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LIDAR OBSERVATIONS AND MODELING OF COLD AIR OUTBREAKS DURING MASEX AND GALE

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As part of MASEX (1983) and GALE (1986) a number of research flights were carried out over the Marine Boundary Layer (MBL) during periods when extremely cold and dry continental air was flowing out over the warm costal waters at the east coast of the United States. Such periods, which are named "cold air outbreaks," are characterized by massive warming and moistening of the MBL resulting in rapid entrainment conditions. As the MBL deepens as a function of fetch over the ocean, clouds develop. The line of cloud formation typically follows the coast line closely as has been observed many times from satellite imagery.

The backscatter data from the NASA Goddard airborne lidar (Nd:YAG, 10 Hz repetition rate, 200 mJ/pulse), which was used to measure the depth of the MBL in great detail, is ideally suited to verify parameterized models of boundary layer growth rate. The data indicates that the deepening MBL gradually develops clouds at its top. Those clouds form an integral part of the MBL and exercise an important influence on the energy cycle within the MBL. First, clouds are only present at the tops of the largest overshooting domes. Later, as the cloud cover increases they expand into the down draft region at the side of the convective domes.

Figure 1 shows a typical flight line of lidar MBL-depth data. The lidar (mounted in the NASA/Electra) was operated in the downward pointing mode at a nominal altitude of 3 km. The picture indicates a distinct increase in local variance of MBL-depth at those times when clouds fill the upper region of the MBL. This could be related to the idea that local production of buoyancy in the presence of clouds introduces a turbulence length scale much smaller than the typical sizes of overshooting convective cells.

Figure 2 shows a map of one research flight over the Atlantic Ocean near Cape Hatteras, North Carolina. In the overcast region the MBL-depth was increasing at a much more rapid rate than in the clear and partly cloudy regions. We performed tests of models specifically developed to study boundary layer evolution during clear and cloudy conditions. One of the models was developed by Stage and Businger (1981, abbreviated as SB), the other by Randall (1980, abbreviated as RA). The two models are identical for clear conditions but differ significantly in parameterizations under cloudy conditions. Figure 3 shows the predictions of MBL-depth for the eastern part of the experimental area. The results from both models do not differ much from one another, even in the presence of clouds. However, both models clearly underpredict the MBL-growth rate in overcast conditions. Since all external conditions should remain the same as the transition from clear to cloudy sky takes place this result gives some important insights into the entrainment mechanism.

We suggest that the rapid entrainment observed during overcast conditions represents an increase in efficiency of conversion of available turbulence kinetic energy into entrainment energy. For SB and RA models this efficiency factor is represented by one model coefficient which has been experimentally determined to be constant around 0.2. There are, however, good arguments to support the idea that under certain conditions this efficiency factor will increase. The formation of large-scale convective rolls, which satellite imagery shows to be present in the form of cloud streets, could effectively organize the upward transport of turbulent kinetic energy. Additional model tests to be presented during the talk suggest an increase of the efficiency factor to .7 to .9 could account for the observed entrainment rate.

References

Randall, D. A., 1980: Entrainment into a stratocumulus layer with distribution relative cooling. J. Atmos. Sci., 37, 148.

Stage, S. A. and G. A. Businger, 1981: A model for entrainment into a cloud topped marine boundary layer during a cold air outbreak, Part I. J. Atmos. Sci., 38, 2213-2229.

