Temperature measurement on the Leighton Telescope: Surface Memo No. 3

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In a previous memo (hereafter called Memo 2[2]) it was found that there was a zenith angle dependence of temperatures measured across the CSO backing structure. The part of the backup structure closest to the ground was up to 3°C. warmer than the the part closest to the sky and this difference depended on the telescope zenith angle. See Figures 7, 8, 9 in Memo 2. The observation of this gradient across the backing structure during nighttime operation was in contrast to an earlier study[3] which observed isothermal behavior for Leighton telescopes operated in open air during the night.

The CSO Leighton telescope is enclosed in dome, see figure 1. The average electrical power draw at the CSO is about 30 KW. Some of the heat generated from this power draw is vented out of the back of the dome enclosure and away from under the telescope structure. However it is likely that most of the heat from the power draw is dissipated into air under the telescope backing structure. When the CSO Leighton Telescope is near zero zenith angle the backing structure is exposed to a more uniform environment. When the telescope tilts over to high zenith angle the top half of the antenna is more exposed to open air and warm air trapped under it can rise more freely. Thus we explain the zenith angle dependent temperature gradient observed in Memo 2.

In the current memo we measured the front and back surface temperatures of three antenna panels using the techniques described in Memo 2. These measurements can enable prediction of the degree of panel warpage ("cupping") due to the temperature difference between the front and back surfaces. The front surface tends to cool relative to the back surface because it faces the cold sky whereas the back surface faces the warm ground and internal dome structure.

[1]Location of memo source file: ulu//home/cham/dometmp/memo_17Sep07b.tex

[2]Temperature measurement on the Leighton Telescope: Surface Memo No. 2, RAChamberlin, http://ulu.submm.caltech.edu/cham/surface/ha5_memo_6may03.pdf

[3]Thermal Behavior of the Leighton 10-m Antenna Backing Structure, J. W. Lamb, & D. W. Woody, OVRO, MM Memo. 234 (1998)

Figure 1: Unlike the OVRO Leighton telescopes which operate in open air, the CSO is housed in a dome.

The panels are an aluminum honeycomb design[4]. The backs of the panels are covered with ~ 1.3cm thick foam insulation[5] to isolate the panel back surface from the warm environment below, thus reducing the heat flow through the panels, the temperature gradient, and the associated warpage.

Pairs of sensors were placed in the centers on the front and back surfaces of three panels: (i) on the left edge of the primary mirror, (ii) on the top edge of the primary mirror; and, (iii) on the right edge of the primary mirror. "Right" and "left" are with respect to the point of view of the control room which is housed in the same enclosure as the telescope and is behind the primary mirror. "Top" refers to the most skyward portion of the primary mirror as it tips over toward the horizon.

Figure 2 is a time series of the temperature data we collected over a period of approximately two days starting on September 13, 2007 at 00:06 UTC. The black points are temperature from a sensor monitored by the antenna computer. This sensor was placed inside the antenna enclosure ("dome_air_temperature") near the left front. The blue set of points are from a pair of sensors near the upper edge ("top") of the primary mirror.

[4]A 10-Meter Telescope for Millimeter and Sub-millimeter Astronomy, R. Leighton, http://ulu.submm.caltech.edu/cham/surface/Leighton10m2.pdf

[5]Design, Construction, and Performance of the Leighton 10.4-m-Diameter Radio Telescopes, D. Woody and D. Vail and W. Schaal, Proc. of the IEEE, 82(5), pp. 673-686 (1994)

The red and green sets of points are from sensors placed on the left and right side of the primary.

A diurnal temperature cycle is the main feature of Figure 2. During the daytime the CSO dome shutter was closed, or mostly closed and the temperature in the enclosure reached $\sim 18°$C. At night when the shutter was open the temperature in the enclosure fell rapidly and reached a minimum of $\sim 0°$C. The pair of sensors with the most excursion were on the "top" panel. This pair also showed the largest difference in temperature. The difference in temperature between the pairs is plotted in Figure 3. Also shown in this figure is the antenna zenith angle (ZA) with the scale shown on the right side.

