UPC-IonSAT research group: Innovation in GNSS-based research and applications

Contributing to Space Weather monitoring and mitigation, Ionospheric and Tropospheric remote sensing, Precise GNSS positioning, Tsunami warning, among other problems

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UPC-IonSAT at a glance (1 of 2)

What **IO**nospheric determination & **N**avigation based on **S**atellite **A**nd **T**errestrial systems (IonSAT) res. group (created on Nov 2013).

Where **U**niversitat **P**olitècnica de **C**atalunya (UPC) @ Barcelona

Staff: *Prof. Manuel Hernández-Pajares*, *Prof. J.Maria Aroca-Farrerons*

Hired: *Dr. Germán Olivares-Pulido*, *Dr. Victoria Graffigna*, *Mr. David Moreno-Borràs*

Main contributions from: *Prof. Enric Monte-Moreno*, *Dr. Alberto García-Rigo*, *Dr. David Roma-Dollase*, *Dr. Heng Yang*, *Dr. Haixia Lyu*, *Dr. Qi Liu*, *Dr. Jiaojiao Zhao*, *Dr. Gabriel Oliveira-Jeréz*, *Dr. Ana L. Christovam*

Roots on Masters (non-exhaustive time-ordered list): *Prof. Juan Garay* and *Prof. Mario Pérez* (IES Torres i Bages L'Hospitalet), *Prof. Jorge Núñez de Murga* (Universitat de Barcelona, UB), *Dr. Ismael Colomina* (Institut Cartogràfic de Catalunya, ICC), *Prof. Antonio Rius* (Consejo Superior de Investigaciones Científicas, CSIC/IEEC), Dr. Oscar Colombo (GSFC/NASA).

UPC-IonSAT at a glance (2 of 2)

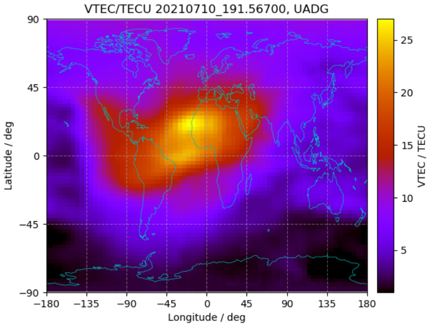
Frequent collaborations with Space Agencies & Universities Such as **European Space Agency** (ESA), German Aerospace Agency (DLR), Univ. Warmia-Mazury (UWM), GSFC/NASA, JPL, Univ. Bern, NRCan, Chinese Acad. Sciences, EUMETSAT, ICAO.

Numbers since Nov. 2013 (in 10 years of UPC-IonSAT existence): **92 peer reviewed papers** have been published in Q1 & Q2 sci. intern. journals, **12 Ph.D. thesis** have been finished, one intern. patent has been registered & **3.106.607 € won by UPC-IonSAT in projects** under just one perm. staff member in **+40 international competitive projects** from Intl. org. & companies.

Research & development **RT Global Ionospheric Maps**, improving **GNSS positioning**: from cycle-slip ambiguity fixing in low cost GNSS receivers to **Precision Agriculture**, precise GNSS **Tropospheric & Deformation** estimation, **RT GNSS Solar Flares** warnings & meas., **Tsunami Detection** from LEO GNSS & from **Iono. Tomography**, **GNSS Iono. Radio -Occultations** & **Polar Iono.**

R&D#1: **RT Global Ionospheric Maps** for International Civil Aviation Organization (ICAO) / International GNSS Service (IGS)

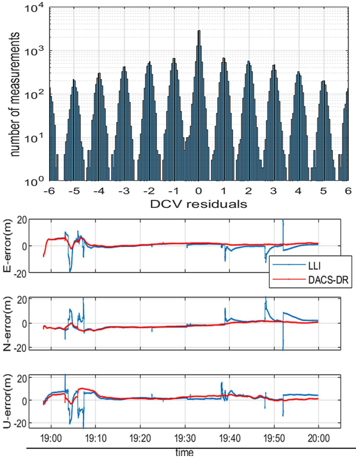
Example: UADG RT-GIM [July 10, 1555UT, from +200 GNSS rec.]



- UPC-IonSAT UADG RT-GIM, is presently the best behaving in IGS after new interpolation[1], provided 24/7 to ICAO.
- UPC-IonSAT is computing as well the likely best behaving rapid (1-day after) GIM at IGS since end of 1996, and the IGS combined RT-GIM.
- The UPC-IonSAT software, TOMIONv1, has been selected by the EU Galileo Reference Center (GRC @ The Netherlands) as reference iono. software.

