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Biogeosciences Discussions



# *Interactive comment on* "Effect of mosaic representation of vegetation in land surface schemes on simulated energy and carbon balances" *by* R. Li and V. K. Arora

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We would like to thank both reviewers for their helpful and useful comments on our manuscript and take this opportunity to address their concerns.

Reviewer #1

Reviewer #1's first concern is why we have not used the observed fractional coverages of PFTs that exist in a grid cell for our simulations, instead of the 50% - 50% fractional coverages of the two dominant PFTs that we have used, given that in the end we compare model simulated vegetation characteristics to observation-based estimates. Although obvious to us, we should probably have made it clear in our manuscript that



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even if we had used observed fractional coverages the simulated energy and carbon fluxes and carbon pool sizes would not have changed for the dominant PFTs in the mosaic approach. This is because in the mosaic approach every PFT tile interacts with the driving climate data independently of the other tiles. The answers, however, would have changed somewhat for the composite approach. However, the smaller the fractional coverage of a PFT in a grid cell the smaller is its influence in determining the overall energy and water balance, in the composite approach. We expect inclusion of sub-dominant PFTs in our analysis would not have changed our conclusions substantially. Our objective in this discussion paper was to highlight the differences in carbon balance that are the result of using the mosaic and composite approaches without other confounding effects, and this is best illustrated by using 50%-50% fractional coverages of the two dominant PFTs in a grid cell. In addition, we found that interpretation of results is much more difficult when the number of tiles is greater than two.

Reviewer #1's second comment is that although our four sites cover temperate, boreal and tropical zones they do not reflect the range of possible differences between the mosaic and composite approaches. We agree with the reviewer that it is possible in certain transition zones the differences between the two approaches may be even larger and that it is worth mentioning this.

We also agree with Reviewer #1's third comment that the results presented are specific to the sites and do not represent global results. In addition, we agree with Reviewer #1 that the sentence about 46% difference in carbon fluxes and pool sizes in the abstract should be clarified. This 46% difference is seen in NPP and soil carbon pool at the Manitoba site.

Reviewer #1 fourth comment "One could disentangle this further by forcing the terrestrial ecosystem model with grid averaged fluxes and states from the mosaic approach and compare this to a forcing with PFT specific fluxes and states from the mosaic approach" is somewhat unclear. Note that it is not possible to drive the terrestrial ecosystem model with fluxes and states. Fluxes and states are the result of the driving the model with climate data. It seems Reviewer #1 is referring to the mixed approach mentioned on line 21 of page 5851.

Finally, we agree with Reviewer #1 that our statement about "mosaic approach offering more realistic representation" is somewhat inconsistent with our earlier statement which said that the mosaic approach is more suitable for landscapes with large patches. However, we would like to mention two additional references [Klink, 1995; Molod and Salmun, 2002] both of which conclude, although from an energy balance perspective, that in general the mosaic approach is somewhat superior and considered better.

Reviewer #2

Reviewer #2's first comment is that composite approach can also involve calculations of energy and water balance separately for each PFT but competing for irradiance and water in a common environment. This is a mixed approach that essentially lies in between the composite and mosaic approaches, and it is mentioned on lines 21-25 of page 5851.

Reviewer #2's second comment is what are the key attributes of each PFT and what are their individual and aggregated values. In CTEM, the structural vegetation attributes that define vegetation are leaf area index (LAI), vegetation height, rooting depth and distribution and canopy mass. Amongst these structural vegetation attributes, values of LAI are shown in the manuscript. Vegetation height and root distribution in CTEM are determined as a function of stem and root biomass, respectively [Arora and Boer, 2003, 2005]. Stem and root biomass are not reported individually but total vegetation biomass is reported in the paper. Reviewer #2 also asked how long were the spin-ups performed. Spin-ups were performed for both approaches until vegetation and soil carbon pools came into equilibrium as mentioned near line 5 on page 5855. Simulated $CO_2$ fluxes are not compared against observations but the simulated carbon pools are in Table 4 since the objective of the paper is to investigate how the mosaic and composite approaches yield different equilibrium carbon pools. Simulated energy fluxes are, therefore, not compared with observations for the same reason. The energy and water balance capabilities of the Canadian land surface scheme (CLASS) have been evaluated in numerous earlier publications [e.g. Verseghy, 2000; Arora, 2001; Marsh et al., 2010]

