Weather at Sierra Negra: 7.3-yr statistics and a new method to estimate the temporal fraction of cloud cover

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ABSTRACT
Sierra Negra, one of the highest peaks in central Mexico, is the site of the Large Millimeter Telescope. We describe the first results of a comprehensive analysis of the weather data measured in situ from 2000 October to 2008 February to be used as a reference for future activity in the site. We compare the data from two different stations at the summit considering the accuracy of both instruments. We analysed the diurnal, seasonal and annual cycles for all the parameters. The thermal stability is remarkably good, crucial for a good performance of the telescopes. From the solar radiation data, we developed a new method to estimate the fraction of time when the sky is clear of clouds. We show that our measurements are consistent with a warm standard atmosphere model. The conditions at the site are benign and stable given its altitude, showing that Sierra Negra is an extremely good site for millimeter and high-energy observations.

Key words: atmospheric effects – site testing.

1 INTRODUCTION
High-altitude astronomical sites are a scarce commodity with increasing demand. A thin atmosphere can make a substantial difference in the performance of scientific research instruments like millimeter-wave telescopes or water Čerenkov observatories. In our planet, reaching above 4000 m involves confronting highly adverse meteorological conditions. Sierra Negra, the site of The Large Millimeter Telescope/El Gran Telescopio Milimétrico (LMT) is exceptional in being one of the highest astronomical sites available with endurable weather conditions. The LMT site combines high altitude (4580 m) and low atmospheric water content. The water vapour opacity has been monitored since 1997 with radiometers working at 225 GHz showing that the zenith transmission at the site is better than 0.89 at 1 mm during 7 months of a year and better than 0.80 at 850 μm during 3 months of the year (Hughes, private communication). There is no telescope as massive as the LMT above 4500 m anywhere else and one can barely expect to operate at that altitude with temperatures above freezing. The development of the LMT site led to the interest and development of other scientific facilities benefiting from the high-altitude conditions and sharing the same basic infrastructure. In 2007 July, the base of Sierra Negra was selected as the site for the High Altitude Water Čerenkov (HAWC) gamma-ray observatory, an instrument whose performance depends critically on its 4100-m altitude location.

2 THE SIERRA NEGRA SITE
Sierra Negra, also known as Tliltepetl, is a 4580-m volcano inside the Parque Nacional Pico de Orizaba, a national park named after the highest mountain of Mexico. With an altitude of 5610 m1 Pico de Orizaba, also known as Citaltepetl, is one of the seven most prominent peaks in the world, where prominent is related with the dominance of the mountain over the region2 (Press & Siever 1982). The Parque Nacional Pico de Orizaba has an area of 192 km² enclosing the two volcanic peaks, separated by only 7 km from top to top, and their wide bases. Tliltepetl is an inactive volcanic cone formed 460 000 yr ago, much earlier than Citaltepetl whose present crater was created just 4100 yr ago and has a record of activity within the last 450 yr, including the flow of 0.1 km3 of lava in 1566 and a last eruptive event in 1846 (Hóskuldsson & Robin 1993; Rossotti 2005). These two peaks are located at the edge of the Mexican plateau which drops at the East to reach the

1 Instituto Nacional de Estadística, Geografía e Informática (INEGI) official figure.
2 Topographic prominence is defined as the elevation difference between the peak summit and the lowest contour level that encircles that summit, but does not encircle any higher summit.

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Gulf of Mexico at about 100 km distance, as shown on the left-hand side of Fig. 1. The weather of the site is influenced by the dry weather of the high-altitude central Mexican plateau and humid conditions coming from the Gulf of Mexico (Erasmus & Van Staden 2002).

In 1997 February, Sierra Negra was selected as the site of the LMT, a 50-m antenna for astronomical observations in the 0.8–3 mm range. The top of Sierra Negra, defined now by the position of the telescope, on the right-hand side of Fig. 1, has Universal Transverse Mercator (UTM) and geographical coordinates \( \{ x_{\text{UTM}} = 677450, y_{\text{UTM}} = 2100092 \} \) and \( \{ 97^\circ18^\prime51.7^\prime\text{longitude West}, 18^\circ59^\prime08.4^\prime\text{latitude North} \} \), respectively. The development of the LMT site led to the installation of further scientific facilities benefiting from its strategic location and basic infrastructure like the 5-m radio telescope RT5, a solar neutron telescope and cosmic ray detectors, among others. In 2007 July, the base of Sierra Negra, about 500 m below the summit, was chosen as the observatory for mapping and surveying the high-energy gamma-ray sky. HAWC will be complemented by two atmospheric air Čerenkov telescopes, the Observatorio MEXicano de GAmmas (OMEGA) formerly part of the High Energy Gamma Ray Astronomy (HEGRA) array (Konopelko et al. 1999).

The seeing of Sierra Negra was monitored between 2000 and 2003 to quantify the potential of the site for optical astronomy. The site has a median seeing of 0.7 arcsec, consistent with that of a prime astronomical site (Carrasco et al. 2003). The wind velocity at 200 mbar has been analysed using the National Oceanic and Atmospheric Administration (NOAA) National Center for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) Reanalysis data base showing that Sierra Negra is comparable to the best observatory sites as Mauna Kea in terms of applying adaptive optics techniques such as slow wavefront correction (Carrasco, Avila & Carramiñana 2005), based on the premise that the global circulation of atmospheric winds at high altitude can be used as a criterion to establish the suitability of a site for the development of adaptive optics technique as the wind velocity at 200 mbar is strongly correlated to the average wavefront velocity allowing to compute the coherence time \( \tau_c \) (Sarazin & Tokovinin 2002).

Different scientific facilities seek particular conditions and their dependence on meteorological conditions vary. Among the Sierra Negra facilities, we can note:

(i) The LMT requires minimum atmospheric opacity in the millimeter range, which translates in a reduced water vapour column density. According to design specifications, LMT operation at 1 mm require wind velocities below 9 m s\(^{-1}\) and the antenna is able to survive winds up to 250 km h\(^{-1}\) (69.4 m s\(^{-1}\)).

(ii) The RT5 5-m radio telescope will operate at 43 and 115 GHz for observations of the Sun. Nighttime work will focus on interstellar masers and monitoring of mm-wave bright active galactic nuclei. RT5 requires absence of clouds in the line of sight.

(iii) Optical and atmospheric Čerenkov telescopes require clear nights and relatively low humidity (below 80 per cent) during nighttime.

(iv) Water Čerenkov observatories like HAWC seek high-altitude environments which allow for a deep penetration of atmospheric particle cascades. They are basically immune to weather, although freezing conditions and large daily temperature cycles are concerns. The same applies to small cosmic ray detectors installed at Sierra Negra summit.

