San Pedro Mártir: Astronomical Site Evaluation

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ABSTRACT

The Observatorio Astronómico Nacional at San Pedro Mártir is situated on the summit of the San Pedro Mártir Sierra in the Baja California peninsula of Mexico, at 2800 m above sea level. For as long as three decades, a number of groups and individuals have gathered extremely valuable data leading to the site characterization for astronomical observations. Here we present a summary of the most important results obtained so far. The aspects covered are: weather, cloud coverage, local meteorology, atmospheric optical extinction, millimetric opacity, geotechnical studies, seeing, optical turbulence profiles, wind profiles and 3D simulations of atmospheric turbulence. The results place San Pedro Mártir among the most favorable sites in the world for astronomical observations. It seems to be particularly well-suited for extremely large telescopes because of the excellent turbulence and local wind conditions, to mention but two characteristics. Long-term monitoring of some parameters still have to be undertaken. The National University of Mexico (UNAM) and other international institutions are putting a considerable effort in that sense.

Keywords: Telescopes, Astronomy, Atmospheric Turbulence, Site Testing

1. INTRODUCTION

For more than 30 years the Instituto de Astronomía of the Universidad Nacional Autónoma de México (IA-UNAM) has been operating and developing the National Astronomical Observatory (Observatorio Astronómico Nacional, hereon OAN) at the summit of the Sierra San Pedro Mártir (SPM) in Baja California, Mexico. The observatory is located in a National Park at 31°02'39" N and 115°27'49" W, some 100 km east of the Baja Californian West Coast, at 2830 meters above sea level, and 2300 meters above the peninsula mainland. Three Ritchey-Chrétien telescopes of 0.84 m, 1.5 m and 2.1 m diameter are in operation (see Fig. 1). A description of the present status of the observatory and facilities are presented in Ref. 1.

The excellence of the OAN/SPM astronomical site is demonstrated by the observational work that has been carried out in the optical and infrared, reaching the 21 μm mid-IR window, and by multiple site testing studies. The OAN/SPM site has been extensively studied covering weather and observing statistics, local meteorology,

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Figure 1. A bird's-eye view of the telescope zone at the OAN in San Pedro Mártir. In the foreground is the 1.5 m telescope, followed by the 0.84 m telescope in the middle and the 2.1 m telescope in the background.

atmospheric optical extinction, seeing, optical turbulence profiles, water vapor content, wind vectors, seismicity and geotechnical characterization. Several institutions have participated in these measurements, including IAUNAM, INAOE, CFE, and CICESE in Mexico, and Carnegie Institution, Steward Observatory, University of Massachusetts, Université de Nice and NOAO, from abroad.

This paper summarizes the most important results of the San Pedro Mártir site characterization for astronomical observations. Four aspects are discussed: sky transparency (§ 2) atmospheric turbulence (§ 3), meteorology (§ 4) and geothecnical studies (§ 5). Further details on the SPM characterization are described in Ref. 2. Note that a complete description of the site testing studies have been put together in a dedicated volume of the Revista Mexicana de Astronomía y Astrofísica (Serie de Conferencias)[2], Vol. 19.

2. SKY TRANSPARENCY

Twenty years of weather and observing statistics of SPM have been reported by Mauricio Tapia[3]. As in his previous compilation[4], the fractional number of nights with totally clear, partially clear and mostly cloudy skies were determined from the nightly SPM observing log. The fraction of nights lost due to bad weather was 22.2% in the period covering from July 1982 to December 2002. From January 1984 to December 2002, 63.1% of the nights were of "photometric" quality and 80.8% were of "spectroscopic" quality. Most likely due to long term climatological fluctuations ("drought" in the area), the fractional number of totally clear, photometric, nights has increased considerably, from 57.2% prior to 1996 to 74.6% in the last seven years. The latest results on cloud coverage provide evidence that the long-term climatological conditions that affect the optical and infrared observations at San Pedro Mártir are similar or better to those presented for shorter periods[4,5]. Based on the comparative data presented by these authors[4,5], San Pedro Mártir is confirmed to have the largest fraction of clear nights of any existing or potential observatory site in North America or even, in the Northern Hemisphere.

