Advanced Computing and Analysis Techniques in Physics Research
ACAT 2010

Online Filtering for Radar Detection of Meteors

- LEITE, E. C. V.
- ALVES, G. O.
- SEIXAS, J. M. de
- ALMEIDA JUNIOR, F. M. L.
- TAKAI, H.
- VIANNA, C. S.

COPPE/Poli/UFRJ

Outline

- Introduction:

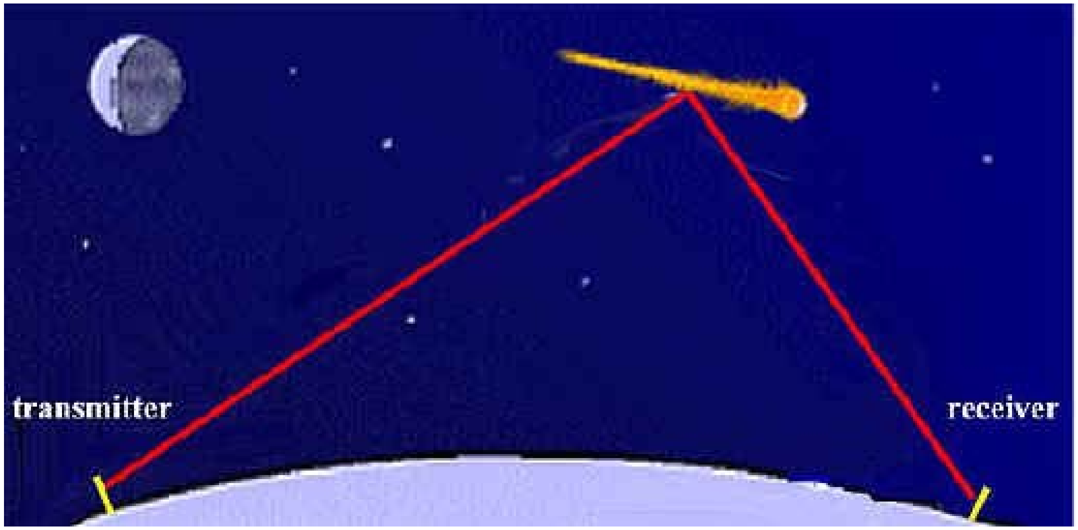
→The Radio Meteor Scatter technique (RMS)

→The detector setup

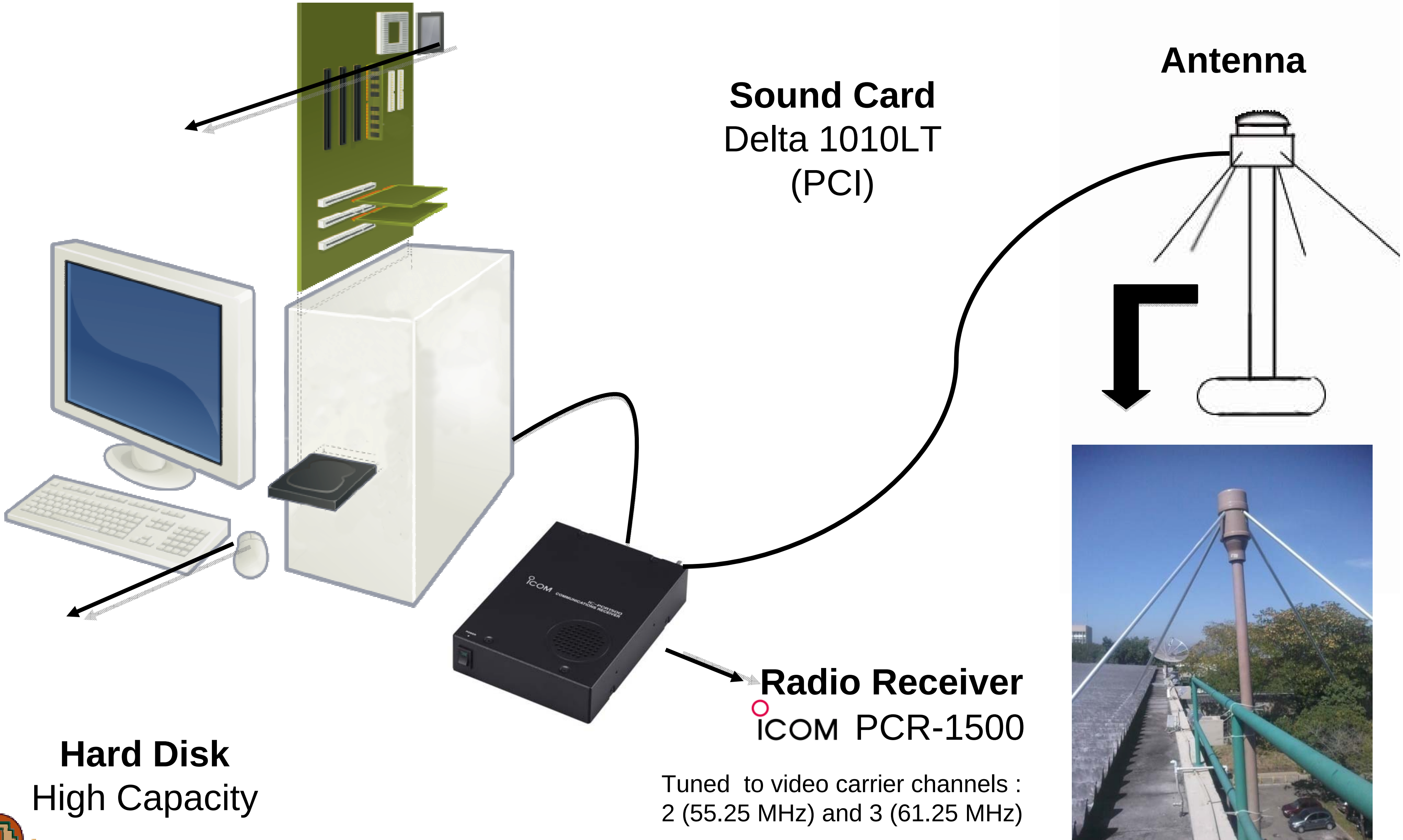
- Objective
- Meteors → signal characterization
- The Power Spectrum Analysis
- Conclusions and Perspectives

