General Comments

The manuscript presents an approach for retrieving the soil moisture (SM) at high resolution (1 km) by using fine resolution observations of Sentinel-1 (Synthetic Aperture Radar Imaging based backscatter coefficient), and Sentinel-2 & 3 (Optical Imaging based NDVI). For high-resolution soil moisture retrievals, the authors adopted the S2MP (Sentinel-1/Sentinel-2 derived Soil Moisture Product) algorithm developed by (El Hajj et al., (2017). The authors used the same approach/ methodology as used for S2MP (neural network with a combination of the Water Cloud Model). This study aims to extend the S2MP from croplands (cereals and grasslands) to herbaceous vegetation types and to explore the use of NDVI derived from Sentinel-3 (S3) instead of Sentinel-2 (S2). The authors provided a comparative analysis of high-resolution soil moisture retrieved through a combination of S1+S2, S1+S3, available soil moisture products of Copernicus Global Land Service (CGLS) SM and Soil Water Index (SWI) and SMAP+S1. For the evaluation of the soil moisture product, the authors used in-situ soil moisture measurements.

Though the topic of the research is important and interesting, I feel there is not much novelty in this research work on high-resolution soil moisture retrieval. The authors adopted a developed approach with only a change of new observations for NDVI (used Sentinel-3 in place of Sentinel-2) without any other improvement/modification. Besides, I feel the authors fail to properly justify why there is a need to use the optical remote sensing-based NDVI to retrieve soil moisture at high-resolution (1 km), which is affected by cloud cover conditions. Since the SMAP-Sentinel products are capable of providing soil moisture at 1 km in all weather conditions, the authors need to identify/justify the adequate research gap to make a novel research statement. On the other hand, extending land cover conditions from “croplands" to “herbaceous vegetation” and using NDVI derived using “Sentinel-3” observations in place of “Sentinel-2) is not a novel research contribution.

Other than scientific fairness, the manuscript structure is poor and needs much improvement. A well-structured “Methodology” section is also missing. A lot of information is redundant and repeated many times in the manuscript. The authors provided a lot of the details on “Datasets” which are well documented in the scientific literature but fail to provide a clear “Methodology” of how the dataset and algorithms are being used. Besides, the manuscript is poorly organized and lacks coherence. The connection in different sections is missing which creates difficulty in understanding the manuscript.

The specific Major/Minor/Editorial (syntax error) issues are listed below.

We truly thank the reviewer for his/her pertinent comments on the manuscript. We regret that the novelty of the study, the global goal and the methodology seem to have been inadequately presented. The goal of the manuscript is to study how to produce 1-km soil moisture maps over large regions using the synergies of different Sentinel satellites. For that, it is needed to (i) extend the S^2MP to other land cover types than croplands and (ii) evaluate the use of S3 instead of S2 NDVI. The S^2MP was originally designed to work at very high resolution (~10 m). Only afterwards, the relative performances of these maps are evaluated against other state-of-the-art datasets. In a revised version of the manuscript we will clarify the goal through the abstract and introduction.

In addition, the descriptions of the Sentinel data and S^2MP algorithm will be entirely revised and the structures of the sections data and method will be improved. The section data will be revised to only present the description of the Sentinel missions, the Sentinel data used for the production of the S^2MP SM maps and the description of the other well-documented datasets will be shortened. In contrast, the description of S^2MP will be moved to section "Methodology". Repetitions as well as not essential descriptions from these sections will be removed in a concerted version.

The SMAP+S1 dataset is certainly a very interesting one and a nice replacement of the originally planned SMAP active / passive dataset. The need for a global product with a resolution of around 1 km is already expressed by several international committees such as GCOS and CEOS and it will increase in the next years. This is certainly an open research topic that requires developing and testing different approaches using different sensors and different methodologies.

