Dynamics of active regions revealed by tracking of Doppler features

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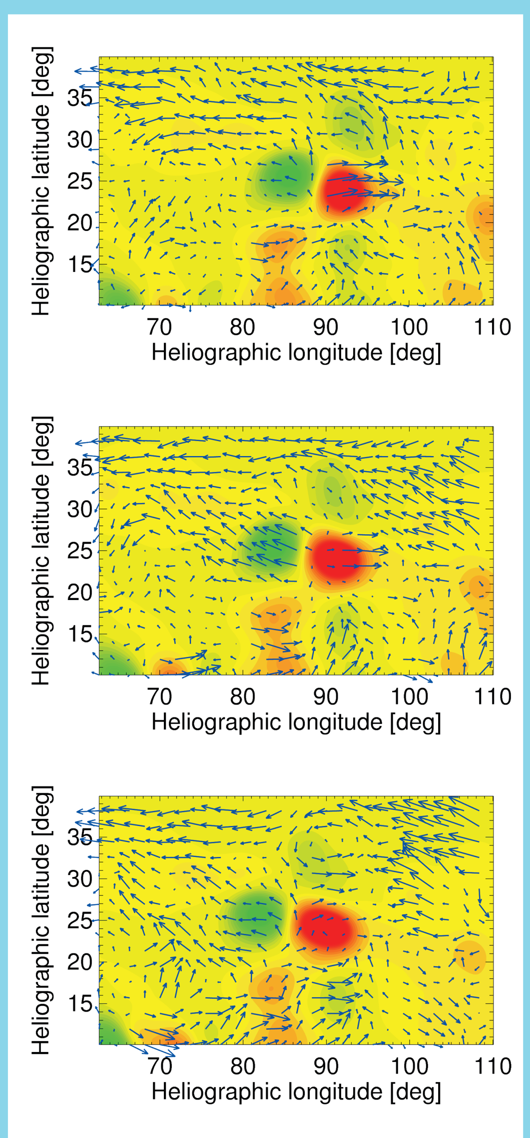
Introduction

The dynamics of active regions in the solar photosphere and in the close sub-photospheric layers is closely related to the solar dynamo process. The magnetic flux emerges from beneath the surface and forms the sunspots and other active phenomena. At some point, the magnetic field starts to disperse, the sunspots disappear and the active region dies, forming the surge-like structures of the trailing polarity expanding to the solar poles, where they contribute to the solar field reversals.



The evolution of the flows in and around the active region NOAA 9368 on March 6, 7, and 8, 2001. The leading polarity rotates significantly faster than the following one and the non-magnetic surroundings in the first day. The whole group slows down in the next two days.

The measurements of the dynamical behaviour of active regions can bring new insights in what is going on with the magnetic field under the surface. In particular, some ideas supported by the theory (Fan, 1994 and Schüssler and Rempel, 2005) suggested that at some point, **bipolar magnetic regions may disconnect from their magnetic roots** and form an isolated island-like feature. The mechanism is based upon the buoyant upflow of plasma along the field lines. Such flows arise in the upper part of a rising flux loop during the final phases of its buoyant ascent towards the surface. The combination of the pressure build-up by the upflow and the cooling of the upper layers of an emerged flux tube by radiative losses at the surface leads to a progressive weakening of the magnetic field in several Mm depth. When the field strength has become sufficiently low, convective motions ablate the flux tube into thin, passively advected flux fragments, thus providing a dynamical disconnection of the emerged part from its parent magnetic structure. This instant **should be observed as the change in the dynamical regime**, because the floating island does not reflect the deep dynamics anymore. In this contribution, we investigate this issue in a more detail.

The data

In recent papers (e.g. Švanda et al., 2006) we introduced a method utilised to measure the large-scale dynamics in the solar photosphere. The method is based on the supergranular-structures tracking in the full-disc processed Dopplergrams. The application of the method allows to compute 24-hours averaged horizontal flow field with resolution of 60" and noise level of 15 m s^{-1}. In the magnetised regions, the method makes it possible to measure the apparent motion of supergranular-scale magnetic features.

The processed dataset contains 1004 full-disc flow maps in 502 days, when the high-cadence MDI data were available and of a good quality. From each map we subtracted the 13-days running average to remove the systematic changes in the differential rotation profile.

