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TEN YEARS OF WEATHER AND OBSERVING STATISTICS IN SAN PEDRO MARTIR, BAJA CALIFORNIA, MEXICO

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RESUMEN

Se presentan estadísticas del uso del telescopio de 2.1-m del Observatorio Astronómico Nacional en San Pedro Mártir, Baja California, Mexico. También se incluyen parámetros climáticos básicos como la temperatura y humedad relativa al nivel del telescopio. La fracción de noches perdidas debido a mal clima fue de 27.4% en el periodo julio 1982 a junio 1992. De enero 1984 a diciembre 1991, el 56.7% de las noches fueron "fotométricas" mientras que el 80.4% de las noches fueron "espectroscópicas". La humedad relativa promedio fue de 54%. La mejor época, en término de noches despejadas y baja humedad, es en primavera y otoño, ya que en el invierno se tiene la influencia de las colas de algunas tormentas del Pacífico norte, mientras que tormentas locales afectan algunas noches de verano. El porcentaje total de noches nubladas en San Pedro Mártir es similar al de Cerro Tololo y La Silla, un poco mejor que en Mauna Kea y considerablemente mejor que en Mount Graham, especialmente en verano.

ABSTRACT

Ten year statistics are presented of the use of the 2.1-m telescope of the Observatorio Astronómico Nacional at San Pedro Mártir, Baja California, Mexico. Also included are some basic climatic and meteorological parameters such as temperature and relative humidity as well as the amount of cloud cover. The fraction of nights lost due to bad weather was 27.4% in the period July 1982 to June 1992. From January 1984 to December 1991, 56.7% of the nights were of "photometric" quality and 80.4% were of "spectroscopic" quality. The average relative humidity near the ground was 54%. Spring and autumn are the best seasons in terms of cloudless and low humidity nights while winter is affected by the tails of North Pacific storms and mid summer is characterized by a mild monsoon season. The total cloud cover percentage in San Pedro Mártir is similar to that of Cerro Tololo and La Silla, slightly better than Mauna Kea and considerably better that Mount Graham, especially in summer.

Key words: **OBSERVATORIES**

I. INTRODUCTION

[n the late 1960's, a search was made to find the .t site for astronomical observations in México. is was done by analysing two years (1969 - 1971) meteorological satellite photographs (Mendoza, na, & Gómez 1972) and several *in situ* tests the most prominent candidate sites. The nmit of the Sierra of San Pedro Mártir in ja California, México was chosen to locate the servatorio Astronómico Nacional, which has :n engaged in continuous astronomical research ›grams since 1971. Several studies of the clima- ›gical properties of this site have been reported, inly based on data covering short periods during the first years of operation of the observatory (Mendoza 1971, 1973; Mendoza *et al.* 1972; Walker 1971, 1984; Westphal 1974; Alvarez 1982, and Alvarez & Maisterrena 1977).

The Observatorio Astronómico Nacional de México at San Pedro Mártir is located at 31°02′40″ N and 115°28′00″ W, some 100 km east of the Baja Californian West Coast. It has has three Ritchie-Chrétien telescopes of diameters 0.84-m, 1.5-m and 2.1-m in operation. The latter started continuous operation in 1981. It is expected that in the near future, the Mexican astronomical community engages in the construction and operation of a larger (4 to 8 meter class) telescope and San Pedro Mártir is a candidate site for this instrument.

The present work describes the data gathered in a consistent manner during the last ten years of operation of the 2.1-m telescope concerning the nocturnal basic climatological parameters, such as temperature and relative humidity as well as cloud cover and observing statistics for this telescope. This is the first long-term report on the weather charateristics of San Pedro Mártir and the data covers from 1st July 1982 to 30th June 1992 (3653 calendar nights) and, unless specifically stated, the results given here refer to that period.

Finally, a comparison is made with similar results published for several other observatory sites, including Mauna Kea (Bely 1987, Merrill & Forbes 1987), Mount Graham (Merrill & Forbes 1987), Kitt Peak (Crawford 1987), La Silla (Sarazin 1990) and Cerro Tololo (Osmer & Wood 1983).

