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THE METEOROLOGICAL STATIONS OF THE 1.5 AND 0.84 M TELESCOPES OF THE OAN: DESCRIPTION AND RESULTS

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RESUMEN

Se describen las estaciones meteorológicas de los telescopios de 1.5 y 0.84 m del Observatorio Astronómico Nacional en San Pedro Mártir (OAN). Las estaciones incluyen dispositivos para medir temperatura, presión atmosférica, humedad relativa y condiciones del viento. Todas las variables climáticas se miden continuamente, y sus valores medios se determinan cada 5 minutos y se escriben en el disco duro de la computadora de control. Esta información se actualiza continuamente en una página HTML a la que se tiene acceso desde la página del OAN. En este trabajo presentamos los resultados derivados de mediciones tomadas durante 2 años. Encontramos que el espejo primario de ambos telescopios está sustancialmente más caliente que el aire que lo rodea durante la noche (hasta $\sim$ 5 °C). Este gradiente térmico deteriora la calidad de la imagen. En el telescopio de 1.5 m se puede corregir este efecto con un sistema de control de temperatura para el espejo primario. En el telescopio de 0.84 m, cuyo espejo primario está en una estructura cerrada, es probable que baste con instalar ventiladores que circulen aire entre el domo y el tubo cerrado. Durante la noche el aire está más frío dentro de ambos domos que afuera, por lo que es innecesario ventilar las cúpulas de estos telescopios.

ABSTRACT

Meteorological stations for the 1.5 and 0.84 m telescopes at the Observatorio Astronómico Nacional at San Pedro Mártir (OAN) are described. The stations include devices for measuring temperature, atmospheric pressure, relative humidity and wind conditions. All the meteorological variables are monitored continuously and mean values are determined every 5 minutes and written on the hard disk of the control computer. This information is continuously refreshed in an HTML page that can be accessed from the OAN home page. In this paper we present the results of measurements taken over 2 years. We find that both primary mirrors are substantially warmer than the surrounding air during the night (up to $\sim$ 5 °C). This thermal gradient degrades image quality. For the primary mirror of the 1.5 m telescope this effect can be corrected with a temperature control system. For the 0.84 m telescope, where the primary mirror is located in a closed structure, ventilators moving air from the dome into the closed tube may suffice. During the night the air is colder within both domes than outside, and we conclude that no dome ventilation is necessary in these telescopes.

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

1. INTRODUCTION

Weather information at the Observatorio Astronómico Nacional (OAN) at San Pedro Mártir, B.C., Mexico, has until now been gathered regularly by night assistants reading analogic sensors for temperature, atmospheric pressure and relative humidity at the floor level of the telescope dome of the 2.1 m telescope. These reports were used by Tapia (1992) in order to conduct a 10-year study of sky conditions and telescope use in this observatory.

Weather conditions at the other two telescopes in operation at the OAN, the 0.84 and 1.5 m telescopes, could not be followed since no night assistants were regularly assigned in these. Several studies of the climatological conditions of this site were conducted prior to Tapia's (1992) work, but these were carried out over short periods of time during the first years of operation of the OAN (Mendoza 1971, 1973; Mendoza, Luna, & Gómez 1972; Walker 1971, 1984; Alvarez 1982; Alvarez & Maisterrena 1977). In the last five years there have been two aditional efforts to characterize atmospheric conditions and sky quality at the OAN. A 2-year experiment was conducted in order to determine the amount of precipitable water vapor above the observatory by measuring the optical depth of the atmosphere at 215 GHz (Hiriart et al. 1997). The radiometer used for these measurements is now permanently installed, and it is very useful for infrared observations. At approximately the same time, image quality was also measured (Echevarría et al. 1998). After three years of observations it was found that the site has very good seeing, with median image FWHM of 0.61 arcsec. A larger estimation (1.06 arcsec) was obtained during an 8 night site testing campaign (Avila, Vernin, & Cuevas 1998).

