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ABSTRACT

Between February and April 2009 a number of ultrasonic anemometers, temperature probes and dust sensors were operated inside the CTIO Blanco telescope dome. These sensors were distributed in a way that temperature and three dimensional wind speeds were monitored along the line of sight of the telescope. During telescope operations, occasional seeing measurements were obtained using the Mosaic CCD imager and the CTIO site monitoring MASS-DIMM system. In addition, a Lunar Scintillometer (LuSci) was also operated over the course of a few nights inside the dome. We describe the instrumental setup and first preliminary results on the linkage of the atmospheric conditions inside the dome to the overall image quality.

Keywords: Atmospheric turbulence, image quality, telescope dome

1. INTRODUCTION

The 4 m Blanco telescope at the Cerro Tololo Inter-American Observatory (CTIO) will receive a major instrument upgrade. The Dark Energy Camera (DECAM[1]) is going to become the new main observing tool for this telescope. Such an instrument will need excellent image quality and observing conditions, both outside and inside the telescope enclosure. The atmospheric conditions, in particular seeing, optical turbulence and general meteorological parameters, have been monitored for several years on Cerro Tololo and the CTIO site monitoring system has received a major upgrade in 2009.[2] Of similar importance as the atmospheric conditions on Cerro Tololo are the conditions inside the telescope shelter: the dome. The impact of these conditions is obvious; wind speeds and temperatures will affect the hardware. For example, strong temperature changes could result in expansion and contraction of parts, or excessive wind load might cause image jitter to occur. But most importantly wind speed and temperature gradients along the line of sight will increase the seeing. In numerous studies it was found that in particular the temperature gradients inside and in the vicinity of the dome affect the seeing[3,4,5]. It is therefore commonly intended to prevent strong temperature gradients from occuring and have the air inside a telescope dome well mixed and keep the air inside the dome at the same level, or slightly cooler, than the outside (ambient) temperature. Measures to achieve this consist of vents and active ventilators which provide a constant airflow throughout the interior of the dome.

As the new instrument for the 4 m Blanco telescope is still a couple of years away, it is now the time to understand better the observing conditions imposed by the telescope dome of the 4 m telescope. It was a lucky coincidence that the site testing for the Thirty Meter Telescope (TMT)[6] came to a close in 2009 and that the instrumentation of one of the TMT site testing stations was in storage at CTIO. This instrumentation includes ultrasonic anemometers, thermometers and particle counters. The TMT project agreed to provide these instruments to conduct a study of the dome of the Blanco telescope.

This paper describes the experimental setup and initial results of a campaign using these instruments to monitor the conditions *inside* the 4 m Blanco telescope enclosure.

