Response to Referee #2

We are grateful to the reviewer for their time and energy in providing helpful comments and guidance that have improved the manuscript. In this document, we describe how we have addressed the reviewer's comments. Referee comments are shown in italics and author responses are shown in regular text.

This manuscript presents a new land surface model to be coupled with the NASA Model E2. The model is a combination of previous land surface schemes and functional modules – TRIFFID, CASA, Biome-BGC, MEGAN, and the ozone damage scheme employed by Sitch et al (2007). The paper is generally well written, though often a little dense. The research represents a great deal of work, model development and evaluation are substantial research efforts, especially for such a small research team. However, this research would benefit from well developed objectives and strong arguments for the model units that were chosen to form the basis of the model.

→ We appreciate the reviewer's positive evaluation and recognition of the hard work (8-years combined total by the co-authors). We have revised the paper accordingly to strengthen the objectives and explanations for the choice of the model components as detailed below.

It appears that the goal of this research was to develop a state of the art LSM that terrestrial ecosystem processes that are important for interactions with atmospheric chemistry, e.g. BVOC emissions, O3 damage to plants, etc. Though this objective is never clearly stated. Without a clearly stated objective the need for another LSM cannot be justified and the choice of how to represent processes within the model are apparently ad hoc. Why not use a complete, state-of-the-art LSM that represents the most processes relevant to your purpose and then include a state of the art BVOC and O3 model. For example, the authors acknowledge their model does not represent N and P cycling. This could have been achieved by collaborating with CABLE, CLM, or JSBACH modelling groups. Furthermore, in my limited understanding of land ecosystem – atmospheric chemistry interactions, gaseous N species are essential to many reactions and so an N cycle would be essential to accurate coupling of terrestrial ecosystems with atmospheric chemistry. Other state-of-the-art LSMs which represent an N cycle such as LM3 or O-CN could have formed the basis of this model. It is as if this model has been developed in isolation from the land surface and terrestrial biosphere modelling community, and the many advances in process representation from that community over the last decade.

The decision making process about which parts from which model to include is not at all discussed and seems ad hoc, there is no evaluation of competing alternative schemes. So much has been learnt over the past decade about LSMs and how to improve them, for example Zaehle et al (2014) is cited but no information from that detailed model evaluation is used to inform the development of this new model. The model purpose, and therefore the criteria to assess how to build the model are not apparent. This research needs, and would really benefit from a clear statement of purpose which would then *provide a decision criteria for how constructing the YIBs model.*

(1) YIBs objective

The reviewer is correct that the objective of YIBs is to provide a fully coupled framework to study carbon-chemistry-climate interactions; a dynamic land carbon cycle component integrated within a global chemistry-climate model. Atmospheric chemistry means reactive radiatively-active species, ozone and aerosols, not the long-lived greenhouse gases CO_2 and N_2O that do not react in the troposphere. The introduction section second paragraph is already devoted to a detailed discussion of the few carbon-chemistry studies available in the published literature, and ends with "These coupled interactions are often not adequately represented in current generation land biosphere models or global chemistry-climate models." We strengthen the case by adding to the end of the paragraph (Lines 76-84):

"Global land carbon cycle models often prescribe off-line ozone and aerosol fields (e.g., Sitch et al., 2007; Mercado et al., 2009), and global chemistry-climate models often prescribe fixed off-line vegetation fields (e.g., Lamarque et al., 2013; Shindell et al., 2013a). However, multiple mutual feedbacks occur between vegetation physiology and reactive atmospheric chemical composition that are completely neglected using these previous off-line approaches. Model frameworks are needed that fully 2-way couple the land carbon cycle and atmospheric chemistry, and simulate the consequences for climate change."

The study objective is now clearly stated in the first sentence of the next paragraph (Lines 86-88):

"Our objective is to present the description and present-day evaluation of the Yale Interactive terrestrial Biosphere Model (YIBs) version 1.0 that has been developed for the investigation of carbon-chemistry-climate interactions."

We add to the first sentence of the abstract (Lines 11-13):

"The land biosphere, atmospheric chemistry and climate are intricately interconnected yet the modeling of carbon-climate and chemistry-climate interactions have evolved as entirely separate research communities."

We add to the Introduction third paragraph (Lines 95-97):

"To our knowledge, this study represents the first description and validation of an interactive climate-sensitive closed land carbon cycle in NASA ModelE2."

In addition to the focus on carbon-chemistry-climate interactions, we assert that YIBs is justified because YIBs outperforms many existing "state of the art" land carbon cycle models as demonstrated in: Yue and Unger, Ozone vegetation damage effects on gross primary productivity in the United States, ACP, 14, 9137-9153, 2014; in this work (e.g.

