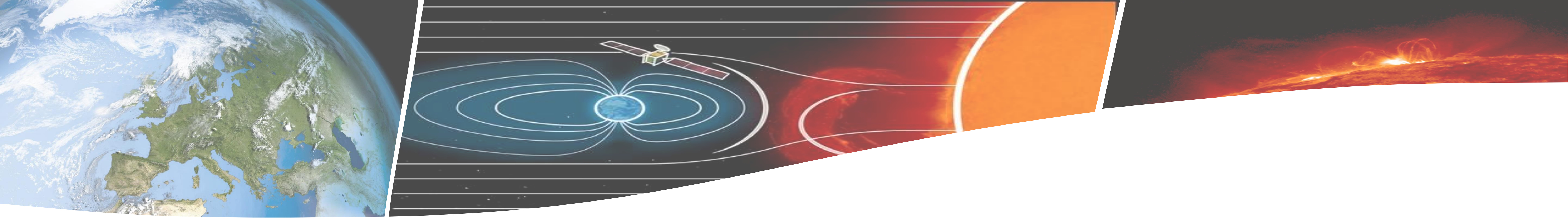

Ionospheric indices GIX and SIDX as proxies to characterize spatial and temporal ionospheric perturbations degree

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Motivation

Severe space weather events cause perturbations of the ionospheric plasma that, consequently, strongly affect the availability, continuity and accuracy of Global Navigation Satellite Systems (GNSS) signals and their applications in telecommunication and navigation systems. With the purpose of assuring reliable information on space weather conditions and, in particular, on the perturbation degree of the ionosphere, **the German Aerospace Center has developed the Gradient Ionospheric indeX (GIX) and the Sudden Ionospheric Disturbance indeX (SIDX) as proxies capable of estimating spatial and temporal perturbations degree of the ionosphere** without the necessity to include historical data in the analysis.

We present an overview about the performance of GIX and SIDX for characterizing spatial and temporal ionospheric perturbations in the framework of the Coordinated Ionospheric Study of Scales and Indices (CISSI) initiative, within the scientific activities of the Committee on Space Research (COSPAR). Namely, we have applied these approaches to GNSS datasets acquired over Europe during selected periods of stormy and quiet geomagnetic conditions, and discuss their scientific potential and applicability in space weather services.

Gradient Ionospheric indeX – GIX

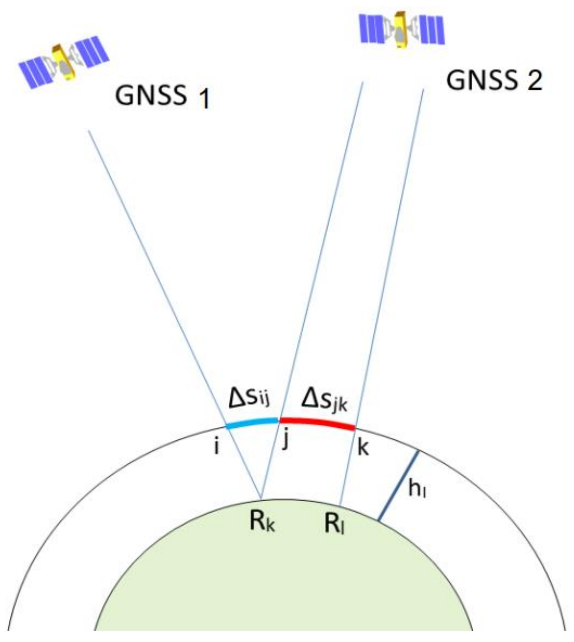
Statistical expression of the horizontal spatial gradient of TEC, between a pair (dipole) of ionospheric pierce points.

Each dipole is defined by a TEC-gradient vector, allowing to characterize the zonal (East-West) and meridional (North-South) ionospheric state.

Total GIX: $\langle \nabla TEC \rangle = \sqrt{\langle \nabla TEC_X \rangle^2 + \langle \nabla TEC_Y \rangle^2}$

Zonal GIX: $\nabla TEC_X = \nabla TEC_{ij} \cdot \sin\delta$

Meridional GIX: $\nabla TEC_Y = \nabla TEC_{ij} \cdot \cos\delta$



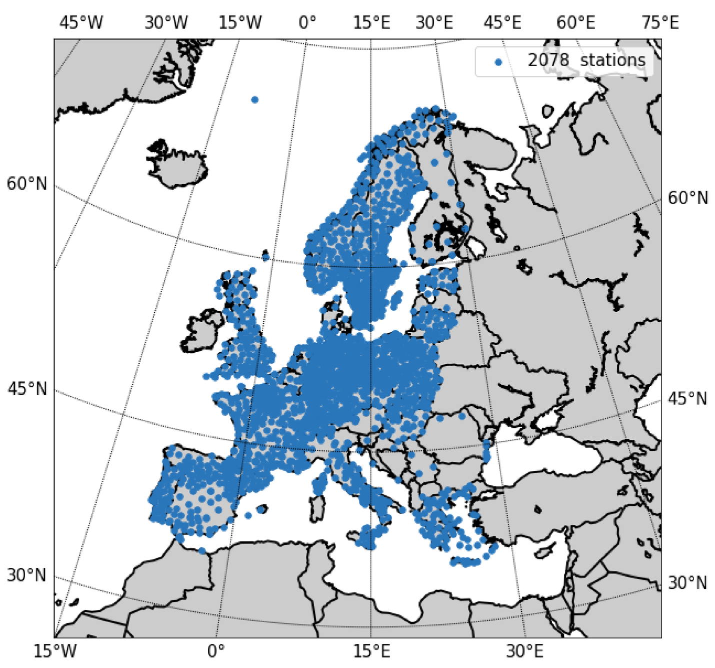
Sudden Ionospheric Disturbance indeX - SIDX

