

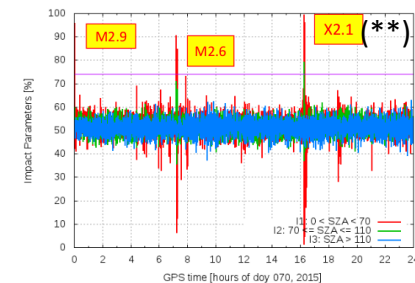
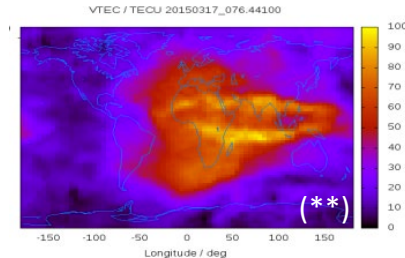
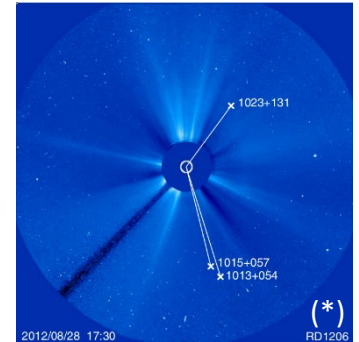
# Overview on GGOS JWG3 - Improved understanding of space weather events and their monitoring

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- IAG's GGOS Joint Working Group 3 is part of GGOS **Focus Area on Geodetic Space Weather Research** – Observation Techniques and Modeling Approaches, and it is joint with IAG's Commission 4, SC 4.3 (2019-2023)
- JWG3 aims at gaining a better **understanding of space weather events and their effect on Earth's atmosphere and near-Earth environment**. In particular, we will analyze representative events in 2013, 2015, 2017 and 2018 using **data from different space geodetic techniques** (e.g. GNSS, DORIS, RO, VLBI, satellite altimetry) combined with **space weather data** from different sources (including observations from spacecraft and radio telescopes).
- **Complementary models/products/services** by the members' of the WG, linked to: TEC GIMs, ionospheric and solar corona electron density, geomagnetic disturbances from the Sun to Earth, DORIS ionospheric products, TIDs and scintillations, solar flares detection/prediction, GNSS-based EUV flux-rate, CMEs and SEPs, solar corona electron density, dimmings and coronal holes, solar wind, polar depletions, among others.
- **Main JWG3 key objectives:**
  - Analysis of the correlation between Space Weather products and perturbed ionospheric/plasmaspheric electron density/TEC. Identify the main parameters that could be useful to improve their real time determination and prediction in extreme conditions.
  - Combination of measurements and estimates derived from space geodetic techniques and from solar spacecraft missions. Possibility to conduct extensive simulations.
  - Conduct comparisons and validation against external data. Interpretation of the results and their impact on end user' applications (e.g. GNSS positioning, EGNOS performance degradation).



(\*) Soja, B., Heinkelmann, R. and Schuh, H., 2014. Probing the solar corona with very long baseline interferometry. Nature communications, 5(1), pp.1-9.

(\*\*) García Rigo, Alberto, et al. (2017), St. Patrick's day 2015 geomagnetic storm analysis based on real time ionosphere monitoring, EGU 2017: European Geosciences Union General Assembly: Vienna, Austria: 23-28 April 2017: proceedings book. 2017.

# JWG3 - Working Group Overview

- In the frame of IAG's GGOS (International Association of Geodesy; Global Geodetic Observing System).
- Joint Working Group 3 is part of GGOS Focus Area on Geodetic Space Weather Research – Observation Techniques and Modeling Approaches, and it is joint with IAG's Commission 4, SC 4.3
- This WG will run up until 2023 for four years.
- JWG3 aims at gaining a better understanding of space weather events and their effect on Earth's atmosphere and near-Earth environment.
- In particular, we will investigate different approaches to monitor space weather events using the data from different space geodetic techniques combined with space weather observations gathered from different sources (including data from spacecrafts and radiotelescopes).
- Furthermore, the correlation between SW products and perturbed ionospheric electron density/Total Electron Content will be analysed, jointly with JWG1.
- As per JWG3 key objectives, these include:
  - Identify the main parameters that could be useful to improve real time determination and prediction of ionospheric/plasmaspheric TEC and electron density estimates, in case of extreme SW conditions
  - Improving (near) real time determination of the electron density within the ionosphere and plasmasphere to detect space weather events in collaboration with JWG1
  - Combination of measurements and estimates derived from space geodetic observation techniques and from solar spacecraft missions. Possibility to conduct extensive simulations
  - Interpretation of the results. Correlate results with SW events' impact on end user applications

