

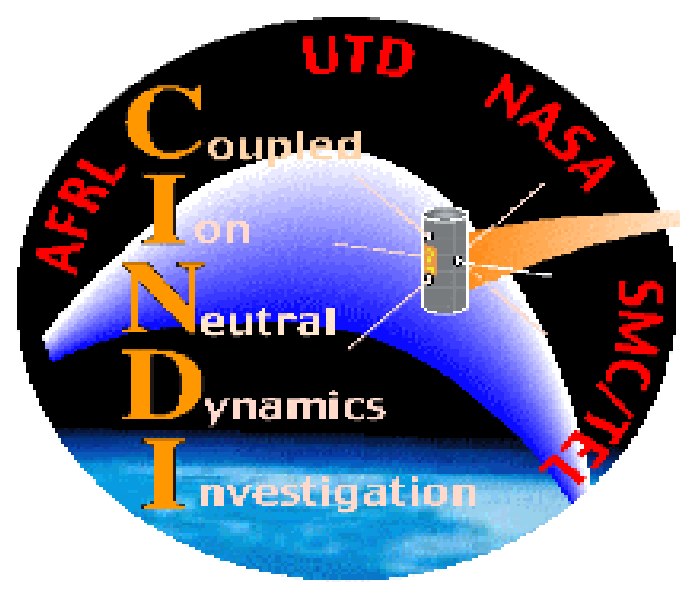
SEPARATING PLASMA IRREGULARITIES AND BACKGROUND SIGNATURE USING



WAVELET TRANSFORMATION

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Abstract:

Plasma irregularities are regions in the low-latitude, night time ionosphere, characterized by significantly reduced plasma density. They are accompanied by perturbations in the vertical ion drift. This signature makes it possible to identify plasma irregularities using density and ion drift measurements. The Ion Velocity Meter (IVM), an instrument used in the Coupled Ion-Neutral Dynamics Investigation (CINDI) mission onboard the Communications/Navigation Outage Forecasting System (C/NOFS) satellite provides measurements of ion density and drift motion.

Plasma irregularities are an important subject to study as they can cause scintillations in radio communication. They are highly non-linear, dependent on temporal factors like local time, season, solar activity, etc. rendering them difficult to model. Here, we make use of the Morlet wavelet to locate the occurrences of plasma bubbles by finding density perturbations (ΔN) and normalized density ($\Delta N/N$) from in-situ IVM data.

Motivation:

- Separate ionospheric responses to irregularities from regular ionospheric features.

Tools:

- Enthought Canopy – a Python scientific computing distribution
- Python
 - ❖ pysat (Python Satellite Data Analysis Toolkit) – to load, clean and process satellite data
 - ❖ pysatWavelet – to find Morlet wavelet and scale variance

Data:

C/NOFS was launched in 2008 during weak solar minimum followed by moderate solar maximum to study the dynamics of Earth's ionosphere. IVM data from C/NOFS, publicly available through NASA Goddard's Coordinated Data Analysis Web (CDAWeb), is used here to study plasma irregularities.

