High-Resolution Reconstruction of the Ionosphere for SAR applications

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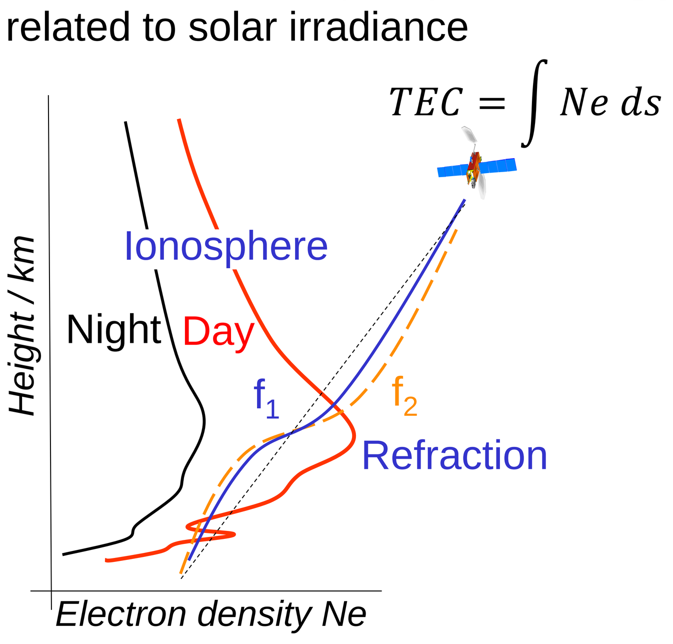
Motivation and Objective

Fig. 1: Electron density *Ne* & Total Electron Content (TEC) are strongly related to solar irradiance