3 INSTRUMENTATION AND LOCATION

The weather data presented here were acquired with three instruments:

(i) Davis meteorological station, hereafter named ‘Davis’, located on a 5-m tower about (139, 65) metres (E,N) from the LMT position. Most of the data shown in this paper come from this station. It has been operational since 2000 October up to now, and is installed at the base of the former seeing monitor. The station tower is at the edge of a sharp slope facing north-east just above the HAWC site – that is approximately 430 m E, 1010 m N and 500 m below the summit. The Davis station consists of temperature and humidity sensors enclosed on a radiation shield, a barometer, an anemometer, a control console and a data logger:

(a) The temperature sensor is a platinum wire thermistor with a resolution of 0.1 °C and a nominal accuracy of ±0.5 °C.

(b) The relative humidity (RH) sensor is a film capacitor element providing a resolution of 1 per cent with an accuracy of ±3 per cent for RH between 0 and 90 per cent and ±4 per cent above 90 per cent.

(c) The barometer has a resolution of 0.1 mbar and an accuracy of ±0.4 mbar in the measurement of atmospheric pressure.
Table 1. Positions of the weather stations relative to the LMT; $x$ increases to the east and $y$ to the north.

| Instrument       | Relative location |
|------------------|-------------------|
| LMT              | $x$ (m) $y$ (m) $z$ (m) |
| Davis            | 139 65 $-15$ |
| Texas            | 40 105 0 |

(d) The wind monitor consists of a three cup anemometer providing a resolution of 0.4 m s$^{-1}$ and accuracy better than 0.9 m s$^{-1}$ for a wind speed interval between 0.9 and 78 m s$^{-1}$.

(ii) Backup Davis station, hereafter named ‘Backup’, of same model and characteristics as the main Davis station, was temporarily installed at the same position and operated from 2002 April until 2003 November, when it ceased functioning.

(iii) Texas Electronics weather station, hereafter named ‘Texas’, consists of:

(a) a temperature sensor, of model TT-101QR, made of a linear thermistor resistor of 0.1°C resolution and 0.5°C accuracy in the range $-34°C$ to $43°C$.

(b) a humidity sensor consisting of a thin film capacitor with a resolution of 1 per cent and an accuracy of $\pm$ 3 per cent.

(c) a radiation sensor made of a solar panel inside a glass dome to obtain maximum cosine response to the Sun’s radiation. The nominal range is up to 1400 W m$^{-2}$ with a resolution of 1 W m$^{-2}$ and 5 per cent accuracy.

(d) a wind monitor consisting of three anemometer cups providing a resolution of 0.2 m s$^{-1}$ and an accuracy better than 0.5 m s$^{-1}$.

The Texas weather station has also a barometer, but the readings of atmospheric pressure were found to be spurious.

The Texas station was installed at about (40, 105) metres (E,N) from the LMT and 110 m apart from the Davis station and 15 m higher than the Davis. Taking the LMT as the reference point, the coordinates of both stations are shown in Table 1. The relative locations of the LMT and the weather stations are shown in Fig. 1.

4 DATA COVERAGE

The data presented here consist of temperature, atmospheric pressure, RH, wind velocities and radiation records acquired with the Davis and Texas stations using sampling times ranging between 0.5 and 30 min. The majority of the data were taken with 1- or 5-min sampling. Data on wind direction and dew points were also acquired and will be presented elsewhere, in specific studies of the wind characteristics and atmospheric water vapour content of the site.

Table 2 summarizes the temporal coverage of the data, expressed in percentage. The data from the Davis station span from 2000 October 30 to 2008 February 18, with a 70 per cent effective coverage of the 7.3-yr sample: data exists for 1986 out of 2668 days. The complete sample contains 2693 146 min; coverage for day and night are almost equal, 1 120 921 compared to 1 122 161 min. Coverage was $\sim$80 per cent between 2002 and 2006, declining to 36 per cent in 2007. The comparison between the general and the wind data shows that bad weather affects our anemometer less than 5 per cent of the time; in fact, our logfile indicates that most of our data losses are not due to bad weather but to logistics.

The Texas station started operation a year and a half later and has a comparable coverage, as shown in Table 3, with a 58 per cent effective coverage corresponding to 1 844 977 min. The data have 3-month gaps in early 2002 and mid-2003. In total, we have data for 1584 days out of the 2163 in the period between 2002 April 12 and 2008 March 13. The data of the Texas station have even coverage for day and night: 774 698 and 763 496 min, but are biased towards the dry period. In Table 4, we present the temporal coverage of radiation as it is higher than for the other parameters, in particular, for 2004 the coverage is almost twice. The complete solar radiation sample contains 990 770 min from which 526 792 min are for the dry season and 463 978 for the wet season.

From Tables 5 and 6, it is clear that the coverage per hour is fairly homogeneous, varying at most from 56 to 59 per cent for the Texas station, while the coverage per month is more variable, specially for the Texas. The coverage per hour for solar radiation, is shown in Table 7. For the early ($\sim$6 h) and late afternoon ($\sim$18 h) hours, the coverage is low mostly due to the variation of the length of the day, for the other hours the maximum difference is 4 per cent.

5 CROSS-CALIBRATION

To cross-calibrate the two data sets considering the measurement accuracies, we compute the best linear regression between the two data sets by minimizing $\chi^2$. The goodness of the fit is given by the correlation coefficient $r$ between the best fit and the data points.

The plots with all the data points and the best fit have more than $10^5$ points for each parameter ($>2$ MB). To display them can be misleading because they tend to look as scatter plots. They would suggest that the fitting errors are underestimated as it is impossible to distinguish if in a given position there is one or $10^5$ points. We decided to present plots with 1/10 of the data points randomly chosen, as in this case the points tend to be located where the density of data is larger and, on the other hand, the files are handled.

For a given plot, the equality between the Davis and Texas data corresponds to a straight line at 45°, not shown. We present the best fit and zero point (bold line) and the fits obtained adding the 1σ error to each parameter.

We report the fits – and the statistics – with two decimal digits as the determination of a statistical value can be made with higher accuracy than the nominal resolution of the instrument for data with high signal-to-noise ratio (S/N). In our analysis, the high S/N is due to a very large data set.

Subscripts $d$ and $t$ stand for the Davis and Texas stations, respectively, for any of the compared parameters: temperature $T$ in °C, RH in per cent and wind speed $w$ in m s$^{-1}$.

