Atmospheric Opacity Observations from the VLBA and CSO Sites on Mauna Kea

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June 13, 1994

Abstract. Fourteen months of atmospheric opacity observations from the Caltech Submillimeter Observatory (CSO) site and the VLBA site on Mauna Kea, Hawaii, are presented in this memorandum. These data, which cover the time period November 1992 through December 1993, were acquired by two of the NRAO 225-GHz tipping radiometers, in continuance of the MMA site testing program. The VLBA site, located at the 3725-m (12,220-ft) level, is adjacent to the potential MMA site on Mauna Kea. The CSO site is at 4072m (13,360ft). A plot of each day's data is shown. Quartile values of the opacity measurements during the 14-month period are (0.052, 0.080, 0.146) Nepers for the CSO site and (0.070, 0.112, 0.216) Nepers for the VLBA site.

Two of the NRAO's 225-GHz tipping radiometers have been in continual, simultaneous operation on Mauna Kea since November of 1992. One is located near the summit, at the site of the Caltech Submillimeter Observatory (CSO). Earlier data from this site, covering the time period September 1989 through August 1991, were presented by Hogg in MMA Memorandum No. 79 [1]. The second instrument is located at the VLBA antenna site, which is adjacent to one of the sites that is under consideration for the proposed Millimeter Array. The VLBA site is at the 3725-m (12,220-ft) level of the mountain and approximately 4km distant from the CSO site, which is at 4072m (13,360ft).

The equipment, the observational technique, and the data-recording scheme that were employed for these observations are identical in all essential respects to those which were used for the earlier observations described by Hogg in [1]. Tipping scans, each producing an estimate of the zenith opacity, were generally performed every ten minutes of the day, except during one-hour periods spaced, typically, five hours apart. (The sky-brightness-temperature fluctuation data which were recorded during these one-hour periods will be described elsewhere.) The observations presented here cover the period November 1992 through December 1993.[1]

Data editing, analysis, and display all were done within the *Mathematica* package from Wolfram Research, Inc.

Data Editing. Data from most of this time period appeared to be of excellent quality, so it was unnecessary to edit the data very heavily. Because of the geographical proximity of the two radiometers, one would expect their outputs to track one another quite closely. Generally this was the case—the data streams appeared to be mutually consistent and strongly correlated, except that during the first couple of months of operation there were periods of erratic behavior from the CSO radiometer and periods when its opacity readings were anomalously high. Also, there were some anomalous spikes in the data. It was decided to apply only two editing operations: (1) Opacity readings from the CSO tipper which were more than 20% higher than the value interpolated from VLBA tipper measurements were discarded; and (2), points deviating by more than 35% from a three-point running average were discarded.

[1]The radiometer at the VLBA site was not operational between mid-January and mid-March of 1994. Because of this, and since the only additional data yet available are from April, the 1994 data will be presented in a later memorandum.

With the exception of the first three months of data, where large fractions (10%–20%) were edited out, generally around a few percent of the data were discarded. The rank-order statistics (quartiles and deciles) presented below were little affected by the data editing, except at the high end (above the fiftieth percentile). Still, in retrospect, I feel the data were somewhat over-edited, but this editing strategy was settled upon for the sake of consistency with the data editing which was used (by me) for the New Mexico and Arizona sites.

Results. Plots of each month's data, and for each day of the month, are shown in Figures 1 through 14. The abscissae of these plots represent time of day, in hours UT. Hawaii is ten hours west of Greenwich; thus the nighttime period is at the middle portion of each plot. The histograms show the distributions of observed opacities from each month, along with quartile values and the ratios of quartiles. (During a few of the months, significant amounts of data were lost, due to equipment malfunction, at one or the other of the sites, so one should exercise caution in interpreting the histograms and summary statistics for these particular months.) It is interesting to compare the November/December data of 1992 with the data from the same two months of 1993: Nov./Dec. 1992 were poor months, while, in contrast, Nov./Dec. 1993 were very good. Conditions of very low opacity prevailed during prolonged periods throughout the months of January through May, 1993.

The ratio of the opacity measured at the VLBA site to the opacity measured at the CSO site is generally around 1.2 when conditions are good at both sites; at other times the ratio tends to be higher. Conditions are generally either good at both sites (e.g., on April 17, 1993—see Fig. 6a), bad at both sites, or good at the CSO site and bad at the VLBA site. The latter circumstance occurs during many of the daytime periods. Compare, for example, the data for April 20, 24, 26, and 27, with those from April 17.

A plot of the frequency distributions of the two sets of Mauna Kea opacity data is shown in Figure 15. The quartile values are (0.052, 0.080, 0.146) Nepers for the CSO site and (0.070, 0.112, 0.216) Nepers for the VLBA site. The decile values are (0.037, 0.047, 0.058, 0.068, 0.080, 0.097, 0.126, 0.175, 0.268) and (0.048, 0.063, 0.077, 0.093, 0.112, 0.137, 0.181, 0.258, 0.391), respectively.

Figure 16 is a comparison of the 1992–1993 data from the CSO site with the 1989–1991 CSO data presented by Hogg in [1] (no previous data are available from the VLBA site). First- and second-quartile values of opacity are plotted for each month. The 1992–1993 CSO data do not stand out as discordant or—insofar as one is able to conclude—atypical.

Copies of any (or all) of the raw or edited data from Mauna Kea could easily be provided to any interested party, as could a copy of the Mathematica command file which was used for editing and displaying the data. If one were interested in applying a different editing strategy, generating additional summary statistics, or generating alternative graphical displays, the Mathematica command file could easily be modified appropriately.

Color versions of the plots presented here were also generated. Bob Hjellming and I may attempt to make these available in the NRAO "Mosaic" pages.

Acknowledgments

The MMA tipping-radiometer site-testing campaign was initiated by Frazer Owen. Continuing organizational oversight has been provided by Bob Brown. Gerry Petencin has been responsible for engineering support and maintenance of the tippers, as well their deployment in the field. Joanne Nance has done an admirable job of organizing and archiving the raw measurements. Operational support has been provided by the local staffs of the CSO and VLBA sites.

Reference

[1] D. E. Hogg, "A summary of the data obtained during the mmA site survey", NRAO Millimeter Array Memorandum No. 79, February, 1992.

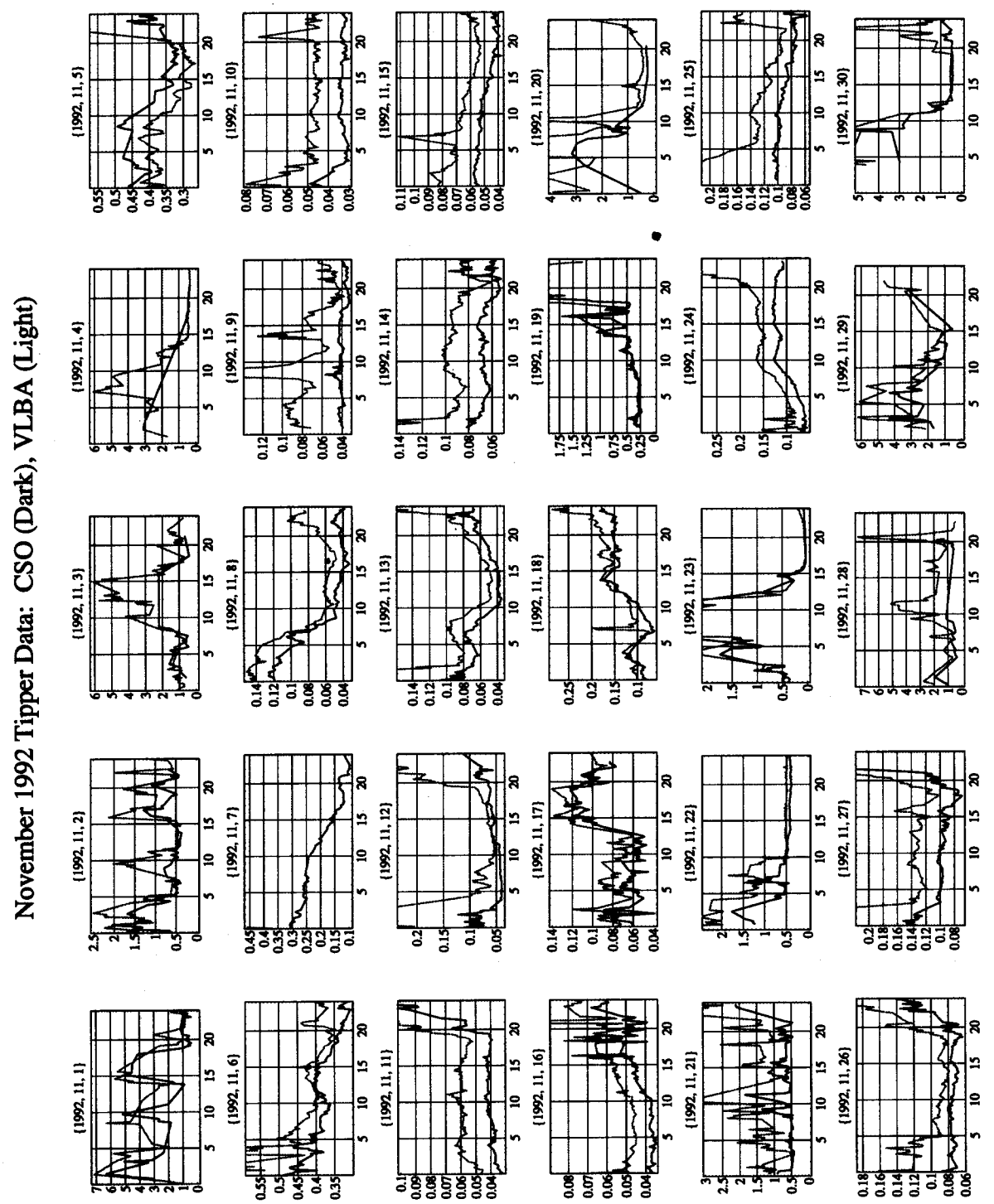

Figure 1a. November 1992, 225-GHz zenith opacity observations (measured in units of Nepers) are plotted versus time of day, in hours UT, for each day of the month.

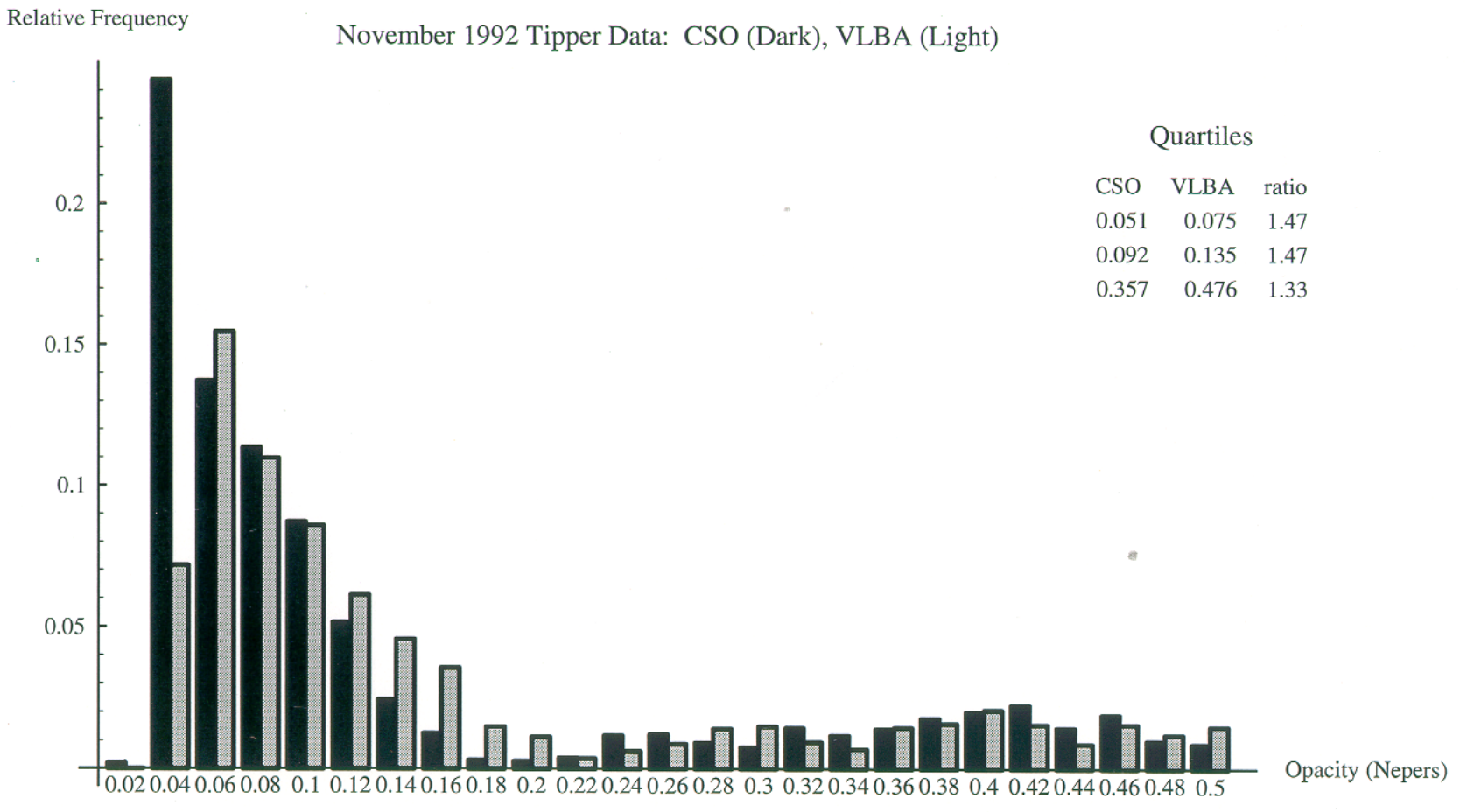

Figure 1b. Histogram of observed zenith opacities, November 1992.

