Focus Area

Geodetic Space Weather Research

Chair: Michael Schmidt

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GGOS-Days 2019, November 12–14, 2019
Rio de Janeiro, Brazil,
Recent news (chronologic)

- **Dr. Ehsan Forootan** (Cardiff University, Cardiff, United Kingdom) became member of the **GGOS Science Panel**

- Furthermore, Dr. Ehsan Forootan became also a member of the **GGOS Committee on Essential Geodetic Variables**

- Performance of 2 **oral sessions** with 6 invited talks related to the topics of the FA-GSWR within the Symposium G06: Monitoring and Understanding the Dynamic Earth with Geodetic Observations at the **27th IUGG 2019 General Assembly** in Montreal, Canada at July 14th.

- Since **Dr. Klaus Börger** changed his job in Germany, he had to step down from being the Vice-chair of the FA GSWR.
  
  ➢ Thus, the position of the **Vice-chair is vacant**.

- One single **GGOS Joint Study Group** (JSG) and three **GGOS Joint Working Groups** (JWG) have been defined and established: Positions of Chairs and Vice-Chairs mainly filled, Terms of Reference, Objectives and member lists available
Scientific content of the FA GSWR

- **Space weather** means today an own, very **up-to-date** and **interdisciplinary field of research**.
- It describes **physical processes** in space mainly caused by the Sun’s **radiation** of energy.
- The **manifestations** of **space weather** are multiple, e.g.
  - variations of the **Earth’s magnetic field**,  
  - **polar lights** in the northern and southern hemisphere,  
  - variations of the upper atmosphere with the compartments **ionosphere** and **thermosphere** (due to **coupling processes**),  
  - **solar wind**, i.e. the permanent emission of electrons and photons,  
  - **interplanetary magnetic field**,  
  - **electric currents**.
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  - **solar wind**, i.e. the permanent emission of electrons and photons,  
  - **interplanetary magnetic field**,  
  - **electric currents**.
- The **interplanetary magnetic field (IMF)** is the component of the solar magnetic field that is dragged out from the solar corona by the **solar wind** flow.
The Earth’s atmosphere can be structured into various layers depending on physical parameters such as temperature or charge state.
Atmosphere structure
Scientific content of the FA GSWR

- The figure illustrates the **structure** of the Focus Area on Geodetic Space Weather Research (FA GSWR) as a rhombus.
- **Satellite Geodesy** deals for a long time with the ionosphere (PPP) and the thermosphere (POD).
- **Thermospheric drag** is the most important force acting on Low-Earth Orbiting (LEO) satellites and objects in the re-entry stage.
Scientific content of the FA GSWR

- **Earth's magnetosphere** is the region of space surrounding the Earth where the dominant magnetic field is the **magnetic field of Earth**, rather than the IMF.

- The magnetosphere is formed by the **interaction** of the **solar wind** with the **Earth’s magnetic field**

- The **pressure** of the solar wind on the Earth’s magnetic field **compresses** the field on the dayside of the Earth and **stretches** the field into a long tail on the nightside

- **Source**: Space Weather Prediction Center, https://www.swpc.noaa.gov/phenomena/earths-magnetosphere
Scientific content of the FA GSWR

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Space-geodetic observation techniques

- The figure shows an overview about the space-geodetic observation techniques which provide valuable information about the coupled thermosphere-ionosphere system.

![Diagram showing various observation techniques for the thermosphere-ionosphere system.](source: NASA)

- **Altimetry**: Jason-2, Jason-3
- **DORIS** (DGXX receivers on board): Jason-2, SARAL, HY-2A, Jason-3, Cryosat-2, Sentinel-3A
- **Precise orbit determination**: SLR observations
- **Radio occultation missions**: F-3/C (in future: F-7/C2)
- **Sun observations**: Stereo A & B, ACE, DSCOVR
- **GNSS**: GPS, GLONASS, ...
Observation techniques from space

- The figure on the previous slide shows an overview about the solar and geodetic observation techniques which provide valuable information about the MIT system.

- The combined evaluation of the measurements from the solar and the geodetic observation techniques is one important basis of the FA GSWR to reach the main objectives, namely the
  1) development of improved ionosphere models and the
  2) development of improved thermosphere models

- The first objective is related to the electron density of the ionosphere, the second objective to the thermospheric density.

