Foldable dome climate measurements and thermal properties

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ABSTRACT

As part of a larger project for measuring various aspects of foldable domes in the context of EST and with support of the Dutch Technology Foundation STW, we have collected over a year of continuous temperature and humidity measurements, both inside and outside the domes of the Dutch Open Telescope (DOT) on La Palma[5] and the GREGOR telescope on Tenerife.[6] In addition, we have measured the wind field around each dome.

Although the structure of both domes is similar, the DOT dome has a single layer of cloth, and is situated on top of an open tower. In contrast, the GREGOR dome has a double layer of cloth, and is situated on top of a tower-shaped building. These differences result in large differences in temperature and humidity insulation when the dome is closed. We will present the changes in temperature and humidity one can expect for each dome within one day, and the statistics for the variations throughout a year.

In addition, we will show that the main advantage of a foldable dome is the near instantaneous equilibration of the air inside the volume originally enclosed by the dome and that of the environment outside the dome. This property allows one to operate a telescope without needing expensive air conditioning and dome skin temperature control in order to limit dome and shell seeing effects.

The measurements give also information about the weather fluctuations at the sites of the domes. It was observed that on small time scales the temperature fluctuations are significantly greater during the day than during the night.

Keywords: Foldable tent domes, dome climate, thermal properties, weather fluctuations

1. INTRODUCTION

The Dutch Open Telescope on La Palma and the GREGOR telescope on Tenerife, both solar telescopes, have similar, completely foldable domes.[1,2] There are several differences between the two domes: the DOT dome is 7 m in diameter,

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Figure 1. The GREGOR telescope on Tenerife (left) and the Dutch Open Telescope on La Palma (right), both with opened domes.

