

Authors' response letter to the reviewers' comments

Title: "GNSS-Reflectometry and Remote Sensing of Soil Moisture Content: A review of measurement techniques, retrieval methods and approaches, and applications"

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27 January, 2020

Dear Editor,

We really appreciated the efforts done by Reviewers and their constructive comments and valuable suggestions. In the followings, comments and suggestions of the 4 reviewers as well as our replies to them are given one by one. We quote in black color the reviewers' comments and in red color our answers.

Reviewer #1:

This is a review paper of the remote sensing techniques to measure soil moisture content (SMC). Three different techniques to do so have been reviewed in depth. My comments are as follows:

We are very much thankful for your valuable suggestions and comments which helped us to improve the manuscript. In the followings, our answers and clarifications are given according to your comments.

(1) It is established early on in the Introduction section that active and passive microwave sensing techniques are disadvantageous compared to the newer GNSS Reflectometry technique. Therefore, it is unclear to me why the authors have chosen to provide an in depth review of these techniques. After reading the introduction section, I was expecting to read mostly about GNSS-R.

We have reduced this part as suggested. In the manuscript, we want to introduce and compare between active/passive and GNSS-R techniques and their respective inversions methods. Therefore, we consider necessary to include at least some review of active/passive.

(2) GNSS-R has been explained in good details in Section 3. However, the structure of this section needs to be greatly improved. Having too many bullet points and sub-sections make it a bit difficult to read.

This section is structured in subsections to clearly present all the available options. We have reduced the bullets and subsections as much as possible.

(3) Section 4, which talks about the applications, feels rushed and does not go into sufficient details. Moreover, subsections 4.1 and 4.4 do not have any citations (a bit strange for a review paper). My suggestion to the authors would be to remove (or significantly reduce) Section 2 and expand Section 4 instead.

The section 4 has been expanded and section 2 has been reduced. More citations have been included in sections 4.1 and 4.2.

Reviewer #2:

The paper provides a review of the state-of-art about the GNSS-R Reflectometry for soil moisture estimation. I've found the paper interesting and well organized. But some revisions should be performed before considering the manuscript for publication in this journal. A list of key points,

which I suggest to elaborate more, is given below.

Thank you very much for your positive comments and suggestions concerning the publication of this manuscript. We read your comments and suggestions, and we believe that they certainly helped us to further improve our manuscript. These are answered and applied as follows:

I would talk about signals of opportunity instead of opportunistic signals, just because it looks more used keyword.

Now we employ “Signals of opportunity” instead “opportunistic signals”.

When talking about the resolution of passive systems (lines 68-69), I would also make reference to SMAP and SMOS, which have a normal resolution equal to about 30 km.

We have included spatial resolution of SMAP and SMOS, ~ 30 km and ~ 35 -50 km respectively.

I am not sure the permittivity of a dry soil is about 6, maybe about 3 is better? Please double check

Water permittivity is $\epsilon \approx 80$, and dry soil $\epsilon \approx 4$.

line 143: please use R and J as subscript for ϵ . 'r' would make confusion with 'relative'

Done, $\epsilon = \epsilon_R + i \cdot \epsilon_J$

line 167: add a space after dot and always insert a space after a comma, please double check all the document

The whole document has been checked. Thank you very much. We apologize for these errors, there are some problems with Microsoft word between old versions and new ones.

line 181: try to start a new section in a new page. Double check all the document, a well-formatted manuscript can make easier the Reviewer's work.

Done, new section on new page.

line 207: no hyphen in L-band. Please double check all the document

Done

line 208: I am not sure 10 m is a good approximation for the active system. It looks too good, to my understanding

We have revised the range, 100 m of resolution for active system (with reference) instead.

section 2.2.1: I would not list the formulas for the considered modeling cases. I am not sure they add insight in this framework. The reader could be simply redirected to the best sources. I would talk about the role of the soil anisotropy to make more complete the review. Some recent investigations have been done also considering small-slope approximation modeling

The formulas in this section are removed, and the sources are written. We talk about soil anisotropy, another factor that influences SMC measurement, for both active microwave and GNSS-R. The example is given in the manuscript, and it was done using first-order small slope approximation. Manuscript has been updated.

line 371-373: I would add some references I would replace refs. 108 and 109 with some papers. They are more important and more focused with respect to a phd thesis. In addition, the paper will be always available somewhere.

The references 106 and 109 are from the thesis instead 108 and 109. They have been replaced by papers. Additional references have been added.

section 3.1.2: the role and the ratio of the coherent/incoherent contribution have been the object recent modeling approaches. They can also include the sphericity of the wavefront. Please consider to revise the most recent literature to make the review more complete and updated

Coherent and incoherent role in bistatic scattering has been discussed in this section. Their proportions depend on the surface properties. Soil anisotropy is another factor that influences the coherent and incoherent components, and the spatial resolution depends on their ratio (coherent-to-incoherent). We have updated the manuscript.

The main challenges about the possibility of a high temporal and spatial resolution monitoring of the soil moisture by means of GNSS-R would require the understanding of some issues related to the fluctuation (somehow also defined decorrelation) of the signals and about the achievable spatial resolution, which is related to the understanding of the scattering phenomenology. If possible, I would give more emphasis to these aspects.

Coherent and incoherent proportions in scattering depend on surface properties (permittivity, roughness...etc). Topography is another factor on which depend their proportions. In turn, the spatial resolution which depends on the coherent-to-incoherent ratio, is directly related to those parameters. This is the case of CYGNSS-R data which depend mostly on topography. We have updated the manuscript.

Reviewer #3:

This manuscript gives a review of soil moisture retrieval using GNSS-Reflectometry and remote sensing technique. It introduces the current status and challenges of soil moisture retrieval from GNSS-R and passive/active remote sensing, also the potential applications of soil moisture content products. It summarized the current studies and is well written and organized, I would accept it in its present format.

We profoundly thank you for accepting the concept of paper and recommending for publication in the present format.

Reviewer #4:

The review is interesting about the GNSS-reflectometry and RS of SMC. However, I think the manuscript is too long for the readers. The authors must consider to summary some parts in the manuscript.

Thank you very much for your positive comments and suggestions concerning the publication of this manuscript. We have reduced section 2 and summarized several paragraphs. The minor comments are answered and applied as follows:

Some minimal observations are:

- The manuscript has some problems in the English.

The manuscript has been revised again several times looking for writing mistakes.

- The abstract requires a new focus about the main of the manuscript.

The main focus of the manuscript is the new and promising GNSS-R technique and its connection to current SMC inversion methods (which are firstly introduced). We have included more derived products and applications, and better defined how conventional active/passive can

connect with GNSS-R.

- Line 58 does not have a reference about the advantage over optical sensors.

Thank you very much, reference has been added.

- The line 63 has two times the reference 1.

My apologies for the error, this line has been corrected.

Thank you very much again,

Sincerely,

K Edokossi, A Calabria, SG Jin, and I Molina