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# SITE PROSPECTION AT SAN PEDRO MÁRTIR

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RESUMEN

Realizamos mediciones climatológicas y de *seeing*, en 5 sitios dentro del área reservada para uso astronómico en el Parque Nacional Sierra de San Pedro Mártir (SPM), durante al menos 15 noches en cada uno de ellos. Las variables climáticas se midieron con una estación meteorológica Davis y un anemómetro ultrasónico Metek. El *seeing* fue medido con un RoboDIMM fabricado por NOAO. Las mediciones climatológicas y de *seeing* fueron comparadas con las obtenidas simultáneamente con la instrumentación del Thirty Meter Telescope Project en el Observatorio Astronómico Nacional (OAN) en SPM. Las diferencias de *seeing* son pequeñas en la mayor parte de los casos. Recomendamos que se realice una campaña de larga duración en Llano Alto 1, ya que es un sitio de fácil acceso y el *seeing* parece ser ligeramente mejor.

ABSTRACT

Seeing and weather observations were conducted at 5 sites within the boundaries of the area reserved for astronomy at the Sierra de San Pedro Mártir National Park (SPM), for at least 15 nights at each one of these. Weather variables were measured using a Davis Weather Station and a Metek Ultrasonic Anemometer. Seeing information was collected with a NOAO RoboDIMM unit. Seeing and weather results were compared to those being delivered at the same time by the instrumentation of the Thirty Meter Telescope Project at the Observatorio Astronómico Nacional (OAN) at SPM. Seeing differences are small in most cases. We recommend a long term campaign at the easily accessible site Llano Alto 1, where we found that seeing may be slightly better.

*Key Words:* atmospheric effects — site testing



## 1. INTRODUCTION

During the past decade there has been a renewed interest in the Sierra de San Pedro Mártir National Park (SPM) as a potential site for large telescopes. Mexico's main optical observatory (OAN) has been at SPM since 1970. The OAN currently has three small class telescopes, the largest being a 2.1 m diameter telescope using three interchangeable secondaries to cover ground based observations from $\sim$ 0.35 to 25 $\mu$m. Though small in size, these telescopes have been kept as useful observational tools by adding a wide variety of instruments operating at all ground level observable wavelengths.

But telescope size limits the scope and depth of astronomical projects, and for a number of years the Mexican astronomy community has been looking for funds and partners in order to have larger telescopes at SPM. In addition, the international community has shown interest in SPM since it has a number of added virtues that are hard to find at other present and potential astronomical sites, such as good seeing, dark skies, low content of precipitable water vapor, a large fraction of clear and usable nights, an adequate infrastructure and a long-time running successful operation as an astronomy observatory (Cruz-González, Ávila, & Tapia 2003). A turning point for SPM in the eyes of the international community was an independent report showing that it has the largest fraction of clear and usable nights among those sites in the Northern hemisphere that

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TABLE 1

LOCATION OF SELECTED SITES

| Site | Lat (N) | Long (W) | Height | Direct | Road |
|---|---|---|---|---|---|
| Lodge | 31 2.224 | 115 28.262 | 2620 | 0.00 | 0.0 |
| 2 m | 31 2.647 | 115 27.824 | 2820 | 1.01 | 2.5 |
| Altar (SE) | 31 1.512 | 115 27.063 | 2790 | 2.30 | 7.2 |
| Camino Viejo (S) | 31 2.620 | 115 27.830 | 2785 | 0.91 | 2.7 |
| Cerro Pelado (TIM) | 31 2.735 | 115 28.116 | 2770 | 0.96 | 2.4 |
| La Mesa (N1) | 31 2.912 | 115 28.217 | 2695 | 2.00 | $\geq$ 3.4 |
| Loma Perdida (N2) | 31 3.335 | 115 28.094 | 2710 | 2.22 | $\geq$ 5.6 |
| Llano Alto 1 (E1) | 31 2.491 | 115 27.243 | 2800 | 1.71 | 3.9 |
| Llano Alto 2 (E2) | 31 2.608 | 115 27.127 | 2760 | 1.82 | 3.9 |

Names and short names (in parenthesis) are given in the first column. Latitudes and longitudes are given as degrees and fractional minutes of arc. Heights are meters above sea level. Direct and road distances are from the lodge, and are given in kilometers.



were considered by the working group (Erasmus & van Staden 2002), a fact long known by the Mexican astronomy community (Tapia 1992, 2003).

In anticipation of the possible success of any one of these projects, UNAM's Instituto de Astronomía, the institution in charge of running OAN, decided to explore SPM looking for viable locations in SPM for large telescopes (besides the site that is currently in use). This paper describes the results of a year-long campaign exploring seeing and weather conditions at 5 locations within SPM, which were previously over-viewed by Sohn (2007). In § 2 we present the geographical location of the area reserved for astronomy within the National Park boundaries, the area currently in use by OAN and the sites where we conducted our research. The equipment used to measure seeing and weather conditions is described in § 3, results are presented in § 4 and conclusions are given in § 5.

## 2. LOCATION OF SELECTED SITES

The Sierra de San Pedro Mártir extends over an area of roughly 250,000 hectares. The San Pedro Mártir National Park, established on April 26, 1947 (`www.conanp.gob.mx/anp/pn.php`), occupies 72,910 hectares within this region. On February 12, 1975, a Presidential Decree established that astronomical research was to be encouraged and protected inside the park boundaries, but no specific provisions were made. In 2005 state and federal authorities defined a $\sim$3,000 hectares area where activities other than research in astronomy were not to be allowed. Astronomy projects in this area still need the usual environmental permits. Night sky illumination is not yet a significant problem at OAN, since there are no major urban centers nearby. Future dark night sky conditions have been recently guaranteed with the approval of regulations for illumination in Ensenada, a municipality extending over an area of 51,952.3 km$^2$. Direct distances (in kilometers) between OAN and the most important population centers in the region are as follows: 250 to San Diego, 220 to Tijuana, 180 to Mexicali, 140 to Ensenada, 70 to Colonet and San Quintín and 60 to San Felipe. Colonet, San Quintín and San Felipe are small towns, with a population between 5 and 10 thousand each.

