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Evaluation of Thermal Performance for the MMT Primary Mirror During January 2003

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Abstract

Thermal data from January 2003 were evaluated with respect to two thermal performance criteria for the 6.5 m MMT primary mirror: 1) a peak-to-valley variation of ≤0.1ºC in glass temperature for the primary mirror, and 2) a contrast of ≤0.2ºC between ambient air and the primary mirror temperatures. Data were restricted to periods in which the chamber was open and the thermal system was actively ventilating the primary mirror. Although it commonly approached the 0.1ºC objective, the MMT primary mirror never met the first of these two criteria during the month. The second criterion was achieved approximately 15% of the total operational time.

Introduction

The two thermal performance criteria that were proposed during the conversion of the MMT (Fabricant *et al*., 1996) to the current honeycomb, borosilicate, 6.5 m primary are as follows:

Criterion #1: the peak-to-valley temperature difference within the glass of the primary mirror must not exceed 0.1ºC, and
Criterion #2: the mirror must track the ambient air temperature to within 0.2ºC.

These two criteria are used to evaluate the thermal performance of the 6.5 m primary during January 2003.

The thermal data herein must be viewed with caution and may represent worst-case performance for the telescope. Before the thermal data are processed, temperature offsets are applied to each thermocouple channel. These offsets were determined by making use of the excellent thermal management at the Steward Observatory Mirror Laboratory during initial optical testing of the 6.5 m primary. As part of the optical testing, the mirror was allowed to equilibrate with the laboratory environment for three days. After that time, the thermocouples were read and offsets were determined to make the temperature distribution of the thermocouples isothermal. Many channels had peak-to-valley offset uncertainties of up to 0.5ºC. These errors resulted from environmental variations and from temporal fluctuations in the multiplexing electronics used for data acquisition [S. West, private communication].

Data

Thermal data for the month of January 2003 were evaluated for those periods of time when the chamber was open and active ventilation of the primary mirror by the thermal system was occurring. During these time periods, thermal data were logged at 5-minute intervals. Data were obtained from a total of 50 E-series thermocouples. Forty-eight of these thermocouples measured glass temperatures with 16 thermocouples located on each of the frontplate, midplate and backplate of the primary. A single E-series thermocouple was suspended in air within the telescope chamber while another E-series thermocouple was located outside of the telescope building. These latter two thermocouples provide chamber ambient and outside ambient temperatures, respectively.

Ambient temperatures from a RainWise WS-2000 remote weather station were also recorded to provide an additional outside ambient temperature. This weather station is located 3 meters above the ground, immediately to the west of the telescope building.

Finally, a new Vaisala DMP248 dewpoint unit was used to obtain a third ambient air temperature. This unit is located on the exterior of the telescope building at approximately the third-floor level.

In all, 3,118 sets of data for all 50 E-series thermocouples, the RainWise weather station, and the Vaisala dewpoint unit were evaluated. These data represent approximately 150,000 separate temperature readings.

Results

Figures 1 and 2 show the results of these thermal data when evaluated against Criterion #1. Figure 1 includes data from only the frontplate thermocouples, while figure 2 incorporates data from the frontplate, midplate, and backplate thermocouples. All of these data are from E-series thermocouples that are connected to a single isothermal junction block. For this criterion, only relative temperatures were compared to obtain the differences shown in the figures. No absolute temperatures were involved in the calculations. The relative accuracy of the E-series thermocouples is not precisely known, but is believed to be smaller than 0.5ºC.

During the month of January 2003, thermal performance Criterion #1 was never met for the MMT primary. However, peak-to-valley differences were occasionally less than 0.2ºC while RMS differences were repeatedly less than the 0.1ºC limit.