- Both are
  - connected to each other by means of physical coupling processes and
  - in our opinion Essential Geodetic Variables (EGV) and will be provided as GGOS products to the users
The discussion before cause the implementation of

- **1 GGOS Joint Study Group (JSG)** and
- **3 GGOS Joint Working Groups (JWG)**

In detail these are:

- **JSG 3**: Coupling processes between magnetosphere, thermosphere and ionosphere
- **JWG 1**: Electron density modelling
- **JWG 2**: Improvement of thermosphere models
- **JWG 3**: Improved understanding of space weather events and their monitoring by satellite missions
Joint Study Group and Joint Working Groups

JSG 1: Coupling processes between magnetosphere, thermosphere and ionosphere

Joint with IAG ICCT and Commission 4, Sub-Commission 4.3

Chair: Andres Calabia Aibar (China, andres@calabia.com)
Vice-Chair: vacant

Objectives:

- Characterize and parameterize the global modes of MIT variations associated with diurnal, seasonal, and space weather drivers, as well as the lower atmosphere forcing.
- Determine and parameterize the mechanisms responsible for discrepancies between observables and the present models.
- Detect and investigate coupled processes in the MIT system for the deciphering of physical laws and principles such as continuity, energy and momentum equations and solving partial differential equations.
Joint Study Group and Joint Working Groups

JWG 1: Electron density modelling

Joint with Commission 4, Sub-Commission 4.3

Chair: Fabricio dos Santos Prol (Germany, Fabricio.DosSantosProl@dlr.de)
Vice-Chair: Alberto Garcia-Rigo (Spain, garciarigo@ieec.cat)

Objectives:

- Develop a database, where the methods from the group members will be able to be evaluated in terms of GNSS, radio-occultation, DORIS, in-situ data, altimeters, among other electron density and TEC measurements.
- Evaluate established methods for 3D electron density estimation in order to define their accuracy related to specific parameters of great importance for Space Weather and Geodesy.
- Generate products indicating the space weather conditions and expected errors of the methods.
- Carry out surveys in order to detect if the products are linked to the user’s specific needs. Based on an analysis of the user needs, re-adaptations will be identified in order to improve the products in an iterative process. It is planned to define which parameters are of interest for the users and to detect additional information that may be required.
Joint Study Group and Joint Working Groups

JWG 2: Improvement of thermosphere models

Joint with IAG Commission 4, Sub-Commission 4.3

Chair: Christian Siemes (The Netherlands, C.Siemes@tudelft.nl)
Vice-Chair: Kristin Vielberg (Germany, vielberg@geod.uni-bonn.de)

Objectives:

- Review space geodetic observations and state-of-the-art processing methods
- Advance processing methods to increase consistency between observational datasets
- Improve thermosphere models through providing accurate and consistent space geodetic observations
- Study the impact of improved observational datasets and advanced processing methods on orbit determination and prediction
Joint Study Group and Joint Working Groups

JWG 3: Improved understanding of space weather events and their monitoring by satellite missions

Joint with IAG Commission 4, Sub-Commission 4.3

Chair: Anna Belehaki (Greece, TBD)
Vice-Chair: Benedikt Soja (USA, benedikt.s.soja@jpl.nasa.gov)

Objectives:

• ...
Selected presentations

Poster presentation at the

- GEO WEEK 2017 in Washington D.C., October 23 to 27, 2017
- EGU 2018 in Vienna, GGOS Session, April 10, 2018
- IX Hotine-Marussi Symposium in Rome in June 18 to 22, 2018
- EGU 2019 in Vienna, GGOS Session, April 9, 2019
- ESA Living Planet Symposium in Milan, May 13 to 17, 2019
- IUGG General Assembly in Montreal, July 8 to 18, 2019

Oral Session

- 2 oral sessions within the Symposium G06: Monitoring and Understanding the Dynamic Earth with Geodetic Observations at IUGG General Assembly in Montreal, July 14, 2019
27th IUGG General Assembly

Session title: G06b - Monitoring and Understanding the Dynamic Earth With Geodetic Observations
Session type: IAG (Geodesy)
Track: G06

Chair

Michael Schmidt, Germany

13:30 - 14:00

**IUGG19-1320: Essential Geodetic (Space Weather) Variables – Mind the Gap in Thermosphere and Ionosphere**
Solicited Speaker: E. Forootan, Germany

