishes,

Sincerely

Cecil

R. C. Gentry, Acting Director
National Hurricane Research Project

Separate cover.

UNITED STATES DEPARTMENT OF COMMERCE
WEATHER BUREAU

DEC 12 1958

RESEARCH OPERATIONS BASE
WEST PALM BEACH, FLA.
10 December 1958

Professor Jule G. Charney, Director
Dynamical Weather Prediction Project
Department of Meteorology
Massachusetts Institute of Technology
Cambridge 39, Massachusetts

Dear Jule:

We would like to tell you once again how greatly the Project and the Society appreciated your participation on the Board of Review at the recent Miami meetings. We have reconstructed the proceedings of the Board from the taped recording and enclose a copy for your use.

After further deliberation we have decided that the evaluations, criticisms and recommendations are of sufficient interest to warrent publication in some form. We are planning to submit a condensed version probably to the American Meteorological Society for early publication. Would you care to examine the enclosed text to see if your remarks have been correctly transcribed? If your views are mis-quoted, please inform us of any errors. We will be glad to do the condensation here if you find the account substantially correct and the press of affairs does not permit the devotion of more of your time to this matter.

The reaction both to the meetings proper and to the Board of Review as a device to place findings in perspective and make recommendations for the future has been just about unanimously favorable. Your contribution was no small part in the success of this venture and on behalf of the Project and myself, again many thanks. May I also take this opportunity to wish you the most cordial greetings of the coming Season.

Sincerely,

R. H. Simpson, Program Chairman
Hurricane Technical Conference

Encl.

UNITED STATES DEPARTMENT OF COMMERCE
WEATHER BUREAU

RESEARCH OPERATIONS BASE
WEST PALM BEACH, FLA.

December 10, 1958

Professor Jule Charney
Department of Meteorology
Massachusetts Institute of Technology
Cambridge 39, Massachusetts

Dear Jule:

We are enclosing two profiles giving the horizontal variation of temperature and wind relative to the hurricane centers and rain bands respectively of Carrie on September 15, 1957 and Daisy on August 25, 1958. We will be preparing more of these profiles which we can supply you later if these do not fulfill your requirements. As to the vertical distribution of the temperature, about all we have are the interpolations which were prepared by Dr. Malkus and Mr. Simpson and presented in the papers they gave at the Miami Beach meeting. Two of these soundings (interpolated from data at the flight levels) are enclosed. At the present time we are making a study of the dropsonde data obtained in the 1958 season. Perhaps some of these soundings will be in the rain area and will make it possible to give you a better representation of the vertical temperature distribution.

Bob has already gone on leave preparatory to departing for school the latter part of this month. Last Monday he turned over his duties to me and I am now acting as Director of the Project.

We appreciated very much the contributions you made to the Conference at Miami Beach and I too deeply regret that we did not have more time for informal discussions of the various problems. We are very pleased, however, that you are still working on hurricane research and will be extremely interested in your results.

With best regards.

Sincerely,

Cecil

R. C. Gentry
National Hurricane Research Project

original copy sent
Mr. Simpson
1/9/59

Paraphrase of Statement at Board of Review Conference

Jule G. Charney

Before making any specific comments I should like to express a feeling that I have and which is perhaps shared by most of you here. It is a feeling of excitement, generated largely by the progress evidenced in this conference, that we are ~~at being~~ on the verge of solving a problem that has baffled humanity for millenia. Just as in the last 20 years or so great progress has been made in our understanding of such atmospheric phenomena as extratropical cyclogenesis and the general circulation, so I feel that, certainly within our lifetime, and probably within a very few years, a continuation of the kind of work that has been reported here will lead to an explanation of the causes of hurricanes. We are in a very privileged position; we possess the scientific technology and are rapidly assembling the theoretical knowledge that will be required to unravel the hurricane problem. My impression is based on the rapidly increasing quantitative character of the modern hurricane studies. As Kelvin remarked: until one can measure a thing, until one can express it in quantitative form, one really does not understand it, or at best one's understanding is of a very meager kind. To me the outstanding attribute of the present conference on the hurricane problem lies in the removal of the problem from the realm of speculation and qualitative description into the realm of quantitative analysis. Indeed, as Dr. Malone has pointed out, the tools that have been developed for probing the hurricane have been so successful that they might very well be applied to the measurement of extratropical systems. Of course, new measurements create new problems, and in a certain whimsical sense one may know a phenomenon too well. The more closely one examines the atmosphere, the more fine-grained structure

it is found to have, and the more new problems arise. I was therefore interested in the statement of Mr. Rockney's to the effect that one will never understand the hurricane until one understands the nature of the rain-bands as revealed by radar. I hope that this is not true. If it is, I may have to revise my prediction of an early solution to the hurricane problem. I do not mean to say that the energy released in the rain-bands is not important, but only that one may hope for an understanding of the hurricane as a whole before the details of its fine-grained convective structure are completely understood.

From these general remarks I should like now to come to some specific thoughts on the papers concerned with circulation and energy processes. Let me begin with the excellent study of the energy problem presented by Professor Palmén. Here is a beautiful example of a quantitative analysis which, to a considerable extent, has pinned down for us the constraints within which our understanding of the physical processes in hurricanes has to proceed. We now have numbers for the rate of energy dissipation in a hurricane; we know where the dissipation occurs; we know what the energy source is — it is condensation — and we know where the energy is released. More work should be done in this direction. For example, Professors Palmén and Riehl have demonstrated that the energy released by condensation is some fifty times the energy needed for driving the storm. This gives an efficiency of the order of two percent. Similar efficiencies have been measured for the circulation of the atmosphere as a whole. Thus the rate at which solar radiation is absorbed by the atmosphere is some fifty times the rate of frictional dissipation. The reason for this is that most of the solar energy does not become available for conversion into mechanical work. Lorenz, following Margules, has discussed the so-called "available potential energy" in the

atmosphere and it is this quantity with which we are really concerned. It occurs to me that a study of the generation of available energy might reveal a great deal more about the nature of the hurricane. The increase of available potential energy is a quantity which is roughly proportional to the integral of the heat added times the temperature at which the heat is added divided by the static stability. Hence, for given horizontal temperatures and heat sources, the energy release increases with the approach to indifferent stability. In this connection I should like to harken back to a remark made by Professor Riehl to the effect that large conditional instability in the atmosphere is not favorable for the occurrence of hurricanes. Professor Riehl suggested that with too unstable a lapse rate the energy would be used up in the form of cumulus convection. But cumulus activity is, after all, the way in which energy is supplied to the storm. The more cumulus activity you get in an organized way, the more energy you get, so that it may be better to think in terms of the release of available potential energy.

Another comment is related to a topic that Professor Palmén stated toward the end of his talk. He indicated that the hurricane cannot be regarded as a closed system, that exchange of momentum and energy with the environment is important. One can say a great deal about this problem. There is no question but that Palmén, Riehl and Pfeffer have shown that there is considerable angular momentum exchange with the environment and some energy exchange. The direct energy exchange (excluding latent heat) does not seem to be essential, but the hurricane constantly loses angular momentum to the earth by friction; hence, if the hurricane is to maintain itself in a quasi-steady state, this momentum must be taken from its environment. I think, however, that the way in which this comes about depends more upon the nature of the environment and the motion of the hurricane as a whole than upon any

intrinsic process in the hurricane itself. In other words, I believe that the momentum exchange is not an essential process, but that the hurricane adapts itself to whatever large-scale eddies happen to be present at its periphery. However, this is only an opinion, and I would certainly like to see more work on the problem.

Two other papers that impressed me very much were those presented by Dr. Malkus on her work in collaboration with Professor Riehl. Here is a good illustration ~~explanation~~ of the kind of accurate quantitative analysis that is made possible by modern observations. One of her conclusions was that in order to account for the pressure deepening near the center of the storm one needs surface air of greater heat content than the surface air outside the storm. I was quite convinced by her argument that the extra energy is picked up by evaporation and by transfer of sensible heat from the ocean surface. But again, when one thinks in terms of complete dynamical models, the question arises: are these essential mechanisms? What would happen if one were to spread some kind of heat or evaporation inhibiting film on the surface of the ocean? Would this prevent hurricanes from forming? ~~Although~~ I do not know the answer to this question, but my feeling is that hurricanes would still form and that they would still be deep, because of the existence of other dynamical requirements for low pressure at the center of the storm. Thus, if the heat sources and sinks that produce vertical circulation in the storm ~~were~~ are given, then the tendency towards conservation of angular momentum in a converging ring of air and the necessity for maintaining near-gradient balance ~~would~~ will in themselves require low pressures. Moreover, the frictional loss of angular momentum at the ground and the necessity for maintaining near-hydrostatic balance ~~would~~ will require a warm core in the storm. The actual hurricane acquires its low pressures, as Dr. Malkus has demonstrated, by absorbing heat from the ocean. If it didn't,

one could imagine other mechanisms: for example, moist-adiabatic ascent outside a diverging eye wall followed by dry adiabatic descent within the eye could conceivably produce enough heating of the upper air to account for the low pressures.

The concept of ventilation and cyclogenesis as introduced by Riehl and Simpson belongs, in my mind, to the same category as that of excess heat content and low pressures. Ventilation has been shown to exist, but its role as a brake on cyclogenesis is still not clear to me. A person who had never seen a hurricane before but had been told that it was a large-scale convective system would, it seems to me, predict some form of ventilation. One cannot expect all of the air that enters the region of active precipitation to come only from the surface. Some of it must come from mid-troposphere, where its wet-bulb potential temperature is lower than that of the surface air. Why the normal tropical air at mid-troposphere is wet-bulb potentially colder than it is lower down or higher up is a question which is bound up with the problem of the entire general circulation of the tropics. However, I should like to pose the simpler question: is ventilation a necessary concomitant of hurricanes, or is it a quasi-independent factor of such a nature that it can prevent the formation of hurricanes? I think that this question, or the one raised by Dr. Malkus, will be answered only by studying complete dynamical models. If, for example, it were found that hurricanes could be generated without local transfer of heat from the boundary surface or with ventilation, we should know that the presence of the former factor or absence of the latter are not necessary attributes of hurricanes.

Professor Riehl's and Mr. Ramage's remarks on hurricane formation were very interesting to me. Both speakers emphasized the necessity of interaction between a pre-existing surface depression and an upper system for hurricane

formation. Precisely what kinds of interactions lead to intensification and ~~which~~ what kinds do not are not yet completely understood. Here is obviously an important clue to hurricane formation and a field for fruitful synoptic and dynamic investigation.

Lack of time prevents me from commenting as much as I would wish on Professor Fultz's paper on model experiments. Work of this nature is of utmost importance and should be encouraged in every way. The obvious advantage of the model experiment is that one has complete control over the external conditions. If it should prove possible to produce hurricane-like circulations, one would know exactly what the relevant factors were. The method of numerical computation with hypothetical dynamical models possesses similar advantages. Just as a great deal of light has been shed on other meteorological problems by numerical experiments, it seems to me that results of equal value could be obtained by numerical studies of hypothetical models of hurricanes and tropical depressions.

Answer to Professor Palmén's Question (page 20 of Minutes)

In my paper I tried to show that the formation of a tropical cyclone is due to a kind of secondary conditional instability whereby the large-scale circulation and the small-scale convective motions support each other, the cumulus cell by supplying the heat energy for driving the large-scale circulation, and the large-scale circulation by producing the low-level convergence for maintaining the cumulus convection. When the necessary mean conditions for instability exist one does not have to look for the initial disturbances, since small disturbances are always present. To pursue these studies further what is lacking is a knowledge of the dynamics of the moist-adiabatic process. I thoroughly agree with Dr. Malkus that it is necessary to study general convective motions of rotating systems, and would add that these studies should include cases where the heat of condensation plays an important role. It is impossible any longer to avoid the study of the influence of condensation on small-and large-scale convective processes. The dynamics of the hurricane, of its eye structure, of the rain-bands and of cumulus convection are all directly bound up with the precipitation process. In particular, with regard to the rain-bands, it seems to me that the approach that has been followed by Dr. Tepper might well be combined with a study of the dynamics of the moist-adiabatic process to yield a more realistic model of the rain-bands. Other mechanisms for rain-band formation and maintenance are also possible. There is a near ~~apparent~~ one-to-one correspondence between the ~~occurrence of the~~ rain-bands and ~~of~~ local maxima in the tangential velocity field. One can imagine a number of possible mechanisms for associating enhanced convective activity with these velocity variations. A small increase in kinetic energy along a streamline near the ground would give rise to an increased frictional convergence on the cyclonic-shear side of the wind maximum, which would increase

cumulo-nimbus activity, and this enhanced activity might in turn react on the wind profile in such a way as to produce a self-amplifying mechanism. There is also the possibility that the rain-bands are associated with inertial instability since small regions of inertial stability can be observed on the anti cyclonic-shear side of the velocity maxima. Here again is a possibility for a self-amplifying interaction between the convective activity and the unbalanced centrifugal forces occurring in the presence of dynamic instability. I mention these possibilities only to emphasize that condensation must be considered as an active ingredient in the dynamical explanation of all hurricane phenomena, whether large or small. I do not think that we shall be able to account for the peculiar properties of hurricanes without taking this ingredient into account. Professor Fultz's work may be an illustration of this point. He was apparently unable to obtain concentrated symmetric vortices without using temperature sources so intense that they produced large horizontal temperature gradients, baroclinic instability, and a breakdown of symmetry. With condensation, however, one may obtain the necessary energy release with much smaller horizontal temperature gradients. One should, of course, add that the kind of experiment that Fultz is performing is of fundamental importance for elucidating phenomena taking place in thermally driven vortices ~~in rotating systems~~, whether they bear a close resemblance to the hurricane or not.

MINUTES OF THE MEETING
of the
BOARD OF REVIEW AND CONFERENCE ON RESEARCH PROGRESS

TECHNICAL CONFERENCE ON HURRICANES

Sponsored By

AMERICAN METEOROLOGICAL SOCIETY

Miami Beach, Florida

22 November 1958

INTRODUCTION

The need for a series of technical conferences to discuss progress of research on hurricanes was recognized by the AMS Committee on Severe Storms in 1956. In 1957 plans were laid for the meetings which culminated at Miami Beach in November 1958.

The objectives of the conference were to review and evaluate progress of research on the hurricane problem in recent years, and to point the course toward which future research can be most profitably directed. Participation was specifically invited of all agencies and institutions known to be engaged in or directly concerned with research on tropical cyclones, and invitations were also sent to weather services of other countries.

A Board of Review comprised of senior members of the profession, who have gained universal recognition of their competence in their meteorological specialty or in meteorology as a domain, was chosen well in advance. Before coming to the meetings all Board members were furnished expanded abstracts of the papers to be presented and were asked in turn to preside over particular sessions of the conference. At the final assembly these mature scientists were then asked: to sum up the salient points of the particular sessions, to place new findings in reasonable perspective, to evaluate the progress on work so far undertaken, and to point out the most promising approaches for research in the immediate future. The following is a nearly verbatim account of the proceedings of the Board of Review.

The Board of Review and Conference on Research Progress was convened by Professor E. Palmen at approximately 2:15 P.M. Constitution of the Board was:

CHAIRMAN: Professor Erik Palmen
Institute of Meteorology
University of Helsinki
Helsinki, Finland.

MEMBERS*: Professor Jule G. Charney
Dr. Thomas F. Malone
Mr. Jerome Namias
Professor Sverre Petterssen
Professor Herbert Riehl

Prof Palmen: We are now confonted with the challenging tasks of summing up the contributions made in individual sessions, and of pointing out their significance and the problems facing us in the future. I am going to call upon the chairmen of the individual sessions to outline the findings of their particular meetings and to highlight the problems thus brought into evidence. Their comments, however, need not necessarily be confined to those specific sessions at which they presided. I will call on Mr. Namias first with reference to Session A - Climatology and Synoptic Climatic Studies.

Mr. Namias**: This session furnished background material which can be exploited by specialization. The function of climatology is primarily to furnish background for forecasting and research. There is, however, also ample opportunity for climatology to provide information on the physics of formation and motion of hurricanes. One of the fundamental papers on formation by Prof. Palmen, only a couple of years ago, combined the climatological and synoptic aspects. One can only deplore the national trends of climatological sections to amass statistics purely upon a calendar basis. Certainly more selectivity in the choice and processing of data is needed; consultations with forecasters and research workers should be arranged so that the parameters chosen become more useful.

I would strongly recommend that future climatological attacks be so directed that the parameters are chosen for research usefulness. At the current time the forecaster is overwhelmed with unwieldy data, which should be directly

* - Prof. Horace H. Byers, Dr. George P. Cressman and Mr. J. J. George of the original board were unable to attend.

** - Mr. Namias' remarks are the only ones which have had to be reconstituted entirely from notes. The recording machine was inoperative at the time. All the other material is essentially as transcribed by machine except for minor editing and interpolation.

pointed for his need.

In the field of synoptic climatology we should base our climatic studies on the dynamic climatology of hurricanes. If properly directed we may gain some insight into the interaction of the hurricane on the environment itself. We might further explore the possibilities of singularities as evidenced in the excellent paper by Captain Church which showed the progressive ten day sequences of typhoon paths in August. Climatology has been fixed to calendar months for too long a period; one obvious substitute is to search these studies for singularities or natural periods. Climatological treatments might also help in further exploitation of Dr. Arakawa's studies on coastal effects along Japanese and Hatteras coasts.

With regard to my own paper, the long range forecasters develop a different feeling with regard to evolutions than do many short range forecasters. The predominant philosophy is that the developments are deterministic and the recurrence of types plays an important role in weather evolutions. This has obvious applicability to shorter range forecasting, that is, in the nature of three, five, possibly seven days.

A very interesting paper by Veigas and Miller related the statistical property of hurricane motion to sea level pressure and to the previous motion of the storm. Long range backgrounds might well explain some of the shorter range biases when comparing the predicted against the observed motion of the storms. In general, I must express satisfaction with the work done and in summation urge that climatology be used to supply background and clues for further research.

Prof. Palmen: Thank you, Mr. Namias. Are there any comments by members of the Board? (There were no comments. There were, however, comments from the audience).

Dr. I. I. Schell (Tufts University): Mr. Namias' remarks are very timely. For many climatological studies we need a long period of record; however, I would like us to consider that we are going to find different variations for a long period of time and therefore we study the changes from one year to the other - consequently we hit more directly upon the elements which involve the storm. One other point I would like to make; Mr. Namias feels that we should consider what he calls medium range, three, four, five or six days. The fact is that over a considerably shorter period of time they are subject to many perturbations and interpretations, and as far as the record goes we should try to develop a relationship on the basis of a single trend in the anomolies from one year to another.

Mr. Namias: I appreciate Dr. Schell's remarks and I did not mean to imply that the study should be directed solely to the medium range problem. I merely said that it is an example of one of the things which I think are on the horizon for more immediate application or more immediate study. The problem of

long period fluctuations in tropical cyclones is immensely important as an economic problem. The question of whether or not the tropical cyclone will affect a given area is, of course, on the tongues of many people, particularly right here in Florida. However, I think that the problem should not be classed as a sort of hurricane problem, but it is part of a much greater problem of broad scale fluctuation in general, which in turn involves the entire form of the circulation and may well be in part, part of the overall picture of abnormal warmth, of warming in the Arctic, of warming of the Pacific waters, etc. These in general are part and parcel of the general circulation itself which is much too vast a question for anything like the hurricane project with its (if you will excuse me) picayune funds.

Dr. Schell: In rejoinder I should like to say that although it is very good to recognize the problem, so far as we are thinking in terms of climatic fluctuation, we can narrow it down to terms of even a single phenomenon such as hurricanes, by considering, for example, conditions over the North Atlantic. And furthermore, in thinking solely in terms of variations of certain years, i.e., ten years. We can think in terms of variations for very few years and not only for the period of the anomaly when the abnormal warmth appeared. In other words, we can study all phases of the problem and we can bring it down to shorter periods as well.

Prof. Palmen: Thank you. If there are not going to be any other remarks I feel we will have to proceed. At the second session at which I presided, and which was held simultaneously with the first session, we had a discussion of storm surges. I would like to make some brief remarks. Mr. Lee Harris presented very impressive maps of the flooding during Hurricane Audrey, and he pointed out the importance to the warning system of having more tidal gauges just at the coastline. Two other papers concerned computations of the slope of the water surface, under different conditions, and concerned basins of different shapes with variable or constant depth. A fourth paper concerned maximum height of swell or waves connected with hurricanes during the 1957 season.

