14D.4 DOPPLER PROFILER AND RADAR OBSERVATIONS OF BOUNDARY LAYER VARIABILITY DURING THE LANDFALL OF TS GABRIELLE

Kevin R. Knupp and Justin Walters

Department of Atmospheric Science, University of Alabama in Huntsville, National Space Science and Technology Center, Huntsville, AL

Michael Biggerstaff

School of Meteorology, University of Oklahoma Norman, OK

1. Introduction

On 14 September 2001 Tropical Storm Gabrielle underwent rapid transformation during landfall on the west Florida coast near Venice. The observations presented in this paper provide details on the spatial/temporal variability in boundary layer (BL) structure that occurred near the coast line around the time of landfall.

2. Instrumentation

The SMART-R and MIPS set up near the Venice airport (along the Florida west coast) at 0235 and 0400 UTC (respectively) at locations ~1 km apart. The MIPS site was located ~100 m from the coast line. The primary MIPS instrument used in this paper is the 915 MHz wind profiler, which sampled to about 11 km AGL. The SMART-R, located 70 km south of the Tampa Bay WSR-88D radar, scanned primarily full volume (360 deg) scans continuously from 0.8° to 19-42°.

3. Surface characteristics and horizontal variability

3.1 Cool surface air

A prolonged production of cool surface air was promoted by evaporation of stratiform precipitation that began about 18 h before landfall. Light to heavy rainfall promoted mesoscale downdrafts, very cool surface temperatures (21-23 °C), low values of θ_e (342-345 K), and a stable BL during a prolonged period of off-shore flow.

3.2 Boundaries

Frontogenesis was achieved within the BL as the cold off shore airflow moved westward over the warm coastal waters. This promoted a surface heat flux of 50-100 W m^{-2} and a mesoscale temperature gradient that was apparently enhanced by the convergent flow within the core of Gabrielle. The warm front was a significant BL feature, as vertical wind profiles exhibited considerable temporal variability within the frontal zone. A sequence of 5 tornadoes was associated with relatively intense deep convection that appeared to be anchored to the warm front 30-50 km southeast of the MIPS.

4. Boundary layer structure and variability

3-D airflow properties of the BL within the coastal zone were determined from MIPS and SMART-R observations. Analyses of horizontal flow isotachs are presented within a vertical plane whose orientation was determined by the 915 MHz profiler mean wind direction within the lowest 600 m. The horizontal wind V_h was determined from SMART-R radial velocity (V_r) using

$$V_h = \frac{V_r - V_T \sin\alpha}{\cos\alpha},$$

where α is the radar elevation angle and V_T is the hydrometeor terminal fall speed (weighted by reflectivity factor) obtained from 915 MHz profiler measurements at vertical incidence around the time of the scanning Doppler radar observations.

3.1 Stable off shore flow boundary layer

During this stable regime surface flow was ENE, veering to SE above 1 km AGL, and cool, nearly saturated surface conditions prevailed. Over the region within 50 km of the MIPS, the stratiform rain rate (15 min average) was locally heavy, up to 23 mm h^{-1}. Even though the BL was stable, considerable temporal variability in wind profiles were apparently tied to gravity waves whose presence is supported by surface pressure oscillations and waves in animations of Z patterns.

The combined Doppler radar and 915 MHz wind profiler analysis, valid for 0550-0600 UTC, is shown in Fig. 1. Figure 1a presents isotachs of the horizontal airflow component within the vertical plane along the mean wind direction over the lowest 500 m. Profiles at the five locations identified in Fig. 1a are plotted in Fig. 1b. In view of the temporal variability at the MIPS location, the spatial variability at this time appears to be dictated primarily by changes in surface characteristics. With the exception of profile E10, wind profiles are remarkably similar above the BL (0.6 km). The flow is jet-like and appears to behave like a density current, consistent the inference that this is an outflow maintained partly by mesoscale downdrafts over the peninsula. Over land (right half of Fig. 1a), considerably more vertical shear is analyzed at levels below the wind maximum (jet) located near 600 m AGL. Small shear values exist over the water beyond 10 km from the coast line. Over water, the BL flow accelerated to the west and the jet descended to a lower level of about 300 m. The jet was less pronounced 10 km offshore (W10), presumably from (i) increased turbulent mixing induced by surface heat fluxes (about 60 W m^{-2}) which promoted an unstable BL; and (ii) stronger flow over the lowest 200 m, resulting from decreased momentum flux over the water. The acceleration in airflow over the lowest 400 m is most substantial within about 5 km of the coastline, i.e., the BL appears to adjust to new surface properties from land to water (decreased friction, increased surface sensible and latent heat fluxes) over a total path length of about 10 km centered on the coastline. The BL transition and flow acceleration occurs on land before the air moves over the water. This is clearly shown in the 915 wind profile, which displays a jet maximum value, and jet height, roughly intermediate between the measured values 5 km over land (E5) and 5 km over water (W5).