II. DATA ARCHIVE AND ANALYSIS

The 2.1-m telescope is the only one at San Pedro Mártir that requires a night assistant for its operation. Since July 1982, it is one of his duties to daily fill in an entry on the log book of the telescope with the following information: Minimum and maximum temperature, wind speed and relative humidity readings at the level of the telescope at the beginning and end of each night; sky conditions in terms of the percentage of cloud cover during the night; estimate of seeing conditions; name of observers and auxiliary instrument used; times of opening and closure of the dome and notes on the reasons for early ending or late start of the observing night.

Unfortunately, due to several failures with the wind meters and lack of a consistent method for estimating the size of the seeing disc, these two parameters are left out of this compilation. All other parameters were accurately recorded on the log book every night except when no observer was scheduled on the telescope. This occurs mainly because of holidays between Christmas and a few days after New Year, telescope maintenance and engineering runs and scattered periods of undersubscription of telescope use. Figure 1 shows the monthly average (ten years) distribution (in percentage over the total number of calendar nights each month) of the time scheduled for observation. Apart from the months of January and December, and maybe some periods in summer when eventual major engineering runs are scheduled, there is no clear explanation for this distribution. It is important to note that for all months, a statistically representative number of nights were recorded and, as will be seen later, this pattern has no relation with patterns of "good" or "bad" weather seasons. A total of 2533 nights were scheduled for observation from July 1982 to June 1992. The statistics of the use of specific auxiliary instruments on the 2.1-m telescope lies outside the scope of the presen work, but it is important to note that 42% of th scheduled nights were used for work requirin clear nights ("photometric" conditions) and 58% for programs which could be carried out durin clear and partially cloudy nights ("spectroscopic conditions).

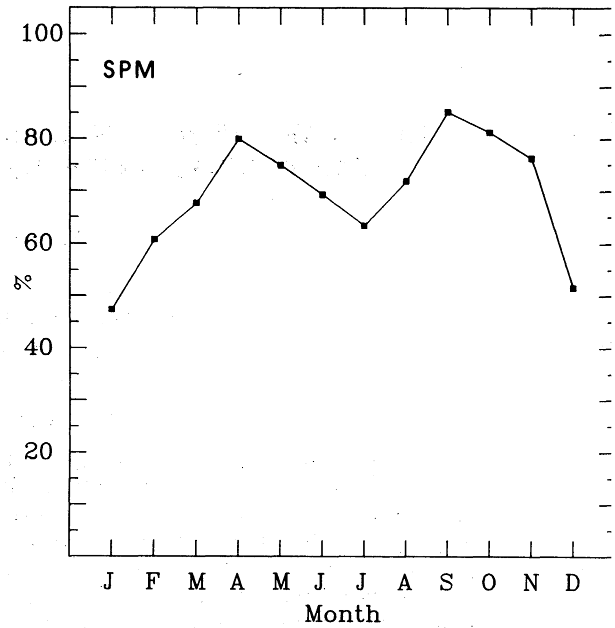

Fig. 1. Monthly fraction of nights scheduled for observation on the 2.1-m telescope at San Pedro Mártir Holiday periods, maintenance and engineering runs anc scattered periods of undersubscription of telescope use are excluded. The total amount of scheduled nights in the studied period was 2533. 43% of these were scheduled for photometric programs.

For the analysis of the data and the presentatio of the results, the following definitions were made The units used were *half nights*, meaning a period o five hours during the night, except for the results o the number of nights of high, intermediate and lo relative humidity.

Photometric sky: When the percentage of cloud cove was less or equal to 15%. In most the cases, i clouds were present, they were reported seen nea the horizon or present anywhere in the sky for n more than thirty minutes in a five hour period.

Spectroscopic sky: When the percentage of clou cover was greater than 65%. This applied eithe to percentage of the sky covered by clouds or t percentage of time with the sky covered.

Time observed: When actual observations took place meaning that they were not impeded by bad weath er (including high winds, very high humidity an very bad seeing) or other causes (including tele scope or instrument failure).

Night of high relative humidity: When anytime durin he night the relative humidity was higher than '0%.

Jight of low relative humidity: When at no time during he night the relative humidity was higher than ·5%.

Jight of intermediate relative humidity: When at all imes during the night the relative humidity was ›etween 45% and 70%.