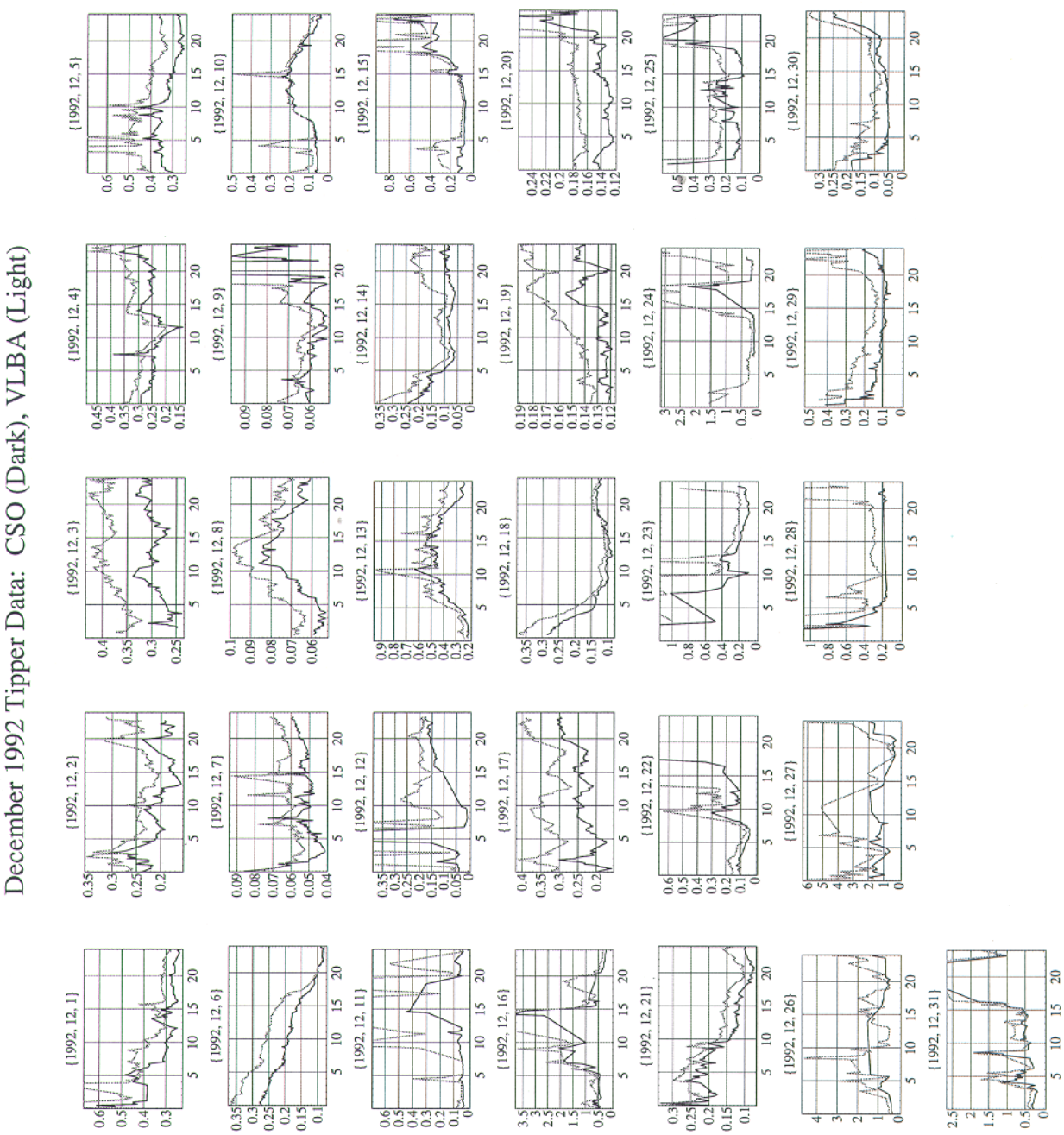

Figure 2a. December 1992, 225-GHz zenith opacity observations (measured in units of Nepers) are plotted versus time of day, in hours UT, for each day of the month.

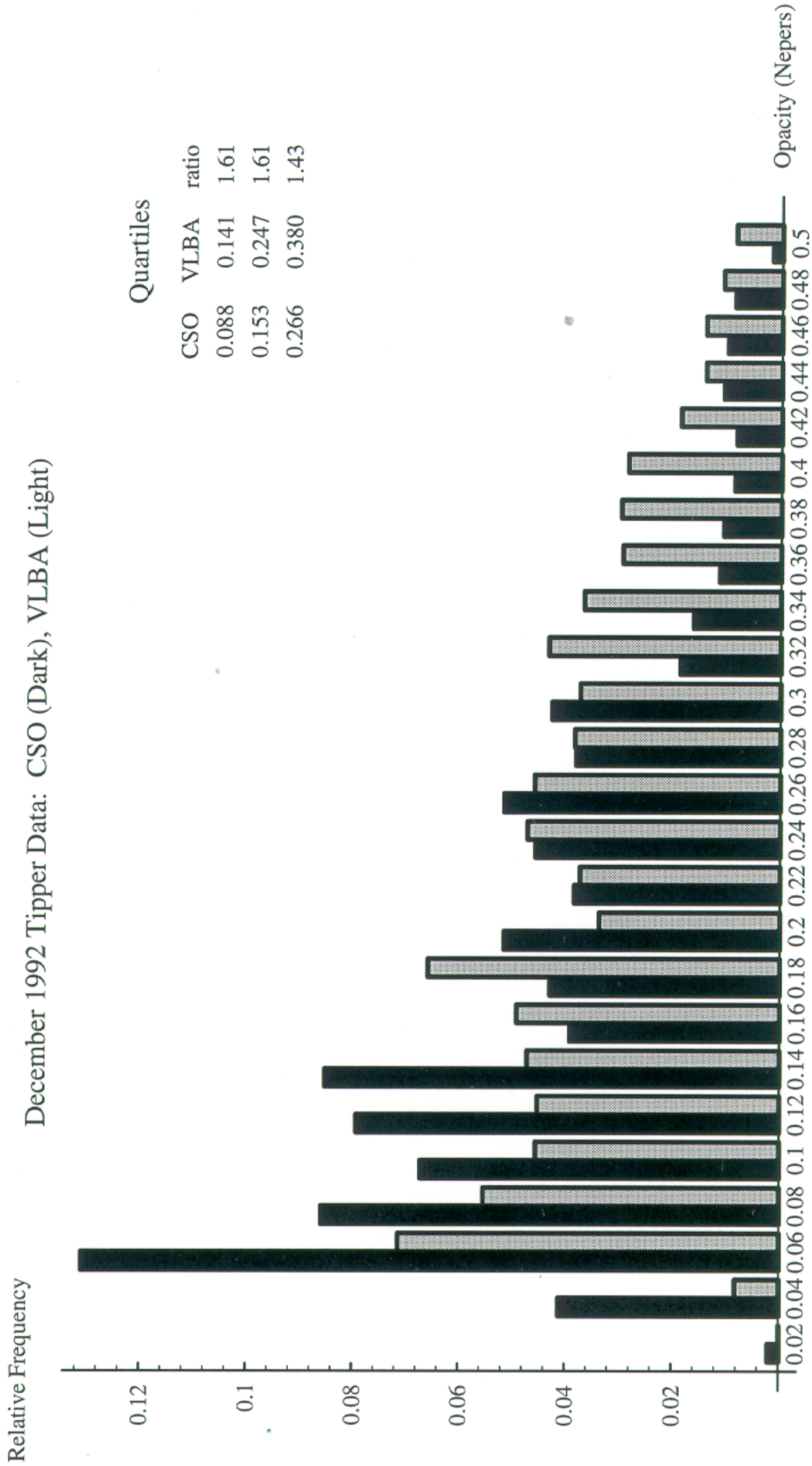

Figure 2b. Histogram of observed zenith opacities, December 1992.

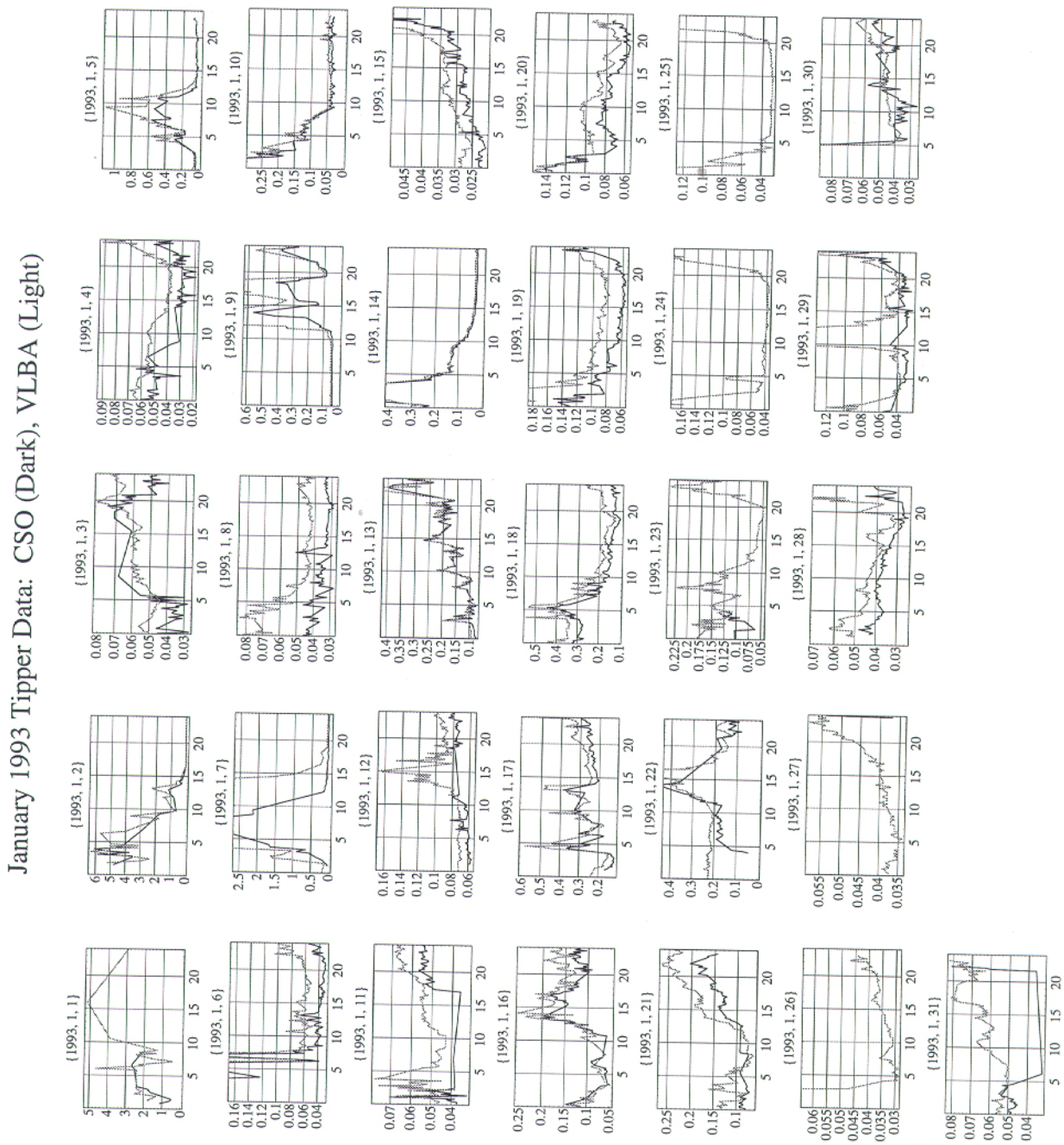

Figure 3a. January 1993, 225-GHz zenith opacity observations (measured in units of Nepers) are plotted versus time of day, in hours UT, for each day of the month.

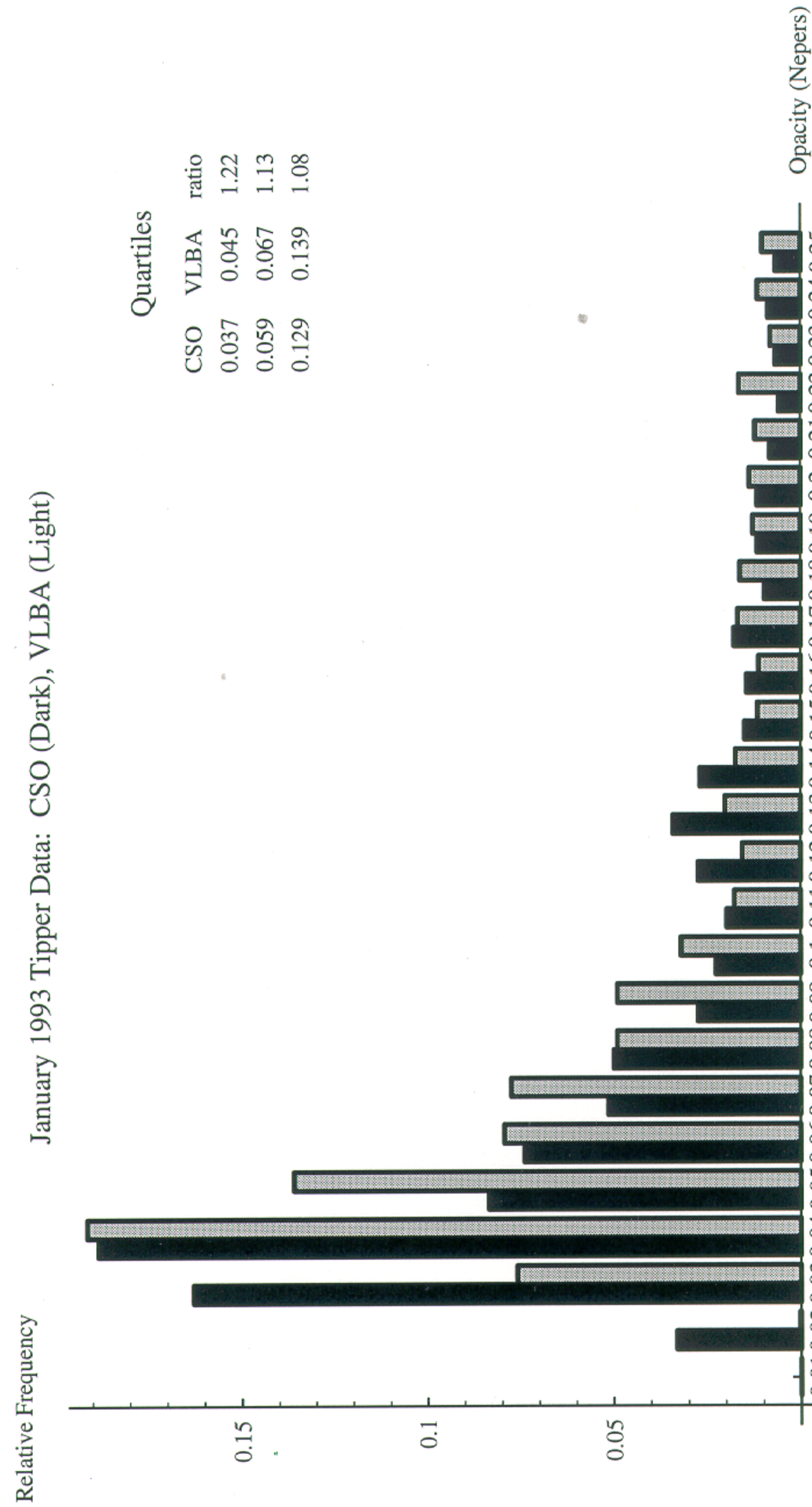

Figure 3b. Histogram of observed zenith opacities, January 1993.