My impression was that most of these papers dealt essentially with the emphasis on engineering or the applied approach, which is quite natural because the problem of warning and prediction is extremely complicated, but nevertheless most essential in the saving of lives. One has to remember that the height of a storm surge depends, not only on the wind stress, the fetch of the wind and the pressure deviation from normal; it also depends on the varying depth of the sea, upon the coastal configurations and all kinds of minor complications. However, I feel perhaps that the time is now coming when it will be also appropriate to look at the problem from a little more physical and theoretical viewpoint. I know that Mr. Lee Harris has begun such an approach, but is it not remarkable that Oceanographers and Meteorologists are still not quite in agreement on such an important parameter as the wind stress, and its dependence upon wind velocity and the stability of the lowest layers of the atmosphere.

I feel also that the wind stress depends upon the roughness of the sea and consequently upon the different types of waves. It is of the utmost importance that we investigate the stress parameter more thoroughly, and I also feel it would be very interesting to make a theoretical investigation of the storm surge in the open ocean.

The problem is obviously a very complicated one. In the case of a hurricane we have a strong field of divergence in the wind stress combined with the movement of the hurricane itself. This naturally results in variations in the level of the sea which are very difficult to study in detail. We have seen in some maps that hurricanes have in their wake a region of somewhat colder water, and I feel that this is a clue concerning the divergence of the wind stress connected with the moving hurricanes. Where such divergence is marked there should be some kind of upwelling of deeper water resulting in a temperature decrease. This is one phase of the problem we feel should be considered for further investigation. Further, it is obvious that since storm surges can cause very serious catastrophes, one has to look upon the problem practically and it is only natural to first attempt a realistic forecast arrived at, if it is necessary, by empirical means in order to avoid such catastrophes. The question of theoretical approach to forecast and prediction of storm surge should naturally be next considered. It almost goes without saying that the forecasting of storm surges is a more complicated field than that of meteorological prediction itself, because we must first have a good weather prediction in order to make a reasonable prediction of water level changes. In addition to which we must take into cognizance all kinds of local effects which are exceedingly difficult to treat theoretically, so one must be realistic in his expectations of the results to be realized from such approach.

Since I have not worked in this field for a long time I would like very much to hear the opinions of some of those people who presented papers, and I take this opportunity to ask Mr. Harris whether he has anything to add.

Mr. Harris: Dr. Palmen, I appreciate your comment and would like to say first that we have been trying to follow an approach which Dr. Malone described on Thursday night. We are trying first to describe, then to explain, and finally to predict. My purpose was to give a description to show what it is that needs explanation. In our office we are also working on the other two phases: Bob Reid and his group have made a number of analyses of the effect of the storm in the open ocean, namely, the divergence of the wind stress. I had originally expected him to speak upon this topic. We have also begun to approach the prediction problem from an empirical point of view, since we have not yet reached the point where a theoretical approach seems indicated. We believe it first necessary to get a good physical description, otherwise there may be much lost time developing theoretical explanations of essentially non-representative oscillations of the water level.

Thank you.

Prof Palmen: Thank you. Now I had no intention of criticizing this particular approach which I have already indicated is quite natural, namely, to start with the description of the phenomena - and we certainly obtained a very good description of Hurricane Audrey. However, I felt it opportune to speak a little about what could be in the future, because of that rather interesting and complex problem, namely, of the interaction between the wind and the water surface. Are there any other comments?

Mr. Bretschneider (U. S. Corps of Engineers): One thing I would like to emphasize very much is the importance of botaining accurate information on hurricanes. We are also interested particularly in the question of maximum probable or maximum possible hurricane; that is, what is the ultimate hurricane that might actually strike a given coast. In some cases it becomes almost an academic question since it is not economically possible to protect by levies, dams and seawalls, etc., any particular coast against the maximum possible stress. However, we can afford to avoid augmenting and exploiting death traps where protection is a minimum.

Prof. Palmen: If I may add, I remember in one of these papers, I believe it was Mr. Lee Harris' paper, it was mentioned that it would be necessary to obtain these local topographical maps of the sea floor and coast and to distribute them to the people living in the regions where storm surges can occur. They would then be aware of the danger and know what action they should take.

Mr. Harris: While this part might well be held until further discussion of the forecast problem, it may be appropriate to mention here that such maps as these are not expensive on the scale at which they are projected. The major point is that it is frequently necessary to interpret a forecast, if you want the public to act upon it in the proper way. The Meteorologist is the best and most competent man we have to interpret the forecast, but he doesn't know all of the necessary fundamental facts - one of these is the information provided by such maps. These, I maintain, should be made available at least to every forecaster concerned.

Dr. Palmen: Thank you. (The third session dealt with the Radar Analysis of Severe Storms, and Mr. Vaughn Rockney was called on to give a summation).

Mr. Rockney: I should like first to agree with Prof. Riehl's remarks of this morning, wherein he said that at the moment radar is a superb observational tool. It tells us with a great deal of precision where a hurricane is and where it has been, but so far there has been very little work done that would directly apply radar to the forecast problem. We have heard from Mr. Gentry a suggestion as to how the resultant wind at a particular level as measured

by aircraft, may be a predictor of the hurricane movement. We should investigate whether the resultant movement of echoes at a particular level at various distances from the storm center might also be a predictor of the hurricane's movement. I would like to suggest to people that work with the hurricane now, that they should take into account what the radar shows so that the models they study are at least realistic in terms of the available observations. I personally feel very strongly that anyone who comes up with a model without taking into account the dynamic and thermodynamic properties, as they are revealed by radar, is ignoring available essential facts. The papers presented from the University of Miami by Professors Hiser and Senn seem to me to contribute a great deal to the understanding of storm structure. The spiral overlays as developed for practical observational use in locating the eye of the hurricane when it is off the scope show great promise. There is also another part of the radar display which should be investigated and was mentioned this morning: that is, the location of the main precipitation area with respect to the eye of the storm, and whether such areas are predictory of a trend in the track. In summary, we are so far only scratching the surface in using radar as a forecast tool. It is at present essentially an observational instrument.

Thank you.

Prof. Palmen: Thank you, Mr. Rockney.

Prof. Hiser (University of Miami): There is one other comment I would like to make. Since Dr. Atlas is not here I am sure he would like someone to mention the idea of using doppler radar as a measure of wind within the hurricane structure. There was a paper given on the use of this doppler radar in measuring winds in a tornado and a number of us in the weather radar business feel that this is certainly a fine tool and that pulse doppler radar would make a fine instrument for measuring winds within a hurricane.

Prof. Palmen: Can you tell us exactly how you measure these winds?

Prof Hiser: You get the frequency shift due to differential motion of different parts of the weather droplets in different areas of the storm. A doppler radar simply measures frequency shifts due to these differential motions. This same principle is applied in aircraft detection. The speed of motion determined with doppler radar can be used in the measurement of wind sheer and wind speed within the precipitation structure of the storm.

Prof. Palmen: Thank you, Prof. Hiser.

Mr. Simpson: I might add to the brief comment of Prof. Riser, that doppler radar and its application to radar study of hurricanes is, I think, an important approach which should be explored from the standpoint of additional development - explored for the following reasons: First, it is another means of tracking the hurricane where you can actually identify a hurricane in terms of difference of wind speeds, and you can home on this through conventional radar means, while in addition you can tell something of the intensity of the storm as well as its location. But I think the work which Mr. Gentry presented here this morning, and other work which is being done on the movement problem, indicate that the maximum winds of the hurricane tend to be preserved with height, or conserved with height, to a degree that we did not earlier expect. This means that the radar or doppler pulse radar can expect to see a little further out and obtain this difference in rather strong wind around the narrow core of the storm for a greater distance than I think we were prone to feel was the case a couple of years ago. Secondly, this information which Mr. Gentry gave this morning indicates that there is some predictive value in knowing what this shear to either side of the core comprises. So much for the development.

I would like further to emphasize on behalf of NHRP a feeling which we have expressed elsewhere, that there is a need for the dynamic meteorologist to get closer together with the radar meteorologists in examining not only the description that radar is providing on the storm, but what this means to the circulation regime in terms of dynamics of the storm itself. I believe there should be closer work on models in connection with both thermodynamics and dynamics of the storm with what is revealed by radar observation, and I believe there is progress along these lines noted here especially in the papers given by Dr. Kessler and Dr. Tepper. So we are beginning to examine the description given by radar and to build a theoretical model which is in accord dynamically.

Prof. Palmen: Thank you. Personally I must confess when I listened to part of that session I was a little confused. Nevertheless I felt it was very important for stydying the structure of storms. However, people seem to be of varying opinions concerning the meaning of radar bands. It seems obvious that specialists in the two fields - radar and dynamic meteorology - should really try to come together and solve some of these problems jointly.

Mr. Showalter: Just one point in connection with the radar, I do not believe anyone this afternoon has mentioned the fact that you can easily identify the melting level via the bright band on radar, which should give us very valuable information on the effects of the thermal distribution in the rain pattern around the hurricane circulation.

Thank you.

Prof. Palmen: Thank you. This matter of the bright band was brought up at

the session, however I did not feel myself enough of a specialist to comment upon it.

Mr Simpson: If I may indulge in one more sentence. I forgot to mention one of the items which impressed me very favorably with radar meteorology. It seems paramount to me that in shortly expanding our facilities and capabilities radar-wise we must place more emphasis on the use of R.H.I. presentation. This adds the third dimension to our picture and should prove valuable in such a well organized vortex as the hurricane.

Dr. Palmen: Since Dr. Malone has to leave shortly I will call for his summarization next.

Dr. Malone: I must say at the outset that as one who has not been intimately associated with hurricane work, I found this to be a very exciting and stimulating and heartening conference. I think the progress that has been made in the past ten years has been nothing short of terrific, with the greatest effort, of course, in the stimulated activity of the past three or four years. In our particular session on Observing and Tracking Facilities, Communications and Warning Dissemination, we caught both ends of this problem; namely, the probing end and the warning end - and the probing end seems to be in very good hands. There has been excellent use of aircraft as a platform for instrumentation used in going out and merely getting some data. The kinds of data being collected here and the kinds of equipment being used to collect the data are nothing short of fantastic. They seem to be working, and the several different kinds of instruments give you the same kind of trace, which is very reassuring in that you are measuring with something that is fairly stable. I think while this is heartening to those who are in instrumentation, feedback of this into the research effort was very apparent in the other sessions. Paper after paper discussed results obtained by flights out into the hurricane where you are measuring all kinds of parameters. There was a report of some work on the hurricane positioning device. Ground station facilities appeared to be quite good along the coast, but I think the most impressive thing was the use of aircraft. This seems to have made great strides. It seems to me in just listening to others going on here that the pioneering work now being done in using the aircraft as a probe, might well be carried over into mid-latitude storms. I would guess offhand that there is much that we do not know and are not going to learn right away from our present radiosonde network that could be learned by the kinds of equipment now available. And more important, and this is the thing which impressed me in this Conference, it is quite clear that the weather reconnaissance missions are being flown and directed to answer specific problems. I think this is very important for it would be quite easy to get all kinds of gadgets and simply go out and just take a whole parcel of data. The tie-in between design of the scientific experiment and

design of the reconnaissance mission is one of the things that makes this whole Project really fruitful.

Now, in looking forward to the future, I think that we would be very remiss if we did not take proper cognizance of the vital momentum which we have obtained in a program like this. There are people, there are equipment, there are going concerns, and, as I gather, there is new equipment constantly coming up. It would be a very sad day for our knowledge about hurricanes, it would be a very sad day for people who are not interested in going out flying but want to do some research on the data, if this momentum is lost. And I feel very definitely that this Board should go on record as supporting the kind of probing program which has been carried on here because it is absolutely essential if we are going to make much more progress. This is a very difficult thing to get started and I think the people who have had the foresight to envision the kind of instrumentation and to stay with it through thick and thin (and I gather there have been some thin moments too) are to be congratulated because this description is the core of our knowledge.

Three years is a short time to do what has been done - it is just really a start, basically, and if anything happens within the next year or so to this probing program, it is going to be a black day for research in meteorology. I have been very impressed with the general tenor of the scientific papers, and while it is not quite appropriate to the scientific problem, I would like to call attention to a very good paper by Mr. Harry B. Williams on Warnings. We must recognize here that we have a certain professional responsibility; there has been, I would say, some good work done in the Warning area, this includes both communications and semantics. Williams has pointed out that there has been a good deal done on the probing end of the hurricane problem, but that the shaping of warnings so that they will be of maximum usefulness in an individual decision making progress remains relatively unexploited. Now don't misunderstand me. I am not saying that there has not been progress here, only that it needs more attention. What has been done has been done well, but it has been a small effort compared to the potential. Williams' talk recommended this as a legitimate field of research - and I think it is. We must remember even though we are interested in the scientific aspects of hurricanes, NHRP got going because there was a need to get some warnings out. I think the approach has been right - mainly to get at what is going on, i. e. the basic physics of the hurricane, and to assume that from this knowledge will follow the kind of application that Congress had in mind when they set up the program. All I am asking here is just a little more attention to this area in communications and decision-making where there is currently good work going on, especially in business and economics. While real progress has been made, I don't think they have begun to express the possibilities in the way that they have been exploited in some of the other areas. That covers my session, Mr. Chairman.

However, since I will be leaving early I would like to make one other comment on what went on outside my session, and that is I like very much the work on

verification that Cecil Gentry reported on this morning. We have got to have some kind of quality control of our product, this control can be useful in two senses: to test our theories or our understanding of the model; and, as a check on our professional responsibility. I know a couple of years ago when we were trying to play around with prediction of hurricanes, it was practically impossible to get your hands on any verification data, and this is a very sticky problem. I congratulate Mr. Gentry for getting his hands dirty in it, because you are going to be criticized with anything that you do - and I think he did a good job and I think we have got to keep this quality control.

Prof. Palmen: Thank you, Dr. Malone. I really didn't know, but it surprised me that there has not been any systematic use of aircraft in studying extra tropical cyclones except for special flights in and across jet streams.

Dr. Malone: What I had in mind here was the type of question which Dick Reed out in Washington and Fred Sanders and many others have asked about the detailed structure of extra tropical cyclones. I feel quite confident that such knowledge is practically within our grasp with this AMQ-15 program which has been described here but if it is possible to do half of the things suggested, it will be possible to answer many of these questions on the fine scale structure of extra tropical cyclones, and will undoubtedly provide a very valuable tool which we should not overlook.

Prof. Palmen: Thank you.

Mr. Lee Harris: I would like to say a little bit more about the warning problem, which Mr. Williams has talked about. As was shown in Mr. Gentry's paper, the accuracy of the forecast we are currently getting is such that there are a lot of protective measures a person is not justified in taking on any 24 to 36 hour forecasts we can make today. I am sure that will still be the situation ten years from now. I think we can justifiably spend some effort in determining how well we can solve specific problems. If it turns out that we cannot make a 36 hour forecast with sufficient accuracy to justify any action, then it doesn't matter how badly someone needs it there is little point in making it. I believe that it is obvious that if the forecast is not useful in decision making or in taking protective action then research must be diverted to the problem, and continued to the point where the forecast is of economic utility. We must spend effort on evaluation for that purpose. There are some purposes for which a 6-hour forecast is highly useful, but others for which a 48-hour forecast is not sufficient. We should work at both ends in determining what is needed for certain protective action and what is possible on reasonable expenditure and effort. I believe this is in line with the paper of Mr. Williams and with Dr. Malone's remarks.

Mr. Namias: I didn't realize that this question was going to arise in this session, but I think it is just as well that it has. The problem, let's say, of usefulness of prediction, as I think it over, I believe it is quite possible that perhaps some work ought to be carried on by the Hurricane Project in assaying that very problem; that is, the usefulness of the different kinds of prediction at all time scales and various problems associated with them. As I pointed out, we are all aware of one type of alert that might be made of a long period nature, and there is a question of whether that has any usefulness. Some people doubt whether it does have any usefulness. There is, however, also a question of the moral responsibility of scientists that enters here. If we have some knowledge of something that has a possibility of occurrence, is the public entitled to that knowledge? These questions, both moral, and the problem of ethical usage, the practical usefulness and the threshold which must be achieved before a thing becomes useful, might very well be a rather important phase of investigation by the Hurricane Project.

Dr. Tepper: I should like to point out that there is another useful prediction than the kind which has been referred to here; that is, the simple use of prediction as a scientific method of testing your knowledge or your forecast ability. This is one way of determining whether a 48-hour forecast would be of practical utility in decision making, or whether any particular use can be made of the prognosis.

Mr. Harris: The scientific utility of 48-hour forecast to which Dr. Tepper refers is well recognized in scientific methods of approach, but it is clearly not what we have been talking about in the previous discussion of the warning problem.

Prof. Palmen: We must now proceed to a question which may lead to a fairly general discussion. I propose that we combine the session about Circulation and Energy Processes in The Storm Core and Energy Cycles and Models. I would like to ask Prof. Petterssen to review his part first. This should not prevent him from discussing anything in the other sessions also.

Prof. Petterssen: Mr. Chairman, as you can see by the program I should not have been here at all, but I responded to a request from Mr. Simpson who asked that I fill in for Prof. Byers. As you all know, I am not working on hurricanes so all I can do is to play the role of a layman and speak with what little common sense I have acquired in working on other and unrelated problems. First, I must say that I was tremendously impressed with this particular session and with all the others. I have been tremendously pleased with everything I have seen. Just to see ourselves struggling with numbers is very pleasing in itself. We didn't do that at the time I came into Meteorology and it was a long time before we were able to express ourselves in numbers. So as I say,

this has pleased me muchly to see such a difficult problem as the hurricane being treated in this manner; however, I am sure it isn't like me to carry on with compliments, so I will not underline that I have been tremendously impressed. All of this leads to a summary of my own observations, some of which go outside of the particular session of which I was Chairman.

First of all, it seems to me that the Hurricane Project has been extremely effective in planning an observational program. Much of this was planned before the research results came in. However, it has also been very successful in collecting and analyzing a large amount of datain a time which I consider to be quite short in the life of the Project so far. My knowledge has increased very greatly, as far as the structure, circulation and energy sources of the hurricane are concerned. Considering the complexity of the problem, I think the problem has moved very, very fast. The important facility of being able to use numbers to describe the internal consistency of the hurricane is a major step forward. The factthat they fit into a consistent and concentric picture is in itself very pleasing. It is only fair that we should also say that little has been learned so far about the genesis of the hurricane. This in itself is a major problem which we can only hope to solve by continuation of the data gathering effort and in using the data so gathered in a meaningful fashion.

My second point is this, and it seems to me although I may be wrong, that the data analyzed so far contained too few cases to enable us to put up, say, a family of different hurricanes. I think we must have in mind, at least for practical use, that we need some classification of family models to which we can refer. I do not believe we have yet come that far. For instance, I was impressed with one hurricane which stood out from all the rest. Although I have never been a believer in one cyclone, and I think there are many types of them, it remains to find out whether this is also true of hurricanes. The logical conclusion of this then, as it seems to me, is that the Hurricane Project, therefore, must continue for several years. I realize that in Washington people say two, three or four years - I like to say several - I don't think we have enough scientific knowledge to say how many, but we certainly shouldn't plan to fold up this soon.

My third observation is this, that from the papers that were presented at this symposium of which I was Chairman, it seems that there has been a considerable amount of theoretical progress, or progress along theoretical lines. So if I were to use Tom Malone's terms, we are somewhat past the descriptive stage and approaching the explanation - we are now in the process of explaining some of the broad features of the hurricane. I think it would be wise now to plan for an increased emphasis along theoretical lines in connection with the Hurricane Project. It seems that theory is well married to the data; theoretical studies may well demand changes in the operational procedure. Too often we see these projects accumulate ten times as much data as can be really used. I think there is reason to say that all the data I know of in the Hurricane Project has been used I have rarely seen such economy and such good planning as I have seen here, but I do think we should realize that theoretical studies may demand

modification of the program, and we should have this in mind. However, it is probably from the practical point of view, very difficult to get the Hurricane Project, or indeed any particular project, to remain within strictly prescribed limits. It will probably run for a good length at least, and at the present stage there is no reason to plan for tapering off the scientific effort.

