External Assessment of the PhD dissertation entitled "Use of GNSS ground-based and satellite observations for tropospheric refractivity investigation" by Ms Elzbieta Lasota

Professor Dr Felix Norman Teferle
Geodesy and Geospatial Engineering
Department of Engineering
University of Luxembourg
6, rue Richard Coudenhove-Kalergi
L-1359 Luxembourg
G.-D. of Luxembourg

In the following I provide an external assessment of the PhD dissertation entitled "Use of GNSS ground-based and satellite observations for tropospheric refractivity investigation" by Ms Elzbieta Lasota, following Article 14 of the Act of 14 March 2003. In my assessment I follow broadly the suggested points for evaluation in their given order. I also acknowledge the fact that the candidate has already published the majority of her manuscripts and that these have undergone the peer-review process of the various journals, i.e., the contribution to new knowledge by a PhD candidate has already been proven by passing through these reviews.

Assessment of the layout

The PhD dissertation of Ms Lasota is of a cumulative type, i.e., a collection of five papers of which four have been published in peer-reviewed journals and one being in review, with some chapters acting as an umbrella to the thesis. Hence in this case the dissertation contains three chapters, Introduction, Content of Publications and Conclusions before the five published papers are listed in an appendix. Important here to mention is that a declaration and statements of authorship is also provided, indicating the PhD candidate as first author and as having performed at least 50% of the work in all papers. The fifth paper is a single author paper, which I find unusual for an average PhD candidate when considering the amount of work involved in top-level research today. Nevertheless, this might be an indication of a hardworking and excellent candidate. On the positive side is, however, the fact that she has managed to already publish four papers during her PhD research over approximately 4 years.

The chapter Introduction prepares the reader for the topics explored in the published papers. It starts by describing the atmosphere in general before switching to severe weather events, atmospheric refractivity, ground-based GNSS remote sensing, GNSS radio occultation and alternative modeling GNSS retrievals using machine learning methods. With a total of 28 pages personally I find this rather short and could be expanded. I understand that the argument may be that each paper provides further introduction to the topic.

The second chapter summarizes the content of the publications, giving a brief introduction, summary and then some conclusions. It is here that a discussion is attempted but it is split into paper-specific discussions rather than one discussion containing all and linking all papers as well as their topics. Also, a discussion should link the current results with previously published results and this could have been stronger. Again, this is more a

personal preference and depends largely on practices at the Institute of Geodesy and Geoinformatics.

The third chapter just briefly concludes the work and makes suggestions for future work. This is followed by the appendices containing the full papers published by the PhD candidate and her co-authors.

Overall, the layout for a cumulative thesis seems acceptable. I note that I find it unusual that there is no discussion chapter which links the results of the papers and of previous publications for a critical analysis. This is partly present in the manuscripts but could be stronger in Chapter 2.

Bibliography

The bibliography is essentially a references list as all of the references are cited in the text. It does contain a good spread of important references from highly ranked journals. Nevertheless, it also feels efficient if not to say a little short. There are certainly other references from good journals that could have been included based on their relevance to, e.g., severe weather or assimilation of GNSS ZTDs in numerical weather models.

As reviewer of the dissertation, I allow myself to suggest two very relevant references from my research group:
- Mahfouf, J.-F., F. Ahmed, P. Moll and F. N. Teferle (2015). "Assimilation of zenith total delays in the AROME France convective scale model: a recent assessment." Tellus A **67**: 26106.
- Ejigu, Y. G., F. N. Teferle, A. Klos, B. Janusz and A. Hunegnaw (2021). "Monitoring and prediction of hurricane tracks using GPS tropospheric products." GPS Solutions **25**(2): 76.

The first could be added in the first line on page 16 when mentioning GNSS ZTD to help and improve NWPs. But more so the latter is of high relevance and directly links to Section 1.2.1. To my knowledge it is one of very few papers attempting to predict the path of TCs using ZTDs.

I note an unusual formatting of the Harvard style list of references with names coming in front of the main author's surname. This may be something commonly in use at the Institute of Geodesy and Geoinformatics but is not the usual way within the relevant literature. I therefore suggest to change from, e.g., J. T. Allen, I. M. Giammanco, …, to Allen, J. T., I. M. Giammanco, … This can be easily performed with modern referencing software both in Word or LaTeX.

I also note to check the capitalization of abbreviations in the references. There are some that are given in small letters. I find this a side effect of using reference management software. Here, the individual record should be checked for correctness.

Methods used in the analysis

The dissertation is a cumulative thesis and consists of five manuscripts published and in review. Therefore, there has already been a check of the methods applied during each of the journal review processes. With the journals being ranked Q1, Q1-Q2 or Q2 by an

international journal ranking, all are of leading status and publication in these is highly valued and follows their stringent peer-review process.

I fully agree with the employed methodologies in the five manuscripts. They are highly adequate, often state-of-the-art to innovative and have been applied to specific tasks. Noteworthy here are the attempts of the candidate in applying the machine learning methods ANN and RF to problems in the analysis of RO profiles. With Ms Lasota being the sole author of this manuscript, it would be suggested that she has employed her understanding of the topic well to these new methods. Although it is indicated that she has been a user of relevant ML Python libraries, her work here is highly recommendable due to the application of these new methods to long-standing problems in geodesy and atmospheric science.

