Comparison of Ionospheric Electron Density Retrieved from Spire Global Radio Occultation Data with Arecibo Incoherent Scatter Radar and Digisonde Measurements

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Abstract: Radio occultation (RO) has been proven to be a powerful technique for ionospheric electron density profile (EDP) retrieval. Commercial GNSS-RO ionospheric measurements collected by the Spire 3U CubeSat constellation could significantly improve the determination of the global ionospheric state. In this work, the EDPs retrieved from Spire total electron content (TEC) measurements using Abel inversion corrected by horizontal asymmetry are compared to Arecibo density measurements. Good agreement is observed in case-by-case EDP comparison. The information about F2 layer peak and height obtained from Spire data is also compared to digisonde measurements at 34 stations around the globe from Global Ionospheric Radio Observatory (GIRO) network.

Introduction: Spire Global, Inc. is an analytics company that utilizes proprietary satellite data and algorithms to provide maritime, aviation, and weather tracking. Spire designs, manufactures, and operates a constellation of low-Earth orbit (LEO) 3U CubeSats with high-gain antennas that perform GNSS RO for atmospheric and ionospheric remote sensing. The receivers onboard of LEO Spire satellites collect the GNSS dual-frequency signal phase data which corresponds to the slant TEC along the radio path. Further, the TEC measurements can be used to extract the EDPs along tangent points (TPs) (or ray perigee’s locations) of ray paths between LEO and GNSS satellites. In the current work, the EDPs extracted from Spire TEC data are compared to digisonde and incoherent scatter radar measurements to examine the accuracy of Spire data.

Data: The majority of Spire’s TEC measurements are collected from each satellite’s zenith-pointing precise orbit determination (POD) antenna, which provides good coverage of the ionospheric portion above the satellite orbit altitude. However, many of these TEC paths may traverse through the bottom-side of the ionosphere and thus provides the potential to convert to EDPs.

EDP retrieval methodology: Traditionally, the Abel transform (or onion-peeling method) is used to retrieve the EDP along the TPs from the calibrated TEC measurements. The approximation of the spherical symmetry in the ionospheric density distribution is the main source of errors in the Abel inversion method (Wei et al., 2009). Guo et al. (2015) take into account the expected horizontal asymmetry of the ionosphere, the Abel inverse assisted by the NeQuick model was developed and used in this study. As an example, the expected density along the radio path during one Spire RO event (20190205 18:21 – 18:27 UT), shown in Fig 2a, has strong asymmetry along the ray path. The asymmetry coefficient, which is shown in Fig 2b) assigned to each raw-shell (i,j) intersection point improves the classical Abel inversion. Fig 2c shows how the asymmetry Abel inversion method improves the reconstruction of the EDP during a test case using synthetic TEC data produced by NeQuick. Also shown a profile retrieved from Spire data (solid red line) which is very different from the model predictions.

Results: 4 events were found when Spire RO occurred within 600 km from 3 digisonde stations. For the comparison with the ground measurements it is important to keep in mind that RO retrieved EDP is not a vertical profile, but a profile along the TP, therefore it is critical how far the part of trace that corresponds to the bottom-side of the profile (Fig 3b) is located from the digisonde station and how spatially extended the occultation trace is. In addition, the topside of digisonde profiles is constructed by fitting a model to the peak density value and should not be considered as a ground truth.

1. Good agreement between Spire retrieved EDP with the closest digisonde at Pohnpei. As expected by NeQuick model (gray contours), the digisonde at Pohnpei shows lower density at the F2 peak and digisonde at Pohnpei observes higher F2 peak.
2. Longer RO trace probably smears the shape of bottom side, however still a good agreement is observed for F2 peak values.
3. Two simultaneous Spire RO events occurred close to 3 digisonde stations. 1st RO has lower F2 peak than the second one, as expected by NeQuick model. Good agreement between 1st RO and Fairford and Chilton digisonde and 2nd RO with digisonde at Dourobes. Vertical orientation of F2 peak density contours stays consistent with both observations.
4. Disagreement between NeQuick prediction and digisonde observations. Geographical location of RO trace suggested that NeQuick model is not valid in the lower geographical latitudes.

Conclusion: Statistical analysis of Spire and digisonde data carried out for 14 magnetically quiet days shows that Spire profiles are in generally good agreement with digisonde profiles. Case-by-case comparison of Spire profiles with Arecibo ISR data also showed a good agreement. This indicates that EDPs retrieved from Spire RO measurements are reliable and can be used for ionospheric physics studies. Spire Global is constantly increasing the number of LEO satellites and has a high potential of making significant contributions to the studies of ionospheric structure and dynamics on the global scale.