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Hydrology and Earth System Sciences Discussions

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Interactive Comment

Interactive comment on "Developing an improved soil moisture dataset by blending passive and active microwave satellite-based retrievals" *by* Y. Y. Liu et al.

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Author response to referee comments #1 and 2

First of all, we would like to thank two referees for their comments, which have provided valuable suggestions to improve this manuscript. Below we offer a response to their comments.

AUTHOR RESPONSE TO ANONYMOUS REFEREE #1

1) General Comments

A general comment on this paper concerns the lack of clarity of the objective of the paper. Is the purpose of the paper to present a new method to blend passive and active and model soil moisture products? Or is the objective to present the new blended product? Or does the paper aim at presenting both methods and results, as suggested by the structure of the paper in Data/methods/results? The content of the paper is clearly more focused on the presentation of the method. Most of the results shown should be actually part of the method section as detailed in the specific comments below. In contrast, some other crucial components of the method, such as the CDF matching approach, are not detailed enough. Concerning results, validation conducted for three sites is very interesting. However the representativeness of these results should be addressed in the paper. And the only global result shown is about temporal coverage. The authors should show more results of the product, or, since the method represents the most important part of the paper it should be acknowledged that the paper is a methodology paper.

RESPONSE: Will revise accordingly, i.e., clarify the objective of this paper, describe the CDF matching in more detail, and show more results of the validation using in situ measurements, and more results of the merged product.

The context of this study is briefly introduced here. Passive and active microwave satellites have been shown to provide useful retrievals of near-surface soil moisture variations at regional and global scales of near-surface soil moisture variations at regional and global scales. The VUA-NASA retrieval algorithm can be used for all bands in the passive microwave domain, allowing data collected by different satellites (e.g., SMMR 1978-1987; SSMI since 1987; TRMM since 1998 and AMSR-E since middle 2002) to yield a long time series. The change detection algorithm developed by TU-Wien can be applied on ERS-1/2 and ASCAT, which can provide a global soil moisture product since 1992. A number of previous studies (Vischel et al., 2008;Brocca et al., 2010;Albergel et al., 2009;Gruhier et al., 2010;Rudiger et al., 2009;Draper et al., 2009;Wagner et al., 2007) evaluated these passive and active microwave soil moisture products using in situ measurements and found that VUA-NASA passive microwave product performs better over sparsely vegetated regions, while the TU-Wien active microwave product has better agreement with in situ measurements over regions of moderate vegetation density. Over the sparsely-to-moderately vegetated regions, both products have similar performances. Additionally, Scipal et al. (2008) and Dorigo et al. (2010) applied triple collocation approach on VUA-NASA passive microwave, TU-Wien active microwave and model simulated soil moisture products to estimate the relative error of each product at global scale. These three products are derived from different approaches and considered having independent error characteristics. The results of triple collocation analysis showed that the errors of VUA-NASA passive microwave are smaller than TU-Wien active microwave product over sparsely vegetated regions and larger over moderately vegetated regions. Their errors are comparable over the regions with low-to-moderate vegetation density. Clearly, there is value in identifying an approach to combine both VUA-NASA passive and TU-Wien active microwave soil moisture products over these varying vegetation types to develop an improved soil moisture product. This approach should be applicable to both past and current microwave satellites, as well as new missions that are expected to bring higher accuracy of soil moisture retrievals. Together these data allow a long term global soil moisture product to be provided and extended.

However, there are several challenges in accomplishing this objective. First, within the domain of passive or active microwave satellites, no single satellite covers the entire period. Differences in sensor specifications (e.g., different microwave frequencies and resolutions) prevent merging soil moisture estimates from different instruments directly. Second, the currently available VUA-NASA passive and TU-Wien active microwave products represent volumetric soil moisture and degree of saturation respectively. Third, the accuracy of soil moisture retrievals over varying vegetation cover differs from passive or active microwave products, making the selection of the better retrievals a difficult task, particularly over regions where both products have comparable performances.

This study, as a step towards developing a long term global soil moisture dataset, aims at developing a method that can address the latter two challenges mentioned above.

