Geosci. Instrum. Method. Data Syst. Discuss., 5, C297–C306, 2016
www.geosci-instrum-method-data-syst-discuss.net/5/C297/2016/

Geoscientific Instrumentation Methods and Data Systems Discussions
Open Access

Interactive comment on "Sodankylä ionospheric tomography dataset 2003–2014" *by* J. Norberg et al.

J. Norberg et al.

johannes.norberg@fmi.fi

Received and published: 22 March 2016

Authors thank the associate editor and anonymous referees for giving valuable comments on the manuscript. The referee comments are listed here with bold text type. After each comment authors' response is given with normal text type.

My general comment is that Section 2 could be made longer, to include a more detailed description of the conception of the data set. Also the discrepancy with IRI results requires more explanation.

My specific comments below mainly concern the explanations. Furthermore I have a few editorial comments.

1 Comments

Page 2, line 25: The phase shift is proportional to the *integrated* number density.

Thank you for pointing this out.

Page 3, line 2: Please provide some references which explain why the problem is ill-posed, and what can be done about it. Maybe also use some more words to explain it in this paper.

We could change the sentence to: "As the measurement geometry cannot provide horizontal ray directions, the information provided on vertical structure is poor. This results in a limited angle tomography inverse problem, which requires some regularization scheme to stabilize the problem."

This is the main problem in tomography and all the referred articles consider this with varying terminology.

Page 4, line 9-10: Up to which latitude can GPS signals be used for direct mea-

surements of the ionosphere? It seems strange that it's not possible in Finland, since they have been used for ionospheric tomography in Finland, e.g. by van de Kamp, Annales Geophysicae, 31, 75-89, 2013, doi:10.5194/angeo-31-75-2013. So please nuance this argument more.

We might have been too harsh here. It is of course possible, but compared to LEO satellites, it has some limitations as all measurement rays are directed southward.

These methods are well-established, but due to the relatively low inclination of $55°$, they do not measure directly the high-latitude ionosphere and provide information essentially southwards from the receiver sites. Therefore, when studying e.g. Traveling Ionospheric Disturbances at high latitudes, the wave structures can be distinguished in instantaneous snapshots but following their propagation is difficult (Van De Kamp et al., 2014).

Page 4, line 15: What is "global ocean"?

We took this term from the cited article. It could be changed to " but only at areas over ocean."

Page 4, line 23: Please provide more info on these "indirect measurements" of hmF2.

"The hmF2 values are derived emprically using routinely scaled ionograms, obtained from ionosondes. For detailed information of the hmF2 estimation in Sodankylä Geophysical Observatory 1957–2014, see Roininen et al. (2015)"

Page 5, section 2: Please provide more information. For instance, some specific questions: How many COSMOS satellites are there / are you using? What is the time resolution of the data? Is VTEC resolved only for the locations of the stations? (The text seems to suggest this.) It should be possible to do it also for the locations inbetween. Are the data publicly available anywhere?

We could add: "The ionospheric tomography reconstructions provided by SGO are solved in two-dimensional latitude-altitude domain. The orbital altitude of COSMOS satellites is approximately 1000 km and one such overflight takes approximately 10 minutes. The measurement geometry then resembles the schematic plot in Fig. 2. During the years 2003–2014 the number of operational satellites has been varying between 3 and 7. Most of the time 4 satellites have been providing transmissions."

And in the later paragraph "Limiting the original data of 66 000 overflights with these criteria results with a data set of around 10 000 tomographic reconstructions, on average little over two overflights per day. "

The SGO's tomographic data set consists of 2D electron density reconstructions. From the reconstructions the VTEC can be integrated for the complete domain. It would be possible to do the comparison with IRI for vertical electron density profiles, or even complete 2D reconstructions. The idea for this article was to promote the data set with a straightforward study for its long time behaviour. Hence, we have concentrated on VTEC measurements over the stations and most importantly only one station, namely Kokkola.

Page 6, line 1-2: "In Fig. 2 the number of satellite overflights are plotted against satellite elevation." Please move this sentence to before your choice

of 60° minimum elevation (previous page), because figure 2 still contains all elevations.

Thank you for pointing this out.

Page 6, line 5-11: The part "The orbital altitude of COSMOS satellites ... start from June 2004." contains information about the geometry of the setup that would useful to know earlier in this section. Please move it, for instance, to after the first sentence of the second paragraph of this section (after ?... is tilted slightly eastwards?).

Thank you for pointing this out.

Page 6, line 12-13: Please provide more information on how the IRI data were integrated. Vertical, or along the signal paths? Between which heights were they integrated? Figure 9 (see below) seems to suggest you calculated the IRI results along the satellite paths. But since you are looking at VTEC at a certain location, it would be better not to include in the IRI results the same artefacts of the motion of the satellites as you have in the VTEC data. If you would have IRI results in a fixed location, a comparison with your measurements would enable you to verify that this artefact is negligible.

We could elaborate: "The IRI-2012 VTEC values are integrated from the model results vertically between the altitudes 0 -1000 km at the receiver locations, similarly to the tomographic VTEC."

Page 6, line 17: Please give the exact definition of "summer" "winter" and "equinox" used here. Which start dates and end dates exactly?

