# A Comparison of Satellite and Sounding Derived Cloud Top Temperatures

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## 1. Introduction

Information regarding cloud top temperature is important for many types of weather forecasts, notably aircraft icing. Automated icing algorithms developed at NCAR use GOES infrared temperature data matched to model temperature and humidity output to determine the cloud top temperature (CTT) and cloud top height. Wang and Rossow (1995) developed a different technique to find these parameters using profiles of moisture from balloon-borne sounding observations. In this paper, results from a comparison of cloud top temperatures derived from these two methods are described.

## 2. Data

Satellite data from GOES-EAST was compared to sounding data from 73 United States and 12 Canadian stations. All sounding locations were south of 55 degrees north latitude with the exception of Annette Island, AK (Fig. 1). Canadian and NWS soundings taken at 1200 and 0000 UTC during the year 2001 were matched to GOES-EAST satellite data from 1115 and 2315 UTC (approximate sounding launch times.)

Several data-quality checks were used to ensure that erroneous data was removed from the sounding database. The first check was to remove any soundings that indicated cloud top temperatures colder than –40$^{o}$C due to problems with the quality of humidity measurements at such cold temperatures (Miloshevich et al, 2001). The second check was to ensure that the uppermost data point in the sounding did not indicate a cloud. If a cloud was indicated at that level, the data was removed because of uncertainty in the location of actual cloud top height. Integrity of the GOES-EAST satellite dataset was completed before this study began, so no additional data-quality checks were needed.

## 3. Analysis and example comparisons

GOES-EAST cloud top temperatures were calculated for a 5x5 box of ~5km resolution infrared satellite pixels centered over each sounding site. Various GOES-EAST fields were used to determine the presence or absence of clouds depending on whether the sounding site was in the daytime, nighttime, or terminator (the border between daytime and nighttime) view of the satellite using a technique described by Thompson et al (1997) and McDonough and Bernstein (1999). All 25 pixels had to be cloudy in order for the data to be considered a valid data point. Using the temperature values for each pixel, a median value temperature was calculated for all 25 pixels and assigned as the cloud top temperature.

Using the Wang and Rossow (1995) technique, cloud top was found using a top-down examination of the relative humidity with respect to water and ice. Cloud top was set to the highest level where relative humidity with respect to water ($RH_w$) or ice ($RH_i$) either a) exceeded 87% or b) exceeded 84% and the level above had $RH_w$ or $RH_i$ that was at least 3% lower than the $RH_w$ or $RH_i$ of the level in question. The temperature at the top of the uppermost layer was the cloud top temperature used for the sounding.

Cloud thickness was also calculated from the sounding to determine if the correlation between cloud top temperatures was dependent upon the thickness of the clouds. Cloud thicknesses were placed into five thickness groups; <500m, 500-1000m, 1000-1500m, 1500-2000m, and >2000m. Due to the coarseness of the actual sounding data, layers would sometimes only extend through one level. In this instance, the cloud thickness was given a value of zero meters, placing it in the first group.