In Figure 3, the difference between the back and front surface sensors was typically $\sim 0.25°$C for the left and right sides. The "top" sensor showed a much larger difference, typically $\sim 0.7°$C. In the plot there may be some dependence of the "top" temperature difference on zenith angle but it was not a simple relationship.

Subsequent to the measurements shown in Figure 2 and 3 the top panel was inspected and it was found that the foam insulating the back of the panel was becoming detached. The insulation was re-bonded by injecting silicon adhesive in between the panel and the foam insulation on November 31, 2007 at about 22:00 UTC.

On January 3, 10:13, 2008 (UT) a new set of measurements was started. The results are displayed in Figures 4 and 5. In Figure 5 the "top" sensor pair difference was closer to the other two pairs. (Compare to Figure 3.) Between hours 23 and 24 the "top" pair difference (blue) showed a slight inversion: the front surface was warmer than the back. During this time the air temperature in the dome (black scatter plot) was changing rapidly and increased by about 1.5 °C. The behavior of the the top pair of sensors may be related to zenith angle: the probable relationship is more clearly seen in Figure 6 where only the top pair of sensors is displayed. The horizontal time scale is relabelled in UTC for easier comparison with other data streams such as in Figure 7.

Figure 7 is a concurrent "Metrogram" acquired by a neighboring telescope: the JCMT. The metrogram shows a transient increase in air temperature between hours 9 and 12 UTC. This transient increase corresponds well the change in dome air temperature shown in Figure 6. Figure 6 shows transient dome air temperature spikes around hour 7.0 and hour 8.7 UTC which are not evident in the metrogram. However, these spikes are associated with sudden changes in the telescope zenith angle. This association adds additional evidence (see Memo 2) that the zenith angle of the telescope may effect circulation of air and temperature gradients in dome.

On January 9, 2008 at about 2220 UTC an additional 2.5cm of foam insulation was added to the back of the top panel. The foam was cutout to go avoid the six-legged aluminum warping harness which spans the back of the panel to control its shape.

After the additional foam was added the measurements were restarted, see Figure 8. If the addition of the insulation had an effect on the temperature difference of the "top" pair it is necessary to do a statistical comparison to clearly see it. A preliminary comparison does not show much change. Before the extra layer of foam insulation was added the "top" difference in Figure 5 is $0.15 \pm 0.12°$ C.[6] After the foam was added the "top" difference in Figure 8 was $0.12 \pm 0.13°$ C.

In Figure 8 between hours 13 and 15.5 UTC the trends of the temperature differences move together and appear to be anti-correlated with the dome air temperature. The dome air temperature may be correlated with zenith angle. Concurrent weather data from the nearby JCMT site are shown in Figure 9. They do not show the abrupt temperature change observed in the CSO dome between hours 13 and 15.5 UTC. We note that this was a windy night.

From the data in this memo we conclude that:

- The bonding of the insulation to the back of the panels is critical.
- The back to front temperature difference across the "top" panel sometimes shows a clear dependence on zenith angle (e.g. see Figure 6).
- Under some circumstances the differences of all three pairs ("left", "top", "right") may move together and are anti-correlated with dome air temperature, e.g. see Figure 8.
- In some cases the dome air temperature registered at the antenna computer thermometer corresponds with trends seen at the JCMT site, but it often appears to be correlated with CSO antenna zenith angle.

[6] Averaging was started after hour 19 when the dome was open.

