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AN ANALYSIS OF SOME TROPICAL CYCLONE BOUNDARY LAYER WIND OBSERVATIONS

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1. INTRODUCTION

Kepert (2001; henceforth K) and Kepert and Wang (2001; henceforth KW) presented 3-dimensional analytical and numerical models, respectively, of the hurricane boundary layer. These models correctly reproduce some well-known features of the tropical cyclone boundary layer (TCBL) wind field, such as the motion-induced asymmetry in the near-surface winds.

An important prediction in K and KW is that the wind speed maximum which is often found in observed profiles within the TCBL, is supergradient. This jet is increasingly supergradient and closer to the surface towards the centre or the storm. It is also stronger and lower on the left of the storm than on the right (Northern Hemisphere). Further, the surface wind factor (SWF), that is, ratio of the near-surface wind speed to that aloft, similarly increases towards the centre of the storm, and is larger on the left (or weaker) side of the storm than on the right. In fact, it can reach unity at the radius of maximum winds (RMW) on the left. This has obvious potential impact on current practices in forecasting and warning, storm surge modelling, wind engineering and climatological risk assessment.

The key ingredient in the models of K and KW, which is missing in one-dimensional models, is the horizontal advection of angular momentum. The jet is produced by the strong inwards advection of angular momentum in the boundary layer inflow; it is able to be supergradient because vertical diffusion and upwards advection of inflow maintain the inflow at the jet height against gradient adjustment. In the asymmetric case, azimuthal advection also plays a role, leading to the asymmetries noted above.

The purpose of this paper is to present three observational case studies which confirm the above predictions.

2. SURFACE WIND FACTOR

Hurricane Andrew devastated Miami in 1992. Powell et al (1996) discussed the wind observations from surface platforms and aircraft in considerable detail, and included tables of surface wind observations with nearly co-located aircraft observations. The SWF's from this table were stratified to left and right of track, and are plotted as a function of distance from the storm centre in Fig 1. It is apparent (i) that there is an increase towards the centre of the storm, and (ii) that the values are significantly higher on the left of the track than on the right. These are both in strong agreement with the modelling work of K and KW, although it should be noted that this is not an ideal comparison, as the flow to the left of the track was off-shore and so not representative of the open-ocean conditions in the modelling work. (The impact of landfall on the surface winds in a stationary storm is discussed further in Kepert, paper P1.3, this conference). The highest values of 0.97 and 1.03 occurred in the left eye-wall, consistent with the models. Similar trends can be seen in the tabulated data in Hurricane Hugo (Powell et al 1991; not shown here).

3. SUPERGRADIENT FLOW

Hurricane Mitch had weakened to a central pressure of 933 hPa at 00UTC on 28 Oct 1998 as it moved slowly southwards, about 36 hours before its first landfall in Honduras. Radar imagery shows the bulk of the convection lay to the north and east of the centre. Between 2100 on the 27th and 0030 on the 28th, a Hurricane Research Division reconnaissance aircraft dropped 30 GPS dropsondes within 100 km of the centre of Mitch. The observations were relocated relative to Mitch, the storm motion was subtracted from the winds, they were resolved into azimuthal and radial components and averaged into 100 m bins to reduce the effects of small-scale turbulence. Pressure data were interpolated to the centres of the same 100 m bins.

Willoughby (this conference) gives an improved parametric hurricane radial wind profile which accurately resolves the sharp transition at the RMW and which has been extensively tested against aircraft data. A radial pressure profile was derived from this by radially integrating the gradient wind equation, and fitted by nonlinear least-squares to the pressure observations at each 100 m level. As part of the fitting process, a small adjustment (about 7 km) was made to the best track, which was only available to 0.1 degree or 10 km. The observations and fitted data at three representative levels are shown in the left of Fig 2. Radial gradient wind profiles were calculated from the pressure fits and are shown, together with the observed winds, to the right. It is apparent the observed winds are about 10% supergradient at 500 and 1500 m, but not at 3 km.

There was concern that this result was due to the parametric pressure profile being unable to resolve the sharp pressure gradient at the rmw. Various polynomial fits (not shown) were carried out to just the data in the vicinity of the RMW. These also showed the winds were supergradient. The thermal wind equation was also analyzed, and it was found that the observed mean shear in the 1-2 km layer was several times greater than could be explained by the observed radial temperature gradient. This is consistent with strongly supergradient flow in the lower part of that layer.

4. JET ASYMMETRIES

Hurricane Georges reached maximum intensity (central pressure 937 hPa) for the first time at about 0600UTC on 20 Sept 1998, about a day before its first landfall on Antigua. Between about 1800 UTC on the 19th and 0100 on the 20th, the two HRD P3' s dropped 56 GPS dropsondes in Georges; here we analyze 15 from in and near the eye-wall. During this period, radar and 85 GHz SSM/I data both show that the core of Georges was highly symmetric, with a closed eye-wall with embedded reflectivity maxima generally to the left front and right rear. With only slight convective asymmetries, this is an ideal case for comparison with K and KW.