Within the area reserved for astronomy we produced a list of potential sites based primarily on height above sea level and proximity to our observatory facilities. A list of these sites, including their geographical coordinates, height above sea level and distance from our lodge, both direct and by road, is given in Table 1. As a reference, we also include data for the lodge and the 2 meter telescope. We still have to make on-site observations at La Mesa (N1) and Loma Perdida (N2), and their coordinates and road distances are based on estimates made from the contour map shown in Figure 1. The Google image of the region, shown in Figure 2, provides a more familiar view. All sites are marked in both figures (using the short names listed in Table 1).

## 3. INSTRUMENTAL SETUP

Since there is no permanent installation at any one of the sites here described, we had to build a 7 meter tower (Figure 3) that could be mounted or dismounted in no more than 4 hours by a crew composed of roughly 4 people. The tower had to

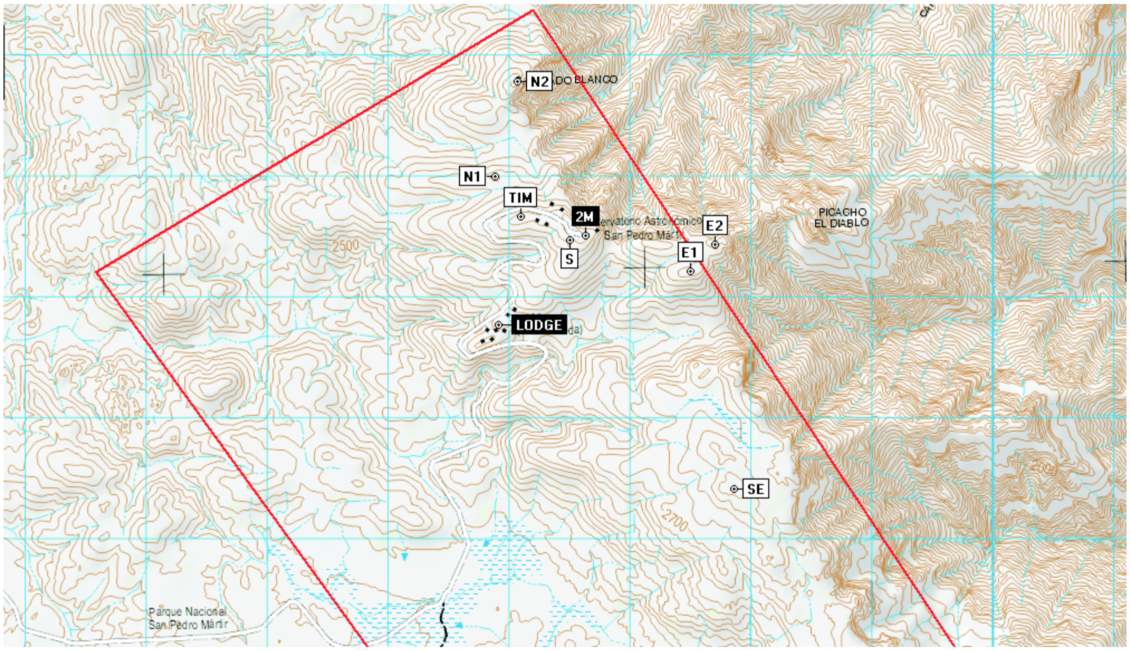


Fig. 1. Contour map of the region which includes the sites discussed in this paper. Contours are drawn every 20 meters and the small blue box size is 1×1 km. Sites labeled as "Picacho del Diablo" and "Venado Blanco" are erroneous identifications. Site locations and boundaries of the area reserved for exclusive astronomical use (in red) are marked.

