Reviewer #2: Anonymous Referee

This study uses an OSSE to estimate improvement of SWE retrievals if satellite-based SAR data from an X- and/or Ku-band sensor was assimilated in an LSM. The authors use a calibrated version of the LSM (nature run) and compare it to an uncalibrated run (open loop) and a Data Assimilation run using synthetic observations with simulated extents using the TAT-C software. This paper is an excellent contribution to the overall field of SAR missions to retrieve SWE. It is very well structured and easy to read with excellent supporting figures. The fact that the analysis was done in a very different study area (Western Colorado), this study complements other similar studies (Garnaud et al., 2019). It provides information on what SWE limit and TCF the SAR mission should be able to detect for this specific domain in Colorado.

[Answer] Thank you for your excellent feedback and the valuable comments on our manuscript. We have carefully revised our manuscript based on your comments.

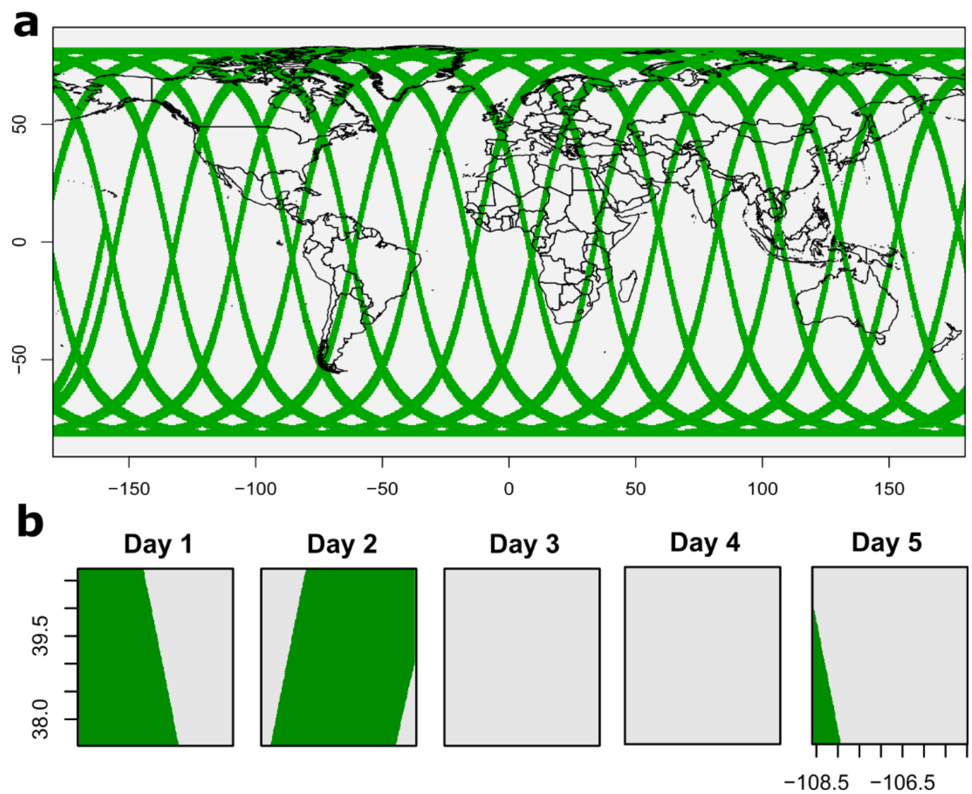
General comments:

One important limitation to this study that is not really discussed and I feel should be feasible with the current OSSE is the inherent geometrical limitations of SAR sensors (i.e. shadow/overlay) which complicates the retrieval of surface properties in mountain regions such as the region of interest in this study. The TAT-C software should allow to estimate the incidence angle and with the SRTM data, it should be feasible to mask out these blind spots. This evaluation might be outside the scope of this study, but I feel it should be discussed a bit further as a limitation of this study and be a future consideration. This would increase the number of masked grid cells that would not have SWE retrievals from satellite observations.

[Answer] Thank you for your valuable comments. We agree with the Reviewer's point. To address the concern, we added summarized discussions as the limitation in the manuscript as below.

L458-463 "Even though the OSSE of this study considers realistic sensor configurations for a volume-scattering SAR mission using the TAT-C software, there are inherent geometrical limitations of SAR sensors (i.e., shadow/overlay) which complicates the retrieval of surface properties in mountain regions such as the region of interest in this study. To design the OSSE more accurately, the geometrical observing gaps related to incidence angles of the SAR sensors and surface elevations should be accurately estimated. This may increase the number of masked grid cells that would not have SWE retrievals from hypothetical satellite observations."

