Role of Vortex Rossby Waves on Tropical Cyclone Intensity

Melinda S. Peng
Naval Research Laboratory
Monterey CA 93943-5502
Phone: (831) 656-4704 fax: (831) 656-4769 e-mail: melinda.peng@nrlmry.navy.mil

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LONG-TERM GOALS

The long-term goal of this project is to improve the prediction of tropical cyclone (TC) genesis and intensity changes through improved understanding of the fundamental mechanisms involved. Accurate prediction of TC intensity changes is critical to Navy missions and civilian activities in coastal areas. Significant gains have been made in the TC track prediction over the past three decades. The intensity forecast, however, has shown very little progress during the same period. A main factor contributing to the lack of skill in the prediction of TC intensity is the inadequate understanding of complicated mechanisms involved. These mechanisms include internal dynamic and thermodynamic processes, external forcing, and scale interactions. Only after we understand these processes, are we then able to tackle the weaknesses in model simulations and forecasts.

OBJECTIVES

The objective of this project is to understand how asymmetric disturbances, often generated by local convection, affect TC structure and intensity change. Two focus areas of the study include: 1) the effect of different characteristics of externally exposed asymmetries on the axisymmetrization of TCs, and 2) the evolution of stable and unstable waves and their impacts on the basic vortex.

APPROACH

For the first part of the study listed under the objectives, our approach is to use an idealized TC model to investigate vortex axisymmetrization for different basic vortex profiles and different asymmetries. The model developed can be used as a barotropic or a baroclinic model. Idealized vortices resembling realistic TC radial profile and asymmetries representing disturbances from convection will be prescribed. Diagnostic tools will be developed to analyze results from model integrations. For the second part of the study, wind profiles with radial shear instability in the inner part, the outer part, or

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14. ABSTRACT
The long-term goal of this project is to improve the prediction of tropical cyclone (TC) genesis and intensity changes through improved understanding of the fundamental mechanisms involved. Accurate prediction of TC intensity changes is critical to Navy missions and civilian activities in coastal areas. Significant gains have been made in the TC track prediction over the past three decades.

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both, will be investigated to understand the growth and decay of vortex Rossby modes with different wave numbers. To investigate the instability characteristics of TC wind profiles, an eigenvector analysis system for the barotropic vorticity equation will be built, and stable and unstable eigenvalues and eigenmodes will be investigated.

WORK COMPLETED

The research of this year is focused on understanding how a weak instability existing in the outer profile of a TC, where the wind associated with the cyclone meets the environmental wind, would impact the basic-state vortex. We first investigate the eigen system using the barotropic vorticity equation with an analytically constructed radial wind profile that possesses a weak instability in the outer part. The eigen analysis shows that the azimuthal wavenumber- two wave has the largest linear growth rate. The time evolutions of unstable disturbances in linear and nonlinear barotropic models are then investigated. The results are discussed in the following section.

RESULTS

The growth of asymmetric perturbations and their interaction with the symmetric flow are investigated for tropical cyclone wind profiles with instability in the outer region. Three tangential wind profiles are examined. TC1 has a strong barotropic instability profile in the outer region. TC2 is a stable wind profile. TC3 has a weak instability profile, with a larger distance between the inner negative and the outer positive vorticity gradient centers comparing to TC1.

An eigenvalue analysis indicates that wave-number two is the most unstable mode in both TC1 and TC3, with an e-folding timescale of about 1 and 9 days, respectively. Numerical simulations using a linear barotropic model, with an initial asymmetry specified in the outer region, confirm the eigenvalue analysis. A mechanism is provided to explain the difference between simulations in TC1 and TC2. In both the stable and unstable case, an inner asymmetry is induced by the initial outer asymmetry. Subsequently, the newly generated inner asymmetry feeds back positively to the outer asymmetry with the unstable profile. Because of this positive feedback, the inner and the outer asymmetries maintain an up-shear phase tilting, leading to a continuous energy transfer from the symmetric flow to the asymmetric perturbation. In the stable TC2, the inner asymmetry could not amplify the outer initial asymmetry as there is no radial vorticity gradient there. Simulations of a nonlinear barotropic model and a primitive equation model further confirm the significant weakening of the maximum tangential wind due to the positive feedback process for TC1. Simulations for TC3 show smaller change of the symmetric tangential wind, as expected.