The extinction coefficients in the optical have been studied since 1973 by William Schuster and collaborators[6]. The most recent results[7] present the mean extinction curve for SPM (1973-1999) and a comparison to other sites. In this work it is shown that San Pedro Mártir is a very good site for photometric astronomy with a mean visual (549 nm) atmospheric extinction coefficient, k_y, of 0.14 mag/air mass. Nearly two-thirds of the photometric nights have k_y values equal or below this mean, with a median and a minimum of about 0.13 and 0.11 mag/air mass, respectively. The extinction is low and very stable in autumn while in spring it is higher and less consistent. The rest of the year the extinction is intermediate. The conclusion is that atmospheric extinction of SPM compares very favorably with all other important astronomical observatories, being equal to or surpassing most, such as La Silla, Kitt Peak, Cerro Tololo, and McDonald. One site which is probably superior to SPM in this respect is Mauna Kea, which shows smaller values of k_y during photometric nights.

Eight years (1995-2002) of radiometric measurements of the zenith atmospheric opacity at 210 GHz (1.4 mm) over SPM have been carried out by David Hiriart and collaborators[8] using a differential heterodyne radiometer. They found the following results: During 1570 days the medial total–sky opacity at 210 GHz was 0.23 nepers. Median values of day–time and night–time zenith opacity of 0.25 and 0.20 nepers respectively were found. Monthly comparisons show that 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. Assuming that $\tau = 0.17$ nepers corresponds to 2.4 mm of precipitable water vapour (PWV) and a linear dependence the opacity values agree with those obtained two decades ago with infrared solar hygrometers (median PWV of 2.5 mm)[9,10] and from satellite measurements (median PWV of 2.7 mm)[5]. The fraction of nights with PWV < 1 mm is around 15 to 20%, except in mid-summer.

3. ATMOSPHERIC TURBULENCE

3.1. Measured parameters

Juan Echevarría[11] briefly reviews the atmospheric turbulence campaigns that have been carried out in SPM for over a decade. The author estimates an overall median value of 0.″55 for the seeing at an altitude of 15 m based on measurements of about 600 nights. Here we review the most recent results. The reader should note that all the atmospheric-turbulence parameters summarized in this section were calculated for the visible range of the spectrum ($\lambda = 0.5$ μm).

Raul Michel and collaborators report almost three year monitoring of the integrated seeing at SPM using a Differential Image Motion Monitor (DIMM). Measurements were made at a height of 8.3 m above the ground and with exposure times of 6 ms. Seeing is reported for a total of 123 nights between August 2000 and June 2003[12,13]. In Ref. 13 it is shown that a median seeing of 0.″60 and a first quartile of 0.″48 are obtained (see upper left panel in Fig. 2). They conclude that the seeing can be excellent and very stable for whole nights, with the best measurements yielding a median of 0.″37 and a first quartile of 0.″32 during more than eight hours of continuous observations. A substantial seasonal variation of seeing was found, in general accordance with previous[14] results: Summer, with a median of 0.″55, is excellent; Spring and Autumn, with median values around 0.″62, are very good, the latter slightly better than previously reported; Winter, with a median of 0.″78, was not as good, and even worse than previous results. Although they note that Autumn and Winter seasons should be better sampled. The expected value of the median seeing 15 m above the ground and extrapolated to null integration time is 0.″61. Finally, San Pedro Mártir is compared with 17 major astronomical sites in the world where seeing has been measured with DIMM instruments (c.f. Table 3 in Ref. 13), showing that SPM is indeed one of the sites with best seeing in the world.