5.1 Temperature

We compared temperature data from both stations registered with same times, allowing for up to one minute difference between clocks. The 233 985 registers common to the Davis and Texas
Table 2. Data coverage of Davis weather station in percentage.

| Month   | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | All |
|---------|------|------|------|------|------|------|------|------|------|-----|
| January | 65   | 87   | 95   | 65   | 99   | 95   | 77   | 99   | 85   |
| February| 69   | 92   | 99   | 68   | 92   | 77   | 19   | 60   | 76   |
| March   | 0    | 99   | 86   | 57   | 70   | 79   | 0    | 56   |
| April   | 0    | 85   | 91   | 96   | 87   | 93   | 0    | 64   |
| May     | 63   | 99   | 74   | 89   | 78   | 79   | 0    | 69   |
| June    | 56   | 94   | 99   | 83   | 88   | 78   | 0    | 71   |
| July    | 37   | 97   | 92   | 85   | 77   | 56   | 67   |
| August  | 97   | 94   | 98   | 89   | 78   | 25   | 56   |
| September| 91  | 93   | 55   | 76   | 98   | 38   | 94   |
| October | 3    | 97   | 46   | 90   | 89   | 76   | 24   |
| November| 14   | 75   | 44   | 81   | 77   | 60   | 60   |
| December| 37   | 82   | 78   | 66   | 48   | 36   | 90   | 63   |
| Year total| 27  | 61   | 84   | 85   | 77   | 79   | 70   |
| Dry     | 26   | 48   | 81   | 86   | 68   | 74   | 82   | 27   |
| Wet     | 54   | 73   | 88   | 83   | 85   | 84   |

Table 3. Data coverage of relative humidity from the Texas weather station in percentage.

| Month   | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | All |
|---------|------|------|------|------|------|------|------|-----|
| January | 88   | 89   | 0    | 82   | 64   | 27   | 58   |
| February| 93   | 88   | 0    | 83   | 80   | 91   |
| March   | 100  | 75   | 68   | 93   | 87   | 41   |
| April   | 48   | 84   | 0    | 61   | 95   | 69   |
| May     | 77   | 0    | 40   | 38   | 78   | 10   |
| June    | 88   | 0    | 0    | 84   | 71   | 23   |
| July    | 97   | 94   | 98   | 86   | 100  | 25   |
| August  | 77   | 61   | 0    | 89   | 42   | 0    |
| September| 85  | 51   | 0    | 99   | 100  |
| October | 99   | 73   | 0    | 100  | 85   | 12   |
| November| 94   | 64   | 0    | 87   | 59   |
| December| 98   | 69   | 0    | 74   | 80   | 56   |
| Year total| 85  | 57   | 24   | 67   | 81   |
| Dry     | 80   | 83   | 42   | 49   | 82   | 71   |
| Wet     | 87   | 31   | 6    | 85   | 79   | 15   |

Table 4. Solar radiation data coverage from the Texas weather station in percentage.

| Month   | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | All |
|---------|------|------|------|------|------|------|------|-----|
| January | 87   | 52   | 60   | 81   | 64   | 28   |
| February| 93   | 87   | 69   | 83   | 80   |
| March   | 99   | 57   | 98   | 93   | 88   |
| April   | 17   | 83   | 8    | 61   | 93   |
| May     | 39   | 0    | 25   | 37   | 82   |
| June    | 87   | 0    | 0    | 84   | 71   |
| July    | 73   | 0    | 29   | 99   | 94   |
| August  | 77   | 26   | 99   | 88   |
| September| 84  | 51   | 50   | 99   |
| October | 99   | 74   | 44   | 99   |
| November| 93   | 64   | 45   | 86   |
| December| 97   | 68   | 46   | 74   |
| Year    | 73   | 52   | 44   | 80   |
| Dry     | 68   | 83   | 49   | 75   |
| Wet     | 76   | 24   | 41   | 84   |

The station are in fair agreement, with a correlation of 0.90 for the linear fit,

\[ T_{tx} = (1.11 \pm 0.4) T_{dv} + (0.23 \pm 1.0) ^\circ C, \]  

the rms scatter around the fit is 1.23 \(^\circ C\), which is 1.7 \( \sigma \), where \( \sigma \) is the combined error accuracy of both stations. The data points with the best fit and the fits obtained adding \( \pm 1 \sigma \) are shown on the left-hand side of Fig. 2.
Table 5. Hourly data coverage of Davis weather station.

|       | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sept | Oct | Nov | Dec | Per hour |
|-------|-----|-----|-----|-----|-----|-----|-----|-----|------|-----|-----|-----|----------|
| 0 h   | 85  | 76  | 55  | 65  | 69  | 72  | 74  | 78  | 78   | 78  | 73  | 52  | 62  | 70       |
| 1 h   | 84  | 77  | 55  | 64  | 69  | 72  | 75  | 78  | 77   | 77  | 73  | 52  | 62  | 70       |
| 2 h   | 85  | 77  | 56  | 64  | 69  | 72  | 74  | 78  | 77   | 73  | 52  | 62  | 70       |
| 3 h   | 85  | 77  | 55  | 64  | 69  | 73  | 74  | 78  | 78   | 78  | 73  | 52  | 62  | 70       |
| 4 h   | 84  | 76  | 55  | 63  | 69  | 73  | 74  | 78  | 78   | 78  | 73  | 52  | 62  | 70       |
| 5 h   | 85  | 77  | 56  | 64  | 70  | 72  | 74  | 78  | 78   | 78  | 73  | 51  | 62  | 70       |
| 6 h   | 85  | 77  | 56  | 64  | 70  | 72  | 74  | 78  | 78   | 78  | 73  | 51  | 62  | 70       |
| 7 h   | 85  | 77  | 56  | 64  | 70  | 72  | 74  | 78  | 78   | 78  | 73  | 52  | 62  | 70       |
| 8 h   | 85  | 77  | 57  | 64  | 69  | 72  | 73  | 79  | 78   | 74  | 52  | 62  | 70       |
| 9 h   | 85  | 75  | 56  | 63  | 69  | 71  | 73  | 78  | 78   | 72  | 51  | 63  | 70       |
| 10 h  | 86  | 75  | 56  | 64  | 68  | 70  | 72  | 77  | 78   | 72  | 51  | 63  | 69       |
| 11 h  | 86  | 76  | 57  | 65  | 69  | 71  | 73  | 77  | 78   | 72  | 51  | 63  | 69       |
| 12 h  | 86  | 76  | 56  | 64  | 69  | 71  | 72  | 77  | 78   | 72  | 51  | 63  | 69       |
| 13 h  | 86  | 76  | 56  | 65  | 68  | 70  | 72  | 77  | 76   | 72  | 52  | 63  | 69       |
| 14 h  | 86  | 75  | 56  | 64  | 69  | 68  | 70  | 72  | 77   | 73  | 52  | 62  | 69       |
| 15 h  | 87  | 74  | 56  | 65  | 68  | 68  | 70  | 72  | 77   | 73  | 52  | 62  | 69       |
| 16 h  | 87  | 74  | 56  | 66  | 69  | 70  | 72  | 78  | 77   | 72  | 51  | 63  | 70       |
| 17 h  | 86  | 76  | 56  | 66  | 69  | 70  | 72  | 78  | 77   | 73  | 52  | 63  | 70       |
| 18 h  | 86  | 76  | 56  | 66  | 69  | 70  | 72  | 77  | 77   | 72  | 51  | 62  | 70       |
| 19 h  | 86  | 75  | 56  | 65  | 69  | 70  | 72  | 78  | 78   | 73  | 51  | 62  | 70       |
| 20 h  | 85  | 76  | 56  | 65  | 69  | 69  | 71  | 77  | 77   | 72  | 51  | 62  | 69       |
| 21 h  | 85  | 75  | 56  | 65  | 68  | 70  | 72  | 76  | 78   | 72  | 50  | 63  | 69       |
| 22 h  | 85  | 75  | 55  | 64  | 69  | 70  | 72  | 78  | 77   | 72  | 51  | 63  | 69       |
| 23 h  | 85  | 75  | 55  | 64  | 68  | 71  | 73  | 78  | 78   | 71  | 52  | 63  | 69       |
| Per month | 85  | 76  | 56  | 64  | 69  | 71  | 73  | 78  | 78   | 73  | 51  | 63  | 70       |

Relation (1) leads to a larger range of temperatures for the Texas station than for the Davis one and differences $\Delta T < 1^\circ C$ for extreme temperature, $|T| > 10^\circ C$. Additionally, the comparison between the Davis station and the Backup station gives a fit with a slope of 1.03, intercept of 0.03 and $r = 0.99$. We consider the temperature data from different stations to be consistent with each other.

