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Sunspot temperatures from red and blue photometry

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Abstract. Photometric images are used to measure the temperature of sunspots at different wavelengths. Images at 672.3 nm and 472.3 nm are obtained at the San Fernando Observatory using the CFDT2 (2.5” x 2.5” pixels). Images at 607.1 nm and 409.4 nm are obtained by the PSPT at Mauna Loa Observatory. Monochromatic intensities are converted to temperatures as in Steinegger *et al* (1990). The pixel by pixel temperature for a sunspot is converted into a bolometric contrast for that sunspot according to Chapman *et al* (1994). Sunspot temperatures, i.e., their bolometric contrasts, are calculated from both red (672.3 nm) and blue wavelengths (472.3 nm) and compared.

Keywords. Sun: irradiance, sun:temperature

1. Introduction

Sunspots create the largest short term fluctuations in the Total Solar Irradiance (TSI). Knowledge of their mean temperature compared to the photosphere can help in the understanding of their influence on TSI. In this paper, photometric images are used to measure the temperature of sunspots at different wavelengths. Images at 673.2 nm, 472.3 nm, 780 nm and 997 nm are obtained at the San Fernando Observatory using the CFDT2 on a daily basis. Figure 1 is a blue (472.3 nm) image from CFDT2.

Monochromatic intensities are converted to temperature using Eq. 1.1 (Steinegger *et al.* 1990)

$$T_i \;=\; \frac{c_2}{\lambda}\left[ln(e^{c_2/\lambda T_o}-1)\frac{I_o(\lambda)}{I_i(\lambda)}+1\right]^{-1} \tag{1.1}$$

where $c_2 \;=\; \frac{hc}{k}$, T_o is the temperature of the disk center, $I_o(\lambda)$ is the intensity of the disk center and $I_i(\lambda)$ is the intensity of pixel i.

The pixel by pixel temperature for a sunspot is converted into a bolometric contrast for that sunspot by Eq. 1.2

$$\alpha_{thermal} \;=\; \frac{1}{N}\sum_i[1-(T_i/T_{ph})^4], \tag{1.2}$$

where the sum is over umbral and penumbral pixels. T_{ph} is the photospheric temperature at the same limb position as T_i.

Images are from the SFO Cartesian Full Disk Telescope no. 2 (CFDT2) which has 2.5” x 2.5” pixels. Data processing is described in Walton *et al.* 1998. Sunspot temperatures, ie. their bolometric contrasts, are calculated from red ($\lambda = 673.2$ nm), blue ($\lambda = 472.3$ nm), near infrared [NIR] ($\lambda = 780$ nm) and infrared [IR] ($\lambda = 997$ nm) wavelengths and compared in Tables 1 and 2.

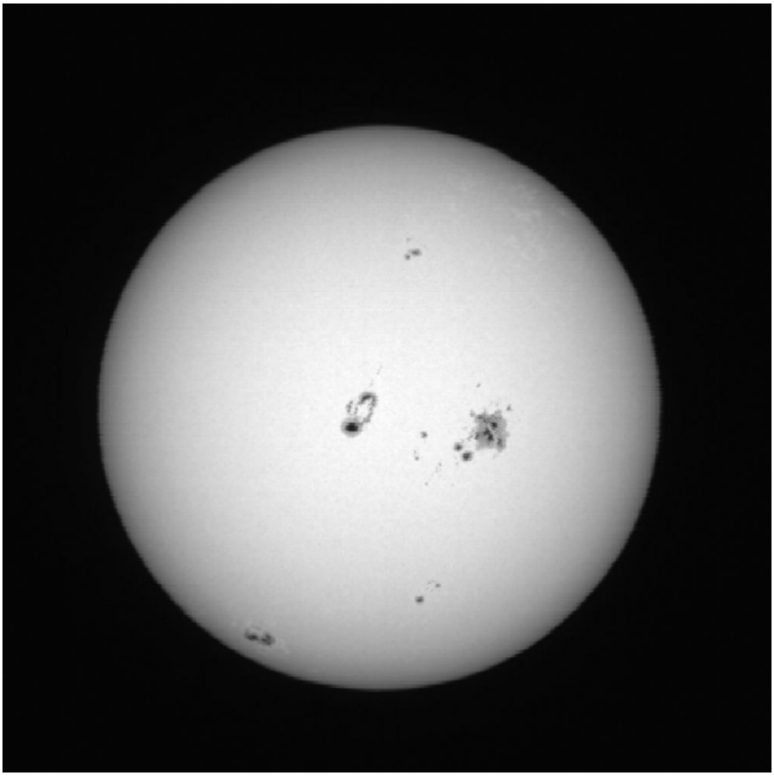

Figure 1. A CFDT2 blue image from 28 October 2003. Spot 1 is on the right (south) and spot 2 to the left of disk center. Geocentric north is at the left.

Table 1. α_x vs. color for spot 1

filter	α_{therm}	α_{eff}
blue	0.252	0.499
red	.255	.362
NIR	.255	.316
IR	.257	.263

Alpha effective (α_{eff}) was defined by Chapman *et al.* (1994)

$$\alpha_{eff} = \frac{DEF}{2PSI} \tag{1.3}$$

where DEF is the photometric sunspot deficit and PSI is the photometric sunspot index.

2. Results

For sunspot no. 1 on 28 October 2003, the following values were determined for α_x (α_{therm} or α_{eff}). These values are given in Table 1.

α_{eff} (Eq. 1.3) is strongly wavelength dependent, varying roughly as λ^{-1} due to the sensitivity of sunspot contrast to wavelength. Spot 2, with a large umbra gave similar α_{therm} values (see Table 2). It was shown in Chapman *et al.* (1994) that α_{eff} was strongly correlated with the ratio of umbral to penumbral area.

Table 2. α_x vs. color for spot 2

filter	α_{therm}	α_{eff}
blue	.247	.481
red	.256	.356
NIR	.253	.308
IR	.277	.281

Using restored red images (Walton and Preminger 1999) gave $\alpha_{therm} = 0.292$ for spot 1 and $\alpha_{therm} = 0.312$ for spot 2. Restoration removes stray light from sunspot images.

The bolometric contrast can also be calculated from mean umbral and penumbral temperatures (Eq. 2.1),

$$\alpha \; = \; \frac{A_u}{A_s}\left[1-\left(\frac{T_u}{T_{ph}}\right)^4\right]+\frac{A_p}{A_s}\left[1-\left(\frac{T_p}{T_{ph}}\right)^4\right] \tag{2.1}$$

where A respresents area and T represents temperature with subscripts u, p, ph and s representing umbra, penumbra, photosphere and total sunspot.

Using sunspot temperatures in the literature (Lites 1984) we find a mean penumbral intensity ratio of 0.83. Using an umbral temperature of 3700 K (Foukal 2004) we calculate $\alpha = 0.302$. This is only slightly greater than the values of $\alpha_{\rm therm}$ in Tables 1 and 2. Hudson *et al.* (1982) obtained $\alpha = 0.315$ using mean sunspot values from Allen (1963)

3. Conclusion

The bolometric contrasts (related to the spot mean temperatures) from four different wavelengths agree closely for the two sunspots studied here. The bolometric contrasts from restored images agree closely with values of α found in the literature.

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