Response to reviewers – details and changes to the manuscript

Following our short commentary posted on November 10th, we provide here a detailed response to the four reviewers' comments. When responses have numbered items we have kept the same numbers. Lines and section numbers refer to the new manuscript attached to this response.

Reviewer 1:

Main points	Response
1.Sensitivity analyses performed on a case study in Cape Fear	We thank the reviewer for this comment and agree that the work on the Budyko framework is appealing. Because of the focus on ecosystem service decisions, we think that the uncertainties associated with the use of the Budyko theory at the pixel level need to be put in context of other model uncertainties so as to appropriately inform decisions. Change: We have clarified the scope of the paper both in the introduction and with an overview of the Methods section [l.97 on, and l. 180 on].
2.No assessment of ecosystem services	The reviewer suggests to emphasize the ecosystem service application. And, it is true that the focus of this paper is on the water yield component, as stated on p11003 ("The biophysical module, the focus of this paper, is based on the Budyko theory"…). At the same time, the emphasis on uncertainty quantification and assessment fits directly with the decision-making context of ecosystem services. Change: we clarified in the introduction the typical applications of the model for ecosystem service assessment [l90-96]
3.Broader implications of the paper (eco-hydrological relevance of the Cape Fear region and the relevance of the results in the Budyko framework)	We thank the reviewer for these comments and have expanded the methods and discussion sections so as to make the results more broadly interpretable and applicable.

Reviewer 2:

Main points	Response
1. Main focus of the paper (including abstract).	As indicated above, we agree that the emphasis on the Budyko theory is appealing. At the same time, our study aims to present an uncertainty analysis of the model and thus has a broader focus. This includes insights into the model empirical parameters and the input parameter uncertainties.

	We understand the reviewer's particular interest in the spatial vs. lumped application, but this is only one aspect of the uncertainties associated with the model, which are of interest to both hydrologists and model users. We note that the structure of the paper is consistent with current approaches to uncertainty assessment: it includes sensitivity analyses, model comparison (lumped vs. pixel-based), and comparison with observations and calibration (cf. Refsgaard 2007 for review of uncertainty analyses).
2.Description of the Budyko theory inconsistent with Eq.1	We agree with the reviewer that the general description of the Budyko theory should be consistent with the expression used in the manuscript. Change: we have revised the text of the description (Section 2.1)
3.Description of the w parameter.	We agree that the explicit relationship between w and vegetation is found in the work by Zhang et al. (2001). In the 2004 paper, the same authors derive the equation (Eq.1 in our paper) from an analytical approach, with a parameter w called "catchment parameter". This parameter is related to vegetation, but also captures local geology or topography. Change: we have clarified the nature of the empirical parameter w (l. 132) ("ω characterizes the partitioning of precipitation between evapotranspiration and runoff, and is a function of climate and physical factors.")
4.Model formulation for distributed predictions	We agree that the presentation of the outputs may have been confusing for the readers. The model uses spatially-explicit inputs, but results are tested on aggregated values, at the catchment scale. Change: We have clarified this point. While the proposed model is capable of providing spatially explicit output, this paper focuses on aggregated yields, consistent with available measurements.
5.Presentation of the distributed predictions in one or more of your study catchments	We thank the reviewer for this suggestion, which will help readers that are unfamiliar with InVEST to picture outputs given by the model. Change: We propose to add a map of the distributed water yields (Figure 4).
6.Test the validity of the spatial patterns without the benefit of data	Indeed, we are unable to test the pixel-based outputs from the model. We do, however, test the aggregated water yields against observed data from ten subcatchments. We think this is now clearer. Changes: See changes in Point 4 above. We renamed the section (section 3.4): "Testing the spatially-explicit outputs against observed data".