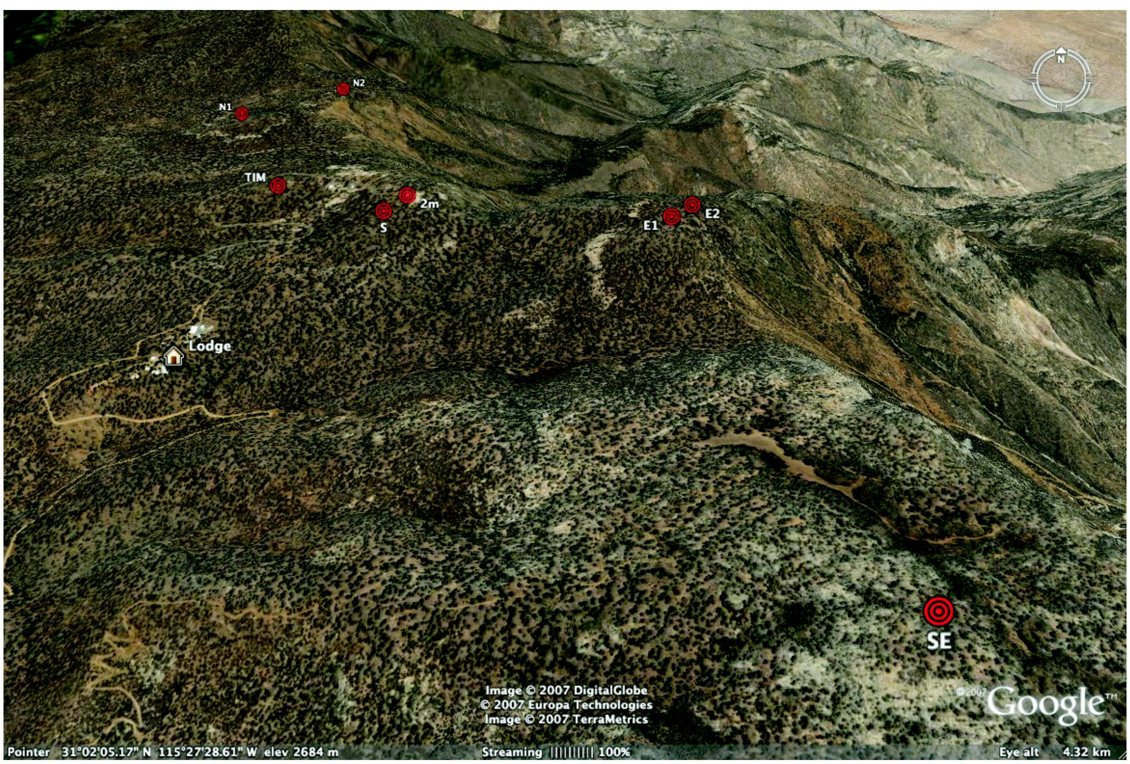


Fig. 2. Google image of the region including the sites discussed in this paper. The observer is located south at a height of 4.32 km.

Fig. 3. Transportable tower at the Camino Viejo site. The RoboDIMM unit, the Davis meteorological station and the Metek ultrasonic anemometer are clearly visible.



be compact and light enough to be transported to the next site, often using improvised roads passing through rough terrains. In most cases we had to use the observatory's machinery to smooth the road. Since the equipment requires personal attention, living quarters including a cabin and a power station, among other things, had to be transported with the tower. The observing crew was usually composed of two persons. Once on the ground, the tower was stabilized with four or more tensors anchored at the base of robust trees or large solid rocks. Even so, observations had to be suspended on several occasions due to vibrations induced by high-velocity winds.

Seeing was measured using a NOAO RoboDIMM unit that was kindly made available to us. RoboDIMM is amply described in Walker et al. (2003) and Bustos, Tokovinin, & Schwarz (2004), as well as in Núñez et al. (2007), where this instrument is compared to the DIMM unit used at SPM in previous seeing campaigns.

Weather information is provided by a Davis wireless Vantage Pro 2 Plus weather station with a fan aspirated radiation shield (henceforth WS) and a Metek Ultrasonic Anemometer USA-1 (henceforth UA). The WS station produces a data point every 60 seconds, and the sampling frequency is 0.2 Hz. The WS has no data filtering algorithm. Their brochure states that the anemometer precision is $\pm 5\%$ for wind speeds between 3 and 34 m/s (between 10.8 and 122.4 km/h), humidity measurements are $\pm 3\%$ precise and temperature is $\pm 0.5$ C accurate if it is between $-18$ C and 27 C. The ultrasonic anemometer delivers sound speed and the three velocity components every second, with a 1 Hz sampling frequency, *i. e.,* we pick all measurements produced by the UA. As with WS, there is no data filtering algorithm. The UA unit yields the speed of sound and wind data in the three directions, from the time-of-flight of high frequency ultrasound pulses sent between three pairs of transducers that act alternatively as transmitters

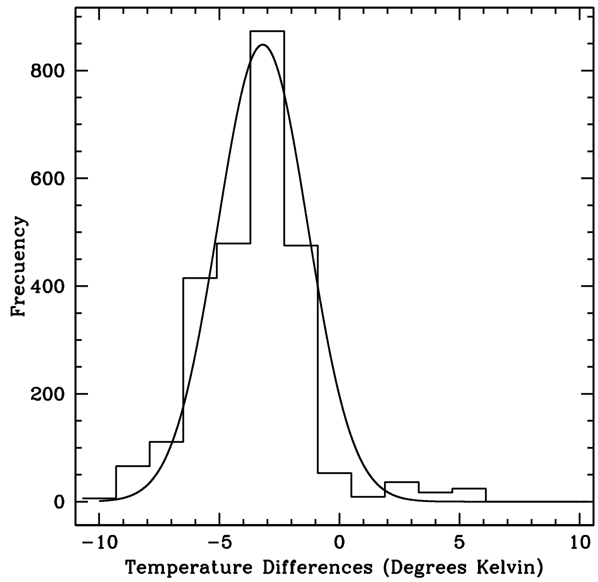


Fig. 4. Histogram for the measured temperature differences T(WS)–T(UA). The continuous line is the Gaussian fit to the histogram.

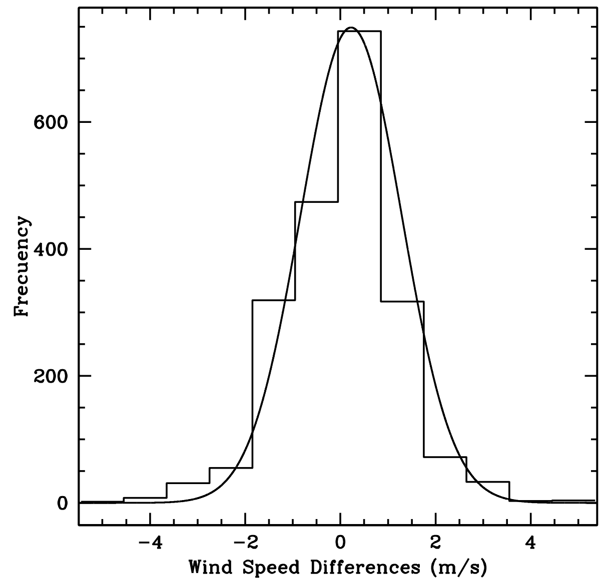


Fig. 5. Histogram for the measured wind velocity differences V(WS)–V(UA). The continuous line is the Gaussian fit to the histogram.

and receivers (e.g. Liu, Peters, & Foke 2001). There are no moving parts in this unit, and the manufacturer states that it can work up to wind speeds of 60 m/s (or 216 km/h). The UA unit estimates the atmospheric temperature $T$ from the following equation,

$$T = (C_{s1}^2+C_{s2}^2+C_{s3}^2+V_{n1}^2+V_{n2}^2+V_{n3}^2)/1209 \text{ K} \quad (1)$$

where $C_{s1}$, $C_{s2}$, $C_{s3}$ are sound speeds measured by each of the three pairs of transducers, and $V_{n1}$, $V_{n2}$ and $V_{n3}$ are wind speeds normal to the axis joining each of the three pairs. Speeds are in m/s. Transverse wind is included to take into consideration that sound arriving at the receiving transducer left the transmitting transducer heading slightly upwind. This is a minor correction, since the wind speed is much smaller than the sound speed. The above equation assumes that the atmosphere is a dry ideal gas ($\gamma$=7/5, 0% humidity). But the sound speed is larger in a humid atmosphere, which implies that for a measured sound speed the real temperature is smaller than prescribed in equation 1.

