Effects of Convective Heating and Air-Sea Interaction on Tropical Cyclone Motion

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LONG-TERM GOALS

To improve prediction of the tropical cyclone motion.

SCIENTIFIC OBJECTIVES

The specific scientific objective of this study is to develop our physical understanding of the mechanisms by which convective heating and tropical cyclone-upper ocean interaction affect the motion and vertical coupling of baroclinic tropical cyclones.

APPROACH

Numerical experiments with a realistic hurricane model and a coupled hurricane-ocean model.
A new diagnostic approach for quantitative analysis of the effects of various processes governing tropical cyclone motion is developed to explain the numerical results.

WORK COMPLETED

1. We proposed a dynamical framework for study of baroclinic tropical cyclone motion, in which a baroclinic tropical cyclone is treated as a positive potential vorticity anomaly relative to its environmental flow. Tropical cyclone motion is directly linked to the axially asymmetric potential vorticity tendency, rather than the ventilation flow over the tropical cyclone center. The vortices at lower and middle levels move to the region with the maximum wavenumber-one component of the

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potential vorticity tendency. Therefore, the contributions of individual physical processes to the vortex motion are equivalent to their contributions to the wavenumber-one component of the potential vorticity tendency. Based on this dynamical framework, a potential vorticity tendency diagnostic approach is described and evaulated with idealized numerical experiments . This new approach is capable of estimating tropical cyclone motion with a suitable accuracy (Fig. 1) and determining fractional contributions of individual physical processes (horizontal and vertical advection, diabatic heating and friction) to tropical cyclone motion (Fig. 2).

2. The movement and vertical coupling of adiabatic baroclinic vortices are first investigated through numerical experiments, in which the initially symmetric baroclinic tropical cyclone is affected by either the vertical differential beta drift or the vertical environmental shear. We revealed the relative importance of various physical processes (including the steering of the asymmetric flow over the tropical cyclone center) and the mechanism by which a baroclinic vortex maintains its coherent structure when it is affected by environmental vertical shears or differential beta drift.

3. We also investigated the factors that determine the motion of a baroclinic tropical cyclone in the presence of convective heating and explained how the diabatic heating affects the tropical cyclone motion and vertical coupling.

4. The influence of tropical cyclone-ocean interaction on the baroclinic tropical cyclone motion was investigated by focusing on the physical mechanism related to the track difference between the coupled and non-coupled experiments.

RESULTS

1. Baroclinic tropical cyclone propagation in the absence of convective heating

Under the influence of the vertical environmental shear or the differential beta drift, the baroclinic tropical cyclone tilts in the vertical. In response to the vertical tilt, the isentropes and potential vorticity are lifted (lowered) down-tilt (up-tilt) of the vortex center. As a result, a pair of asymmetric potential anomalies develops with a three dimensional meso-scale asymmetric circulation (Fig. 3). In this case, we cannot use only the asymmetric flow averaged over the TC core to account for the tropical cyclone motion (Fig. 4). The three dimensional tropical cyclone motion, defined as the vertical mean of the vortex motion at various levels, is determined by the horizontal advection of the symmetric potential vorticity component by the asymmetric flow, the advection of the asymmetric potential vorticity component by the symmetric flow, and the vertical potential vorticity advection associated with the asymmetric vertical motion. Although the asymmetric flow over the tropical cyclone core may affect the vertical coupling of the baroclinic vortex through a so-called rotatory mechanism (Jones 1995), most of the asymmetric flow arises from the mesoscale gyres associated with the vertical tilt, instead of the penetration flow. It is found that the resulting three dimensional asymmetric circulation plays an important role in the vertical coupling.