Major comment:

Notably, the reported research is just an adaptation of the previous approach (El Hajj et al., (2017)) without any other improvement/modification. Since the only changes in the study are “Herbaceous vegetation” land cover in addition to “cropland” and the use of Sentinel-3, I feel there is not much novelty in this research work. The validation of high-resolution soil moisture retrievals on “Herbaceous vegetation” using in-situ measurement is not properly investigated. I can find some correlation comparison in Table 2, but the bias and standard deviation of the difference is not presented for the “Herbaceous vegetation” in Table 3. Besides, the discussion on the different statistics (R2, bias, and STDD) missing in the context of their significance (i.e., are these statistics fulfill the accuracy requirement/goal).

Table 3 presents the performances of the different SM datasets against in-situ measurements in terms of correlation (R), bias, and standard deviation of the difference (STDD). While being a significant extension in the type of regions where the S^2MP approach has been tested and validated with respect to El Hajj et al. and Bazzi et al., this study is limited to 6 regions of 10^4 km^2 and then a small number of in-situ stations are available for the evaluation. This is the reason why the metrics (R, bias and STDD) cannot be computed separately for each type of land cover.

However Table 2 does present the comparison between the S^2MP SM maps and those from the other high resolution datasets in terms of R over pixels that include a fraction of croplands or herbaceous vegetation. Please find below a new version of Table 2 that presents the bias and STDD in addition to R over pixels dominated by croplands or herbaceous vegetation. This new table can replace Table 2 in a revised version of the manuscript. The addition of these additional metrics in this table do not change the conclusions discussed in the paper but we fully agree with the reviewer that they can be shown for completeness.

Regarding their significance, one must bear in mind that they are just datasets intercomparisons and not absolute evaluation/validation results with respect to a "ground truth" (which by the say does not exist: calibration and uncertainties of in situ measurements, depth and spatial representativeness issues…). For instance, regarding the STDD (or unbiased-RMS as some colleagues call it now), the relative values obtained for HR maps for herbaceous regions are in between 0.04-0.06 m3/m3, so, similar but a bit larger than the ideal overall performances of remote sensing and model-based products usually quoted in validation documents. But they are similar values with respect to those obtained for croplands.

Table 2. Comparison of S^2MP_{S1S3} against $CoperSSM$, $CoperSWI$ and $SMAPS1$, in terms of R, bias and $STDD$, over 1-km^2 pixels where croplands or herbaceous vegetation are the dominant land cover classes, respectively. The metrics are also derived according to the degree of coverage of the land cover. One set of metrics is computed considering only pixels covered by less than 75% of croplands or herbaceous vegetation. Another set of metrics is computed considering only pixels covered by at least 75% of croplands or herbaceous vegetation. The analysis was performed from January to December 2019.