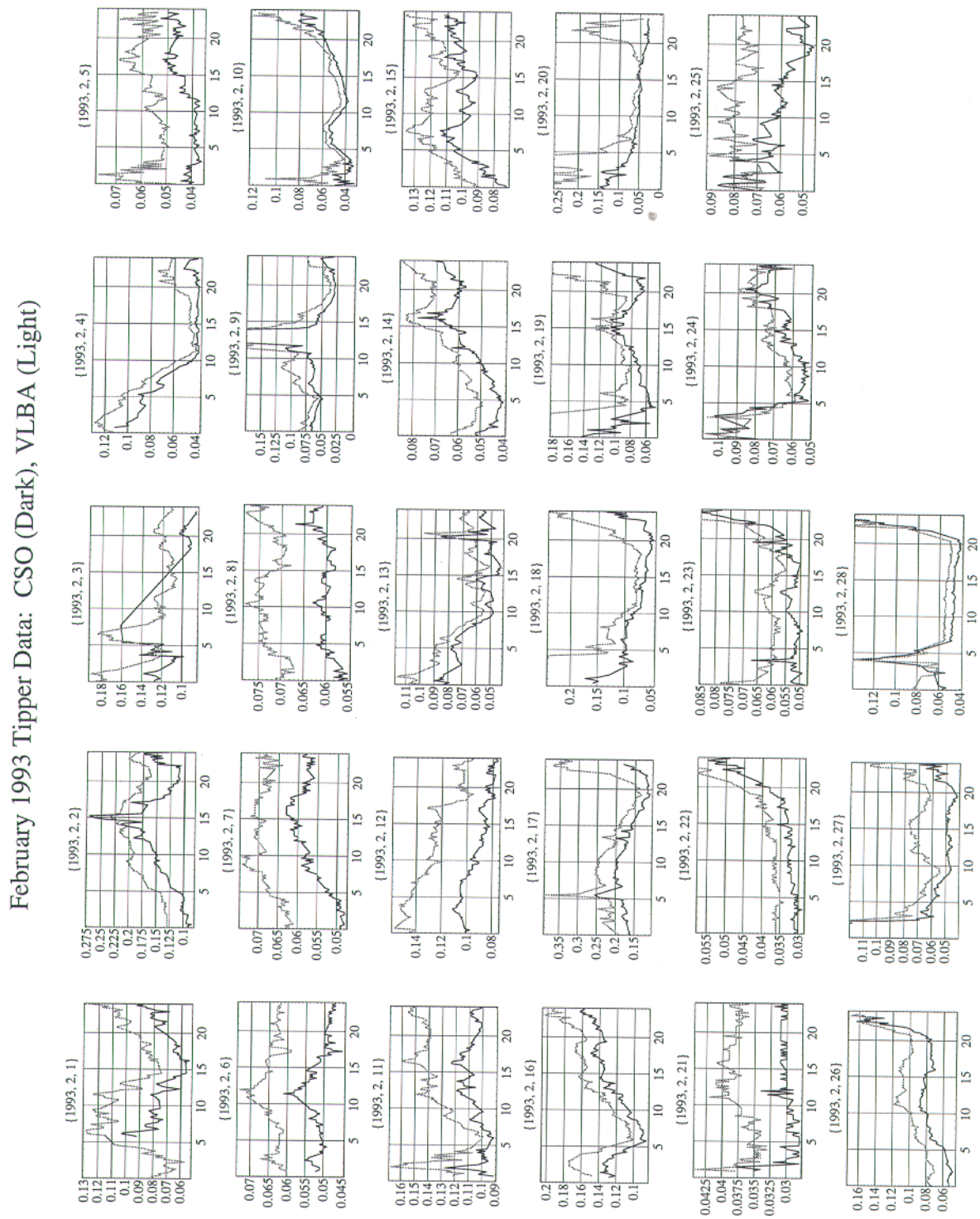

Figure 4a. February 1993, 225-GHz zenith opacity observations (measured in units of Nepers) are plotted versus time of day, in hours UT, for each day of the month.

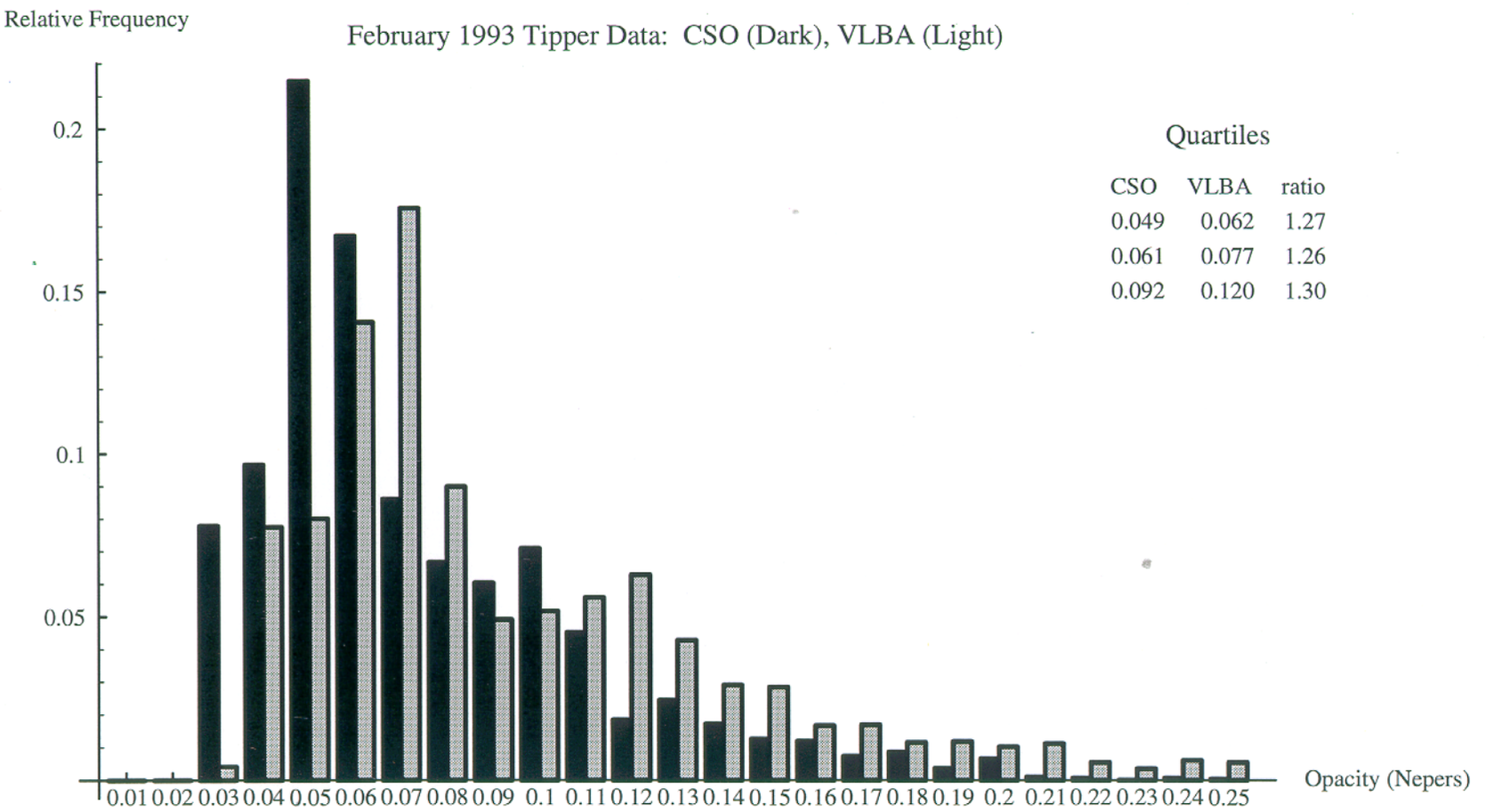

Figure 4b. Histogram of observed zenith opacities, February 1993.

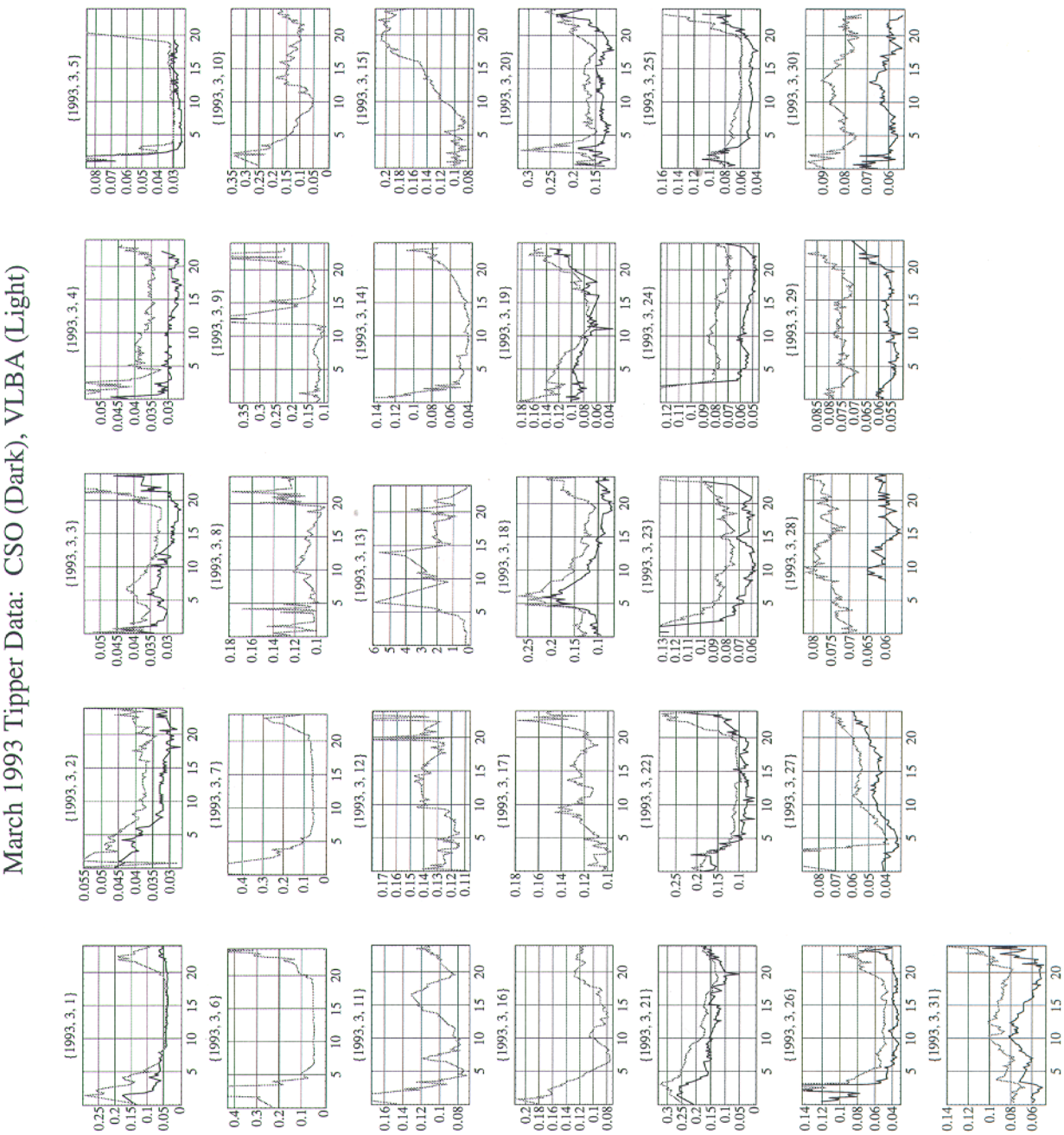

Figure 5a. March 1993, 225-GHz zenith opacity observations (measured in units of Nepers) are plotted versus time of day, in hours UT, for each day of the month.

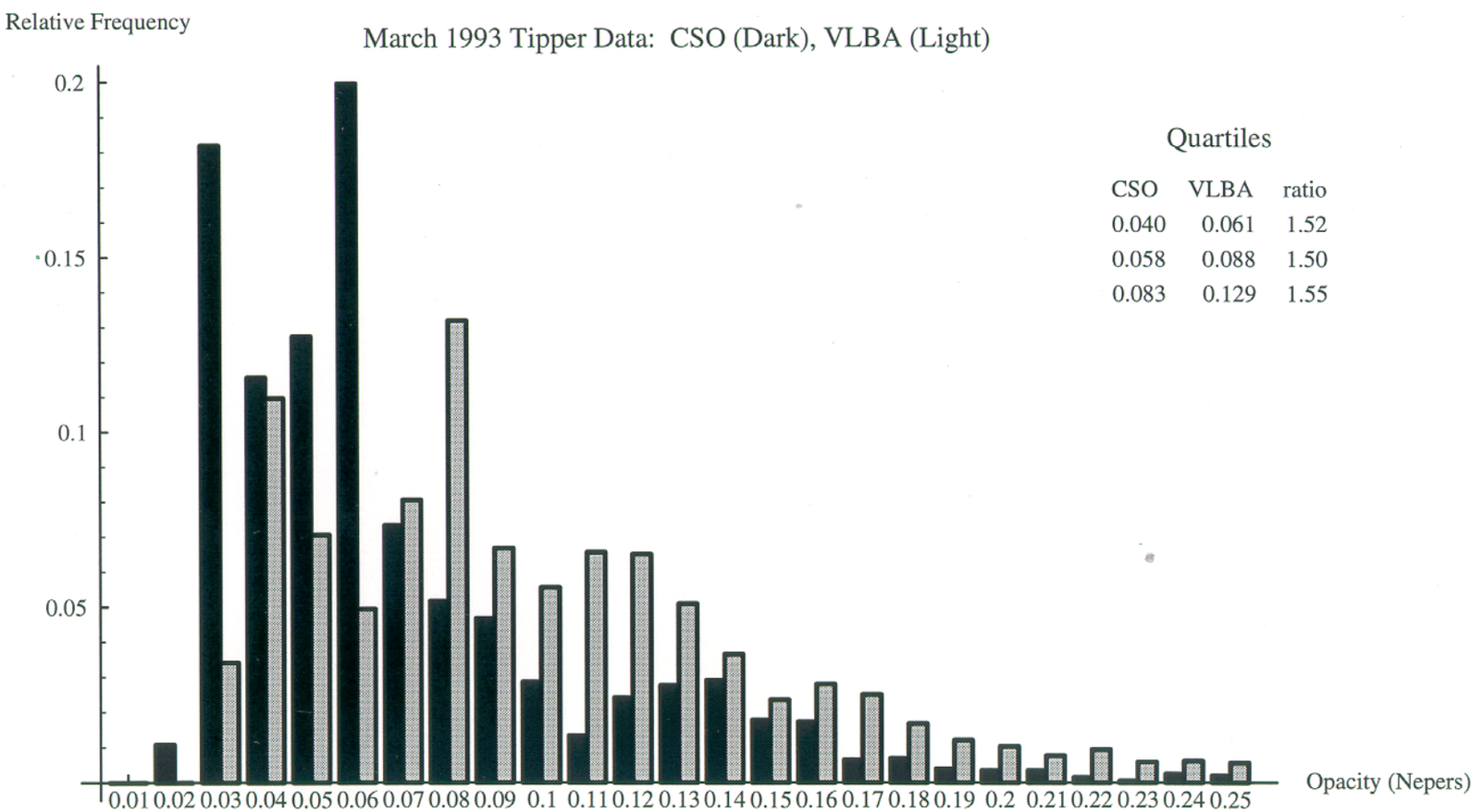

Figure 5b. Histogram of observed zenith opacities, March 1993.

