Rebuttals to interactive comment on "Modelling stream flow with a discrete rainfall–runoff model and 37GHz PDBT microwave observations: the Xiangjiang River basin case study" by Haolu Shang et al.

Anonymous Referee #2

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The authors have developed a discrete rainfall-runoff model which uses ground data as well as retrievals of Water Saturated Soil (WSS) and inundation area from 37GHz microwave observations. I had a difficulty in understanding the objective, finding, and the contribution of this manuscript. There are many questions which were not addressed by authors clearly, for example.

Q1. Use of 37 Ghz (which sensor/satellite?) for WSS and inundation estimation why not other frequencies, which are commonly used for soil moisture and inundation area estimation?

Answers: Thanks a lot for this comment. Lower frequencies are commonly used for soil moisture retrieval, such as at 1.4 GHz. There are some cases where 19 GHz was used together with 37 GHz to monitor surface wetness, e.g. Basist, A. et al.: Using the Special Sensor Microwave Imager to monitor surface wetness, Journal of Hydrometeorology, 2, 297-308, 2001. But for inundated area, 37 GHz is a widely used frequency due to its shallow penetration depth in the soil. The spatial resolution is higher at 37 GHz than at lower frequencies, e.g. 1.4 GHz and 19 GHz. We added references on the comparison between 19 GHz and 37 GHz on their applications in data assimilation. To apply a data assimilation method was not our purpose in this study, however. Accordingly, we modified the text as follows:

Page 2, Line 22 – 26: "*A possible method to bridge this difference is to assimilate regional soil moisture using a soil-canopy-atmosphere model and the observations from the Special Sensor Microwave Imager (SSM/I) as shown by Lakshmi et al. (1997a, 1997b). In their study, microwave observations at lower frequencies (e.g. 19 GHz), however, were preferred, rather than at 37 GHz, because the penetration depth at 37 GHz is too shallow (i.e. 0.08cm – 0.8 cm). The parameterization of the soil-canopy-atmosphere model adds to the difficulty and uncertainty in this assimilation method (see e.g. Lakshmi et al. (1997a))"*

Page 12, Line 6 – Line 12: the information of the SSM/I radiometer was added in the section "Data and study area", together with the description of the data product and its spatial resolution.

Q2. What is discrete rainfall-runoff model, why it is better than other models?

Answers: Thanks a lot for this comment. The discrete rainfall-runoff mode is a lumped hydrological model that simulates stream flow by integrating the contributions of antecedent precipitations. The advantages are:1) it is easier to calibrate with the linear regression method than other hydrological models; 2) it requires much less input data, and most of the data can be derived from satellite observations. Accordingly, we modified the text as follows:

Page 3 Line 24 to Page 4 Line 3: we defined the discrete rainfall-runoff model as a lumped hydrological model that simulates stream flow by integrating the contributions of antecedent precipitations. We also introduced its relationship with other hydrological models.

Page 4 Line 7 – 18 : we summarized the advantages of the discrete rainfall-runoff model as: 1) it is easier to calibrate with linear regression method than other hydrological models; 2) it requires much less input data, and most of the data can be derived from satellite observations.

Q3. Why the model was used at a time step of 10 days? Under which circumstances this approach is valid?

Answers: Thanks a lot for this comment. This time interval is constrained by the available observations of in-situ ground water table depth, and other input data are all daily. In our study, only the 10-day mean ground water table depth is freely available, due to the data policy in China. In the future, we would like to use daily values of the ground water table depth, if available.