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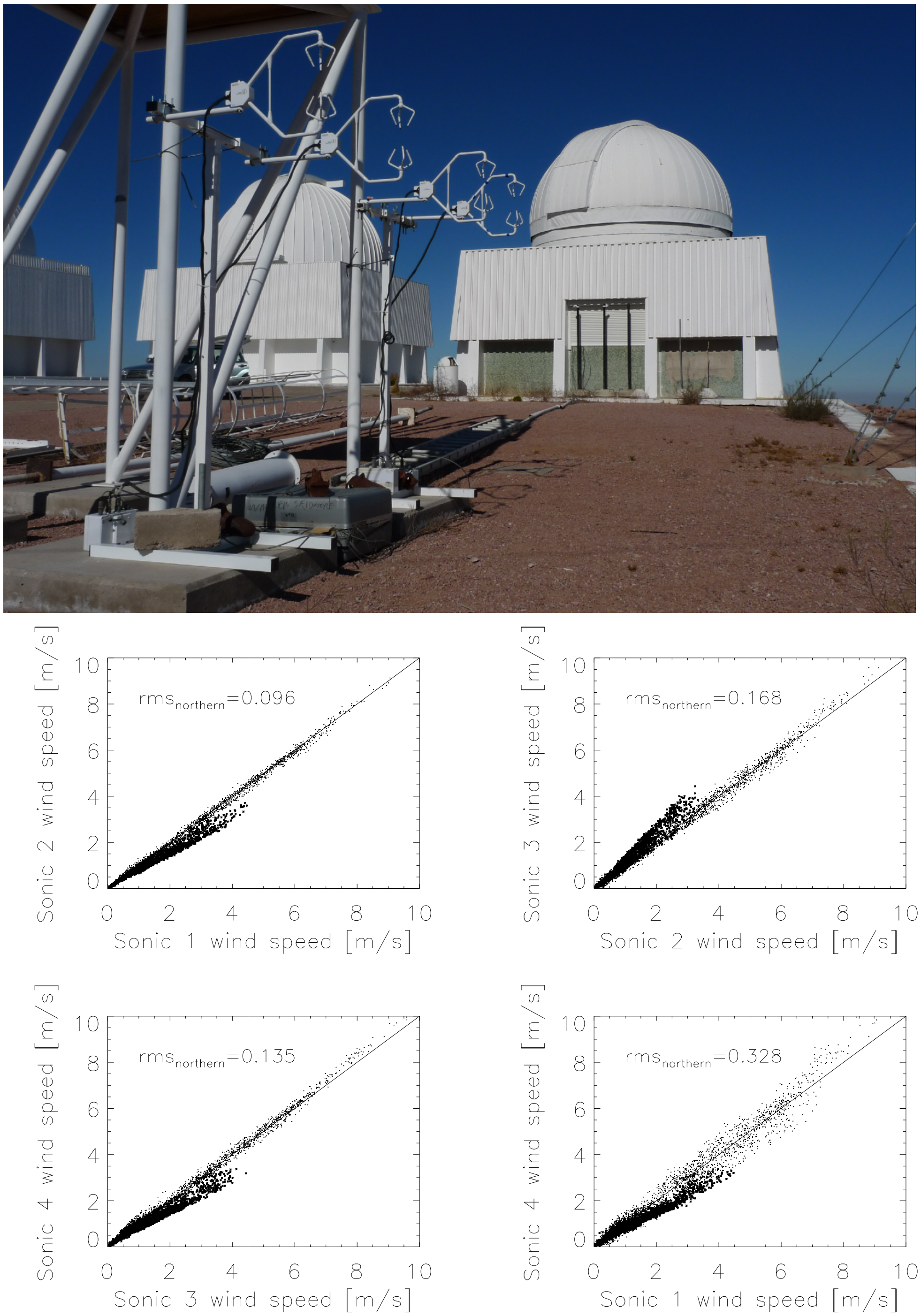

Figure 1. (color online) *Top panel:* Image of the test setup at the northern edge of Cerro Tololo. The sonic anemometers are mounted to a tower structure and the sensor heads (the white braces) point North. The sensors are numbered 1 to 4 from the back to the front of the image. The thermometers were placed in the gray box on the ground. *Lower panel:* Comparison of the sonic anemometer wind speed measurements. Measurements taken during northern winds are indicated as thin black crosses, southern winds – passing through the support structure – are indicated as larger asterisks. A larger scatter and systematic difference is apparent during southern winds. It can also be seen that the scatter increases with increasing separation of the sensors. From these figures we infer a precision of the 1 min average wind speed measurements of better than 9 cm/s *rms*.

2. INSTRUMENTS, CALIBRATION AND EXPERIMENTAL SETUP

In January 2009 it was decided to install a set of instruments within the dome of the 4 m Blanco telescope. The TMT site testing had dismantled its station on Cerro Tolonchar[6] (also referred to as T3) by the end of 2008. While the site testing telescope belongs to NOAO and is now permanently installed on Cerro Tololo,[2] the meteorological sensors of the 'T3' instrument suite were lent by TMT in order to conduct the described study. The set of sensors consisted of four ultrasonic anemometers (type CSAT-3 by Campbell Sci.), four temperature probes (by MeteoSensors Inc.) and two dust sensors (by Met One Instruments). The instrumentation and the initial calibration is described in detail in various TMT site selection reports*. The data of the CSAT-3 ultrasonic anemometers were collected at 60 Hz but in this paper we will only make use of one minute averages of these data. The thermometers were read once every second, providing instantaneous measurements. The dust sensors sample every minute two different particle sizes. While one channel measures always the 0.3 μm particle concentration, the second channel records one of five possible particle sizes (0.3, 0.5, 1, 2 and 5 μm). Therefore, it takes minutes to complete a cycle through all channels.

