Response to 1st Referee's Comments

1. The first issue comes in the second sentence of the abstract and is repeated in the introduction and numerous places throughout the paper, with the claim that the CLM 4 parameters are not available at a resolution finer than 0.5 degrees. This is stated despite the fact that Lawrence and Chase (2007) state in their abstract and introduction that:

"The new model parameters are calculated at 0.05 degrees resolution so they can be aggregated and used over a wider range of model grid resolutions globally"

And that these global 0.05 degree CLM datasets are publicly available to the CESM community at:

https://svn-ccsm-inputdata.cgd.ucar.edu/trunk/inputdata/lnd/clm2/ rawdata/pftlanduse.3minx3min.simyr2000.c110913/mksrf_landuse_rc2000_c110913.nc.

Prior to these datasets being publicly available with CLM4 they were available on request to any member of the CESM community from the release of CLM 3.5.

Response:

The reviewer pointed out that our claim of the CLM 4.0 parameters not available at a resolution finer than 0.5 degrees was with factual error and that the 0.05 degree model parameters developed by Lawrence and Chase (2007) are available to the CESM community.

We recognize that Lawrence and Chase (2007) generated land surface parameters originally at 0.05 degrees resolution. We also understand that the global 0.05 degree PFT dataset is available via the above link from a CESM developer's account. However, at the time of our manuscript, these finer resolution datasets had not been OFFICIALLY released from NCAR and the DEFAULT CLM 4.0 land surface parameters were still provided at 0.5 degrees resolution. We decided to use the default CLM 4.0 parameters as standard for comparison purpose in our study for the following reasons:

(1) Although Lawrence and Chase (2007) stated that the model parameters were calculated at 0.05 degrees resolution, only PFT parameter was available to the CESM community and the corresponding 0.05 degree PFT LAI dataset was not available even by request.

(2) From our personal communications with NCAR scientists David M. Lawrence and Peter J. Lawrence (December, 2011-Febuaray, 2012), we learned that the 0.05-degree LAI dataset developed by Lawrence and Chase (2007) was noisy so that it had to be aggregated to coarser resolution to alleviate the noise. Therefore, the default CLM 4.0 datasets (both PFT and LAI at 0.5 degrees) were suggested to be used for the comparison purpose in this study by the NCAR scientists.

(3) The CLM4 preprocessing package does not support the use of high-resolution datasets as a source at the time of this manuscript. To our knowledge, the use of high-resolution datasets as inputs will be added as an option to the CLM4.5 preprocessing package by the time of CLM4.5 release (estimated to be by the end of 2012). Currently, only developers have access to the high-resolution option from the code repository at NCAR (Lawrence 2012).

Lawrence, D., Introduction and CLM project update, CESM Land Model Working Group Session, Tuesday, 19 June 2012, Breckenridge, Colorado

In our revised paper, we will include the reasons for using CLM 4.0 default parameters as stated above to avoid misunderstanding.

2. The next major issue comes in the misrepresentation of the CLM Plant Functional Types as land cover classes which is completely counter to the CLM ecosystem representation as described in Bonan et al (2002) which states:

"Vegetation units such as associations or biomes are arbitrary products of classification rather than natural units clearly defined in the field [Gleason, 1926, 1939; Whittaker, 1956]. They are not emergent units, but are merely composed of plant species that coexist at a given point in space and time. As a result, plant functional types, which reduce the complexity of species diversity in ecological function to a few key plant types, are being advocated to predict the composition and functioning of ecosystems in a changing environment [Woodward and Cramer, 1996; Smith et al., 1997]. Indeed, models of vegetation dynamics and biogeography routinely use PFTs [Running and Coughlan, 1988; Running and Gower, 1991; Prentice et al., 1992;

Running and Hunt, 1993; Neilson, 1995; VEMAP members, 1995; Foley et al., 1996; Haxeltine and Prentice, 1996; Schimel et al., 1997; Kucharik et al.,2000].”

