Reviewer #2

Data assimilaiton is important for improving our underestanding of Earth system via combining models with data. The booming of satellite data provide the chance to constrain large scale Earth system processes and can give us a more accurate estimate of land surface variables (LSVs). In this paper, the authors discussed the possibility of assimilating VOD into the land surface model (LSM) together with soil moisture. This is a good starting point, as pointed out by the authors, because the LSMs need a better constraint with more observations.

We thank the referee #2 for her/his positive comments about our work. Responses to comments and subsequent changes are detailed below.

Comment 2.1:

After reading this work, I admit that the data assimilation algorithm and the experiments conducted with LDAS-Monde is reasonable, but the only thing I am not convinced is the replace of LAI with VOD. This paper made the assumption mainly based on Kumar et al. (2019) with showed VOD can be seen linear with LAI. But we need to keep in mind that Kumar et al. (2019) also pointed out that VOD is different from LAI. The authors also showed in Fig.2. From a modeler's perspective, I feel this is too bold to do so and use this data for assimilation. Because this looks more like a forced matching of VOD to LAI. Some other papers (e.g. Rodríguez-Fernández et al., 2018) have pointed out that VOD contained both information about LAI and biomass, and the assimilation of VOD together with soil moisture has been successfully conducted in the Carbon Cycle Data Assimilation System (CCDAS) by Scholze et al. (2019). So I think the simulation of VOD by LSM is already possible. Therefore I do not agree that the re-scaling of VOD to LAI is due to the lack of model representation on VOD.

Response 2.1:

Your primary concern is regarding the seasonal linear re-scaling technique to match VOD to LAI, and the subsequent assimilation of the re-scaled VOD. In this research, the seasonal linear re-scaling is a statistical generalization, but it is also a method that has been nearly identically performed in Kumar et al. (2020). This article advances the same methodology by applying it to LDAS-Monde. A novelty with respect to the work of Kumar is that this assimilation directly impacts the model root-zone soil moisture layers (1-100cm), which is a unique capability of LDAS-Monde so far. The authors do fully acknowledge that VOD is not LAI. This is why a complex seasonal rescaling had to be performed to obtain a proxy of LAI from VOD. We realize that writing “linear rescaling” or “linearly rescaled” can be misleading. This has been corrected in a revised version of the paper, noting that it is a seasonal linear re-scaling. It is also true that VOD observations may convey other information such as biomass as demonstrated in Fig. 8 of Rodríguez-Fernández et al. (2018), and by Scholze et al. (2019). However, the latter studies used L-band VOD (from SMOS), while in this study X-band VOD is used. The L-band allows a much better penetration of the microwave signal through vegetation than at X-band. As a result, the latter is mainly sensitive to the leaf biomass while SMOS VOD data are mostly related to the wood biomass in forested areas. Teubner et al. (2021) showed that while X-

band VOD correlates well with in situ FLUXNET observations of GPP, L-band VOD is poorly correlated to GPP over either low of high vegetation types. The better GPP-VOD correlation at X-band could be explained by a better sensitivity of X-band VOD to the leaf biomass. In the analysis of the X-band VOD vs. LAI relationship, we have found that overall, there is a link between the two variables, as also shown in previous literature. This is an argument for seasonally rescaling X-band VOD. Additionally, while it may be possible to directly assimilate L-band VOD in CCDAS as performed by Scholze et al. (2019), this is not possible in LDAS-Monde, as the NIT version of ISBA now used in LDAS-Monde does not simulates the wood biomass capable of simulating VOD, nor changes in specific leaf area (SLA), that would be needed to simulate VOD. Moreover, studies have shown that VOD may be sensitive to rainwater interception by leaves (e.g. Saleh et al. 2006). The ISBA model is able to simulate interception but as far as we know, there is no simple way to simulate the physical interception effect on VOD. It is for this reason that a statistical re-scaling of VOD towards an LAI proxy was pursued. As described in the discussion section, these results will be used to pave the way towards more efficient assimilation of level 1 observations using machine learning techniques.

This discussion will be added to Section 4.1.:

"In the comparison of VOD and LAI before linear re-scaling, it is immediately apparent that vegetation type plays a large role in their relationship. These values seen and described in the results seem to indicate that heavily forested regions have only weak correlations between VOD and LAI observations. Saatchi et al. (2011) demonstrates that L-band satellite radar estimations of above ground biomass (AGB) are strongly impacted by forest structure, and Mialon et al. (2020) shows poor correlations between L-band VOD and estimated AGB over heavily forested areas of the Northern hemisphere. Additionally, RodríguezFernández et al. (2018) and Scholze et al. (2019) found that L-band VOD conveys large amounts of information relative to AGB, primarily related to wood biomass in forested areas. Teubner et al. (2021) found that while X-band VOD correlates well with in situ FLUXNET observations of GPP, L-band VOD is poorly correlated to GPP over either low of high vegetation types. In this research, the improvements to GPP from the assimilation of X-band VOD can be explained by a better sensitivity of X-band VOD to the leaf biomass."

We will include the following references:

Kumar, S. V., Holmes, T. R., Bindlish, R., de Jeu, R., and Peters-Lidard, C.: Assimilation of vegetation optical depth retrievals from passive microwave radiometry, Hydrol. Earth Syst. Sci., 24, 3431–3450, https://doi.org/10.5194/hess-24-3431-2020, 2020.