Remy Avila and collaborators[15] present their monitoring results of optical–turbulence profiles and velocity of the turbulence layers at SPM using the Generalized Scidar of Nice University installed on the 1.5–m and 2.1–m telescopes. Their results are part of the so called SPM2000 campaigns, and are detailed in § 2.2 of their paper.[15] The data were collected during 27 nights (11 in April–May 1997 and 16 in May 2000). The statistical analysis of the 6414 turbulence profiles obtained shows that the seeing produced by the turbulence in the first 1.2 km, not including dome seeing, at the 1.5–m and the 2.1–m telescopes have median values of 0.″63 and 0.″44, respectively.

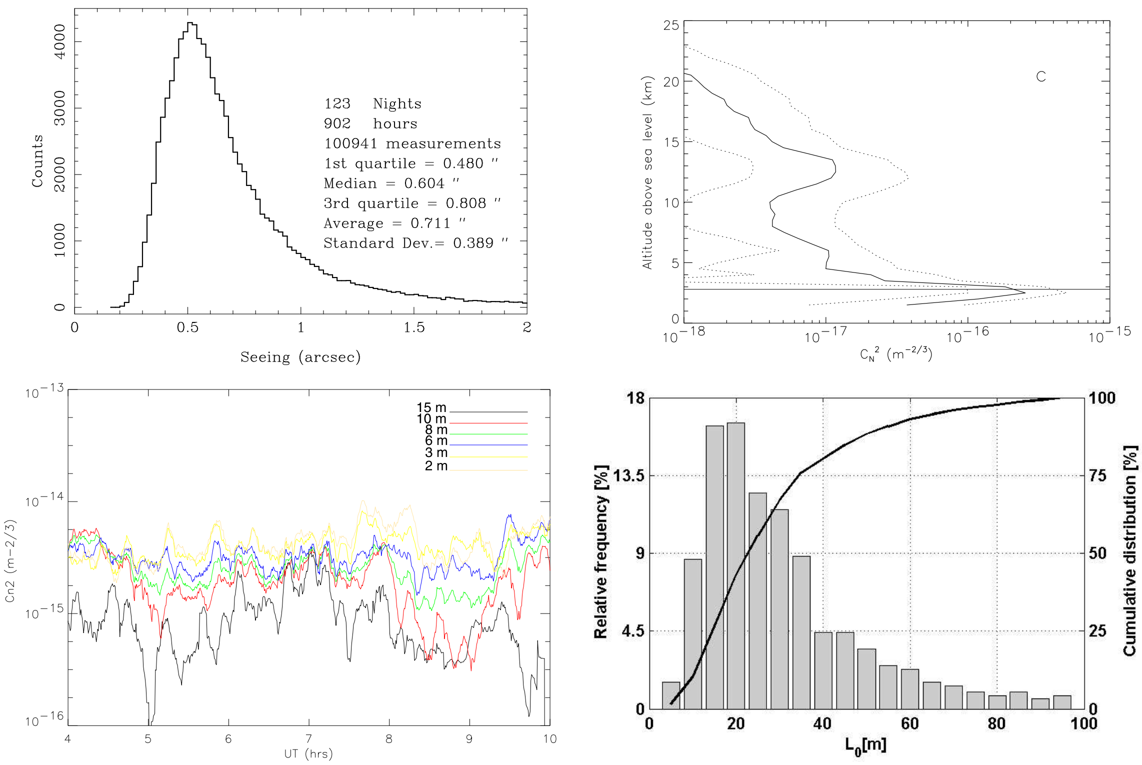

Figure 2. OAN/SPM Results. Top left: Histogram of DIMM measurements on 123 nights in 2000-2003, median seeing is 0.″60[13]. **Top right:** Median (full line), 1st and 3rd quartiles(dashed lines) of the $C_N^2(h)$ values obtained with the GS at the 1.5m and 2.1m telescopes, during 1997 and 2000 campaigns. The horizontal axis represents C_N^2 values, in logarithmic scale, and the vertical axis represents the altitude above sea level. The horizontal line indicates the observatory altitude. Dome seeing has been removed[15]. **Bottom left:** Temporal evolution of C_N^2 measured with the micro-thermal sensors at the heights of 2, 3, 6, 8, 10 and 15-m. Example of one night (May 13 2000) of "normal" data. The integrated C_N^2 from 2.3 to 15 m for the whole campaign is 1.63×10^{-14} m$^{-2/3}$ which yields a mean value of the surface layer seeing of 0.″11[17]. **Bottom right:** Histogram of the wavefront outer scale, $\mathcal{L}_0$, values for the Generalized Scidar Monitor 2000 campaign[18].

