Responses to anonymous Reviewer #3

We thank the respected reviewer for the criticism that helped us in improving the manuscript. We hope that the material added in the revised version will contribute to illustrate the performances of the developed approach. Below our responses to all criticisms of the reviewer are presented.

1. It took me quite a while to figure out that AMSR SWE product is used in two totally different ways: 1) to initialize the snowpack model; 2) in parallel with the snowpack model estimates to force the runoff generation model. The authors paragraph on page 5508, lines 16-25 needs to describe exactly how each of the datasets are pulled together and used. This could be done relatively easily; as is, this paragraph conveys very little information about what the authors have done.

We changed the mentioned paragraph.

> In this paper we present a technique for constructing spatial fields of snow cover characteristics using satellite data products combined with available standard meteorological data and a physically based snow model. The model is first calibrated against available snow measurements at meteorological stations. Next, it is applied to simulate the spatial distribution of snow characteristics (SWE, snow depth, water outflow from snowpack, etc.) using satellite data and interpolated ground-based meteorological data as input. Satellite data consist of products derived from observations of MODIS and AMSR-E instruments onboard Terra and Aqua satellites and include maps of snow coverage, SWE, land surface temperature and albedo. The listed satellite data are used in the following way. Maps of snow coverage are used for refinement of snow model parameters in comparison with ones adjusted to ground-based snow measurements. Satellite-derived SWE field is utilized as the initial condition for snow model; a special correction procedure is presented for improvement of SWE values for forested areas. Land surface temperature and albedo are used as the model inputs in addition to meteorological data. Finally, the modeled spatial distribution of snow cover characteristics is incorporated in a distributed physically based model of runoff generation to calculate snowmelt runoff hydrographs. The correspondence of simulated and observed hydrographs may be considered as an indicator of the accuracy of reconstructed fields of snow characteristics.

Thus, the main use of the satellite-derived SWE data in the presented technique is for initialization of snow model. Utilizing AMSR SWE data for driving the runoff generation model is not mentioned as a part of the presented technique. It is just an additional numerical experiment aimed to assess applicability of the SWE data for reproducing spatial patterns of snowmelt.

2. How did the authors use the AMSR SWE product to drive the runoff generation model to get the results shown in Figure 10?

Satellite-derived SWE maps were used for calculation of snowmelt. Intensity of melt M_i for a ith day was calculated for each pixel as: $M_i = \begin{cases} SWE_i - SWE_{i-1}, \text{if } SWE_i > SWE_{i-1} \\ 0, \quad \text{otherwise} \end{cases}$.

The calculated values of M_i were then utilized as inputs into the runoff generation model.

3. It is well-known that the AMSR product has significant errors during snowmelt… Driving the runoff generation model using the AMSR SWE product is fundamentally ill-conceived...

We have two main objectives in the research: to represent a continuous characterization of snow cover in time and space before the beginning of melt season (it is necessary to simulate the heat and moisture transfer in the soil before melt) and to assign the initial value of SWE for calculation of snowmelt rates. The snowmelt in the Vyatka basin begins in the end of March. Maybe, it would be better to begin the simulation for the first task earlier, but it seems that a month or more is enough for a demonstration of the technique. It is known that the errors of the AMSR SWE product during snowmelt is increasing but we do not know when we have to stop using these data. So the comparison of the computed snow fields and the AMSR SWE product during snowmelt can be, in some sense, useful also.

Moreover, the authors' suggestion that the errors are due to forest is most likely incorrect.

We have changed the conclusion

This underestimation can be explained by significant errors in satellite-derived SWE during snowmelt and for forested areas.

4. How was the snowpack model used to calculate SCA shown in Figure 7?

New paragraphs and new Figure are added in the end of Section 5 in order to clarify calculation of SCA and present the procedure of refinement of snow model parameters using satellite-derived SCA.