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2) Specific comments

P6700 line 16-17, P6702 lines 1-3, P6708 lines 3-7, P6710 lines 21-22: The transitional regions are defined as regions with high correlation between ASCAT and AMSR-E. They also delineate the boundary between sparsely and moderately vegetated areas. These two assessments are used several times in the paper. The paper cited in support of this rule is Dorigo et al. (HESSD) who show that AMSR-E has larger errors than ASCAT in region with 'moderate vegetation' and smaller errors in regions with 'sparce' vegetation. So, the transitional regions are just the common regions for which AMSR-E and ASCAT have medium errors. Dorigo et al. is cited several times along the paper but no physical explanation is given. However the question remains for the reader: what is the relation between ASCAT/AMSR-E correlation and the transition between sparsely and moderately vegetated areas? One would expect that regions of lowest vegetation coverage are the best for the two products. It would be useful (i) to provide a physical explanation of the reason why ASCAT soil moisture product has smaller errors in "moderately" vegetated area than in sparsely vegetated areas (ii) to define the transitional regions once and clearly in the method section, because it is used to define the areas where the two products are blended (instead of providing incomplete information all the paper along the paper). Actually Figure 5 which come late in the paper is useful to understand how the data sets are blended and it should be shown in the methods section.

RESPONSE: Following the suggestion (ii), we will move Figure 5 into the methods section in the revision to clearly present the transition regions. As for the suggestion (i), a number of previous studies (Vischel et al., 2008;Brocca et al., 2010;Albergel et al., 2009;Gruhier et al., 2010;Rudiger et al., 2009;Draper et al., 2009;Wagner et al.,

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2007) evaluated these passive and active microwave soil moisture products using in situ measurements and found that VUA-NASA passive microwave product performs better over sparsely vegetated regions, while the TU-Wien active microwave product has better agreement with in situ measurements over regions of moderate vegetation density. Over the sparsely-to-moderately vegetated regions, both products have similar performances and show a clear equifinality. Theoretically, both passive and active microwave instruments with similar frequencies should give similar response over the same region regardless of vegetation density. Thus the primary reason for different performance between VUA-NASA and TU-Wien soil moisture products should lie in their different ways of treating vegetation component. The TU-Wien algorithm uses the seasonal variation of the backscatter-incidence angle relationship to correct for seasonal vegetation effects. Empirical evidences indicate that the TU-Wien soil moisture performs reasonably over the regions with apparent seasonal vegetation variation. The VUA-NASA algorithm uses a linear radiative transfer model to extract soil moisture and vegetation density simultaneously. Within this model, the vegetation is considered to behave like a one-layered semi-transparent medium. With the increasing of vegetation density, the accuracy of soil moisture is expected to decrease, which is also supported by empirical evidences (De Jeu et al., 2008).

P6702 line16: remove 'at the retrieval level'. Since the approach proposed in this paper consists in blending soil moisture products, it is not conducted at the retrieval level. Rather working at the retrieval level would consist in using brightness temperature and backscattering coefficients directly.

RESPONSE: Will change into something like ‘at the soil moisture products level’.

Introduction: A discussion concerning the interest of the proposed approach versus other approaches (e.g. data assimilation) would be useful.

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RESPONSE: Large scale (e.g., continental to global) soil moisture estimates can be derived from model simulation and remote sensing observation. From the modeling aspect, soil moisture is simulated based on the understanding of the physical processes; whereas remotely sensed soil moisture is retrieved from the signals captured by satellite instruments. They are two different approaches and may show different responses (e.g., different inter-annual variations and long term trends).

With assimilating remotely sensed soil moisture into model, the final product is modeled soil moisture optimized by satellite soil moisture. This is of course a good approach, but the final product is largely a modeled soil moisture product. It is not clear whether the data-assimilated product keeps the inter-annual dynamics and trends as detected by the satellite-based soil moisture data.