By using the “Plant Functional Type” mapping of Friedl et al. this ecosystem representation is lost, as the MODIS Land Cover product only specifies a single Plant Functional Type per grid cell.

Response:

We completely agree with and follow Bonan’s argument (2002) that plant functional types are natural units of vegetation instead of biomes and associations, and land cover/land use on a model grid should be represented as continuous PFT abundances.

Bonan et al. (2002) and Lawrence and Chase (2007) follow this idea by using the 1km AVHRR Continuous Field Tree Cover Project data or/and 500m MODIS Vegetation Continuous Field data, both representing vegetation distribution as composition within a grid cell. In Lawrence and Chase (2007), the generation of PFT parameters was described as:

“The fractions of land covered by tree, herbaceous and bare soil were determined directly from the MODIS Vegetation Continuous Fields data set from Hansen et al. [2003]. The further breakdown of the tree fraction to Needleleaf and Broadleaf, as well as Evergreen and Deciduous components was derived from AVHRR Continuous Fields Tree Cover Project data from Defries et al. [2000]. The breakdown of the herbaceous fraction was derived directly from the global cropping of Ramankutty and Foley [1999] for crop fraction, with the remaining grass and shrub fractions determined from the MODIS global land cover mapping of Friedl et al. [2002]. All mapping and climate rules were applied at the 0.05 degree grid increment before aggregation to the CLM 3.0 model grid.”

In the above statement and as summarized in Table 1 in our manuscript, the MODIS VCF data set from Hansen et al. (2003) was at 500m resolution representing the year of 2001. The AVHRR Continuous Fields Tree Cover Project data was at 1km resolution representing the year of 1992-1993. The Willmott and Matsuura Climate data used to break down PFTs into different climate regions were at 0.5 degree resolution. The global crop data represent the year of 1992. As emphasized on page 1438 line 6016 and page 1456 line 2-5 in our manuscript, we believe that using these mixed data sets with mixed years and different resolutions will bring great uncertainties in PFT representation. This was one of the major motivations of our research.

To our knowledge, the 500m PFT classification of the MODIS land cover product MCD12Q1 C5 was by far the most updated PFT distribution product. The reviewer argued that ecosystem representation will be lost by using this product because this product only represents one PFT within a grid cell. We disagree with this argument. Even though by definition PFTs are defined as "plant species co-exist at a given point in space and time", the resolution of space and time matter. At fine spatial resolutions such as 500m, it is highly possible that a grid cell may be occupied or dominated by a single PFT. By aggregating the 500m grid cells to 0.05 degree (around 5km at equator) model grid, the model grids can be represented by compositions of multiple PFTs and each PFT can be represented as fraction of vegetation within a model grid. In fact, Figure 3 in our manuscript showed that the new PFT parameters generated from MODIS PFT land cover resulted in richer abundances than the CLM 4.0 PFT parameters due to the higher resolution of the source data.

3. The misrepresentation of Plant Functional Types continues into bare soil fraction. In the new datasets bare soil fraction is used interchangeably with the Bare Land land cover class of land cover mapping products. This is at best a reflection of the authors misunderstanding of the way PFTs are represented in CLM, and at worst a deliberate attempt to make the new dataset look like an improvement over the existing CLM 4 datasets. The scope to which this new method fundamentally misrepresents the land surface is evident in Figure 1 a) and b). In this plot we see that Australia, Namibia, the South West US, Central Asia and many other regions lose vast amounts of bare soil fraction in the new CLM dataset. By making these areas 100% shrub or grassland PFT is a complete distortion of the global distribution of vegetation.