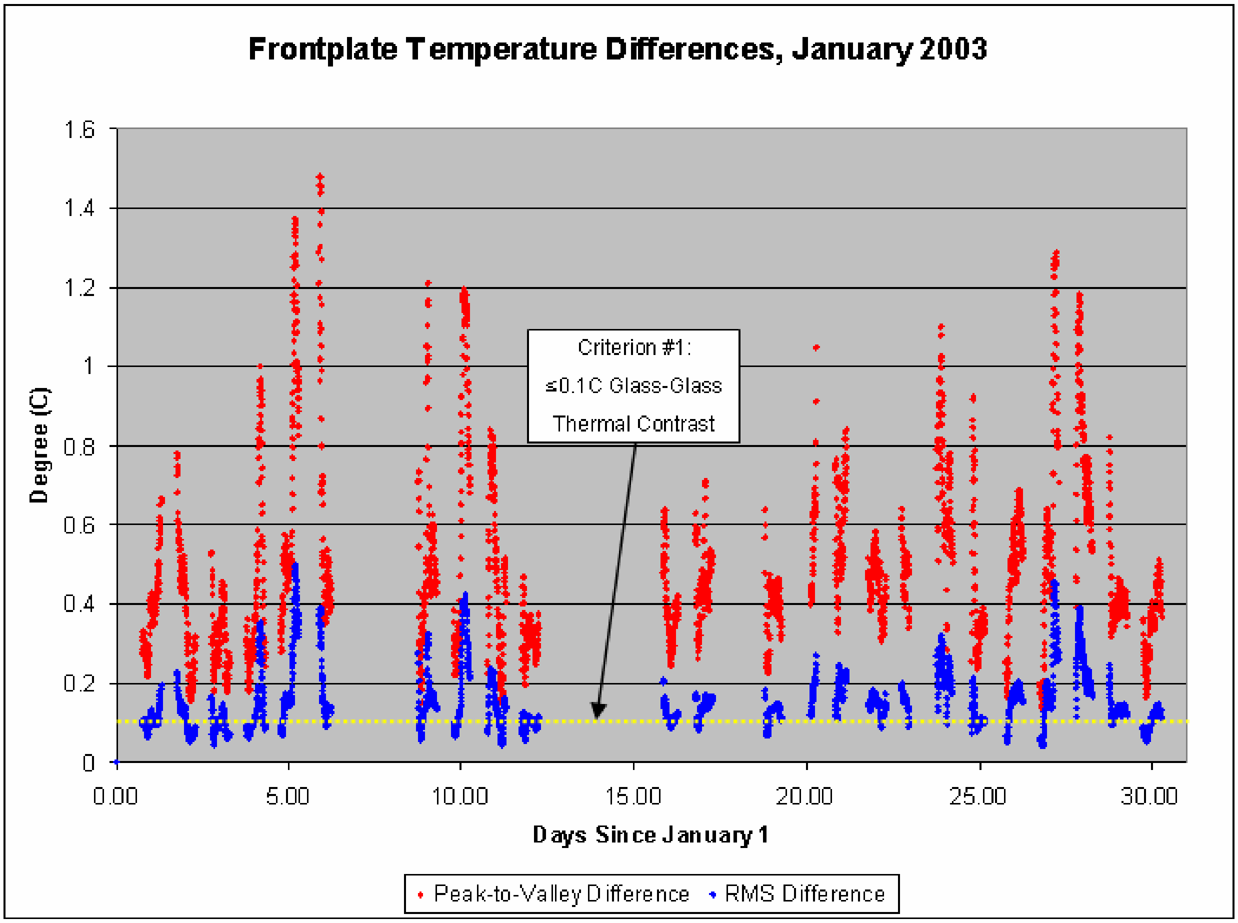


Figure 1: Peak-to-valley temperature differences for the frontplate of the MMT primary mirror, shown in red, while the RMS temperature differences are shown in blue. The performance criterion of ≤0.1ºC is shown in yellow.