Reviewer #2's next comment is related to the large net radiation difference between the needleleaf evergreen tree and C3 grass tiles in the mosaic approach for the Manitoba location (in Figure 2 of the discussion paper) and that, while he/she takes the point about the albedo differences, this large difference should still be explained. Net radiation at the surface is given by

Rn = S_down (1-a) + L_down - L_up

where S_down is the shortwave radiation reaching the Earth's surface, a is the albedo, L_down is the longwave radiation received at the surface and L_up is the emitted longwave radiation that depends on the surface temperature (T) and emissivity of the land and atmosphere (L_up = emissivity x Stefan-Boltzmann constant x Tˆ4). Warmer surface temperatures imply larger values of L_up. At the Manitoba location the surface temperature is higher by as much as 4°C during the middle of the growing season for the C3 grass tile compared to the needleleaf evergreen tree tile. So both higher albedo and warmer simulated surface temperature for the C3 grass tile (see Figure 1 in this reply), compared to the needleleaf evergreen tree tile, contribute to its lower net radiation.

Reviewer #2's next comment, in the context of the Manitoba location, is that grasses can transpire rapidly (LE up to 400 W/m2) while conifers maintain a stable but relatively low LE (∼ 200 W/m2). While the simulated daily mean (averaged over 21 years) latent heat flux from the needleleaf evergreen tree tile is higher than that for the C3 grass tile (Figure 2 of the discussion paper), there are years with durations when simulated latent heat flux for C3 grasses is similar to, or even higher than, that for needleleaf evergreen trees despite lower net radiation (see Figure 2 in this reply). It appears Reviewer #2's values of 400 W/m2 for grasses are instantaneous values from a specific year. On an annual average, and for daily mean values, the simulated lower latent heat flux for C3 grasses is the response to lower net radiation than that for needleleaf evergreen trees. However, we do appreciate Reviewer #2's comment that a more stringent test of the coupled land surface scheme and the terrestrial ecosystem model would be validation against eddy covariance data.

For the Siberia location (Figure 3 in the discussion paper) the soil moisture for the C3 grasses rises earlier in the spring than needleleaf evergreen trees because of simulated warmer soil temperature in the C3 grass tile. In regards to the question of how grass NPP (Fig. 5a of the discussion paper) can rise in spring before grass LAI (Fig. 5b of the discussion paper) – Figure 3 in this reply shows this is actually not the case. Reviewer 2 likely misread Figure 5 in the discussion paper due to so many lines in that figure.

Reviewer #2 also asked if stem intercepts radiation in CLASS. Radiation in the CLASS land surface scheme is intercepted by plant area index which is composed of leaf and stem area index. In the absence of leaves, only stem intercepts radiation.

In Figure 4 of the discussion paper the net primary productivity of C3 grasses almost increases three times in the composite approach compared to the mosaic approach. Reviewer #2 suggested that this tripling of NPP does not seem to be the response to just the increased radiation received by C3 grasses in the composite approach and should be explained. Reviewer #2 is correct. Had the terrestrial ecosystem model not simulated LAI dynamically, i.e. if fixed specified LAI were used, the response to increased radiation received by C3 grasses in the composite approach would have been much smaller. However, since CTEM simulates LAI dynamically there are feedbacks involved. More received radiation in the composite approach leads to higher LAI which leads to even more intercepted radiation and eventually results in much higher NPP for grasses. We think this feedback is much more pronounced for grasses because they do not allocate carbon to the stem component, so a larger fraction of NPP is allocated to leaves, compared to the woody PFTs. In Figure 6 of the paper a similar effect is seen for crops at the eastern United States location where the NPP for crops more than doubles in the composite approach. In the model, crops do allocate some carbon to their stem component but not as much as trees do.

In regards to Reviewer #2's question if decomposition rates are really lower in grasslands than in woody ecosystems, the current literature seems to suggest yes. Soil carbon amounts in grasslands are higher both because of higher allocation of carbon belowground as well as their more recalcitrant nature with lower decomposition rates [Schlesinger, 1977; Guo and Gifford, 2002; Jackson et al., 2002].