The last thing I would like to say is something not necessarily proper to the Hurricane Project itself, but someone should be taking interest in the devastating hurricanes that redevelop after they come up into high latitudes. I think that this is a fascinating problem and some effort should be spent upon it. In this connection we might well extend the observation program so that hurricanes are also studied with aircraft data after they have gone inland so that further studies on redevelopment can be attempted.

Finally, I would like to make a point which concerns many projects, namely, that of attempting to plan or to study a problem, or phenomenon, in isolation. Now I know that the atmosphere is a peculiar system where phenomena of different scales are superimposed on one another, the thunderstorm is imbedded in something else, that something else is imbedded in a larger system, etc., and I don't think any study will be really successful unless these larger scale phenomena are simultaneously considered. I was pleased to see the session on Climatology which indicates that a start in placing the hurricane in its proper perspective has been made. I would like to see the tropical storm, or hurricane, studied in relation to the large scale synoptic situation. Having in mind that this may involve a large united effort by the Universities, I feel nevertheless this aspect of the problem should be exploited as soon as possible. I think in reviewing the past that this sort of thinking has often been neglected so that results have on many occasions been found short of that which was anticipated. The placing of the hurricane in it larger environment, the monsoon, and the interaction of the monsoon, with the long waves in the westerlies, should be an important part in the practical and theoretical research.

Thank you, Mr. Chairman.

Prof. Palmen: Thank you very much, Prof. Petterssen. I would like to add just these few remarks. Wouldn't it be practical to have the aircraft, during the winter season when there are no hurricanes, used in the study of extra-tropical cyclones.

Mr. Simpson: Yes. It is the present planning of the Weather Bureau in extending the work that has been done on hurricanes, to use the facilities which we are now having developed in just such a manner. In view of the fact that they cannot be leased and equipped economically on a short seasonal basis, the proposal is that they will be used continually for hurricane work in the hurricane season, and to launch into some tornado investigations during the tornado season, and for such use as was suggested by Prof. Petterssen to explore extra-tropical cyclones and special other problems, that we have not been able to study in this fashion heretofore.

Prof. Palmen: I would now like to call on Prof. Charney to discuss the sessions in general, and, if possible, to comment specifically on the session on Energy Cycles and Models.

Prof. Charney: Before making any specific comments I would like to express the feeling that I have and which is perhaps shared by most of you here, that is, I have a feeling of excitement which has been generated by the progress evidenced here where it seems to me that we are on the verge of solving a problem which has baffled humanity for the last 2,000 years at the very least. I have a very strong feeling that just as in the last 20 years or so, tremendous progress has been made in the understanding of various other kinds of atmospheric phenomena, the problem of the general circulation has been greatly clarified - much better understood; the problem of extra-tropical cyclogenesis is again far better understood than it ever was before; and I feel in very much the same way that within our life time certainly, and probably within a very few years, a continuation of the kind of work which is being done here will lead to an explanation of the causes of hurricanes.

Now it seems to me that we are in a rather privileged position; because we have the technology and we are rapidly assembling the theoretical knowledge that will be required to unravel these problems. The reason for my impression is the fact that we are becoming rapidly more quantitative in our analysis. You will recall that Kelvin has stated - until you can measure a thing, until you can express it in quantitative form, you really do not understand it, or your understanding is of a very meager kind at best. It seems to me that the outstanding attribute of the discussions of the hurricane problem is that the work is being taken out of the realm of idle speculation and qualitative description and being put into the realm of quantitative analysis. In fact, as Tom Malone pointed out, the excellence of the physical description of the hurricane which has been made possible in very recent years, and particularly by the National Hurricane Project, is better in some respects than measurements of extra-tropical systems. Now this, of course, is a great advantage. At the same time another thought occurs to me: that sometimes if you know a thing too well it becomes confusing. It seems to me, although I won't dwell on the point, that the more you examine the phenomena, the more closely you look at it, the more fine-grained structure it appears to have, and the more problems arise. I was interested in the statement which was made by Mr. Rockney that one will never understand the hurricane until one understands the structure of the cloud bands as revealed by radar. I hope that this isn't true; maybe it is, and in that case I will perhaps have to extend my prediction. This is not to say that the energy released in these cloud bands is not important; but, I think from experience in the past, it is to be hoped that an understanding will come before a complete knowledge of all the fine-grained structure which undoubtedly exists. From these general comments I would like to now come to some more specific thoughts that have occurred to me in the course of the presentation of these papers. Assuming that I am permitted to discuss all papers which are concerned with circulation and energy processes, intensification, etc., I would like to begin with the very excellent summary of the energy problem

~~which was~~ presented by Prof. Palmen. Here is a beautiful example of quantitative analysis, which has pinned down for us the constraints within which our understanding has to proceed. We now ~~know that~~ we have numbers ~~available to~~ use: for instance, for the dissipation of a hurricane - we know where the dissipation occurs, we know what the energy source is, we know how the energy is released in the hurricane. There are, it seems to me, a great many more ~~things~~ that can be done in this direction. For example, Profs. Palmen and Riehl have demonstrated that the energy released by condensation is some 50 times, or nearly 40 times, the energy which is needed for driving the storm. This gives you an efficiency, I think, which is something of the order of 2.7 percent - this number 2 percent, or so, has come up in ~~other~~ connections and we find it also in the general circulation of the atmosphere. That is, if you take the total amount of solar radiation ~~which~~ is absorbed you find ~~this to be~~ some 50 times greater than the amount which is dissipated by friction. Now the reason for that is that the energy which is liberated is not, of course, all converted into mechanical work. Now there has been some work done on the exact process by which energy becomes available. Lorenz, following Margules, has discussed the so-called available potential energy in the atmosphere and it is this quantity with which we are really concerned. One suggestion that occurs to me is that this potential energy be studied, because, I think that in such a study, a great deal more about the nature of the hurricane will be revealed. The available potential energy is a quantity which is proportional to the heat added, times the temperature at which the heat is added (so this is a little ~~bit~~ like entropy) divided by the static stability. This means that the process is much more efficient when you have near indifferent stability. Now in this connection I would like to harken back to a remark that Prof. Riehl made, in which he pointed out that apparently when you have a lot of conditional instability in the atmosphere, this is not favorable for the occurrence of hurricanes. Or, at any rate, that within hurricane circulations you have merely indifferent lapse rates. This must be some kind of a necessary characteristic, and the explanation, I think, must lie somewhere along these lines rather than along the explanation which Prof. Riehl offered. You will recall that he suggested that with too unstable a lapse rate, the energy would be used up in the form of cumulus convection cells. It seems to me that this is, after all, the way in which the energy is applied to a storm. The more cumulus activity you get in an organized way, the more energy you get, so that it may be better to think of it in terms of available potential energy.

Another comment is that related to a topic at which Prof. Palmen hinted towards the end of his talk: that the hurricane cannot be regarded as a closed system, that exchange with the environment is important. One can say a great deal about this problem. There is no question that from the work of Palmen, Tepper, Riehl and others, that there is momentum exchange with the environment - angular momentum exchange, and some energy exchange. Although the energy exchange with the environment does not seem to be terribly important. Thus the hurricane is constantly losing angular momentum to the surface by friction, which must be obtained from somewhere, it follows that if it is to maintain itself in a quasi-steady state, there must be some exchange with the environment. It makes use

of the eddies that exist in the environment and would probably use any kind of eddy present there. In other words, I do not believe that this exchange is an essential process - but that is only an opinion. However, I feel certainly one should look into this particular phase.

Another paper that impressed me very much, or rather two papers - were those presented by Dr. Malkus on work that she did in collaboration with Prof. Riehl. Here is a good example of the kind of accurate quantitative analysis that is now made possible by the excellent observations which we have. The physical viewpoint brought out here was whether to account for the deepening (the pressure deepening at the center of the storm) one needs to have air of heat content which cannot be explained simply in terms of the heat content of the surface air which rises in the storm, and which comes from outside the immediate center of the storm. I was quite convinced by Dr. Malkus' argument that this is indeed the case, and that in all probability this energy is picked up by evaporation and by transfer of sensible heat from the ocean surface. When one thinks in terms of complete dynamical models, I would like to ask the question: is this an essential mechanism? What would happen if you were to spread some kind of heat or evaporation inhibiting film on the surface of the ocean - would this prevent hurricanes from forming? I can't, of course, answer that question, but I will again merely express my intuition, namely, that hurricanes would still form and they would still be deep because there are other requirements for low pressure at the center of the storm. Namely, if you have a ring there, which is converging toward the center, and, given the heat sources and sinks which produce vertical circulation in the storm, then conservation of angular momentum in itself and the necessity for balance will produce low pressures. Since the balance is bound to be quasi-hydrostatic, some mass changes are going to have to take place which will give rise to these pressure falls. The hurricane does this, as Dr. Malkus has demonstrated, by absorbing heat from the ocean. If it didn't do that, one can imagine other mechanisms which might work - for example, the descent in the eye, that is moist adiabatic ascent in the eye-wall, followed by dry adiabatic descent in the eye, could probably produce a considerable heating of the upper air and could produce temperatures which would be hot enough to account for the low pressures. Again, I just throw this out and run as fast as I can.

The question of ventilation is one that again has been demonstrated rather conclusively to exist, I thought, and to play an important role. Precisely what that role is, again as part of a consistent dynamical picture, I find it difficult to understand. However, I do not regard this as any kind of criticism; in fact, to a person who has not seen a hurricane before, who was merely told it was a convective system, it would seem to me that some form of ventilation would be natural. That is, you can't expect all of the air which comes into the region of active precipitation to come only from the surface. Some of it must come from mid-troposphere - air which is colder. Why the air is colder, is again another question which is bound up with the

whole general circulation of the tropics. Then again, there is the question whether hurricanes would form independent of ventilation or whether ventilation may be of such a nature that it can possibly prevent formation of typical hurricanes. I think this question can only be answered in terms of complete dynamical models, and this again points out to me the necessity for studying such models.

I would like to comment also if I could for a moment on Prof. Riehl's very complete summary. Perhaps we should combine that with Mr. Ramage's paper on hurricane formation. I was amused by the sentence with which Prof. Riehl began his paper, namely, he said that the problem of formation is not wholly solved. I think this was the understatement of the conference. This might seem to be in contradiction to my earlier remark about a feeling of optimism, but it seems to me that the problem of formation can only be solved when they can say why they form and why they do not form, and it is obvious that this problem has not been solved. Not that there are not very attractive possibilities, some of which Prof. Riehl mentions himself, but as he honestly and frankly admitted, just when he thought he had the answer that there was a certain kind of upper air disturbance that gave rise to the hurricane, he found that there was another case where this didn't occur. This, I think, is the kind of study that is going to be needed - a study about the kind of interactions that can occur and do occur between the lower and upper atmosphere. This is a new field of investigation, although some qualitative descriptive work has been done, but we need to know a good deal more quantitatively about the exact way in which the systems do interact. Why it is that sometimes there is no apparent interaction between upper and lower troposphere and at other times the interaction seems to be decisive.

There are many other comments I would like to make, for instance, concerning Prof. Fultz' paper on Model Experiments. This is an example of the kind of work that should be done in the sense of trying to build complete models, which may not resemble the actual motions very well, but at least have the virtue that they have all the ingredients, so that they can be completely analyzed. There are two ways of doing this - one, of course, is by means of laboratory experiments, another by computations. Just as a great deal of light has been shed on the problem of the general circulation and on the problem of extra-tropical cyclogenesis, by computation, it seems to me equally possible that when we set up hypothetical models of hurricanes and tropical depressions and solve these by numerical computations we can expect to learn a great deal about the hurricane.

Prof. Palmen: Thank you, Prof. Charney, for the interesting expose of all of these problems. Now before the meeting I really promised Prof. Riehl not to ask him to say anything on this subject; however, I feel that he probably has some appropriate comments which should be entered at this point.

Prof. Riehl: Well, in a meeting of this kind there is some subject or other

of importance which doesn't quite get the attention which it deserves, and in this case I think the subject which was cheated a little is the mark of distinction which appears to exist, not just between the tropical depression and the hurricane, but between what is known as the tropical storm and the hurricane. Now the tropical storm is a disturbance which has been observed to exist as a steady state phenomenon, and in at least several instances as has been demonstrated by the Hurricane Project data, is a warm core type of disturbance and appears to have all of the characteristics of the hurricane, except it lacks the wind concentration at low altitudes. There is any amount of release of latent heat in these, and a tremendous amount of generation of kinetic energy, just as much apparently as in the hurricane. But, the winds do not become concentrated near the center, the maximum wind remains at a radius of 150 miles, or thereabouts, with a strength of something about 40 to 50, maybe 55, knots. With a solid rotation profile existing in the interior inside of the maximum wind radius. This I find to be a really most extraordinary phenomenon. One can see by studying, for instance, the net mass inflow into the tropical storm, that when one goes some 4 or 5 degrees from the center, and then takes mass inflow, that this is not very different in vertical distribution from the hurricane. The level of nondivergence is very high in both of these systems, 400 to 500 millibars, and the mass inflow through a deep layer of the troposphere is very appreciable. One finally comes in the end to a conclusion which has been emphasized by Dr. LaSeur, as much as anyone, that in most of these hurricanes there is an outer envelope of wind which is greatly similar to the distribution of winds in the tropical storm; for instance, even in such cases as Ella, where the eye was destroyed over the Cuban mountains, the tropical storm structure is retained and that which really distinguishes the tropical storm from the hurricane is the existence of the eye in itself. Dr. LaSeur has mentioned to me cases where he has been able to find, from detailed flight data, two rings of maximum wind in passing in cross-section flight through the disturbance: Namely- one, the outer ring, the tropical storm maximum, then some decrease, and finally, a secondary inner rise to a maximum near the eye. Consequently, when Dr. Charney says that there would be hurricanes with or without the extra pick-up of heat from the ocean, I think that another question might be asked - namely, why are there any hurricanes at all? A tropical storm is the principal vehicle and the predominant vehicle for the release of the major convective activity which is pent up in a certain way. The principal thing to be determined is the reason for the existence of the tropical storm rather than the hurricane (the thing that one would ordinarily think of as natural, so to speak, would be the hurricane, but it isn't). The formation of an eye within a general envelope is, I would say, an event which would be questionable without special surface conditions. Since the energy problem has come up I would like to emphasize this point - that one really has a double problem here: namely, there is a general tropical storm as one thing, and then the extra but much rarer formation of an eye with particularly strong winds within it as a secondary phenomenon.

Dr. Palmen: Thank you, Prof. Riehl. I am glad that we have had your opinion, for after all it would be silly to have the greatest expert on that problem

here on the Board and not to have him express his opinions. Now although time is running short, I would still like to ask the one who, in my opinion, presented the most interesting papers here, namely, Dr. Malkus, to say a few words about the subject, and to inquire whether she has anything to add to what she has already presented.

Dr. Malkus: I have only one thing to add in connection with the interesting question which Dr. Charney has asked. I am not interested in hurricanes only for the practical reason that they exist, but also as a prototype of the circulation in a rotating system. The question of how we get such a circulation is a very interesting one. I was glad to note Dr. Fultz' paper which showed that we can simulate some of the essential features of the hurricanes, by somewhat different techniques in the laboratory models. Just what comprises the essential ingredients is unknown as yet I am sure: however, apparently for a real hurricane this extra heat source is of significant importance. It is certainly not beyond controversy that this kind of circulation necessarily requires it, but from what Dr. Fultz said it looks to me as if we do have to get a special arrangement of heat imput. But this is certainly only one aspect of the problem. It would be interesting to look not only at real hurricanes, but of all hurricanes with classical thermal circulations from which this might be a kind of solution.

Prof. Palmen: Are there any other comments? Dr. Charney has already taken up the question of the formation of cyclones; however, he really did it without my permission, but at least I feel that something should be said in addition, because it is an area in which no real progress has yet been made. I would like to inquire whether Prof. Riehl would like to add anything on this subject in view of the fact that for the forecasting problem this is an extremely important point.

Prof. Riehl: Well, I really don't have anything to add on this subject, I have already spoken 42 minutes on it last night. However, since Dr. Palmen brings up the practical aspect of this, I would say that it may be entirely possible, at least in areas of observation, to arrive at schemes for predicting the formation of hurricanes without actually understanding the precise physical process. This is entirely within the realm of possibilities. Also, very little work has been done on this subject, partly because of the fact that formation, inparticular, occurs in the areas without observations of the routine type, and that the dispatching of special aircraft for investigation into these very formative stages, has proved, at least so far, a particularly difficult task because there are always several of these potential areas on the map, and one never knows which one should be explored. Certainly one of the most important facts, I think everybody recognizes, in the future of this program, is the systematic investigation of these early stanges. Nevertheless, it may very well be possible that one can arrive at a forecasting scheme in regions with observations without actually understanding the process itself.

Prof. Palmen: As I remember in Prof. Charney's very interesting paper, he also touched on, to some extent, this same question, in spite of which he never discussed the type of disturbance that really should start the process of formation, not necessarily tropical hurricanes, but tropical cyclones. However, perhaps Prof. Charney would like to add something on this subject.

Prof. Charney: Well, this is just a general remark which has been prompted by Dr. Malkus' statement, that it is necessary to study general convective motions of rotating systems. I thoroughly agree that what has been lacking, I think, on a theoretical basis at least, is that very little work has been done on the moist adiabatic process; that is, how are the dynamics governed when condensation is occurring. Convection of every kind has been studied where due to ordinary thermal instability, heating at low levels, in rotating systems, in magnetic fields, and goodness knows what; but it hasn't been studied for condensation. I mean, given such a simple thing one might say as the dynamics of the cumulus cloud - little work has been done on that. Well, perhaps a fair amount has been done, I would say, but not very much on the dynamics or the thermodynamics. We must now, because of its obvious importance, concentrate on this particular topic, because other obviously important phenomenon in the atmosphere are bound up with condensation. I mean large scale phenomenon, not merely the cloud itself. The whole dynamics of the hurricane, its eye structure, undoubtedly the phenomenon of the rain band in the hurricane, all are things that are directly connected with precipitation. Even, actually, the eye of the storm looks very much like a front and there are very close analogies actually with extra-tropical fronts and eyes in the sense that both of them may really be one thing that can give rise to discontinuities in motion.

However, the extra-tropical front itself is not too well understood and could stand further investigation. Similarly, further investigation of the rain band is indicated for, in accord with Dr. Tepper's paper, I believe that we need models for the rain bands. It seemed to me that an approach such as the one Dr. Tepper used, if it were combined with the very evident release of energy which occurs through condensation, might lead to something that would readily explain the active details of motion in rain bands. I just wanted to put in a plug for a possible mechanism which one might propose; namely, you might regard this as another kind of instability, essentially if you have a little increase in kinetic energy along a streamline, then near the ground this would give rise to a frictional convergence which will then produce cumulus and cumulonimbus activity. This in turn, of course, will change the circulation and therefore you could conceivably get a self-propogating effect. The fact that the rain bands are associated with velocity maximum in middle and upper levels and presumably near the ground too, suggests that maybe this is an important factor to look into. I only mention this now to emphasize that the condensation must not be a passive factor of this phenomena but an active ingredient in its dynamics in any explanation. It is not going to be possible to explain any of these peculiar properties of hurricanes without constructing

models of the moist adiabatic processes. Fultz' paper illustrated this point, I think, because he was not able really to get this kind of concentrated vortex, since in order to do so he would have needed temperature sources which were so high that they would produce horizontal temperature gradients which lead to baroclinic instability, and so we could not produce a symmetric storm. If, however, you have condensation you can get this energy release with much smaller horizontal temperature gradients. Here is an example where conceivably it would not be possible to produce a hurricane in a dishpan without in some way simulating the condensation mechanism. Of course, the kind of experiments that Fultz is doing are absolutely necessary - they are invaluable for shedding light on the general phenomenon.

Prof. Palmen: Thank you. I just wondered if we shouldn't proceed to the last session, because I feel we have to finish this meeting in a reasonable amount of time. There are a number of persons present who would like to leave by plane this evening, so I will ask Prof. Riehl to comment about the session on Prediction of Hurricane Movement.

