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Project Title: Diagnosis of the Kinematics and Dynamics
of Rapidly Developing Maritime Cyclones

PROGRESS REPORT

Reporting Period: 1 April 1992 through 31 March 1993
ONR Grant N00014-92-J-1532



1) Progress and Future Plans

The overall objective of this project is to diagnose the structure and evolution of rapidly developing maritime cyclones from kinematic and dynamical perspectives in order to interpret and extend emerging conceptual models of these phenomena, as well as to assess the realism and applicability of existing theoretical models. The proposed research is divided among three related lines of investigation. The first addresses the possibility of classifying rapidly deepening maritime cyclones on the basis of characteristic signatures evident in visible and infrared satellite imagery and interpreting these signatures in terms of conventional kinematic and dynamic parameters. The second involves diagnosing regional-scale numerical model simulations of the QE II and ERICA IOP-4 storms in order to infer the dynamical characteristics of the conceptual model of the low-level temperature structure of maritime cyclones proposed recently by Shapiro and Keyser. The third is to conduct life-cycle studies of the ensemble of rapidly developing maritime cyclones that occurred during the ERICA period. Emphasis in these studies is placed on analyzing cyclone structure and evolution in the potential-vorticity framework in order to expedite comparison with emerging theoretical paradigms, and on diagnosing interactions between cyclones and their environmental, large-scale flow in order to discern the role of the large-scale flow pattern in shaping cyclone structure.

i) As part of the effort in classifying rapidly developing maritime cyclones using satellite imagery, I visited the Naval Postgraduate School and NRL/Monterey, and presented the seminar, "A Satellite-Derived Classification Scheme for Rapid Maritime Cyclogenesis," at NRL/Monterey on 20 July 1992. Informal discussions with colleagues at both institutions were extremely useful in allowing me to bring this work into sharper focus and to begin the transition from M.S. thesis to paper. I have completed the final draft of a journal article based on this research, which will be submitted to **Monthly Weather Review** for publication within the next several months. One of the most interesting and surprising scientific findings to emerge from this paper is the consistency of our classification scheme with those developed previously for other geographical regions and for ordinary rates of deepening. This finding suggests that although extratropical cyclogenesis is believed (in most cases) to occur in response to the interaction of pre-existing finite-amplitude disturbances, these interactions are not random or accidental, but seem to occur in repeatable, identifiable patterns, with characteristic signatures evident in satellite imagery. Explanation of why such a deterministic outlook should be applicable is required, and the search for explanations contributes in part to the research effort underway in the third line of investigation, described below in (iii).

ii) The research phase of Jeffrey Chapman's M.S. thesis research on dynamical validation and interpretation of the Shapiro-Keyser conceptual model of frontal structure in rapidly developing maritime cyclones has been completed.

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Chapman now is in the process of writing his M.S. thesis, entitled "An Examination of the Shapiro-Keyser Conceptual Model of Maritime Cyclones: Representativeness, Vertical Structure and Dynamical Interpretation," the results of which he presented at the Eighth Extratropical Cyclone Project Workshop in Val-Morin, Quebec, on 16 October 1992. The main emphasis of this research is on identifying the potential-vorticity and the vertical-motion signatures of each stage of the conceptual model and relating these to cyclone development and to distributions of clouds and precipitation. Numerical simulations of two well-known cases of rapid maritime cyclogenesis derived from the Penn State/NCAR regional-scale model (MM4; model histories provided by Evelyn Donall Grell of NOAA/ERL/WPL) have been analyzed: the QE II storm and ERICA IOP-4. Chapman should complete writing his M.S. thesis by the end of summer 1993; I expect to transform his thesis into a form suitable for journal publication later this year or during the first half of CY1994.