The Radio Meteor Scatter technique

- Very High Frequencies (VHF) radio waves – 30 to 300 MHz;
- Advantages: Covers large areas at low cost regardless of weather conditions and detects meteors and micrometeors;
- Other events could also be detected, e.g. cosmic rays;
- Motivation of meteor study:
  - Determine signal parameters to study the ozone layer at 80 to 100 km above sea level;



The Detector Setup



Objective

- Signal Detection:

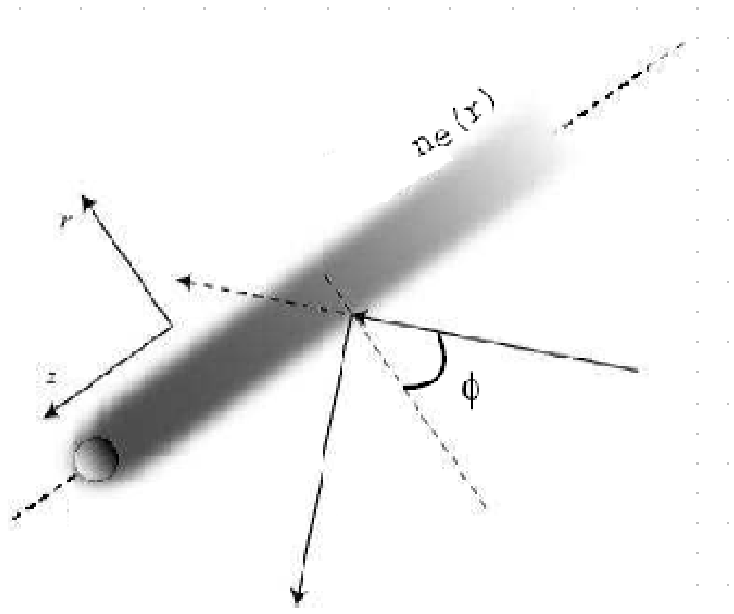
  → In frequency-domain: Cumulative power spectrum analysis and narrowband demodulation.

  → Online filtering: storage requirement reduction.(~10 gigabytes per day of raw data) ; efficient classification.

Meteor Trail

- The meteor trail is a plasma with a characteristic frequency:

$$\omega_p = \sqrt{\frac{N_e e^2}{\epsilon_0 m_e}}$$



- Two types:

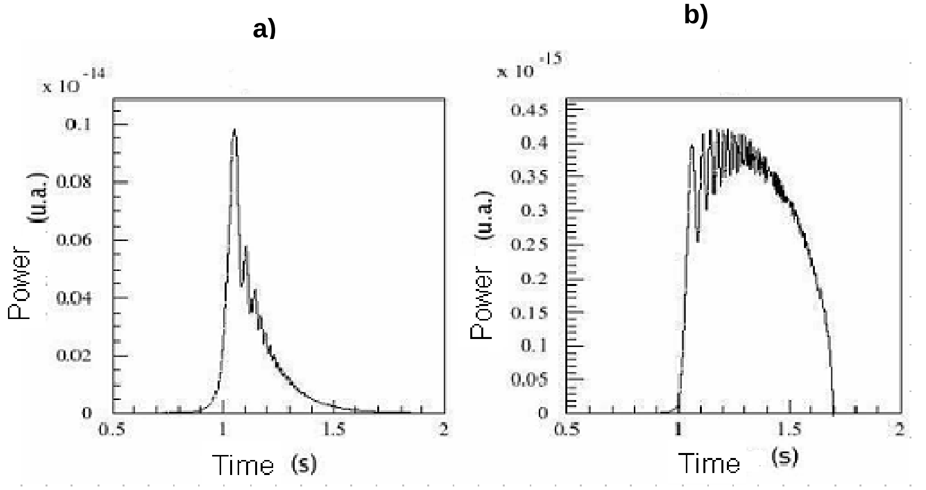
- Underdense trails: Low N_e. The scattering is done by individual electrons. Fraction of events: 90%. Duration: tenths of seconds.