5.2 Relative humidity

Even though both stations have similar humidity sensors, we found significant systematic differences in simultaneous measurements. Some of these might be attributed to local differences in humidity, due to fog moving across the site, as the stations are located 130 m...
Table 7. Hourly data coverage of radiation from the Texas weather station.

| Hourly data | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sept | Oct | Nov | Dec |
|-------------|-----|-----|-----|-----|-----|-----|-----|-----|------|-----|-----|-----|
| 6 h         | 0   | 2   | 29  | 48  | 30  | 43  | 36  | 37  | 24   | 12  | 0   | 25  |
| 7 h         | 51  | 80  | 88  | 63  | 51  | 61  | 75  | 66  | 66   | 67  | 66  | 61  |
| 8 h         | 60  | 83  | 88  | 64  | 32  | 47  | 51  | 61  | 74   | 66  | 64  | 63  |
| 9 h         | 61  | 82  | 88  | 64  | 33  | 46  | 51  | 61  | 75   | 66  | 69  | 70  |
| 10 h        | 61  | 82  | 88  | 64  | 32  | 47  | 51  | 61  | 74   | 66  | 70  | 70  |
| 11 h        | 61  | 83  | 87  | 64  | 32  | 48  | 52  | 61  | 73   | 70  | 71  | 70  |
| 12 h        | 62  | 84  | 87  | 65  | 32  | 48  | 52  | 52  | 73   | 70  | 72  | 65  |
| 13 h        | 63  | 85  | 87  | 65  | 32  | 48  | 52  | 61  | 75   | 66  | 70  | 64  |
| 14 h        | 63  | 86  | 87  | 65  | 33  | 49  | 52  | 61  | 73   | 72  | 71  | 65  |
| 15 h        | 63  | 86  | 87  | 66  | 33  | 50  | 52  | 61  | 73   | 72  | 72  | 66  |
| 16 h        | 64  | 86  | 88  | 66  | 33  | 50  | 52  | 63  | 73   | 72  | 73  | 66  |
| 17 h        | 64  | 86  | 88  | 66  | 33  | 50  | 52  | 63  | 74   | 72  | 67  | 64  |
| 18 h        | 7   | 28  | 41  | 39  | 26  | 49  | 52  | 59  | 45   | 12  | 0   | 29  |
| Per month   | 62  | 84  | 87  | 64  | 32  | 48  | 51  | 61  | 74   | 69  | 71  | 70  |

Table 8. Linear fits, RH(Texas) = slope * RH(Davis) + intercept, to common data on relative humidity.

| Sample | Slope (per cent) | Intercept (per cent) | rms (per cent) | Correl | Npoints |
|--------|------------------|----------------------|----------------|--------|---------|
| 2002   | 0.97 ± 0.10      | −1.00                | 11.5           | 0.94   | 72025   |
| 2003   | 0.94 ± 0.10      | −2.22                | 9.0            | 0.96   | 52103   |
| 2004   | 0.90 ± 0.10      | −1.90                | 9.2            | 0.96   | 12705   |
| 2005   | 0.88 ± 0.08      | −4.27                | 11.2           | 0.88   | 33024   |
| 2006   | 0.89 ± 0.09      | −4.63                | 9.1            | 0.96   | 36622   |
| 2007   | 0.82 ± 0.01      | −0.82                | 11.8           | 0.93   | 3284    |
| 2008   | 0.89 ± 0.09      | −5.78                | 8.9            | 0.94   | 2354    |
| All    | 0.92 ± 0.09      | −1.77                | 11.2           | 0.94   | 212117  |

Apart. The common data are well correlated ($r = 0.94$) with a linear fit marginally consistent with an one-to-one relation,

$$RH_{tx} = (0.92 \pm 0.09) RH_{dv} - (1.8 \pm 7.1) \text{ per cent}.$$  \hfill (2)

The values from the Davis station tend to be 10 per cent higher than those from theTexas. The comparison between the Backup and Davis stations gives a similar fit, of slope 0.91, with a correlation equal to 0.99, being more consistent with the data from Texas weather station. The data points with the best fit (bold line) and the fits obtained adding $\pm 1\sigma$ are shown in Fig. 2, on the right-hand side.

Of further significance is the variation of this fit with time, shown in Table 8. The fits for 2002 and 2003 are compatible with equal measurements from both stations, $RH_{tx} = RH_{dv}$, while those 2005 onwards become deviant. The measurements of the stations were similar at earlier times and diverged with time. The slope drifted from 0.97 $\pm$ 0.10 in 2002 to 0.82 $\pm$ 0.10 in 2007, resulting in larger humidity measurements for the Davis station, by about 10 per cent. In fact, the Davis weather station data show such a trend. The best fit of the yearly median $RH_{tx}$ versus year shows a 4 per cent increase per year with a correlation coefficient of 0.91. However, the Texas station does not show this trend as the best fit of the yearly median $RH_{tx}$ versus year shows a slope of $-2.1$ per cent per year and a correlation coefficient of $-0.25$. 

Figure 2. Fits between the Davis and the Texas stations for temperature (left-hand panel) and RH (right-hand panel). The fit with the best slope and zero point is indicated with a bold line. The fits adding $\pm 1\sigma$ error to each fitting parameter are also shown: the two parallel fits to the best one correspond to $1\sigma$ and $-1\sigma$ in the ordinate; the other two fits correspond to $1\sigma$ and $-1\sigma$ error in the slope.
To complement the RH analysis, we used the RH monthly mean data at 600 MB provided by the NCEP/NCAR Reanalysis project. The NCEP data, included in Fig. 3 in dotted lines, follow the same trend as those measured in situ, but with lower values by up to 40 per cent. The offset can be explained by the fact that some variables as RH are partially defined by observations but also are strongly influenced by the local topography and the characteristics of the NCEP analysis model, as pointed out by Kalnay et al. (1996). Even with an offset, these data can be used to look for a tendency. In the case of annual trend, the NCEP Reanalysis data does point to an increase of RH of 0.9 per cent per year with a correlation coefficient of 0.7. The data actually shows a 1 per cent per year decrease in RH from 2001 (39 per cent) to 2004 (36 per cent) followed by increased mean values of 42 per cent between 2005 and 2007. This increase is not comparable to the Davis one. We conclude that the RH sensor of the Davis station drifted with time proving higher values than the real ones.