It has been obvious for several years that there is a need for permanent and automatic weather stations, that can measure all the fundamental meteorological variables at the three telescopes. Of particular importance is the determination of temperature gradients between the primary mirror and the telescope dome, between different parts of the dome, and between the inside and outside air. This information is vital in order to establish adequate strategies to improve image quality and observing efficiency. This was partly solved with the installation of weather stations at the 0.84 and 1.5 m telescopes at the end of 1998. In this paper we describe the characteristics of these stations, and we present measurements for the first two years of operation. Both stations include devices for measuring atmospheric pressure and relative humidity, as well as 5 temperature probes located at key positions. Since these telescopes are separated by less than about 50 meters, only one anemometer was installed. It is connected to the 0.84 m weather station. With the exception of the anemometer, these stations have the same hardware and software. In the next section we describe these weather stations. Our most important results are presented and briefly analyzed in § 3. Conclussions are given in the last section.

2. DESCRIPTION

2.1. *Hardware*

The hardware consists of a series of sensors connected to an interface card, designed and built in house, where signals are conditioned before being sent to a data acquisition board inserted into one of the slots of the control computer (a PC). A block diagram of the hardware is shown in Figure 1. The data acquisition board is model CIO-DAS08 from Computer Boards, which contains a 12 bit AD converter with 8 multiplexed inputs, 3 counters and 31 digital inputs and outputs.

The relative humidity (RH) sensor is a model HX92V from Omega Engineering Corp. The sensor produces an output which varies from 0 to 1 volt, corresponding to a relative humidity variation from 0 to 100%. This sensor is guaranteed by the manufacturer to operate with a precision of ±2.5% RH in the range between 3 and 95% RH. Its response time for a sudden and large change in humidity (between 90 and 10% RH) is approximately equal to 15 seconds. The sensor was calibrated with the Omega HX92-CAL kit. The output signal, as all analogical signals, is processed by a low pass-band filter in the interface board before being sent to the AD converter.

The atmospheric pressure sensor is a model MPX4115 from Motorola. Absolute pressure is given by $P = 836.43\ (V/V_s + 0.095)$, where P is the atmospheric pressure in mm Hg, V is the voltage delivered by the sensor, and V_s is the supply voltage. Pressure measurements are guaranteed to be accurate within 1.5% for ambient temperatures between 0 °C and 85 °C.

The temperature sensors are of type LM335 from National Semiconductors. Because of the long distances involved, each sensor is fed by an LM334 current source. These sensors yield a voltage that varies by 10 mV/°C. Temperature measurements are precise at the 0.3 °C level for a temperature range from −40 to 100 °C. Once installed, the offsets of these sensors were calibrated independently with an Omega DP460 digital thermometer, which has a resolution of 0.1 °C.

The anemometer used is model 05103 from R.M. Young Company. Wind direction is supplied by a precise potentiometer (0.25% linearity) that, when properly fed, produces a voltage directly proportional to wind direction. Propeller rotation produces a sinusoidal signal whose frequency is proportional to wind speed. The wind speed, in km/h, is given by $V_w = 0.3528\ \nu$, where ν is the frequency of the sine wave signal. This analogical signal is used to

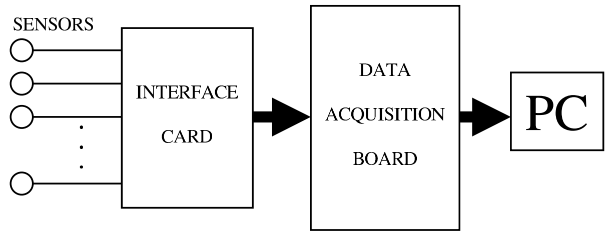

Fig. 1. Block diagram of the hardware.

generate a digital signal with the same frequency by means of a circuit designed and built in house. The digital signal is then fed to a counter in the data acquisition board, where its average frequency is determined from the difference of counts in a given time interval.

2.2. *Software*

The control program is written in the C programming language, and runs under the Linux operating system with the Slackware 7 distribution. In this section we describe the program running in the weather station for the 0.84 m telescope, which includes the anemometer. Except for this, the program running at the 1.5 m telescope weather station is identical.