- Overdense trails: High N_e . Fully reflect the incident wave and the trail is treated as a cylinder reflector. Fraction of events 10%. Duration: few seconds.

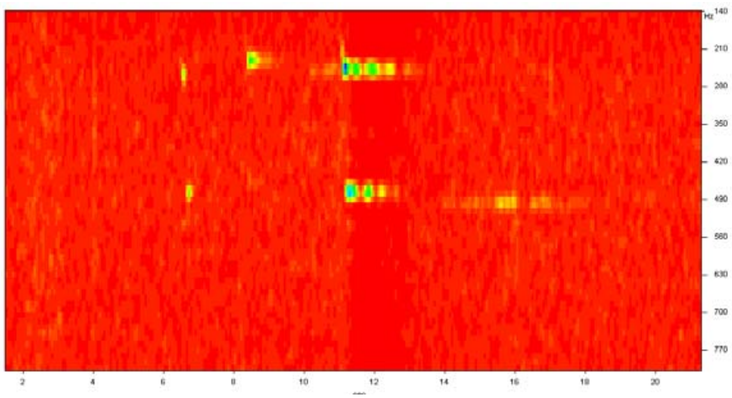
Meteor Trail

- Simulation:

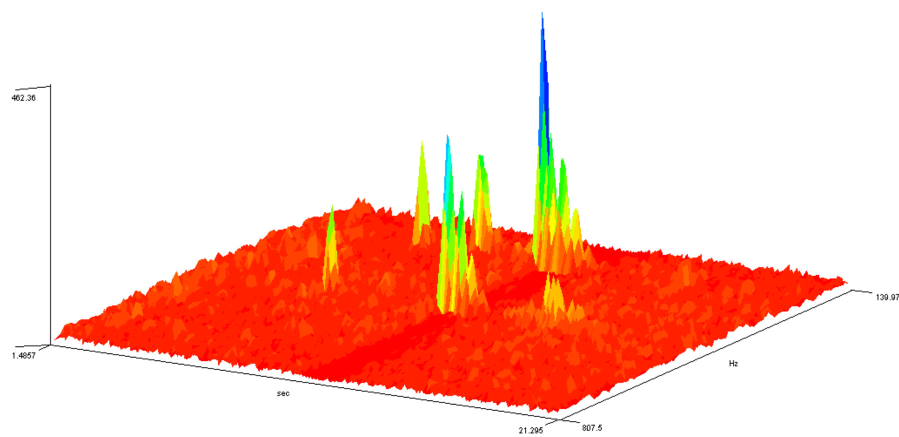
a)	Underdense trail
b)	Overdense trail



- Signals of underdense trails:



2D Spectrogram



3D Spectrogram

Meteor Data

- Acquired at Custer Institute and Observatory, by the Brookhaven National Laboratory team from June 1st to 7th, 2008;
- Audio Characteristics:
  - 2 Channels;
  - Sampling rate: 22050 Hz;

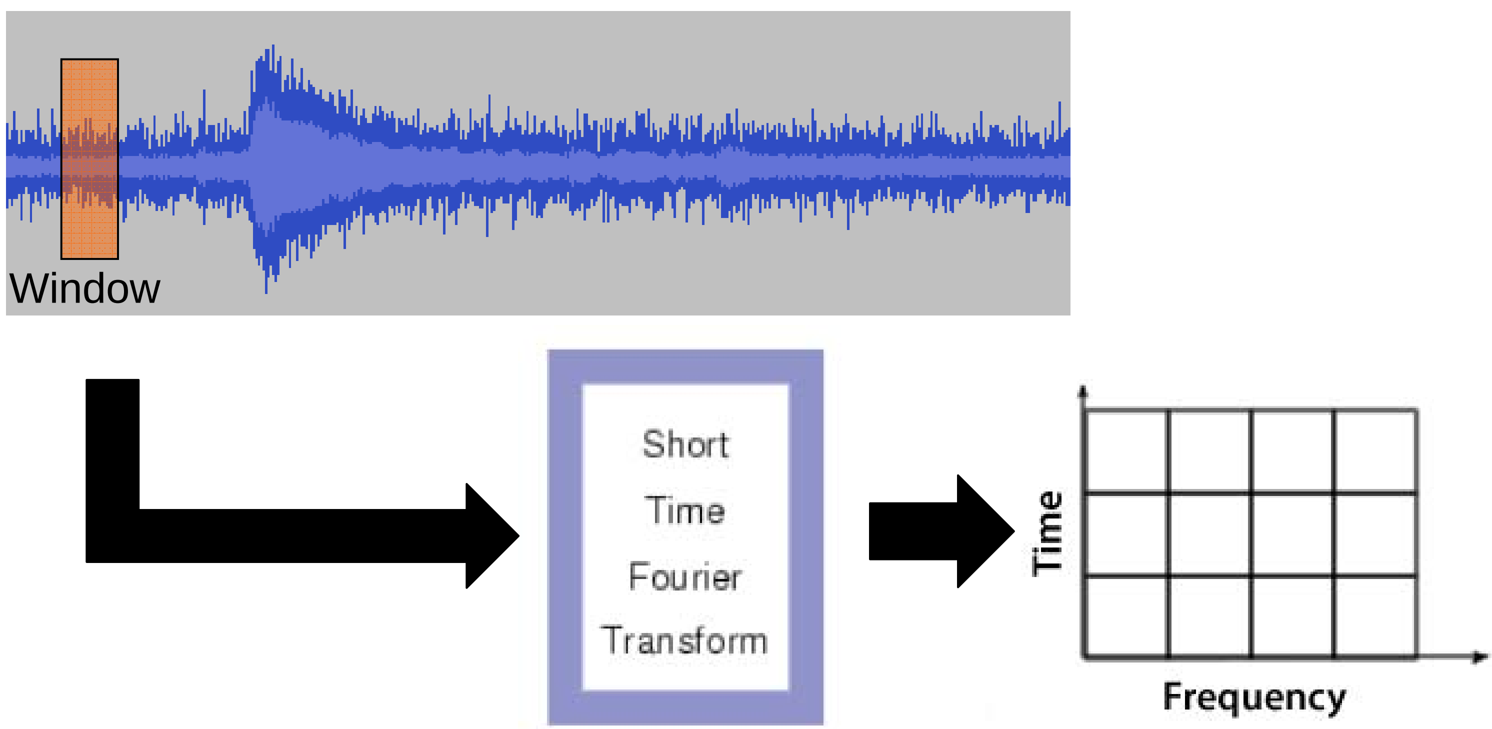
- Data from different days were split into two sets:

