Response to editor:

The authors thank the editor, and highly appreciate the efforts made by the editorial team in handling the manuscript. The overall review comments indicate positive feedback with minor revision of the manuscript and for further consideration. The authors have taken sincere efforts to address each concern raised by the reviewer to improve the manuscript. The comments raised by the reviewer and the response from authors are added below.

Response to reviewer 1:

The authors sincerely thank reviewer-1 for his valuable efforts in reviewing our manuscript titled "Passive Microwave Remote Sensing based High Resolution Snow Depth Mapping for Western Himalayan Zones using Multifactor Modelling Approach". The suggestions and feedback shared by the reviewer are highly helpful in enhancing the manuscript. The response to the queries and suggestions provided by the reviewer are attached in the response document below in the point-by-point manner. Kindly note that reviewer comments are in black colour font, response from the author is in blue colour font, whereas the changes made in the manuscript are highlighted in blue colour italic font.

Reviewer feedback: Authors have developed a region-wise multifactor model to map the snow depth at 500m spatial resolution in the western Himalayas (particularly three lower, middle and upper zones). This study is essential regarding hydrology, climatology and other natural hazard perspectives and is recommended for consideration.

Author response: We thank the reviewer for his kind remarks and overall positive feedback about the manuscript.

Reviewer comment 1(a): Under the abstract, the authors have written about the very limited studies that were conducted on snow depth estimation using the passive microwave dataset. I suggest adding more information for more clarity.

Author Response: Thank you for suggesting this. The statement mentioning the limited number of studies i.e., 'However, only a limited number of PMW SD estimation studies are carried out for WH till date' is revised with additional details for providing more clarity to the readers. Further it must be noted that all necessary studies in a comprehensive manner are already included in the introduction of the manuscript (kindly refer the information present from Line-80 to Line-125 in the introduction section of the manuscript).

'However, fewer PMW SD estimation studies are carried out for WH till date, which are mainly confined to small subregions of WH.'

Reviewer comment 1(b): I also advised them to shorten the abstract by removing the information about the LHZ, MHZ, and UHZ (this is obvious information).

Author Response: The authors sincerely acknowledge the suggestion given by the reviewer that the statement in the abstract mentioning about the division of WH into LHZ, MHZ and UHZ is obvious information. However, the authors opine it would be difficult to make the reader understand the results part of the abstract without introducing LHZ, MHZ, and UHZ. Additionally, it can be confusing to few of the readers whose region of interest is not Himalayan if LHZ, MHZ, and UHZ are not introduced prior. Therefore, authors believe it is necessary to state that WH is divided into three zones i.e., LHZ, MHZ, and UHZ for which models are built separately and request the reviewer to consider it.

Reviewer comment 1(c): Are you sure about the different regression approaches developed in this study? Recheck this statement.

Author Response: We thank the reviewer for pointing this out. The authors agree that the statement – 'Different regression approaches (i.e., linear, logarithmic, reciprocal, and power) are developed and evaluated ….' is not very clear as the study focus is standard regression approaches (i.e., linear, logarithmic, reciprocal, and power) to develop the snow depth models using different input variables. Therefore, the statement is revised as suggested by the reviewer.

'Different regression approaches (i.e., linear, logarithmic, reciprocal, and power) are used to develop snow depth models, which are evaluated further to find if any of these models can address the heterogeneous association between SD observations and PMW TB.'

Reviewer comment 1(d): Mention the full form of AMSR2.

Author Response: The full form of AMSR2 i.e., Advanced Microwave Scanning Radiometer 2 is already present in both abstract as well as in manuscript.

Comment 1(e): Results need to be mentioned in a precise manner.

Authors response: Authors welcome the suggestion shared regarding the results mentioned in the abstract. The information pertaining to results is now revised as given below.

