Prediction of Nighttime VLF Signal Amplitude for Mid-and High-Latitude Paths

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The amplitude of Sub-ionospheric Very Low Frequency (VLF) propagation is sensitive to the lower ionospheric. Accordingly, VLF waves have been proposed to study and monitor the lower ionospheric conditions. However the temporal dependence of VLF amplitude has complicated and large daily variabilities in general due to combinations of both effects from above (space weather effect) and below (atmospheric and crustal processes) of the ionosphere. Thus the modelling and prediction of VLF wave amplitude are important issues to study the lower ionospheric responses from various external parameters and to also detect the anomalies of the ionosphere.
In this paper, the NARX (Nonlinear Autoregressive with Exogenous Input) neural network is used as a novel method for predicting daily nighttime averaged amplitude of VLF transmitter signals indicating the ionospheric perturbation around the transmitter-receiver path. The NARX neural networks has a good accuracy in predicting time series data and thus are more suitable for dynamic modelling. The NARX model, which was built based on daily input variables of various physical parameters such as stratosphere temperature, cosmic rays, total column ozone, K-index, AE-index and Dst, possessed good accuracies during the model building. The NARX model for VLF transmitter in Hawaii, USA (NPM) and receiver in Chofu (CHF) Tokyo, Japan (mid-latitude path), which was constructed based on above mentioned. In addition, the high-latitude path from the transmitter in Washington, USA (NLK) to receiver in Chofu (CHF) Tokyo, Japan, which was built as well.
As a result, the constructed models are capable of performing accurate one step (1 day) ahead predictions of the nighttime VLF amplitude from January 1st, 2011 to December 31st, 2013 for NPM-CHF path with the Pearson correlation coefficient (r) of 0.93 and with Root Mean Square Error (RMSE) of 2.0 dB and also the results for multi-step ahead 5 days prediction (r = 0.86, $RMSE$ = 1.88) and multi-step ahead 10 days prediction (r = 0.74, $RMSE$ = 2.35). Furthermore, result for NLK-CHF path with r of 0.91 and RMSE of 2.64 dB. In addition, we will demonstrate multi step ahead prediction of daily nighttime VLF amplitude for NLK-CHF paths. We conclude the model built according to the proposed methodology provides accurate predictions of the electric amplitude of VLF wave for both NPM-CHF and NLK-CHF propagation paths.

Keywords: very low frequency, VLF transmitter, nonlinear autoregressive with exogenous input, one-step ahead prediction, multi step ahead prediction

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