Comparison between Observed Convective Cloud-Base Heights and Lifting Condensation Level for Two Different Lifted Parcels

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6 January 2002 and 16 April 2002

ABSTRACT

Approximately 400 Automated Surface Observing System (ASOS) observations of convective cloud-base heights at 2300 UTC were collected from April through August of 2001. These observations were compared with lifting condensation level (LCL) heights above ground level determined by 0000 UTC rawinsonde soundings from collocated upper-air sites. The LCL heights were calculated using both surface-based parcels (SBLCL) and mean-layer parcels (MLLCL—using mean temperature and dewpoint in lowest 100 hPa). The results show that the mean error for the MLLCL heights was substantially less than for SBLCL heights, with SBLCL heights consistently lower than observed cloud bases. These findings suggest that the mean-layer parcel is likely more representative of the actual parcel associated with convective cloud development, which has implications for calculations of thermodynamic parameters such as convective available potential energy (CAPE) and convective inhibition. In addition, the median value of surface-based CAPE (SBCAPE) was more than 2 times that of the mean-layer CAPE (MLCAPE). Thus, caution is advised when considering surface-based thermodynamic indices, despite the assumed presence of a well-mixed afternoon boundary layer.

1. Introduction

The lifting condensation level (LCL) has long been used to estimate boundary layer cloud heights (e.g., Stackpole 1967). If the surface temperature and dewpoint are known, the LCL can be determined using either a skew *T*–log*p* chart or LCL table/diagram such as the convective cloud-base diagram in OFCM (1982) (Fig. 1).

Stull and Eloranta (1985) used a ground-based lidar system to measure cumulus cloud bases during the 1983 Boundary Layer Experiment in Oklahoma. LCL heights based on surface temperature and dewpoint were shown to be a better indicator of actual cloud-base heights than were many of the reported cloud heights on nearby National Weather Service and Federal Aviation Administration observing sites. Differences of 500 m (1564 ft) between the reported cloud height in the surface observations and the LCL were common, with the reported height consistently lower than the actual height as measured by lidar.

The LCL is typically calculated using a parcel representative of a well-mixed boundary layer that has a dry-adiabatic temperature profile (constant potential temperature in the mixed layer) and a moisture profile described by a constant mixing ratio. However, a parcel can be defined several ways, including at any single level in the vertical (usually in the lowest 300 hPa), or using the mean temperature and dewpoint in a near-surface layer (often either 50 or 100 hPa deep). The surface parcel has been utilized for some time because of the greater frequency of surface observations in both time and space (e.g., Hales and Doswell 1982). Although rawinsonde soundings released at 0000 UTC in regions not affected by precipitation commonly have a dry-adiabatic lapse rate in the lowest 1 km, it is not unusual to observe skin layers with a much higher surface dewpoint (i.e., the lapse of dewpoint is not along a mixing-ratio line through the entire boundary layer, as would be expected). Strong evapotranspiration from crops during the warm season, particularly in the Corn Belt (e.g., Pinty et al. 1989), is just one possible cause of the skin layer of greater moisture at the surface during the afternoon hours. Also, in semiarid environments, it is not uncommon for the near-surface temperature to exhibit a superadiabatic lapse rate just above the ground (Slonaker et al. 1996). The potential for gross errors in LCL height and potential instability calculations is possible if the surface temperature and/or dewpoint is not