Discussion of the results

Each paper contains a discussion of the results. Chapter 2 summarizes the papers and their results. There are also paper-specific conclusions and discussions, separately for each manuscript. While this provides structure, it also, let's say mentally separates one discussion from the next one and maybe failing to create a unified picture. Personally, I feel that this could have been done better by bringing the discussions into one section where the findings are discussed more thematically rather than associated to a particular paper. This is my personal opinion and I am not sure if at this stage the assessment process allows for such extra work or corrections.

Contrary to the papers there is less of a page limit issue with a dissertation. Therefore, the discussion can be widened to beyond that of the published manuscripts. This is particularly relevant for cumulative theses. Also, a discussion is a critical reflection of one's results in relation to previously published literature. Despite the results being at the forefront of science it is always possible to enrich a discussion by referring to related results achieved by other teams before. If possible, the candidate should carefully review this and see if an enrichment with other references than those in the manuscripts would make an improvement.

Potential applications of the obtained results

This PhD dissertation deals to a large degree with the prediction of severe weather and aims at improving various related methods in relation to GNSS. Climate change is believed to both increase the frequency and intensity of severe weather events such as tropical cyclones. It is therefore a must towards a better understanding of these events and to be able to better their predictions. All the methods and results presented ultimately improve the application of ground- and space-based GNSS measurements to allow a better sensing of the troposphere, the layer in which weather is happening. In this sense, once the here developed advanced methods are applied routinely in numerical weather prediction models or in the analysis of the various data, especially RO profiles, before their assimilation into models, the ability to forecast weather, in particular, severe weather events, will improve.

Scientific significance of the results

In line with the previous point "Potential applications of the obtained results", the significance of the results lies in their potential to improve weather forecasts, and here in particular of severe weather events, such as tropical cyclones. Large TCs have the potential to enormous downpours, strong winds and flooding along coastlines and riverbanks. Large TCs have catastrophic consequences involving destruction of built assets, damages to business and displacement of people or loss of life. Improving our ability to monitor, track and predict such events is of importance to human society.

Although large TCs mainly occur in the tropical to sub-tropical regions adjacent to warm oceans, smaller events, i.e., thunderstorms, do occur also in the mid-latitudes and can have disastrous outcomes as was the case in central Europe in July 2021. The same methods and data will also help in improving our understanding of these.

<u>Errors or drawbacks</u>

There are no real scientific errors present in this work. As the manuscripts have been published, I can really only comment on some statements in Chapters 1-3. For example, I disagree with the statement on page 38 "TCs have been of second importance in ground-based GNSS studies and current applications have been limited only to IWV analysis during TC transition (Liou and Huang, 2000)". By listing only this reference, firstly, the author suggests that no studies on this topic have been carried out during the past 22 years and, secondly, nothing was done to employ transitional IWV changes. The above suggested manuscript by Ejigu et al (2021) demonstrated that using these IWV estimates the tracking and prediction of the path of a hurricane using spaghetti analysis. This should be corrected in the dissertation although the related paper of Ms Lasota was already published in 2019, i.e. before the paper of Ejigu et al. Therefore, a further question arises as to whether the author is a aware of more recent research concerning her earlier publications in 2018 (A.1), 2019 (A.2) and 2020 (A.3). Although the manuscripts cannot be amended with these, she should include these recent works in her dissertation part, especially in the discussion of her papers.

For grammar errors I have included a scan of the pages 1-66 with my annotations. I was a bit surprised to find such a large number of mistakes, suggesting that this part was not well proof read.

<u>Final conclusion</u>

I find it highly recommendable that the candidate Ms Lasota has managed to publish four papers and get a fifth paper into review during her PhD research. I assume this is a 4-5 year degree at Wroclaw University of Environmental and Life Sciences. In all cases the journals are highly ranked (Q1-Q2) and publications go through a full peer-review process. This demonstrates her aptitude to research and scientific work. It would also support the thought of Ms Lasota being an efficient and hardworking team member of Prof Rohm and Prof Guerova. Based on this alone I would have no issue for a positive recommendation with honors.

However, the actual dissertation part (Chapters 1-3, pages 1-68) is less convincing for a positive recommendation with honors. As mentioned, I feel that there could be more emphasis on the discussion of all paper's results in a unified manner not separately as this was already done in each paper. It also seems that more recent publications, i.e., those after the publications of Ms Lasota, are missing and should definitely be part of the dissertation parts, Chapters 1-3, especially the discussions. It would not make her scientific contributions any less important but potentially demonstrate that some of her earlier work in 2018 and 2019 has already influenced other research, underlining her scientific impact.

I assume that the dissertation presented is in a near final stage and that more or less only cosmetic changes can be done now. I would strongly recommend to check the English in the dissertation part. I have provided an annotated PDF of this with suggested corrections. By no means do I claim them to be complete but it seems that the candidate has a weakness in the use of the definite article "the". I would strongly recommend the correction of such grammatical mistakes.

In my opinion, the doctoral dissertation fulfills 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 pózn. Zm.). In view of possible corrections to the dissertation parts and based on Ms Lasota's five peer-reviewed publications in highly ranked journals I agree to recommend **"positive with honors"**.

Felix Norman Teferle