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THE EFFECT OF EXTERNAL FORCING ON THE STRUCTURE CHANGE OF TROPICAL CYCLONES

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1. INTRODUCTION

In the present study, tropical cyclones are considered as axially symmetric vortices in which the gradient wind relationship holds between the wind and mass fields. The azimuthal wind decreases with height in the free atmosphere. This implies the inward increase of temperature and existence of a warm core in the interior. We discuss how a tropical cyclone (TC) undergoes the structure change when it is influenced by various kinds of forcing. The key concept we utilize is the gradient wind adjustment.

2. CAUSE OF THE TC STRUCTURE CHANGE

Given the wind field, we subtract an appropriate uniform flow from the wind at each level. This is done so that the axis with no wind stands on the TC center at the surface. The vortex thus obtained consists of the axisymmetric and asymmetric components. The former component is called TC in this study.

The structure change of TC are described by the prognostic equations of the relative angular momentum, potential temperature and the mixing ratio of the water vapor together with the diagnostic formula determining the radial and vertical circulation. Such a scheme is based on the concept of the gradient wind adjustment. With the use of the diagnosed circulation, the gradient wind relationship is held after the structure change. The prognostic equations contain the forcing terms such as (1) azimuthal averages of the latent heat release, radiation effect, diffusion effect including exchange of physical properties at the surface, (2) the effect of transport by the asymmetric wind, (3) the effect due to the uniform flow relative to the moving TC. The category (1) may be called the internal forcing, (2) and (3) as the external forcing. The physical processes of various scales in TC contribute to the forcing through azimuthal averages taken. The asymmetry in category (2) includes both the internally generated and the superposed synoptic scale systems.

3. GRADIENT WIND ADJUSTMENT

When any forcing is put force on the TC fields in the gradient wind balance, the TC structure is adjusted to a new balanced state. Conceptually, this structure change is analogous to the geostrophic wind adjustment. The gradient wind adjustment is achieved by the radial vertical circulation which is determined diagnostically under the constraint of the quasi gradient wind approximation. Complex processes of adjustment are represented simply by the diagnosed circulation.

In an adjusted balanced state, impact of the forcing is retained in a relaxed form. For instance, if a forcing is to increase (decrease) the vertical shear of the gradient wind, its impact is partially reduced by the radial flow. Namely, the outward (inward) wind is induced which carries smaller (larger) absolute angular momentum. At the same time, the downward (upward) vertical motion has to be induced in the interior which causes temperature increase (decrease) needed for the gradient wind balance. The condition for the gradient wind adjustment to function is that the potential vorticity in the TC is positive.

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4. EXAMPLES OF STRUCTURE CHANGE

The azimuthal mean of the relative angular momentum at a certain radius is related to the integral of the vorticity within the circle (Stokes theorem). The vorticity flux across the circular boundary causes change in the azimuthal mean wind there.

In the following, the TC structure changes for three kinds of external forcing are described.

a) Import of a positive vorticity into TC domain at low levels

Influx of the positive vorticity at low levels causes increase in azimuthal mean wind. Resulting impact on TC is to increase the vertical shear of the azimuthal wind above. Then, the gradient wind adjustment should properly reduce the vertical shear of the wind and increase the temperature in the interior. It is achieved by outward transport of the relatively small absolute angular momentum and sinking motion in the interior. The increased azimuthal wind at low levels in the adjusted state can contribute to the enhancement of inward transport of the latent heat in the planetary boundary layer.

b) TC motion into the upper level anticyclonic region

Assume that a TC moves into the upper level anticyclonic region. In such a situation, forcing is to increase the vertical shear of the azimuthal wind. In contrast to the preceding example, however, it is caused by the decrease in the relative angular momentum at the upper level. The gradient wind adjustment in the present case is achieved by the inward transport of the relatively large angular momentum and the warming by the sinking motion in the interior. Depending on the situation, the structure change in the interior may involve the TC intensity change and possibly reshaping of the eye wall structure.

c) Effect of the environmental wind on TC

In this study, we subtracted an appropriate uniform flow from the given wind field at each level. An effect of the subtracted wind on TC is the horizontal advection of TC vortex relative to the TC motion. It is known that a weak easterly shear of the environmental wind is favorable for TC development in the tropics. The reason for this is that, as TC tends to move westward in the tropics, the easterly wind of proper magnitude at upper levels eliminates the relative advection effect. Accordingly, the vertical axis above the moving TC center is not disturbed. On the other hand, when the TC is exposed to the strong westerly shear in the extratropical latitudes, the upper level vortex and a warm core are sheared off from the storm axis. The azimuthal mean of such a feature becomes forcing in TC structure change and, hence, takes part in the extratropical transition of TC. Also, the azimuthal mean of the advection of the planetary vorticity by the meridional component of the relative mean flow affects the TC structure, especially at large radii.

In the presence of multiple forcing, a proper combination of each forcing can be provided to the diagnostic formula to determine the radial vertical circulation.