- Development set: Feature extraction and system design;

- Test set: For evaluating performance generalization;

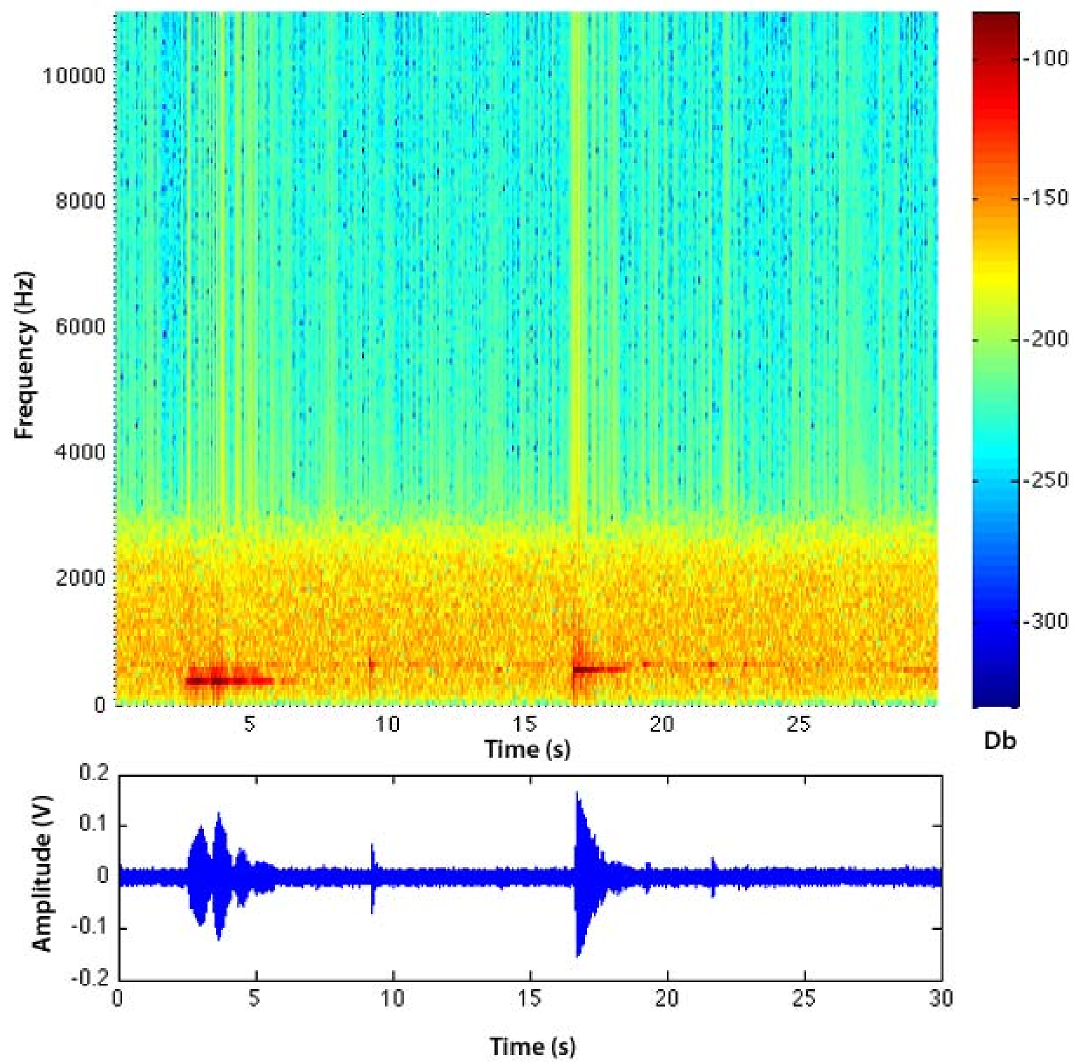
The Power Spectrum Analysis

- In frequency-domain, the event information is concentrated within a narrow band of the spectrum, corresponding to the video carrier demodulated;
- Apply Short-time Fourier Transform on time windows: spectrogram;



