4B.7 VERTICAL TRANSPORT OF MOMENTUM WITHIN AND SURROUNDING ISOLATED CUMULUS CLOUDS

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1. INTRODUCTION

Numerical models indicate that the inclusion of shallow convection can increase the accuracy of simulated mean tropical circulations. However, model convection is based on conceptual and theoretical models often developed without the aid of detailed observations. Since cumulus clouds exist in large fields over the tropical oceans and land, it is vital to understand how these small clouds transport momentum and what effects they have on the environmental wind profile. Currently, there is no observational study of how vertical momentum transports evolve in small cumulus clouds.

Organized cumulus convection, in the form of squall lines and mesoscale convective complexes, are observed to alter the shear within the vertical wind profiles by way of large momentum transports induced by the storm circulation. Tropical squall lines (LeMone et al., 1984) transport line normal momentum up the shear gradient, acting to increase the environmental vertical wind shear. Non-linear convective complexes (Wu and Yanai, 1994) transport momentum down gradient, acting to reduce the vertical wind shear.

However, at the smaller scales, little is known about the vertical transport of momentum within "ordinary" isolated cumulus clouds. This is the result of the limitations of past observing platforms and the difficulty in obtaining detailed observations from clouds that evolve and decay on short time scales (8-20 min). Consequently, previous studies describing aspects of cumulus cloud lifecycles (e.g., Warner 1977, and Barnes 1995) are limited to sampling one altitude numerous times, or one pass each, at varying altitudes.

The Convection and Precipitation/ Electrification Experiment (CaPE), conducted during the summer of 1991 near Cape Canaveral, offers the opportunity to probe clouds with two highly maneuverable, well-equipped King Air aircraft, both of which execute coordinated patterns for a nearly simultaneous penetration of a cloud at different altitudes. This allows for a detailed analysis of the vertical transports of momentum within and surrounding the cloud as a function of the cloud's lifecycle.

2. DATA AND SAMPLING STRATEGY

We are currently studying a subset of 14 clouds, sampled from July 18 to August 10 of 1991,encompassing 149 aircraft penetrations. The aircraft data are supported by an upper-air sounding network of 10 stations as well as an automated surface mesonet comprised of 47 stations to aid in the determination of the environmental stability and surface forcing in the region of cloud development.

The aircraft sampled the clouds using either a rosette or bow-tie pattern. The rosette pattern allows sampling on all sides of the cloud, enabling the determination of fields normal and parallel to the mean wind. The bow-tie pattern would essentially retrace and sample the same track through the target cloud.

The cloud edges are determined using the forward-scattering spectrometer probe (FSSP), which is designed to measure the smallest particles (0.5-47 μm). More information on the CaPE dataset and sampling strategies can be found in Barnes et al. 1996.

3. Goals

We will present trends in the vertical transport of momentum as a function of cloud lifecycle along with comparisons between the aircraft levels. Findings will be discussed in light of the previous work on various conceptual models of cloud growth and mixing. Relationships between vertical velocity, liquid water content, wind speed and cloud mass flux will be explored.

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We will address the following issues:

1) Do updrafts (downdrafts) preferentially transport lower (higher) momentum air?
2) How would the diagnosed momentum transports change the environmental shear?
3) Does the magnitude of the momentum transfer increase or decrease with height or age of cloud?
4) Does the transfer of momentum within the cloud yield important evidence, which leads one to support or reject any of the conceptual models for cumulus?

4. PRELIMINARY RESULTS

Starting with the application of perturbation theory, the kinematic variables of each aircraft pass are separated into a mean and an eddy component. Segments of the aircraft pass are selectively sampled to determine cloud mean and updraft and downdraft mean values of momentum transports. FSSP measurements define cloud edges and in-cloud vertical velocity measurements define the updrafts and downdrafts. Assuming a circular cloud based on observations by Barnes (1995) and Barnes et al. (1996), cloud area averaged mean and eddy momentum fluxes are calculated for each pass.

Small cumulus clouds are believed to function as mixers. In an environment where winds increase with height, an upward (positive) mass flux ($\overline{\rho w}$) would indicate a negative eddy momentum flux ($\overline{\rho}\overline{u'w'}$). Figure 1, shows the u-component eddy momentum flux curves for the upper and lower aircraft during the lifecycle of one intriguing cloud. The wind profile for this cloud's environment is one of winds increasing gradually upward. Wind shear from cloud base to the upper aircraft altitude is a modest 1.2 X 10^{-3} s^{-1}. The evolution of cloud mean vertical velocities indicate updrafts dominate the first pass at both upper and lower aircraft altitudes (1.77 and 1.07 m s^{-1} respectively) transitioning to mean downdrafts by the third pass that last until dissipation. Both peak updrafts and downdrafts are stronger at the upper aircraft level. The cloud area averaged eddy momentum fluxes show an oscillating pattern.

Eddy fluxes are initially positive at both levels indicating updrafts are carrying higher momentum air. By the third pass, where both levels measure downward vertical velocities, the lower aircraft is capturing lower *u*-momentum air while the upper aircraft continues to measure higher *u*-momentum air. By pass four, the lower aircraft records downdrafts with an increase in the u-component perturbations resulting in a negative eddy flux. Upon first inspection, this cloud does not function as a mixer, the eddy fluxes are mostly acting to increase the local shear. Further investigation of individual up and downdraft characteristics, as well as analysis of other clouds will determine if the momentum transports for this cloud are typical.

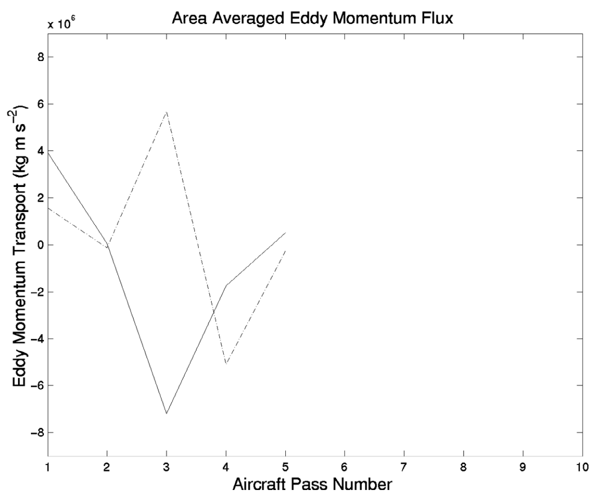

Figure 1. The cloud area averaged eddy momentum flux for cloud 10 sampled July 26, 1991. The upper aircraft (solid) and lower aircraft (dash-dot) are separated vertically by a distance of 900 m.

5. REFERENCES

Barnes, G.M., 1995: Updraft evolution: A perspective from cloud base. *Mon. Wea. Rev.,* **123,** 2693-2715.

Barnes, G.M., J. C. Fankhauser, and W. D. Browning, 1996: Evolution of the vertical mass flux and diagnosed net lateral mixing in isolated convective clouds. *Mon. Wea. Rev.*, **124**, 2764- 2784.

LeMone, M. A., G. M. Barnes, and E.J. Zipser, 1984: Momentum flux by lines of cumulonimbus over the tropical oceans. *J. Atmos. Sci.*, **41**, 1914-1932.

Warner, J., 1977: Time variation of updraft and water content in small cumulus clouds. *J. Atmos. Sci.*, **34**, 1306-1312.

Wu, X and M. Yanai, 1994: Effects of vertical wind shear on the cumulus a transport of momentum: observations and parameterization. *J. Atmos. Sci.*, **51**, 1640-1660