III. RESULTS

Nocturnal air temperature variations in San 'edro Mártir are illustrated in Figure 2. Monthly .bsolute minima and maxima and average (10 'ears) minima and maxima are shown. Temperature 'ariations within a single night are relatively small. n the period 1985–1991, the maximum minus minmum nocturnal temperature ΔT was less than 1.5 ‹ in 61% of the recorded nights (1261 in total), ›hile $\Delta T < 2.5$ K in 81% and $\Delta T < 3.5$ K in 89% ›f the nights. Unfortunately, no information is a'ailable for the daytime temperatures and therefore ıo day-night temperature gradients can be estimaed. Figure 3 shows the monthly average relative ıumidity from all nights of observation *and* those ıights when the observations were stopped or canelled because of very high humidity (usually with elative humidity larger than 90%) for the period anuary 1984 to June 1992. The average value is ›4%, being May and June the dryest months and \ugust and September the most humid. Note that hese are night-time readings and the relatively low 'alues for the summer months are surprising since during the monsoon season (from late July to early September) it is quite common to have rainstorms in the afternoon which in most cases dissapear at sunset. Probably more useful for our purposes is Figure 4 which shows the average monthly value of the percentage of nights with high, low and intermediate relative humidity as defined in §II.

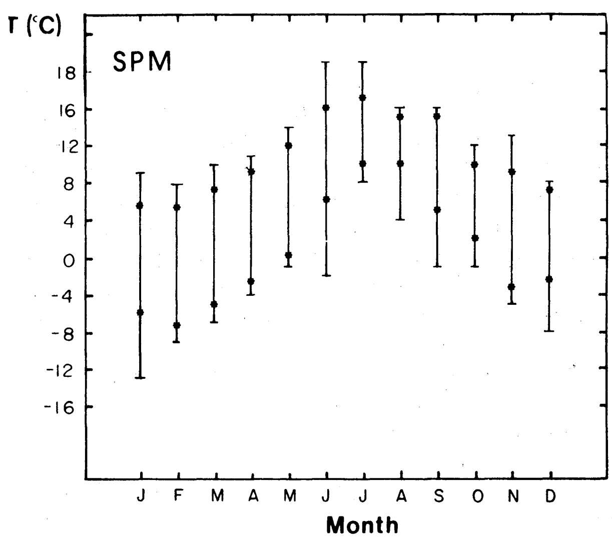

Fig. 2. Monthly ranges of night temperatures recorded nside the open dome of the 2.1-m telescope during the ɔeriod July 1982 to June 1992. The bars mark the ɜxtreme temperatures registered during that month and :he asterisks correspond to the monthly average maxinum and minimum temperatures.

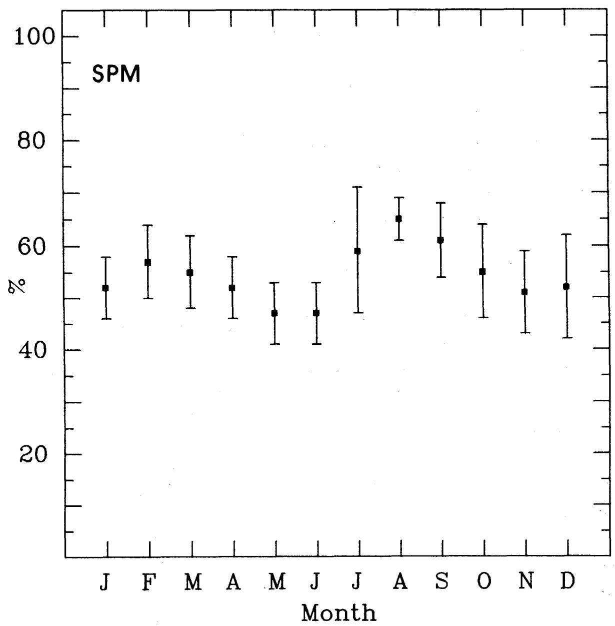

Fig. 3. Monthly mean relative humidity near the ground and its standard deviation in San Pedro Mártir.