'Based on a detailed analysis of the results, it is observed from the analysis that power regression SD model has improved accuracy in all WH zones with the less Root Mean Square Error (RMSE) in MHZ (i.e., 27.21 cm) compared to LHZ (32.87 cm) and UHZ (42.81 cm). Spatial distribution of model derived SD is highly affected by SCDs, terrain parameters, geolocation parameters and have better SD estimates compared to regional and global products in all zones. Overall results indicate that the proposed multifactor SD models have achieved higher accuracy in deep snowpack (i.e., SD >25 cm) of WH compared to previously developed SD models.'

Reviewer comment 2(a): Under the introduction part, the authors have covered all the aspects overall. But proofreading is required in some sentences such as their approach (L105), their models are developed (L110) etc.

Author Response: The authors have rephrased the lines suggested by the reviewer. Additionally, proof reading is also carried out to see for any other such occurrences.

L105 is revised as below:

'Das and Sarwade (2008) used 18.7 GHz and 36.5 GHz horizontally polarized data from AMSR-E and modified the coefficients of Chang et al. (1987)'s model to suit the Indian Himalaya. The modified model has shown a mean absolute error (MAE) of 20.34 cm in SD estimates but failed to estimate SD above 60 cm. '

L110 is revised as below:

'In another study, Singh et al. (2015) developed PMW SD models for the Dhundi and Patseo regions of Himalaya using data from ground-borne radiometers and in-situ observations. However, SD models are developed using observations collected from only two field surveys, evaluated using a single day observation of AMSR-E TB data, and not tested spatiotemporally.'

Reviewer comment 2(b): Revision is required for the second objective (L135) due to some grammatical issue. Under the third objective, variables could be mentioned.

Author Response: As advised by the reviewer, the second objective has been rephrased and included in the manuscript.

'Comparison and evaluation of the proposed multifactor model(s), previous SD models and AMSR2 SD products in different WH zones.'

Also, in the objective variables are now mentioned and included in the manuscript as follows:

'Analysis of multifactor SD model's retrieval accuracy with respect to the selected auxiliary variables (such as elevation, slope, land cover types, and SCDs).'

Reviewer comment 3(a): Under the study area, many terms are repetitively defined such as LHZ, MHZ, and UHZ (165) as you have already explained under L40. Underline 165 Upper Himalayan Zone is incorrectly abbreviated as MHZ.

Author Response: The authors thank the reviewer for rightly pointing this out. Now, authors have corrected the manuscript as advised. The statements mentioning the presence of three zones are now removed to avoid repetition (similar information as given in L40). Further, the line (L165) in the manuscript is removed in the revised manuscript. The updated study area information in the revised manuscript is as follows from line 165 to 170.

'In this study, three WH zones i.e., LHZ, MHZ, and UHZ defined based on the historical local meteorological and avalanche occurrence data (Sharma and Ganju, 2000) are used for developing multifactor SD models. The geomorphic and climate characteristics of these zones are given in Table 2.'

Reviewer comment 3(b): Under the methodology part, the flowchart is well-defined but the five steps need to be mentioned in the flowchart as explained in the subsections. The flowchart must be the stepwise reflection of the subsection (3.1 to 3.5).

Author Response: Based on the reviewer suggestions, the flowchart is now updated as follows in the revised manuscript.

