Observations

A CASE STUDY OF THE ACCURACY OF ROUTINE, FAIR-WEATHER CLOUD-BASE REPORTS

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ABSTRACT

Based on a field experiment conducted in Oklahoma in 1983, it is concluded that cloud base heights reported by the operational weather services are frequently inaccurate for scattered, fair-weather cumulus clouds. Lifting condensation levels (LCLs) are shown to be a better measure of cloud base heights than many of the "reported" heights. LCL estimates of cloud base should be used only locally, because of the large horizontal variability of LCLs. LCLs also vary with a diurnal cycle, starting low in the morning, rising rapidly in late morning, reaching a peak about 3 hours before local sunset, and then rapidly decreasing in the early evening.

1. INTRODUCTION

With the increased interest in cumulus-topped mixed layers, (3) there will be a greater need to gather information about cloud-base heights. Some researchers might want to rely on the cloud-base heights routinely reported by an operational weather service when studying problems such as venting of pollutants through clouds. Indeed, if the researcher has no specialized cloud-base instruments available, then routine weather-service data might be the only source of information.

Unless care is taken, it might not be appropriate to apply operational data to research needs. The purpose of this paper is to document some of the problems that can arise using operational cloud base data, and to suggest how to make the best use of existing data. A case-study approach is used to develop these suggestions.

During the 1983 Boundary Layer Experiment (BLX83) in Oklahoma, we were able to make precise cloud-base height measurements using a ground-based lidar system (4). In this paper, we will compare the cloud-base heights measured by lidar, reported by operational weather services, and calculated based on the lifting condensation level (LCL).

2. DATA SOURCE

Two disparate types of data are used in this study. One is research-quality data obtained during BLX83. The other is routine operational-quality data obtained from civilian and military weather services.

This study in not meant to be a complete climatology of cloud base information, but instead is a case study employing data from the BLX83 field experiment. The BLX83 field experiment ran from May 25 through June 18, 1983. Out of this period, not all days had fair weather, and not all fair-weather days had convective, boundary-layer clouds. The resulting set of good data days used here are June 6, 7, 10, 11, 12, 13, 14 and 17. Only convective cloud-base reports of scattered coverage are included in the data set. Days 10-12 were predominantly characterized by forced convection and strong winds, while the remaining days were predominantly free convection with light winds.

2a. RESEARCH DATA

BLX83 was designed to study the interaction between the mixed layer and fair-weather cumulus clouds over land. Chickasha, Oklahoma, was the center of the experiment, where the University of Wisconsin lidar system was deployed. A Portable Automated Mesonetwork station (PAM) was situated 3.3 km north northeast of the lidar, under the lidar scan plane. In addition, the NCAR instrumented Queen Air aircraft flew over the PAM station along the lidar plane. Details of the field experiment are reviewed by Stull and Eloranta (4).

The lidar scanned in a range-height indicator (RHI) mode, making about a 6 km long slice through the boundary layer. Within this plane, cloud-base heights could easily be observed, with an accuracy of about 25m. This accuracy was verified both by the aircraft observations, and by using a kytoon instrument platform operated by Argonne National Laboratory as a lidar target.

The PAM station measured pressure, temperature, humidity, and other variables every 5 minutes. From the temperature dew-point data, we calculated LCLs using Barnes' method (5). If measurement uncertainties of 1 mb for surface pressure, 0.25 C for temperature, and 0.5 C for dew point are assumed, then LCL uncertainties range from about 25 to 50m (6).

The PAM LCL data was observed to have a low diurnal trend, with short oscillations superimposed on it that were caused by individual convective elements. The amplitude of these oscillations was small - only about 5% of the total magnitude of the LCL height. In the following analysis, these high-frequency oscillations are filtered out using a 60-point binomial filter (6).

2b. OPERATIONAL DATA

Operational data will be used from the National Weather Service office in Oklahoma City (OKC), from Tinker Air Force Base (TIK) just east of Oklahoma City, and from the Ft. Still Army base (FSI) near Lawton, Oklahoma. Table 1 lists the locations of these sites. At each of these sites, trained weather observers make routine hourly observations. USAF Air Weather Service units make the weather observations at both Tinker and Ft. Sill.

