

SECULAR CHANGE IN EQUIVALENT WIDTH OF C 5380, 1978 - 90.

William C. Livingston

National Solar Observatory, Tucson, Arizona 85726

Abstract

The equivalent width of the high excitation photospheric line of C 5380Å has been measured 3-4 times monthly in the solar irradiance spectrum since 1978. C 5380 behaves differently than other spectral lines in that it is unmodulated by the activity cycle, yet has increased in strength by $0.081 \pm .008$ mÅ in 12 years. Nominal equivalent width is 22.25 mÅ. Implied is a temperature increase of 4.6 K which is an order of magnitude greater than constraints allowed by ACRIM results.

Introduction

Twelve years of monthly measurements of selected Fraunhofer lines in the full disk irradiance spectrum now provide us with a good picture on the response of various spectral features to a changing Sun. Chromospheric lines such as Ca K, H alpha and Ca 8542 all weaken a percent or so with an increase of solar activity, Fig. 1. Resolved disk observations suggest this weakening is due to active region plage. In such areas chromospheric lines become shallow or even display emission components.

He 10830, on the other hand, is a maverick that strengthens in plage. From solar minimum to maximum the depth of this line can double in the irradiance spectrum.¹ It has been demonstrated that the strengths of these chromospheric lines correlate well with Ly alpha emission and thus can serve as surrogates for the EUV-UV solar output.²

At the photospheric level the pattern is not so simple. One might expect strong photospheric lines to show the greatest variability. Eclipse "flash" spectra,³ which clearly represent the chromosphere, tell us that emission strength goes hand-in-hand with disk equivalent width. If we think of this emission component as "filling in" the cores of strong lines, then they should weaken at solar maximum. The central depths of such lines do display a slight chromospheric weakening with activity (not reproduced herein). Equivalent width, on the other hand, seems constant in our data, for example Fe 5250.6 in Fig. 2. Probably this is a matter of line saturation⁴ combined with insufficient instrumental sensitivity.

The equivalent widths of most moderate to weak photospheric lines track nicely the chromospheric lines in cyclic variability, see Mn 5394 in Fig. 2. In terms of percentage change they are in fact comparable indicators, although observational error is greater owing to their relatively small central depths.

Like He 10830, the "photospheric" oxygen triplet at 7774Å is another loner. Unlike all other photospheric lines O 7774 increases in strength with activity. Probably there is some NLTE effect at work here.

Finally we come to the behavior of C 5380Å. The equivalent width of this line shows no detectable cycle variability, but curiously has increased in strength over our observing time interval of 12 years.

C 5380 on the Resolved Disk

CI 5380.3231Å has an excitation potential of 7.65 V. The species has an ionizing potential of 11.26 V and is always completely neutral in the photosphere (compared to Fe, which is not). At disk center C 5380 has a central depth with respect to the continuum of about 0.155 and an equivalent width of 26.3 mÅ. At the limb ($\mu = 0.1$) the central depth reduces to about 0.04. According to the HSRA model atmosphere, the peak in the physical height of the response function for C 5380 lies only slightly above (~25 km) the contribution function for the $\lambda 5380\text{\AA}$