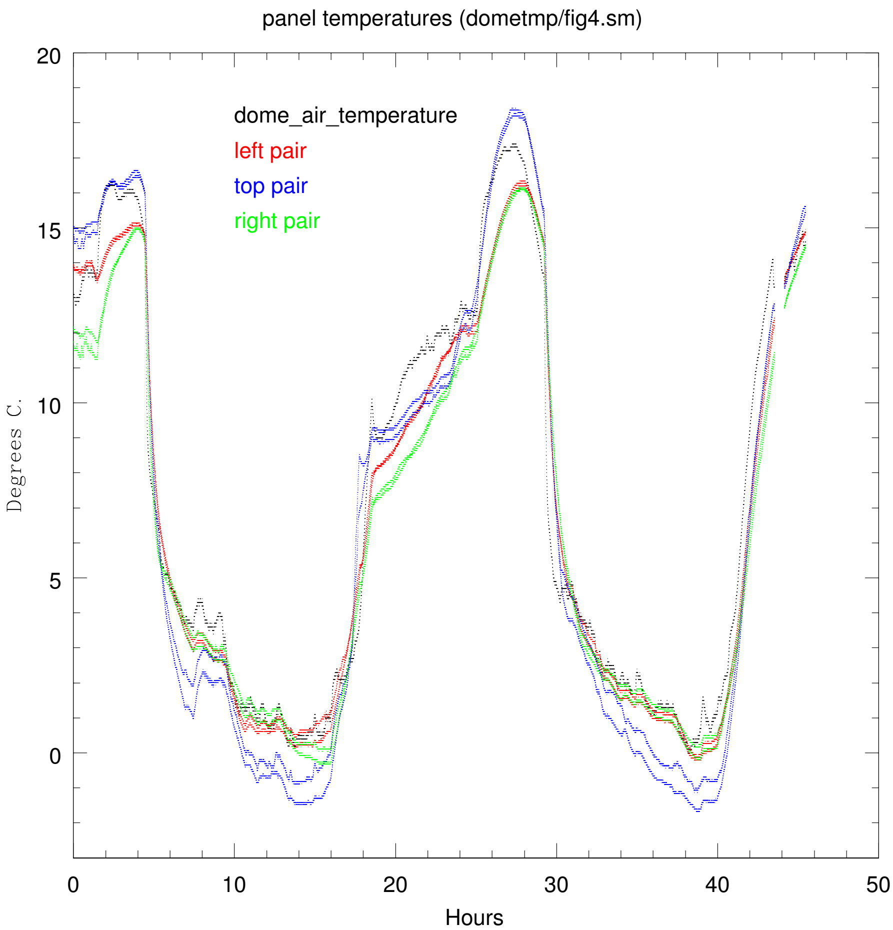

Figure 2: Measurements starting on September 13, 2007. See text for explanation.

