Response to 1st Referee's Comments

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

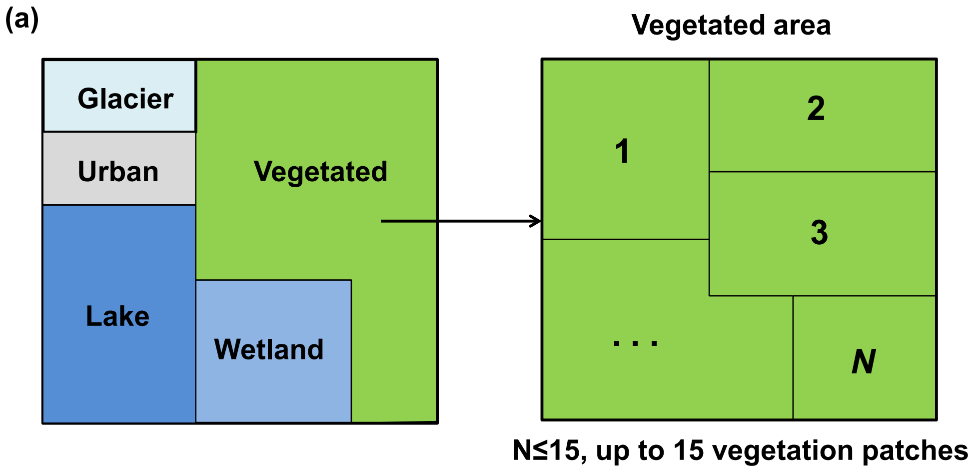
General Comments

(1)Section 2.3

(a) A simple schematic diagram of one grid cell showing default CLM subgrid classification method on one side and new SGC method on the other side would be helpful. Particularly, highlighting the advantages of new SGC method compared to the default CLM method.

Response:

We thank the reviewer's suggestion. In the revised manuscript, we will add a schematic diagram of subgrid patches for both the default CLM and SGC method. The diagram is shown as follow.



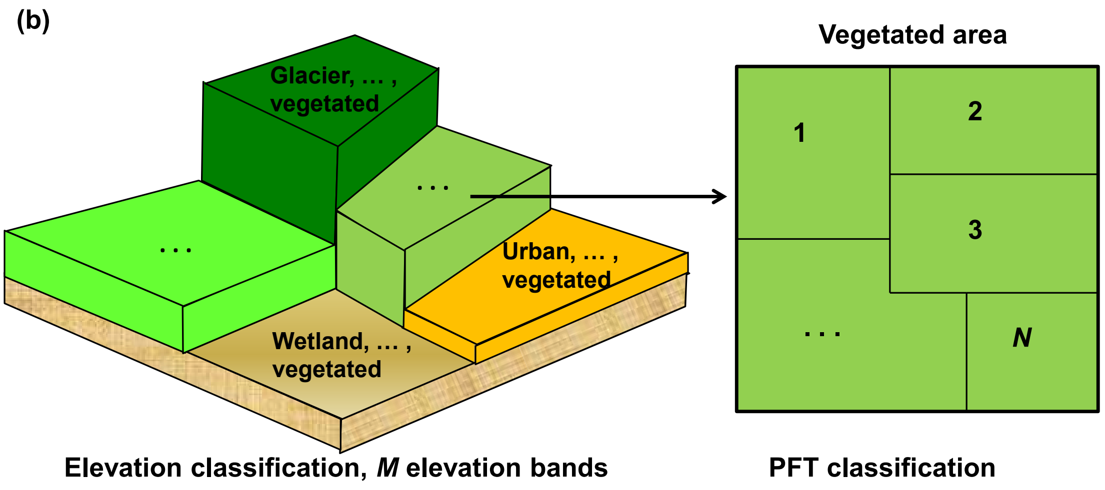


Figure 1. A schematic subgrid representation in (a) default CLM and (b) the SGC method. For each grid cell in the new SGC method, *M X N* should be no more than the pre-defined *N_class*.

(b) For "M X N subgrid classes" or "N_class": you may want to use the term e.g. Land Response Unit (LRU) or something similar to that. Where LRUs are unique combination of elevation and vegetation classes in the given grid cell. Otherwise, it is difficult to differentiate between 'elevation classes', 'vegetation classes/types' and 'M X N subgrid classes'

Response:

We thank the reviewer's suggestion. In the revised manuscript, we will use the term Land Response Units (LRUs) to replace the phrase "total subgrid classes". The term total number of classes "*N_class*" is also replaced with "*N_LRU*" to be discriminated from "elevation classes" and "vegetation classes/types". For example, line 8-11 on page 2184 will be modified as:

"…, with each elevation-PFT class treated as a unique computational land response unit (LRU) in the land surface model. To reduce computational burden, we set the maximum-allowed total number of LRUs (or subgrid classes) to "N_LRU" (e.g., 18 LRUs) for each model grid."

