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Interactive Comment

Interactive comment on "Using sparse regularization for multiresolution tomography of the ionosphere" *by* T. Panicciari et al.

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We thank the reviewer for the time taken to review the paper and for their helpful comments. We have replied to the optional comments/questions below.

1 - Question. In Sec 2.4, the authors made a comparison between the l1 and l2 norm, however, which is the choice of this work?

1 - Answer. We compared the l_1 regularization with the more standard (in computerized ionospheric tomography) l_2. We included the comment in Sec. 2.4:"[...] Different regularizations exist to stabilize Eq. (15) and make the solution unique and physically meaningful. In this section the two regularizations based on the l_1 and l_2 norm, which are both used for the reconstructions in Sec. 3.1, will be described. [. . .] The main goal

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of regularization is finding the best representation of the ionosphere that matches the observations and at the same time obviates the lack of data we usually face (e.g. in the oceans between continents). [. . .] The l_1 and l_2 regularizations used in this work both aim to create a sufficiently detailed solution by maintaining as much information as possible from the observations .[. . .]".

2 - Question. What is new in this paper?

2 - Answer. Although wavelets have been previously used in ionospheric tomography, the l_1 regularization has not been applied for the ionosphere yet. We expanded the comment in Sec. 1 to:"[...] Sparse regularization techniques which minimize the l_1 norm have not been used before in ionospheric tomography and this is what we believe is the first implementation in CIT. The sparse minimization should allow us to exploit more effectively the potential of wavelets to produce a compact reconstruction of the ionosphere. [. . .]"

3 - Question. Did the authors make any comparisons between different P(n)?

3 - Answer. We used P(x) in order to explicitly describe that the regularization acts on x instead of n. This is especially important for the l_1 regularization to exploit the compactness of wavelets. Such compactness cannot be exploited with the l_1 norm of the n vector. However we included the comment in Sec. 2.3: "[...] The regularization term P(x) reminds us that the x coefficients are considered regularised instead of the electron density values n. [. . .]"

4 - Question. Page 7, Line 13, what are N1 and N2 please clarify.

4 - Answer. Thank you, this was actually omitted by mistake. We included in Sec. 2.1: "[...] and N_1 and N_2 are the integer ambiguities in the phase cycle measurements for the frequencies L1 and L2 respectively. [. . .]"

5 - Question. There is also a typo in Line 14 for n1 and n2.

5 - Answer. Thank you. We corrected the error in Eq. (6): "[...] $(\lambda_1 N_1 - \lambda_2 N_2)$ [...]"

NPGD

2, C314–C317, 2015

Interactive Comment

6 - Question. Page 35 and 36, there are significant differences between the Model-aided reconstruction fig10 and norm based reconstruction. Does that mean both are correct, what is advantage and disadvantage of two method? Please add more discussions in Sec.3.1?

6 - Answer. We have realised that there was not enough description in this section. The Model-aided reconstruction relies on a priori information about the state of the ionosphere. In general this is obtained with a empirical or first principle model. In the reconstruction in Sec. 3.1 there was not a priori information that could aid the inversion. We included more comments in Sec. 3.4 where we discussed more about the Model-aided reconstruction (we think the reviewer meant Sec. 3.4 instead of 3.1, but please let us know if it was otherwise) in Sec. 3.4:

"[...] We implemented a model-aided inversion by imaging the residual after removing from the observations a background model of the ionosphere. This is called Three-Dimensional Variational (3DVar) data assimilation and assumes the knowledge of a priori information about the state of the ionosphere. This is generally obtained with an empirical model (like IRI2012) or a first principle physics model. For the sake of this paper we wanted to test the algorithms with Eq. (18) and Eq. (20) under these conditions. Therefore, we considered there was almost perfect knowledge of the ionosphere, i.e. we set the background model n_0 to IRI2012 (without the added structures) and considered the residual $\delta\mathbf{n}$

$\delta\mathbf{n} = \delta\mathbf{n} - \mathbf{n}_0$ (22)

This residual is associated with a residual δz in the measurements z calculated as

$\delta\mathbf{z} = \delta\mathbf{z} - \mathbf{A}\mathbf{n}_0$ (23)

Therefore, the problem in Eq. (15) becomes

$F(\delta\mathbf{x}) = \|\delta\mathbf{z} - \mathbf{A}\mathbf{K}\delta\mathbf{x}\|^2_{\mathbf{C}} + \alpha P(\delta\mathbf{x})$ (24)

where $\delta\mathbf{x} = \mathbf{K}^{-1}\delta\mathbf{n}$. Hence, the inverse problem is applied to Eq. (24), which will

NPGD

2, C314–C317, 2015

calculate the residual information that the a-priori model could not reproduce (in this case the structures added to IRI2012). The final reconstruction is obtained by summing the estimated $\delta\mathbf{n}$ to the background model $\mathbf{n}_0$. To make the problem more difficult we also added the noise term into the data z as in the previous section. [. . .] This scenario can be considered as the best case, where we had background knowledge of the ionosphere, in comparison with the worst case of the previous subsection where such knowledge was lacking. [. . .]".

7 - Question. The authors should add some information about how the simulations is done, especially how Eq. (18) and (20) is numerically solved. 7 - Answer. Thank you. For clarity we included in Sec. 2.4: "[...] In the implementation of this paper P is set to the identity matrix and the minimization of Eq. (15) with Eq. (18) is solved with the LU decomposition similarly to the framework in (Mitchell and Spencer, 2003). [. . .]" and "[. . .] The minimization of Eq. (15) with Eq. (20) is implemented with the Fast Iterative Shrinkage-Thresholding Algorithm (FISTA, see (Beck and Teboulle, 2009). [. . .]".

Interactive comment on Nonlin. Processes Geophys. Discuss., 2, 537, 2015.