Prof. Reihl: Thank you, Dr. Palmen. I can probably make this rather brief. Not knowing how this afternoon's session would go, I proceeded to summarize the movement session at the close of this morning's meeting. What I feel needs to be done now is to run down the list briefly for the benefit of those who did not hear the summation this morning. Several of the papers dealing with movement have already been mentioned, for instance, the work by Mr. Gentry on verification and Kasahara's numerical work. I think we must realize when it comes to the prediction of movement in contrast with some of the other topics we have just heard about, that they are very brave souls who undertake this kind of investigation. It is not like Astronomy, for instance, where you can think millions of years ahead and you are quite safe in your predictions; but here in the next day or the day after the news is in, and you have had it one way or another. So I think that all of us here should have a great deal of appreciation for those who spoke and are undertaking work on hurricane prediction. They, in a manner of speaking, jump directly into the middle of the firing line more so than anyone else working in the general subject. One of the main things that came out of this morning's session and was emphasized by Mr. Gentry was this: that while most calculations that one now makes are for a 24-hour interval from the time the data are taken, the interval is too short for practically all warning purposes. It is true that sometimes a six or twelve hour warning can do a great deal of good, but for the most part, the warning of coastal populations and the making of preparations against inundations, and things of this type, it is necessary to have a warning some 36 hours ahead of map time, which is about 30 hours from the time the forecast is issued. I realize, of course, that for certain special purposes much longer warnings than this are necessary to close down and protect factories and military installations, etc. The 72-hour forecast verifications shown by Mr. Hubert, indicate that they were too far off to warrant much discussion. Essentially then, the aim, at least for the present, should be a

36-hour prediction from map time, and possibly a discussion of what types of calculations should be undertaken.

Mr. Gentry's method involving computations made directly from aircraft data is a very appealing one. They were, however, only for 24-hours, but could perhaps be extended to 36-hours. It is possible that this time may be too long and the general circulation features alter too greatly to make this extension practicable. Nevertheless, it is a very appealing scheme whereby one simply lets an airplane run around the storm, takes certain observations and directly obtains the forecast. This, of course, was also the essence of the little scheme which I once worked up with several collaborators at the project AROWA of the U. S. Navy. Now with faster jet planes coming into operation the very exciting possibility arises that this can be done at high altitudes, where there are not enough rawin stations available at any time to get satisfactory statistical samples, or from balloon soundings. It would have to be purely an aircraft program. The few complete B-47 flights that already exist with the National Hurricane Project should be thoroughly investigated for this purpose. Again the sample is too small, but one of the approaches that should be encouraged for the future is: to deploy the high altitude aircraft which NHRP and perhaps others hope to have in the future years in such a manner that one can see whether a useful scheme for 36-hour movement can be directly taken and calculated during the aircraft flights in a short period of time.

Other methods of computations depend on charts with calculation schemes of one sort or another. Here one has to distinguish between charts which have a certain amount of observational stability in them and charts which do not. The question of observational stability arises of course from the fact that the hurricane exists over water where there are very few weather observation stations. This situation is much worse in the Atlantic than in the Pacific. There have been two types of charts mentioned which seem to have the required stability, one is the 5-day mean chart at 700 millibars, prepared by Mr. Namias' unit, and he has shown very interesting correlation between 3 to 5 day tracks and the 5-day mean charts. It should be a matter of great interest to develop these computations further and to investigate the possibilities of using these 5-day charts to serve for 48 to 72-hour forecasts. The other stable chart is the surface map where, of course, there is the most data. This has recently been exploited by the group of Tom Malone in Hartford, using this statistical forecast system, which has shown what, to many people, has been a surprising amount of success. This also has been a 24-hour scheme which, however, one should certainly try to extend to 36 hours or more, and also to include parameters not currently used in this statistical treatment. There are some fairly clear ways to proceed here - one of the most attractive things is that the surface map, with relatively copious data, can probably be processed entirely numerically without any hand analysis. This means that in the end we would not encounter the situation where one forecast center gets one answer and another forecast center gets something else. Consequently, for computational purposes these two stable charts seem to offer interesting possibilities.

Everything else that has been done has been based on grid systems - either at 700, 500 or 300 millibars, and out over the oceans where the configurations of the chart depend on the experience and notions of the analyst. Different forecast centers do not come up with the same solution, and computations made from such charts also come out differently. One never knows then in such cases whether the errors one gets are inherent in the models or the computational schemes that have been devised, or whether they are purely in the data. This applies to the statistical objective systems, such as that of Miller in the Miami forecast office here, and the system that I have produced, as well as the numerical prognoses made on the electronic computer. Dr. Kasahara has shown a very interesting set of verifications, and another interesting set was shown for the Pacific this morning by Dr. Arakawa and Dr. Gambo. One could see from these verifications that the hope in numerical prediction for hurricanes which existed 4 years ago at the Tokyo Conference on hurricanes has not been fully realized. Some people came away from that conference thinking that there was only one thing to do and everything else could be discontinued. Subsequent history has not borne that out, and again this need not necessarily be the fault of the models that have been employed for this purpose, but simply because the computations have been carried out over wide oceanic stretches, where there are no observations.

So there is no answer at all at the present time as to whether the errors in these forecasts come from such things as the barotropic model employed, the subtraction of the storm center from the general circulation, or simply from data deficiencies. It seems unlikely we will come to any solution in this matter until such time as the data situation is clarified. But there is not in existence at the moment a single occasion in which there have been sufficient data available from the oceans to draw 500 or 700 millibar maps in a unique way so as to give an answer to this question, even in the case of a single cyclone. It almost goes without saying then that if significant improvement in working with grids is to be achieved, then there must be more observations. These observations, as nearly as one can see at the moment, have to be airplane observations. There does not seem to be anything else in the picture - perhaps constant pressure balloons at high altitudes, but certainly aircraft in the middle troposphere.

For a number of years I have advocated, as have a lot of other people, especially those working in numerical prediction (for instance, Dr. Platzman), that every effort be made to have the reconnaissance deployed in such manner that the blank sectors of the map are filled in with respect to existing hurricanes. The history of reconnaissance, if you review it in recent years, has been that there has been no change in the practice, namely - for the aircraft to fly directly to the center, to stay there to take dropsonde, and put other devices in the center, and to relay this data to the forecaster. The winds and temperatures collected on the way to and from the storm area are also made available in due course. In addition to this, of course, when a storm is now located near land there are radar fixes, and a great deal of operational effort has been put into these aircraft fixes and land based radar fixes. Unfortunately, a considerable amount of misinformation now exists in

the public mind where there is a wide spread impression that in order to predict the hurricane it is necessary to have a radar trained on the storm and to have an airplane in it, and with these the forecast is given. Well, this as you all know is a completely wrong impression.

This kind of data, at least as far as we have it at the moment, is of little value in predicting except to fix the place from which the prediction starts. It can also tell you something about where the storm has been, but in a broader sense it will not help the prediction problem in itself, so that we need a complete change of heart in the reconnaissance program if any real use is to come of the physical and empirical models of hurricane prediction by means of open grids over the oceans. Even if the perfect model was developed it would be of absolutely no use if the data requisite for carrying out the model were not available. However, it is in my mind very questionable at the moment what is to be gained through continuing investigations of the type that utilize open grids as long as one has to practically imagine the data over the oceans that form the basis for these predictions. It is rather obvious that improvements can be made on computations utilizing the data, but there seems little use in, for instance, trying a second approximation that would be valid at 36 hours unless some improvement in the basic data is going to be possible. When one then looks at the prediction models and realizes that there are certain second derivatives involved in making these predictions, you can see that it is astounding indeed that results have been obtained as good as those of Dr. Kasahara and Dr. Arakawa.

In conclusion, my impression is this for recommendations for the future - in the first place there seems to be not very much use in trying out 24-hour forecasts since they are not for a long enough period to achieve a great deal of good. One must then aim to develop a 36 to 48-hour forecast technique, preferably the requisite data should be supplied directly from aircraft, possibly being exploited on the aircraft itself. The calculations should be based on charts that are observationally stable, mainly, the 5-day mean and the surface chart. Also, perhaps, one should at least for coastal warning purposes abandon the notion that he should find a forecast scheme which is valid in all latitudes and all longitudes and is universally applicable. This of course would be the nicest thing if it were possible. But more realistically we must develop prediction schemes for 36 to 48-hours in advance in specific areas where regularly functioning upper air stations are available and can be relied upon. These station data can be utilized to develop regressions and other means to arrive at the requisite forecast. This is approximately a summary of my conclusions from this morning's session, and from following the evolution of efforts in forecasting the motion of hurricanes over the past few years.

Prof. Palmen: Thank you very much, Prof. Riehl. I am afraid that it has become too late in the afternoon to have a break in the program, and unless there are some very urgent questions I feel that we should go over to the last point

on today's program, namely - the question of the future plans for the Hurricane Project. We have heard here all kinds of recommendations, all kinds of possible investigations. Many of these could naturally depend on the possibility of continuing the work on a large scale. We will ask if Mr. Simpson could give us a brief review of the plans for the near future: how the Project will be organized, what kind of observations made, etc.

Mr. Simpson: I realize it is getting late and many of you have planes to catch. I will try to keep this to the point and as brief as possible. I believe that we will be able to comply with the recommendations which have been made so well and effectively here.

In stating what we propose to do from here on out I think it would be well to place this a little bit in perspective by reviewing just for a moment what our objectives were at the outset and what we planned to do by this time. You can see for yourself then how the pattern for the future has shaped itself. To begin with, and I'll not go into all the details, of course, because most of them are known to you, it was our feeling that the Project should move ahead along two lines. One, we would attempt to organize information already available to us in the best possible fashion to permit improvement right away in the techniques for prediction, and to this end we established additional positions at our forecast centers for forecasting research work and have given some contract work where people were able to take this on to try to develop improved techniques for forecasting without waiting to get new information. In addition to this we felt that the real heart of our problem was, if we are to materially improve our ability to predict, to understand the physics of atmospheric circulations involving the hurricane and its movement. While we have learned a great deal of this in terms of radiosonde data, in terms of information near the fringe of the storm, it has become apparent that one of the things we should do would be to study more carefully the hurricane at the point of inception where we rarely fortuitously have a radiosonde or a good network. Also, to obtain information from the core of the more mature systems to see if the extrapolation of knowledge and reasoning we had used about the fringes was proper.

We have proceeded then to set up a program which has operated the past three years. We stated that the aircraft probes that we would operate should attempt to get at least three good samples, as a minimum, from storms first in the incipient stage, three good samples from storms in the mature stage, and three good samples from storms in the late or decaying stages. These to be done with all three of the probes available in the storm sufficiently close to each other that we could analyze the circulation volumetrically. We have to date managed to get six such three-plane missions accomplished while flying a total of nearly a hundred sorties into hurricanes of all kinds, but many of these individual flights, where we got only a fragment of our total objective, cannot be subjected to volumetric analys s. As you have seen here in the reports at this meeting, which have opened up new and other avenues of interest, many problems have

developed. These demand more extensive investigation than we ever thought was going to be necessary at the outset. We have felt, and have planned now for over a year to extend the aircraft facilities and the type of probing investigation that we have carried out for the past three years. We now are in an advanced state of planning and almost at the point of implementation in equipping three new planes to carry on continuously for another three years. I say three years because, in Government when one plans, it is usually necessary to be rather quantitative in talking about years and specific endurance of projects which are not intended to be permanent when they are established. We have never had any scientific notion that we could accomplish any specific thing in one or two years, or three years - this has been forced on us, but we think that another three years is a realistic goal to shoot at.

I should pause at this juncture to do something that has not been formally done anywhere in these sessions, and I think it has not been demanded, certainly. That is simply this - to point out that the work done so far has been, in the best sense of the word, a collaborative effort involving agencies, institutions, research institutions, and Government organizations on a very broad scale. We have first of all had the Department of Defense and, specifically, the Air Weather Service supporting the aircraft program by providing first two B-50's and one B-47 aircraft. They have provided personnel to operate these planes for us, and have flown them at the expense of the U. S. Air Force. We have had as our immediate collaborators the very best people that are available in this field, from various Universities and Research Institutions; Florida State University has provided an active contingency, especially through Dr. LaSeur, who has served as Associate Director of the Project in the planning phase right straight through. Dr. Riehl has been active from the very first and in the last two seasons he has flown a number of missions with us and helps us immeasurably. Dr. Malkus has made many trips to Palm Beach and has worked actively from Woods Hole on various portions of the work, planning and otherwise, and you have seen the results of her contributions here. It is our intent to continue this type of collaboration for the next three years. Another thing I do want to mention is that the Navy also assisted this year in monitoring our cloud physics work.

This next year it will be necessary for us to equip leased commercial aircraft and to operate these completely under the Department of Commerce. We have really imposed upon the Air Force during the past three years for the support that they have so willingly and effectively given. We are in the process now of advertising bids for aircraft. We will require two DC-6B aircraft which will be equipped with essentially the same system we had in the old planes, but with some modifications that will extend the capability of our probing and data collection. In addition, the B-47 which we have had before will be replaced by a B-57 which is, while it is a little shorter range aircraft, a higher flying, more flexible aircraft and can be staged from many fields. These three planes then will be used to continue the investigations we have been carrying out the last three years. It is our intent gradually to use these planes more

and more in seasons of the year other than during the hurricane season for investigations, as I have said earlier, of the tornado problem, of the extra-tropical cyclone problem, and of the sub-tropical and equatorial jet stream problem, a very important item which has not received much attention at this conference. We will gradually phase out of the hurricane investigation as we get enough samples from enough different storms to feel that we may confidently set up the range of models, or the galaxy of models, that has been indicated here as desirable. We will move ahead confidently in theoretical and other avenues of research on the hurricane problem.

Next April 1st there will be a basic change in the organization of NHRP when our shop at West Palm Beach will be closed and we will combine here at Miami with Mr. Dunn's organization which has recently moved to the Aviation Building. We will form what will be known from there on out as the National Hurricane Central of which Mr. Dunn will be the head. This center will proceed with the objective of melding and combining advantageously operations and research in addition to the supervision of the data collection effort such as we have conducted at West Palm Beach. Little by little at this joint center the U. S. Weather Bureau effort will be devoted to the applied research problem, trying to work into the forecast techniques the benefits from the more fundamental knowledge and understanding of the dynamics of the hurricane which we are now beginning to obtain. At the same time collaboration through the Universities and other research institutions will continue to be fostered and supported by the Weather Bureau. It is our hope that we can have much of this done, not exclusively at the institutions, but at the National Hurricane Central also, for the simple reason an atmosphere in which fundamental research is being conducted should be provided at this new center as a stimulus, i.e., a means of stabbing awake our people who are devoting themselves to the operational problem and to the applied research problem. We do feel that perhaps some feedback of experience into the fundamental research effort will be gained thereby. I could go on into other facets of these plans but essentially this is the summary of what we expect to do in the coming years, and with good luck we will be on our way next season.

Thank you.

Prof. Palmen: Thank you very much, Mr. Simpson, for this explanation of the plans for the future. At the beginning of this meeting I had at first thought that we should make some quite specific recommendations; however, so many recommendations came up here already during the discussion and the time is late. I appeal that if nobody here has any objection we now could consider this meeting to be at an end. Before that, however, I would like to say that I, at least, personally feel great confidence in the future of this Project. I have read so many of the publications published by the Project and I have read these papers here and listened to the discussions. I had several times the impression that the time has come from which we can look forward to a great future in this field. By comparing this meeting with some other meetings on tropical

hurricanes, I feel that this has really provided much more new information and promising theories. With this I would like to declare the meeting closed. However, before we leave, Prof. Petterssen, as President of the American Meteorological Society, would like to say a few words.

Prof. Petterssen: Thank you, I shall be very brief. First of all, on behalf of the Society I wish to thank Profs. Hiser and Simpson, the two Chairmen of the Arrangements Committee and their associates, for the immense amount of work which they have done to make such a pleasant meeting for us. I think I am quite honest when I say that I have rarely been to a meeting which has been more pleasant to attend. Also, on behalf of the Society, I should like to thank our foreign guests who came from far and wide to make this meeting so successful, and I know many of them have had to leave already. I see some here and I am sure I speak for all when I thank Dr. Palmen for his contribution to this meeting. Well, so much for the Society, now a few words just from myself. I have been in Meteorology for 35 years; I have seen quite a lot of progress and particularly how slow progress normally is. I must say that I am impressed by what I have seen at this meeting and what has been done in such a short time. It is, of course, very pleasant for us visitors to come here, but I think we all leave with the impression that this is a very, very excellent team at work here. I am optimistic enough to think that this might be one of the prettiest pages in the history of Meteorology, and I wish the Project all the luck they deserve. I think now I shall turn the meeting over to the Program Chairman.

Thank you all very much.

Mr. Simpson: Well, Dr. Petterssen, I want to thank you first personally for those very kind words, and I'll not take more time in extending this meeting, but before I do so I want to acknowledge gratefully the participation of what we have called a Board of Review, for lack of a better way to describe it, people who are key individuals in our profession who have made key contributions and represent, I think, as much maturity as we could get together on one platform representing our profession. They are busy people and they have come here in the midst of their own undertakings, and I know many of them have very trying schedules. I want to express appreciation on behalf of the Program Committee for the sacrifice they have made in coming here and in participating in this rather arduous task this afternoon. It has meant a great deal to all of us, I am sure. Thank all of you on the local committee, Mr. Dunn in particular, and all his people who have done so much in making this Conference a success in their planning, and of course it goes without saying that I appreciate the work of my staff that backed me in the program planning.

Thank you very much.

December 1, 1958

Mr. Robert H. Simpson
National Hurricane Research Project
P. O. Box 271
West Palm Beach, Florida

Dear Bob:

Thank you very much for your letter. I enjoyed the conference very much, and only regret that there was not more time to talk to you about concrete problems.

I have some further ideas about rain bands and would very much appreciate it if you could send me, or tell me where I could locate, the latest material concerning detailed horizontal wind and temperature profiles in relation to the location of the rain bands, and, if possible, the vertical temperature structure. This data, as I said at the conference, is a model of what accurate observations in the atmosphere should be. I congratulate you upon it!

Please express my regrets to your wife, to Hawkins, Gentry, and their wives that my peculiar hours and the general hurly-burly prevented my spending more time with them. I look back with fond recollection to the pleasant time I spent in your midst last spring.

With best regards,

Sincerely,

Jule Charney

jc:tg

DEC 1 1958

UNITED STATES DEPARTMENT OF COMMERCE
WEATHER BUREAU

RESEARCH OPERATIONS BASE
WEST PALM BEACH, FLA.

P.O. Box 271
November 26, 1958

Professor Jule G. Charney, Director
Dynamical Weather Prediction Project
Department of Meteorology
Massachusetts Institute of Technology
Cambridge 39, Massachusetts

Dear Jule:

This is just a hurried note, as I catch my breath from the rather vigorous activity of last week's meetings, to tell you how very much we all appreciate your participation on the Board of Review at the Hurricane Technical Conference. It is always an imposition to ask people with a schedule as crowded as yours is to take on such a job as that, and it is especially gratifying when a person not only agrees but contributes so effectively as you did.

Again many thanks for your contributions, and the pleasure of working with you again.

Sincerely,

R. H. Simpson, former Chairman
Committee for Promotion of
Research on Severe Storms

2nd draft
Hurricane Conference
Miami

On the Formation of Tropical Depressions

by

Jule G. Charney

1. Introduction.

Hurricanes develop from preexisting tropical depressions that, in their early stages, are indistinguishable from depressions that do not deepen into hurricanes. Here is at once a clue and an enigma. The organized motion of the tropical depression is a necessary precursor of the hurricane, yet only a very small fraction of these depressions ultimately grow into hurricanes. What is it that limits their growth? And what is the pathological factor that unleashes the storm in the few exceptional cases? To answer these questions it would seem desirable to begin with the first, for without an understanding of the normal behavior of the tropical depression, it does not seem possible to arrive at an understanding of its pathology. Another and perhaps more compelling reason for such a study stems from the work of Malkus ( ), Riehl ( ), Simpson ( ) and others who find that the depression is an essential element in the general circulation of the tropics. Deep cumulonimbus convection, the mechanism by which latent and sensible heat are supplied to the upper tropical troposphere, is apparently not the random phenomenon it has sometimes been thought to be, but is a

highly concentrated and organized activity confined almost exclusively to the inner regions of tropical depressions. The foregoing reasons have supplied the motivation of the present study which is concerned with the dynamics of the tropical depression.

