Finding multi-scale connectivity in our geospace observational system: Network analysis of total electron content

McGranaghan et al. [2017]

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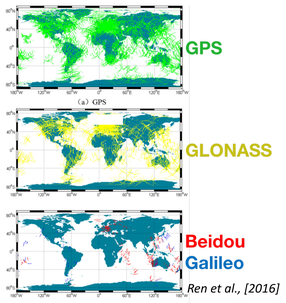
Key Findings

- New approach can increase utility of total electron content (TEC) data and enhance efficiency of analysis of diverse our geospace observational system in the future
- First complex network theory based analysis of high-latitude TEC data shows significant structure exists in the correlation patterns
- Important characteristic scale sizes in TEC data vary across season and hemisphere

Introduction

Global Navigation Satellite System (GNSS) signals are one of the premier remote sensing tools to facilitate new understanding of the magnetosphere-ionosphere-thermosphere (MIT, or geospace) system

Total electron content (TEC) data, inferred from GNSS signal delays during passage through the ionosphere, provide critical information about the Earth's ionosphere at higher cadence and over a larger portion of the globe than any other single data set



Global, high-latitude response of TEC data is the result of numerous complex geospatial processes, and is, therefore, rich with information about the Earth's space environment

However, characteristics of TEC data at high-latitudes are not well understood and **novel, sophisticated approaches are needed** to:

- Understand the information content of these data and
- Gain the most scientific utility from them

We introduce a new data-driven approach to the analysis of high-latitude, hemispheric-specific, TEC data known as **network analysis**

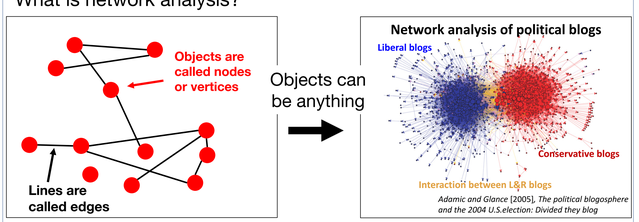
We discover:

1. Significant new relationships in high-latitude TEC data that extend the utility of these data
2. Exciting new ways that TEC data can be used to study complex geospace phenomena

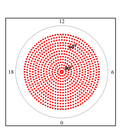
This work illustrates the critical importance of embracing new data-driven discovery methods to usher in a 'new frontier' of geospace understanding

Network Analysis (NA) Technique

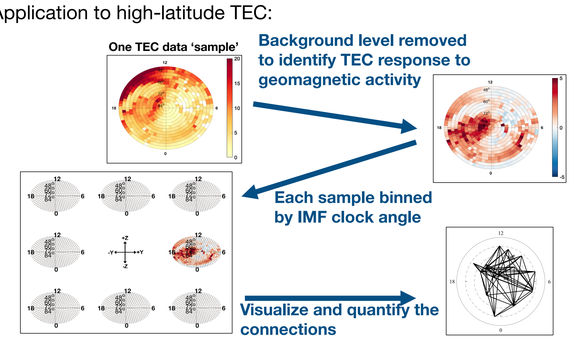
What is network analysis?



In geophysical applications, objects are grid points:



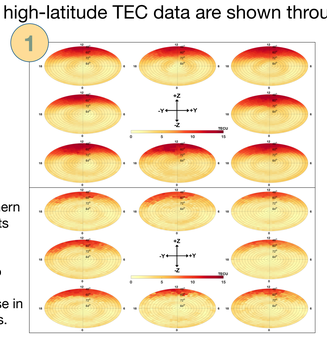
Application to high-latitude TEC:



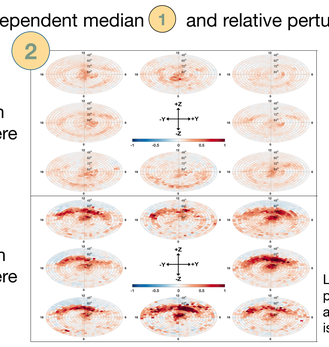
High-latitude, IMF–dependent network analysis results

We show results for the northern and southern hemispheres during local winter in 2016 (see *McGranaghan et al.*, [2017] for analysis of extended periods)

First, the characteristics of the high-latitude TEC data are shown through IMF-dependent median (1) and relative perturbation (2) figures



Local winter monthly median TEC distributions for northern (top) and southern (bottom) hemispheres. Data are TEC units (TECU, 1 TECU = 10^{16} el/m^2) in AACGM MLAT-MLT coordinates with 3° MLAT resolution and variable MLT resolution to yield equal area bins. Interplanetary magnetic field (IMF) clock angles increase in the clockwise direction in 45° increments.



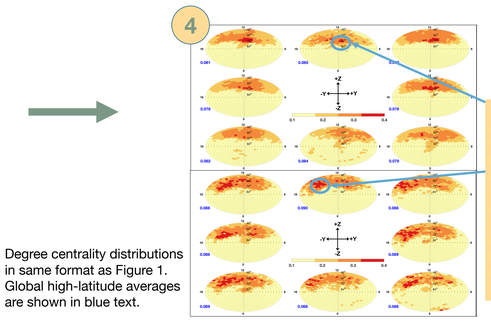
Local winter average relative TEC perturbation distributions for northern (top) and southern (bottom) hemispheres. Format is the same as Figure 1.

