

Matthew D. Eastin*

Colorado State University, Fort Collins, Colorado

1. INTRODUCTION

Moist convection has long been recognized to play a crucial role in the evolution of hurricanes, but the role of particular forcing mechanisms, such as buoyancy, during the hurricane's evolution are not well understood. Malkus and Riehl (1960) first argued that a few isolated buoyant "hot towers" were required to explain the low surface pressures. Emanuel (1986) argues that buoyancy plays a secondary role to air-sea thermodynamic instabilities in hurricane maintenance. Ooyama (1982) argues that buoyant convection is required during intensification to import high angular momentum air above the friction layer. Gray (1997) argues that substantial buoyancy is required for both maintenance and intensification. These arguments have been made with minimal *direct* observational support. Accurate in situ thermodynamic data near convection is difficult to obtain via aircraft due to possible instrument wetting errors that produce erroneously cool(warm) temperatures(dewpoints) on the order of 2-5°C. Eastin (1999) utilized a radiometer to construct a large radial leg database with accurate flight-level temperatures in hurricane inner-core convection. This database is used to provide the first reliable estimates of parcel buoyancy in convective cores of hurricane eyewalls and rainbands.

2. DATA AND METHODOLOGY

The flight-level data used in this study consists of 553 radial legs obtained from 25 hurricanes at levels ranging from 850 to 500 mb. Each radial leg consists of storm-relative observations of three-dimensional winds in cylindrical coordinates, temperature, dew-point, geopotential height, cloud water content, and the aircraft location, partitioned in 0.5 km bins. The thermodynamic data was further processed according to Eastin (1999) to remove instrument wetting errors.

Vertical velocity biases were removed from each radial leg. Following Jorgenson et al. (1985) (hereafter referred to as JZL) convective updraft and downdraft cores defined as having $|w| > 1$ m/s for 0.5 km were then identified. Cores were designated in the eyewall if they were located within 20 km of the radius of maximum wind (RMW). Cores outside (inside) RMW+20 are designated rainband (not con-

sidered). The altitude, average vertical velocity (\bar{w}), maximum vertical velocity (w_{max}), diameter (D), average cloud water content (q_c), and virtual potential temperature deviation ($\Delta\theta_v$) from the local environment at w_{max} (i.e. buoyancy) were tabulated for each core.

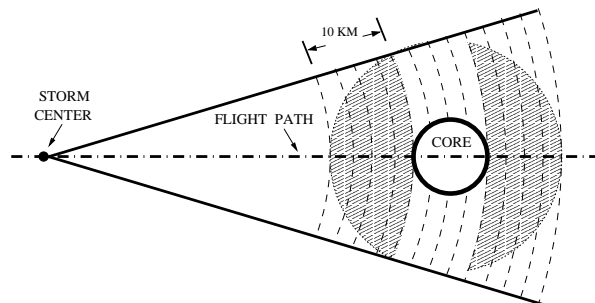


Figure 1: Schematic diagram of a core and its environment (hatched area).

Each core's environment is calculated *locally* using a method believed to best represent the environment of a parcel rising within, but offset from the center of, an axisymmetric thermal field (i.e a hurricane). It seems reasonable to assume that the local environment of an air parcel within a larger body of air can be represented by an annulus about that parcel, without assuming geometry for the larger air body. Analogously, the local environment of each core can be represented as a 10 km wide annulus about the core without assuming geometry for the updraft or downdraft. Thus, the core environment can be estimated from the radial leg data as an area-weighted average θ_v adjacent to the core but within the local 10 km annulus (Fig. 1). The environmental θ_v is thus weighted toward values radially *outside* the core. The method also assumes that the radial leg θ_v profiles is representative of a locally axisymmetric θ_v field.

Pilots rarely maneuver in flight to avoid or penetrate convection. Thus, there is an equal likelihood of penetrating convection at any given stage, and the identified cores are believed to be representative of hurricane convection on a statistical basis. JZL showed that not penetrating the center of a circular core can result in w_{max} and \bar{w} being biased too low by a factor of 2. To the extent that $\Delta\theta_v$ and w are directly correlated, $\Delta\theta_v$ may also be biased too low by a factor of 2. The 2 km running filter applied during initial radial leg processing may further bias values too low.