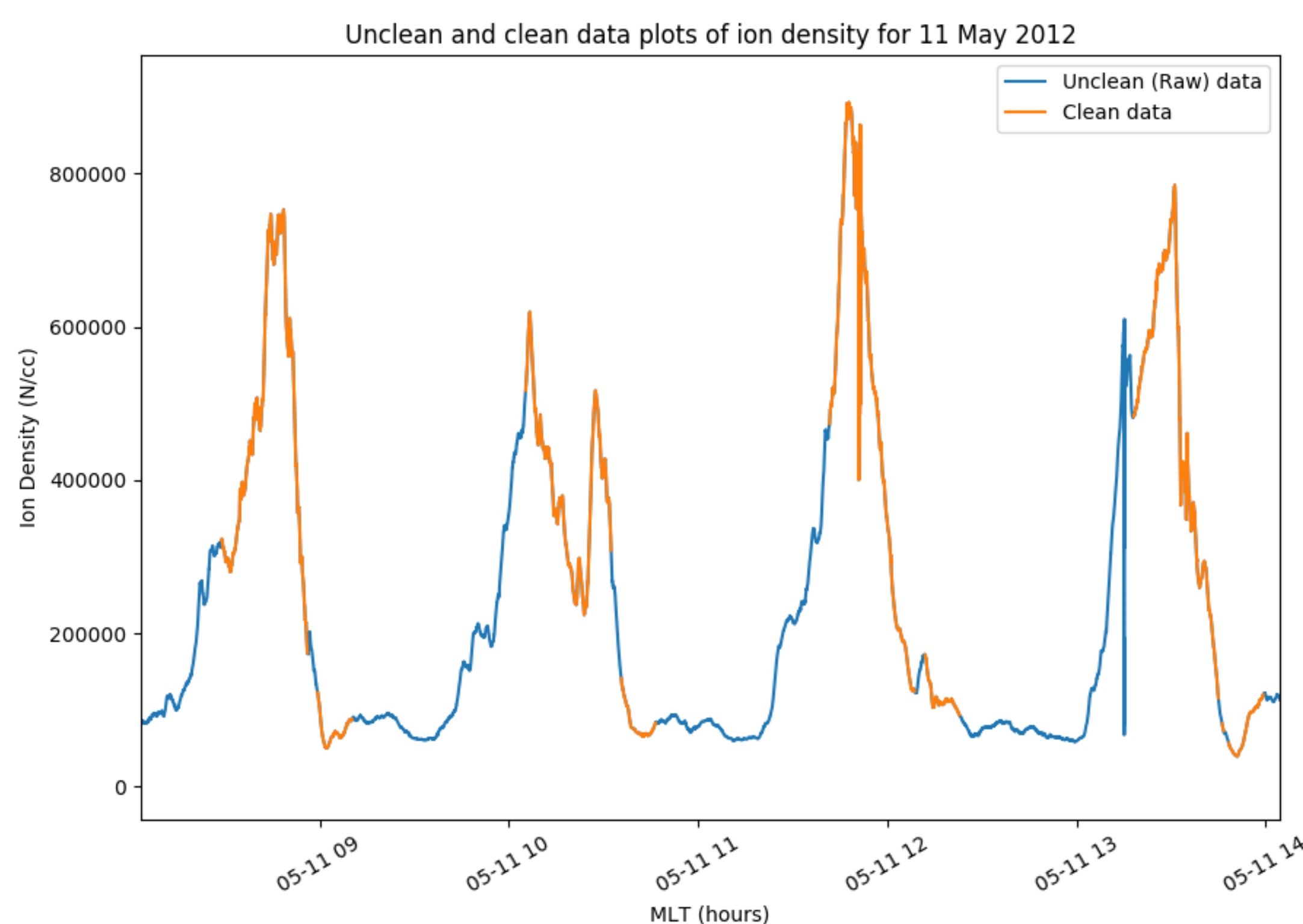


Fig 1. Unclean & Clean data plot for 05/11/12. Clean data traces unclean data precisely except when the data is unreliable

Introduction:

The data downloaded from CDAWeb is categorized into different quality levels [0-9] with quality flag value 0 indicating the highest quality data and 9 indicating the lowest quality data. For our work, we consider quality flag values ≤ 4 . Python Satellite Data Analysis Toolkit (PYSAT) (Stoneback, Burrell, Klenzing, Depew, 2018) is used to download, load and clean data and to perform data analysis. As can be seen from Figure 1, clean data traces the unclean data precisely, except at places where the data is untrustworthy. Ion density values (N_{raw}) in the clean data is then used to find scale limited variance (ΔN) and change in ion density (ΔN) by Morlet Wavelet transformation. We can find the background ion density signal using –

$$N_{bkgd} = N_{raw} - \Delta N \quad \dots(1)$$

All measurements are restricted up to 550km of altitude in order to avoid impact of altitude variations of the satellite. The process was repeated and

observed multiple times to get good values of scale range and threshold. Fig.2 describes the process in a nutshell.

Method:

Morlet Wavelet, used in this study, is similar to a Fourier transform constructed using complex exponential wave and enveloped within a Gaussian window to retain time information of the signal (Torrence and Compo, 1998). We identify plasma irregularities by noticing large variation or sharp changes in ion density. The non dimensional frequency of Morlet wavelet is taken as six to satisfy the admissibility condition for wavelets.

One approach to identify plasma irregularities is by using a background signal and finding normalized ion density. Morlet wavelet transform with scale range of up to 850km is used to find the delta signal as given in equation 1.

Another approach is by finding the variance of ion density. A scale-limited variance is calculated using wavelet (Torrence and Compo, 1998, eqn. 14) equation. The scale size range was fixed up to 100km for finding variance to avoid confusion of variation in ion density with the varying altitude of the satellite. An irregularity is identified based on threshold values - $\Delta N > 5E3 N/cc$ and $\Delta N/N > 0.15$ (Stoneback and Heelis, 2014).