# JWG3 – Space Geodetic techniques

- Several space geodetic techniques are capable of measuring effects caused by space weather events.
- Most notably, space weather events cause ionospheric disturbances that can be detected and monitored thanks to estimates of the vertical total electron content (VTEC) or the electron density (Ne) of the ionosphere.
- Various space geodetic observation techniques, in particular GNSS, satellite altimetry, DORIS, radio occultations (RO) and VLBI are capable of determining ionospheric key parameters, namely VTEC or Ne.
- For the monitoring of space weather events, low latency data availability is of great importance, ideally in real time (RT) or near real time (NRT), to enable triggering alerts.
- At present, however, only GNSS is greatly suited for this task. The use of the other techniques is still restricted or even impossible, in particular due to their latencies of hours (altimetry) or even days (RO, DORIS, VLBI).
- Interests on how well models can reproduce changes during storms, understanding the interactions with the solar wind and magnetosphere, correlation of data from different available measurement techniques.

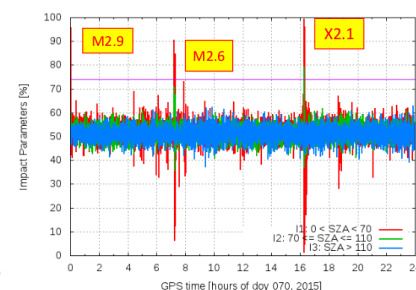
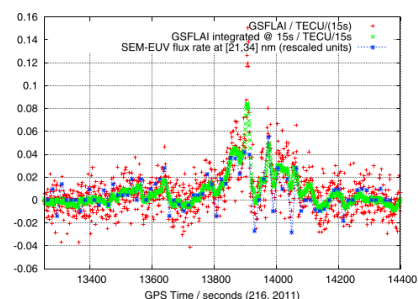
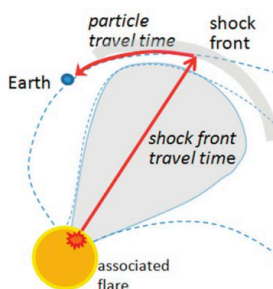
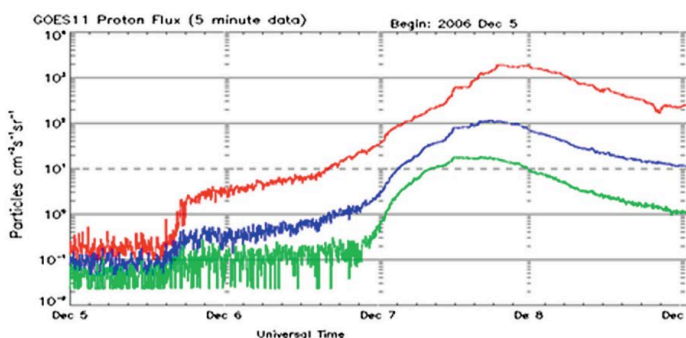
## JWG3 – Combination and joint evaluation of SW data

- Multiple and complementary models/products/services by the members' of the WG, linked to: TEC GIMs, ionospheric and solar corona electron density, geomagnetic disturbances from the Sun to Earth, DORIS ionospheric products, TIDs and scintillations, solar flares detection/prediction, GNSS-based EUV flux-rate, CMEs and SEPs, solar corona electron density, dimmings and coronal holes, solar wind, polar depletions, etc.
- The geodetic measurement of the ionospheric electron density will be complemented by direct observations of the solar corona, where solar storms originate.
- Space crafts like SOHO or ACE have monitored the solar corona and the solar wind for decades and will be beneficial, together with data from other space crafts like SDO, in assessing the performance of geodetic observations of space weather events.
- Data from Solar Parker Probe (SPP), which will allow even greater insights through very close approaches to the Sun, has just recently been made publicly available.
- Geodetic VLBI is also capable of measuring the electron density of the solar corona when observing targets angularly close to the Sun and might be useful for comparisons.
- Other solar-related satellite missions such as Stereo, DSCOVR, GOES, etc. provide valuable information on solar radiation, particle precipitation, magnetic field variations, among other parameters.
- The combination and joint evaluation of these data sets with the measurements of space geodetic observation techniques is still a great challenge.
- Other indications for solar activity - such as the F10.7 index on solar radio flux, SOLERA as EUV proxy or rate of Global Electron Content (dGEC), could also be used.

