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Analyzing cloud base at local and regional scales to understand tropical montane cloud forest vulnerability to climate change

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S1 Low and Minimum Cloud Base Metrics: Design, Rationale, and Calculation

Metrics based on the frequency distributions of ceilometer observations were developed to summarize the cloud-base altitude data for altitude ranges of interest in the tropical montane cloud forest (TMCF) in the Luquillo Experimental Forest (LEF). Specifically, we were interested in clouds in the altitude range that had been previously reported to contain cloud forest, a range of ~600-1077 m. We wanted to understand how consistently clouds were low (forest altitude range) in a given day, since spurious low clouds would not be expected to sustain a TMCF. To this end, we designed quantile-based metrics that summarized clouds at each hour of the day and throughout the day. Quantile-based metrics can take into account clear-sky observations by setting them as an infinite cloud base, or a cloud base higher than any other observation, whereas average-based metrics must ignore clear-sky observations. It is possible that an average-based metric could always lie above 1077 m, therefore not providing any information about the altitude range of interest.

To develop metrics for a different TMCF, the protocol based on this study is described here. We set hourly low and minimum metrics respectively as 1) a quantile that represented observations from a *considerable* portion of the hour but still resulted in the metric values falling in the altitude range of interest a majority of the time (50% of the time across each season in the present study); and 2) the hourly minimum, representing the lower bound of cloud influence in the hour. These hourly metrics can then be used to compute daily low and minimum metrics, set respectively as 1) a quantile that represents observations from a *considerable* portion of the day but still results in the metric values falling in the altitude range of interest a majority of the time; and 2) the value that the daily minimum is below *almost* every hour (such that the metric values fall in the altitude range of interest a majority of the time), representing the lower bound of cloud influence continual throughout the day. The italicized words here indicate a seemingly qualitative measure, but in fact are quantitatively constrained by the altitude of the TMCF; their resulting quantiles may be applied to studies on the sustainability requirements of the cloud forest. If too low of a quantile is chosen to define the metrics, (e.g. a daily first octile O_1) all the metrics will calculate below the altitude range of interest, whereas if too high of a quantile is chosen (e.g. a daily third quartile Q_3) all the metrics will calculate above. These choices will not inform about the uniqueness of the altitude the TMCF ranges in.

Due to the available data format of the regional Automated Surface Observation System (ASOS), average-based metrics had to be used to analyse the regional system. For these, the mean-hour calculation omits clear-sky observations. In order to represent usual atmospheric conditions, mean-hour cloud base was considered clear sky (in calculation of the daily metrics) if the cloud cover fraction was less than 50% of the period of record mean cloud cover. In the case of the LEF site, this was < 0.3 cloud cover (> 0.7 frequency of clear-sky observations in the hour).

The following diagrams show the three steps of creating the metrics for two days of ceilometer observations. First, the 30-second data is collected for one day and cloud cover is computed. Second, each hourly metric is computed from the 120 observations within each hour. Third, the hourly metrics are used to compute the daily metrics. The two days shown were chosen randomly and so are not necessarily representative of typical days in their seasons. All metrics are shown in km (Figs S1 and S2; bold black text) as computed; except cloud cover, which is in fractional cover per day.