Regions	Products	Croplands						Herbaceous vegetation					
		$< 75\%$			$\geq 75\%$			$< 75\%$			$\geq 75\%$		
		R	$Bias$	$STDD$	R	$Bias$	$STDD$	R	$Bias$	$STDD$	R	$Bias$	$STDD$
Spain	$CoperSSM$	0.63	0.01	0.06	0.72	0.01	0.06	0.67	0.06	0.06	0.69	0.07	0.06
	$CoperSWI$	0.61	0.01	0.06	0.68	0.01	0.06	0.65	0.04	0.06	0.70	0.06	0.06
	$SMAPS1$	0.54	-0.01	0.07	0.65	-0.01	0.06	0.64	0.06	0.08	0.71	0.09	0.08
Tunisia	$CoperSSM$	0.37	-0.02	0.06	0.55	-0.01	0.05	0.32	-0.01	0.06	0.31	-0.01	0.06
	$CoperSWI$	0.37	0	0.05	0.45	-0.01	0.05	0.36	0.01	0.05	0.34	0.01	0.05
	$SMAPS1$	0.38	-0.03	0.07	0.51	-0.03	0.06	0.32	-0.02	0.07	0.27	-0.01	0.07
Southwest of France	$CoperSSM$	0.56	0.03	0.06	0.71	0.03	0.06	0.69	0.07	0.06	0.62	0.09	0.06
	$CoperSWI$	0.48	0.06	0.06	0.59	0.05	0.06	0.55	0.09	0.06	0.58	0.09	0.06
	$SMAPS1$	0.28	0.01	0.09	0.48	-0.01	0.07	0.36	0.09	0.10	0.34	0.11	0.10
Southeast of France	$CoperSSM$	0.63	-0.04	0.04	0.75	-0.05	0.03	0.44	0.02	0.05	0.72	0.06	0.02
	$CoperSWI$	0.47	-0.03	0.04	0.56	-0.03	0.04	0.48	0.06	0.05	-	-	-
	$SMAPS1$	0.45	0.02	0.07	0.45	0.04	0.08	0.49	0.04	0.05	-	-	-
Australia	$CoperSSM$	-	-	-	-	-	-	-	-	-	-	-	-
	$CoperSWI$	-	-	-	-	-	-	-	-	-	-	-	-
	$SMAPS1$	0.56	0.05	0.06	0.59	0.05	0.06	0.55	0.05	0.06	0.60	0.06	0.05
North America	$CoperSSM$	-	-	-	-	-	-	-	-	-	-	-	-
	$CoperSWI$	-	-	-	-	-	-	-	-	-	-	-	-
	$SMAPS1$	0.68	0.07	0.06	0.71	0.08	0.06	0.58	0.06	0.06	0.53	0.09	0.06

My other concern regarding validation is "why did the authors not calculate the "RMSE" and "unbiased-RMSE" error matrices which are the most important/critical statistics being used in satellite soil moisture product validations?

We did. The standard deviation of the difference has been used all along the study and this metric is identical to the unbiased-RMSE. Since the bias has also been computed independently, we think the computation of the RMSE will not add value to the study. In addition, those are just some metrics among others. For instance, it is relatively easy to have pretty good STDD (unbiased RMS) with a time series that is flat but close to the mean of the real time series but without really capturing the temporal dynamics. Therefore, other metrics such as different types of correlation coefficient computations are as important as any STD or RMS.

I feel that the proposed approach suffers from the cloud cover situation due to the dependency on optical remote sensing-based NDVI observations. Since the approach of this study mostly depends upon the NDVI in addition to the SAR backscatter, the approach might fail during cloud cover conditions. Though the authors used a gap-filling linear interpolation approach to obtain two cloud-free NDVI images per month (1st and 15th of each month), this approach still has limitations during long (> 10-15 days) rainy seasons or cloud cover conditions. Besides, it's worthful to use only two NDVI images (15 days apart) in the month to retrieve daily high-resolution soil moisture where NDVI is an important component of the algorithm?

Of course, clouds are something that has to be taken into account when using optical data as input. The advantage of using S3 is that due to its high revisit it is not likely to have not a single cloud free day in 15 days except in some tropical regions with dense vegetation forest, which currently are out of the scope of the S^2MP algorithm application. Otherwise, one must bear in mind that the NDVI is just a predictor used as input to the neural network, but it is not the main predictor (that with the highest weight) to estimate soil moisture. In addition, the higher temporal revisit of S3 compared to S2 allows the instruments onboard to acquire optical images without cloud or rainy conditions more frequently. Thus, only several cloud-free optical images are required to compute robust NDVI estimates. And NDVI variation in a 15 days timescale is slow enough to have the flexibility of using this auxiliary predictor variable with this timescale and therefore minimizing the risk of having gaps due to clouds. Finally, there must be a misunderstanding, because not only two images per month are used. In the construction of those two images all S3 images have been used. We will clarify this if we are asked to send a revised version of the manuscript.

