Exploration of global ionospheric dynamics with neural networks

Principal Investigator: Olga Verkhoglyadova (335); Co-Investigators: Xing Meng (335), Jacob Kosberg (322)

Program: FY21 R&TD **Strategic Focus Area: Innovative Spontaneous Concepts**

Objectives

The objective was to expand upon promising first results of Global Ionospheric Maps characterization obtained with neural networks and to explore occurrences and locations of high density regions with robust significance tests.

Background

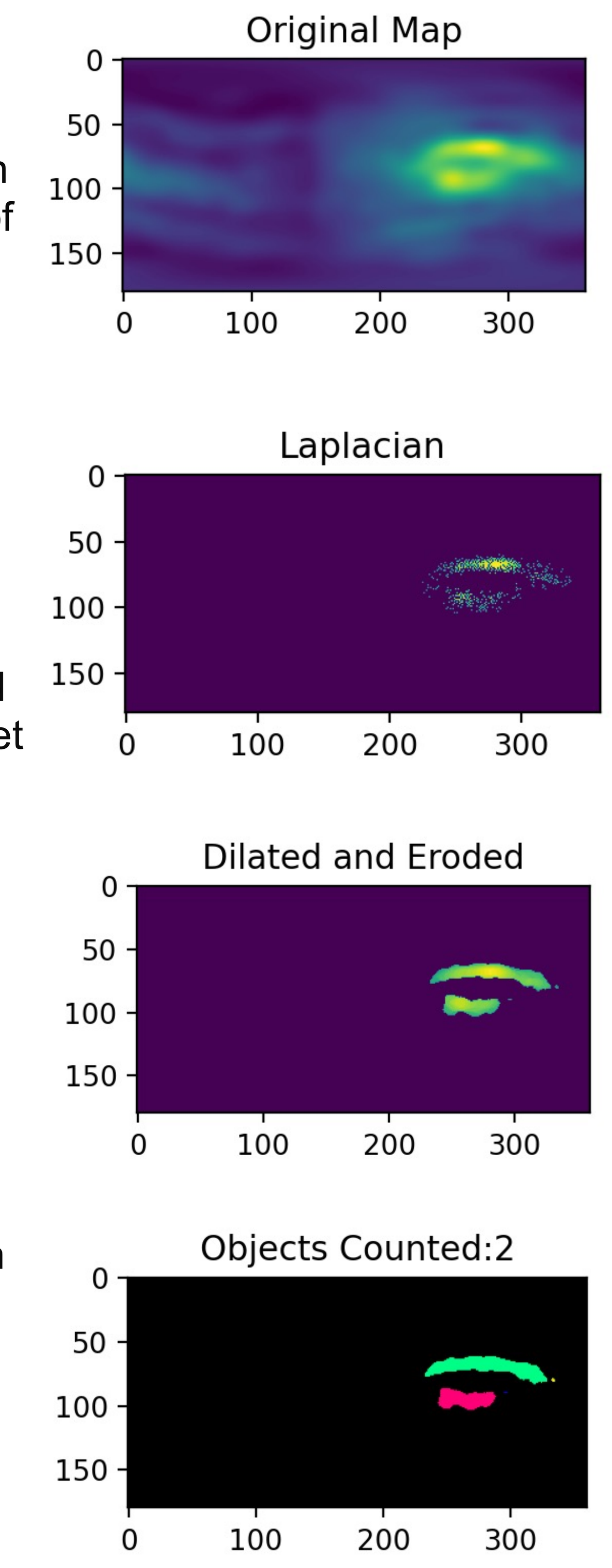
Global ionospheric state is frequently characterized by the total electron content (TEC) that is vertically integrated electron density. Global TEC distribution features prominent daytime equatorial ionization anomalies and other regions with elevated TEC, i.e., high density regions (HDRs). Global ionospheric map (GIM) is a gridded 2D data product for TEC that is commonly used to visualize global ionospheric state. Our proposed approach was to train Neural Networks (NNs) on the GIM dataset (binned 1 degree by 1 degree every 15 minutes) produced by JPL and apply classical statistical methods to conduct significance tests on the relationship between temporal sparsity of number of HDRs and external factors, including solar phase and geomagnetic activity. The research is based on first results of our recent paper (Verkhoglyadova, Maus and Meng, 2021; https://doi.org/10.1029/2021EA001639) that applied NNs to classify High Density Regions (HDRs) of TEC.

Approach and Results

We performed evaluation of standard statistical techniques vs machine learning approach. We realized the need to inter-compare these two methods and identify benefits of using a specific method for classification of GIMs before proceeding with training a NN. We considered and tested several alternative algorithms to the NNs, following suggestions of the Referees' on the proposal. Unsupervised Gaussian Mixture method (GMM) was utilized to identify unique TEC sub-populations or clusters. We developed Python-based software to extend existing GMM algorithm to use periodic boundary conditions. Alternatively, we performed a robustness analysis of and improved upon our image classification approach. We applied the image processing library OpenCV together with edge-enhancing technique to identify HDRs. In the future, it will be feasible to utilize trained NNs to classify a large dataset of GIMs as was shown in (Verkhoglyadova, Maus and Meng, 2021). With the improved algorithm we confirmed that three and more HDRs are common features of GIMs. Our analysis does not show a preference for multiple HDRs to occur during elevated geomagnetic activity. The important and unexpected result is a realization that different approaches to GIM classification extract different information on global TEC. This raises an important question of how to robustly and adequately define HDRs in GIMs. The results were presented and discussed at the Virtual Conference on Applications of Statistical Methods and Machine Learning in the Space Sciences [A]. Abstract based on results of this study was submitted to the Fall AGU meeting [B]. Outcome of this research prompted writing a proposal "A retrospective analysis toolbox for ionospheric total electron content maps" that was submitted to the NASA ROSES Call "Heliophysics LWS Tools and Methods".

Significance/Benefits to JPL and NASA

This is the first attempt to utilize a novel approach for characterization of global ionospheric structuring (in GIMs) with an image-processing method and advanced statistical clustering algorithm. We worked towards exploring an appropriate tool to quantify high-density regions in the Earth's ionosphere. This study is important for future analysis of space weather processes and causal connections between ionosphere structuring and external space weather factors. The initial study demonstrated feasibility of the proposed approaches and their future potential to addresses one of the science goals of NASA's Heliophysics program: "Advance our understanding of the connections that link the Sun, the Earth, planetary space environments, and the outer reaches of our solar system". The PI served on Scientific Organizing Committee of the Virtual Conference on Applications of Statistical Methods and Machine Learning in the Space Sciences, organized by Space Science Institute on 17-21 May 2021(http://spacescience.org/workshops/mlconference2021.php) and chaired a session. She promoted JPL research in application of advanced statistical methods to analysis of remote sensing measurements.



Example of an output of the image processing algorithm.

Publications

[A]Olga P. Verkhoglyadova, Jacob Kosberg, Natalie Maus and Xing Meng, "Approaches to identification of highdensity regions in ionospheric maps", presentation at the Virtual Conference on Applications of Statistical Methods and Machine Learning in the Space Sciences, organized by Space Science Institute, Boulder, CO, 17-21 May 2021(http://spacescience.org/workshops/mlconference2021.php) [B] Olga Verkhoglyadova, Xing Meng, Jacob Kosberg and Natalie Maus, "How to identify and understand large-scale structuring in global ionospheric maps?", presentation abstract, submitted to the Fall AGU meeting, New Orleans, December 2021.

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov

PI/Task Mgr Contact
Email: Olga.Verkhoglyadova@jpl.nasa.gov

Poster No.
Clearance No. 21-4373
JPLTask#R21229