Statistical expression for regional temporal TEC variations defined as the average of rate of change of TEC measurements.

Total SIDX: $\left\langle \frac{\partial TEC}{\partial t} \right\rangle \approx \frac{1}{N} \sum_{i=1}^{N} \left(\frac{\Delta STEC}{M\,\Delta t} \right)_i$

SIDX characterizes large-scale temporal variations of the ionospheric ionization as for instance caused by solar flares.

Coordinated Ionospheric Study of Indices and Scales – CISSI by COSPAR



Main objective

Identify, compare and develop indices and scales well suited to estimate the impact of ionospheric perturbations on ground- and space-based radio systems.

Selected periods of study in 2015

- *Perturbed:* St. Patrick's Day storm 16-19th March (DoY 75-78)
- *Quiet:* low activity period 22-25th May (DoY 142-145)

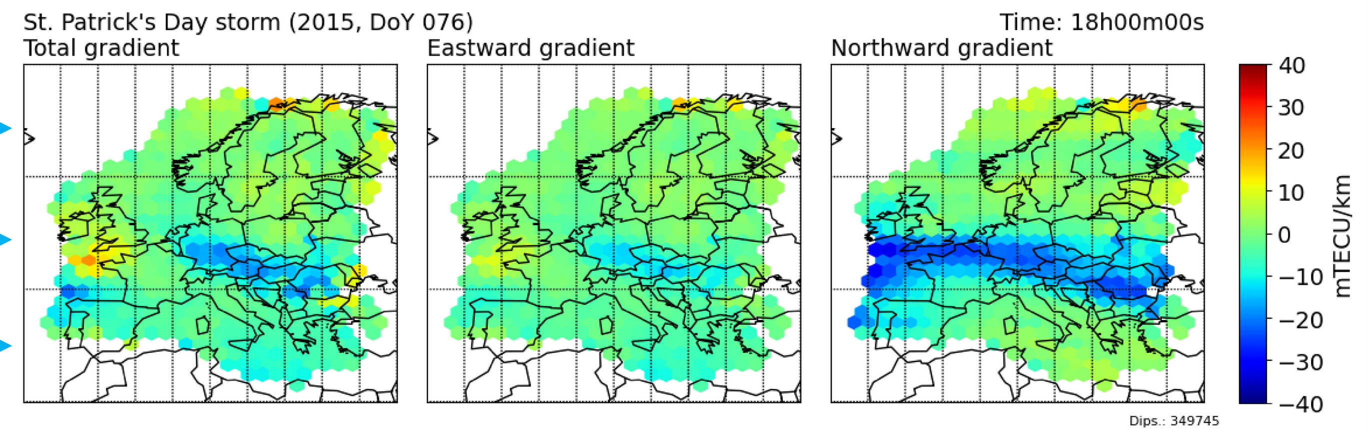
Regions of study

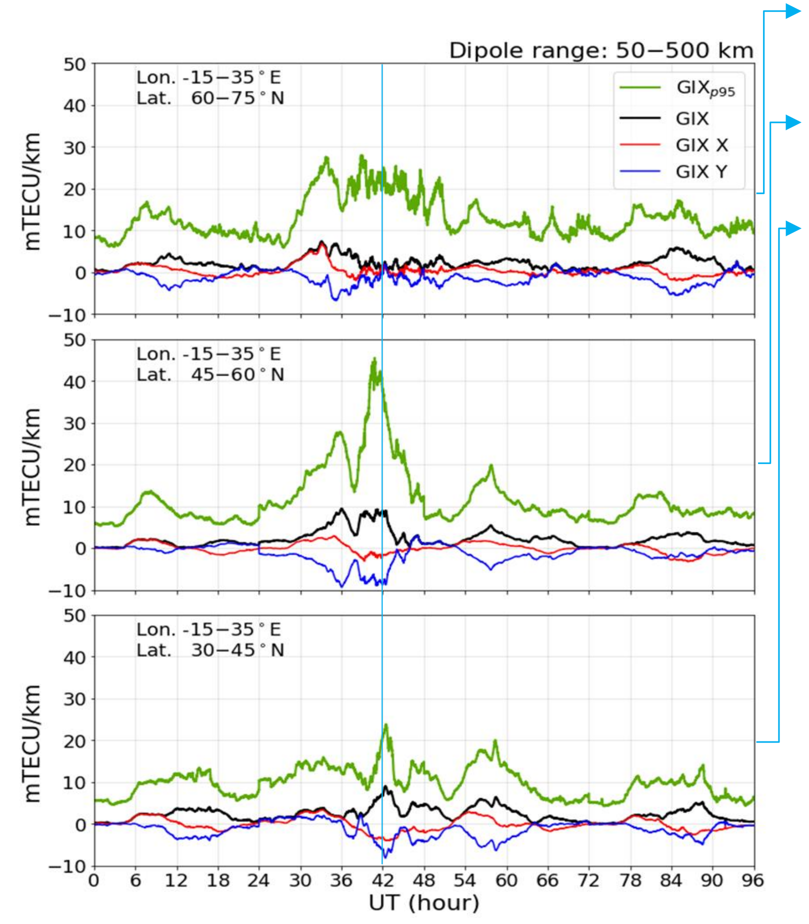
- Europe (GNSS data from >2000 ground stations)
- South-America

