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WORKSHOP SUMMARY

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RESUMEN

En este resumen, se hace un compendio de los resultados más significativos relacionados con el sitio de San Pedro Mártir presentados en este taller. Para tener una visión más completa de las características del sitio, recomendamos la lectura de todos los artículos incluidos en el presente volumen.

ABSTRACT

In this summary, a brief review is given of the main results presented during the workshop on astronomical site evaluation of San Pedro Mártir in Northern Baja California, Mexico, leading to to a summary of the most significant results related to San Pedro Mártir as a site for housing optical and infrared telescopes.

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

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1. OBSERVATORY LOCATION AND CURRENT STATUS

For more than 30 years the UNAM has been operating and developing the National Astronomical Observatory (OAN/SPM) at the summit of the Sierra San Pedro Martir in Baja California state in Mexico. The observatory is located in a National Park at 31°02'40" N and 115°29'W, some 100 km east of the Baja Californian West Coast, at 2830 meters above sea level, and 2300 meters above the peninsula mainland. A description of the present observatory status and facilities is described by López & Gutiérrez (2003).

- **Location:**
- Latitude: 31°02'40" N
- Longitude: 115°29'W
- **Elevation:** 2830 m.

2. ATMOSPHERIC TURBULENCE

All the atmospheric-turbulence parameters summarized in this Section were calculated for the visible range of the spectrum ($\lambda = 0.5\ \mu$m).

- **Integrated Seeing:**
- Median Value: $0.59''$
- Instrument: DIMM (Differential Image Motion Monitor)
- Altitude Range: 8m–∞
- Reference: Michel et al. (2003)
- Note: The DIMM measurements reported by Michel et al. (2003) were performed during 90 nights between August 2000 and October 2002. Prior to these measurements, the seeing had been measured using other instruments in different epochs. Echevarría (2003) briefly reviews the seeing campaigns and estimates an **overall median value of $0.55''$ for an altitude of 15 m.**

- **Turbulence and Wind Profiles:**
- Seeing at Different Altitude Ranges:

Altitude Range[a]	Median seeing
2–4 (km)	0.44″
4–9 (km)	0.17″
9–16 (km)	0.24″
16–21 (km)	0.08″
21–25 (km)	0.02″

[a]Above sea level

- Turbulent-Layer Speed:

Altitude Range[a]	Median speed
2–5 (km)	2.3 m s^{-1}
5–10 (km)	11.3 m s^{-1}
10–17 (km)	24.4 m s^{-1}
17–25 (km)	9.2 m s^{-1}

[a]Above sea level

- Instrument: Generalized Scidar
- Reference: Avila et al. (2003)
- Notes: The Generalized-Scidar data were obtained during 11 nights in April–May 1997 and 16 nights in May 2000. The seeing values for the slab 2–4 (km) do not include dome-turbulence. The median speed of the turbulent layers between 2 and 5 km does include the turbulence inside the dome, where the mean velocity is zero. Thus, the median speed reported can be considered as a lower limit.

• **Surface Layer Seeing:**

- Mean Value: 0.11″
- Instrument: Instrumented Mast
- Altitude Range: 2.3–15 m
- Reference: L. J. Sánchez et al. (2003)
- Notes: The turbulence in the surface layer was studied using seven pairs of microthermal 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 the optical turbulence in the entire atmosphere (2.3 m–∞).**

• **Wavefront Outer Scale**

- Median Value: 27 m
- Instrument: GSM (Generalized Seeing Monitor)
- Altitude Range: 1.5–∞
- Reference: Conan et al. (2003)
- Notes: The outer scale measurements took place in December 2000 during 8 nights. The histogram of the values obtained shows a log-normal distribution. The most frequent values lie between 15 and 20 m and 25% of the values are less than 15 m. Conan et al. (2003) discuss the implications of such values for the adaptive-optics performance in Extremely Large Telescopes, coming to very positive conclusions.

3. SKY TRANSPARENCY

• **Cloud cover**

- Fraction of photometric nights (1984 - 2002): 63.1%
- Fraction of photometric nights (April to October): 68.5%
- Fraction of photometric nights (November to March): 53.3%
- Fraction of spectroscopic (usable) nights (1984 - 2002): 80.8%
- Fraction of spectroscopic (usable) nights (April to October): 85.8%
- Fraction of spectroscopic (usable) nights (November to March): 71.8%
- Method: Statistics from 2.1 m telescope observing log
- Reference: Tapia (2003)
- Notes: Probably due to long-term climatic fluctuations, the fraction of photometric nights has increased from 52.7% prior to 1996 to 74.6% in the last seven years. At the same time, the fraction of spectroscopic nights has remained constant. These values are similar to those reported by Erasmus & van Staden (2002) from satellite data for this site. SPM has the largest measured fraction of clear nights of any existing or potential ground-based observatory in the northern hemisphere.