5.3 Wind velocity

Simultaneous wind measurements from both stations follow the best fit,

\[ w_{tx} = (0.76 \pm 0.26) w_{dv} + (1.7 \pm 1.4) \text{ m s}^{-1}, \]

(3)

with a correlation coefficient of 0.75. The simultaneous outputs from the anemometers are less correlated than the temperature and humidity data. The Davis weather station tends to give lower values. The fit marginally excludes \( w_{tx} = w_{dv} \) in the parameter 1σ error contour. The rms deviation of the fit is 2.29 m s\(^{-1}\), more than twice the combined measurement error of 1.02 m s\(^{-1}\). The data points with the best fit and the fits obtained adding ±1σ error are shown in Fig. 4.

The median velocities of both stations are below the LMT operation threshold of 9 m s\(^{-1}\). Furthermore, looking at the distributions, we note that the percentage of wind speeds below the LMT operation threshold are very similar for both stations. We compared the best fit with the fit \( w_{tx} = w_{dv} \) and we found that the zero point in the best fit cancels the effect of the different slope giving the same statistical behaviour of both data, although not necessarily simultaneous values. The fact that the statistical behaviour of the two data sets is similar supports the premise that there can be genuine differences in wind speeds due to the topography of the mountain top.

6 DATA ANALYSIS AND RESULTS

Median and quartile values were computed for different parameters and data sets. The data points were weighted by sampling time. A time interval larger than 16 min without data is considered a gap. We did not compensate for gaps in the data.
The samples were divided in different subsamples for their study, defined as follows: daytime is the 10-hr interval between 8:00 AM and 5:59 PM; nighttime ranges from 8:00 PM to 5:59 AM. These two definitions avoid the transition times of sunrise and sunset to analyse the weather under stable conditions. The dry season is the 181-day period from November 1 to October 31; the wet season goes from May 1 to October 31, covering 184 days. The time span of the Davis data comprises 1378 dry season days (978 with data) and 1290 wet season days (1008 with data); the time span of the Texas data comprises 1059 dry season days (889 with data) and 1104 wet season days (695 with data).

### Table 9. Weather data statistics. Temperature, pressure and wind speed are from the Davis station while relative humidity is from the Texas weather station, as explained in the text. Quartiles are estimated with an accuracy of \( \Delta x /100 \), where \( \Delta x \) is the sampling of the parameter under consideration.

| Parameter                  | Cov. (per cent) | Min  | \( q_1 \) | Median | \( q_3 \) | Max. |
|----------------------------|-----------------|------|----------|--------|----------|------|
| Temperature (°C)           |                 |      |          |        |          |      |
| All                        | 71              | −10.6| −0.30    | 1.07   | 2.32     | 11.8 |
| Dry                        | 71              | −10.6| −1.42    | 0.34   | 2.10     | 9.9  |
| Wet                        | 72              | −4.8 | 0.38     | 1.39   | 2.48     | 11.8 |
| Day                        | 71              | −10.4| 0.73     | 2.12   | 3.36     | 11.8 |
| Night                      | 71              | −10.2| −0.82    | 0.35   | 1.37     | 6.7  |
| Atmospheric pressure (mbar)|                 |      |          |        |          |      |
| All                        | 71              | 580.2| 589.19   | 590.11 | 590.99   | 594.7|
| Dry                        | 71              | 581.6| 588.85   | 589.82 | 590.74   | 594.3|
| Wet                        | 72              | 580.2| 589.51   | 590.39 | 591.19   | 594.7|
| Day                        | 71              | 580.8| 589.26   | 590.22 | 591.14   | 594.7|
| Night                      | 71              | 580.2| 589.22   | 590.13 | 591.00   | 594.7|
| Relative humidity (per cent)|                |      |          |        |          |      |
| All                        | 58              | 1    | 36.73    | 68.87  | 92.59    | 100  |
| Dry                        | 65              | 1    | 20.82    | 50.92  | 78.52    | 100  |
| Wet                        | 51              | 2    | 64.86    | 84.92  | 96.18    | 100  |
| Day                        | 58              | 1    | 40.70    | 68.19  | 88.73    | 100  |
| Night                      | 58              | 1    | 33.18    | 69.35  | 93.96    | 100  |
| Wind speed (m s\(^{-1}\)) |                 |      |          |        |          |      |
| All                        | 69              | 0    | 2.31     | 3.77   | 5.88     | 36.2 |
| Dry                        | 68              | 0    | 2.36     | 3.80   | 5.91     | 36.2 |
| Wet                        | 70              | 0    | 2.27     | 3.74   | 5.85     | 35.8 |
| Day                        | 69              | 0    | 2.28     | 3.57   | 5.45     | 35.8 |
| Night                      | 68              | 0    | 2.36     | 3.98   | 6.18     | 35.8 |

### Table 10. Median values of the meteorological parameters per year and season.

| Parameter                  | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 |
|----------------------------|------|------|------|------|------|------|------|
| Temperature (°C)           | 0.90 | 1.02 | 1.54 | 0.89 | 1.28 | 0.91 | 0.93 |
| Dry season                 | −0.10| 0.25 | 0.80 | 0.10 | 0.87 | 0.32 | 0.08 |
| Wet season                 | 1.25 | 1.28 | 1.93 | 1.18 | 1.57 | 1.35 | 1.25 |
| Pressure (mbar)            | 589.93| 589.97| 590.12| 590.24| 590.32| 590.12| 590.15|
| Dry season                 | 589.38| 589.81| 589.85| 589.75| 590.12| 589.89| 589.84|
| Wet season                 | 590.29| 590.11| 590.42| 590.59| 590.47| 590.40| 590.40|
| Relative humidity (per cent)| 68.86| 65.06| (74.50)| 68.10| 74.80| 63.13|      |
| Dry season                 | 42.01| 53.53| (49.21)| 49.94| 52.69| 58.30|      |
| Wet season                 | 99.56| 86.07| (89.50)| 78.95| 85.28| 81.47|      |
| Wind (m s\(^{-1}\))       | 3.81 | 3.94 | 3.54 | 3.68 | 4.07 | 3.86 | 3.71 |
| Dry season                 | 4.28 | 4.01 | 3.60 | 3.78 | 3.74 | 3.95 | 3.81 |
| Wet season                 | 3.49 | 3.88 | 3.48 | 3.60 | 4.42 | 3.74 | 3.66 |

### 6.1 Parameter statistics – seasonal and diurnal

The data statistics of the meteorological parameters, except solar radiation, are summarized in Table 9, for the entire samples and for the day/night, dry/wet season subsamples. The columns indicate from left to right, coverage percentage, minimum, first, second, third quartile values \( (q_1, q_2, q_3) \) and maximum. Temperature, atmospheric pressure and wind speed statistics are from the Davis data, while statistics for RH statistics were computed for the Texas weather station. The ‘all’, ‘day’ and ‘night’ statistics were estimated compensating for the uneven seasonal coverage of the Texas data, using 695 days out of the 889 days dry season data. For solar radiation, the subdivision ‘day’ and ‘night’ become meaningless. The results of the analysis of solar radiation data, including the influence of daytime cloud cover, are described in Section 7.