Relative perturbations are then used to calculate spatio-temporal correlations between each high-latitude (50-90°) grid point and networks are constructed (a connection occurs if the correlation between grid points exceeds a threshold). We use several robust mathematical measures to quantify and study network behavior. These measures are described (3) and visualized (4) - (6) below.

(3)

Network measures used to study network behavior

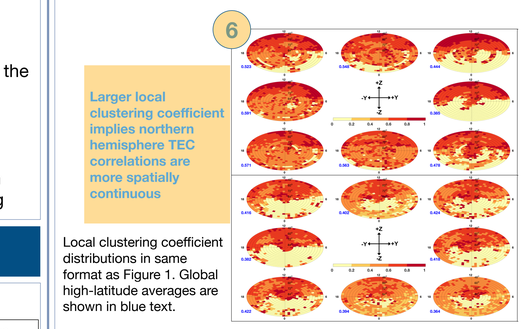
Measure	Significance (Interpretation)
Degree Centrality (4)	Influence of grid points on network function (larger = greater influence)
Median geodesic separation distance (5)	Scale sizes of connectivity (larger = longer range connections)
Local clustering coefficient (6)	Spatial continuity of TEC (larger = more spatially continuous)



Degree centrality distributions in same format as Figure 1. Global high-latitude averages are shown in blue text.

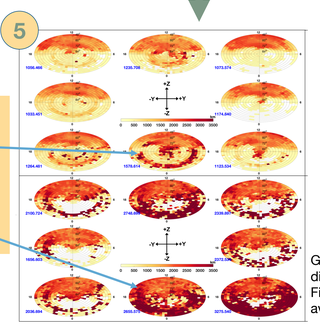
Cusp and ionospheric projection of magnetospheric boundary layers different between hemispheres

Different magnetosphere-ionosphere connection



Larger local clustering coefficient implies northern hemisphere TEC correlations are more spatially continuous

Local clustering coefficient distributions in same format as Figure 1. Global high-latitude averages are shown in blue text.



IMF dependency greater in northern hemisphere

Longer range connections in southern hemisphere

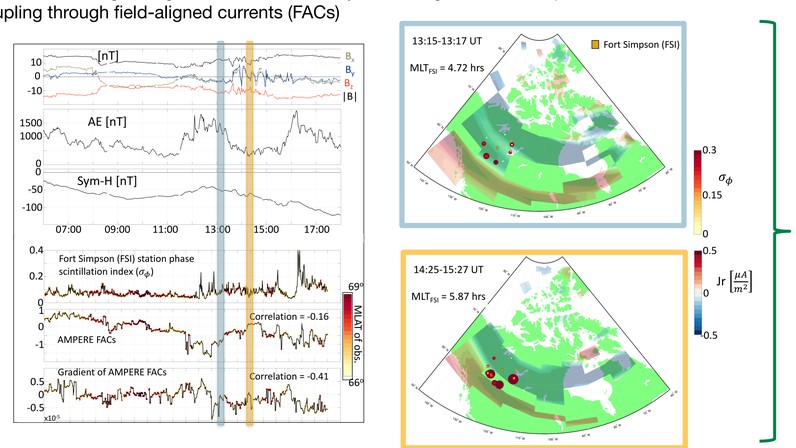
Geodesic separation distributions in same format as Figure 1. Global high-latitude averages are shown in blue text.

Enabling TEC data to investigate complex geospace phenomena

TEC networks suggest TEC data contain information about magnetosphere-ionosphere (MI) coupling

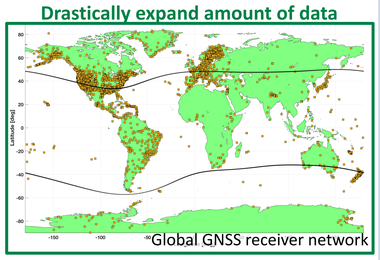
⇨ Can TEC data be used to study/proxy complex phenomena in geospace?

December 20, 2015 geomagnetic storm case study to investigate relationships between TEC and MI coupling through field-aligned currents (FACs)

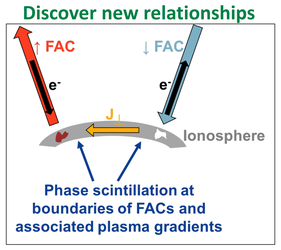


What's next?

Drastically expand amount of data



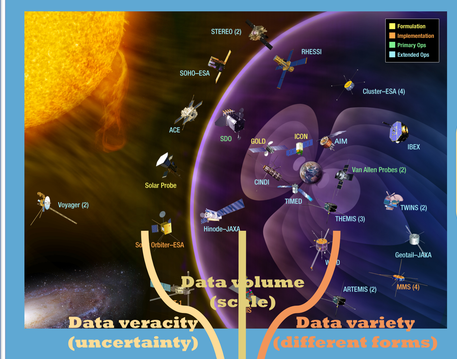
Discover new relationships



Significance: A 'new frontier'

'New frontier' in geospace sciences

- Data-driven discovery complements existing approaches
- Relationships among diverse data sets
- Increase utility of geospace observational system



Increased amount and complexity of geospace data

New forms of discovery complement existing approaches

Conclusions

Network analysis increased utility of TEC data:
NA provides important new information about high-latitude TEC data and elucidates physically related phenomena

Network analysis will enhance the efficiency of diverse geospace observational system:
Multivariate analyses can help discover new relationships between diverse data sets

New data-driven techniques critical to improve geospace understanding:
'New frontier' of geospace science can be built on intersection of existing approaches and new data-driven discovery

References

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