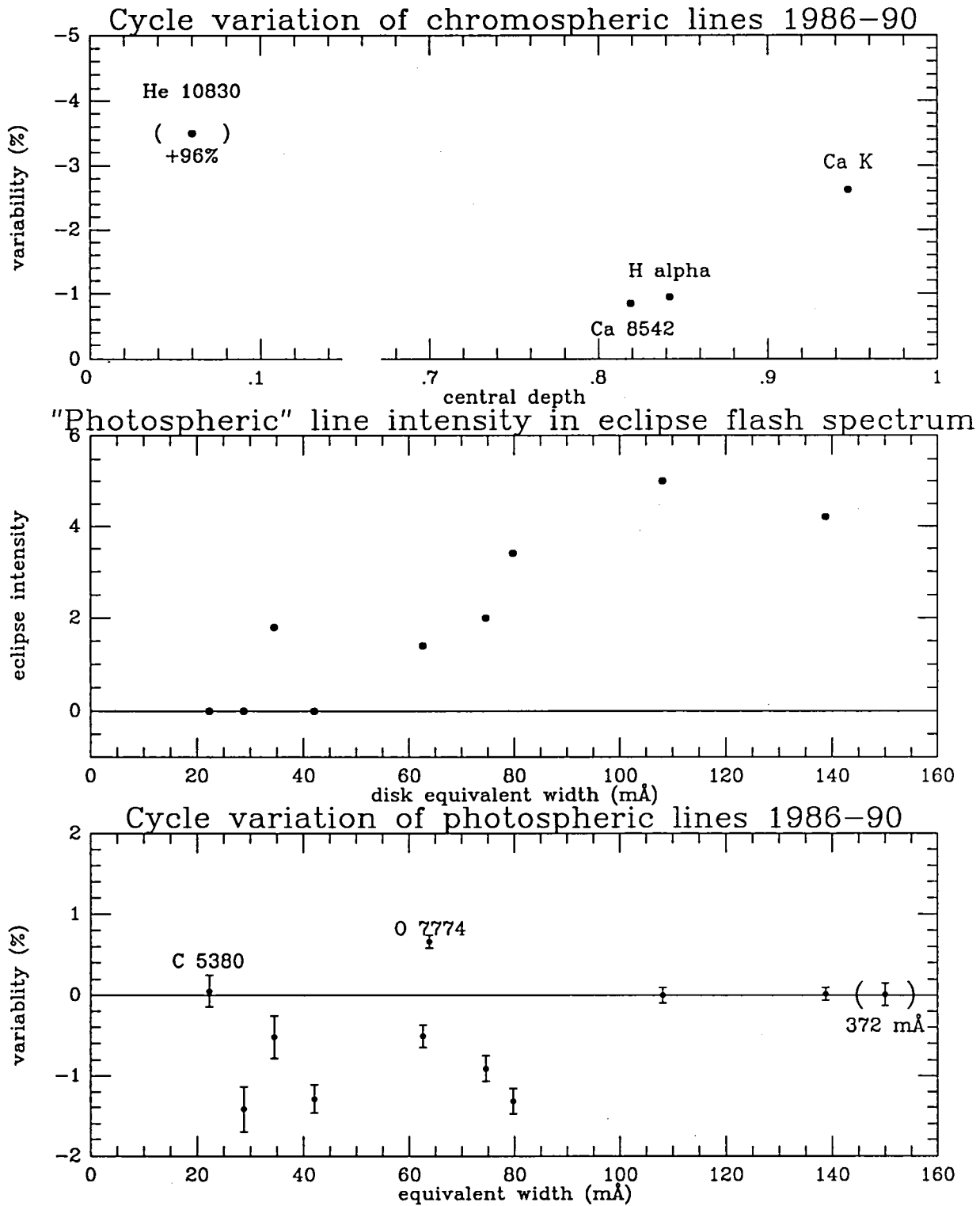


Fig. 1. Observed cycle modulation of a variety of chromospheric (top panel) and photospheric lines (bottom). Strength of the photospheric lines in an eclipse flash spectrum is indicated in the middle panel. Eclipse intensity of zero means the line is not seen. The lines shown are the same as in the lower panel except for O 7774, which is off scale, and the 372 mÅ line which was outside the wavelength coverage. All chromospheric lines are off scale in this representation.

continuum. At disk center $\Delta W/W = +.00086/K$, i.e. the line should strengthen with increasing temperature. Compare this with $\Delta W/W = -.00063/K$ for the typical moderate strength Fe line such as Fe 5250.6. See Livingston, et. al.,⁵ and Livingston and Holweger,⁶ for more details and references. From 105 days of observation we obtain at disk center, $W_\lambda = 25.024 + .0117 \pm .0025$ (year) mÅ, or an increase of $0.14 \pm .03$ mÅ/12 year.