• **Extinction in the optical range**

- Mean value of the extinction coefficient in visual (549 nm): 0.14

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- Mean value of the extinction coefficient in far-red (800 nm): 0.055
- Method: Bouguer extinction pair
- Visual photometric bands: y-band (Strömgren) and 800 nm (13-C)
- Time base: 182 and 271 nights, from 1973 to 1999
- Reference: Parrao & Schuster (2003)
- Notes: Nearly two thirds of the photometric nights have values of k_y below the mean value. The extinction is low and very stable in autumn while in spring the extinction is higher and less consistent. The rest of the year the extinction values are intermediate.

• **Millimeter atmospheric opacity**

- Mean value of the daytime zenith opacity at 210 GHz (Sept. - June): 0.18 nepers
- Mean value of the nightime zenith opacity at 210 GHz (Sept. - June): 0.17 nepers
- Instrument: Differential heterodyne radiometer
- Time base: 1570 days spanning from 1995 to 2002
- Reference: Hiriart (2003)
- Notes: During July to mid-September the mean opacity increases nearly twofold due to summer monsoon. The opacity at this wavelenght is dominated by water vapour. Assuming that $\tau = 0.17$ nepers corresponds to 2.4 mm of precipitable water vapour (PWV), this value agrees with values obtained two decades ago by Westphal (1974) and Alvarez & Maisterrena (1977) with infrared solar hygrometers (median PWV of 2.5 mm) and by Erasmus & van Staden (2002) from satellite measures (median PWV of 2.7 mm). The fraction of nights with PWV < 1 mm is around 15 to 20%, except in mid-summer.

4. METEOROLOGY

References to early meteorology studies are presented in Tapia (2003) and Echevarría (2003). Recent meteorological stations data and wind studies have been reported by Echevarría et al. (1998) in 1992-1994, Michel et al. (2001) in 2001, Hiriart et al. (2001), Michel, Hiriart, & Chapala (2003) in 1998-2002, and Carrasco & Sarazin (2003) in 1980-1995.

• **Temperature:** 1998-2002

- Winter minimum: -13° C
- Summer maximum: 25° C
- Annual night to day gradient: 10° C
- Reference: Michel, Hiriart, & Chapala (2003)
- Atmospheric mean pressure: 560 mm Hg during 1998-2002
- Reference: Michel, Hiriart, & Chapala (2003)

• **Wind measurements:**

- **Velocity:** median values are 3.9 m s^{-1} during the day and 5.3 m s^{-1} at night; steady night-time wind speed seldomly exceeds 11 m s^{-1}.
- **Direction:** predominant and strongest wind comes from the SSW; the night-time wind rarely comes from the E and WNW.
- Time base: 150 days (2002-2003); 386 nights (1992-1994)
- Instrument: Ultrasonic Anemometer at 6.8 m height; propel anemometer..
- Reference: Michel, Hiriart, & Chapala (2003); Echevarría et al. (1998)
- Notes: 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 (Echevarría et al. 1998). 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 (Michel et al. 2003).
- High altitude wind
- Annual average: 27±3.6 m s^{-1} (GGUAS) and 26.5±1.7 m s^{-1} (NCEP).
- Period: 1980-1995
- Reference: Carrasco & Sarazin (2003)

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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) and is summarized by B. Sánchez et al. (2003). It includes geotechnical exploration at three selected locations, consisting of borings with no recovery of rock cores, reaching a maximum depth of 22 m. They reveal that excavations of only 2 to 3 m are required to reach a layer (B) of fractured rock adequate for foundations. The geotechnical characterization of this layer is listed below.

- **Geotechnical parameters**

- Layer depth: 1.3-3 m and 13 m.
- Rock quality designation (RQD): 65 to 80%
- Dynamic modulus of elasticity: 6283 and 19076 MPa.
- Dynamic modulus of rigidity: 2324 to 7273 MPa.
- Static modulus of deformability (E_m): 7300 MPa.
- Poisson's ratio: 0.34.
- Reference: B. Sánchez et al. (2003)
- Notes: The layer or horizon B between 1.3-3 m and 13 m in depth is constituted by gray schist, encroached by granite dikes, it evidences a moderate fracturing which is found generally closed and sealed with silica. According to the geomechanical classification, this horizon has been assigned a GSI value of 73, equivalent to rock masses of regular to good quality.

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