These instruments were confronted using 10 minute averages for the measured quantities, involving up to 10 data points for WS and 600 data points for UA. The comparison was carried out only when at least 80% of the data points from each instrument were valid. The mean and median temperature differences, T(WS)−T(UA), for 2566 simultaneous 10 minute averages, are $-2.78\pm2.18$ and $-2.16$ K. That is, the temperature derived from the ultrasonic anemometer is larger, as expected since the atmosphere is never dry. The mean and median wind speed differences, V(WS)–V(UA), for 2075 simultaneous 10 minute averages are $+0.53\pm1.31$ and $+0.66$ m/s (or $1.91\pm4.72$ and 2.38 km/h), very close to the 5% precision of the WS for wind speeds between 3 and 38 m/s. The large dispersion in wind speed differences is probably connected to the fact that wind gusts are over-represented when taking the mean. Thus, it is wiser to use medians when assessing wind behavior. As can be noticed, median wind speed differences are sufficiently small so as to conclude that both instruments deliver essentially the same number. We deduce that, within instrumental errors and unaccounted but well understood effects (such as humidity), these two instruments produced very similar results. Since WS and UA work under different principles and were calibrated separately, this implies that there is a high level of confidence in our weather measurements.

In order to inspect if there is any bias in the data, as well as to study the nature of errors, histograms for T(WS)–T(UA) and V(WS)–V(UA) are presented in Figures 4 and 5. As can be seen, excellent Gaussian fits extending to the wings of the distributions are found in both cases, with correlation coefficients equal to 0.95 (temperature), and 0.97 (wind velocity). The Gaussian distributions are centered at


Fig. 6. Image of the Cerro Pelado site. The location of both observing stations, TMT and ours, is clearly marked.

$-3.19$ K and $+0.23$ m/s, and their variance is 1.87 K and 1.06 m/s. Notice that the histogram for temperature differences is shifted towards negative values, as expected from the fact that the temperature delivered by the UA is overestimated, since it does not consider the sound speed dependence on humidity.

## 4. RESULTS

We only had one DIMM unit, so we inspected one site at a time for a period of at least 15 clear nights each. Notice that all tested sites are no more than $\sim$5 km away from each other, which implies that seeing differences should be mostly due to variations in ground-layer turbulence induced by local topography. Since such a small amount of nights is doubtless insufficient to characterize any site, all our measurements are referred to those obtained by the site testing team of the Thirty Meter Telescope Project (henceforth TMT, see Schöck et al. 2007), which stands at the location where practically all seeing campaigns have been carried out at our observatory (seeing observations at SPM are summarized in Echevarría 2003). Comparisons between data from any one of our selected sites and data produced by TMT do not span the entire range covered by weather variables at SPM. Thus, we only report general recommendations on locations at SPM that are worth exploring in more detail, and on some others that can probably be discarded as potential astronomical sites.

In order to assess any systematic difference between data produced by TMT and data produced by our equipment, we carried out seeing and weather measurements at Cerro Pelado, some 40 meters away from the TMT site (see Figure 6). TMT's MASS-DIMM unit sits on top of a 7 meter concrete tower which is far more robust than our collapsible unit. Their weather station is some 10 meters away and 2 meters above ground level, and data are recorded every 2 minutes.

RoboDIMM delivers a seeing measurement roughly every 60 seconds, after some two hundred 5 and 10 ms exposures designed to correct exposure time bias in the manner described by Tokovinin (2002) and Tokovinin et al. (2005). The measurement is considered valid only if the Strehl ratio is larger than 0.5. The experimental setup and accuracy of TMT's DIMM measurements has been amply described by Wang et al. (2007). The TMT DIMM unit records one seeing measurement every 80 to 90 seconds, after some six thousand 6.1 ms exposures. Exposure time bias is corrected with six equally spaced exposure times (from 6.1 to $6\times6.1$ ms). Since the Strehl ratio depends on seeing as well as optical aberrations, TMT does not use a fixed Strehl number for data validation, arguing that this procedure will introduce a bias toward better seeing measurements. Instead of doing so, they optimize the telescope optical alignment beforehand and correct telescope focus whenever necessary (monitoring

TABLE 2

SEEING AND WEATHER DIFFERENCES (SITE - TMT)

| Cerro Pelado (TIM) | Mean | Median | NC |
|---|---|---|---|
| Seeing | +0.039±0.190 | +0.037 | 1094 |
| Temperature | −0.66±0.90 | −0.66 | 320 |
| Humidity | +0.58±9.82 | +0.18 | 320 |
| Wind Speed | +0.57±1.34 | +0.52 | 180 |
| Camino Viejo (S) | Mean | Median | NC |
| Seeing | +0.163±0.207 | +0.152 | 2551 |
| Temperature | −0.43±0.59 | −0.53 | 453 |
| Humidity | +3.88±3.30 | +4.18 | 453 |
| Wind Speed | −0.44±.80 | −0.45 | 412 |
| Altar (SE) | Mean | Median | NC |
| Seeing | +0.017±0.226 | +0.026 | 1446 |
| Temperature | −1.38±2.77 | −0.21 | 795 |
| Humidity | −0.02±10.88 | +0.15 | 795 |
| Wind Speed | +0.96±1.40 | +0.92 | 793 |
| Llano Alto 1 (E1) | Mean | Median | NC |
| Seeing | +0.004±0.242 | +0.015 | 5530 |
| Temperature | −3.17±1.59 | −2.83 | 2246 |
| Humidity | +6.22±6.04 | +8.06 | 2246 |
| Wind Speed | +0.15±1.75 | +0.01 | 1770 |
| Llano Alto 2 (E2) | Mean | Median | NC |
| Seeing | +0.052±0.229 | +0.034 | 6960 |
| Temperature | −1.77±1.40 | −1.93 | 2621 |
| Humidity | +4.77±6.59 | +4.18 | 2621 |
| Wind Speed | −0.24±1.63 | −0.41 | 1612 |