The objective of our study is to generate one satellite-based long term global soil moisture product by combining TU-Wien active and VUA-NASA passive microwave products. This paper describes the first step of this task. In our approach we try to keep the dynamics and trends as given by the satellite soil moisture data. Essentially, only the CDF curve of modeled soil moisture is used to adjust the range of satellite-based soil moisture. That is, both VUA-NASA and TU-Wien soil moisture products are rescaled into the same range. This has no impact on the relative dynamics (e.g., relative soil moisture variations from day to day) and trends.

So in the end it is still a satellite derived and not a modeled soil moisture product. During the revision, we will add global maps showing the relationship between satellite-based and model simulated products before and after the rescaling to present the impacts of CDF matching on the satellite-based products.

P6703: Please introduce the content of the paper.

RESPONSE: Will add one paragraph briefly describing the structure and content of this paper.

P6704 from line 18: Form here it seems that the description concerns both AMSRE and ASCAT. It is the case at least for the re-sampling. Please clarify on line 25 if masking also applies to AMSR-e. If it is the case the authors should add a new subsection from line 18 (for example ‘Data pre-processing’).

RESPONSE: Will add one sub-section at the end of ‘Data sources’ to describe the pre-processing on all soil moisture datasets.

P6706: line 11: replace ’absolute’ by ’volumetric’ everywhere in the paper.

RESPONSE: Will revise accordingly.

P6707: The CDF-matching approach is an important component of the approach since it is used to rescale and correct bias of the two soil moisture products in terms of volumetric surface soil moisture. CDF matching needs to be described in more details in the paper. The authors use a piece-wise linear CDF-matching approach. It is important to discuss the choice of 8 intervals since usually only one interval that covers the entire range of soil moisture is used. The authors should tell how many parameters they use for each segment for each pixel. If they have 2 linear parameters per segment (which is most probably the case), then they have many 16 parameters per grid points.

Again what it the interest of the segment approach compared to a second of third order CDF matching performed on the entire range of values? And the authors also have to explain how they compute the matching parameters: do they consider both mean and variance to compute the matching parameters? On which period do they calibrate the matching parameters? In addition global maps of ASCAT and/or AMSR-E products

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before and after CDF matching, together with global map of Noah surface soil moisture should be provided to illustrate the effect of the CDF matching on the product.

A more general comment is that using a CDF-matching approach to rescale products on the land surface model leads to have a strong contribution of the land surface model in the final product. While correlation with ground stations results from the satellite product, RMSE is strongly constrained by the Land Surface Model (LSM) volumetric soil moisture. The author should more clearly acknowledge that the proposed approach consists of blending microwave satellite products and model product of surface soil moisture. However to take advantage of satellite products and land surface model data assimilation approaches would be more relevant to reach an optimal combination.

This should be discussed to clarify the interest of this approach compared to other methods. What is the benefit of developing a global volumetric soil moisture product in which satellite and model products are combined using non-optimal approaches? Shall the method use only ASCAT and AMSR-E (rescaled in terms of index) to provide a blended product expressed in soil moisture index?

RESPONSE: CDF matching approach will be described in more detail, e.g., which values are used to construct CDF curve and how to compute the matching parameters. The advantages of piece-wise linear CDF matching approach will be discussed.

From the modeling aspect, soil moisture is simulated based on the understanding of the (simplified) physical processes; whereas remotely sensed soil moisture is retrieved from the signals captured by satellite instruments. They are two different approaches and may show different responses (e.g., different inter-annual variations and long term trends). With assimilating remotely sensed soil moisture into model, the final product is modeled soil moisture optimized by satellite soil moisture. This is of course a good approach, but the final product is largely a modeled soil moisture product. It is not clear whether the data-assimilated product keeps the inter-annual dynamics and trends as detected by the satellite-based soil moisture data.

The objective of our study is to generate one satellite-based long term global soil moisture product by combining TU-Wien active and VUA-NASA passive microwave products. This paper describes the first step of this task. In our approach we try to keep the dynamics and trends as given by the satellite soil moisture data. Essentially, only the CDF curve of modeled soil moisture is used to adjust the range of satellite-based soil moisture, and this has no impact on the relative dynamics (e.g., relative soil moisture variations from day to day) and trends on the satellite-based soil moisture. So in the end it is still a satellite derived and not a modeled soil moisture product. During the revision, we will add global maps showing the relationship between satellite-based and model simulated products before and after the rescaling to present the impacts of CDF matching on the satellite-based products.