The operational services in the United States use units of feet above ground level, rather than meters, for cloud-base observations. For this reason, both units are included in most of the diagrams and text. In fact, some of the problems associated with the operational cloud-base data examined is related to the apparent subjective rounding of cloud-base heights by observers to an integer multiple of 152 meters (500 feet).

As specified in the Federal Meteorological Handbook No. 1, Surface Observations for 1982 (7), cloud base heights can be operationally determined using ceilometer instruments, pilot reports, LCL diagrams, persistence, and estimates based on observer experience. Regardless of which method is used, the handbook specifies a cloud-base height accuracy of ± 30 meters (100 feet) for bases below 1524 meters (5000 feet), and $\pm$ 152 meters (500 feet) for bases between 1524 and 3048 meters (5,000-10,000 feet).

In addition to using the "reported" cloud-base heights from these operational weather services for our case study, we also calculated LCLs from the reported temperature and dew-point data. Although the LCL scheme is one of the operationally acceptable approaches for estimating cloud base, it appears from the data presented here that it was not used by the three operational weather offices studied during our case-study days.

To be consistent with operational practices, the LCLs were calculated using the "Convective Cloud-Base Diagram" in the federal handbook, rather than from the Barnes formula. The accuracy of LCLs found using the diagram are estimated to be about 50 to 100 meters.

3. RESULTS

Figure 1 shows an example of the evolution of cloud-base from the BLX83 systems for 7 June 1983. Central Daylight Time (CDT) is Greenwich Mean Time (GMT) minus 5 hours. The solid line shows the filtered PAM LCLs, and the rectangular data blocks indicate the range of cloud-base heights observed by the lidar for those periods when the lidar was operating on this day. There is very good agreement between the measured cloud bases and the LCLs. Such good agreement was observed on all of the days studied, as is shown in Figure 2. Small deviations between the LCL and the actual cloud base are expected because of entrainment into the rising thermal, and because the PAM site (or any one site, for that matter) might not be representative of the surrounding area (6).

Based on these two figures, we will assume here that the LCL is an adequate measure of the expected height of the local cloud base. Such a measure should not only work for research-quality data, but should also work for routine weather-service data. We will thus assume here that routine temperature dew-point based LCLs from the operational weather services also provide an adequate measure of the actual local cloud base heights.

In operational weather data, however, the actual local cloud base heights and LCLs might be different from the "reported" heights. An example is shown in Figure 1, where the solid circles are the LCLs for OKC, and the open circles are the "reported" cloud-base heights. Although the LCLs display a diurnal change, the "reported" heights are constant throughout the day for this case.

Figures 3, 4, and 5 and similar to Figure 2, except that they are based on routine operational data. Figure 3 is for Oklahoma City, Figure 4 is for Tinker AFB, and Figure 5 is for Ft. Sill. We see that there is much greater scatter in the operational data between the LCL and the reported cloud bases than between the LCL and the measured cloud bases of Figure 2. Since the physics of the situation has probably not changed between the research and the operational cases, one must conclude that the operational cloud-base reports are inaccurate. Differences of 500 meters between the reported cloud base and the LCL are common. Compare this to the desired precision as specified in the federal handbook and indicated by the dashed lines in Figures 3-5.

4. DISCUSSION

Substantial variations in LCL heights are exhibited during the diurnal cycle, as is shown in Figure 6 for the smoothed Oklahoma data. LCLs are often low during the early morning, rise rapidly in late morning, remain high with less rise during the afternoon, and then decrease in the evening. Such a daytime cycle closely matches the change in depth of the mixed layer (6). Note that the LCLs for these days often began decreasing at about 1700 to 1800 CDT, well before the local sunset at 2040 CDT.

Research observations made during BLX83 support the notion that when clouds exist, the cloud bases exhibit the same diurnal cycle as the LCLs. The cloud bases are lower in the morning and rise to a peak in the late afternoon. Although not shown here, there is some evidence that cumulus cloud bases become decoupled from the boundary layer in the evening, because there were a number of cases when cloud bases remained constant or rose with time while the LCLs were decreasing in the evening. Clouds would normally dissipate shortly after this behavior was observed in the evening.