14:00 - 14:30

**IUGG19-3118: Towards a global 3D ionospheric model for space weather monitoring and GNSS positioning**
Solicited Speaker: F. Prol, Germany

14:30 - 15:00

**IUGG19-1373: Thermosphere Modeling Including Thermosphere-Ionosphere Coupling**
Solicited Speaker: K. Vielberg, Germany
27th IUGG General Assembly

Session title: G06c - Monitoring and Understanding the Dynamic Earth With Geodetic Observations
Session type: IAG (Geodesy)
Track: G06

Chair

Michael Schmidt, Germany

16:30 - 17:00

**IUGG19-0248: Upper Atmospheric Characterization through Neutral and Electron Density Observables**

Solicited Speaker: A. Calabia Aibar, China

17:00 - 17:30

**IUGG19-3546: Very Long Baseline Interferometry as a tool to probe the solar corona**

Solicited Speaker: B. Soja, USA

17:30 - 18:00

**IUGG19-1258: Geodesy for Space Weather Monitoring at GFZ: Overview and Recent Results**

Solicited Speaker: J. Wickert, Germany
Very Long Baseline Interferometry as a tool to probe the solar corona

Benedikt Soja\textsuperscript{1}, R. Heinkelmann\textsuperscript{2}, H. Schuh\textsuperscript{2,3}, J. Böhm\textsuperscript{4}, J. Sun\textsuperscript{5}, O. Titov\textsuperscript{6}, J. Lovell\textsuperscript{7}, J. McCallum\textsuperscript{7}, S. Shabala\textsuperscript{7}, L. McCallum\textsuperscript{7}, D. Mayer\textsuperscript{8}, M. Schartner\textsuperscript{4}, A. de Witt\textsuperscript{9}, F. Shu\textsuperscript{10}, B. Xia\textsuperscript{10}, T. Jiang\textsuperscript{10}, A. Melnikov\textsuperscript{11}, D. Ivanov\textsuperscript{11}, A. Mikhailov\textsuperscript{11}, S. Yi\textsuperscript{12}, E. Kawai\textsuperscript{13}, R. Haas\textsuperscript{14}

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\textsuperscript{2}GFZ German Research Centre for Geosciences, Potsdam, Germany, \textsuperscript{3}Technische Universität Berlin, Berlin, Germany
\textsuperscript{4}Technische Universität Wien, Vienna, Austria, \textsuperscript{5}National Astronomic Observatory, Beijing, China
\textsuperscript{6}Geoscience Australia, Canberra, Australia, \textsuperscript{7}University of Tasmania, Hobart, Australia,
\textsuperscript{8}Federal Office of Metrology and Surveying, Vienna, Austria,
\textsuperscript{9}South African Radio Astronomy Observatory, Krugersdorp, South Africa,
\textsuperscript{10}Shanghai Astronomical Observatory, Shanghai, China, \textsuperscript{11}Institute of Applied Astronomy, Saint Petersburg, Russia,
\textsuperscript{12}National Geographic Information Institute, Sejong, South Korea, \textsuperscript{13}NICT, Tokyo, Japan,
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GGOS
GLOBAL GEODETIC OBSERVING SYSTEM

Focus Area on Geodetic Space Weather Research

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² Institute of Physics and Meteorology, University of Hohenheim, Stuttgart, Germany
³ University of Cardiff, Cardiff, Wales

Space Weather

- Space weather is a very up-to-date and interdisciplinary field of research.
- It describes physical processes in space mainly caused by the Sun's radiation of energy.
- There are multiple manifestations of space weather, e.g., the variations of the Earth magnetic field, the polar lights in the northern and southern hemisphere as well as the variations of the Ionosphere and thermosphere (due to coupled processes), or the solar wind.
- The most extreme known space weather event happened at September 1, 1859 – the Carrington storm.
- Prominent recent events are the Halloween storm at October 28 – 30, 2003, the Bastille Day Event at July 14, 2000 or the St. Patrick's storm at March 17, 2015.
- The strength of these events, their impacts on modern society and the possibility of much stronger future events have brought several countries to recognize the necessity
  – of studying these impacts scientifically,
  – to establish space weather data centers and space weather services.

