## Author Response to Editor

# Virtual joint field campaign: a framework of synthetic landscapes to assess multiscale measurement methods of water storage

Till Francke et al.
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**RC:** ***Referee Comment***, AR: *Author Response*, ☐ Manuscript text

Dear referee,

thank you very much for your positive response, and for the time and effort spent to examine the manuscript and the data set.

Your comments are very helpful in improving the quality of our manuscript. Please find a point-by-point reply below on how we intend to implement them. If you feel that some of these changes would not satisfy the needs you indicated, we would appreciate further advice on these matters.

Kind regards,
Till Francke (on behalf of the author team)

## Comments and responses

**RC:** ***The paper is well written, well-structured and clear. The topic is surely of interest for the readers of Geoscientific Model Development (GMD) as the paper introduces a new virtual framework to assess measurement methods of soil moisture and biomass in controlled experiments.***

AR: We appreciate this positive perception our study.

**RC:** ***MAJOR COMMENT 1: The virtual framework is, in principle, suitable for any measurement technique. The paper analyses three methods: cosmic-ray, remote sensing and gravimetric measurements. However, while cosmic-ray are well developed and described, this is not the case for remote sensing and gravimetric measurements. Remote sensing and gravimetric measurements are only used in the hexland_tracks experiment, cosmic-ray in all the experiments.***

AR: We agree that the framework could be suitable for various measurement techniques. We tried to demonstrate this with our case study "hexland_tracks", in which CRNS, passive optical remote sensing and hydrogravimetry are used. These examples are by no means exhaustive: active microwave remote sensing, GNSS reflectometry or ground penetrating radar are other possible examples. However, as these other methods require specific expertise, we must confine ourselves to our area of knowledge. Thus, we can only invite the respective communities to this endeavour, but cannot cover all possible examples for the framework.

Our focus was on the presentation of the framework, not on specific case studies. We used one realization (hexland_tracks) to demonstrate the applicability *across different sensor types*. As such, the other two case studies merely underline the versatility of the framework *across different landscape realizations*, specifically in representing terrain or resembling non-artificial landscapes.

We will clarify our focus on the framework and the illustrative and selective nature of our case studies and support this with the following table:

Table 1: Overview realizations

| realization | description | generated virtual observations |
|---|---|---|
| *hexland_tracks* | synthetic landscape with max. contrasts | CRNS, remote sensing, hydrogravimetry |
| *sierra_neutronica* | synthetic landscape with high-relief | CRNS |
| *agia* | realistic Mediterranean landscape | CRNS |

**RC:** ***In addition, optical remote sensing data are considered, but currently no soil moisture products from optical data are available, only results from scientific papers.***

AR: The output of the radiative transfer model is spectral reflectance (resampled to the 13 bands of Sentinel 2). It is correct that we do not use the reflectance data to retrieve a soil moisture product, but just illustrate the use of thespectral response by more common indices related to the presence of water and chlorophyll (NDV, NDWI, VWC). The same essentially applies to the virtual CRNS sensors which we use to simulate the measurement of neutron count rates, but not to retrieve a soil moisture product in the context of this study. The focus of this study is to provide a consistent framework to simulate virtual observations which could be used to experiment with soil moisture retrieval (by using each technique for itself or by combining their strengths). Including this analysis step, however, is beyond the scope of this study. In the revised version of the manuscript, this will again be emphasized in the introduction as well as in the conclusions section.

**RC:** ***The use of microwave observations (e.g. from SAR data) would have been more appropriate. I suggest that the authors restructure the text to make it more balanced. Some parts can simply be put in the supplementary material. The remote sensing case study is very weak.***

AR: We agree that SAR is an important approach to derive soil moisture via remote sensing. As explained in the previous reply, we acknowledged this in the introduction, but focused only on optical remote sensing for the examples. We will make this point clearer in the revised version.

Despite the strengths of SAR, we think that optical remote sensing is likewise worth to be analyzed in this context. Especially in the face of the limited penetration depth of active microwave sensors (or none at all in case of radar in dense forests with e.g. S1 C-band in dense forests), optical imagery can reveal water induced effects in vegetation vitality, thus potentially integrate over the entire root zone. Consequently, vegetation indices that show reduction in leaf water content, chlorophyll or even soil moisture directly (for sparse vegetation and bare soil) can be useful to derive strategies to manage irrigation systems, assess wildfire risk and other disturbance. They are widely applied (e.g. Li et al., 2022), also because of their usually higher spatial and temporal resolution, e.g. Buitink et al, 2020. Moreover, there are hardly any SAR-based RTMs available, which use high spatial resolution S-1 data - one exception is https://doi.org/10.3390/rs12183037, but the model is not publicly available, via GIThub etc. For other wavelenghts like L-band, the respective spatial resolutions is approx. 1000 m, so far to coarse for detailed analyses on the spatial scale of the vJFC. . We will add these explanations to the respective RS-section.

We are not sure which "parts can simply be put in the supplementary material" and would appreciate concrete suggestions on this matter.

**RC:** ***MAJOR COMMENT 2: While reading the paper, I wondered how the virtual truth was developed. It is only clear after carefully reading the methodology, I would suggest adding a paragraph at the end of the introduction clearly describing it. For example, I was expecting virtual experiments with time-varying soil moisture, but this is not the case. This should be mentioned, and I also wondered if this might be a strong limitation of the current design of the framework. I would suggest that the authors discuss this point.***

Again, we would like to stress that the intended focus of the manuscript is the framework, not the presented application examples. Therefore, we would like to keep the general aspects on the generation of the virtual truth generic and in the Methodology section. We do not think they should already be spelled out in the introduction, as they constitute a major part of the conceptual novelty. Therefore, we described these aspects already in Section 2.2.1" Construction: extent, resolution, recombination". The current focus on single snapshots in time is also mentioned there. However, we will improve the explanation that this is more a current pragmatic reduction, rather than a fundamental limitation of the concept.