To help reader understand the masked swath using TAT-C, we added a figure in Supporting Information (Figure S3).



To add to the other reviewer's comment: it would be useful to set the priorities of this study and give examples of what kind of mission would be relevant for these priorities since there is no "one-size fits all" mission. As mentioned the range of SWE values given for the Tundra class is not what you will find in other Tundra environments. Would a mission that would provide such improvement for the Tundra high SWE values work for other Tundra environments knowing the SWE values, snow stratigraphy (grain type/microstructure) and landscape conditions are very different? Adding some discussion on the specific snow conditions of the AOI would be relevant to this study.

[Answer] Thank you for making the reasonable point. We acknowledge it is possible that our findings for a certain snow classification (such as Tundra) cannot be guaranteed to be applicable to other Tundra regions with different snow stratigraphy and landscape conditions (e.g., forest types). The best way to fully address this is to design OSSE for a larger study domain including multiple locations with the same classification but likely different snow and land characteristics. For this, we are currently working for a new OSSE study embracing the entire western U.S. and parts of north-central U.S.

To better address the Reviewer's concern, we extended our existing discussion part by including additional discussion on specific snow conditions of the AOI in this study.

L445-450 "There are limitations to this study that may need to be considered in future research. First, the domain of this study (i.e., western Colorado) contains four seasonal snow classes and wide elevation ranges, enabling us to represent mountainous environments and quantify approximate performances in other regions that have similar snow regimes and land surface characteristics. However, we acknowledge that it is not enough to extrapolate our findings to global coverage of a future mission concept. For example, the snow condition of Tundra class in the domain of this study can be different from that of Tundra environments in Alaska. Further OSSE investigations with multiple domains in different snow climates, vegetation characteristics, and terrain complexity (e.g., steep vs. flat terrain) will complement current efforts."

To add, this study only focuses on SAR retrieval from backscatter values. But what if the sensor has single-pass altimetry/interferometry capabilities? This would help to retrieve snow depths at least, especially during melt season from differential DEMs. Wouldn't that improve the estimation of SWE from the LSM? This might again be outside the scope of this study based on the priorities, but I feel this should be discussed as SAR missions are very rich data sources.

[Answer] Thank you for the Reviewer's comment. We are not sure what the comment "what if the sensor has single-pass altimetry/interferometry capabilities?" Does this mean either a hypothetical sensor has both SAR and altimetry/interferometry capabilities or altimetry/interferometry capabilities as one of the hypothetical sensor options to test within OSSE. Generally, we agree that the altimetry/interferometry sensors can help retrieve snow depths and have a potential to synergistically improve SWE estimates from LSMs using assimilation.

The altimetry/interferometry capabilities (such as ICESat-2) for snow depth retrievals within an OSSE framework have been examined in another recent study (Kwon et al., 2021). They found that the smaller number of available snow depth observations given the narrow ICESat-2 sampling geometry led to relatively small improvement of SWE estimates.

Specific Comments:

L.39-44: No need to list the different PMW sensors here, I would keep "Historically, a series of satellite-based passive microwave radiometers have been used to develop spatially distributed snow depth and SWE information (Cho et al., 2017; Derksen et al., 2005; Foster et al., 2005; Vuyovich et al., 2014).

[Answer] Agreed. We have removed the list of the PMW sensors.

l.220: to make this OSSE more realistic, what would be the incidence angle range of such a SAR mission configuration?

[Answer] The reviewer makes a reasonable point. We agreed that the result would be more realistic if we consider the incidence angle ranges in the OSSE framework.

Fig 4.: provide the TCF ranges for the different elevations. I suspect there is not much TCF over low and mid elevations where there is not much improvements in runs with more TCF capability.

[Answer] Thank you for the suggestion. We added the TCF percentages for the different elevations in Supporting Information (Table S2). As you expected, for low elevations, low TCF areas were dominant (e.g., 86% of areas with TCF up to 20%), resulting in small improvements with more TCF capability. For mid elevations, there were still small improvements, even though more than half of the areas are with high TCFs (e.g., 51% areas with TCFs above 20%)

We mentioned the inclusion in the caption of Figure 4 like below.