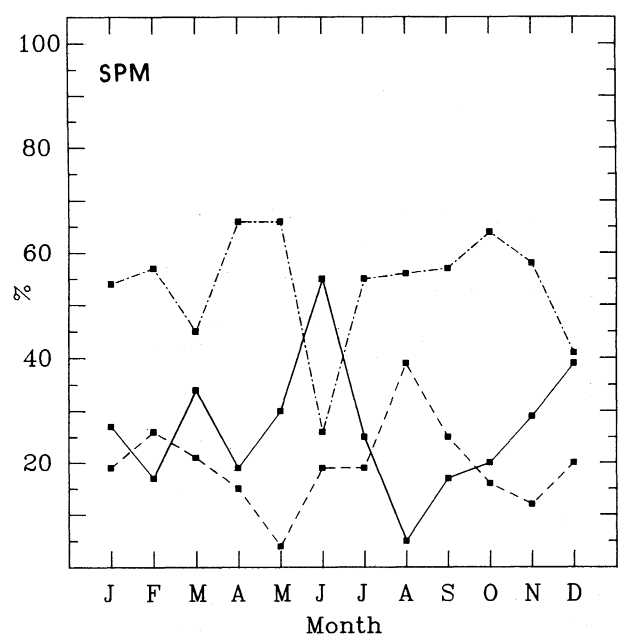

Fig. 4. Monthly fraction of nights of low (continuous line), intermediate (broken line) and high (dotted line) relative humidity, according to the definitions given in §II.

TABLE 1

SPM 2.1-M TELESCOPE. OBSERVING STATISTICS
July 1982 – June 1992

	Number of nights	% over total number of calendar nights	% over number of scheduled nights
Total calendar	3653	100.0	...
Engineering	205	5.6	...
Scheduled for observation	2533	69.3	100.0
Observed	1588	43.5	62.7
Lost due to weather	693	...	27.4
Lost due to telescope/dome/guider failure	51	...	2.0
Lost due to instrument failure	110	...	4.3
Lost due to other circumstances	82	...	3.2
Not scheduled	916	25.1	...

TABLE 2

NIGHTS LOST DUE TO WEATHER
July 1982 to June 1992

Month	No. scheduled nights	% over scheduled nights
January	147	28.9
February	172	38.7
March	210	35.7
April	240	32.1
May	240	15.4
June	207	16.3
July	197	23.9
August	223	25.6
September	256	21.9
October	252	29.0
November	229	33.6
December	160	32.5
Total	2533	27.4

TABLE 3

PERCENTAGE OF PHOTOMETRIC AND SPECTROSCOPIC NIGHTS
January 1984 to December 1991

Month	% over scheduled nights	
	photometric	spectroscopic
January	43.7	78.6
February	41.9	65.9
March	49.7	78.5
April	55.6	79.4
May	72.9	95.0
June	70.4	90.5
July	59.1	84.7
August	56.2	81.1
September	64.9	84.5
October	61.3	78.9
November	54.1	75.0
December	47.1	64.4
Total	57.6	80.4

TABLE 4

PERCENTAGE OF PHOTOMETRIC AND SPECTROSCOPIC NIGHTS
January 1984 to December 1991

Year	% over scheduled nights		
	photometric	observed	spectroscopic
1984	63.8	65.3	86.2
1985	59.9	61.5	81.8
1986	57.3	60.7	79.7
1987	56.0	60.7	77.8
1988	67.7	69.7	80.2
1989	53.6	74.0	79.8
1990	48.1	64.7	79.0
1991	54.9	62.9	77.6
Total	57.6	64.2	80.4

The ten-year observing statistics for the 2.1-m telescope is given in Table 1. All entries are self explanatory. Table 2 gives the monthly percentage of nights lost due to bad weather in the 2.1- m telescope over the ten years considered. In this category are included the (half) nights lost due to cloud cover, high humidity, high winds and very bad seeing, but no difference is made between time lost for photometric or spectroscopic/imaging programs. Clearly, the percentages are calculated over the total number of scheduled nights, as no weather information is recorded for the nights not scheduled for observation.

From the nightly data on the percentage of cloud cover, the average number of "photometric" and "spectroscopic" nights (as defined in §II) was computed for the January 1984 to December 1991 period. Previous to 1984, the log book did not contain detailed cloud cover information. In order to include only full years, the 1992 data was omitted. The results are shown in Tables 3 and 4 and displayed graphically in Figure 5 (monthly averages) and Figure 6 (yearly averages). In the atter, note the dip in the percentage of observed ıights in late 1982 and 1983. This was caused by the vell known El Niño phenomenon. It is interesting hat, in spite of reports of the re-appearance in 1992 ›f a similar phenomenon, it has only barely been ·eflected in the amount of cloudy nights in San ›edro Mártir up to the end of June 1992. Figure ; also shows the yearly fraction of nights of actual ›bservation with the 2.1-m telescope (excluding the ime lost due to telescope/instrument failure) from uly 1982 to June 1992.

