# Comments on "Trends in Low and High Cloud Boundaries and Errors in Height Determination of Cloud Boundaries"

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Chernykh et al. (2001, hereafter CAE) report trends in cloud-base height, cloud-top height, the number of cloud layers, and the frequency of clouds based on analysis of global radiosonde data during 1964–98. We are concerned that the changing vertical resolution of radiosonde observations over time, combined with the sensitivity of the method used to deduce cloud layers (Chernykh and Eskridge 1996, hereafter CE) to vertical resolution, undermine the credibility of the reported trends. This comment provides evidence both that the CE method is very sensitive to vertical resolution, and that the vertical resolution of soundings has increased over the past four decades. From this evidence we argue that the reported trends are, at least in part, artifacts of changing observing practices. We also raise other questions regarding the influence of data sampling on the results.

The CE method for determining cloud layers from radiosonde temperature and humidity profiles involves identifying vertical layers in which the second derivative of temperature with respect to height is zero or positive, and the second derivative of relative humidity with respect to height is zero or negative. The endpoints of layers meeting these criteria are interpreted as cloud bases and tops. CAE apply this method to data from 967 radiosonde stations and report a globally averaged increase in cloud-top height of about 154 m decade$^{-1}$, a decrease in cloud-base height of about 44 m decade$^{-1}$, a 1.7% decade$^{-1}$ increase in the frequency of clouds, and an unquantified increase in the frequency of multilayer clouds.

Given the implications of these findings for interpreting other changes in climate, it is important to determine whether they are robust. Changes in instruments and observing practices are manifest in time series of radiosonde temperature (Gaffen 1994; Parker and Cox 1995) and humidity (Elliott and Gaffen 1991) records and, if not accounted for, can severely undermine attempts to estimate temperature trends (Gaffen et al. 2000). Since the CE method infers cloud layers from temperature and humidity profiles, it is reasonable to question whether temporal data inhomogeneities also impact radiosonde-derived cloud trends.

**SENSITIVITY OF CUBIC SPLINE INTERPOLATION TO DATA RESOLUTION.** Radiosonde data are reported at discrete pressure levels, resulting in a piecewise linear vertical profile. However, because piecewise linear functions have discontinuous first derivatives, the CE method involves fitting a cubic spline to sounding data to allow evaluation of the second derivatives of temperature and humidity with the respect to height. As an aside, we note that spline fits are contradictory to the reporting requirements for radiosonde data, which stipulate that a data level be reported when the soundings departs significantly from a linear fit between reported levels (Hooper 1986; WMO 1996; OFCM 1997). Although it seems likely that atmospheric profiles have continuous second derivatives, their structure cannot be uniquely determined from sounding data. Therefore, the most faithful method of interpolating soundings is linearly, not with a spline.

Figure 1 shows the sensitivity of a cubic spline interpolation of a simple piecewise linear function $f(x)$, and its second derivative $d^2f(x)/dx^2$, to the resolution $\Delta x$ of the data that define $f(x)$. Because the spline must have continuous second derivatives and is forced to pass through the data points, the higher the resolu-