2. The role of hydrodynamic instability in the formation of the tropical disturbance.

In analogy with the theory of extratropical cyclones, it is tempting to attribute the formation of a tropical depression to some form of hydrodynamic instability; and in fact such mechanisms have been proposed to explain hurricane formation. The growth of disturbances has been variously attributed (Riehl, 1954) to the instability of temperature discontinuities (frontal instability), of horizontal tempreature gradients (baroclinic instability), or of radially decreasing angular momentum in the case where the disturbance is a circular vortex (dynamic instability). There is little evidence, however, to indicate that such instabilities exist, or if they did that they would give rise to the observed motions. But there is a fourth kind of instability which undoubtedly does exist. This is the gravitational (conditional) instability associated with negative lapse-rates of equivalent or wet-bulb potential temperature. Large regions in the tropics are unstable for upward displacements of saturated air. Can one account for the growth of a tropical disturbance as simply a large-scale convective overturning? Again we must say that this mechanism is unlikely, for it has been shown by J. Bjerknes (1935) and E. Höiland (1939) that conditional instability favors small-scale cumulus convection rather than large-scale convection. Indeed, were it not for friction and en-

trainment of dry air the preferred cumulus cell would have an infinitely narrow ascending branch. Even when the motion is absolutely and not conditionally unstable, the theory of Benard cell convection (Rayleigh, 1916) suggests that the convection cells would have roughly the same horizontal and vertical dimensions. The energy of a cumulus cloud is derived from the unbalanced vertical forces acting on a buouyant element of saturated air. Such forces do not exist in the mean in a large-scale depression, otherwise the motion would not be quasi-hydrostatic as we know it in fact to be. We must therefore reject gravitational instability per se, as the direct causal agent.

Nevertheless conditional instability by permitting cumulonimbus convection must play a role in the formation and maintenance of the tropical depression. The most striking characteristic of the tropical depression is the enormous amount of precipitation in the region of convergence. The latent heat energy released is two orders of magnitude greater than the amount needed to maintain the kinetic energy against frictional dissipation. This energy is liberated at temperatures several degrees above that of the surrounding air at the same levels. The efficiency of the process is therefore of the order of 10^{-2} as the energy available for doing work is of the order $10^{-2} \times 10^{2}$, or 1, times the rate of dissipation.

NOV 3 1958

UNITED STATES DEPARTMENT OF COMMERCE
WEATHER BUREAU

RESEARCH OPERATIONS BASE
WEST PALM BEACH, FLA.

P. O. Box 271
October 29, 1958

Dr. Jule G. Charney, Director
Dynamical Weather Prediction Project
Department of Meteorology
Massachusetts Institute of Technology
Cambridge 39, Massachusetts

Dear Jule:

Thanks for forwarding the abstracts of your paper so promptly. I am sure that all of us would be delighted to have Ogura and Gambo attend and participate in the discussions at Miami. I know both of these people and regard them highly. If they have specific contributions which they wish to present as formal papers, it is too late to include these in the printed program or the Proceedings; however, we can probably work them into one or another of the sessions. Please let me know as soon as possible if they will bring papers to be presented.

Work on the Proceedings is expected to be completed next Wednesday, and you should have your printed and bound copy in the mail next weekend.

With best regards,

Sincerely,

R. H. Simpson, Director
National Hurricane Research Project

October 17, 1958

Mr. Robert Simpson
National Hurricane Research Project
P. O. Box 271
West Palm Beach, Florida

Dear Bob:

Enclosed herewith are two copies of the abstract of my talk at the Hurricane Conference.

I am very much looking forward to seeing you and hearing about your new observations. The summer was too hectic to get any work done on hurricane dynamics, but in the last week or so I have become hot on the trail again.

We have two Japanese with us: Ogura, who is attached to our project, and Gambo who is visiting. Would it be possible to bring one or both along as spectators at the conference?

With best regards,

Sincerely,

Jule Charney

jc:tg

Enc: Abstract

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
CAMBRIDGE 39, MASSACHUSETTS

DEPARTMENT OF METEOROLOGY

October 17, 1958

Mr. Robert Simpson
National Hurricane Research Project
P. O. Box 271
West Palm Beach, Florida

Dear Bob:

Enclosed herewith are two copies of the abstract of my talk at the Hurricane Conference.

I am very much looking forward to seeing you and hearing about your new observations. The summer was too hectic to get any work done on hurricane dynamics, but in the last week or so I have become hot on the trail again.

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With best regards,

Sincerely,

Jule Charney

jc:tg

Enc: Abstract

On the Formation of Tropical Depressions

Abstract

The hypothesis is developed that tropical depressions owe their origin to an organized release of latent heat through cumulus activity in a convectively unstable tropical atmosphere. Contrary to the usual assumption, the motion is not regarded as a free convection in a gravitationally unstable atmosphere, but as a forced convection driven by the latent heat released in the regions of mean upward flow.

On the basis of this hypothesis it becomes possible to calculate the dimensions and velocity and temperature structure of the incipient disturbances as functions of the dry and moist adiabatic lapse-rates and the vertical component of the earth's angular velocity.

An important part of the argument is concerned with the justification of a method for relating the heat released in cumulus convection to the properties of large-scale flow.

OCT 20 1958

UNITED STATES DEPARTMENT OF COMMERCE
WEATHER BUREAU

RESEARCH OPERATIONS BASE
WEST PALM BEACH, FLA.
P. O. Box 271
October 16, 1958

Dr. Jule G. Charney
Director, Dynamical Weather Prediction Project
Department of Meteorology
Massachusetts Institute of Technology
Cambridge 39, Massachusetts

Dear Jule:

Since you were here last spring, I have heard nothing further from you but have assumed that we may still count upon your participation in the Hurricane Technical Conference at Miami Beach in November--both as a member of the Board of Review and for the paper on your hurricane model.

This hasty note is to ask that you send me some manner of abstract, preferably as expanded as time will permit, for inclusion in the proceedings which is to go to press in about 10 days. This will be distributed in advance to all members of the Board of Review and made available to all registrants at the beginning of the conference. While it is not necessary for the expanded abstract to include illustrations, we are prepared to reproduce these if they are available.

I hope you had a very pleasant summer at UCLA and that the fall session is shaping up per your expectations. We are looking forward to having you with us next month.

Very truly yours,

Bob

R. H. Simpson, Director
National Hurricane Research Project

rec 3/14/58

UNITED STATES DEPARTMENT OF COMMERCE
WEATHER BUREAU

RESEARCH OPERATIONS BASE
WEST PALM BEACH, FLA.

P. O. Box 271
March 7, 1958

Dr. Jule Charney
Department of Meteorology
Massachusetts Institute of Technology
Cambridge 39, Massachusetts

Dear Jule:

The AMS Committee for the Promotion of Research on Severe Storms is sponsoring a Technical Conference on Hurricanes at Miami next November 19-22. The purpose of the meeting is to survey progress, and to point up those areas in which furhter research is most needed. It has been decided that for best results the scientific program should consist entirely of invited papers from research units or individuals known to have concentrated on some aspect of hurricane research in recent years. A copy of the provisional program and list of invited papers are enclosed for your information.

In view of the work which your organization has done on the hurricane problem, we would like to invite you to present a paper at these meetings. It is desired that all invited papers be comprehensive in scope, reporting not only on the background, and the progress of work thus far accomplished, but also the prospective benefits of and requirements for further research of the kind discussed in the paper.

Most sessions will contain no more than four papers, and approximately thirty minutes will be allotted for the presentation of each, with at least half that much time reserved for discussion. We have tentatively scheduled your paper for session VIIa, Friday afternoon, November 21st. The suggested topic and arrangement of the session is quite tentative, and any alternative suggestions you may wish to offer will be much appreciated. In any event the final title of your paper should of course be of your own choosing.

Finally, all authors are being requested to submit manuscripts, or expanded abstracts of their papers, to the local committee (Mr. Gordon Dunn, Chairman) not later than October 20, 1958. Shorter abstracts should be forwarded in the usual fashion to the Executive Secretary of the Society at Boston not later than September 1, 1958.

We shall look forward to having you with us during these meetings.

Sincerely,

R. H. Simpson, Chairman
Committee for the Promotion of
Research on Severe Storms

Encls.

Draft
March 7, 1958

AMERICAN METEOROLOGICAL SOCIETY

Technical Conference on Hurricanes
Miami, Florida
November 19-22, 1958

(Sponsored by the Committee for the Promotion of Research on Severe Storms)

Wednesday, November 19th

I	1600-1800	Registration
II	1700	Buffet Supper at Poolside. (Sponsored by the A.M.S. Committee on Radar Meteorology).

Thursday, November 20th

III	0900-1200	(a) Climatology and Synopto-Climatic Studies. (CHAIRMAN: Mr. J. J. George).
		(b) Storm Surges. (CHAIRMAN: Prof. Erik Palmen).
IV	1330-1630	Radar Analysis of Severe Storms. (Joint session).
V	2000-2230	Cyclogenesis and Intensification. (CHAIRMAN: Prof. Jule Charney).

Friday, November 21st

VI	0900-1200	Circulations and Energy Processes in the Storm Core. (CHAIRMAN: Prof. H. R. Byers).
VII	1330-1630	(a) Energy Cycles and Models (CHAIRMAN: Dr. George P. Cressman)
		(b) Observing and Tracking Facilities, Communications and Warning Dissemination. (CHAIRMAN: Dr. Thomas Malone).
VIII	1900	Banquet. (Address by Dr. Lloyd Berkner).

Saturday, November 22nd

IX	0900-1200	Prediction of Hurricane Movement. (CHAIRMAN: Prof. H. Riehl)
X	1300-1700	Board of Review, and Conference on Research Progress. (CHAIRMAN: Prof. Erik Palmen MEMBERS: Dr. H. R. Byers, Prof. Jule Charney, Dr. George P. Cressman, Mr. J. J. George, Dr. Thomas Malone, Dr. Herbert Riehl)

Draft
March 7, 1958

AMERICAN METEOROLOGICAL SOCIETY

Technical Conference on Hurricanes
Miami, Florida
November 19-22, 1958

LIST OF INVITED PAPERS

Session IIIa:

U.S.W.B., Office of Climatology:
On the climatology of hurricanes

U.S.W.B., Extended Forecast Section:
Synopto-climatic studies of hurricanes

Travelers Insurance Company:
On probabilistic methods of hurricane prediction

Eastern Airlines:
On synoptic studies of hurricane behavior

Air Weather Service, Weather Central, Tokyo:
Synopto-climatic studies of typhoons

Session IIIb:

U.S.W.B., Office of Meteorological Research:
Evaluation of models and techniques for predictior
of storm surges

A&M College of Texas:
Storm-induced high water levels

Beach Erosion Board:
The nature of storm-induced high water levels

Japanese Meteorological Agency:
Coastal inundations caused by typhoons

Session IV:

University of Miami:
The spiral rainband as a predictor of hurricane
movement and intensity

Dr. Raymond Wexler:
On the spiral rainbands of hurricanes

(Other papers to be invited by the Committee on radar meteorology)

Session V:

University of Chicago (Prof. Riehl):
Tropical cyclogenesis

U.S.W.B., Office of Meteorological Research (Mr. Hubert):
Frictional dissipation in hurricanes

National Hurricane Research Project (Mr. Gentry)
Case studies of tropical cyclogenesis

Massachusetts Institute of Technology (Prof. Wurtele):
Numerical prediction of tropical cyclogenesis

Session VI:

Prof. Palmen:
Recapitulation of energy problems in the hurricane

Florida State University:
Eye circulations

Woods Hole Oceanographic Institution (Dr. Malkus):
Energy processes at the storm core

National Hurricane Research Project (Mr. Simpson):
Energy processes in the rain area

University of Chicago (Dr. Braham)
Cloud physics in the hurricane

Session VIIa:

Massachusetts Institute of Technology (Dr. Charney):
A physical model of the hurricane

Florida State University:
Energy cycles in the hurricane

University of Chicago (Prof. Riehl):
Numerical evaluation of energy processes in the hurricane

University of Chicago:
A hydrodynamic model of a warm core circular vortex

Session VIIb:

Geophysics Research Directorate:
The hurricane beacon device

Air Weather Service:
Hurricane reconnaissance facilities

Session VIIb continued

U. S. Navy:
Hurricane reconnaissance facilities

Project AROWA:
The use of the transosonde in hurricane predictions

U.S.W.B., O&SF Division:
Ground station facilities for detection, tracking, and prediction of hurricanes

National Hurricane Research Project (Mr. Hilleary):
Aircraft recording and sensing instruments for weather investigations.

FCDA:
The public relations problem in disseminating hurricane warnings

Session ~~VIII~~ IX:

National Hurricane Research Project:
Prediction of hurricane movement

U.S.W.B., Hurricane Center, Miami, Fla.:
Prediction of hurricane movement

U.S.W.B., Forecast Center, Washington National Airport:
Hurricane prediction

University of Chicago (Prof. Platzman):
Numerical prediction of hurricane movement

Australian Meteorological Service:
Prediction of tropical cyclone behavior

fill
U.S.
Weather Bureau

June 20, 1958

Mr. Cecil Gentry
National Hurricane Research Project
Research Operations Base
P. O. Box 271
West Palm Beach, Florida

Dear Mr. Gentry:

Thank you very much for sending a copy of the paper, "Meso-scale Circulations in the High Energy Core of a Hurricane," to Professor Charney. He is spending the summer in Los Alamos and Los Angeles at the University of California. I am forwarding the paper and a copy of your letter to him. I'm sure he'll be happy to receive both.

Sincerely,

Theresa Grant
Secretary to Dr. Charney

tg

cc: Professor Charney

sent letter & paper to Charney
at Los Alamos
6/20/58
tg

JUN 20 1958

UNITED STATES DEPARTMENT OF COMMERCE
WEATHER BUREAU

RESEARCH OPERATIONS BASE
WEST PALM BEACH, FLA.

P. O. Box 271
June 18, 1958

Dr. Jule Charney, Director
Dynamical Weather Prediction Project
Department of Meteorology
Massachusetts Institute of Technology
Cambridge 39, Massachusetts

Dear Jule:

Enclosed is a copy of the paper "Meso-scale Circulations in the High Energy Core of a Hurricane", by the staff of the National Hurricane Research Project. This paper describes several interesting features of the circulation of hurricane Carrie. Another paper will be prepared which will go further into thermodynamical features and energetics of the storm.

We are forwarding this paper for your information and for your files. At the present time the paper is being reviewed, preparatory to publication in the NHRP preprint series, and we would appreciate any comments you care to make.

Thanks again for the helpful discussions of the Carrie data.

With best personal regards,

Sincerely,

Cecil Gentry
for R. H. Simpson, Director
National Hurricane Research Project

Encl.

Nov. 19-22
Conference

March 12, 1958

Mr. Robert H. Simpson, Director
National Hurricane Research Project
P. O. Box 271
West Palm Beach, Florida

Dear Bob:

Thanks for your letters of March 7th. I shall be very glad to participate in the conference on hurricanes in Miami November 19-22, 1958. From the looks of the program it should be a very interesting one.

With regard to my visit to your project at Palm Beach - I have been looking forward to it but last week I got banged up in a skiing accident and will not be in a fit condition to travel for another month and a half. This would bring us to the middle of April. If it would be convenient for me to visit you at that time, I would be very glad to do so. To be specific,I could visit you on April 17-20. I could take the Eastern Airlines flight out of Boston on Thursday, April 17 at 8:30 a.m., arriving at West Palm Beach at 2:10 p.m. How would that suit you?

With best regards.

Sincerely,

Jule G. Charney, Director
Dynamical Weather Prediction
Project

jgc:tg

rec 3/11/58

UNITED STATES DEPARTMENT OF COMMERCE
WEATHER BUREAU

RESEARCH OPERATIONS BASE
WEST PALM BEACH, FLA.

P. O. Box 271
March 7, 1958

Dr. Jule Charney
Department of Meteorology
Massachusetts Institute of Technology
Cambridge 39, Massachusetts

Dear Jule:

This will confirm my recent request that you participate in the Technical Conference on Hurricanes at Miami next November 19-22. The Conference is being sponsored by the AMS Committee for the Promotion of Research on Severe Storms, and its purpose is to review progress made on the hurricane problem and to illuminate those areas in which further research is needed. To accomplish this the Committee is asking a group of "elder statesmen" of our Society to act as chairmen of individual sessions during these meetings, then to participate during the last session of the Conference in a Board of Review. Each Board member will be requested to review critically those papers presented under the session for which he was chairman, and indicate what he believes these papers add up to in terms of progress made, deficiencies remaining, and the direction which further research in this area should take. It would be expected that discussion on the comments of each Board member would be developed first among the Board members, and later by inviting participation from the audience. The proceedings from the Board of Review will be recorded and, if practicable, be published in some properly edited form.

The Committee would appreciate very much your assistance by serving as a member of the Board of Review, and acting as Chairman of the session entitled "Cyclogenesis and intensification," scheduled for Thursday evening, November 20th.

We look forward to having you with us on this occasion.

Sincerely,

Bob

R. H. Simpson, Chairman
Committee for the Promotion of
Research on Severe Storms

Draft
March 7, 1958

AMERICAN METEOROLOGICAL SOCIETY

Technical Conference on Hurricanes
Miami, Florida
November 19-22, 1958

(Sponsored by the Committee for the Promotion of Research on Severe Storms)

Wednesday, November 19th

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Draft
March 7, 1958

AMERICAN METEOROLOGICAL SOCIETY

Technical Conference on Hurricanes
Miami, Florida
November 19-22, 1958

LIST OF INVITED PAPERS

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U.S.W.B., Office of Climatology:
On the climatology of hurricanes

U.S.W.B., Extended Forecast Section:
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Travelers Insurance Company:
On probabilistic methods of hurricane prediction

Eastern Airlines:
On synoptic studies of hurricane behavior

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Synopto-climatic studies of typhoons

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U.S.W.B., Office of Meteorological Research:
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A&M College of Texas:
Storm-induced high water levels

Beach Erosion Board:
The nature of storm-induced high water levels

Japanese Meteorological Agency:
Coastal inundations caused by typhoons

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Session VI: Prof. Palmen:
Recapitulation of energy problems in the hurricane

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Eye circulations

Woods Hole Oceanographic Institution (Dr. Malkus):
Energy processes at the storm core

National Hurricane Research Project (Mr. Simpson):
Energy processes in the rain area

University of Chicago (Dr. Braham)
Cloud physics in the hurricane

Session VIIa: Massachusetts Institute of Technology (Dr. Charney):
A physical model of the hurricane

Florida State University:
Energy cycles in the hurricane

University of Chicago (Prof. Riehl):
Numerical evaluation of energy processes in the hurricane

University of Chicago:
A hydrodynamic model of a warm core circular vortex

Session VIIb: Geophysics Research Directorate:
The hurricane beacon device

Air Weather Service:
Hurricane reconnaissance facilities

Session VIIb continued

U. S. Navy:
Hurricane reconnaissance facilities

Project AROWA:
The use of the transosonde in hurricane predictions

U.S.W.B., O&SF Division:
Ground station facilities for detection, tracking, and prediction of hurricanes

National Hurricane Research Project (Mr. Hilleary):
Aircraft recording and sensing instruments for weather investigations.

FCDA:
The public relations problem in disseminating hurricane warnings

Session VIII: National Hurricane Research Project:
Prediction of hurricane movement

U.S.W.B., Hurricane Center, Miami, Fla.:
Prediction of hurricane movement

U.S.W.B., Forecast Center, Washington National Airport:
Hurricane prediction

University of Chicago (Prof. Platzman):
Numerical prediction of hurricane movement

Australian Meteorological Service:
Prediction of tropical cyclone behavior

RPH;mac

WB Form 255-2
(Formerly 3059)

UNITED STATES DEPARTMENT OF COMMERCE
WEATHER BUREAU

June 5, 1958

REFERENCE: A-3.32

Dr. Jule G. Charney
Room 24-508
Massachusetts Institute of Technology
Cambridge 39, Mass.

Reference: Your travel voucher for $ 51.20 covering expenses under travel order No. 1187 dated 3/19/58 for the period 4/17-4/20/58

SIR:

The voucher is incorrect or incomplete as to the points indicated. (The abbreviations used are "SGTR" for "Standardized Government Travel Regulations" and "WBM" for "Weather Bureau Manual").

