Department für
Geodäsie und Geoinformation
Technische Universität Wien
Wiedner Hauptstraße 8-10/E120
1040 Wien

Univ.-Prof. Dr. Johannes Böhm
johannes.boehm@tuwien.ac.at
https://geo.tuwien.ac.at/

Wien, 30. Mai 2022

Prof. dr hab. inż. Krzysztof Sośnica
President of the Discipline Council for Civil Engineering and Transport
Institute of Geodesy and Geoinformatics
Wrocław University of Environmental and Life Sciences

Review the Ph.D. thesis of Mateusz Drożdżewski

Dear Prof. Sośnica,

Satellite Laser Ranging (SLR) plays a critical role for the determination of the terrestrial reference frame and the gravity field. SLR observations are highly accurate, not least because of their insensitivity to the ionosphere and the reduced impact by the wet part in the troposphere. Troposphere delay modeling in SLR analysis is typically based on the models by Mendes and Pavlis (MP), which require pressure and temperature as input parameters and ignore azimuthal asymmetry around the stations. However, with increasing demands on the accuracy of global geodetic reference frames, research is required and more sophisticated models need to be developed and tested. Thus, the work by Mateusz Drożdżewski comes at the right time.

In the peer-reviewed papers of the cumulative PhD thesis, Mateusz Drożdżewski provides an original solution to the limitations of the current models in SLR analysis, which pose a pending scientific problem. His approach is carried out in three steps (in analogy to the papers): first, Mateusz Drożdżewski estimates

UID ATU37675002, DVR 0005886

gradient parameters in SLR analysis finding reduction in the standard deviation of the observation residuals. Then, he applies troposphere delay models for SLR from GFZ Potsdam including parameters for the azimuthal asymmetry in SLR analysis yielding improved consistency with other space geodetic techniques. In the third step, he estimates tropospheric zenith delays along with other parameters, such as range biases at the station. This step is very innovative and has the potential of detecting and removing elevation-dependent errors, such as wrong pressure values at the sites. I consider this task to be highly important for the SLR community, because biased pressure values at the SLR stations have not been detected and corrected before. It is evident that Mateusz Drożdżewski has acquired excellent knowledge in the topic of the thesis and that he is able to independently conduct scientific work.

For his investigations, he uses state-of-the-art methods in geodetic analysis, such as parameter estimation based on least-squares methods, along with statistical approaches to describe errors and uncertainties. The discussion of the results is appropriate, and he outlines a clear path for future studies based on his achievements so far. I do agree with the conclusions and I would like to see this approach being used in standard SLR analysis by more groups. Furthermore, I would like to stress the scientific significance of the work and I do not see errors or drawbacks.

The dissertation is clearly structured. The main chapters are *Introduction*, *Methods and data processing scheme*, *Content of publications*, and *Conclusions and outlook*, next to the three peer-reviewed articles. The figures are instructive and the bibliography contains all references needed.

In conclusion, I recommend that the thesis is marked **positive (sufficient) with honors (very good)**.

In my opinion, the doctoral dissertation fulfils the requirements for a doctoral degree in particular under Article 13 of the Act of March 14, 2003 Ustawa o stopniach naukowych i tytule naukowym oraz o stopniach i tytule w zakresie sztuki (Dz.U. 2003 Nr 65 poz. 595 z późn. zm.).

Reading the papers and the PhD thesis, several questions came to my mind, which I would like to summarize here:

- Mapping functions in space geodesy are developed for observations to natural and artificial sources, such as quasars, GNSS satellites or LAGEOS. I wonder whether they are also applicable for observations to low earth orbiting satellites or whether additional corrections are necessary to account

UID ATU37675002, DVR 0005886

for the low altitudes. More specifically, I refer to the difference between geometric and outgoing elevation angle varying with the height of the satellite. Does the Bernese software package consider this effect?

- I find the estimation of zenith delays from SLR observations very interesting and highly useful. Clearly, this approach provides the possibility to detect and correct errors in the pressure measurements at the stations. In case the coefficient (related to k1) in Equation 2.26 is not correct, does the estimation of zenith delays mitigate or remove those deficiencies? In other words: Could you estimate tropospheric zenith delays without using a priori zenith delays, provided that there are enough observations within a certain time interval? Would those total zenith delays then be the same?

- Related to the question above: How sensitive is SLR to changes in values of CO_2? Is it important to use the correct value which has been changing over the past forty years?

- Mateusz Drożdżewski estimates weekly zenith delays. How about going to longer intervals, does this make sense? On the other hand, the pressure at station Graz seems to drift from 2015 onwards, thus longer intervals might not make sense. Could you please comment on that?

Thank you for considering me as a reviewer for the PhD thesis by Mateusz Drożdżewski.

With kind regards,

TECHNISCHE UNIVERSITÄT WIEN
Department für Geodäsie und Geoinformation
Wiedner Hauptstraße 8-10/E120-04
1040 Wien, Austria

Univ.-Prof. Johannes Böhm

UID ATU37675002, DVR 0005886

TECHNISCHE UNIVERSITÄT WIEN
Department für Geodäsie und Geoinformation
Wiedner Hauptstraße 8-10/E120-04
1040 Wien, Austria