(c) Criteria for optimal classification: "(1) the elevation range for each elevation band is less than or close to 100m". I think, fixing 100m values is affecting your results, e.g., you have more elevation classes at the expense of less PFT classes in the complex topography terrain of western

United States regions (e.g. Fig. 6(a) and (b)). I was wondering if making '100m' values a variable, something similar as you did for PFT, would be of any help. For example, for PFT you have a criteria of minimum 80% of PFT variability in the given grid cell. Can you come up with a similar criteria for elevation too?

Response:

We thank the reviewer's suggestion. The SGC classification method is aimed to represent the joint variability of both elevation and PFT in an optimal way. To best explain PFT variability, we set the minimum threshold of 80% for PFT, i.e., the method requires at least 80% of total PFT is explained. The maximum threshold of the elevation is similar to the criteria of PFT. It restricts the elevation variations within each elevation band to ensure that elevation variability can be explained as much as possible.

The elevation interval method has been used in representing subgrid topography in land surface models. For example, Nijssen et al. (2001) used elevation bands with a 500m interval to represent the subgrid topography; Leung and Ghan (1998) also used pre-determined elevation intervals for elevation classification.

In our study, the threshold 100m was fixed conditionally to allow us to capture differences in atmospheric forcing and land surface response due to topographic variations. The use of a 100m interval is important to capture snow variability near the snowline (a 100m change in elevation can correspond to 0.65^{o}C change in surface temperature). First, a minimum area threshold of 1% was used to limit the area of each elevation band. An elevation band containing less than 1% of the land area of the model grid is added to the neighboring elevation band. In this case, the elevation band can have elevation interval greater than 100m. Second, the criterion of PFT is used as priority. If none of the combinations satisfies both conditions (average elevation interval less than 100m and %PFT explained greater than 80%), the classification explaining more than 80% of PFTs and with elevation range greater than but closest to 100m is selected. Thus, in areas of complex terrain, although less PFT variabilities are explained, the total percentage of PFT is still greater than 80%, but the elevation interval can be greater than 100m.

(2) Some clarity is needed in default CLM computation burden and the computational burden from the new method. For example, in default CLM a grid cell can have maximum 4 PFT classes, where as in SGC method a grid cell can have maximum 24 LRUs, that is 6 times increase in the computational burden of CLM.

Response:

In the current version of CLM (CLM 4.0), there are no restrictions on the maximum number of PFT classes as in the earlier version of CLM (e.g., CLM 3.0); that is, the total number of PFTs within a grid cell can be as many as 15 (Oleson et al., 2010). In the manuscript, the default CLM was compared with the SGC method using the same number of LRUs (*N_LRU=18*) to specifically address this question and to reveal the advantages of SGC over the baseline default CLM subgrid method at similar computational burden (line 1-4, page 2185, Figs. 3, 5, 6). The purpose of using 24 LRUs and 12 LRUs was to assess SGC method at different computational burdens against SGC1 and SGC2.

In the revised manuscript, we will further clarify the computational burden of the SGC method and the default CLM. We will also separate "Section 3.1 The SGC method" into "Section 3.1 The SGC method vs. baseline CLM subgrid method" and "Section 3.2 The SGC method with different LRUs and model resolutions" in order to clarify different evaluation analysis.

(3) Figs. 9 and 11 are hard to follow through. Please consider simplifying these figures. One idea could be separating the effects of 'N_classes' from the effects of 'SGC, SGC1 and SGC2 methods'.

Response:

We thank the reviewer's suggestion. We acknowledged that Figs. 9 and 11 are a little crowded as there are three variables in each figure (different methods, different computational burdens and varying model resolutions). However, in the manuscript, these figures were interpreted not only by comparing the three methods at a certain *N_class* (will be changed to *N_LRU* in the revised manuscript), but also by comparing the trend of the three methods with the change of *N_class* and model resolutions. For example, we see in Fig. 9a that compared to the other two methods, the total PFTs explained by SGC decreases more rapidly with less computational burden as the model grid size increases (Page 2192 line 5-10). Such comparison would be harder to make if the effects of *'N_class'* are separately presented from the effects of 'SGC, SGC1 and SGC2 methods'. Moreover, separating the effects of "*N_class*" from the effects of different methods as suggested will produce more figures. For example, each plot of Fig. 9 will be separated into three plots, which will result in 12 plots in total. This will also complicate interpretations of the figures. For these reasons, we decide to keep the layout of Fig. 9 and Fig. 11, but we will change the line styles and enlarge the symbols to make the figures more easily interpreted.

Detail Comments

(1) Line 19, Page 2178: "different perspective of surface cover classification". At this point reader does not know what different perspective is? Please clarify".

Response:

We thank the reviewer's suggestion. We will clarify the different perspectives of surface cover classification in SGC1 and SGC2 methods. The revised sentence is as follow:

"The new method was also evaluated against two other subgrid methods (SGC1 and SGC2) that assigned fixed numbers of elevation and vegetation classes for each model grid with different perspectives of surface cover classification (SGC1: M *elevation bands*-N *PFTs method; SGC2:* N *PFTs*-M *elevation bands* method)."