In order to check for the comparability of the data, the thermometers and ultrasonic anemometers were installed side by side on the summit platform of Cerro Tololo between January 27 and February 12, 2009; the setup is shown in Fig. 1. The dust sensors were cross checked in the lab. Our measurements re-confirmed the precision which was found during the studies conducted by TMT for these instruments in 2007. We find the precision of the measurements to be better than 0.09 m/s and 0.12°C rms for the anemometers and thermometers, respectively. The dust sensor agreement was typically within 10%. It must be noted that, according to the manufacturer of the CSAT-3, the accuracy of these anemometers is in the order of mm/sec and that our comparative measurements are dominated by the impact of the local environment and turbulence on the flow. In Fig. 1 it can be seen that the noise increases with increasing distance of the anemometers, and when winds are coming from the South. As the support structure to mount the anemometers was South of the sensors it can be expected that these structures affect the airflow. Therefore, we assume the precision of these instruments to be much better than what we measure in our non-perfect test setup. The thermometers were calibrated by the manufacturer to 0.1°C accuracy. In our measurements (the sensors were installed inside a box) we could clearly see the impact of thermal turbulence on the measurements, but the overall agreement we found was 0.12°C.

After finishing the calibration campaign, the instruments were distributed over four locations inside the dome of the Blanco telescope on February 13, 2010. These stations are indicated in Fig. 2. Two stations, labeled 1 and 2 in Fig. 2, were directly attached to the telescope tube (see also Fig. 7). The other two stations were located at the inside of the dome, along the shutter. The layout aimed primarily at tracing the air along the line of sight of the telescope. The details of the setup were:

- Station 1: approximately 1.5 m above the primary mirror (M1) cell, equipped with CSAT-3, temperature probe and dust sensor.
- Station 2: mounted at the top ring at the level of the secondary mirror (M2). Only a CSAT-3 and temperature probe were installed here.
- Station 3: close to the dome shutter, approximately 4 m above the lower shutter edge. The same sensors were installed as at Station 2.
- Station 4: at the top walk way in the center of the dome, equipped similarly to Station 1.

During the nights between end of February and begining of March 2010, the observers using the Blanco telescope were asked to take sequences of focus frames using the MOSAIC II camera. This resulted in a total of 28 useful seeing estimates from these focus images, spread out over 10 nights between February 21 and March 1. Unfortunately, only 7 of those turned out to be simultaneous with measurements of all other sensors.
The main part of the campaign ended with the begining of the Blanco maintenance period on April 8, 2010.

Later, during the full moon period in May 2009, two Lunar Scintillometers (LuSci[7]) were deployed; one inside and one outside the dome. As the 4 m Blanco telescope was still in technical maintenance it was was possible

