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Automatic Extraction of the Dispersion Coefficients of Lightning Whistler Waves Observed By SCM Boarded On ZH-1 Satellite

Jing Yuan[1], Le Zhou[1], Qiao Wang[2], Dehe Yang[2], Zeren Zima[2], Ying Han[1], Zijie Wang[1], Xuhui Shen[2], and Lei Hu[1]

[1]Institute of Disaster Prevention , Department of Information Engineering, Hebei, China (371430266@qq.com)
[2]National Institute of Natural Hazards, Ministry of Emergency Management of China, Beijing, China (yuanjing20110824@sina.com)

Lightning whistler waves, as an important tool for geospace exploration, can be found from the vast amount of electromagnetic satellite data. In recent years, with the development of computer vision and deep learning technologies, some advanced algorithms have been developed to automatically identify lightning whistler waves from the massive archived data of electromagnetic satellites. However, these algorithms fail to automatically extract the dispersion coefficients of lightning whistlers(DCW). Since the DCW are depended on the propagation path of lightning and geospace environments, it is extremely important for further geospace exploration.

We proposed an algorithm that can automatically extract the dispersion coefficients of lightning whistler: (1) using two seconds time window on the SCM VLF data from the ZH-1 satellite to obtain segmented data; (2) generating time-frequency profile (TFP) of the segmented waveform by performing a band-pass filter and the short-time Fourier transform with a 94% overlap; (3) annotating the ground truth of the whistler with the rectangular boxes on the each time-frequency image to construct the training dataset; (4) building the YOLOV3 deep neural network and setting the training parameters; (5) inputting the training dataset to the YOLOV3 to train the whistler recognition model; (6) detecting the whistler from the unknown time-frequency image to extract the whistler area with the rectangle box as a sub-image; (7) conducting the BM3D algorithm to denoise the sub-image; (8) employing an adaptive threshold segmentation algorithm on the denoised sub-image to obtain the binary image which represents the whistler trace with the black pixel and other area with white pixel. (9) removing isolated points in the binary image with the open operation in morphology; (10) extracting lightning whistler trajectory region using connected domain analysis; (11) converting the trajectory coordinates from (t-f) to ($f^{-0.5}$-t); (12) taking into account the Eckersley formula, which depicts the relationship between the scattering coefficient and the time frequency, we use the least-squares method on the converted trajectory coordinates to fit a straight line and obtain the slope of the line as the dispersion coefficient.

In order to evaluate the effectiveness of the proposed algorithm, we construct two dataset: a simulation set and an observational dataset. The simulation set is composed of 1000 lightning whistler trajectories, which are generated according to the Eckersley formula. The observational dataset containing 1000 actual single-trace lightning whistler, are generated by collecting the data from the SCM VLF from the ZH-1 satellite. The experiment results show that: the mean-square error on the simulation set is below 2.8×10^{-4}; The mean-square error on the observational dataset is below 2.1054×10^{-3}.

Keywords: ZH-1 Satellite, SCM, Lightning Whistler, YOLOV3, Dispersion Coefficients