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# Development of Ionospheric 3D Tomography with Data from GNSS-TEC and Ionosonde

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**Introduction:**
Measurement of ionospheric total electron content (TEC) by using ground-based Global Navigation Satellite System (GNSS) receivers is now widely used, which we refer to as GNSS-TEC. In Japan, there is one of the densest network of GNSS receivers which is named as GEONET (GNSS Earth observation network system) operated by Geospatial Information Authority of Japan (GSI). The data are widely used for the study of the ionosphere. Studies of medium-scale traveling ionospheric disturbance (MS-TID) were the famous application of these data.

**GNSS-only tomography:**
We were developing three-dimensional (3D) tomography analysis based on the GNSS-TEC data from GEONET [1]. The efforts have continued for more than ten years. Our basic analysis technique was the constrained least-squares fitting method. In our case, the constraint was "reducing spatial gradient between neighboring cells". Another advantage was that we did not start the analysis from any model density distributions. We showed that we can reach the realistic spatial distribution of ionospheric plasma in most cases. We started the near real-time analysis with 15-minute intervals and about five minutes of latency since March 2016 [2]. For this GNSS-only tomography, however, there were some problems. One was the possible appearance of negative plasma density outputs in the solution. Another was that the heights of the ionosphere were higher than true, especially during the autumn and winter seasons.

**GNSS plus ionosonde analysis:**
In this paper, we report the recent development of improved tomography based on both GNSS-TEC and ionosonde data. The analysis technique is reported by Ssessanga et al. [3] The earlier part of the analysis is the same as the GNSS-only tomography. After that, we include height and density of the ionosphere peak based on the ionosonde data. In the later part of the analysis, the logarithm of the density is evaluated to avoid negative outputs. Also, the new analysis is based on the 3D assimilation technique. Results from this GNSS plus ionosonde analysis are much improved compared with the GNSS-only tomography. Especially height of the ionosphere can be well compared with the MU radar IS observation data that are independent to the tomography analysis.

**Summary:**
In the presentation, we show the analysis technique of this new tomography based on both GNSS-TEC and ionosonde data. The results from the analysis are evaluated by comparing them with the MU radar IS observations. Also, we show some case studies with this analysis including the large disturbance of the ionosphere by the Tonga volcanic eruption in January 2022 [4]. We try to show efforts toward running this GNSS-TEC plus ionosonde tomography on near real-time bases.

**References:**
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[4] Saito S. (2022) Ionospheric disturbances observed over Japan following the eruption of Hunga Tonga-Hunga Ha'apai on 15 January 2022, *Earth Planets Space*, **74**:57.