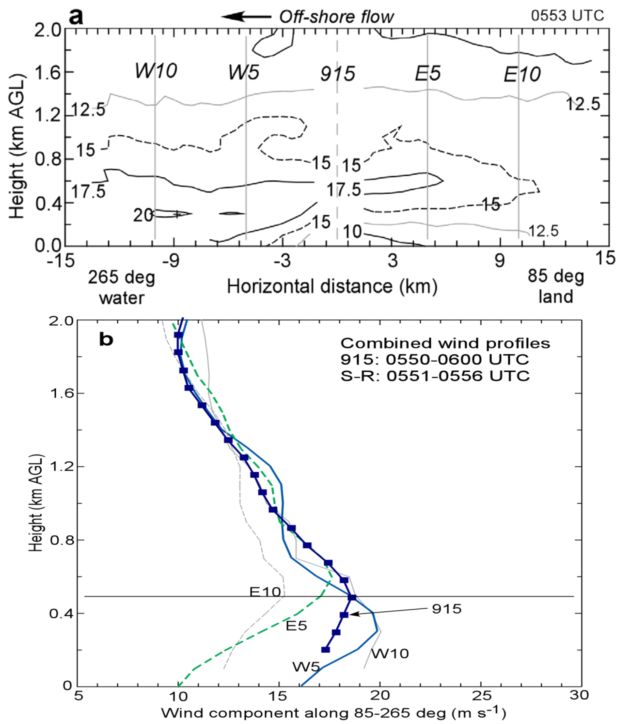

Fig. 1. (a) Isotach analysis of the horizontal velocity component within the vertical plan that passes over the SMART-R and MIPS along the direction 265-85 degrees, roughly parallel to the wind direction at 400 m AGL. Contours are labeled in m s^{-1}. W10, W5, E5, and E10 represent locations of vertical profiles of this wind component, plotted in panel b. 915 represents the location of the wind component within this plane derived from the MIPS 915 MHz profiler. (b) Vertical profiles of the wind component analyzed in panel a. The 915 MHz wind profile represents a 10 min average.

3.2 On-shore flow boundary layer

Measurements of the BL during relatively strong on-shore flow conditions at 1355 UTC were acquired during a break in precipitation just north of a shallow rainband. The mean wind direction in the lowest 600 m was from about 320 deg over the water, with some cyclonic turning towards 125 deg over land southeast of the radar. Figure 2a displays the horizontal wind component within this plane, and Fig. 2b shows profiles at the locations indicated in Fig. 2a. The key points include the following:

a) Over the width of this domain, a general flow deceleration is most significant at low levels, and even apparent within the 1-2 km layer, i.e., above the BL.

b) The deceleration in low-level onshore flow begins over water, about 5 km upwind of the coast line. This produces a greater vertical shear over land, consistent with common knowledge.

c) Within the lowest 200 m over land, a variation in wind speed suggests the presence of large eddies in the BL. Although the flow is more uniform over the water, we note that streaks in radial velocity, approximately aligned with the flow direction, were prominent in V_r fields over water. Such longitudinal streaks are common in landfalling TCs (Wurman and Winslow 1998).

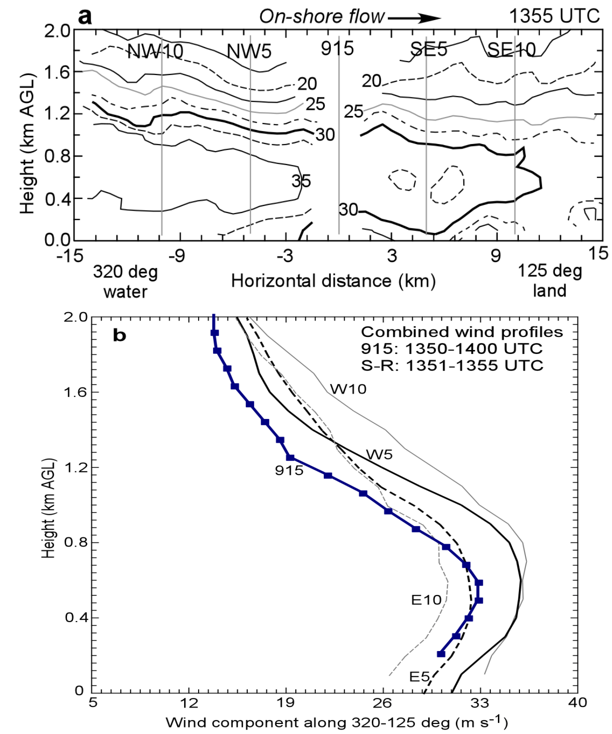

Fig. 2. As in Fig. 1except for 1355 UTC. In panel a, the vertical plane is oriented along 320 deg on the water side, and along 125 deg on the land side.

d) The BL height is not well defined by the isotachs. The jet axis (Fig. 2a) appears to descend from 800 m over the water to 500-600 m over land.

e) Interestingly, the vertical shear above the jet over water is about 50% greater than that over land.

One unexpected finding is the descent of the jet from water to land. This behavior is counter intuitive to the perceived deepening of the BL from increased friction and momentum transport over land.

The observed acceleration upstream from the coastline is a feature common to both off-shore and on-shore BL flows. For the off-shore case, this acceleration begins over land, while for the onshore flow the deceleration begins several kilometers over the water. In each case, it appears that the flow (and BL) begins to adjust to new surface conditions prior to air crossing the coastline.

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