Instituto Nacional de Astrofísica, Optica y Electrónica.

Weather Conditions at Sierra Negra Site

REPORTE TECNICO: RTO 548
COORDINACION DE ASTROFISICA

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Abstract

Sierra Negra, one of the highest peak in central Mexico, has been chosen as the site of the Large Millimeter Telescope as it combines high altitute and extremely low atmospheric water content. We have initiated a campaign to investigate the astronomical potential of the site in the optical/infrared. Here we report on one aspect of our campaign to be used as a reference for future activity in the site. After a brief description of the region we describe, for the first time, detailed analysis of weather data measured *in situ* from October 2000 to May 2002. The results show mostly benign climatic conditions, given the altitude of the site.

1 Site description

Sierra Negra (18°59′06” N 97°18′53” W) at an altitude of 4580m is the site selected for the Gran Telescopio Milimétrico/Large Millimeter Telescope (GTM/LMT), a 50-m antenna to work in the millimeter range. The site is in the boundary between Puebla and Veracruz states. It is located at about 100 kms from the Gulf of Mexico and 300 kms from the closest Pacific coast. It is at about 100km from Puebla City and at 250km from Mexico City. Sierra Negra is bounded to the north east by Pico de Orizaba, known as Volcan Citlaltepetl, the highest mountain in Mexico that peaks at 5740m. Both volcanoes are within the east - west band, known as the Trans-Mexican volcanic belt. Among the highest peaks in the vicinity, to the west at 139 km is Popocatepetl (5400m), which started a period of volcanic activity in december 1995, Iztaccihuatl (5110m) at 141 km and La Malinche (4400m) at 80 km. To the north north-east, at 60 Km, is Cofre de Perote (4200m).

Around Sierra Negra, quite small human settlements are found in the vicinity, at 5.39 km is Texmalaquilla with about 1000 inhabitants at an altitude of 3100m and Atzitzintla, located to the south, is at 9 km with a population of about 2700 and 2680m above sea level. Atzitzintla host the municipality administration whose total population is about 8000 distributed in very small villages. The nearest large urban center is Orizaba-Córdoba with a combined population of about 180 000 to the south-east at 40km approximately. At about 14km to the west is Cd. Serdán with 30 000 inhabitants. At 93 km to the southwest is Puebla City with a population of about 1 200 000 and farther west, at about 200 km, is Mexico City and its Metropolitan Zone with about 17 500 000 inhabitants.

Access to Sierra Negra is through the Mexico-Veracruz highway, taking the road in direction to Ciudad Serdán, deviating towards Atzitzintla and following the road past Texmalaquilla. The whole journey from INAOE's headquartes in Tonantzintla to the summit takes 2 hours. The GTM/LMT project has its local headquarters in Atizitzintla. Traffic is unlikely to increase in the vicinity of Sierra Negra as the motor way continues towards Córdoba.

The use of light might increase in the vicinity of Sierra Negra, although the likelihood of future strong developments is remote. Texmalaquilla and Atzitzintla are rural communities that grow mainly potato, pees and corn corps. Sizeable sources of water in the region are absent. Precipitacion is only seasonal. About 35% of young men work as emigrates in the USA. The population annual average grow was 2% from 1900 to 2000 in the whole Atzitzintla municipality, according to the Instituto Nacional de Estadística,

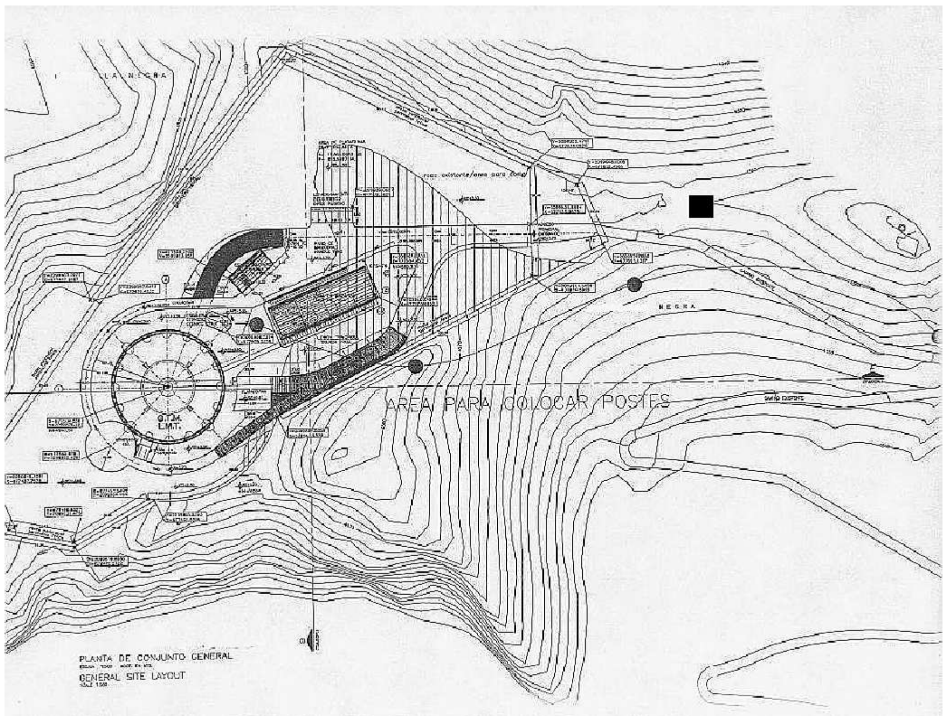

Figure 1: Layout of the Large Millimeter Telescope site. North is up and East to the right. The LMT is located at the middle left. The circle corresponding to the LMT track is clearly marked; it has 40 meters of diameter. The approximate location of the seeing monitor and weather station is marked by the black square, to the North-East from the LMT.

Geografía e Informática (INEGI, http://www.inegi.gob.mx). The most serious potential sources of light pollution are Cd. Serdán and Orizaba-Córdoba. Nevertheless, due to their lower altitude Orizaba and Córdoba, 1284m and 924m, respectively, most often they are covered by clouds. Carrasco E. *et al.* (2002) carried out a qualitative analysis of light pollution following Walker's law. A campaign to measure the sky brigthness, already programmed, will allow us to quantify the contribution of each city.