From Figures 3 to 5, it is evident that many cloud-base reports are given as an integer multiple of 305 meters (1000 feet), with an additional large number of multiples of 152 meters (500 feet). Unfortunately, these reported cloud base heights were held constant throughout large periods of time, even though the LCLs (and, we infer, actual cloud bases) were varying significantly. The reports were often not rounded to the "nearest" 152 meters (500 feet) to the current LCL, but were at a height more related to some previous cloud base (as in Figure 1).

Based on the results of Section 3, it appears that LCLs are a better measure of the true convective cloud-base height than the heights "reported" by the operational weather services. Thus, we recommend that researchers discard the reported bases and use estimated bases calculated from the LCL. These estimated bases will be closer to the actual cloud base heights, and will show the proper diurnal variations.

The previous recommendation, however, should be used only for estimating cloud base at the same location where the LCLs were calculated. There are very large variations in LCL height over relatively short horizontal distances, as shown in Figure 7. Here, PAM LCLs are compared to simultaneous LCLs found for OKC, TIK, and FSI. The FSI location is 65 kilometers to the southwest of the PAM site, while OKC and TIK are 47 kilometers and 61 kilometers to the northeast, respectively. Thus, we recommend that local LCLs be used when available to estimate cloud base, rather than LCLs from some distant observation point.

5. CONCLUSIONS AND RECOMMENDATIONS

Research-quality data obtained during the BLX83 field experiment in Oklahoma has been compared with the operational-quality data from neighboring National Weather Service and Air Weather Service weather units in an 8-day case study in June, 1983. It is found that for scattered fair-weather convective (cumulus and stratocumulus) clouds:

(a) surface-based temperature dew-point data, when used to calculate the LCL, provides an adequate measure of the actual local cloud-base height.
(b) "reported" cloud base heights from the operational weather services are often inaccurate measures of the local LCL. We infer from this that they are also inaccurate measures of the true cloud base height.
(c) LCLs during this case study were often low during the early morning, rose rapidly later in the morning, and then continued to rise gently to a maximum value about 3 hours before local sunset.
(d) large variations in LCL are possible over small distances (50-60 kilometers).

We recommend to researchers needing cloud-base data that they either measure the local cloud-base directly, or infer the cloud base from local standard instrument shelter measurements of temperature and dew point. The use of cloud-base data from the operational weather services is not recommended.

Finally, we recommend that the operational weather services use LCL estimates of convective cloud base to update their reports whenever other direct observations or pilot reports of cloud-base height are lacking. Although the LCL method is listed as one of the acceptable techniques in the federal handbook for surface observations, it appears that it was not used during the days studied.

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REFERENCES AND FOOTNOTES

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2. Edwin Eloranta earned a B.S. in Physics in 1965, a M.S. in meteorology in 1967, and a PH.D. in meteorology in 1972. All degrees were obtained at the University of Wisconsin in Madison. He is currently a Senior Scientist in the Department of Meteorology directing research projects dealing with the development of lidar systems for atmospheric measurements and for application to boundary layer studies. He is also a pilot and a sailboat racer who presents lectures to sailors throughout the Midwest on mechanisms producing local wind fluctuations.

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7. Federal Meteorological Handbook No. 1, Surface Observations, 3rd Ed. effective January 1, 1982. U. S. Depts. of Commerce, Defense, and Transportation. Washington, D.C. A3-9, A5-13, A5-22. Available from NOAA Logistics Supply Center, 619 Hardesty St., Kansas City, MO 64124.

Site Name	Service	Abbrev.	Latitude (N)	Longitude (W)	Distance from PAM (km)
Chickasha	BLX83 field research prog.	PAM	35 02	97 51	—
Oklahoma City	Nat'l Weather Service	OKC	35 24	97 36	47
Tinker AFB	Air Weather Service	TIK	35 25	97 23	61
Ft. Sill	Air Weather Service	FIS	34 27	98 24	65

Table 1. Locations of the data sites in Oklahoma.

