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Automated Detection of Solar Flare-Induced Ionospheric Disturbances via Hidden Markov Models and VLF Propagation

Solar flares induce Sudden Ionospheric Disturbances (SIDs) that can significantly impact global radio communication and satellite-based navigation systems. Monitoring Very Low Frequency (VLF) signal propagation serves as a low-latency alternative for tracking solar activity in real time, bypassing the inherent delays of orbital X-ray observation platforms, which frequently exhibit data latency exceeding five minutes. This study presents the training of a model for the immediate detection of solar flares utilizing Hidden Markov Models (HMM). To enhance sensitivity beyond conventional fixed-threshold techniques, the proposed method incorporates dynamic features, including relative amplitude and temporal derivatives of the signal. Solar flare events are modeled as latent states to effectively filter noise-induced oscillations, with transition probabilities derived from historical training datasets. Our results demonstrate the robustness of this HMM-based approach for real-time monitoring, significantly outperforming traditional statistical models in handling the complexities and non-linearities of ionospheric time-series data.

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