Sierra Negra is within Pico de Orizaba National Park. A natural reserve of 27000 Ha. INAOE has the property of the summit 10 Ha. INAOE and the GTM/LMT project are working with the Enviromental Authorities and with the community in the ellaboration of a Management Programme for the park that will include the protection of the site for astronomical work.

2 Weather

2.1 Data and analysis

The weather station is on a 5m tower at about 200 meters from the LMT site as shown in Figure 1. The station location is at the edge of a sharp

Month	Number of data points		Time Coverage			
			Minutes		Percentage	
	Wind	Other	Wind	Other	Wind	Other
October 2000	1557	1557	1557	1557	54.1	54.1
November 2000	6402	6402	6402	6402	14.8	14.8
December 2000	9393	9393	16709	16709	37.4	37.4
January 2001	957	976	28710	29280	64.3	65.6
February 2001	940	940	28200	28200	69.9	69.9
May 2001	8295	13377	12671	28405	28.4	63.6
June 2001	6990	7009	13202	13245	30.6	30.7
July 2001	10070	10216	15902	16544	35.6	37.1
August 2001	16539	22227	33027	42007	74.0	94.1
September 2001	18163	18680	38683	39432	89.5	91.3
October 2001	24904	25237	43008	43469	96.3	97.4
November 2001	17948	18118	32512	32762	75.3	75.8
December 2001	13258	13780	27734	28280	62.1	63.4
January 2002	10555	11897	33325	39135	74.7	87.7
February 2002	16321	19497	32933	37341	81.7	92.6
March 2002	22582	23727	43174	44435	96.7	99.5
April 2002	18453	18558	31185	31330	72.2	72.5
May 2002	18841	18888	44114	44218	98.8	99.1
Day 8am-6pm	92645	100006	202849	218666	58.5	63.1
Night 8pm-6am	92987	100611	200001	216877	57.7	62.5
Total 2000	17352	24668	17352	24668	19.1	27.2
Total 2001	118064	130560	273649	301624	52.1	57.4
Total 2002	86752	92567	184731	196459	85.0	90.4
Total 2000→2002	222168	240479	483048	522751	58.0	62.8

Table 1: Meteorological data available. The percentage of coverage is accounted for the 578 days from October 30, 2000 to May 31, 2002. If we exclude the 80 day gap due to work at the site, the relative coverage becomes 67% for wind speed and 72% for the other % for the wind data and 68.7% for the rest of the weather parameters.

slope facing North-East. Weather data were recorded using a meteorological station. The station consists of an anemometer, temperature and humidity sensors, both enclosed in a radiation shield, a control console and a data logger with limited amount of data storage. The data collected by the station are downloaded to a laptop regularly. Specification accuracies are typically of a few percent.

Data presented here span 578 days from October 30, 2000 to May 31, 2002 and their coverage is shown in Table 1. The station was removed from site on February 20, 2001, to allow work there, and re-installed on May 11, producing a 80 day gap in the data. The weather conditions were generally sampled every 1 minute, during working days or 5 minutes during weekends, except for the months of January and February 2001, where data

Parameter	Statistic				
and sample	Mean	Sigma	q_1	Median	q_3
Wind speed (m/s)					
ALL	5.04	3.60	2.69	4.03	6.69
Day (8am-6pm)	4.71	3.35	2.22	4.03	5.81
Night (8pm-6am)	5.27	3.73	2.69	4.47	6.69
Temperature (°C)					
ALL	0.79	2.43	-0.7	0.9	2.3
Day (8am-6pm)	1.77	2.44	0.2	2.0	3.4
Night (8pm-6am)	0.00	2.12	-1.2	0.3	1.4
Relative Humidity (%)					
ALL	59.69	33.12	31	64	93
Day (8am-6pm)	63.62	30.36	39	68	94
Night (8pm-6am)	56.21	34.82	22	59	93
T - Dew point (°C)					
ALL	10.31	11.55	0.9	6.0	15.4
Day (8am-6pm)	8.55	9.68	0.9	5.2	12.4
Night (8pm-6am)	11.82	12.70	1.0	7.1	19.5
Atmospheric Pressure (mbar)					
ALL	589.91	1.35	589.1	589.9	590.8
Day (8am-6pm)	590.23	1.41	589.1	590.0	590.9
Night (8pm-6am)	590.18	1.37	589.1	589.9	590.7

Table 2: Global weather statistics for the period from end of October 2000 to May 31st, 2002. q_1 and q_3 refer to the low and high quartiles.