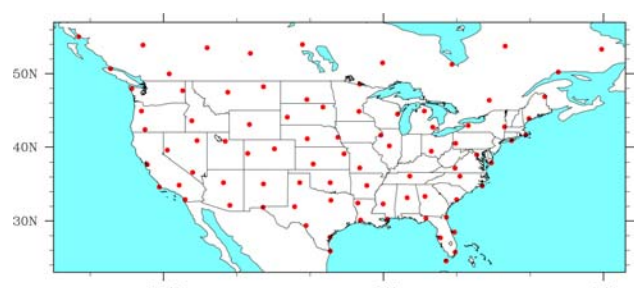


Fig. 1 – Sounding locations in the US and Canada

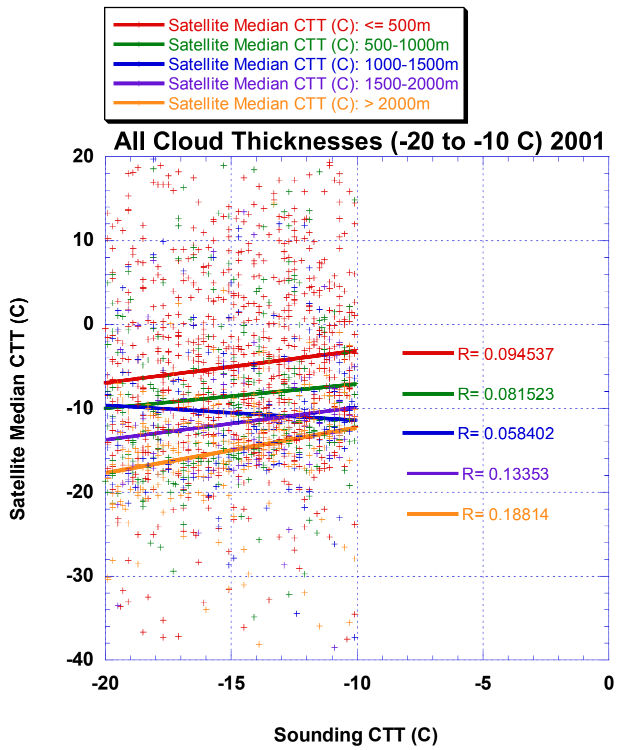


Fig. 2a - All cloud thicknesses for sounding cloud top temperatures from –20º to –10º C.

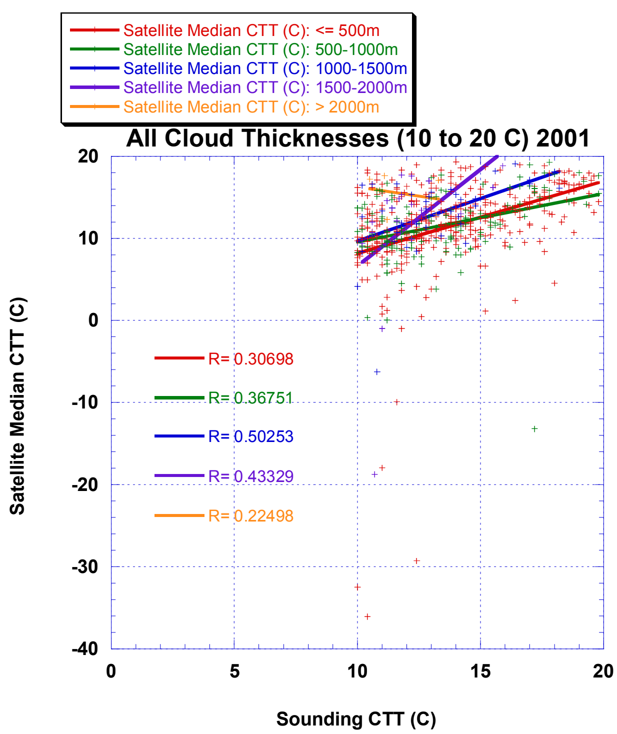


Fig. 2b - All cloud thicknesses for sounding cloud top temperatures from +10º to +20º C.

In an effort to stratify the results by cloud top temperature range, the cloud thickness groups were broken down into 10°C bins based on the sounding cloud top temperatures. Correlation values for all cloud thicknesses increased with increasing cloud top temperature (see Figs. 2a, b).

Temperature differences between the satellite and sounding covered a wide range. Large temperature differences occurred when soundings were launched near the edge of cloud decks or into broken or scattered sky conditions. Figure 3a shows the locations of six soundings that had large (>30º C) differences between the satellite- and sounding-derived cloud top temperatures. The Flagstaff, Arizona sounding was launched on the edge of a stratus deck and the soundings in Fort Worth Texas, Davenport Iowa and Slidell Louisiana were launched in broken sky conditions. Figure 3b shows the locations of eight soundings where the sounding-derived cloud top temperatures differed by less than 1° C. These sondes ascended through more consistent, widespread stratus clouds. Differences in cloud character appear to be a primary driver behind the amount of disparity between the cloud top temperatures derived by the two techniques

Figure 4a shows the 1115Z sounding from Flagstaff, Arizona on September 12, 2001. The cloud top temperature was calculated to be –36.3º C, using the Wang and Rossow technique, 43º C different from the 7.16º C value found in the satellite data (Fig 3a). The Buffalo, New York for 12Z, January 20, 2001 had a sounding derived cloud top temperature of –26.9º C, only 0.2º C different from the satellite-derived value (Fig 3b) at 1115 UTC. Looking at Figure 3b, the Buffalo, NY site is clearly in a stratiform cloud layer. Since the satellite temperatures around the site are uniform and widespread, any sounding going up in this location should detect the same cloud top temperature as it ascends through the cloud. The Flagstaff, Arizona sounding was launched on the edge of a cloud deck as seen in figure 3a. Depending on the winds as the sonde ascends, the sonde can either ascend through the cloud deck or ascend through clear air. In this case, the satellite temperature came from the clear air while the sonde ascended through the cloud deck causing the wide range in cloud top temperatures between the two.

