Visibility of Active Region emergence in magnetogram data

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Introduction

- The emergence of a new Active Region (AR) on disk is typically detected via analysis of full-disk continuum images or line of sight magnetograms.
- Histograms of locations of new emergences as deduced from continuum (sunspot) data, show an East-West asymmetry (see Figs. 1 and 2).
- The asymmetry can be explained as a visibility effect caused by the centre-to-limb variation of sunspot visibility combined with the solar rotation.
- Here we analyse whether a similar asymmetry is observed when new AR emergences are identified by means of line of sight magnetogram data.
- We use full-disk magnetograms from the NSO Kitt Peak 512-channel magnetograph and a morphological detection technique on difference images to identify new emergences.

Sunspot data

Asymmetry in the location of emergence

- Several techniques can be used to identify the locations on the solar disk where new sunspots emerge. The simplest is to make use of sunspot catalogues: by comparing entries for adjacent days, new regions can be identified. Alternatively, automated sunspot detection can be used.
- Because emergence of a new active region is a relatively rare event, datasets spanning a large number of years are needed.
- An asymmetry in the longitudinal distribution of new sunspot emergence was first reported by Maunder [1], who analysed catalogues of Greenwich Royal Observatory observations.
- Dalla et al [2] used data from the USAF/Mount Wilson catalogue, for times between 1981 and 2005, to obtain the emergence asymmetry shown in Fig 1a. This figure also shows the asymmetry in the locations where sunspots are seen to disappear from disk (Fig 1b).
- Watson et al [3] applied automated techniques to detect sunspots in MDI quasi-continuum data and obtained the asymmetry shown in Fig 2.

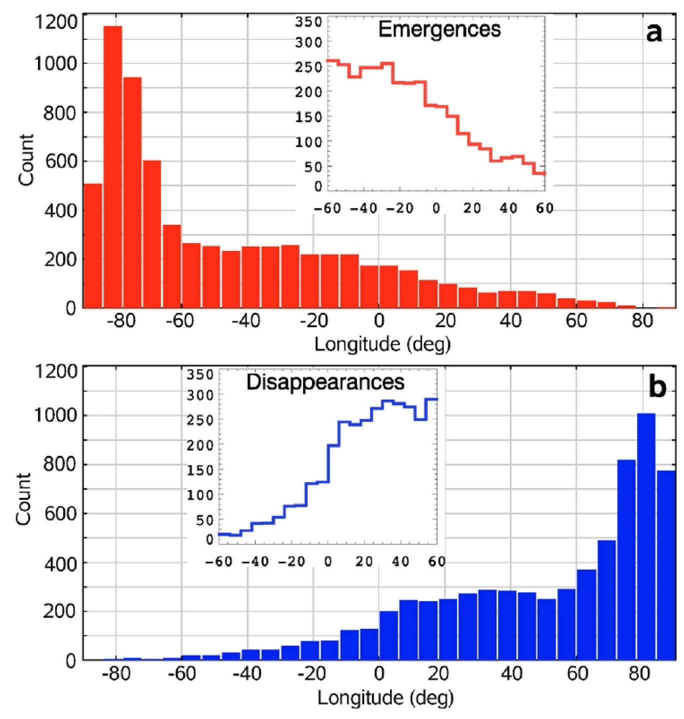

Fig 1: Histograms of number of sunspot regions versus their longitude at 12:00 UTC on the day when they were first a) and last b) observed in the USAF/Mount Wilson sunspot catalogue. Each longitude bin is 6° wide and the total number of regions is 6862. Longitude 0° is the Earth-Sun line (From Ref [2]).