Table 10 displays the annual statistics of each parameter, considering also the dry and wet seasons. In Fig. 5, we plot the median values of the measured parameters per year and per month, with bars going from the first to the third quartile. Fig. 6 shows the statistics of the data folded per month and per hour of day, in order to show the seasonal and daily modulations.

### 6.2 Temperature

According to the Davis weather station, the median temperature for the site is 1.07 °C, with quartile values of −0.30 °C and 2.32 °C. The extreme temperatures recorded by the Davis station on site are relatively mild: the minimum temperature in the data is −10.6 °C while the maximum 11.8 °C. The Texas station registered the same median temperature, but with somewhat larger variations and more marked extremes: −13.3 °C and 14.4 °C. As it would be expected that both stations register the same extreme temperature, it is required to perform some experiments to determine if these differences are real or are due to the distinct temperature sensors sensitivity to extreme conditions. We plan to carry out such experiments. In any case, the temperatures at the site do not show large variations.

The daily cycle, quantified as the difference between the night and day medians, is 1.77 °C, going from 0.26°C to 2.03°C, respectively. A similar value is obtained for seasonal variations: the median and third quartile \( (q_3) \) values for dry/wet differ by only 1.76°C and 1.09°C, respectively. The lowest quartile does show a larger but still mild difference, close to 2°C. In Fig. 6, the amplitude of the curve between the lowest median, −0.22°C at 5 AM, and the highest median, 4.15°C at 11 PM, is 4.37°C. The coldest month is December.
with a median of $-0.59\,^\circ C$, $2.5\,^\circ C$ below the warmest month, June, with a median of $1.91\,^\circ C$.

Temperature distributions are shown in the cumulative histograms on the left-hand panel of Fig. 7. The distributions for nighttime, daytime, dry and wet seasons are shown as indicated. The temperature differences due to the diurnal cycle are larger for values above the median while the seasonal temperature differences are larger for values below the median. The right-hand panel of the same figure shows in a grey-scale diagram the medians per hour and month. Temperatures are at their lowest during the nights of the dry months, specifically between December and February, and highest around or just after noon between April and June. Note that the period between July and September is not warmer than April and May, due to the effect of rain.

If we consider the altitude of the site and the temperature gradient of a standard atmosphere model, $dT/dz = -6.5\,^\circ C/km^{-1}$, the corresponding sea-level temperature is $T_0 = 30.9\,^\circ C$, about $16\,^\circ C$ above the standard atmosphere base value. This is clearly an effect due to the low latitude, which results in a warmer temperature at a high-altitude site. A final remark is that the site presents a good degree of thermal stability, beneficial for scientific instruments: thermal stability will help the performance of the LMT, designed to actively correct its surface to compensate for gravitational and thermal deformations.

### 6.3 Atmospheric pressure

The barometer of the Texas weather station did not provide meaningful data and these had to be discarded. We discuss only the data from the Davis weather station. To verify the calibration of the Davis barometer, we performed a comparison with a basic water barometer, for about 3 h during daytime, obtaining a pressure of 594 mbar, in very good agreement with the Davis barometer reading.
of 592.4 mbar. Therefore, the Davis weather station gives readings accurate to within 2.4 mbar.

The site presents a low atmospheric pressure which is characteristic of a high-altitude site. The median is 590.1 mbar with a daily cycle of 1.45 mbar, as measured by the difference between the median of the 4 AM sample (589.36 mbar) and that of the 11 AM data (590.81 mbar), displayed in Fig. 6. The daily cycle is in fact a double 12-h cycle, with maxima at 11 and 23 h and minima at 5 and 17 h. This semidiurnal pressure variation of a few mbar is well known for low-latitude zones. It is associated with atmospheric tides excited by heating due to insolation absorption by ozone and water vapour (Lindzen 1979). The yearly cycle is not as well defined, see Fig. 10, with relative minima in February (589.37 mbar), June and December, and maximum value in July (590.87 mbar), for a peak to peak amplitude of 1.5 mbar.

High and low pressures are usually related to good and bad weather, respectively. The largest pressure recorded on site is 597.4 mbar, 3.8 mbar above the median, just before the midnight on the 2001 August 17 and again at noon 2001 August 18. The weather was dry as RH values were 18 and 22 per cent, respectively, with temperatures of 1.4°C and 4.7°C. We note that while the weather is usually poorer in the wet season, these good conditions happened in August, indicating that good observing conditions can happen at any time of the year; the largest atmospheric pressure during the dry season occurred on 2001 August 17 at 6:20 AM, a RH of just 12 per cent.

The lowest pressure corresponded to what has presumably been the worst weather on site: the relatively close passage of hurricane Dean, on 2007 August 22. At 4:30 AM when the pressure dropped to 580.2 mbar, practically 10 mbar below the site median, with a temperature of −0.1°C and RH of 92 per cent. The same day registered the lowest daytime pressure, 580.8 mbar, at 10 AM, when the temperature had dropped to −0.3°C. Bad weather occasionally occurs early in the year, like on 2004 January 17 at 6:20 AM when the pressure reached its lowest dry season value, 581.6 mbar, with a temperature of −3.7°C and 85 per cent RH.

As shown in Fig. 8, there is no significant difference between the cumulative distribution of atmospheric pressure values between day and night, presumably because of the actual 12-h cycle. The seasonal distributions show that pressure tends to be 0.57 mbar lower during the dry season compared to the wet season. The grey-scale diagram in Fig. 8 shows that the main seasonal effect on pressure seems to be a shift in the daily cycle to later hours in June–July; the minima move from 4 AM and 4 PM in December/January to 6 AM/6 PM in June/July.

The temperature and atmospheric pressure agree with a standard atmosphere model,

$$ T(z) = T_0 - \theta z, \quad P(z) = P_0(1 - \theta z/T_0)^\alpha, $$

with the usual temperature gradient of a standard atmosphere, $\theta = -dT/dz = 6.5\,\text{C km}^{-1}$, and the constant $\alpha = \mu m_n g/k \theta \approx 5.256$, with $m_n$ the atomic mass unit, $g$ the acceleration of gravity, $k$ the Boltzmann constant, $P_0 = 1013.25\,\text{mbar}$ and $\mu = 28.9644$ is the mean atomic mass of air. The data departure from the standard model requires a warmer base temperature, $T_0 = 51.7°C$ ≈ 304 K, which results in $T(4.6\,\text{km}) = 1.1°C$ and $P(4.6\,\text{km}) = 588.2\,\text{mbar}$, close to the measured value. A warm standard atmosphere model appears reasonable for the site although it would be convenient to validate it with measurements of pressure and temperature at different elevations.