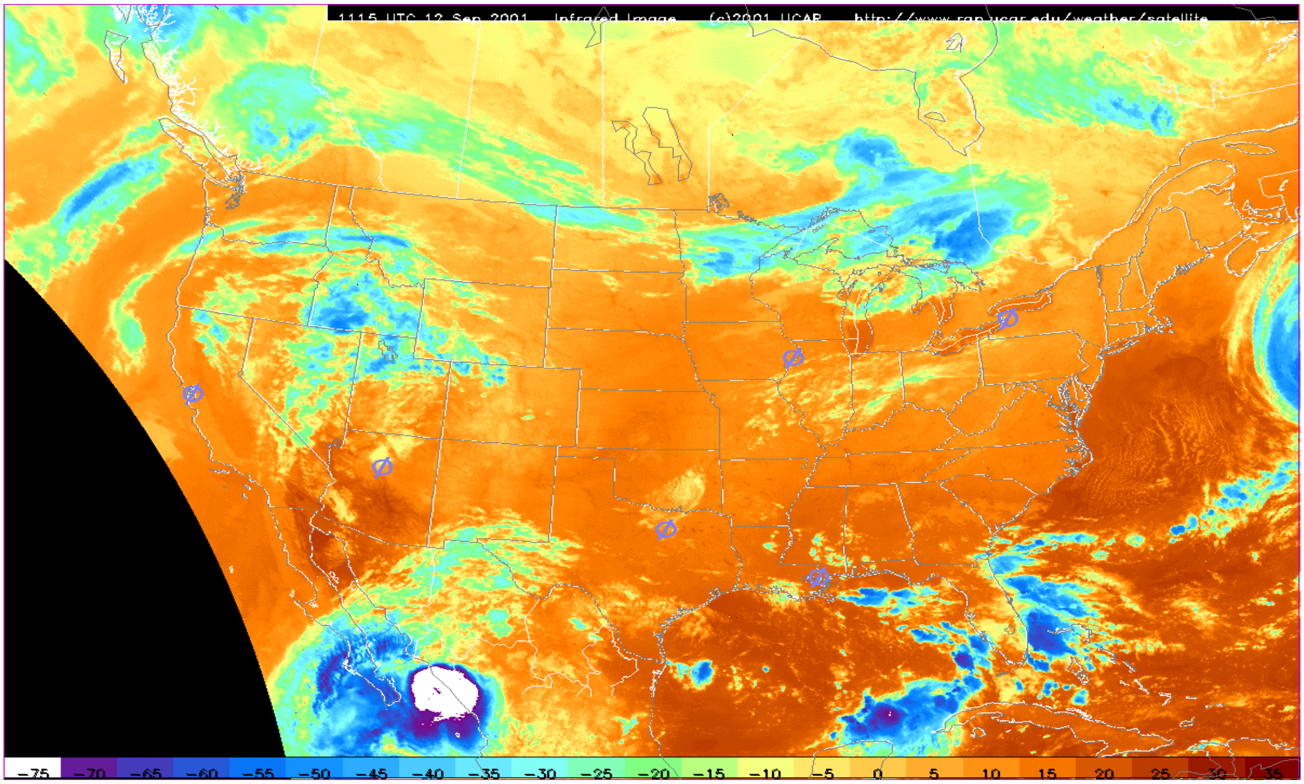


Fig. 3a – GOES-EAST IR image for September 12, 2001, 1115 UTC. Six sounding locations where sounding-derived cloud top temperatures differed from the satellite temperatures by more than 30$^{o}$ C.