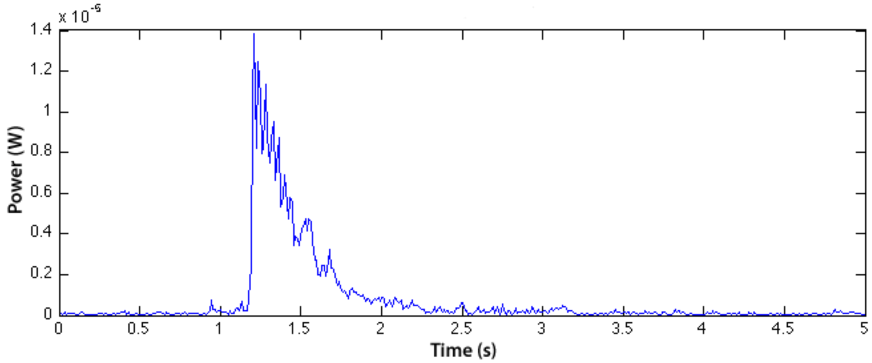
The Power Spectrum Analysis (2)

- 30 seconds of acquired data are analyzed at a time;
- The STFT is performed with non-overlapping rectangular windows (256 samples) and the PSD is estimated through periodogram;
- The PSD determines the frequency bin in which information is maximun;
- The power peak value for each data window is stored;

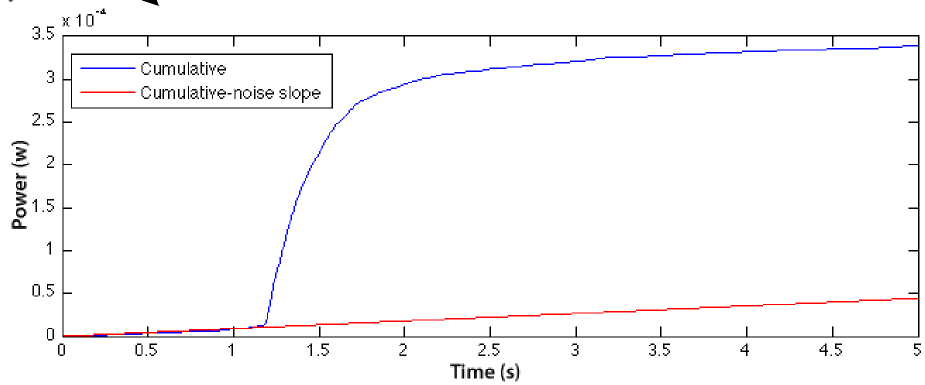


The Power Spectrum Analysis (3)

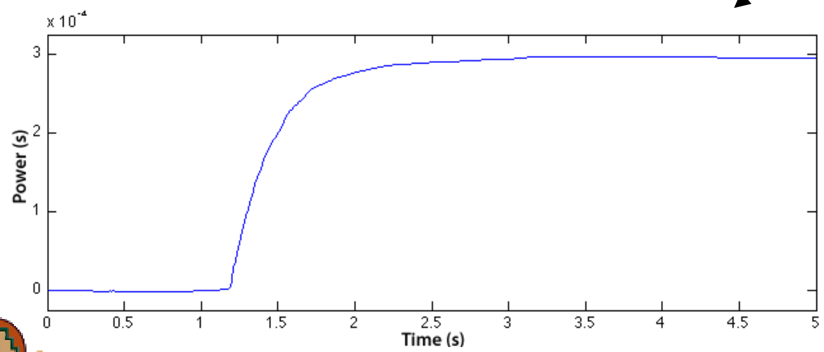
- Power peak received over time for an underdense trail:



- Accumulating process:
  - Produces a curve that has less fluctuations and monotonically increases;



- The slope in the cumulative power due to the background noise is estimated through a linear fit and subtracted from it;



- Fluctuations in the slope:
  Threshold values for defining the start and end samples of the triggered event.