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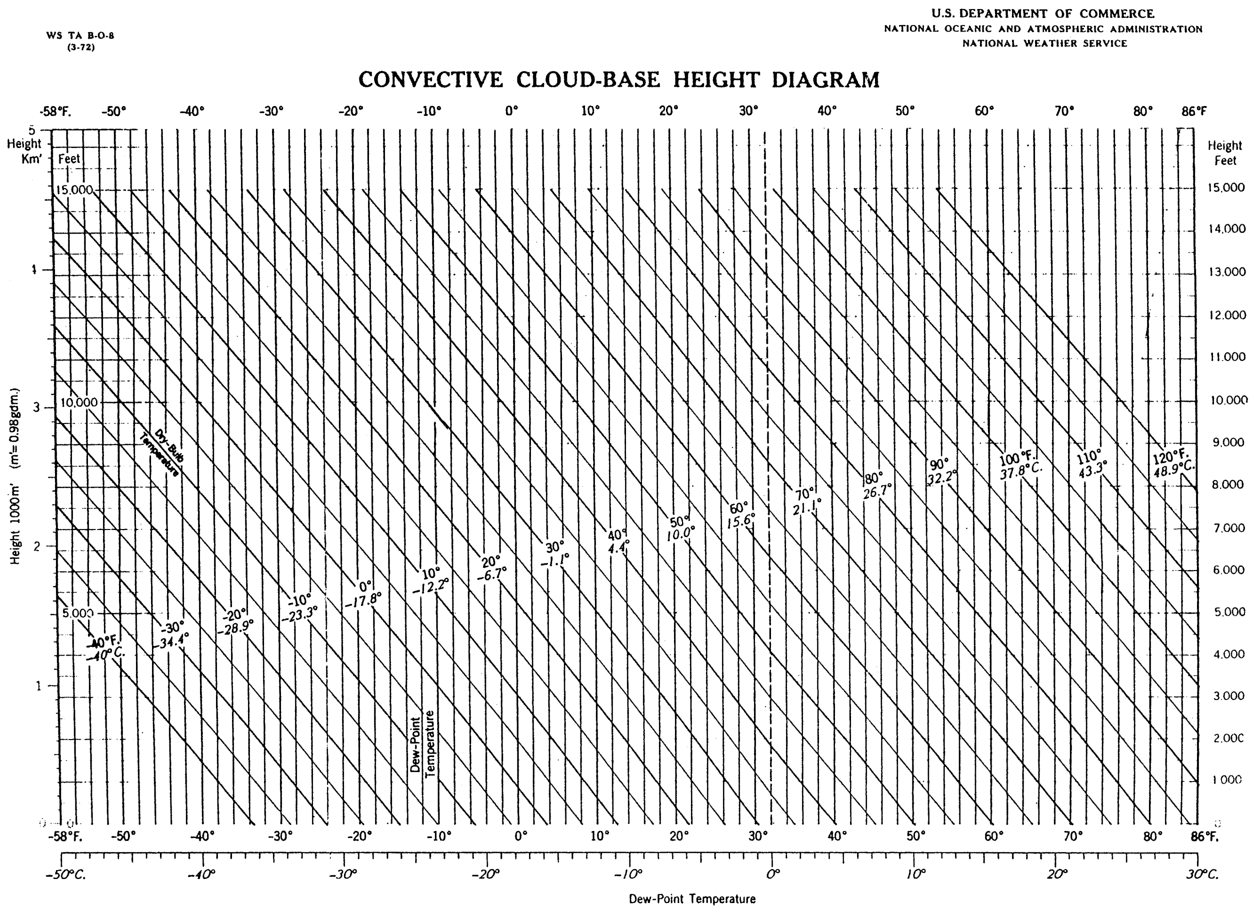

FIG. 1. Convective cloud-base height diagram (from OFCM 1982). Temperatures (diagonal lines) and dewpoints (vertical lines) are in degrees Fahrenheit, and height is in feet AGL.

representative of the thermodynamic profile in the boundary layer. See Figs. 2 and 3 for examples of well-mixed and skin-layer moisture profiles, respectively.

Earlier work with computation of stability parameters determined parcel characteristics using layers in the lower troposphere. For example, Galway (1956) defined the lifted index, as used at the Severe Local Storms Unit of the National Severe Storms Forecast Center (now known as the Storm Prediction Center), using the mean temperature and mixing ratio in the lowest 3000 ft (959 m) above ground level (AGL). Stackpole (1967) suggested that simply using the surface temperature and dewpoint versus a 100-hPa-thick layer had obvious deficiencies, implying that results from the layer method would be more representative. The purpose of this paper is to consider differences in the estimate of the convective cloud-base heights AGL between a surface-based LCL (SBLCL) and a mean-layer LCL (MLLCL) and to verify which parcel technique is more representative of convective processes in the real atmosphere.