Geodetic Monitoring

- Figure 1 illustrates the structure of the Focus Area on Geodetic Space Weather Research (FA-GSWR) as a rhombus.
- Satellite Geodesy deals for a long time with the Ionosphere (PPP) and the thermosphere (POD).
- Thermosteric drag is the most important force acting on Low-Earth Orbiting (LEO) satellites and objects in the re-entry stage.
- Figure 2 gives an overview about the space-geodetic observation techniques which provide valuable information about the coupled thermosphere-ionosphere (TIC) system.
- The properties of the upper atmosphere have a strong impact on the execution of fundamental geodetic tasks.
- Geodesy has a long history and large experience in developing sophisticated analysis techniques and modelling approaches.

Objectives of the FA-GSWR

The main objectives are:
- Improvement of positioning and navigation by developing high-precision and high-resolution models of the electron density (PPP).
- Improvement of precise orbit determination by developing high-precision and high-resolution thermospheric drag models (POD).
- Study of the coupled processes between thermosphere and ionosphere (TIC).

New Joint Study Groups (JSG) and Joint Working Groups (JWG)

- JSG 1: Improved understanding of the coupled processes (implemented within IAG ICCT and joint with GGOS); chair person: Andreas Catabia Alcar
- JWG 1: Electron density modelling (joint with IAG Com. 4); chair person: Fabricio dos Santos Prol
- JWG 2: Thermosphere modelling including physics-based realisations of the coupled thermosphere-ionosphere processes (joint with IAG Com. 4); chair position: still vacant
- JWG 3: Improved understanding of space weather events and their monitoring by satellite missions (joint with IAG Com. 4); chair position still vacant

Essential Geodetic Variables (EGV)

Since main geodetic tasks are depending on the properties of the upper atmosphere, the electron density and the neutral density are the most important EGVs from the view of the FA-GSWR.
### Website of the Focus Area

#### Focus Areas

- Geohazards
- Sea Level Change, Variability and Forecasting
- Unified Height System

**Geodetic Space Weather Research**

- Chair: M. Schmidt (Germany)

#### GGOS Core Sites

- [Enlarge map](#)
### Solar signals

- EUV, X-ray radiation
- Solar flare
- Coronal Mass Ejection (CME)

### Propagation

- Electromagnetic wave propagation
- Solar Wind
- Solar Storm

### Interactions

- Geomagnetic Field
- Ionosphere
- Thermosphere
- Lower atmosphere

### Effects

- Ionization
- Heating
- Electron density variations
- Polar lights
Sun rotation: EUV vs. VTEC time series

- The two Morlet wavelet spectra show a very similar behaviour around the solar rotation period of 27.2753 days.
- At this frequency band the time delay between EUV and VTEC amounts around 19 hours, i.e. VTEC has a delay of around \( \frac{3}{4} \) of a day.
Planned activities for the period 2019-2023

In the following years the Focus Area will mainly work on the following three aspects:

- extensive **simulation studies** have to be performed in order to assess the impact of space weather on technical systems and to define – as a consequence – necessary actions in case of severe space weather events

- **development of ionosphere** and **thermosphere models** as stated above as **GGOS products** for direct application

- establishment of **recommendations for applications** of the models, e.g., in precise satellite orbit determination, collision analysis and re-entry computations.
Planned next Actions and Milestones 2019/2020

- An oral presentation about up-to-date topics of the FA-GSWR will be given at the AGU Fall Meeting 2019 at December 9, 2019 in San Francisco, USA in the GGOS Session: Incubation of new initiatives. The title of the presentation will be: GGOS Focus Area on Geodetic Space Weather Research – Observation Techniques and Modeling Approaches.

- The main topics of the FA-GSWR are again included in the description of the PICO Session G5.1: Ionosphere, thermosphere and space weather: monitoring and modelling of the EGU GA 2020. The main convener of this session will be Ehsan Forootan, co-conveners are Benedikt Soja and Michael Schmidt. Deadline for submitting abstracts will be January 15, 2020; the EGU GA 2020 will take place from May 3 to 9, 2020 in Vienna, Austria.

