Response to 2nd Referee's Comments

We would like to thank the reviewer's comments on our manuscripts. We will modify the manuscript accordingly, and the detailed responses are listed below.

General Comments

1. The authors proposed an alternative subgrid classification method of sub-grid variability in topography and vegetation cover and claimed it will enhance the representation of subgrid land characteristics in land surface models. Yet it is not clear, based on the paper, how the proposed method enhances the representation of subgrid land surface characteristics. The authors did not explain what weakness the existing methods of subgrid classification have and whether the new method does better.

Response:

In the revised manuscript, we will further clarify the benefit from the new subgrid method in detail as followed:

Both atmospheric and land surface processes vary across a wide range of spatial scales. To improve simulations of precipitation and surface hydrology associated with surface heterogeneity in elevation and vegetation, high spatial resolution is needed. However, even with computational resources available today, climate models cannot explicitly resolve land surface heterogeneity at scales finer than the model grids that typically vary between 10 km to 200 km so representations of subgrid land surface heterogeneity are needed. In some LSMs, elevation heterogeneity is represented using subgrid elevation classes so that the effects of subgrid topographic variations on precipitation and subsequently land surface processes such as snow and soil moisture can be parameterized. The Variable Infiltration Capacity (VIC) model is one example of LSMs that divides a model grid cell into multiple subgrid elevation bands to achieve improved simulations of surface hydrology. Variability in vegetation cover is usually represented in LSMs by specifying subgrid fractional coverage of vegetation to resolve more vegetation types to improve the simulations of surface fluxes. The Community Land Model (CLM) is one example of LSMs that divides a model grid cell into multiple subgrid Plant Function Types (PFTs). However, neither of the methods considers both subgrid distributions of topography and vegetation cover.

The method developed in our study jointly represents both subgrid elevation and vegetation to enhance the simulations of surface fluxes and surface hydrology that are influenced by heterogeneities in both elevation and vegetation. While this may be accomplished by dividing a model grid cell into a large number of subgrid elevation/PFT classes, it can greatly increase the computational burden in land surface modeling as land surface processes must be calculated for each subgrid class. This study examines approaches to derive subgrid classification schemes that account for subgrid variability of both surface elevation and PFT without significantly increasing the computation burden of current LSMs using CLM4 as an example.

In the manuscript, we compared the new method with the baseline method which follows the CLM4 vegetation representation and assigns a single elevation class to each PFT. The results showed that new method provides an obvious advantage in representing topographic variability at a similar computational efficiency as the average standard deviation of surface elevation in each subgrid elevation band was greatly suppressed (page 2188, line 8-25).

With the new subgrid method, each surface elevation class can be forced by different atmospheric conditions by disaggregating the atmospheric forcing from each model grid cell to the subgrid elevation class based on temperature and precipitation lapse rate or the subgrid parameterization of orographic precipitation described in Leung and Ghan (1995; 1998). Separate calculations of surface processes can be performed for each subgrid PFT within each subgrid elevation class. This allows the interactions between soil, vegetation, and atmosphere to be represented for each subgrid vegetation-elevation class to improve the simulation of land surface processes and feedbacks to the atmosphere.

2. The authors mentioned repeatedly the computational burden of a certain number of total classes without being specific how computationally costly it is. The 18 total number of classes appears to be arbitrary depending on how many classes are used.

Response:

In LSMs simulation is performed for each computational unit. With the existing subgrid method such as that used in CLM4, each of the 15 PFTs within a model grid is a computational unit, while with the new subgrid method each subgrid vegetation-elevation class is a computational unit. Computational burden scales linearly with the number of computational units. For example, the computational burden of using 24 total number of vegetation-elevation classes in the new subgrid method is more costly than the existing CLM subgrid method in which 15 PFTs are classified.

One of the objectives of this study is to examine the new subgrid classification scheme that accounts for subgrid variability of both surface elevation and PFT without significantly increasing the computational burden of the current land surface models. The classification scheme with 18 total number of classes was evaluated because it is similar to the number of PFTs in the standard CLM4 that was used as an example of LSM. Using the CLM4 PFT-based classification scheme as a reference, we assessed the accuracy and computational efficiency of several classification schemes to derive an optimal method to account for both subgrid surface elevation and vegetation in LSMs.

In the revised manuscript, we will further clarify the concept of the computational burden and the reason to use 18 as the total number of classes.

3. The authors failed to present a convincing case that the proposed method has any advantages over other methods in improving the performance of land surface models. The work is superficial and lacks scientific value.

Response:

Although our manuscript did not include a case study to examine the performance of the proposed method in improving the LSMs, Leung and Ghan (1998) provided evidence that consideration of both subgrid topography and vegetation improves the simulation of surface temperature and precipitation, which then improves the simulation of snow water equivalent compared to observations. Similarly, using the new subgrid scheme that represents the subgrid joint distribution of surface elevation and vegetation, the LSM simulation will be improved because different atmospheric conditions will be assigned to each elevation band. For example, elevation band corresponding to higher elevation will have cooler near surface air temperature and increased precipitation compared to the grid cell mean values. Applying such atmospheric forcing to different PFT classes within the same elevation class will simulate surface fluxes and soil hydrology that reflect the influence of atmospheric forcing for the higher elevation on different PFTs to improve land surface simulations for the specific subgrid elevation/PFT class as well as the overall grid cell averaged conditions.

Although Leung and Ghan (1998) and subsequently Ghan et al. (2006) already implemented a subgrid method to a regional and global climate model, respectively, they did not compare different classification schemes to arrive at an optimal method to account for subgrid variations for both surface elevation and vegetation. Using updated datasets of high resolution DEM and PFTs, this study provides a systematic analysis and comparison of different ways to classify subgrid surface elevation and vegetation to provide an optimal approach that improves both accuracy and computational efficiency. However, implementation of the subgrid scheme in CLM and assessing the effects of representing both subgrid elevation and vegetation on land surface simulations will be discussed in a follow-on study.

4. The paper is not well written, especially the first half, disorganized with many repetitions.

Response:

We thank the reviewer's comment. We will make the revised manuscript more concisely. For example, we will simplify sections "Introduction" and "Results and Discussion" to avoid repetitions.