Response:

By stating that "In the new datasets bare soil fraction is used interchangeably with the Bare Land land cover class of land cover mapping products", the reviewer seems to have misunderstood our method of generating the new datasets. In the new datasets, "the bare soil and the 15 PFTs in the 500m grids were aggregated to 0.05° grids and the fractional cover of each PFT was calculated" (page 1440 line 15-18). For example, for each 0.05 degree model grid the bare soil fraction was calculated as:

$$\text{bare soil fraction} = \frac{\text{bare soil area}}{\text{model grid area}}$$

The "bare soil area" in this equation was calculated as the total area of the 500m grids that were classified as bare soil and the "model grid area" was the area of the 0.05 degree grid. We used the bare soil land cover class and bare soil fraction at two different resolutions (500m for the former and 0.05 degree for the latter) rather than "interchangeably". We will add a clarification in the revised manuscript to explain this.

We acknowledged that there were considerable differences between the new and CLM 4.0 PFT parameters for bare soil and shrub coverage especially for the area of Australia and South West US etc. We discussed on page 1456 line 15-20 that these differences were caused by the discrete representation of both MODIS land cover product and the NLCD dataset.

"Evaluation over CONUS shows that the shrub lands and bare soil estimated by the new parameters are more accurate when NLCD is used as reference. This could be partially attributed to different land cover representations in land cover classification product and vegetation continuous field product. Both MCD12Q1 and NLCD data classified pixels (500m in MCD12Q1 and 30m in NLCD) into dominant land cover types (e.g., NLCD defined "barren land" as area that has at least 85% non-vegetated coverage), while MODIS VCF estimated the composition of 20 bare soil, trees, and herbaceous within each pixel."

We stated that assuming 100% of shrub or bare soil introduced some distortions in this landscape, but we believed that using MODIS VCF in which the bare soil fraction product was not validated will introduce greater uncertainties.

"Although the MODIS VCF seems to be able to produce more realistic estimation of the fraction of each PFT within grid cells, the bare soil fraction has not been validated. Previous study showed that VCF underestimate tree cover, i.e., overestimate the bare ground in south western US (White et al., 2005). This is consistent with our findings using NLCD. Our evaluation shows that the MODIS VCF has considerable overestimation of bare soil, even if only land with over 85% of bare soil is considered (3.5% compared to 2.0% in Table 3).” (Page 1456 line 20-26)

Therefore, we pointed out the need for more work to improve the representation of MODIS land cover product grid cell to solve the problem of discrete land cover classification.

“Potential improvement can be made by estimating fraction of PFTs within each MCD12Q1 grid cell based on both dominant classes provided by MCD12Q1 and supporting remotely sensed data such as vegetation indices or vegetation vertical structure from Light Detection and Ranging (LiDAR) data” (page 1461 line 1-5).

4. We would like to respond to the reviewer’s statements one by one.

(1) The paper makes the claim that the new parameters are a substantial improvement on the existing CLM4 parameters which are available at the same spatial resolution with no evidence to support this claim.

Response:

This argument comes with the reviewer’s first complain that CLM 4 parameters are available at 0.05 degree resolution. First, as stated above we believed CLM 4 default datasets officially released from NCAR should be used as the standard. Second, only PFT dataset is available at 0.05 degree resolution in CLM 4, all other parameters including PFT LAI, SAI, urban, lake etc are still only available at 0.5 degree resolution.

We stated several times in the manuscript that the issues with the CLM 4.0 parameters are (a) coarse resolution and (b) derived from information that spans across 1991 to 2008 with no internal consistency (page 1445 line 2-8). We claimed that the contributions of this new datasets were (a) higher resolution compared to the current default CLM 4.0 parameters and (b) data generated consistently from the most updated MODIS land cover and LAI product which have been systematically validated (page 1460 line 16-21). While these are the methodological improvements we intended to introduce in developing the new dataset, whether the new parameters are indeed better than the CLM 4.0 parameters is harder to judge because there are large uncertainties in existing land cover/land use datasets used to evaluate the parameters. Therefore, the goal of our paper is mainly to document the methods we used and the differences between the old and new parameters and evaluate, to the extent possible, using other datasets such as NLCD. Nowhere in the manuscript did we claim that the new parameters represent substantial improvements over the existing CLM 4 parameters. We only emphasized the advantages of the methods and datasets we used in developing the new parameters. We will further emphasize the challenges in evaluating the new and old parameters and make sure that there is no implication anywhere in the revised manuscript that the new parameters represent substantial improvements over the old parameters.