Figure 7); and pointed out by Referee #1. Given the poor performance status of GPP simulations in existing land models (e.g., Schaefer et al., 2012) and the large uncertainties in future land carbon cycle model responses (Friedlingstein et al., 2006; Friedlingstein et al., 2014), we argue that there is, in fact, an urgent need for fresh interdisciplinary perspectives.

(2) Choice of model components in YIBs and development strategy

The reviewer raises some interesting questions pertinent to interdisciplinary Earth system science research. It was an option that we could have taken an existing land carbon cycle model, added BVOC emissions and ozone damage and coupled that to NASA ModelE2 global chemistry-climate model. Indeed, at the start of the project, we actively discussed use of an existing community land model. The top candidates were JULES, CLM or LPJ because of our on-going relationships with these groups. We do run JULES and CLM on our local supercomputer already and we were given access to LPJ code several years ago. In the end, we decided to adopt a less conventional strategy and build up YIBs step by step for several reasons including: (i) The major advantage of our strategy is that we know first-hand the intimate details of the scientific processes included in YIBs, because we coded it ourselves over a period of 5 years. We assert that this intimate interdisciplinary knowledge offers potentially deeper insights and a greater possibility for advances in carbon-chemistry interactions research than taking an existing land model as a “black box”; (ii) A technical concern was that we needed to have 30-minute or maximum 1-hour integration time-step for full coupling to the atmospheric chemistry (to simulate the strong diurnal cycles important in the chemistry). Many land carbon cycle models use longer integration time-steps (e.g. minimum daily) as their default because they incorporate dynamical climate-sensitive PFT distributions and because their main applications are longer-term (decadal, century scales) evolution of atmospheric CO_2. The time-step is described up front in the abstract because of its central importance to carbon-chemistry coupling “Off-line YIBs has hourly and on-line YIBs has half-hourly temporal resolution.”; (iii) A budget concern at the start of the project was that we did not have resources for a multi-institute collaboration. Our approach was the much less expensive option, with successful results because YIBs outperforms many existing models.

YIBs has been developed step-by-step with solid decision-making at each stage choosing the most appropriate sub-component for our purpose. Co-author Unger has > 13 years experience documented in > 40 publications with NASA ModelE/ModelE2 global chemistry-climate model and therefore the model’s land surface scheme. Until now, the NASA ModelE2 land surface sub-model did not incorporate an interactive climate-sensitive closed land carbon cycle model and the atmospheric chemistry “saw” a different prescribed vegetation cover than the climate model’s internal scheme (Section 3.7 Lines 531-533: “the default NASA ModelE2 computes dry deposition using fixed LAI and vegetation cover fields from Olson et al. (2001), which are different from the climate model’s vegetation scheme (Shindell et al., 2013b).”).

We have replaced the original Introduction paragraph: “Previously, we presented and evaluated an off-line regional version of YIBs that was applied to assess ozone damage effects on GPP in the U.S. (Yue and Unger, 2014); and an on-line global version of YIBs that was used to investigate BVOC-chemistry-climate interactions (Unger, 2013; Unger et al., 2013b; Unger, 2014a, b; Unger and Yue, 2014). Here, we describe the recent updated functionalities of the YIBs model that now represents the complete land carbon cycle: interactive carbon assimilation, allocation, autotrophic and heterotrophic respiration, and dynamic tree growth (changes in both height and LAI). The model also implements updated phenology schemes developed based on the inter-comparison of 13 phenological models (Yue et al., 2015)."

with a new clearer section:

"**1.1 YIBs design strategy**
Many land carbon cycle models already exist (e.g. Sitch et al., 2015 and references therein; Schaefer et al., 2012 and references therein). We elected to build YIBs in a step-by-step process such that our research group has intimate familiarity with the underlying scientific processes, rather than adopting an existing model as a "black box". This unconventional interdisciplinary approach is important for discerning the complex mutual feedbacks between atmospheric chemistry and the land carbon sink under global change. The development of YIBs land carbon cycle model has proceeded in three main steps. The first step was the implementation of vegetation biophysics, photosynthesis-dependent BVOC emissions and ozone vegetation damage that have been extensively documented, validated and applied in 7 previous publications (Unger, 2013; Unger et al., 2013a; Unger, 2014a, b; Unger and Yue, 2014; Yue and Unger, 2014; Zheng et al., 2015). The second step was the selection of the YIBs default phenology scheme based on rigorous inter-comparison of 13 published phenological models (Yue et al., 2015). This study represents the third step to simulate the closed climate-sensitive land carbon cycle: implementation of interactive carbon assimilation, allocation, autotrophic and heterotrophic respiration, and dynamic tree growth (changes in both height and LAI). For this third step, we purposefully select the mature, well-supported, well-established, readily available and accessible community algorithms: TRIFFID (Cox, 2001; Clark et al., 2011) and the Carnegie-Ames-Stanford Approach (CASA) (Potter et al., 1993; Schaefer et al., 2008). TRIFFID has demonstrated previous usage in carbon-chemistry-climate interactions research."