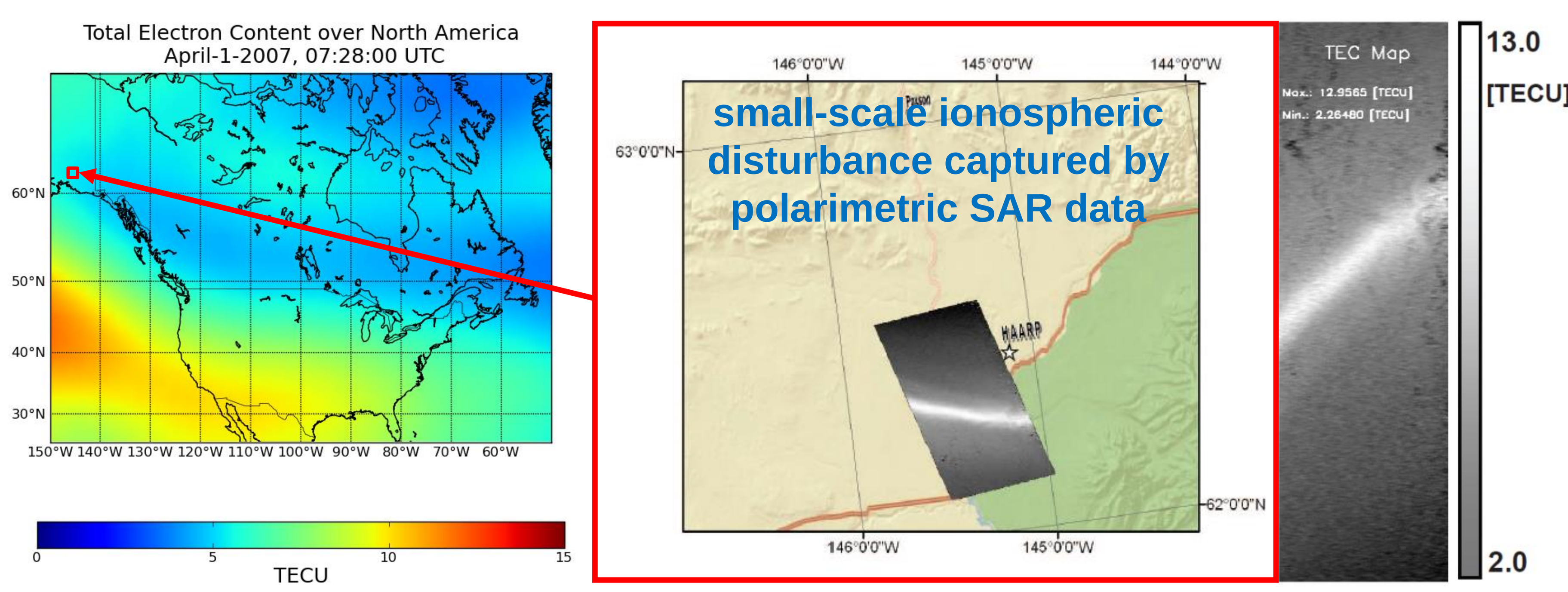


Ionosphere causes significant impact on transionospheric radio signal propagation below 10 GHz frequencies. In order to mitigate ionosphere induced propagation effects a high-resolution and highly accurate reconstruction of the ionosphere electron density is required for a large number of GNSS as well as Synthetic Aperture Radar (SAR) applications. As a new generation of remote sensing satellites the TanDEM-L radar mission is planned to improve the understanding and modelling ability of global environmental processes and ecosystem change. TanDEM-L will operate in L-band with a wavelength of approximately 24 cm enabling a stronger penetration capability compared to X-band (3 cm) or C-band (5 cm). Due to the lower frequency of the TanDEM-L signals the influence of the ionosphere will be much more higher.

In particular small-scale irregularities, cf. Fig. 2, of the ionosphere might lead to electron density variations within the synthetic aperture length of the TanDEM-L satellite and in turn might result into blurring and azimuth pixel shifts. Hence the quality of the radar images worsens if the ionospheric effects are not mitigated.

In the scope of WP G2 in the HGF project „Remote Sensing and Earth System Dynamics“ we intend regional high-resolution reconstructions of the 3D ionosphere in the radar volume and the assessment of the achievable reconstruction accuracy based on the given measurement geometry. For this purpose the analysis of the global and small-scale spatial and temporal behaviour of the ionosphere is of crucial importance.

Fig. 2: Ionospheric gradients like detected in the polarimetric ALOS PALSAR data by (Meyer, et al. 2009) on April-1-2007, 07:27:33am UTC are not visible in commonly available TEC map products and can significantly worsen the radar image quality if not mitigated



Approach and first Results

First step: regional 2D TEC maps by Ordinary Kriging over Europe and Germany

Assumptions: stationary and isotropic Gaussian random field

$$Z(x_i) = VTEC_{meas}(x_i) - VTEC_{model}(x_i)$$

Tool: calculate experimental and theoretical semivariograms to model the spatial correlation between measurements as base for the weights estimation during Kriging

$$\gamma(h) = \frac{1}{2|N(h)|} \sum_{N(h)} \left(Z(x_i) - Z(x_j) \right)^2 \; with$$

$$N(h) = \{(x_i, x_j) : |x_i - x_j| = h; i, j = 1, \ldots, n\}$$

Fig. 3: Investigations of stationarity of $Z(x_i)$ over Europe using different ionospheric background information

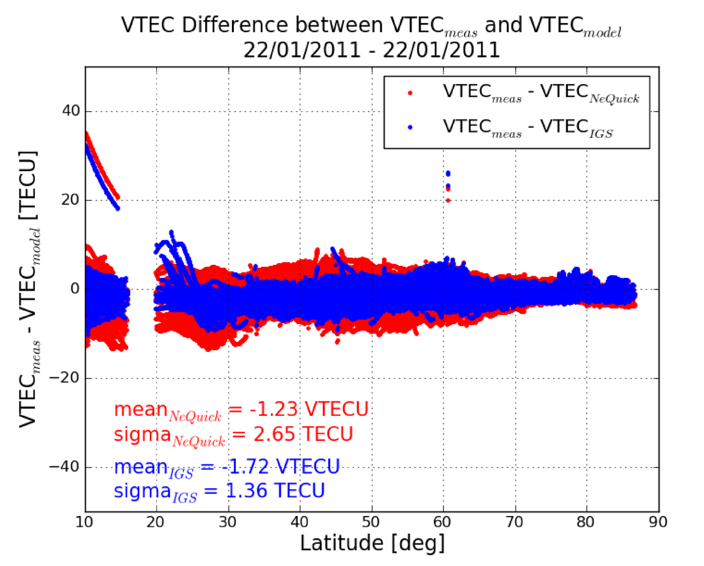


Fig. 4: Semivariogram for TEC measurements over Europe (left), TEC map derived from Ordinary Kriging on base of the semivariogram (middle) and the IGS TEC map used as background (right)

