RevMexAA (Serie de Conferencias), **19**, 90–96 (2003)

EIGHT YEARS OF MILLIMETRIC ATMOSPHERIC OPACITY MEASUREMENTS AT SAN PEDRO MÁRTIR SIERRA IN BAJA CALIFORNIA

David Hiriart

Instituto de Astronomía, UNAM, Ensenada B.C., México

RESUMEN

Se presentan los resultados de ocho años de mediciones de la opacidad de la atmósfera a 210 GHz (1.4 mm) sobre la Sierra de San Pedro Mártir B.C. Éstos comprenden el periodo de 1995 a 2002, reportando mediciones de un total de 1570 días. El valor medio de la opacidad al cenit obtenido fue de 0.23 nepers. Los valores de la opacidad al cenit durante el día y la noche fueron 0.25 y 0.20 nepers, respectivamente. Durante el verano, se encontró un marcado ascenso en la opacidad a frecuencias milimétricas debido al aumento en la cantidad de vapor de agua en la atmósfera producido por el monsón americano. Los resultados de 1998 muestran el efecto de la actividad del fenómeno de El Niño.

ABSTRACT

The results of eight years of radiometric measurements of the zenith opacity at 210 GHz (1.4mm) over San Pedro Mártir Sierra, Mexico, are presented. The measurements cover the period from 1995 to 2002. Observations were carried out during 1570 days. The total median sky opacity at this frequency was 0.23 nepers. The median values of day–time and night–time zenith opacity of 0.25 and 0.20 nepers respectively were found. During the Summer, the opacity rises to a maximum in August due to the water vapor carried by the American Monsoon. Results for 1998 reflect the presence of El Niño activity during that year.

Key Words: **ATMOSPHERIC EFFECTS — SITE TESTING**

San Pedro Mártir: Astronomical Site Evaluation (México, D. F. and Ensenada, B. C., México, April 3-4, 2003)
Editors: Irene Cruz-González, Remy Avila & Mauricio Tapia

1. INTRODUCTION

Atmospheric opacity measurements at millimetric wavelengths in San Pedro Mártir, began in 1992 when the site was considered for the Large Millimeter Telescope (LMT) Kaercher & Baars (2000).

Data were taken for one year in 1992 with a prototype radiometer at 215 GHz. In 1994 improved radiometers operating at a frequency of 210 GHz were built to continue the LMT site survey. One of these radiometers was installed from 1995 to 1997 in La Botella Azul Mountain, about 6 miles South-East of the Observatory. During that period the radiometer was operating remotely through a radio link with great success until the transmitter antenna was vandalized. In 1998 this radiometer was installed back at the facilities of the Observatory, where it has been operating to the present in almost a continuous manner.

A large archive of atmospheric opacity measurements at millimetric wavelength for Sierra San Pedro Mártir has been accumulating since 1995. Results have been published for the years of 1992 (Hiriart et al. 1997) and 1999 (Hiriart 2003).

In this paper the results of zenith opacity measurements at 210 GHz over San Pedro Mártir Sierra covering the years from 1995 to 2002 are presented.

Since the zenith opacity at millimetric wavelengths is proportional to the amount of precipitable water vapor (PWV) in the atmosphere, the data presented here is directly related to the PWV over San Pedro Mártir. However, the data showed in this paper is in terms of the zenith opacity at 210 GHz measured in nepers.

Measurements regarding PWV content, cloud cover and humidity for San Pedro Mártir, have been reported in the past. Westpal (1974) obtained low precision measurements of sky emission at 10 μm for San Pedro Mártir, during a 10 month survey in 1971-1972. For the same period, Alvarez & Maisterrena (1977) measured the amount of PWV by means of a infrared solar hygrometer, obtaining a median value close to 2.5 mm of PWV (mean = 3.3 mm).

Recently, Erasmus & van Staden (2002) have revised fifty-eight months of meteorological satellite observations made between 1993 and 1999 to study the water vapor conditions and cloudiness in the Southwestern USA and Northern Mexico. They found for San Pedro Mártir a median PWV of 2.67

San Pedro Mártir: Astronomical Site Evaluation (México, D. F. and Ensenada, B. C., México, April 3-4, 2003)
Editors: Irene Cruz-González, Remy Avila & Mauricio Tapia