Accordingly, we modified the text as follows:
Page 11, Line 25 – 27 : "*We used observations of the ground water table depth at 9 wells in Changsha (at the pixel numbered 1 in Fig. 1). Only mean values over 10 days were freely available and were used to calculate the spatially averaged values over this pixel, without knowing the precise location of each observation site, due to the data policy in China.*"

Q4. What is the purpose of 3 step implementation? Where do get the evapotranspiration data from? What happened to this approach if we do not enough data from the ground (e.g water table)

Answers: Thanks a lot for this comment.
A1. The three implementations were developed with increasing complexity. We wanted to evaluate whether increasing complexity can reduce the required duration of antecedent precipitation, thus can reduce the number of model parameters. Accordingly, we modified the text as follows:

Page 1, Line 10 – 14, in the abstract: "*The model assumes that specific runoff integrates the contributions of precipitation over a certain period. This duration determines the number of model parameters and can vary from weeks to months. The model was implemented at three levels of increasing complexity with observations of precipitation, ground water table depth, and the WSS and inundated area, which are designed to reduce the duration required to achieve a reasonable performance.*"

A2. The evapotranspiration data are not needed in this study. ET consumes precipitation and component flows. Our model does not specify how much water is used by ET. The retrieval of the WSS and inundated area and the weights assigned to antecedent precipitation both account for the ET. Accordingly, we modified the text as follows:
Page 4, Line 12 – 15 : "*Another advantage of using the retrieved WSS and inundated area is fewer data are required for calibration, compared with other conceptual models, since some complicated hydrological processes, e.g. evapotranspiration and interaction between storage elements, are not described explicitly in our model, but accounted for by the retrievals and by the weights assigned to antecedent precipitation*."
Page 6, Line 13 – 15: "*The evapotranspiration and interactions between storage elements are not represented explicitly by the weights, but contribute to determine the weight value*"

A3. The ground water table depth is a very important data input for our model. Currently the model cannot run without the ground water table depth.

Q5. What is the role of calibration in the model results?

Answers: Thanks a lot for this comment. In the calibration experiments, we wanted to evaluate the assumptions we made to develop each implementation. If the model performance in the calibration experiments is very poor, there is no need for validation. The calibrated model parameters would be used to predict stream flow in the validation experiments and evaluate model performance against observations of stream flow. Accordingly, we modified the text as follow:
Page 11, Line 3 – 8: We explained that we divided the data set into two subsets, one for calibration and one for validation. The parameters derived in the calibration period are used to predict stream flow in the validation period and evaluate model performance against observations of streamflow.

Q6. What is the purpose of this manuscript? Model development? Or use of satellite observation for improving model simulation?

Answers: Thanks a lot for this comment. Our purpose includes both aspects. We explained our objective as follows:
In Page 4,Line 19 – 20: "*our objective is to develop the discrete rainfall-runoff model with the help of the retrievals of the WSS and inundated area from 37 GHz microwave observations and evaluate different implementations of it*

Q7. In addition, manuscript was not well written and arranged. I recommend authors to restructure the paper in a way that readers can understand the concept, their applications to solve the practical issues using your model or approach.

Answers: Thanks a lot for this comment. The revised manuscript is organized as Introduction, Method, Data and study area, Results, Discussion and Conclusion. The section Introduction now includes the physical background of the discrete rainfall-runoff model, the relationship with other hydrological models, and the advantages of the discrete rainfall-runoff model. The detailed description of our model has been moved to the section Method. The description of the Cross validation method was added to the section Method, in order to evaluate the overfitting problem in our implementations. The information about the used radiometer and the retrieval method was explained in the section Data and study area. The section Results illustrates the results of calibration, cross validation, and validation for each implementation. The section Discussion includes the comparison of model performances between implementations, and interprets performance differences with the model weights in each implementation. .

We improved the structure of the manuscript as follows:
Page 2, Line 5 to Page 4 Line 35: The Introduction now includes: the explanations on the retrievals of WSS and inundated area, and about the application of the retrievals to the conceptual hydrological models, the possible solutions and their limitations, the physical basis of the discrete rainfall-runoff model, the relationship between our model and other hydrological models, the advantages of our model, the objective and the organization of the is manuscript..

