A Physics-informed neural network approach in CYGNSS soil moisture retrieval

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Abstract

Soil moisture determination is essential in the environmental sciences. Global Navigation Satellite System - reflectometry (GNSS-R) reflected signal strength has shown correlations to moisture content of soil. Despite the high sensitivity between GNSS reflected signal power and soil moisture, the model between measurements and estimates is difficult to solve mathematically due to the complexity of the electromagnetic relationship. Since use of Neural Network (NN) algorithms eliminates the need for explicitly solving a defined parametric model, application of NNs in GNSS-R soil moisture retrieval has been studied by various authors. However, Neural Networks are trained without respecting any laws of physics; therefore, neglecting physical foundations.

In the current study, a new methodology was developed using “Physics-Informed Neural Networks (PINN)”. In PINN, the objective is to minimize the loss function of both Neural Network regression and physics equations. The application of PINN to retrieve soil moisture from reflected signals of Cyclone Global Navigation Satellite System (CYGNSS) is confirmed in this research. In the PINNs structure, reflected GPS signals from CYGNSS and land surface geophysical parameters are used as input features. The geophysical data include normalized difference vegetation index (NDVI), vegetation water content (VWC), soil texture data, and surface roughness parameters. Soil moisture measurements from the International Soil Moisture Network (ISMN) are used in both training and validation. The proposed PINN model generates promising daily soil moisture values from CYGNSS signals with a root mean squared error (RMSE) of 0.006 , which is an improvement from 0.0562 for the underlying NN model due to adding physical models.