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RADAR- AND MODEL-DERIVED MASS CONVERGENCE PROFILES OF A SEA-BREEZE CIRCULATION ALONG A COMPLEX COASTLINE

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1. INTRODUCTION

Sea breezes are perhaps the most widely recognized, and among the most studied examples of density currents in the atmosphere. In general, much of what is known about the vertical structure of sea-breeze (hereafter SB) circulations has been provided by two-dimensional modeling and theoretical efforts that have disregarded the intricate three-dimensional flow structure that is produced along regions of complex coastline. Studies of SB structure have generally used the term “return flow” to describe that part of the SB that is returned toward the ocean above the SB inflow. The structure, strength, and, under certain conditions, the existence of the SB return flow remains controversial. With few exceptions, observational studies of SB circulations have been unable to provide the comprehensive analyses necessary to evaluate model results and examine the SB return flow because of limited data available above the surface. Our study addresses these unresolved issues using dual-Doppler radar measurements collected during the Convection and Precipitation Electrification (CaPE) experiment in combination with idealized three-dimensional model simulations to examine the vertical structure and strength of the SB inflow and return flow.

2. RADAR DATA and MESOSCALE MODEL

The dual-Doppler radar measurements used in this study were collected by the National Center for Atmospheric Research (NCAR) CP3 and CP4 5-cm wavelength radars during CaPE in the vicinity of Cape Canaveral, Florida. Figure 1 shows the location of our 150-km^2 radar analyses region behind the SB front on 26 July 1991. The radar analysis region was 15×10 km with a horizontal grid spacing of 250 m and a vertical grid spacing of 200 m. Dual-Doppler syntheses of the horizontal winds were performed using the NCAR Custom Editing and Display of Reduced Information in Cartesian space program (CEDRIC, Mohr et al. 1986).

The Colorado State University Mesoscale Model (CSUMM) used for this study is a three-dimensional, hydrostatic, incompressible, primitive-equation model (e.g., Pielke 1974). Simulations were performed using flat topography and a sinusoidal coast to provide an idealized framework similar to the coastal region near Cape Canaveral. The model simulations were performed on a $76 \times 76 \times 29$ grid with horizontal grid spacing of 10 km and 18 levels below 2 km. The model requires input of vertical profiles of temperature, specific humidity, and wind. The 1600 UTC CaPE sounding at Orlando, FL on 26 July was used to initialize the model and provide the synoptic environment. A sea surface temperature of 292 K was prescribed based on buoy data collected offshore of Cape Canaveral.

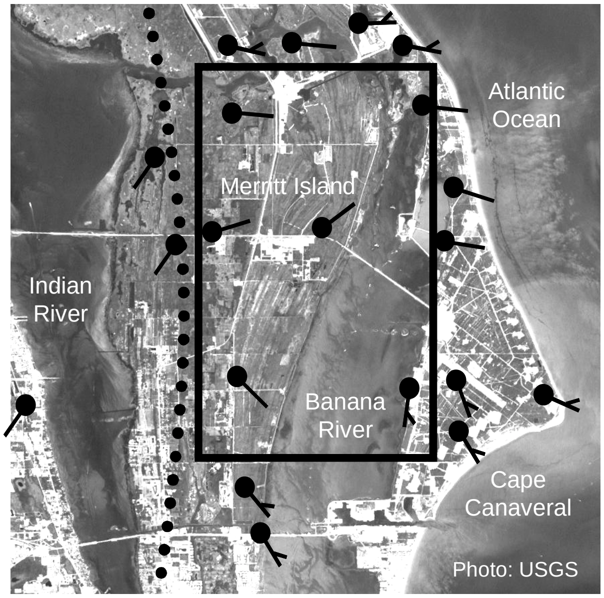

Fig. 1 Dual-Doppler analysis region (rectangle). Sea breeze location at 1824-1834 UTC (dotted line) on 26 July. Surface winds also shown. Short barb corresponds to 5-10 m s^{-1}.

3. RADAR MASS CONVERGENCE PROFILES

Previous observational studies have generally been unable to quantify the depth and magnitude of SB return flows because they are often weak perturbations within a synoptic flow having a significant shore-perpendicular component. Calculations of horizontal mass convergence at several levels within the SB inflow and return flow were determined using dual-Doppler radar and surface wind fields (NCAR PAM & KSC mesonet) and allowed for a removal of the synoptic flow (SSW at ~ 4 m s^{-1} on 26 July).

The SB front was the strongest boundary-layer feature evident in the region during the early afternoon. Surface and radar data indicated the SB inflow was nearly perpendicular to the orientation of the coastline

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and resulted in a SB front that was roughly parallel to the Atlantic coastline (Fig. 1). Dual-Doppler analyses indicated the depth of SB inflow was generally 400 m, except in local regions (Laird et al. 1995).

