Long-Term Datasets for the Understanding of Solar and Stellar Magnetic Cycles
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Flux emergence rate of active regions as a probe for turbulent dynamo action

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Abstract. We analyze the flux emergence rate of solar active regions (ARs). Numerical simulations by other authors suggest that the flux emergence rate depends on the AR's twist. To prove this statement observationally, we make a comparison of the flux emergence rate and twist of 215 emerging ARs. Our results confirm that the correlation exists: the higher the twist the higher the flux emergence rate of an AR. We suppose that the difference in the twist can be caused by chaotic influence of the convective plasma motions on the lifting magnetic flux tube.

Keywords. Sun: magnetic fields, (Sun:) sunspots, Sun: photosphere, Sun: interior

1. Introduction

Active regions (ARs) are supposed to be a manifestation of emerging magnetic tubes. It is believed that these tubes are formed as a result of the solar dynamo action in the convection zone (Babcock 1961; Leighton 1969). During formation and/or rise through the convection zone, magnetic flux tubes are influenced by the Coriolis effect and by the differential rotation. These factors generate helicities of magnetic tubes.

Recently Abramenko *et al.* (2017) showed that the flux emergence rate of ARs differs significantly for different ARs. In this work we make an attempt to find out what is the reason for this variation. Numerical simulations of emergence of twisted magnetic tubes by Murray *et al.* (2006) revealed that the flux emergence rate increases along with the increase of the tube's twist. We intend to compare the flux emergence rate and twist of ARs in order to figure out whether this result can be approved by observational means.

2. Data and methods

In this study, we used magnetic field data provided by SDO/HMI instrument (Scherrer *et al.* 2012). The total unsigned flux, $\Phi(t)$, was calculated as a sum of flux densities in individual pixels of the AR. The procedure is described in details in Abramenko *et al.* (2017).

To evaluate the flux emergence rate, R, we made a linear fit to the quasi-linear section of the flux curve at the emergence phase (Fig. 1, green line). The maximum total unsigned flux of the AR, Φ_{MAX}, was determined as a difference between the preexisted magnetic flux (Fig. 1, blue line) and the maximum observed magnetic flux (Fig. 1, red line).

To determine the twist of an AR, we used SHARP data also provided by SDO/HMI team. For each AR we calculated the map of the z-related part of current helicity, H_{C}, using the procedure described in Abramenko *et al.* (1996) and evaluated AR's twist as $\alpha = \sum H_{\mathrm{C}} / \sum B_{\mathrm{z}}^2$.

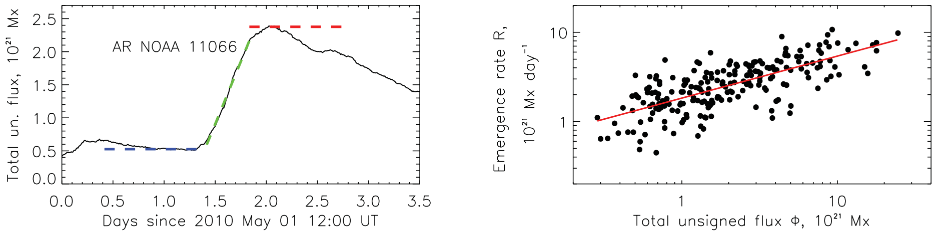

Figure 1. Left: Variations of the total unsigned flux of AR NOAA 11066. Dashed colored lines show the best linear fit, values of pre-existed and maximum flux. Right: Flux emergence rate versus total unsigned flux for 215 ARs.

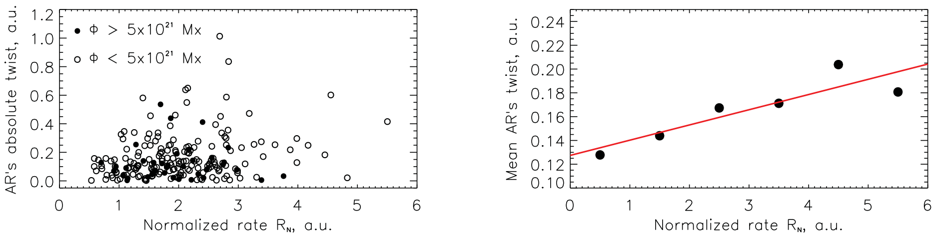

Figure 2. Left: AR's twist versus normalized flux emergence rate. Right: Mean twist in bins versus normalized flux emergence rate.

3. Results and conclusions

All in all, data on 215 emerging ARs were used in the analysis. The analyzed interval (2010-2017) covers cycle 24. The flux emergence rate of an AR versus its maximum total magnetic flux is shown in the right panel of Fig. 1, the linear fit results in the relation $R = \Phi_{\rm MAX}^{0.47}$.

To compare strong and weak ARs, we introduced the normalized flux emergence rate, $R^N = R/\Phi_{\rm MAX}^{0.47}$. The normalized rate reflects the variations in emergence rate of ARs caused by any physical characteristic of magnetic tube rather than by its magnetic flux. We compared the normalized flux emergence rate and twist (Fig. 2, left panel). We also binned the ARs by R^N value and calculated the mean twist in each bin (Fig. 2, right panel). The result suggests that the twist of ARs increases along with the increase of its normalized flux emergence rate.

We suppose that the turbulent plasma flows can cause additional twisting motions of the magnetic tube roots as it lifts up through the convection zone, that is we observe the turbulent dynamo action.

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