Conclusion

GIX and SIDX have the potential to characterize ionospheric perturbations by providing reliable estimation of strength and direction of middle and large scale gradients, which are crucial for precise GNSS applications including augmentation systems.

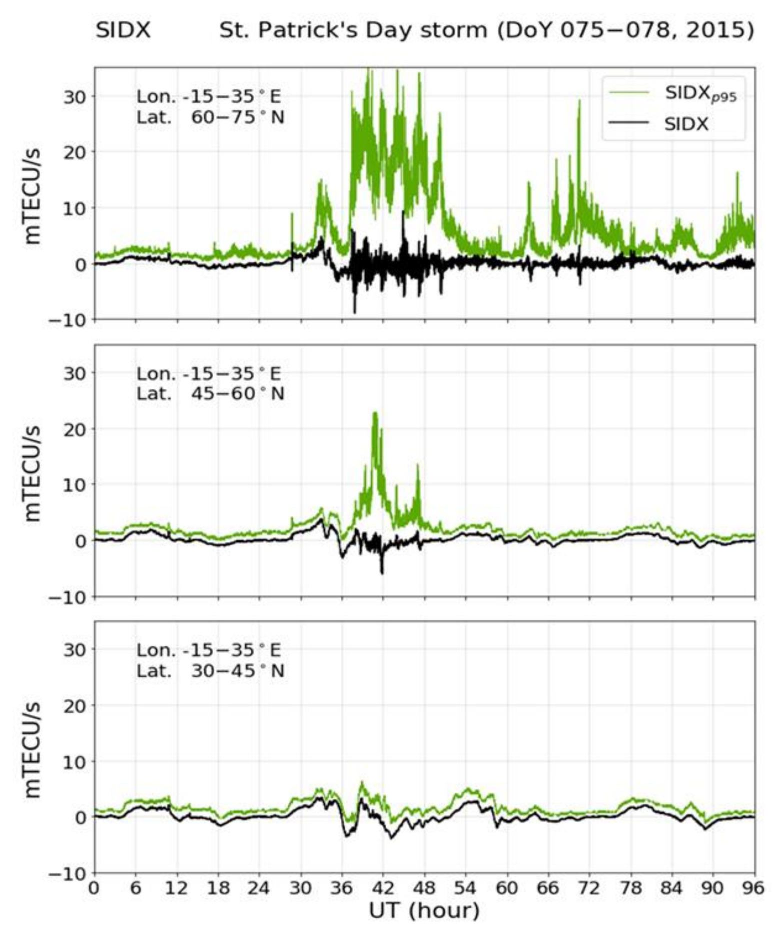
GIX during perturbed geomagnetic activity





- The *top figure* shows a sample map of the GIX gradients during the peak of the St. Patrick's Day storm.
- The *left figure* shows the 4-day timeseries of GIX and their X (red), Y (blue) components for 3 latitude sectors over Europe, as seen in the maps above.
- *High-latitudes:* a ionospheric perturbance with no clear structure and diffuse pattern is identified.
- *Mid-latitude:* a strong perturbance with clear peak that diminishes towards lower latitudes is observed.
- *Low-latitudes:* a perturbance with low amplitude variation is seen. The X and Y components characterize the propagation front southwards (ca. 300 m/s).

SIDX during perturbed geomagnetic activity



- During quiet conditions, SIDX tipically characterizes small diurnal variations with peaks at the time of highest ionization variability (e.g. during night).
- The *left figure* shows the 4-day timeseries of the mean (black line) and the 95-percentile (green line) of SIDX for 3 latitude sectors over Europe.
- *High-latitudes:* the mean profile (black) shows strong perturbation patterns, similar in both directions, that last for ca. 18 hours and indicate some degree of periodicity. Similar features, but with greater amplitude, are also observed for the 95-percentile values.
- *Mid-latitude:* the mean profile of the perturbation has a small amplitude at late afternoon/sunset that disappears towards lower latitudes. The profile of the 95-percentile proxy shows a strong peak at the same time.
- *Low-latitudes:* the SIDX timeseries shows none or very small perturbations.

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

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