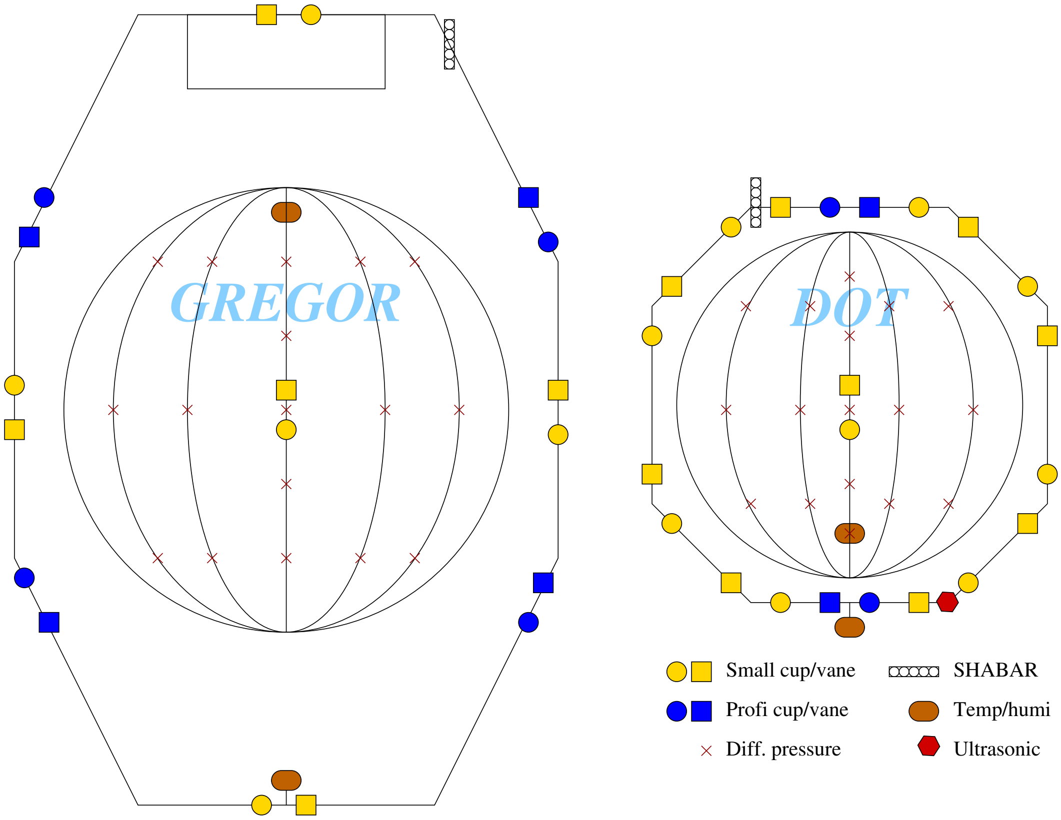

Figure 2. Schematic view of the various sensors installed inside, outside and on the domes of the DOT and GREGOR telescopes in spring 2010. On the DOT, 10 cup and vane pairs are placed around the dome, on the GREGOR 8. On both domes, there is also a cup and vane pair on top. At both sites, two combined temperature and humidity sensors are placed, one inside the dome and one outside. There are also 17 differential pressure sensors mounted on the GREGOR and DOT domes. At the DOT, a short-baseline SHABAR is mounted on the north side of the dome. Later in 2010, a SHABAR will also be placed at the GREGOR on the north side.

while the GREGOR is 9 m in diameter. The DOT is standing on an open tower, and the platform on top of the tower has many small holes, while the GREGOR on the other hand has a solid concrete floor, and a building beneath it (see figure 1). Finally, the DOT dome consists of only one layer of cloth, whereas the GREGOR dome has two layers.

As part of an STW project to study these completely foldable domes, several different sensors have been placed inside, outside and on the domes, see figure 2. Sensors include wind sensors (both cup and vane sensors and one 3D ultrasonic anemometer), pressure sensors, temperature and humidity sensors and shadow band rangers (SHABARs). In this paper, we focus on the data from the temperature and humidity sensors.

Sensor data is being captured 24 hours a day since August 2008. Unless stated otherwise, we have used a dataset that includes a virtually continous recording of temperature and humidity data from both the DOT and GREGOR from August, 2008 through July, 2009, to investigate the climate at both sites and the effects of the different domes on the internal climate. The sensors are sampled at 1 kHz, but only the average of 64 samples are stored. This reduces the readout noise to levels below the resolution of the temperature sensors (0.065 °C) and humidity sensors (0.028 %). Although we store approximately 15 samples per second for each sensor, we have further reduced this to a managable 1 sample per 2 minutes by simple averaging before calculating the statistics presented in this paper. We have also created daily statistics for each sensor, including minimum, maximum and average values, which are used in some of the plots.

2. CLOSED DOME CLIMATE

The characteristics of the closed telescope domes are evaluated by comparing the humidity and temperature inside the dome to those values outside the dome. Before we compare the two domes to each other, we first compare the climate

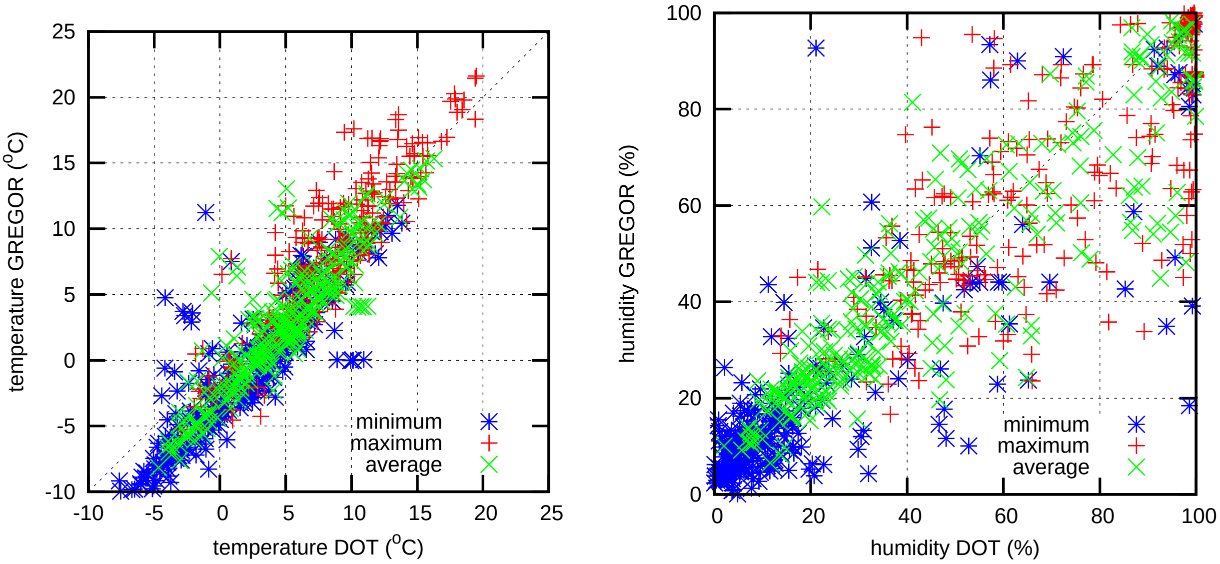

Figure 3. Comparison of daily temperature and humidity statistics between the DOT and the GREGOR sites outside the domes. Each point represents a minimum, maximum or average of a single day of the year. La Palma and Tenerife have similar weather each day, although the GREGOR experiences slightly larger temperature variations that the DOT.

outside the domes at the two sites to each other.