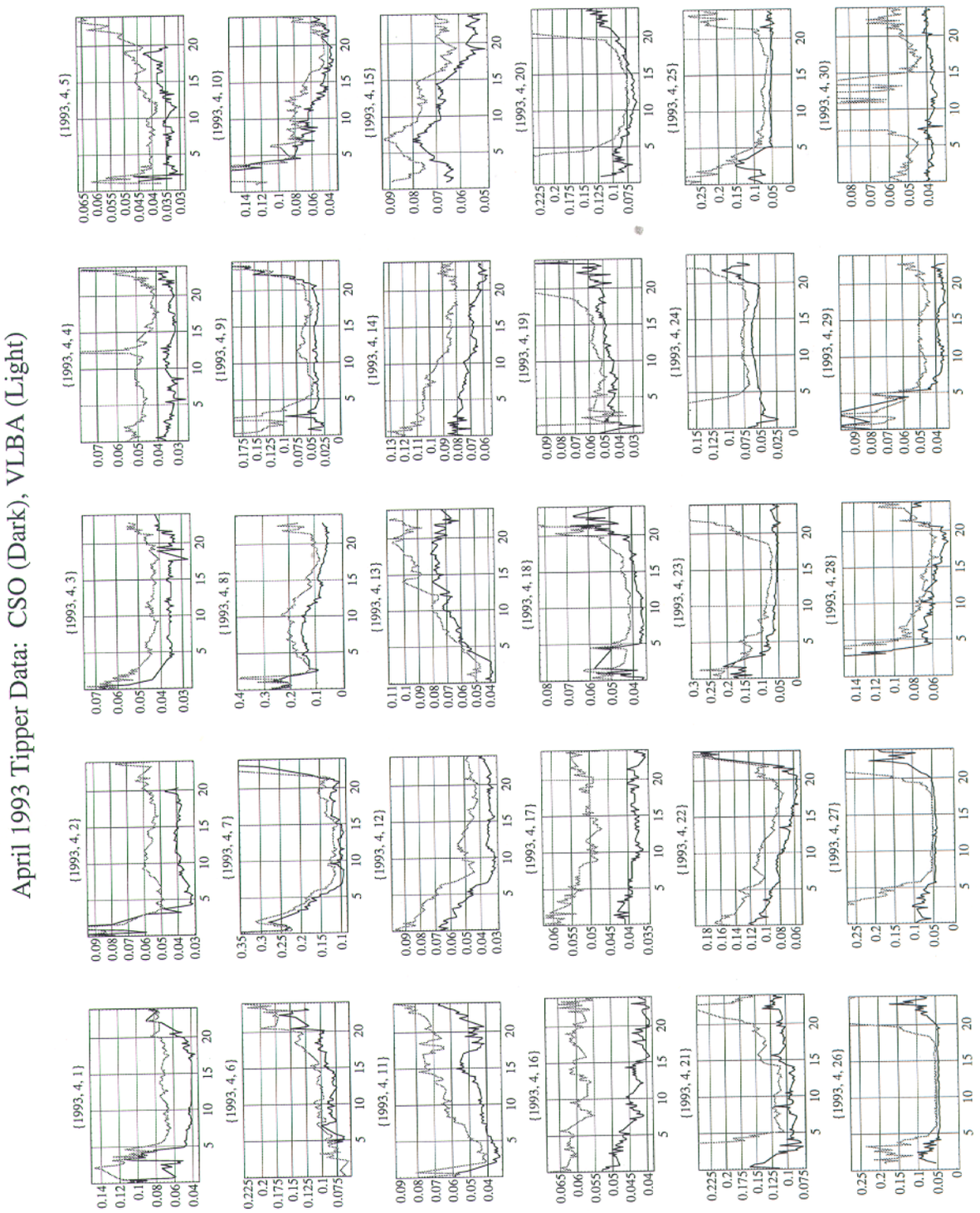

Figure 6a. April 1993, 225-GHz zenith opacity observations (measured in units of Nepers) are plotted versus time of day, in hours UT, for each day of the month.

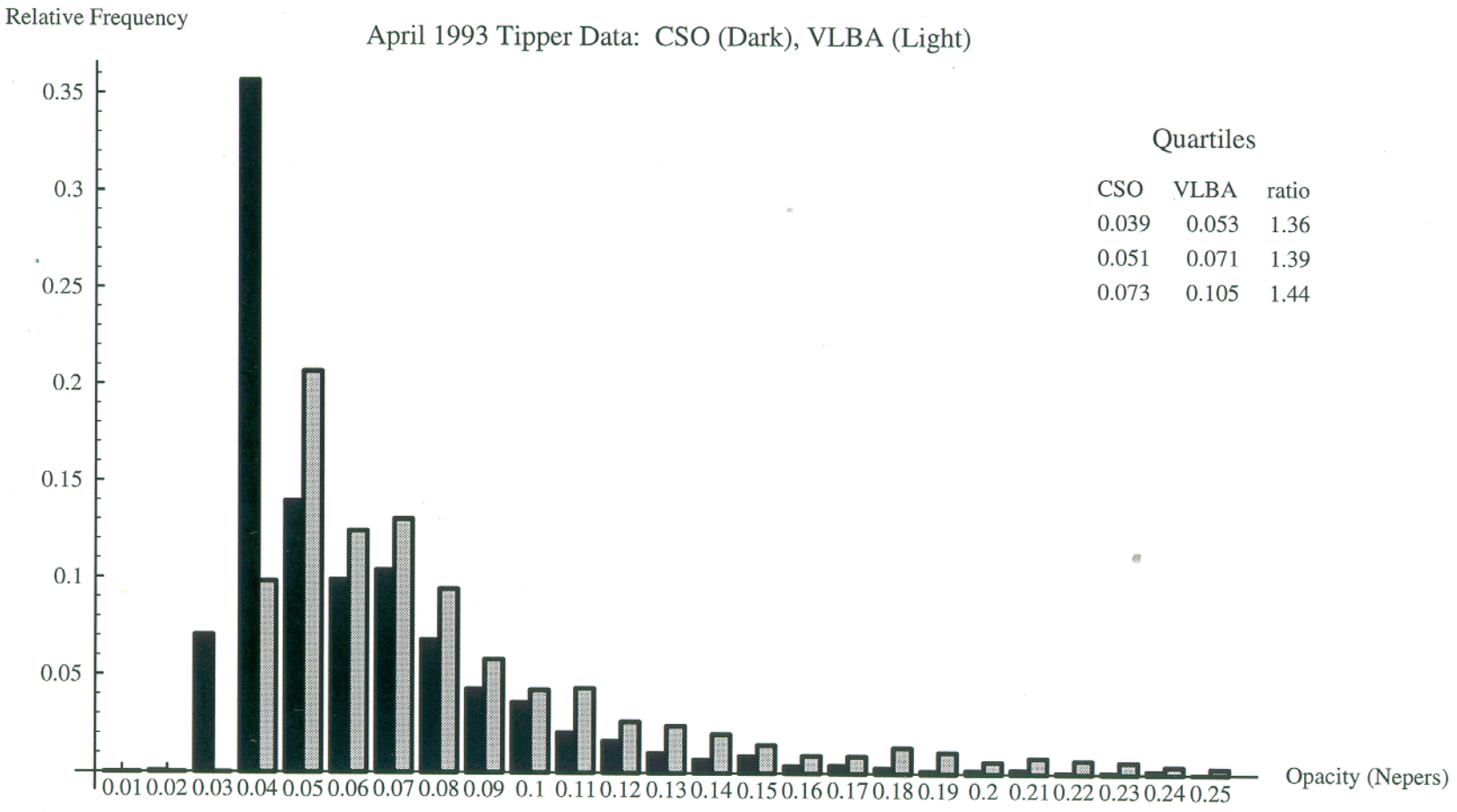

Figure 6b. Histogram of observed zenith opacities, April 1993.

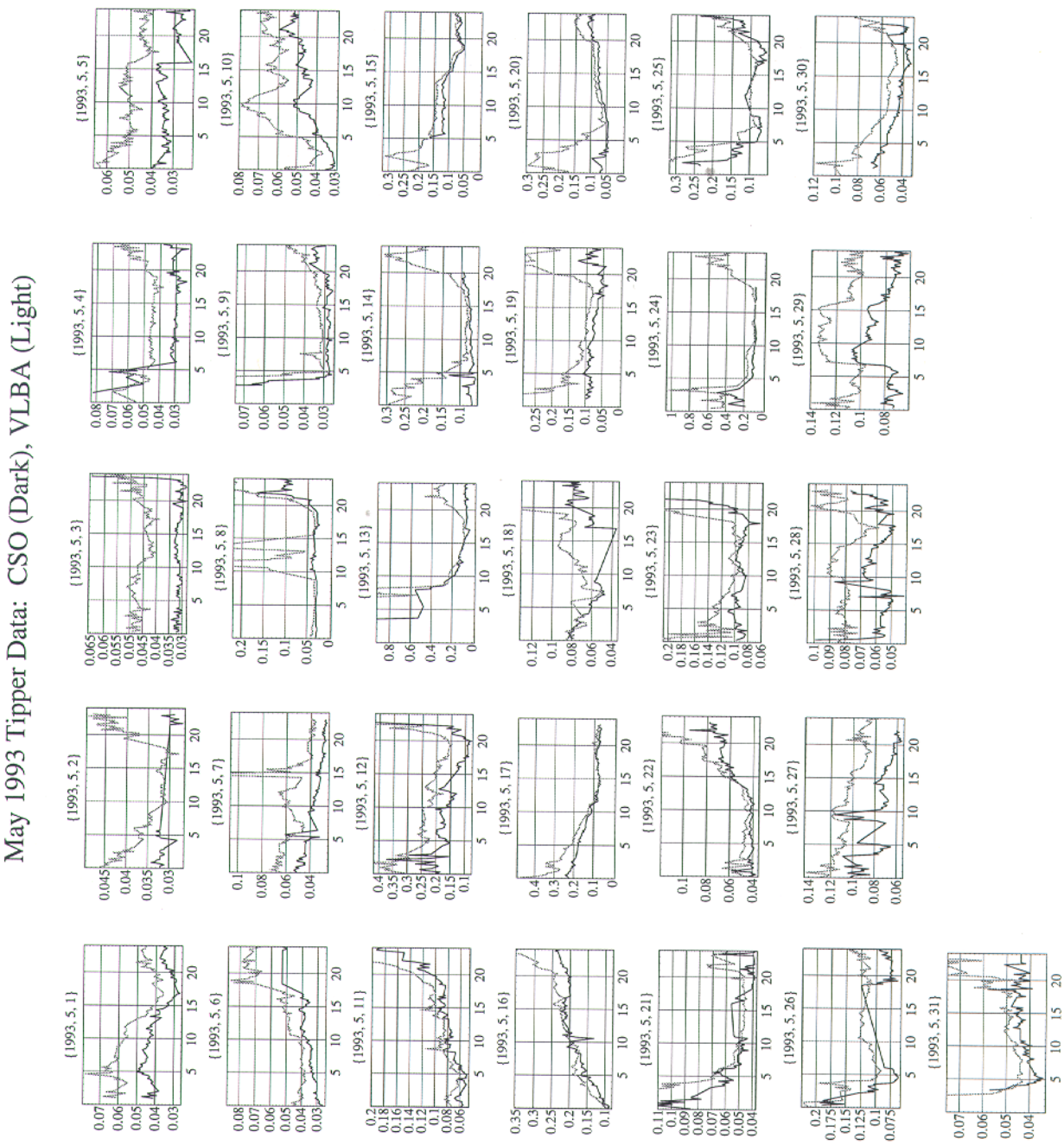

Figure 7a. May 1993, 225-GHz zenith opacity observations (measured in units of Nepers) are plotted versus time of day, in hours UT, for each day of the month.

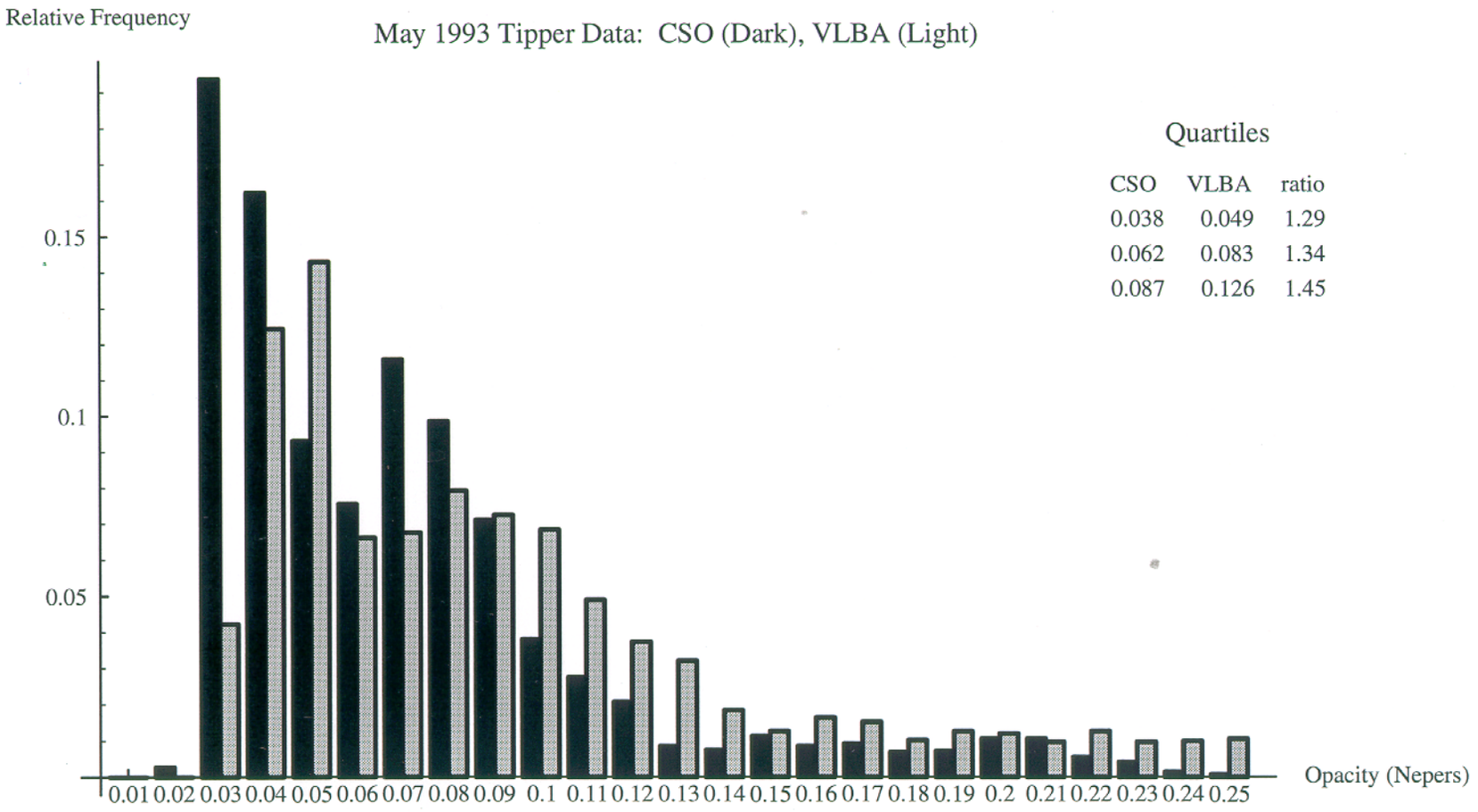

Figure 7b. Histogram of observed zenith opacities, May 1993.