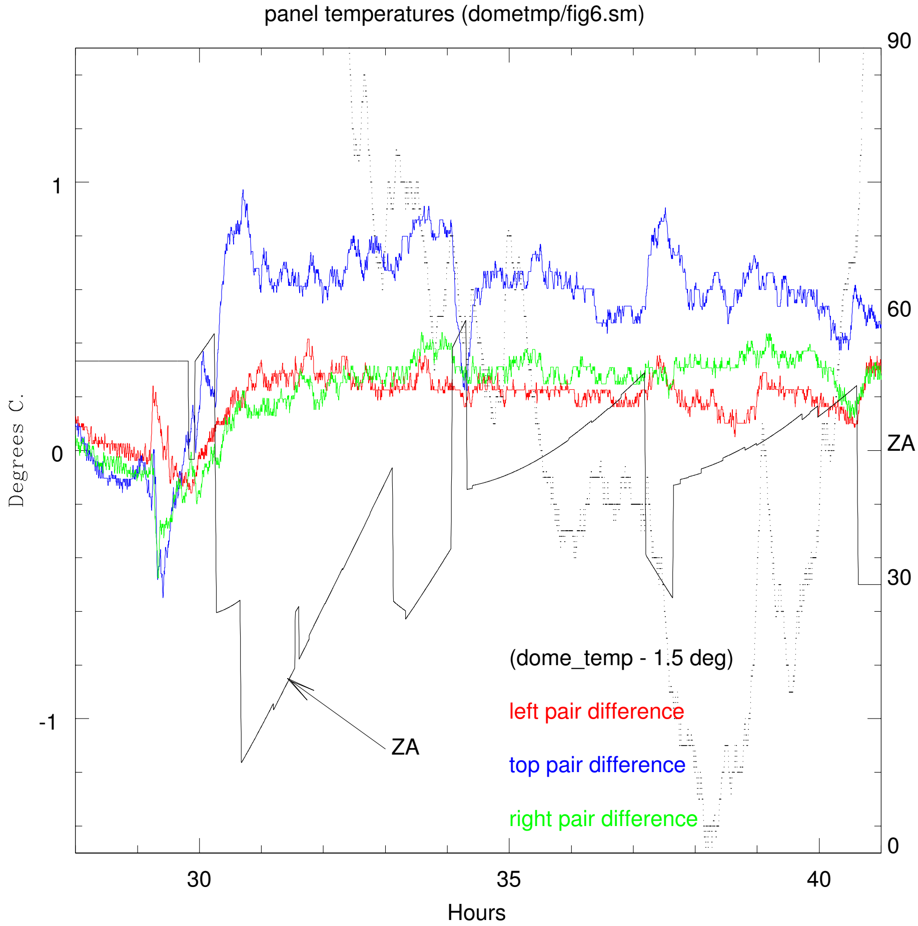

Figure 3: Measurements from September 14, 2007. Plotted is the temperature difference between the back and front panel sensor pairs (red, blue, and green points). A positive difference indicates the back of the panel is warmer than the front. Also shown is the dome air temperature (“dome_air_temperature”, black scatter plot) and the antenna zenith angle. Note that the pair of sensors on the “top” panel (blue points) showed a significantly greater difference than the other pairs. To improve plot clarity temperature data are boxcar averaged over 5 adjacent values.