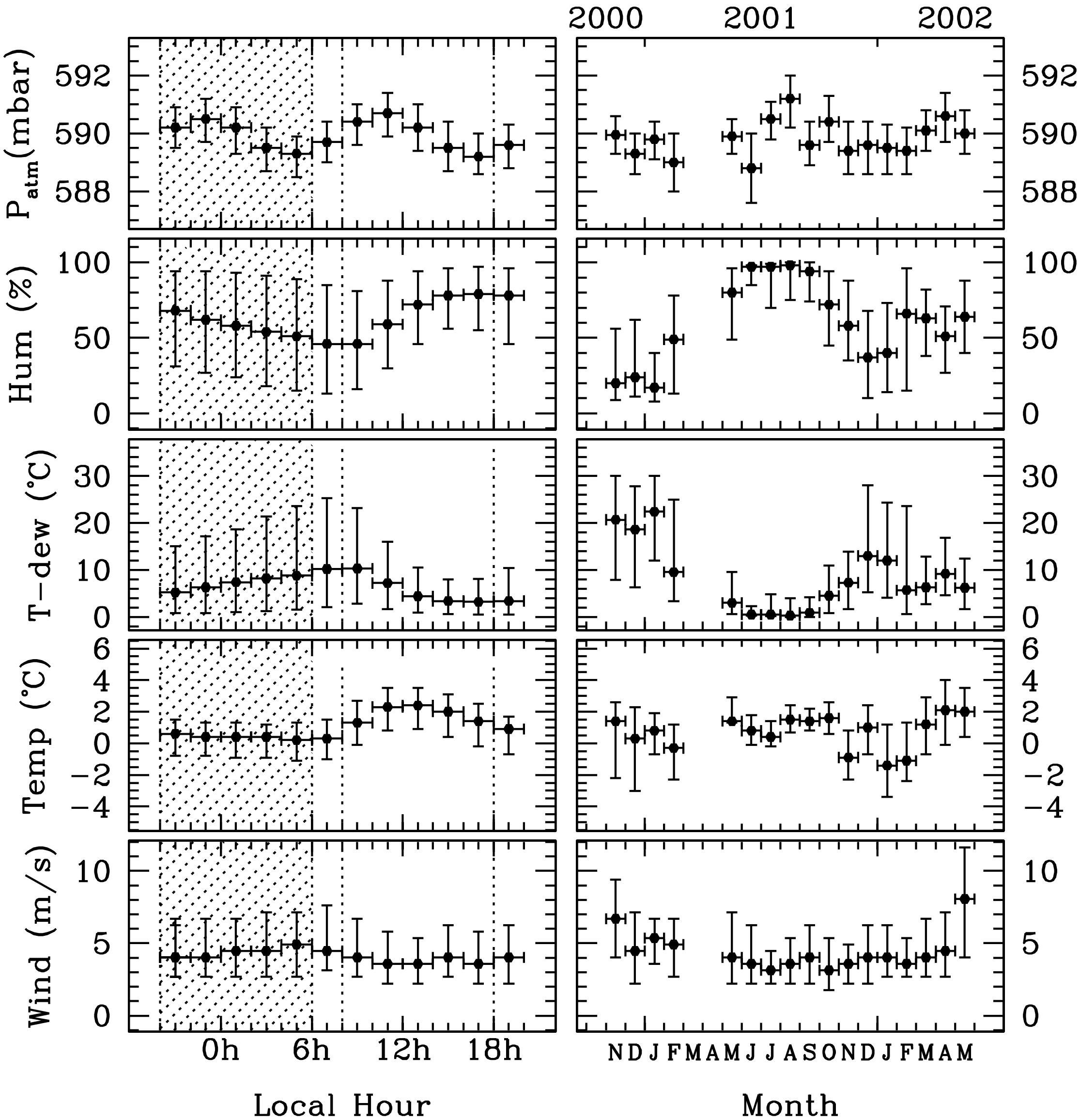

Figure 2: Weather statistics versus time of day in two hour bins (*left*) and by month (*right*). Points indicate median values, with error bars going from the 1^{st} to the 3^{rd} quartiles. The shaded region indicates night-time.

were sampled every 30 minutes and at the beginning of 2002 when 15 minutes were used. Data strings include temperature, chill, dew point, humidity, wind speed, wind maximum, wind direction and atmospheric pressure.

Standard statistics were estimated for the data, weighting each point with its integration time. No data rebinning was performed. Global statistics of temperature, wind speed, humidity and atmospheric pressure are shown in Table 3 while hourly and monthly statistics are shown in Figure 2. As the station reports simultaneously temperature and dew point, we included the difference between the air temperature and the dew point as a parameter which measures the risk of condensation in a given surface, like the LMT panels. In this case, this risk depends on the temperature difference between the ambient air and the panels, which remains to be estimated.

Complementary weather logs are regularly filled by the site keeper. These are extremely useful to check particular events and will be used eventually to complement present statistics, as they provide semi-quantitative wind data, fog, snow, rain and cloud coverage.

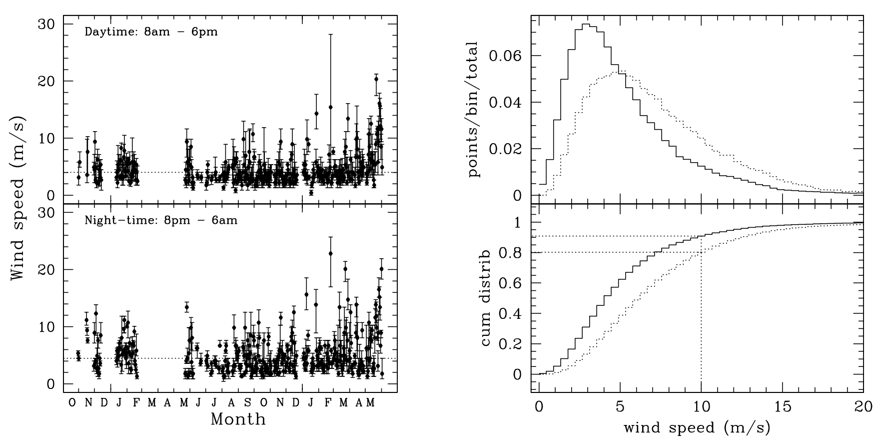

Figure 3: *Left:* daily statistics of wind speeds, with daytime and night-time separated. *Right:* differential (*upper panel*) and cumulative (*lower panel*) distributions of wind speeds (full line) and maxima (dotted line) during an integration interval.

2.2 Wind

2.2.1 General wind speed statistics

Global wind statistics are shown in Table 2. The main result is the median speed of about 4 m/s, with a third quartile of about 6 m/s, both below LMT 25 m/s operating specification. We note that wind speeds statistics give higher values at night than during the day.

The differential and cumulative distributions of wind speed and wind highs, *i.e.* maximum wind speed during each sampling, are shown in Figure 3. For 90% of the recorded time the sampled wind was below 10 m/s while 80% of the maxima are below the same value. As the data coverage is not unity, we can only assert that the sampled wind was below 10 m/s for at least 54% of total time the station has been on site and at most 92% of the time. These limits are under the extreme assumptions that the wind was either always above or always below 10 m/s while the station was not recording wind. While a more accurate interval might be asserted by checking why the station was not recording wind data during some particular period of time, we are confident that the 92% value is representative of the conditions of the site.

If we look to the statistics of each individual day, considering daytime, defined as 8am to 6pm, and night-time, from 8pm to 6am, we find that in only 14 days out of 335 the median wind speed was above 10 m/s while in 20 days the third quartile exceeded 10 m/s. Night-time statistics indicate somewhat less favorable conditions, with 18 out of 335 medians above 10 m/s and 24 third quartiles above 10 m/s (Figure 3).