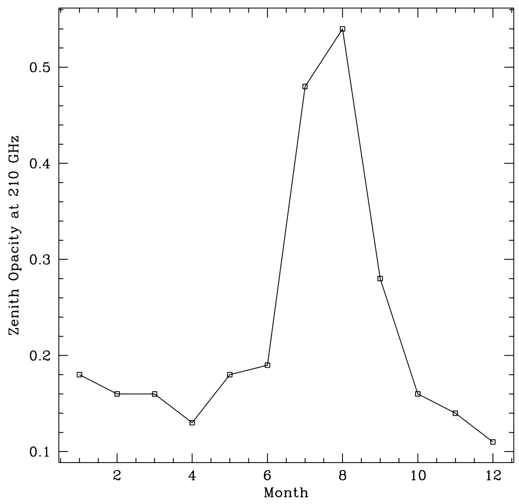

Fig. 1. Weighted monthly mean opacity for San Pedro Mártir Sierra for the period of 1995-2002.

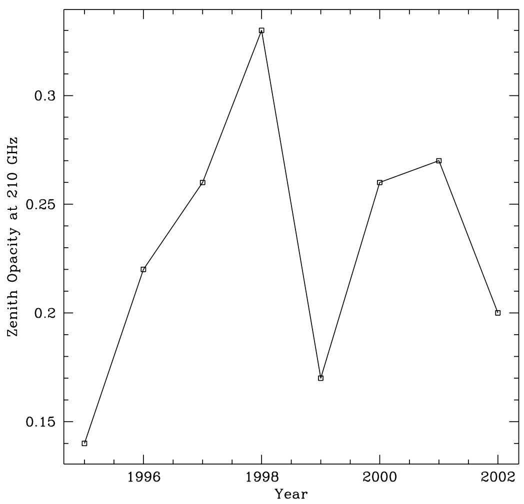

Fig. 2. Weighted yearly mean opacity for San Pedro Mártir Sierra for the period of 1995-2002.

mm and a fraction of 74% photometric nights and 81% spectroscopic nights. These results are consistent with Tapia (1992) and Tapia' s contribution in these proceedings. He compiled 20 years of weather statistics and found an average of 80.8% of espectroscopic and 63.1% of photometric nights.

2. MEASUREMENTS

A detailed description of the first radiometer at a frequency of 215 GHz, the data reduction technique, and the method used to measure the sky opacity may be found in Hiriart (1997). The new radiometers operating at 210 GHz are described in Hiriart (2003). Measurements presented here were made using the latter system.

From 1995 to 1998 a radiometer was installed in La Botella Azul Mountain to assert the possibility of that site as a candidate to install the LMT. In 1996 simultaneous measurements of zenith opacity at San Pedro Mártir and La Botella Azul for a period of 14 days were made. Sky opacity variations in both places followed each other pretty well. Thus, measurements made in any of these two places may be considered representative of the millimetric opacity in the region.

In 1998 the radiometer in Botella Azul was installed back at the Observatory near the building of the 84 cm telescope, where it has been operating in almost a continuous manner to the present.

The present zenith sky opacity, and a graph with the last three days of available measurements, are shown at the web page `http://haro.astrossp.unam.mx/~hiriart/radiometro`. The page also contains the data and statistics archives in monthly and yearly format from September 1995 to May 1998 for la Botella Azul, and from May 1998 to the present for San Pedro Mártir Observatory.

Figure 1 shows the weighted mean monthly values of the zenith sky opacity for San Pedro Mártir for the period of 1995 to 2002. The weighted mean yearly values are shown in Fig. 2.

Table 3 presents the monthly mean zenith opacity at a frequency of 210 GHz for the years 1995-2002 in San Pedro Mártir. The values for the year of 1992 at a frequency of 215 GHz are also shown. Numbers in parenthesis are the percentage of samples obtained during that month. Monthly and yearly mean values are shown at the right and bottom of the table, respectively. The mean total opacity for the data is shown in the lower right corner.

To account for the uneven sample of measurements in each month, the monthly and yearly mean opacities reported are the weighted mean, w_m, of the monthly means

$$w_m = \frac{\sum_i w_i \cdot x_i}{\sum_i w_i} \, , \tag{1}$$

where w_i is the percentage of sample coverage for each month, and x_i is the mean value of the month.

Tables 1 and 2 present the data of the zenith opacity at day–time and night–time, respectively. The bottom lines show the year weighted mean and the last columns show the month weighted mean. In these cases the same weights in parenthesis from Table 3 have been used.