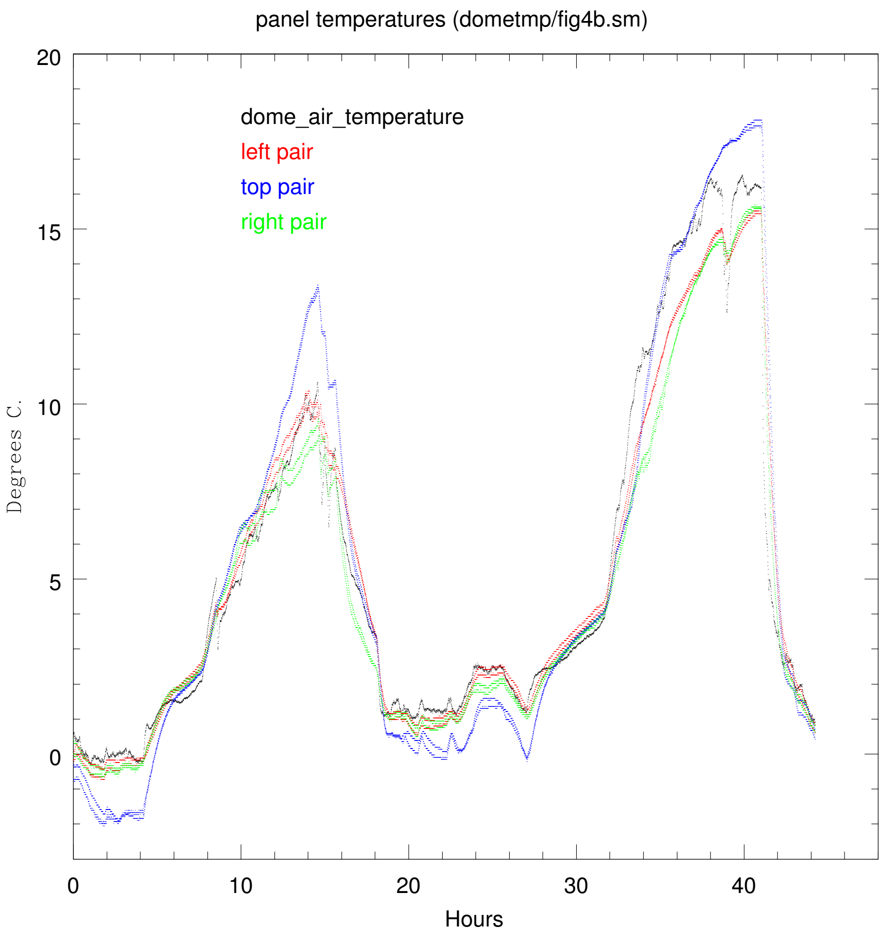

Figure 4: Measurements from January 3 & 4, 2008.

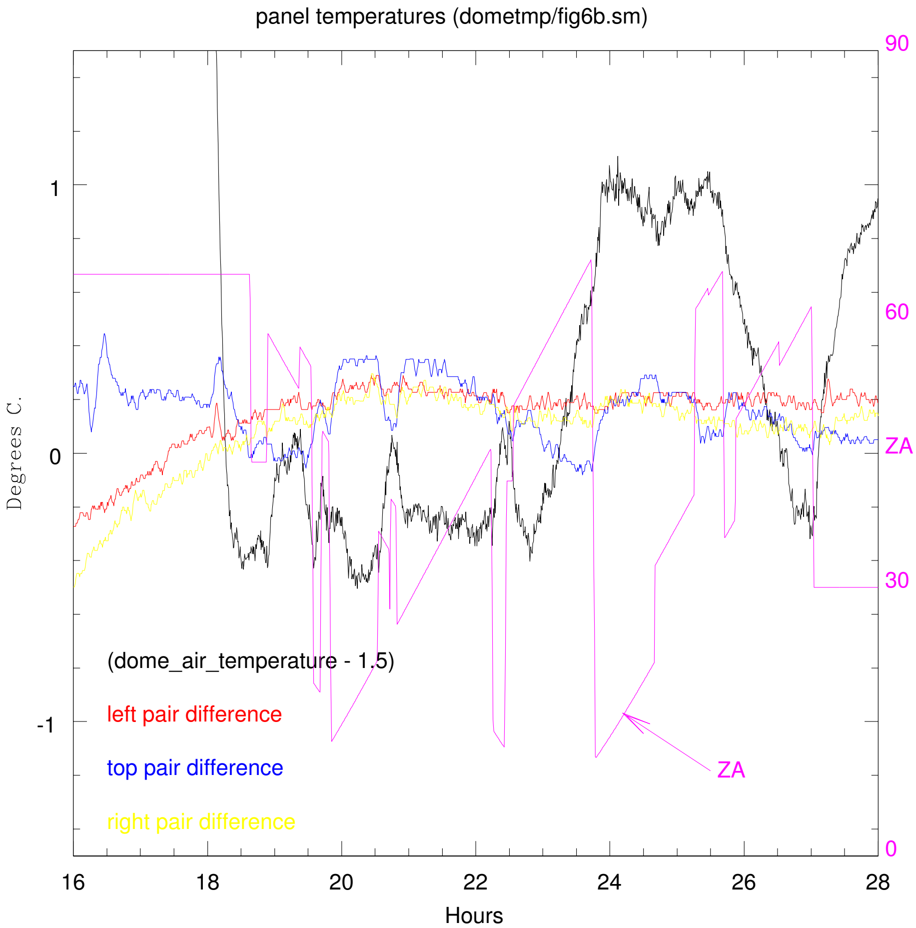

Figure 5: Measurements from January 4, 2008. For an explanation of the plotted quantities see the Figure 3 caption. Subsequent to the measurements in September 2007 (Figures 2 and 3) the insulation on the back of the "top" panel was re-bonded. Note that compared to Figure 3, the "top" pair sensor difference is not as large. The "dome_air_temperature" is offset by $-1.5°$C. to center the data in figure.