Online Signal Detection

- On the detector setup, the computer runs both signal acquisition end processing;
- Signal Detection:
  - Requires a buffer to store a block of data (30 seconds);
  - Processes the current data block;
- Time required for processing each block of data: ~ 0.7 seconds;
- No parallel processing is required for online implementation;

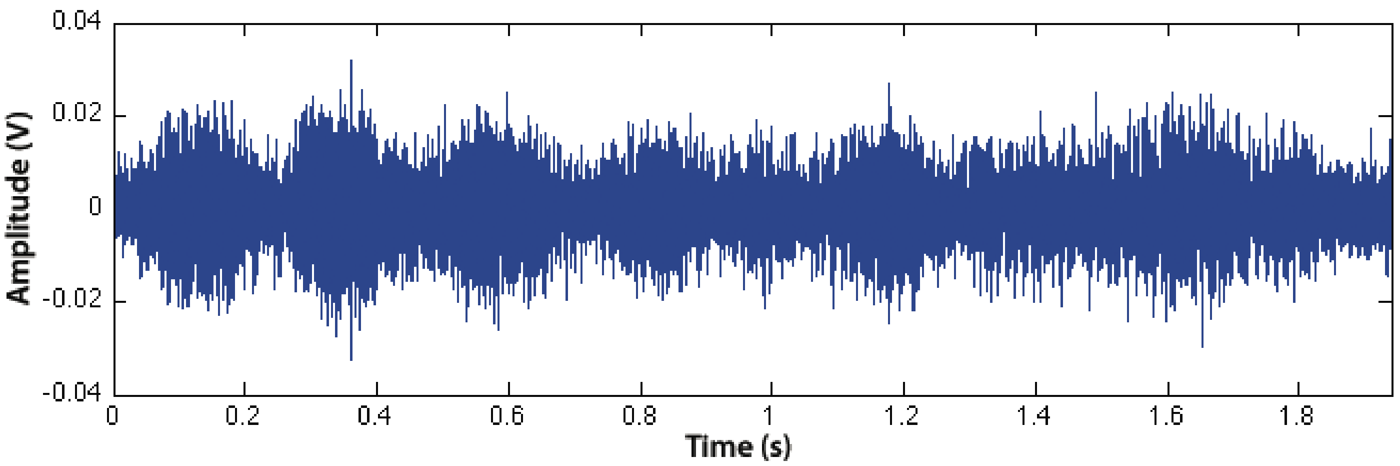
Results

- **Detection Results:**

  - Test set:
    - 50 blocks of data, which contain 261 meteor events (visual inspection);
    - 246 events correctly detected (94.2% efficiency);
  - False Alarm Rate: 17 fake events over 1,500 seconds of data (~1 fake event per 100 seconds);
  - Avoids 220 fake events to be recorded (144 MB less per hour);
  - The Filter avoided to record 3.45 GB of noise. Each 24h.

Additional Triggers

- VHF waves can be scattered by not only meteor trails, but also by e-clouds, airplanes, lightning and other atmospheric phenomena (might be interesting);
- The signal received from these reflections are constantly triggered;



Conclusions and Perspectives

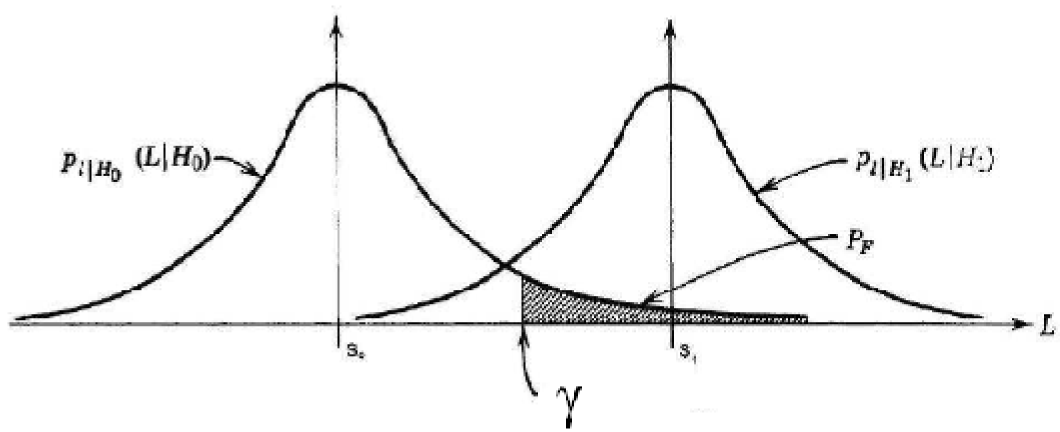
- The proposed technique provided an efficient online meteor signal detection and efficient usage of computing resources (for continuous data storage);

- Perspectives:
    - Accumulate received power at full width at half maximum, instead of using peak values;
    - Data processing under white noise conditions;
    - Optimal stochastic detection: Matched Filter;
    - Extract signal envelope: Narrowband Demodulation;

Signal detection by Matched-Filter

- Decision between two possible hypotheses → H_0 (only noise) e H_1 (signal + noise)

Likelihood ratio: $$\Lambda = \frac{f_{\mathbf{L}|H_1}(\mathbf{l}|H_1)}{f_{\mathbf{L}|H_0}(\mathbf{l}|H_0)} \underset{H_0}{\overset{H_1}{\gtrless}} \gamma$$