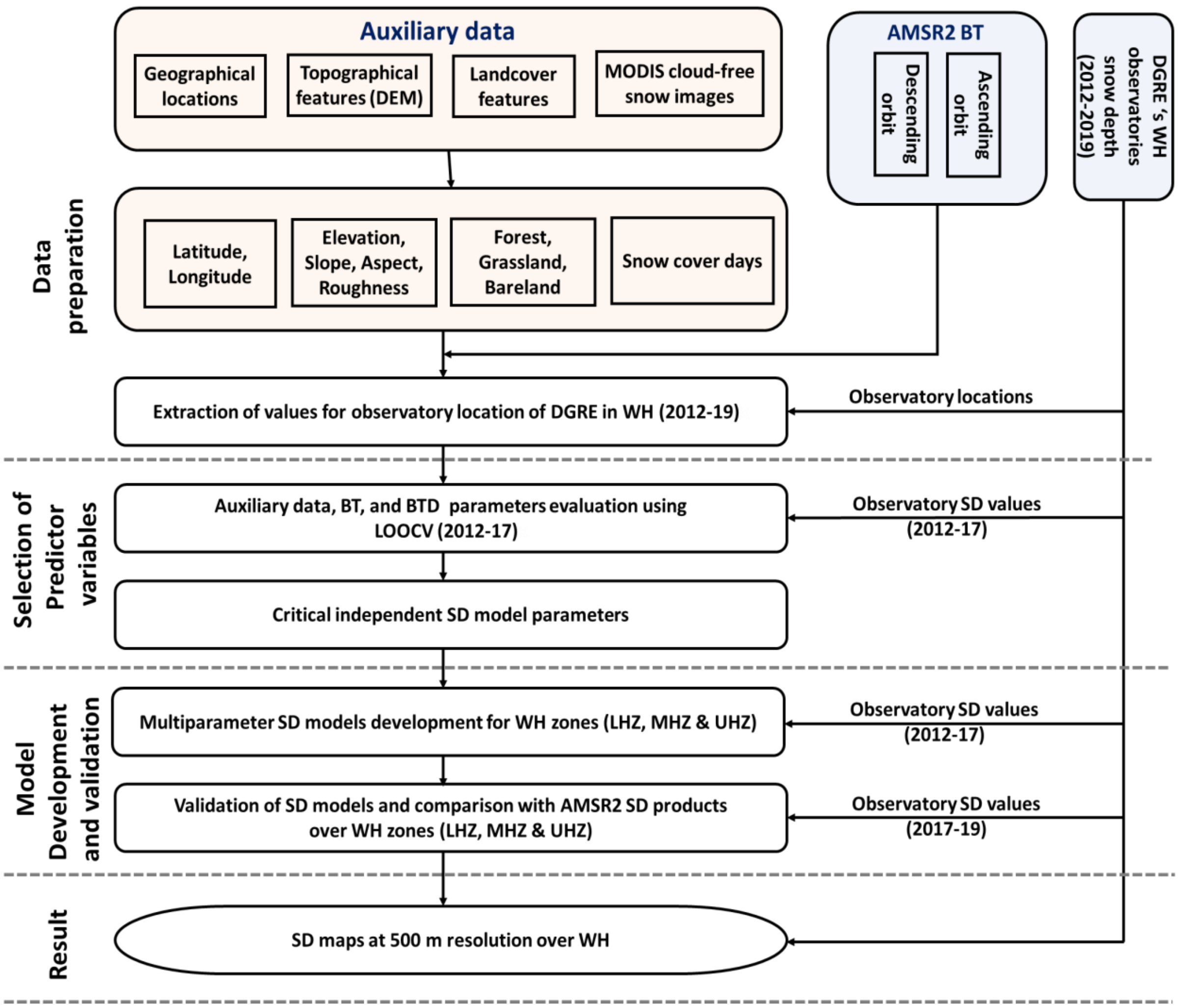

Figure. 2. Flowchart representing the methodology

Reviewer comment 4: Results and discussion are well explained. The challenges are also defined in the discussion part. However, could you please also highlight any scope of the advanced machine learning or deep learning approach in the snow depth estimation? (Some of the previous studies also involved the neural network/deep learning approach in snow depth estimation). I think this point may increase the interest of the readers.

Author Response: We thank the reviewer for suggesting this. In this study, the proposed multifactor SD model has an advantage that it uses a specific equation to predict the complex, non-linear relationship between SD and independent multifactor. The SD predicted using the proposed model(s), on the other hand, has a substantial error. The Machine learning algorithms can help get around some of these problems. Different machine learning approaches are widely used for SD estimation in different studies for example artificial neural networks (Tedesco et al., 2004) over Finland, support vector machines (Liang et al., 2015) over Northern China, and Extremely randomized trees (Tanniru and Ramsankaran, 2023) over Alaska. However, specific information related to machine learning approaches and their potential is not in the scope of the current manuscript. Therefore, authors have mentioned and updated some information related to machine learning as a possible scope for improvement in the manuscript under the conclusions and summary section. The revised information is as follows.