From January 1984 to June 1992, the fraction of ›hotometric and spectroscopic nights in San Pedro Mártir were 56.6% and 79.9% while astronomical ›bservations were actually carried out on the 2.1-m elescope (1984 - 1992) 69.7% of the scheduled ıights, 25.4% of the nights were lost due to poor veather and 9.1% due to telescope/instrument ailures and other causes. From July 1982 to June 1992, 27.4% of the scheduled nights were lost due o bad weather (Table 1).

IV. COMPARISON WITH OTHER SITES

From the first studies of its climatological prop- ›rties, San Pedro Mártir has been recognized as one ›f the potentially best sites for optical/infrared ob- servations in the Northern Hemisphere (Mendoza *et al.* 1972; Walker 1971; Alvarez & Maisterrena 1977). It is only after ten years of continuous mon- toring of the metereologial characteristics of this site, that proper comparison can be made with other existing (or well studied) observatory sites like Mauna Kea, Hawaii, Kitt Peak and Mt. Graham, Arizona, Cerro Tololo and La Silla, Chile. Graphic comparisons of the monthly percentage of the cloud cover will be made using plots on the same scale of published data and those reported in §III.

Geographically speaking, San Pedro Mártir is the Northern Hemisphere counterpart of Cerro Tololo or La Silla. They are at roughly the same latitude and at similar distance to the Pacific coast, though San Pedro Mártir is at an elevation some 500 m higher. The data on the monthly fraction of photometric nights considered in this work for the Chilean sites is the weighted (by number of nights) average of those published by Osmer & Wood (1984) for Cerro Tololo in the period 1973 - 1982 and by Sarazin (1990) for La Silla in the periods 1965 - 1972 and 1983 - 1990. The fraction of spectroscopic nights, defined as "one with at least 50% [of the sky] free from clouds or at most 20% absorption over a major part", refer to the period 1984 - 1986 in La Silla only (Sarazin 1990). These values are plotted in Figure 7a. The upper continuous line connects the points corresponding to the spectroscopic sky and the lower line, the photometric sky. Note that for direct comparison with the Northern sites, the abscissa has been shifted six months. The average values for San

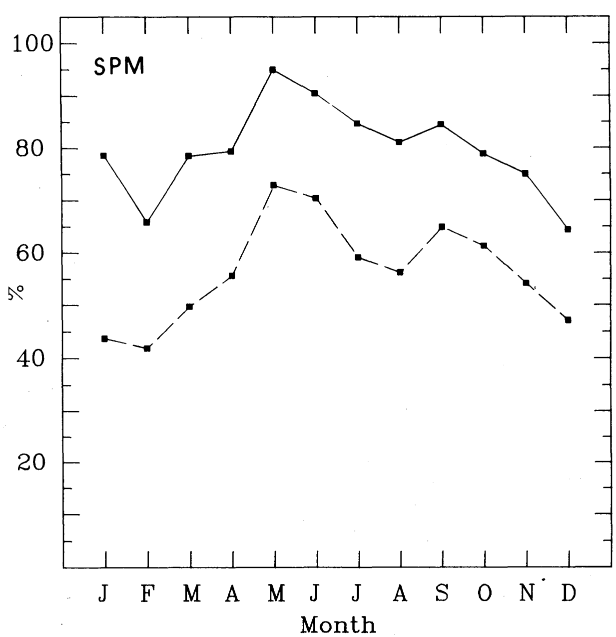

Fig. 5. Monthly fraction of nights of photometric (broken line) and of spectroscopic quality (continuous line) in San Pedro Mártir during the period January 1984 to December 1991.