2.2.2 Wind direction

The wind rose is shown in Figure 4, where the histogram of wind direction including all data is presented. The length of each line represents the fraction of time. The dotted circles represent 5% and 10% of total time. Citlaltepetl is in the NE direction. The data suggest that must of the time there is not a strong particular prevailing direction except for high speed winds that come from the North Nort-West direction.

To study the wind direction and velocity distribution we plot the wind direction histogram for three different wind velocity intervals, as can be seen in Figure 5. The left wind rose shows the wind direction distribution for $v<3$m/s, at the center is the one for $3\text{m/s}<v<9\text{m/s}$ and the one at the right is for $v>9$m/s. North is up. As can be seen 31% of the time wind velocities are less than 3m/s, 57.2% of the time the wind velocity is $3\text{m/s}<v<9\text{m/s}$

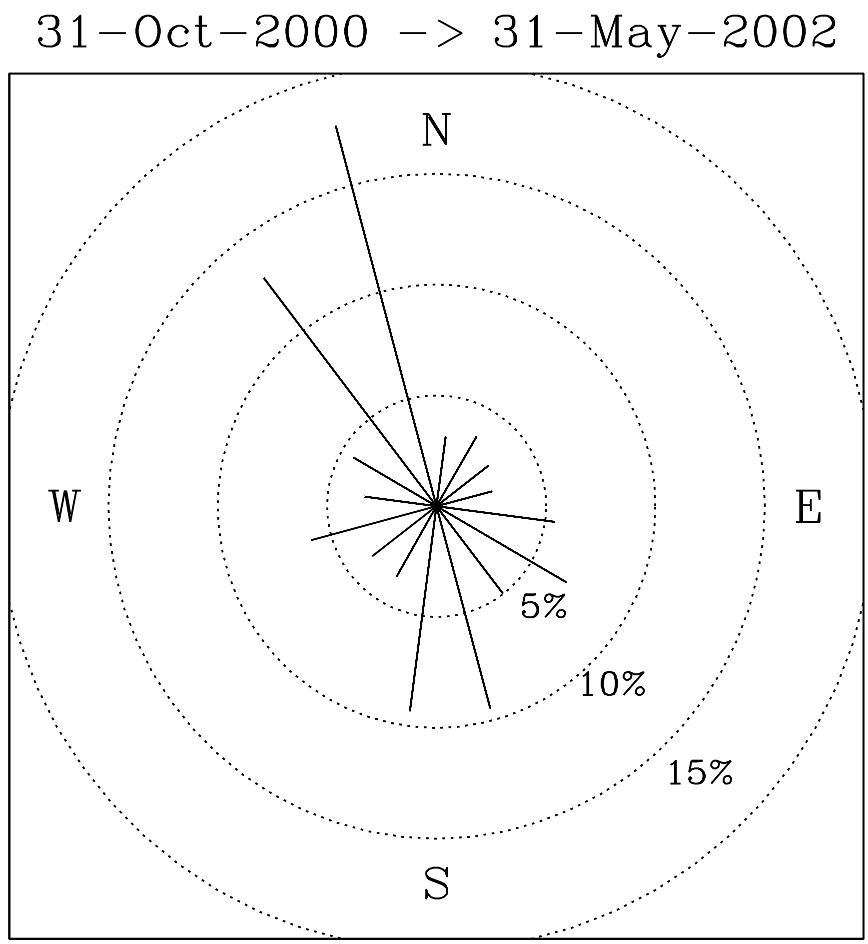

Figure 4: The length of each line represents the fraction of time. The dotted circles represent 5% and 10% of total time. Citlaltepetl is in the NE direction.

and only 11.8% is larger than 9m/s.

The seasonal trend can be seen in Figure 6 where the wind rose is shown for the wet and dry season and for day and night-time. The top three panels correspond to the day time wet season for the same wind velocity intervals shown in Figure 5 as indicated. The next three panels show the

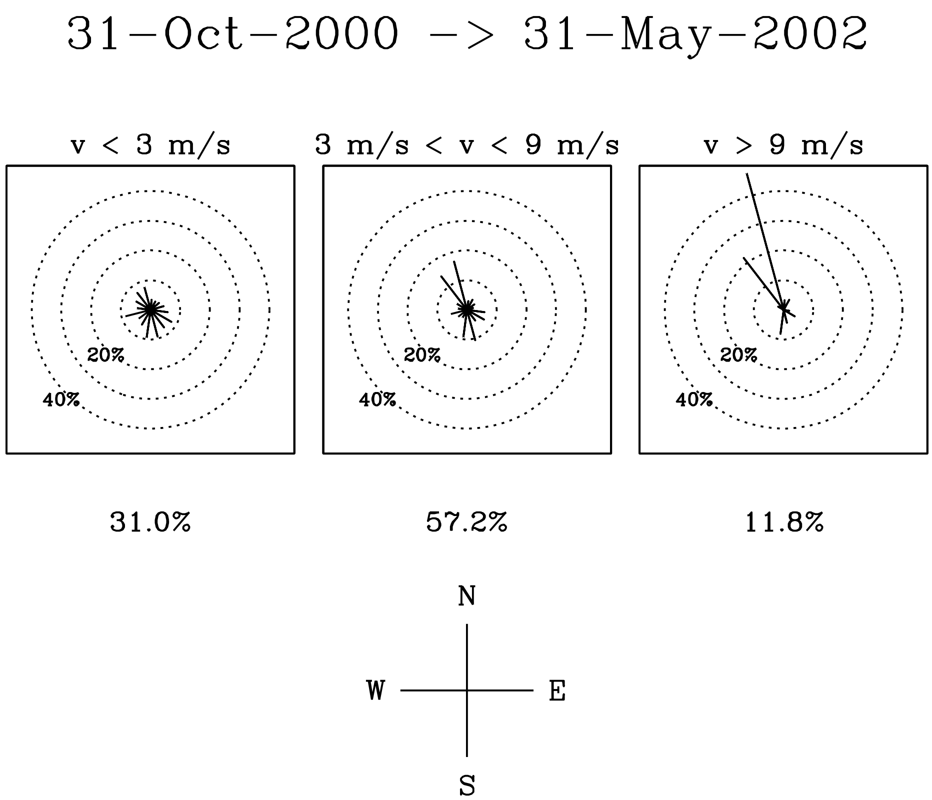

Figure 5: Wind direction histogram for three different wind velocity intervals. The length of each line represents the fraction of time. The dotted circles represent 5% and 10% of total time. The left panel shows the wind direction distribution for v<3m/s, at the center is the one for 3m/s<v<9m/s and the panel at the right side is for v>9m/s. As it can be seen 31% of the time wind velocities are less than 3m/s, 57.2% of the time the wind velocity is 3m/s<v<9m/s and only 11.8% is larger than 9m/s.