(2) The deliberate reclassification of the CLM4 PFTs into arbitrary land cover classes makes the CONUS evaluation misleading at best.

Response:

We question the argument that the CLM4 PFTs should not be reclassified into broader land cover classes in our evaluation analysis. In fact, the CLM4 PFTs in Lawrence and Chase (2007) were derived from broader land cover classes including trees, bare, and herbaceous of the MODIS VCF product.

We reclassified the CLM4 PFTs into broader categories including trees, shrub, grass and bare land to be comparable with the NLCD-derived class. The broader categories we used are not arbitrary, but have been used by many including the MODIS VCF product. “Considering the difference in the CLM PFT and NLCD classification scheme, the land cover classes in the new PFT parameters, CLM 4.0 PFT parameters, and the NLCD were reclassified into five general land cover types, i.e., bare soil, trees, shrub, grass, and crops, based on the recoding method in Table 2.” (page 1442 line 13-16). We argue that reclassification is needed when comparing and evaluating vegetation products since our community has not adopted a unified classification scheme.

(3) The statement that the new single PFT land cover classes of Friedl are a better representation than those derived from Vegetation Continuous Fields is never demonstrated.

Response:

We believe that reviewer may have misunderstood or misread our manuscript. Throughout the manuscript, we did not have such statement as “the PFT land cover classes of Friedl are a better representation than those derived from MODIS VCF". We did not compare Friedl's MODIS land cover product and MODIS VCF in this study. All comparisons in this study were based on the new PFT parameters which were derived from MODIS PFT land cover classes and CLM4 PFTs which were derived from mixed datasets including MODIS VCF and AVHRR Vegetation Continuous Field Tree Cover project etc.

(4) *The statement that the Vegetation Continuous Fields has not been extensively evaluated is false and the Montesano et al (2009) reference given to support this statement actually demonstrates the flawed mapping assumptions used in this study:*

"The forest gaps and patches that form the spatial patterns of the taiga-tundra ecotone represent internal heterogeneity that is difficult to capture on a continental-global scale map. The continuous tree cover mapping provided by the VCF product allows groups of pixels that represent patches and gaps to have attributes representing internal variability that capture the gradual nature of the boundary. The spatial variability, or texture, of the VCF product along with ancillary data may produce maps that replicate forest cover variability in a way that discrete land cover classification cannot, and may facilitate closer monitoring of subtle changes in the ecotone."

Response:

In both the MODIS VCF development algorithm paper and the evaluation paper by the product developer (Hansen et al. 2002; Hansen et al. 2003), only tree cover was evaluated and validated. For bare soil and herbaceous cover data, which caused the biggest differences between the new data and CLM 4 PFT data, no evaluation and validation publications are available.

There is no doubt that the purpose of the MODIS VCF product development was to provide a better representation of spatial heterogeneity of landscape than discrete land cover classification as stated in Montesano et al (2009). But, the point is: what is the quality of this data? Has it been systematically evaluated like the MODIS land cover products? When combined with AVHRR data that was acquired ten years ago to generate CLM 4 PFTs, what is the quality of the PFT dataset?

The purpose of Montesano et al (2009) was to evaluate the performance of the MODIS VCF product in the taiga-tundra transition zone. The study presented that "the relationship of the VCF estimates and ground reference indicate to potential users that the VCF's tree cover values for individual pixels, particularly those below 20% tree cover, may not be precise enough to monitor 500 m pixel-level tree cover in the taiga–tundra transition zone." The study then suggested that the product MAY be used to "*produce maps that replicate forest cover variability in a way that discrete land cover classification cannot",* and MAY *"facilitate closer monitoring of subtle changes in the ecotone.*" These statements, however, were not substantiated in Montesano et al (2009) because they were beyond the scope of their study. Given the narrow focus of Montesano et al. (2009) on evaluating the MODIS VCF product in the taiga-tundra transition zone, and the reviewer's quote from the study is also limited to the taiga-tundra transition, our statement that the VCF product has not been extensively evaluated should still stand. We will add a clarification in the revised manuscript to emphasize that Montesano et al. (2009) only evaluated the MODIS VCF product in the taiga-tundra transition zone.