* *Corresponding Author Address:* Matthew D. Eastin, Department of Atmospheric Science, Colorado State University, Fort Collins, CO 80523; e-mail: eastin@mpi.atmos.colostate.edu

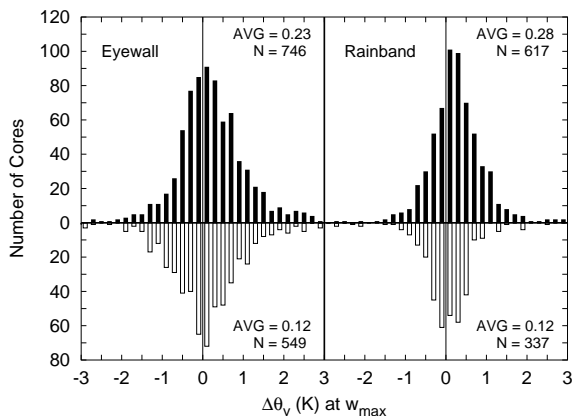


Figure 2: Distribution of $\Delta\theta_v$ at w_{max} for updraft (solid) and downdraft (open) cores at all levels in eyewall and rainband regions.

3. RESULTS AND DISCUSSION

The distributions of \bar{w} , w_{max} , and D (not shown) were well represented as straight lines on log-normal probability plots, in agreement with JZL. Distributions of $\Delta\theta_v$ are nearly normal (Fig. 2). The $\Delta\theta_v$ distribution means are *positive* for both updrafts and *downdrafts* in eyewalls and rainbands. The means are statistically significant at the 95% level or higher. The mean $\Delta\theta_v$ for eyewall (rainband) updraft cores is 0.23 K (0.28 K) but over 20% (10%) of the cores have $\Delta\theta_v > 1.0$ K. These values are comparable in magnitude to oceanic convection elsewhere within the tropics (e.g. Jorgenson and LeMone 1989). The distribution median and upper 10% level (>90% of the population) values of w_{max} and $\Delta\theta_v$, plotted as a function of height (Fig. 3), indicate that positive $\Delta\theta_v$ is commonly found within hurricane inner-core updrafts at lower to middle levels, and updrafts tend to increase in magnitude with height (i.e. accelerate).

Parcel theory predicts that in the absence of entrainment, water-loading, and non-hydrostatic pressure forces a $\Delta\theta_v$ of only 0.2 K will accelerate a stationary parcel to 8 m/s over 5 km. Only the upper 10% of eyewall updrafts attain 8 m/s. Jorgenson and LeMone (1989) argued that water-loading significantly prevents buoyant updrafts in tropical convection from achieving w expected from parcel theory. A liquid water content (LWC) of 0.6 g/kg (3.0 g/kg) is required to reduce a $\Delta\theta_v$ of 0.2 K (1.0 K) to zero. With LWC rarely > 3.0 g/kg in hurricanes (Ackerman 1963), mean $q_c \simeq 0.5$ g/kg, and LWC maxima located in downdrafts (Black and Hallett 1986), buoyant updraft cores are *common* in eyewalls and rainbands, despite the presence of liquid water.

Entrainment acts to decay isolated buoyant updrafts. However, in hurricanes entrainment imports high angular momentum air above the frictional inflow layer that can be used to spin-up the vortex and maintain it against frictional spin-down. Fur-

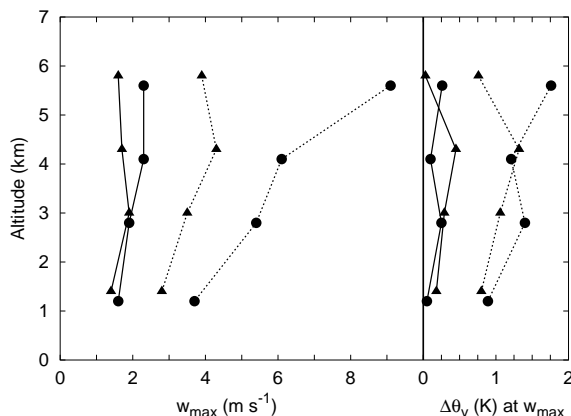


Figure 3: Variation with altitude of the median (solid) and upper 10% level (dashed) values of w_{max} and $\Delta\theta_v$ for eyewall (circle) and rainband (triangle) updrafts.

thermore, an average updraft with $q_c \simeq 0.5$ g/kg will acquire an additional 0.3 K of $\Delta\theta_v$ upon passing the 0°C level due to freezing. This " $\Delta\theta_v$ input" can help sustain the buoyant updraft against entrainment and further spin-up the hurricane. Therefore, the presented results and simple entrainment arguments suggest that buoyancy may play a *primary* role in hurricane evolution and maintenance.

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