MAPPING AURORA ACTIVITY WITH SAR – A CASE STUDY

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1. ABSTRACT

Ionospheric propagation effects can have significant impact on the signal properties of Synthetic Aperture Radar (SAR) systems and they increase with decreasing carrier frequency. Recently, theoretical analyzes of ionospheric distortions in low-frequency SAR signals have indicated a multitude effects that are likely to affect the quality of SAR, interferometric SAR (InSAR), and polarimetric SAR (PolSAR) data (see [1-5]). Faraday rotation, relative range shifts, internal deformations of the image amplitude, range and azimuth blurring, and interferometric phase errors are some of the most significant effects that need to be considered. While the theory presented in the papers is consistent, direct proof and verification of ionospheric effects in SAR data is still only partly available.

The intention of this paper is to unambiguously verify the ionospheric effects on low-frequency SAR data as predicted in [1-5]. A qualitative and quantitative comparison of observed effects with theoretical predictions is provided based on internal and external verification methods. Real data examples, mainly stemming from the Advanced Land Observing Satellite (ALOS) PALSAR mission, are the backbone of the verification approach. Ground based measurements of ionospheric activity are provided by ionospheric observatories across Alaska, USA and are used for external validation. In this publication, we focus on small scale ionospheric disturbances caused by aurora activity as a representative for polar ionospheric anomalies.

The following methods are applied for internal and external verification:

- Internal verification
    - Method
      It's generally accepted that the presence of free electrons in the ionosphere causes Faraday rotation in linearly polarized microwave signals. This rotation can be mapped from calibrated full-polarimetric SAR imagery with high accuracy as predicted in [1] and proven in [5]. The potential of deriving ionospheric total electron content (TEC) from these Faraday rotation maps has been shown in [6]. TEC maps derived from full-polarimetic SAR imagery are the basis for simulating ionospheric effects on SAR and InSAR as caused by the ionospheric conditions during image acquisition. Besides the simulation, ionospheric effects are extracted directly from the SAR data using detection methods published in [1, 2 and 6]. A comparison of simulated and measured effects serves as internal verification method. The statistical properties of the respective data sets are considered for stochastically sound hypothesis testing. A comparison of both spatial pattern and signal amplitude is performed.
    - Significance
      Cross comparison and verification of individual ionospheric effects in SAR data validates the correctness and relative consistency of the developed theory. It is not able to detect consistent scaling errors in the established literature.
- External verification
    - Method
      Ionospheric observatories provide measurements of the ionospheric activity on a 24/7 basis.

The observatories “Poker Flat Research Range” and “HAARP (High Frequency Active Auroral Research Program)”, both located in Alaska, USA, are equipped with observation methods operating at optical and microwave frequencies. Measurements include point-like TEC records as well as spatial maps of aurora arcs, and can be compared to SAR data acquired in collocation. The ground based measurements are used for the detection of auroral anomalies. Detailed analysis of the recorded data allows determining the altitude of the ionospheric electron center of the aurora signature. Collocated full-polarimetric SAR imagery is selected from the ALOS PALSAR archive at the Alaska Satellite Facility. Algorithms published in [1] are employed to derive ionospheric maps from the full-polametric SAR data. The generated ionospheric maps are subsequently geocoded considering the altitude of the auroral anomaly. For validation, aurora arcs mapped from ground are compared to SAR-derived geocoded TEC maps in shape, magnitude, and position, in order to establish a direct relationship between ionospheric anomalies and their signature in SAR images.

- Significance
  External validation allows validation of the correctness of SAR derived TEC maps and serves as unambiguous proof of the ionospheric origin of the observed distortions by establishing a direct relationship between observed ionospheric turbulence and measured image distortions.

The study exploits the vast ALOS PALSAR archive available at the Alaska Satellite Facility and illustrates the findings with a rich set of examples.

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