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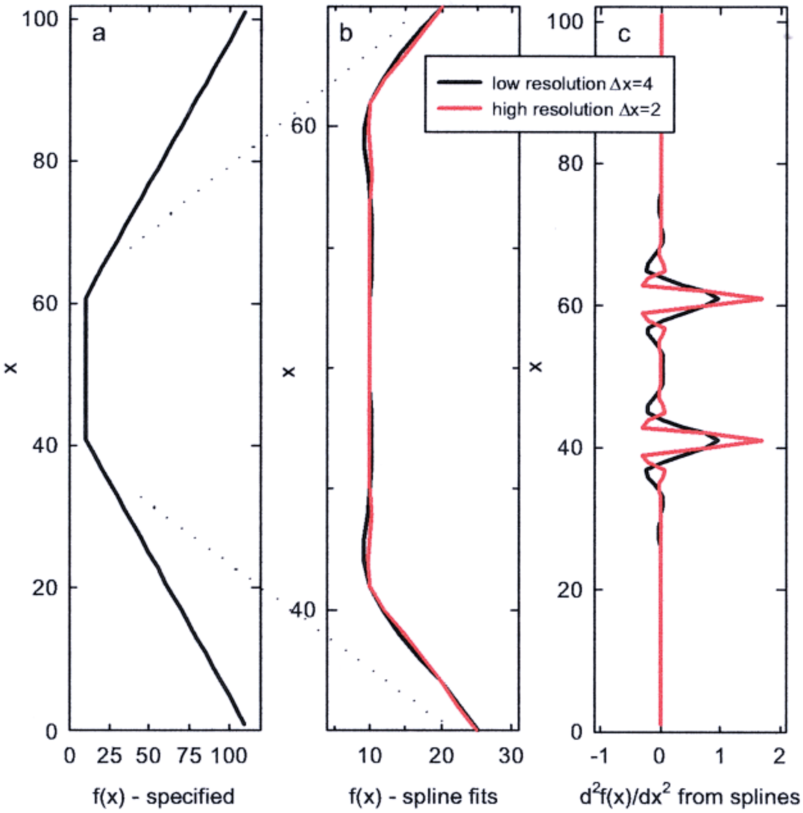


**Fig. 1. (a) A piecewise linear function *f(x)* defined at low resolution (at *x* intervals of 4 units) and high resolution (*x* intervals of 2 units). (b) Spline fits to the data in (a) meander through the data points rather than reproducing the straight line segments of the original function *f(x)*. [Note that only a portion of the domain is shown in (b).] (c) The second derivatives $d^2f(x)/dx^2$ obtained from the spline fits are nonzero over much of the domain and have different structure, and at some values of *x* a different sign, depending on the resolution of the original function.**

tion, the more the spline will meander about the straight line segments that define *f(x)*. The meanders are most noticeable near the inflection points of *f(x)* (Fig. 1b). They are more pronounced for the low-resolution case than at high resolution, but, because there are more meanders in the high-resolution case, the structure of its $d^2f(x)/dx^2$ is more complex. In both cases, $d^2f(x)/dx^2$ in no way resembles the second derivatives of the original *f(x)*, where $d^2f(x)/dx^2 = 0$ over most of the domain, except at the inflection points, where it is undefined.

This hypothetical example demonstrates (i) that spline fits artificially introduce inflection points to data that are actually linear and, (ii) that the number of such inflection points increases as the number of data pairs increases.

**A SAMPLE SOUNDING.** Figure 2 demonstrates these issues with real sounding data, specifically the 2300 UTC 30 July 2001 sounding data from Bethel, Alaska, in the layer from the surface to 10 km (the layer used by CAE). The reported temperature (Fig. 2a) and humidity (Fig. 2b) data are plotted in black, with linear interpolation between the reported 35 data levels. We have also interpolated the data to 100-m resolution using cubic splines applied to all 35 reported data levels (blue curves) and to only the standard pressure level data (red). The splines fit to the standard level data do not capture the vertical structure associated with the significant levels. The splines fit to all the data introduce curvature to the plot and exaggerate the variability in the profile. For temperature, differences between the raw data and the spline fit are as large as ~0.5°, and for relative humidity they are as large as ~8%.

Figures 2c and 2d show the second derivatives of the temperature and relative humidity profiles, evaluated from the two pairs of spline fits. The splines fit to the higher-resolution data yield many more regions of positive and negative second derivatives (and with much larger values) than the splines fit to the mandatory level data only, as expected from Fig. 1.

Using the CE criteria for cloud layer identification, Fig. 2e shows layers of clouds that would be deduced from the two pairs of spline fits to the sounding. For the mandatory-level-only case, three cloud layers are identified in the following regions: surface–800, 2700–3700, and 7800–10 000 m. For the higher-resolution case, 12 separate cloud layers are identified. Note that the original sounding has two layers of 100% relative humidity (surface–3826 m and at 4485 m, as shown in Fig. 2b), suggesting a deep cloud layer in the lower troposphere. The sounding report includes weather data, which indicate overcast conditions, with a low stratocumulus deck with cloud base at 200–299 m, with continuous light rain falling. However, regardless of the true number of cloud layers, we are concerned that the number and extent of layers identified by the CE method varies so dramatically with the number of data levels.

