

Magnetic evolution of emerging active region 11856 using a potential field model

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Abstract

Active region 11856 was observed on the solar surface in October 2013. It provides an example of emerging flux in an already established active region – the distribution of the photospheric magnetic field shows an initial bipolar configuration, into which a second bipolar field emerges over the following days. The timing of this event coincided with the production of several C-class flares.

The active region is studied using a newly developed and fast potential field algorithm to construct the coronal magnetic field from the SDO/HMI magnetogram data. By applying this method over the time period in which the flux emergence occurred, the changes in the magnetic field caused by the emerging flux can be revealed with a focus on the topological changes due to the interaction between the newly emerged and pre-existing bipoles. This then allows for a quantitative comparison of the expected magnetic energy of the region as it evolves.

The method

- The extrapolations were performed using the HARP series magnetograms (Hoeksema et al. 2014) as boundary conditions input to the code. The other boundaries of the computational box have open conditions to allow the field to leave.

- The time range was selected based on the quality of the data (near disk centre) and to capture the main period of flux emergence.

- The technique is a vector potential formulation (Amari et al. 1999) designed to satisfy the divergence free condition for \mathbf{B} . Calculations are performed on a staggered grid, solving the following equations using finite differences:

$$\nabla^2 \mathbf{A} = 0$$

$$\nabla \times \mathbf{A} = \mathbf{B}.$$

- When the field has been computed, the magnetic energy is found:

$$E_m = \int_V \frac{B^2}{2\mu_0} dV.$$

- An estimate of the upper limit of the energy can be given by the unipolar field ($B_n = |B_n|$) (Aly 1984, Sturrock 1991).

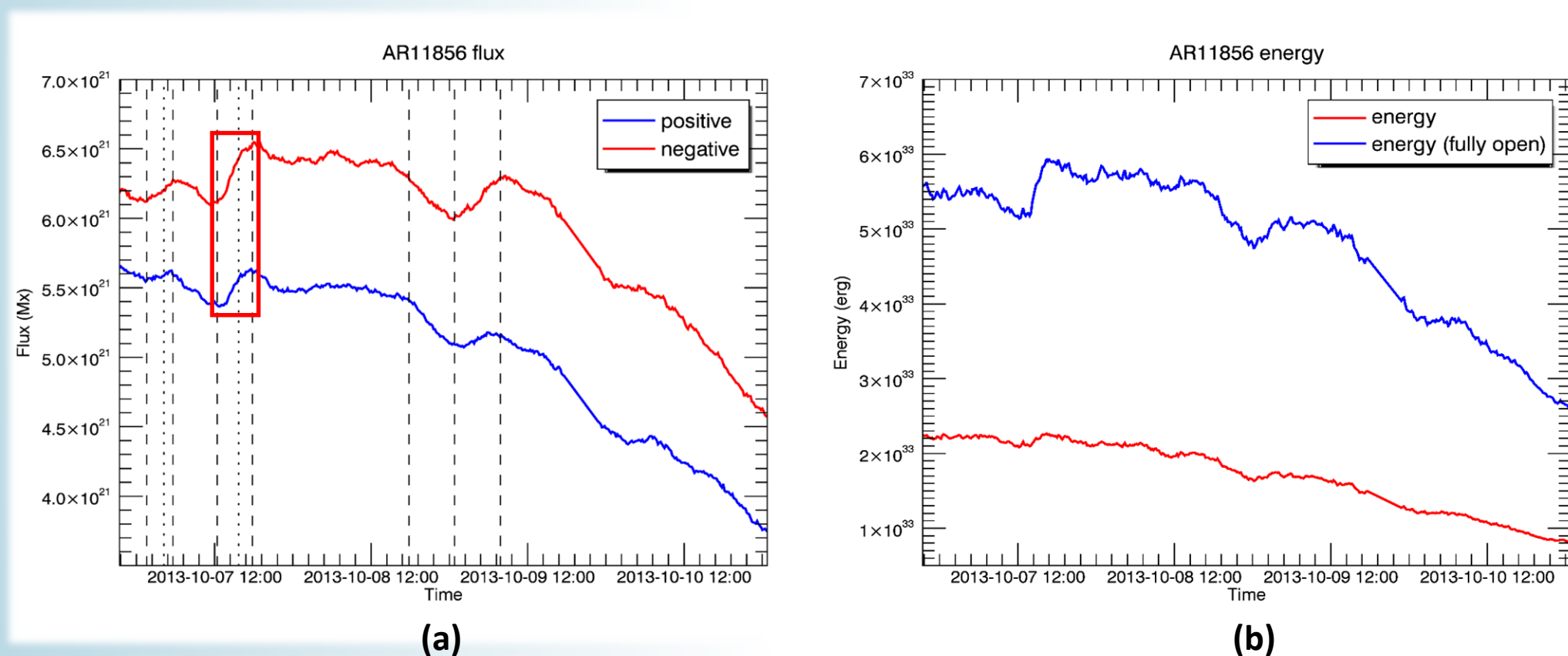


Figure 2: Graphs showing the change of the magnetic flux of the active region during the period of study. Plot (a) shows the fluxes on the bottom boundary of the computational volume (as given by the magnetograms) while plot (b) shows the variation of the magnetic energy of the active region with time as calculated from the extrapolated fields. The upper limit is the energy obtained from the extrapolated unipolar field.