2. Baroclinic tropical cyclone propagation in the presence of convective heating

It is found that the dominant physical processes that contribute to TC motion is different from the corresponding adiabatic case. The diabatic TC motion is also not necessarily due to horizontal PV advection by the asymmetric flows over the vortex core region (Fig. 2). It is primarily determined by the advection of the symmetric PV component by the asymmetric flow (steering) and the influence of the asymmetric component of diabatic heating, which is directly associated with the vertical differential asymmetric diabatic heating, rather than the asymmetric heating. The influence of the asymmetric diabatic heating also play a critical role in the observed enhancement of the vertical coupling of diabatic baroclinic vortices. In addition, we find a level at which the influence of diabatic heating vanishes and the TC moves with the asymmetric flow weighted by the horizontal symmetric PV gradient (Fig. 2). Such a level is located at the place where the vertical gradient of the asymmetric heating rate is zero, rather than at the mass center of the baroclinic TC.

3. The influence of air-sea coupling on TC propagation

We compared the results of two numerical experiments in a resting environment on a beta-plane. The beta drift in the control run has fixed uniform SST, while the other run in the coupled model (CE) with the same initial SST as in the CTL. Two types of track differences are observed. With an initial SST of 28.5 ^{o}C, in agreement with Bender et al. (1993), the TC in CE moved more northward than the track in the CTL. We reduced the initial SST by 1 ^{o}C, the TC in CE moved with a larger southward speed than in the CTL. This agrees with Khain and Ginis (1991). The track difference is primarily caused by the difference of the asymmetric diabatic heating fields between the coupled and uncoupled experiments since the air-sea coupling significantly modifies the asymmetric structure of baroclinic vortices.

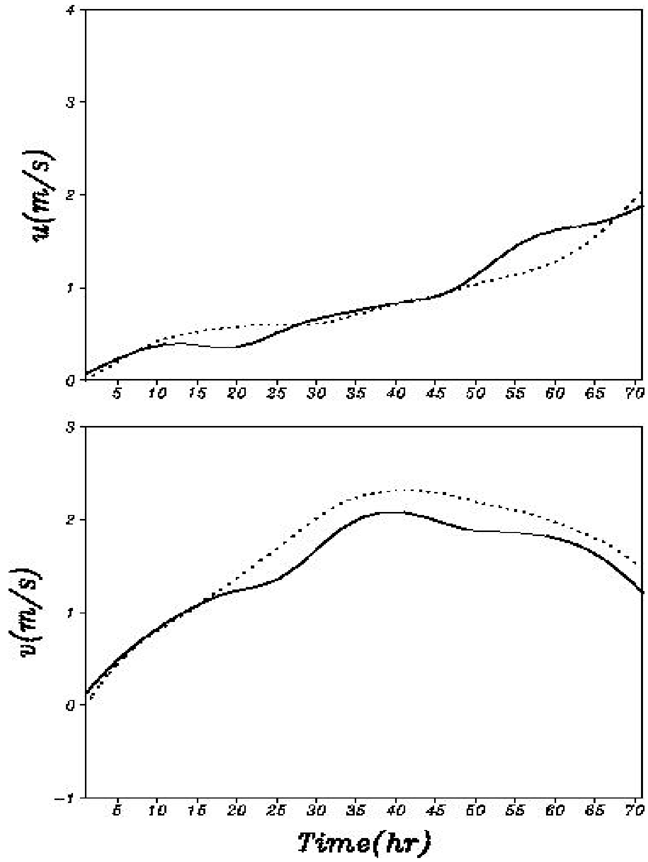

Figure 1 Comparisons of the zonal (upper) and meridional (lower) velocities estimated from tropical cyclone center positions (dashed) and potential vorticity tendency (solid) in the diabatic beta drift experiment.