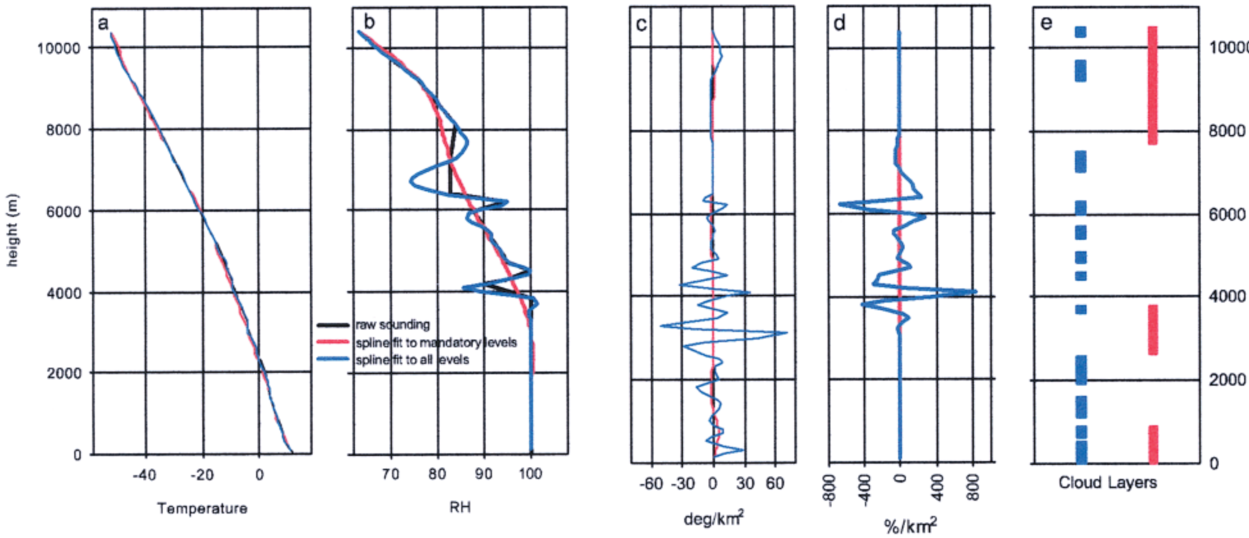


**Fig. 2. The 2300 UTC 30 Jul 2001 profiles from Bethel, AK. (a) Temperature and (b) relative humidity observations are shown in black, with linear interpolation between reported levels, consistent with national and international reporting practices. Spline fits to the standard level data and to all 35 reported data levels are shown in red and blue, respectively, and deviate considerably from the linear interpolation. Second derivative profiles for (c) temperature and (d) relative humidity based on the low- (red) and high- (blue) resolution splines, yield (e) very different "cloud layers" when applying the CE method.**

**INCREASING VERTICAL RESOLUTION OF SOUNDING DATA.** The CAE analysis examined four fixed vertical layers: 0–2, 2–6, 6–10, and 0–10 km. The dependence of the number of identified cloud layers on the vertical resolution of the sounding suggests that cloud-base (top) heights within fixed layers will decrease (increase) to approach the layer limits as the resolution of the sounding increases. The CAE results (showing increases in the frequency of multilayer clouds, decreases in cloud-base heights, and increases in cloud-top heights) are consistent with a general increase in the number of reported levels in radiosonde data over the period of the analysis, 1964–98. As data reduction procedures have become automated, more levels are generally reported, as shown in Fig. 3. For 10 representative stations from different countries around the world, there is an obvious upward trend in the number of reported data levels. There is no reason to think such a trend would not be evident at most stations globally. We believe that this trend, associated with changing reporting practices, contributes to (and may dominate) the trends that CAE interpret as changes in cloudiness.