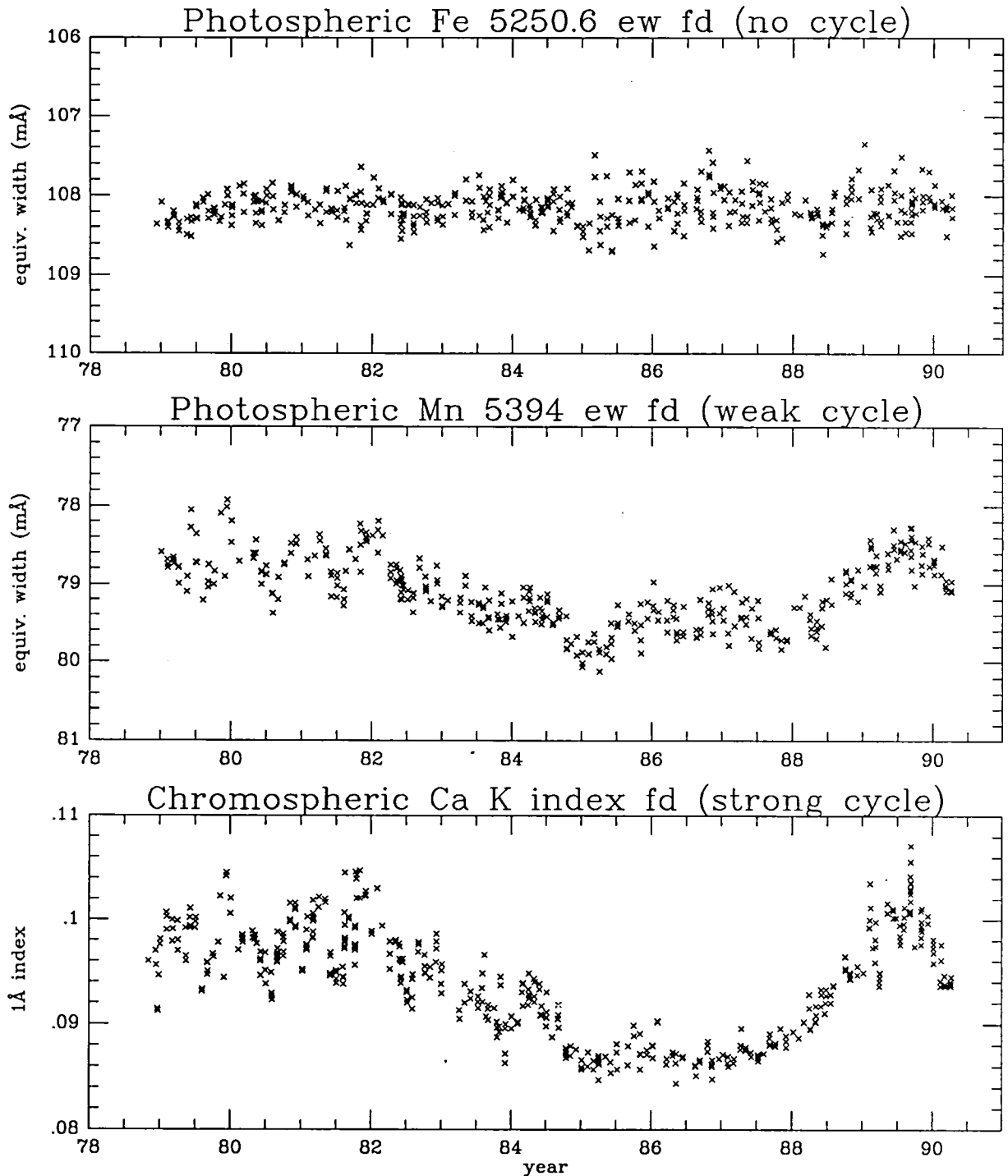


Fig. 2. Examples of solar cycle behavior of selected lines in Fig. 1. The Mn 5394 plot is inverted to agree in sense with Ca K.