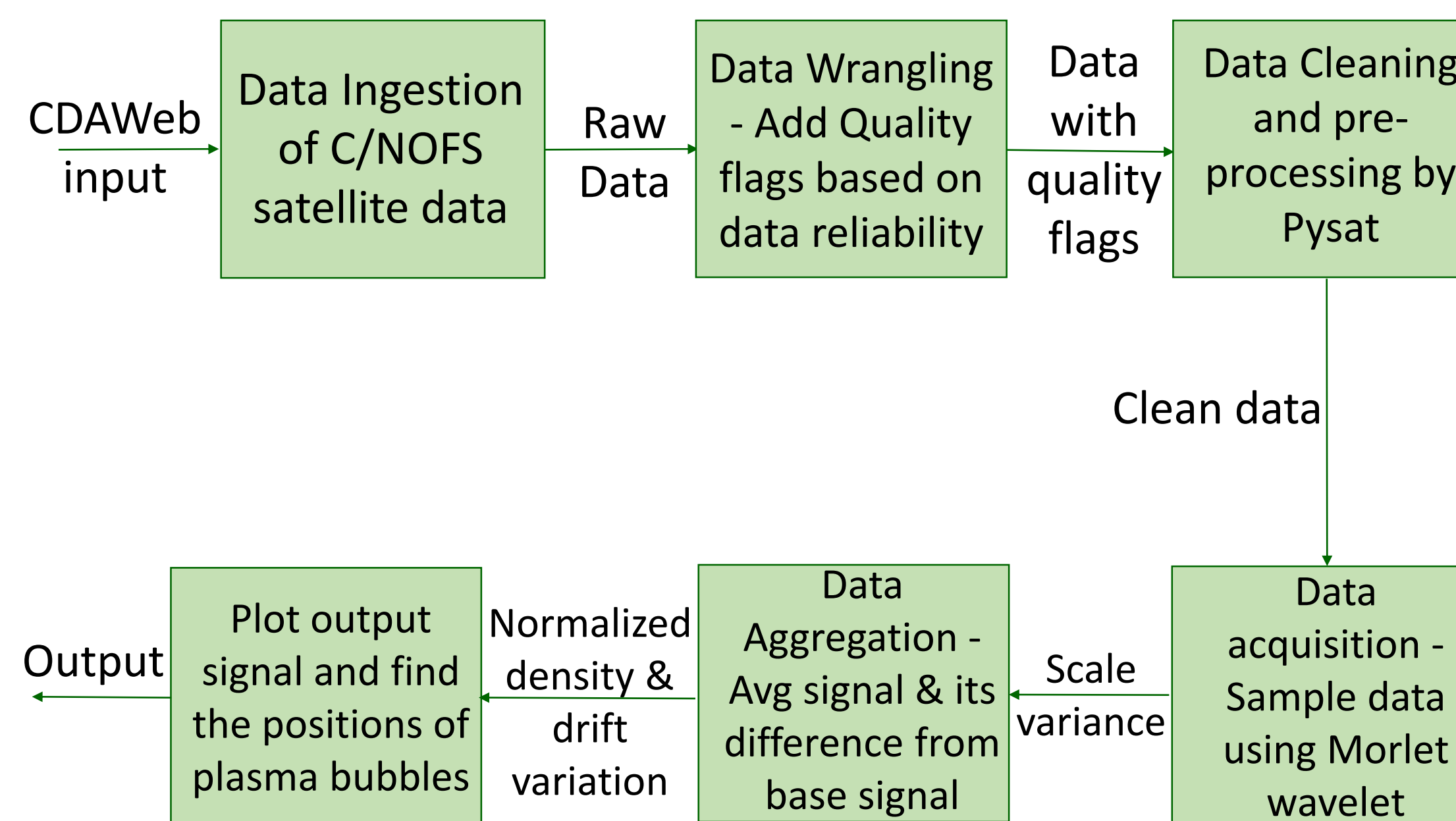


Fig 2. Block diagram representation of the entire process

Fig.3 shows the plot of scale-limited variance and normalized ion density obtained using Morlet wavelet transformation. Both methods identify plasma irregularities at most places consistently.