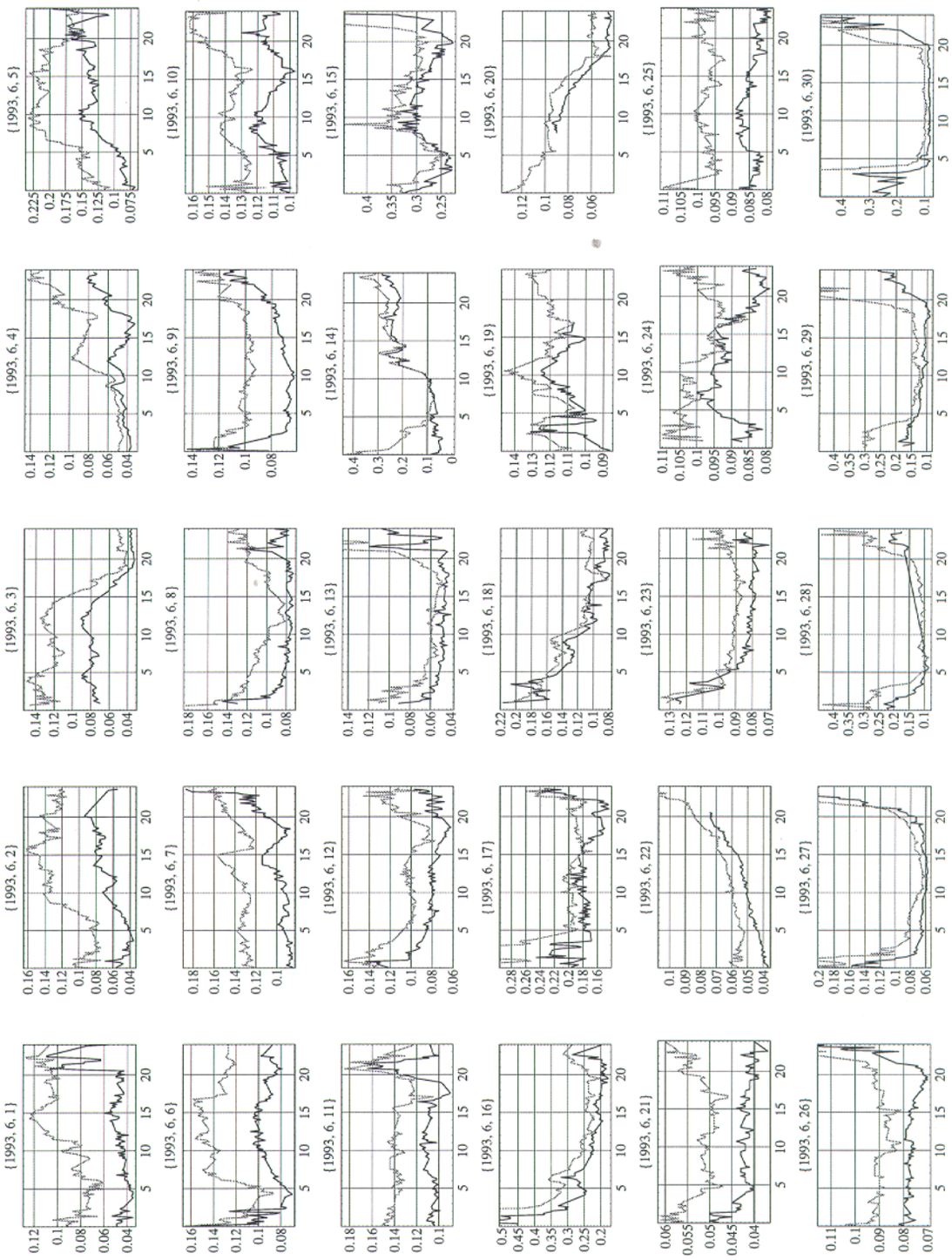

Figure 8a. June 1993, 225-GHz zenith opacity observations (measured in units of Nepers) are plotted versus time of day, in hours UT, for each day of the month.

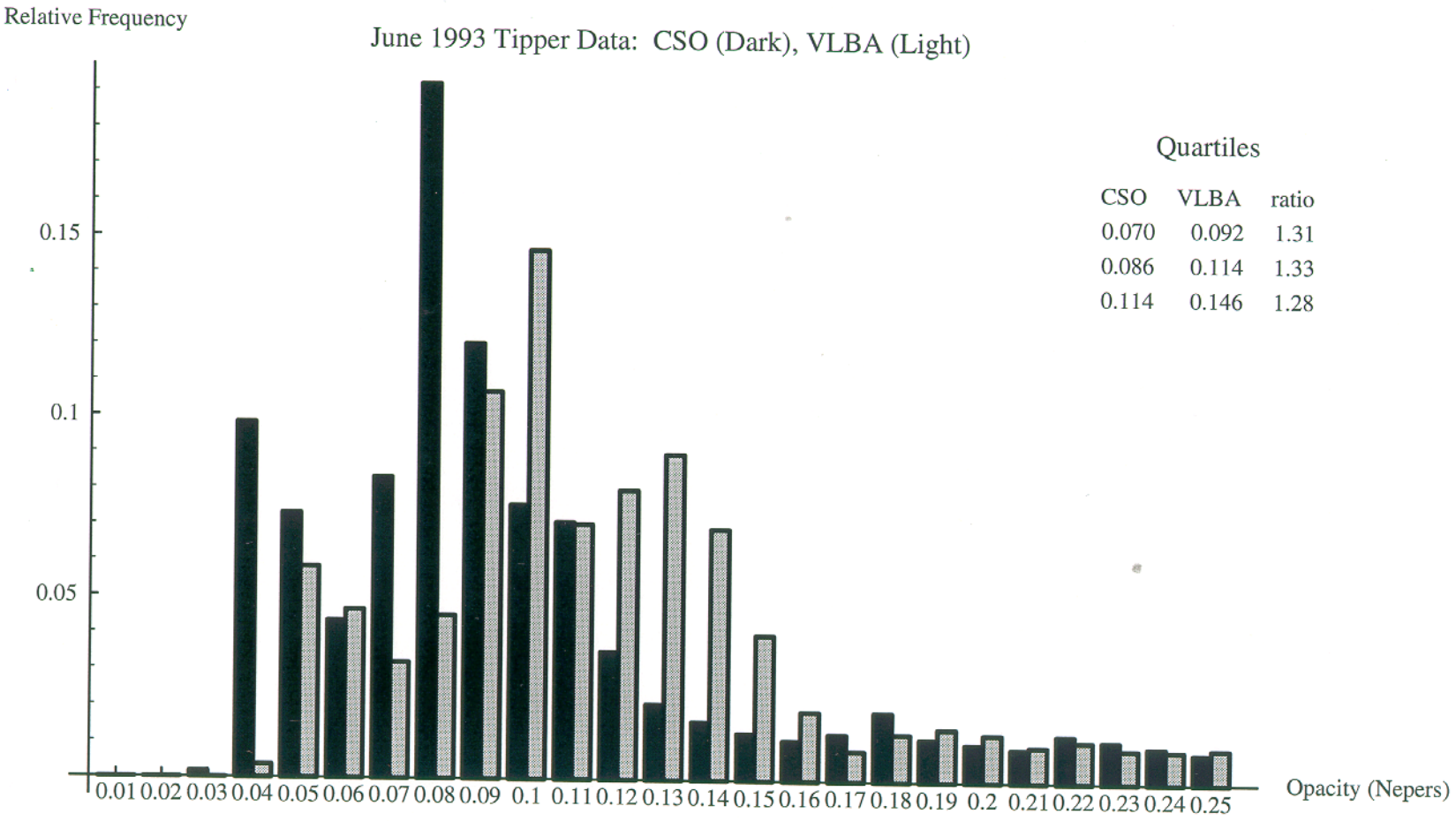

Figure 8b. Histogram of observed zenith opacities, June 1993.

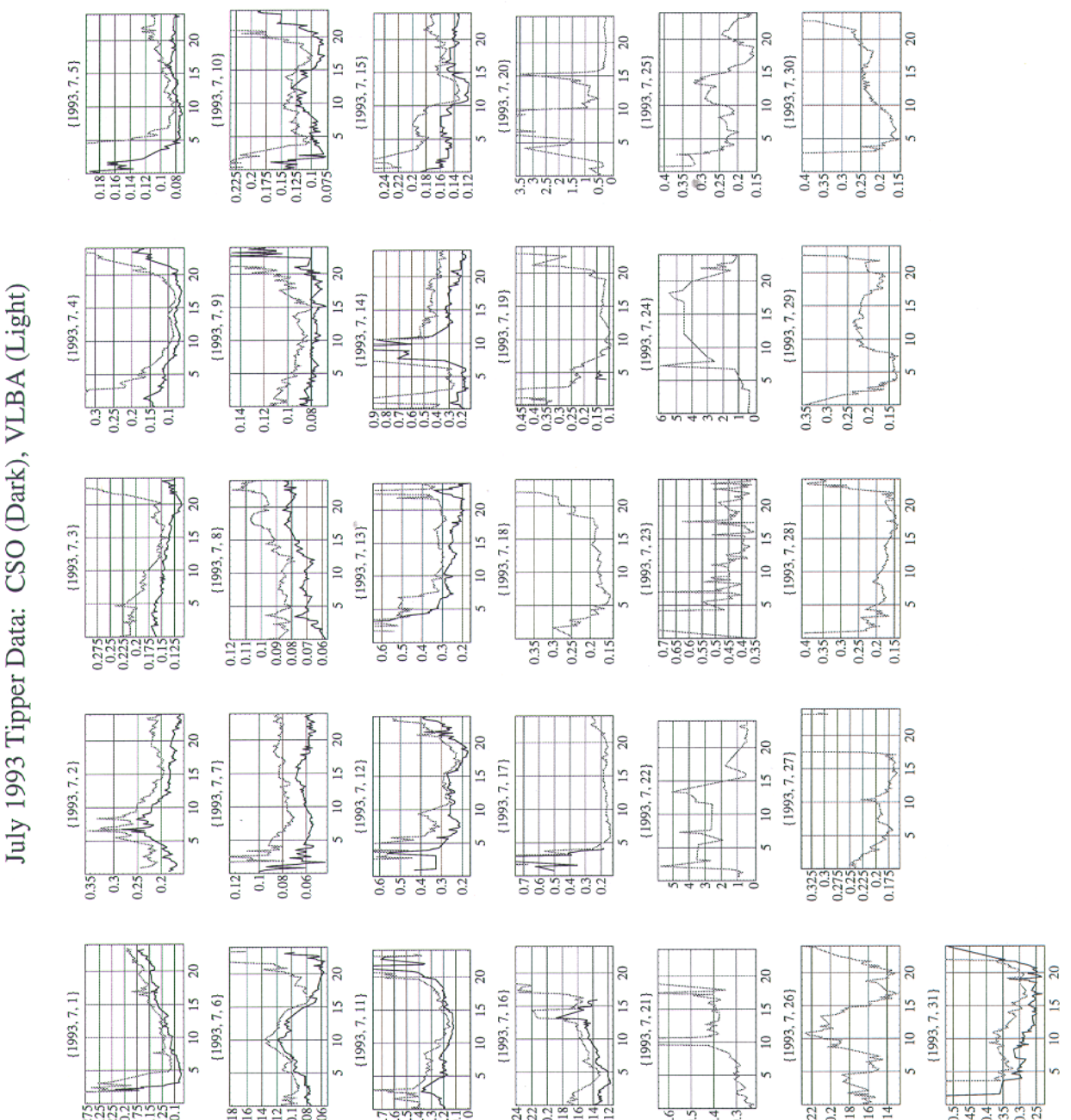

Figure 9a. July 1993, 225-GHz zenith opacity observations (measured in units of Nepers) are plotted versus time of day, in hours UT, for each day of the month.

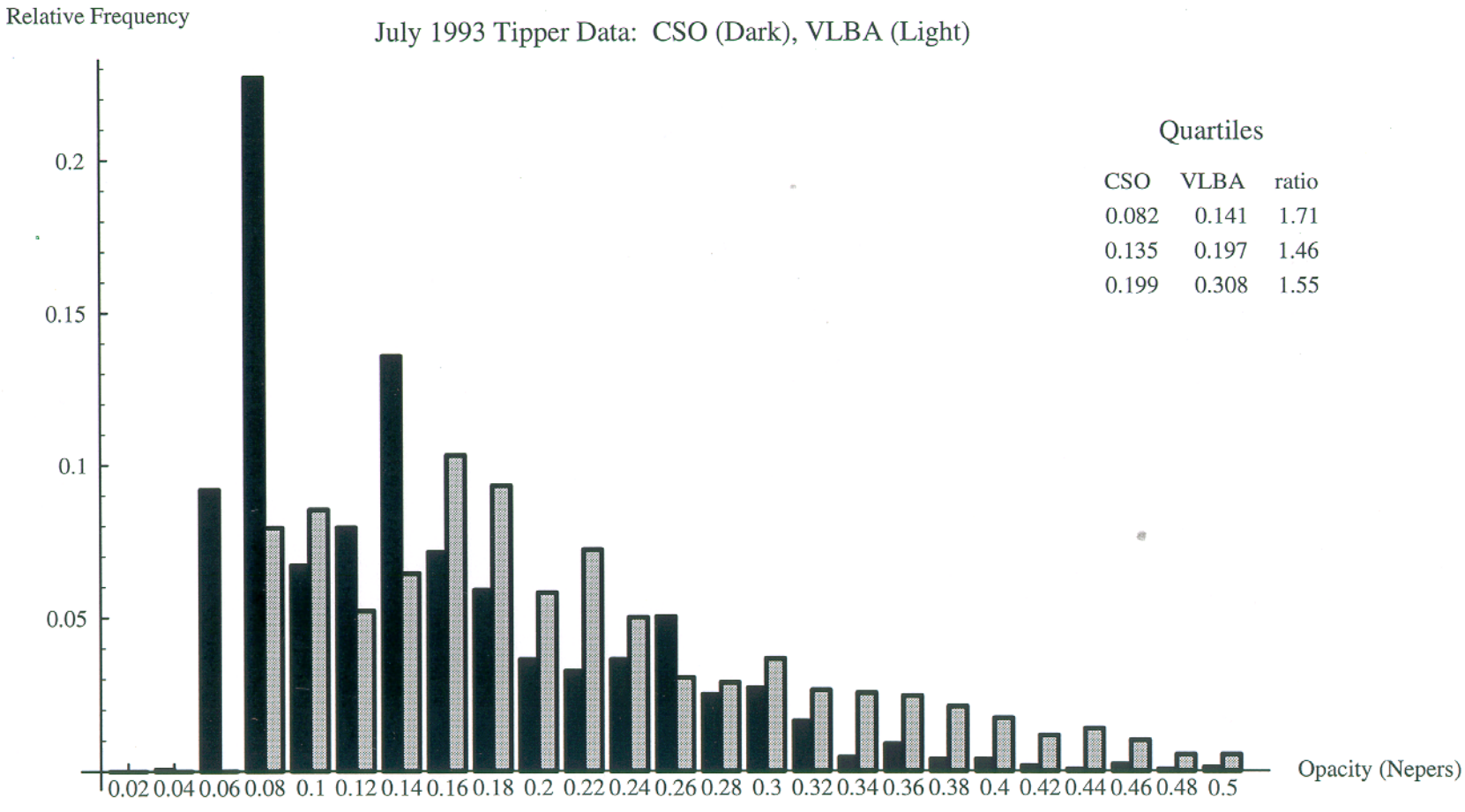

Figure 9b. Histogram of observed zenith opacities, July 1993.