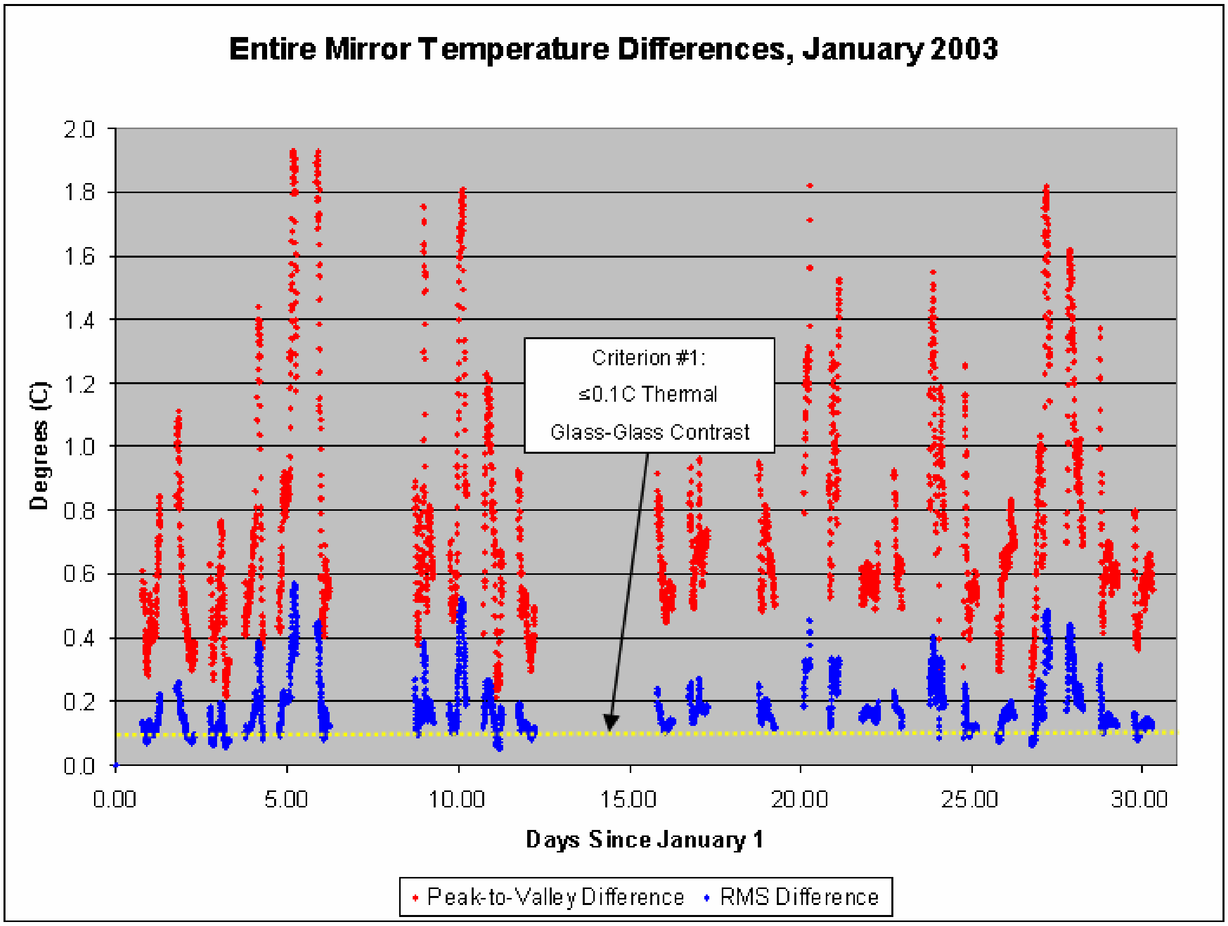


Figure 2: Peak-to-valley temperature differences for the entire MMT primary mirror, shown in red, while the RMS temperature differences are shown in blue. The performance criterion of ≤0.1°C is shown in yellow.

Figure 3 illustrates the results during January for thermal performance Criterion #2. Since up to several degrees of temperature variation can be seen in ambient air temperatures at any given time between different temperature sensors, the average mirror glass temperature was contrasted with four different ambient air temperatures: 1) the chamber temperature as measured by an E-series thermocouple, 2) the outside temperature as measured by an E-series thermocouple, 3) the outside temperature as measured by the RainWise unit, and 4) the outside temperature as measured by the Vaisala unit. The differences between the mirror glass and ambient air temperatures will not be known in an absolute sense until the temperature differences between the various ambient temperature sensors are reconciled. Active thermal control of the primary mirror would then involve minimizing the difference between the most correct ambient air temperature and the primary glass temperature.