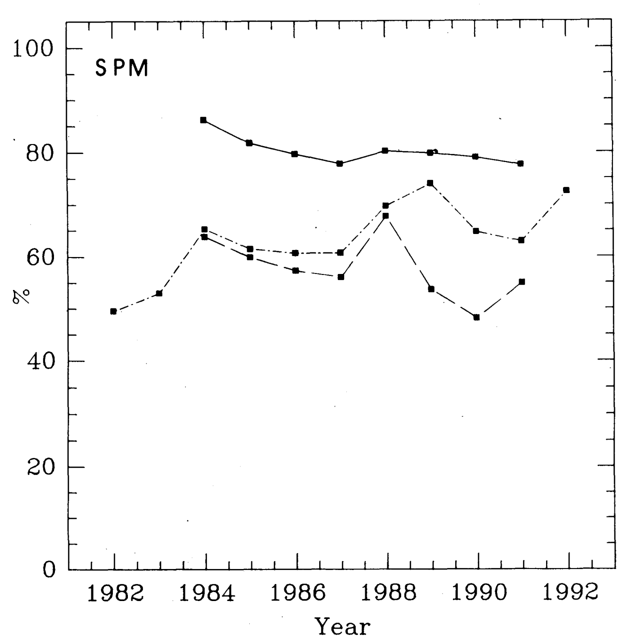

Fig. 6. Yearly fraction of nights of photometric (broken line) and of spectroscopic quality (continuous line) in San Pedro Mártir during the period January 1984 to December 1991. The dotted line marks the actual use of the 2.1-m telescope (excluding the time lost due to telescope/instrument failure) in the period July 1982 to June 1992.