Although the authors have presented the details on the use of optical remote sensing (which is susceptible to errors associated and large data gaps due to the clouds, and atmospheric effects) with microwave remote sensing (active/passive) for high resolution soil moisture retrievals, a proper justification or criticism is missing between the synergistic use of purely microwave remote sensing-based approach like SMAPSentinel active-passive approach. I suggest the authors should provide justifications in this regard. My concern is "if SMAP-Sentinel has the capability to provide 1-km soil moisture product using Sentinel-1 SAR observations to a global extent then what is the value addition with the proposed approach, which also uses Sentinel-1 SAR observations to provide 1-km soil moisture retrievals which are limited only to the study regions? Is the performance of the proposed approach better than the SMAPSentinel to provide high-resolution soil moisture? If yes then provide adequate analysis and proper comparison. If not, then justify why this study is important.

As already mentioned, the SMAP+S1 dataset is certainly a very interesting one and a nice replacement of the originally planned SMAP active / passive dataset. The need for a global product with a resolution of around 1 km is already expressed by several international committees such as GCOS and CEOS and it will increase in the next years. This is certainly an open research topic that requires developing and testing different approaches using different sensors and different methodologies.
For instance, downscaling by data merging is not an exact science and part of the high spatial frequencies in the merged dataset are noise. The fact that, when compared to in situ measurements, the performances of SMAP+S1 increase significantly when the downscaled data are aggregated back at 25 km resolution is an example. We do not

share the point of view that no more research in the topic is needed because there is a SMAP+S1 product. Hundreds of works in the remote sensing of soil moisture litterature have already shown that active or passive, single resolution/sensor or merging of different revolution datasets, using optical data such as NDVI as auxiliary data (as SMAP does because it cannot retrieve simultaneously soil moisture and optical depth) or only microwaves, using physical, statistical or change detection approaches... sometimes perform better in some places and some periods and in other regions/times it is another dataset that perform the best. Or simply, they differ significantly as in the Equatorial and Boreal regions where third party data, in particular in-situ measurements, is not available to determine which one can be closer to the reality.

The authors did not show any spatial pattern of the high-resolution soil moisture retrievals. I suggest the authors show a few spatial maps (i.e., dry, wet, and moderate soil moisture conditions) of the retrieved soil moisture using the proposed approach and its comparison to SMAP-Sentinel products. Since both the products are based on the Sentinel-1 observations, there will be a similar areal coverage in both the products and will help to understand the spatial distribution of high-resolution soil moisture and the reasoning behind the error difference.

We do think that comparing to SMAP+S1 is interesting and this is the reason that we used it in the comparison. However, we disagree with the idea that it should be the main reference. The main reference is the Copernicus surface soil moisture dataset because it is S1 based without merging with a very different resolution sensor, which introduces additional uncertainties in the comparison. However, we do agree that it is interesting to compare the datasets in shorter time periods than one year and to show maps in different time periods. For instance, please find below a figure showing soil moisture maps averaged over the period of study (from January to December 2019) for each dataset and region.