We also appreciate Reviewer #2's comments about the somewhat unrealistic seasonality of simulated LAI for grasses and crops, and that the seasonal amplitude of LAI for needleleaf evergreen trees is also somewhat too large. CTEM is a dynamic vegetation component of an earth system model designed to operate at and capture large-scale terrestrial ecosystem processes. We are currently in process of fine-tuning CTEM's parameters to make its behavior more realistic. However, we believe this limitation of CTEM does not effect the overall conclusions of our paper that the composite and mosaic approaches yield different equilibrium vegetation and soil carbon pools.

In regards to the difference in net radiation between the composite and the mosaic approaches for the two boreal sites - the differences are very similar. At the Manitoba location the simulated grid-averaged net radiation is 51 and 53 W/m2 for the mosaic and composite approaches, respectively (Figure 4 of the discussion paper). At the Siberia location, simulated grid-averaged net radiation is 42 and 44 W/m2 for the mosaic and composite approaches, respectively (Table 1 of the discussion paper).

In regards to the overall sensitivity of the simulated NPP to changes in radiation, Reviewer #2 says that all the eddy covariance data he/she has seen shows that net CO2 exchange is fairly insensitive to changes in radiation. CTEM does not take into account



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the direct and diffused components of radiation for modeling photosynthesis, and uses total PAR which is expected to increase its sensitivity to radiation. However, current literature also suggests that plant growth is co-limited by both radiation and temperature at high latitudes [see Figure 1A of Nemani et al., 2003]. In fact, a quick analysis of Figures 1B, 1D and 2 of Nemani et al. [2003] show that NPP shows increasing trends over parts of Europe, for the period 1980 to 1999, where temperature trends are negative (i.e. cooling) but radiation trends are positive (i.e. more radiation). This suggests that NPP is sensitive to radiation.

Reviewer #2 suggests that the seasonality of simulated LAI for dry deciduous broadleaf trees at the tropical African site (Figure 8 of the discussion paper) looks too pronounced. An earlier evaluation of CTEM at a site in Mexico [Arora and Boer, 2005] showed that the model was able to reproduce the seasonality of LAI that varied from around 5 m2/m2 in the wet season to around 1 m2/m2 in the dry season. For the simulations performed at the African site we have used the same model parameters for the dry deciduous broadleaf tree PFT.

Finally, we are in process of setting up simulations that will investigate the effect of using mosaic versus composite approaches at the global scale. This is a focus of a future study.

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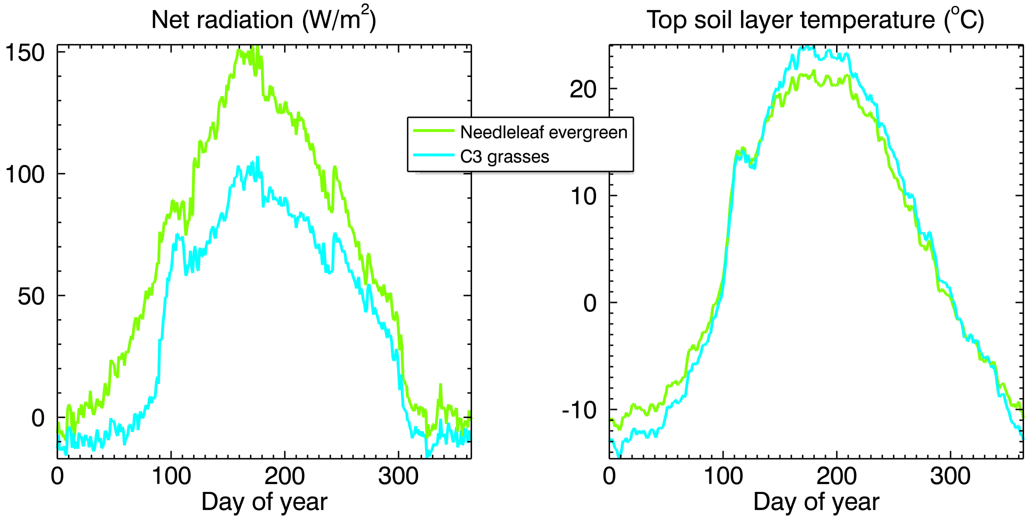


**Fig. 1.** Daily mean (averaged over 21 years) net radiation and temperature of the top soil layer for the needleleaf evergreen tree and C3 grass tiles at the Manitoba location.