2. Data and methodology

A total of 397 observed 0000 UTC [1800 central standard time (CST)] rawinsonde soundings, mostly across the central United States, were analyzed from April through August of 2001 (Fig. 4). The dataset was selected to enhance the likelihood of having a well-mixed boundary layer given the time of day during the warm season. Areas with rugged terrain were excluded (i.e., western states) because of the possibility that convective clouds drifting from adjacent mountainous terrain into the valley locations (where most surface observing sites are located) might yield erroneous results. In addition, the frequent occurrence of deep boundary layers and relatively low moisture values sometimes resulted in LCL heights above 12 000 ft AGL, which is the maximum reported cloud height on laser ceilometers currently used at most automated observing sites.

High-resolution (1 km) visible satellite imagery was utilized to determine if convective clouds were present at the site of the rawinsonde release during the period between 2200 and 0000 UTC. In situations in which widespread and/or dense middle- or high-level cloudiness made identification of boundary layer convective cloudiness difficult, the rawinsonde was not included in the dataset. Given the late time of day along the eastern seaboard, very few rawinsondes were included in that

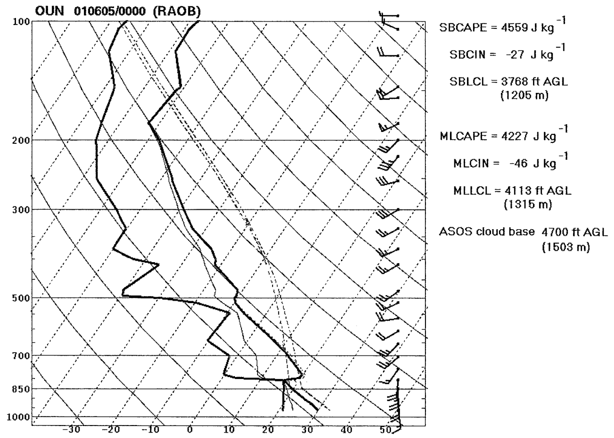

FIG. 2. Example of a well-mixed 0000 UTC sounding from Norman, OK, on 5 Jun 2001. Dashed lines compare the parcel paths for a surface-based parcel and a 100-hPa mean-layer parcel. Parcel paths are calculated using virtual temperature correction.

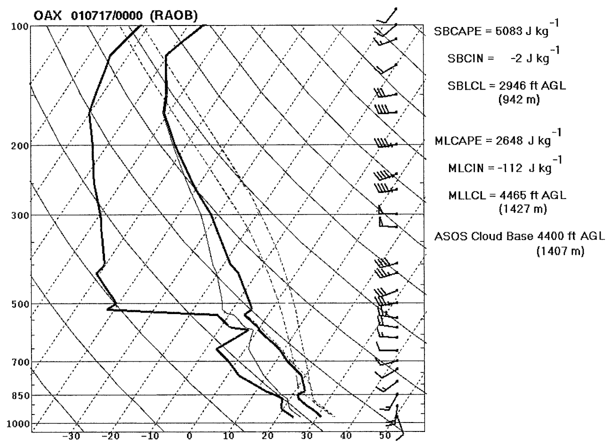

FIG. 3. As in Fig. 2, but for a skin-layer 0000 UTC sounding from Omaha, NE, on 17 Jul 2001.

area because of either poor sun angle (darkness) on the imagery or sparsity of remaining convective clouds for the ceilometers to detect around sunset.

Observed laser ceilometer cloud-base heights AGL were obtained from Automated Surface Observing System (ASOS) sites (ASOS Program Office Staff 1998) that were collocated with rawinsonde sounding release sites. The National Centers Advanced Weather Interactive Processing System Skew *T* Hodograph Analysis and Research Program (NSHARP; Hart et al. 1999), which includes a virtual temperature correction (Doswell and Rasmussen 1994), was used to calculate SBLCL, surface-based convective available potential energy (SBCAPE), MLLCL, and mean-layer CAPE (MLCAPE). The MLCAPE was calculated using the mean temperature and dewpoint in the lowest 100 hPa (which is approximately 1 km in depth). Although the choice of a 100-hPa layer is completely arbitrary, this layer has been utilized in mean-layer parcel calculations at the National Severe Storms Forecast Center and Storm Prediction Center for about 50 yr (e.g., Galway 1956; Prosser and Foster 1966; Doswell et al. 1982). This is also consistent with observed mean mixing depths of about 1 km ($\sim$100 hPa) for 0000 UTC rawinsonde soundings at Peoria, Illinois (e.g., Benkley and Schulman 1979).