The dome seeing at those telescopes have median values of 0.″64 and 0.″31. The turbulence above 1.2 km and in the whole atmosphere produces seeing with median values of 0.″38 and 0.″71. The temporal correlation of the turbulence strength drops to 50% in time lags of 2 and 0.5 hours, approximately, for altitudes below and above 16 km above sea level, respectively. The turbulence above ∼9 km remained notably calm during 9 consecutive nights, which is encouraging for adaptive optics observations at the site. The 3016 profiles of the turbulent–layer velocity that are analyzed show that the fastest layers are found between 10 and 17 km, where the tropopause and the jet stream are located, with median speed of 24.4 m s^{-1}. In the first 2.2 km and above 17 km, the turbulent layers move relatively slowly, with median speeds of 2.3 and 9.2 m s^{-1}. The median of the wavefront coherence–time is 6.5 ms, in the visible. The C_N^2 and **V** profiles are extremely important for the choice of the site for an ELT or any optical telescope with adaptive optics. The studies performed at the OAN–SPM have revealed that the site has truly excellent turbulence conditions. However, a longer–term monitoring is desirable, in order to confirm our results and identify seasonal behaviors, which is the motivation for developing a GS at UNAM[16].

The turbulence in the surface layer was studied by Leonardo Sánchez and collaborators[17] using seven pairs of micro-thermal probes located at different levels of a 15-m-high mast. The measurements took place during 9 and 4 nights in May and August 2000. Incorporating DIMM data obtained simultaneously to the mast data, it was found that the optical turbulence located between 2.3 and 15 m represents 16% of that in the entire atmosphere

(2.3 m–∞). The mean value of the surface layer seeing obtained is 0.″11.

Rodolphe Conan and collaborators[18] show that monitoring of atmospheric parameters such as the wavefront outer scale, $\mathcal{L}_0$, has a strong impact on the performance of high angular resolution instrumentation. In Ref. 18 they report the first measurements of $\mathcal{L}_0$ at SPM using the LUAN (Nice) Generalized Seeing Monitor. The histogram of the values obtained shows a log-normal distribution (c.f. Fig. 2) based on a single campaign in December 2000. The most frequent values lie between 15 and 20 m and 25% of the values are less than 15 m. A median value of 27 m has been found. Sporadic $\mathcal{L}_0$ bursts appear on some nights. The SPM results are very similar to those obtained at other astronomical sites but longer missions performed in different periods of the year during a few years would bring valuable information concerning the temporal/seasonal variation of the $\mathcal{L}_0$ parameter. They[18] also discuss the implications of such values for the adaptive-optics performance in Extremely Large Telescopes, coming to very positive conclusions.

We conclude that the atmospheric turbulence results obtained implies that San Pedro Mártir is among the best suited sites for installing next generation optical telescopes.