[1] Heng Yang et al. “Real-time interpolation of global ionospheric maps by means of sparse representation”. In: *Journal of Geodesy* 95.6 (2021), pp. 1–20.

R&D#2: **Improving GNSS positioning**



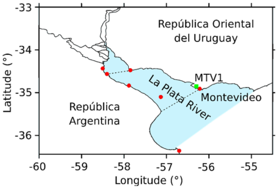
- A new high-rate Doppler-aided cycle slips detection & repair (DACS-DR method) induces an improvement in positioning conv. time & errors, for single-frequency low-cost GNSS rec.: 44.2% & 21.2% in hor. & vertical comp. at high latitude urban canyon under iono. scintillation[2].
- Wide Area RTK for Precision Agriculture[3].
- A new undifferenced uncombined ionospheric tomography common clock (ITCC) technique ([4]).

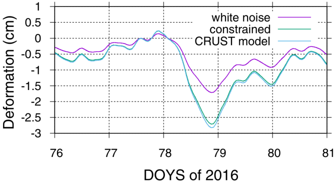
[2] Jiaojiao Zhao et al. "High-rate Doppler-aided cycle slip detection and repair method for low-cost single-frequency receivers". In: *GPS Solutions* 24.80 (2020), p. 80.

[3] Manuel Hernández-Pajares et al. "Wide-Area GNSS Corrections for Precise Positioning and Navigation in Agriculture". In: *Remote Sensing* 14.16 (2022), p. 3845.

[4] Germán Olivares-Pulido et al. "Ionospheric tomographic common clock model of undifferenced uncombined GNSS measurements". In: *Journal of Geodesy* 95.11 (2021), pp. 1–13.

R&D#3: precise GNSS **Zenith Tropospheric Delay (ZTD) & deformation** estimation



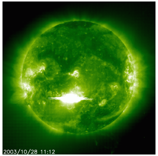


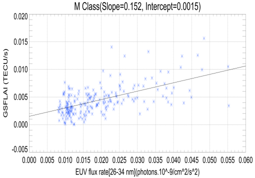
- The retrieval of reliable vertical displacement of GPS station (MTV1) very close to La Plata River, during a strong storm surge event, was addressed in[5]
- The optimal modelling in TOMIONv2 of both, the GPS receiver atomic clock (random walk), & the physical deformation model lead to an accurate vertical coor. time series.
- In[6] the ZTD & gradients were accurately estimated under the hurricane Harvey.

[5] Victoria Graffigna et al. "Interpretation of the tropospheric gradients estimated with GPS during hurricane Harvey". In: *Earth and Space Science* 6.8 (2019), pp. 1348–1365.

[6] Victoria Graffigna et al. "Interpretation of the tropospheric gradients estimated with GPS during hurricane Harvey". In: *Earth and Space Science* 6.8 (2019), pp. 1348–1365.

R&D#4: **RT GNSS Solar Flares** detection





- A new First Principles based way to measure with GNSS the solar EUV flux rate during flares, from the associated ionospheric overionization, was conceived by MHP[7] & developped & applied in[8],[9].
- The SF products, including warnings, are being provided in RT 24/7 since more than one solar cycle[10], with customers like the ESA SSA-SWE Service.

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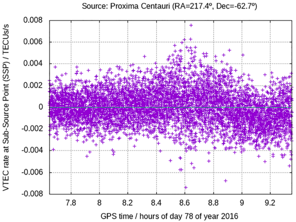
[7] Manuel Hernández-Pajares et al. "GNSS measurement of EUV photons flux rate during strong and mid solar flares". In: *Space Weather* 10.12 (2012), pp. 1–16. DOI: 10.1029/2012SW000826. URL: https://doi.org/10.1029/2012SW000826.

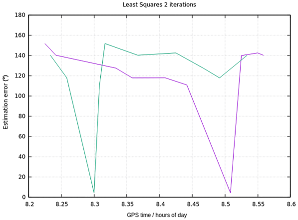
[8] Talwinder Singh et al. "GPS as a solar observational instrument: Real-time estimation of EUV photons flux rate during strong, medium, and weak solar flares". In: *Journal of Geophysical Research: Space Physics* 120.12 (2015), pp. 1–11. DOI: 10.1002/2015JA021824. URL: https://doi.org/10.1002/2015JA021824.