### 6.4 Relative humidity

The median RH is 68.87 per cent with quartile values of 36.76 and 92.59 per cent. The RH values for day and nighttime are 68.19 and 69.35 per cent. When folded by months, the data show a clear seasonal modulation with lower values between November and March, ≤50 per cent and higher humidity between June and October with a median ~90 per cent as illustrated in Fig. 6. A second clear trend is an increase of the RH at around 8 h to reach a maximum at 18 h, ~80 per cent. Once the Sun sets, the RH starts decreasing to reach its minimum value of 49 per cent. Nevertheless, it must be mentioned that for the daily cycle plot the very low-RH conditions is

![Median temperature (°C)](https://example.com/figure7.png)

Figure 7. Left-hand panel: the temperature distribution for the whole data set is shown in black with a median of 1.07°C. The distributions for nighttime, daytime, dry and wet season are shown as indicated. The median values are 0.35°C, 2.12°C, 0.34°C and 1.39°C, respectively. Right-hand panel: a three-dimensional representation of the temperature behaviour where the grey-scale intensity corresponds to the temperature median for a given month and hour. The annual and daily cycle are apparent in the horizontal and vertical structure of the figures, behaving as expected. See the electronic edition of MNRAS for a colour version of this figure.
values measured during the dry season are merged with those obtained during the wet season at the same hour.

The cumulative distributions of RH are shown on the left-hand side of Fig. 9 where the seasonal differences are better appreciated. For the dry season, the first, second and third quartile are 20.82, 50.92 and 78.52 per cent. In contrast, for the wet season the corresponding values are 64.86, 84.92 and 96.18 per cent. The right-hand side of the same figure shows the median per hour and month in a grey-scale. For November, December, January and February, the driest times are from about 8 PM up to noon while for February, March, April and May the RH is lowest from dawn up to midday.

6.5 Wind velocity

Wind velocity is an important factor for the LMT, specified to perform at $\lambda \leq 1$ mm for wind velocities below 9 m s$^{-1}$. Both stations give similar percentage of data below the critical value of 9 m s$^{-1}$ (Davis: 91.5 per cent; Texas: 87.7 per cent). The Davis weather station has two wind values in each data record: one (wind) corresponding to a mean value acquired during the sampling interval ($\geq 1$ min) and a second one (whigh) corresponding to the maximum value during the same time interval. The median value of whigh is 6.03 m s$^{-1}$ and whigh $\geq 9$ m s$^{-1}$ for 22 per cent of the time.
The wind is fairly constant at the site, with a mild decrease less than 1 m s$^{-1}$ during daytime compared to nighttime. Differences between months are also small, except for a marked increase in wind velocities during the month of May ($\approx 1.5$ m s$^{-1}$), noted by both data sets, and a small decrease ($\lesssim 0.5$ m s$^{-1}$) of wind velocities in the last months of the year.

The wind distributions are shown in Fig. 10 in black for the whole data set; for nighttime, daytime, dry and wet seasons as marked. In the three-dimensional plot, a seasonal pattern cannot be as clearly identified as in the case of other parameters, but we can still note that the wind is slightly higher during the nights and the effect is more pronounced during the winter months. A special mention deserves the strong winds in one year in May as can be seen from Fig. 6. The daily cycle is better appreciated in the right-hand panel of the same figure if we look at the third quartile pattern.

The LMT has two other specified wind limits: operations at any wavelength are to stop if wind velocities reach 25 m s$^{-1}$ and the telescope has to be stowed. In the extreme, the design survival wind speed is 70 m s$^{-1}$ ($\approx 250$ km h$^{-1}$). The two data sets show extremely rare wind velocities above 25 m s$^{-1}$, with which exceeding that value 0.3 per cent of the time. The largest wind speed registered so far corresponded to the storm recorded on 2002 February 22, with which $= 42.5$ m s$^{-1}$. More recently, the near passage of hurricane Dean in 2007 August gave peak wind speeds of 40.7 m s$^{-1}$, the highest endured successfully by the LMT prior to the installation of its stow pins.

### 7 SOLAR RADIATION AND INFERRED CLOUD COVERAGE

Solar radiation data was acquired by the Texas weather station between 2002 April 25 and 2008 March 13. The coverage for this time interval was 62 per cent (Table 3), with due consideration of the diurnal cycle. The data are output as time ordered energy fluxes in units of W m$^{-2}$. We obtain daily plots of the radiation flux which show the expected solar cosine modulation. We present here a preliminary analysis regarding a method to retrieve the cloud coverage from the radiation data.

The radiation flux at ground level is modulated by the position of the Sun according to

$$F(t) = F_\odot \cos \theta_\odot(t) \psi(t),$$

where $F_\odot$ is the solar constant, which for working purposes we take as exactly equal to 1367 W m$^{-2}$; $\theta_\odot$ is the zenith angle of the Sun and $\psi(t)$ is a time-dependent factor, nominally below unity, which accounts for the instrumental response, the atmospheric absorption on site and the effects of the cloud coverage on the radiation transfer through the atmosphere.

Given the site coordinates, we computed the modulation factor $\cos \theta_\odot$ as a function of day and local time. Local transit cosine values range between 1 around May 18 and July 28 (for 2008) and 0.74 at winter solstice (December 21). Knowing the position of the Sun at the site as a function of time, we can study the variable $\psi = F/(F_\odot \cos \theta_\odot)$. The histogram of values of $\psi$ is shown in Fig. 11. It has a bimodal distribution, with a first maximum at around $\psi \approx 0.2$ and a narrow peak at $\psi \approx 0.75$, with a minimum around 0.55. We interpret the narrow component as due to direct sunshine, while the broad component is originated when solar radiation is partially absorbed by clouds; we then use the relative ratio of these as the ‘clear weather fraction’. Separating the data in intervals of $\cos \theta_\odot$, we observe that the minimum of the distribution of values of $\psi$ increases with $\cos \theta_\odot$ for small airmasses to become constant at lower Solar elevations, following the empirical relation

$$\psi_{\text{min}} = \begin{cases} 0.44 \cos \theta_\odot + 0.195 & \text{for } \cos \theta_\odot > 0.625, \\ 0.47 & \text{for } \cos \theta_\odot \leq 0.625. \end{cases}$$

For this first analysis, we separated data with $\psi \leq \psi_{\text{min}}$ as cloudy weather and data with $\psi > \psi_{\text{min}}$ as clear weather. We computed the fraction of clear weather (clear/clear + cloudy), for every hour of data. Only hours with at least 30 min of data were considered for the analysis, adding to 15 223 h of data. We considered data with airmasses lower than 10.
The observed distribution of normalized solar fluxes for the wet and dry seasons. The bimodal distribution of the solar flux divided by the nominal solar flux at the top of the atmosphere, $F_\odot \cos(\theta)$, is shown. The distribution shows a bimodal behavior which can be reproduced by a two component fit, shown in solid lines. The relative area of both components determines the clear/cloud fraction. See the electronic edition of MNRAS for a colour version of this figure.

