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Structure function analysis of plasma density fluctuations during total loss of lock of GPS signal events

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Background Information

- Ionospheric Irregularities have scale sizes from a hundred meters to hundreds of km
- They are a major source of disturbance for propagation of radio waves
- Total loss of lock events (acquisition of fewer than 4 GPS satellites) are a proxy for severe ionospheric irregularities
- We use Swarm mission plasma density and GPS receivers data for this research.
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Traditional methods and explanations

Plasma density irregularities are typically characterized by spectral slope index alpha, i..e PSD proportional to $\frac{1}{f^{\alpha}}$

A single value of α is indicates scale invariance

The scale-invariant structure of variability is explainable with a monofractal formalism where a single scaling (Hurst) exponent is enough for describing the fractal structures.

Multifractal Analysis

- Two similar multifractal analysis methods are: Structure function(SF) and detrended fluctuation analysis (DFA)
- The structure function of one-dimensional variable X(t) is :

$$S_q(\tau) \equiv \langle [\![X(t_{i+\tau}) - x(t_i)]\!]^q \rangle$$

$$S_q(\tau) \approx \tau^{h(q)}$$

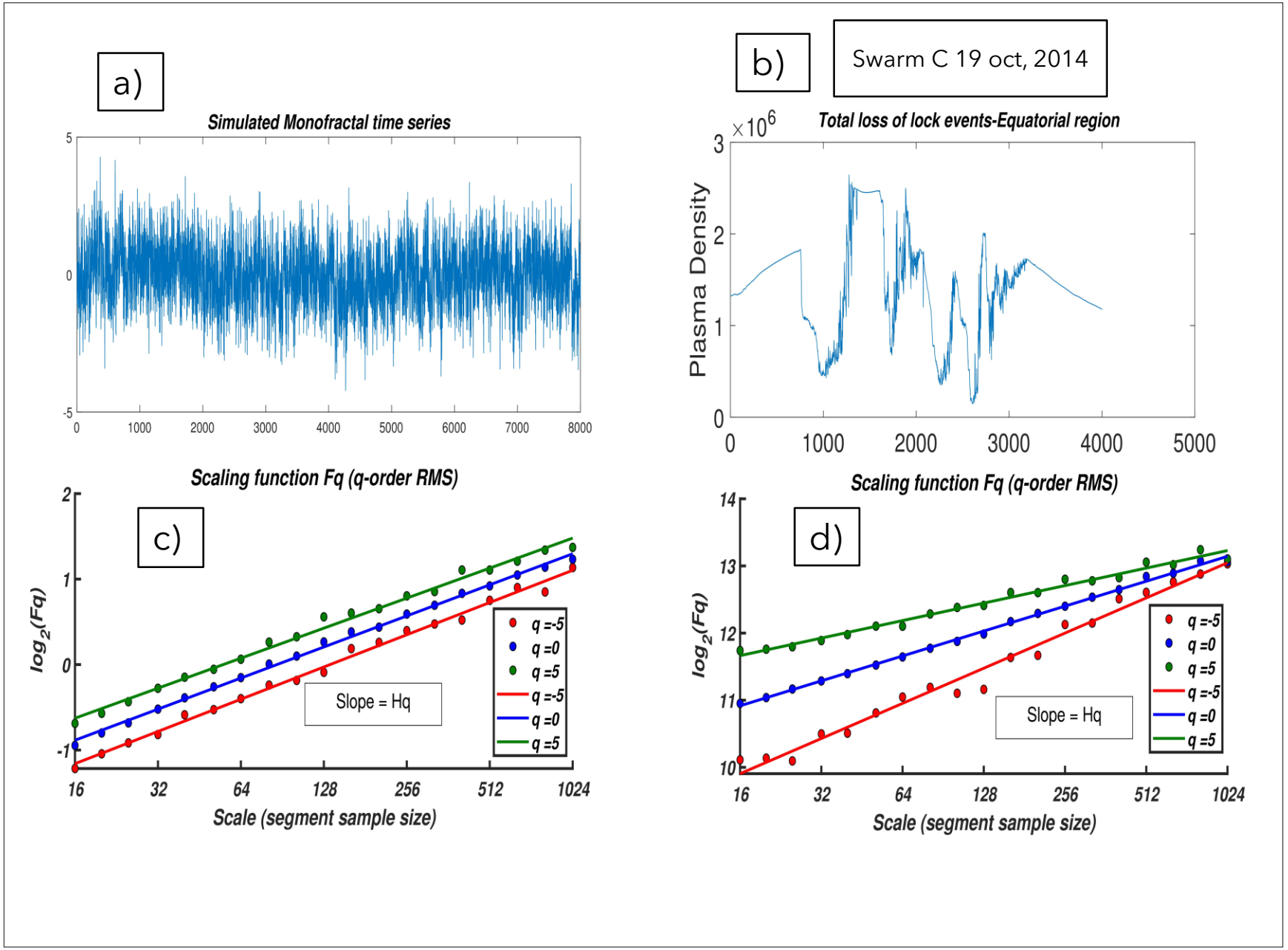
- The exponent factor of the first order structure function(H) is called Hurst exponent

$$S_1(\tau) \approx \tau^H$$

- For monofractals there is a relation between Hurst exponent and exponent factors of the different order structure function h(q) = qH
- For this research we use Detrended Fluctuation Analysis, which differs from the SF in that negative orders exist.

