Amplitude domain estimation of narrow incoherent radar targets

Juha Vierinen
Markku Lehtinen

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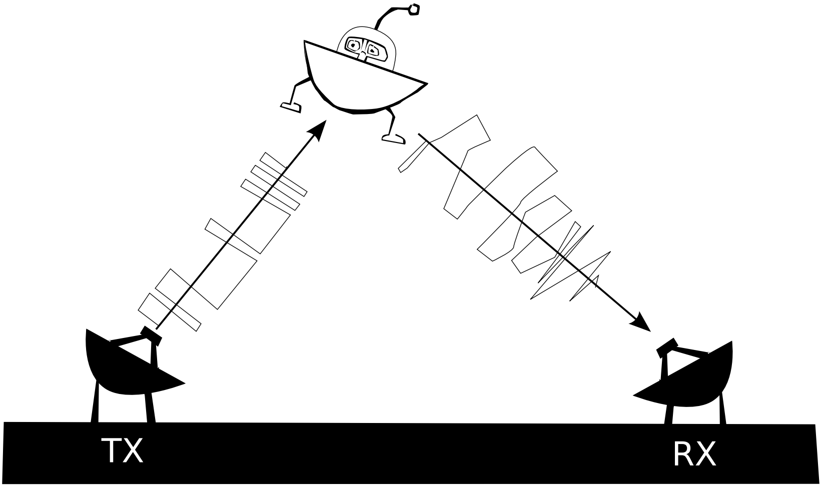
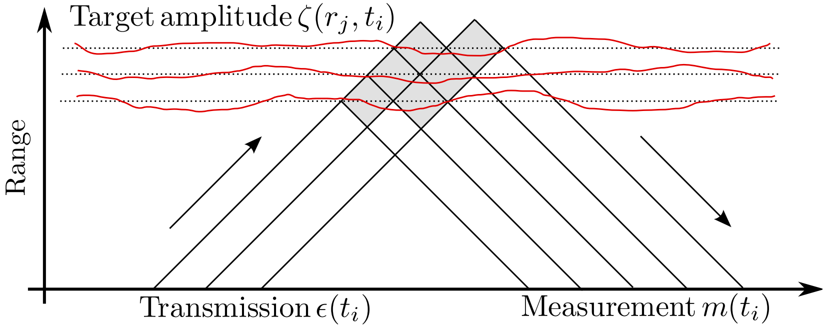
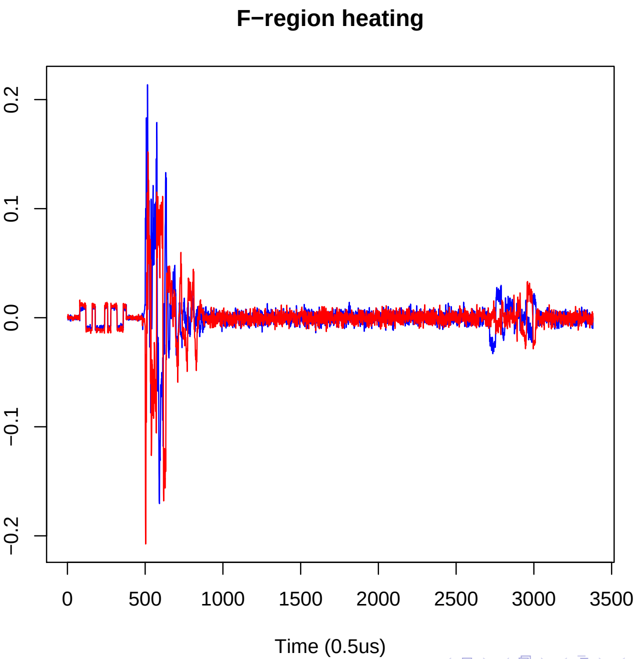
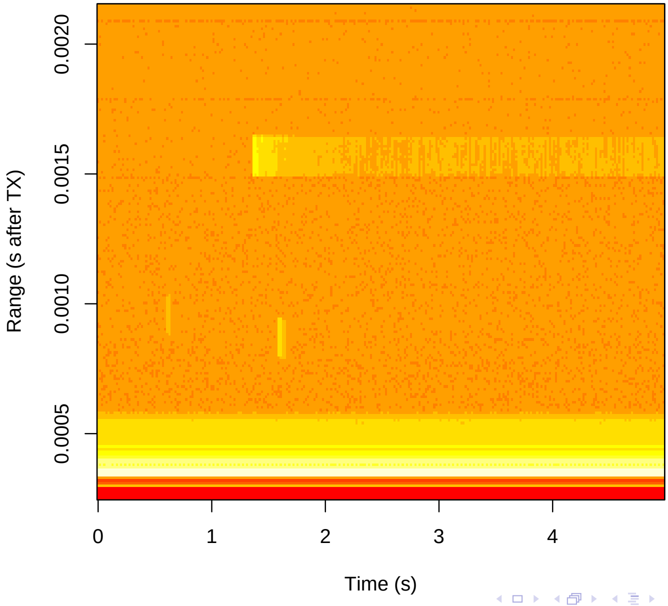
Problem description