Figure 3 shows the minimum, maximum and average temperatures and humidities of all days the dome was closed, of the site of the GREGOR telescope versus the DOT. Since the two telescopes are relatively close to each other geographically, they experience roughly the same weather on the same day. However, temperatures vary more from season to season at the GREGOR than at the DOT; in the winter on average 2.3 °C colder than the DOT, in the summer on average 1.7 °C warmer. The DOT experiences slightly more days of high humidity than the GREGOR. At the DOT site, 11.5% of the days have an average humidity of 90% or higher, whereas at the GREGOR site it is only 8.1% of the days. The differences in weather between the two sites are small enough that we assume that there is no bias introduced by this in the comparison of the climate inside the domes.

Figure 4 shows the average temperatures and humidities of all days the dome was closed, of the climate inside the dome versus the climate outside. The temperature inside the DOT dome is on average 1 °C warmer than outside, except when the temperature drops below 3 °C and the heaters turn on because of high humidity. There are two electric radiator heaters of 1.5 kW each on the DOT platform, which are automatically switched on when the humidity is higher than 60 %. However, the open nature of the DOT platform allows cold air to enter the dome, and the temperature can drop below zero if the humidity is low and the heaters will stay switched off. The inside of the GREGOR dome is on average 5 °C warmer than outside, and when the temperature drops below 5 °C, the heat coming up from the lower floors of the building through the telescope platform will keep the inside air from dropping below zero, even when outside temperatures reach -10 °C.

Both domes insulate enough to prevent condensation inside; the humidity inside the DOT rarely reaches over 95%, while the humidity inside the GREGOR dome stays under 80%. The open platform of the DOT keeps the humidity inside the dome close to the humidity outside, however the humidity in the GREGOR is trapped, resulting in much more constant levels, around 35% on average and almost never below 20%.

3. OPEN DOME EQUILIBRATION

A primary advantage of a completely open-foldable dome over traditional domes is that, when the dome is opened, air can flow freely through the telescope, thereby minimising temperature differences with the surrounding air. This effect is indeed clearly visible from the sensor data. In figure 5, the temperature inside and outside the DOT of a day the dome was opened has been plotted with a higher time resolution (0.1 Hz). The dome takes five and a half minutes to open, but the temperature inside the dome drops to the outside temperature in only six minutes. When the dome is closed later around