3.2. Numerical Simulations: Meso-Nh model

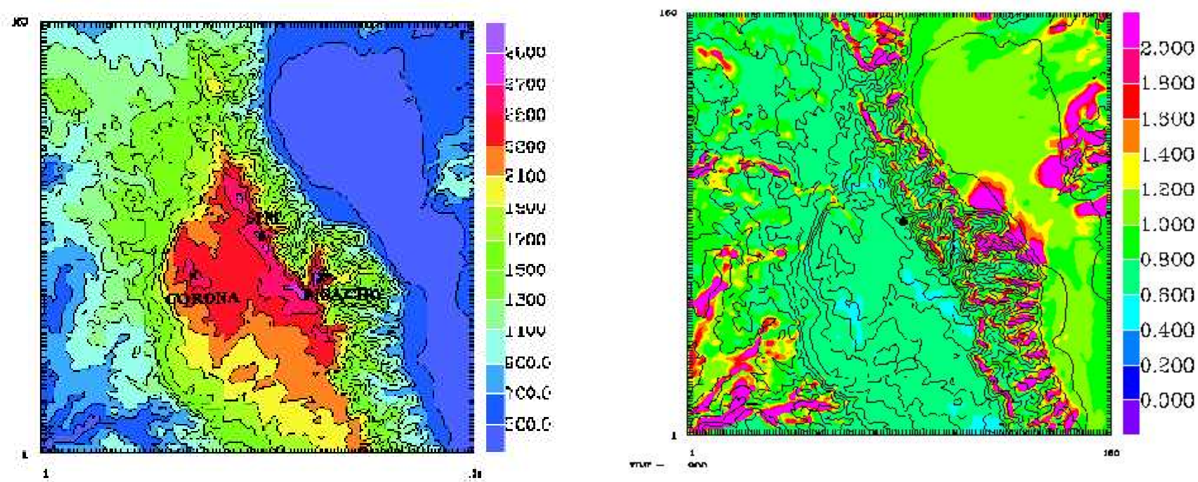

Figure 3. Left: Orographic map extended over 60 km × 60 km centered above SPM Observatory. The horizontal resolution is 400 m. **Right:** Seeing map obtained numerically after 1 hr simulation. (E. Masciadri, personal communication)

The SPM2000 campaigns are part of an ongoing study of optical turbulence (OT) characterization, which has been planned with the goal of obtaining the most detailed information possible. For this reason, different instruments were used to monitor the vertical distribution and the integrated value of the turbulence in the region around the site. At the same time, it was envisaged to apply numerical techniques. This work has been conducted by Elena Masciadri and collaborators. An innovative technique, that consists of using an atmospheric model (Meso-Nh model), conceived to simulate the classic meteorological parameters (V, T, p) and recently adapted to inclusively simulate the optical turbulence was developed. The goals of Masciadri's study are: A) To validate the atmospheric model, that is, to calibrate the model on the SPM site and study its reliability, i.e. the dispersion of the simulations with the measurements. B) To carry on a climatological study, extended over 1 year of the C_N^2 vertical profiles and all the integrated astroclimatic parameters above the SPM site. As an example, Fig. 3 presents the SPM orografic map and the numerically simulated seeing map. The principal results of Masciadri's work are the following: 1) A new technique of the model calibration was proposed, which proved to be reliable and was tested for a few nights[20]. 2) The statistical reliability of the model was studied comparing simulations with measurements related to the site testing campaign SPM2000[21], showing that both are well correlated due to a better model calibration. Fig. 3.2 shows[19] a good agreement between measurements and simulations from a quantitative and a qualitative point of view. 3) First evidence of the finite horizontal

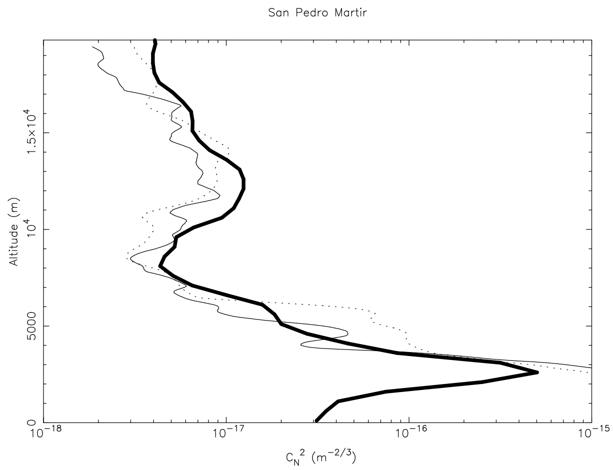

Figure 4. Mean vertical C_N^2 profiles measured and simulated over the whole SPM2000 campaign. Bold line: GS. Thin line: radio-soundings. Dotted line:Meso-Nh model[19].