The program runs in an infinite loop, which can only be terminated by the superuser. An archive is read at the beginning of the loop. This archive contains a set of calibration parameters used to transform raw measurements to real units, and two constants that determine how frequently the counters associated to wind velocity are read, and the time taken before mean values and statistics are determined. With the exception of the wind speed counter, all sensors are sampled in a continuous cycle during the time interval defined in the archive containing the configuration and calibration constants. The wind counter is read every 10 cycles. Mean values and standard deviations are calculated at the end of this time interval (5 minutes). The complete set of data is written to hard disk in daily archives whose names are codified according to year, month and day. These archives can then be used to perform extensive analysis of the data. A few climatic variables are written in an HTML page that is constantly being refreshed, and can be accessed through the OAN homepage (http://astrosen.unam.mx/).

3. RESULTS

3.1. *Atmospheric Pressure*

Measurements of the atmospheric pressure between June 1999 and February 2001 are plotted in Figure 2. Between April and October the atmospheric pressure varies between $\sim$ 560 and 565 mm Hg. In the mean it is somewhat smaller during the winter months, a season where low pressure systems are more likely to move into the region.

3.2. *Relative Humidity*

Monthly averages of relative humidity during the night (between 9 pm and 3 am) from June 1999 to February 2001 are presented in Figure 3. The driest period is between October and December and, less so, April and June. Humidity is higher during the first months of the year due to the storms that hit the Pacific coast of Baja California. Relative humidity also increases during late summer and early autumn. In this case it is entirely due to local conditions (notice that no major changes in the atmospheric pressure occur during this period). The cumulative function for the night and daytime (from 9 am to 3 pm) values of relative humidity for the year 2000 is displayed in Figure 4. Nighttime humidity is less than 50% slightly more than half of the time, and less than 80% some 90% of the time. Notice too that humidity can be up to $\sim$ 10% smaller at daytime.

3.3. *Wind Direction and Velocity*

An anenometer was installed at the end of 2000. Measurements of the incoming wind speed and direction during January and February 2001 are plotted in Figure 5. The predominant incoming wind directions are at $210° \pm 19°$ (SSW) and $4° \pm 13°$ (N), with nearly no wind coming from any other direction (and, if so, at a very low speed). The strongest incoming winds were from the SSW, with speeds reaching up to 50 km/h.

3.4. *Thermal Gradients*

The 1.5 m telescope has an open structure, and the dome air flows freely around the primary mirror. A temperature probe is in direct thermal contact with the primary mirror (T_P). Three additional

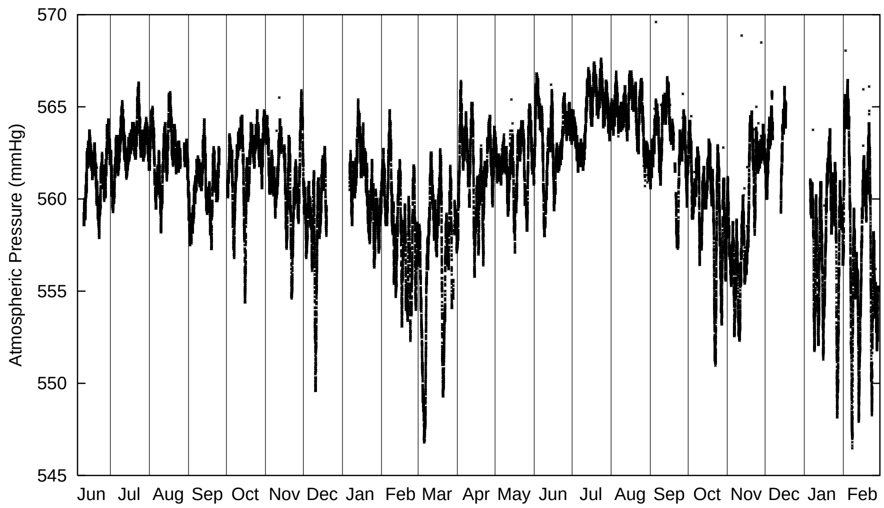

Fig. 2. Atmospheric pressure between June 1999 and February 2001.