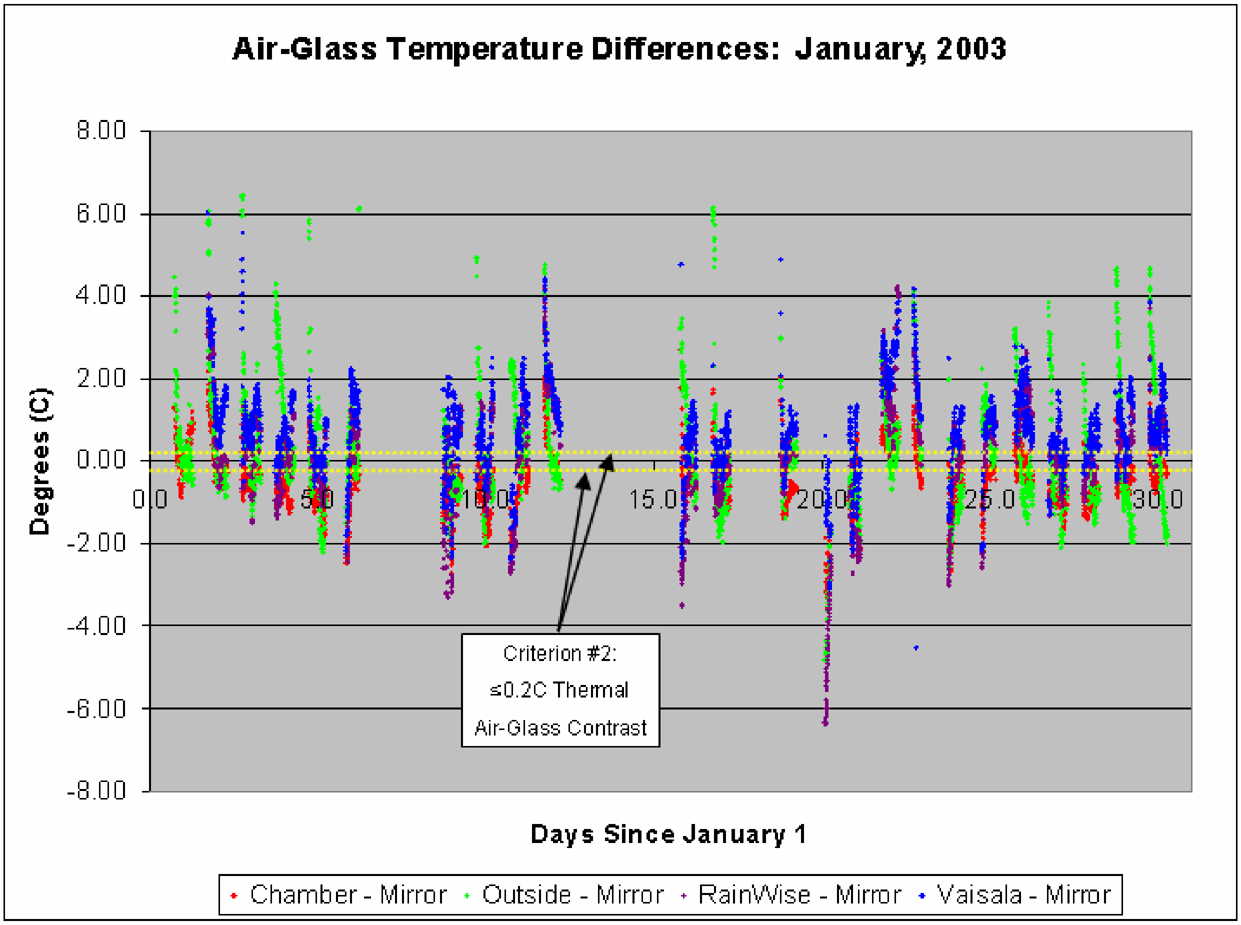


Figure 3: Temperature differences between various ambient air temperatures and the average mirror glass temperature. Four temperature differences are charted: 1) chamber ambient temperature as measured by an E-series thermocouple (in red), 2) outside ambient temperature as measured by an E-series thermocouple (in green), 3) outside ambient temperature as measured by the RainWise weather station (in purple), and 4) the outside ambient temperature as measured by the Vaisala unit (in blue). Thermal performance Criterion #2 of ±0.2ºC contrast between air and glass temperatures is shown in yellow.

Table 1 shows the percentage of time of compliance with Criterion #2 versus the total operational time during January 2003. In general, the primary mirror was in compliance with Criterion #2 around 15% of the total operational time. Interestingly, during much of the month, the thermal system was operated in an automatic mode in which an offset was specified by the operator from the Vaisala ambient temperature. This offset was typically in the range of -1.0ºC to -1.5ºC. Despite the fact that the mirror was being controlled relative to the Vaisala temperature, the air-to-mirror temperatures showed the least percentage of time in compliance for the Vaisala compared to the other ambient temperature sources. It should be noted that, at the scale of a few tens of a degree Centigrade, the four ambient temperatures are relatively independent of each other. Typically, no more than one of the four approaches is in compliance at any one time.

Table 1: Percentage of time in which the MMT primary mirror was in compliance with thermal performance Criterion #2, based upon different sources for ambient temperature. The same average mirror glass temperature was subtracted from each of the four ambient temperatures for these calculations. The average mirror seeing is also shown for each of the four ambient temperatures. See text for details.