*available from `http://sitedata.tmt.org`

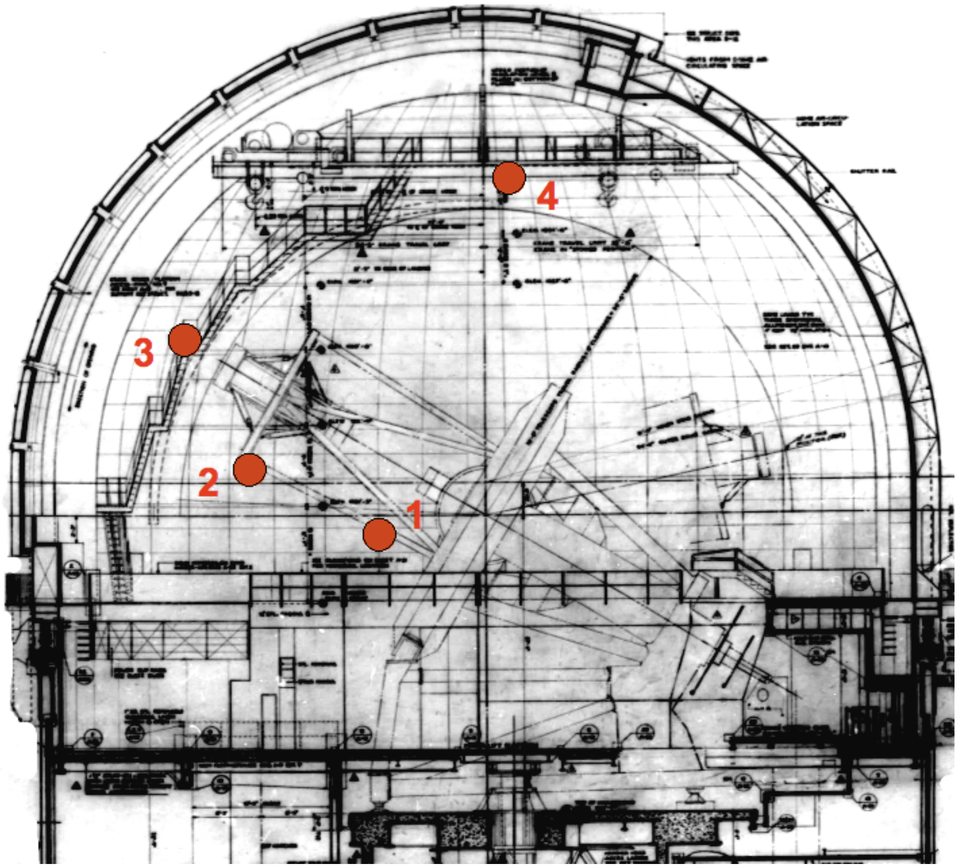

Figure 2. (color online) Cut through the 4 m Blanco dome and telescope. Stations 1—4 are the locations at which instrumentation was deployed (see text for details).

to track the moon by rotating the dome and have both LuSci instruments observing the moon. Their difference should provide a direct measurement of the dome induced seeing. These measurements are currently under analysis.

3. CONDITIONS INSIDE THE DOME

In this section the statistics of the various atmospheric conditions inside the dome of the 4 m Blanco telescope are presented. Ambient conditions were measured by the Tololo weather station which is mounted on a 30 m tower on the Eastern flank of Cerro Tololo. The sensors are ranging 6 m above the Tololo summit platform. The presented measurements refer only to night time data, defined as times when the sun elevation$< -30°$. These conditions can be assumed representative for the conditions inside the dome after some adaptation time at the begin of the night, during summer months.

3.1 Temperatures

A total of one month of measurements of the atmospheric conditions within the Blanco telescope dome have been collected using the described setup. In particular the gradients of air temperature and wind speeds throughout the dome are of importance.

In Fig. 3 the statistics of the temperature differences between the stations and also with respect to the outside temperature are shown. The distributions of the gradients involving Station 1 (which we refer to as the primary