Because 0000 UTC rawinsonde soundings are typically released close to 2300 UTC (i.e., 1 h prior to the official time of the observation), the cloud height on the 2300 UTC ASOS observation was preferred because the ceilometer measurement likely occurred just a few minutes prior to the release of the sounding. The sounding data were included in the data sample in real time if the following criteria were met: 1) The lowest cloud height AGL measured by ASOS was the boundary layer–based convective cloud. 2) If no clouds were reported at 2300 UTC, then either the 2200 or 0000 UTC observations were used for reported cloud heights. However, the sounding was excluded from the database if 1) no clouds were reported during the 2200–0000 UTC period, 2) the lowest cloud base varied more than 1000 ft (320 m) during the 2200–0000 UTC time period (because the most representative cloud height was impossible to determine given the degree of change in the cloud base over a period of 1 or 2 h), and 3) no precipitation occurred up to 3 h prior to cloud observation time [because of concerns of nonconvective low clouds (e.g., stratus fractus, or ''scud,'' which is typically present beneath a layer of nimbostratus) being observed by ASOS].

3. Results

Scatterplots of observed cloud heights versus the MLLCL and SBLCL illustrate the primary differences in the two LCLs as estimates of convective cloud-base height (Figs. 5, 6). Both LCLs underestimate the actual convective cloud-base height for observed clouds above 4000 ft AGL, but the SBLCL has a much larger mean absolute error of 843 ft (270 m), as compared with only 144 ft (46 m) for the MLLCL height. Linear regression (i.e., least squares fit) indicates a better fit for the MLLCL data than for the SBLCL, with linear correlation coefficients of 0.916 versus 0.852, respectively. There is also less variance in the MLLCL heights, with a standard error of 531 ft (170 m) versus 748 ft (239 m) for SBLCL heights. The lower value of SBLCL versus MLLCL in the mean is consistent with earlier research (i.e., Stull 1984). Although LCL (i.e., SBLCL) has been shown to provide a better estimate of convective cloud heights (Stull and Eloranta 1985) than do manually reported surface station values, the results from the current study indicate that MLLCL probably is a more accurate tool for meteorologists.

CAPE was also computed for the surface parcel (SBCAPE) and the mixed layer parcel (MLCAPE). The scatterplot of SBCAPE versus MLCAPE (Fig. 7) indicates that the SBCAPE had larger values in nearly all

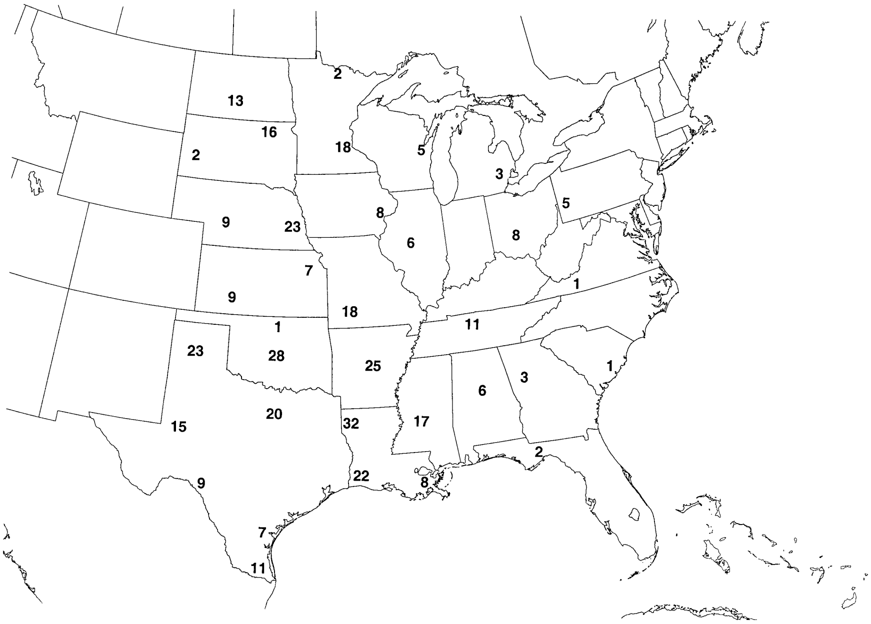

FIG. 4. Location and number of 0000 UTC rawinsonde soundings included in analysis.

