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Probabilistic Solar Wind Speed Forecasting Using Deep Distributional Regression With Solar Images

The solar wind, a stream of charged particles originating from the Sun, poses significant risks to technology and astronauts. It is driven by large structures on the solar surface like coronal holes and active regions, which can be identified in extreme ultra-violet (EUV) solar images several days before they become geoeffective. In this work, we propose to use a distributional regression algorithm to forecast the solar wind speed at the Lagrange 1 point from solar images. Instead of predicting a single value, this method models the entire conditional distribution as a function of input features. It allows computing the uncertainty of predictions and specifying the probability of the solar wind speed exceeding certain thresholds, which is especially useful for extreme event predictions like coronal mass ejections and high-speed solar wind streams (HSSs). In a deep learning approach, we couple a vision transformer with a probabilistic regression head, additionally using physical input parameters, such as past solar wind properties and solar cycle information. We predict the solar wind speed distributions with a one-hour cadence four days in advance. Our method is trained and evaluated using cross-validation on 15 years of data. We perform a large study comparing different combinations of SDO channels and show that a combination of three different wavelengths provides the most accurate predictions. Our model reaches an RMSE of 75 km/s and an HSS peak RMSE of 78 km/s for the means of the predicted distributions. Additionally, the model approximates the heavy-tailed solar wind speed distribution well and predicts accurate confidence intervals. We show that our model is on par with current state-of-the-art models regarding the general accuracy of predictions, but predicts extreme events significantly better and furthermore enables full uncertainty quantification. That demonstrates the advantages of probabilistic models over standard regression approaches and highlights the potential for operational space weather forecasts.

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