We thank Anonymous Referee #2 (AR2) for providing a detailed and well underpinned review. Below, we will respond to the points made by AR2 in the same order as in the review: starting with the general comments, followed by the specific comments and finally the technical corrections.

General comments

<u>Summary</u>

We thank AR2 for the kind words on the manuscript and model, and hope to clarify the problems raised in the following sections.

<u>Originality</u>

Whether or not the hydrological community needs more models has been a long debated topic. We should stress that we would not have developed the models without the belief that it fills an important niche. There are a few important things that make this model stand out from the already existing conceptual models, and we believe that we can learn from the model.

First of all, the underlying concept of the dS2 model, the simple dynamical systems (SDS) approach, is based directly on discharge observations (Kirchner, 2009). The SDS approach is popular and sparked many scientific studies/discussions: the original paper is cited over 300 times according to Web of Science. The dS2 model allows us to apply a proven concept in a way that it supports larger catchments with more spatial variability. In contrast to this, the many bucket based conceptual models are based on our conceptual understanding of the hydrological system rather than observations. Therefore, dS2 relies on a different philosophy than the vast majority of conceptual models. Additionally, the SDS approach calculates changes in storage only expressed in terms of discharge rather than absolute storage values. As this is different from the large majority of conceptual models, dS2 can give new insights into the hydrological response.

Furthermore, as this is a computationally efficient hydrological model (though we do not state that this is the most efficient hydrological model, see our reply in the "Efficiency" section), it allows for relatively cheap sensitivity uncertainty and sensitivity studies. This is also something the majority of existing conceptual models cannot achieve.

Another point made by AR2 is that dS2 is solely a rainfall-runoff transformation tool. Simply stating, this is correct, but the same point can be made for every model – when discharge is the main variable of interest. Furthermore, the term rainfall-runoff transformation tool can be perceived as something 'black box', while there is definitely a physical hydrological understanding underlying the concept of this model. This ties directly to another point made by AR2: that this model will not help understanding processes within a catchment. This is correct, as these processes are all indirectly captured by the sensitivity function. However, the model can definitely help with understanding how the discharge of a catchment will respond under different scenarios, and how this relates to storage in a catchment. We understand how the current formulation of the introduction might suggest that dS2 will help with understanding specific hydrological processes, while we refer to the hydrological response. This will be clarified in the next version of the manuscript.

In order to more explicitly state the niche of this model, we propose to slightly alter the title of the manuscript to: A distributed simple dynamical systems approach (dS2 v1.0) for computationally efficient hydrological modelling at high spatial and temporal resolution.

Efficiency

AR2 correctly states that we sacrificed some computational efficiency to ensure code readability. Maybe the word "efficiency" in the title suggests that we tried to build the most computationally efficient conceptual hydrological model, but this was not our main goal. If this were the case, it would indeed make a lot more sense to use compiled languages such as C++ or Fortran. Of course, we do wanted to utilize the characteristics of the SDS approach in order to have a model that is computationally efficient. Within the Python programming language, we tried to write the code as efficient as possible. Therefore, the model heavily depends on the Numpy library, which utilizes C libraries for its calculations. This library allows for example the vectorization of functions, something that is not supported by the default Python functions.

Furthermore, as Python is continuously getting more and more popular, it allows other users to understand, improve and/or extend the model, or change part of the code depending on the research question at hand. We see models not as static entities, but rather as flexible environments in which ALL elements (not just parameterizations but also the numerical "core") can easily be adapted. A widely known language such as Python is much better tailored to this task . This could indeed also be done with using Python as an interface, but given the previous arguments we have chosen Python as the preferred programming language. We will include this reasoning as well the manuscript.

Applicability

We thank AR2 for their compliments on the readability of the code. Based on the comments and testing by the reviewer, we understand and agree that application of the model is currently rather ambiguous. It should be noted that we have several MSc students currently working with the model, and they don't experience any difficulties once the input data is provided. Therefore, we already started working on an example, with some documentation on how to setup and run the model. This can be found in the GitHub repository of the dS2 model (https://github.com/JoostBuitink/dS2/tree/master/example_application, see model_guide.ipynb). Please note that this is still work in progress, and will also be evaluated by the MSc students who are working with the model.

Sensitivity analysis

AR2 is correct in stating that we did not account for parameter interaction in the applied Sobol' sensitivity analysis, even though we are aware that correlation exists. This is also the reason why we both show the main and total effect in the figures showing the results from this analysis, as they give an insight into the individual and combined effects of the parameters. We will take a look at the covariance matrix (as stated later in the specific comments) and decide which method for sensitivity analysis is best for our case.

Specific comments

- p2L26-27: AR2 has a valid point, we also wanted to refer here to data available both at high spatial and temporal data such as radar data. We understand that this is currently not clearly stated, and we will add this to the next version of the manuscript.
- p2L29-30: The second sentence refers to the first part of the sentence before this one: applying a lumped model to each pixel, so not utilizing function vectorization for example. This is indeed not clear in the text, and we will rephrase this to improve the connection between the two parts.

- p2L34-35: AR2 is correct that HPCs and other solutions allow for many iterations within reasonable amounts of time. However, an efficient distributed conceptual model such as dS2 allows a user to do many runs on their own computer, without requiring HPCs and the costs related to the usage of these infrastructures. We agree that increasing the number of iterations from millions to billions is unlikely to add anything regarding uncertainty analyses and parameter estimations.
- p9L3-4: Here we aim towards the popularity of Python and its flexibility in changing and adapting the model code. We understand the confusion, and will clarify this in the next version of the manuscript. As stated before, we agree that adding a simple test case with definitely help others to use dS2.
- p9L18: AR2 is right that this doesn't really make sense to do this with dS2. We added this value as a reference, as this is likely to speak more to the reader than just the number of pixels within the region of interest.
- Section 3.2: We agree with the suggestion of AR2 and will add some more explanation about the numerical integration and the common approaches in currently existing models.
- Comment on numerical integration: AR2 is correct that the computationally efficiency character of the model allows for more advanced numerical integration methods. There is a tradeoff however, since a large part of the current computation time is already consumed by the numerical integrator. After extensive stress testing of our custom time stepping scheme and comparisons with known implicit solvers, we are convinced that our integrator is able to produce accurate results. Furthermore, it gives the user some control over the numerical precision and number of additional time steps to reach this precision, something not all already established solvers allow.
- p13L2: This is indeed the case, and we will make sure this is better described in the next version of the manuscript.
- p13L8-9: $Q_{internal}$ is currently not used in the model at all, as we added it here only to check the water balance. We understand the origin of the confusion and make sure this is clarified in the next version of the manuscript.
- Fig. 8: AR2 correctly spotted that there are more than 5 parameters in the model. However, most other parameters are related to either numerical stability or administrative functions within the model. We will explicitly state that we are investigating the five parameters influencing the hydrological response (α, β, γ, ε, τ).
- Section 4: See our reply in the section *Sensitivity analysis* above. Regarding the sizes between the total and main effect: the total effect is always bigger than the main effect, as both bars start at 0. We understand that the current visualization might look like stacked bars, while they are in fact not. We will slightly shift both bars to depict that they are separate bars. For the KGE – β (bias), the total effect is indeed close to zero for four out of five parameters, as only the ε (evaporation correction parameter) affects the bias.
- p16L1: We do indeed mean the discrepancy between main and total effects, and we will clarify this in the next version of the manuscript
- p17L8-9: AR2 is correct, this text was still belonging to an old (incorrect) version of this graph. We will update the text and explanation accordingly.

Technical corrections

We thank AR2 for their suggestions for technical corrections. We will implement those in the next version of the manuscript.