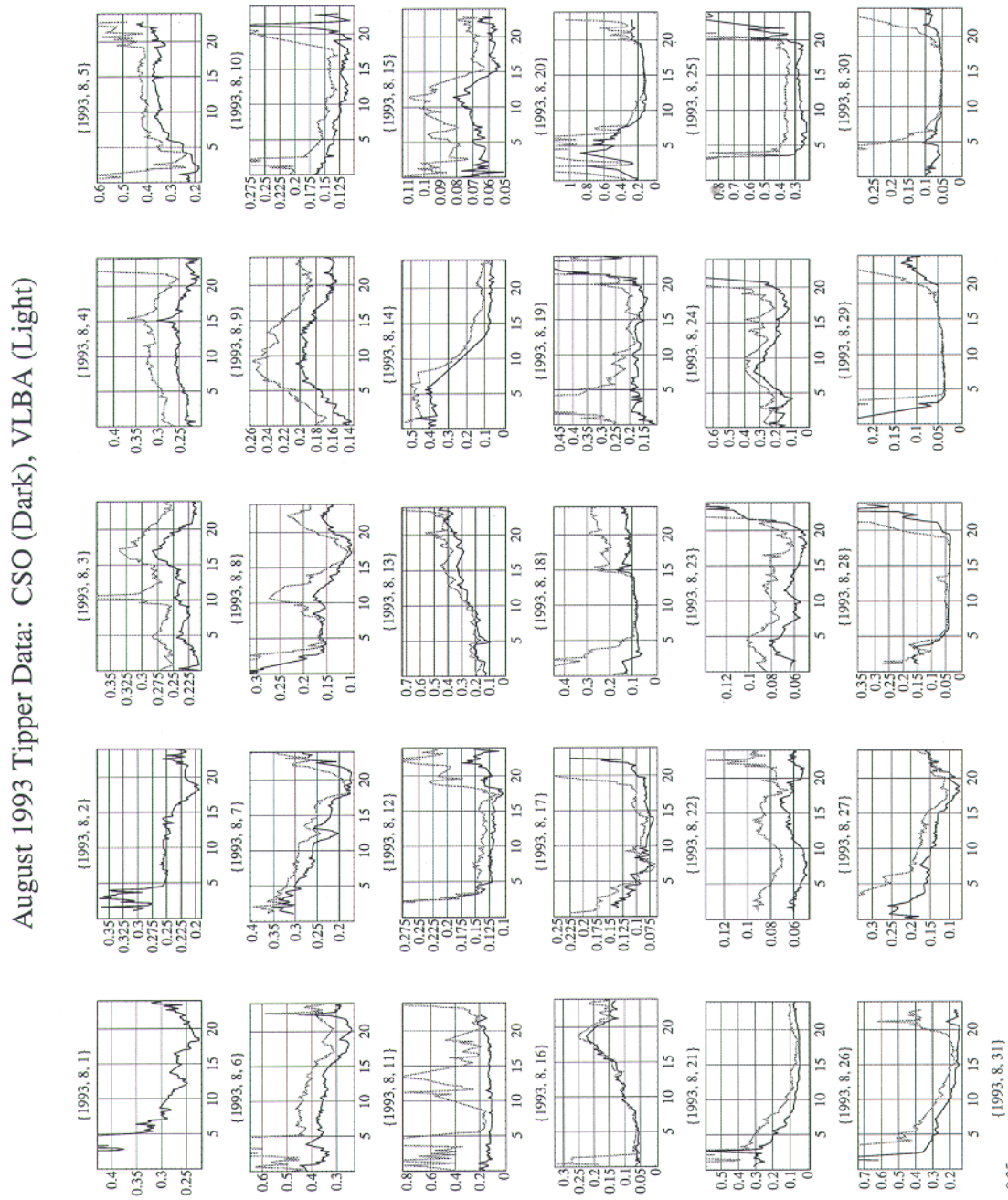

Figure 10a. August 1993, 225-GHz zenith opacity observations (measured in units of Nepers) are plotted versus time of day, in hours UT, for each day of the month.

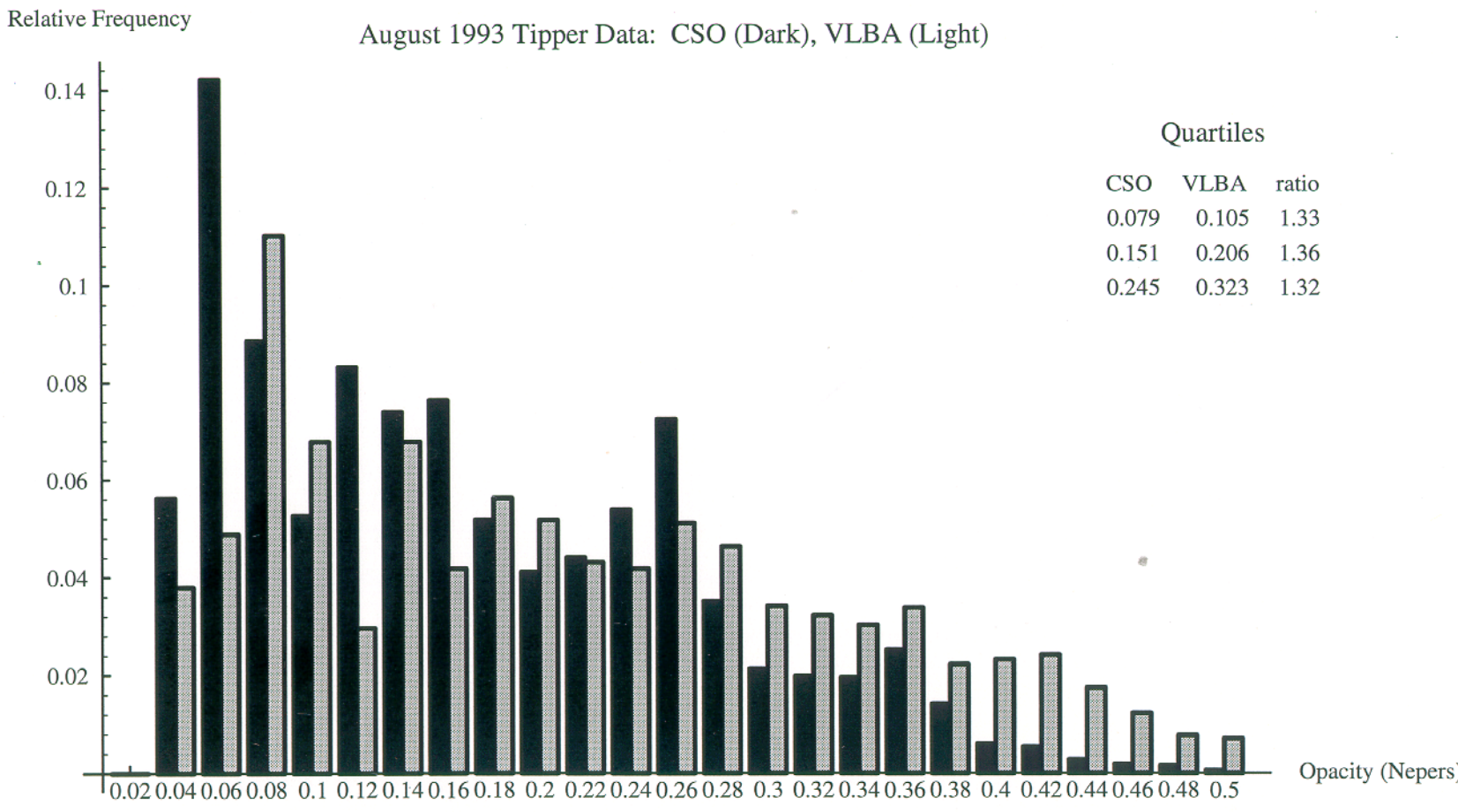

Figure 10b. Histogram of observed zenith opacities, August 1993.

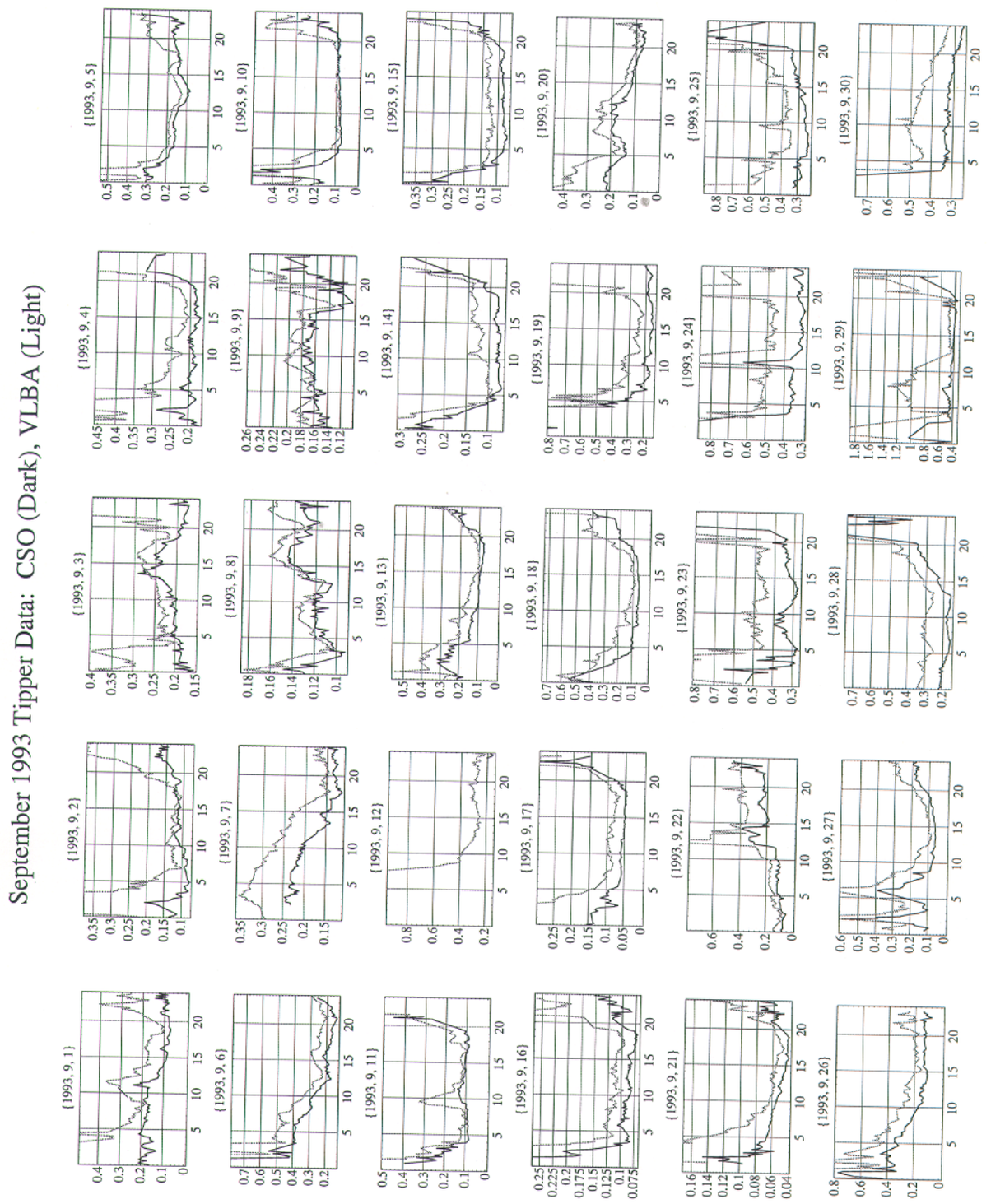

Figure 11a. September 1993, 225-GHz zenith opacity observations (measured in units of Nepers) are plotted versus time of day, in hours UT, for each day of the month.

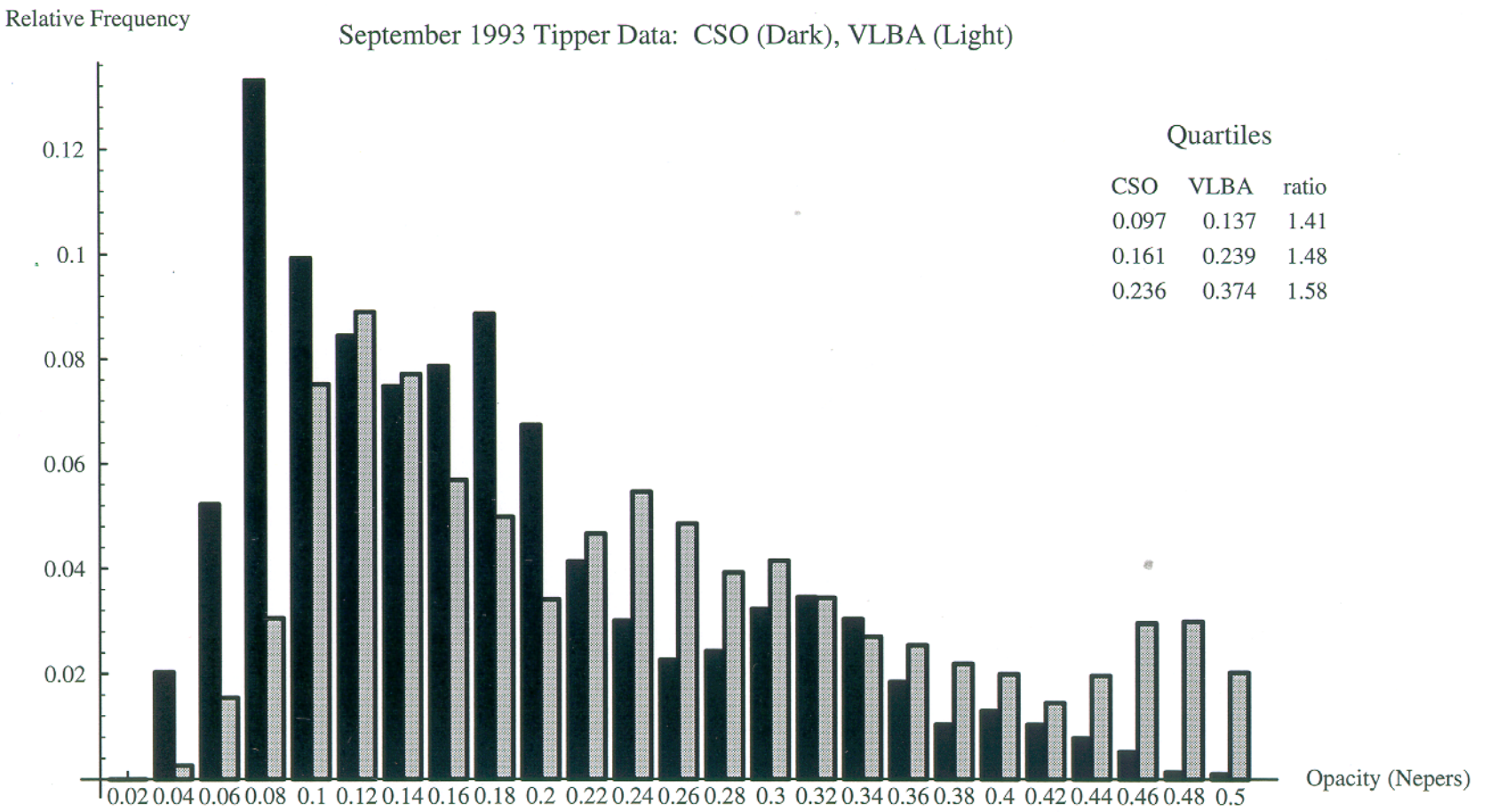

Figure 11b. Histogram of observed zenith opacities, September 1993.