extent of the optical turbulence layers was shown[22,23]. 4) A study on the use of numerical techniques to characterize seasonal variations of the wavefront coherence time on SPM was carried out[24]. 5) A study[25] was done aiming to test the ability of the Meso-Nh model in selecting sites having an extremely low wind intensity near the ground, particularly important for the ELTs. 6) The climatologic study of C_N^2 extended over a whole year to characterize the seasonal variation of the turbulence at different altitudes and the seasonal variations of the principal integrated astroclimatic parameters: seeing, isoplanatic angle, wavefront coherence time, spatial coherence outer scale, is in progress.

4. METEOROLOGY

A number of studies on the climatological properties of this site have been reported, mainly during the first years of operation of SPM. References to early meteorology studies are presented in Refs. 3 and 11. Recent meteorological stations data and wind studies have been reported in several papers: Ref. 14 for the period 1992-1994; Ref. 26 for 2001; Refs. 27, 28 for the period 1998-2002 and Ref. 29 for the period 1980-1995.

Temperature measurements in 1998-2002 show a Winter minimum of -13° C, a Summer maximum of 25° C, and an annual night to day gradient of 10° C, c.f. Ref. 28. The relative humidity shows a seasonal dependence, high variations in short timescales specially occur during the summer nights[28]. Measured atmospheric pressure values are in the range 550 and 565 mm Hg during 1998-2002[28].

Wind measurements[14] on 386 nights (1992-1994) with a propel anemometer show a steady night-time wind speed that rarely exceeds 11 m s^{-1}. Although the predominant and strongest wind comes from the SSW, while the wind rarely comes from the E and WNW, the wind speed distribution appears almost uniform. Seasonal effects show that the spring wind direction distribution is uniform, while the summer distribution shows a gap in the W direction. During the summer, winds appear to come more uniform from the E with very few W-NW winds. Wind speed during summer and spring are almost constant at 5.5 m s^{-1}. Winter predominant winds come from the NE and SW, autumn predominant winds come from NW and SE. Both season speed distributions have more or less uniform value of 5.5 m s^{-1}, although with higher dispersions to higher speeds for winds coming from the N[14].

The most recent wind measurements[28] with an Ultrasonic Anemometer at 10 m height yield for 150 days (2002-2003) median values of 3.9 m s^{-1} during the day and 5.3 m s^{-1} at night. Wind speed tend to be more stable during the day; winds are stronger during the night and the wind rarely blows during the day from the East. Wind characterization and modelling in SPM is also an area that still needs more work.

Esperanza Carrasco and Marc Sarazin[29] have revised the work on high altitude wind at about 12 km above sea level for the SPM site. They analyse the wind velocity monthly variation over a period of 16 years, between 1980 to 1995, for San Pedro Mártir, Mauna Kea and other existing observatories and sites of interest. The authors compare the results obtained from two different data sets, the GGUAS and NCEP. For SPM they obtained annual average values of 27±3.6 m s^{-1} (GGUAS) and 26.5±1.7 m s^{-1} (NCEP). They note that their results show that San Pedro Mártir and Mauna Kea are comparable and are among the most suitable sites to apply slow wavefront corrugation correction techniques.