We would like to add " Winter is defined as one third of a year centred around the winter solstice. Summer starts one third of a year after winter solstice and lasts for one third of a year. Everything else is defined as Equinox."

Page 7, line 20: Can you calculate how a period of 105 minutes leads to the shift in daily times as observed in figure 9?

In one period of 105 minutes, the projected satellite orbit is shifted approx. 26.25° westwards. When a satellite is first observed, the next time the satellite is in the same longitudinal vicinity at the same latitude is first after 13 orbits and 22 h 45 min, when satellite is approximately 18.75° eastwards from the original position. Then, after one more orbit, so in total 14 orbits and 24 h 30 min, the satellite trajectory will be shifted approximately 7.5° westwards from the previous day. This, or some of this information can be added to text, if recommended.

Page 7, line 23: Please provide some thoughts on the cause of the 40% discrepancy, in particular whether you think IRI is overestimating or the tomography results are underestimating.

We would like to elaborate on this discrepancy as follows:

"The overestimation of high latitude Ne has been widely reported for different versions of IRI model. Zhang et al. (2006) reported that IRI-2001 overestimates Ne at the peak altitude and above, especially in winter time compared to ISR measurements.

One of the main improvements for IRI-2007 was the topside Ne modeling (Bilitza & Reinisch 2008). Lühr and Xiong (2010) compared the IRI-2007 model results to orbital averages of CHAMP and GRACE satellite measurements from 2000-2009, with the satellite height range from 300 to 500 km. Especially during the solar minimum period the overestimation was up to 60%. The overestimation was concentrated on the lower latitudes, but in Xiong et al. 2011 a 20% overestimation also for trough area was reported. Xiong et al. (2011) utilized CHAMP and GRACE satellite based Ne measurements from 2005 to 2010.

These studies then suggest that despite the development, the modelling of F peak and topside Ne still carries some problems. The improvements for IRI-2012 were made for the thickness and the shape of the bottom-side F2 layer, as well as for the description of storm effects in the auroral E region (Bilitza et al. 2014).

We have found it difficult to find out a comprehensive account on the different measurements used in the IRI model. In Altadill et al. (2008) a network of 27 ionosondes were used for the enhanced bottom-side modelling of Ne. The closest ionosonde measurements to Fennoscandia in the network were from Chilton, UK. In all, the network comprises two high latitude ionosondes, both located in Greenland.

The Sodankylä tomographic set-up employs numerous measurements from the high-latitude area which is poorly populated by ionosonde stations. However, ionospheric tomographic inversion is well-known to be an unstable inverse problem, and its performance, especially in small scale details in vertical structures, can be argued. The Bayesian approach (Markkanen et al. 1995.) utilized here assumes zero electron density a priori, and variations from zero background are then controlled with a Chapman profile shaped standard deviation. The approach is hence more likely to underestimate than overestimate the electron densities. Then again, as mentioned in the Introduction of our manuscript, improved inversion methods for this measurement

concept are under development. The upgrading work includes also better methods to estimate the quality of inversion results. Therefore, we believe that beacon-based tomography could be used more intensively in future research, perhaps even in IRI-validation and upgrading."

Page 19, figure 9: Why do the IRI data contain the same periodicity as the tomography data? Is it because you are calculating VTEC along the satellite paths?

The VTEC is integrated from IRI model with the same time resolution than the tomographic VTEC data, i.e. from every suitable overflight we have taken the tomographic reconstruction and integrated the VTECs over each station. Then, the same integral is calculated from the IRI model results from the same location at the same time.

Page 19, figure 9: In the lower graph, a relative difference (i.e. absolute difference divided by one of the two) would be more useful than the absolute difference, to evaluate the performance.

When compared to tomographic results, some individual relative differences become very large making the range cumbersome for visual presentation.

2 Editorial comments

Several places: The words "descending" and "ascending" are misleading; the satellites are not really going down or up. Please replace these terms by

"southward" and "northward" respectively.

We have understood that this would be standard terminology with satellite orbits. We could add in the text "descending, i.e. southward" etc. However, we can of course change the words, if they are considered more explicit in this context.

Page 2, line 9: "three-to-five" → "three to five"

Page 3, line 7: "development, similar" → "development, a similar" Page 4, line 2: "stabile" → "stable"

page 4, line 20: "in data" → "in the data"

Please rearrange the figures in the order in which the are referred to. This means moving figure 2 to after figure 4 (and of course, change their numbers accordingly).

Thank you for pointing these out.

Page 5, line 16: "the direction is tilted eastwards" is not really clear. I would suggest to write: "eastwards from south".

We mean here the direction of the satellite progress that is all the time slightly eastwards. It can be of course modified.

Page 5, line 20: "As in" → "Since in"

Page 7, line 15: remove "the differences between" ("indistinguishable" means that differences are invisible.)

Page 7, line 28: "11-13 MLT" is inconsistent with the caption of Figure 10: "11-14 MLT".

Page 8, line 14: "higher of" → "higher than"

Page 8, line 21: "consists only" → "consists of only"

Thank you for pointing these out.

Interactive comment on Geosci. Instrum. Method. Data Syst. Discuss., 5, 385, 2015.