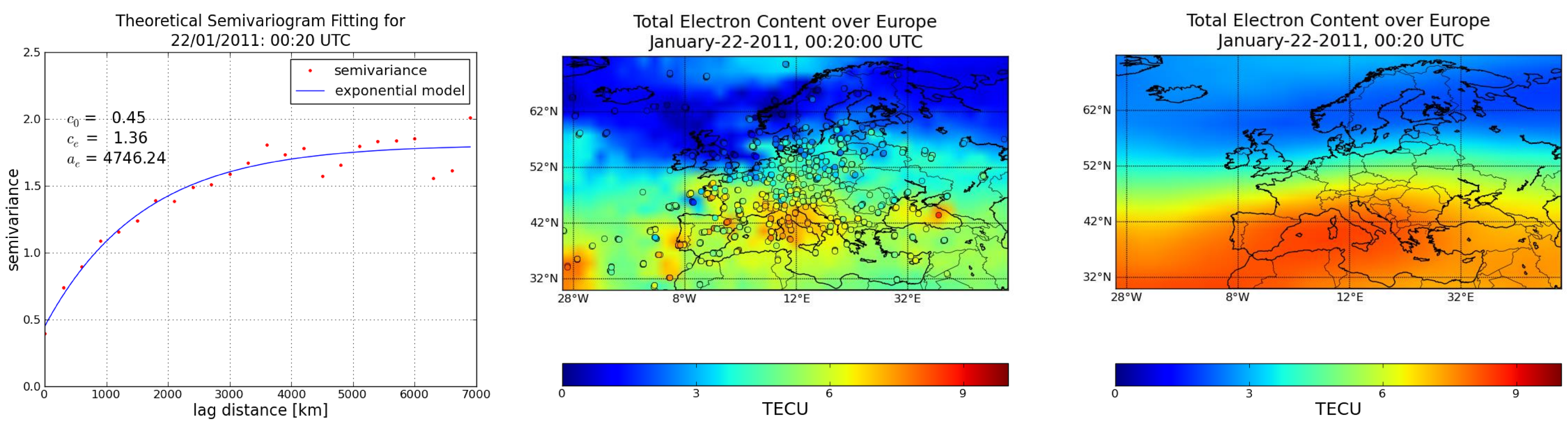
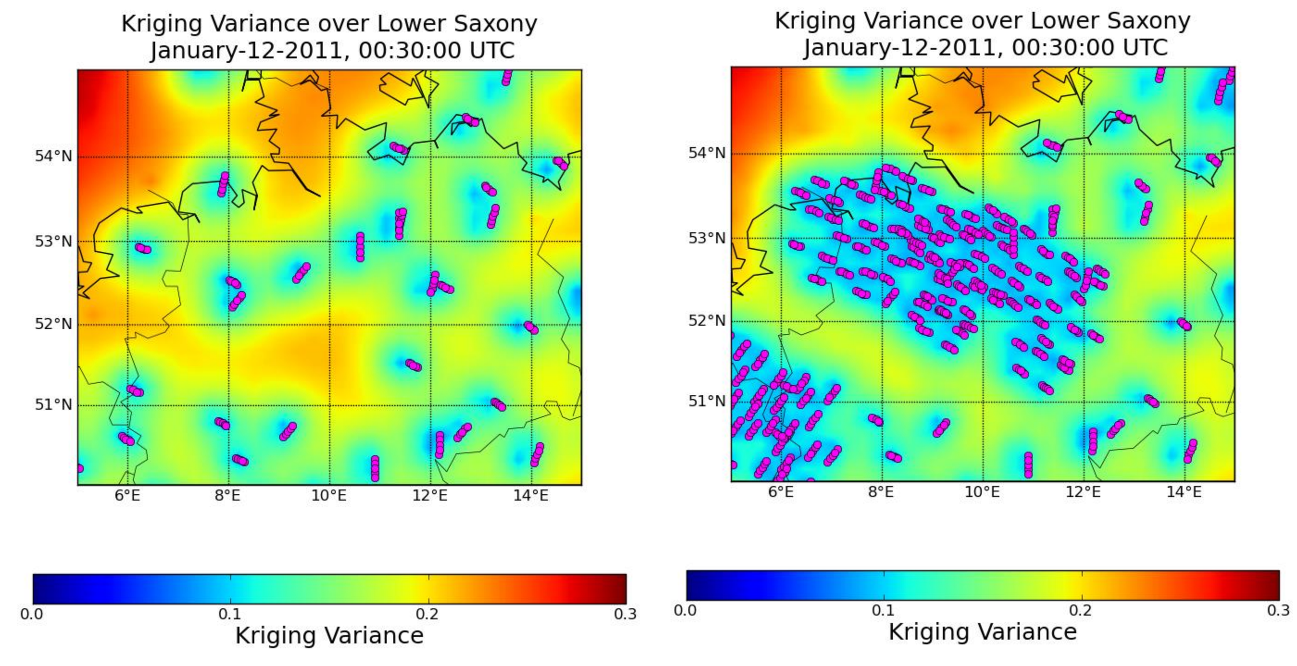