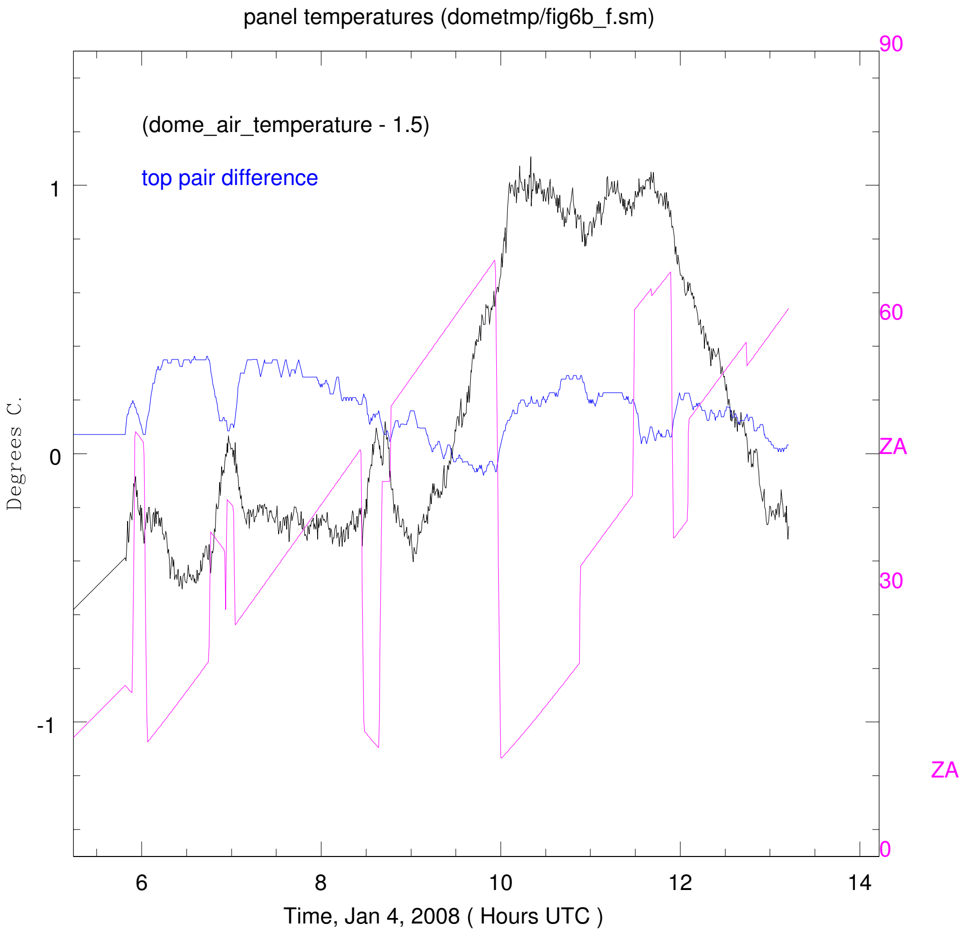

Figure 6: Measurements from January 4, 2008. The same data as in Figure 5 is presented except that the horizontal scale is expanded slightly and time is presented in UTC for comparison with concurrent weather measurements acquired by the Joint Astronomy Center (JAC), see the next figure. To simplify the figure only the front/back temperature difference from the "top" panel is shown. Between hours 7.5 and 10 UTC, while the zenith angle is steadily increasing during an observation track, the "top" panel back-front temperature difference steadily declines.