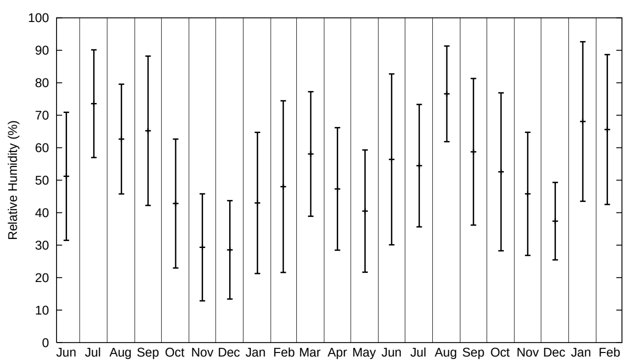

Fig. 3. Mean monthly values of nighttime relative humidity (9 pm to 3 am) between June 1999 and February 2001.

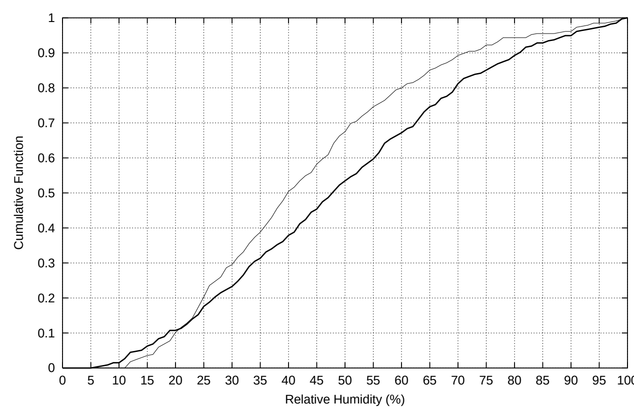

Fig. 4. Cumulative function of the night (9 pm to 3 am, thick line) and daytime (9 am to 3 pm, thin line) relative humidity between June 1999 and February 2001.

thermometers are installed along the telescope structure, all of them in direct air contact: one is located some 30 cm above the primary mirror (T_L), another, at the top of the structure (T_D, close to the secondary mirror and about a meter below the telescope dome), and a third one between these two (T_M, about 1 m above the primary).

In Figure 6 we show the time variation of $T_P - T_D$ and $T_M - T_D$ for 9 consecutive days. We can conclude that, since $|T_M - T_D| \leq 1°$C, the dome temperature was nearly uniform during the whole period. Notice that the air in the upper layer of the dome was slightly warmer at noon, as expected since the dome remains closed during the day. Let us now turn our attention to the quantity $T_P - T_D$. Due to its large thermal inertia, the primary mirror

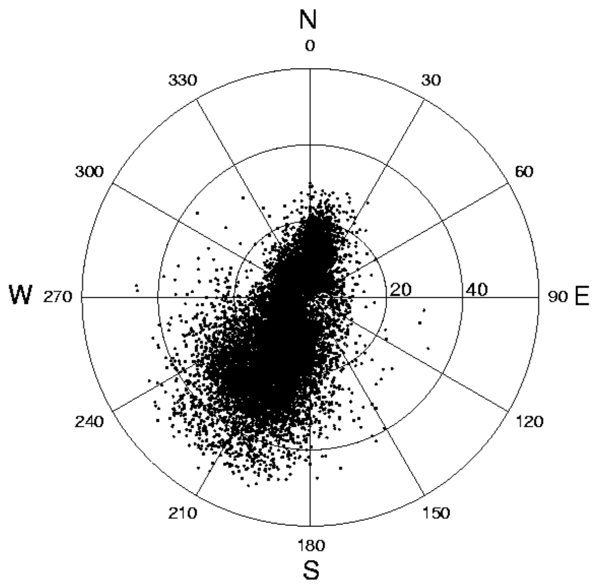

Fig. 5. Relationship between wind speed (in km/h) and direction from January to February 2001.