Reviewer 3:

Main points	**Response**
1.Recent studies testing InVEST	Unfortunately there are not many other studies that have tested the model in a systematic way. The two studies highlighted are the only ones to our knowledge that have gone further in the model testing than comparing a

	single model output (average annual water yield) to observed data, for a single point. Changes: We clarified the introduction (l. 95-96: “In particular, they assess the effects of climate variables uncertainty, but do not examine the ability of the model to represent land use change.”)
2.Main focus in abstract/paper	We agree that the original structure of the paper was confusing. We have now clarified the structure to highlight the different uncertainty analyses that are performed, using standard terms in the field: “sensitivity analyses, model comparison, testing against observed data”. This helps emphasizing the scope of the paper. Changes: In addition to the changes in the paper structure, we have also clarified the scope of the paper in the introduction and in the overview of the methods section (see Reviewer 1 – Comment 1)
3.Paragraph explaining the increased demand for spatially explicit ES tools	We agree that this point could be made clearer. In addition to citing recent work by Guswa et al. (2014), where the demand for ecosystem services tools is analyzed in more details, we provide examples of typical applications of these tools. Change: In the second paragraph of the introduction (l.51), we added: “Typical applications of the model include the development of land planning policies, such as the delineation of priority areas for conservation or for agricultural development.”
4.Consistency in terminology	We agree that the lack of consistency in terms is confusing to readers and apologize for overlooking this point. Changes: We have revised the text with a consistent terminology. We now use exclusively “water yield”, “groundwater withdrawal”, “crop factor”, “spatially-explicit”, and “lumped model”. We also use the term “subcatchment” only, except when referring to the Cape Fear basin.
5.Paper structure	We thank the reviewer for his concrete suggestions on the paper structure. We agree that the parallel structure for methods, results and discussion will help readers understand the key points of the analyses. In particular, we clarify that some analyses do not require observed data (i.e. sensitivity analyses, and comparison between spatially-explicit and lumped models) , whereas the last part of the analyses rely on observed data . Changes: We propose the following structure, which may entail minor text revisions to keep the logical flow: 1. Introdution 2. Spatially-explicit InVEST annual water yield model 3. Methods 1.1 Cape Fear study area 1.2 Sensitivity analyses - K and Z - Climate inputs

	1.3 Comparison of spatially-explicit and lumped models 1.4 Testing the spatially-explicit model against observed data 4. Results 4.1 Sensitivity analyses 4.2 Comparison of spatially-explicit and lumped models 4.3 Testing the spatially-explicit model against observed data 5. Discussion 4.4 Sensitivity analyses 4.5 Comparison of spatially-explicit and lumped models 4.6 Model performance in calibrated and uncalibrated 4.7 Practical implications 6. Conclusion For memory, below is the previous structure: 1 Introduction 2 Methods 2.1 InVEST annual water yield model 2.2 Cape Fear study area 2.3 Sensitivity to Z and Kc 2.4 Comparison of distributed and lumped application of the water-balance model 2.5 Performance of the InVEST model 3 Results 3.1 Sensitivity of Water Yield to climate, Z, and Kc 3.2 Comparison of spatially explicit and lumped models 3.3 Performance of the InVEST model 4 Discussion 4.1 Sensitivity to Z and Kc 4.2 Comparison of spatially explicit and lumped models 4.3 Model performance in gauged and ungauged basins 4.4 Practical implications 5 Conclusion
Minor comments	The typo and the reference to climate input uncertainty were rectified.

Reviewer 4:

Main points	**Response**
1.Absolute discharges	We agree that the sensitivity to precipitation could be better illustrated with a graphical form. We believe that Table 2 provides sufficient information about the water balance for each subcatchment, with the predicted and observed discharge values being reported. Change: We have added the baseline run values to Table 2, and we revised Figure 3 to include sensitivity to precipitation
2.Sensitivity to precipitation (for Cape Fear and more generally)	The sensitivity to precipitation error is a very important factor when assessing model performance, and this point motivated our work on precipitation error assessment in the manuscript. We agree that the discussion would benefit from the extrapolation of this idea to other catchments

	Change: [l.583] we have elaborated on the expected sensitivity to precipitation, based on the example of arid climates.
3.Value of omega for lumped models	We thank the reviewer for this suggestion, reporting the values of omega will improve the clarity of the discussion. Change: we have added these values in the Results (Section 4.2) and discuss them in Section 5.2
Minor comments	Minor comments have been addressed or discussed above, in other reviewers' response.