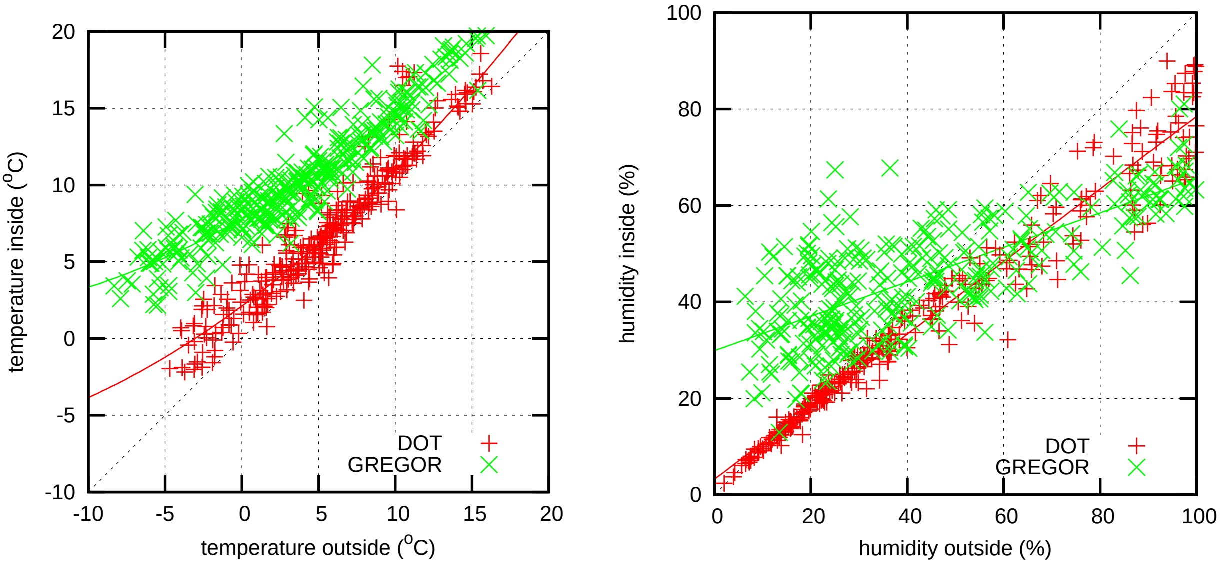

Figure 4. Comparison of temperature and humidity insulation between the DOT and GREGOR. Each point represents an average of the inside versus the outside temperature or humidity of a single day of the year. It is clear that the GREGOR is much better insulated than the DOT.

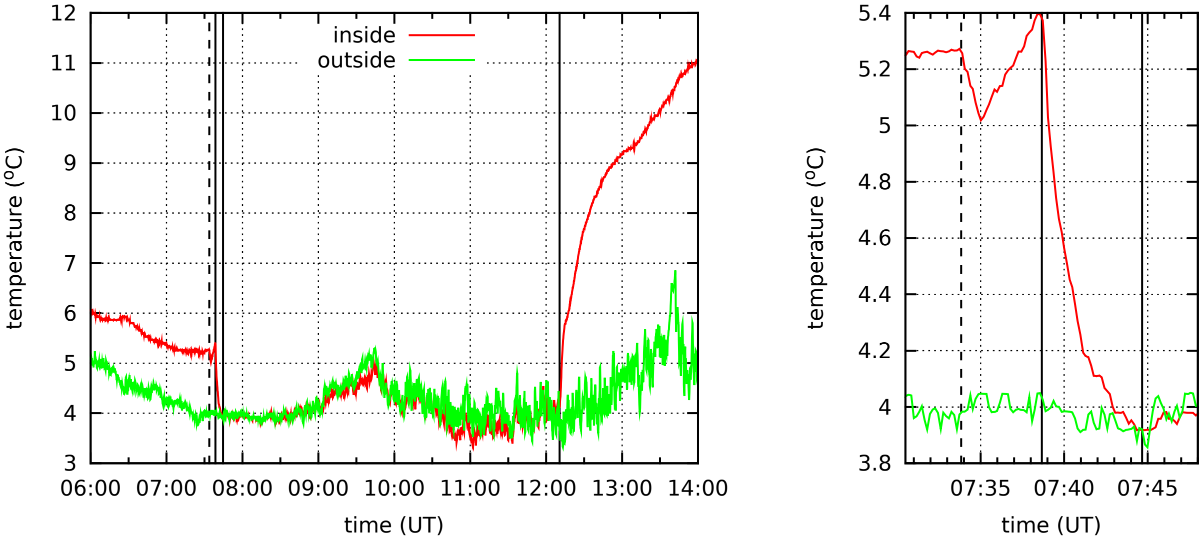

Figure 5. Temperature variations during an observation day at the DOT, May 2nd, 2009. The hatch of the DOT is opened at 7:34 UT (dotted vertical line), resulting in brief temperature variations. The dome starts to open around 7:39 UT (first solid vertical line), which will take five and a half minutes. The temperature inside the dome has become in equilibrium with the outside around 7:45 UT (second solid vertical line). At 12:10 UT the dome is closed due to rising clouds.