Discussion:

It is worthwhile to note that the normalized density uses a background density profile in its denominator rather than the raw density. Raw density has lower value in the bubble, would result in increased $\Delta N/N$ and hence false

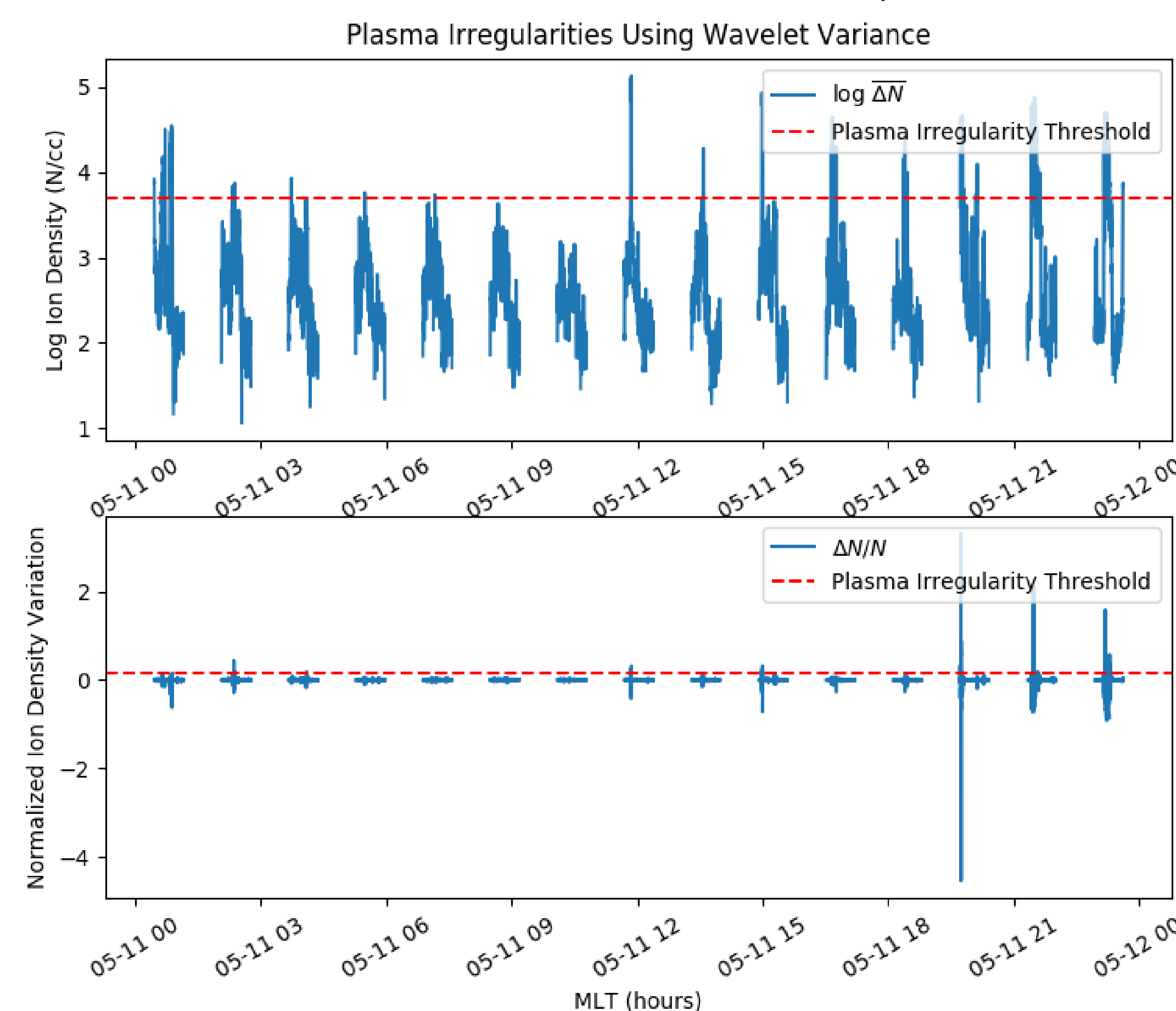


Fig. 3 Finding plasma irregularities using scale wavelet variance and normalized ion density