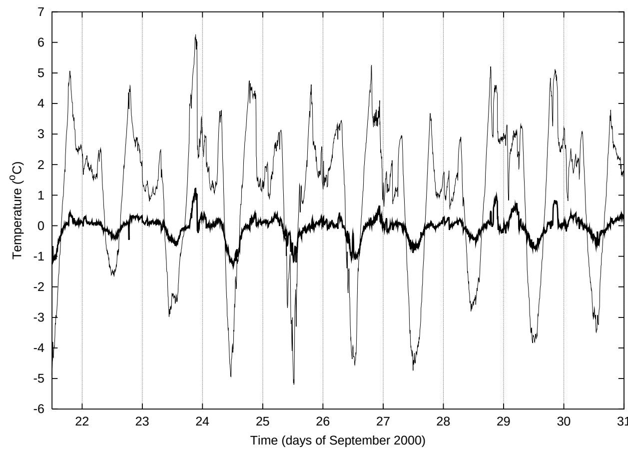

Fig. 6. Temperature gradients in the 1.5 m telescope. Midnight is plotted at integer values of time. The thin line corresponds to the temperature difference between the primary mirror and the dome (T_P – T_D), and the thick line to the temperature difference between a place $\sim$ 1 m above the primary and the dome (T_M - T_D).

was always colder than the dome air during the day, but substantially warmer at nighttime (up to ~ 3 °C hotter at midnight). In this circumstance warm air will rise from the primary, generating turbulence and producing image degradation. Our measurements for $T_L - T_M$ (not shown) indicate that the warm bubble is confined some 50 cm above the primary mirror. Beyond this point the temperature gradient in the dome is practically zero. This pattern occurs during the whole year, regardless of the dome temperature. This is shown in Figure 7, where only the night averages (between 9 pm and 3 am) of T_D and $T_P - T_D$ between April 2000 and February 2001 are displayed. As can be seen, the primary mirror is always 3 to 4 degrees warmer, at night, regardless of the large temperature excursions in the dome (between 15 and -8 °C).

The 0.84 m mirror is mounted in a closed tube. In this case there is no direct thermal contact between the primary mirror and the dome air. As in the 1.5 m telescope, a temperature probe was placed in direct thermal contact with the primary mirror (T_P). Two thermometers were installed within the closed tube, but in contact with the air: one at the top of the tube and $\sim$ 1.5 m below the top of the telescope dome (T_D), and the other approximately a meter above the primary mirror (T_M).

The time variation of $T_P - T_D$ and $T_M - T_D$ for 9 consecutive days is shown in Figure 8. The dome was closed during the last three nights. These are not considered in the following discussion. It is immediately apparent that the thermal behaviour of this telescope is very different. The temperature difference between the primary mirror and the dome is smaller than at the 1.5 m telescope. It is clear that the enclosing tube tends to smooth temperature gradients within it. Nighttime averages for the dome temperature and $T_P - T_D$ are displayed in Figure 9. It must be noticed that this telescope remained closed for extended periods of time. When working, we also find that $T_P - T_D$ does not change significantly throughout the year. We conclude that the warm primary is less effective in degrading image quality in the 0.84 m telescope.

An additional interesting quantity is the difference between dome and external (T_E) temperatures. The diurnal variation of this quantity ($T_D - T_E$) for 9 consecutive days at the 1.5 m telescope is shown in Figure 10. The difference between dome and external temperatures changes rapidly during the day, but within a relatively small range (+2 to -4 °C). Furthermore, the air in the dome is between 1 and 4 °C colder than the air outside the telescope during the night. The same behaviour was found in the 0.84 m telescope. This implies that dome conditions in both telescopes are convectively stable, and should not be a source of image degradation.