Synthesized wind fields from four radar volumes during the period 1824-1834 UTC were used to calculate mass convergence profiles. Horizontal winds behind the SB front were retrieved from 0.4-2.0 km height and were supplemented with surface wind measurements obtained by the high spatial resolution mesonet. Dual-Doppler winds at each 0.2 km level were used to calculate the mass flux ($U \cdot \Delta z \cdot \rho \cdot L$) through the boundaries of the analysis region, where U is the average wind component perpendicular to a side, L is the length of a side, Δz is the vertical spacing of the dual-Doppler analysis, and ρ is the density of air. The low level (< 0.4 km) mass convergence due to the SB inflow was determined using surface winds and distributed equally within the layer below 0.4 km, since dual-Doppler winds could not be retrieved in this layer. The analysis region was located directly behind the SB front to allow the SB inflow to be represented by the low-level mass convergence and SB return flow as the mass divergence at higher levels.

Figure 2 shows the temporally-averaged north-south (*n-s*), east-west (*e-w*), total, and vertically cumulative (*cum*) mass convergence profiles for the period 1824-1834 UTC. Nearly equivalent low-level *n-s* and *e-w* mass convergence existed due to the complex coastline and natural region of convergence that develops within the SB inflow over Cape Canaveral (Laird et al. 1995). Examination of the total and vertically cumulative mass convergence in Fig. 2 shows, with the ambient flow removed, the mass convergent SB inflow below 0.4 km was compensated by a weaker mass divergent SB return flow (0.4-2.0 km) nearly four times the SB inflow depth.

4. MODEL MASS CONVERGENCE PROFILES

Our model simulations of a SB developing along a complex (sinusoidal) coastline capture the primary characteristics of the flow exhibited in the observed radar and surface wind fields on 26 July 1991. Figure 3 shows the simulated vertical motion and low-level wind fields for a developed SB. Mass convergence profiles were developed from the model data for seven regions along the idealized coastline. An area roughly corresponding to our data analysis region (Fig. 1) showed good agreement with the observed average mass convergence profile retrieved from the CaPE dual-Doppler analyses. Simulated mass convergence profiles and kinematic fields in other regions along the idealized coastline indicate noteworthy variations in the depth of the SB inflow and return flow. These variations are related to the complex SB inflow winds (Fig. 3) and the development of coastline-shape-induced regions of convergence and divergence throughout the depth of the SB. Our poster presentation will include further discussion of these variations in the SB inflow and return flow and their potential impact on regions for storm development.

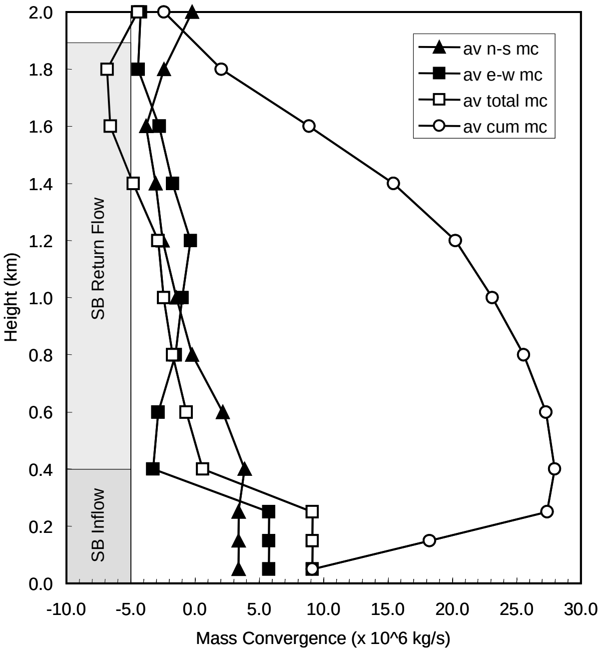

Fig. 2 Radar-derived average mass convergence profiles for 1824-1834 UTC on 26 July 1991 in analysis region (Fig. 1).

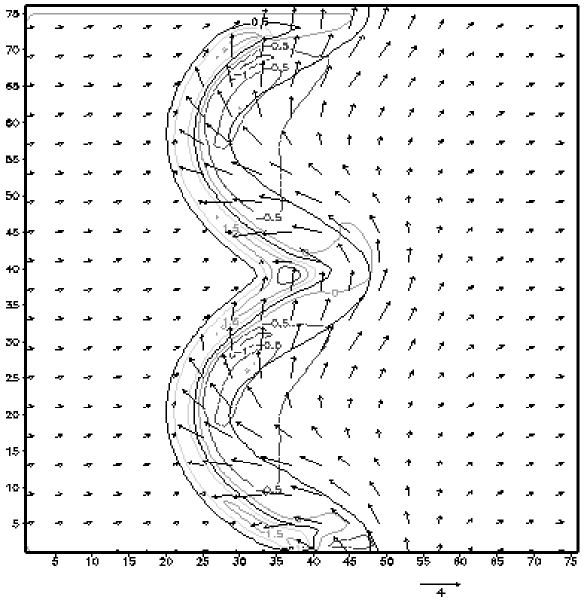

Fig. 3 Simulated 10-m wind and 250-m vertical velocity fields.

6. REFERENCES

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