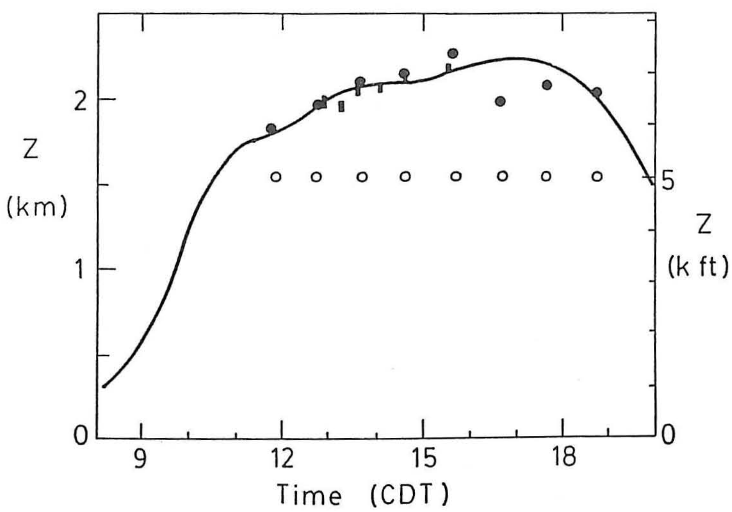

Figure 1. Example of cloud base and LCL evolution on June 7, 1983. Solid Line shows LCL heights based on filtered PAM surface data in Oklahoma, while the rectangular data points show the convective cloud-base height observed overhead by a lidar system. As expected, the cloud base is close to the LCL. Solid circles show the LCLs calculated from the routine hourly temperature and dew-point observations taken at the Oklahoma City National Weather Service Office, while the open circles indicated their "reported" local cloud-base heights. There is a large discrepancy between the LCLs and "reported" cloud base for this latter case.

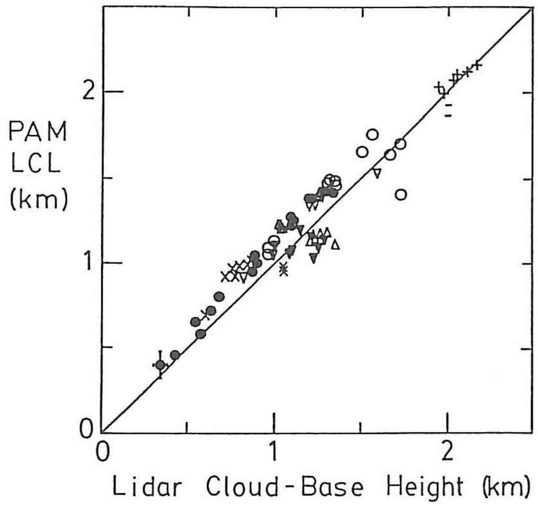

Figure 2. Comparison of local LCLs with research-quality cloud-base heights determined by lidar over the PAM station near Chickasha, Oklahoma during the BLX83 field experiment. June 6:▽ ; 7:+; 10:△ ; 11:▼ ; 12:●; 13:x; 14:-; 17:0. Error bars are indicated on the lowest left data point.