**CHANGES IN HUMIDITY DATA REPORTING PRACTICES.** The spatial pattern of trends in cloud-top heights depicted in Fig. 3 of CAE suggests that changes in humidity reporting practices at low temperatures may also play a role. In the United States, a −40°C temperature cutoff for humidity re-

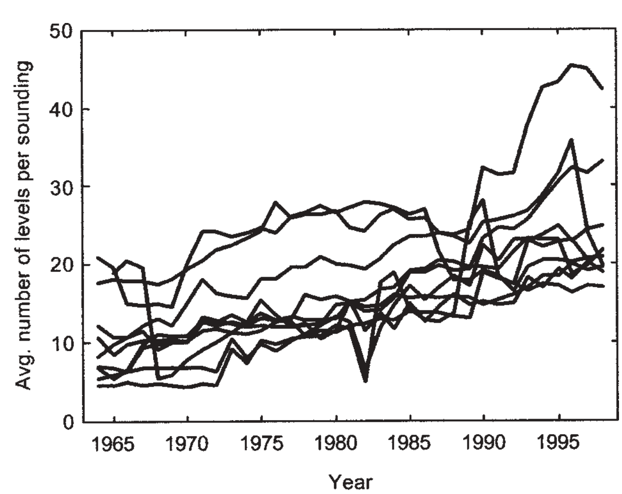


**Fig. 3. The annual average number of data levels per sounding increased during 1964–98, the period of CAE analysis, at 10 representative radiosonde stations: Lerwick, United Kingdom; Uccle, Belgium; Payerne, Switzerland; Kagoshima, Japan; Bangkok, Thailand; Capetown, South Africa; Bethel, AK; Antofagasta, Chile; Honiara, Solomon Islands; and Adelaide, Australia. The number of levels between the surface and 250 hPa with valid temperature and relative humidity data is shown, to approximate the 10-km cutoff in the CE method.**

ports was dropped in 1993. In the former Soviet Union, this practice was introduced in 1986 (Gaffen 1993). Consequently, the top of the humidity profile increased over time in the United States, and decreased over time in the former Soviet Union.

Wang et al. (2000) showed that latitudinal variations of cloud-top heights deduced from radiosonde data follow variations in the top of humidity profiles. We suspect that the strong negative trends in cloud-top height reported by CAE over the former Soviet Union, and the positive trends over the United States are influenced by these changes in humidity reporting associated with temperature cutoffs.

**DATA SAMPLING ISSUES.** We have further concerns that spatial and temporal sampling of the radiosonde data archive is not sufficient to support the assessment of trends over the domain used by CAE. We summarize these as follows:

- The use of data from 795 time series (from 967 stations) suggests that many far from complete records must have been used, leading to inconsistency in the data periods. Radiosonde data records are spotty over much of Africa, South America, parts of Asia, and the southern oceans. As a result, other studies using radiosonde data for trend analysis have employed far fewer stations, to ensure a sufficient number of samples for statistically and physically meaningful results.
- Humidity data in the upper troposphere are sparse, particularly in the early decades of the analysis, due to known problems with humidity sensors. This would inhibit the analysis of clouds in the 6–10-km layer, suggesting inconsistency between the trends in the lower and higher layers.
- The spatial domains are different for trends in cloud-top and cloud-base height (compare CAE, Figs. 3 and 4), suggesting that different stations were used in each analysis and that the bases and tops in question are not from the same clouds or stations.
- CAE required 10 cloudy soundings per month, and then performed analysis of trends in each of four different cloud categories for four separate calendar months. This could easily lead to a very small number of soundings in a sample for a given year, with long-term trends estimated from highly unrepresentative samples.

In summary, we question the methods used by CAE to determine cloudiness trends from radiosonde data. The importance of clouds in the climatic system requires that other methods, preferably using more direct cloud observations, be employed to better characterize their long-term changes.

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