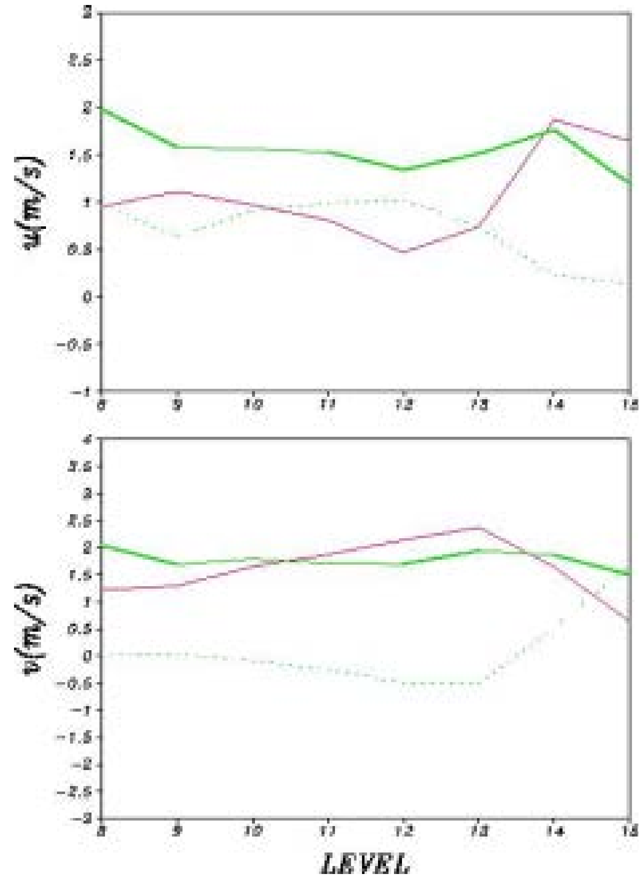

Figure 2 24-h mean contributions of horizontal advection (solid) and diabatic heating (ditted) to the total (thick solid) zonal (upper panel) and meridional (lower panel) velocities in the diabatic beta drift .

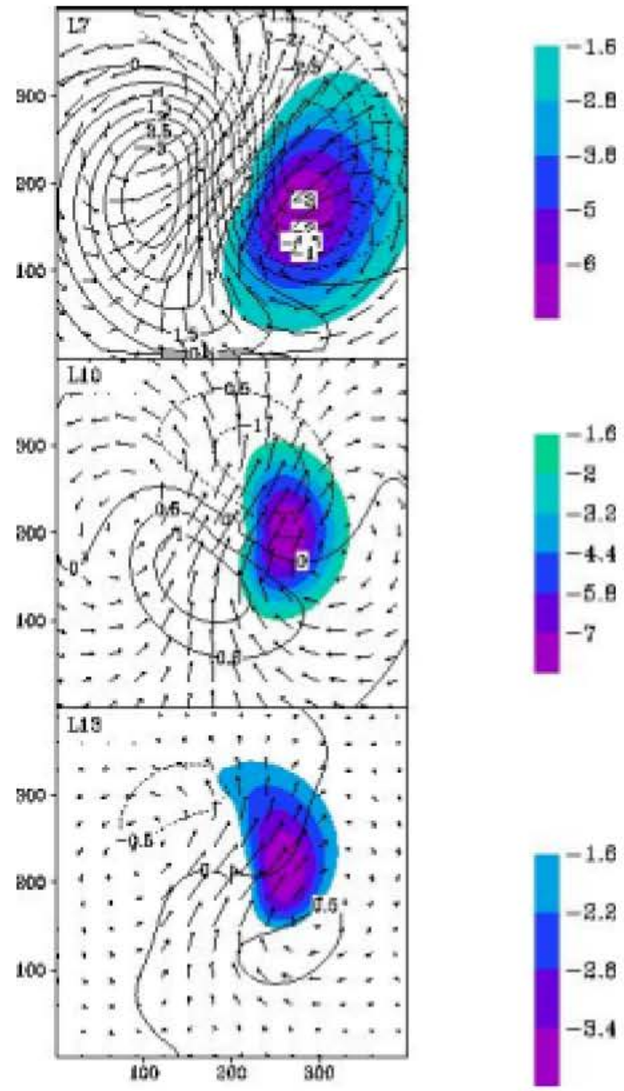

Figure 3 Fields of vertical motion (shading), potential temperature anomaly (contours), and relative asymmetric wind fields associated with the vertical tilt of an intitially symmetric adiabatic vortiex at 440, (upper), 660 (middle) and 850 hpa (lower).