5. GEOTECHNICAL STUDIES

The geotechnical characterization of SPM was carried out in 2000 by the Gerencia de Estudios de Ingeniería Civil of the Comisión Federal de Electricidad (GEIC/CFE). The principal aim of the series of topographic, geological and geotechnical studies was to characterize the subsoil performance at one of the possible construction sites of a new telescope, which may also provide an idea of the characteristics of other possible locations at the SPM summit. The geotechnical study[30] involved the following aspects: a) Topographic survey at scale 1:500 covering an area of 250 m × 200 m, and the location of three reference points with a GPS. b) A detailed geological survey covering an area of 5 hectares, to show lithological units, structures and geological discontinuities. c) Geotechnical exploration at selected locations near the 1.5m telescope position 31°02'43" N and 115°28'0"W, which lie close to the Differential Image Monitor tower was carried out. Three borings reaching a maximum depth of 22 m with no recovery of rock cores were done. d) Geophysical studies inside the boreholes and seismic refraction surveys to determine the ground resistivity. e) Sampling of rock blocks representative of the *in-situ* material, to perform index and mechanical tests in the laboratory. The main conclusions are that the subsoil can be classified in three principal horizons or layers (A, B and C). The A-horizon consists of decompressed rock of depth 1.3 to 3.0 m, which has to be removed for the foundations. Layer B consists of fractured rock with an RQD (rock quality designation) between 65%-80%, a thickness of 10-12 m, and a high load bearing capacity. This implies that the required depth excavations for the foundation footings ranges from 2 to 3 m, where an adequate dynamic modulus of elasticity can be reached. Horizon C from 13 to 22 m, the maximum depth explored, consists of rock (gray schist) of massive nature with some granite intrusions that appears slightly fractured, with an RQD above 90%. The geotechnical parameters of the three layers A, B and C are presented in Table 1[30].

Table 1. San Pedro Mártir Subsoil Geotechnical Characterization.

Horizon	Depth (m)		Thickness	RQD[a]	GSI[b]	E_m[c]	Dynamic parameters (Average)[d]				
	From	To		Inferred			V_P[e]	V_S[f]	E_d[g]	G_d[h]	ν[i]
			(m)	(%)		(MPa)	(m s^{-1})	(m s^{-1})	(MPa)	(MPa)	
A	0.00	1.30-3.00	1.30-3.00	<2.5	<40	2300	1398	594	2313	832	0.39
B	1.30-3.00	13.00	10.00-11.70	65-80	83	7300	2567	1230	10945	4104	0.34
C	13.00	22.00	>9.00	>90	92	22600	4045	2192	32620	12624	0.29

[a]Rock Quality Designation
[b]Geological Strength Index
[c]Modulus of deformability (static)
[d]The dynamic are taken from the cross-hole study results.
[e]Primary or compressional velocity
[f]Secondary or shear velocity
[g]Dynamic elasticity modulus
[h]Dynamic shear modulus
[i]Dynamic Poisson's ratio

6. CONCLUSIONS

We have described site testing studies of San Pedro Mártir Observatory carried out over the last three decades. These cover many of the characteristics that have to be assessed for an ELT. Including fractional cloud cover, precipitable water vapor, long-term weather patterns, prevailing winds and wind flow across local topographic features, seeing (upper and ground layer turbulence profiles), geologic activity, geotechnical characteristics and light pollution. We conclude that the summit of the Sierra San Pedro Mártir in the Baja California peninsula of Mexico, is one of the best candidate sites for the next generation of telescopes. San Pedro Mártir's characteristics place it among the best three astronomical sites in the Northern Hemisphere. These results praise the astronomical intuition of Guillermo Haro, who selected this Mexican observatory site.

ACKNOWLEDGMENTS

We are grateful to the OAN technical staff for their technical support, observing assistance and help, which have been crucial for all the site testing studies. We thank the IA-UNAM director, Jose Franco, for his encouragement and support. This work has been sponsored by UNAM and CONACYT.