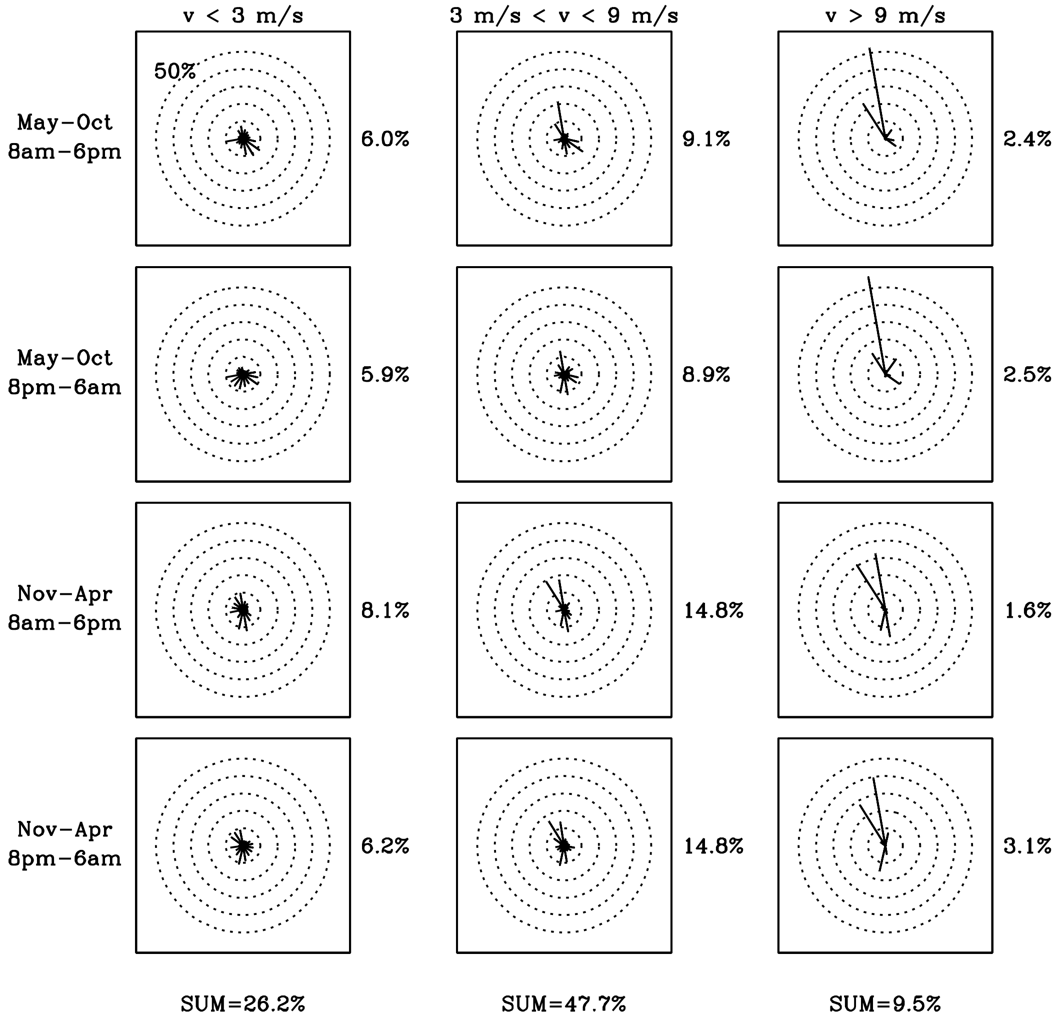

Figure 6: Wind direction histogram for three different wind velocity intervals for the day and night time of the wet and the dry season. The length of each line represents the fraction of time. The dotted circles represent 10% of total time. The wind velocity intervals are indicated.

same information for the night-time wet season. The following row show the day-time dry season results and the last three panels are the data for the night-time dry season. The dotted circles represent 10% of total time.

