Size Distributions of Boundary-Layer Clouds

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Cumulus Triggering by Surface-Layer Thermals

Scattered fair-weather cumulus clouds are triggered by thermals rising from the surface layer. Not all surface-layer air is buoyant enough to rise. Also, each thermal has different humidities and temperatures, resulting in inter-thermal variability of their lifting condensation levels (LCL). Thus, even some of the rising thermals might not rise high enough to trigger clouds (Figure 1).

For each air parcel in the surface layer, its virtual potential temperature θv and its LCL height z_{LCL} can be computed.

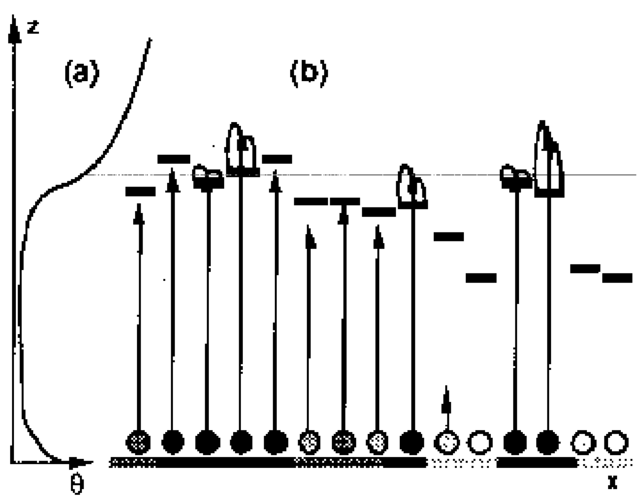

Figure 1. Heterogeneous land use, illustrated with the black and gray line segments at the bottom, cause turbulent temperature fluctuations in the surface-layer air, illustrated with air parcels of different shading. These parcels rise to their level of neutral buoyancy, shown by the vertical arrows. Moisture also varies from parcel to parcel, causing corresponding fluctuations in the height of the lifting condensation level (LCL), shown by the black horizontal dashes. Those parcels that rise above their own LCL can create cumulus clouds.

These variables measure the potential for a parcel to rise, and the amount of rise needed to form a cloud. By sorting all parcels in the surface layer, a joint frequency distribution (JFD) can be computed, giving the number of air parcels having various θv and z_{LCL} values. Such a JFD is idealized with the elliptical frequency contours in Figure 2.

If the mean environmental sounding is plotted on the same JFD diagram (Figure 2), then the portion of the JFD that is to the right of the sounding indicates the fraction of thermals that can rise to form cumulus clouds. The shaded region in Figure 2 shows those air parcels that are warm enough to rise and for which their LCL is below their level of neutral buoyancy. This region gives the cloud coverage.

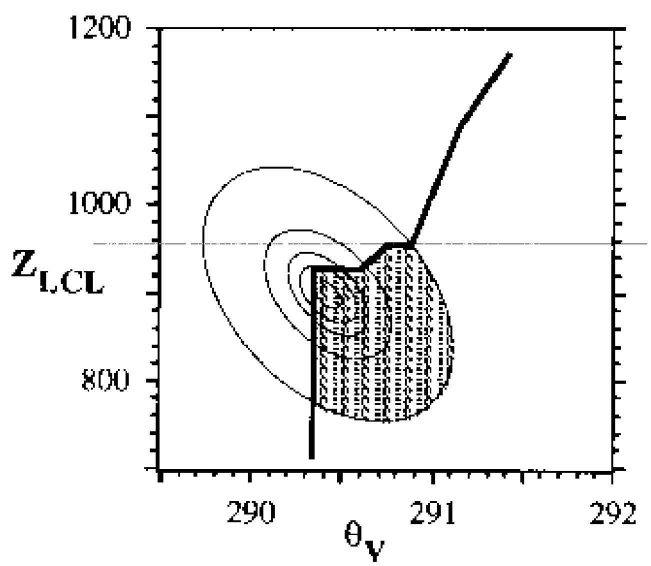

Figure 2. Idealized smooth contours represent values of constant frequency distribution of virtual potential temperature θv (K) vs Z_{LCL} (m) for surface-layer air. Superimposed as the heavy line is a plot of the mean environmental sounding of θv vs height z. Shaded region indicates those surface-layer thermals that can form cumulus.

Distributions of Cumulus Bases, Tops, and Depths

Cloud ensemble size distributions can also be determined from the joint frequency distribution. To do this, the joint distribution must be conceptually (Figure 3) divided into three sectors that represent different physics:

1. points cooler than that of the mean mixed layer (ML) temperature (extrapolated vertically across the whole figure)

2. points warmer than the mean ML temperature but which are above the sounding

3. points warmer than the ML but which are below the sounding.

As sketched in Figure 4, Sector 1 indicates the fraction of air that will not likely rise. Sector 2 contains those points that will rise from the surface layer, but which will not likely form clouds. Sector 3 contains those points that rise and form clouds. The range of cumulus base heights and top heights is marked by the starting and ending points of the diagonal arrows in Figure 4.