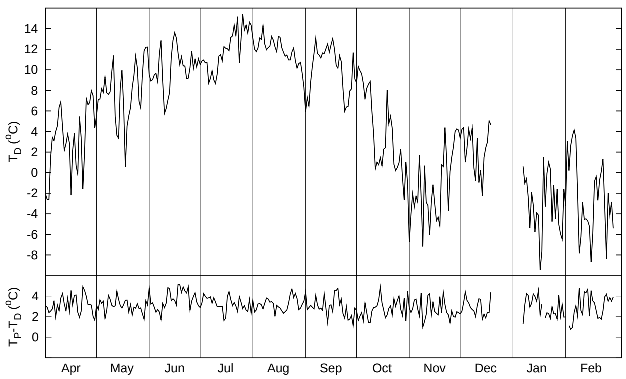

Fig. 7. Epochal variation of the mean nighttime (between 9 pm and 3 am) value of the dome temperature (T_D) and the temperature difference between the primary mirror and the dome ($T_P - T_D$) at the 1.5 m telescope.

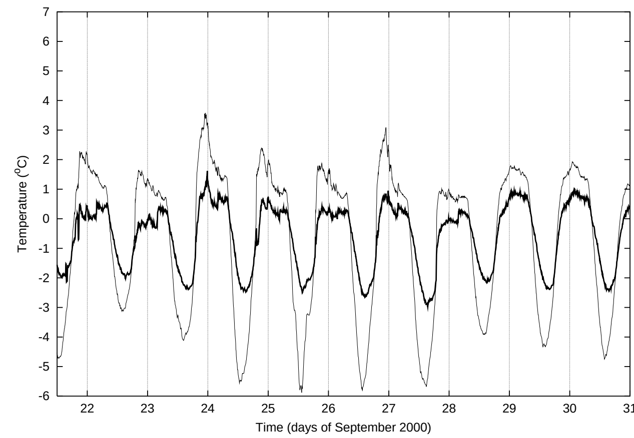

Fig. 8. Temperature gradients at the 0.84 m telescope. Midnight is plotted at integer values of time. The thin line corresponds to the temperature difference between the primary mirror and the dome ($T_P - T_D$), and the thick line represents the temperature difference between a place about a meter above the primary mirror and the dome ($T_M - T_D$). During the last three nights (September 28, 29, and 30) the telescope was not used, and the dome remained closed.

4. CONCLUSIONS

1. It has been found that the primary mirror of the 1.5 m telescope can be up to $\sim$ 5 °C warmer than the air in the dome during the night. It is well known that this has a major impact on image quality. For instance, tests at the CFH 3.6 m telescope have shown that image spread due to this effect amounts to FWHM = 0.40" $(T_P - T_D)^{6/5}$, with $T_P - T_D$ positive and in °C (Racine et al. 1991). Laboratory tests with a 254 mm mirror gave the same temperature dependence, but in this case the constant is $0.21''$ (Lowne 1979). Other observatories have addressed this problem by controlling the mirror temperature during daytime, keeping it close to the predicted dome temperature at the beginning of the night. Results have been excellent. For instance, the median image size changed from $1.78''$ to $1.25''$ in the CTIO 0.9 m telescope (Schommer 1995), and from more than $1.4''$ to $0.93''$ in the 4 m telescope at Kitt Peak (Massey & Claver 1996) once this system was installed. Experience has shown that the best image quality at the 1.5 m telescope at the OAN is currently close to $1''$, but the median is closer to $1.5''$. Subarcsecond images at this telescope should be common if a temperature control system for the primary mirror were installed.

2. The closed mechanical structure of the 0.84 m telescope prevents a large temperature difference between the primary and the secondary (the primary is $\sim$ 2°C hotter in the mean). It is likely that a ventilator moving air from the dome into the telescope tube would be sufficient to improve image quality. This simple and cheap arrangement has been installed in several small telescopes, such as the 0.9 m telescope at Kitt Peak (Jacoby et al. 1995) where, in conjunction with other improvements, it has produced stellar images with FWHM less than $0.85''$. A similar effort should yield excellent results at the 0.84 m telescope.

3. Surprisingly, both domes are always colder than the external air during the night. This implies that this thermal gradient has no effect on image quality if air circulation in the dome is kept to a minimum during the night (keep all doors shut!).