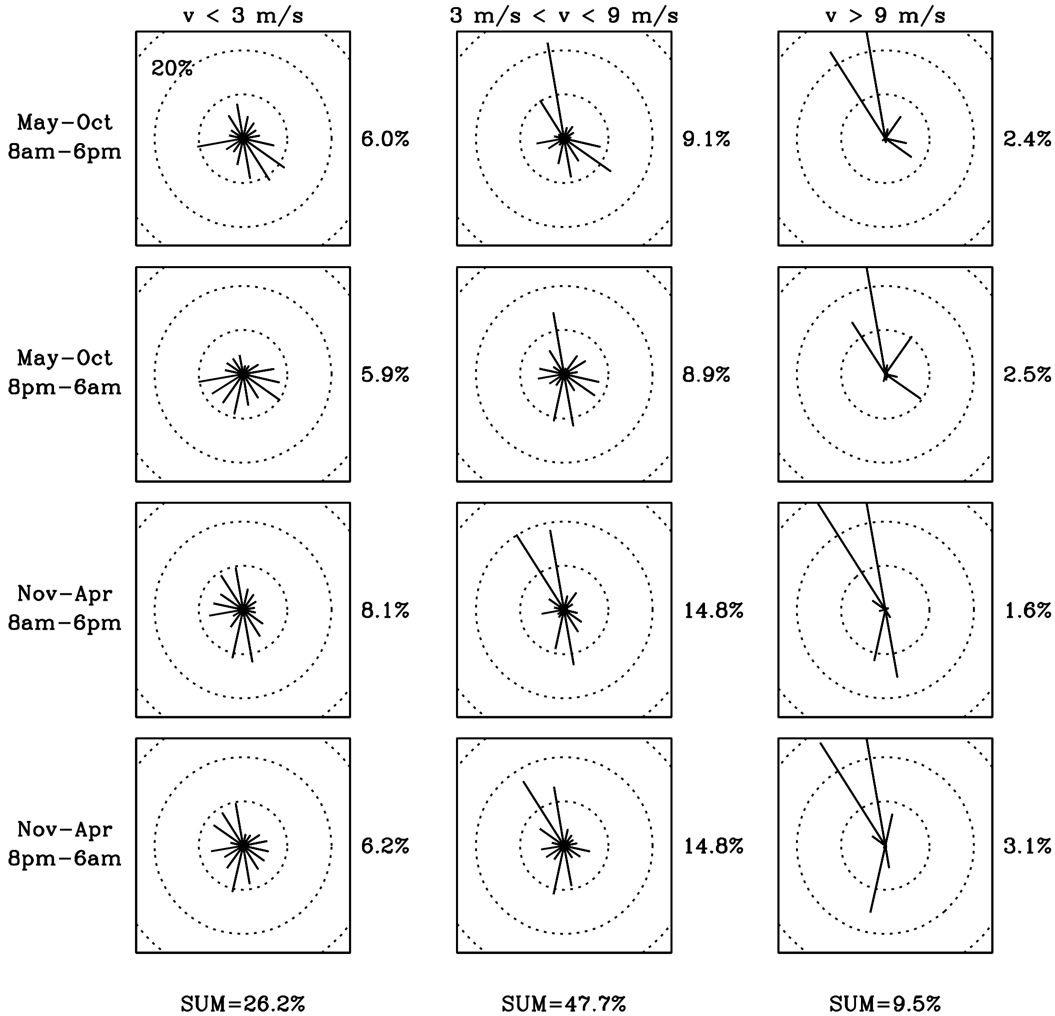

Figure 7: An amplification of the wind direction histogram for three different wind velocity intervals for the day and night time of the wet and the dry season. The length of each line represents the fraction of time. The dotted circles represent 20% of total time. The wind velocity intervals are indicated.

There is not a wind prevailing direction, for the dry or the wet season at day or night-time. This uniform pattern can be better apreciated in Figure 7 where a zoom of Figure 6 is shown. In this figure the dotted circles represent 20% of the total time. The wind velocity is less than 3m/s, 26.2% of the time. For velocities 3m/s<v<9m/s the North North-West direction starts to appear part of time during the dry season and less time during the wet season. For strong winds v>9m/s, there is a clear prevailing North North-West direction. Nevertheless it must be emphasized that the strong winds are present only about 10% of the time.

2.3 Temperature

The site statistics show very small variations in median temperature, with almost constant temperatures at night and an increase of a couple of degrees during the day, Figure 2. The median temperature is just 0.9°, with daytime and night-time medians of 2 ° and 0.3° respectively. Daily and nocturnal temperatures, shown in Figure 8, indicate very low variations, with the noon third quartile barely reaching 3.5°. The temperature stability is reflected in that in only 8 out of 419 daytime and 4 out of 429 night-time samples the standard deviation of the temperature exceeded 2.0°C. We note that the criteria chosen for daytime and night-time avoids sunrise and sunset, when time variations of temperature are bound to be the largest. Monthly statistics show also little variations, with medians ranging between -0.9°C in November 2001 and 2.2°C in October 2000. The warmest and coldest day have mean temperatures of +6.3°C and −5.2°C respectively, while the warmest and coldest nights have mean temperatures of +3.3°C and −8.4°C respectively.

Simultaneous temperature measurements were carried with another temperature sensors (Dallas Semiconductor DS1820) to check the relative calibration. Four datasets with a total coverage of 18 hours were taken on December 8 and 20, 2001, and on January 11, 2002. The longest of these datasets are shown in Figure 11. The data used the same clock but were sampled at slightly different rates. A spline was fitted to both temperature curves. The difference between these fits had an average of about 1° with a standard deviation $\sim 0.3°$, as shown in Table 3. If we assume that both sensors have the same measuring error we conclude that they have a difference in absolute calibration of about 1° and measurement errors of about 0.2°. This is within the specified 0.5° measurements uncertainty of each sensor. In fact, the temperature curves of the Davis station look smoother than those of the DS1820 sensor.

Sample	Duration (hrs)	ΔT (°C)
8-dic-01	4.0	1.02±0.19
20-dic-01	7.9	1.10±0.33
20-dic-01	3.1	0.95±0.36
11-jan-02	3.1	1.04±0.29

Table 3: Mean and standard deviation of the difference in temperatures measured by the Davis temperature sensor and the DS1820 reference sensor. The longest comparison data are shown in Figure 11.

2.4 Relative Humidity

Figure 2 shows the hourly and monthly variations in humidity, indicating drier nighttime than daytime conditions and a more noticeable contrast between winter (drier) and summer (wetter) months. The median relative humidity is 64%, the daytime median is 68% while the nightime median is 59%. The histogram and cummulative distribution can be seen in figure 10, the solid line indicates the total relative humidity, the upper dash line denotes the winter relative humidity while the lower dash line corresponds to