'Recently, different machine learning models are extensively used for modelling SD in many studies (Tedesco et al., 2004, Liang et al 2016, Tanniru and Ramsankaran, 2023). The potential of such machine learning approaches can be investigated for improving the SD estimation.'

Tedesco, M., Pulliainen, J., Takala, M., Hallikainen, M., and Pampaloni, P.: Artificial neural network-based techniques for the retrieval of SWE and snow depth from SSM/I data, Remote Sens Environ, 90, 76–85, https://doi.org/https://doi.org/10.1016/j.rse.2003.12.002, 2004.

Liang, Jiayong, et al. "Improved snow depth retrieval by integrating microwave brightness temperature and visible/infrared reflectance." *Remote Sensing of Environment* 156 (2015): 500-509.

S. Tanniru and R. Ramsankaran, "Machine Learning-Based Estimation of High-Resolution Snow Depth in Alaska Using Passive Microwave Remote Sensing Data," in *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, vol. 16, pp. 6007-6025, 2023, doi: 10.1109/JSTARS.2023.3287410.

Reviewer comment 5: The conclusion part needs to be specific. However, it has been observed that many contents of the conclusion don't make any significant impact like the WH region is divided into three zones, i.e., LHZ, MHZ, and UHZ. So, such types of lines could be removed.

Author Response: We thank the reviewer for suggesting this. The conclusions section is revised by as suggested by the reviewer.

'*The contrasting climate and snow conditions prevailing in WH zones present new challenges in accurate SD retrievals using PMW remote sensing. The limited access to in-situ SD data, rugged topography, and inclement weather resulted in fewer SD studies over the WH region. In the* *mountainous region, the topography parameters, i.e., elevation and slope, affect the snow precipitation and its persistence.*

In this study, different regression approaches (i.e., linear, logarithmic, reciprocal, and power) are used for developing the multifactor SD models using multifrequency AMSR2 TB observations and auxiliary parameters (such as terrain (elevation, slope), location, SCD, etc.,) to estimate SD at 500 m spatial resolution in each WH zone. The overall results indicate power regression performed better compared to other tested approaches in all zones. Further, the results of the multifactor model from power regression are evaluated by comparing the SD estimates with ground SD, other SD products, and PMW models. The results indicate under deep snow (>25 cm) conditions the developed multifactor model has shown higher accuracy compared to the AMSR2 operational SD product and other SD models. However, the accuracy of SD from the multifactor model is affected by variations in auxiliary parameters such as SCD, elevation, etc. With an increase in SCD, the SD increased in each WH zone. Additionally, the RMSE error associated with SD is also increased alongside SCD and SD in each WH zone. The MHZ has stable snow conditions with relatively less thick snowpack. Therefore, the multifactor SD model in this region has shown improved accuracy for a given SD class compared to other WH zones. Overall, the proposed multifactor SD models for WH zones have demonstrated substantial improvement in estimating SD compared to the operational AMSR2 SD product, heritage SD model, i.e., Chang's model, and previous models developed within WH zones.

Though multifactor SD model has outperformed other tested models and products, there is still scope for improving PMW SD estimates in WH. The developed model(s) have shown poor performance compared to AMSR2 products when SD <25 cm. This can be possibly attributed to wet snow conditions prevailing in the early winter, i.e., when SD will be shallow. Further, the inclusion of snowpack characteristics such as snow grain size, wetness, density data during the model development can improve the accuracy of SD estimates. The available in-situ SD observations are very limited considering the high spatiotemporal variability of SD in this region. Therefore, there is an immediate need of expanding the in-situ network of monitoring stations, and field-based studies to determine the first-hand knowledge of snowpack information in WH region. Recently, different machine learning models are extensively used for modelling SD in many studies (Tedesco et al., 2004, Liang et al 2016, Tanniru and Ramsankaran, 2023). The potential of such machine learning approaches can be investigated for improving the SD estimation.'

Reviewer comment 6: Overall, many aspects have been disclosed in this article and recommended for further consideration.

Authors response: We greatly thank the reviewer for the kind remarks on the manuscript.