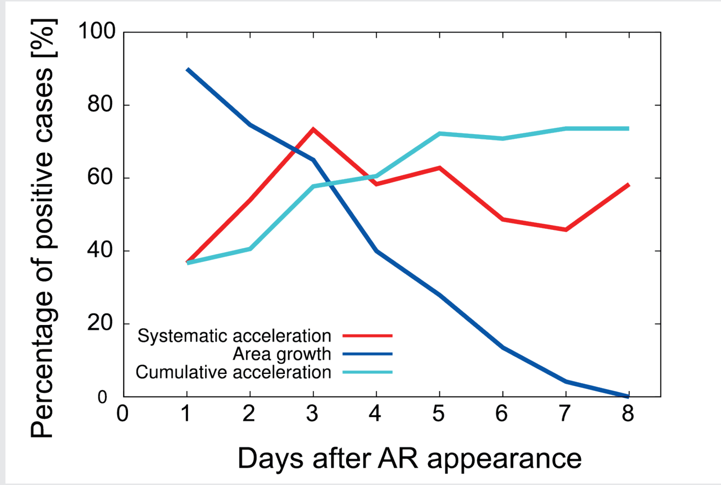
In these maps we identified 564 numbered active regions, from them 522 were observed in more than one flow map. 194 active regions in the dataset emerged less than 60 degrees from the central meridian. From this set we selected 69 bipolar regions that survived at least 4 days in central meridian distance less than 60 degrees. This drastical reduction of the sample was necessary to avoid any possible disturbing effect.

The method

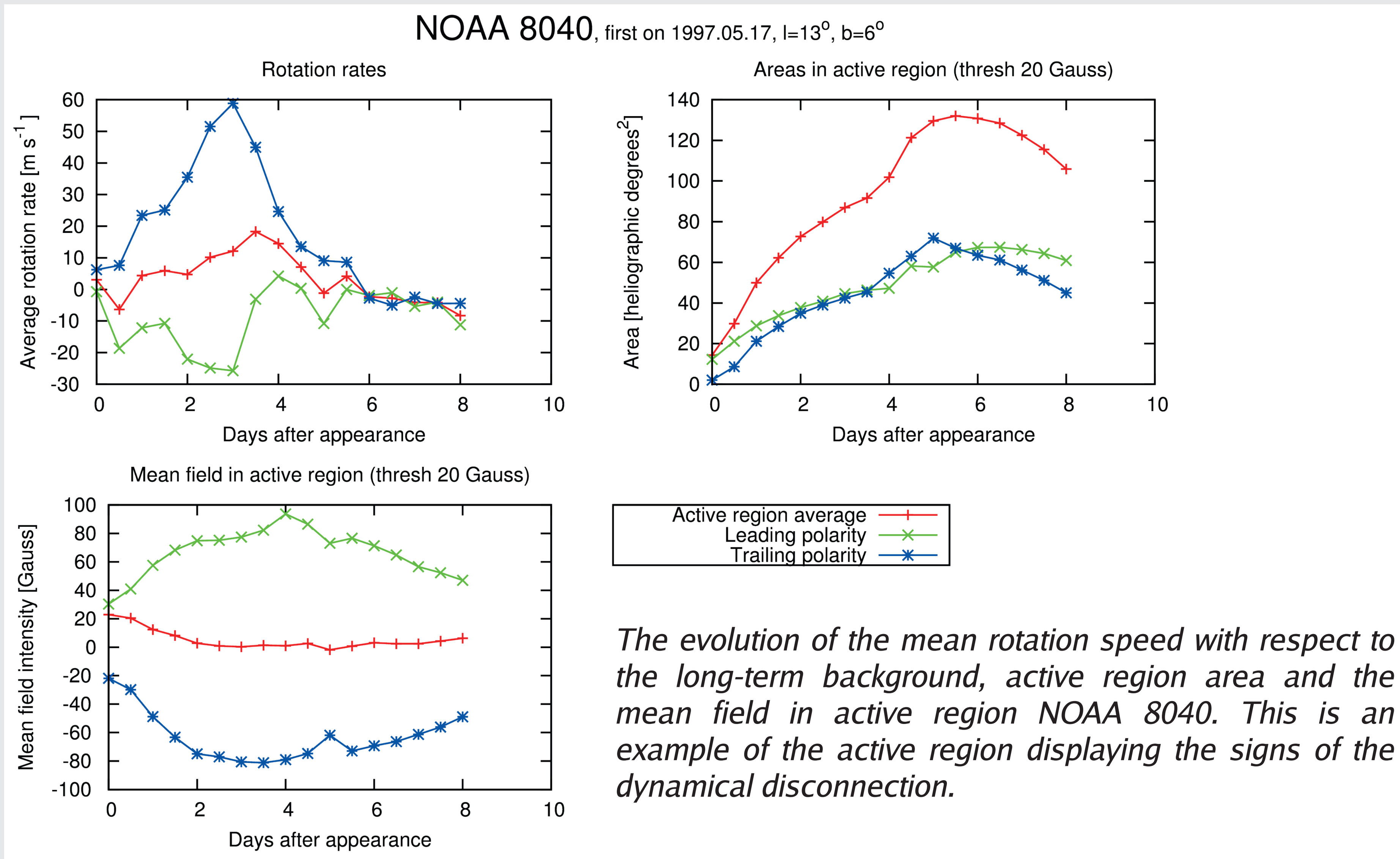
For each active region in the sample we computed the large-scale flow field in the area, its average rotation speed, magnetic field area (with threshold of 100 G) and mean magnetic field intensities in both leading and trailing polarities, sampled by 12 hours. We investigated the change in the dynamics, which could be connected to the effect of the disconnection from the magnetic roots. The expected change should reveal as a sudden deceleration, because the radial gradient of the mean rotation is negative in close subphotospheric layers.