4. Resources (minimal) should be allocated to install a similar meteorological station at the 2 m telescope to monitor these parameters.

5. Readings from the thermometers installed close to the secondaries of both telescopes can be used to adjust the focus of the telescope when the temperature changes.

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REFERENCES

Alvarez, M. 1982, Reporte Técnico, No. 5, Instituto de Astronomía, UNAM

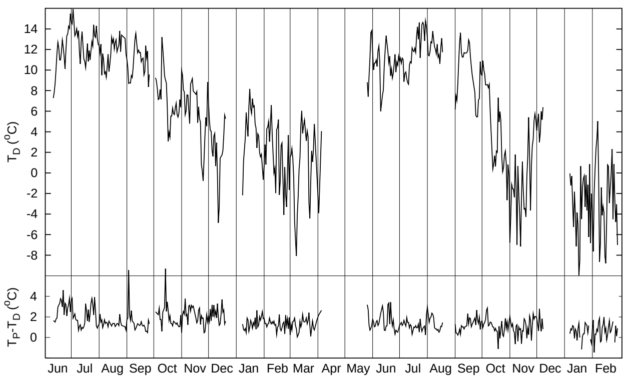

Fig. 9. Epochal variation of the mean nighttime (between 9 pm and 3 am) value of the dome temperature (T_D) and the temperature difference between the primary mirror and the dome ($T_P - T_D$) at the 0.84 m telescope.

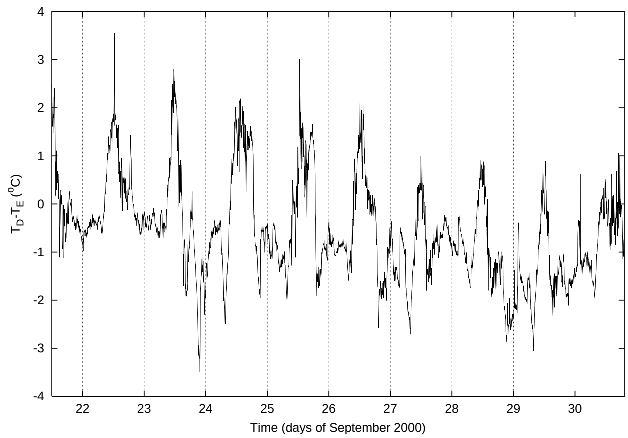

Fig. 10. Temperature difference between the dome and external air at the 1.5 m telescope. Midnight is plotted at integer values of time.

Alvarez, M., & Maisterrena, J. 1977, RevMexAA, 2, 43
Avila, R., Vernin, J. & Cuevas, S. 1998, PASP, 110, 1106
Echevarría, J., et. al. 1998, RevMexAA, 34, 47
Hiriart, D., Goldsmith, P. F., Skrutskie, M. F., & Salas, L. 1997, RevMexAA, 33, 59
Jacoby, G, Massey, P., Armandroff, T, Schoening, W., Boronson, T., & Probst, R. 1995, NOAO Newsletter Jun. 1995, p. 44
Lowne, C. W. 1979, MNRAS, 188, 249
Massey, P., & Claver, C. 1996, NOAO Newsletter Dec. 1996, p. 19
Mendoza, E. E. 1971, Bol. Obs. Tonantzintla y Tacubaya, 6, 95
________. 1973, Mercury, 2, 9
Mendoza, E. E., Luna, J., & Gómez, T. 1972, Bol. Obs. Tonantzintla y Tacubaya, 6, 215
Racine, R., Salmon, D., Cowley, D., & Sovka, J. 1991, PASP, 103, 1020
Schommer, R. 1995, NOAO Newsletter Dec. 1995, p. 25
Tapia, M. 1992, RevMexAA, 24, 179
Walker, M. F. 1971, PASP, 83, 401
________. 1984, in Site Testing for Future Large Telescopes, eds. A. Ardeberg & L. Woltjer, ESO Conference and Workshop Proceedings No. 18, p. 3

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