——1. Check-mailing address. See Exhibit C-29-1 WBM.
——2. The name of the permanent official station.
——3. Per-diem computation when more than one rate is involved. See Pars. C-2614 (c) and C-2903 (e 4) WBM.
——4. Per-diem computation for travel of not more than 24 hours. See Par. C-2614 (a) WBM.
——5. Reason for travel outside the hours of 8 a. m. to 6 p. m. since the travel period was not more than 10 hours. See Par. C-2604 WBM.
——6. Per-diem may not be allowed for travel of less than 3 hours, nor for travel wholly between the hours 8 a. m. 6 p. m. See Par. C-2604 WBM
——7. Statement as to whether or not meals and/or lodgings were furnished free of charge by a Government agency. See Pars. C-2612 and C-2903 (c) WBM.
——8. Statement as to whether or not leave was taken. See Pars. C-2504, C-2506 (a), C-2605, and C-2903 WBM.
——9. The period of leave is not clearly shown. See Pars. C-2605, C-2903, Exhibits C-29-1, and C-29-2 WBM.
——10. Information as to duty status on _____. See Pars. C-2606 and C-2903 WBM.
——11. A record of the transportation requests used. See Exhibit C-29-2 WBM.
——12. Memorandum copies of transportation requests were not received. See Exhibit C-24-1 WBM.
——13. Notation as to difference between transportation purchased with request and that actually furnished on TR C- _____ from _____ to _____. See Exhibit C-24-1 WBM.
——14. Time of cancellation of accommodations reserved on TR C-_____. See Pars. C-2410 and C-2412 WBM.
——15. Unused ticket (or portion) purchased with TR C-_____ was not received. See Par. C-2409 and Exhibit C-29-2 WBM.
——16. Complete information as to members of the family who traveled at Bureau expense. See Pars. C-2309, C-2911, and Exhibit C-29-1 WBM.
——17. Transportation request book No._____ was not returned. See Par. C-2404 and Exhibit C-29-2 WBM.
——18. Cost of a round trip ticket and reason for purchasing two one-way tickets. See Par. C-2407 WBM.
——19. Reason for not using a Government transportation request. See Par. C-2413 WBM.
——20. Certification as to necessity for use of superior accommodations. See Pars. C-2307 and C-2310 WBM.
——21. Statement as to expenses of transportation between lodging and place of duty. (Such expenses are personal to the traveler when normally incurred by the public or resident Government employees in daily travel to and from work). See Pars. C-2303 and C-2305 WBM.
——22. The necessity for the use of taxicabs. See Pars. C-2303 and C-2305 WBM.
——23. Statement as to hire of special conveyance. See Pars. C-2004 (d), C-2510, and C-2909 WBM.
——24. Receipt for cash payment for Pullman accommodations. See Pars. 80 (n) SGTR., C-2306, and C-2413 WBM.
——25. Comparative cost statement. See Exhibits C-25-1, C-29-1 and C-29-2 WBM.
——26. Statement that travel was by the most direct route. See Exhibit C-29-1 WBM.
——27. Itineraries for both the actual indirect journey and a direct journey. See Pars. C-2306, C-2506 (b), Exhibits C-29-1, and C-29-2 WBM.
——28. Itineraries for both the actual interrupted journey and an uninterrupted journey. The cost must be limited to a direct uninterrupted journey. See Pars. C-2005 (b), C-2506, Exhibits C-29-1, and C-29-2 WBM.
——29. Statement of travel by privately-owned automobile. See Par. C-2506 and Exhibit C-29-1 WBM.

(530)

(OVER)

WB Form 255-2

——30. The cost to the Bureau may not exceed that for mileage for a direct automobile journey plus per diem for a train trip. See Par. C-2506 (b) and Exhibit C-29-1 WBM.
——31. Explanation of the excess of_____ miles over the Rand-McNally mileage. See Par. C-2506 (b) WBM.
——32. Under the provisions of your travel order, the cost by airplane may not exceed that for the same journey by rail. See Pars. C-2311 and C-2906 WBM.
——33. Receipt for the expense incurred on_____. See Pars. C-2413, C-2507, C-2702-2710 incl. WBM.
——34. The 10 percent transportation tax of $ _____ on the excess transportation cost ($_____) was deducted from your voucher. See Par. C-2912 WBM.
——35. The official necessity for using a different mode of transportation on the return trip must be shown.
——36. The amount of the voucher has been applied against your advance of funds account. The amount for which you are now accountable is $_____.
——37. References to the WBM and correspondence should not be made on vouchers.
——38. The names and ages of your immediate family. See Par. C-2911(b).
——39. A reimbursement voucher is required to cover the transportation requests issued for travel of the members of your family even though no other expenses were incurred. See. C-2904 WBM.
——40. Computation of the charges covering transportation of household goods should be at the rate of $ _____ per Cwt., for_____pounds. See Pars. C-2803, C-2804, and C-2915 (a3, 4) WBM.
——41. Reimbursement for transportation of your household goods must be supported by:
——A. Evidence of shipment in the form of a commercial bill of lading or statement on the carrier's bill head including the points of pick-up and delivery. The bill of lading should include all charges and should be receipted by the Carrier's Agent to show receipt of payment. C-2915 (a1) WBM.
——B. Weightmaster's certificate showing the gross, tare and net weights. C-2915 (a1) WBM.
——C. Temporary storage receipt showing inclusive dates of storage, weight of the goods stored, and location of the storage. C-2915 (a2) WBM.
——D. Statement as to unallowable items in the shipment of household goods or personal effects. See Pars. C-2001(k) and C-2914(d) WBM.
——42. WB Form 274-1 (Formerly 6060) has not been received. See Par. C-2105(b2) WBM
——43. The number of the trip authorization was not entered on the memorandum copy of the voucher. The expenses theron have been charged to Trip Authorization No._____. We should be informed as to the correct number if that number is not applicable. See Par. C-2105(b) WBM.
——44. Computation of per diem should be as shown on the attached sheet.
✓45. The correct per diem is 3 3/4 days insteadof 4 days. Therefore the allowable per diem is $45.00 instead of $48.00. Also the allowance for mileage is 40 miles at $0.07 per mile instead of at $0.08 per mile. We have therefore deducted an amount of $3.40 for excess costs.

——Voucher submitted for _____ $ 51.20
has been reduced by suspension in the amount of _____ 3.40
has been placed in course of settlement in the amount of _____ 47.20

——Any suspended items may be resubmitted in a subsequent reimbursement account, which must be *accompanied by this letter*, in accordance with the provisions of paragraph 88, Standardized Government Travel Regulations.

Very truly yours,

J. W. McCook
Chief, Fiscal Section.

Commerce-Wea. Bur., Wash., D. C. 530

——Voucher returned for correction.
——All corrections and/or changes on the voucher must be initialed.
——All supporting statements must be in duplicate.
——Voucher retained pending receipt of required_____
——Receipts (subvouchers) submitted with the voucher:
——have been retained.
——are returned with the voucher.

Standard Form No. 1012a—Revised
Form prescribed by
Comptroller General, U. S.
November 7, 1950
General Regulations No. 88
(Amended Feb. 20, 1952)

TRAVEL VOUCHER

D. O. Vou. No. _____

Bu. Vou. No. _____

U. S. Department of Commerce, Weather Bureau
(Department, bureau, or establishment)

Payee's name Jule G. Charney, Room 24-508

Mailing address Massachusetts Institute of Technology

Cambridge 39, Massachusetts

Cambridge
(Official duty station)

(Residence—For use by Postal Service employees only)

PAID BY

Travel and other expenses in the discharge of official duty from April 17, 1958 (Date) to April 20, 1958 (Date) under authority No. 1187 dated March 19, 1958, copy of which is attached, or has been previously furnished. I have a travel advance of $ 00 to which $ _____ of this voucher should be applied.

MEMORANDUM

	DOLLARS	Cents
AMOUNT CLAIMED →	51	20
(For Administrative Use) Differences:		
APPROVED:		
Total verified correct for charge to appropriation(s) (initials)		
Applied to travel advance (appropriation symbol)		
NET AMOUNT TO TRAVELER		

The next previous voucher paid under the same travel authority was:

D. O. Vou. No. _____, paid _____ (Month—year) by _____ (Insert name and symbol of disbursing officer)

MEMORANDUM

ACCOUNTING CLASSIFICATION (Appropriation Symbol must be shown; other classification optional)

APPROPRIATION		ALLOTMENT			OBJECTIVE CLASSIFICATION	
			AMOUNT			
SYMBOL	AMOUNT	SYMBOL	VOUCHER	LIQUIDATION	SYMBOL	AMOUNT

PROJECT (for Working Funds)	
SYMBOL	AMOUNT

Paid by Check No. _____

Dated _____

MEMORANDUM

16—63078-3

SCHEDULE OF EXPENSES AND AMOUNTS CLAIMED

WHEN TYPED
USE SINGLE SPACE

1. Departed from official duty station April 17, 1958 (Date) 8:30 a.m. (Hour)

2. Temporary duty station on last day of next preceding voucher period was _____;

date of arrival at such temporary duty station April 17, 1958.

(Fill in 1 and 2 above only when dates are prior to period covered by this voucher)

DATE 58	DESCRIPTION (Include all information required by current regulations; if speedometer readings are used to compute distances, show beginning and ending readings in this column)	NUMBER OF MILES 8 cents per mile	AMOUNT CLAIMED Mileage	Subsistence	Other
	Per Diem as authorized at $12.00 (departed 8:30 a.m., April 17; returned 11:17 p.m., April 20)			48 00	
4-17	West Newton, Mass. to Boston airport	20			1 60
4-20	Boston airport to West Newton, Mass.	20			1 60
	Grand total to face of voucher (Subtotals, to be carried forward if necessary) → $51.20			48 00	3 20

TRANSPORTATION OBTAINED WITH GOVERNMENT TRANSPORTATION REQUESTS

(Not to be claimed by traveler)

Transportation Request Number	Agent's Valuation of Ticket	Initials of Carrier Issuing Ticket	Mode and Class of Service†	Date Issued	Points of Travel From—	Points of Travel To—
AO,478,328/330	168.00	EAL	S	4-8-58	Cambridge, Mass.	West Palm Beach, Fla., and return

†"Pullman accommodations: MR, master room; DR, drawing room; CP, compartment; BR, bedroom; DSR, duplex single room; RM, roomette; DRM, duplex roomette; SOS, single occupancy section; LB, lower berth; UB, upper berth; LB–UB, lower and upper berth; S, seat."

16—63078-1 U. S. GOVERNMENT PRINTING OFFICE

The Monte Cristo Hotel
Palm Beach, Florida

404
ROOM
1
PERSONS

FR.
TO

Dr J. Charney
NAME
288 Prince St
West Newton Mass

BILLS PAYABLE WHEN PRESENTED

ARR. DATE 4/17/58 RATE 8.00 CLASS REG. No. 9267

DATE	Apr 17	18	19	20	TOTAL
AMOUNT FOR'D		8.24	16.48	26.35	
ROOMS	8.00	8.00	8.00		
3% FLORIDA SALES TAX	.24	.24	.24		
DINING ROOM			1.63		
BEVERAGES					
PHONE					
PHONE L. D.					
VALET					
LAUNDRY					
TELEGRAMS					
BAGGAGE					
SOLARIUM					
CASH ADVANCED					
MISC.					
TRANSFER FROM					
TOTAL	8.24	16.48	26.35		
CASH RECEIPTS					
ALLOWANCES					
TRANSFER TO					
BALANCE					

PAID
APR 20 1958
MONTE CRISTO HOTEL
PALM BEACH

FORM 5051 CARB. BARNETT'S, MIAMI - MIAMI BEACH - PL 4-3457

FORM CD-29 (7-23-53) Pres. by A.O.-204-2

U.S. DEPARTMENT OF COMMERCE

TRAVEL ORDER

1. DATE OF PREPARATION	2. NO. OF ORDER
	1187

BUREAU OR OFFICE	3. DATE OF ORDER	4. T.R. NUMBER(S)
Weather Bureau	March 19, 1958	AO,478,328/330

5. PURPOSE OF TRAVEL

To consult with and advise the National Hurricane Research Project personnel on Hurricane Research.

6. NAME AND TITLE OF TRAVELER(s)

Dr. Jule G. Charney
Director, Dynamical Weather Prediction Project

7. ITINERARY

From Cambridge, Mass., to West Palm Beach, Fla., and return to Cambridge, Mass.

8. ORGANIZATION UNIT

9. PRESENT OFFICIAL STATION

Cambridge, Mass. (residence)

10. TOTAL ESTIMATED COST	TRAVEL	EFFECTS
	$ 191.00	$

11. APPROPRIATION AND ALLOTMENT

1381400 & 0181201

12. PERIOD OF TRAVEL	BEGIN ON OR ABOUT	END ON OR ABOUT
	4/17/58	4/21/58

13. FUNDS AVAILABLE *(For use of Accounts Section)*

GWC

14. MODE OF TRANSPORTATION

- [x] Common carrier *(except Extra Fare train)* Via Plane
- [ ] Privately-owned automobile at _____ per mile
  - [ ] Reimbursable cost not to exceed cost by common carrier
  - [ ] Common carrier determined to be impracticable
  - [ ] Determined to be more advantageous to the Government
- [ ] Other means *(Specify)*

15. PER DIEM RATE(S)

$12.00

16. CHANGE OF OFFICIAL STATION

TO

- [ ] AUTHORIZATION FOR SHIPMENT OF HOUSEHOLD EFFECTS IN ACCORDANCE WITH E.O. 9805, AS AMENDED

FROM	TO	ESTIMATED WEIGHT *(Pounds)*

- [ ] AUTHORIZATION FOR TRANSPORTATION OF _____ MEMBERS OF IMMEDIATE FAMILY IN ACCORDANCE WITH E.O. 9805, AS AMENDED

17. SPECIAL PROVISIONS OR REMARKS

If this order directs a transfer of official station, it is hereby certified that this transfer is not made primarily for the convenience or benefit of the officer or employee or at his request.

18. SIGNATURE OF REQUESTING OFFICER

TITLE

	DATE	PLACE
20. DETACHED		
21. REPORTED		

22. CERTIFIED TO BE A TRUE COPY

19. CERTIFICATE OF AUTHORIZATION BY DESIGNATED AUTHORIZING OFFICER

You are hereby authorized to travel at Government expense under the conditions noted on this authorization and in accordance with the Standardized Government Travel Regulations. The number and the date of this authorization must appear on each voucher claiming reimbursement for expenses incurred consequent to this order.

Signature R. P. Hamann
Acting Chief of Bureau

Title _____

A8.4

COMM-DC 1016

LO 7-474 CAT-4520

April 21, 1958

Mr. Robert H. Simpson, Director
National Hurricane Research Project
P. O. Box 271
West Palm Beach, Florida

Dear Mr. Simpson:

Having been informed of the operational difficulties of the National Hurricane Project in collecting low level observations, I should like to make the following statement:

> It will not be possible to make significant improvements in our ability to predict the formation and movement of tropical cyclones, or to exert a measure of control, without a thorough understanding of their physical nature. For this purpose a detailed knowledge of the structure of the storm in the so-called friction layer is essential. The friction layer is the region which determines the downward transport of momentum and hence the frictional drag on the storm. It also is the region which determines the flux of moisture from the sea surface and hence the latent energy supplied to the storm. Moreover, it is possible that variations in frictional stress are responsible for the eye and the rain-band structure. Thus, in the absence of low level observations it would be very difficult, if not impossible, to piece together the various parts of the hurricane structure into a dynamically complete whole. Since low level aircraft reconnaissance is the only presently available method for collecting such observations over the sea, and since this method is not likely to be superseded in the near future, every effort should be made to conduct the necessary flights within reasonable limits of air safety.

Sincerely yours,

Jule G. Charney
Professor of Meteorology
Director, Dynamical Weather
Prediction Project

jgc:tg

April 21, 1958

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P. O. Box 271
West Palm Beach, Florida

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Sincerely yours,

Jule G. Charney
Professor of Meteorology
Director, Dynamical Weather
Prediction Project.

jgc:tg

April 7, 1958

Mr. Bowen
Raymond & Whitcomb Company
572 Washington Street
Wellesley, Massachusetts

Dear Mr. Bowen:

Here is the Transportation Request for Dr. Jule Charney's trip to West Palm Beach in April 1958. Will his schedule be as follows: April 17, leave Boston at 8:30 a.m. on flight 817, arriving West Palm Beach at 2:10 p.m.; April 20, leave West Palm Beach at 5:30 p.m. on flight 612, arriving New York at 9:06 p.m., leaving New York at 9:40 p.m., arriving Boston at 11:17 p.m.

Many thanks for your help.

Sincerely,

Terry Grant
Secretary to Dr. Charney

tg

Enclosure

File: Raymond & Whitcomb
✓Weather Bureau - Hurricane Project

MAR 18 1958

UNITED STATES DEPARTMENT OF COMMERCE
WEATHER BUREAU

RESEARCH OPERATIONS BASE
WEST PALM BEACH, FLA.
P. O. Box 271
March 14, 1958

Dr. Jule G. Charney, Director
Dynamical Weather Prediction Project
Massachusetts Institute of Technology
Department of Meteorology
Cambridge 39, Massachusetts

Dear Jule:

We were sorry to learn about your skiing accident. However, it is fine to know you are counting on visiting us this April. The times you suggest are excellent, and we shall have travel orders cut and forwarded to you in ample time.

With best wishes,

Sincerely,

R. H. Simpson, Director
National Hurricane Research Project

Night letter sent April 14, 1958

March 12, 1958

Mr. Robert H. Simpson, Director
National Hurricane Research Project
P. O. Box 271
West Palm Beach, Florida

Dear Bob:

Thanks for your letters of March 7th. I shall be very glad to participate in the conference on hurricanes in Miami November 19-22, 1958. From the looks of the program it should be a very interesting one.

With regard to my visit to your project at Palm Beach - I have been looking forward to it but last week I got banged up in a skiing accident and will not be in a fit condition to travel for another month and a half. This would bring us to the middle of April. If it would be convenient for me to visit you at that time, I would be very glad to do so. To be specific,I could visit you on April 17-20. I could take the Eastern Airlines flight out of Boston on Thursday, April 17 at 8:30 a.m., arriving at West Palm Beach at 2:10 p.m. How would that suit you?

With best regards.

Sincerely,

Jule G. Charney, Director
Dynamical Weather Prediction
Project

jgc:tg

rec 3/11/58

file WB-
hurricane project

UNITED STATES DEPARTMENT OF COMMERCE
WEATHER BUREAU

RESEARCH OPERATIONS BASE
WEST PALM BEACH, FLA.

P. O. Box 271
March 7, 1958

Dr. Jule Charney
Department of Meteorology
Massachusetts Institute of Technology
Cambridge 39, Massachusetts

Dear Jule:

I recall that during my recent visit to M.I.T. we agreed that you would try to set aside a time to visit our Project at Palm Beach sometime during the latter part of March or early April. While we can write travel orders on short notice to cover your trip here, it would assist our planning if we could know approximately the date you expected to depart. As soon as I hear from you I will have our Business Manager in Washington, Mr. Youmans, issue the necessary authorizations and provide you with a Government Transportation Request.

With best regards,

Sincerely,

R. H. Simpson, Director
National Hurricane Research Project

UNITED STATES DEPARTMENT OF COMMERCE
WEATHER BUREAU
WASHINGTON

March 7, 1956

IN REPLY, PLEASE ADDRESS
CHIEF, U. S. WEATHER BUREAU
WASHINGTON 25, D. C.
AND REFER TO

H-1

Dr. Jule G. Charney, Director
Meteorology Project
The Institute for Advanced Study
Princeton, New Jersey

Dear Dr. Charney:

We are pleased that you can be with us March 23. Enclosed are three papers which will give you background information concerning the National Hurricane Research Project. If you have time to read these before visiting our headquarters in Washington, we believe it will expedite our discussions and make possible more efficient use of your time as an advisor.