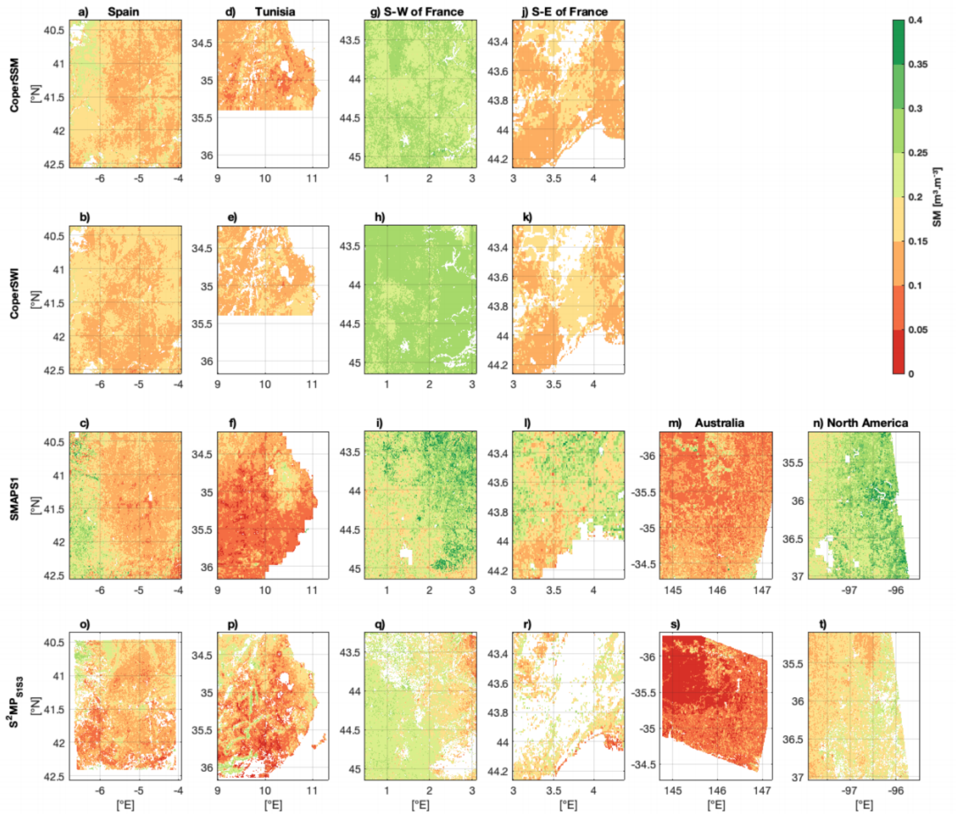

Figure 4. SM mean of $CoperSSM$, $CoperSWI$, SMAPS1andS$^2MP_{S1S3}$ over the 6 regions of study in 2019.

The mean maps are quite similar between the Copernicus SM and SWI (CoperSSM and CoperSWI) datasets for all the 4 regions in Europe.
In Spain, S^{2}MP is quite similar to the Copernicus and SMAP+S1 maps. However, SMAP+S1 is wetter in the southwest of this region and S^{2}MP is dryer.
In Tunisia, SMAP+S1 is drier than the 3 other datasets. S^{2}MP shows wetter SM estimates than the other datasets over pixels close to river basins.
In the southwest of France, SMAP+S1 shows wetter SM estimates than the Copernicus datasets over forest areas while S^{2}MP shows dryer SM estimates.
In the southeast of France, SMAP+S1 is clearly wetter than the Copernicus datasets. Over the regions in Australia, in particular over herbaceous vegetation, and America, S^{2}MP is dryer than SMAP+S1.

The introduction needs much improvement. Firstly, the manuscript needs to critically discuss why this study is important. What is the novel research statement/objective of this study? Secondly, the introduction needs details for an international context. How do the findings of this study inform or build upon the wide range of international research that has been carried out in high-resolution soil moisture retrievals? What does this research contribute? Since ANN-based retrievals are limited only to the study regions, what information from this study will be relevant to international researchers outside of the specific six regions location investigated?

Retrieving soil moisture is currently done globally at low spatial resolution (40 km) or over smaller regions at high (~1 km) or very high spatial resolution (10-100 m) as the

original S^2MP algorithm does over croplands. The goal of this manuscript is to study how the S^2MP approach could be used to produce 1-km soil moisture maps over large regions using the synergies of different Sentinel satellites. Of course, the first step is to be able to use it over larger regions and to extend S^2MP to other land cover types than croplands. In addition, since for soil moisture mapping at large scale, 1 km is a high spatial resolution, using S3 instead of S2 becomes possible. In spite of the lower spatial resolution of S3, its higher revisit frequency with respect to S2 makes possible to reduce uncertainties in the NDVI estimations used by S^2MP introduced by clouds and gaps in the optical time series.
In this context, we understand that comparing the S1+S2 vs S1+S3 results and continuing showing the performances of S1+S2 against those of other state-of-the-art datasets was a bad choice. In a revised version of the manuscript we will focus on the results for S1+S3 in addition to clarify the goal in the abstract and introduction as well as improve the structure and content of the data and method sections.
Finally, this manuscript is also an evaluation of the S^2MP approach over regions with different conditions with respect to those in El Hajj et al. and Bazzi et al. papers.
ANN-based retrievals are not limited to the six regions. There is no local data used for the training but this paper does not present any kind of operational algorithm, it is a research paper, we cannot process the whole globe.