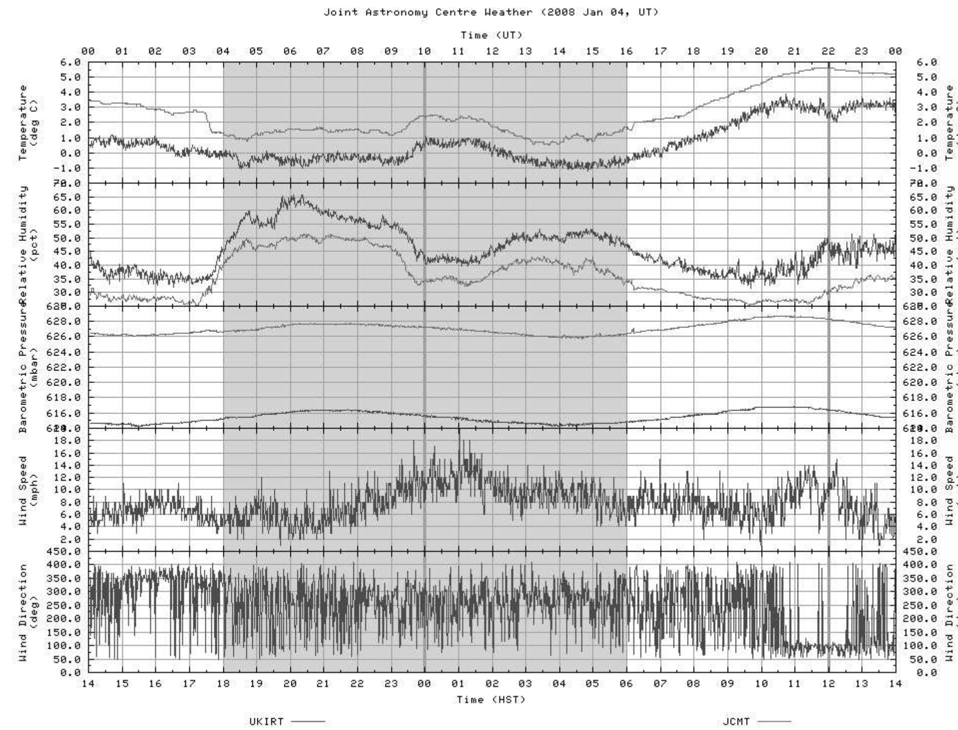

Figure 7: Weather measurements acquired by the Joint Astronomy Center (JAC) on January 4, 2008.