C 5380 Observed Full Disk

Although our C 5380 full disk archives extend back to 1976, various changes in the instrument and observing technique contaminate the data before November 1978. Since then, however, all aspects of the observations and data reduction have remained fixed. Annually the telescope mirrors are recoated and once, in April 1980, the spectrograph mirrors were also re-aluminized. Otherwise the system has remained immutable (a beneficial aspect of poor funding).

Fig. 3 displays the temporal record for individual observations. A least square fit to the 487 days of data gives $W_\lambda = 21.67 + .00675 \pm .00066$ (year) mÅ. The formal probable error in the slope is one-tenth the value. Implied is an increase of $0.081 \pm .008$ mÅ/12 years. This is slightly smaller than the center disk value, and for various reasons the probable error is less. If the HSRA model were applicable, a temperature increase of 4.6 K is deduced. Assuming the Sun is a black body this leads to an increment in the solar constant of 0.3%, an amount incompatible with ACRIM results. Evidently the HSRA model is inappropriate here.

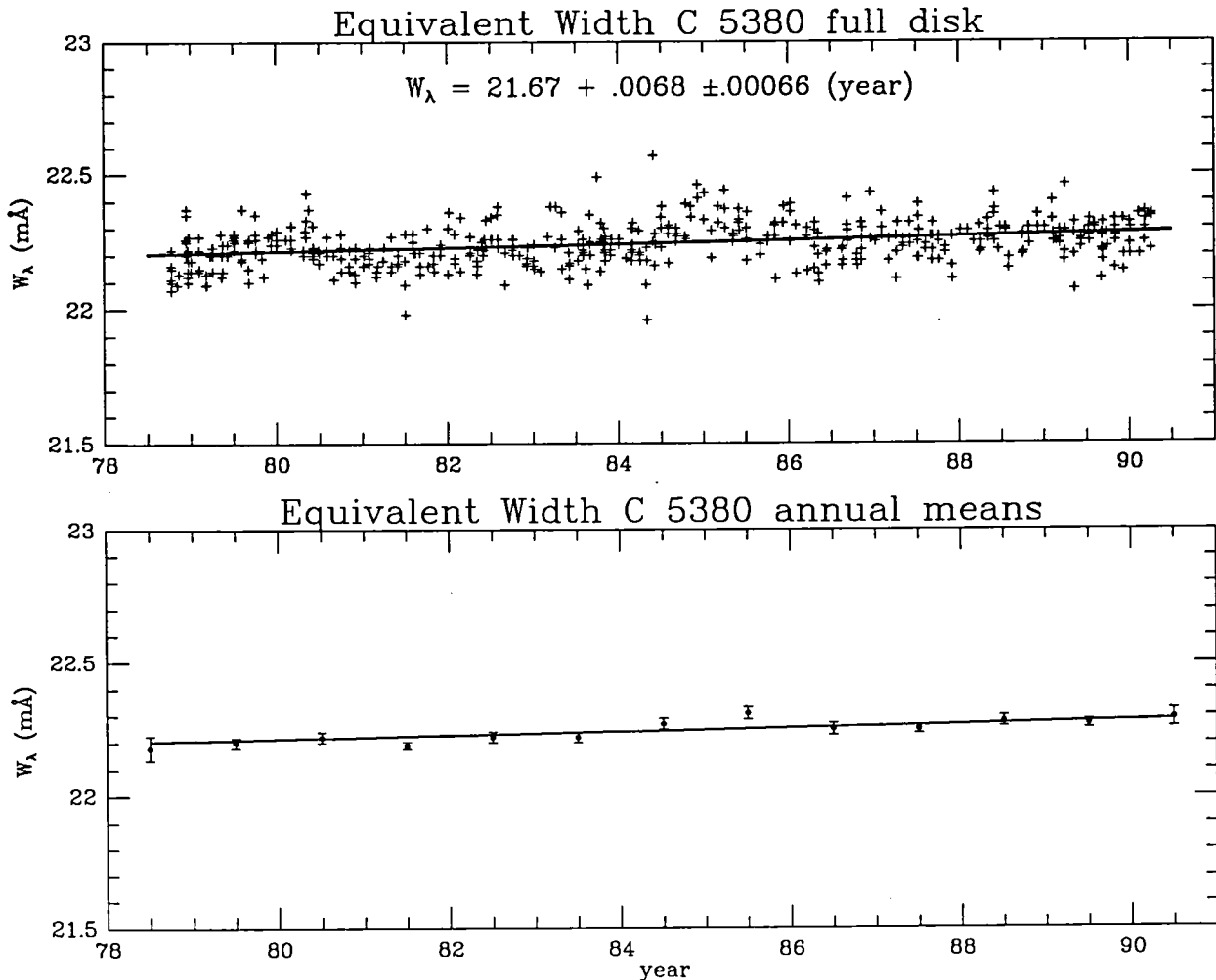


Fig. 3. Temporal record of C 5380. Top panel is individual days, each an average of 6 observations. Bottom, the same data averaged into one year bins. The straight line fit is from the un-binned data.

Summary and Conclusions

A comparison between a wide variety of Fraunhofer lines, and how they empirically respond to the solar activity cycle, leads us to conclude that C 5380 is a unique indicator of conditions in the low photosphere. Model calculations suggest it is more temperature sensitive (and should respond in an opposite sense) compared with other lines, yet it displays no significant cycle modulation. Its equivalent width appears to have increased by $0.081 \pm .008$ mÅ over a time span of 12 years. Formal statistics suggest this trend is real, and implies a 4.6 K increase in surface temperature. Such a temperature rise translates to 0.3% in the solar constant, and is much too large for compatibility with ACRIM results.

