El Roque de Los Muchachos Site Characteristics. I. Temperature Analysis

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ABSTRACT. We present an analysis of temperature taken at two telescopes located at the Observatorio del Roque de Los Muchachos, in the Canary Islands. More than 20 years of measurements at the Carlsberg Automatic Meridian Circle (CAMC; now called the Carlsberg Meridian Telescope) are included. Analyses of data from the Telescopio Nazionale Galileo (TNG) and CAMC are compared in order to check local variations and long-term trends. Furthermore, the temperatures at different heights are correlated with the quality of astronomical seeing. We consider a correlation between the North Atlantic Oscillation (NAO) Index and annual downtime with mean annual temperatures. The final aim of this work is to better understand the influence of wide-scale parameters on local meteorological data. The analysis is performed using a statistical approach. From each long series of data, we compute the hourly averages and then the monthly averages in order to reduce the short-term fluctuations due to the day-night cycle. Particular care is taken to minimize any effect due to biases due to missing data. Finally, we compute the annual average from monthly averages. The two telescopes show similar trends. There is an increase in temperature of about 1.0°C per 10 yr from the annual means, and in addition, the annual minimums increase more rapidly than the maximums. We find that a positive NAO Index reduces the increase of temperature and accelerates the decrease. Moreover, there is no evidence that a positive NAO Index corresponds to a lower number of nonobservable nights. Finally, seeing deteriorates when the gradient of temperatures between 2 and 10 m above the ground is greater than −0.6°C.

1. INTRODUCTION

Since 1970, La Palma Island, located about 400 km off the Moroccan coast of northwest Africa, has appeared to be a favorable geophysical site from the point of view of the sky conditions, due to the proximity of the semipermanent Azores high-pressure system, and it was chosen to host Europe’s main astronomical telescopes. It is known that the very good astronomical conditions of the island are mainly due to a stable subsiding maritime air mass, which typically prompts the telescopes to be placed near the top of the mountain, well above the inversion layer occurring in the range between 800 and 1200 m (McInnes & Walker 1974). All the telescopes are located along the northern edge of the Caldera de Taburiente, at the northwest side of La Palma Island, where the irregular shapes produce a complex orography, and the crowdedness of the top, due to the presence of all the astronomical observa-

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Table 1

| Location | Latitude | Longitude | Height (m) |
|----------|----------|-----------|------------|
| TNG      | 28°45′28″3 north | 17°53′37″9 west | 2387 |
| CAMC     | 28°45′36″0 north | 17°52′57″0 west | 2326 |

Table 2

| Year  | TNG  | CAMC  | Year  | TNG  | CAMC  |
|-------|------|-------|-------|------|-------|
| 1985  | 8.8  | …     | 1996  | 8.6  | …     |
| 1986  | 8.9  | …     | 1997  | 8.9  | …     |
| 1987  | 9.1  | …     | 1998  | 10.1 | 10.0  |
| 1988  | 7.4  | …     | 1999  | 9.6  | 9.3   |
| 1989  | 5.2  | …     | 2000  | 9.9  | 9.6   |
| 1990  | 8.8  | …     | 2001  | 10.7 | 10.1  |
| 1991  | 8.7  | …     | 2002  | 9.7  | 9.6   |
| 1992  | 7.9  | …     | 2003  | 9.7  | 9.8   |
| 1993  | 7.0  | …     | 2004  | 8.9  | 9.0   |
| 1994  | 9.8  | …     | 2005  | 9.5  | …     |
| 1995  | 9.5  | …     | …     | …    | …     |

1 See http://www.ast.cam.ac.uk.
an oscillation of the values, with a period of about 3–4 yr, which seems to be slightly smoothed during the last 10 yr. Additional evidence is that in the oscillation, the points of local minimum and local maximum have different behaviors; in fact, the minimums increase more rapidly than the maximums. Further tests of our modus operandi were performed in order to check the reliability of the results. In the first test, we computed the annual averages using direct raw data (bypassing hourly and monthly averages), which gives almost identical mean values. In the second test, the annual averages were derived from daytime (10:00–16:00) and nighttime (22:00–4:00) data, following the recipe of Jabiri et al. (2000). The results are reported in Figure 2 and confirm the trend shown in Figure 1.

It is interesting to note that in Figure 2, the mean annual temperatures are closer to the nighttime temperatures than to the daytime temperatures. Using our monthly means, we have carefully investigated whether this is a result of a seasonal bias, but no evidence has been found (examples for 1991, 1992, and 1993 are reported in Fig. 3). Jabiri et al. (2000) show a very similar trend for a monthly analysis of temperatures at CAMC in the period 1990–1993.

