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OUTILS ET MÉTHODES INTELLIGENTES POUR LES RADIO-SCIENCES

Approches de type RNN pour la diffusion des ondes de mode siffleur

Recurrent neural network approaches for whistler-mode waves induced diffusion

G. Tran[1], C. Godard[2], L. Dallain[2], M. Mougeot[2,3], J.-F. Ripoll[1,4]

[1] CEA, DAM, DIF, F-91297 Arpajon, France, e-mail: gtran.pro@gmail.com, jean-francois.ripoll@cea.fr
[2] CNRS UMR 9010 Borelli Center, École normale supérieure Paris-Saclay, France, e-mail: constantin.godard3@gmail.com, lancelot.dallain.pro@gmail.com, mathilde.mougeot@ens-paris-saclay.fr
[3] ensIIE, Evry-Courcouronnes, France
[4] Université Paris-Saclay, CEA, LMCE, 91680 Bruyères-le-Châtel, France

Mots clés (en français et en anglais) : ondes siffleur, diffusion, ceintures de radiations ; whistler-mode waves, diffusion, radiation belts.

Whistler-mode waves are plasma waves operating in the Very Low Frequency (VLF) range. These waves propagate over global distances when emitted by ground-based VLF transmitters and occur naturally within the Earth's inner magnetosphere being generated by the ambient hot and cold plasma. Their interactions with electrons lead to electron precipitation into the atmosphere through the physical process of pitch-angle diffusion. These fluxes impact the vulnerability of spacecraft electronics and cause ionospheric disturbances that can degrade long-range VLF communication and navigation signals. The computation of pitch-angle diffusion relies on quasi-linear theory and is often time-consuming. In this work, we start from a global machine-learning model of event-driven pitch-angle diffusion coefficients for storm conditions. The model is based on a neural network model (DNN) fed with the data of a variety of 32 high-speed stream storms observed by the NASA Van Allen Probes from 2012 to 2016 [1, 2]. The model has a two-parameter dependence, with both the Kp geomagnetic index and the time, which is kept as when one does an epoch analysis following the storm evolution.

We further enhance the model by leveraging the Deep-Jointly Informed Neural Network (DJINN) [3] framework which maps a random forest to a neural network committee. This ensemble approach allows for statistical prediction by averaging the committee's outputs. It results in up to a 74% improvement in the prediction of pitch angle diffusion coefficients compared to the previous RMSE. This refined model is then used to analyze how mean diffusion coefficients behave compared with individual ones and to assess the model's ability to extrapolate solutions for sparse data such as missing Kp indices, rare to find in nature. This DJINN model enables more accurate and physically consistent prediction and allows simple and fast data exploration of pitch-angle diffusion among its multiple features.

Reduced Order Modeling (ROM) linked to Radial Basis Function (RBF) have been introduced on one hand to model continuously the evolution of a storm over time for given Kp indices. The ROM-RBF approach helps us to naturally increase the sample frequency of storms. We propose on another hand to model the storm evolution thanks to the use of recurrent neural network approaches. The time-dependence is handled by a long short-term memory (LSTM) approach. The temporal data are then extended by interpolation and fed to a convolutional neural network (CNN), which learns local patterns in the data images. This approach let to forecast the storm signal on a short term. We newly explore the results and provide comparisons with naive forecast methodology and with the first DNN model, discussing similarities, differences, improvements, and the sensivity of the results to geomagnetic conditions. Transformers are currently under investigation for comparison.

References

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