# JWG3 – Few Examples

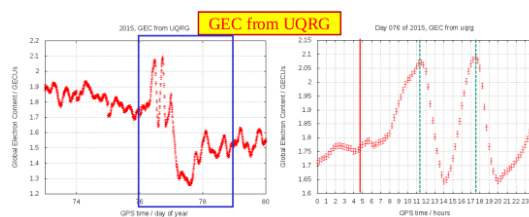
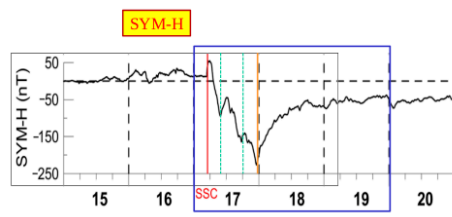
## Space weather events and their impact on Near-Earth environment

Multiple space geodetic techniques are capable of measuring effects caused by space weather events. Space weather events cause ionospheric disturbances correlated with variations in the vertical total electron content (VTEC) or the electron density (Ne) of the ionosphere.

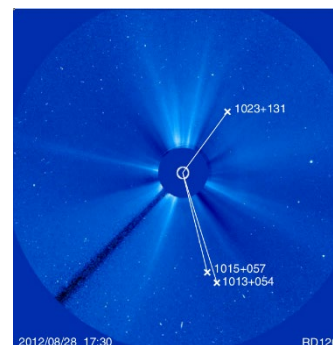


Intensity-time profile and shock interaction with the interplanetary magnetic field of SEP events associated to eastern events (\*).

EUV flux rate proxy & solar flare detectors (SOLERA & SISTED) based on GNSS-based ionospheric overionization



Correlation between SYM-H geomagnetic index and the rate of Global Electron Content (dGEC from UQRG 15-min resolution GIMs)