Differences are in arcseconds (seeing), degrees Kelvin (temperature), a percentage (humidity) and meters-per-second (wind velocity). NC stands for the number of comparisons used to determine the mean and median differences.



the separation of stellar images). Seeing differences between TMT and RoboDIMM were determined for all simultaneous data, *i. e.,* data where time tags do not differ by more than ∼90 seconds. Notice that there will be some scatter in seeing differences when the turbulence time-scale is less than the time difference between synchronous data. This is specially noticeable in an unstable atmosphere, *i. e.,* when seeing is bad.

Mean and median seeing, temperature, humidity and wind speed differences between all inspected sites (Table 1) and TMT are shown in Table 2. Comparisons for weather variables were made by averaging these quantities every 10 minutes (10 data points for the WS Davis weather station and 5 data points for the TMT weather station). The number of comparisons carried out at each site for each of these variables, NC, is also given in this table. The main results for the five inspected sites are described in the following paragraphs.

### 4.1. *Cerro Pelado*

As mentioned above, Cerro Pelado (TIM) is located some 40 meters from the site occupied by TMT (see Figure 6). There were no trees within ∼20 meters from the seeing tower, which was standing 20 to 30 meters below TMT. We assume that mean and median seeing and weather conditions are identical

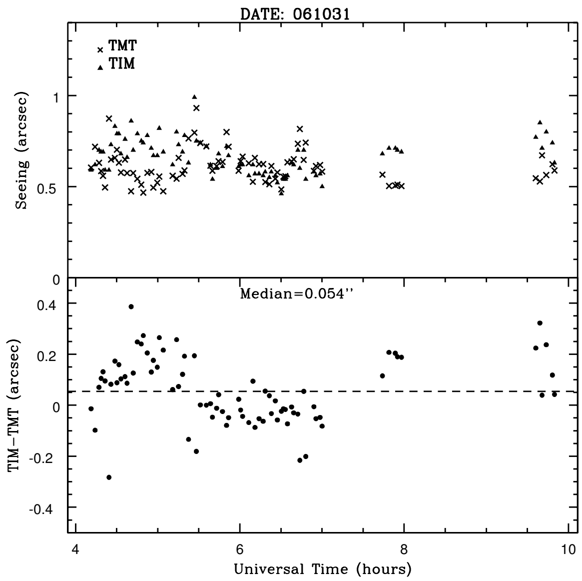


Fig. 7. Seeing measured at the Cerro Pelado (TIM) site and TMT on October 31, 2006, is presented in the upper panel. In the lower panel we show the seeing difference TIM–TMT. The horizontal line is the median seeing difference for the night (+0.054″).

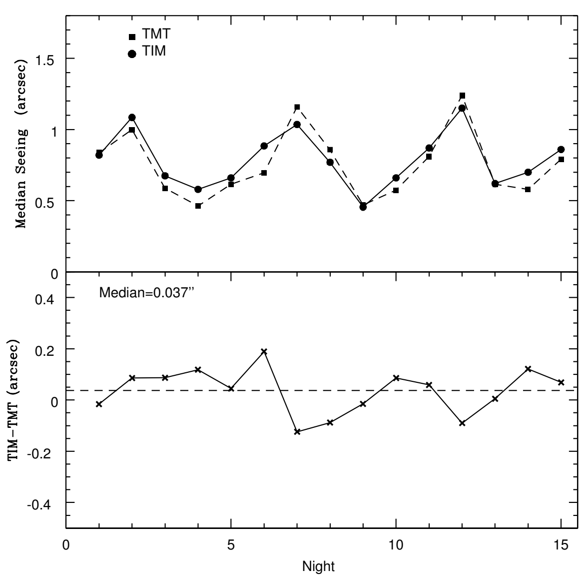


Fig. 8. Median night seeings at the Cerro Pelado (TIM) site and TMT are shown in the upper panel. The lower panel is for the median night seeing differences TIM–TMT. The horizontal line is the median night seeing difference for all measurements taken during the entire run (+0.037″).

at both sites, and that instruments are the underlying cause of any differences in the reported measurements. Simultaneous measurements were carried out for 15 nights between October 27 and November 19, 2006. Seeing measured by us and TMT during one of these nights, as well as differences between these quantities, are shown in Figure 7. Median night seeings (and differences) measured by TMT and RoboDIMM are presented in Figure 8.

From the mean and median values reported in Table 1 we conclude the following: (1) RoboDIMM delivers a worse seeing than TMT (close to +0.04″), (2) WS yields a slightly smaller temperature (∼0.7 K) than TMT, (3) WS and TMT measure the same humidity and (4) the reported wind velocity is slightly higher in WS (about 0.5 m/s or 1.8 km/s). Temperature and wind speed differences are very close to what is anticipated from the combined effect of the instrumental precision from both weather stations. In the case of seeing, the discrepancy may be within the expected instrumental precision or due to slightly different topographical conditions. These instrumental corrections, small as they are, will be considered when discussing seeing and weather at the remaining sites.