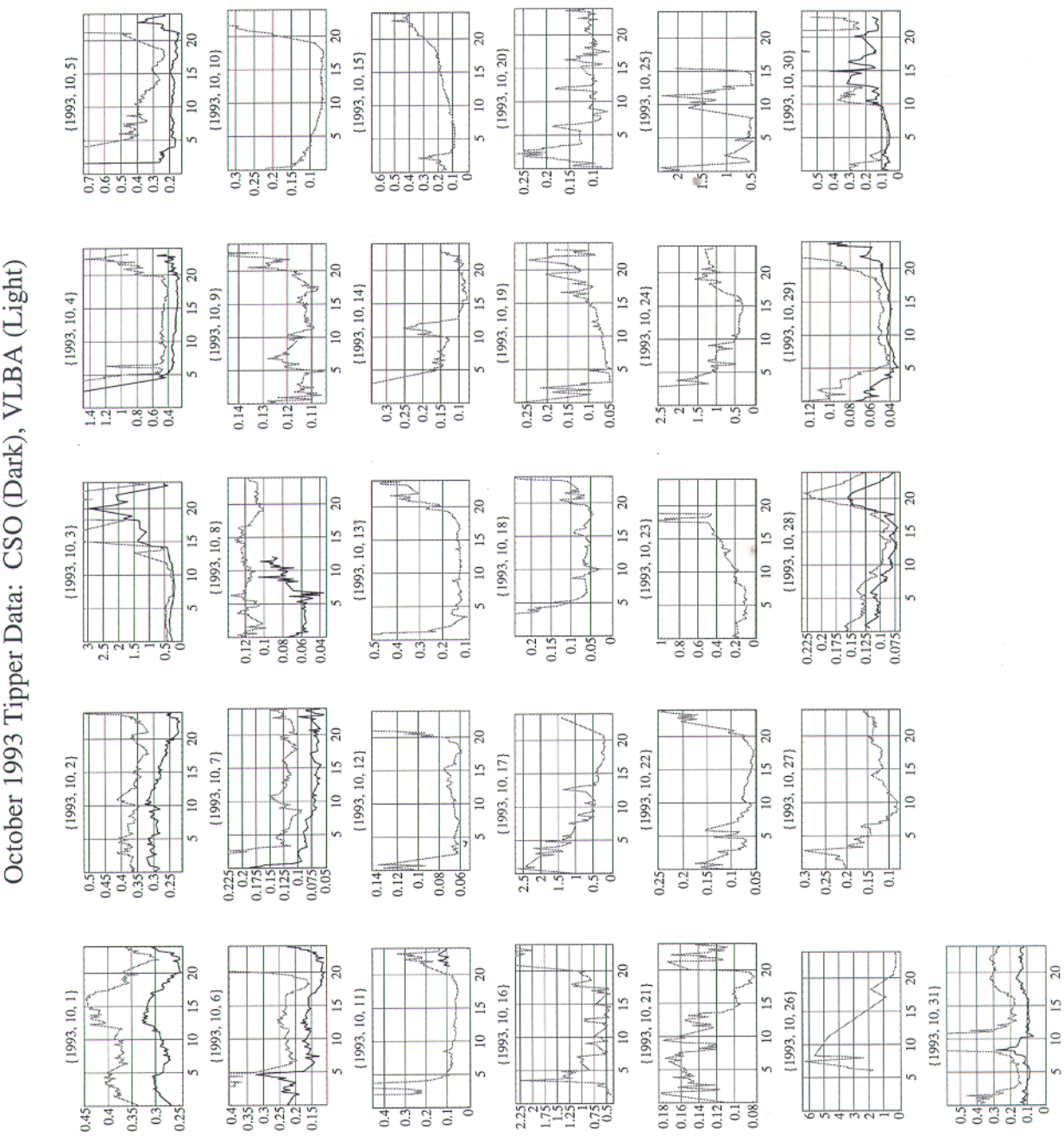

Figure 12a. October 1993, 225-GHz zenith opacity observations (measured in units of Nepers) are plotted versus time of day, in hours UT, for each day of the month.

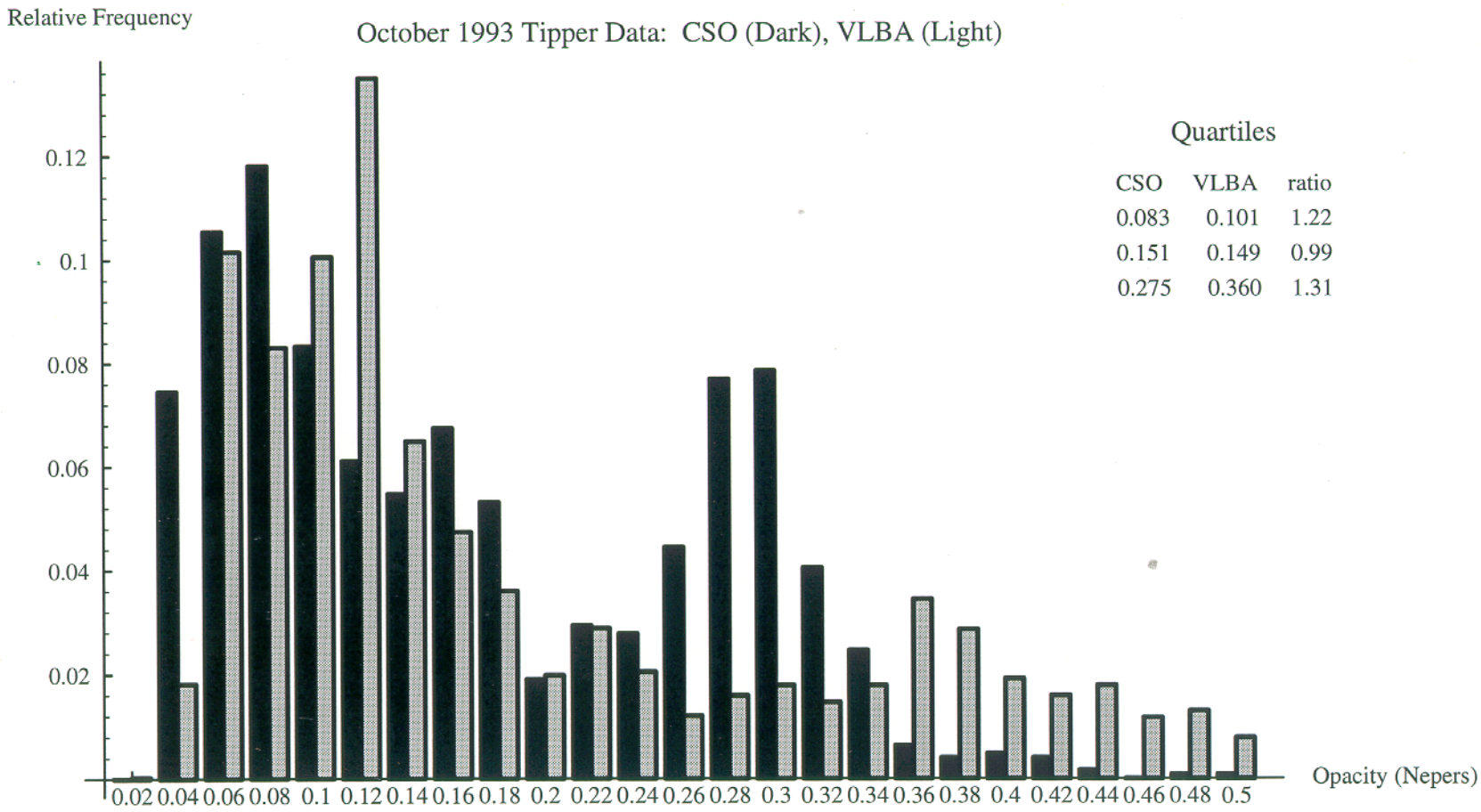

Figure 12b. Histogram of observed zenith opacities, October 1993.

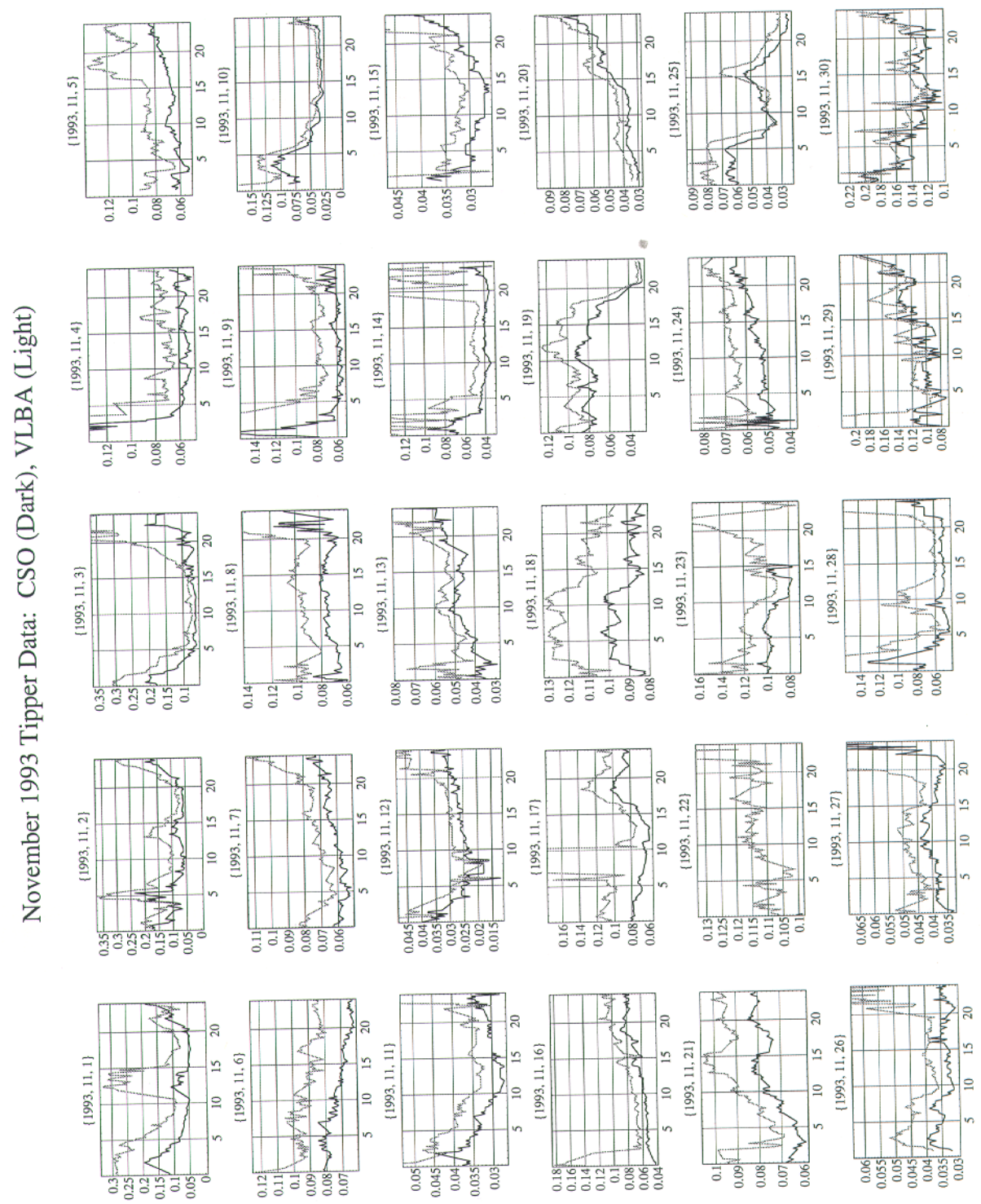

Figure 13a. November 1993, 225-GHz zenith opacity observations (measured in units of Nepers) are plotted versus time of day, in hours UT, for each day of the month.

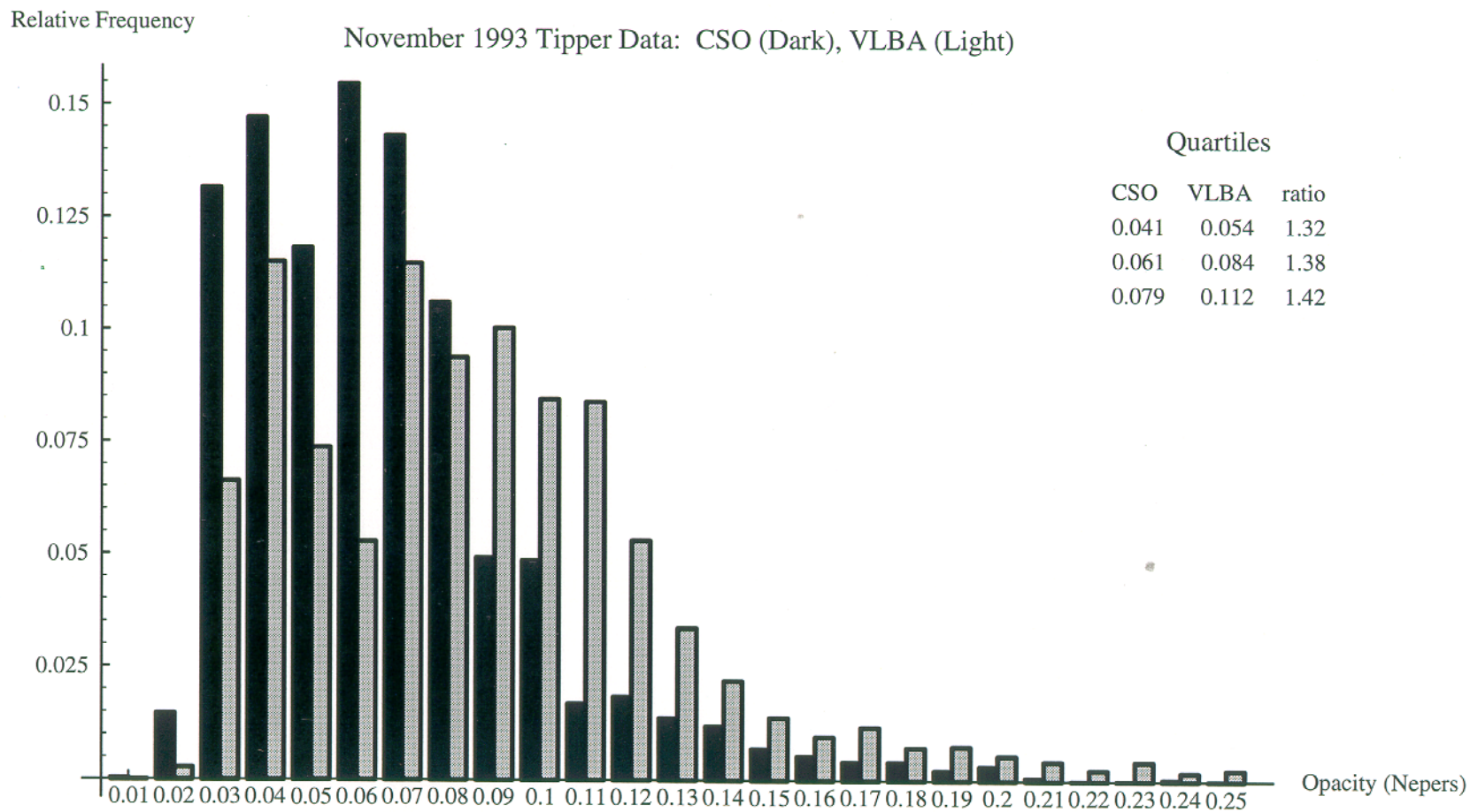

Figure 13b. Histogram of observed zenith opacities, November 1993.