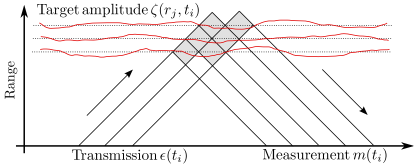

Target amplitude $\zeta(r_j, t_i)$
Range
Transmission $\epsilon(t_i)$
Measurement $m(t_i)$


F−region heating
0.2
0.1
0.0
−0.1
−0.2
0
500
1000
1500
2000
2500
3000
3500
Time (0.5us)

Raw F−region heating and meteor head echo



Measurement equation



$$m(t_i) = \sum_j \epsilon(t_i - r_j)\,\zeta(r_j, t_i - r_j) + \xi(t_i). \quad (1)$$

- $m(t) \in \mathbb{C}$ is the measured base band IQ signal
- $\epsilon(t) \in \mathbb{C}$ is the transmission modulation envelope
- $\zeta(r, t) \in \mathbb{C}$ is range dependent scattering amplitude
- $\xi(t) \in \mathbb{C}$. Measurement noise.
- Ranges r_j are defined in round-trip time

Parametrisation

$$\hat{\zeta}(r_j, t) = \sum_k c_{j,k} \exp i\omega_k t, \qquad (2)$$

There are many possible ways to model $\zeta(r, t)$. One possibility is to use a Fourier series, so our model parameters will consist of k terms of a Fourier series representation of the target reflection amplitude. This has the advantage that we can define the frequency characteristics that we want to measure from a target, as it is often the spectral properties that are of interest. Thus, we can express $\zeta(r, t)$ using coefficients $c_{j,k} \in \mathbb{C}$ of the series

Likelihood function

$$z(t_i, \theta) = \sum_j \epsilon(t_i - r_j) \sum_k c_{j,k} \exp i\omega_k t_i \tag{3}$$

We can write a likelihood function as a product of independent complex Gaussian densities, as our measurements are assumed to be distributed this way. Here D represents the set of measurements $D = \{m(t_1), ..., m(t_N)\}$:

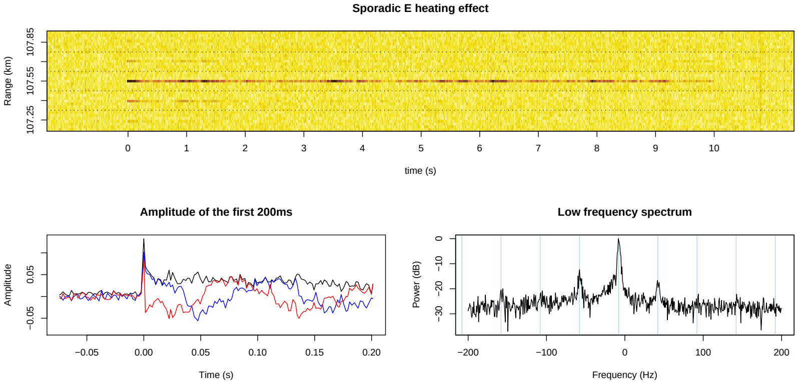
$$p(D \mid \theta) = \prod_i \frac{1}{\pi\sigma^2} \exp\left\{-\frac{|m(t_i) - z(t_i, \theta)|^2}{\sigma^2}\right\}$$