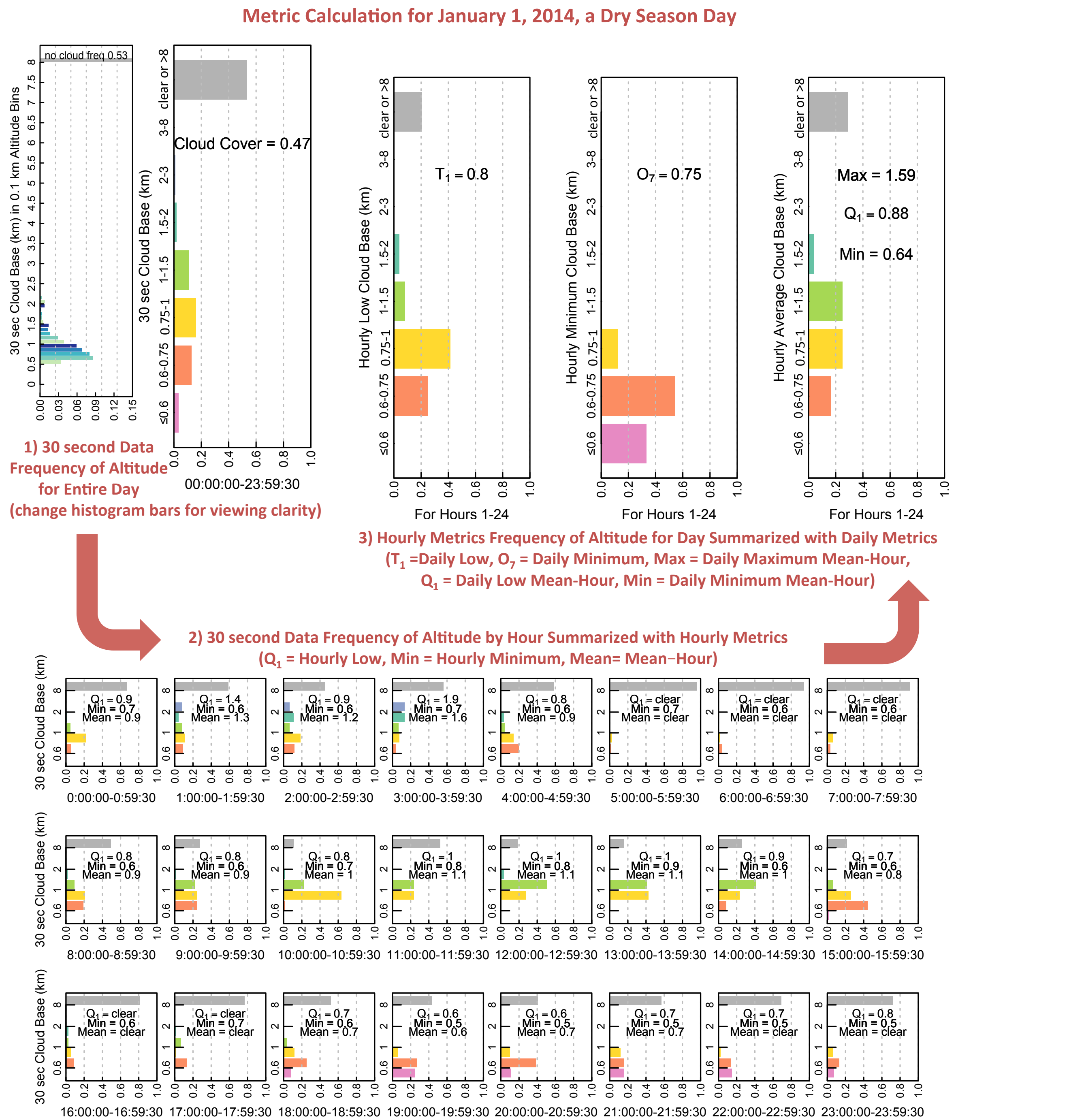

Figure S1: Three steps creating metrics for January 1, 2014. Note that the histogram bins, after the first part of step 1, are uneven in size and grouped in site-specific altitudes of interest for viewing clarity. Bar colors are for clarity and are consistent across figures and plots.

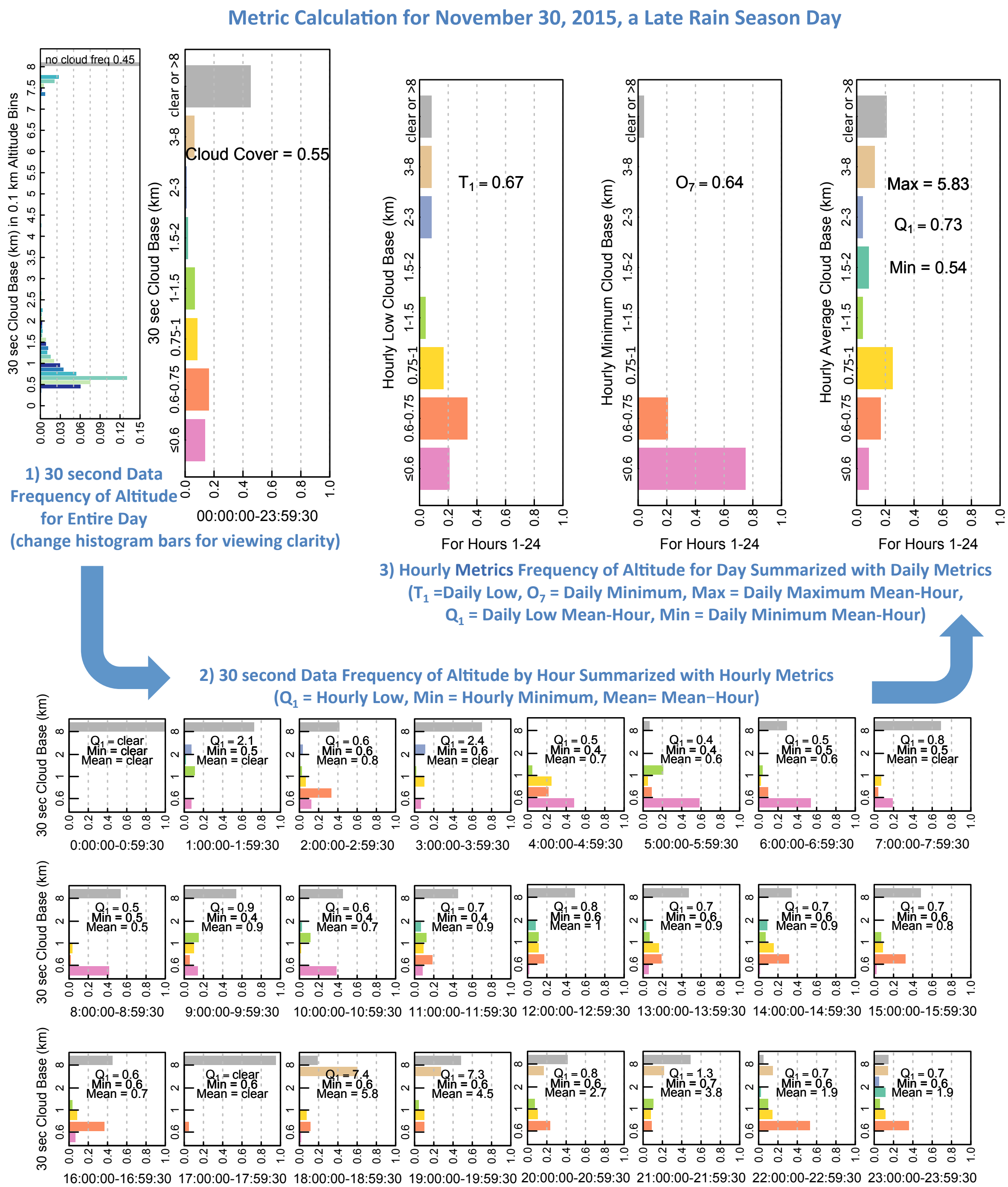

Figure S2: Three steps creating metrics for November 30, 2015. Note that the histogram bins, after the first part of step 1, are uneven in size and grouped in site-specific altitudes of interest for viewing clarity. Bar colors are for clarity and are consistent across figures and plots.