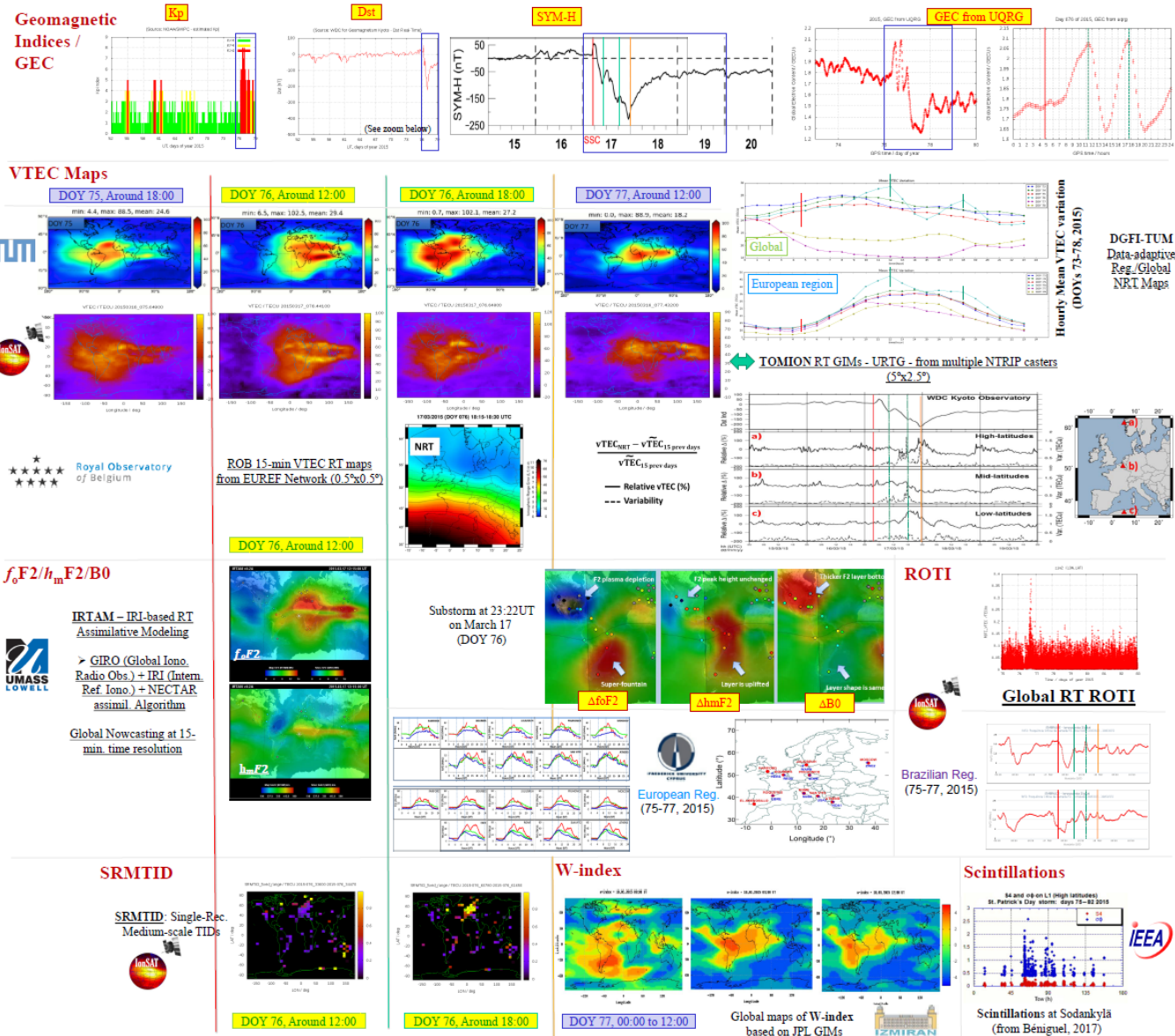


Radio source geometry and coronagraph images for VLBI experiment to assess the electron density of the solar corona (\*\*)

(\*) García-Rigo, A., Núñez, M., Qahwaji, et al. (2016). Prediction and warning system of SEP events and solar flares for risk estimation in space launch operations. J. Space Weather Space Clim., 6, A28 (2016)

(\*\*) Soja, B., Heinkelmann, R. and Schuh, H., 2014. Probing the solar corona with very long baseline interferometry. Nature communications, 5(1), pp.1-9.

# JWG3 – Few Examples



# JWG3 – Activities

## Past and Recent activities:

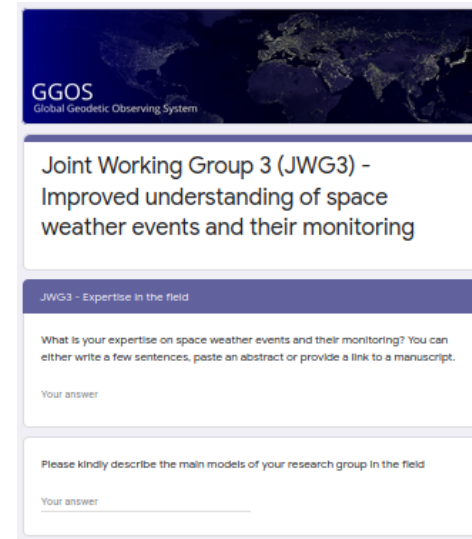
1. Google Form Survey to gather feedback from JWG3 members
2. Selection of a set of historical representative space weather events to be analysed
3. Identification of SW data sources accessible by the team members
4. Coordination with JWG1

## Present work:

1. Generation and provision of data & plots to JWG1 (possibility to be integrated in JWG1 database).
2. Analysis of the correlation between SW products and perturbed ionospheric electron density/TEC
3. Identify the main parameters that could be useful to improve real time determination as well as prediction of ionospheric/plasmaspheric TEC and electron density estimates, in case of extreme solar weather conditions.

## Next Future plans:

1. Improving (near) real time determination of the electron density within the ionosphere and plasmasphere to detect space weather events in collaboration with JWG1.
2. Combination of measurements and estimates derived from space geodetic observation techniques and from solar spacecraft missions by conducting extensive simulations, combining different data sets and testing different algorithms.
3. Comparison and validation using external data, in particular data from spacecraft.