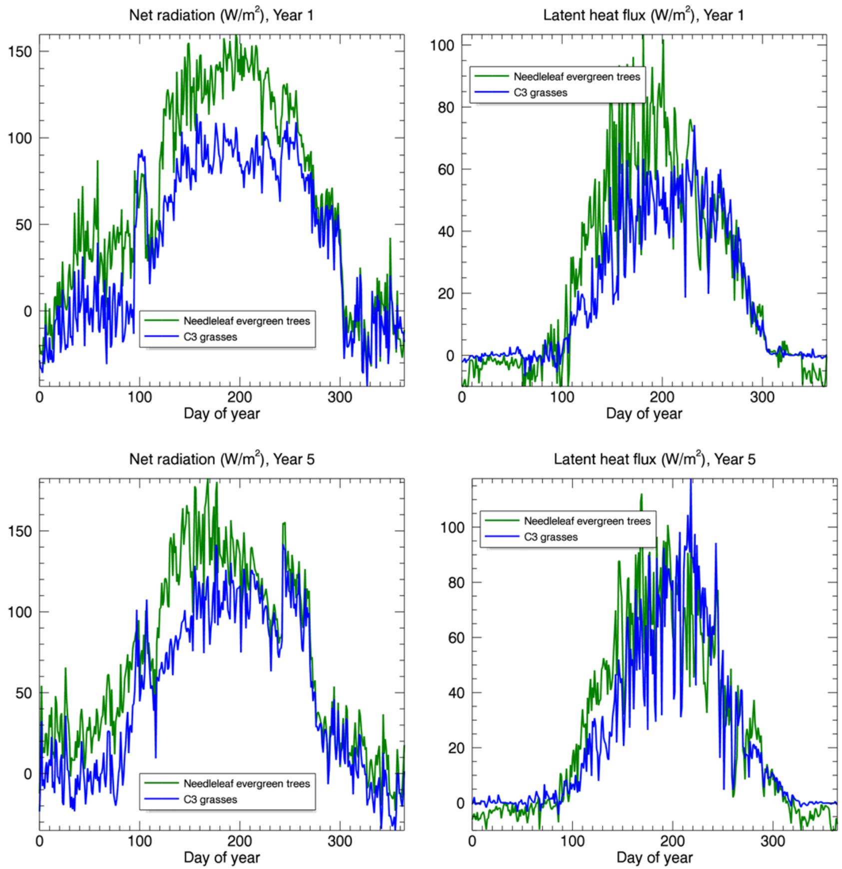


**Fig. 2.** Net radiation and latent heat flux for years 1 and 5, for the needleleaf evergreen and C3 grass tiles, at the Manitoba location when using the mosaic approach.



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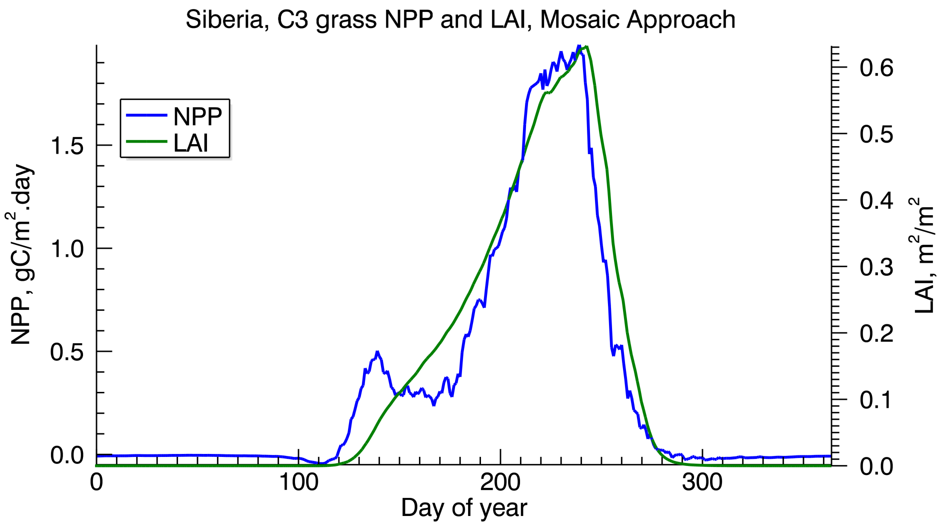


**Fig. 3.** Daily mean (averaged over 21 years) NPP and LAI for C3 grass at the Siberia location, when using the mosaic approach.



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