Network analysis of Pc waves using the SuperMAG database of ground-based magnetometer stations

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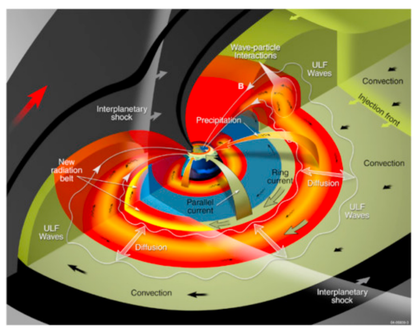
ABSTRACT

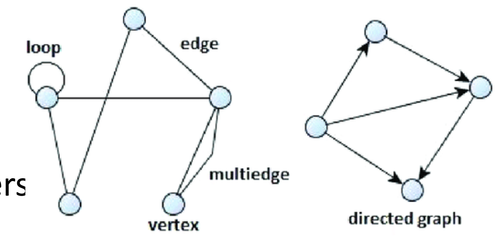
Network-based analysis of 1 min cadence SuperMAG data has resolved the dynamics of substorm current systems (Dods et al. JGR 2015, Orr et al. GRL 2019) and the magnetospheric response to IMF turnings (Dods et al. JGR 2017). Now, with the availability of 1 sec data across the entire network of SuperMAG magnetometers we are able to apply network analysis to obtain new quantitative understanding of Pc waves. Prior to constructing the network, time series data is band-pass filter using Pc wave frequency intervals and cross-correlated ensuring the window is twice the Pc wave period of interest. To construct the network we use noise surrogates to establish a threshold to filters out insignificant cross-correlation values. Once a network is constructed, it can be characterized by a few network parameters. This may lead to the identification of new Pc indices that capture the spatial coherence and propagation of Pc activity. Quantifying the full spatio-temporal response of the magnetosphere across 100s of ground based magnetometers with a few parameters also forms the basis of statistical studies across many events. First results will be presented for the dynamical directed network for Pc wave intensity and coherence during intervals of enhanced geomagnetic activity

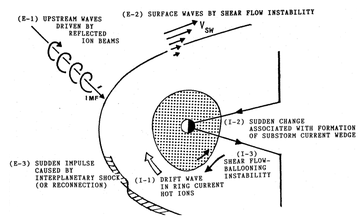
Why?



Wave type	Period range (s)
Pc1	5-10
Pc2	10-45
Pc4	45-160
Pc5	150-600

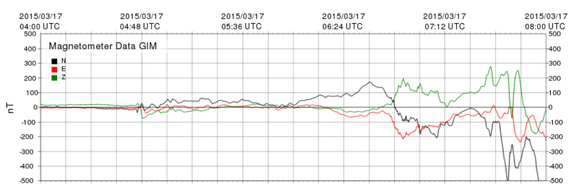
- **Space weather has severe impacts on earth systems including:**
  - Induction of geomagnetic storms and substorms
  - Power grid, radio and satellite communications failure
- **Pc waves used to understand Geomagnetic storms and substorms**
  - Pc waves are ULF (MHD) waves measured on the ground via magnetometers
  - Pc waves occupy different frequency bands (resonant modes)
  - Each Pc band can give insight into different magneto-solar interactions
  - New 1s SuperMag data allows greater Pc frequency resolution
- **Dynamical networks can give a spatio-temporal response**
  - Dynamical network can be applied to storms and substorms
  - Network parameters can be found and key insights extracted
  - New Pc wave indices can be generated



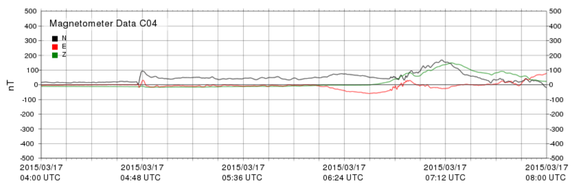


How?