The opportunity arose during this past year to initiate a new study using the model histories of the QE II storm archived at SUNY/Albany as part of Jeffrey Chapman's M.S. thesis research. In developing vertical-motion diagnostics for analysis of the various phases of the life cycles of the QE II and ERICA IOP-4 storms, it was noted that these diagnostics might be applied to the well-defined jet streak that preceded the development of the QE II storm to determine whether well-known jet-streak circulation signatures could be isolated in this particular case. Experimentation revealed that the classic four-quadrant pattern of vertical motion beneath an upper-level jet streak can be isolated very clearly in the "adiabatic run" of the QE II storm, provided that the vorticity-advection forcing is partitioned among respective terms involving shear and curvature vorticity, or the Q-vector forcing is partitioned among respective terms comprising the components of the Q vector normal to and parallel to the isentropes. In each of these natural-coordinate partitions of the vertical-motion forcing, the classic four-quadrant pattern is isolated by the former terms, and a dipole pattern, consistent with the presence of the jet streak at the base of a short-wave trough, results from the latter terms. These findings suggest a quantitative means for determining the relative importance of jet-streak circulations in realistic flow patterns, which has been the subject of ongoing debate in the synoptic community. A preliminary version of this work was presented by D. Keyser at the Eighth Extratropical Cyclone Project Workshop, on 15 October 1992. This presentation generated sufficient interest among Workshop participants to encourage preparation of a journal paper based on the results of this study.

A third activity, tangentially related to Chapman's M.S. thesis research, deserves mention at this point. Professor Patricia Pauley (Naval Postgraduate School) and a graduate student have successfully implemented and applied a methodology for isolating frontal circulations in baroclinic-wave regimes, the initial development of which was funded by ONR through my ERICA contract. (Their work concerns ERICA IOP-4 as simulated with NMC's Nested Grid Model.) This methodology is referred to by us as the "psi-vector technique"; it allows representation of vertical circulations in baroclinic disturbances in terms of a vector streamfunction, analogous to the use of the Q vector to represent the forcing of vertical circulations. Developed originally for idealized applications in channel-model simulations of extratropical cyclogenesis, this methodology has

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been modified to apply to real-data cases in limited-area domains, in collaboration with a former M.S. student, Andrew Loughé, who was supported by NSF. Professor Pauley and I plan to prepare companion papers for publication in **Monthly Weather Review** documenting the extension of the psi-vector methodology to real-data applications (Keyser), and the report of such an application in the context of ERICA IOP-4 (Pauley). Our parallel writing efforts are scheduled to begin within the next several months. I expect these articles to be submitted during the latter part of CY1993.

iii) A hypothesis that emerged from the satellite-based classification effort summarized in (i) is that to the extent that there exist characteristic types of cyclone development as revealed through satellite imagery, these types will exhibit systematic differences in the evolution of the synoptic-scale flow and in the nature of the interactions among pre-existing disturbances during cyclogenesis. Furthermore, the success of our classification effort suggests that extratropical cyclogenesis viewed as a superposition of a number of discrete, finite-amplitude, antecedent disturbances is not a "random" or "fortuitous" process, but one which is manifested in identifiable, repeatable patterns. These patterns quite likely are linked to characteristics of various large-scale flow regimes that may influence a geographical region for a period of time, as well as to fixed, physiographic features such as orography in continental regions and surface temperature and moisture contrasts (e.g., those associated with the Gulf Stream and Kuroshio) in maritime regions and coastal zones.

The emphasis on such a "large-scale," "big-picture" perspective is consistent with the sense expressed in the original proposal to ONR that the details of the mechanics of the process of explosive cyclone intensification are increasingly well-examined and -understood, suggesting that gains in basic knowledge are to be made in exploring this process from a larger-scale perspective, especially regarding the issue of the origin and evolution of antecedent disturbances. Another opportunity lies in my observation that there has been only a modest amount of theoretical attention to date on the view expressed herein of cyclogenesis as a multi-body interaction (i.e., the work of Brian Farrell and close associates), suggesting the need for fundamental observational work to continue to define, illustrate and promulgate this view within the research community.

Exploration of the foregoing hypothesis is guiding the dissertation research of Gary Lackmann, a portion of which consists of conducting an overview of the planetary-scale flow evolution during the three-month ERICA period (December 1988-February 1989) in order to describe systematically the evolution of antecedent disturbances that eventually interact to produce ERICA-type cyclones, as well as to distinguish the factors that distinguish between those sets of antecedent disturbances that do and do not interact to produce cyclogenesis. Preliminary results suggest that, in the western North Atlantic region, the North American coastal zone and the north wall of the Gulf Stream provide a rich source of antecedent disturbances in the lower troposphere, so that the crucial question becomes that of the origin, structure, and evolution of tropopause-based disturbances, as well as of a tropospheric environment conducive to vertical coupling between lower- and upper-level disturbances. To

concise diagnostic displays of the evolution of antecedent disturbances based on the potential-vorticity perspective of cyclogenesis. Preliminary findings include the following:

a) Distinguishing characteristics of disturbances (i.e., short-wave troughs) that initiate the strongest cyclogenetic response at low levels are the diffluent character of the flow immediately downstream of their axes, and the more southerly latitudes of their tracks. In potential-vorticity terms, the former means compaction in the along-stream direction, and the latter means an environment characterized by smaller static stability, both of which favor vertical coupling between upper- and lower-level disturbances.