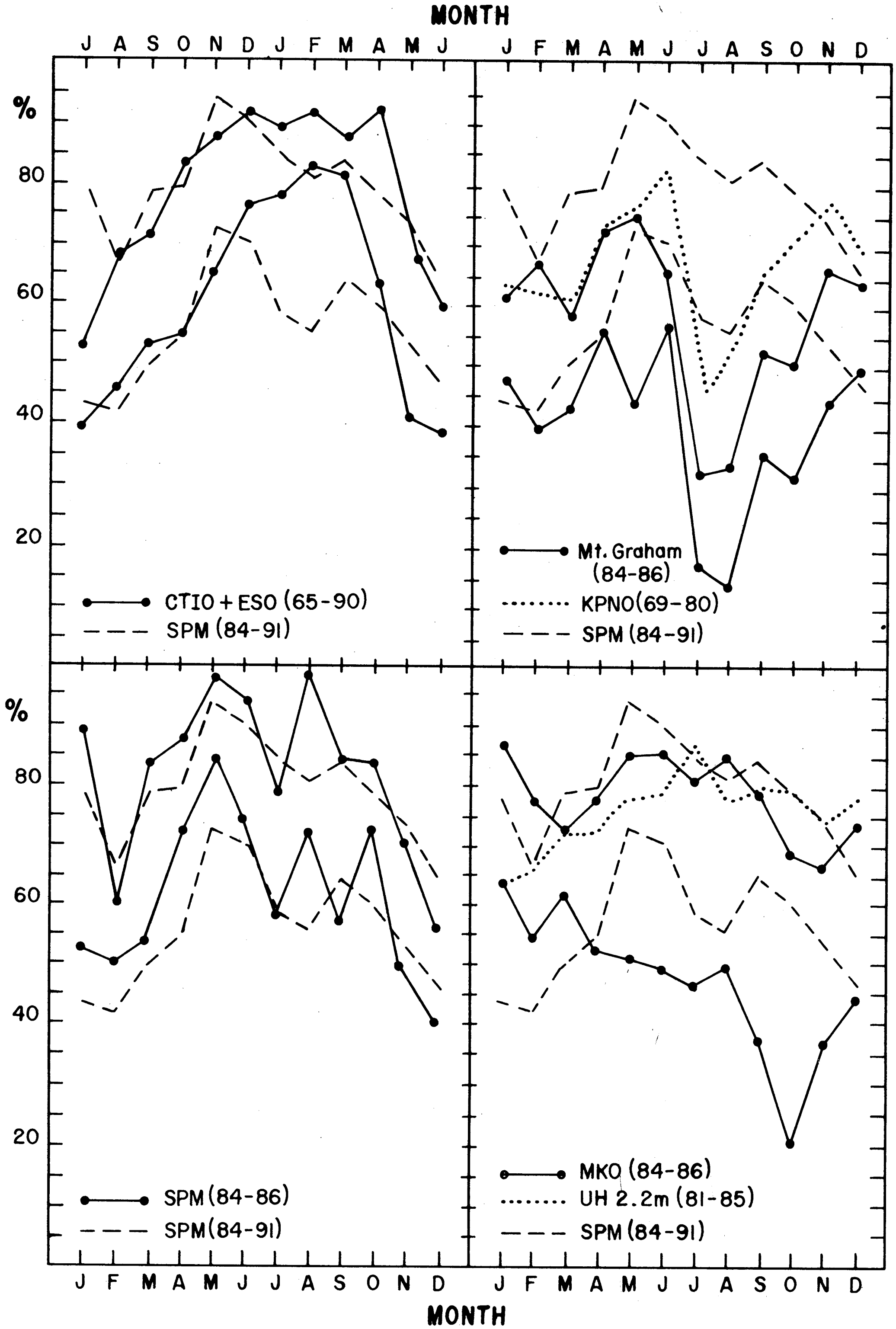

Fig. 7. Monthly fraction of nights of photometric (lower lines) and of spectroscopic quality (upper lines) in several sites (continuous lines) compared to those of San Pedro Mártir (broken lines). The dotted lines in pannels b and d are the actual KPNO 4-m and 2.1-m telescope fractions used (b) and of the University of Hawaii 2.2-m telescope on Mauna Kea (d). The abscissa for Cerro Tololo and La Silla (a) runs from July to June, while for the Northern Hemisphere sites the abscissae run from January to December.

edro Mártir are shown connected by broken lines. 'he average fraction of photometric nights in the :hilean sites is 59.8% (Sarazin 1990; Osmer & Vood 1983) and there seems to be no appreciable ifference between Cerro Tololo and La Silla; the raction of spectroscopic nights at La Silla is 82.8% Sarazin 1990).

The Mauna Kea Observatory in the Big Island f Hawaii is the largest observatory in the Northern Iemisphere (in terms of collecting area of existing nd planned telescopes). It is also the highest and lryest site in continuous operation. Mt. Graham, rizona, has also been studied extensively as a posible site for some of the largest telescopes planned. Merrill & Forbes (1987) made a comparison study f the astronomical site quality between Mauna Kea nd Mt. Graham and concluded that the former as superior astronomical qualities. This study was ased on similar simultaneous (February 1984 to March 1986) tests on the basic parameters which afect the optical and infrared astronomical observaions. For the purpose of this work, only the cloud over and relative humidity on the ground will be onsidered.

Figures 7b and 7d show the monthly average raction of photometric (lower continuous curves) nd spectroscopic (SKYOK; upper curves) nights at oth sites as reported by Merrill & Forbes (1987). The definition by these authors of SKYOK nights "times when the cloud cover was $\leq$ 60% and ntermitent") is analogous to that adopted here for 'spectroscopic" nights and therefore, these data re directly comparable. Merrill & Forbes (1987) tate that their results are representative of the ong term weather behaviour in each place, based n comparison with similar values recorded for onger periods at Kitt Peak, some 200 km SW of Mt. Graham and the log book of the University of Hawaii 2.2-m telescope on Mauna Kea. To illustrate his, also included in Figures 7b and 7d are the reported (dotted lines) values of the fraction of *observed time* with the 2.1-m and 4-m telescopes on Kitt Peak (Crawford 1987) and the U. of Hawaii 2.2-m telescope. Finally, Figure 7c shows that for San Pedro Mártir, the weather in the period March 1984 to February 1986 (continuous lines) was not very different from the long term weather pattern observed for 1984 - 1992. In all panels of Figure 7, the San Pedro Mártir monthly average fraction of photometric (lower broken lines) and spectroscopic (upper broken lines) are presented for comparison.

V. CONCLUSIONS

The results reported in this work and those published for Mt. Graham, Mauna Kea and Cerro Tololo and La Silla are summarized in Table 5. From this and the plots in Figure 7, the following conclusions can be reached concerning the amount of cloud cover and relative humidity at the ground:

1. San Pedro Mártir has proved to be a site with a very low fraction of nocturnal cloud cover in the long term. The figures presented here for the period 1982 to 1992 are in agreement with the observations made over shorter periods (up to three continuous years) in the early 1970's. Winter is the worst season; spring and autumn have a larger number of clear nights. Local afternoon rainstorms during the summer months cause a moderate increase in the number of cloudy nights in July and August, combined with an increase in relative humidity. Apart from this, no seasonal pattern is observed in the nocturnal readings of relative humidity near the ground.

