

DIAGNOSIS OF TROPICAL CYCLONE STRUCTURE AND INTENSITY CHANGE

Daniel Keyser

Department of Earth and Atmospheric Sciences, ES-224

University at Albany, State University of New York

1400 Washington Avenue

Albany, NY 12222

Phone: (518) 442-4559 Fax: (518) 442-4494

E-mail: keyser@atmos.albany.edu

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LONG-TERM GOALS

To improve and refine understanding of the dynamics of tropical-cyclone structure and intensity change. A guiding theme of this research effort is to apply and extend well-established dynamical perspectives on extratropical cyclogenesis and cyclone life cycles, particularly in maritime regions, to the tropics.

OBJECTIVES

- a. To conclude investigations of the origins and life cycles of tropopause-based precursor disturbances that culminate in rapid maritime cyclogenesis over the western North Atlantic Ocean.
- b. To investigate the roles of trough interactions in tropical-cyclone intensity change with a view toward determining the factors that distinguish between cyclogenetic and cyclolytic trough interactions.
- c. To investigate the roles of environmental dynamical effects on tropical-cyclone structure and intensity change.

APPROACH

Objectives (a) and (b) are being conducted through extensive diagnostic analysis of gridded datasets produced by the National Centers for Environmental Prediction (NCEP) and the European Centre for Medium-Range Weather Forecasts (ECMWF). Objective (a) is being performed in collaboration with Professor Gary M. Lackmann (State University of New York, College at Brockport); objective (b) is being undertaken in collaboration with Professor John Molinari and Deborah E. Hanley (University at Albany, State University of New York). Objective (c) is being conducted using an idealized three-layer shallow-water numerical model that includes parameterizations of convection, sea surface energy exchange, and surface friction. Objective (c) is being addressed by Dr. Klaus Dengler and the principal investigator (University at Albany, State University of New York) in collaboration with Professor Roger K. Smith (University of Munich).

WORK COMPLETED

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- a. The relationship between jet streaks, upper troughs, and the low-frequency flow has been analyzed in terms of the evolution of eddy kinetic energy for a representative life cycle of a tropopause-based precursor disturbance that culminated in rapid cyclogenesis over the western North Atlantic Ocean during the Experiment on Rapidly Intensifying Cyclones over the Atlantic (ERICA).
- b. The trough interaction event that led to the reintensification of Hurricane Elena on 1 September 1985 has been analyzed and interpreted using potential vorticity and ageostrophic circulation diagnostic methodologies.
- c. An idealized three-layer shallow-water numerical model has been applied to investigate the effect of uniform zonal background flows on the intensification of tropical-cyclone-like vortices for f - and β -plane geometries.

RESULTS

a. Life cycles of tropopause-based precursor disturbances

Previous research has identified a characteristic life cycle of tropopause-based cyclogenetic precursors, which involves the development of an elongated region of depressed dynamic tropopause in association with an intensifying midtropospheric jet/front. A representative event of this type during the field phase of the Experiment on Rapidly Intensifying Cyclones over the Atlantic (ERICA, December 1988–February 1989) has been examined from the perspective of local energetics, allowing determination of the mechanisms that led to jet streak intensification and documentation of the three-dimensional eddy kinetic energy (EKE) distribution within the developing jet/front system. Computation of the local EKE budget during the second Intensive Observation Period of ERICA indicates that Reynolds stresses play an important role in jet streak intensification over North America. Troposphere-deep ridging over western North America favors jet intensification through Reynolds stresses as high-frequency northerly flow east of the ridge axis results in a favorable orientation of the local E vector with respect to the dilatation axis of the low-frequency flow over central North America. Localized EKE increases accompany strengthening transverse circulations, facilitating the downward advection of stratospheric values of potential vorticity and eventually resulting in the development of a mobile upper trough. This sequence of events is consistent with the preference for upper-trough genesis over central North America in the presence of a northerly flow component, a finding documented previously by Sanders.

b. Trough interaction event leading to the reintensification of Hurricane Elena (1985)