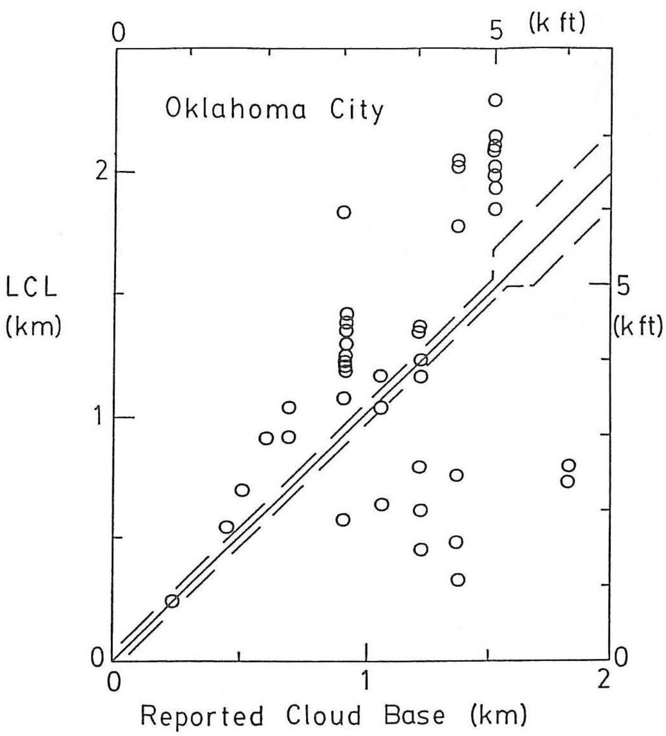

Figure 3. Comparison of local LCLs with routine hourly "reports" of convective cloud base height, as observed by the National Weather Service Office in Oklahoma City. Dashed lines indicate that the desired cloud-base accuracy is $\pm$ 30 meters (100 feet) below 1524 meters (5000 feet), and $\pm$ 152 meters (500 feet) above, as specified in FMH1.

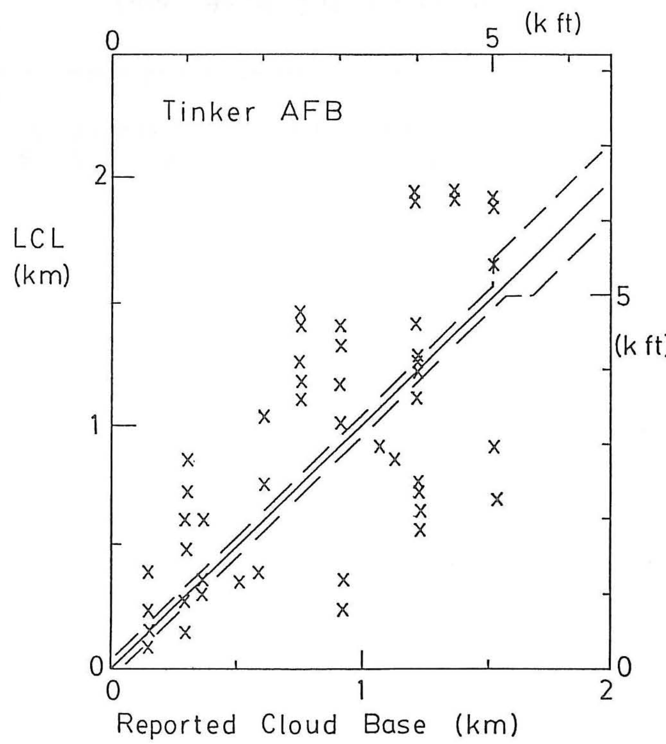

Figure 4. Same as Figure 3, but taken by the Weather detachment at Tinker Air Force Base, near Oklahoma City.

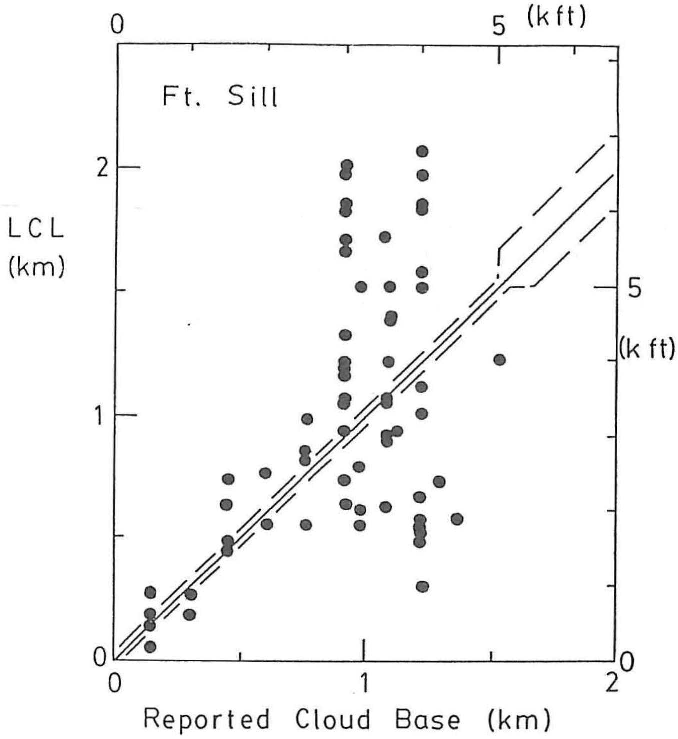

Figure 5. Same as Figure 3, but for the Air Weather Service detachment at Ft. Sill, an Army base near Lawton, Oklahoma.

