ABSTRACT

The Extreme ultraviolet Imaging Telescope (EIT) of SoHO incessantly observes small coronal and transition region features: EUV bright points, ephemeral regions, brightenings, network enhancements, loop segments, etc. In this work, the small objects are extracted and characterized automatically in terms of their scale, location, peak and background intensities. We correct for the visibility bias introduced by the expansion of bright regions that develops with the solar cycle, and we plot the resulting instantaneous densities over the 1996-2001 period. The four time-series exhibit dissimilar trends. The 171 Å and 195 Å channels are found to show a moderate anti-cyclic behaviour.

Keywords: Sun, corona, solar cycle, bright points

1. INTRODUCTION

“God is in the detail” said the prominent architect Mies Van der Rohe (1868-1969). This is probably true for the solar atmosphere edifice as well. The complex connection between all scales entails a lot of physics, and remains challenging, if not out of reach, for modelling. Causal links across the scales also escape intelligibility, pointing at observational shortcomings [1, 2]. The quest for instruments with higher resolution and cadence is underway [3], but it is of interest to already push the limits of existing data sets, especially when synoptic observations cover an extended time interval. The Extreme ultraviolet Imaging Telescope (EIT) of SoHO [4, 5] has accumulated a long-term image record of the Sun atmosphere over the first half of the solar cycle 23. We verify in this paper that the randomness of small features, apparent in individual images, actually screens systematic trends [6]. If so, they would have a key significance regarding the quiet Sun dynamics, the irradiance models, and the dynamo processes at work below the surface.

Algorithmic tools have been developed and adapted to EUV images. They are briefly described in the next section. Systematic extraction of the small objects has been performed from January 1996 till May 2001. The results are presented and discussed in section 3.

2. EXTRACTION AND DATA SET

Given the great amount of “small” objects in an EIT image, it seems commonsensical to seek for an automated method. This is however not straightforward, and the simple techniques, such as plain thresholding, do not work. The scale being a meaningful attribute, it is natural to look for multi-scale approaches, among which the wavelet analysis has proven favourable. The Continuous Wavelet Transform (CWT) [7] is a pseudo-filter that enhances any particular scale, or rather, attenuates the others [8]. It is more flexible than the Discrete Wavelet Transform when the scales of interest are continuously variable. Fast algorithms exist; they avoid computing every convolution. The CWT is thus not only a more sophisticated tool, but also more CPU-effective in comparison to our earlier scheme [6]. The algorithm extracts the potential candidates across scales, and is fully described in [9]. Its application to one individual image provides a list of objects described by their respective location on the solar disc, main scale, maximum and integrated intensity, estimated background, contour coordinates… See figure 1 and 2.
is smaller than the pixel. Many such objects are solar though [6, 9]. The upper end was set at 50 pixels in diameter for full resolution images, which corresponds to 90 Mm. Objects that still have a component above the threshold at this largest scale, were not further considered. This is illustrated in figures 1 and 2. The purpose of this option is to exclude the “normal” active regions. The 90 Mm threshold value was derived from the visual inspection of several images.

Figure 2. Sub-window of the EIT image taken in the 171 Å bandpass on May 10, 2001 at 19:07:26. The intensity scale is logarithmic. Contours of individual events are over-plotted. The black one is discarded.

The dataset consists of a sampling of the EIT archive. Images in each of the four bandpasses are selected with a regular interval of five days, leading to approximately 5 images per solar rotation. An additional requirement is the absence of telemetry missing blocks, which would otherwise complicate the image processing and the interpretation. Except bakeouts and attitude losses, this constraint never introduces more than one-day syncopation. The selected files are then processed according to the December 2001 preparation procedure that corrects for the in-flight degradations [10, 11, 12]. The dataset is hence made of ~1400 Level-1 EIT images spanning from January 1996 to May 2001 in the 4 channels: 171 Å (Fe IX, 1 MK), 195 Å (Fe XII, 1.5 MK), 284 Å (Fe XV, 2 MK), and 304 Å (He II, 80000 K).

3. RESULTS AND DISCUSSION

Once a small-feature inventory is available, there are many accessible studies, from differential rotation assessments to various distributions survey. In the present paper, we concentrate on the cycle dependence, as it is a rather straightforward question to address, it is a matter of research [e.g. 13, 6, 14], and it is the theme of the SOHO-11 symposium.

The principal pitfall is the changes of the background on top of which the small objects occur. This introduces an observational bias, since the visibility of the smaller and fainter features decreases when the background brightness rises. The anti-cyclic variation was first reported in [15], and the visibility problem had therein been already recognized and rectified. This observational bias, and the potential anti-cyclic correlation are two competing effects. At present, the net result remains questioned [6, 13, 14], and needs to be confronted to the EIT data [6, 16].

Figure 3. Time-series of the on-disc histograms in all bandpasses. The vertical axis is the decimal logarithm of the corrected (level-1) intensities. The grey scale is logarithmic, and represents the number of occurrence. The plotting procedure made use of the SSW utplot routine, which interpolates in time. The plain curve outlines the peaks of the histograms (i.e. the vertical slices). The horizontal dashed line indicates the threshold discussed in the text.
In an attempt to tackle the visibility issue, we determine a background threshold for each EIT channel. These values are permanent in time, but had to be channel-dependent to accommodate for the discrepant fluxes. Except at 284 Å, they were chosen roughly equal to the most represented signal during solar minimum (see figure 3). They visually correspond to the lowest active Sun intensities. Below them, the visibility can be assumed maximal and constant. This admittedly needs quantitative assessment, but it convincingly avoids the regions susceptible to bias the trends. At 284 Å, a higher value tries to maintain together visibility and statistics throughout.

The time-series of the projected darker areas covered by the darker regions are shown in figure 4. While they present little long-term drift at 171 Å, they have an inverse correlation with the cycle at 195 Å, at 304 Å, and more pronounced at 284 Å, for which the canopy is the most perceptible. The number of objects whose estimated background is below the limit is plotted as a function of time in figure 5, and the normalized ratio in figure 6. The solar rotation modulates all time series. The 304 Å channel shows a regular growth of the normalized density of small features, artificially caused by the dark area shrinkage. The density of such events in He II thus appears steady. This can be related to the stable density of the photospheric drivers [14].
Once normalized, the two cooler coronal lines 171 Å and 195 Å still present an anti-cyclic variation, with factors 2.2 and 1.7 respectively, while [15] had found one order of magnitude. It stems from the growth in the number of features, which dominates the contraction of the dark regions. Our procedure includes objects that a visual extraction procedure would reject: it combines EUV coronal BPs, loop segments, and CRHs. The loops are likely to be in phase with the cycle, while the CRHs must on average negatively correlate. Since the CRHs are not expected to control the observed modulation, and since the subtraction of the loop artefacts will only enhance the anti-cyclic pattern, the phase opposition seems real. Moreover, the hotter the coronal temperature, the less distinct becomes the trend. The unbiased 284 Å time-series exhibits no clear correlation, but the shrinkage of the darker regions exceeds the reduction of the counts after 1999. Although its threshold is too large with respect to the 1996 histograms, it gathers only a few pixels in 2000. As a consequence, the visibility correction and the statistics are not good. Further investigation is required.

The anti-cyclic correlations do not reflect the long-term constancy of the expected drivers [14], but evolving coronal conditions could control this variability. In future work, we will better categorize the small objects by their morphology, their time and spectral properties, and their associated magnetic structures.

SOHO is a project of international cooperation between ESA and NASA. The authors acknowledge the support of ESA/PRODEX and the Belgian OSTC.

4. REFERENCES

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