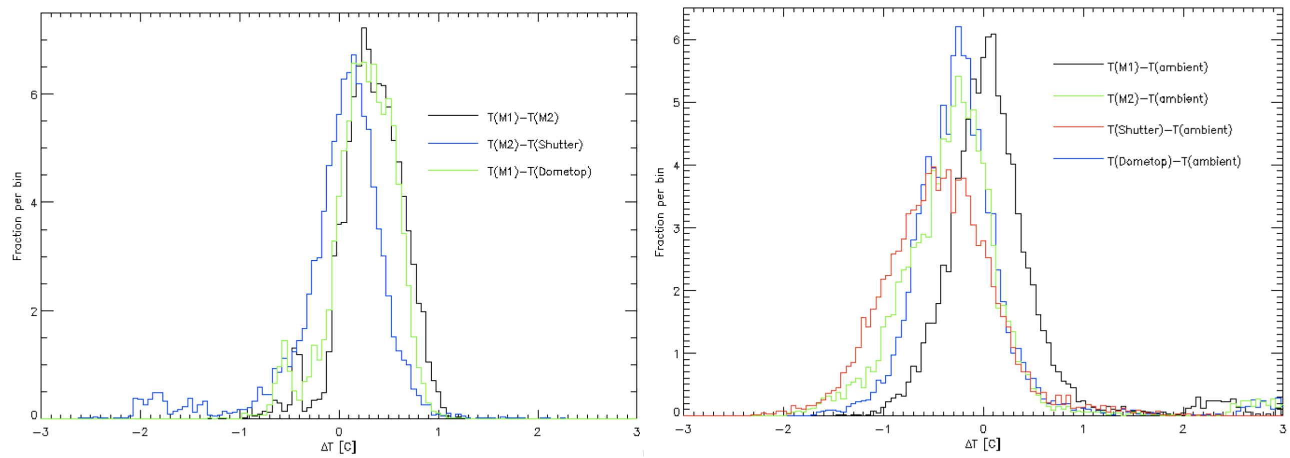

Figure 3. (color online) Night time temperature gradients measured within the Blanco telescope dome. These histograms are based on more than 15,000 individual measurements. M1=station 1, M2=station 2, Dome shutter=station 3, top of dome=station 4. *Top panel:* Temperature gradients of stations inside the dome. *Lower panel:* Temperature differences between the various stations inside the dome and ambient temperature which is measured by the CTIO meteostation.

mirror M1) peak at small positive values, indicating that the air surrounding the M1 is mostly warmer than the stations higher up in the dome; by (0.2°C to 0.3°). The air around M1 appears also warmer most of the time when compared to the outside air; but to a somewhat lesser extent, e.g., the distribution peaks at very small positive values (0.1°).
It is interesting to see in Fig. 3 (right panel) that the air within the dome is mostly cooler than the outside air, in particular the temperatures recorded close to the shutter (station 3). The width of the distribution indicates also a large change of temperature difference during the night and might hint towards radiative cooling of the dome structure. Also, we suspect the air conditioning system circulating cold air throughout the dome, lowering temperatures below ambient. From this we expect that the shell seeing, i.e., the seeing caused by temperature differences between the dome skin and the air, to be small during most of the night.

On the other hand, our measurements indicate also that the lower region within the dome (the air around the M1) is mostly the warmest region inside the dome. This could cause convective motion to set in and thus increase the dome and/or mirror seeing.

3.2 Wind speeds

In the right panel of Fig. 4 the histograms of the recorded wind speeds are shown. The ambient wind speeds were very low during the measurement period (typically less than 5 m/s). The wind speeds inside the dome were largely zero but show also some significant fraction of values up to 0.3 m/s. Some airflow in the inner dome is of importance in order to suppress the onset of natural convection.[5]

Similar to the temperature gradients, the left panel of Fig. 4 shows the histograms of differential wind speeds inside the dome. These distributions appear much more uniform throughout the dome as compared to what was found for the temperatures. They peak at small – negative – values, indicating that the wind speed mostly increases from the inside to the edge of the dome but only by a small margin, i.e., $\lesssim$0.5 m/s. But it is remarkable that all of the distributions in the right panel of Fig. 4 show also a pronounced tail towards positive values. This indicates that the wind speed in the inner part of the dome can be somewhat higher than towards the skin. This shows that the vents are indeed 'flushing' the interior of the dome air and might also hint to some sort of slow circulation within the dome.

3.3 Seeing

As was noted in Sec. 2 only seven seeing measurements were taken simultaneous with the temperature probe and anemometer data. Obviously, these are too few to look for correlations. We can therefore only attempt to

