Guy Bomford Prize Lecture 2011

Atmospheric Effects in Space Geodesy

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The atmosphere is surrounding the solid Earth and the oceans, and with its variations at time scales from seconds to decades it opens up a wide field of challenging and fascinating tasks in space geodesy. The investigation of these atmospheric effects and the analysis of geodetic Very Long Baseline Interferometry (VLBI) observations have dominated my research in the past decade. Geodetic VLBI with its very simple geometric concept, the unbelievable observations of extragalactic radio sources billions of light years away, its fundamental advantages of linking the terrestrial and the celestial reference frame or providing the full set of Earth orientation parameters, is still as exciting to me as in 2000 when I first got in touch with this technique at the first General Meeting of the International VLBI Service for Geodesy and Astrometry in Kötzting, Germany. Moreover, VLBI with its high accuracy of single observations has always enabled me to test new models of atmospheric effects, like those for signal propagation, loading, or thermal deformation. I am eagerly looking forward to the new generation of VLBI observations (VLBI2010) that will allow the determination of positions with an accuracy of close to 1 mm in near real-time. And I am aware that this will pose new requirements on the models of atmospheric effects that are needed to correct the observations.

The thorough treatment of atmospheric effects is essential to reach an accuracy of 1 mm and 0.1 mm/year for positions and velocities of observing sites which is the overall goal of the Global Geodetic Observing System (GGOS) of the International Association of Geodesy (IAG) to detect Global Change like sea level rise, the melting of ice masses over Antarctica or Greenland, or hydrology. Atmospheric effects influence all three pillars of geodesy, i.e., figure, gravity field, and rotation of the Earth, and they should be treated consistently by GGOS. Moreover, the atmosphere affects signals from satellites and extragalactic radio sources, which has to be modelled properly or otherwise degrades the accuracy of geodetic parameters.

In terms of signal propagation the atmosphere is usually divided into the neutral atmosphere (up to about 100 km) and the ionosphere (50 to 1500 km) where the number of ions and free electrons is large enough to influence radio waves. The neutral atmosphere is non-dispersive for microwaves as, e.g., observed by the Global Navigation Satellite Systems (GNSS) or geodetic VLBI, and the delays therein are usually modelled as the product of zenith delays and mapping functions. Specifically, the a priori zenith hydrostatic delays are determined from the surface pressure at the site and mapped down to the elevation of the observation with the hydrostatic mapping functions, and the wet mapping functions are then used as partial derivatives to estimate the zenith wet delays. In recent years, the accuracy of mapping functions has been improved considerably by taking to data from numerical weather models, and even more improvement can be expected for ray-tracing strategies. However, VLBI simulations based on turbulence show that the troposphere will remain the limiting factor for the accuracy of space geodetic techniques. On the other hand, space geodetic observations at microwave frequencies contribute to meteorology and even climatology when converting the estimated zenith wet delays to the amount of water vapour in the troposphere in near real-time or for sites with long observation histories, respectively.

The ionosphere is a dispersive medium for microwaves, i.e., different frequencies suffer different group delays and phase advances. Consequently, by observing at two or more frequencies, the ionospheric delays can be determined or eliminated very precisely. These ionospheric delays can then be converted to values of Total Electron Content (TEC) and − together with TEC values from altimetry and occultation missions − expanded into global TEC maps which are highly beneficial for single frequency observations or as source of information about the ionosphere.

Atmospheric excitation of Earth rotation occurs at time scales from hours to decades, i.e., from thermally induced atmospheric tides at 12 and 24 hours, to atmospheric normal modes at about 10 days, to seasonal and in particular annual variations, to El Nino Southern Oscillations (ENSO). In combination with oceanic and hydrological excitation as well as with observed Earth rotation parameters, we can improve the understanding of the system Earth, in particular in combination with the degree-2 coefficients of the gravity field. Furthermore, predicted values of atmospheric excitation of the Earth rotation are highly beneficial for spacecraft navigation or the availability of GNSS orbits in real-time.

Alternating high and low pressure systems as well as seasonal variations not only influence the Earth rotation as described above (degree-2 terms), but they move the centre of mass of the solid Earth with respect to the centre of mass of the whole Earth including atmosphere and oceans (degree-1 terms), they change coefficients of higher degrees and orders of the gravity field of the Earth, and they deform the solid Earth by up to one or two centimetres. Furthermore, the algorithms are complicated by the indirect effect of atmospheric loading on the gravity field or by the oceanic response to the pressure variations, in particular at coastal regions. This shows the complexity of atmospheric effects in space geodesy, and underlines the importance that all these effects are treated in a consistent way to achieve the goals envisaged by GGOS.

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Furthermore, I want to thank all the colleagues worldwide for the excellent and friendly cooperation. Also, I would like to acknowledge the Austrian Weather Service (ZAMG) for granting me access to the data of the European Centre for Medium-Range Weather Forecasts (ECMWF), and the Austrian Science Fund (FWF) for supporting various projects.

Johannes Böhm

Young Authors Award

Citation for Elizabeth Petrie

The IAG Young Authors Award is granted at each IAG General or Scientific Assembly for important contributions of young authors in the Journal of Geodesy. In 2011 is was presented to Elizabeth Petrie, Newcastle University, UK, for her paper "A first look at the effects of ionospheric signal bending on a globally processed GPS network" published in Journal of Geodesy, Vol. 84, 491-499, 2010.

Elizabeth Petrie

The paper deals with the general area of higher order ionospheric effects in dual frequency GPS positioning. In particular, it considers for the first time on a global level the effect of presently unmodelled ionospheric signal bending. This effect remains after forming the ionosphere-free linear combination. Elizabeth Petrie shows that its implementation must be considered for most precise geodetic applications. Two things are particularly striking in the results. Firstly, the bending term appears to be almost entirely absorbed by the tropospheric zenith delay terms, hence biasing them, in particular at low latitudes. Secondly, even though this represents an important correction term, the exact approach for modelling the bending term remains unclear, especially for historic data where information on the peak electron content is less well established. The paper will therefore spark further studies on how best to resolve this dilemma.

As part of this project Liz Petrie conducted several IGS-style reprocessing in GAMIT, estimating ground station coordinates, satellite orbits and EOP, with different model options - a considerable undertaking. Fixing pre-computed IGS orbits may well have led to misleading results, so there is a demonstration to scientific rigour in her work.