3. DAYTIME AND NIGHTTIME VARIATION

The annual averages of the differences between daytime and nighttime temperatures ($\Delta T$) have been computed, and the results are reported in Figure 4 (top). In this plot, the oscillations of $\Delta T$ also seem to reduce the amplitude over the years. Comparing the trends of annual temperatures of CAMC (Fig. 1) and the corresponding $\Delta T$ (Fig. 4, top), we note some correlation between the two trends, because coolest years present a small difference in temperature from day to night, and vice versa. A Spearman correlation test between the two data series gives a significance of 50%, very far from what we expected.
It is known that a decreasing diurnal temperature range is linked to an increase in cloud coverage, generating a faster rate of increase in the daily minimums than in the maximums. We conclude that the effect can be explained as the direct influence of the number of cloudy days during the year in which the Sun is prevented from warming the atmosphere. This explains the correlation between the lost nights at CAMC due only to weather conditions (downtime), and \( \Delta T \). As shown in Figure 4 (bottom), high values of \( \Delta T \) correspond to lower downtime. The Spearman correlation test in this case gives a significance of 97%. To better see this difference, we investigate two particular years: 1989 (the coolest one) and 2001 (the warmest). In Figures 5 and 6 the behavior is confirmed, with the exception of some peculiar months (in particular, in the summertime), which will be investigated by taking into account other parameters, such as pressure, wind direction, and Saharan dusts (G. Lombardi et al. 2006, in preparation).

4. NORTH ATLANTIC OSCILLATION ANALYSIS

The North Atlantic Oscillation (NAO) is the dominant mode of atmospheric circulation in the North Atlantic region (Wanner et al. 2001). It consists of a north-south dipole of pressure anomalies, with one center located over Greenland and the other center of opposite sign spanning the central latitudes of the North Atlantic between 35\(^\circ\) and 40\(^\circ\) north. The NAO Index is generally defined as the difference in pressure between the Azores high pressure and the Icelandic low pressure. The positive phase of the NAO reflects below-normal pressure heights.
Fig. 7.—NAO Index (middle) vs. CAMC downtime due to local weather conditions (top) and annual temperatures (bottom).

across the high latitudes of the North Atlantic and above-normal pressure heights over the central North Atlantic, the eastern United States, and western Europe. The negative phase reflects an opposite pattern of pressure anomalies over these regions. The NAO exhibits considerable interseasonal and interannual variability, and prolonged periods (several months) of both positive and negative phases of the pattern are common. Because of the great influence of the NAO on the meteorological conditions in the Northern Hemisphere, it is important to investigate a possible correlation between NAO and other key parameters determining good or bad astronomical observing conditions. For these reasons, we calculated the annual averages for NAO from the monthly averages retrieved from the National Weather Service Web site.

Figure 7 compares the NAO Index (middle) from 1985 to 2004 and the respective downtime at CAMC (top) due to weather conditions. No correlation is found between the NAO Index and the number of nonobserving nights (the significance in this case is about 25%). A careful inspection shows some particular effects of delay or different correlations (i.e., years 1989 and 1998) that are probably caused by peculiar events and should be investigated in other studies. Figure 7 also shows a comparison between the NAO Index (middle) and temperatures (bottom) computed from CAMC data archive. In this case, the correlation between the amount of variability of the temperatures from year to year and the trend in the respective NAO Index has a significance of 86%. The effect of a positive NAO Index is as a brake for the increase in temperatures, and an accelerator for the decrease. Conversely, a negative NAO Index acts in the opposite way. An interesting point is the assumption by E. Graham (2005, unpublished) that there is a poor correlation on annual basis between NAO and air temperature at the Mazo Airport in La Palma. This seems to indicate that the influence of the NAO above or below the inversion layer is different.

Fig. 8.—Seeing in \( V \) band vs. \( \Delta T_{2}^{10} \) at TNG.

