

Quantifying space-weather events using dynamical network analysis of ground based magnetometers

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ABSTRACT

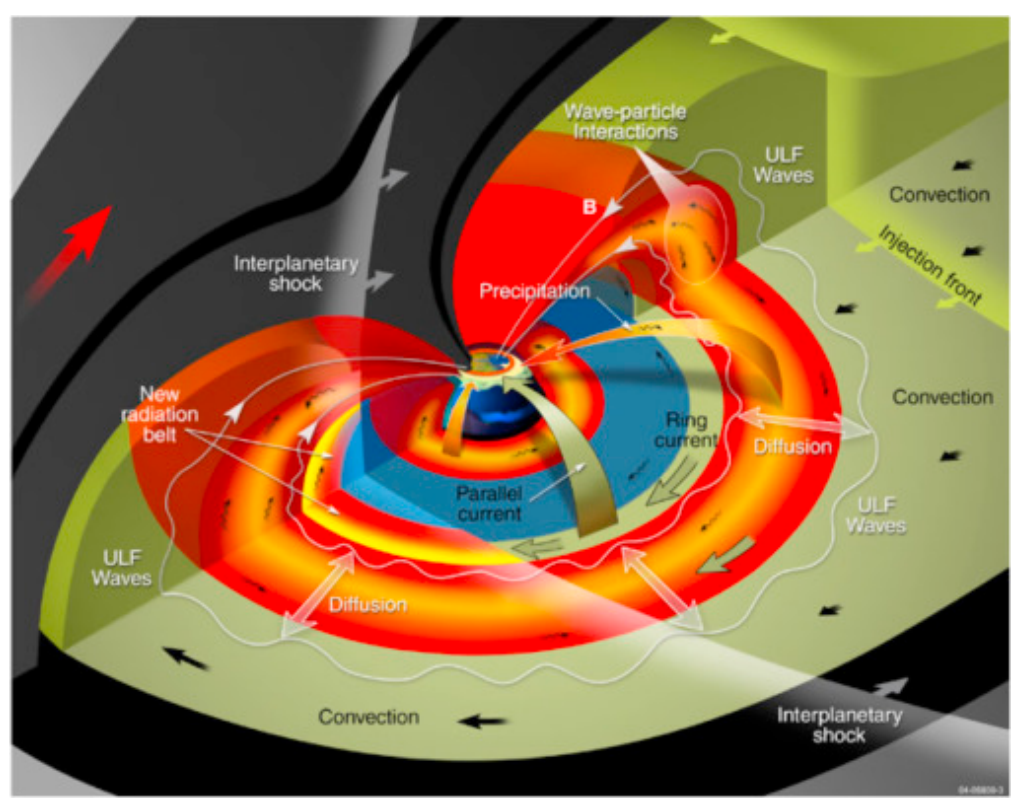
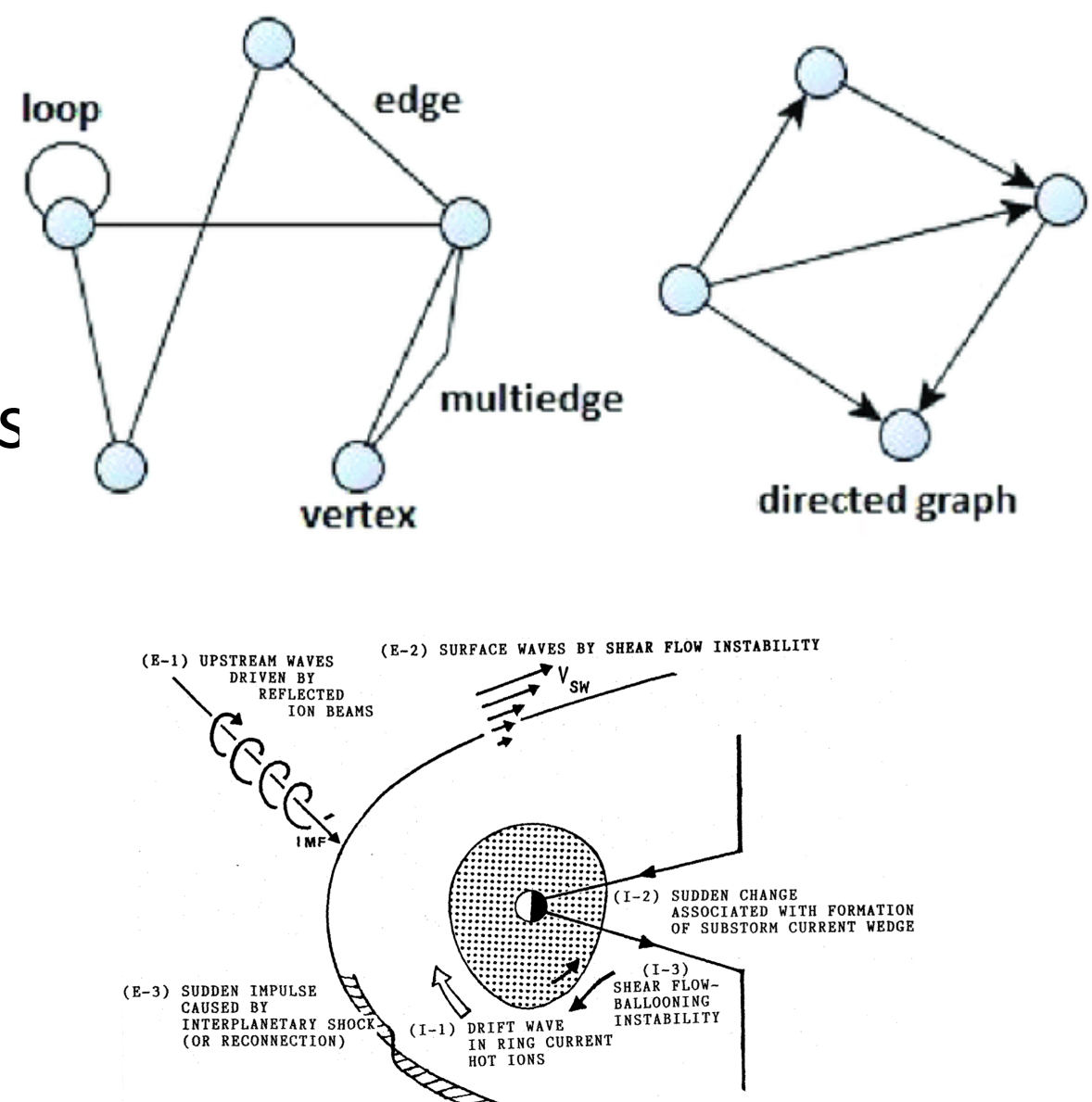
Space-weather events known as storms/sub-storms can have severe impacts on technological systems, on the ground and in space, including damage to satellites and power blackouts in severe cases. Quantitative understanding of the highly non-linear magnetospheric system during storms/sub-storms is important as our reliance on space based systems increases. We perform network analysis on the 100+ ground-based magnetometer stations collated by SuperMAG. One of the key geomagnetic responses to space weather events are Pc waves which are oscillations along whole magnetospheric magnetic field lines. Recently SuperMAG has offered the full set of Pc measurements collating magnetometer data globally. High quality Pc wave data has only been available locally across magnetometer chains. However, now with SuperMAG these measurements are available globally with uniform background calibration and time-base. To fully exploit this data requires a new application of analysis tools, for the first time we apply dynamical network analysis to this data set. Obtaining Pc waves over a range of frequencies allows us to probe multiple time and length scales, likely corresponding to different physical generation mechanisms. We will aim to obtain the global Pc wave dynamical networks over individual space weather events in order to quantify the full spatio-temporal response of the magnetosphere to storms/sub-storms with a few network parameters.