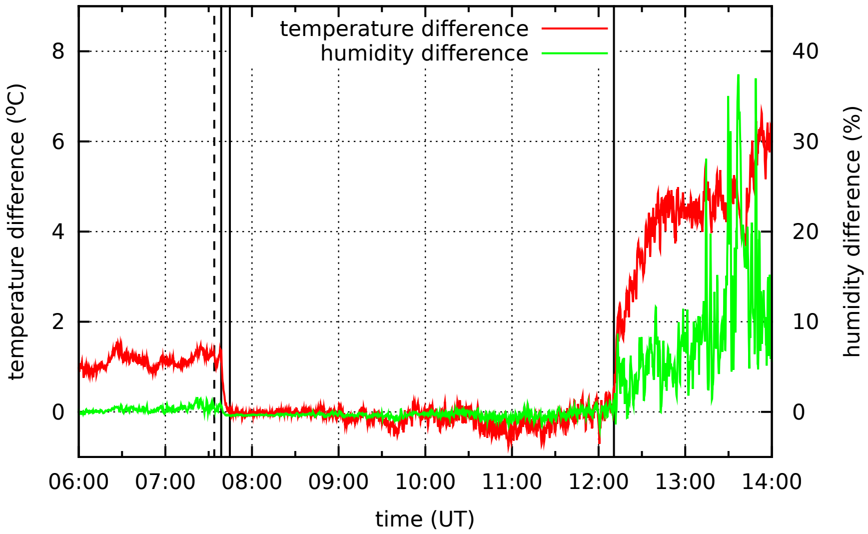

Figure 6. Temperature and humidity at the DOT during May 2nd, 2009. This plot shows the difference in inside versus outside temperature and humidity. At 12:10 UT the dome is closed because of rising clouds, which result in increasing fluctuations of temperature and humidity outside the dome.

noon, the temperature inside the dome is decoupled from the temperature outside, and quickly rises due to solar irradiation of the dome.

Figure 6 shows the difference in temperature and humidity inside and outside the dome. While the dome is open, temperature inside differs less than 1 °C from the outside, the RMS difference is 0.4 °C. The humdity inside stays within 1 % of the outside.

Both the equilibration time and the small difference between inside and outside areas are virtually the same every time the dome is opened, for both the DOT and GREGOR telescopes.

4. TEMPERATURE AND HUMIDITY FLUCTUATIONS THROUGHOUT THE DAY

It is clear from figure 5 that temperature and humidity fluctions increase in amplitude during the day. This is caused by solar irradiation heating the ground, resulting in an increase in temperature variations and turbulence in the air. During the night, there is no irradiation, and consequently variations are much smaller in amplitude. The temperature variations during the day can be quite strong, even when there are observations. This can be seen clearly in figure 7, where a drop of 3 °C in only 15 minutes is observed. If a closed dome with a slit was used for a solar telescope, and the air inside had to be actively cooled to keep it in equilibrium with the outside air, then we can use the following formula to determine the power required just to cool the volume of air inside the dome:

$$P = 1297 \cdot p \cdot \frac{2}{3}\pi r^3 \cdot \frac{\mathrm{d}T}{\mathrm{d}t} \tag{1}$$

Where P is the required power in watt, 1297 is the volumetric heat capacity of dry air at sea level in $\mathrm{J}/(\mathrm{m}^3 \cdot \mathrm{K})$, p the pressure in bar, r the radius of the dome, and $\mathrm{d}T/\mathrm{d}t$ the rate of change in temperature. For the DOT, with $r = 7$ m and $p = 0.75$ bar, this results in a power requirement of $P = 2.3$ kW. However, for a larger dome, such as the proposed 28 m dome[3] for the European Solar Telescope (EST), the power requirement would be almost 150 kW.

To show the statistics of temperature variations throughout the day, we have plotted a histogram of the absolute value of the derivate of temperature versus time, for both telescopes, both inside and outside the domes, in figure 8. We have used the complete dataset as mentioned in section 1. It is clear that from 20:00 UT in the evening to 8:00 UT in the morning, the rate of change of temperature outside the domes is small and constant, only 0.04 °C/min. However, from 8:00 UT to 20:00 UT, the rate of change varies considerably, up to 0.09 °C/min at the DOT and 0.12 °C/min at the GREGOR. The values