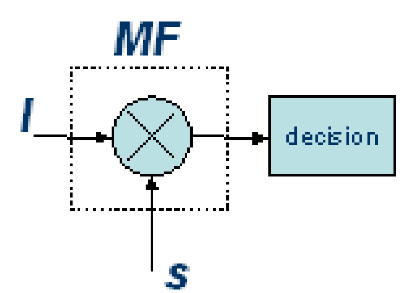


$$P_f = \int_{\gamma}^{+\infty} f_{\mathbf{L}|H_0}(\mathbf{l}|H_0)d\mathbf{l}$$

$$P_d = \int_{\gamma}^{+\infty} f_{\mathbf{L}|H_1}(\mathbf{l}|H_1)d\mathbf{l}$$

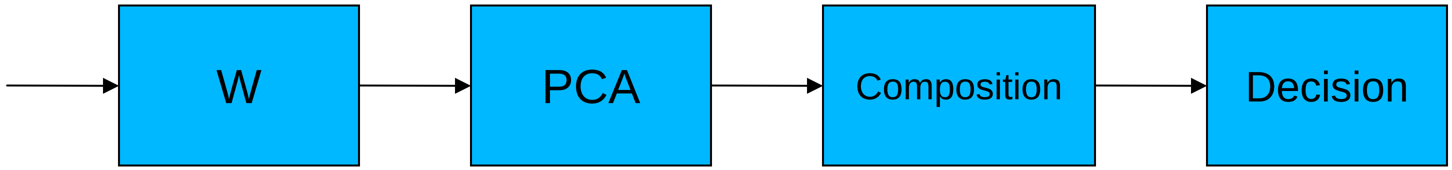
- Correlation: If the noise is Gaussian

and white → $$\mathbf{l}^T\mathbf{s} \underset{H_0}{\overset{H_1}{\gtrless}} \gamma'$$



The matched filter equation

Matched Filter for Gaussian Processes



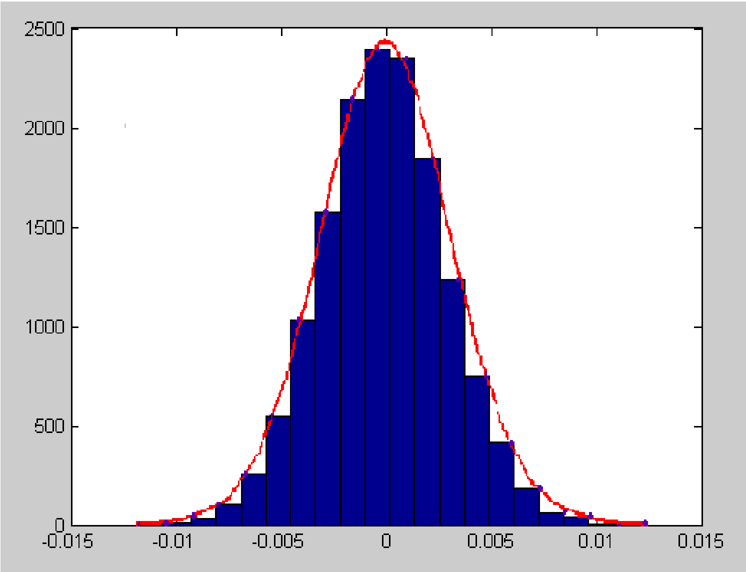
- Problems:

1.Number of components to retain;
2.Noise power estimation;
3. Pure signal (without noise) is not available

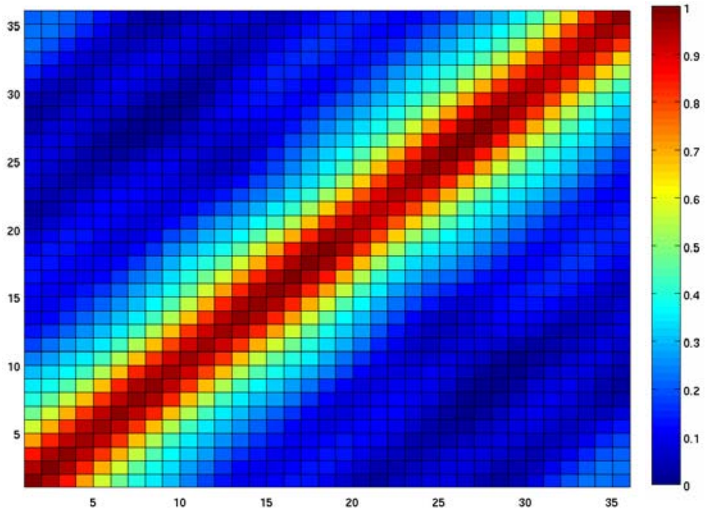
- First approximation: mean signal (easy implementation)

Noise Characterization

Noise distribution



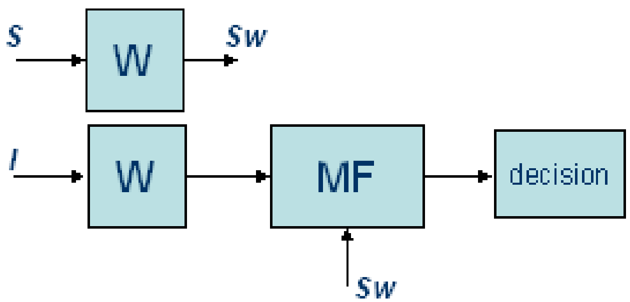
- Gaussian fit;
- Mean: -0.092696 mV;



