# Capability study of GNSS based ionospheric indices

**N. Jakowski and M. M. Hoque**

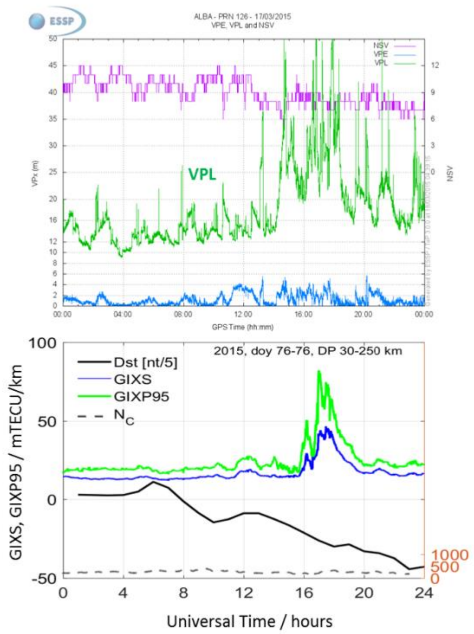
Institute for Solar-Terrestrial Physics, German Aerospace Center, Kalkhorstweg 53, 17235 Neustrelitz, Germany
(E-mail: Norbert.Jakowski@dlr.de, Mainul.Hoque@dlr.de)

## ABSTRACT

Safety of life and precision applications of Global Navigation Satellite Systems (GNSS) require key information on space weather conditions to stop the application or to warn users if certain protection or accuracy levels are violated due to severe ionospheric perturbations. Ionospheric perturbations characterized by severe spatial (horizontal) gradients and/or rapid changes of the electron density integrated along the used satellite-receiver links (slant total electron content) may seriously degrade the performance of GNSS and other trans-ionospheric radio systems like remote sensing radars. It is well-known that the usage of geomagnetic indices for characterizing ionospheric perturbations at different spatial and temporal scales is not sufficient for challenging customer needs. In order to provide the required ionospheric information, several attempts have been made to use GNSS based ionospheric variables for estimating type and strength of ionospheric perturbations. Thus, a variety of ionospheric perturbation indices have been introduced to describe ionospheric perturbations in order to fulfil requirements of potential users. The number of different approaches indicates the difficulty to find appropriate proxies for filtering out appropriate customer needed information from an extreme broad spectrum of spatial and temporal scales of ionospheric perturbations. As has been discussed at the COSPAR 2018 $42^{nd}$ Assembly in Pasadena, USA (http://cospar2018.org/scientific-program/associated-events/) the definition of internationally acceptable standards for ionospheric indices and scales is an important task to essentially improve the product portfolio of space weather services according to user needs. Consequently, to contribute to the discussion, capability studies of different ionospheric indices are needed. Here we focus on demonstrating the capabilities of two new indices, the Gradient IndeX (GIX) and the Sudden Ionospheric Disturbance index (SIDX) whose computational approaches have been published recently [2]. Both indices are able to estimate the perturbation degree of the ionosphere instantaneously taking into account only GNSS measurements from the current and previous epoch which is a big advantage in near real time services.

Real data tests approve the applicability of the basic GIX and derivatives like the standard deviation GIXS or the related 95% percentile GIXP95 to monitor spatial gradients. The gradient index provides instantaneous measures of ionospheric TEC gradients in a selected area specified by the customer. If different GNSS are used (at least GPS and GLONASS) the data coverage is usually sufficient to define single station indices. Based on those approaches regional and global gradient maps can be constructed. Of course also averaged indices covering a selected region or the full globe can easily be computed. Real data tests have been made also for SIDX and derivatives like the standard deviation SIDXS showing the capability to recognize the type of ionospheric perturbation causing rapid electron density variations like solar flares related solar radiation bursts or intense energetic particle precipitation at high latitudes. The knowledge of the type of ionospheric perturbation (e.g. mid- or large scale ionospheric gradients or temporal variations at different scales) helps to estimate the risk in radio systems. Related topics will be

discussed for different ionospheric perturbation events demonstrating the capability of indices, e.g. as shown in Figure 1 for different GIX derivatives in relation to the availability of the European Geostationary Overlay Service (EGNOS) for air craft landing. Figure 2 shows the detection of intense solar flares from 6 - 9 September 2017 which may impact precise positioning [1, 2].



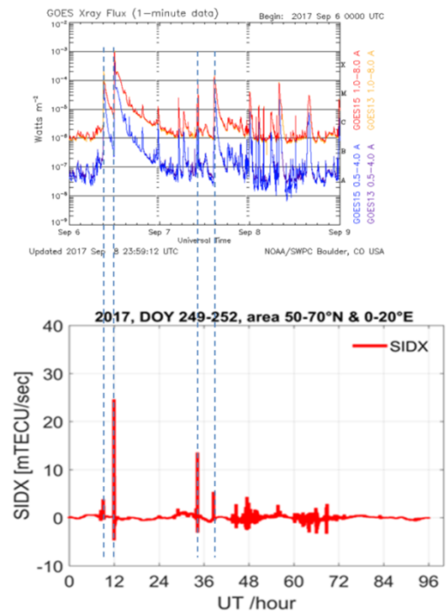




Fig. 1 EGNOS system performance comparison with ionospheric indices GIXS and GIXP95 and the geomagnetic Dst index

Fig. 2 Solar flare events during 6-9 September 2017 recorded by GOES in X-ray band (upper panel) compared with SIDX detections.

As shown in both Figures, the indices and their derivatives discussed here are able to characterize different types of ionospheric perturbations directly suitable for customers in near real time services. Because the indices are provided in physical units like TECU/km and TECU/s, customers, using a trans-ionospheric ranging system at a certain frequency, can directly estimates their risk after transforming TECU into the frequency dependent equivalent range (e.g. at L1 GNSS frequency 1 TECU corresponds with 162 mm). The potential of these approaches to serve as objective ionospheric indices for scaling horizontal TEC gradients and rapid changes of ionospheric densities during solar flares or particle precipitations will be discussed.

## References

[1] Berdermann, J., M. Kriegel, D. Banyś, F. Heymann, M. M. Hoque, V. Wilken, C. Borries, A. Heßelbarth, and N. Jakowski (2018), Ionospheric response to the X9.3 Flare on 6 September 2017 and its implication for navigation services over Europe, Space Weather, 16(10), doi:10.1029/2018SW001933.

[2] Jakowski, N. and M. M. Hoque (2019), Estimation of spatial gradients and temporal variations of the total electron content using ground based GNSS measurements, Space Weather, Wiley. ISSN 1542-7390, doi: 10.1029/2018SW002119