Efficient solution: FLIPS

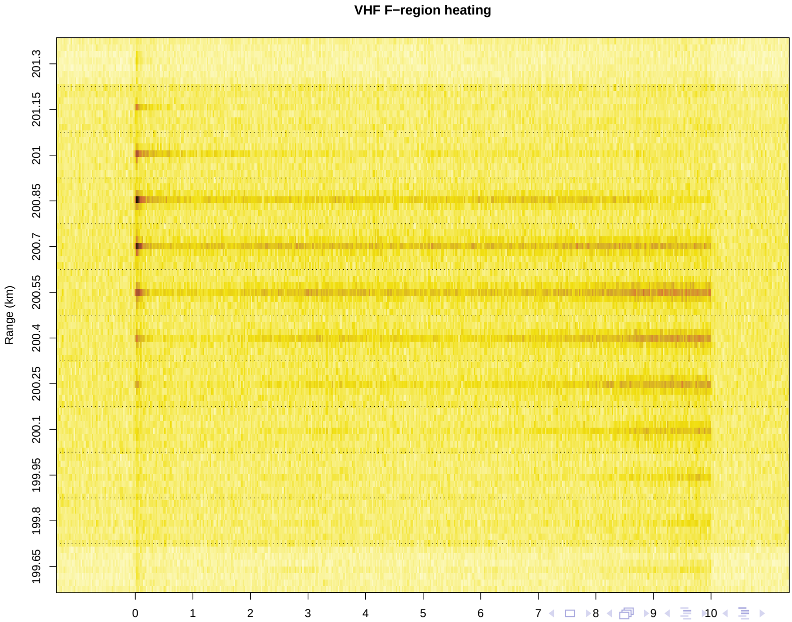
- When target sufficiently narrow, problem over-determined
- Can be easily solved

$$\mathbf{m} = \mathbf{A}\boldsymbol{\theta} + \boldsymbol{\xi}, \tag{4}$$

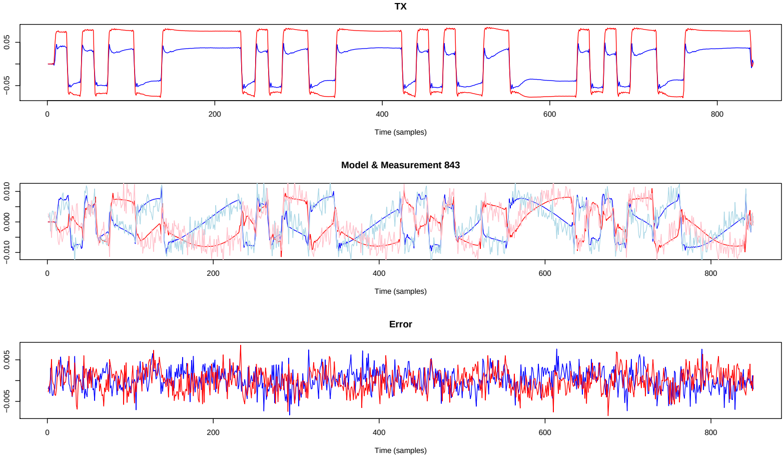
Example: Sporadic E-layer heating



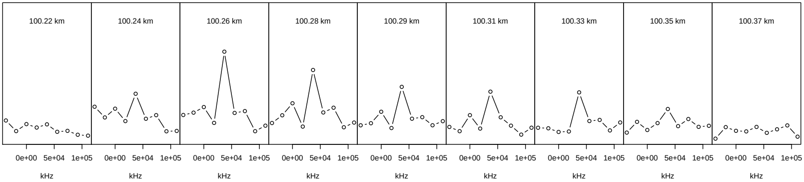
Example: F-region heating



Example: Meteor head echo



Example: Meteor head echo



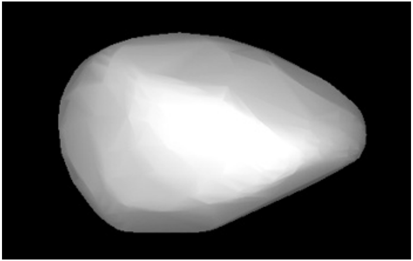
- Meteor head echo is about 100 m wide.
- Radial velocity about 52 km/s
- Range dependence could be used to study, e.g., meteor composition

Future wok

- Code optimality (the posteriori covariance matrix depends on the transmission codes)
- Study estimation errors more carefully
- Study different efficient regularization schemes
- Would it be possible analyze wide targets, which result in an underdetermined problem?
- Try out different parametrizations for $\zeta(r, t)$

Possibilities

- Higher range and time resolution
- Meteors, small asteroids, artificial and natural ionospheric irregularities
- Range-Doppler measurements provide information about target shape and scattering law (Kaasalainen)



Questions?