### 4.2. *Camino Viejo*

Observations at Camino Viejo (S) were carried out for 17 nights between October 31 and November 25, 2005. Seeing measured by us and TMT during one of these nights, as well as differences between these, are shown in Figure 9. Median night seeings (and differences) measured by TMT and RoboDIMM for these 15 nights are plotted in Figure 10.

In terms of seeing, this is the worst place (∼0.11″ larger). This is not surprising since the site is at the southwestern slope of the mountain topped by the 2.1 meter telescope (see Figures 1 and 2). Tree density is also larger in this location than in the other 4 sites. Within a 20 meter radius there were 21 *Pinus jeffreyi* with heights ranging from 6 to 15 meters above ground level. Most of the trees are aligned along a NW-SE axis, *i. e.,* nearly orthogonal to the prevailing wind axis (NE-SW). Only one of these trees was in the usual wind direction (to the SW), rising about a meter above the tower. It should be pointed out that we started our campaign at this site in order to test the entire operation. Being close to the observatory facilities, we were able to solve promptly any unforeseen problem.

### 4.3. *Altar*

Altar (SE) observations were performed for 15 nights between February 1 and May 4, 2006. This is the most remote site and access is very difficult.

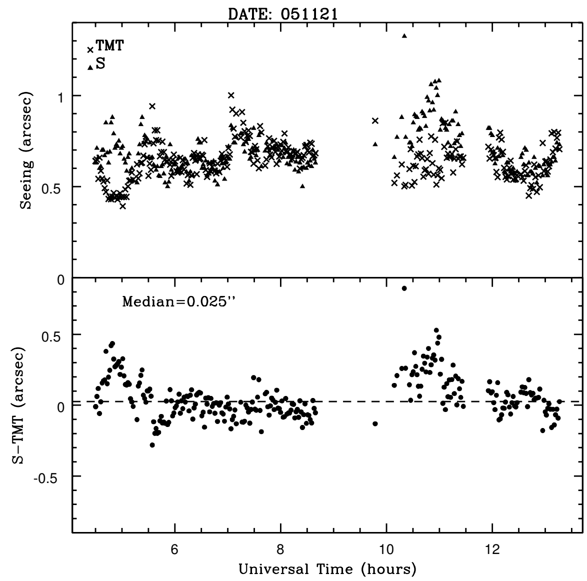


Fig. 9. Seeing measured at the Camino Viejo (S) site and TMT on November 21, 2005, is presented in the upper panel. In the lower panel we show the seeing difference S–TMT. The horizontal line is the median seeing difference for the night (+0.025″).

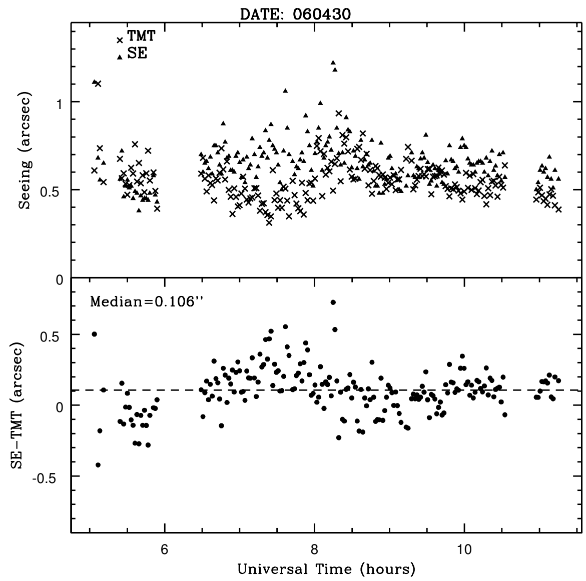


Fig. 11. Seeing measured at the Altar (SE) site and TMT on April 30, 2006, is presented in the upper panel. In the lower panel we show the seeing difference SE–TMT. The horizontal line is the median seeing difference for the night (+0.106″).

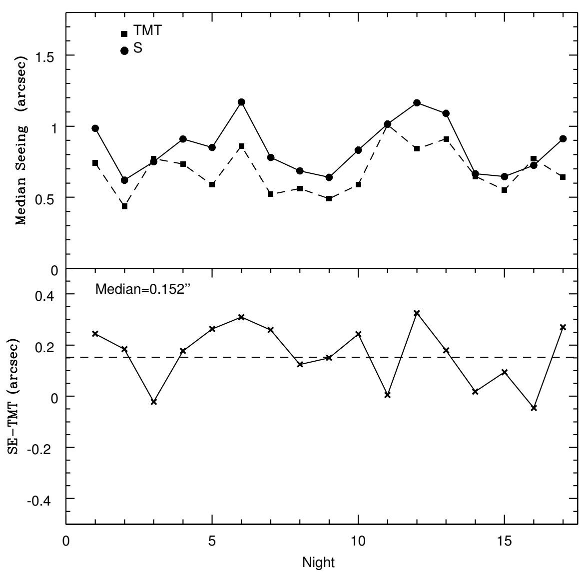


Fig. 10. Median night seeings at the Camino Viejo (S) site and TMT are shown in the upper panel. The lower panel is for the median night seeing differences S–TMT. The horizontal line is the median night seeing difference for all measurements taken during the entire run (+0.152″).

Conditions were particularly harsh during the observing run. As can be seen from Figures 1 and 2, it is the only site located at the SW ridge of the area reserved for astronomy, directly above the Vallecitos valley. This is the main reason why we decided to explore it. Within a distance of 20 meters from the seeing tower there were 2 *Pinus jeffreyi* standing 8 meters above ground, and 4 *Abies concolor* between 3.5 and 9 meters tall. Thus, the tower was in a relatively obstacle-free environment. The terrain is rockier and the tree density is smaller than usual in the Altar region.

