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Structure of the photospheric magnetic field during sector crossings of the heliospheric magnetic field

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The photospheric magnetic field is the source of the coronal and heliospheric magnetic fields (HMF), but their mutual correspondence is non-trivial and depends on the phase of the solar cycle. The photospheric field during the HMF sector crossings observed at 1 AU has been found to contain enhanced field intensities and definite polarity ordering, forming regions called Hale boundaries. Here we study the structure of the photospheric field during the HMF sector crossings during solar cycles 21-24, separately for the four phases of each solar cycle. We use a refined version of Svalgaard's list of major HMF sector crossings, mapped to the Sun using the solar wind speed observed at the Earth, and the daily level-3 magnetograms of the photospheric field measured at the Wilcox Solar Observatory in 1976-2014. We find that the structure of the photospheric field corresponding to the HMF sector crossings, and the existence and properties of the corresponding Hale bipolar regions varies significantly with solar cycle and with solar cycle phase. We find evidence for Hale boundaries in many, but not all ascending, maximum and declining phases of solar cycles but no minimum phase. The most clear Hale boundaries are found during the (+,-) HMF crossings in the northern hemisphere of odd cycles 21 and 23, but less systematically during the (+,-) crossings in the southern hemisphere of even cycles 22 and 24. We also find that the Hale structure of cycles 23 and 24 is more systematic than during cycles 21 and 22. This may be due to the weakening activity, which reduces the complexity of the photospheric field and clarifies the Hale pattern. The photospheric field distribution also depicts a larger area for the field of the northern hemisphere during the declining and minimum phases, in a good agreement with the bashful ballerina phenomenon. The HMF sector crossings observed at 1AU have only a partial correspondence to Hale boundaries in the photosphere, indicating that the two HMF sectors often originate from the opposite hemispheres across the equator. Our results also give evidence for hemispheric and polarity related differences in the photospheric field between the odd and even solar cycles.