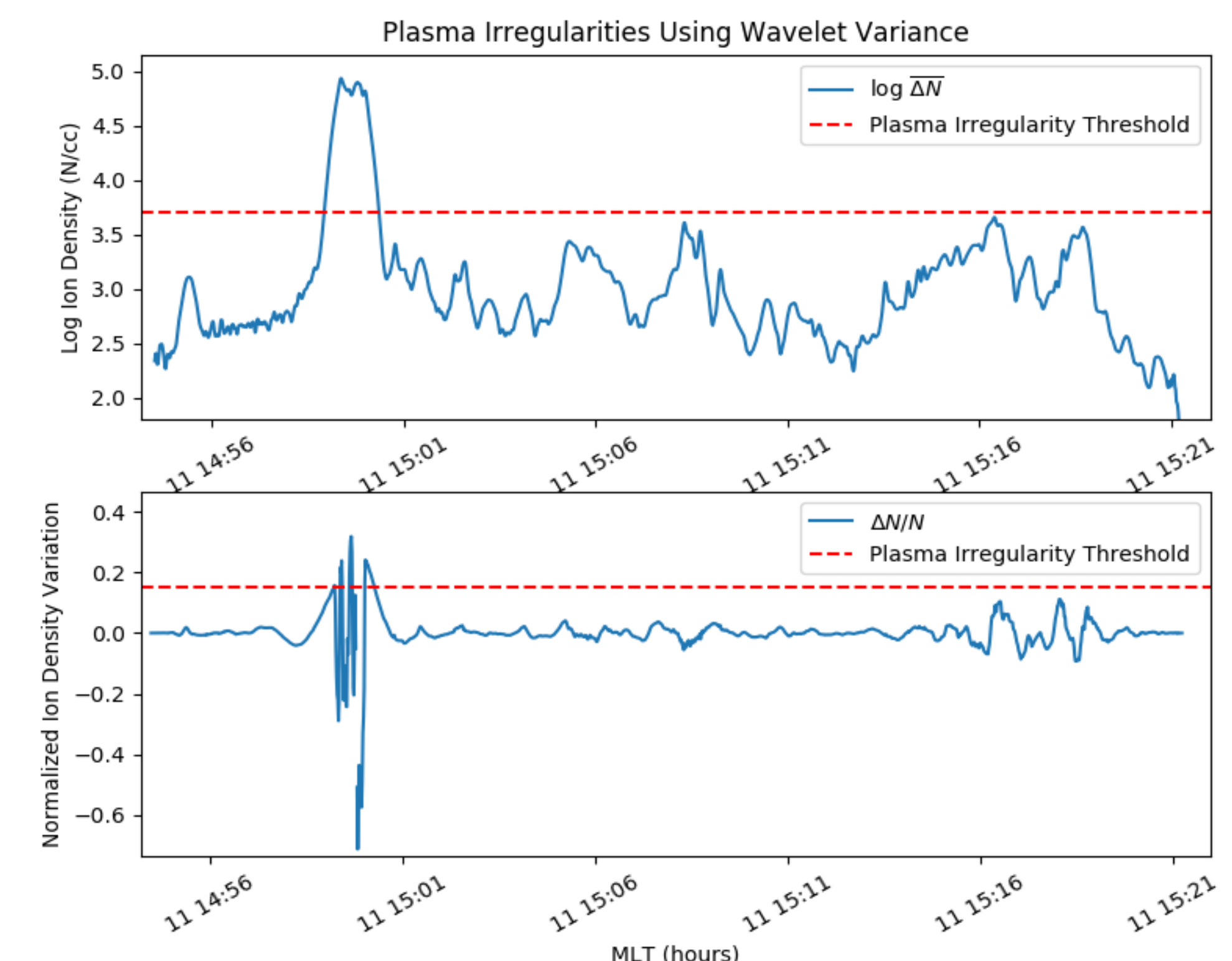


Fig 4. Comparison of both approaches to identify plasma irregularities

identification of plasma bubbles. $\Delta N/N$ may not identify plasma irregularity in its early stage of formation as the change in density is not significantly different than the background. ΔN uses only the real part of wavelet transform and hence can be seen (see Fig.4) to show strong coupling towards the center of the irregularity.

On the other hand, the use scale variance increases the temporal range to identify elevated response because variance includes imaginary component of the wavelet power, which maximizes with an oscillation out of phase with the current time. Fig. 5 indicates the correlation between scale-limited ion density variance and raw ion density. It is essential to understand the advantages and shortcomings of each method to decide which suits our need the best.

Numerous studies are focused on the power spectrum of irregularities in density measurements. The successful use of wavelets here can be used to isolate perturbations in ion density and enable the study of its power spectrum (Stoneback and Heelis, 2014).