cases. In fact, the median value of SBCAPE (1492 J kg^{-1}) was more than 2 times the median value of MLCAPE (685 J kg^{-1}). Readily apparent are the large number of soundings for which there is MLCAPE of near 0, but SBCAPE of several hundred joules per kilogram. Because the mean-layer parcel more accurately estimates the height of the convective cloud base, it is reasonable to assume that the MLCAPE value should be more representative of the potential buoyancy than is the SBCAPE value, given a well-mixed boundary layer. This likelihood highlights the potentially unrepresentative nature of a skin layer of relatively high surface dewpoints, which would have obvious implications in thunderstorm forecasts (see Fig. 3, in which SBCAPE is 5083 J kg^{-1} and surface-based convective inhibition is -2 J kg^{-1}, vs MLCAPE of 2648 J kg^{-1} and mean-layer convective inhibition of -112 J kg^{-1}).

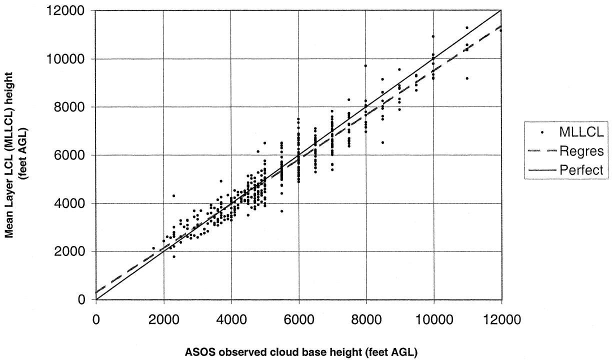

FIG. 5. Scatterplot of ~2300 UTC ASOS-observed convective cloud bases (ft AGL) vs MLLCL heights from 0000 UTC rawinsonde data. Perfect-fit and linear regression lines are also plotted.

4. Conclusions/recommendations

In convective forecasting, one of the main problems a meteorologist faces is determining a representative value of potential instability. Deciding which parcel to "lift" in the computation of CAPE is crucial in this diagnostic process. Operational meteorologists have access to many different numerical models and automated sounding analysis algorithms that calculate current or forecast values of CAPE. The Internet has numerous sites that contain weather data, including analysis and forecasts of CAPE. Because many of these products are labeled simply as CAPE, with no reference to which parcel is used in the calculation, the usefulness of such quantitative information is questionable. For forecasters to utilize convective parameters such as CAPE intelligently, we believe it is vitally important that the computational technique used in the calculation, including details such as a definition of the lifted parcel and use

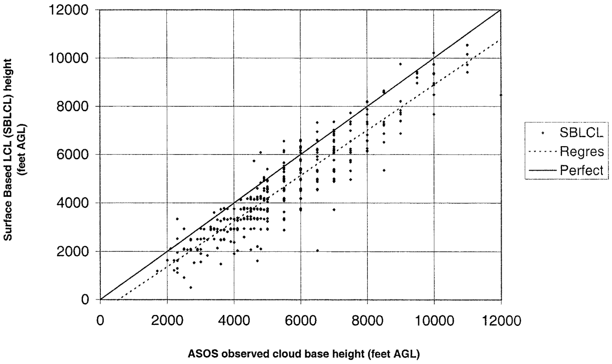

FIG. 6. As in Fig. 5, but for SBLCL heights.