TABLE 1

MONTHLY DAY–TIME MEAN ZENITH OPACITY AT 210 GHZ OVER SAN PEDRO MÁRTIR, MEXICO

Month	1992	1995	1996	1997	1998	1999	2000	2001	2002	TOTAL
January	0.18			0.14		0.13	0.35		0.17	0.20
February	0.33			0.15		0.06	0.18	0.14	0.07	0.17
March	0.25		0.13	0.28		0.06	0.15	0.15		0.17
April	0.20		0.15	0.13		0.11	0.16	0.13	0.14	0.15
May	0.28		0.15	0.33	0.23	0.15	0.20	0.22	0.18	0.21
June	0.22		0.17	0.12	0.21	0.20	0.20	0.21	0.36	0.21
July	0.49		0.67	0.35	0.54	0.47	0.50	0.43	0.39	0.49
August	0.36		0.58	0.47	0.70	0.36	0.69	0.60		0.55
September	0.36	0.21	0.23	0.76	0.36	0.25	0.39			0.34
October	0.23	0.12	0.17		0.19	0.09	0.21	0.23	0.16	0.17
November	0.23	0.17	0.14		0.14	0.11	0.15	0.21	0.17	0.16
December	0.22	0.09	0.13		0.12	0.07	0.17	0.12	0.11	0.12
TOTAL	0.29	0.14	0.23	0.29	0.34	0.19	0.38	0.27	0.20	0.25

TABLE 2

MONTHLY NIGHT–TIME MEAN ZENITH OPACITY AT 210 GHZ OVER SAN PEDRO MÁRTIR, MEXICO

Month	1992	1995	1996	1997	1998	1999	2000	2001	2002	TOTAL
January	0.17			0.14		0.28	0.28		0.17	0.18
February	0.30			0.16		0.06	0.18	0.14	0.07	0.17
March	0.24		0.12	0.23		0.07	0.14	0.13		0.15
April	0.16		0.14	0.07		0.10	0.13	0.12	0.14	0.13
May	0.22		0.11	0.26	0.16	0.11	0.17	0.19	0.16	0.17
June	0.16		0.13	0.07	0.19	0.13	0.12	0.18	0.35	0.17
July	0.46		0.69	0.34	0.51	0.43	0.45	0.42	0.44	0.47
August	0.31		0.55	0.32	0.65	0.25	0.64	0.55		0.49
September	0.31	0.18	0.16	0.64	0.31	0.12	0.37			0.27
October	0.20	0.11	0.14		0.17	0.05	0.17	0.23	0.15	0.15
November	0.16	0.15	0.14		0.13	0.09	0.13	0.19	0.17	0.14
December	0.12	0.09	0.12		0.12	0.08	0.17	0.11	0.11	0.11
TOTAL	0.24	0.13	0.21	0.23	0.31	0.15	0.24	0.25	0.20	0.22

3. DISCUSSION

Regarding the sky opacity at 210 GHz, San Pedro Mártir and Botella Azul showed to have the same opacity values of the sky. Thus, data collected in Botella Azul may also be used as representative of San Pedro Mártir for the period 1995-1998.

Sky opacity measurements in 1992 were influenced by El Niño activity. In 1997-1998 there was another "El Niño" period from which there are interesting Fourier Transform Spectroscopy data covering 300-1000 GHz from Mauna Kea, Hawaii (Pardo, Serabyn, & Cernicharo 2001). In the middle of the Pacific, the opacity statistics reveal much drier atmospheres during that event than during a normal year. This is the opposite to what occurs in the Pacific Coast (Reyes & Mejía-Trejo 1991). The 1998 "El Niño" event shows Fig. 1 as a raise of the yearly weighted mean for that year.

San Pedro Mártir: Astronomical Site Evaluation (México, D. F. and Ensenada, B. C., México, April 3-4, 2003)
Editors: Irene Cruz-González, Remy Avila & Mauricio Tapia