To create the network we first band-pass filter magnetometer time series data into four known frequency intervals. Next the data is time-lagged-cross-correlated (TLXC) for each band ensuring a window at least twice the Pc wave period of interest. We then use noise surrogates to establish a threshold to filter out insignificant peak TLXC values. For each windowed TLXC we build a peak-classification routine (PCR) to determine whether a signal is wavelike or not to then determine the phase difference. The PCR determines whether a network connection is directed or undirected between two geospatially located magnetometer stations for each time window. If the signal/time-series phase difference is found as non-zero for the TLXC function there is a directed network connection pair, otherwise an undirected network connection pair is formed. We perform the TLXC and PCR for each frequency band and between all magnetometer time-series pairs to obtain four dynamical directed and four dynamical undirected networks. The undirected networks quantify the onset time, and spatial extent, of large-scale coherent Pc wave activity. While directed networks also quantify how Pc wave activity is propagating across the magnetosphere for non-coherent Pc wave 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.

Why?

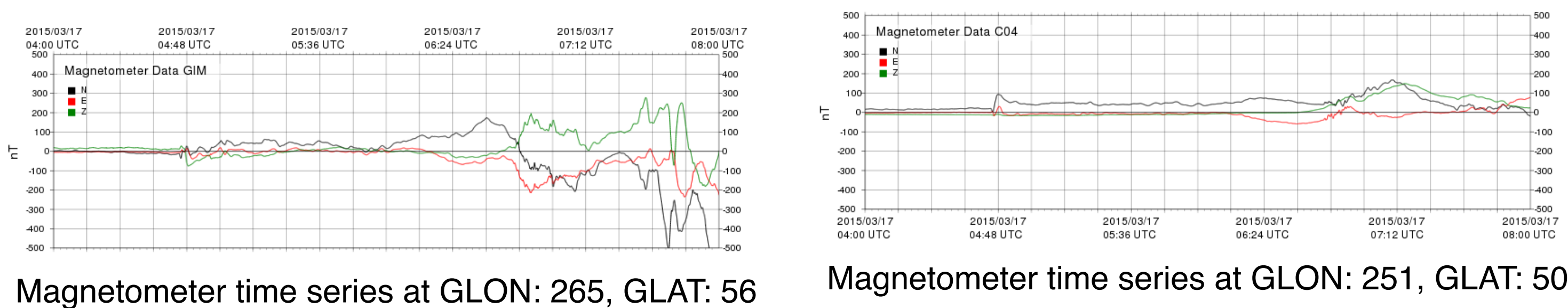
- **Space weather has severe impacts on earth systems including:**
 - Induction of geomagnetic storms and substorms
 - Power grid, radio and satellite communications failure
- **Pc waves used to understand Geomagnetic storms and substorms**
 - Pc waves are ULF (MHD) waves measured on the ground via magnetometers
 - 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



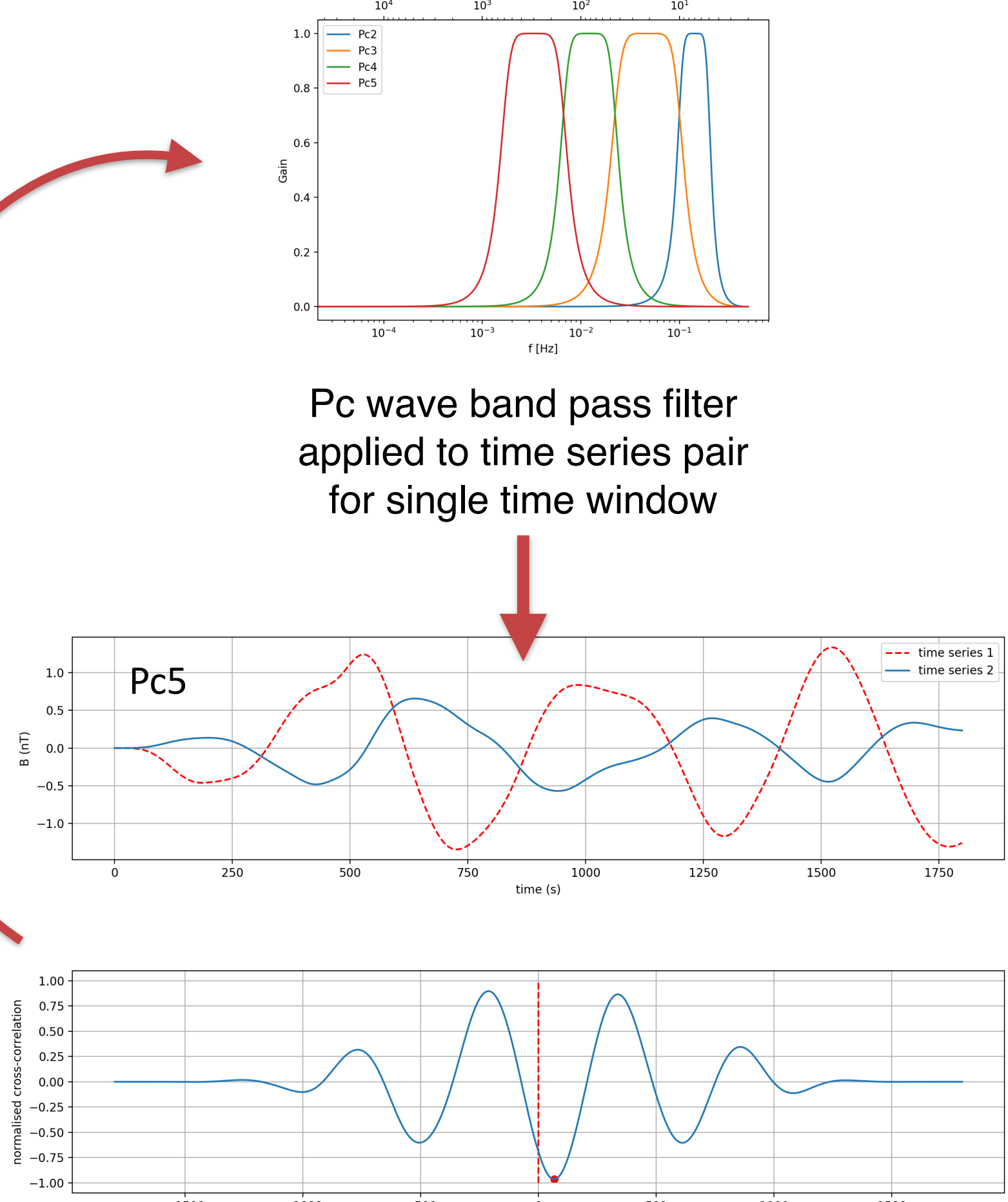
Wave type	Period range (s)
Pc1	5-10
Pc2	10-45
Pc4	45-160
Pc5	150-600