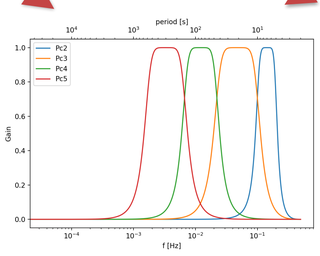
Building networks



Magnetometer time series at GLON: 265, GLAT: 56

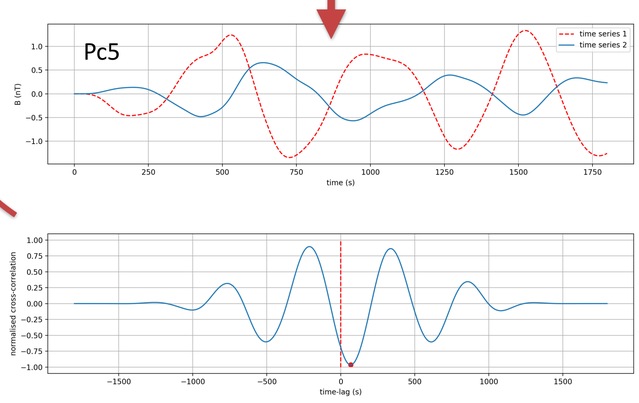


Magnetometer time series at GLON: 251, GLAT: 50



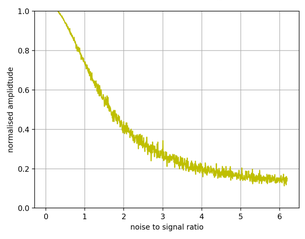
Pc wave band pass filter applied to time series pair for single time window

Repeat band pass filtering and cross correlation for all other Pc bands and time windows

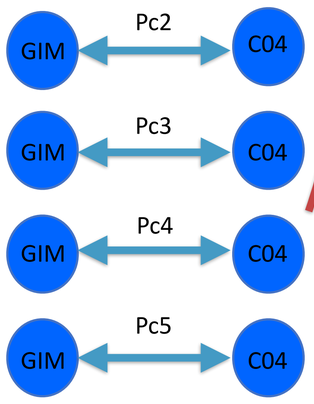


Normalised time-lagged cross correlation to find lag at peak closest to zero to find leader follower relationship between time series for single time window

Repeat process for all other magnetometer station pairs to generate complete dynamical networks for all Pc bands



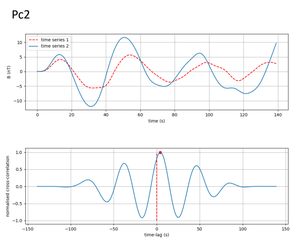
Model: sinusoid + white noise. Use this to determine threshold to be applied to cross correlation to determine whether each station pair is connected or not



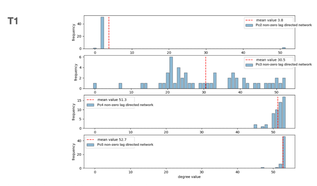
Direction of each network connection (arrow) varies in time.

What?

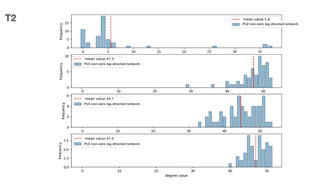
Network analysis



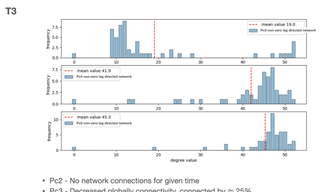
Non zero lag network connection pair formed



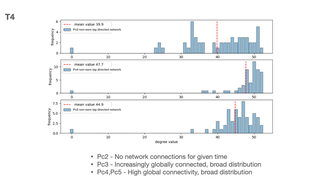
- Pc2 - Low global connectivity to rest of network
- Pc3- Intermediately globally connected ≈ 60%, broad range of degree
- Pc4, Pc5 - High global connectivity, most nodes connected with the entire network, narrow distrib



- Pc2 - Low global connectivity, broader distribution
- Pc3, Pc4, Pc5 - Higher global connectivity with similar average connections, broad distribution