The median clear fraction for the site is 48.4 per cent, consistent with values reported by Erasmus & Van Staden (2002). In a comprehensive study for the California Extremely Large Telescope (CELT) project, the authors surveyed cloud cover and water vapour conditions for different sites using observations from the International Satellite Cloud Climatology Project (ISCCP). The study period is of 58 months between 1993 July to 1999 December using a methodology that had been tested and successfully applied in previous studies. For Sierra Negra, they measured a clear fraction for nighttime of 47 per cent.

We note that the set of hourly clear fractions behave in a rather bimodal fashion, as shown in the histogram in Fig. 12: 20.3 per cent of the hours have $f(\text{clear}) = 0$, while 25.0 per cent have $f(\text{clear}) = 1$. The remaining (55 per cent) have intermediate values. The histogram shows a strong modulation in terms of wet and dry months. If we consider the semester between May and October, the $f(\text{clear}) = 0$ peak contains 32.5 per cent of the data, while the $f(\text{clear}) = 1$ has 11.4 per cent. During the complementary dry months the $f(\text{clear}) = 0$ peak contains 9.0 per cent of the data, while the $f(\text{clear}) = 1$ has 37.4 per cent. Intermediate conditions prevail around 55 per cent of the time in both semesters.

The contrast between dry and wet semesters is well illustrated in Fig. 13, showing the median and quartile fractions of clear time for successive wet and dry semesters. Semesters are taken continuously, from May to October representing the wet season and November to April of the following year for the dry season. The bars represent the dispersion in the data, measured by the interquartile range. Large fluctuations are observed at any time of the year. The contrast between the clearer dry months, with median daily clear fractions typically above 75 per cent, and the cloudier wet months, with median clear fractions below 20 per cent, is evident. The seasonal variation can be seen with more detail in the monthly distribution of the clear weather fraction, combining the data of different years for the same month, shown in Fig. 14. The skies are clear [\(f(\text{clear}) > 80\text{ per cent}\)] between December and March, fair in April and November [\(f(\text{clear}) \sim 60\text{ per cent}\)], and poor between May and October [\(f(\text{clear}) < 30\text{ per cent}\)]. The fluctuations in the data are such that the clear fractions above 55 per cent can be found 25 per cent of the time in the worst observing months.

Fig. 15 shows the median and quartile clear fractions as function of hour of day for the wet/dry subsets. The interquartile range practically covers the (0–1) interval at most times. We note that good conditions are more common in the mornings of the dry semesters, while the worst conditions prevail in the afternoon of the wet season, dominated by monsoon rain storms. The trend in our results for
daytime is consistent with that obtained by Erasmus & Van Staden (2002). By analysing the clear fraction during day and nighttime, they found that the clear fraction is highest before noon, has a minimum in the afternoon and increases during nighttime.

Fig. 16 shows a grey level plot of the median percentage of clear time for each month and hour of day. Squares are drawn when more than 10 h of data are available; crosses indicate less than 30 h of data.

Figure 14. Graph showing the median and quartile values of the fraction of clear weather for the different months of the year.

Figure 15. Graph showing the median and quartile values of the fraction of clear weather for each hour of day. The lower and upper are for wet and dry semesters, respectively.

8 SUMMARY AND CONCLUSIONS

We have presented for the first time data and analysis of long-term meteorological data directly obtained from local meteorological stations at Sierra Negra. A comparison of the measurements from two weather stations was carried out by cross-calibrating the data; to include the accuracy errors of both stations, we obtained a fit for each parameter by minimizing $\chi^2$. In the case of the temperature, the values of both stations are consistent. For the wind velocities, the fit is not consistent with the equality between the two data sets. However, we showed that their statistical behaviour is similar, probably the two stations are sampling the same wind but not simultaneously and the differences might be due to the topography of the site. We will present a more detailed analysis of the wind in a forthcoming paper. The RH sensor of one of the station slides up with time providing data higher than the real ones. We verified our results with a third station and data from the NCEP/NCAR Reanalysis project data base. In the case of atmospheric pressure and solar radiation, we only have data from one of the stations. We reported the daily, seasonal and annual behaviour of temperature, atmospheric pressure, RH, wind speed and solar radiation. The site presents a median temperature of 1.07°C and an atmospheric pressure median of 590.11 mbar. The results for these two parameters agree with a warm standard atmosphere model for which the base temperature would be $T_0 = 30.9^\circ$ C. As the site is influenced by the tropical storms moving off the Gulf of Mexico, the median RH has a strong seasonal dependence: while the median value for dry season is 50.92 per cent for the wet season is 84.92 per cent. The wind velocity median is 3.77 m s$^{-1}$, with a third quartile of 5.88 m s$^{-1}$ and a maximum of 36.2 m s$^{-1}$. These values are below the three LMT specifications: to perform below 1 mm the wind speed must be below 9 m s$^{-1}$; operations at any wavelength are stopped if the wind velocity is 25 m s$^{-1}$ and the design survival wind speed is 70 m s$^{-1}$. From the solar radiation data, we developed a model for the radiation that allowed us to estimate the
fraction of time when the sky is clear of clouds. The results obtained are consistent with Erasmus & Van Staden (2002) measurements of cloud cover using satellite data. This consistency shows the great potential of our method as cloud cover is a crucial parameter for astronomical characterization of any site. To our knowledge, this is the first time that the solar radiation data from the ground are used to estimate the temporal fraction of clear sky. The results presented here show that the meteorological conditions at Sierra Negra are stable daily and seasonally and have been so for the 7 yr measured. We consider that this period is representative of the climate at the site. Therefore, Sierra Negra offers exceptional conditions for such a high altitude, specially during the dry season, and is an ideal site for millimeter and high-energy observations.

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REFERENCES

Carrasco E., Carramiñana A., Avilés J. L., Yam O., 2003, PASP, 115, 879
Carrasco E., Avila R., Carramiñana A., 2005, PASP, 117, 104
Erasmus A., Van Staden C. A., 2002, A Satellite Survey of Cloud Cover and Water Vapor in the Western USA and Northern Mexico. A Study Conducted for the CELT Project. Internal report
Höskuldsson A., Robin C., 1993, Bull. Volcanol., 55, 571
Kalten E. et al., 1996, Bull. Amer. Meteor. Soc., 77, 437
Konopelko A. et al., 1999, Astrop. Phys., 10, 275
Lindzen R. S., 1979, Ann. Rev. Planet Sci., 7, 199
Press F., Siever R., 1982, Earth, 3rd edn. W.H. Freeman & Co., San Francisco, CA
Rossotti A., 2005, PhD thesis, Geociencias, UNAM
Sarazin M., Tokovinin A., 2002, in Vernet E., Ragazzoni R., Esposito S., Hubin N., eds, ESO Conf. Workshop Proc. Vol. 58, Beyond Conventional Adaptive Optics, ESO, Garching, Germany, p. 321

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