

1. Introduction

- Horizontal roll vortices (or rolls, Fig.1) are frequently observed in the hurricane boundary layer (HBL).
- These rolls significantly contribute to the vertical momentum and heat transports, but their formation and evolution mechanisms are not well understood.
- Using a numerical model, we examine how the inflection point instability generates rolls in the HBL and the conditions favorable for their formation. Our particular focus is on the impact of the mean wind and stratification.

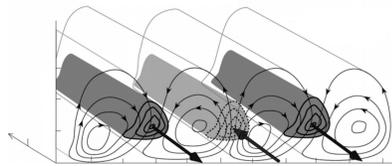


Fig.1 Schematics of rolls in HBL (Morrison et al. 2005)

2. Method

- We use a 2D-LES model (Ginis 2004) to resolve linear rolls, with given basic-state wind and stratification.
- The basic-state wind profiles (Fig.2) are derived from a steady and axisymmetric HBL model.
- Idealized potential temperature profiles (Fig.3) are used as basic-state stratification.
- We examine the formation of rolls under various background conditions in a set of idealized numerical experiments.

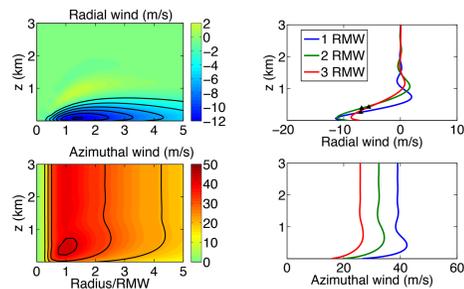


Fig.2 Basic-state wind distributions in HBL. The eddy viscosity (K) is parameterized by a 1st-order scheme. The inflection points in the radial wind profiles are indicated by black triangles. RMW (Radius of Max Wind)=40km.

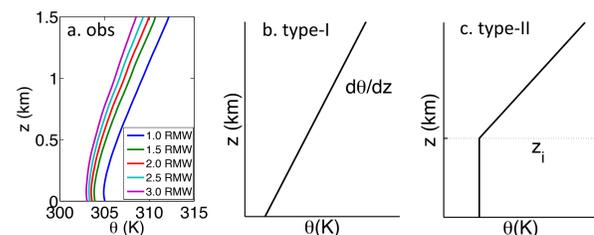


Fig.3 Potential temperature profiles in HBL. (a) Observations obtained by GPS dropsondes (Zhang 2011); (b) Idealized type-I, the lapse rate is subject to change; (c) Idealized type-II, the mixed layer height is subject to change.

3. Rolls in neutral HBL

3.1 Basic Structure

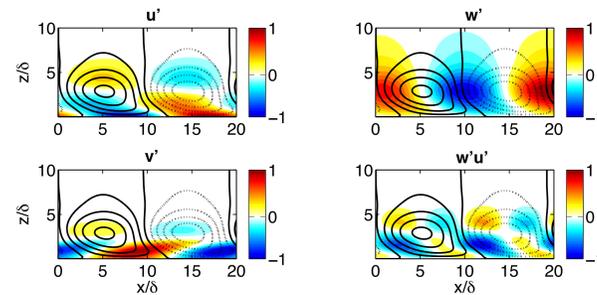


Fig.4 Structure of rolls in the neutral HBL. All variables are normalized by their maximum values. x and z axes are normalized by the HBL height scale δ^* . Contours are streamlines: solid (dashed) contours represent clockwise (counterclockwise) circulations.

* HBL height scale: $\delta = \sqrt{2K/\Gamma}$, where $\Gamma^2 = (f + 2V_g/r)(f + 2V_g/r + \partial V_g/\partial r)$

3.2 Radial Variations

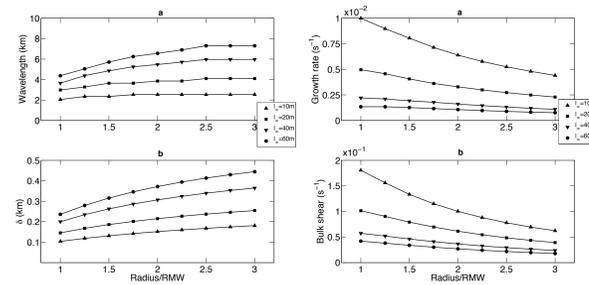


Fig.5 (a) Wavelength of rolls and (b) the HBL height scale as functions of radius.

Fig.6 (a) Growth rate of rolls and (b) bulk wind shear as functions of radius.