"Using the assumptions formulated above, we simulated daily maps of SCA and compared them with NASA MOD10_L2 maps for the snowmelt season of the years 2002 to 2005. The comparison was carried out in order to refine the snow model parameters adjusted against the ground-based point measurements (see previous section) and use the refined parameters for further characterization of snow fields. The region was divided on to 19 Thissen polygons according to the location of the meteorological stations. Simulated, SCA_{calc}, and satellite-derived, SCA_{sat}, values were estimated for each polygon and the dates when most of the polygons were free of cloudiness. The value of SCA was calculated as the number of open (free of forest) pixels covered by snow divided on the total number of open pixels within the polygon. When calculating SCA_{sat}, only free of cloudiness pixels were taken into account. Two criteria were applied to summarize the goodness of fit of the simulated and satellite snow maps for each selected date: (1) mean relative error $ME = \frac{1}{19}\sum_{i=1}^{19}\left(1-\frac{SCA_{calc_i}}{SCA_{sat_i}}\right)$ and (2) root mean square error $RMSE = \sqrt{\frac{\sum_{i=1}^{19}\left(SCA_{sat_i}-SCA_{calc_i}\right)^2}{\sum_{i=1}^{19}\left(SCA_{sat_i}-\overline{SCA}_{sat}\right)^2}}$ where $\overline{SCA}_{sat}$ is the satellite SCA estimated for the whole polygon. It was appeared that minimum values of the both criteria are achieved under almost the same values of the snow model parameters (α =1.03, q_T =0.98 J m^{-2} s^{-1}, and q_E = 0.12 J Pa^{-1} s^{-1}) as the values obtained through the model calibration against the ground-based point measurements.

As an illustration of the obtained results, temporal changes of the criteria ME and RMSE are shown in Fig. 7 for 3 of 19 polygons.