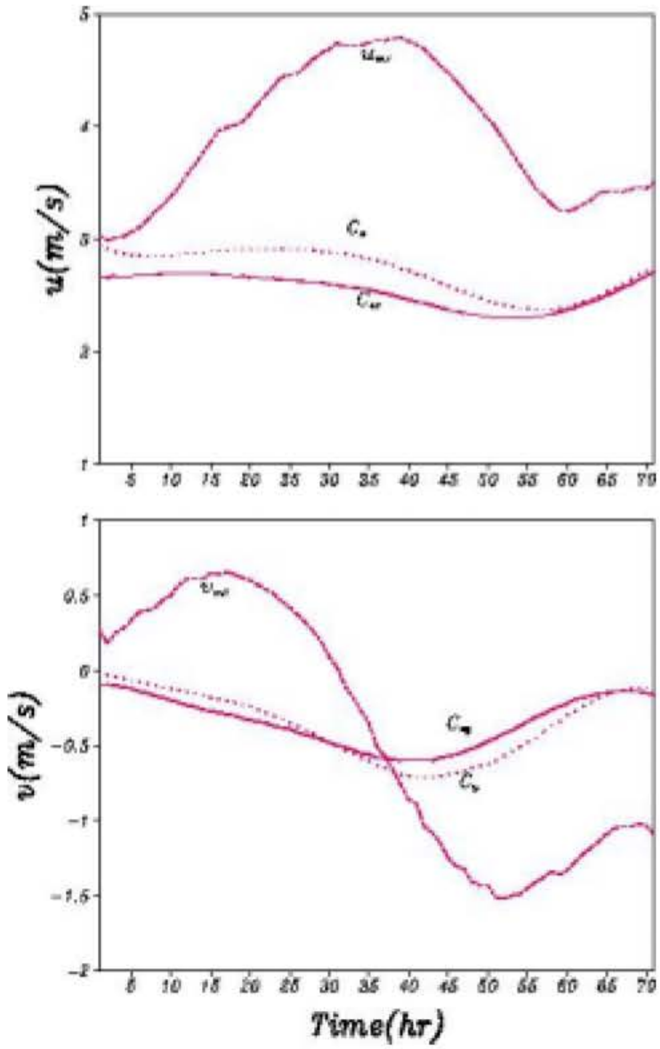

Figure 4 Time series of zonal (upper) and meridional (lower) vertical mean tropical cyclone calculated from the center positions (C , dotted), potential vorticity tendency (C_m, solid), in comparison with the vertical mean asymmetric flow (V_m, dashed) in the experiment with vertical environmental shears.

RELATED PROJECT

A project entitled Dynamics of Intertropical Convergence Zone and Tropical Cyclone Genesis has been supported by Augmentation Awards for Science and Engineering Research Training (AASERT) (Award number N00014-95-1-1230, Mod No. A00003). Two graduate students have been supported by this grant. Mr. Patric Goda finished his Master Thesis, entitled Four to six day oscillations in OLR and meridional wind in the eastern-central Pacific . Another graduate student, Kevin Mullen is currently working on this topic.

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PUBLICATIONS

The following publications are supported or partially supported by this grant.

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Dissertation and Thesis

Wu, L., 1999: Study of tropical cyclone motion with a coupled hurricane ocean model. Ph. D dissertation, University of Hawaii, 2525 Correa Rd,. Honolulu HI 96822, USA.

Goda, M. P., 1998: Four to six day oscillations in OLR and meridional wind in the eastern-central Pacific. Master thesis, University of Hawaii. 2525 Correa Road, Honolulu, HI96822, USA.

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