[9] Enrique Monte-Moreno and Manuel Hernández-Pajares. "Occurrence of solar flares viewed with GPS: Statistics and fractal nature". In: *Journal of Geophysical Research: Space Physics* 119.11 (2014), pp. 9216–9227. DOI: 10.1002/2014JA020206. URL: https://doi.org/10.1002/2014JA020206.

[10] Manuel Hernández-Pajares et al. "GNSS Solar Astronomy in real-time during more than one solar cycle". In: *Advances in Space Research* (2023).

R&D#5: Potential **detection of stellar flares** with GNSS Ionosphere

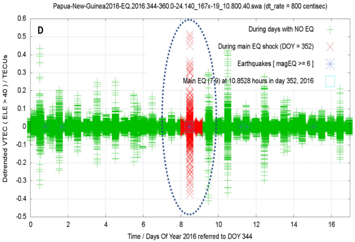


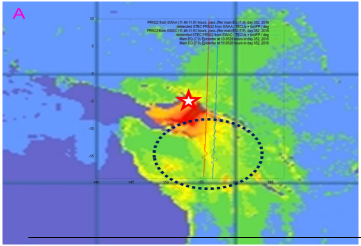


- In[11] the solar EUV flux rate proxy during flares is generalized to the very challenging scenario of stellar superflares, with a much weaker expected geoeffectiveness on the Earth ionosphere.
- The new algorithm (BGEES) is able to detect stellar EUV superflares without the previous knowledge of the position of the source, which is also simultaneously estimated, providing an additional quality check of the detection.
- BGEES has detected the Proxima Centauri (18 March 2016, 08:32UT) and NGTS J121939.5-355557 (1 February 2016, 04:00UT) superflares.

[11] Manuel Hernández-Pajares and David Moreno-Borràs. "Real-Time Detection, Location, and Measurement of Geoeffective Stellar Flares From Global Navigation Satellite System Data: New Technique and Case Studies". In: *Space Weather* 18.3 (2020), e2020SW002441. DOI: 10.1029/2020SW002441. URL: https://doi.org/10.1029/2020SW002441.

R&D#6: **Tsunami Detection from** Low Earth Orb. (**LEO**) GNSS data

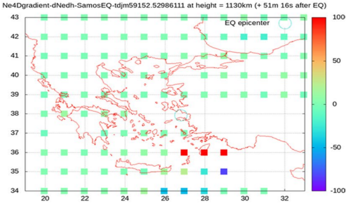


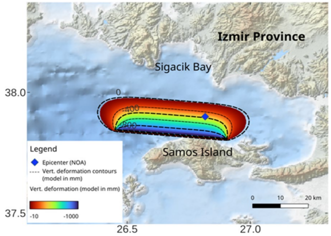


- The capability of GNSS POD LEO data to detect iono. signatures of tsunamis has been recently shown in Papua New Guinea 2016 event[12].
- Such iono. signals above the Swarm LEOs have been confirmed with independent data: in-situ LEO electron density meas., DORIS and ground -based GNSS co-located meas.
- The feasibility of a potential future monitoring tsunami system has been shown, triggered by hundreds of cubesats bringing POD GNSS rec. with RT or NRT confirmation and characterization by thousands of worldwide ground GNSS rec.

[12] Heng Yang et al. "Systematic detection of anomalous ionospheric perturbations above LEOs from GNSS POD data including possible tsunami signatures". In: *IEEE Transactions on Geoscience and Remote Sensing* 60 (2022), pp. 1–23.

R&D#7: **Tsunami Detection from ground-based GNSS iono. tomography**

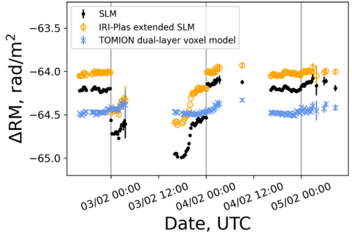


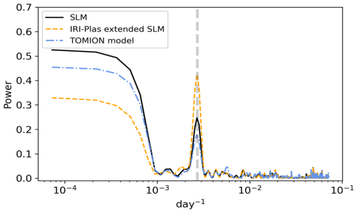


- The capability of ionospheric tomography, based on ground based GNSS data only, to detect iono. signatures of co-tsunami and post-tsunami response is shown within the multi-instrumental study[13].
- It was focused on the Samos 2020 earthquake and tsunami: in October 2020 at 11:51 UT, a magnitude 7.0 earthquake occurred in the Dodecanese sea (37.84°N, 26.81°E, 10 km depth) and generated a tsunami with an observed run-up of more than 1 m on the Turkish coasts.