YIBs has been developed in close connection with the land carbon cycle modeling community. The phenology sub-model was developed in collaboration with leading internationally-renowned phenology and carbon cycle experts (Yue, X., N. Unger, T.F. Keenan, X. Zhang, and C.S. Vogel, Probing the past 30 year phenology trend of US deciduous forests, *Biogeosciences Discuss.*, 12, 6037-6080, doi:10.5194/bgd-12-6037-2015, 2015). We have an on-going relationship with the JULES community development team who are always encouraging and responsive to our group. Co-author Unger spent sabbatical with the JULES development team in the UK. One could make a strong case that implementing TRIFFID into a different host global climate model (other than the Hadley Center models e.g. HadGEM2/3) is in of itself a worthy scientific endeavor. We eagerly anticipate that YIBs will participate in future multi-model inter-comparison projects focused on the land carbon cycle. YIBs results have been and will continue to be submitted for presentation at land carbon cycle and chemistry-climate conferences and meetings. As such, YIBs is becoming well integrated into the land modeling community. Finally, in making the code publically available (Code Availability Section), we anticipate expanding the user base beyond our group and thereby facilitating new developments.

(3) C-N coupling

We agree with the reviewer that N and P cycles are important processes for the terrestrial C cycle. The coupled C-N was not an initial priority for YIBs because of the massive uncertainties in the current models, for instance in sign of response. In the future, with adequate resources and personnel, we do plan to include N and P cycles in NASA ModelE2-YIBs. For example, we are especially curious about P in the Amazon (e.g., Mercado et al., 2011). To our knowledge, the existing state of the art coupled C-N models may simulate N_2O emissions (e.g., Zaehle et al., 2011) but interactive NO_x ($NO+NO_2=NO_x$) emissions are not yet available. NO_x emissions are relevant for tropospheric ozone and aerosol chemistry (not N_2O, which does not react in the troposphere). The NASA ModelE2-YIBs framework already includes climate-dependent soil NO_x emissions (described in Section 3.7). We have already emphasized that NASA ModelE2-YIBs simulates the speciated interactive deposition of inorganic and organic nitrogen to the terrestrial biosphere in Section 3.7.

We strengthen the case for not yet incorporating coupled C-N into YIBs in Section 3.7 (Lines 540-543) through additional updated key references:

"However, the YIBs biosphere currently applies fixed nitrogen levels and does not yet account for the dynamic interactions between the carbon and nitrogen cycles, and the consequences for carbon assimilation, which are highly uncertain (e.g., Thornton et al., 2007; Koven et al., 2013; Thomas et al., 2013; Zaehle et al., 2014; Houlton et al., 2015)."

And in the Conclusions section (Lines 774-777):

"The model does not yet include a dynamic treatment of nitrogen and phosphorous availability because current schemes suffer from large uncertainties (Thornton et al., 2007; Zaehle et al., 2014; Houlton et al., 2015)"

Since the paper is already rather long, an additional paragraph detailing the state of C-N models, what we know and don't know, is not justified here.

As a last point, recent 'state of the science' carbon-chemistry-climate research on ozone vegetation damage effects on the carbon and water cycles used CLM and did not use CLM-CN (Lombardozzi et al., 2015).

Minor comments:

The physiology references are incorrect, the Collatz et al (1991) equations for photo-synthesis are presented (equations 2-4), but Farquhar et al (1980) are cited. Why cite Collatz for the Ball-Berry model of stomatal conductance? Cite Ball et al (1987). And why use this model, later versions are available, e.g Medlyn et al 2011.

→ We have corrected the reference typos in the revised manuscript.

Testing alternative stomatal conductance models is way beyond the scope of this particular paper but will be a subject of future YIBs research, not least because it is critical for chemistry-climate interactions. We have added the following statement (Lines 219-221):

"In future work, we will investigate the carbon-chemistry-climate impacts of updated stomatal conductance models in YIBs (Berry et al., 2010; Pieruschka et al., 2010; Medlyn et al., 2011)."

The general definition of PFT is 'plant functional type', this should be unified through the manuscript as 'plant functional type', 'plant function type', and 'land cover type' are used interchangeably.

→ Corrected. We use "plant functional type" and the abbreviation PFT throughout the manuscript.

Figure 4 are not histograms, they are bar charts. To be histograms each x-axis should be on a single scale. For example plot 4c, intervals (from left to right) of 42, 17, 33, 50, 50, and 396 are all given the same distance on the x-axis. Also, there should be less or no space between the bars, the x-axis is a continuous variable. I suggest using box and whisker plots to represent these distributions.

→ We appreciate the referee's suggestion of the box and whisker plots, but those would be incapable of distinguishing PFTs as the colored bars. We now refer to Figure 4 as "bar charts".

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