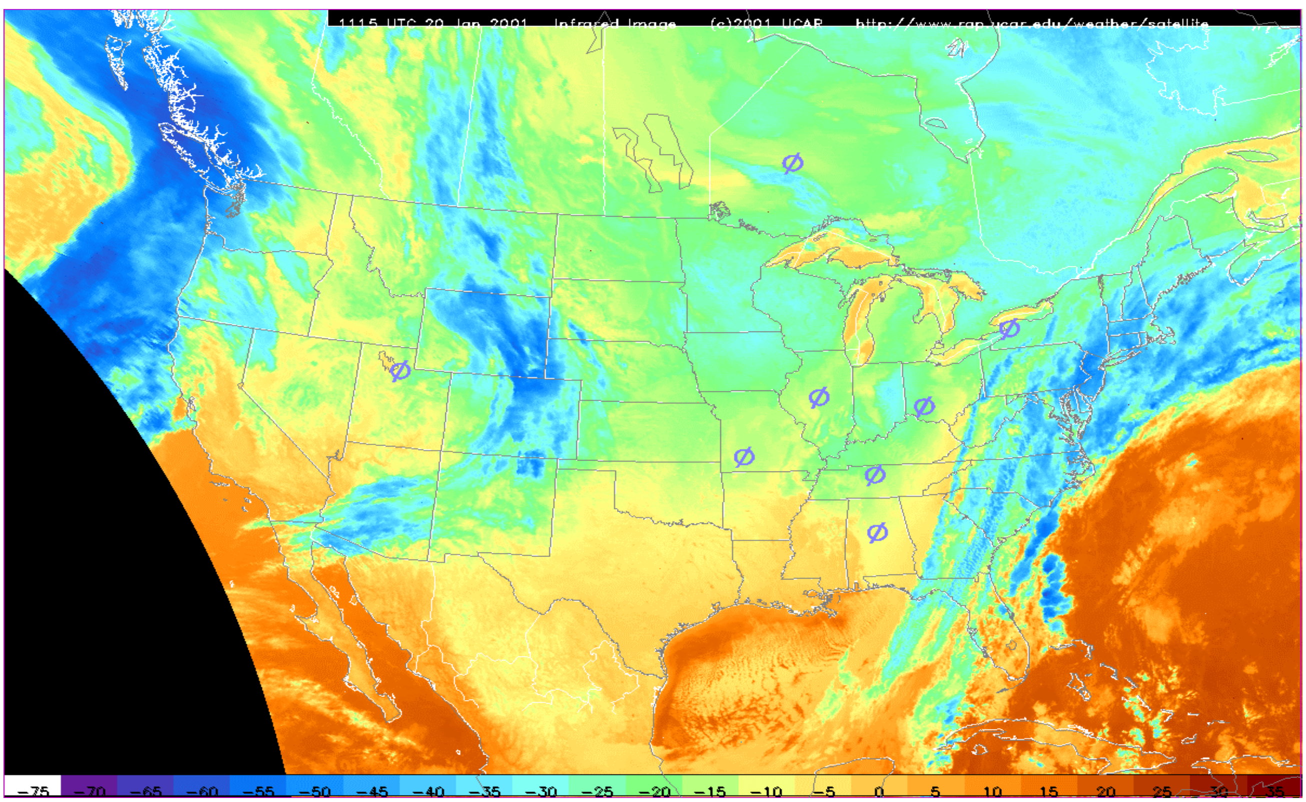


Fig. 3b – GOES-EAST IR image for January 20, 2001, 1115 UTC. Eight sounding locations where sounding-derived cloud top temperatures differed from the satellite temperatures by less than 1$^{o}$ C.

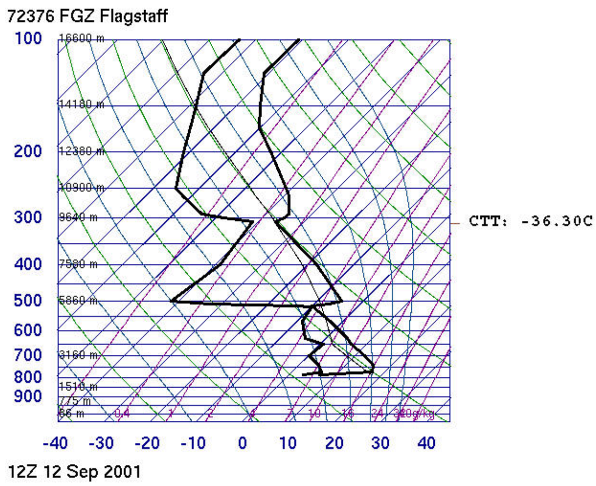


Fig 4a – Flagstaff, AZ 1115UTC sounding with associated CTT indicated.

