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Bayesian ionospheric multi-instrument 3D tomography

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The tomographic reconstruction of ionospheric electron densities is an inverse problem that cannot be solved without relatively strong regularising additional information. Especially the vertical electron density profile is determined predominantly by the regularisation. Despite its crucial role, the regularisation is often hidden in the algorithm as a numerical procedure without physical understanding.

The Bayesian methodology provides an interpretative approach for the problem, as the regularisation can be given in a physically meaningful and quantifiable prior probability distribution. The prior distribution can be based on ionospheric physics, other available ionospheric measurements and their statistics. Updating the prior with measurements results as the posterior distribution that carries all the available information combined. From the posterior distribution, the most probable state of the ionosphere can then be solved with the corresponding probability intervals. Altogether, the Bayesian methodology provides understanding on how strong the given regularisation is, what is the information gained with the measurements and how reliable the final result is. In addition, the combination of different measurements and temporal development can be taken into account in a very intuitive way.

However, a direct implementation of the Bayesian approach requires inversion of large covariance matrices resulting in computational infeasibility. In the presented method, Gaussian Markov random fields are used to form a sparse matrix approximations for the covariances. The approach makes the problem computationally feasible while retaining the probabilistic and physical interpretation.

Here, the Bayesian method with Gaussian Markov random fields is applied for ionospheric 3D tomography over Northern Europe. Multi-instrument measurements are utilised from TomoScand receiver network for Low Earth orbit beacon satellite signals, GNSS receiver networks, as well as from EISCAT ionosondes and incoherent scatter radars.