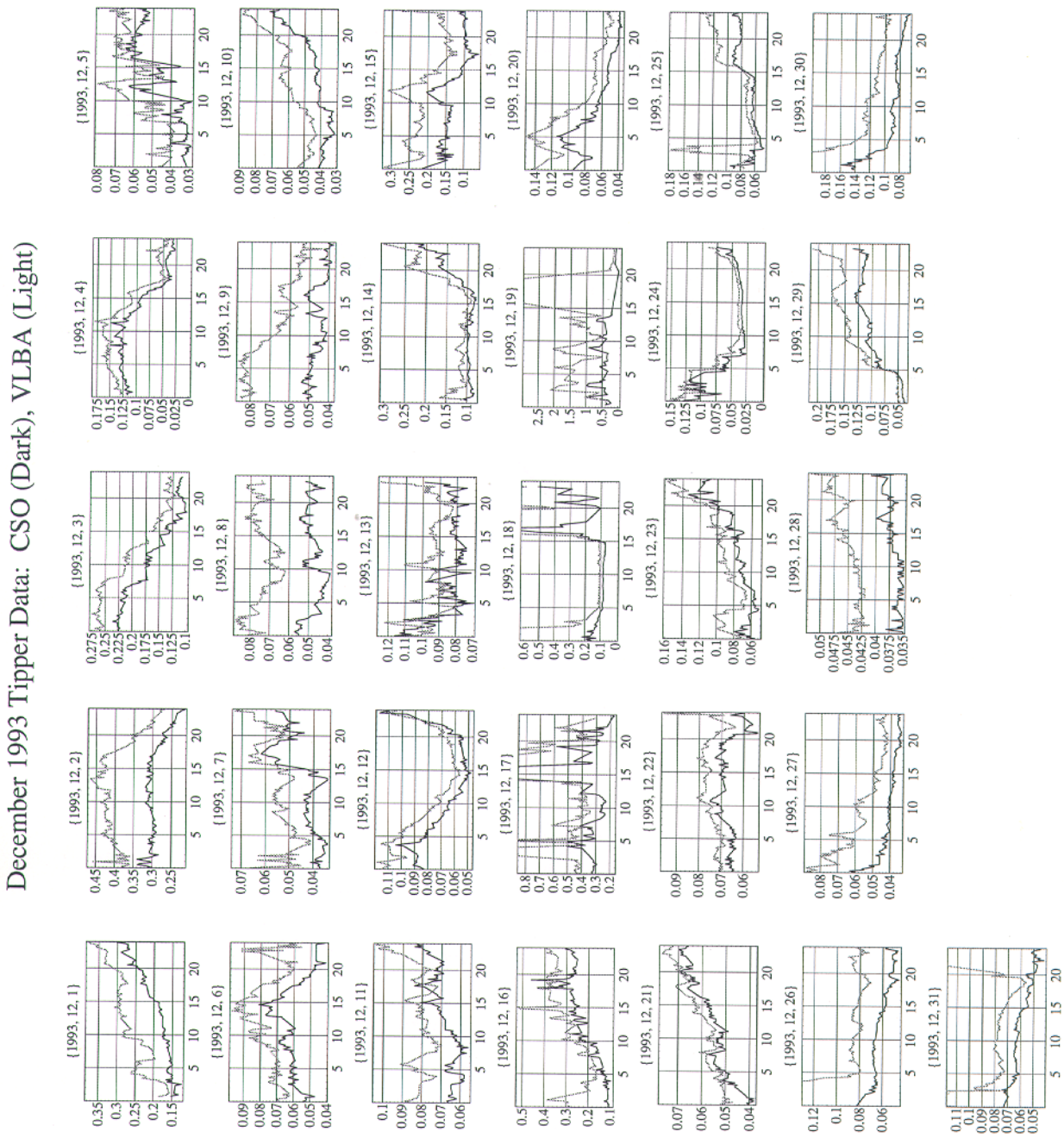

Figure 14a. December 1993, 225-GHz zenith opacity observations (measured in units of Nepers) are plotted versus time of day, in hours UT, for each day of the month.

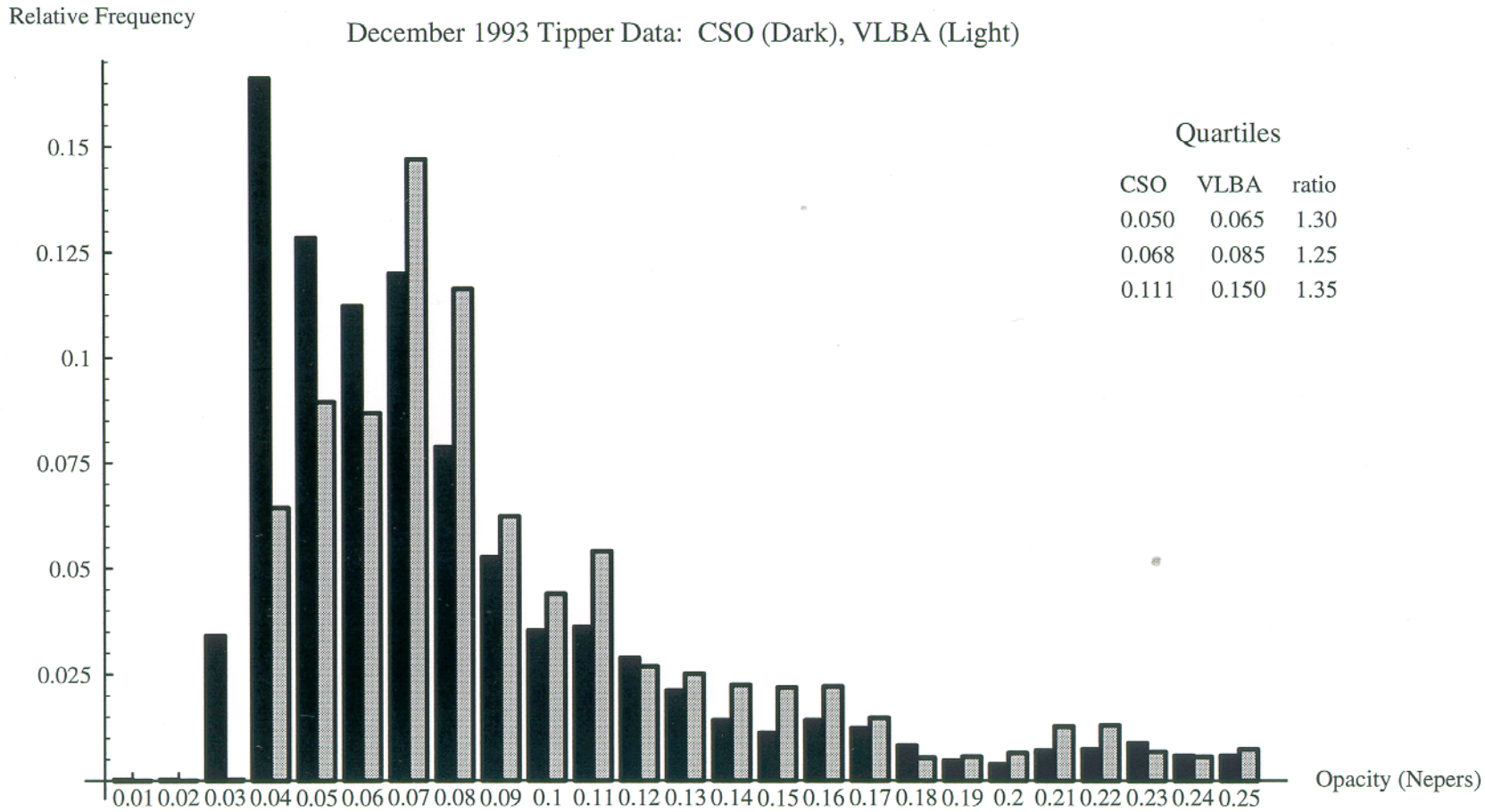

Figure 14b. Histogram of observed zenith opacities, December 1993.

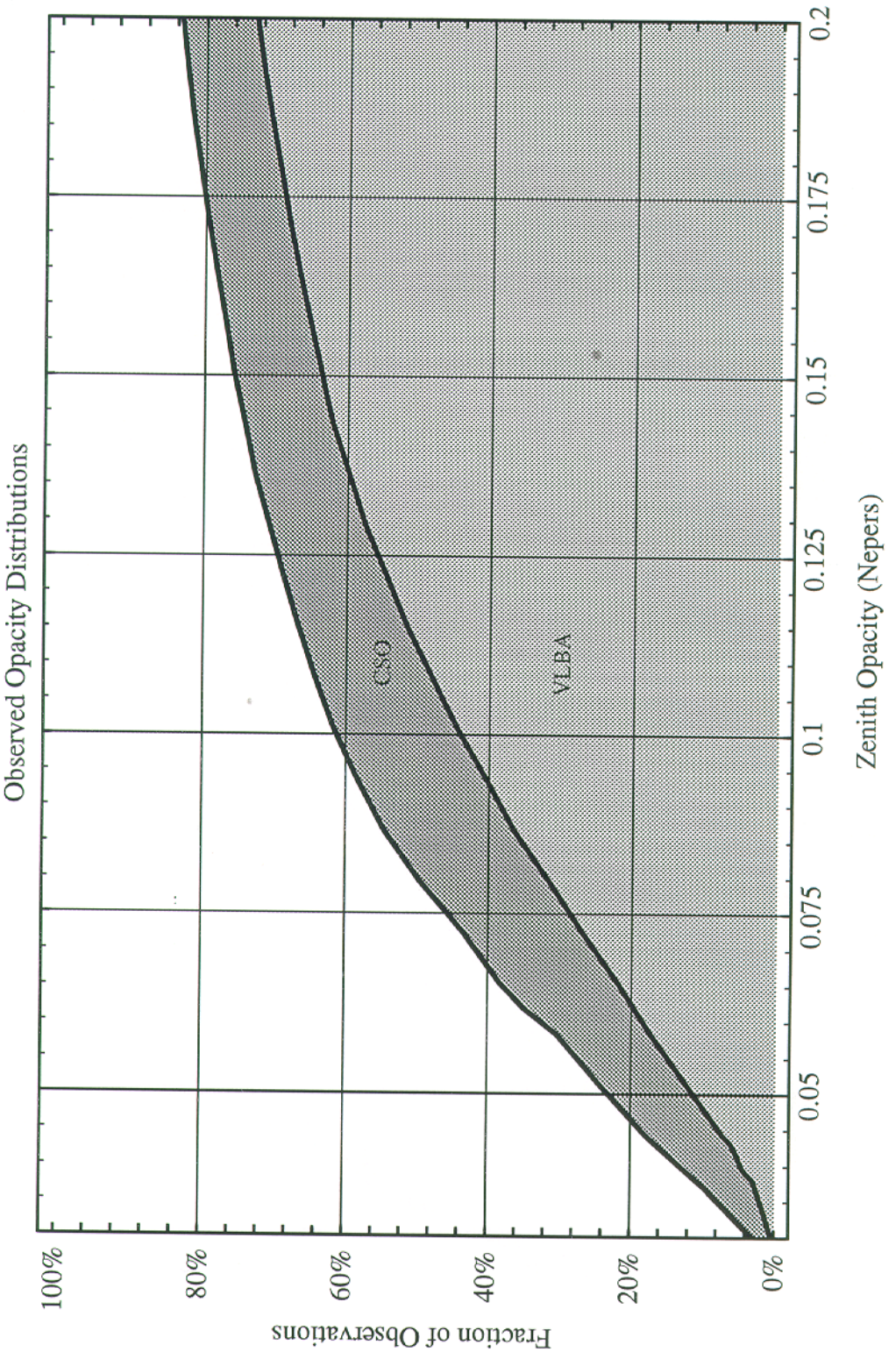

Figure 15. Frequency distribution of the Mauna Kea opacity observations from the fourteen month period November 1992 through December 1993. The quartile values are (0.052, 0.080, 0.146) Nepers for the CSO site and (0.070, 0.112, 0.216) Nepers for the VLBA site. The decile values are (0.037, 0.047, 0.058, 0.068, 0.080, 0.097, 0.126, 0.175, 0.268) and (0.048, 0.063, 0.077, 0.093, 0.112, 0.137, 0.181, 0.258, 0.391), respectively.

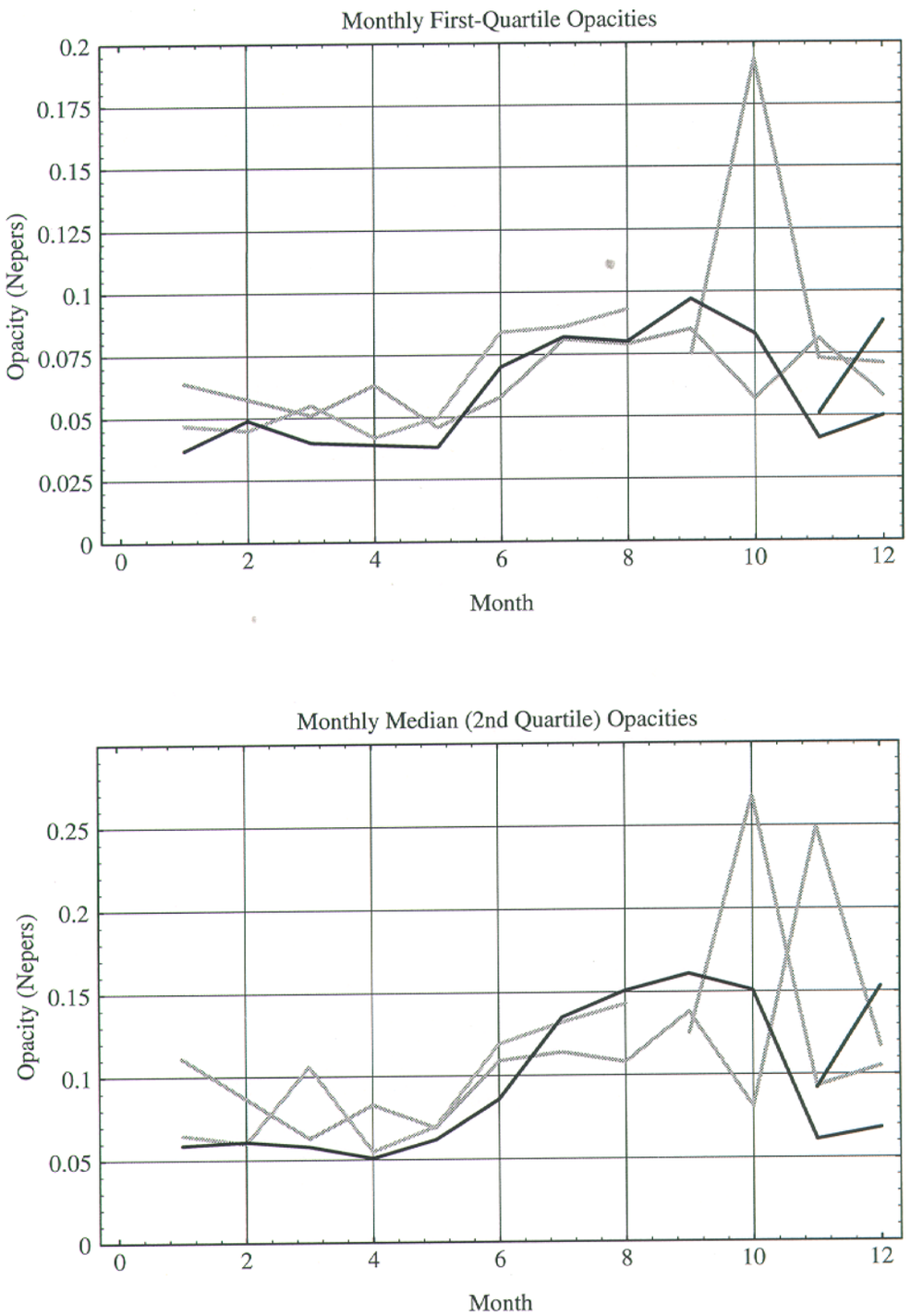

Figure 16. Comparison of first- and second-quartile values of opacity at the CSO site, for the time period November 1992 through December 1993, with data given by Hogg [**1**] for the period September 1989 through August 1991. The 1992–1993 data are represented by the darkest pair of lines.