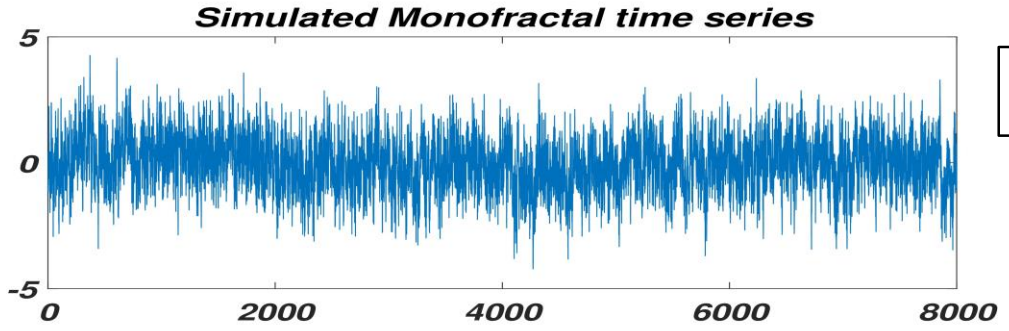
Scale exponent of different orders of detrended fluctuation analysis (DFA)

- a) Simulated monofractal time series
- b) Measured plasma density of a total loss of lock event at the equatorial region
- c) Slope of different order of DFA for monofractal data
- d) slope of different order of DFA for total loss of lock event
- Different slopes for different orders of DFA is a sign of multifractality

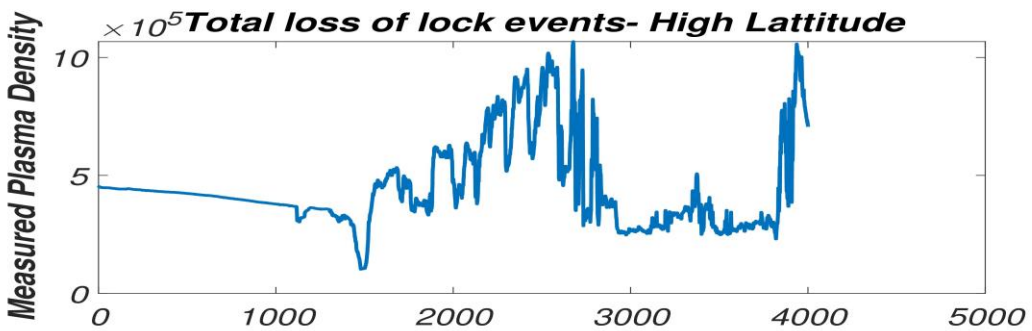


Swarm C 8 oct, 2014

a)



b)



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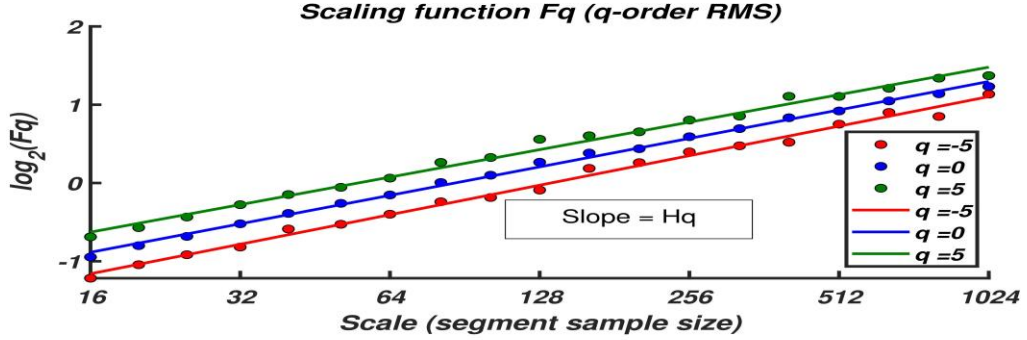
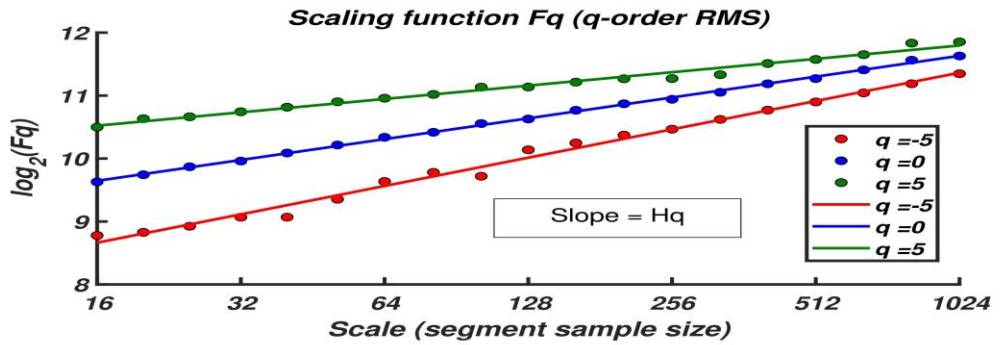


d)



Scale exponent of different order of detrended fluctuation analysis (DFA)

- In this slide we repeat the same procedure, but for a total loss of lock even at high latitude

Summary

- We present evidence for multifractality in the equatorial region and high latitude region of the ionosphere during total loss of lock of the Swarm GPS receivers

- For a better understanding of physics of ionospheric irregularities that cause total loss of lock and severe scintillation we need to consider multifractal structures instead of monofractal structures