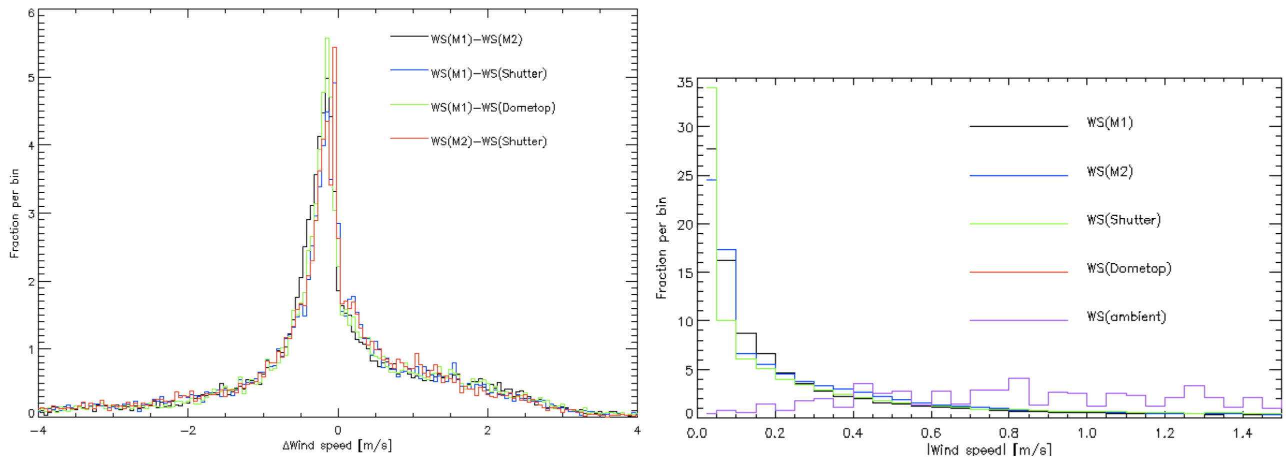

Figure 4. (color online) Night time (sun elevation$< -30°$) wind speed gradients measured within the Blanco telescope dome. These histograms are based on more than 15,000 individual measurements. M1=station 1, M2=station 2, Dome shutter=station 3, top of dome=station 4.

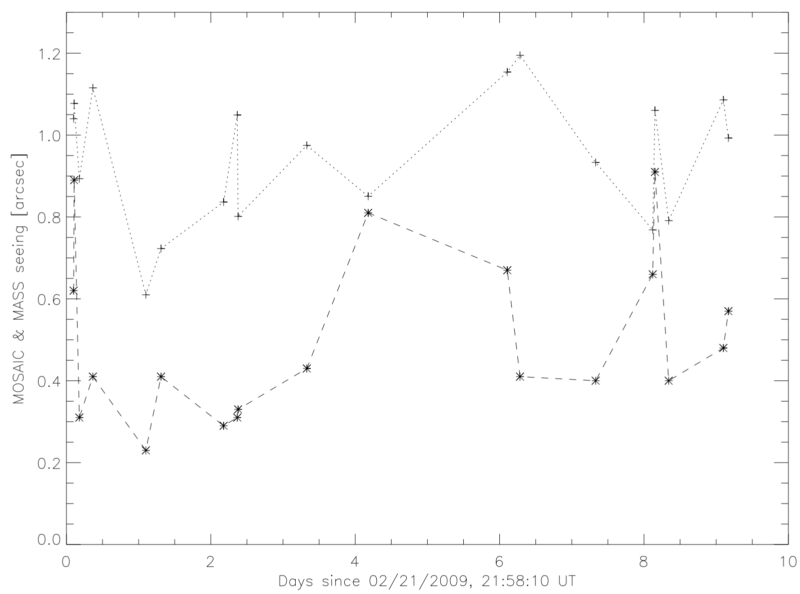

Figure 5. Time series of seeing estimates from MOSAIC II focus runs (crosses connected with the dotted line) and simultaneous MASS seeing (asterisks connected by the dashed line).

assess the dome seeing in a crude manner and the reader has to keep in mind that these are not representing any significant amount of data, nor covering any significant period of time. Nevertheless, the results should give an indication if dome seeing is substantial or basically non-existing for the Blanco telescope.

The CTIO site monitor† contains a MASS device which measures the seeing which an observer being located 500 m above the site would see. In Fig. 5 the simultaneous seeing measurements of MASS and the image quality from on the MOSAIC II frames are shown (corrected to zenith and for $\lambda = 500$ nm). The MASS and MOSAIC II measurements were obtained for different lines of sight which adds a major complication in using these data, as the MASS seeing can vary across the sky by more than 30%.[2] Still, there are occasions during which the

†During the period of the experiment inside the Blanco dome, only the 'old' site monitor was operational; the new TMT style system was installed in April 2009.[4]

MOSAIC seeing closely resembles, to within 0"05, the MASS seeing. But as these are only very few such cases were observed this could instead be due to the non-uniformity of MASS seeing across the sky. At Cerro Tololo the non-uniformity has previously been found to be up to 0"4.[2]

Still, this might indicate that the dome seeing can be extremely low. But it is not sensible to do the computation of the difference between MOSAIC and MASS seeing with such a low number of observations.

