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Bayesian statistical ionospheric multi-instrument 3D tomography

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ABSTRACT

Ionospheric satellite tomography is an ill-posed inverse problem, which cannot be solved without some additional regularizing information about the unknown electron density. Due to its distinctive measurement geometry, especially the vertical electron density profile is poorly determined by the measurements. Hence, some kind of regularization scheme is needed regardless of the actual tomographic method in use, and the solutions are also strongly dictated by it. As the role of the regularization is so significant, it is important to understand the nature of this information and how it can be changed systematically for different ionospheric conditions.

With the Bayesian statistical inversion the additional information can be given as a stabilizing prior probability distribution. Here we assume a Gaussian normal prior distribution. As Gaussian distribution is characterized by its mean and covariance, these parameters provide a physically interpretable interface to control the required stabilization.
The statistical approach itself is not new, and it has been reported in tomographic literature. However, due to computational limitations it has not been applicable for high dimensional problems. Norberg et al. (2015) presented how this approach can be applied to 2D ionospheric tomography with the aid of Gaussian Markov random field approximations. The approach provides the statistical interpretation, yet enables near real-time computation. Here this approach is generalized for the 3D situation.

The Bayesian statistical method also provides a very natural scheme for combining different measurements as the data from distinct sources are weighted with their corresponding measurement errors. The main data component used here is the phase difference measurements of low Earth orbit beacon satellite signals (150/400 MHz) observed with

Finnish Meteorological Institute's receiver network. The network consists of 7 receivers in the area of Norway, Sweden, Finland and Estonia. In addition, we use network of over 400 GPS receivers provided by SWEPOS (Sweden) and GEOTRIM (Finland) companies. Besides the satellite signal measurements, we use ionosonde measurements from EISCAT dynasonde, Tromsø.

We present the method and validate the 3D electron density reconstructions with incoherent scatter radar measurements carried out with EISCAT UHF, Tromsø radar.

Key words: Tomography, Ionosphere, Bayesian statistics, Beacon satellite, GNSS.

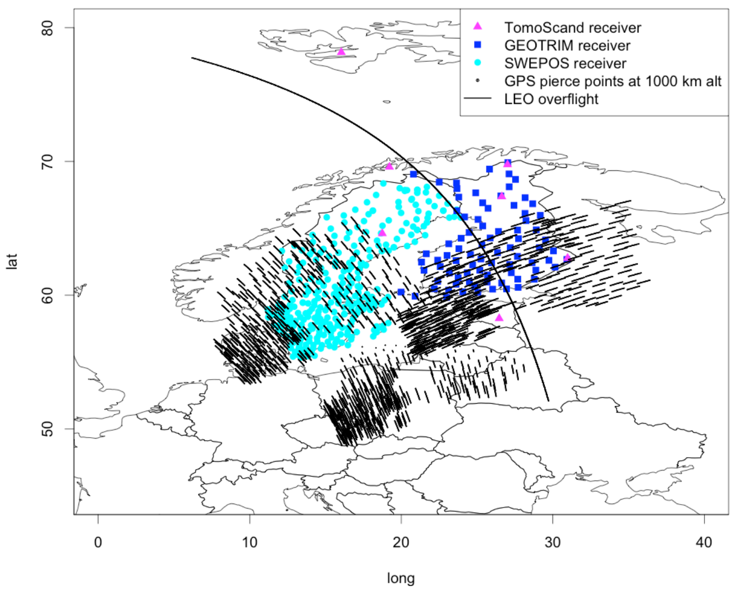

Figure 1: Measurements from 2015-11-08 10:18:00 - 10:26:00 UTC.

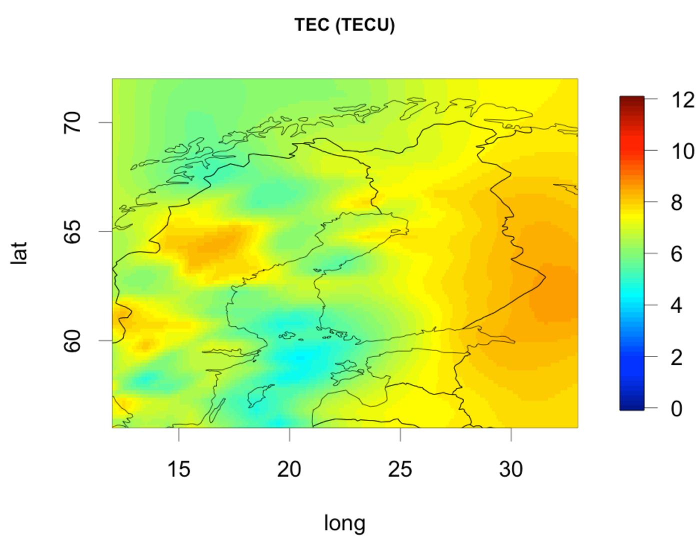

Figure 2: Altitude integrated total electron content from the 3D reconstruction (2015-11-08 10:18:00 - 10:26:00 UTC).

Norberg, J., Roininen, L., Vierinen, J., Amm, O., McKay-Bukowski, D., and Lehtinen, M. S., (2015). Ionospheric tomography in Bayesian framework with Gaussian Markov random field priors, Radio Sci., 50, Pages 138–152, doi:10.1002/2014RS005431.