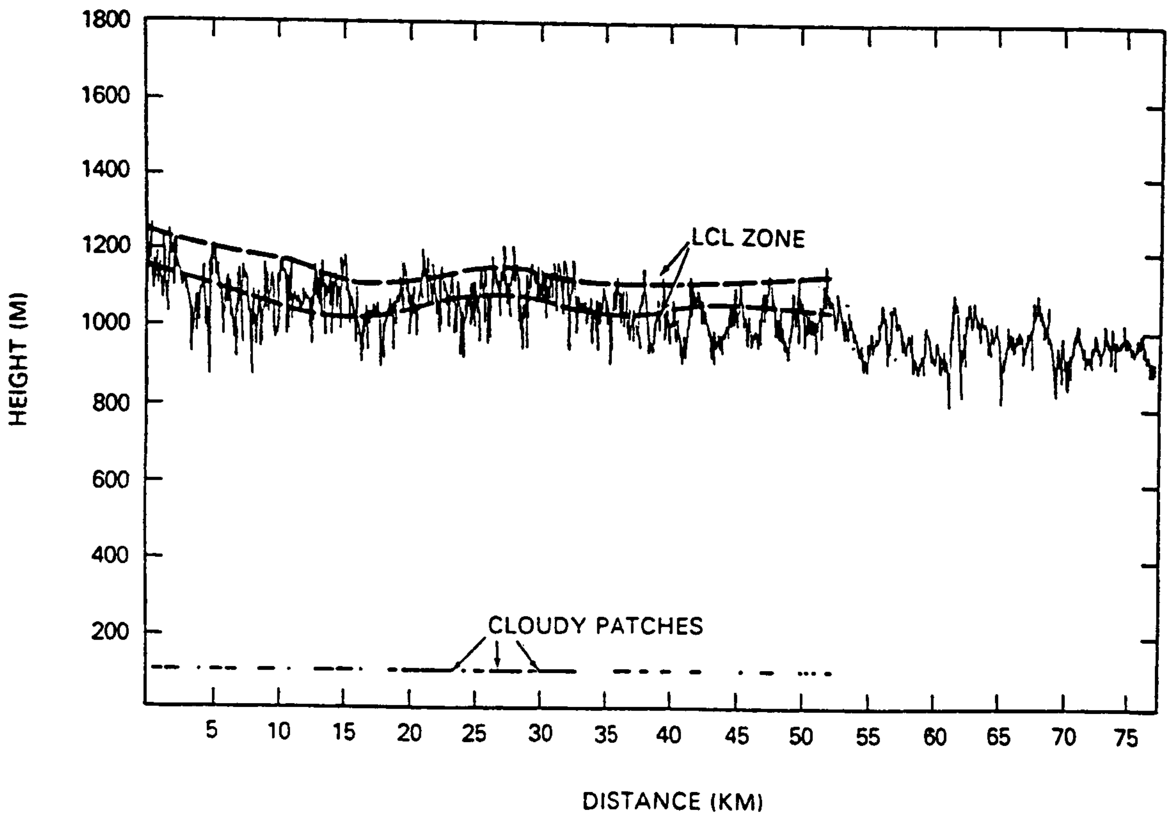

Figure 1. MBL-depth as function of distance in partly cloudy region. Broken horizontal line at bottom indicates clouds.

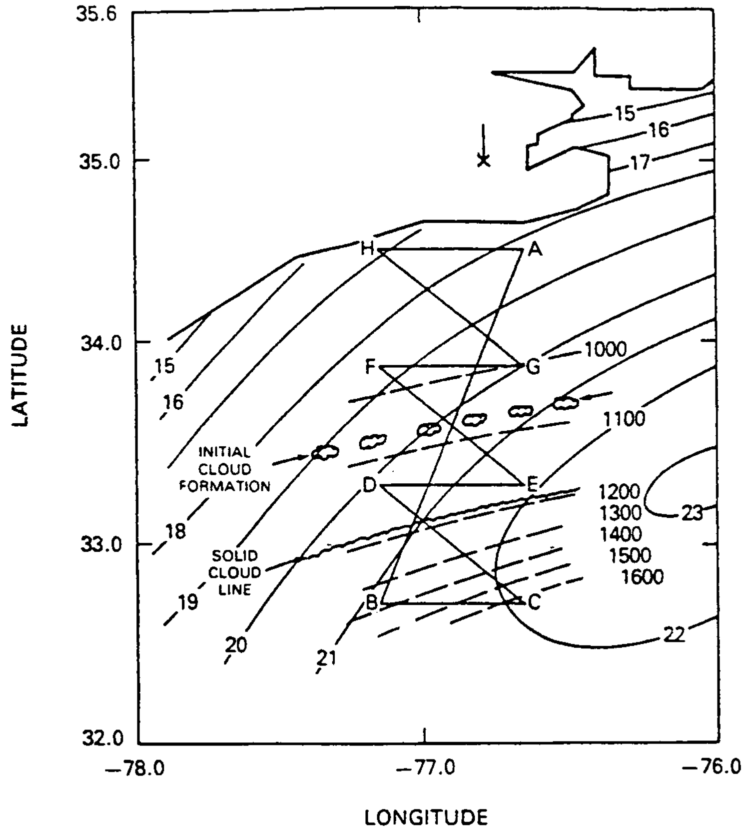

Figure 2. Map of flight near Cape Hatteras, North Carolina, on January 19, 1983. Way points are alphabetically ordered. Sea surface temperatures MBL-depth isopleths and cloud formation are indicated on the plot.

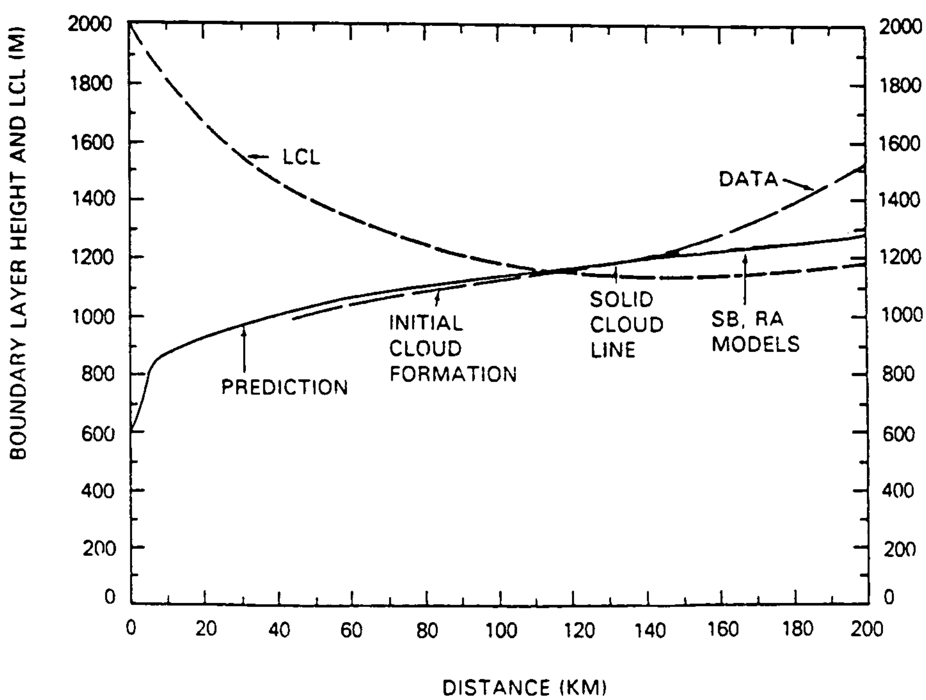

Figure 3. Model prediction and MBL-depth data as function of fetch.