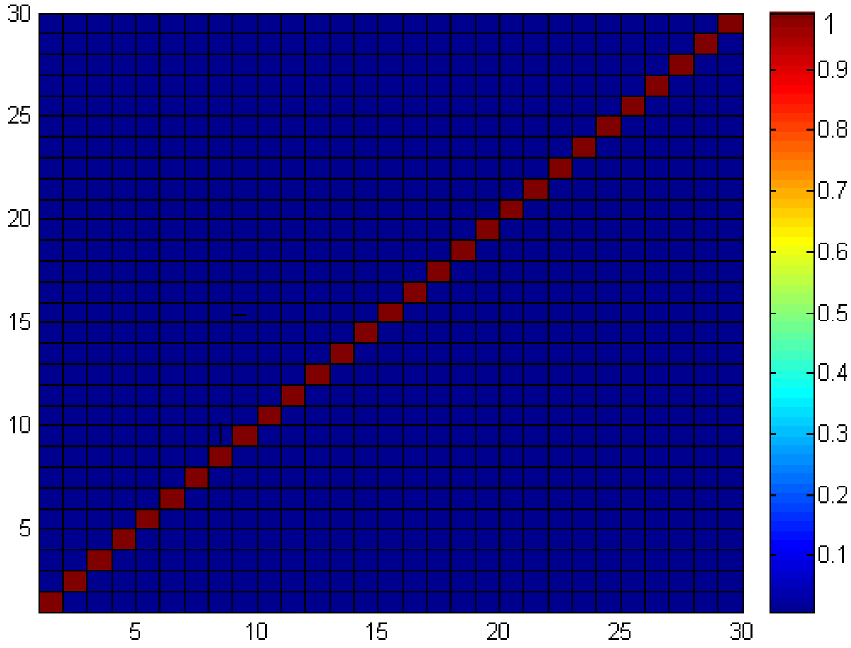
Noise covariance matrix

- Whitening pre-processing should be done;

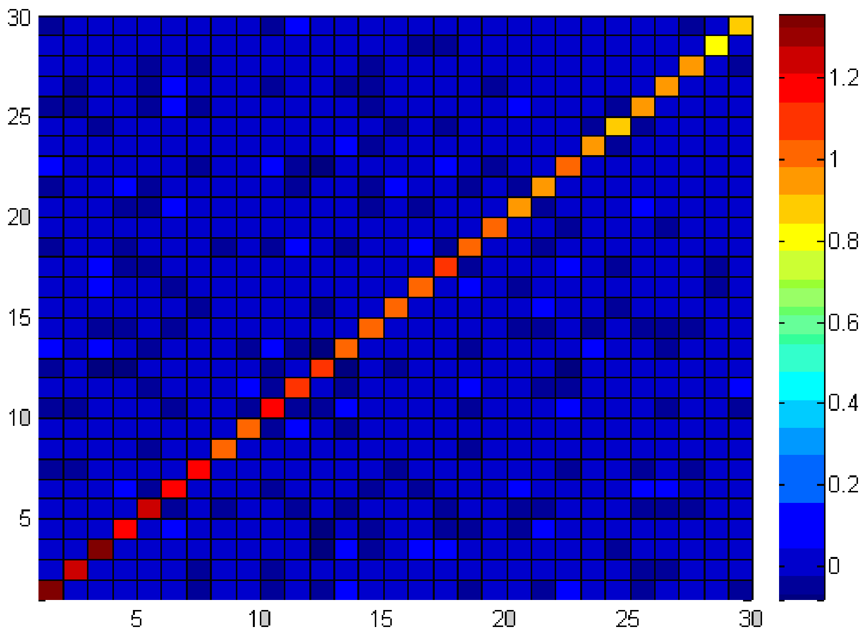
Whitening



- Projection in a decorrelated base.
- Normalize each component ($\sigma^2 = 1$)



Covariance of the whitened noise - Train

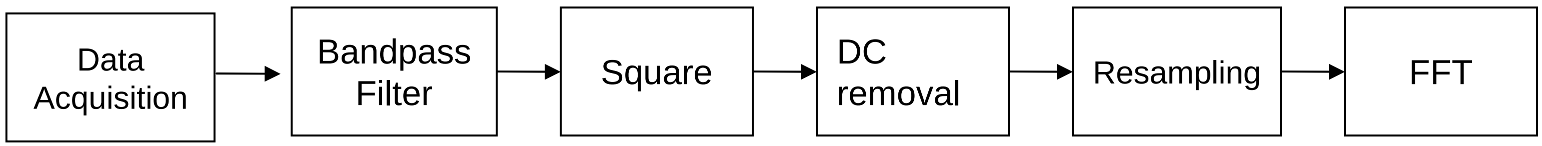


Covariance of the whitened noise - Test

A Narrowband Demodulation

→ Basically consists in performing demodulation in filtered data in order to obtain only the envelope of the signal;

Blocks diagram:



Applied to meteors:

Oscillations in signal reception due to the phase difference of signals that reach the receiving station → Delays