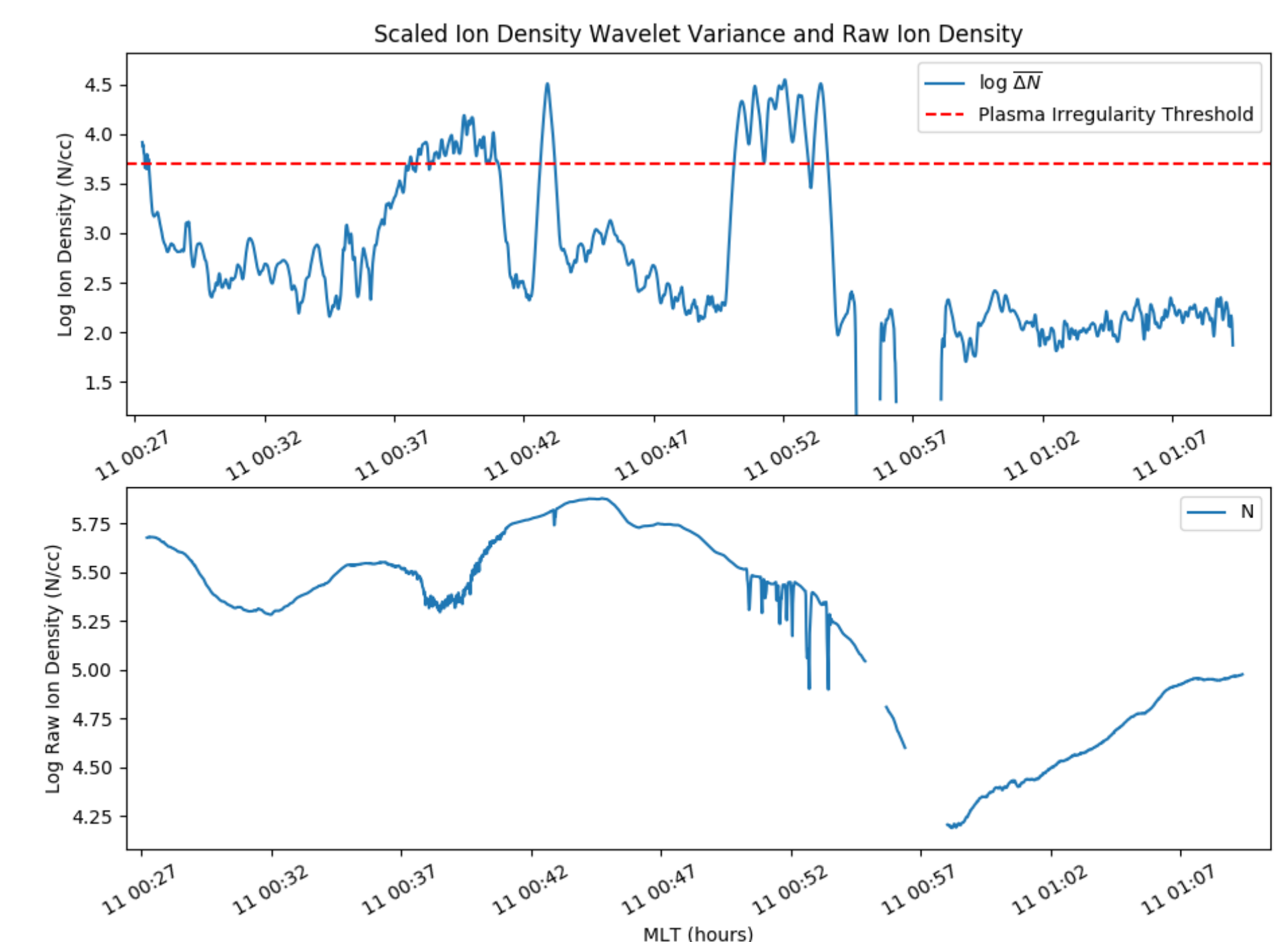


Fig 5. Scale-limited ion density variance and corresponding raw ion density signal

Conclusion:

Morlet wavelet and continuous wavelet transform are successfully used to separate perturbations in ion density find the presence of plasma irregularities. This method allows us to separate the ionospheric response to irregularities from other regular ionospheric features, making it possible to learn more about the undisturbed equatorial ionosphere at this local time.

References:

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- Torrence, C. and Compo, G. P.: A Practical Guide to Wavelet Analysis, *B. Am. Meteorol. Soc.*, 79, 61–78, 1998.