HGF-Alliance: Remote Sensing and Earth System Dynamics
Reconstruction of the ionosphere for TanDEM-L applications

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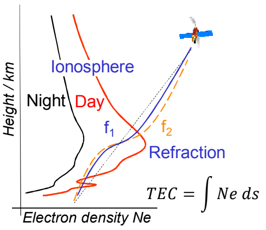
Motivation and Objective

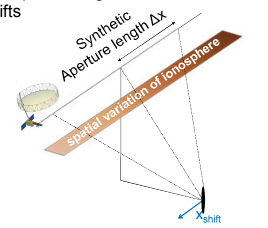
Fig. 1: Electron density *Ne* & Total Electron Content (TEC) are strongly related to solar irradiance



The ionosphere is the ionized part of the upper Earth's atmosphere reaching from around 50 km height to above 1000 km. This region is ionized by ultraviolet radiation of the Sun. From the applications perspective the electron density, Ne, is one of the most important parameters of the ionosphere because of its strong impact on radio signal propagation. The electron density varies with time and location, cf. Fig. 1, and results from a complex physical interplay between solar radio flux and the Earth's magnetic field.

TanDEM-L applications operating in L-band will be influenced by the Total Electron Content (TEC), defined as the integral of Ne along a ray path. In particular small scale irregularities of the ionosphere which might lead to TEC variations within the synthetic aperture length of TanDEM-L , cf. Fig. 2, will result into azimuth pixel shifts x_{shift} (cf. [2]). Fig. 3 represents spatial variations of the TEC during high solar activity (F10.7 = 193) for a radar orbit height of 760 km and outlines that radar processing requires mitigation of ionospheric effects to obtain high resolution radar images. Hence, a reliable and accurate reconstruction of the electron density and consequently the ionosphere's state is essential.

Fig. 2: Spatial irregularities of the ionosphere might lead to azimuth shifts



$$x_{shift} = -\frac{40.3R \cdot \Delta vTEC \cdot M(\epsilon)}{f^2 \Delta x}$$

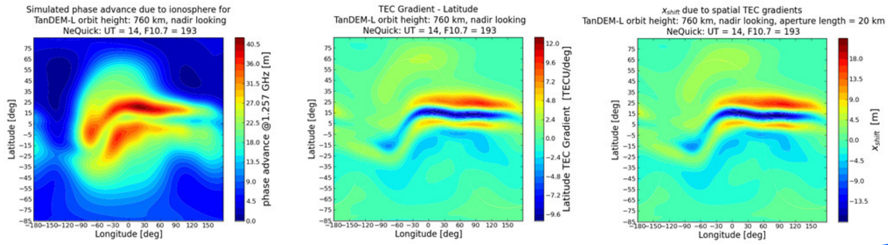


Fig. 3: *Left subfigure:* Ionospheric phase advance for TanDEM-L satellite operating at 1.257 GHz simulated by 3D electron density model NeQuick at 14 UT for high solar activity; *middle*: latitude gradients found for the ionospheric conditions simulated in the left subfigure; *right:* spatial variations of the ionosphere will result into azimuth shifts if no ionospheric correction is applied

Approach

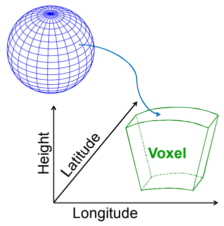
Assimilation of different measurements into 3D electron density model

Step 1: Voxelization of Ionosphere and calculation of electron density for each voxel by 3-dimensional background model, e.g. NeQuick (cf. [4])

Step 2: Acquisition and filtering of ionospheric measurements providing information about ionosphere's horizontal and vertical structure

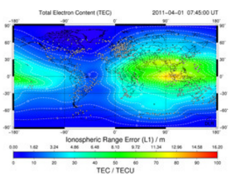
Step 3: Data assimilation of ionosonde measurements and vertical TEC maps on coefficients level to update background electron density

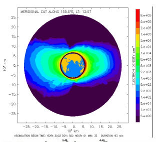
Step 4: Data assimilation of ground-based GNSS slant TEC measurements, ionosonde and space based GNSS measurements into background model: calculation of intersection between ray paths and voxels, distribution of measurements on intersected and adjacent voxels



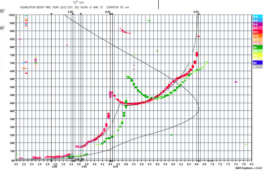
Decomposition of ionosphere into 3-dimensional voxels aligned at Earth's latitudes and longitudes

Vertical TEC maps



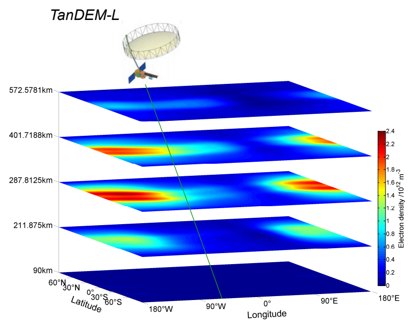


Ground-based GNSS measurements



Ionosonde measurements

Space based GNSS measurements
Geo-plasma reconstruction
Vertical electron density profiles



3D electron density models, like the Neustrelitz Electron Density Model (NEDM) and NeQuick, are able to calculate the electron density along an arbitrary ray path within the ionosphere. Nevertheless models normally describe the mean behaviour of the ionosphere and thus measurements of the current ionospheric state are essential in order to determine the TEC with an accuracy sufficient for TanDEM-L applications.

The integration process of current measurements into a model is commonly called "data assimilation". Within the scope of the project two methods are conceivable: "row action methods" (cf. [6]) associated with the "successive corrections method" (cf. [3]) and the update of the measurements by a BLUE technique suggested for example in [1]. Both methods require the knowledge of the relation between adjacent voxels.to distribute the measurements in a proper way around the measurement location. Subsequently, the determination of the correlations between voxel's electron density will play a substantial role for the 3D reconstruction of the ionosphere.

Outlook on upcoming tasks

- Further investigations of vertical and horizontal correlation between the voxels of the ionosphere in order to refine the assimilation procedure
- Further development of Neustrelitz Electron Density Model (NEDM) as possible background model for 3D reconstruction of ionosphere
- Data filtering including the detection and rejection of outliers which might corrupt the reconstruction
- Implementation of the 3D reconstruction and validation of the applicability of the 3D reconstruction for radar processing in collaboration with DLR's Remote Sensing Technology Institute

References

[1] Angling, M. J. (2008) First assimilations of COSMIC radio occultation data into the Electron Density Assimilative Model (EDAM), Annales Geophysicae 26:353-359.

[2] Chen, J., Zebker, H. A. (2012) Ionospheric Artifacts in Simultaneous L-Band InSAR and GPS Observations, IEE Transactions On Geoscience And Remote Sensing 50/4:1227- 1339.

[3] Cressmann, G. P. (1959) An operational analysis system, Mon. Wea. Rev. 87:367-374.

[4] Radicella, S. M. (2009) The NeQuick model genesis, uses and evolution. Annales Geophysicae-Italy 52/3:417-422.

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