Rodríguez-Fernández,N. J., Mialon, A., Mermoz, S., Bouvet, A., Richaume, P., Al Bitar, A., et al.: An evaluation of SMOS L-band vegetation optical depth (L-VOD) data sets:High sensitivity of L-VOD to above-ground biomass in Africa, Biogeosciences, 15, 4627–4645. https://doi.org/10.5194/bg-15-4627-2018, 2018,

Saleh, K., Wigneron, J.-P., de Rosnay, P., Calvet, J.-C., Kerr, Y., Waldteufel, P., Escorihuela, M.J.: Impact of rain interception by vegetation and mulch on the L-band

emission of natural grass, Remote Sens. Env., 101, 127-139, https://doi.org/10.1016/j.rse.2005.12.004, 2006.

Scholze, M., Kaminski, T., Knorr, W., Voßbeck, M., Wu, M., Ferrazzoli, P., et al.: Mean European carbon sink over 2010–2015 estimated by simultaneous assimilation of atmospheric CO_2, soil moisture, and vegetation optical depth, Geophysical Research Letters, 46, https://doi.org/10.1029/2019GL085725, 2019,

Teubner, I. E., Forkel, M., Wild, B., Mösinger, L., and Dorigo, W.: Impact of temperature and water availability on microwave-derived gross primary production, Biogeosciences, 18, 3285–3308, https://doi.org/10.5194/bg-18-3285-2021, 2021.

Comment 2.2: *Therefore, I do not think this paper can be published in its current shape, unless the authors solve the problems in simulating VOD by the LSM. Before doing that, I do not think the detailed comments on the context is helpful for the authors, even I made some from my side.*

Response 2.2:

In order to avoid misunderstandings, we will emphasize that assimilation in LDAS-Monde differs from the assimilation in CCDAS. While the objective of CCDAS is to constrain model parameters values, LDAS-Monde consists of sequentially assimilating observations in order to constrain the day-to-day trajectory of the ISBA state variables, without changing model parameter values. Although being an uncalibrated model, ISBA performs as well as other state-of-the-art models in intercomparison experiments (e.g. Fig. B2 in Friedlingstein et al. 2020), even without assimilation. In order to improve the paper, we propose rewording parts of the discussion section to better describe the shortcomings of the re-scaling methodology, and how it is leading to more efficient assimilation of microwave level 1 observations in future studies.

The following has been added in section 4.1:

"While direct assimilation of VOD may be possible in some data assimilation systems (such as L-band VOD in CCDAS, as performed by Scholze et al. (2019)), this is not possible in LDAS-Monde, as the NIT version of ISBA simulates neither wood biomass nor specific leaf area (SLA), both necessary for simulating VOD. Additionally, the objective of VOD data assimilation in CCDAS is to constrain certain model parameters, while the objective of assimilating re-scaled X-band VOD in LDAS-Monde is to sequentially assimilate observations in order to constrain the day-to-day trajectory of the ISBA state variables, without changing model parameter values. Although ISBA is an uncalibrated model, it performs as well as other state-of-the-art models in inter-comparison experiments (e.g. Fig. B2 in Friedlingstein et al. (2020)), even without assimilation. Moreover, studies have shown that VOD may be sensitive to rainwater interception by leaves (e.g. Saleh et al. (2006)). The ISBA model is able to simulate interception, but there is no simple way to simulate the physical interception effect on VOD. It is for this reason that a statistical re-scaling of VOD towards an LAI proxy was pursued."

We will include the following reference:

Friedlingstein, P., O'Sullivan, M., Jones, M. W., Andrew, R. M., Hauck, J., Olsen, A., Peters, G. P., Peters, W., Pongratz, J., Sitch, S., Le Quéré, C., Canadell, J. G., Ciais, P., Jackson, R. B., Alin, S., Aragão, L. E. O. C., Arneth, A., Arora, V., Bates, N. R., Becker, M., Benoit-Cattin, A., Bittig, H. C., Bopp, L., Bultan, S., Chandra, N., Chevallier, F., Chini, L. P., Evans, W., Florentie, L., Forster, P. M., Gasser, T., Gehlen, M., Gilfillan, D., Gkritzalis, T., Gregor, L., Gruber, N., Harris, I., Hartung, K., Haverd, V., Houghton, R. A., Ilyina, T., Jain, A. K., Joetzjer, E., Kadono, K., Kato, E., Kitidis, V., Korsbakken, J. I., Landschützer, P., Lefèvre, N., Lenton, A., Lienert, S., Liu, Z., Lombardozzi, D., Marland, G., Metzl, N., Munro, D. R., Nabel, J. E. M. S., Nakaoka, S.-I., Niwa, Y., O'Brien, K., Ono, T., Palmer, P. I., Pierrot, D., Poulter, B., Resplandy, L., Robertson, E., Rödenbeck, C., Schwinger, J., Séférian, R., Skjelvan, I., Smith, A. J. P., Sutton, A. J., Tanhua, T., Tans, P. P., Tian, H., Tilbrook, B., van der Werf, G., Vuichard, N., Walker, A. P., Wanninkhof, R., Watson, A. J., Willis, D., Wiltshire, A. J., Yuan, W., Yue, X., and Zaehle, S.: Global Carbon Budget 2020, Earth Syst. Sci. Data, 12, 3269–3340, https://doi.org/10.5194/essd-12-3269-2020, 2020.