The “Conclusions" section is full of results only. I feel the conclusion should be a take home message for the readers and should be related to the work's problem statement in a concise manner. Please revise this section.

We appreciate the feedback of the reviewer and we will certainly revise this section making it more concise and including perspectives to the summary section.

Minor comments:

L4: “agricultural plot scale”- What scale are you talking about? It should be quantitative. Since the proposed method is for 1-km soil moisture, using the term “agricultural plot scale” is not optimistic.

This sentence will be edited to explicitly specify that the agricultural plot scale corresponds to a 10-m resolution.

L9-10: “A target resolution of 1 km also…”- In what way does 1-km spatial resolution allows to explore the use of NDVI derived from Sentinel-3 (S3) instead of S2? Is S2 not having the potential to provide NDVI at 1-km?

We understand that this sentence is not clear. Both S2 and S3 have the potential to provide NDVI at 1-km resolution. This sentence will be edited to avoid potential misunderstandings.

The authors need to revise the section “Section 2. Data”. I suggest providing brief details about the well-known datasets. Most of the details look redundant.

Taking into account this comment and those from other reviewers, the section data will be entirely revised to include a better description of the Sentinel data used as input to the S^2MP algorithm and to avoid non-essential information concerning the well-known datasets used in this study.

Figure-1 is missing the details of in-situ soil moisture measurement locations.

Please find below a new version of Figure 1. As advised, it has been modified to help the reader to better locate the different regions of studies. Locations of in-situ stations have also been added. This new figure will replace the original Figure 1 into the revised manuscript.