GGOS  
Global Geodetic Observing System

Joint Working Group 3 (JWG3) -  
Improved understanding of space  
weather events and their monitoring

JWG3 - Expertise in the field

What is your expertise on space weather events and their monitoring? You can either write a few sentences, paste an abstract or provide a link to a manuscript.

Your answer

Please kindly describe the main models of your research group in the field

Your answer

# JWG3 – References

- Berdermann, J., Kriegel, M., Banys, D., Heymann, F., Hoque, M. M., Wilken, V., Borries, C., Heßelbarth, A. and Jakowski, N. , (2018), Ionospheric response to the X9.3 Flare on 6 September 2017 and its implication for navigation services over Europe, Space Weather, Volume 16, Issue 10, Pages 1604-1615, <https://doi.org/10.1029/2018SW001933>.
- Bloßfeld M., Zeithöfler J., Rudenko S., Dettmering D. (2020), Observation-Based Attitude Realization for Accurate Jason Satellite Orbits and Its Impact on Geodetic and Altimetry Results, Remote Sensing, 12(4), 682, <https://doi.org/10.3390/rs12040682>, 2020.
- Borries, C., Wilken, V., Jacobsen, K. S., Garcia-Rigo, A., Dziak-Jankowska, B., ... & Hoque, M. M. (2020), Assessment of the capabilities and applicability of ionospheric perturbation indices provided in Europe, Advances in Space Research, 66(3), 546-562.
- Flores-Soriano, M., C. Cid, and R. Crapolicchio (2021), Validation of the SMOS Mission for Space Weather Operations: The Potential of Near Real-Time Solar Observation at 1.4 GHz, Space Weather 19, no. 3 (2021): e2020SW002649.
- García Rigo, Alberto, et al. (2017), St. Patrick's day 2015 geomagnetic storm analysis based on real time ionosphere monitoring, EGU 2017: European Geosciences Union General Assembly: Vienna, Austria: 23-28 April 2017: proceedings book. 2017.
- Garcia-Rigo, A., & Soja, B. (2020), New GGOS JWG3 on Improved understanding of space weather events and their monitoring, EGU General Assembly Conference Abstracts (p. 20492).
- Mannucci, Anthony et al. (2020), Chapman Conference on Scientific Challenges Pertaining to Space Weather Forecasting Including Extremes: Recommendations for the Community, Recommendations from the Chapman Conference on Scientific Challenges Pertaining to Space Weather Forecasting Including Extremes, 11-15 February 2019, Pasadena, CA, USA, <https://doi.org/10.5281/zenodo.3986940>.
- Monte-Moreno, E., M. Hernandez-Pajares, H. Lyu, H. Yang and A. Aragon-Angel (2021), Estimation of Polar Depletion Regions by VTEC Contrast and Watershed Enhancing, IEEE Transactions on Geoscience and Remote Sensing, doi: 10.1109/TGRS.2021.3060107.
- Sato, Hiroatsu und Jakowski, Norbert und Berdermann, Jens und Jiricka, Karel und Heßelbarth, Anja und Banyś (geb. Wenzel), Daniela und Wilken, Volker (2019) Solar Radio Burst events on September 6, 2017 and its impact on GNSS signal frequencies. Space Weather. Wiley. Volume17, Issue 6, 2019, Pages 816-826 DOI: 10.1029/2019SW002198 ISSN 1542-7390.
- Schunk, Robert Walter, Ludger Scherliess, Vince Eccles, Larry C. Gardner, Jan Josef Sojka, Lie Zhu, Xiaoqing Pi et al. (2021), Challenges in Specifying and Predicting Space Weather, Space Weather 19, no. 2 (2021): e2019SW002404.
- Soja, B., Heinkelmann, R. and Schuh, H., 2014. Probing the solar corona with very long baseline interferometry. Nature communications, 5(1), pp.1-9.
- Verkhoglyadova, O., X. Meng, A. J. Mannucci, J-S. Shim, and R. McGranaghan (2020), Evaluation of Total Electron Content Prediction Using Three Ionosphere-Thermosphere Models, Space Weather 18, no. 9 (2020): e2020SW002452.
- Zucca, P., M. Núñez, K.L. Klein (2017), Exploring the potential of microwave diagnostics in SEP forecasting: The occurrence of SEP events, Journal of Space Weather and Space Climate 7, A13, 2017