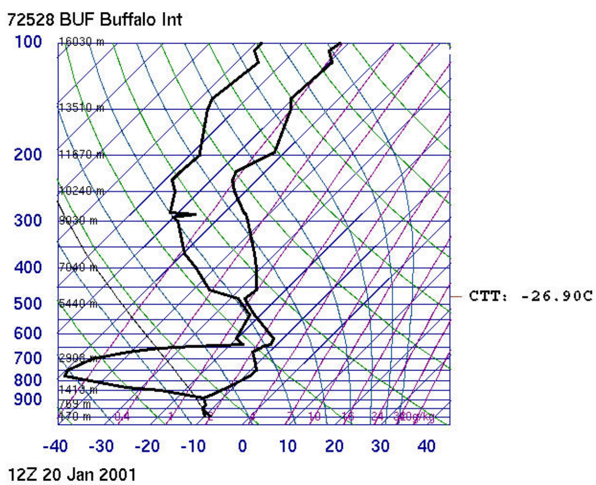


Fig. 4b – Buffalo, NY 1115UTC sounding with associated CTT indicated.

## 4. Results

The dataset was broken down into three-month seasons to see if any seasonal variation existed in the correlations (e.g. spring was defined as March, April and May). The seasonal comparisons showed the 'spring' season having the best correlations and the 'winter' season having the worst (Figs. 5a,b). As discussed earlier, correlations were best for warm clouds. Of the five thickness groups, the 1500-2000m thickness showed the best correlation for both the winter and spring seasons while thicknesses under 500m had the worst correlation. The correlation for cloud thicknesses greater than 2000m was not as good as that for the 1500-2000m thickness because there were relatively few clouds of that thickness.

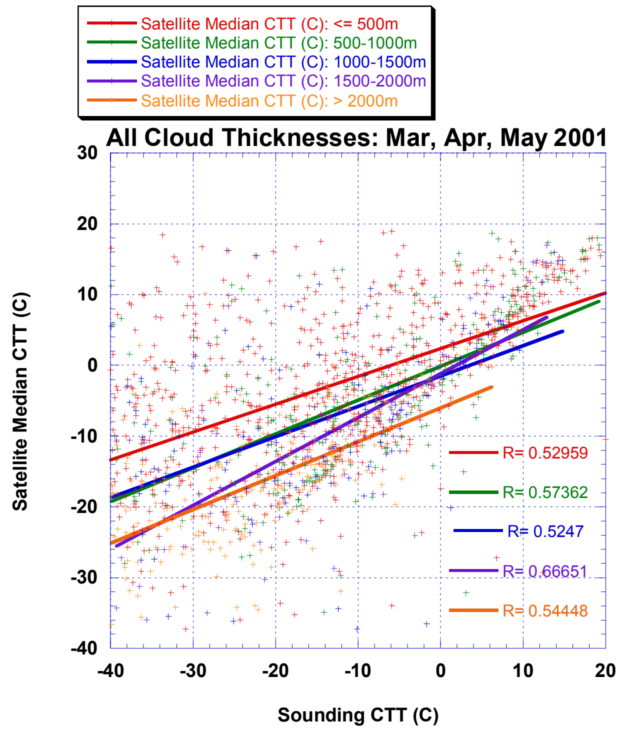


Fig. 5a – Spring season CTT comparison.

