Design and Test of an Instrument for Measuring Microthermal Seeing on Magdalena Ridge

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Background

Magdalena Ridge is the site of an ambitious multi-element imaging interferometer under construction by New Mexico Tech and Cambridge University. The Magdalena Ridge Observatory Interferometer (MROI) is located west of Socorro in the Magdalena Mountains at an altitude of 10,500 ft. We have designed and built an instrument for performing microthermal measurements of ground-level seeing at the MROI site. High-speed thermocouple pairs are used to take temperature measurements. The rapid temperature measurements are directly related to the local turbulence which in turn is responsible for the ground-level astronomical seeing.

Magdalena Ridge

Theory

Variations in the refractive index of the atmosphere affect astronomical seeing. The refractive index of the atmosphere changes with temperature fluctuations in the air. By measuring temperature fluctuations, it is possible to derive the refractive index and thus the contribution to astronomical seeing from the air at the point of measurement.

Following the work of Pant et al. (1999), the full width at half maximum atmospheric seeing is

$$\varepsilon_{fwhm} = 5.25\lambda^{-1/5}\left(\int_0^H C_{N(h)}^2 dh\right)^{3/5} \tag{1}$$

where $C_{N(h)}^2$ is the refractive index coefficient. The temperature structure coefficient, $C_{T(h)}^2$, is used to find $C_{N(h)}^2$ at temperature, T, and pressure, P,

$$C_{N(h)}^2 = \left(80.1\times10^{-6}\frac{P_{(h)}}{T_{(h)}^2}\right)^2 C_{T(h)}^2 \tag{2}$$

Our instrument measures the temperature structure function, $D_{T(\vec{r},h)}$, associated with $C_{T(h)}^2$ via

$$D_{T(\vec{r},h)} = C_{T(h)}^2\left|\vec{r}\right|^{2/3} \tag{3}$$

This is performed by taking the average of the temperature difference between two points squared, at height, h, and separated a distance, $\left|\vec{r}\right|$,

$$D_{T(\vec{r},h)} = \left\langle\left(T_{(\vec{r}_0,h)} - T_{(\vec{r}_0+\vec{r},h)}\right)^2\right\rangle \tag{4}$$

Instrument

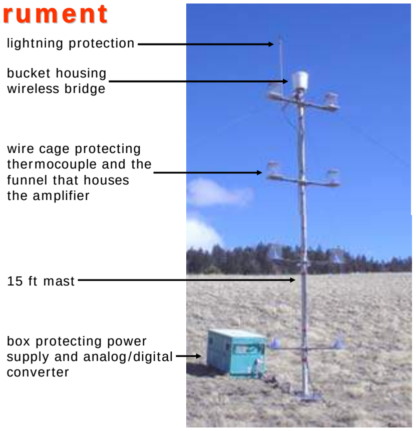

Figure 1 A microthermal tower is shown with the box that protects both the analog/digital converter and the batteries that power the instrumentation.

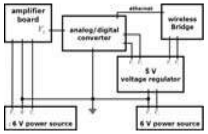

Figure 2 Layout of the Instrumentation.

The instrument consists of sensors, amplifiers, data collection system, transmitter, and power supply. The sensors are high speed thermocouples that take rapid temperature measurements. They are evenly spaced in pairs along a 15 ft mast. The voltage across each thermocouple is amplified. The amplified voltage, V_0, is converted to a digital signal using an analog/digital converter. A wireless bridge transmits the digital signal to a computer for processing. The amplifier is powered by a DC source that delivers +6V, 0V, and -6V. The analog/digital converter and wireless bridge is powered by a 6V DC source that is regulated at 5V.

Figure 3 Thermocouple sticking out the end of a funnel.

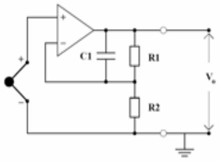

Figure 4 Diagram of the low pass amplifier used to increase the voltage across the thermocouple.

Results

Preliminary results are given in Figure 5. Shown are log plots of the temperature structure coefficient, $C_{T(h)}^2$, for each height above the ground and the ratio of $C_{T(h)}^2$ for consecutive levels. The values are computed on a 1 minute basis. The voltages are converted to temperature and the difference between sensors at each height is found. Baselines are subtracted separately in each 1 minute sequence to produce a zero-mean time series for all intervals. The RMS of the zero-mean time series is what is used to make the plots.

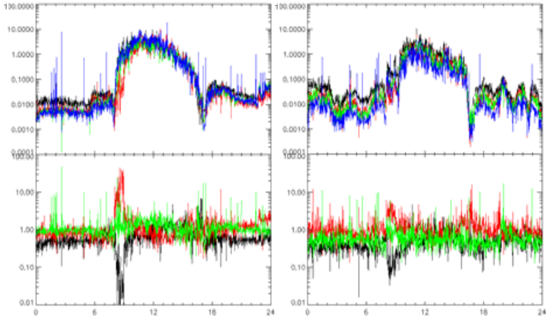

Figure 5 Two plots of data from a microthermal tower in a 24 hour period local time. The panels on the left are from 12/20/05 and the panels on the right are from 12/18/05. The colors black, red, green, and blue correspond to the 1st, 2nd, 3rd, and 4th sensor pairs from the bottom. The top panel shows the log of the temperature structure coefficient, $C_{T(h)}^2$. The bottom panel is the log of the ratio of $C_{T(h)}^2$ for each consecutive level.

The System Works

The difference in temperature is often less for sensor pairs at higher altitudes than for sensor pairs at lower altitudes. This is the behavior we expect of ground-level turbulence. Also notice how it is quite easy to distinguish daytime from nighttime. During the daytime, the fluctuations in temperature are much greater than they are during the nighttime.

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Reference P. Pant, C. S. Stalin, & R. Sagar. Microthermal measurements of surface layer seeing at Devasthal site. AstronAstrophysSuppl. 136:19-25, 1999.

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