3.4 Dust

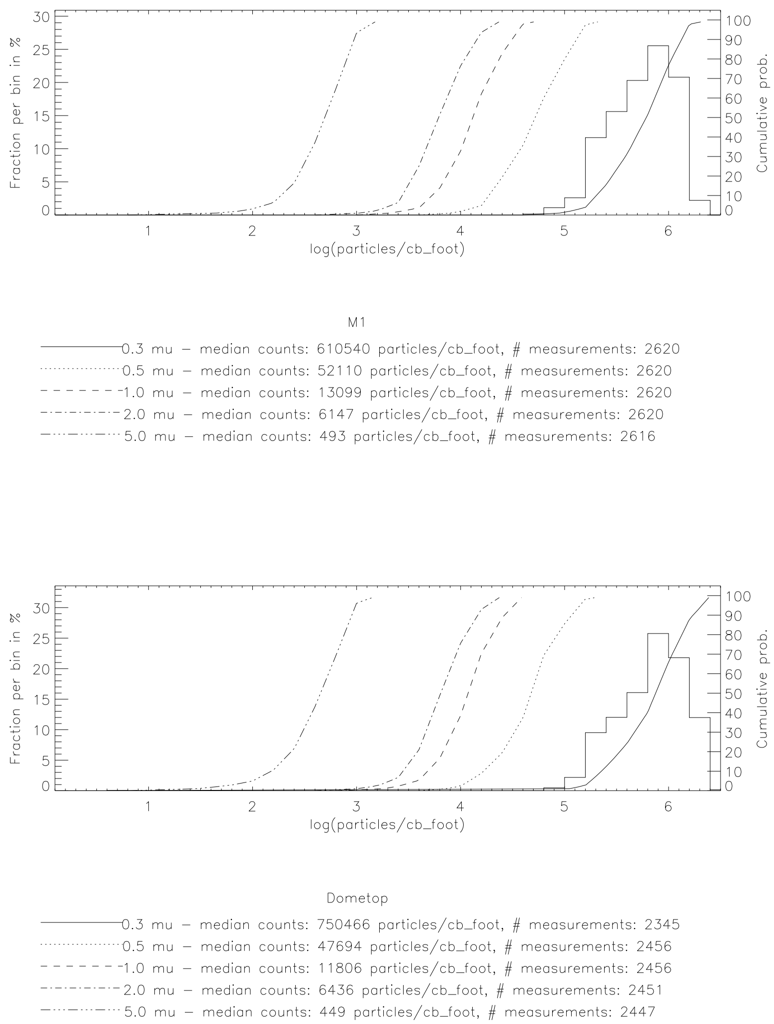

Figure 6. Measured night time dust distributions inside the telescope dome. Note that due to the measurement cycles of these sensors, there are four times more measurements for the 0.3 μm channel than indicated by the corresponding numbers in the Figure. *Upper panel:* Data collected by sensor at Station 1, i.e., 1.5 m above the M1. *Lower panel:* Data collected at the center of the walk way in the top of the dome, i.e., Station 4.

The two dust sensors were installed at Station 1 and Station 4, thus 1.5 m above the primary mirror M1 and the top of the inside of the dome. Figure 6 shows the measured dust distributions for the various channels. The 0.3 μm channel shows a somewhat (by 23%) higher concentration of the smaller particles in the upper part of the dome than at M1. For the other particle sizes at both locations very similar numbers are found (within 10%). Due to the measurement cycles of these sensors, there are four times more measurements of the 0.3 μm channel than for the other channels. We computed for each cycle the average particle count of the 0.3 μm channel and the statistics of this channel is based on four times more measurements than indicated in Fig. 6. Therefore, the increased concentration of 0.3 μm particles in the upper dome is significant.

This significant concentration increase of small particles towards the higher region of the dome might be due to the decreased air flow at the inner dome skin, noted in Sect. 3.2. Particles are carried quickly away from the M1 region and are then transported upwards by the airflow along the dome skin. The slow(er) air motion in the top of the dome, in combination with the upward temperature gradient, causes these small particles to accumulate in the higher dome area.