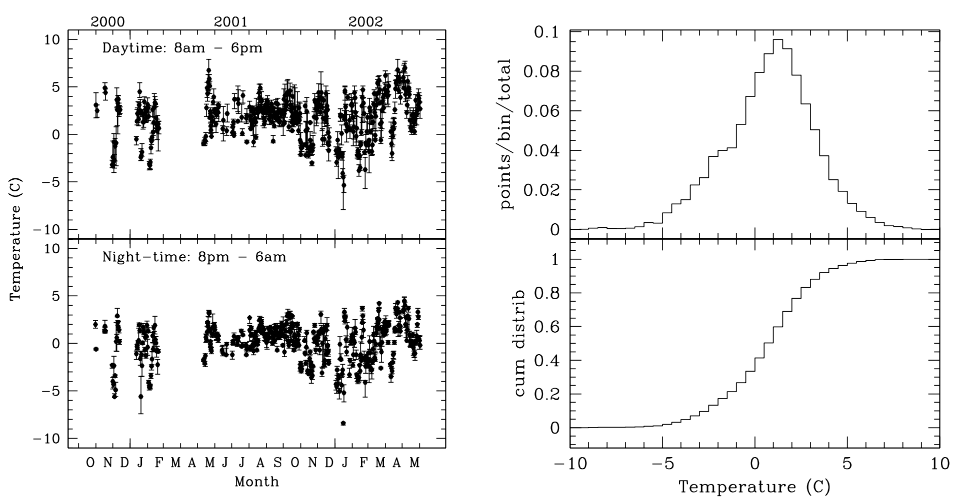

Figure 8: *Left:* Daily statistics of temperature, with daytime and night-time separated. Points indicate medians and error bars go from the 1st to the 3rd quartiles. *Right:* statistical distribution of the temperature data: 96.6% of the data points are in the interval $-5°C \leq T \leq +5°C$.

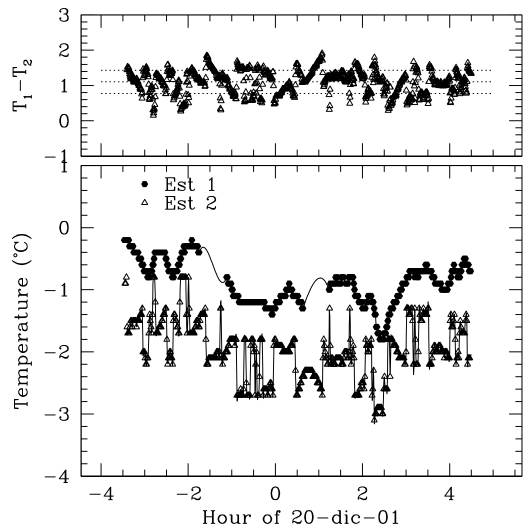

Figure 9: Comparison of temperatures measured with the Davis Weather monitor temperature sensor (labeled Est 1) and the Dallas Semiconductor DS1820 sensor (labeled Est 2). The points show the data and the continuous lines the spline fit. The upper panel shows the difference between these fits with the dotted lines indicating the mean difference (1.1°C) and the mean $\pm 1\sigma$.

the summer time. Clearly there is a seasonal trend. During the dry season 80% of the time, the relative humidity is less than 80%, meaning that the conditons are suitable for astronomical work. In contrast duriny the wet season 45% of the time the relative humidity is $<$80%.

Very large humidity variations at any particular moment of the year have been found. As an example the first twelve nights of December 2000 show variations in humidity from very dry to humid conditions, lasting a sizeable fractions of a day.

2.5 Atmospheric pressure and severe weather

Determining and measuring the atmospheric air pressure is useful for general weather diagnostics, as well as for modelling processes related to the atmosphere depth like atmospheric opacities. The statistics of monthly and 2-hour bin intervals atmospheric pressure measurements are shown in Fig. 2. The median atmospheric pressure measured at the site is 590.3 mbar compared to 582 mbar computed with an online public model at the NASA web site http://nssdc.gsfc.nasa.gov/space/model/models/msis.html
for a standard atmosphere at the geographical coordinates of the site, altitude 4560m, at noon 1^{st} January 2001.

A storm hit the site on January 13. The weather data for two weeks around that event are shown in Figure 11. The temperature was below 0°C