On plot (a), the dashed lines indicate the different identified stages of the evolution and the dotted lines show the peak times of solar flares. The red box highlights the time frame from which the images in **Figure 1** were taken.

Summary

- Using a potential field model, the energy of active region 11856 was calculated over a period of several days at a time of flux emergence. This is compared with an upper estimate of the energy as given by the unipolar field, where the difference between the two energies giving an estimate of the free magnetic energy.

- The HARP series magnetograms were used to perform the extrapolations, which have a time cadence of 720 seconds.

- The method developed has been shown to be suitable for studying the evolution of active regions over time in terms of the geometry and energy of the extrapolated potential fields. It is also stable and applicable to high resolution data.

References

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Amari T., Boulmezaoud T. Z., Mikic Z., 1999, A&A 350, 1051
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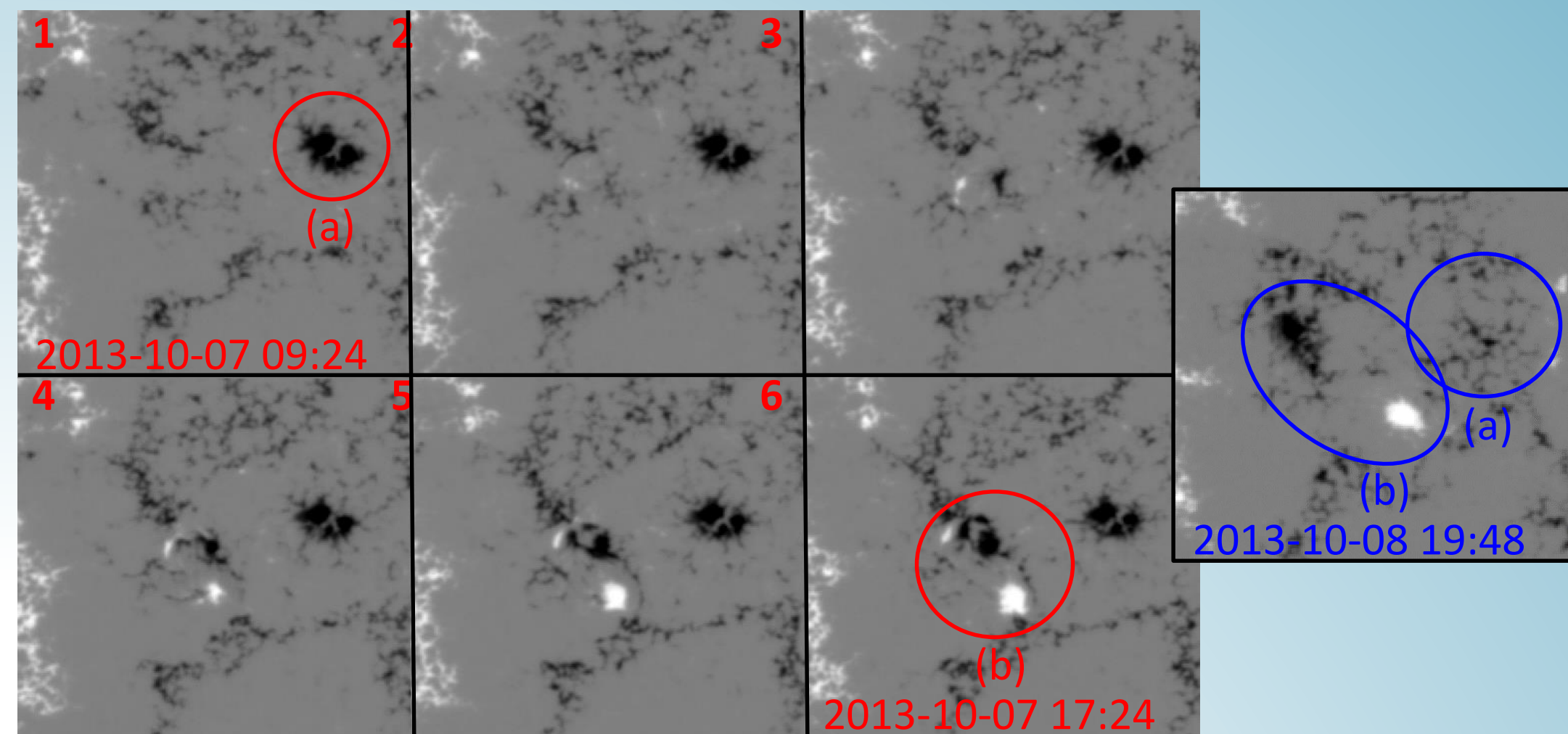


Figure 1: Sub-sections of the magnetograms showing the normal component of the magnetic field in equal time steps over a period of eight hours. A bipole emerges into the established field. (a) shows the sunspot that is initially present while (b) shows the flux that has emerged. A final image indicates that the sunspot has almost disappeared a day after the emergence.