Page 5, Line 1 to Page 11, Lin 16: The section Methods now explains the discrete rainfall model (section 2.1), its three implementations (from section 2.2 to section 2.4), and the model calibration, validation and metrics for model performance (section 2.5)

Page 11, Line 17 to Page 12, Line 19: The section Data and study area was improved by adding the information about the SSM/I radiometer and the retrieval of WSS and inundated area.

Page 12 Line 20 to Page 16, Line 15: The section Results was re-organized into three subsections, i.e. one subsection for each implementation. In each subsection, we illustrated the results on calibration, cross validation and validation respectively.

Page 16, Line 16 to Page 20, Line 16: The section Discussion was added. Calibration and validation results, the model performance of the three implementations with mean parameters, the interpretation of model weights and the recharge period of the ground water were discussed.

Page 20, Line 17 to Page 21, Line 23: Conclusions were re-stated.

Specific issues are listed here for future modification.

Q8. Page 2: Line 1-5: Introduction does not explain the advantages and short coming of 37 GHz for estimating soil wetness and inundation area. I do think that use of 37 GHz for the estimation of soil wetness as well as inundation area is not the right choice since it is affected by clouds and water vapor and thus affecting the PDBT significantly. I believe the authors may know much better about the soil moisture estimation from low frequency microwave observation (1, 6.9 and 10 GHz). Provide reasons why 37 GHz was used rather than 6.9 and 10 GHz. I could not able to understand why does the discrete rainfall-runoff modeling approach better than other available or physical model approaches and what are the advantages?. If you use 36 GHz for inundation why not use 89 GHz which has high resolution than 36 GHz.

Answers: Thanks a lot for this comment. Choosing PDBT at 37 GHz is based on the tradeoff between spatial resolution and the influences of the atmosphere. Lower frequencies, e.g. 10 GHz, are less influenced by the atmosphere, but have much coarser spatial resolution than 37 GHz. Though the spatial resolution at 89 GHz is higher than 37 GHz, observations at 89 GHz are too sensitive to the scattering and absorption of hydrometeors, e.g. rain droplets, thus are seldom used to observe the land surface. The influence of the atmosphere on 37 GHz PDBT has been removed using a time series method according to Shang, H., Jia, J., and Menenti, M.: Modeling and Reconstruction of Time Series of Passive Microwave Data by Discrete Fourier Transform Guided Filtering and Harmonic Analysis, Remote Sensing, 08, 970, 2016. The advantages of the discrete rainfall-runoff model are: 1) it is easy to calibrate; 2) it requires few input data. Accordingly, we modified the text as follows:

In Page 2 Line 13 -16: we explained that the influence of atmosphere has been removed in the retrieval of WSS and inundated area.

In Page 2 Line 22 – 26: we refer to an assimilation method that uses microwave radiometer data at lower frequencies, e.g. 19 GHz, to estimate the regional water storage, and explained that this method is limited by the complexity in model calibration.

Page 4, Line 7 – 18: we summarized the advantages of the discrete rainfall-runoff: 1) it is easier to calibrate with linear regression method than other models; 2) it requires much less input data, and most of the data can be derived from satellite observations.

Q9. Page 2-5: Mixer of everything very difficult to follow. Better to improve the introduction and move equations and description of model to Section: Method, especially page 5.

Answers: Thanks a lot for this comment. We have improved the Introduction as explained in our answer to Q7. The text on Page 5 has been moved to and modified in the section 2.1 from Page 5, Line 16 to Page 6, Line 26 in the revised manuscript.

Q10. Page4: Equation 3: Confusing. Weight w is divided by P and again multiplied by P? Please simplify and explain clearly.