3.3 Kinetic Energy Budget

$$\frac{d}{dt} \int \bar{e}' dz = \int \left(-\overline{w'u'} \frac{\partial \bar{u}}{\partial z} + \frac{g}{\theta_0} \overline{w'\theta'} - \bar{D} \right) dz$$

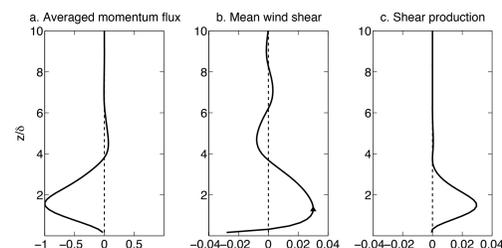


Fig.7 An example of vertical distributions of (a) averaged momentum flux of rolls, (b) mean wind shear, and (c) shear production. The averaged momentum flux shown is normalized by its maximum value. The shear production is the product of the two variables shown on the left with a negative sign. The location of the inflection point is indicated by the black triangle in (b).

4. Rolls in stratified HBL

4.1 Basic Structure

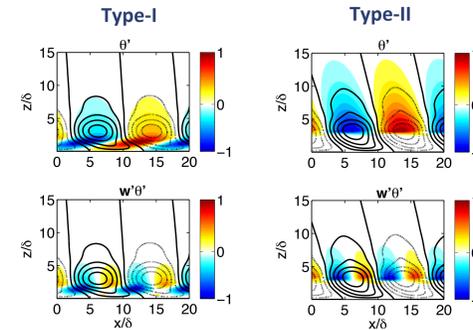


Fig.8 Structure of rolls in stratified HBL. Left: type-I stratification; Right: type-II stratification.

4.2 Radial Variations

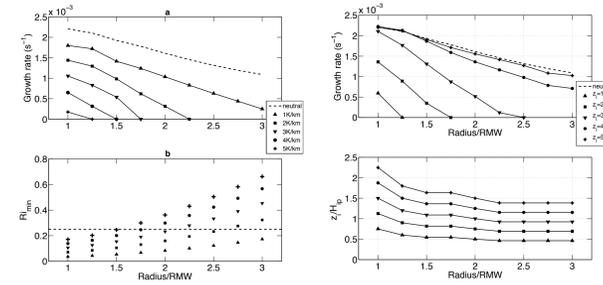


Fig.9 (a) Growth rate of rolls and (b) the minimum Richardson number as functions of radius.

Fig.10 (a) Growth rate of rolls and (b) the ratio of the mixed layer height (z_i) to the inflection point height (H_{ip}) as functions of radius.

4.3 Kinetic Energy Budget

$$\frac{d}{dt} \int \bar{e}' dz = \int \left(-\overline{w'u'} \frac{\partial \bar{u}}{\partial z} + \frac{g}{\theta_0} \overline{w'\theta'} - \bar{D} \right) dz$$

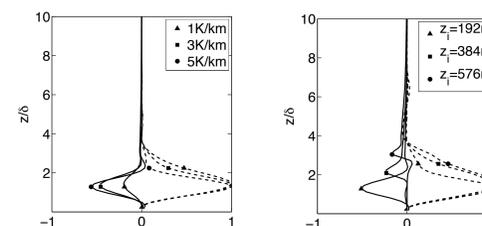


Fig.11 Vertical distributions of buoyancy work (solid lines) and shear production (dashed lines). These variables are nondimensionalized by the maximum value of the shear production. Left: type-I stratification; Right: type-II stratification.

5. Conclusions

- Rolls generated by the inflection point instability are characterized with tilted streamlines in the vicinity of the inflection. Such tilted streamlines is a necessary feature of the rolls to extract kinetic energy from the mean flow.
- The characteristic height scale of the HBL determines the spatial scale of rolls. The wind shear determines the growth rate of rolls in neutral stratification.
- The stratification with a constant lapse rate tends to depress the rolls growth because of the negative work done by buoyancy. For a well-mixed boundary layer capped by a stable inversion layer, the stratification has less depressing effect on rolls.

6. Future work

- The grid spacing of the majority of current hurricane models is too coarse to resolve rolls. As a result, the effect of rolls is not explicitly included. To properly parameterize the effect of rolls, we need to investigate their formation, nonlinear evolution and decay.
- In our future work we plan to investigate 1) another possible mechanisms of rolls generation, i.e., thermal instability, and 2) nonlinear dynamics of rolls, and their impact on the mean HBL structure.
- We also plan to develop a new HBL scheme with consideration of roll-induced fluxes, and incorporate it into US Navy's tropical cyclone forecast model COAMPS-TC.

References

- Ginis, I., A.P. Khain and E. Morozovsky, 2004: Effects of large eddies on the structure of the marine boundary layer under strong wind conditions. *J. Atmos. Sci.*, 61, 3049-3064.
- Morrison, I., S. Businger, F. Marks, P. Dodge, and J. Businger, 2005: An observational case for the prevalence of roll vortices in the hurricane boundary layer. *J. Atmos. Sci.*, 62, 2662-2673.
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