Diagnostic perspectives based on potential vorticity (PV) and ageostrophic circulations (ACs) have been used extensively to reveal signatures of interactions between tropopause- and surface-based disturbances during midlatitude cyclogenesis. PV and AC perspectives have been applied to develop complementary interpretations of the trough interaction event that led to the reintensification of Hurricane Elena on 1 September 1985. From the PV perspective, the trough interaction leading to the reintensification of Elena occurred on the equatorward end of a positively tilted upper-level trough associated with a Rossby-wave breaking event. The location of Elena with respect to the trough is consistent with intensification through PV superposition, whereby the close approach of

discrete PV anomalies results in an increase of total perturbation energy in the volume containing these anomalies. Intensification is hypothesized to occur through air–sea interaction instability. From the AC perspective, a well-defined upper-level jet streak was oriented southwest–northeast on the downstream side of the trough, placing Elena in the right-entrance region of the jet streak. The location of Elena with respect to the jet streak is consistent with intensification through divergence situated over the tropical cyclone. Intensification is hypothesized to occur through an enhanced low-level circulation that develops in response to vortex stretching associated with convergent inflow toward the tropical-cyclone center. The enhanced low-level circulation is expected to lead to increased surface fluxes of heat and moisture, consistent with the occurrence of air–sea interaction instability as in the PV perspective.

c. Effect of uniform zonal background flows on the intensification of tropical-cyclone-like vortices

The effect of uniform zonal background flows on the intensification of tropical-cyclone-like vortices has been investigated using a three-layer shallow-water numerical model that includes parameterizations of convection, sea surface energy exchange, and surface friction. In calculations performed on an f -plane, it was found that, in the developing stage, stronger zonal background flow increases the intensification rate of the vortex for both westerly and easterly flows. This increase in intensification rate is due to strengthened convection in response to enhanced surface moisture fluxes in the presence of zonal background flow. After the vortex achieves hurricane strength, the region of boundary-layer convergence contracts considerably, convection ceases, and the vortex stops developing before it can reach the intensity of its counterpart in a resting environment. On a β -plane, it was found that uniform westerly flow is more favorable for intensification, as measured by the maximum middle-layer wind speed, than easterly flow of the same strength (Fig. 1, upper-left). The largest value of maximum wind speed in the β -plane experiment with zero background flow lies between the respective cases involving nonzero background flow. This behavior is due to stronger convection in the case of uniform westerly flow compared with the corresponding cases of easterly flow and zero background flow (Fig. 1, upper-right). The vortex embedded in uniform easterly flow moves west-northwestward, encountering regions of relative dry boundary-layer air (Fig. 1, lower-left), resulting in diminished convection and, therefore, in a weaker storm at the mature stage compared with the corresponding westerly flow case. In the latter, the vortex moves eastward continuously into a region of convectively unstable air (Fig. 1, lower-right).

IMPACT/APPLICATIONS

The diagnostic methodologies developed and implemented during the course of this research effort may be considered for eventual application in a real-time forecasting environment. The interpretations of tropical-cyclone intensity change emerging from the idealized numerical modeling investigation offer a conceptual bridge between analytically based theoretical models and realistic numerical prediction models applied to forecasting tropical-cyclone intensity change in experimental and operational settings.