- Planning of a splinter meeting of the FA-GSWR during the EGU GA 2020 in Vienna.
Terms of Reference

IAG-GGOS FOCUS AREA 4: Geodetic Space Weather Research

Chair: Michael Schmidt (Germany)
Co-Chair: Klaus Börger (Germany)

Introduction
Space weather means today an own, very up-to-date and interdisciplinary field of research. It describes physical processes in space mainly caused by the Sun’s radiation of energy. The manifestations of space weather are multiple, for instance, the variations of the Earth’s magnetic field or the changing states of the upper atmosphere, in particular the ionosphere and the thermosphere.

The most extreme known space weather event happened at September 1, 1859 – the Carrington storm. Other prominent recent, but much weaker events have been the Halloween storm at October 28 – 30, 2003, or the St. Patrick’s storm at March 17, 2015. The strength of these events, their impacts on modern society and the possibility of much stronger future events have brought several countries such as US, UK, Japan, Canada and China to recognize the necessity of studying these impacts scientifically, of developing protection strategies and procedures and to establish space weather data centres and space weather services. As a consequence of these activities the FA4 was initiated. The following statements summarize the necessity of geodesy to cover scientific research on the coupled processes within the ionosphere and the thermosphere: Geodesy has

- to deal with the ionosphere, since the measurements of almost all space-geodetic observation techniques are depending on the properties of the ionosphere along the ray path of an electromagnetic wave between transmitter and receiver,
- to deal with the thermosphere, since the thermospheric drag is the most important deceleration effect on Low-Earth Orbiting (LEO) satellites and objects in the re-entry stage,
- a long history and large experience in developing and using sophisticated analysis techniques and modeling approaches.

To put the aforementioned issues in a nutshell, the main objectives of the FA4 are the

1. development of improved ionosphere models,
2. development of improved thermosphere models and
3. study of the coupled processes between the thermosphere and the ionosphere.

Objective (1) aims at the high-precision and the high-resolution (spatial and temporal) modelling of the electron density. This finally allows to compute a signal propagation delay, which will be used in many geodetic applications, in particular in positioning, navigation and timing (PNT). Moreover, it is also important for other techniques using electromagnetic waves, such as satellite- or radiocommunications. Concerning objective (2), satellite geodesy will obviously benefit when working on precise orbit determination (POD), but there are further technical matters like collision analysis or re-entry calculation, which will become more reliable when using high quality thermosphere models. Objective (3) links the first two objectives by introducing physical laws and principles such as continuity, energy and momentum equations and solving partial differential equations.

For a long time geodesists looked at the ionosphere just as a disturbing factor, whose impacts on electromagnetic signal propagation, i.e. the signal delay and the bending of the ray path, have to be corrected by applying ionospheric correction model of sufficient accuracy. On the other hand as already mentioned above the observation data of various geodetic measurement techniques that are influenced by the atmosphere in different ways provide valuable information on state and dynamics of the ionosphere. These are of great interest also for other disciplines such as meteorology. Now
Terms of References (extract)

• For a long time geodesists looked at the ionosphere just as a **disturbing factor**.

• On the other hand, the observation data of geodetic measurement techniques provide **valuable information** on **state** and **dynamics** of the ionosphere. These are of great interest also for other disciplines such as meteorology.

• For Geodetic Space Weather Research geodesy has to go another step forward by **introducing physics**. Interdisciplinary research has to start with **processes** and **events** on the Sun, continuing with the effects on the geosphere and, finally, considering the impact on (geodetic) applications and systems.

• Geodetic Space Weather Research is **fundamental research**, too, particularly to detect structures such as bubbles or special phenomena like electrojets.

• Summarizing, **geodetic space weather research** has to be based on
  a) the use and **combination** of all space geodetic observation methods,
  b) the use of **Sun observations**,
  c) **real-time** modelling,
  d) the development of deterministic and stochastic **forecast approaches**,
  e) **assimilation** strategies.
Terms of References (extract), cont.

Planned activities of the FA-GSWR are:

• extensive simulation studies which have to be performed in order to assess the impact of space weather on technical systems and to define – as a consequence – necessary actions in case of severe space weather events,

• the development of ionosphere and thermosphere models as stated above as GGOS products for direct application,

• the establishment of recommendations for applications of the models, e.g. in satellite orbit determination, collision analysis and re-entry computations,

• updates of the models as needed and based on the future improvements of modelling strategies, observing systems, etc., and

• the establishment of roadmaps for improving the models by including future satellite measurement systems and missions such as the Formosat-7/COSMIC-2 mission.