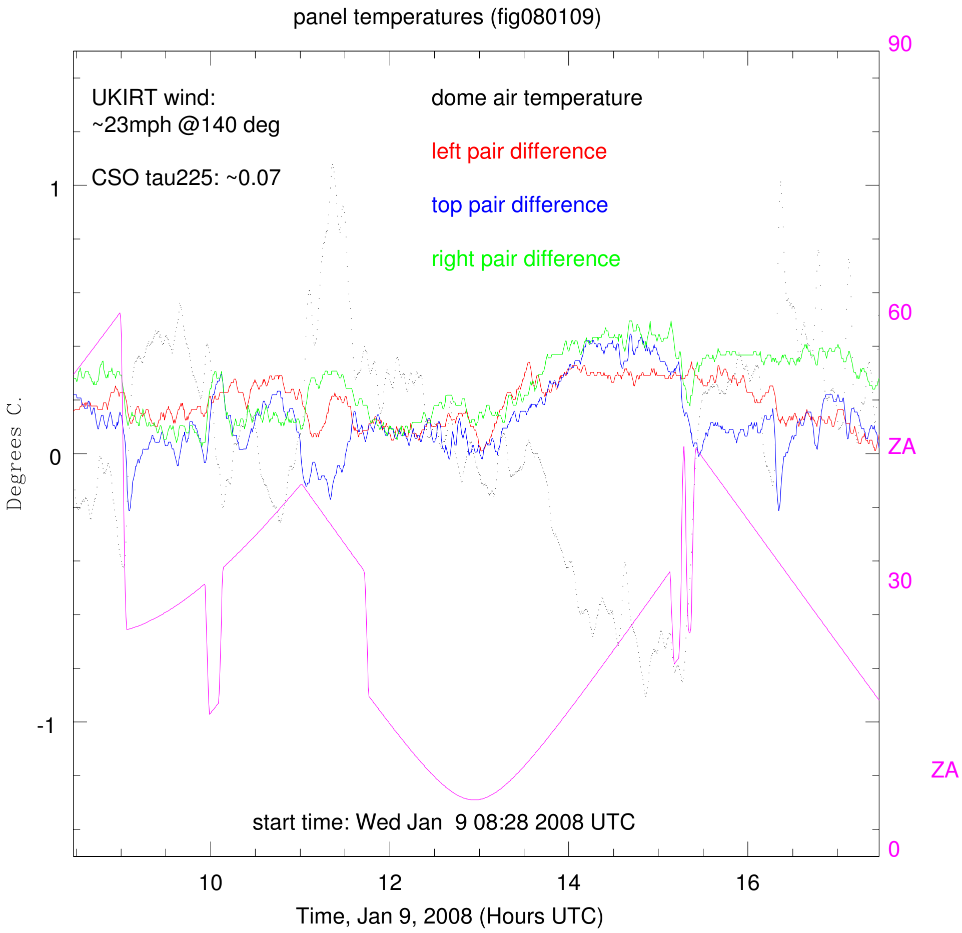

Figure 8: Measurements from January 9, 2008. This data was taken on windy night. Compare to Figure 6. Between hours 13 and 15.5 UTC the trends of the temperature differences move together and appear to be anti-correlated with the dome air temperature. The dome air temperature may be correlated with zenith angle. Concurrent weather data from the nearby JCMT site are shown in Figure 9. They do not show the abrupt temperature change observed in the CSO dome between hours 13 and 15.5 UTC. We note that this was a windy night.

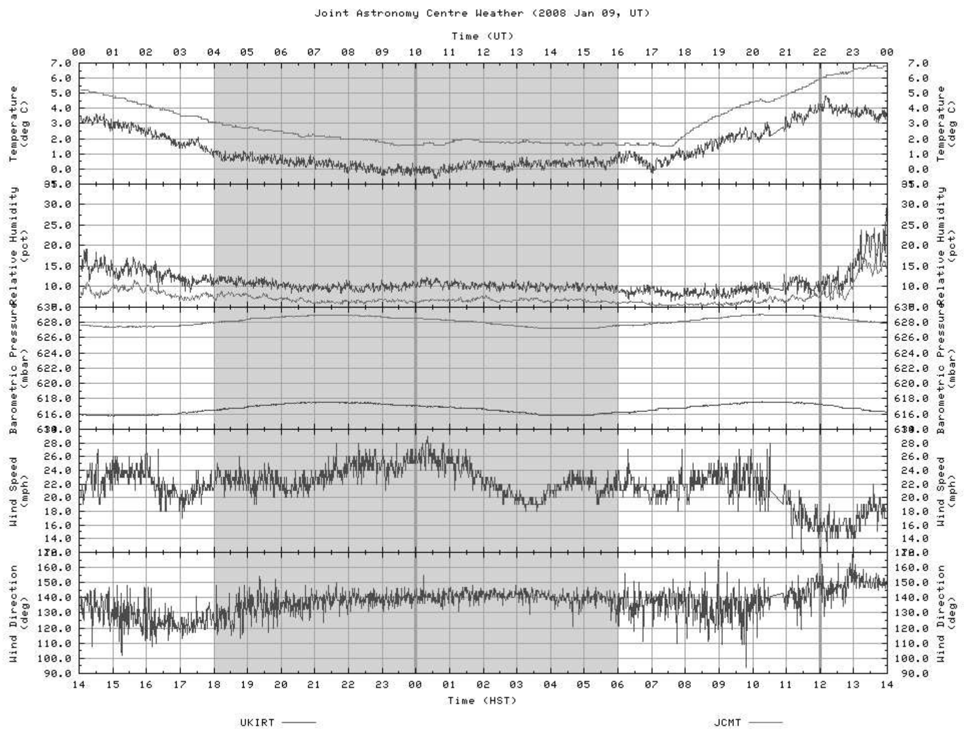

Figure 9: Weather measurements acquired by the Joint Astronomy Center on Jan 9, 2008 (JAC).