REFERENCES

1. López, J. A. & Gutiérrez, L., RevMexAA(SC), 19, in press, 2003.
2. Cruz-González, I., Avila, R., Tapia, M., RMxAA(SC) 19, in press, 2003.
3. Tapia, M., RevMexAA(SC), 19, in press, 2003.
4. Tapia, M., RevMexAA, 24, 179, 1992.
5. Erasmus, D. E., & van Staden, C. A., *A Satellite Survey of cloud Cover and Water Vapour in the South-western U.S.A. and Northern Mexico*, A study conducted by CELT project (Pasadena: California Institute of Technology), 2002.
6. Schuster, W. J., Parrao, L., & Guichard, J., The Journal of Astronomical Data, 8, No. 2, 1, 2002.
7. Parrao, L. & Schuster, W. J., RevMexAA(SC), 19, in press, 2003.
8. Hiriart, D., RevMexAA(SC), 19, in press, 2003.
9. Westphal, J. A., Infrared Sky Noise Survey. Final report NASA Grant NGR-05-002-185 (Pasadena: California Institute of Technology), 1974.
10. Alvarez, M. & Maisterrena, J., RevMexAA, 2, 43, 1977.
11. Echevarría, J., RevMexAA(SC), 19, in press, 2003.
12. Michel, R., Echevarría, J., Costero, R., & Harris, O., RevMexAA(SC), 19, in press, 2003.
13. Michel, R., Echevarría, J., Costero, R., Harris, O., Magallón, J., & Escalante, K., RevMexAA, 39, in press, 2003.
14. Echevarría, J., Tapia, M., Costero, R., Salas, L., Michel, Ramón, Michel, Raúl, Rojas, M. A., Muñoz, R., Valdéz, J., Ochoa, J. L., Palomares, J., Harris, O., Cromwell, R., Woolf, N., Persson, S., & Carr, D. M., RMxAA, 34, 47, 1998.
15. Avila, R., Ibañez, F., Vernin, J., Masciadri, E., Sánchez, L. J., Azouit, M., Agabi, A., Cuevas, S., & Garfias, F., RevMexAA(SC), 19, in press, 2003.
16. Cruz, D. X., Angeles, F., Avila, R., Cuevas, S., Farah, A., González, S. I., Iriarte, A., Martínez, L. A., M. Martínez, M., Sánchez, B., & Sánchez, L. J., RevMexAA(SC), 19, in press, 2003.
17. Sánchez, L. J., Cruz, D. X., Avila, R., Agabi, A., Azouit, M., Cuevas, S., Garfias, F., González, S. I., Harris, O., Masciadri, E., Orlov, V., Vernin, J., & Voitsekhovich, V., RevMexAA(SC), 19, in press, 2003.
18. Conan, R., Avila, R., Sánchez, L. J., Ziad, A., Martin, F., Borgnino, J., Harr is, O., González, S. I., Michel, R., & Hiriart, D., RevMexAA(SC), 19, in press, 2003.
19. Masciadri, E., Avila, R., Sánchez, L. J., Cuevas, S., Garfias, F., Agabi, A., Azouit, M., & Vernin, L., RevMexAA(SC), 19, in press, 2003.
20. Masciadri, E., Jabouille, P., A&A, 376, 727, 2001.
21. Masciadri, E., Avila, R., Sánchez, L. J., RevMexAA, submitted.

22. Masciadri, E., Bougeault, P., Vernin, J., Angeles, F., in Interferometry in Optical Astronomy, eds. P. Lena, & A. Quirrenbach, Vol. 4006, SPIE, 1136, 2000.
23. Masciadri, E., Avila, R., Sánchez, L., A&A, 382, 378, 2002.
24. Masciadri, E., Garfias, T., A&A, 366, 708, 2001.
25. Masciadri, E., RMxAA, 39, No. 2, in press, 2003.
26. Michel, R., Bohigas, J., Arroyo, E., Zazueta, S., RevMexAA, 37, 165, 2001.
27. Hiriart, D.; Ochoa, J. L.; García, B., RevMexAA, 37, 213, 2001.
28. Michel, R., Hiriart, D., & Chapela, A., RevMexAA(SC), 19, in press, 2003.
29. Carrasco, E., & Sarazin, M., RevMexAA(SC), 19, in press, 2003.
30. Sánchez, B., Díaz, G., Castilla, J. E., Grijalva, J., Porres, R., Garay, F., & Castellanos, V., RevMexAA(SC), 19, in press, 2003.