Magnetic field evolution

- An initial bipolar configuration with a second bipole emerging in the heart of the active region over several hours (**Figure 1**). Extrapolations show strong connectivity between the emerging bipole and the original distribution from an early stage. A C-class flare is observed during this period of emergence.

- Over the next day the measured flux shows a slow but steady decrease. The separation between the polarities of the emerged bipole is increasing in this time.

- The emerged positive polarity has moved towards the initial negative, where a rapid destruction of the sunspot and decrease in total flux and energy of the region follows (**Figure 2**).

- Some further flux emergence occurs shortly after this event, though it does not lead to any flares or significant changes in the field geometry.

- The active region decays in flux and energy, with field lines becoming more closed and closer to the bottom boundary.

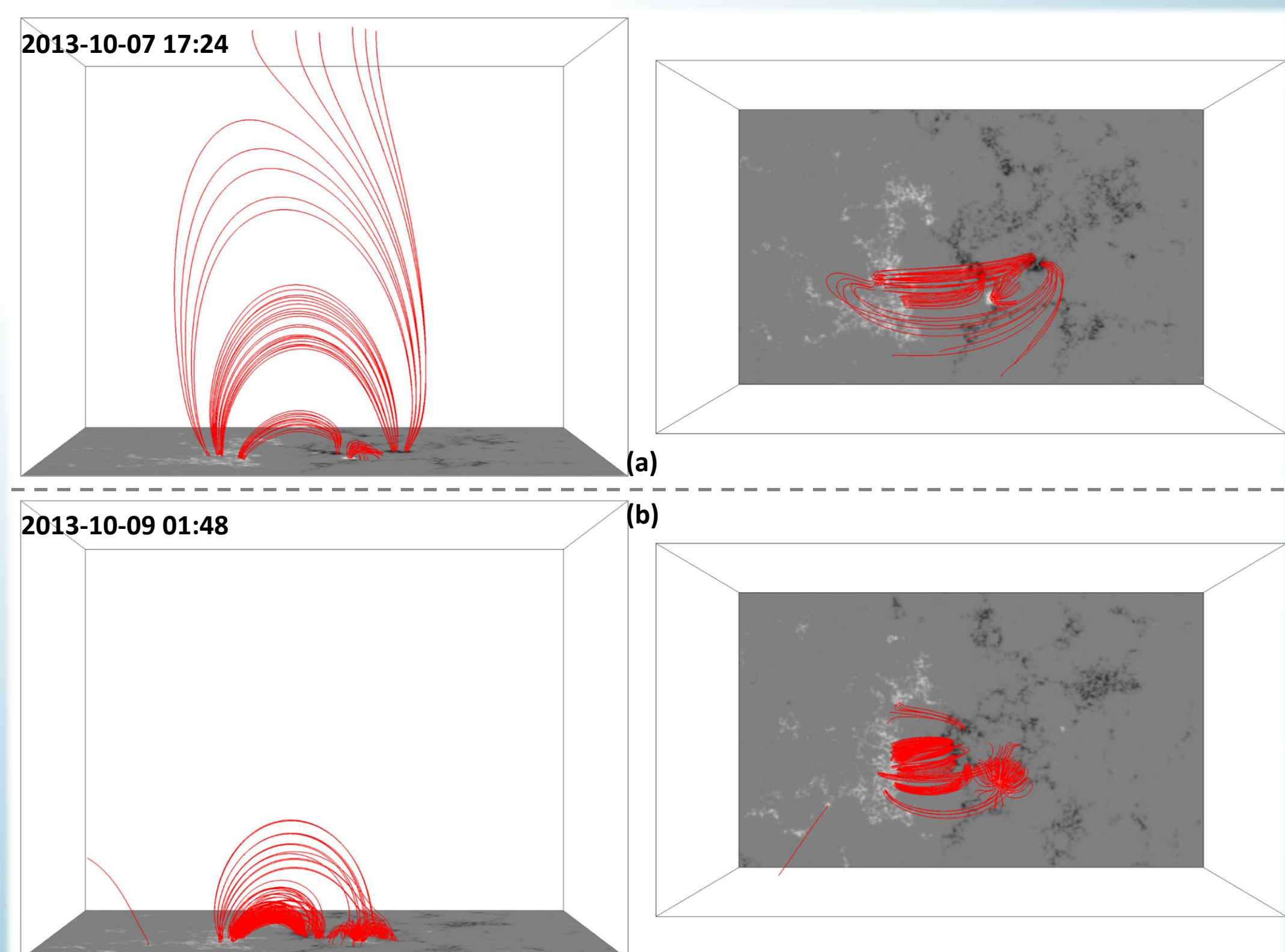


Figure 3: (a) Potential field extrapolation of active region 11856 at time 17:24 on 2013-10-07, shortly after a solar flare occurred and during a period of flux emergence. (b) Another extrapolation at time 01:48 on 2013-10-09, when the sunspot has disappeared and the active region is decaying. The field lines reach an apex that is now much lower to the photosphere.