How?

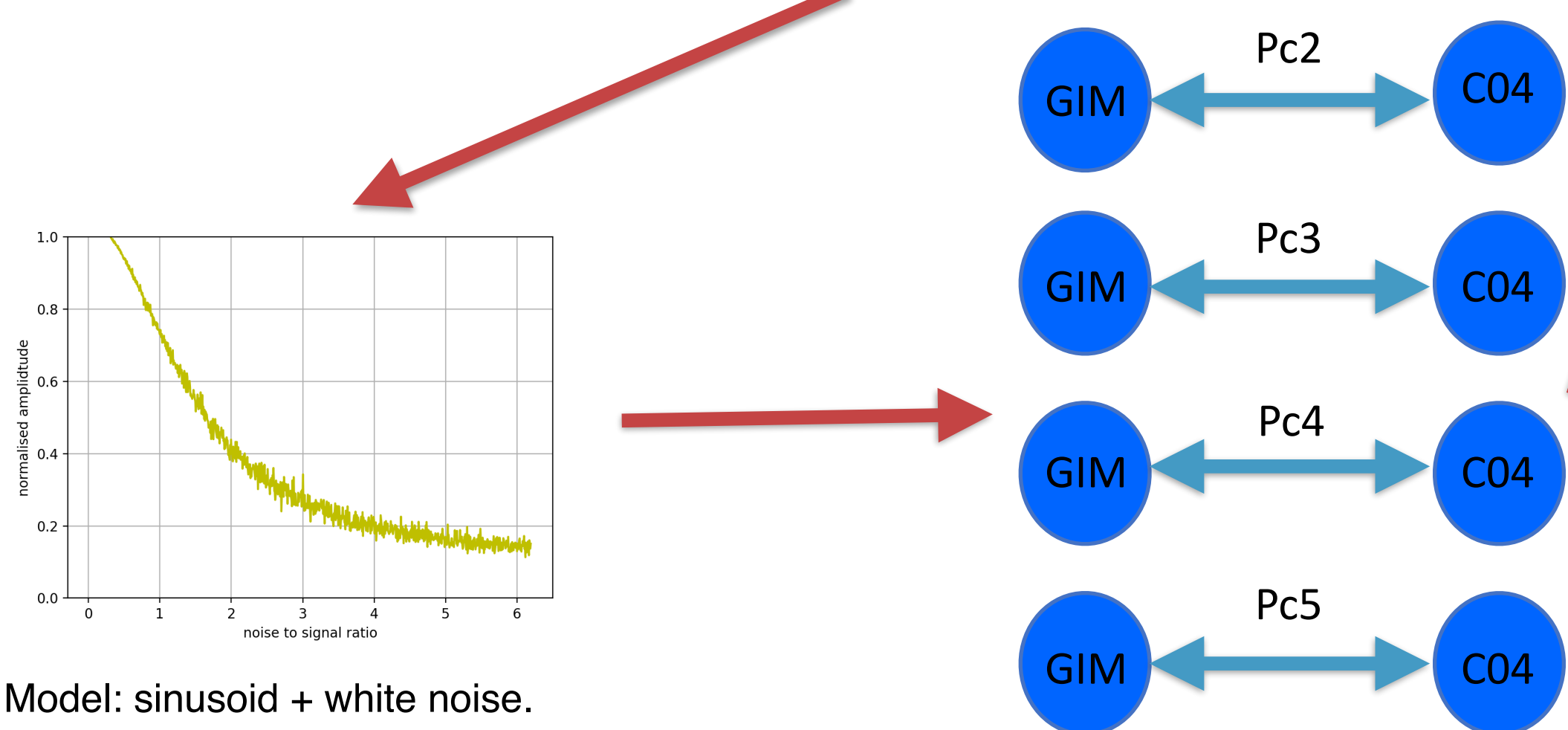
Building networks



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

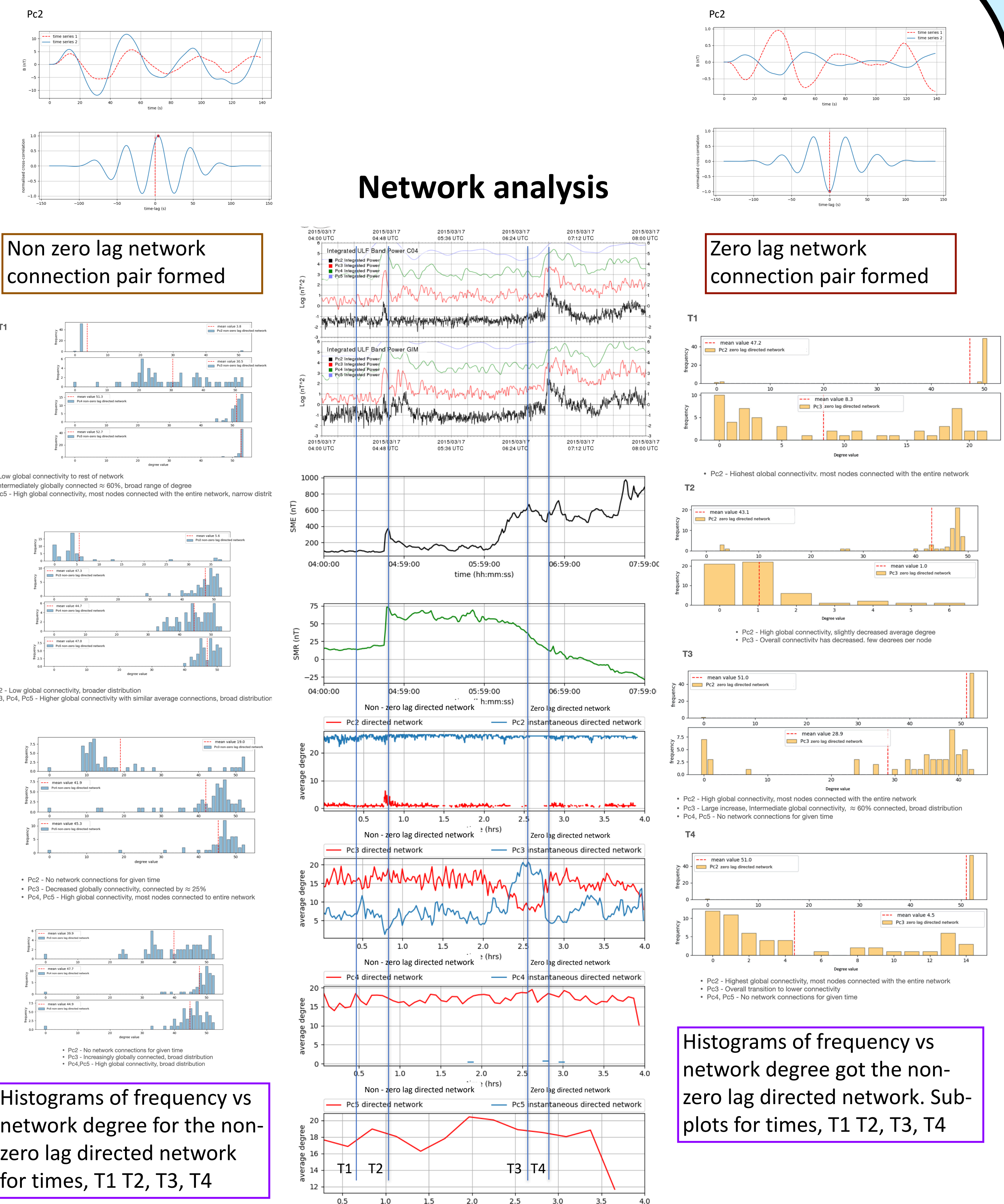


Model: sinusoid + white noise. Use this to determine threshold to be applied to cross correlation to determine whether each station pair is connected or not

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

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

What?



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

On-going Work

- Preliminary study demonstrates the potential for dynamical networks to capture the details of spatial correlation.
- Performing network analysis on relevant clusters in magnetic local time co-ordinates.
- 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.