TABLE 3

MONTHLY MEAN ZENITH OPACITY AT 210 GHZ OVER SAN PEDRO MÁRTIR, MEXICO

Month	1992	1995	1996	1997	1998	1999	2000	2001	2002	TOTAL
January	0.14 (28)			0.14 (7)		0.13 (72)	0.31 (43)		0.17 (16)	0.18
February	0.26 (75)			0.13 (7)		0.06 (48)	0.18 (80)	0.14 (77)	0.07 (36)	0.16
March	0.20 (49)		0.12 (87)	0.26 (47)		0.06 (25)	0.15 (83)	0.15 (62)		0.16
April	0.15 (46)		0.14 (100)	0.10 (42)		0.10 (33)	0.14 (90)	0.13 (61)	0.14 (47)	0.13
May	0.19 (54)		0.13 (100)	0.28 (52)	0.25 (15)	0.13 (75)	0.18 (77)	0.22 (71)	0.18 (37)	0.18
June	0.14 (42)		0.15 (98)	0.09 (42)	0.20 (94)	0.17 (91)	0.16 (37)	0.21 (85)	0.36 (58)	0.19
July	0.37 (53)		0.68 (86)	0.36 (52)	0.54 (69)	0.45 (96)	0.48 (91)	0.43 (100)	0.39 (29)	0.48
August	0.44 (53)		0.57 (40)	0.42 (27)	0.67 (73)	0.31 (62)	0.67 (56)	0.60 (88)		0.54
September	0.25 (78)	0.19 (18)	0.18 (28)	0.70 (12)	0.33 (85)	0.18 (89)	0.38 (68)			0.28
October	0.18 (91)	0.12 (100)	0.16 (100)		0.18 (35)	0.07 (90)	0.19 (56)	0.23 (89)	0.16 (62)	0.16
November	0.16 (97)	0.16 (94)	0.14 (100)		0.14 (80)	0.10 (100)	0.14 (83)	0.21 (28)	0.17 (20)	0.14
December	0.12 (25)	0.09 (35)	0.12 (43)		0.12 (36)	0.08 (46)	0.17 (21)	0.12 (22)	0.11 (40)	0.11
TOTAL	0.22	0.14	0.22	0.26	0.33	0.17	0.26	0.27	0.20	

Radiosonde calibration is necessary in order to relate the zenith sky opacity at 210 GHz to the amount of precipitable water vapor (PWV). Alternatively, a conversion factor may be obtained from theoretical models such as Atmospheric Transmission at Microwaves (ATM) model (Pardo, Cernicharo, & Serabyn 2001).

Figure 3 presents the daily variations of the zenith opacity at 210 GHz for the year of 1999 and Fig. 4 the monthly statistics for that year. This opacity behavior is the typical seasonal variations of the opacity in San Pedro Mártir Sierra. The water vapor content increases from the end of July to the beginning of August. It reached its maximum at the middle of August and began to decline in first days of September. Similar behavior is observed in other high altitude observing sites in North America such as Mount Graham and Kitt Peak in Arizona. These two observatories have the advantage of being at almost the same height and latitude as San Pedro Mártir. Also they have radiometer system that measure the sky opacity at millimeter wavelengths. Based on the data from these observatories, Hiriart (2003) has compared the seasonal variations in the amount of water vapor during the Summer of 1999 and has found that the opacity maximum occurs later, has a shorter duration, and declines earlier in San Pedro Mártir than in these two other observatories.

4. CONCLUSIONS

The results of eight years of atmospheric opacity measurements at 210 GHz over San Pedro Mártir, Baja California, Mexico were presented. The total mean value of the sky opacity at this frequency was 0.23 nepers. The mean of the day–time and night–time opacity was 0.24 and 0.20 nepers, respectively.

I acknowledge the technical staff at San Pedro Mártir Observatory: F. Barbosa, E Colorado, A. Cordova, B. García, V. García, B. Martínez, F. Murillo, J. M. Murillo, J. L. Ochoa, J. Palomares, F. Quirós, J. Valdez, and S. Zazueta for their support to operate the equipment.

REFERENCES

Alvarez, M., & Maisterrena, J. 1977, RevMexAA, 2, 43

Erasmus, D. A.,& van Staden, C. A. 2002, A Satellite Survey of Cloud Cover and Water Vapor in the Southwestern USA and Northern Mexico. Final Report CELT Project (Pasadena: California Institute of Technology)

Hiriart, D., Goldsmith, P. F. Skrutskie, M., & Salas, L. 1997, RevMexAA, 33, 59

Hiriart, D. 2003, RevMexAA, 39, 119

Kaercher, H., & Baars, J. W. 2000, Proc. SPIE, Vol. 4015 ed. Harvey R. Butcher, p.155

Pardo, J. R., Serabyn, E. , & Cernicharo, J. 2001, J. Quantitative Spectrosc. Radiat. Transfer, Vol 68, 419

Pardo, J. R., Cernicharo, J., & Serabyn, E. 2001, IEEE Transactions on Antennas and Propagation, Vol 49, No. 12, 1683

Reyes, S. & Mejía-Trejo, A. 1991, International Journal of Climatology 11:515-518

Tapia, M. 1992, RevMexAA, 24, 179
Westphal, J. A. 1974, Infrared Sky Noise Survey, Final Report Nasa Grant NGR-05-002-185 (Pasadena: California Institute of Technology)

San Pedro Mártir: Astronomical Site Evaluation (México, D. F. and Ensenada, B. C., México, April 3-4, 2003)
Editors: Irene Cruz-González, Remy Avila & Mauricio Tapia

David Hiriart: Instituto de Astronomía, Universidad Nacional Autónoma de México, Apartado Postal 877, Ensenada, B.C. 22800, México (hiriart@astrosen.unam.mx).