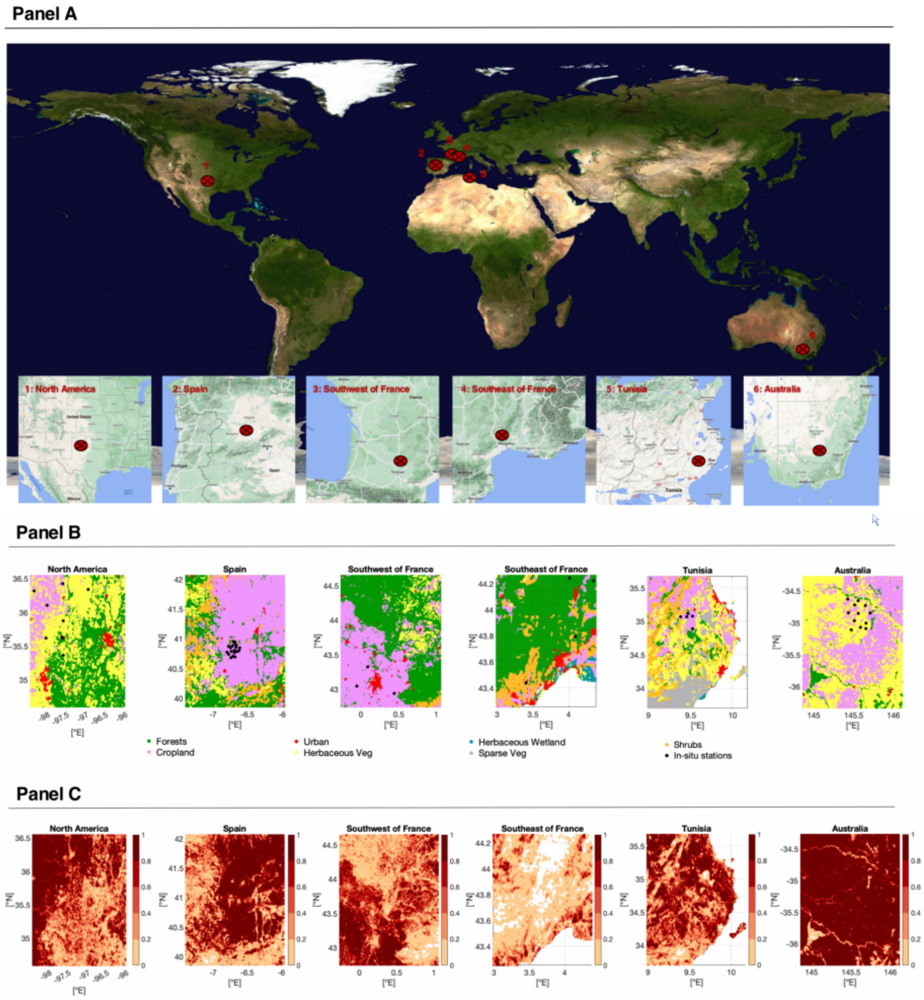

Figure 1. Panel A: Global locations of the 6 regions of study. **Panel B:** Copernicus land cover maps of the 6 regions of study aggregated at 1-km spatial resolution. Only the dominant land cover type within a 1-km^2 pixel is shown. For instance, a pixel characterised as forests can contain 27% of forests, 26% of croplands, 24% of herbaceous vegetation and 23% of shrublands, or 90% of forests and 10% of herbaceous vegetation. The in-situ stations are shown as black dots. One black dot can correspond to several sensors since some of them have the same coordinates. **Panel C:** Proportion of croplands and herbaceous vegetation within each 1-km^2 pixel for the 6 regions of study. The proportion is expressed as a percentage ranging from 0 to 1. Pixels with no cropland or herbaceous vegetation at all are shown as white areas.

Table-1: In North America, USCRN locations consist of only two measurement locations. Are two locations optimal to represent the spatial distribution with 1-km grid cells? Past studies show that at least 3 locations are required to up-scale the soil moisture within a 1-km grid-cell.

The way in situ measurements have been used along the study will be clarified in the section method in the revised manuscript. We confirm that more than 3 in-situ stations have been used to scale the Copernicus data for each region. In the new version of the manuscript, we will distinguish the in-situ measurements used for the scaling from those used for the evaluation of the remotely sensed time series. Indeed, several in-situ stations have been discarded from the evaluation because some metrics (R, bias, STDD) computed between the in-situ and remotely sensed time series were not significant (P value below 5% - Interval of confidence of 95%). This distinction is actually not present in the manuscript and only in-situ measurements used for the evaluation are shown. Table 1 will be updated as follows.

Table 1. In-situ measurements that were used in this study. The depths are quoted as two numbers: the first one is the upper depth, and the second one is the lower depth of the sensor. Both numbers are equal when the sensor is placed horizontally. The fourth column gives the number of sensors that provide SM measurements in 2019. These measurements were used to convert the relative indices from $CoperSSM$ and $CoperSWI$ into SM estimates with volumetric units ($m^3\ m^{-3}$, Section 3.2). The number in parenthesis corresponds to the number of in-situ locations where the evaluations of the remotely sensed data were significant (P-value below 5%, Section 3.3).

Measurements	Location	Depth (m)	Sensors	Reference
REMEDHUS	Spain	0–0.05	19 (12)	Gonzalez-Zamora et al. (2018)
SMOSMANIA	Southwest of France	0.05–0.05	4 (3)	Calvet et al. (2007)
SMOSMANIA	Southeast of France	0.05–0.05	5 (0)	Calvet et al. (2007)
OZNET	Australia	0–0.05	11 (10)	Smith et al. (2012); Young et al. (2008)
USCRN	North America	0.05–0.05	2 (1)	Bell et al. (2013)
ARM	North America	0.05–0.05	24 (13)	Cook (2016, 2018)
MERGUELLIL	Tunisia	0–0.05	5 (2)	Gorrab et al. (2015)

This was the opportunity to update the in-situ measurements form the ISMN and to include additional sites to the evaluations.