4. SUMMARY

During the period of February to April 2009 the conditions inside the 4 m Blanco telescope were monitored using ultrasonic anemometers, temperature probes and dust sensors. These were installed in a way that these sensors trace mostly the air along the line of sight of the telescope. During 10 nights also the image quality on

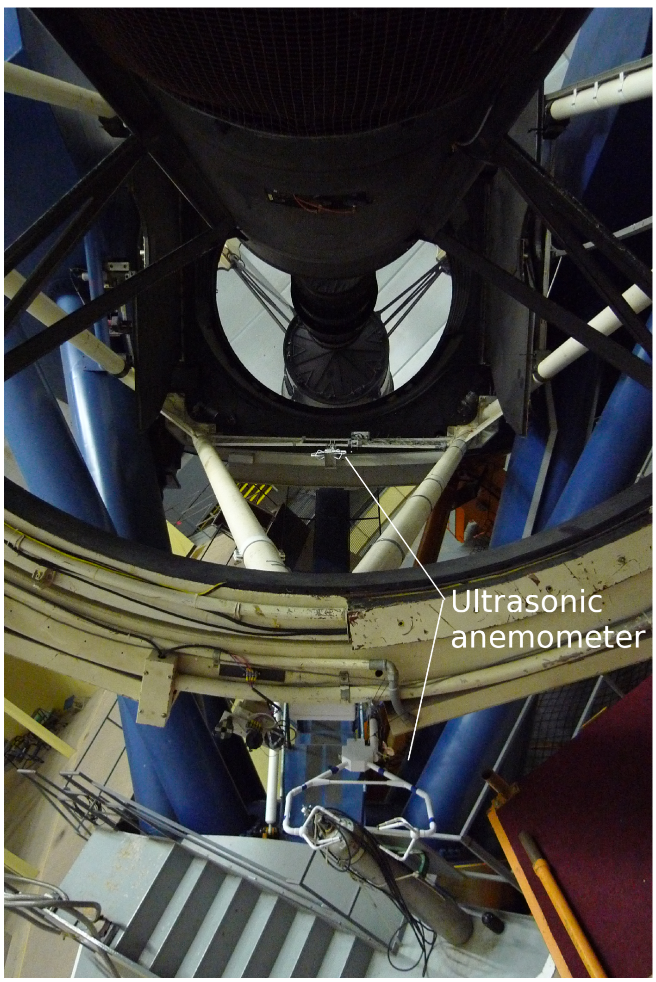

Figure 7. (color online) View from the top ring, down the 4 m telescope tube. The marked white structures at the top ring and at the M1 cell are the ultrasonic anemometers, these correspond to Stations 1 and 2 in Fig 2, respectively. The temperature probes are not clearly visible in this image, neither is the dust sensor close the ultrasonic anemometer at M1.

the MOSAIC II camera was recorded. The first analysis of the collected data, presented in this paper, shows that small temperature and wind speed gradients occur inside the dome. It was found that the air inside the dome, but close to its skin, is largely cooler than outside. The air surrounding the primary mirror is slightly warmer than the outside air. This also reflects itself in the temperature increase of air being close to the dome skin towards the inner part of the dome.
Wind speeds during the campaign were quite low and typically below 5 m/s. Still, the air inside the dome and in particular the air surrounding the primary mirror showed some non-zero wind speeds. Also a wind speed gradient between air in the area of the primary mirror and the dome skin was observed. This indicates an effective flushing of air in the central area of the dome by means of the vents.
This air speed gradient inside the dome could also be responsible for the measured 22% increase of the concentration of small size (0.3 μm) dust particles in the upper part of the dome. No such increase was found for larger dust particles.

Unfortunately, only very few seeing estimations could be obtained with the 4 m telescope using a science camera. Comparing these seeing estimates to the free atmosphere seeing show that the 4 m dome seeing can be very small, but from these few measurements it is not possible to draw any solid conclusion. To properly characterize the dome seeing component, it will be necessary to record the image quality on a regular basis and compare those to the ground layer (or boundary layer seeing) measured outside the dome. The already collected LuSci observations might shed light on the seeing component of this telescope.

But for the future a proper data base to monitor the image quality found using science data should be considered also for the 4 m Blanco telescope, similar to what is done at other major observatories.[8]

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