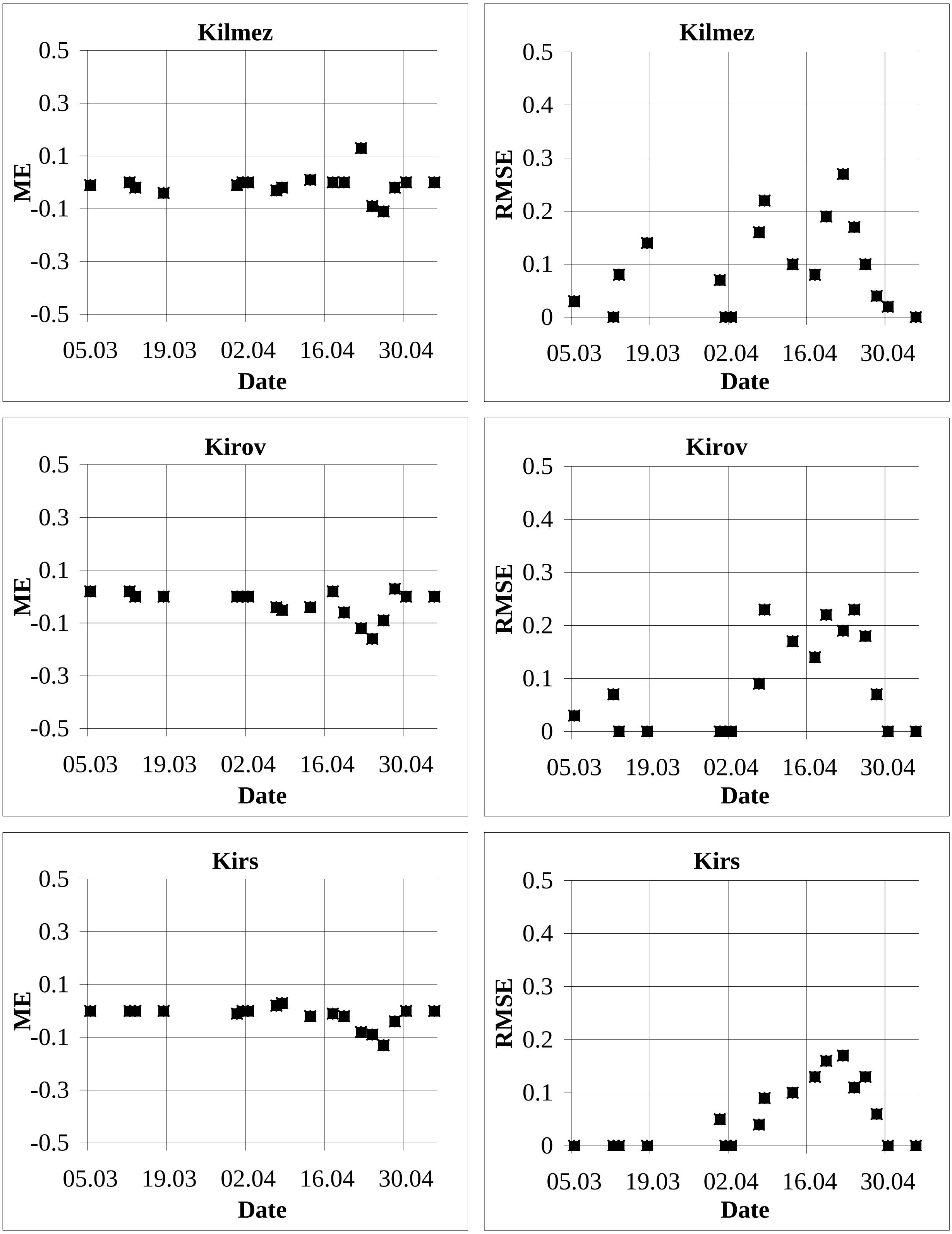

Fig. 7 Mean error (ME) and root mean square error (RMSE) of simulated snow covered area in comparison with one obtained from NASA MOD10_L2 maps for three Thissen polygons surrounding meteorological stations Kilmez, Kirov, and Kirs (forested pixels are not taken into account).

One can see from Fig. 7 that ME and RMSE are close to zero in the beginning of spring, then the both criteria increase in the period of intensive melt and return to small values in the end of melt season. In general, the model allowed us to reproduce well temporal changes of SCA for the open areas.

The results are much worse if we take into account forested pixels in addition to open ones when SCA calculating. Fig. 8 shows the temporal change of SCA for two polygons which are located correspondingly in the south-eastern and north-eastern corners of the study area and have the coniferous forest percentage of 9 % and 76 % respectively. It can be seen from this Fig. 8 that, again, for the sparsely forested area the calculated values of SCA are close to the values defined from the satellite data while for the area with dense forest there is a significant difference between these values.”