Adjusting VUA-NASA and TU-Wien soil moisture to the range of model soil moisture is to put these two products 'on the same page' for merging purpose. This indeed changes the RMSE of the satellite-based soil moisture dataset. However, in some applications, it is more important that the general dynamics of soil moisture (i.e. the relative soil moisture variations from day to day) is reproduced rather than their actual values. That means the best indicator to assess the data reliability should be the correlation coefficient instead of the RMSE. It may be more appropriate to consider the satellite-based and modeled soil moisture as an indicator of the wetness condition (Brocca et al., 2010).

P6708: From line 10 the authors should add a sub-section 3.3 on "validation method". Bullets 2 and 3 concern rescaling, already addressed in the previous sub-section 3.1, so they should be removed. Then remaining bullets 1, 2, 5 all focus on the validation of the products at different stages of the rescaling and merging approach which is more consistent with the text introducing the bullets.

RESPONSE: Will revise.

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P6710: Results are presented for three sites only. Are they representative of other sites? This needs to be discussed.

RESPONSE: Will show results of comparison with all in situ measurements in the revised manuscript.

P6710, section 4.2: This section is supposed to show results. Figure 3 shows correlation between ASCAT and AMSR-E. This is part of the method and it is used to define the regions where the products are merged. So it should be moved to sub-section 3.2. Figure 4 shows results from Parinussa et al, (submitted to another journal). It should be discussed and not shown since it is not a result of this paper. In addition it is not a results, it is again part of the method. Figure 5 shows the contour of the regions for which the blended product uses only AMSR-E, only ASCAT and merged products. Again it is part of the method. The only results shown in the paper are the validation results (for three sites) and Figure 6 showing temporal coverage of the blended product.

Figure 4 is from Parinussa et al. which is submitted to another journal. It should be removed.

It would be interesting to provide more results in this paper. A table summarizing the blended product characteristics would be useful. (period, mean resolution, mean temporal resolution). It would be also useful to discuss the interest of such a product for the user community. For what applications is this product expected to be beneficial?

RESPONSE: Will move Figure 3 and 5 to method section. Figure 4 will be removed and replaced by one map of annual average vegetation density derived from VUA-NASA algorithm. Will show the differences and similarities between the original two products and the blended product. Will discuss the benefits of this product to the user community.

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3) Technical comments

P6713: use the correct reference for SMAP (Entekhabi et al.: The Soil Moisture Active Passive (SMAP) Mission, Proceeding of the IEEE, vol98, N5, May 2010)

P6709-6710: It is useful to use numbering in the text to organize and make it clear the structure of the sentences. However it is used too often in these two pages. In section 4.1 four sentences are structured using numbering. Please use less often numbering in this section.

Figures 3 and 6: The quality of these figures is very poor and the colorbar scales are much too small. In figure 6 it is not possible at all to read the values.

RESPONSE: Will revise accordingly, i.e., correct SMAP reference, rephrase the section 4.1 and reduce the use of numbering, and enhance the quality of Figure 3 and 6.

AUTHOR RESPONSE TO ANONYMOUS REFEREE #2

Introduction

From reading the introduction it does not become clear to me what is to be expected. I would suggest write a few sentences on the followed approach. Moreover, I think also that the research problem is not placed in the proper scientific context. Njoku et al. (TGRS 2002) and Piles et al. (TGRS 2009) have for example also worked combining passive and active microwave using a statistical approach.

RESPONSE: Will make the introduction clearer in terms of the objective and structure of this paper. The ultimate objective of our study is to develop an approach to combine both VUA-NASA passive and TU-Wien active microwave soil moisture products over these varying vegetation types for an improved soil moisture product. This approach should be applicable to both past and current microwave satellites, as well as new

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missions that are expected to bring higher accuracy of soil moisture retrievals. Together these data allow a long term global soil moisture product to be provided and extended.