[13] Lucilla Alfonsi et al. "Ionospheric response to the 2020 Samos earthquake and tsunami". In: *Earth, Planets and Space* 76.1 (2024), p. 13.

R&D#8: **High order** ionospheric corrections in **Radioastronomy**

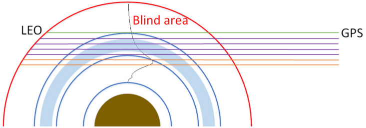


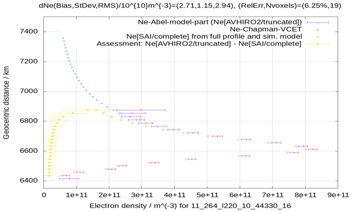


- A performance test of three GNSS-based models of the ionosphere using long term ionospheric Faraday rotation observations of PSR J0332+5434 taken with the LOw Frequency ARray (LOFAR) is studied and summarized in[14].
- The SLM is compared with IRI-Plas and with the dual-layer voxel TOmographic Model of the Ionosphere (TOMION), both of which partially account for the thickness and vertical dynamics of the terrestrial plasma, improving the reconstruction of the ionospheric Faraday rotation.

[14] Nataliya K Porayko et al. "Validation of global ionospheric models using long-term observations of pulsar Faraday rotation with the LOFAR radio telescope". In: *Journal of Geodesy* 97.12 (2023), p. 116.

R&D#9: Inverting **truncated** LEO-based GNSS ionospheric radio-occultations



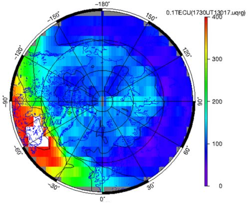


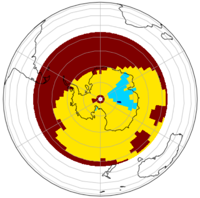
- A new way of combining Abel inversion and the Chapman model with a linearly increasing scale height to retrieve ionospheric electron density vertical profiles from truncated-sounding radio-occultation data, has been developed[15],[16].
- The results, show that this method can retrieve EDVPs with a predominant absolute and relative error of 10^{10} $e^{-}m^{-3}$ and 5%, respectively, and in less than 10 s per profile, which makes this method suitable for near real-time applications in upcoming missions such as EUMETSAT Polar System-Second Generation.

[15] Haixia Lyu et al. "Electron density retrieval from truncated radio occultation GNSS data". In: *Journal of Geophysical Research: Space Physics* 124(6) (2019), pp. 4842–4851.

[16] Germán Olivares-Pulido et al. "Real-Time Tomographic Inversion of Truncated Ionospheric GNSS Radio Occultations". In: *Remote Sensing* 15.12 (2023), p. 3176.

R&D#10: Realistic **Polar Ionosphere** from GNSS Global Ionospheric Maps





- The realistic electron content distribution of the north and south polar ionosphere from 2001 to the beginning of 2019 by using the UQRG Global Ionospheric Map (GIM) of vertical total electron content (VTEC), computed every 15 min by UPC-IonSAT with a tomographic-kriging combined technique, is confirmed in[17].
- The same input UQRG GIMs provides in particular realistic estimation of the polar depletion regions by VTEC contrast and watershed enhancing, in[18].

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[17] Manuel Hernández-Pajares et al. "Polar Electron Content From GPS Data-Based Global Ionospheric Maps: Assessment, Case Studies, and Climatology". In: *Journal of Geophysical Research: Space Physics* 125.6 (2020), e2019JA027677.

[18] Enrique Monte-Moreno et al. "Estimation of polar depletion regions by VTEC contrast and watershed enhancing". In: *IEEE Transactions on Geoscience and Remote Sensing* 60 (2021), pp. 1–20.

Conclusions

The following active R&D activities of UPC-IonSAT have been summarized:

1. RT Global Ionospheric Maps.
2. Improving GNSS positioning: from cycle-slip ambiguity fixing in low cost GNSS receivers to Precision Agriculture.
3. Precise GNSS Tropospheric & Deformation estimation.
4. RT GNSS Solar Flares warnings & meas.
5. Potential detection of stellar flares with GNSS Ionosphere.
6. Tsunami Warnings from Low Earth Orb. GNSS data.
7. Tsunami Warnings Iono. GNSS-based Tomography.
8. High order ionospheric corrections in Radioastronomy.
9. Inversion of truncated LEO-based Iono. GNSS Radio-Occultations.
10. Polar Ionosphere.

https://scholar.google.es/citations?user=Tm-DcsMAAAAJ&hl=en&oi=ao