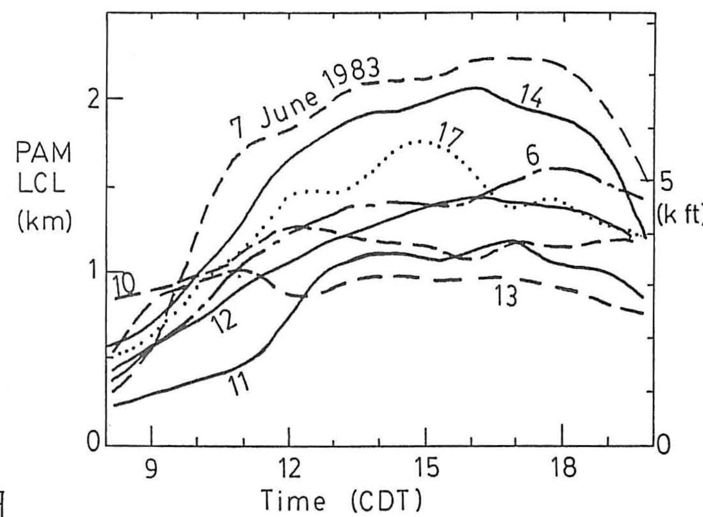

Figure 6. Example of the diurnal evolution of LCLs calculated from smoothed PAM surface data near Chickasha, Ohlahoma for 8 days in June, 1983.

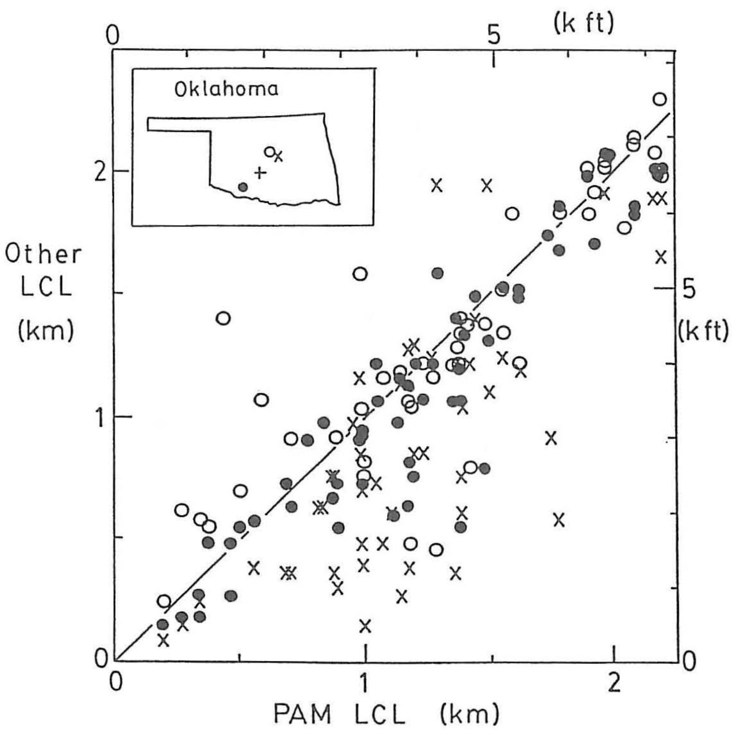

Figure 7. Example of horizontal inhomogenieties in LCL heights, as indicated by simultaneous temperature dew-point data from four sites in Oklahoma. The PAM is near Chickasha, as indicated by the + in the insert. Other LCLs are for Oklahoma City NWS:o; Tinker AFT:x; and Ft. Sill:o.