Editorial comments:

Authors should be consistent with either "soil moisture estimates" or "soil moisture retrievals" - sometimes authors used "soil moisture dataset" – the terminology used should be consistent throughout the manuscript.

As advised, the terminology will be revised (soil moisture estimates) and will be consistent throughout the manuscript.

L3: What are other purposes?

Meteorology, climate monitoring and climate impact assessment at regional impact, landslide predictions…. we cannot cite all applications of soil moisture in the first introductory sentence of an abstract. Alternatively we could suppress it.

L3: The term "For instance" is not appropriate here.

This term will be removed.

L3-6: “For instance… as inputs to a neural network trained with Water Cloud Model simulations”- the statement is not clear. What is meant by “inputs to a neural network trained with Water Cloud Model simulations”?

This sentence will be edited. To estimate soil moisture, the S^2MP algorithm uses a neural network that takes data derived from S1 radar signal (backscattering coefficients) and S2 optical images (NDVI) as inputs. The neural network was trained using a synthetic database gathering (i) SAR C-band backscatter coefficients in the VV polarization (ii) incidence angles (from 20 to 45 degrees), and (iii) NDVI as inputs and soil moisture as target. This synthetic database was built using a Water Cloud Model combined with an Integral Equation Model that was specially modified and optimized for this application. This will be explained in detail in the section method in the revised manuscript.

L6: “However, for many applications…” – Why the use of “However”? Is this statement contradicting statement with the previous one?

This sentence will be edited.

L6 “future climate impact assessment”- why suddenly climate change?

Because there is a need for global 1 km soil moisture data expressed by CEOS, GCOS and ESA CCI users.

L6-8: statement is very long and difficult to understand.

“However, for many applications, including future climate impact assessment at regional level, a resolution of 1 km is already a significant improvement with respect to most of the publicly available SM data sets, which have resolutions of about 25 km” means that for many applications estimating SM at agricultural plot level (previous sentence) is not needed and 1 km will be considered as a real step forward with respect to most available datasets. Even the climate community is already looking forward to this resolution.

L10-11: “…Europe and other regions of the globe, for which S1 coverage is poorer.”-revise the statement.

This mention to the coverage can be removed from the abstract because nothing is mentioned first regarding the coverage in Europe to say afterwards that outside Europe is poorer. That’s for pointing this out.

L15-16: “…maps were compared to each other and to those of the 1-km resolution Copernicus Global Land Service (CGLS) SM and Soil Water Index (SWI) data sets as well as to the SMAP+S1 product” – this statement has no meaning. Revise it.

We mean that maps were compared to each other. In addition, both were compared to the 1-km resolution Copernicus Global Land Service (CGLS) SM and Soil Water Index (SWI) and the SMAP+S1 datasets”.

L25: change “data sets” to “datasets”

The term “data sets” will be changed to “datasets” all along the manuscript.

L25: “HR data sets were also compared …” What high-resolution dataset refers here please specify for clarity.

In this sentence, the HR datasets will be named for a better clarity: S^2MP_{S1S2}, S^2MP_{S1S3}, CoperSSM, CoperSWI, SMAPS1.

L49: change “data sets” to “dataset” or delete it.

The term “data set” will be changed to “dataset”.

L64: change “in situ data” to “in-situ measurements” – correct throughout the manuscript

The term “in-situ measurements” will be used all along the manuscript.

Section “4.3.1 Absolute values” What absolute values refer here : This heading is not complete/and doesn’t have a clear meaning-please revise.

The title of this subsection will be changed to “Comparison of the order of magnitude”.