Results

We found that **75 % of the active regions** in the reduced sample **show the characteristic change in the dynamics**. This part of our sample displays a sudden descrease in the proper rotation rate within **typically 3 days after its emergence**. The dynamical disconnection from their magnetic roots is a natural explanation for this behaviour. Our study suggests that this phenomenon is quite common among bipolar active regions.



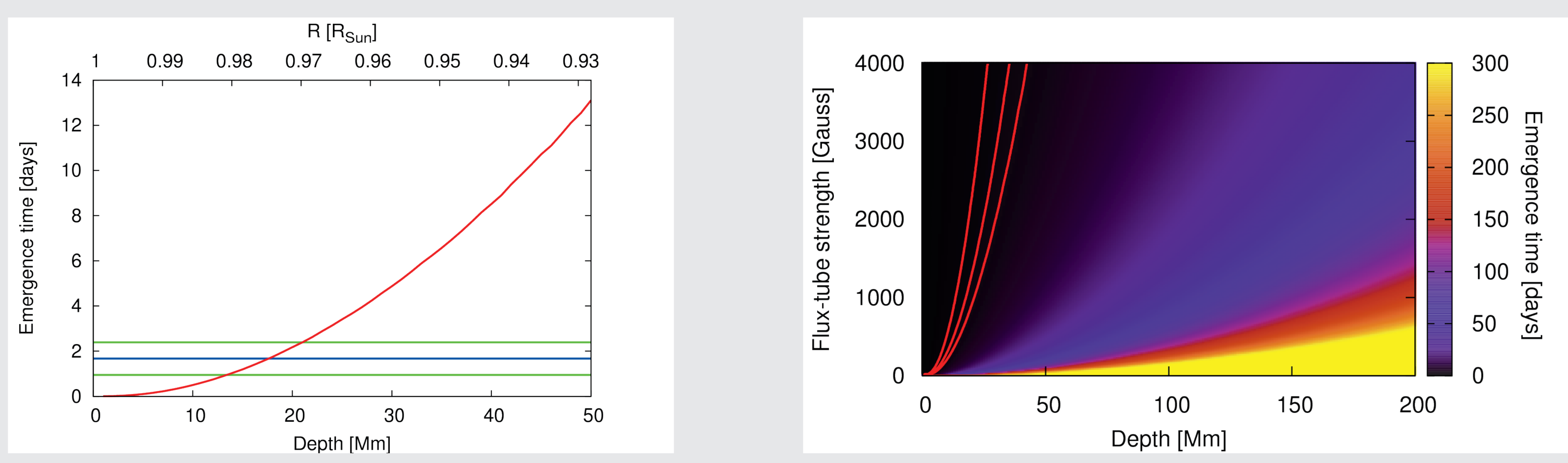
Most of the active regions in the sample of 69, lifetimes of which were more than 4 days, accelerate in first 3 days of their existence. In general, this may mean that for a significant part of active regions, the dynamic regime changes, on average, after 3 days.



The evolution of the mean rotation speed with respect to the long-term background, active region area and the mean field in active region NOAA 8040. This is an example of the active region displaying the signs of the dynamical disconnection.

We observe a systematic phase shift between the time of the dynamical regime change and the time of the maximum in the area. We interpret this as the time, during which the magnetic island rises from its parent magnetic structure to the surface after disconnection. After the disconnection takes place, no more magnetic field is fed into the region and the region starts to diminish.

The systematic shift is 1,67±0,72 days. Assuming 1 kG flux-tube emerging with the Alfven speed, the theoretical shift is 180 days if the flux-tube emerges from the bottom of the convection zone and 7 days, when emerging from the subsurface shear at 0,95 R_{Sun}. Although these numbers represent a very rough estimate, our results show that **the disconnection takes place few Mm below the photosphere.**



The theoretical time-shift between the disconnection time and the time when the maximum in area is reached, based on the assumption that flux-tube rises with the Alfven speed (left – for 1 kG flux-tube as the function of depth, right – as the function of depth and flux-tube strength). The measured time-shift including the error is displayed in contours. This very rough estimate shows that the disconnection cannot occur deeper than some 40 Mm for 4 kG flux-tube to reproduce the observed behaviour. The Alfven speed computation is based on model S of Christensen-Dalsgaard (1996). The real rising speed of an expanding flux-tube should not differ from the Alfven speed in the order of magnitude.

Conclusions

We conclude that the dynamical disconnection is an important part of the life of bipolar active regions. Our results favour the sub-surface shear layer as the place of the origin of the surface magnetic activity. We plan to investigate this important phenomenon in more detail.

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References

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