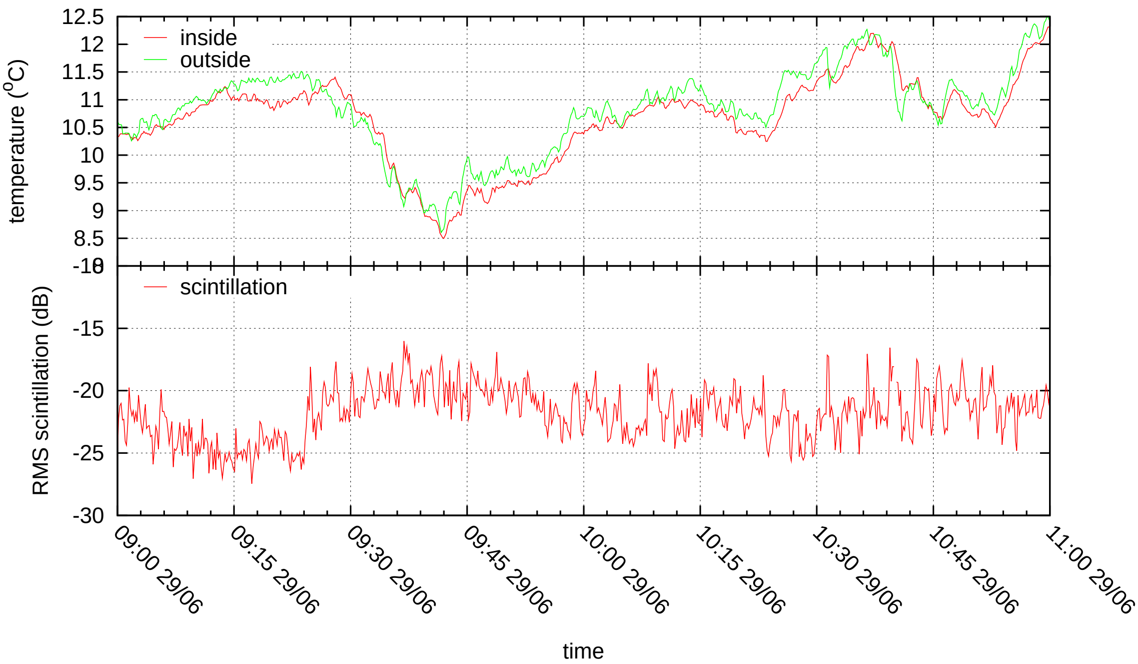

Figure 7. The temperature and scintillation at the DOT during June 29th, 2009 when the dome was opened for observations. This plot shows a period of two hours. We see the variations in temperature during daytime. A steep drop of 3 °C in 15 minutes was observed between 9:30 UT and 9:45 UT. The scintillation signal of a single photocell was recorded at the same time, and is plotted in a logarithmic scale in the lower part of the graph. The scintillation is mainly sensitive to fluctuations of the index of refraction of the lower atmosphere, the first 100m above the ground, because the Sun is an extended source and the contribution of the higher atmosphere is averaged. Depending on the higher seeing and the changeability of the seeing, a value of -20 dB can be sufficient good to use the recorded images for speckle reconstruction, which provides images with diffraction limited spatial resolution (0.2 arcsec for the 45 cm DOT mirror and the 400 nm wavelength region. A value of -25 dB can be qualified as very good seeing. The completely open-foldable dome avoids problems with the dome seeing, which would develop due to fluctuations of the outside temperature near the light-entrance opening of a closed dome.

plotted are only averages, we have recorded changes of up to 0.5 °C/min around 14:00 UT, although this is very rare. The temperature variations inside the closed domes are much smaller of course, the double layer of cloth of the GREGOR dome having the most insulating effect. In figure 9 the same has been plotted for humidity. The difference in insulation between the DOT and GREGOR dome is even more pronounced here.

Figures 8 and 9 used a dataset with one sample every 2 minutes, and the fluctuations in those figures are therefore only valid within 2 minute intervals. If we go to larger time intervals, we will see see smaller rates of temperature change within those intervals on average, since temperature will go both up and down within that interval, and fluctuations cancel each other out. However, the absolute change over the whole interval will be larger. This has been illustrated in 10. For the DOT site, temperature will change, on average, almost 0.2 °C every 2 minutes around 14:00 UT, but in 20 minutes it will change, on average, only 0.5 °C.

5. CONCLUSIONS

Although there are more differences between the DOT and GREGOR telescopes than the number of cloth layers, we can conclude that the double layer and closed floor of the GREGOR result in a much better insulation of the dome. Once a dome is opened, the climate inside reaches equilibrium with the outside in only 5 minutes, which is excellent for solar telescopes that are built to operate in the open air. The temperature and humidity fluctuations are much higher during the day than during the night, which means that solar telescopes need to have better thermal control, but with a completely open dome they do not need to control the temperature of the dome skin and the air inside the dome. The heat flux due to solar irradiation around a telescope has to be removed anyhow. In the case of a closed dome with only an opening for the