Fig. 5: Kriging variance over Lower Saxony/Germany using TEC measurements of IGS network (left) and data combined of IGS and SAPOS network (right)

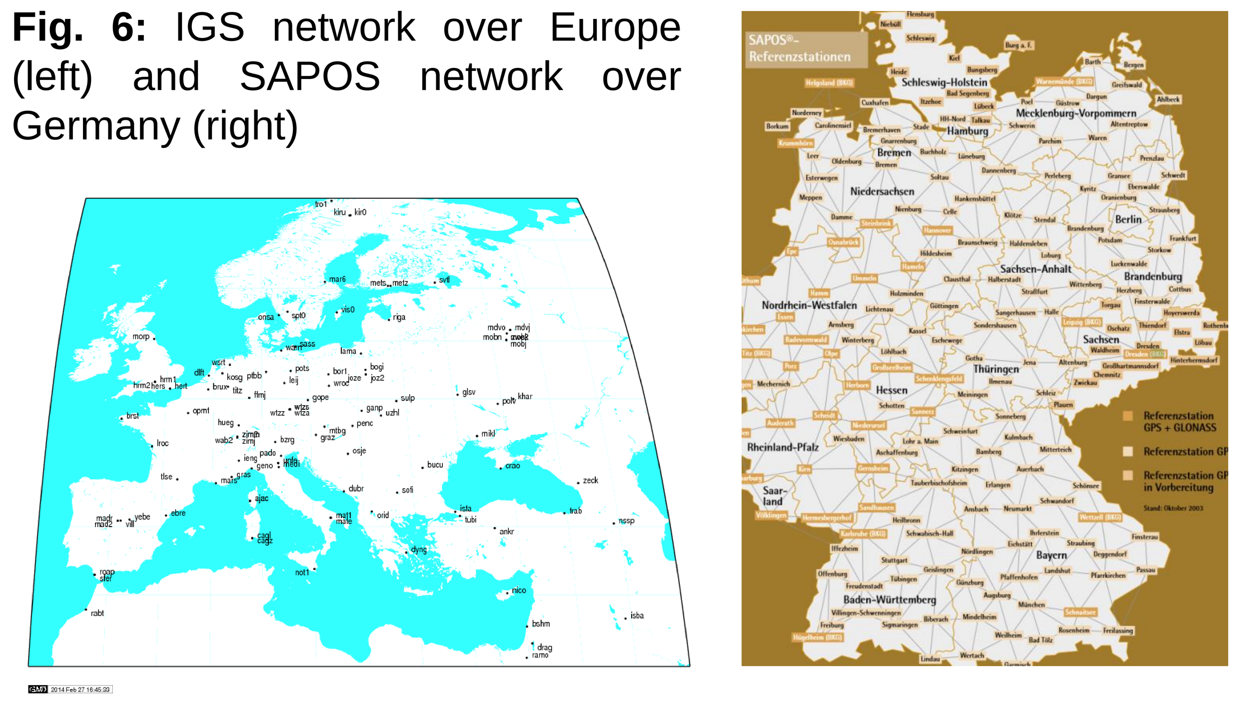


- Shape of semivariogram will depend on different parameters, e.g. investigated region and solar activity
- Assimilation of a dense cluster of TEC measurements into background model might allow the visibility of small-scale ionospheric structures
- Estimation variance depends on the data availability and the underlying semivariogram

Data Availability

- Different measurements are available for reconstruction, e.g.: ground-based GNSS measurements, space-based GNSS measurements (top-side and occultation) and ionosonde measurements
- Challenging resolution requirements imply necessity of a dense measurement network
- High-resolution reconstructions might be only possible for certain regions, e.g. Germany having the SAPOS GNSS ground-station network at its disposal

Fig. 6: IGS network over Europe (left) and SAPOS network over Germany (right)



Summary and Outlook

- SAR data processing requires ionospheric corrections, especially small-scale irregularities are of interest
- Common ionospheric TEC maps are not appropriate due to the restricted resolution, additional errors caused by the mapping function and the fact that these products represent the whole ionosphere from the Earth to the GNSS orbit
- Regional reconstruction of 3D electron density is intended to achieve required spatial resolution and accuracy
- As first step Ordinary Kriging of TEC over Europe and Lower Saxony/Germany
- Next steps: validation of 2D Kriging and development of 3D Kriging approach

Acknowledgement and References

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Meyer, F. J., Nicoll, J., Bristow, B. (2009) Mapping Aurora Activity with SAR – A Case Study, IGARSS 4, p. 1-4, Cape Town, South Africa, IEEE

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