Hansen, M. C., DeFries, R. S., Townshend, J. R. G., Carroll, M., Dimiceli, C., and Sohlberg, R. A.: Global Percent Tree Cover at a Spatial Resolution of 500 Meters: First Results of the MODIS Vegetation Continuous Fields Algorithm. *Earth Interact.*, 7, 1–15, 2003.

Hansen, M.C., DeFries, R. S., Townshend, J. R. G., Sohlberg, R. A., Carroll, M., and Dimiceli, C.: Towards an operational MODIS continuous field of percent tree cover. *Remote Sensing of Environment*, 83, 303-319, 2002.

(5) The statement that the Vegetation Continuous Fields has not been extensively validated is false as Landsat TM imagery was used as both training and validation products. In fact the use of the MODIS VCF and Landsat products have been shown to be extremely reliable representation of vegetation globally as in:

Hansen, M.C., Stehman, S.V., Potapov, P.V., Loveland, T.R., Townshend, J.R.G., De-Fries, R.S., Pittman, K.W., Stolle, F., Steininger, M.K., Carroll, M., Dimiceli, C. (2008) Humid tropical forest clearing from 2000 to 2005 quantified using multi-temporal and multi-resolution remotely sensed data. PNAS, 105(27), 9439-9444

Where:

"Moderate spatial resolution (250 m, 500 m, and 1 km) data from the MODerate Resolution Imaging Spectroradiometer (MODIS) are imaged nearly daily at the global scale, providing the best possibility for cloud-free observations from a polarorbiting platform. However, MODIS data alone are inadequate for accurate change area estimation because most forest clearing occurs at sub-MODIS pixel scales. High-spatial-resolution Landsat data (28.5 m), in contrast, do allow for more accurate measurement of forest area cleared. However, because of infrequent repeat coverage, frequent cloud cover, and data costs, the use of Landsat data for biome-scale mapping is often precluded. Integrating both MODIS and Landsat data synergistically enables timely biome-scale forest change estimation."

Response:

The reviewer's citation of Hansen et al. (2008) to support his/her opinion that "*Landsat TM imagery was used as both training and validation products*" and "*the use of the MODIS VCF and Landsat products have been shown to be extremely reliable representation of vegetation globally*" is questionable.

1) The purpose of Hansen et al. (2008) was to analyze forest clearing using MODIS and Landsat imagery. Landsat imagery was used in combination with MODIS imagery to produce maps of forest change in the humid tropical area. It was not used as training or validation products for the MODIS VCF development.
2) In that study the MODIS VCF product was used as auxiliary data to "regress against the forest masks derived for the Landsat block samples and extrapolated for all blocks within the biome". This in fact implies that the authors acknowledged that MODIS VCF alone was inadequate to represent forest cover and thus used Landsat-derived forest cover to calibrate MODIS VCF. Similar discussion can also be found at the associated project website: http://globalmonitoring.sdstate.edu/projects/gfm/humidtropics/data.html.
3) The study area was limited to the humid tropical area and not global.
4) In that study Landsat imagery at 28.5m resolution was used to produce forest MASK, i.e., forest or non-forest. If as implied by the reviewer, resolution is not an issue, then even at the Landsat resolution, vegetated and non-vegetated fractions should be further unmixed using spectral information (see Asner et al, 2005). That means the validation dataset for Hansen et al has limitations according to the reviewer's standard.

Asner, G. P., D. E. Knapp, A. N. Cooper, M. M. C. Bustamante, and L. P. Olander (2005), Ecosystem structure throughout the Brazilian Amazon from Landsat observations and automated spectral unmixing, *Earth Interact*, 9, 1 – 31.