However, there are several challenges in accomplishing this objective. First, within the domain of passive or active microwave satellites, no single satellite covers the entire period. Differences in sensor specifications (e.g., different microwave frequencies and resolutions) prevent merging soil moisture estimates from different instruments directly. Second, the currently available VUA-NASA passive and TU-Wien active microwave products represent volumetric soil moisture and degree of saturation respectively. Third, the accuracy of soil moisture retrievals over varying vegetation cover differs from passive or active microwave products, making the selection of the better retrievals a difficult task, particularly over regions where both products have comparable performances. This paper, as a step towards developing a long term global soil moisture dataset, aims at developing a method that can address the latter two challenges mentioned above.

In this context, Njoku et al. (2002) and Piles et al. (2009) will be cited to support the promise of combining passive and active microwave soil moisture. However, there is a significant difference in these two papers and our work because these studies experimented with airborne data and our work is directly focused on well established global soil moisture datasets.

Method

The description of the method is not very clear. The first sentence states that the method consists of two steps rescaling and merging. Then in section 3.1 the rescaling through the CDF matching technique is described, which later comes back in the description of the merging. I would suggest first to describe the merging and then the go into detail about rescaling.

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RESPONSE: Will revise.

Conclusions

In the conclusions I find that the authors are discussing their results and present even some discussion on the refinement of the applied method. The authors should make a clear distinction between the discussion and conclusion, which also mean that some of the discussion points need further investigation. For example, the uncertainty due to the inherent characteristics of the Noah soil moisture could easily be investigated by using the soil moisture from a different LSM.

RESPONSE: Will make new structure for the revised paper, e.g., Introduction, Data sources, Methods and results, and Discussions and conclusions. And move the text into the appropriate section in the revised manuscript.

Specific comments:

P.6701L5: "are sensitive to water on the earth surface". I don't think you mean here open water. So I would suggest changing the text into something as "soil water".

RESPONSE: Will change accordingly.

P.6701L25-28: "Both passive and active microwave techniques have inherent advantages and disadvantages. Higher accuracy of passive microwave soil moisture is expected over regions with low vegetation density, as the effects of vegetation attenuation are less (Jackson and Schmugge, 1995; Njoku and Entekhabi, 1996)."

These two sentences confuse me.

If a higher accuracy of passive microwave soil moisture is expected over regions with

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low vegetation because the attenuation by vegetation is less then one would also expect a higher accuracy under more dense vegetation.

Further, in the first sentence the authors write that “both passive and active microwave techniques have advantages and disadvantages”. A lot of text is devoted to explaining the advantages of passive microwaves, but are there also advantages of active microwaves.

P6704L7-9: “After removing the effect of vegetation growth and senescence.” I am not aware that the change detection algorithm used for developing ASCAT product truly corrects for the effect of vegetation. If the authors refer for this to the seasonal variant backscatter-incidence relationship, this should not be considered as a vegetation correction. Please revise the text or provide a better description.

RESPONSE: In the revised manuscript, instead of generally talking about advantages and disadvantages of passive and active microwave soil moisture, we will focus on VUA-NASA and TU-Wien soil moisture products from the beginning, as features of soil moisture retrievals from different algorithms may be different even using the same satellite signals.

A number of previous studies (Vischel et al., 2008;Brocca et al., 2010;Albergel et al., 2009;Gruhier et al., 2010;Rudiger et al., 2009;Draper et al., 2009;Wagner et al., 2007) evaluated these passive and active microwave soil moisture products using in situ measurements and found that VUA-NASA passive microwave product performs better over sparsely vegetated regions, while the TU-Wien active microwave product has better agreement with in situ measurements over regions of moderate vegetation density. Over the sparsely-to-moderately vegetated regions, both products have similar performances. Additionally, a recently used technique called the triple collocation approach has shown to have the ability to validate the representation of soil moisture anomalies in remote sensing products (Miralles et al., 2010). Scipal et al. (2008) and Dorigo et al. (2010) applied this technique on VUA-NASA passive microwave, TU-Wien active

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microwave and model simulated soil moisture products to estimate the relative error of each product. These three products are derived from different sources and considered having independent error characteristics. The results of triple collocation analysis showed that the errors of VUA-NASA passive microwave are smaller than TU-Wien active microwave product over sparsely vegetated regions and larger over moderately vegetated regions. Their errors are comparable over the regions with low-to-moderate vegetation density.