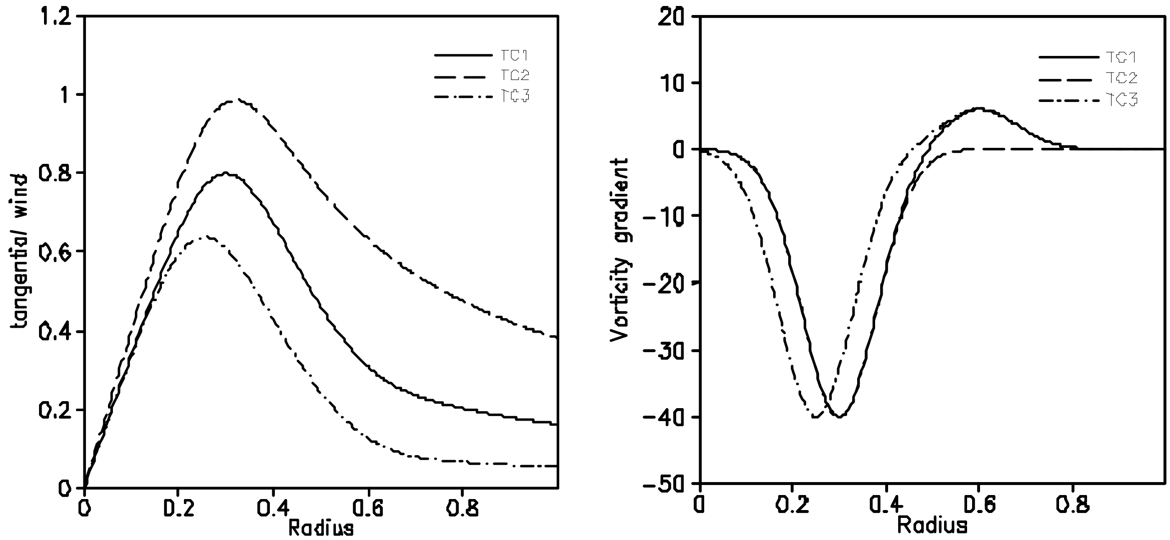

Figure 1. Basic radial wind profile investigated (left): TC1 (Solid) for an unstable profile; TC2 (dashed) is for a stable profile and TC3 (dot-dashed) is for a weak unstable profile. The corresponding vorticity gradient is given in the right panel.