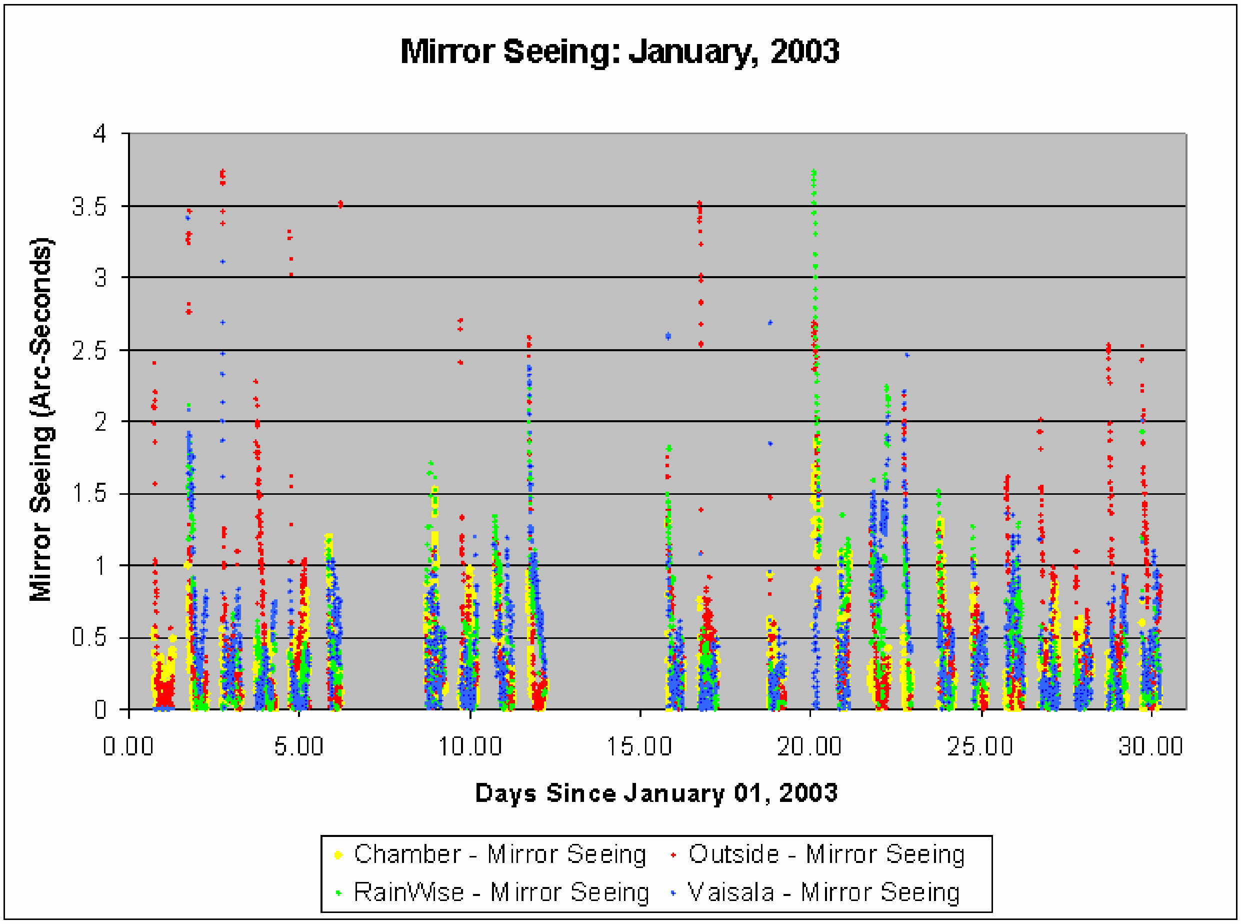
Ambient Temperature Source	**Percentage of Time in Compliance**	**Average Mirror Seeing During Month (in arcseconds)**
Chamber E-series Thermocouple	14%	0.29
Outside E-series Thermocouple	17%	0.45
RainWise Weather Station	19%	0.37
Vaisala Dewpoint Unit	11%	0.42

Table 1 also includes an average of the mirror seeing as attributed to turbulence from a contrast between ambient air and mirror glass temperatures. For these calculations, the following equation, as obtained from the MMT conversion document (Fabricant *et al*., 1996), was used:

$$F = 0.4 * (\Delta T)^{\frac{6}{5}}$$

where 'F' is the calculated seeing in arcseconds and 'ΔT' is the temperature difference between ambient air and glass in degrees Centigrade. Limitations of this equation for application to the MMT are described in the conversion document. This equation was used to calculate an approximate mirror seeing value for each 5-minute period during the month (see Figure 4). It is assumed for these seeing calculations that the telescope is in a zenith-pointing orientation. Turbulence would become less as the telescope is tilted away from zenith. These calculations, therefore, represent the worst-case seeing.

Figure 4: Calculated mirror seeing during the month of January 2003, assuming that the telescope was pointed at zenith. See text for details.



References

D. Fabricant, B. McLeod, and S. West, 1996, "Optical Specifications for the MMT Conversion", available at: http://cfa-www.harvard.edu/cfa/oir/MMT/mmt/foltz/mmt_conv5/mmt_conv5.html