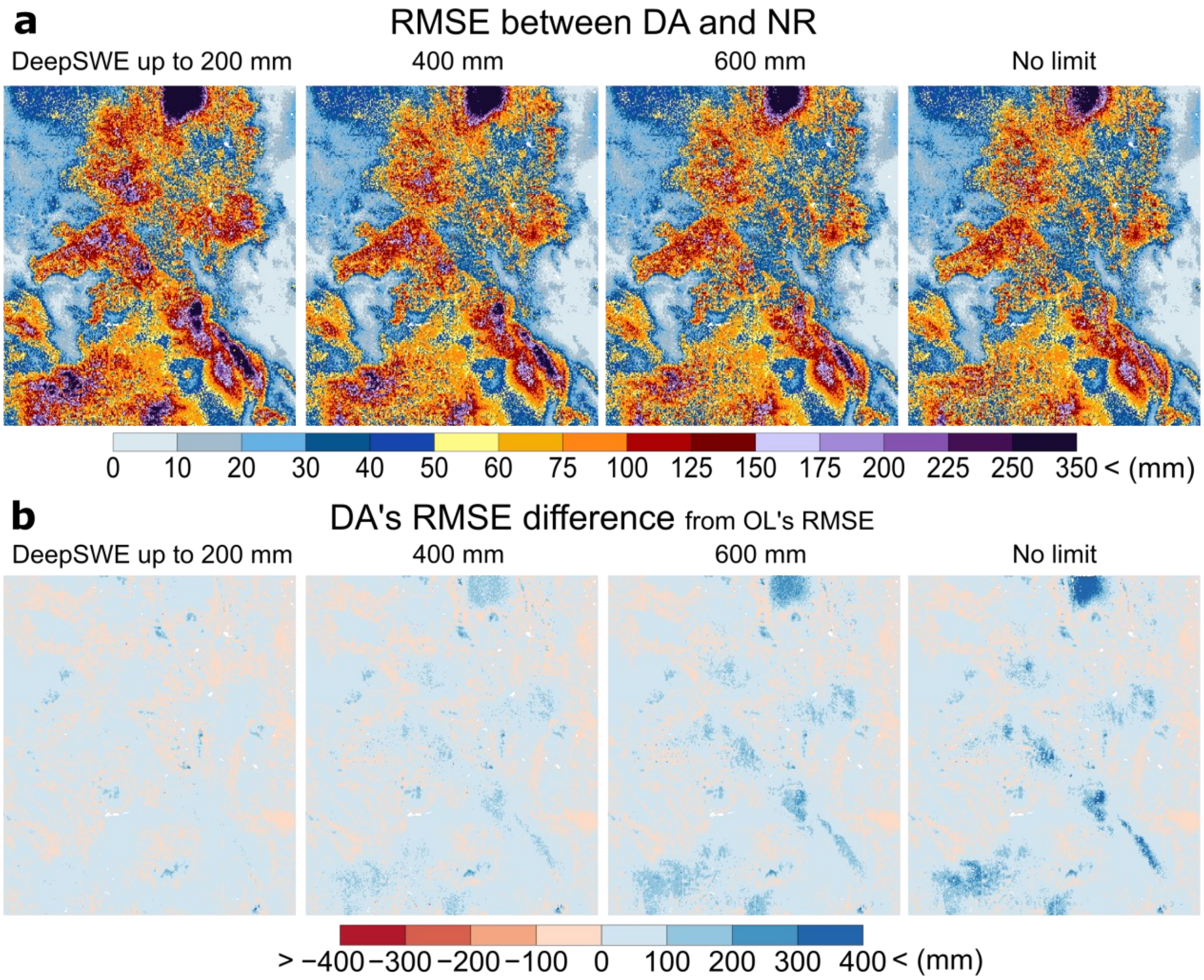
"Figure 4. Domain-average SWE comparison between NR, OL, and DA experiments with different levels of detection capability in areas with bare ground and tree cover fraction (TCF) limits up to 10, 20, 40, 60, and 80%. The areal proportion of TCFs for three elevation ranges are provided in Table S2."

Table S2. The areal proportion of the different TCF ranges for three elevation ranges

	Low elev. (0-2500 m)	Mid elev. (2500-3000 m)	High elev. (3000-4000 m)
TCF = 0%	14	3.5	0.6
TCF up to 10%	76	36	25
TCF up to 20%	86	49	39
TCF up to 40%	96	73	69
TCF up to 60%	99	93	93
TCF up to 80%	100	100	100

Fig 7.: Change RMSD to RMSE

[Answer] We changed this. Thank you.


a
RMSE between DA and NR
DeepSWE up to 200 mm
400 mm
600 mm
No limit
0 10 20 30 40 50 60 75 100 125 150 175 200 225 250 350 < (mm)
b
DA's RMSE difference from OL's RMSE
DeepSWE up to 200 mm
400 mm
600 mm
No limit
> −400 −300 −200 −100 0 100 200 300 400 < (mm)