What is needed to understand C 5380? Obviously patience and a longer archival time base is desirable. We may also search for clues on the resolved solar disk. How does C 5380 behave in plage and faculae? Earlier work was inconclusive. Or perhaps the Sun is evolving in a non-thermal fashion on a time scale of 22 years, or longer. Other evidence has been proposed for long term excursions in solar temperature, but such ideas are speculative at present.^{7,8,9}

References

1. Foukal, P., and Lean, J., 1988, "Magnetic Modulation of Solar Luminosity by Photospheric Activity", *Astrophys. J.*, **328**, 347 - 357.
2. White, O. R., Rottman, G. J., and Livingston, W. C., 1990, "Estimation of the Solar Lyman Alpha Flux From Ground Based Measurements of the Ca II K Line", *Geophysical Res. Let.*, (in press).
3. Dunn, R. B., Evans, J. W., Jefferies, J. T., Orrall, F. Q., White, O. R., and Zirker, J. B., 1968, "The Chromospheric Spectrum at the 1962 Eclipse", *Astrophys. J. Suppl.* **15**, 275 - 458.
4. Mitchell, W. E. Jr., and Livingston, W. C., 1990, "Line-blanketing Variations in the Irradiance Spectrum of the Sun from Maximum to Minimum of the Solar Cycle", *Astrophys. J.* (submitted).
5. Livingston, W., Milkey, R., and Slaughter, C., 1977, "Solar Luminosity Variation. I. C I 5380 as a Temperature Indicator and a Search for Global Oscillations", *Astrophys. J.* **211**, 281 - 287.
6. Livingston, W., and Holweger, H., 1982, "Solar Luminosity Variation. IV. The Photospheric Lines, 1976 - 1980", *Ap. J.* **252**, 375 - 385.
7. Kuhn, J. R., Libbrecht, K. G., and Dicke, R. H., 1988, "The Surface Temperature of the Sun and Changes in the Solar Constant", *Sci.* **242**, 908 - 911.
8. Schatten, K. H., and Orosz, J. A., 1990, "Solar Constant Secular Changes", *Solar Phys.*, **125**, 179.
9. Kroll, R. J., Hill, H. A., and Beardsley, B. J., 1990, "A Correlation Between Changes in Solar Luminosity and Differential Radius Measurements. (this conference).