Response to Reviewer 3

We thank anonymous reviewer 3 for their considered and constructive comments on our manuscript "A framework for modelling the complexities of food and water security under globalisation". Following is our response. The reviewer's comments are written in *Italics*.

General comments

Although Integrated Assessment Models (IAMs) are powerful tools to investigate complex long-term issues of global change, their coarse spatial resolution hampers effective treatment of spatiotemporally heterogenous phenomena such as water constraint in food production. The framework proposed in this manuscript has a potential capability to relieve this limitation by expressing the cities as agents that are interlinked with transportation network and receiving information from both IAM and spatially detailed biophysical models.

If a numerical model was successfully developed based on this framework, it would largely enhance the capability of IAMs. Consequently, it would contribute to seek practical solutions for complex global issues such as achievement of the Paris Agreement and the Sustainable Development Goals, which will be an important advancement in the global environmental science. Nonetheless, it was hard for me to comment on this manuscript as a referee because this paper only shows the framework of a forthcoming model (i.e. I took this paper as an elaborated research plan). One can hardly judge the validity of the authors' framework unless the concept is actually implemented and validated. What I could do was to comment on the validity of logical flow of the paper.

We are glad that the reviewer has provided comments on the paper despite the model not yet being operational. We believe that exposing our vision to critical peer review and a wider audience will help develop the ideas put forward, further. It is also our hope that the framework outlined here will stimulate debate, innovation and new ideas about how to move the discipline of global change modelling forward.

We begin by stating that in the revised manuscript, we have rewritten section 1 to immediately outline the knowledge gaps in understanding food and water security under globalisation that we set out to fill with our framework. Namely, it remains a knowledge gap to capture regional and sectoral interdependencies and cross-scale feedbacks associated with food and water security within a single model framework. Following this, we introduce the main aspects of the framework: cities and hinterlands and the networks that connect them. We explain why these are important elements to capture in order to understand food and water security under globalisation.

In addition, in the revised manuscript we have integrated section 2 and 3 into a new section 2 which is more concise. In the new section 2, we have focused on explaining how regional interdependence, sectoral interdependence and cross-scale feedbacks are captured to differing extents in existing models and approaches. We then outline the knowledge gaps in existing approaches that our framework sets out to fill. Namely, integrating regional and sectoral interdependencies and cross-scale feedbacks within a single model framework.

I observe two major concerns in the logic of this paper. First, the authors little refer to the published land use models. Land use models allocate land use under given socio-economic conditions and shocks which largely overlap with the key concepts and functions of the authors' framework. For example, Lotze-Campen et al. (2008), Wise et al. (2009), Konar et al. (2013), Hejazi et al. (2015), Bonsch et al. (2016), and Hasegawa et al. (2017) have already resolved multiple challenges raised by the authors. It should be more clearly elaborated what are the literary unresolved challenges of IAMs and what would

be the key differences between the approaches of the forerunners and the authors. Further focused review should be added to text.

In section 2 of the revised manuscript, we have provided a comprehensive review of land use model approaches. We outline the progress made in understanding land use change from these approaches and specific challenges that remain, which can be addressed to a certain extent with our approach. Specifically, we highlight that although existing approaches capture regional and sectoral interdependencies or cross-scale feedbacks to differing extents, capturing these factors within one framework has yet to be accomplished, to our knowledge. We outline how our framework can provide a means to begin to close this knowledge gap.

Second, I am wondering the authors may overvalue the international food trade. Although important, for example, the fraction of the traded major grains to the total production is approximately 15% in 2005. A major part of food production is consumed domestically. An excessive emphasis on trade might distort the reality. Further discussion should be added on non-traded food production and water use.

By trade we mean international and domestic trade. In the revised manuscript, we provide a definition of what we mean by trade to avoid confusion. As we mention in the discussion manuscript (Page 2, line 28-31), the magnitude of virtual water / food trade is underestimated because most studies focus only on international trade. In section 2 of the revised manuscript, we underline that the domestic trade fluxes are an important knowledge gap in existing approaches that our framework sets out to close. Our framework sets out to begin to close this knowledge gap by capturing spatially explicit demand and production potential as well as infrastructural networks which constrain the how food is redistributed within countries to meet demand and the associated impact on food and water security.

We have included discussion of non-traded food in section 2 of the revised manuscript.

Specific comments

Page 2 Line 14 "The redistribution of food via trade is central to determining water resources use": I don't believe this statement is right. Only a limited portion of food is internationally traded, and it only partly determines the water. I would like to see here the total production of agricultural products and the fraction of internationally traded. I believe similar figures can be easily made using the total water use for food production (NB: include green water as well) by consulting earlier works (e.g. Aldaya et al., 2010; Hanasaki et al. 2010; Hoff et al. 2010; Fader et al. 2011; Gerten et al. 2011).

We underline that 54% of people currently live in urban areas and depend on domestic or international trade for food security. Thus, we argue that domestic and international trade plays an important role in determining water resource use (see chapter 6 of the United Nations Water Development Report 2015: Water for a Sustainable World).