5. SEEING AND TEMPERATURES

We also investigated the influence of temperature on astronomical seeing. Making use of 118 images obtained at TNG, pointed at zenith, from 2000 January 31 to February 4 with the OIG (Optical Imager of Galileo) camera, we computed the FWHM of several stellar images in the \( V \)-band frames. The images were processed following the standard procedures (bias subtraction and flat-fielding) using IRAF packages. Following Racine et al. (1991), we checked to see if any correlation exists between the temperature \( T_{\text{mir}} \) of the TNG primary mirror (M1) and \( T_{10} \). The comparison between the monthly averages shows no appreciable difference, so we can consider \( T_{10} \) to be the temperature of M1. We compute the temperature gradients as \( \Delta T_{2}^{10} = T_{2} - T_{10} \) (where \( T_{2} \) is the temperature measured by the sensor at 2 m) at the same UTs of the 118 images for which we computed the FWHM. Figure 8 shows the comparison between \( \Delta T_{2}^{10} \) and the FWHM. In the plot, the seeing deteriorates when \( \Delta T_{2}^{10} > -0.6^\circ \text{C} \). This can be explained as a consequence of the lower temperature at 2 m, because the higher temperature

\(^2\) See http://www.cpc.ncep.noaa.gov.
Table 3: TNG and CAMC Percentages of Annual Downtime Due to Weather

| Year | TNG  | CAMC |
|------|------|------|
| 2000 | 27.4 | 16.5 |
| 2001 | 27.6 | 19.9 |
| 2002 | 26.1 | 30.2 |
| 2003 | 28.2 | 23.2 |
| 2004 | 37.3 | 35.5 |

at 10 m inhibits thermal convection below the height of the primary mirror.

6. CLOUDINESS AND SITE COMPARISON

The fraction of available telescope time is one of the most important requirements for selecting astronomical sites. In particular, nighttime cloudiness is strongly correlated with the closing of the dome.

There are now long-term records from many telescopes, listing the number of available nights; in particular, the CAMC records, starting in 1984, are the longest available at La Palma, covering a baseline of 22 yr. Records from the TNG report data starting in the year 2000 up to the present. All these data are in excellent agreement. In particular, a comparison between weather conditions at TNG and CAMC from 2000 to 2004 shows no evidence of a systematic trend of observing time lost from bad weather conditions, although a seasonal periodic oscillation does appear. Table 3 reports the yearly mean values of the downtime due to weather, while Figure 9 plots the monthly averages. The first detailed reports on nighttime cloudiness at La Palma were given by Murdin (1985), who reported 78% of the nights in La Palma as usable during the period of 1975 February–September (see Table 2 in Murdin 1985). Restricting our data set to the same range in Murdin (February–September) we found new percentages of downtime, as reported in Table 4.

In spite of their distance of about 1000 m apart and difference in height of about 60 m (see Table 1), the two telescopes seem to have a marginally different amount of downtime. There is evidence that in the last few years, the fraction of observing time lost at CAMC and TNG is increasing. On average, the annual values reported in Table 3 are considerably higher than the 22% estimated by Murdin (1985). Instead, the restricted data show a lower number of lost nights. This may reflect the fact that we are in the presence of a strong seasonal effect. To fully understand this point, it would be worthwhile to investigate the homogeneity of the downtime databases and to check the downtimes of the other telescopes at ORM, and also to study the local weather conditions. This is a key point for the study of the site of future large telescopes.

Table 4: TNG and CAMC Percentages of Downtime Due to Weather (February–September)

| Year | TNG  | CAMC |
|------|------|------|
| 2000 | 12.7 | 7.0  |
| 2001 | 10.5 | 7.0  |
| 2002 | 15.3 | 17.9 |
| 2003 | 13.2 | 11.6 |
| 2004 | 19.9 | 21.1 |

7. CONCLUSIONS

We have presented for the first time an analysis of long-term temperature data directly obtained from local meteorological towers at TNG and CAMC, at a height of about 2300 m above sea level, far from urban concentrations and well above the inversion layer. Annual mean values show a similar trend between TNG and CAMC. The linear fit to the 20 yr long baseline of CAMC data gives an increase in annual mean temperatures of about 1.0°C per 10 yr. It is interesting to note an oscillation of the values, with a period of about 3–4 yr, which seems to be slightly smoothed during the last 10 yr. Additional evidence is the different behavior of local minimums and local maximums; in fact, the minimums increase more rapidly than the maximums.

A comparison between the NAO Index and the annual mean temperatures shows a correlation with a significance of 86%. In fact, the action of a positive NAO Index is as a brake for the increase in temperatures, and an accelerator for the decrease.

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3 See http://www.tng.iac.es.
Conversely, a negative NAO Index acts in the opposite manner. Moreover, no correlation is found between the NAO Index and the number of nonobserving nights. We also investigated the influence of temperature on astronomical seeing, and we found that the seeing deteriorates when the temperature gradient measured at 2 and 10 m above the ground is greater than $-0.6^\circ C$. This can be explained as consequence of the lower temperature at 2 m because the higher temperature at 10 m inhibits thermal convection below the height of the primary mirror.

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