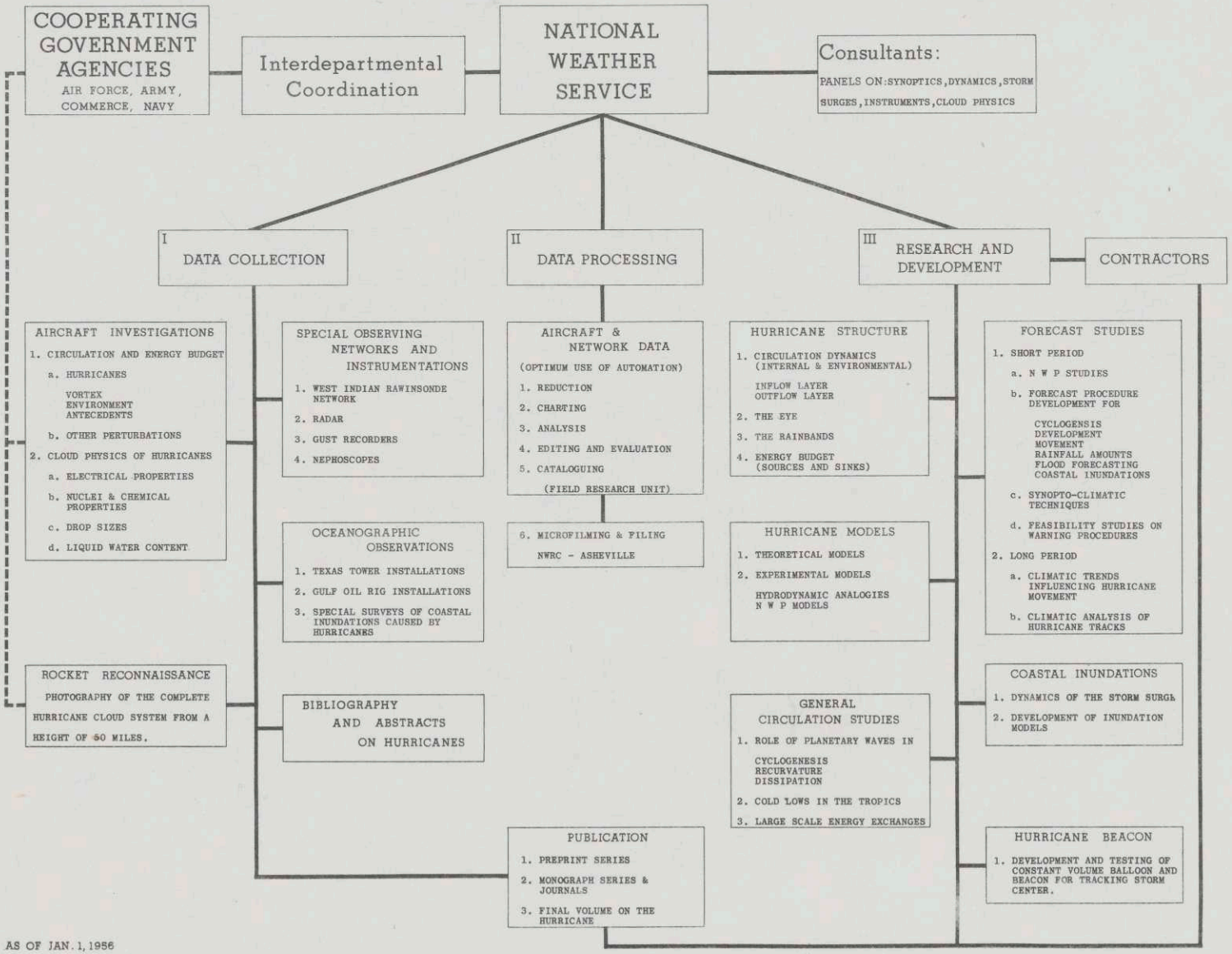
Very truly yours,

R. H. Simpson, Director
National Hurricane Research Project

Encls.

NATIONAL HURRICANE RESEARCH PROJECT

Task Organization Plan



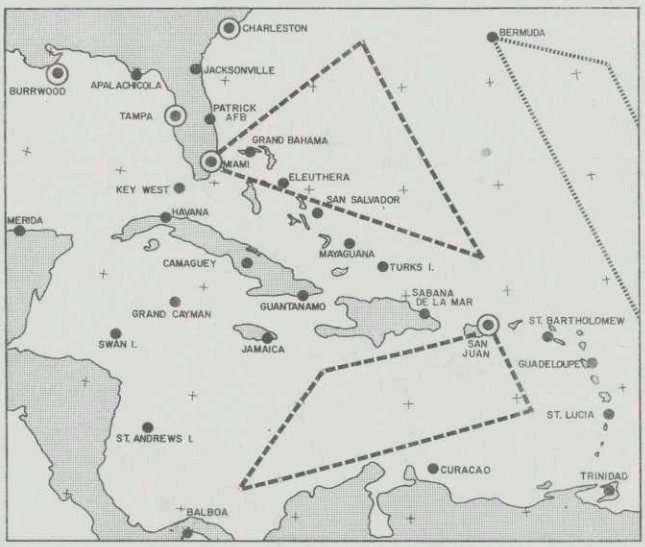
AS OF JAN. 1, 1956

NATIONAL HURRICANE RESEARCH PROJECT

PHASE I - 1956

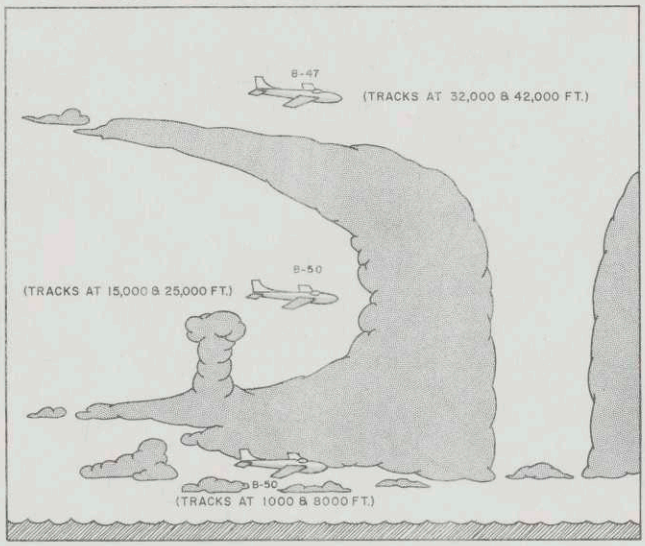
I. WEST INDIES OBSERVATIONS NETWORK & EXPERIMENTAL ANALYSIS AREA

(TWICE DAILY RAWINSONDE FLIGHTS TO 80,000 FT.)



II. AIRCRAFT INVESTIGATIONS: HURRICANES, EASTERLY WAVES, OTHER PERTURBATIONS

(ROUTINE SIMULTANEOUS FLIGHTS BY 1 B-47 AND 1 B-50, TWICE WEEKLY;
SPECIAL HURRICANE MISSIONS: SIMULTANEOUS FLIGHTS OF 1 B-47, 2 B-50S COVERING 6 LEVELS)



SPECIAL OBSERVING FACILITIES

LEGEND:

- ● TWICE DAILY RAWINSONDES AND COMPLETE SURFACE OBSERVATIONS
- GUST RECORDERS, NEPHOSCOPES (ALL COASTAL AND ISLAND FIRST ORDER STATIONS)
- ○ RADAR PHOTOGRAPHY AND RAINBAND ANALYSES
- ----- PROPOSED RESEARCH FLIGHT TRACKS
- ..... AIR WEATHER SERVICE OPERATIONAL RECON TRACK

SPECIAL AIRCRAFT INSTRUMENTATIONS

a. PRECISION NAVIGATION EQUIPMENT

b. SEARCH RADAR

c. VORTEX, STAGNATION, ASPIRATOR THERMOMETERS

d. INFA RED HYGROMETER

e. PRECISION MEASUREMENT AND RECORDING OF SPOT WINDS AT FLIGHT LEVEL

f. PRECISION EQUIPMENT FOR MEASURING AND DIRECTLY RECORDING D VALUES

g. RADIOMETERS FOR SEA SURFACE TEMPERATURES

h. ELECTRIC ACCELEROMETERS

i. LIQUID WATER, ICING RATE, DROP SIZE MEASURING EQUIPMENT

j. CONDENSATION AND FREEZING NUCLEI COUNTERS

k. ELECTRIC FIELD RECORDERS

l. TIME LAPSE CLOUD PHOTOGRAPHY CAMERAS

m. CONTINUOUS RADAR PHOTOGRAPHY FROM PPI REPEATERS

n. DIGITAL RECORDING ON PUNCH CARDS FOR ALL DATA REQUIRING RAPID MACHINE PROCESSING

o. HEILAND RECORDER FOR CLOUD DATA

p. SUPPLEMENTAL PHOTOPANEL RECORDING FOR ALL NAVIGATIONAL AND METEOROLOGICAL DATA

III. RESEARCH OPERATIONS BASE MIAMI, FLA.

a. PLANNING AND DIRECTION OF AIRCRAFT INVESTIGATIONS

b. MACHINE PROCESSING AND ANALYSIS OF AIRCRAFT DATA

c. OPERATION OF EXPERIMENTAL TROPICAL ANALYSIS UNIT... DAILY ANALYSIS AND FORECASTS FOR WEST INDIAN TEST AREA

d. COORDINATION OF PROJECT ACTIVITIES AT LARGE

IV. SPECIAL RESEARCH TASKS

a. FORECAST DEVELOPMENT STUDIES MIAMI, WASHINGTON

b. N W P STUDIES (CONTRACT)

c. HYDRODYNAMIC MODEL STUDIES (CONTRACT)

d. GENERAL CIRCULATION STUDIES

e. CLIMATIC TRENDS AFFECTING HURRICANES

f. INSTALL OCEANOGRAPHIC RECORDERS (CONTRACT)

g. R AND D ON STORM SURGES (SEVERAL CONTRACTS)

h. ROCKET RECONNAISSANCE OF HURRICANE CLOUDS (CONTRACT)

i. HURRICANE BEACON DEVELOPMENT (CONTRACT)

NATIONAL HURRICANE RESEARCH PROJECT

RESEARCH OPERATIONS BASE

Description of Research and Development Tasks

The primary purpose of the Research Operations Base is to design and conduct a program for the collection of data of importance to the analysis of hurricanes and other basic problems in tropical meteorology, and to initiate such research and development with these data as may contribute to the solution of the forecast problem.

The research and development to be conducted at the Research Operations Base (R.O.B.) is divided into ten tasks. The staff of the R.O.B. has been divided into teams which have been assigned specific responsibility for the research and development effort on each task. It is proposed that the three members of each team not only collaborate in the research effort but also in the publication of papers pertaining to these tasks. Each staff member is assigned to two or more tasks and in most instances is designated as a task leader in at least one. The task leader ordinarily would be expected to be the senior author in reporting work by the team. It is not intended, however, that the latter be an invariable rule or that the task assignments unduly restrict the scope of interest of individual staff members. For example, if research on one phase or task by an individual develops an idea or a specific interest in some quite separate facet of importance to the overall problem, it would be expected that the individual pursue work on this new area of interest.

The following will describe and outline generally the objectives and initial procedures which should be considered by the several research teams in planning work on each task assignment.

1. Hurricane Circulation and Structure.

DESCRIPTION: This task will attempt to determine the nature of circulation throughout the storm volume and the immediate environment, delineating the sectors or layers of inflow, outflow, and large-scale turbulent flow; the horizontal variation of temperature and pressure throughout the storm volume, the description of the major structural components and their dynamical nature including the spiral rainband, the eye, and stratiform or outflow cloud layers.

OBJECTIVES:

a. To develop a reliable model of hurricane circulation and structure which may be useful in diagnostic analyses of the hurricane for specifying the state of development in terms of minimum available data.

b. To provide a basis for accurate evaluation of energy distribution and flux in the hurricane system, and to better understand environmental sources which control the development of the hurricane.

c. To distinguish between conservative and transitory aspects of the hurricane circulation.

PROCEDURES: The first undertaking should be to obtain, through simultaneous flights of three aircraft as complete a quasi-synoptic description of the entire circulation of the storm as possible, assuming that circulations within the storm are reasonably steady. The second step should probably involve sector sampling to determine the degree to which circulations are nonsteady and characterized by surges of energy. Finally, it may prove both desirable and important to utilize all three aircraft to detect and

track the progress of a surge in circulation as it moves through the storm. As a measure of the steadiness of circulations it will be necessary to take repeated samplings of circulations in the eye at a number of levels during the course of a ten- or twelve-hour reconnaissance of the storm. As a by-product of the large area reconnaissance effort, specific attention should be given to small-scale variations in circulation, or circulation anomalies, in the vicinity of individual rainbands.

As a further means of determining circulation characteristics, various tracer materials should be used, release being made in or near the eye, and samplings made to determine its ratio and manner of distribution.

2. Energy Processes and the Hurricane Energy Budget.

DESCRIPTION: A quantitative specification of energy sources and sinks in the hurricane, the distribution of kinetic energy, the nature of momentum and heat fluxes and of energy exchanges between the hurricane and its environment.

OBJECTIVES:

a. To describe precisely the manner in which energy is released within the hurricane and the specific environmental sources from which the critical energy supply is drawn.

b. To define precisely the manner in which energy is returned to the environment and the areas primarily affected by this return.

c. To compute an energy budget for the hurricane which delineates all sources and avenues of energy input to the storm and output to the environment, and the potential effect of the latter upon larger scale circulations.

PROCEDURES: Collect information in the manner and order described for Task I, including frequent measurements of wind, temperature and pressure, first in a mature storm, second in immature and developing storms, and third in hurricanes in advanced states of decay.

3. Momentum transfer within the Hurricane and between the Hurricane and its Environment.

DESCRIPTION: The momentum balance of the hurricane and its environment will be studied.

OBJECTIVES: To determine the source of the cyclonic momentum which is concentrated in a hurricane, and to estimate the transfer of momentum from the hurricane to the sea; also to estimate the flux of momentum through the various portions of the storm.

PROCEDURES: The data available to the project should make possible a meso-analysis of circulations in the hurricane and its environment of sufficient detail to compute the momentum flux between the hurricane and its atmospheric environment. The net gain to the hurricane from the atmospheric environment should equal the amount lost to the sea. A census of the ocean waves will be made to make possible a calculation of momentum transferred to the sea.

4. Dynamics of Hurricane Movement.

DESCRIPTION: This task will attempt to delineate specific factors and energy exchanges which contribute to the movement of the hurricane.

OBJECTIVES: To separate and describe the specific contribution to movement of the hurricane by (1) the momentum of environmental

circulations and (2) by the internal dynamics of the storm.

PROCEDURES:

a. Measure and describe in fine detail the distribution of mass divergence in the columns near and immediately in advance of the eye, and determine the contribution to pressure change provided thereby.

b. Measure the vorticity of the inflow layer near the inflection point of streamlines and attempt to relate the changes therein to the change in distribution of divergence near and in advance of the eye.

c. Obtain precise measurements of pressure gradient forces and of the momentum of environmental circulations and examine the relation of changes here to changes in storm movement.

d. Measure divergence in outflow layers.

5. Antecedent Conditions.

DESCRIPTION: The analysis and description of all manner of perturbations in the tropical field of motion, and the specification of circumstances under which these become unstable or develop, or otherwise contribute to the inception of hurricane or subtropical cyclones.

OBJECTIVES:

a. To determine whether there are specific processes in which energy is transported in the tropical atmosphere on a large-scale and concentrated under circumstances leading to

the formation of hurricanes, or whether such formation results from less well organized synoptic events contributed primarily by the lowest layers of the atmosphere and the ocean surface.

b. To describe the distribution of mass divergence in the easterly wave and to define if possible the origin of the waves and the specific process by which they move.

c. To determine specifically the source and evolutionary process of instability in easterly waves.

PROCEDURES: Utilize two aircraft, a B-50 and a B-47 to reconnoiter and sweep out in fine detail the distribution of mass divergence at approximately four layers, varying the flight elevations on successive days as necessary to determine the level of major contribution, and variations in this level, as the easterly wave becomes unstable.

6. Analysis of Observational Errors.

DESCRIPTION: An analysis of synoptic anomalies in data from the West Indian rawinsonde network.

OBJECTIVES: To determine the extent to which deviations from the synoptic pattern by individual radiosonde reports in the tropics may be attributed to instrumental, to procedural, and to local variations in the atmosphere.

PROCEDURES:

a. Reports which are apparently inconsistent with the overall synoptic pattern should be "flagged" on daily

analyses at the R.O.B. and the original records of rawinsonde observations analyzed, an attempt being made to determine whether the apparent error is:

(1) Persistent at a single station.

(2) Random but attributable to instrument instability or observational error.

(3) Attributable to the pathof the radiosonde (e.g. through cloud and rain).

(4) Attributable only to vertical motions or other local variations encountered by the radiosonde in transit. A station by station record of distributions of these errors and their types should be kept. Methods should be evolved for eliminating biases in the analysis which might tend to concentrate more errors on one station than another.

b. Measure temperature and pressure gradients between rawinsonde stations by aircraft reconnaissance to check accuracy of rawinsonde data.

7. Large-scale Energy Transport in the Tropics.

DESCRIPTION: This task will undertake a day-to-day analysis of tropical circulations and surges of energy which appear and move with these circulations and will investigate the manner in which they sometimes contribute materially to or associate themselves

with the process known as confluence.

OBJECTIVES: To determine the generative source of cold lows in the tropics, of their development, and the specific manner in which the flow of energy from the tropics contributes to the general circulation of the westerlies.

PROCEDURES: The combined use of aircraft, transosonde, and the West Indian network should provide the basis for a daily meso-analysis of circulations and circulation anomalies, and the development and movement of energy surges in the tropics.

8. Cloud Physics.

DESCRIPTION: This task will attempt to determine the amount of liquid water and drop size distributions, and distributions of condensation and freezing nuclei, the extent of super-cooled water, and the electric field properties of the hurricane cloud system.

OBJECTIVES:

a. To determine the relative importance of the sublimation-coalescence and condensation-coalescence mechanisms in hurricane precipitation release.

b. To compute water and energy budgets of the individual convective storms which align into band structures characteristic of many sectors of a hurricane.

c. To study the electric field generated in a hurricane.

PROCEDURES: Cloud sampling and data collection would proceed as a routine part of the larger-scale hurricane reconnaissance

program, with flights being diverted or delayed in accordance with prearranged plans for specific investigations of cloud elements or local cloud structures with the storm. In addition, in order to accomplish the above tasks, certain features of the following kinds of data will be analyzed in terms of the microphysical processes of clouds: (1) air temperature in and around cloud elements, (2) moisture distribution in and around cloud elements, (3) radar pictures of precipitation cores in clouds, (4) turbulence and sustained vertical air motions inside clouds and in the cloud environment, and (5) cloud visual and optical density.

9. Weather Modification.

DESCRIPTION: This task will investigate the artificial release of latent heat of fusion in the hurricane and the measurement of its effect upon hurricane development and movement.

OBJECTIVES:

a. To seed hurricane cloud systems in a manner which will result in the glaciation of supercooled clouds, and the release thereby of latent heat of fusion.

b. The measurement of changes in temperature and pressure gradients resulting therefrom.

c. To evaluate the effect of this modification, if any, upon the development or movement of the hurricane.

PROCEDURES: In designing the program, the scientists will draw heavily upon the work accomplished under task "8" and the past several years of experience of the University of Chicago Cloud Physics Project and others who have seeded tropical clouds. One plan which may be used follows. Careful surveillance of a single sector of the hurricane adjacent to the eye should be made prior, during and following the seeding operation, to include measurement of detailed temperature and pressure gradients, icing rates and amount of liquid water and humidity. Seeding probably should be accomplished in a sector of the altostratus outflow layer several thousand feet above the freezing level between the eye of the first or second distinct spiral rain band, with a view to producing an optimal amount of glaciation in the altostratus shield and which in turn would seed the convective area of the adjacent rainband as a consequence of out-flow circulation of the altostratus.

10. Forecast Applications.

DESCRIPTION: This task will apply results from research and development at the Research Operations Base to design and test improved methods of hurricane forecasting.

OBJECTIVES:

a. To conduct essential liaison between the major hurricane forecast offices and the R.O.B. to assure

(1) that the data collection program obtains information which will specifically benefit forecast development

projects, and

(2) the R&D results of interest and importance to hurricane forecasting are made known to research forecasters at these centers.

b. To design aircraft operational procedures which will permit the collection of data for testing specific forecast methods or hypotheses.

c. To conduct studies designed to organize and incorporate R&D findings into forecast procedures and conduct preliminary tests of their usefulness.