Seeing measured by us and TMT during a typical night, as well as differences between these two quantities, are shown in Figure 11. Median night seeings (and differences) measured at TMT and Altar are displayed in Figure 12. As can be seen from Table 2, seeing at the Altar is nearly the same as in TMT (possibly $\sim 0.02''$ better), and the weather is quite similar. Since conditions at the Altar and TMT are comparable, we believe that the large investment and effort that would be required to develop this site, plus the impact it could have on the environment, would be difficult to justify on scientific terms.

### 4.4. *Llano Alto 1*

Llano Alto 1 (E1) seeing and weather was monitored for 34 nights, between May 13 and June 28, 2006. The site is at a high small ridge at the SW edge of an open extended plateau at the top of a

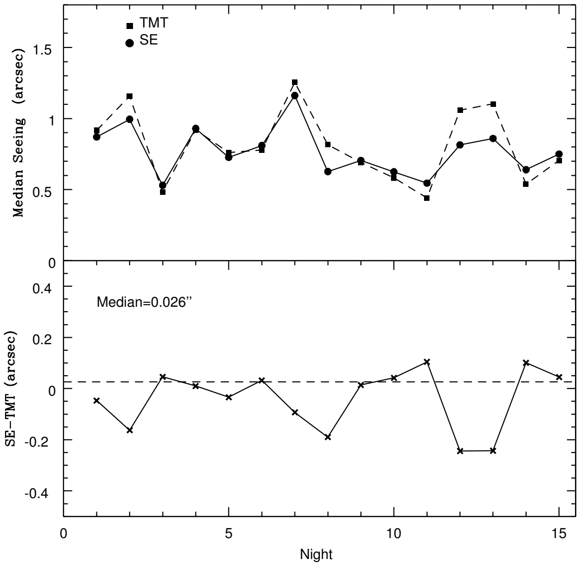


Fig. 12. Median night seeings at the Altar (SE) site and TMT are shown in the upper panel. The lower panel is for the median night seeing differences SE–TMT. The horizontal line is the median night seeing difference for all measurements taken during the entire run (+0.026″).

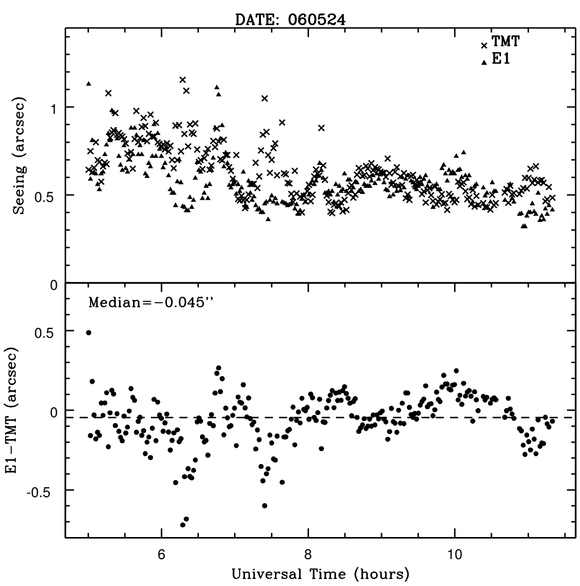


Fig. 13. Seeing measured at the Llano Alto 1 (E1) site and TMT on May 24, 2006, is presented in the upper panel. In the lower panel we show the seeing difference E1–TMT. The horizontal line is the median seeing difference for the night (−0.045″).

mountain (see Figures 1 and 2), commonly known as Llano Alto. Access from the Observatory lodge is very easy. There are many old grown trees in

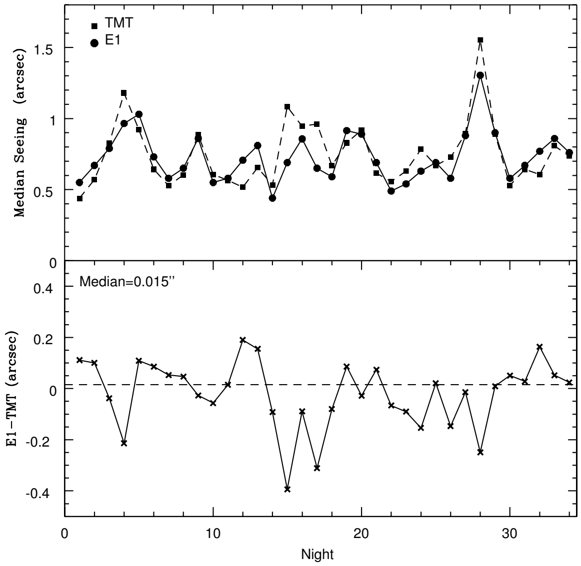


Fig. 14. Median night seeings at the Llano Alto 1 (E1) site and TMT are shown in the upper panel. The lower panel is for the median night seeing differences E1–TMT. The horizontal line is the median night seeing difference for all measurements taken during the entire run (+0.015″).

this plateau, but there were very few in the region surrounding our seeing tower. Within a 10 meter radius from the seeing tower there were 6 *Pinus jeffreyi* between 3 and 7 meters tall, and 4 *Abies concolor* standing 2 to 10 meter above ground level. All tree tops were at a lower height than the seeing tower.

Seeing measurements from us and TMT during one night, as well as differences between these two quantities, are shown in Figure 13. Median night seeings (and differences) measured at TMT and Llano Alto 1 during the 34 nights are plotted in Figure 14. As can be seen from Table 2, Llano Alto 1 may be the best site as far as seeing is concerned, close to 0.04″ better than at TMT and the present location of OAN telescopes. On the other hand, the site is between 2 and 3 K colder and significantly more humid ($\sim 8\%$), as evinced by the relatively large frog population in the plateau. There is hardly any difference in wind speed with respect to TMT. All things considered, the SE ridge of Llano Alto seems to be an excellent location for future developments. A more extensive inspection is strongly advised, at least to confirm if seeing is indeed better than elsewhere.