San Pedro Mártir: Astronomical Site Evaluation (México, D. F. and Ensenada, B. C., México, April 3-4, 2003)
Editors: Irene Cruz-González, Remy Avila & Mauricio Tapia

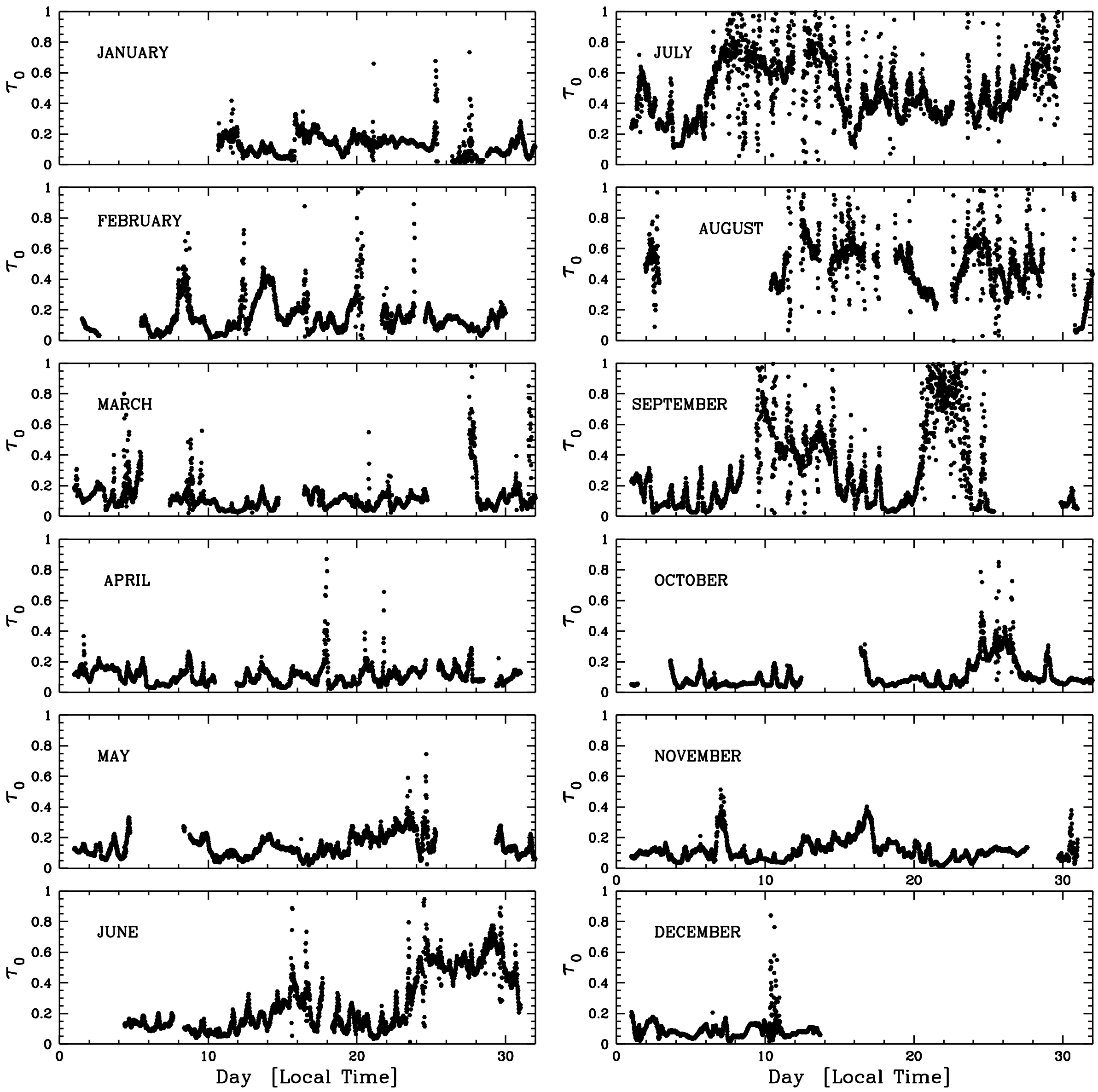

Fig. 3. Time evolution of the 210 GHz zenith atmospheric opacity τ_0, in nepers, for each month in 1999 over San Pedro Mártir, México (see also Hiriart 2003).