In the revised manuscript, we provide examples of the amount of green and blue water used in food production and embedded in traded food based on the references recommended by reviewer 3.

Page 7 Line 18 "Water footprint studies : : : (van Beek et al. 2011; Wada et al. 2011)": I don't believe these two papers are on water footprint. The works by Hanasaki et al. (2010) and Fader et al. (2011) are more directly relevant in this context. Hanasaki (2016) provides an overview of the water footprint studies by applying global hydrological models.

We have included the recommended literature in the revised manuscript.

Page 8 "3.2 Sociohydrological Studies": I hardly found any direct or concrete linkage of the sociohydrology and the framework proposed in this study. I would see more focused discussion why and how sociohydrogy is relevant to this study.

In the revised manuscript, we have focused on three core topics which we feel are key to understanding water resource use within the globalised food system. These are regional interdependence, sectoral interdependence and cross-scale feedbacks. In section 2 we discuss how existing models and approaches capture each of these to differing extents and highlight knowledge gaps in existing approaches that our framework sets out to fill. The text given over to sociohydrology is shortened and included in subsection 2.3 dealing with cross-scale feedbacks. In this section, we outline that sociohydrology studies set out to understand cross-scale spatiotemporal feedbacks by capturing how short term or small-scale interactions between humans and the environment can bring about long term and large scale emergent changes in water resources (Sivapalan et al., 2012; Sivapalan and Blöschl, 2015). We highlight that sociohydrological studies suffer from a disciplinary focus on water and do not capture important sectoral interdependencies. Equally, they have so far assumed the systems of concern are isolated entities in space, e.g., an agricultural river basin, whereas in a globalised world, many different such entities may interdependent with other regions owing to trade in goods (e.g., food). In the discussion section of the revised manuscript, we add a short discussion about how sociohydrological studies can benefit from incorporating regional and sectoral interdependence in order to better understand human-water dynamics in a globalised world.

Page 12 "Food production and water use": As mentioned in General Comments, a review on earlier efforts linking water-land-food models and IAMs seems largely missing here. I note that earlier studies seldom applied agent-based model (ABM), but still clarifications are needed what has been achieved without ABM, and what would be potentially achieved by adopting ABM based on a fair literature survey.

In section 2 of the revised manuscript, we have expanded the literature review on work done to link water, land and food within IAMs. We outline specific gaps in knowledge in these studies that our framework sets out to fill.

Page 14 "The framework can be applied across scales to investigate changes at catchment, city or global scale": The statement sounds a bit too strong since no concrete evidence of the capability of framework is presented in this paper. The dominant force or process of linkage between cities would be substantially different across scales. For instance, even if the connection between New York and London and that of Seoul and its commuter towns can be both expressed as nodes and links, their link must be formulated fundamentally differently. More specifically, local connections are strongly influenced by local non-market circumstances such as regulations, custom, and cultures, which is hardly obtained from neither IAMs nor biophysical models. If you wish to keep this argument, elaborate how the scale issues would be basically resolved.

We agree with the reviewer that the above statement is too strong and have removed it from the revised paper. Nonetheless, we elaborate on the reviewer's comments below. We have strived to clarify these issues in the explanation of the framework in section 3 of the revised manuscript.

In terms of trade regulation, as stated in the discussion manuscript (P10, Line 25-35), we define city hinterlands based on the hierarchical overlay of supra-sub national administrative borders and theissen polygon operation among cities based on cost-distance of trade via road, rail and inland water ways. Our framework thus provides a structure that can capture regulation at the scale of an administrative region, where the data are available. Currently CGEs used in IAMs contain regulatory

data at the scale of countries or regions. If regulatory data is available at a finer scale, our framework provides a structure to incorporate that data. If regulations between two hinterlands stimulate free trade, then the effective hinterlands of those cities may expand. We have provided a more detailed version of figure 5 in the revised manuscript to illustrate the how a city and its hinterland are defined.

In terms of issues such as customs and culture, the framework described does not provide a structure to capture those societal elements at this time.

Following, we provide an illustration of how an executed version of the model framework would simulate trade between New York and Tokyo as opposed to Seoul and its commuter cities. To take the example of New York and Tokyo first. The upper level network of socioeconomic trade links will constrain the probability of trade between Japan and the US based on the CGE. The share of that trade that will come from New York will depend on the production of goods in the hinterland of New York that meet Japanese demand. It will also depend on the competition among American cities and hinterlands to meet that demand. Given, the lower cost-distance for trade, a west coast city may be more likely to meet demand from Japan than a city on the east coast. If trade data becomes available at state level, the framework structure allows for that to be incorporated and a finer scale estimation of food and virtual water fluxes from the hinterland of New York city to Japan to be made.

Contrast that with Seoul and its commuter cities. Assuming the finest scale data on food production and consumption is at national-level, fluxes in food and virtual water among Korean cities will be estimated based solely on spatially explicit population demand, production potential and the cost-distance between cities based on transport cost along infrastructure networks. This provides an estimation of resource redistribution within Korea based on these factors. As finer-scale sub-national trade data become available, these redistribution estimates can be improved.

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