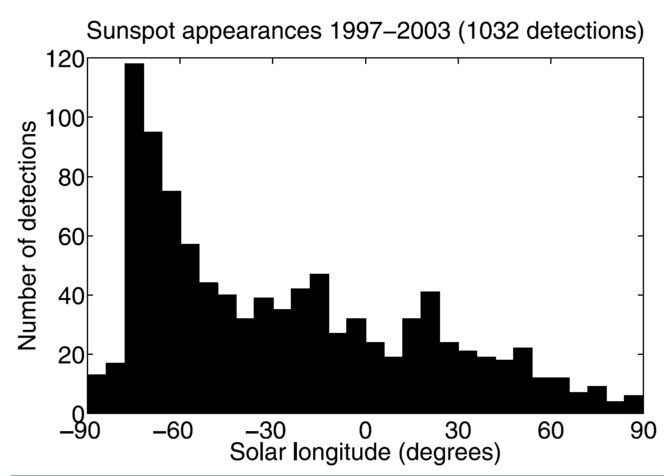

Fig 2: Histogram of the number of sunspots versus their longitude from automated detection on MDI data (From Ref [3]).

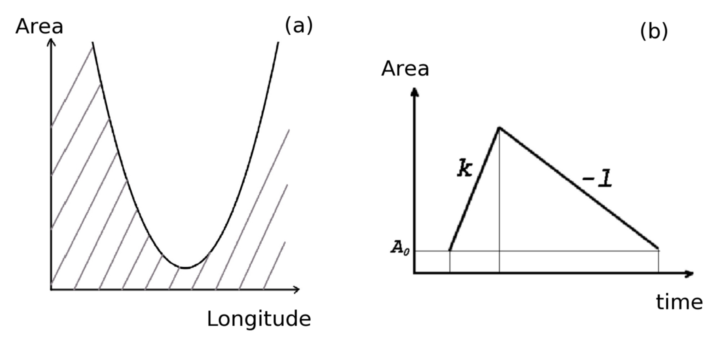

Fig 3: (a) Visibility function. (b) Schematic of sunspot area evolution.

Explanation of observed asymmetry

- The East-West asymmetry shown in Figs. 1 and 2 is very strong: from Fig 1a, 825 new regions are seen to emerge in the bin [$-60°$,$-40°$], while only 177 in [$+40°$,$+60°$], a ratio of 4.7:1.
- The asymmetry is caused by the fact that visibility of small sunspots is best at the centre of the disk and has a strong centre to limb variation (see visibility function, Fig 3a) [4,5].
  Two phenomena combine to produce this effect:
  - sunspot regions are evolving: their evolution can be characterised in terms of their area and in a zero-th order approximation can be described by a curve such as shown in Fig.3b: a growth phase with slope *k* and a decay with slope *-l*.
  - the solar rotation carries sunspots that emerged in the East of the Sun towards regions of better visibility (i.e. towards the centre of the disk) and regions that emerge in the West towards regions of worse visibility.
- To be observed, a sunspot needs to cross the visibility threshold, and this is more likely for spots born in the East of the Sun (see Fig 3a).
- Watson et al [3] modelled the reduction in sunspot visibility due to the Wilson effect and were able to estimate the depth of the Wilson depression by fitting the asymmetry data.

Automated detection of new emergences in magnetograms

- In this study we focus on magnetogram data, with the aim of verifying whether an asymmetry in the location of emergence of new ARs exists.
- We use full-disk magnetograms from the 512-channel magnetograph at the NSO Vacuum Telescope located at Kitt-Peak (data available at http://diglib.nso.edu).
- A number of algorithms for automated identification of ARs and ephemeral regions in magnetograms have been developed in recent years [6-10].
- Our detection method is based on applying morphological techniques to magnetogram difference images.

Generating a difference image

- Firstly, magnetogram pairs are identified, with each pair consisting of images separated by $\sim$1 day. We indicate the image at the first time as I_1 and the image at the second time as I_2.
- Images are smoothed using a gaussian filter.
- I_1 is rotated forward in time to the time of I_2 using the Solarsoft mapping software, giving rot(I_1).
- Absolute values of the images are calculated and a difference image D is derived as:

$$D = \mathrm{abs}(I_2) - \mathrm{abs}(\mathrm{rot}(I_1)) \qquad (1)$$

- Fig 5a shows an example of a difference map obtained with the above procedure.