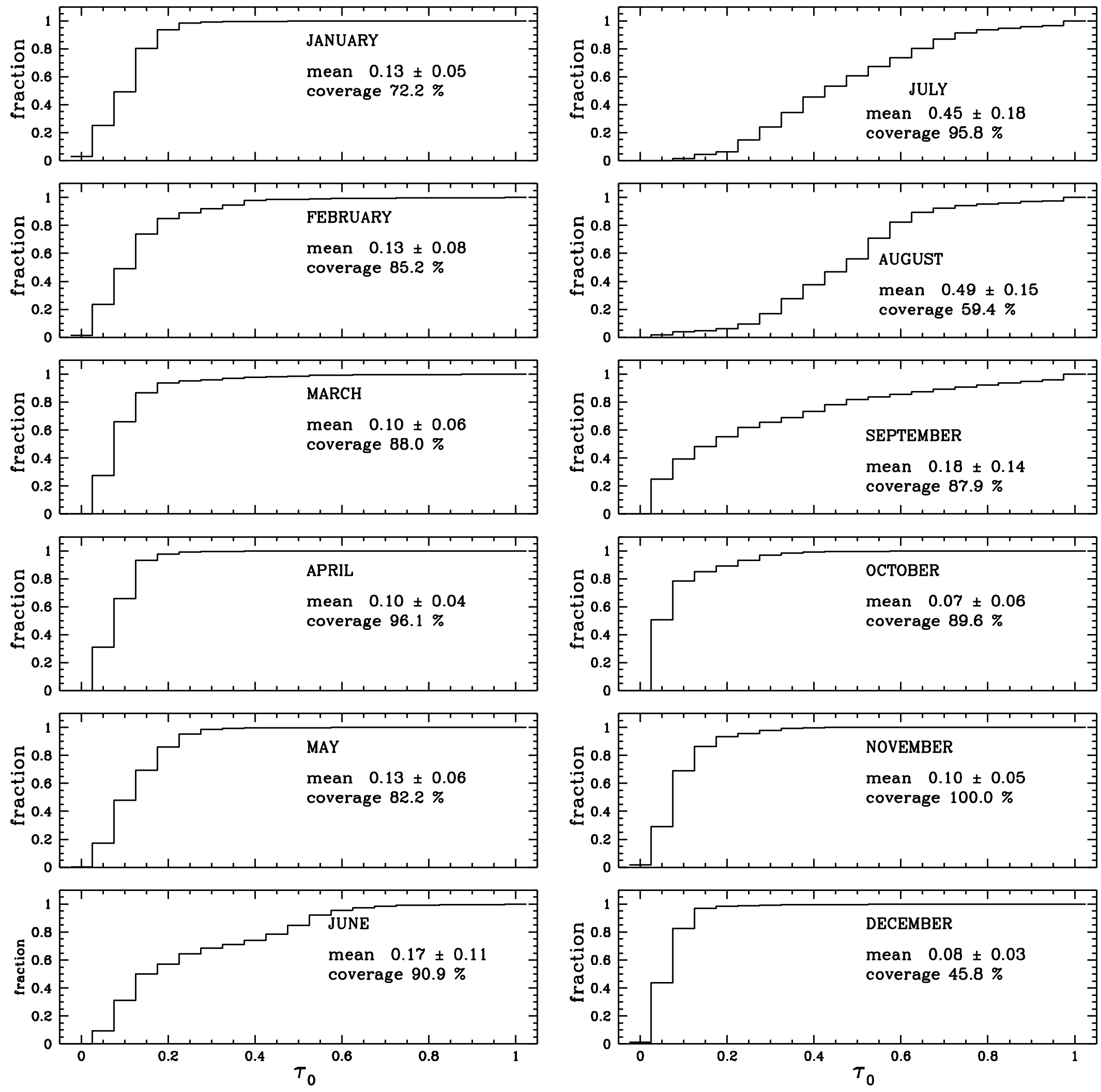

Fig. 4. Cumulative distributions of the 210 GHz zenith atmospheric opacity τ_0 from data on Figure 3. Mean values and sample coverage for each month are shown (see also Hiriart 2003).