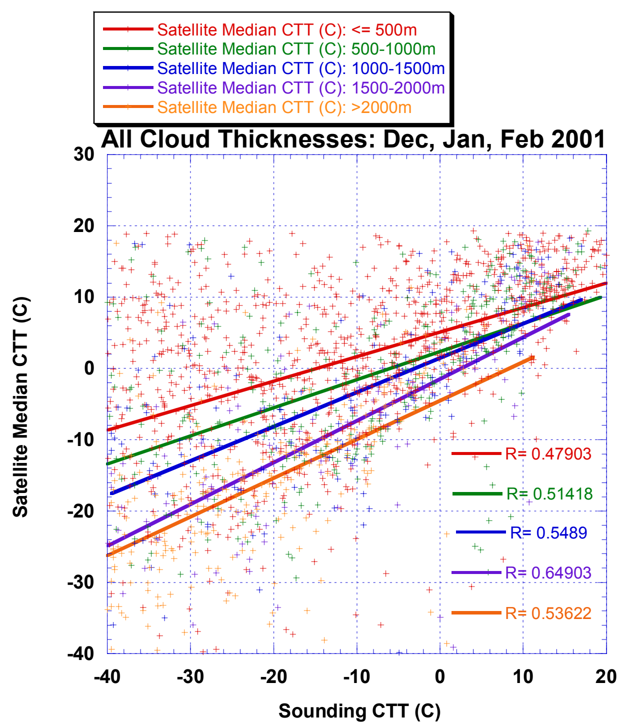


Fig. 5b – Winter season CTT comparison.

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In an attempt to better understand the potential errors in the dataset, the absolute difference between the satellite- and sounding-derived cloud top temperatures was calculated for each sounding. The results were broken down into 2.5° C bins and normalized to produce a percentage of all errors that fell within each bin (Fig 6). The values show that errors of ≤ 2.5° C were most frequently present, but that much larger errors are also common. To rule out satellite viewing angle as a potential contributor to the errors, this dataset was broken down into various longitudinal sections of the US and Canada. Stations to the east of 80°W, between 95°W and 105°W and west of 118°W were classified as being in the "eastern", "central" and "western" sections, respectively (see Fig 1). Figures 7a-c show that the error distributions do not change much between longitudinal bands. Small differences appear to be most common at western longitudes, even though the clouds are being viewed by the GOES-EAST satellite. This implies that viewing angle did not significantly impact the final error values in the dataset.

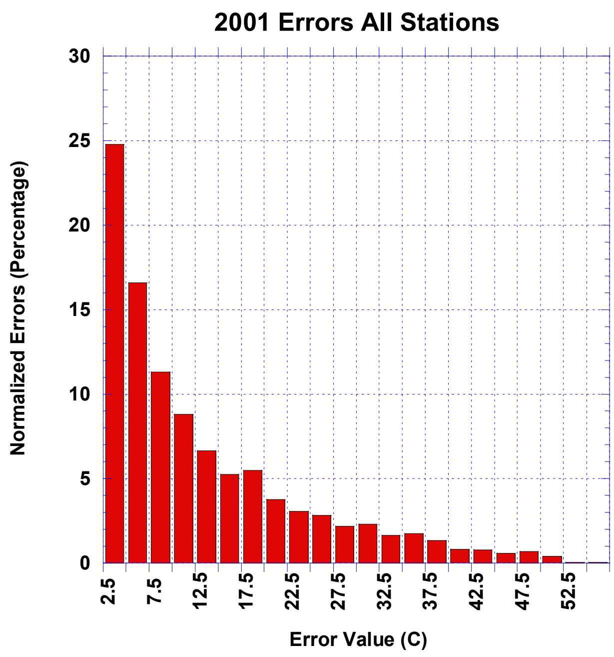


Fig. 6 – Percent error values for all sounding locations for 2001.

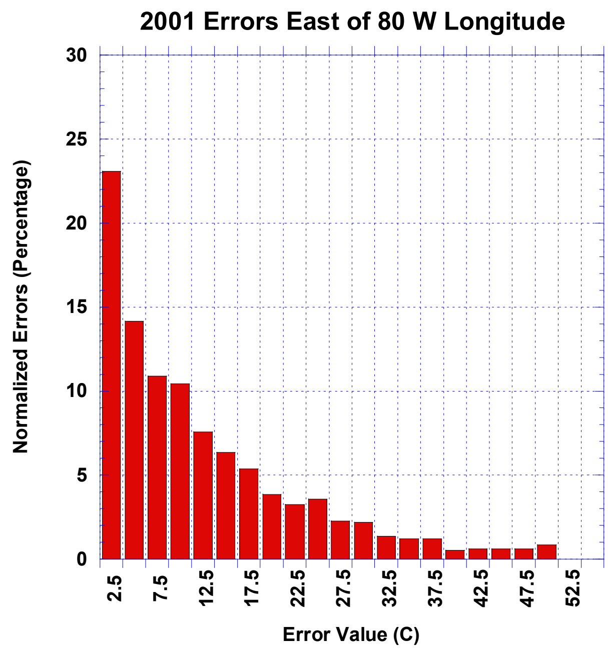


Fig. 7a – Percent error values for sounding locations east of 80 degrees west longitude.

