National Aeronautics and Space Administration

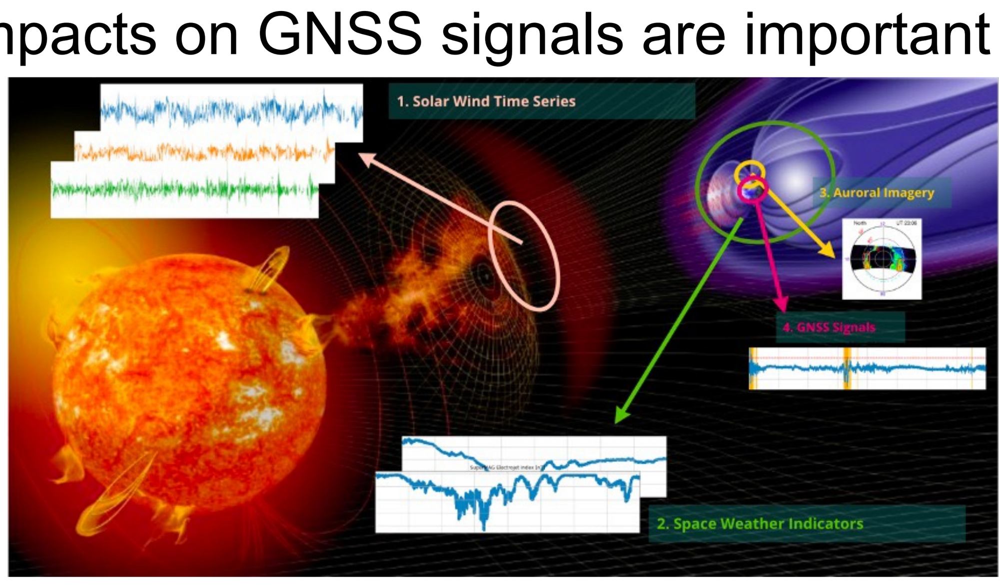
FY23 Innovative Spontaneous Concepts Research and Technology Development (ISC)

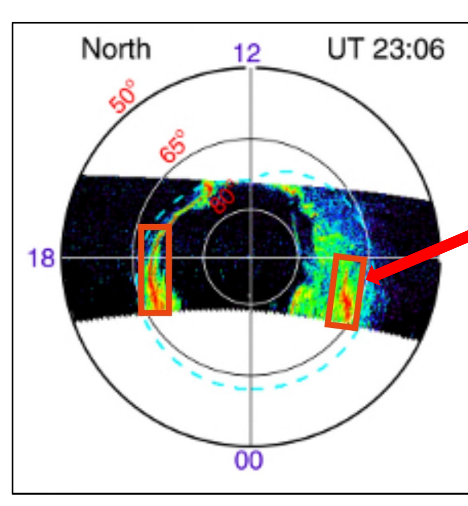
Towards Quantification of Risk to GNSS Signals due to Space Weather

Principal Investigator: Olga Verkhoglyadova (335); **Co-Investigators:** Attila Komjathy (335), Ryan McGranaghan (398)

Objectives: The integrity and reliability of Global Navigation Satellite Systems (GNSS) signals are strongly affected by the state and dynamics of the Earth's ionosphere. Understanding *space weather and multi-scale processes in the geospace* is based on measurements from different instruments at different temporal and spatial scales. It *requires multi-platform analyses and uncommon data and information integration*. The objective of this research is to demonstrate a data pipeline that integrates information from heterogeneous datasets to ultimately quantify risk of space weather to GNSS communications.

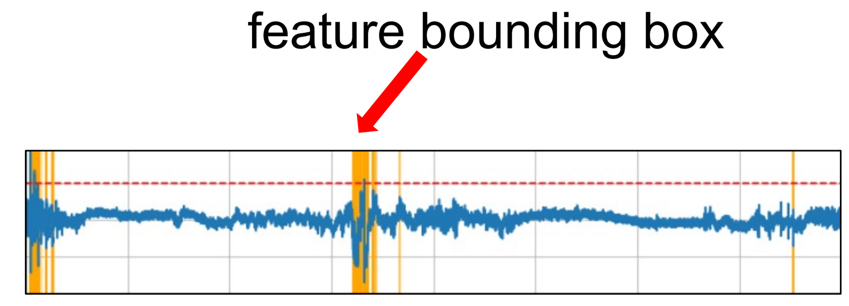
Background: *Systems approach* has been missing from our understanding of the near-Earth space environment in the context of how solar activity may cause potentially catastrophic impacts on our communications systems and space-based technologies. The focus of our study was on high-latitude ionosphere (at latitudes above 45°), where space weather and particularly aurora impacts on GNSS signals are important and difficult to predict.





Spatial regions of interest in the temporal window

Region in GNSS time series in auroral feature bounding box



Approach and Results: General schematic of our approach is fusing data over the space weather system: 1) solar wind plasma time series; 2) geomagnetic activity indices; 3) auroral imagery; and 4) regional ionospheric disturbances identified in GNSS time series. The data integration requires three steps for a given time: select the data from that time from all databases, identify the auroral forms in the auroral imagery data, and find the GNSS signals that pass through those auroral forms.

1. Ionospheric data selection and processing: We selected 6 GNSS ground sites and processed daily rinex files containing measurements in 2015 and 2016. Input data are publicly available from NASA CDDIS archive of space geodesy data. In-house processing of GNSS data (Section 335) was utilized to derive total electron content (TEC) between the ground receivers and GPS satellites. TEC is an integrated measure of electron density along the line of sight and a useful proxy for ionospheric space weather.

2. Aurora images processing and collocation with GNSS measurements: We utilized aurora observations by Special Sensor Ultraviolet Spectrographic Imager (SSUSI, https://ssusi.jhuapl.edu/) instrument onboard DMSP satellites. To select auroral forms we adapted bounding box image analysis tools available in group 398J. Relevant GNSS data were selected corresponding to spatio-temporal bounds in the auroral image.

3. Database creation: Python-based software that searches over a user-specified time period and outputs AI analysis-ready data for each of the selected time intervals was developed. This database combines information of heterogeneous dataset (images and time series) and can enable quantification of TEC variations driven by auroral activity in vicinities of GNSS ground sites.

Significance/Benefits to JPL and NASA:

The team developed a prototype Python-based software that can combine heterogeneous datasets and created a corresponding test database, enabling future systems-level analyses of space weather-driven disturbances in communications signals. This research provided a proof of concept for open-source software and a foundation for future proposal to ROSES Call "Heliophysics innovation in technology and science". Further development of this approach would facilitate quantification of space weather risks to GNSS communication systems and provide a tool to address important science questions on multi-scale space weather processes in the Sun-magnetosphere-ionosphere system.

Publications:

O. Verkhoglyadova, R. McGranaghan, and A. Komjathy "Towards Quantification of Risk to GNSS Signals due to Space Weather: Multi-modal, multi-platform data integration to study the multiscale ionosphere," invited talk at CEDAR Workshop, San Diego, CA, 2023

R. McGranaghan "Complexity Heliophysics: A lived and living history of systems and complexity science in Heliophysics", https://arxiv.org/abs/2307.03287, 2023

PI/Task Mgr. Contact Information:

Olga.Verkhoglyadova@jpl.nasa.gov

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov

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