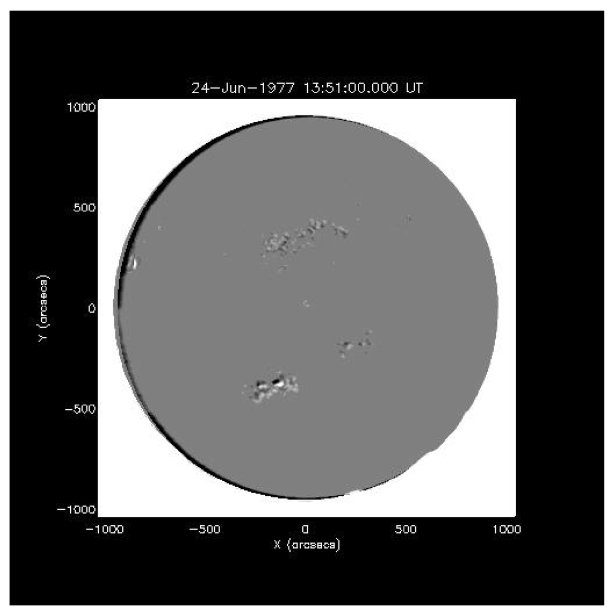

Fig 5a: Difference image showing a newly emerged region in the centre of the disk in white, and some old regions having both black and white pixels.

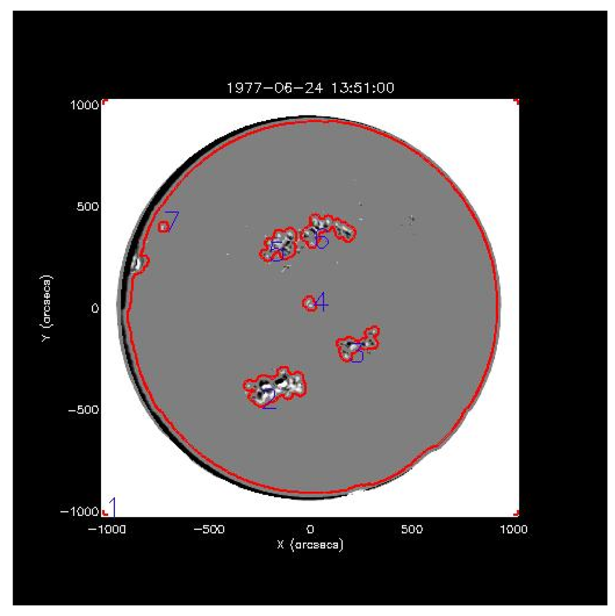

Fig 5b: Result of automated detection on the difference image. A large imbalance between positive and negative pixels is indicative of a new or disappeared region.

Identifying new emergences

- A newly emerged AR appears in the difference image D as a fully positive (white) region.
- A pre-existing region which has evolved will have a combination of positive pixels (indicating new emergences and flux increases within the region) and negative ones (due to disappearence or flux reduction) in D.
- A region that has disappeared will appear in D as fully negative (black).
- Regions are identified in D by means of a morphological opening operation using a circular disk followed by dilation also using a disk.
- An example of regions detection in D is shown in Figure 5b. Region 4 is identified as a new emergence.
- Parameters of each region are then calculated, in particular the positive/negative imbalance defined as I=$(p_+ - p_-)/(p_+ + p_-)$ where p_+ is the number of positive pixels in the region and p_- the number of negative ones.

Results

- The automated detection algorithm was run on a set of 1768 NSO Kitt-Peak magnetogram pairs from the time interval from 1972 to 1988.
- Fig. 6 shows a histogram of the imbalance parameter I.

