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磁束管の動径方向形状が太陽風速度に与える影響

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The effect of the radial profile of flux-tube shape on solar wind speed

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The solar wind is a key factor in the space weather and its forecasting. In particular, the temporal and spatial structure of the wind speed is closely linked to the occurrence of co-rotating interaction regions (CIRs) and the propagation of interplanetary coronal mass ejections (ICMEs). Most space weather forecasting models adopt empirical methods to specify the solar wind parameters at the inner boundary, aiming to reduce computational costs. One of the conventional empirical laws for the solar wind speed is the Wang-Sheeley relation (Wang & Sheeley 1990; Arge & Pizzo 2000), which describes an inverse correlation between the solar wind speed and the flux-tube expansion factor. However, it has been suggested that this model overestimates solar wind speeds by up to several hundred km s^{-1} in regions between coronal holes with the same magnetic polarity, known as pseudostreamers (Riley et al. 2015; Tokumaru et al. 2024). Pseudostreamers exhibit non-monotonic expansion of magnetic flux tubes, with the expansion factor reaching a peak (Panasenco et al. 2019), which may contribute to the overestimation. Observational studies also indicate that expansion height, rather than the expansion factor, is a key parameter (Dakeyo et al. 2024). These findings suggest that the shape of magnetic flux tubes in the intermediate region between the coronal base and the source surface plays a crucial role in determining solar wind speed.

To develop a novel empirical law for solar wind speed that incorporates the radial profile of flux-tube shape, we investigate the effect of magnetic flux tube shape variations using physical simulations. To this end, we solved a one-dimensional wave-driven magnetohydrodynamic (MHD) simulation from the photosphere to interplanetary space, with calculations performed while varying the magnetic field and expansion factor. As a result, we find that variations in the magnetic flux tube shape in the intermediate region significantly alter solar wind speed by up to several hundred km s^{-1}. Moreover, we find that features which reflects the information about the radial profile of flux-tube shape are found to correlate more strongly with the solar wind speed than with the expansion factor at the source surface. This is attributed to the effects of expansion height on density and changes in wave energy dissipation processes, and implications for solar wind speed prediction and observational validation are discussed.