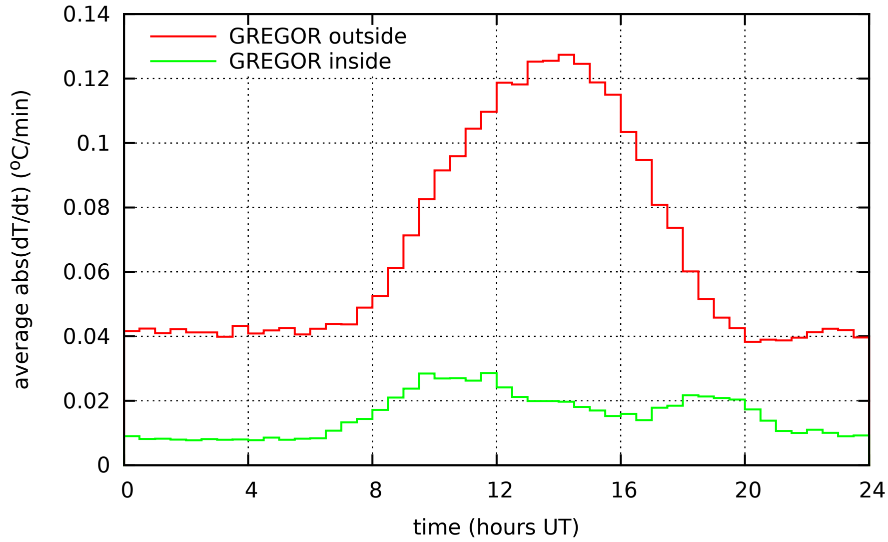

Figure 8. The average absolute derivative of temperature versus the time of the day for the inside and outside of the GREGOR dome. The temperature fluctuations outside during the day are up to three times as large as during the night. The GREGOR dome, with its two layers of cloth, reduces temperature fluctuations effectively when closed.

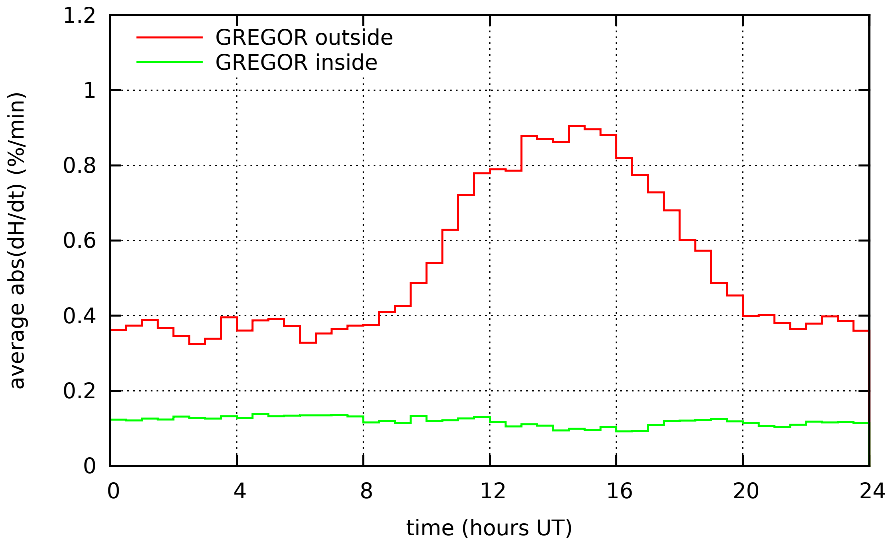

Figure 9. The average absolute derivative of humidity versus the time of the day for the inside and outside of the GREGOR dome. The humidity fluctuations outside during the day are up to two and a half times as large as during the night. The GREGOR dome removes the humidity fluctuations very effectively when closed.