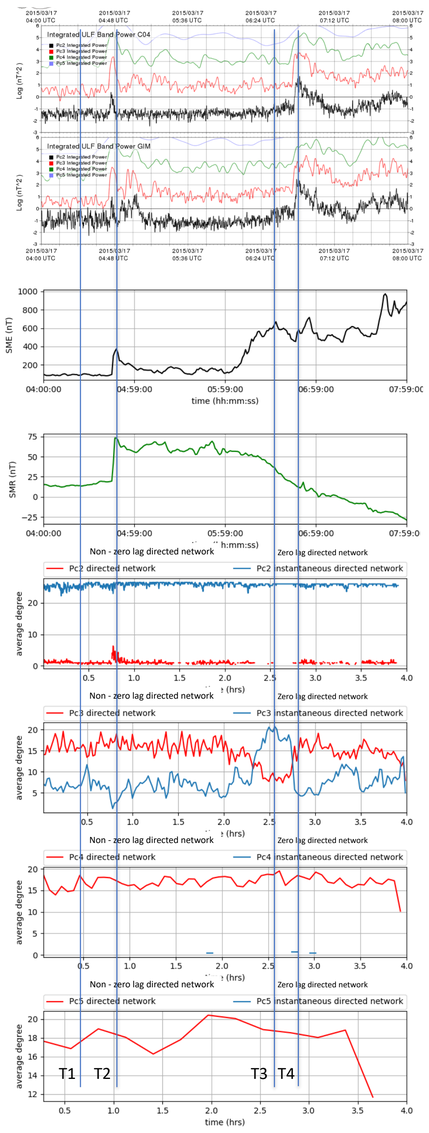


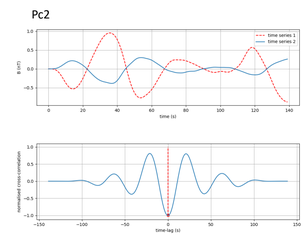
- Pc2 - No network connections for given time
- Pc3 - Decreased globally connectivity, connected by ≈ 25%
- Pc4, Pc5 - High global connectivity, most nodes connected to entire network



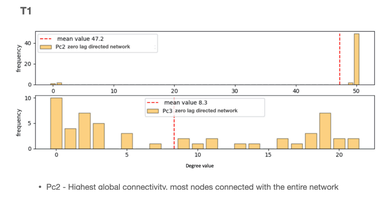
- Pc2 - No network connections for given time
- Pc3 - Increasingly globally connected, broad distribution
- Pc4,Pc5 - High global connectivity, broad distribution

Histograms of frequency vs network degree for the non-zero lag directed network for times, T1 T2, T3, T4

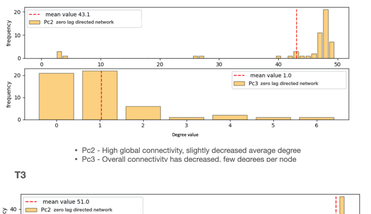




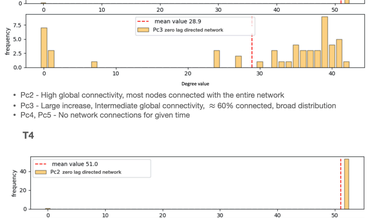
Zero lag network connection pair formed



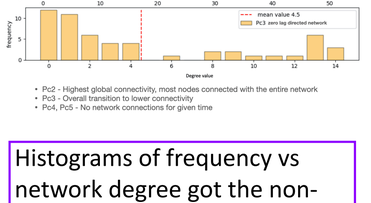
- Pc2 - Highest global connectivity, most nodes connected with the entire network



- Pc2 - High global connectivity, slightly decreased average degree
- Pc3 - Overall connectivity has decreased, few degrees per node



- Pc2 - High global connectivity, most nodes connected with the entire network
- Pc3 - Large increase, Intermediate global connectivity, ≈ 60% connected, broad distribution
- Pc4, Pc5 - No network connections for given time



- Pc2 - Highest global connectivity, most nodes connected with the entire network
- Pc3 - Overall transition to lower connectivity
- Pc4, Pc5 - No network connections for given time

Histograms of frequency vs network degree got the non-zero lag directed network. Sub-plots for times, T1 T2, T3, T4

Network degree variation over time for both networks for Pc bands 2,3,4,5 created with data from 54 magnetometer stations obtained with SuperMAG. Compared with (SME and SMR) geomagnetic indices and Pc wave power (top) for all bands. Time axes have been aligned for all subplots and four times of interest have been selected for further analysis T1-T4. Data taken on the St. Patrick's Day storm,17/03/15, 4am - 8am UTC

Future Work

- Preliminary study demonstrates the potential for dynamical networks to capture the details of spacial correlation.
- Data visualisation challenge.
- Understand the mapping between network properties and physical processes.
- Statistical significance of results through the use of surrogates.
- Comparison of dynamical networks between larger number of storm/sub-storm events. Parameterisation of the network makes statistical studies possible between many events.