b) The large-scale flow is important in amplifying antecedent upper-level disturbances (through upper-level frontogenesis), in determining the tracks of these disturbances, and in determining the flow character (i.e., diffluent or confluent) in the vicinity of these disturbances.

c) The cyclogenetic events are clustered in time, suggestive of an important preconditioning role for precursor cyclogenesis events. Such events perhaps allow the large-scale flow to become diffluent; cold advection in the wake of such events appears to drive the polar-front baroclinic zone south, where it is heated by the underlying ocean. This could result in a more diffuse jet structure ahead of subsequent upper-level disturbances and an environment in which the static stability is considerably reduced, thereby favoring vertical interactions between upper- and lower-level disturbances.

Lackmann presented these preliminary findings at the Eighth Extratropical Cyclone Project Workshop, on 13 October 1992. He will continue work on his dissertation through the duration of the proposal. Work planned during the second year of the project primarily consists of systematic documentation of the life cycles of the ERICA cyclones, using diagnostic tools developed to date, with emphasis on the origin, structure and evolution of antecedent upper-level disturbances. Issues of particular interest are how to distinguish between upper-level disturbances that do and do not interact with their lower-level counterparts to produce cyclogenesis, as well as how to distinguish between rapid and ordinary development. Another avenue of investigation will consist of attempting to reconcile results emerging from these life-cycle studies with the characteristic signatures isolated in the satellite-based classification scheme.

2) Publications, Reports, and Presentations Acknowledging ONR Support

Evans, M. S., D. Keyser, L. F. Bosart, and G. M. Lackmann, 1993: A satellite-derived classification scheme for rapid maritime cyclogenesis. *Mon. Wea. Rev.*, 121 (to be submitted).

Lackmann, G. M., D. Keyser, and L. F. Bosart, 1992: Evolution of quasi-geostrophic potential vorticity anomalies during explosive maritime cyclogenesis. Presented by G. M. Lackmann at the Eighth Extratropical Cyclone Project Workshop, Val-Morin, Quebec, Canada, on 10/13/92.

Keyser, D., and J. A. Chapman, 1992: Diagnosis of vertical motions in the vicinity of a numerically simulated jet streak. Presented by D. Keyser at the Eighth Extratropical Cyclone Project Workshop, Val-Morin, Quebec, Canada, on 10/15/92.

Chapman, J. A., D. Keyser, and E. G. Donall-Grell, 1992: An examination of the Shapiro-Keyser conceptual model of maritime cyclones: Representativeness, vertical structure, and dynamical interpretation. Presented by J. A. Chapman at the Eighth Extratropical Cyclone Project Workshop, on 10/16/92.



SEMINAR

A SATELLITE-DERIVED CLASSIFICATION SCHEME FOR RAPID MARITIME CYCLOGENESIS

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ABSTRACT

A classification scheme is proposed for differentiating between various types of rapid maritime cyclogenesis in the western North Atlantic region. The scheme is based on characteristic signatures in satellite imagery observed prior to and during rapid deepening. Examination of satellite imagery for an ensemble of 50 cyclogenesis events that occurred during the 1970's and 1980's, 46 of which satisfy the ERICA (Experiment on Rapidly Intensifying Cyclones over the Atlantic) criterion for rapid deepening [a pressure decrease of at least 10 mb/(6 h)], yields four categories of cyclone development. These categories will be described schematically, and then illustrated by integrating satellite imagery with a variety of kinematic and dynamical diagnostics for representative cyclogenesis events, with particular emphasis on reconciling cloud shape and structure with the synoptic-scale flow pattern. Finally, the proposed classification scheme will be related to other satellite-derived conceptualizations of extratropical cyclogenesis described in the meteorological literature.

Place: FNOC Auditorium
Date: Monday, 20 July 1992
Time: 1000 hrs.

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