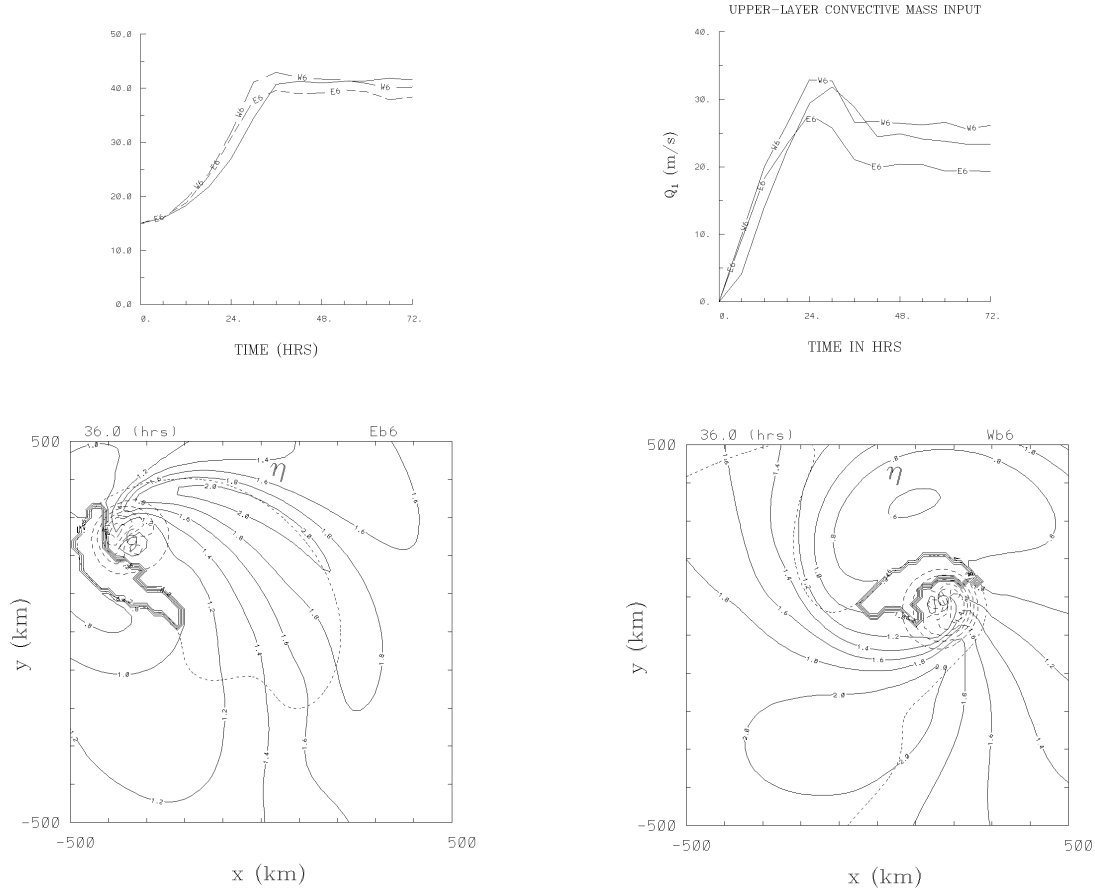


Figure 1.

Upper-left: Time evolution of maximum middle-layer wind speed (m s^{-1}) of the vortex on a β -plane for experiments in which an initial vortex is embedded in westerly (dashed line labeled W6) and easterly (dashed line labeled E6) zonal background flows of 6 m s^{-1} , and in a zero background flow (solid unlabeled line).

Upper-right: Time evolution of the total upper-layer mass input Q_1 (m s^{-1}), an areally integrated measure of the strength of convection, calculated in the region where the boundary-layer convergence exceeds $-5 \times 10^{-5} \text{ s}^{-1}$, for cases W6 and E6 (labeled solid lines), and zero background flow (unlabeled solid line).

Lower-left: Horizontal distribution of the convective entrainment parameter η (solid, contour interval 0.2) and boundary-layer convergence (dashed, contour interval $1 \times 10^{-4} \text{ s}^{-1}$, value of the outermost contour is zero) for case E6 at 36 h. The thick solid contour surrounds the region where boundary-layer convergence coincides with η values less than unity, implying a convectively stable stratification. (Values of η greater than unity correspond to a convectively unstable stratification.) The vortex center is indicated by the hurricane symbol.

Lower-right: As in the lower-left panel except for case W6.

TRANSITIONS

The ageostrophic circulation diagnostic package used in the present project, which was developed previously by the principal investigator and graduate students at the University at Albany, is being applied by Professor John Molinari's research group to diagnose observed trough-interaction events.

RELATED PROJECTS

The present project involves collaborative efforts with Professors John Molinari (University at Albany) and Roger K. Smith (University of Munich), both of whom are funded by the ONR Marine Meteorology Program. These respective collaborations are concerned with the trough-interaction problem, addressed through diagnostic studies of observed events and idealized numerical model experiments designed to elucidate the basic components of the trough-interaction process.

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