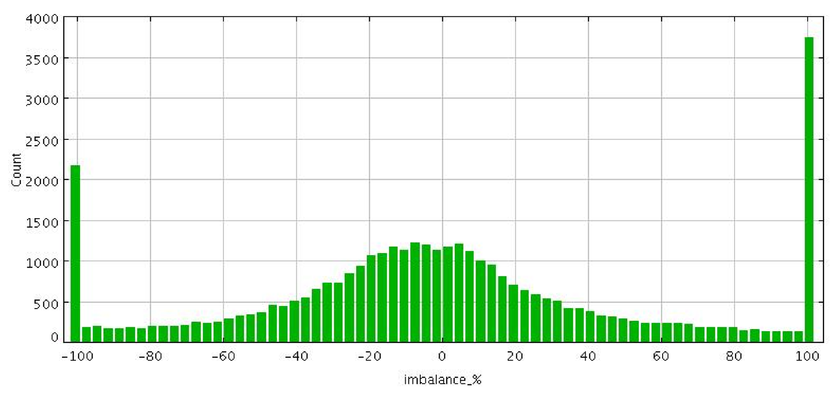

Fig 6: Histogram of imbalance parameter. Regions in the peak near I=100% are identified as new emergences and those in the peak near I=-100% as disappearances.

- We classify all regions with I>99% as newly emerged regions and those with I<$-$99% as disappeared regions.
- Fig. 7a shows the histogram of locations of new emergences and Fig. 7b that of locations of disappearances.

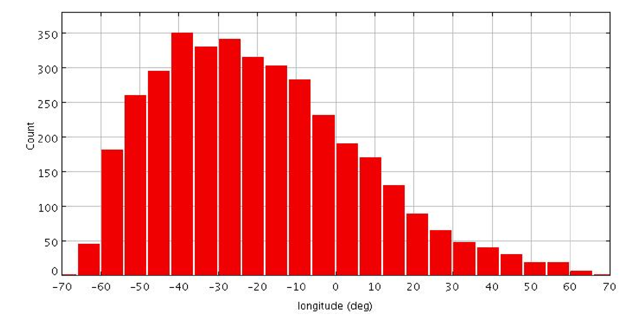

Fig 7a: Histogram of locations of new AR emergences as identified from magnetogram data.

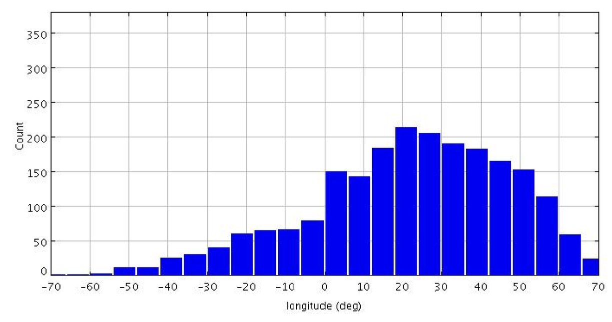

Fig 7b: Histogram of locations where ARs disappeared as identified from magnetogram data.

- As was the case for sunspot data, the asymmetry in emergence location is very strong. From Figure 7a, 851 new regions are seen to emerge in the bin [$-60°$,$-40°$], while only 79 in [$+40°$,$+60°$], a ratio of 11:1.

Conclusions

- We developed a method for automated detection of new AR emergences in line of sight magnetograms.
- A strong asymmetry in the location of emergence of new regions has been found by using the method on NSO Kitt-Peak full disk magnetograms. The asymmetry is similar to the known sunspot emergence one.
- An asymmetry in locations where regions disappear is also seen.
- The total number of regions detected emerging is larger than the number of disappearing regions, possibly due to the fragmentation of ARs as they decay.
- Initial results show that the visibility of new emergence is worse in magnetogram data than in suspot data.
- Many new ARs emerging in the West of the Sun are invisible in magnetogram data.

References:

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