Theoretically, both passive and active microwave instruments with similar frequencies should give similar response over the same region regardless of vegetation density. Thus the most likely reason for different performance between VUA-NASA and TU-Wien soil moisture products lies in their different ways of treating vegetation component. The TU-Wien algorithm uses the seasonal variation of the backscatter-incidence angle relationship to correct for seasonal vegetation effects. Empirical evidences indicate that the TU-Wien soil moisture performs reasonably over the regions with apparent seasonal vegetation variation. The VUA-NASA algorithm uses a linear radiative transfer model to extract soil moisture and vegetation density simultaneously. To some extent, vegetation is considered to behave like a one-layered semi-transparent medium. With the increasing of vegetation density, the accuracy of soil moisture is expected to decrease, which is also supported by empirical evidences.

P.6702L1-15: In this part of the text and throughout the complete manuscript the terms low, sparse and moderate vegetation are used. Could the authors give some definition as to which vegetation cover is considered low, sparse and moderate?

RESPONSE: In the revised paper, we will show a map of vegetation density to illustrate the definitions of low, moderate and high vegetation density.

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P6705L17-25: Could the authors please provide some more information on the different soil moisture networks, such as type of instrumentation, accuracy, number of station within the network, climate?

RESPONSE: In the revised paper, we will add one table showing more information about different soil moisture networks.

P6706L11: I think the term “absolute” is a bit unfortunate here because both the AMSRE and ASCAT products are rescaled. Perhaps it is better to use “physical and relative units”.

RESPONSE: Will use ‘volumetric’ and ‘degree of saturation’ for AMSR-E and ASCAT respectively in the revised paper.

P6707L04: Do you mean soil texture?

RESPONSE: Yes, here soil property mainly represents soil porosity and percentage of clay and sand. Will make it clear in the revised manuscript.

P6707L07: Why do you create daily averaged and not use 3 hourly Noah soil moisture product?

RESPONSE: Essentially, the only role played by Noah modeled soil moisture is to provide the CDF curve against which we adjust the range of satellite-based soil moisture. This has no impact on the relative dynamics (e.g., relative soil moisture variations from day to day) and trends on the satellite-based soil moisture. The CDF curve of daily averaged from a year (i.e., 365 points) and the CDF curve of soil moisture corresponding to the same time of everyday for a year (i.e., 365 points) should be quite similar. Also, the blended product is intended to have daily interval, not hourly or 3-hourly interval.

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P6707L21-23: Why do you use eight linear equations? I am afraid that when using such relative coarse discretization you may get some ambiguous results at the points where the Noah and Satellite CDF's cross each other.

RESPONSE: CDF matching approach will be described in more detail to remove the confusion, e.g., which values are used to construct CDF curve and how to compute the matching parameters.

P6708L14: It is not clear to me what "this" is and why it needs examining? Moreover I do not think there is a detailed analysis presented.

RESPONSE: Will revise the method section thoroughly and present the methods and results in more detail.

P6709L10-13: The text here in combination with Table 1 is very confusing. Are the three situations in the text the same as the three cases in the table? What happened to the Italian soil moisture network? Were the soil moisture products compared to a single in-situ measurements or an average? And if an average of multiple measurements were used what was the variation among the measurements?

RESPONSE: Will show results of all sites (including Italian soil moisture network) and the variations if more than three (inclusive) in-situ measurements are located within one 0.25-degree grid cell.

P6711L01: "Thus we can use the error of passive . . .". How would you determine that error?

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RESPONSE: In the revised paper, we will remove the Figure 4 (and also this sentence) and replace it with one global map showing the vegetation density which will help us illustrate the error of VUA-NASA passive microwave soil moisture.

Reference:

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Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 7, 6699, 2010.