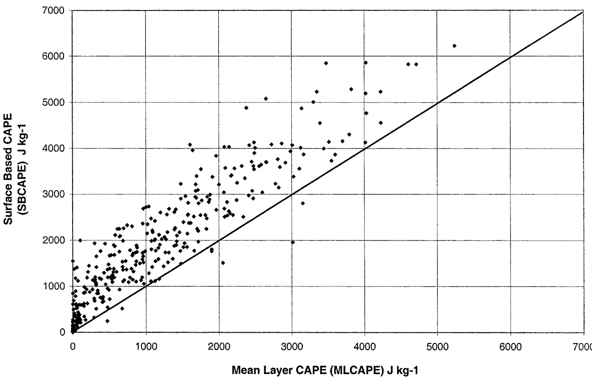

FIG. 7. Scatterplot of SBCAPE vs MLCAPE for 0000 UTC rawinsonde soundings. Perfect-fit line is also plotted.

of virtual temperature correction, *is well documented and is understood* by the forecaster.

For computing parameters such as convective cloud-base height and CAPE, the results from this study support the use of a mean-layer parcel instead of a surface-based parcel, even in the warm season during the afternoon when the boundary layer is most likely to be well mixed. This result suggests that, for boundary layer–based convection, meteorologists should use parameters based on mean-layer parcel theory to obtain a better estimation of convective potential. However, for deep convection that is elevated (i.e., updrafts are ingesting potentially unstable air above a cooler and more stable boundary layer), another parameter such as most-unstable CAPE (using the most unstable parcel in lowest 300 hPa) should be used.

Forecasts of thunderstorm intensity, mode, and initiation, along with aviation forecasts of convective cloud heights, would all benefit from the most accurate parcel forecast possible. Recent work has shown that significant tornadoes [i.e., strong/violent tornadoes, F2 or greater in intensity; Hales (1988)] tend to be associated with relatively high boundary layer moisture and thus lower LCL heights. This likely reduces the strength of downdrafts and decreases the likelihood of strong, cold thunderstorm outflow, which can undercut a mesocyclone and disrupt tornadogenesis (e.g., Rasmussen and Blanchard 1998; Edwards and Thompson 2000; Markowski et al. 2000, 2002). If a skin layer of moisture is present, the low and unrepresentative SBLCL height may mislead the forecaster into believing that there is the likelihood for significant tornadoes.

Despite the potential advantages to using a mean-layer parcel approach, there are also disadvantages. A late-afternoon or evening sounding is only available once per day at 0000 UTC at about 70 locations across the lower 48 states. When compared with hourly surface observations at over 1100 locations in this same area, there is a large reduction in the availability of mean-layer versus surface-based parcel data both temporally and spatially (Steyaert and Darkow 1973; Darkow and Tansey 1982; Hales and Doswell 1982). Although MLLCL height and MLCAPE values can be calculated using model point forecast soundings, caution is advised because the results will only be correct if the boundary layer temperature and moisture profiles are accurately predicted by the model.

SBLCL and SBCAPE data remain useful in providing the highest-resolution depiction in both time and space of estimated cloud-base heights and potential instability. When observed rawinsonde soundings are available during the midday and afternoon hours (e.g., at 1800 and 0000 UTC), we recommend using a mean-layer parcel, such as the lowest 100 hPa, to estimate LCL heights and CAPE. The selection of a 100-hPa layer is arbitrary, and additional study is required to determine what depth would best represent the actual parcel path/LCL height (i.e., 50, 75, etc., hPa). When using surface-based parameters during the daylight hours, caution is urged because unless the boundary layer is well mixed (i.e., adiabatic temperature profile and constant mixing ratio), the LCL height will be underestimated and the CAPE will be overestimated. More realistic values are likely when using a mean-layer parcel, which will temper the effects of a relatively high surface mixing ratio relative to the remainder of the boundary layer. If the boundary layer is completely mixed (i.e., the lapse rate is adiabatic and the mixing ratio is constant) through at least the lowest 100 hPa, then the surface-based and mean-layer parameters will be identical.

Acknowledgments. The authors thank Steven Weiss for his thorough reviews and suggestions. Barry Schwartz, an anonymous reviewer, David Imy, and Joseph Schaefer also provided reviews and insightful recommendations for the manuscript. We thank Roland Stull for supplying a wealth of information about previous research.

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