(2) Line 2-4, Page 2179: This line may be not required. Because, you have already discussed before that you are implementing SGC method in CLM.

Response:

The last sentence (line 2-4, page 2179) in the abstract stated our future work that involves implementing the SGC subgrid classification method in CLM model simulation and comparing with the default CLM simulation to evaluate the impact of the new subgrid method on the model simulation results. In the revised manuscript, we will clarify the future work.

(3) Line 26 to 27, Page 2180: "However, conventional subgrid methods usually considered only one parameter, i.e. either vegetation or topography distribution". I think, generally land surface model only considers the vegetation types and not the elevation variability. Also, as you have found vegetation distribution, and elevation variability is generally correlated in complex terrain.

Response:

We agree with the reviewer that a majority of land surface models only considers subgrid vegetation types in surface cover representation and do not consider the elevation variability of vegetation distribution. However, representations of subgrid topography in the parameterization of precipitation, temperature and snow processes do exist. We provided a series of references at line 22-23, and using Leung and Ghan (1995, 2003) as an example, we provided more details on their subgrid parameterization of topography in precipitation and snow processes (line 27, page 2180 – line 5, page 2181). Although vegetation and elevation are correlated in mountainous areas, models that only account for subgrid vegetation do not assign different elevation to the different vegetation classes so the effects of topography on temperature, precipitation, and land surface processes are still not accounted for. Analysis of surface elevation and vegetation still needs to be performed to determine the mean elevation to be assigned to each vegetation class, which is what our revised default method does.

(4) Line 4, Page 2185: "… with similar computational burden at different model resolution". This line is not clear to me. Please clarify.

Response:

In the revised manuscript, we will clarify the meaning of "similar computational burden" and "different model resolutions". The revised statement is as follow:

"We used this method as a baseline to assess the performance of the SGC method that results in similar computational burden (N_LRU = 18) at different model resolutions (0.1°, 0.25°, 0.5°, 1.0°, and 2.0°)."

(5) Line 14, Page 2187: "At both spatial resolution …" I do see this statement true for 1.0° model resolution (Fig. 3(b)).

Response:

In the revised manuscript, we will modify the statement as:

"At both spatial resolutions, more PFT classes per grid (i.e., greater subgrid variability of vegetation) are found in the eastern Coastal Plain, western Coastal Range and Rocky Mountains (6-8 PFTs at 0.1° resolution, over 8 PFTs at 1.0° resolution) than in the Great Plains (1–2 PFTs at 0.1° resolution, 3-5 PFTs at 1.0° resolution) where crop dominates the landscape."

(6) Line 9, Page 2188: "… number of elevation band per PFT ..". Please consider adding "… number of elevation band per PFT (= 1)….".

Response:

In the revised manuscript, we will follow the reviewer's suggestion and make the technical corrections.

(7) Line 26 to 27, Page 2188: Figure reference does not seem right. For example, Fig. 4(b) shows number of elevation classes and not the N_class or LRUs, if I understood it correctly.

Response:

In the revised manuscript, we will make corresponding corrections as follow:

"The comparison between different N class (Fig. 4a vs. Fig. 5a, Fig. 4b vs. 5b) and varying model resolutions (Fig. 5a vs. Fig. 6a, Fig. 5b vs. Fig. 6b) shows that both the number of elevation bands and number of PFTs demonstrate similar spatial pattern in North America."

(8) Line 8, Page 2189: Please remove 'because driven by climate'.

Response:

In the revised manuscript, we will follow the reviewer's suggestion and remove "because driven by climate".

(9) Line 6-- -9, Page 2191: Please write an equation in the methodology section for % PFT explained.

Response:

We will follow the reviewer's suggestion and add an equation in Section 2.4 for %PFT explained. In the following equation, $\%PFT$ is the percentage of PFT explained in a given model grid,

$$\%PFT = \sum_{i-1}^{N_b} \left[\mathrm{PA}_{\mathrm{eb}}(i) \times \sum_{j=1}^{N_p} \mathrm{PA}_{\mathrm{pft}}(i,j) \right]$$

where $\mathrm{PA}_{\mathrm{eb}}(\mathrm{i})$ is the percent area of the i-th elevation band in that grid, $\mathrm{PA}_{\mathrm{pft}}(\mathrm{i,j})$ is the percent coverage of the j-th dominant PFT in the i-th elevation band, N_p is the number of dominant PFTs within each elevation band, and N_b is the number of elevation band in that grid.

(10) Line 2, Page 2193: Fig. 10a. - > I am not sure if this figure reference is correct. Also I find it hard to verify "9.4 to 63.4" in Fig.11a.

Response:

We thank the reviewer's comment. The figure reference should be Fig. 11a. Also, we will modify the statement as follow:

"…, while the average σ_{ep} substantially decreased and the ranges narrow down from 16.1m to 28.8m (Fig. 11a) for the SGC method with similar computational burden (*N_LRU = 18*)", where the number 16.1m refers to the red square symbol at 0.1 degree resolution in Fig. 11a, and the number 28.8m refers to the red square symbol 1.0 degree resolution.