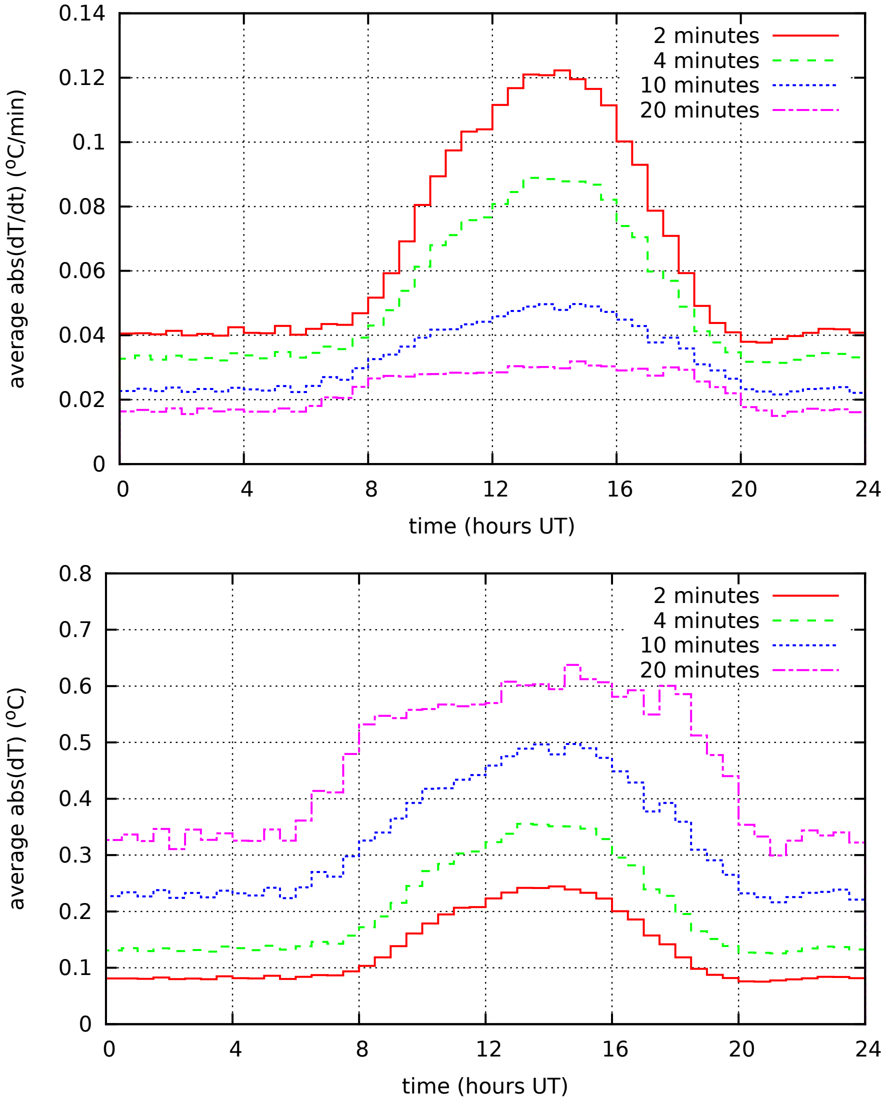

Figure 10. The temperature fluctuations at the GREGOR site for various time intervals. The graph at the top shows that rates of change decrease for larger time intervals due to an averaging effect, however the graph at the bottom shows that the absolute change itself increases with larger intervals. Note that this graph shows the average over a whole year, individual absolute changes, even over short time periods, are much higher.

incoming optical beam, the heat is accumulated in the outer surface of the dome. In the case of a completely open foldable dome, the heat is accumulated in the floor. Since the skin of a closed dome is near the incoming optical beam, small temperature variations of the skin with respect to the surrounding air will already affect the incoming beam. The floor of an open dome is farther from and beneath the incoming beam, which allows larger temperature variations, especially cooler with respect to the surrounding air, before the incoming beam is equally affected. Consequently, removal of the solar heat without disturbing the incoming beam is easier with the completely open foldable dome.[4]

6. ACKNOWLEDGEMENTS

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REFERENCES

[1] F.C.M. Bettonvil, R.H. Hammerschlag, A.P.L. Jägers and G. Sliepen, ”Large fully retractable telescope enclosures still closable in strong wind”, Astronomical Instrumentation, Proc. SPIE **7018-60**, 2008.

[2] A.P.L. Jägers, G. Sliepen, F.C.M. Bettonvil and R.H. Hammerschlag, ”Fast foldable tent domes”, Astronomical Instrumentation, Proc. SPIE **7018-64**, 2008.

[3] J.N.M. Kommers, R.H. Hammerschlag, S.J. van Leverink, F.C.M. Bettonvil, S. Visser, A.P.L. Jägers and G. Sliepen, ”Mechanical design of a completely open-foldable dome for EST in the range of 20 to 30m diameter with optional an effective semi transparent windscreen for telescope protection”, Astronomical Instrumentation, Proc. SPIE **7733-15**, 2010.

[4] F.C.M. Bettonvil, R. Codina, R.H. Hammerschlag, A.P.L. Jägers, H. Kommers, S.J. Leverink, G. Sliepen and S. Visser, ”The enclosure for the European Solar Telescope (EST)”, Astronomical Instrumentation, Proc. SPIE **7733-109**, 2010.

[5] Dutch Open Telescope, `http://dot.astro.uu.nl/`.

[6] GREGOR telescope, `http://gregor.kis.uni-freiburg.de/`.