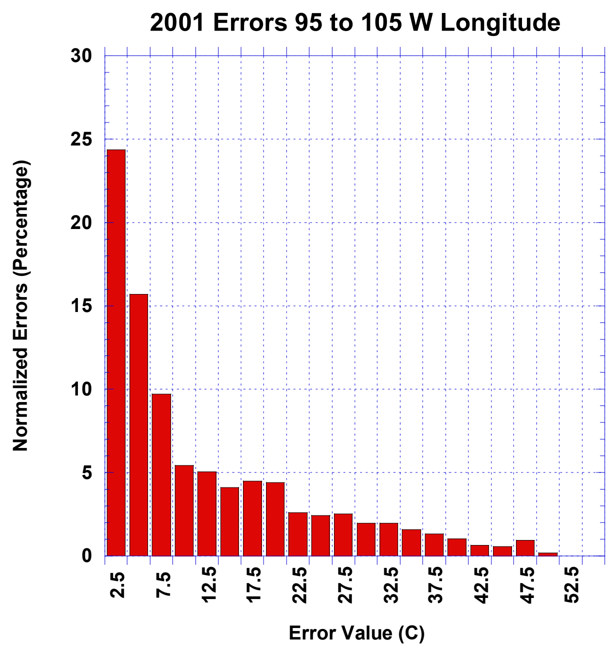


Fig. 7b – Percent error values for sounding locations between 95 and 105 degrees west longitude.

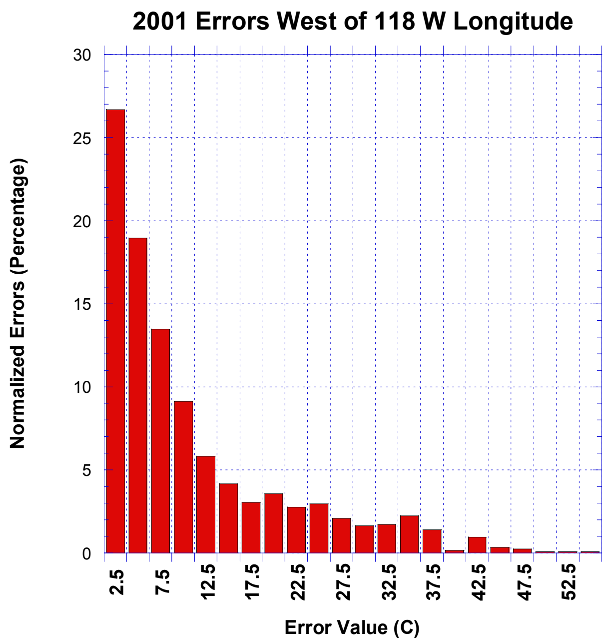

Figure 7c – Percent error values for sounding locations west of 118 degrees west longitude.

## 5. Conclusions

When comparing satellite and sounding-derived cloud top temperatures, results can vary widely. While there were not strong seasonal correlations observed, values are most similar for thick, warm clouds and most disparate for thin/sparse, cold clouds. The amount of error can depend strongly on the consistency of the cloud cover through which the sounding traveled. Results appeared to be best for widespread stratus clouds and worst for inconsistent, broken clouds. This would indicate that the Wang and Rossow technique for identifying cloud layers and cloud top temperatures works well for relatively thick, stratiform clouds. However, the Wang and Rossow technique often fails when broken and/or thin cloud layers are present. While results tended to get better for warmer clouds as opposed to colder clouds, the key factor was cloud thickness. Distributions of error indicated that the most common errors were <2.5$^{o}$C, but that large errors certainly do occur. No significant errors were attributed to satellite viewing angle.

## 6. References

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