Moreover, we will add an outline and justify the structure of the manuscript at the end of the intro section. That might help to manage expectations with regard to the content of the various sections/subsections.

**RC:** ***MAJOR COMMENTS 3: The second experiment (sierra-neutronica) is briefly described. While potentially interesting, as it was in the current version, it is described too briefly. I would suggest either removing the experiment or improving its description and relevance. What understanding do we gain from such an experiment?***

AR: The case study "sierra_neutronica" focusses on the effect of relief, which is potentially affecting all of the three involved sensors, i.e. CRNS, optical remote sensing and hydrogravimetry. As the understanding of relief effects on CRNS-signal is especially limited, we chose to focus on this sensor in the example. We will extend this justification in the manuscript.

**RC:** ***SPECIFIC COMMENTS L37: for remote sensing, active and passive microwave are mentioned here. In the paper optical remote sensing is considered, and also thermal data are used for retrieving soil moisture. Please improve the text here.***

AR: We do not quite understand this request. The mentioned section in the introduction introduces the relevant state-of-the-art methods for measuring soil moisture beyond the point scale. It does not and should not describe the methods applied in the three case studies. Therefore, we suggest to leave this section as it is.

**RC:** ***L39: Also, gamma-ray technique is worth to be mentioned here.***

AR: Thanks for the suggestions, will be added.

**RC:** ***L46: "(reference welcome)" something is missing here***

AR: Will be removed.

**RC:** ***L52: Just a comment, interesting to see that such "virtual campaign" is similar to the concept of "digital twin" for developing scenario on the potential behaviour of the Earth System. The connection between the two concepts might be mentioned here.***

AR: Thanks for this suggestion. Indeed, we had discussed this point already during the writing of the manuscript. However, we decided against it as the vJFC's primary use is the provision of a virtual testbed for different sensors. These testbeds *may* resemble real systems, but (as in two of our three examples) can also be completely synthetic. Thus, we found the analogy to "digital twin" misleading.

**RC:** ***L72: The free availability of scripts and data is very welcome, but it cannot be considered as a requirement for developing a virtual landscape.***

AR: We agree that this is not a strict scientific requirement. However, for practical reasons we consider it a very beneficial and desirable point, especially in the face of re-use and re-combination of the existing building blocks. We will modify the sentence accordingly.

**RC:** ***L118: The spatial scale of remote sensing "$10^{-}1\ldots 10^{2}$ m" is not correct; it should be, at least, "$10^{1}\ldots 10^{3}$ m", if high-resolution data for soil moisture and biomass are considered.***

AR: The given figure refers to the *support* (see Blöschl and Sivapalan, 1995) of the single sensor unit, i.e. the spatial extent that influences the single measurement. For remote sensing, this translates to the area covered by a single raster cell. Starting from UAV imagery with ground resolution at the cm-scale to satellite products with several hundred meters resolution. However, as some related remote sensing products also feature km-sizes grid cells, we will correct the given range to "$10^{-}1\ldots 10^{3}$.

**RC:** ***L124: "single fixed point in time". This is mentioned here for the first time, likely better to underline it before (see also the second major comment).***

AR: This is not a fundamental restriction of the vJFC, but just a pragmatic decision for its current implementation. See also reply to MAJOR COMMENT 2.

**RC:** ***L138: The "pattern" concept is not clear here. I would suggest clarifying.***

AR: 'pattern' is a meta-component defining spatial patterns, which can be referred to in the construction of other compartments to create coherent spatial patterns. For example, a pattern defining the extent of grassland and forest may serve as a basis for generating coherent compartments of vegetation ("grass" and "forest"), soil density ("medium" and "low") and soil moisture ("medium" and "low") corresponding to these areal entities.

We will add this explanation to the respective section.

**RC:** ***L146-151: Also here, the different combination techniques are not fully clear. I would suggest clarifying.***

AR: The combination techniques describe the options how the different compartments are intersected by mixing or replacement.

We will extend the description to the respective section.

**RC:** ***L281: I would add "spatial", i.e., "its spatial variability".***

AR: The respective subheading is "A landscape with maximized field-scale heterogeneity". We think that "field-scale" clearly implies that this refers to *spatial* variability. We also think that "field scale" is more informative than just "spatial", as we address the variability at the scale of several meters to decameters, opposed to e.g. cm-scale variability in soil moisture (which can also be relevant, but which we do not cover).

**RC:** ***Table 2: The combination for soil moisture should be 12 (4x3), not 8. Why?***

AR: The number of 8 combinations results from the fact that the two values for mean soil moisture state "dry" and "wet" can only be combined with the profile "homogenous". In other words, a soil profile with a dry topsoil cannot have a decreasing profile shape (as it would result in negative soil moisture in greater depths). If it has a increasing profile shape, its mean soil moisture is 33%.

**RC:** ***Figure 3: In the caption, "top" and "bottom" should be "left" and "right". "tops layer" should be "top layer".***

AR: Agreed, will be fixed.

**RC:** ***L367-368: Indeed, no soil moisture products from optical data is currently being developed.***

AR: We assume the line numbering is a mistake, as line 367 contains the subheading "3.2 sierra_neutronica: Synthetic mountains to explore topographic effects". Concerning the productions of a soil moisture product, please see reply to MAJOR COMMENT 1.

**RC:** ***Figure 6: It is missing the y-label in the plot on the right.***

AR: Will be added.

## References

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