Preface

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Since today the measurements of space-geodetic observation techniques are an important source for ionosphere modeling the members of the International Association of Geodesy (IAG) Study Group 4.3.1. *Ionosphere Modeling and Analysis* decided to publish a special issue on

Geodetic Contributions to Ionosphere Research.

Generally, the ionosphere is defined as a thick shell of electrons and ions, which envelopes the Earth from about 60 to 1,200 km altitude. As a consequence of many years of research, the climatology of the ionosphere is quite well known today. Variations of the solar activity and emissions of plasma from the solar corona, however, change the conditions of the Sun–Earth environment and may disturb the ionospheric mean conditions dramatically. Modern sophisticated high technological systems for navigation and communication as well as the current and future space missions require the prediction of the space weather conditions. Ionospheric disturbances caused by massive solar flares can interfere with or even destroy telecommunication systems, Earth satellites and power grids on Earth. The application of high-resolution ionospheric models will provide, e.g., (near) real-time corrections and integrity information for aircraft navigation.

Because of the importance of the ionosphere and the variety of weather disturbances, various approaches to model the ionosphere including empirical/physical models, analytical and parametrized models, tomography models, and physics-based data assimilation models have been proposed and developed within the last decade.

Basically, the knowledge of the electron density is the key point in correcting electromagnetic measurements for ionospheric disturbances. Hence, for many disciplines of geosciences modeling, the spatial–temporal distribution of the electron density means a very important task at present and in the future. To benefit from different disciplines, a scientific link between geodesists, geophysicists and aeronomy experts seems necessary.

The observations of various space-geodetic techniques contain ionospheric information. The most important ones are the Global Navigation Satellite Systems (GNSS) such as the Global Positioning System (GPS). Within the last decade other space(-geodetic) techniques and/or missions provide huge data sets for ionosphere modeling, e.g., the Constellation Observing System of Meteorology, Ionosphere and Climate and Taiwan's Formosa Satellite Mission #3 (COSMIC/FORMOSAT #3), the Challenging Minisatellite Payload (CHAMP) or the Gravity Recovery and Climate Experiment (GRACE) as well as several altimetry missions, such as Envisat or Jason-1/2.

Due to the precision and the availability of the space-geodetic observation techniques, the importance of ionosphere models is twofold:

1. For many space-geodetic observing techniques, models have to be used to correct the effects caused by the ionosphere on the electromagnetic wave propagation; typical examples are the single frequency GNSS positioning, single frequency altimeter missions or real-time ambiguity resolution,
2. The poorly understood complex structure and the highly dynamic nature of the ionosphere require a significant improvement of the physical and empirical models on various space- and time-scales; a typical example is the Equatorial Anomaly.

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Whereas the first item, the more classical one, interpretes the ionosphere as an *error term* which has to be eliminated, the second item understands the ionosphere as the *target quantity* which shall be improved.

In this Special Issue, we treat the ionosphere in the sense of the second item, i.e. we aim at the determination of target functions of ionospheric parameters such as the electron density or the vertical total electron content (VTEC). The electron density depends on space and time, i.e. is a four-dimensional (4-D) function. VTEC, however, is defined on an infinitely thin spherical shell (around 450–500 km above the Earth's surface) depending on longitude, latitude and time; thus, VTEC means a 3-D function. The altogether nine articles of the Special Issue cover a broad spectrum of geodetic research activities in ionosphere modeling. Since geodetic observations are either geometrical or gravimetrical and not of geomagnetic or geophysical kind, the resulting ionosphere models are rather mathematical, i.e. empirical than physical. However, currently so-called physics-motivated model parts, such as the Chapman function for describing the height-dependency of the electron density distribution within the ionosphere, are introduced into the space- and time-dependent approaches for ionospheric target parameters.

In the first paper of the Special Issue, Hernández-Pajares et al. provide an overview on ionospheric research mainly based on GNSS observations. Various approaches such as voxel-based models, the spherical harmonic expansion, the Chapman profile or the Abel transform are studied. The authors not only discuss the calculation of the model parameters from space-geodetic observations, but also treat the reverse question, namely how today space geodesy benefits from the precise knowledge of the ionosphere.

For many decades, the International Reference Ionosphere (IRI) became the recommended standard for specifying ionospheric parameters. Bilitza et al. describe in their paper the latest version of IRI and discuss future improvements; special attention is paid to the electron density, because it is as already mentioned before the most relevant parameter for geodetic applications.

In general, a key role of modeling plays the validation process by means of external data from other observation techniques or models. In the paper of Lee et al. the authors describe how in situ measurements of the GRACE K-band ranging system and the CHAMP planar Langmuir probe can be used to validate different versions of IRI.

Besides the partitioning of ionosphere models into empirical and physical approaches, we distinguish between 4-D and 3-D models for the electron density and VTEC, respectively. Brunini et al. provide a 4-D approach for ingesting ground-

and space-based GNSS data into a global empirical electron density model by applying an adaptive and robust Kalman filter.

With the launch of the six satellites of the COSMIC/FORMOSAT #3 constellation mission in 2006, ionosphere models could be derived with an unprecedented accuracy. Since each satellite is equipped with a GPS occultation measurement system, the mission provides more than 2,000 globally distributed occultation measurements per day. Tsai et al. discuss the derivation of electron density profiles from radio occultation measurements based on a compensatory Abel inversion technique, which considers, e.g., large-scale horizontal gradients.

The official 3-D VTEC maps provided by the International GNSS Service (IGS) are derived from spherical harmonic expansions with a sampling interval of 2 h. Krankowski et al. discuss the question whether radio occultation profiles can be used for an additional IGS VTEC validation. For that purpose, comparisons between radio occultation profiles and ionosonde measurements have been evaluated.

An empirical ionosphere model covers the climatology as function of the spatial position, the diurnal and seasonal behaviour as well as the solar activity. Jakowski et al. derive a new global model with a simple and easily accessible representation of the spatio-temporal variations of VTEC under permanently varying solar activity. The few coefficients of the model are estimated from the VTEC maps of the Center for Orbit Determination in Europe (CODE).

As mentioned before, several data sources can be used to estimate the ionospheric model parameters. Consequently, parameter estimation strategies were recently derived for combining data from different space-geodetic techniques. Alizadeh et al. model VTEC by means of a spherical harmonic expansion and estimate the unknown coefficients by combining GNSS data, satellite altimetry and global VTEC data derived from COSMIC/FORMOSAT #3 occultation measurements.

Whereas the models described before are all global, regional models allow not only the study of specific phenomena like the Equatorial Anomaly, but also a higher spatial and temporal resolution if high resolution input data is available. Dettmering et al. present a regional model based on B-spline expansions. The model coefficients are again calculated by combining data from different space-geodetic techniques.

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