PROCEDURES: The closest possible liaison and interchange of ideas between the R.O.B. and the Miami WBO-FSU group will be a responsibility of the forecast applications team. This will involve frequent trips to Miami for coordination of forecast development plans by the two units. In addition, similar coordination must be maintained with the applied research teams in Washington. In connection with the tropical analysis unit of the R.O.B., procedures should be developed for daily application and verification of forecast techniques which apply in the tropics, and especially for hurricane inception and movement methods. This should be a part of the daily map discussion. Refinements of these methods and design of new ones should be continually in progress with a view of deriving quantitative results based primarily upon physical and dynamic approaches to the problem.

11. The Hurricane Beacon:

DESCRIPTION: The testing of a constant volume balloon, launched by aircraft in the eye of hurricanes, whose purpose is to ride with the storm center and act as a radio beacon to the movement of the storm.

OBJECTIVES:

a. To use hurricane beacon kits to determine the circulation in the lower layers of the eye and variations in these circulations.

b. To determine whether the balloon, gauged to level off at 2000 to 4000 feet pressure altitude, will remain in the eye and if so whether changes in its position may cause it to become an important hazard to navigation of reconnaissance aircraft.

c. To determine whether the stability of the balloon would make it practicable to carry a signal generator by which the storm center could be tracked from a distance of many hundred miles.

PROCEDURES: Penetrations of low level aircraft should incorporate a procedure for dropping at least three balloon packets on each reconnaissance day during the forthcoming season. Operating procedures should include the individual identification and radio tracking of these balloons during a minimum of six hours if necessary to determine clearly the character of trajectories and extent of vertical motions experienced by the balloons. Self destruction

devices for the balloons must be incorporated into the design to prevent their remaining in the air longer than 12 hours during the initial test periods. Depending upon the results of the first year's operation, further engineering should be attempted in succeeding years to improve the transmitter device and permit it to be detected from a distance of many hundreds of miles.

OBJECTIVES AND BASIC DESIGN OF THE NATIONAL HURRICANE RESEARCH PROJECT

Staff of the National Hurricane Research Project*

Washington, D. C.

(For publication in the Bulletin of the American Meteorological Society)

The hurricane catastrophies of 1954 and 1955 provided the impetus for acceleration of research on the hurricane prediction problem. In the spring of 1955 Congress appropriated funds specifically for special investigations of severe storms including hurricanes. Planning for the Project actually began somewhat earlier at an interdepartmental conference held in Washington on December 17, 1954. Recommendations of this conference formed the basis for plans which have gradually taken the form outlined below. The program, under the sponsorship of the U. S. Weather Bureau, will include the cooperation or active participation of outstanding authorities on tropical meteorology from universities and other institutions as well as other government agencies. The general organization of the Project is outlined in figure 1. Some of the work was started as early as Fall, 1955. The more intensive data collection program, beginning in May, 1956, will continue for approximately 30 months. The research and development program is expected to require a minimum of four or five years.

The data collection and aircraft investigation programs will be designed to permit the testing of a number of working hypotheses concerning hurricane

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*Project personnel contributing to this paper include R. H. Simpson, Project Director; N. E. LaSeur, Associate Director; R. C. Gentry, Assistant Director; L. Hubert; C. L. Jordan;

inception, movement, and development, but will be primarily for collection of information needed to accomplish the following objectives:

a. To investigate synoptic disturbances of the type that develop into hurricanes and to study the structure and behavior of these systems and their relation to large scale flow features in an effort to discover the mechanisms of hurricane formation.

b. To examine the details of hurricane structure in order to understand the manner in which energy is released and transferred within the storm, and between the hurricane and its environment; and to determine the contribution to movement and changes of intensity respectively by the environment and by the internal mechanism of the storm.

c. To study the formation of clouds and rain in hurricanes and to investigate possible thermodynamic imbalances which may permit modification of the structure and movement of hurricanes.

d. To determine important parameters in hurricane forecasting and to investigate how these can best be observed by the reconnaissance aircraft and by other means.

To improve forecasts immediately as much as possible, a number of units have already begun to re-examine information at hand, seeking to develop more exact methods for predicting hurricane movement and for anticipating and describing its destructive potential. A portion of this work will be conducted under Public Law 71 (84th Congress, First Session) by the Hydrologic Services Division of the Weather Bureau, under transfer of funds from the U. S. Army Corps of Engineers. Applied research is being initiated at each

of the hurricane forecast offices. In addition, the Climatological Services Division and the Extended Forecast Section of the Weather Bureau will attempt to evaluate climatological trends and the degree to which they may influence the occurrence and tracks of hurricanes.

Research on the hurricane problem will be expanded as additional data are assembled. Some of the research will be undertaken at the Research Operations Unit and by other divisions of the Weather Bureau. In addition, work vital to solution of the hurricane problem will be done by contractors at several universities.

REVIEW OF THE PROBLEM

A. INCEPTION. Tropical cyclones invariably form over oceanic regions where the water temperature is high and convective activity is pronounced. In this connection Palmén (1948) defined the threshold temperature of the ocean surface that is usually a prerequisite to hurricane formation. The high ocean surface temperatures are usually required for the air mass to be unstable. If temperatures in the upper troposphere are well below normal, the ocean temperatures may be slightly below the threshold figure given by Palmén, and the lapse rate in the air still be unstable. It is not surprising, therefore, that the early explanations of the inception of tropical cyclones emphasized convective processes. These hypotheses merely associated the convective activity and the cyclogenesis but offered no definite mechanism for organizing the disturbance or any means of predicting where it would form. These are serious limitations since convective processes are active over large areas during much of the year and since only a very small percentage of all rain-producing disturbances ever develop to tropical cyclone intensity. Among

the mechanisms for concentrating and intensifying tropical disturbances, one of the first to be suggested was the Norwegian unstable frontal wave model in the tropics, but this idea has been gradually abandoned as it became recognized that true fronts rarely, if ever, exist over the tropical oceans (Palmer, 1952). Some of the more recent hypotheses emphasize the upper-level flow patterns (cf. Sawyer, 1947; Riehl, 1954). In part, these hypotheses call for an upper-level divergence field as a means of initiating low-level convergence and accounting for the pressure falls.

The structure of easterly waves and other types of tropical disturbances will be investigated in an attempt to delineate, in terms of forecast parameters, the basic differences between disturbances which develop into hurricanes and those which do not. It is important that we know why only a small portion of tropical perturbations develop into hurricanes. Thermodynamic aspects of this problem include sea surface temperature, depth of the moist layer, and horizontal and vertical temperature and moisture gradients in the disturbance and in the air moving into the disturbance. An attempt will be made to isolate the significant dynamic factors by investigating the basic wind field and the associated fields of vorticity and momentum. This will include studies of the effect of advection of these quantities to and from the environment at all levels and interactions with neighboring disturbances.

B. STRUCTURE. One of the impressions which is common among those who have made many flights into hurricanes is that no two of the storms are quite alike. One of the more difficult tasks of the Project will be to distinguish structural features that are conservative from those that are transitory. Objectives in the investigation of structure are:

1. To establish the general features of the wind field and its variation with height and the variability of the wind over various space and time intervals.
2. To determine the geometry and dynamics of inflow and outflow layers and their variation with time.
3. To study the thermal structure of the hurricane as it relates to energy processes in the storm.
4. To study the structure and evolution of circulations in the eye.
5. To study the genetical source and development of the spiral rainbands and their relation to movement and intensification of the storm.
6. To derive an energy budget for the hurricane during several stages of development.

There will be several derived benefits if the above objectives are accomplished. When the structure of the hurricane is fully understood, we should be able to compute the effects of small changes in structure. This should add to the understanding of what makes a hurricane develop, move, and intensify, or decay.

As a base line for designing the investigation of structure, the Project will draw upon the tentative model of hurricane circulations in figure 2 (Simpson, 1954) which has evolved from evaluations of earlier reconnaissance and rawinsonde data.

C. MOVEMENT. In a recent symposium on hurricanes at Florida State University, the point was made that meteorologists must now decide what they are attempting to track and forecast in dealing with the hurricane: the radar eye, the wind eye, the pressure center? As observational facilities increase, it becomes apparent that these features do not always coincide and that considerable error in tracking the storm may occur by plotting

alternately the position of first one and then another of these centers. The Project expects to investigate these centers and attempt to determine which offers the most conservative means of tracking the progress of the storm.

The primary objective in studying hurricane movement will be to delineate insofar as possible the physical mechanism for movement of the storm. Various hypotheses and forecasting methods that have been advanced employ the concept of steering of hurricanes. The steering mechanisms include both thermal and kinematic properties, (cf. Riehl and Haggard, 1955; Gentry, 1951; and Simpson, 1946). Most of the forecasting methods assume that a hurricane is steered essentially by its environmental circulations, except for contributions from internal forces as described by Yeh (1950), Rossby (1948), Eressman (1952), and Gentry (1952). Actually a major hurricane drains from its environment several billion tons of air per minute at low levels and returns that mass to its surroundings in the upper atmosphere. The internal dynamics of the storm itself cannot be assumed a priori to play an insignificant role in the overall physics of movement. It will be the objective of the Project to determine the individual contribution to storm movement by the environmental circulations, by interaction forces, and by purely internal forces.

It is reasonable that the internal dynamics of the hurricane should contribute to the movement of the hurricane for several reasons. Low level wind data and radar observations of hurricanes indicate that locations of areas of maximum mass convergence in the lower levels vary considerably with respect to the hurricane center. Similar variations of the areas of mass divergence in the upper levels of the storm would also be expected. Although the locations

of these convergent and divergent areas are partially determined by the vorticity of the air entering the hurricane circulation, they may also be influenced by the internal dynamics of the hurricane, the amount of moisture in the ambient air, the latent heat released in the hurricane, and other factors. When mass divergence at high levels is not balanced by equal mass convergence at low levels, the pressure at the surface near the hurricane changes and the storm moves and/or changes intensity. If the upper divergent and lower convergent areas shift with respect to each other and with respect to the center of the hurricane, the direction and/or speed of movement of the hurricane should also change. Since there is such intense convective activity in a hurricane, changes in the low level convergent areas should affect the locations of the higher level divergent areas and vice versa. The extent of this internal influence may depend not only on the intensity of the convective activity, but also on the amount of latent heat released and the location of maximum release.

If a means is ever to be found for modifying or diverting the movement of the hurricane, it will likely depend upon a modification of the force fields within the storm itself, possibly through some means of shifting or intensifying the release of latent heat of fusion in one storm sector. Most of the energy of a hurricane arises from the release of latent heat. While precipitation may be initiated in natural clouds by either the sublimation-coalescence or condensation-coalescence mechanisms and the net gain to the atmosphere of energy is approximately the same for the two mechanisms, the energy distribution in the storm and energy redistribution to the environment of the storm may be markedly different in the two cases. Based on our present knowledge of the

physics of clouds and rain formation the shifting or intensifying of the release of latent heat of fusion in a sector would require the existence in the hurricane of large amounts of supercooled water drops. It would also probably depend on locating potentially unstable situations since small changes in stable situations will be rapidly compensated. The possibility, however, that the formation or the movement of a hurricane can at cricital times rest upon a very delicate balance of forces offers an intriguing challenge.

D. CHANGES OF INTENSITY (DEVELOPMENT). Investigations will be undertaken to evaluate the importance of friction, moisture variations, and changes in temperature gradient surrounding the storm vortex upon intensification and decay of hurricanes.

E. STORM SURGE. The greatest loss of life in hurricanes usually comes from inundation as the storm crosses the coastline and cascades large quantities of sea water upon land. In spite of this, many storms apparently cross the coastline without producing important flooding or damage from sea water. It will be a primary objective to study oceanographic and hydrographic conditions in relation to the hurricane itself in an effort to determine the conditions which are both necessary and sufficient for producing important inundations.

F. FLOODS. Except for the storm surge, floods caused by rains associated with hurricanes cause more loss of life and greater property damage than anything else connected with hurricanes. Hurricane Diane was the first "billion dollar hurricane" and largely because of the floods that devastated valleys from Eastern Pennsylvania to Eastern Connecticut. Investigations of the flood producing potential of hurricanes already underway will be intensified.

DATA COLLECTION PROGRAM

The collection of additional data required for research on the hurricane problem will make use of a dense network of rawinsonde stations in the West Indies, specially equipped aircraft for research flights into hurricanes and other synoptic disturbances in the tropics, and rocket reconnaissance of hurricane cloud systems.

Figure 3 shows the proposed network of rawinsonde stations which will operate continuously for a 30-month period beginning 1 May 1956. The network includes 8 stations to be operated by the Air Force, 3 by the Navy, 2 by the British, 2 by the French, 2 by Cuba, and 1 each by the Dutch, Dominican Republic, Mexico, and Colombia.

At each of these stations two soundings per day will be made using instruments and methods of operation which will insure optimum compatibility of observations. Specially trained technicians at each station will attempt to obtain upper-air soundings consistently above 80,000 ft.

To supplement the rawinsonde network and obtain details of the structure of hurricanes in various stages of development, specially instrumented aircraft will be operated routinely in the West Indies area. These aircraft assigned to the Project by the Department of Defense and operated by the Air Weather Service include one B-47 and two B-50's. Flights will probably be made several times per week by two or three planes flying at elevations ranging from near the surface to above 40,000 ft. During hurricanes every attempt will be made to put three aircraft into the storm area simultaneously, one collecting data first at approximately 1,000 ft., then later at 8,000 ft.; the second aircraft, flying first at 15,000 ft. will later climb to 25,000 ft.;

the third aircraft entering the storm at 30,000 to 35,000 ft. will eventually climb to above 40,000 ft. Each of the aircraft will be instrumented with the most advanced meteorological equipment, including vortex-, aspirator-, and stagnation-temperature probes, infra-red absorption hygrometers, sea surface temperature radiometers (for low level flights), accurate D-value computers, automatic wind measuring equipment, and considerable supplemental equipment for cloud physics studies. The latter will include instruments for measuring drop sizes and distributions, liquid water content, electric field strength, and both condensation and freezing nuclei distributions. All meteorological and some navigational data will be recorded in digital form and/or on a photopanel. The more important meteorological elements will be recorded digitally and in such form as to permit great speed in data reduction and plotting. Automatic processing equipment will enable Project scientists to complete within 24 hours after the planes return the preliminary analysis of these elements, thus permitting adjustments and revisions of plans before the next research reconnaissance flight is made.

A number of rocket launchings will be made under the direction of the Office of Naval Research in an attempt to photograph, from altitudes above 50 miles, the entire hurricane cloud system and its immediate environment. This, if successful, will permit an assessment of the overall size and influence of the storm on hydrometeors of the region during the time that aircraft are sweeping out details of the fine structure of the hurricane.

The Project expects also to obtain from the U. S. Navy's transosonde flights valuable observations at the 200 mb level in the tropical areas.

RESEARCH OPERATIONS BASE

A Research Operations Base will be set up in Florida for the purpose of directing the data collection program, analyzing the results, and conducting at least the first phases of research with the aid of these data. As a part of the R.O.B. program, an experimental tropical analysis unit will be operated in which daily analyses and experimental prognoses will be made for the West Indian test area. One objective of this center will be to develop more useful tools of analysis and modes of presentation for tropical regions. This unit will study energy sources and energy transport in the tropics, and determine the best means of detecting and representing these through synoptic analyses compatible with network limitations in such areas.

RESEARCH AND DEVELOPMENT

While limited forecast development studies will be pursued at all hurricane forecast centers of the Weather Bureau, a more intense study of the forecast problem will be undertaken at the Miami hurricane center which will have more opportunity for direct collaboration with the work at the Research Operations Base than other forecast offices.

Elsewhere in the Weather Bureau and among Weather Bureau contractors, research has already started on the storm surge problem, and on preparing dynamical and numerical prediction models of hurricanes.

Eleven research tasks have been assigned to the Research Operations Base. These research studies will be in addition to the ones outlined previously that are being conducted by other divisions in the Weather Bureau on climatological trends, storm surge, and the work being done by the

Hydrologic Services Division under transfer of funds from the U. S. Army Corps of Engineers. The meteorologists at the Research Operations Base will be divided into teams to work on the following phases of the hurricane problem:

1. Hurricane circulation and structure.
2. Energy processes and the hurricane energy budget.
3. Momentum transfer within the hurricane and between the hurricane and its environment.
4. Dynamics of hurricane movement.
5. Conditions antecedent to hurricane formation.
6. Analysis of errors in observations made in the tropics.
7. Large scale energy transport in the tropics and from the tropics to other areas.
8. Cloud physics of hurricane clouds and precipitation.
9. Artificial modification of hurricane structure and movement.
10. Forecast applications of findings of the National Hurricane Research Project.
11. The hurricane beacon, a radio balloon designed to float at constant pressure in the eye and signal its position as an aid in studying circulations in the eye, and possibly in tracking the movement of the storm center.

PUBLICATION OF RESULTS

It is tentatively planned to issue progress reports and results of special studies growing out of the Hurricane Project as promptly as possible. The more important papers and investigation results will be offered for publication in scientific journals and monograph series which insure very wide circulation.

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March 5, 1956

Mr. R. H. Simpson
United States Department of Commerce
Weather Bureau
Washington 25, D. C.

Dear Mr. Simpson:

This is to let you know that I will be able to come to Washington on March 23rd to serve on the panel of dynamic meteorology for the Hurrican Project.

Very truly yours,

Jule G. Charney, Director
Meteorology Project

JGCesg

UNITED STATES DEPARTMENT OF COMMERCE
WEATHER BUREAU
WASHINGTON

February 2, 1956

IN REPLY, PLEASE ADDRESS
CHIEF, U. S. WEATHER BUREAU
WASHINGTON 25, D. C.
AND REFER TO

H-1

Dr. Jule Charney
The Institute for Advance Study
Meteorology Project
Princeton, N. J.

Dear Dr. Charney:

We are very pleased that you accepted Dr. Reichelderfer's invitation to serve on the panel of dynamic meteorology for the Hurricane Project. Although we have not progressed in our plans as rapidly as we had originally hoped to do we would like for you to come to Washington to advise us for one or possibly two days sometime in March or April to expediate completing our arrangements. We suggest that you come March 23. Please let us know if this date is satisfactory or suggest a date (other than March 10-19) when it would be convenient for you to inspect our Project plans and offer your suggestions.

After we have set a date for your visit, we will prepare travel orders that will enable us to pay your traveling expenses and per diem.

We are looking forward to discussing the Hurricane Project with you.

Very truly yours,

R. H. Simpson

R. H. Simpson
Director, Hurricane Project

UNITED STATES DEPARTMENT OF COMMERCE
WEATHER BUREAU
WASHINGTON

IN REPLY, PLEASE ADDRESS
CHIEF, U. S. WEATHER BUREAU
WASHINGTON 25, D. C.
AND REFER TO

T-1

NOV 15 1955

Dr. Jule Charney
Electronics Computer Unit
Institute for Advanced Study
Princeton, New Jersey

Dear Dr. Charney:

The Weather Bureau is now completing its plans for the hurricane project. A part of the plan calls for the establishment of several advisory panels on specialized phases of the investigations. Because of your broad experience in dynamic meteorology and interest in the hurricane problem, the Weather Bureau would like to be able to draw upon your services as consultant on the panel on dynamic meteorology. The work of the panel will involve perhaps one session of a day or so with the project here in Washington sometime between now and January 31, 1956, and periodic visits both here in Washington and at the field research operations base in Florida to review progress of the various experiments and studies and to counsel the project scientists on their work.

Please advise if you will be able to serve on this panel and let us know what time would best suit you to visit Washington before the end of January.

Very truly yours,

F. W. Reichelderfer

F. W. Reichelderfer
Chief of Bureau

November 17, 1955

Dr. F. W. Reichelderfer
Chief, U. S. Weather Bureau
Washington, 25, D. C.

Your reference: T-1

Dear Dr. Reichelderfer:

Thank you for your invitation to become a consultant on the dynamic meteorology advisory panel to the Weather Bureau hurricane project. I am indeed very interested in the hurricane problem and would be glad to serve in this capacity.

Regarding the time of my visit, since it is to be only for a day or so I can accommodate myself to your needs, with the exception of the first three weeks of January when I must be elsewhere.

Sincerely yours,

Jule Charney

JC:sc