Answers: Thanks for this comment. We have completely revised this section and adopted a slightly different notation. Specific changes are summarized below .
Page 5, Line 17 – 29: We expressed the water balance of each antecedent precipitation in a catchment as Eq. (1) in the revised manuscript shows, which takes the redistribution of precipitation in time into account.
Page 5, Line 30 to Page 6, Line 5: We calculated the observed stream flow as the integration of water flow released by precipitation in a given antecedent period, as Eq. (3) in the revised manuscript shows.
Page 6, Line 6 – 26: We expressed the contribution weights as the released water flow normalized by the antecedent precipitation as Eq. (5) in the revised manuscript shows, so that the contribution weights can be calibrated with a linear regression model (see section 2.5 in the revised manuscript). The weight values take the other terms of catchment water balance into account, as Eq. (5) shows.

Q11. Page 10: Line 10-25. What happened to evapotranspiration? What data was used to calculate evapotranspiration to solve eq. 3?

Answers: Thanks for this comment. Please see answers to Q4

Q12. Page 11: why does the model have the time steps of 10 days? What is the advantage of this approach? Can you use this approach for simulating peak discharge?

Answers: Thanks a lot for this comment. The time interval is constrained by the available observations of ground water table depth, i.e. only 10-day mean depth data is freely available. Other input data are daily. We did not simulate daily peak discharge, due the limitation in the time interval of available ground water table depth. In the future, we hope to run with daily data when the daily ground water table depth is available. For sure, we can simulate 10-day averaged peak discharge. Accordingly, we modified the text as follow:

Page 11, Line 25 – 27: "*We used observations of the ground water table depth at 9 wells in Changsha (at the pixel numbered 1 in Fig. 1). Only mean values over 10 days were freely* *available and were used to calculate the spatially averaged values over this pixel, without knowing the precise location of each observation site, due to the data policy in China.*."

Q13. Page 11-15: what is the target this manuscript? Reproduction of stream flow? In that case why other available physical model cannot be used? How to understand that WSS and inundation area really improved the model performance?

Answers: Thanks a lot for this comment. Our targets are to reproduce and predict stream flow. The applications of other physical models are limited due to heavy model calibration in a new catchment or require data not easily available in many river basins, e.g. soil porosity or texture. Thus we developed the discrete rainfall-runoff model with easy calibration and few input data. The WSS and inundated area is used to reduce the required duration of antecedent precipitation, i.e. reduce the number of model parameters in the implementation of the discrete rainfall-runoff model. Long duration will lead to the overfitting in our models, thus a relatively short duration is preferred. The results of calibration and validation experiments are illustrated for each implementation in the section Results. In the calibration experiments, the second and third implementations have better model performance than the first implementation when the duration is the same. In the validation experiments, the second and third implementations require shorter duration than the first one to achieve a similar model performance. This proves that the retrievals of WSS and inundated area can reduce the required duration of antecedent precipitation, i.e. to achieve a satisfactory performance with fewer model parameters, and justifies the method to estimate the potential subsurface flow. The results of the cross validation experiments proved that the model improvement from the first to the second and third implementations is due to the application of WSS and inundated area. Accordingly, we modified the text as follows:

Page 4, Line 7 – 18 : we summarized the advantages of the discrete rainfall-runoff model: 1) easier to calibrate with linear regression method than other models; 2) require much less input data, and most of the data can be derived from satellite observations.

Page 12 Line 20 to Page 16, Line 15: The section of Results was organized into three subsections, i.e. one subsection for each implementation form. In each subsection, we illustrated the results on calibration, cross validation and validation. In calibration experiment, the second and third implementations have better model performance than the first implementation when the duration is the same. In validation experiment, the second and third implementations require shorter duration than the first one to achieve a similar model performance. The results of cross validation show that when the duration $\leq$ 10 time steps (100 days), overfitting problem did not occur in the three implementations. This proves that the model improvement from the first to the second and third implementations is due to the application of WSS and inundated area, within this duration range. The calibration and validation process proves that the retrievals of WSS and inundated area can reduce the required duration of antecedent precipitation, i.e. to achieve a satisfactory performance with fewer model parameters, and justifies the method to estimate the potential subsurface flow.

I could not able to follow the results and discussion completely since the previous sections could not explain clearly.