### 4.5. *Llano Alto 2*

The excellent seeing conditions found at the SE edge of Llano Alto prompted us to inspect the northeastern edge of this tabletop at Llano Alto 2 (E2).

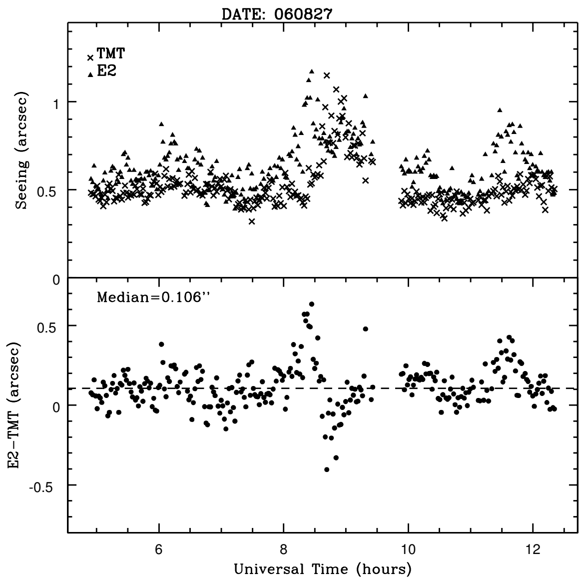


Fig. 15. Seeing measured at the Llano Alto 2 (E2) site and TMT on August 27, 2006, is presented in the upper panel. In the lower panel we show the seeing difference E2–TMT. The horizontal line is the median seeing difference for the night (+0.106″).

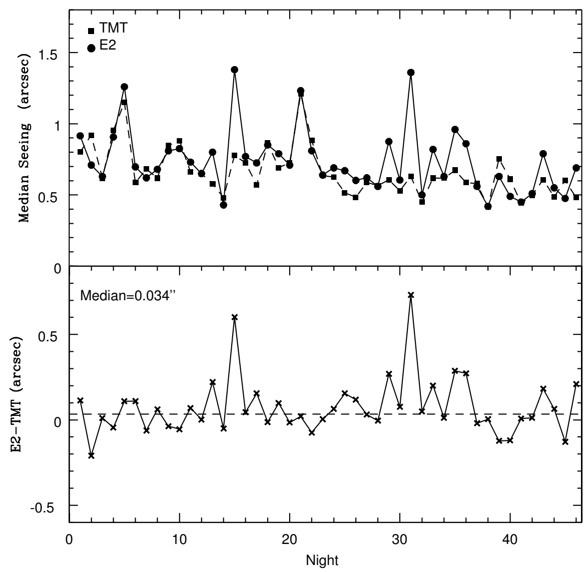


Fig. 16. Median night seeings at the Llano Alto 2 (E2) site and TMT are shown in the upper panel. The lower panel is for the median night seeing differences E2–TMT. The horizontal line is the median night seeing difference for all measurements taken during the entire run (+0.034″).

This site has a direct view of the Gulf of California (see Figures 1 and 2). The terrain surrounding the seeing tower is covered by *Arctostaphylos patula* bushes, locally known as "manzanita". Obstructions were minimal. Within a distance of 20 meters from the tower there were 4 *Pinus jeffreyi* and 3 *Abies concolor*, none of them more than 8 meters above ground. Seeing and weather measurements at Llano Alto 2 were obtained for 46 nights between July 9 and October 4 2006.

Seeing measurements at TMT and this site during one of these nights, as well as differences between these two quantities, are shown in Figure 15. Median night seeings (and differences) measured at TMT and Llano Alto 2 are plotted in Figure 16. As can be seen from Table 2, seeing at his site is almost identical to the one measured at Cerro Pelado and TMT, and apparently not as good as the one found at Llano Alto 1. Weather conditions also seem milder than those found at Llano Alto 1. Thus, if new generation telescopes were to stand at Llano Alto, it is our belief that they should be closer to its SE edge.

## 5. CONCLUSIONS

There are a large number of potential telescope sites within the boundaries reserved for astronomy at the San Pedro Mártir National Park. We conducted seeing and weather observations at 5 sites that were selected based on their height and relative proximity to OAN. Seeing data were collected with a NOAO RoboDIMM unit. Weather variables were measured with a Davis Weather Station and a Metek Ultrasonic Anemometer. No significant differences between these two very different instruments were found in connection to temperature and wind speed, which implies that these data are very reliable.

Seeing and weather results were compared to those being delivered by the TMT experiment close to the Cerro Pelado site. We found that, compared to TMT, our instruments deliver a slightly worse seeing (some 0.04″), a smaller temperature (about 0.7 K), a higher wind velocity (close to 0.5 m/s) and nearly no difference regarding humidity. It is not clear to what extent these are systematic differences, since they can also be credited to instrumental errors and minor topographical differences.

We find that all mountaintop locations within the area reserved for astronomy at SPM are characterized by similarly good median seeing conditions, which implies that the effect of ground layer turbulence in the area is relatively uniform. Nevertheless, seeing plots show that there may be substantial image quality differences between any two sites on an hourly basis (e.g. Figure 13) and, in a few cases, even during an entire night (e.g. Figure 16). There are some indications that the seeing at mountaintop locations facing west, such as Altar and Llano Alto 1, is slightly better than in mountain top sites facing directly towards the Gulf of California. We found the best seeing at the easily accessible site Llano Alto 1 (SE1), a somewhat colder and more humid location than the present site occupied by OAN, but the difference is not large and may be mostly due to instrumental errors. Thus, a long duration campaign at this promising site is recommended. On the other hand, though seeing at the Altar region is at least as good as at the present site occupied by OAN, we do not recommend developing it, since ecological damages could be substantial, and the effort and investment required are likely to be very large. We were unable to carry out this campaign at two additional locations on the area reserved for astronomy, La Mesa (N1) and Loma Perdida (N2). These sites may be of some interest, given their relative disposition with respect to the Picacho del Diablo, the highest peak at SPM.

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