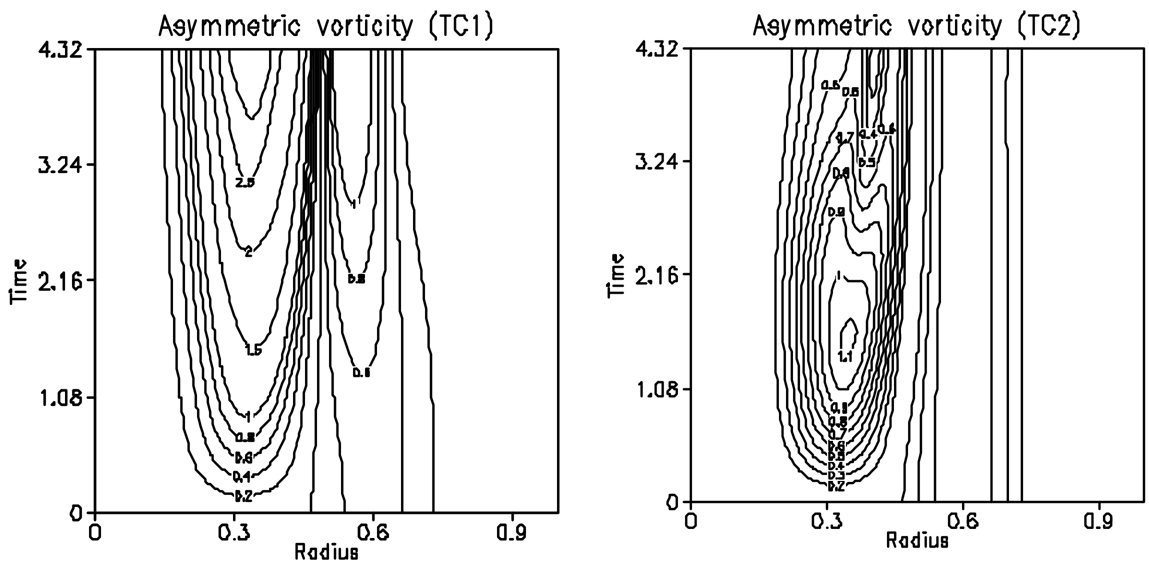

Figure 2. Evolution of the asymmetry disturbance for the unstable profile TC1 (left) and stable profile TC2 (right). The initial disturbance is place at the outer part at r= 0.6 where the basic sate vorticity gradient changes sign (Fig.1). Not that the outer disturbance and the newly induced inner disturbance grow at simultaneously in the unstable case while the inner disturbance grow first then decays along with the outer disturbance at later time.

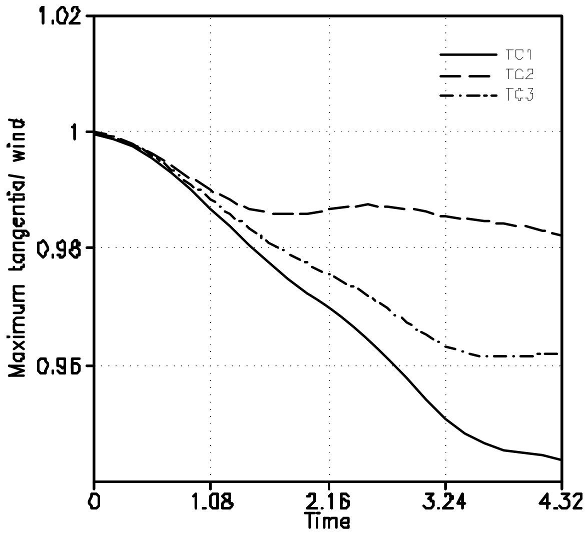

Figure 3. Time evolutions of the symmetric part of the vortices in non-linear simulations for the three profiles displayed in Fig. 1. Note the more significant decay of the most unstable profile TC3.

IMPACT/APPLICATIONS

The understanding of how a hurricane-like vortex can gain or lose energy to and from asymmetric disturbances is critical to improve our predictions of TC genesis and TC intensity change.

TRANSITIONS

Results from this study that lead to modeling improvements in the ability of NOGAPS to predict tropical cyclones will transition to 6.4 projects within PE 0603207N (SPAWAR, PMW-180) that focus on the transition of COAMPS to FNMOC.

RELATED PROJECTS

This project is closely related to the NRL 6.2 funding on "Predicting tropical cyclone genesis using NOGAPS". Knowledge gained from this project will help to improve the prediction of tropical cyclone genesis.

PUBLICATIONS

Peng, J.-Y., M. S. Peng, and T. Li, 2008: Dependence of vortex axisymmetrization on the characteristics of the asymmetry. *QJRMS*, (in press).

Peng, J., T. Li, and M. S. Peng, 2008: Formation of tropical cyclone concentric eyewalls by wave-mean flow interactions. Advances in Geosciences, (in press).

Peng, J., T. Li, and M. S. Peng, 2008: Barotropic instability in the tropical cyclone outer region. *Q. J. R. Meteor. Soc*, (Submitted).

PRESENTATIONS

Peng, M. S. Jiayi Peng, and T. Li, 2007: Dependence of vortex axisymmetrization on the characteristics of the asymmetry. IAMAP, 2-13 July 2007, Perugia, Italy. (Invited talk).