The Wind-Field Structure of the Tropical Cyclone Boundary-Layer

Thesis submitted for the degree of

Doctor of Philosophy

by

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This thesis contains no material which has been accepted for the award of any other degree or diploma in any university or other institution, and, to the best of my knowledge, contains no material previously published or written by another person, except where due reference is made in the text.

The work described in chapter 2 (with the exception of section 2.5) was published as:

Kepert, J.D., 2001: The dynamics of boundary layer jets within the tropical cyclone core. Part I: Linear theory. *J. Atmos. Sci.*, **58,** 2469-2484.

The work described in chapter 3 was published as:

Kepert, J.D. and Y. Wang, 2001: The dynamics of boundary layer jets within the tropical cyclone core. Part II: Nonlinear enhancement. *J. Atmos. Sci.*, **58,** 2485-2501.

Dr. Wang's contribution to that paper was in formulating and coding the dynamics portion of the model, writing that section of the paper, and in some discussions during the analysis of the results. The remainder of the model was coded and the analysis performed by myself.

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Abstract

The recent massive increase in observations within the tropical cyclone boundary-layer has emphasised that a low-level wind speed maximum, or jet, commonly occurs there. Two complementary tools are developed here to diagnose the boundary-layer winds in a translating tropical cyclone: a linear analytical model, and a high-resolution numerical model with sophisticated parameterisations of the sea-air transfers and turbulence.

The solution to the linear model has three components: a symmetric one due to the cyclone, and two asymmetric ones which result from the interaction of the moving cyclone with the earth's surface. The asymmetric components are shown to be frictionally stalled inertia waves, while all three components are modified Ekman spirals. It is argued that this simple Ekman-type model may be appropriate in tropical cyclones since diurnal effects are weak or absent, turbulence is predominantly shear-generated, and baroclinicity is weak.

The jet is similar to the supergradient flow found at the top of the classical Ekman spiral. It is only a few percent supergradient in the linear model, because the neglect of vertical advection there substantially reduces the strength. The jet height scales as $(2K/I)^{1/2}$, where K is the turbulent diffusivity and I the inertial stability, is typically several hundreds of metres in the cyclone core, and increases with radius. In a moving storm, the jet is most supergradient – several times stronger than in a stationary storm – at the eyewall to the left (right) and front of the storm in the Northern (Southern) Hemisphere, and extends into a significant area around to the left (right) of the storm. It is, however, much less marked to the right (left), where the strongest near-surface winds are found. The ratio of near-surface to gradient-wind speed is shown to have a substantial spatial

variability. Larger values are found near the eye, and there is a marked increase from right to left (left to right) of the track of a moving storm.

The second tool used is a high resolution, full primitive equations, dry, hydrostatic, numerical model. It relaxes the constraint of linearity and includes sophisticated physical parameterisations. Strong inwards advection of angular momentum produces a strong jet, typically from 10% to 25% supergradient near the radius of maximum winds (RMW). The inflow is maintained against the outwards acceleration resulting from gradient-wind imbalance in a stationary vortex mainly by vertical diffusion and vertical advection. In a moving cyclone, horizontal advection also becomes important. The jet height, motion-induced asymmetries, and spatial variability of the surface-wind factor compare well in the two models.

Predictions from the modelling work are tested against observations in five tropical cyclones. Hurricane Mitch (1998) had strongly azimuthal-mean supergradient flow near the RMW from 400-m to 2-km height, while the flow in Hurricane Georges (1998) was apparently close to balanced. This difference may be because Georges was commencing an eyewall-replacement cycle. The asymmetric part of the near-eyewall flow in both these storms is shown to have a similar structure to the frictionally stalled inertia wave and numerical simulations, although the frictional asymmetry which forces this is provided in Mitch by proximity to land rather than by motion. Severe Tropical Cyclone Vance (1999) also showed a large area of supergradient flow at about 1.5 km height ahead of and to the right of the storm, the strength and height of which was consistent with numerical simulations.

The observed ratio of near-surface wind speed to the wind aloft is also shown to be in good agreement with the models. In particular Hurricanes Hugo (1989), Andrew (1992) and Georges displayed an increase of this ratio towards the centre of the storm, and higher values on the left of the track than on the right. Hurricane Mitch had an increase towards the centre, but different asymmetry. The observed ratio was lower than modelled in the outer core of Tropical Cyclone Vance. The agreement could be improved by increasing the ocean-surface roughness in the model to account for the shallow ocean and limited fetch in this case.

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