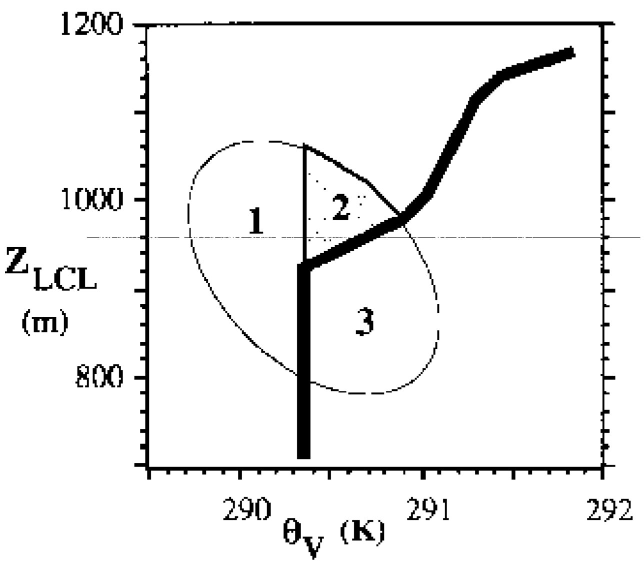

Figure 3. Three sectors of the joint frequency distribution: Sector (1) contains parcels that probably will not rise; (2) contains parcels that will rise without forming a cloud; and (3) contains parcels that will rise and form clouds.

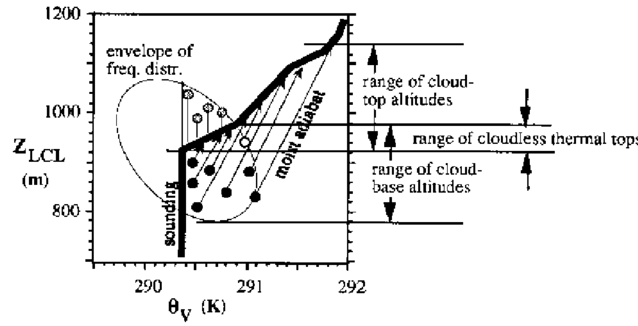

Figure 4. Parcels in Sector 2, indicated with gray shading, rise from the surface layer until they hit the sounding, without forming clouds. The other parcels, colored black, reach their LCL, and then continue rising along a moist adiabat. For many of these latter parcels, such as the one colored white, they rise without condensation past other cloud bases before reaching their own cloud base.

The set of cloud tops and bases for each parcel determines the cloud size distribution. Preliminary results from the Atmospheric Radiation Measurement Cloud and Radiation Testbed (CART) Southern Great Plains (SGP) site give a lognormal depth distribution. Case studies have been made for May 1, 1994, during the spring intensive observation period (IOP), and for July 27, 28, and 31, 1994, during the summer IOP.

Three Layers Associated with Boundary-Layer Cumulus

When the extent of buoyant rise for points from Sectors 2 and 3 of Figure 4 are plotted, taking into account rise along moist adiabats from Sector 3, the result indicates that there are three layers in the cloudy boundary layer (Figure 5). The bottom layer is the well-known sub-cloud layer, where all the updrafts are cloud-free. The top layer is the cloud layer, where all the updrafts are cloudy.

In between is an “overlap” layer, with both cloudy and cloud-free updrafts. This layer is not quite like the transition layer described by Malkus (1958) for tropical cumulus, nor is it quite like the entrainment zone described by Deardorff et al. (1980) or the LCL zone described by Wilde et al (1985). The nature of this overlap zone determines the coupling between the subcloud and cloud layers.

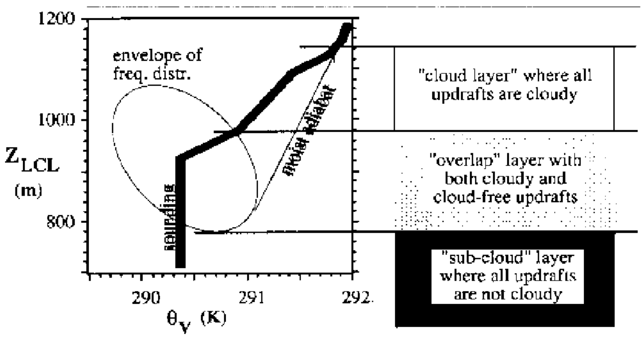

Figure 5. Three layers can be identified in the boundary layer. The cloud and subcloud layers have the conventional definitions of cloudy and non-cloudy air. The middle "overlap" layer has both cloudy and cloud-free updrafts.

For more details about these methods, see the following papers: Schrieber et al. (1996) and Berg and Stull (1996).

Planned Research

The heuristic model will continue to be refined and validated against new IOP data from the SGP CART site. As other field sites come on line, we will test our parameterization for other parts of the globe.

Daily forecasts of cloud attributes will be made by inserting this cloud parameterization scheme into an operational numerical forecast model.

During the upcoming July 1996 IOP, we propose to bring the University of Wyoming King Air aircraft to the SGP CART site to make turbulence measurements in the surface layer. These will be used to define the JFD for that area.

Acknowledgment

This research was supported by the U.S. Department of Energy under grant DE-FG02-92ER61361.

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