2. The percentage of clear (photometric) and partially clear (spectroscopic) nights in San Pedro Mártir is slightly lower than in the Chilean sites. The main difference occurs in the summer months, due to a moderate monsoon season in the Baja Californian site. The rest of the year they show similar statistics, though in winter it seems to be

TABLE 5

SUMMARY OF AVERAGE DATA

Parameter	San Pedro Mártir	Mt. Graham	Mauna Kea	La Silla/Cerro Tololo
Longitude	115° W	110° W	155°W	71° W
Latitude	31° N	33° N	20° N	30° S
Elevation	2950m	3300m	4200m	2400m
Photometric nights	56.6%[a] 61.6%[b]	41%[b]	48%[b]	59.8%[c]
Spectroscopic nights	80.0%[a] 85.2%[b]	54%[b] 58%[d]	73%[b] 69%[d]	82.2%[e]
Relative humidity	54%[a]	73%[b]	25%[b]	~30%[f]

[a] January 1984 to June 1992. [b] March 1984 to February 1986. [c] January 1965 to December 1989. [d] Same as *b* but corrected for long-term behaviour. [e] January 1983 to December 1989. [f] January 1986 to December 1986.

slightly less cloudy in San Pedro Mártir. The ESO definition of "spectroscopic" nights (cf. §IV) is slightly more relaxed than the ones adopted for San Pedro Mártir.

3. The fraction of spectroscopic nights in Mauna Kea is slightly lower than in San Pedro Mártir though there is a marked difference in the number of photometric nights.

4. Mount Graham seems to be the site with the smallest fraction of clear and partially clear nights. This is most dramatic during the period May to October, when the rather long monsoon season (caused by winds from the Gulf of Mexico) make the chances of having cloudless, or even partially cloudy, nights rather slim. In the winter and early spring, the weather in Mt. Graham and San Pedro Mártir seems to be similar, affected by winter storms from the North Pacific. From late spring to late autumn, San Pedro Mártir has a much larger percentage (almost 30% difference) of clear and astronomically usable nights than Mt. Graham.

5. The average relative humidity near the ground at San Pedro Mártir is 54%, implying that it is a dryer site than Mt. Graham (73%; Merrill & Forbes 1987) but a more humid site than Mauna Kea (25%; Merrill & Forbes 1987) and La Silla ($\simeq$ 30%; Sarazin 1990).

Clearly, many other factors apart from those discussed here should be considered for the qualification of a site for optical and infrared observations. Of prime importance is the mean size, or rather, the distribution of the size of the seeing disk over a single night and throughout the year. Only very few proper measurements of the seeing in San Pedro Mártir have been made by Walker (1971, 1984) in 52 nights from April to July 1970. He found that the seeing was less than $1''$ in 17% of the nights and in about 60% of the nights seeing was better than $2''$. A continuous monitoring program of seeing is now being carried out in San Pedro Mártir in collaboration with Steward Observatory. Results from a very limited number of nights suggest that the seeing is extremely good (J. Echevarría, private communication). These data are being supplemented with a second seeing measuring system on loan from Las Campanas Observatory.

Sky brightness over San Pedro Mártir, as in all other observatories, has varied considerably in the years following the eruption of the Chichón and Pinatubo volcanoes. The 1970 observations reported by Walker (1971) show that the sky brightness (V magnitude) is 21.9 at the zenith while it is 21.7 at zenital distance 45° in the direction of the nearest large cities (Mexicali, Tijuana, San Diego, Imperial Valley and Ensenada), all located at distances greater than 150 km. These sky brightness values are similar to those for Mauna Kea and Cerro Tololo and better than Mt. Graham (Garstang 1989) for the same epoch.

Finally, the amount of precipitable water in the atmosphere, critical to evaluate the quality of the sky for infrared observations, is also being monitored continuously from January 1992 in San Pedro Mártir with a radiometer in collaboration with the University of Massachusetts. Up to the end of May, the observed distribution of the amount of precipitable water in the atmosphere above San Pedro Mártir (L. Salas *et al.*, in preparation) is similar to those reported for La Silla for winter and spring (Sarazin 1990).

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