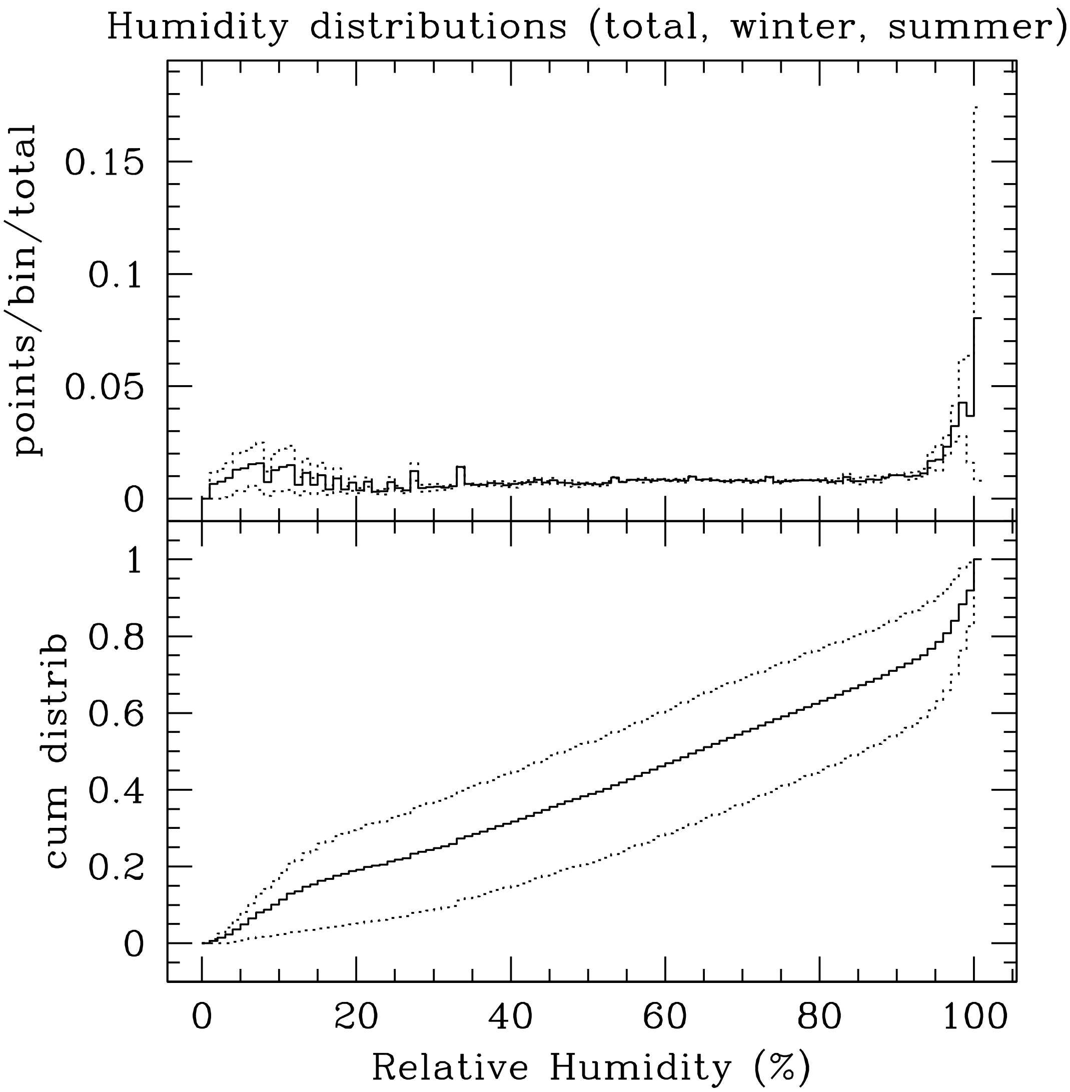

Figure 10: Cummulative distribution of relative humidity. The solid line is the total relative humidity. The upper dash line is the winter months distribution and the lower dash line is the summer distribution.

most of the time, particularly after January 11. The log records changing conditions on January 10 and windy on the 11^{th}. Snow fall began at 4am on January 12 and continued for two days, with episodes of fog and wind. We do not know exactly when was lightning present but the lightning-counter

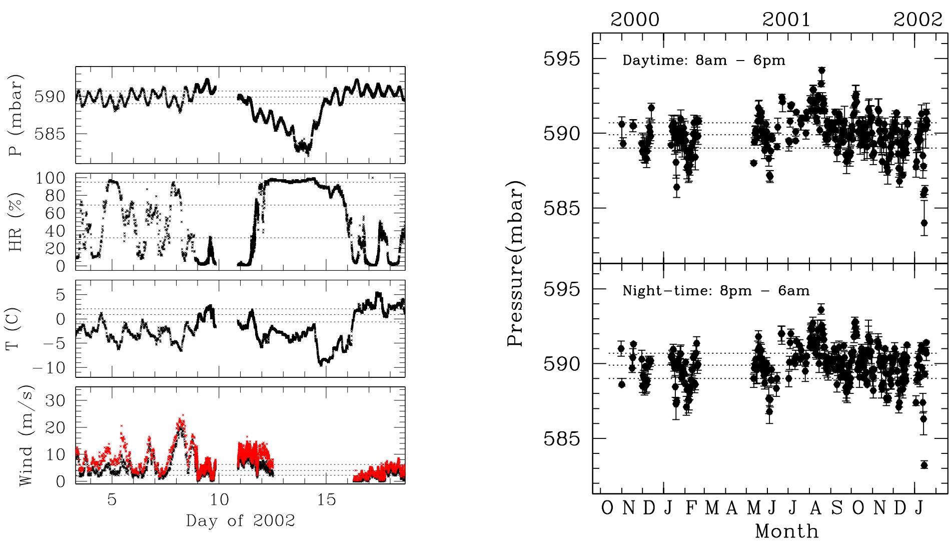

Figure 11: *Left:* Weather recording between the 4^{th} and 18^{th} of January, 2002. The storm is registered between the 12^{th} and 13^{th}, probably around the time when the wind data was lost. Note the decrease in atmospheric pressure which started one day before. The dotted lines indicate median and quartile values. *Right:* daily median values of the atmospheric pressure. The lowest point clearly identifies the January 13, 2002, storm.

registered 10 hits during the storm versus 4 in the previous three months. Electricity cables fell presumebly under the ice weight.

Figure 11 show how the atmospheric pressure went to the lowest values recorded so far. This type of storms are not very frequent (we have observed only one in over a year) but they are definitively frequent enough as to expect some of them during the lifetime of the telescope. One suggestion from the data is that a pressure below 587 mbar (or 3 mbar below the median or mean) might be a sign of warning.

2.6 Cloudiness

The cloud coverage of the sky above Sierra Negra is due to two different components: the high level clouds and the low level clouds giving mainly fog or high humidity effects. Sarazin *et al.* 1990, define a photometric night for six hours of consecutive photometric night time, where photometric time is used to describe time without any clouds in the sky. From October 2001 to April 2002 we have taken visual records of the cloud cover at the site.

In this period the percentage of photometric nights is 64% with a 74% of useful nights. The figure is similar to that obtained by Giovanelli and his team visual records (Giovanelli *et al.* 2001) at Chajnantor. He reports 80% of useful time. Undoubtly it is necessary to have a long term cloud coverage records to study the seasonal varitions. As a reference the maximum fraction of photometric nights at Mauna Kea is 67%, reported by Sarazin, M. *et al.* (2002) for a ten years period.

3 Conclusions

We have performed the first systematic study of observing and weather conditions at Sierra Negra. The meteorological data from October 2000 to May 2002 consist of 240479 data points covering 522751 time minutes, equivalent to 69% of time coverage. When the winds have been strong the wind direction and velocity have been lost therefore the wind time coverage is 64%. Conditions of the site are mostly good, mild wind speeds and temperatures, given the site altitude. The main concern is the variable humidity which might result in damping of reflective surfaces for up to 66% of the time in summer and 25% of the time in winter, depending on the temperature difference between the ambient and the surface. We have compared our results with those obtained with a more robust weather station and they are in good agreement. These results will be reported elsewhere.

We will continue with our measurements to have a longer time record. We have programmed sky brightness and extincion measurements for the winter 2002. The results obtained so far show that Sierra Negra is comparable to the best sites of the world such as Hawaii.

References

Carrasco, B.E., Carramiñana, A., Avilés, J.L & Yam, O. 2002, INAOE Technical Report **228**.

Giovanelli, R. *et al*, 2001, PASP.

Sarazin, M. *et al.* 2002, ESPAS Site Summary Series: Mauna Kea.