The dropsonde trajectories were relocated relative to the moving storm, and the storm motion subtracted from the wind observations, which were then resolved into radial and azimuthal components. Profiles of storm-relative azimuthal wind for the 15 near-eye-wall drops are shown in Fig 3, together with their storm-relative location. The wide variation in profile shape and jet height are readily apparent. However, it is also clear that this variation has a systematic azimuthal structure, with the jet being more marked and lower to the left and rear of the storm, and less marked and higher to the right, consistent with K and KW.

A Holland (1980) parametric pressure profile was fitted to the dropsonde hydrostatic surface pressures, and used (together with the motion from the National Hurricane Center best-track) to force the numerical model of KW. The predicted vertical profiles of storm-relative azimuthal wind are also shown in Fig 3. It can be seen that the predicted profiles reproduce the major part of the variation noted above. Differences are believed to be largely the effects of small mislocations of the data relative to the storm, as the track data is only given to 0.1 of a degree, or roughly 10 km, which is a large fraction of the radius of maximum winds. Temporal variability in the winds also contributes, as can be seen by comparing profiles I, J and K in Fig 3; the latter is 34 minutes after the first two.

5. DISCUSSION

Three case studies of characteristics of TCBL winds were briefly presented. The results are in good agreement with the theoretical and modelling results of K and KW, with regard to (i) the spatial distribution of the SWF, (ii) that the winds in the jet are super-gradient, and (iii) the spatial distribution of the jet.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

Holland, G.J., 1980: An analytic model of the wind and pressure profiles in hurricanes. *Mon. Wea. Rev.,* **108,** 1212-1218.

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.

Kepert, J.D. and Y. Wang, 2000: The dynamics of boundary layer jets within the tropical cyclone core. Part II: Nonlinear enhancement. *J. Atmos. Sci.*, **58,** 2485-2501.

Powell, M.D., P.D. Dodge and M.L. Black, 1991: The landfall of Hurricane Hugo in the Carolinas: Surface wind distribution. *Wea. and Forecasting,* **6,** 379-399.

Powell, M.D. and S.H. Houston, 1996: Hurricane Andrew's landfall in south Florida. Part I: Standardizing measurements for documentation of surface wind. *Wea. and Forecasting,* **11**, 304-328.

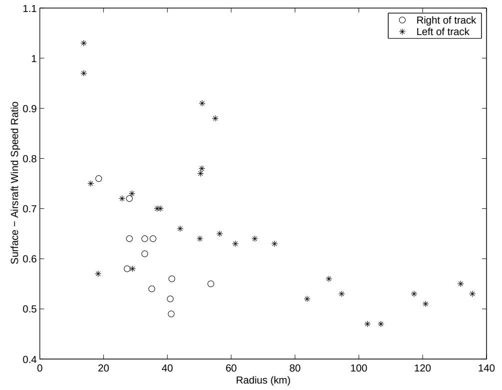

Fig 1: Ratio of observed surface to aircraft wind speeds in Hurricane Andrew to the left (*) and right(o) of track, as a function of distance from the storm centre.

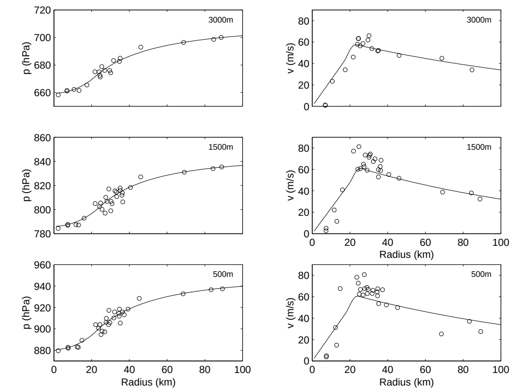

Fig 2: Hurricane Mitch pressure observations and fitted curves (left) at 500m, 1500m and 3 km, and calculated gradient wind and observed storm-relative azimuthal wind (right).

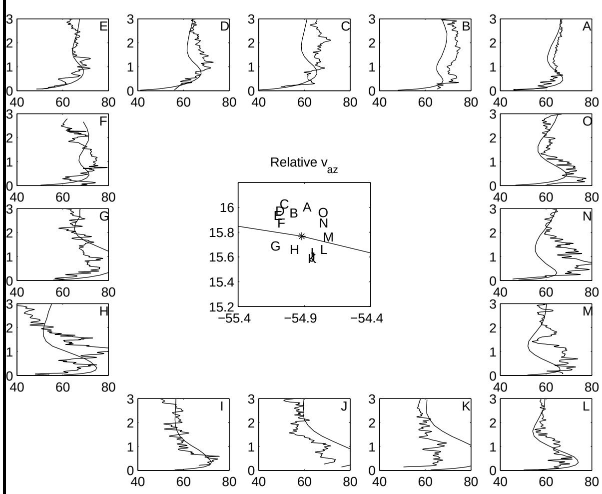

Fig 3: Hurricane Georges observed (rough) and modelled (smooth) profiles of storm-relative azimuthal wind. Winds in m/s, heights in km.