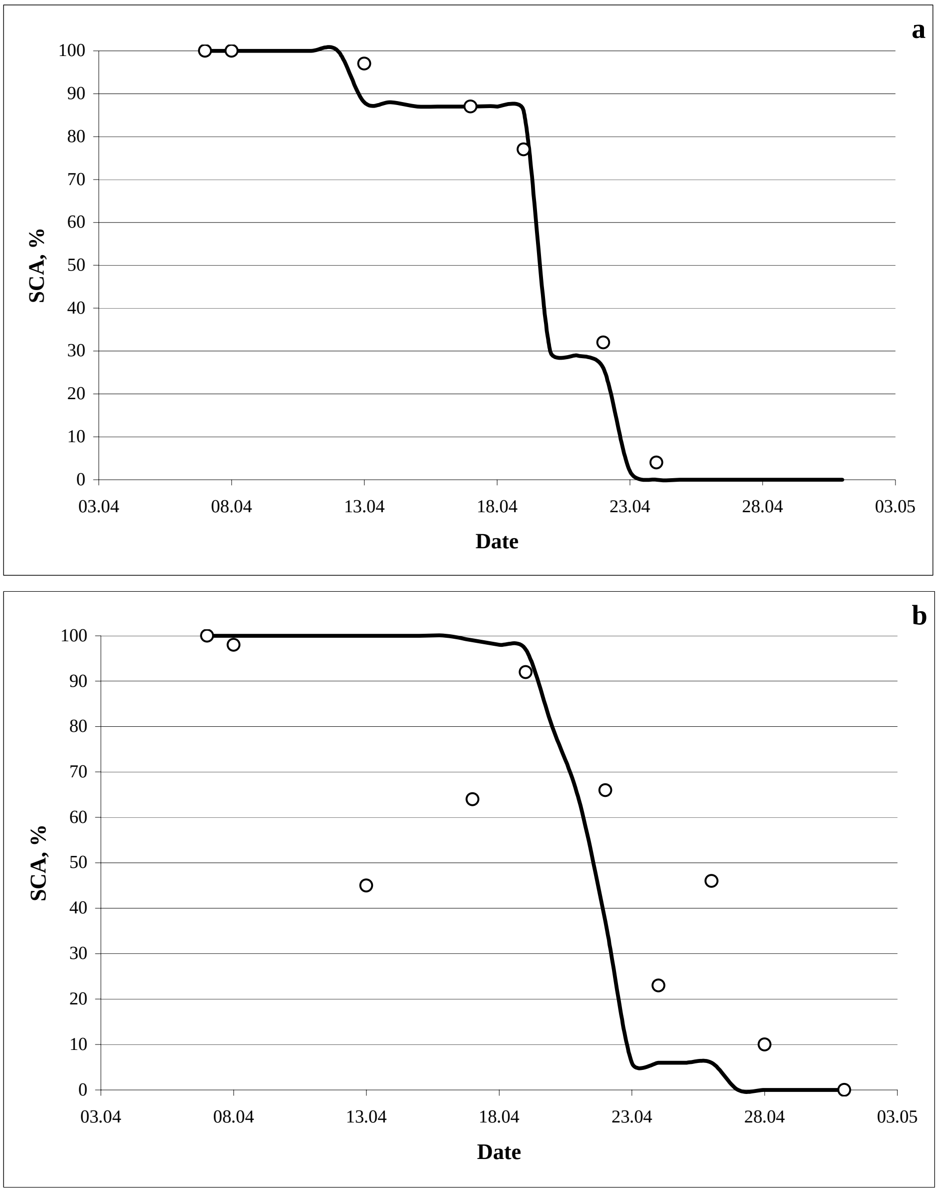

Fig. 8. Changes of the calculated (line) and MODIS-based (points) SCA for two Thiessen polygons with different cover percentages of coniferous forest (a - 9%; b – 76%).

5. It seems that the snowpack model was calibrated and validated using snow depth measurements at 19 stations within the basin, which are presumably the same 19 stations where meteorological data are available. This must NOT be used to develop an estimate of the overall performance of the model. Inevitably, at pixels where the meteorological data are interpolated rather than measured, the uncertainties and the errors will be larger.

We applied one of the typically used interpolation method, namely, the inverse distance squared method. We did not analyze an accuracy of this method in this study.

However, in the revised manuscript we have added results of numerical experiment aimed to assess advantage of using satellite data when meteorological observations are scarce. We calculated alternative hydrographs without using satellite data and the obtained results are discussed in the 5th section. The following new discussion and new Figure 12 for illustration of this discussion are added in the revised manuscript.

Numerical experiment was carried out to assess whether or not utilizing satellite data in the model of runoff generation can result in improving hydrograph simulations when comparing with simulations utilizing meteorological observations only. Meteorological observations at the Vyatka basin were used to simulate processes of runoff generation from the beginning of snow accumulation in the previous autumn to the end of snowmelt flood. Satellite data were not used in the experiment. Two sets of hydrographs were simulated distinguishing in the number of meteorological stations providing meteorological inputs into the model. The first set of hydrographs was simulated using all available 19 stations and only 4 stations were used for calculation of the second set. The results of the numerical experiment are shown in Fig. 12. As one can see from Figure 12, utilizing the satellite data does not improve hydrograph simulations in comparison with the case when relatively dense network of meteorological observations exists. Moreover, hydrographs simulated using the data of 19 meteorological stations appeared to be slightly more accurate than ones calculated with the use of satellite data. This result can be explained by lower accuracy of the initial SWE field derived from satellite data in comparison with one calculated from meteorological data. However, in the case of scarce meteorological observations (only 4 stations per 120,000 km^2), the result is opposite, as it is seen from Fig. 12. It means that initial SWE field taken from satellite date is more accurate than ground-based SWE data and has advantage for hydrograph simulation in the case of a catchment poorly gauged by snow observations.

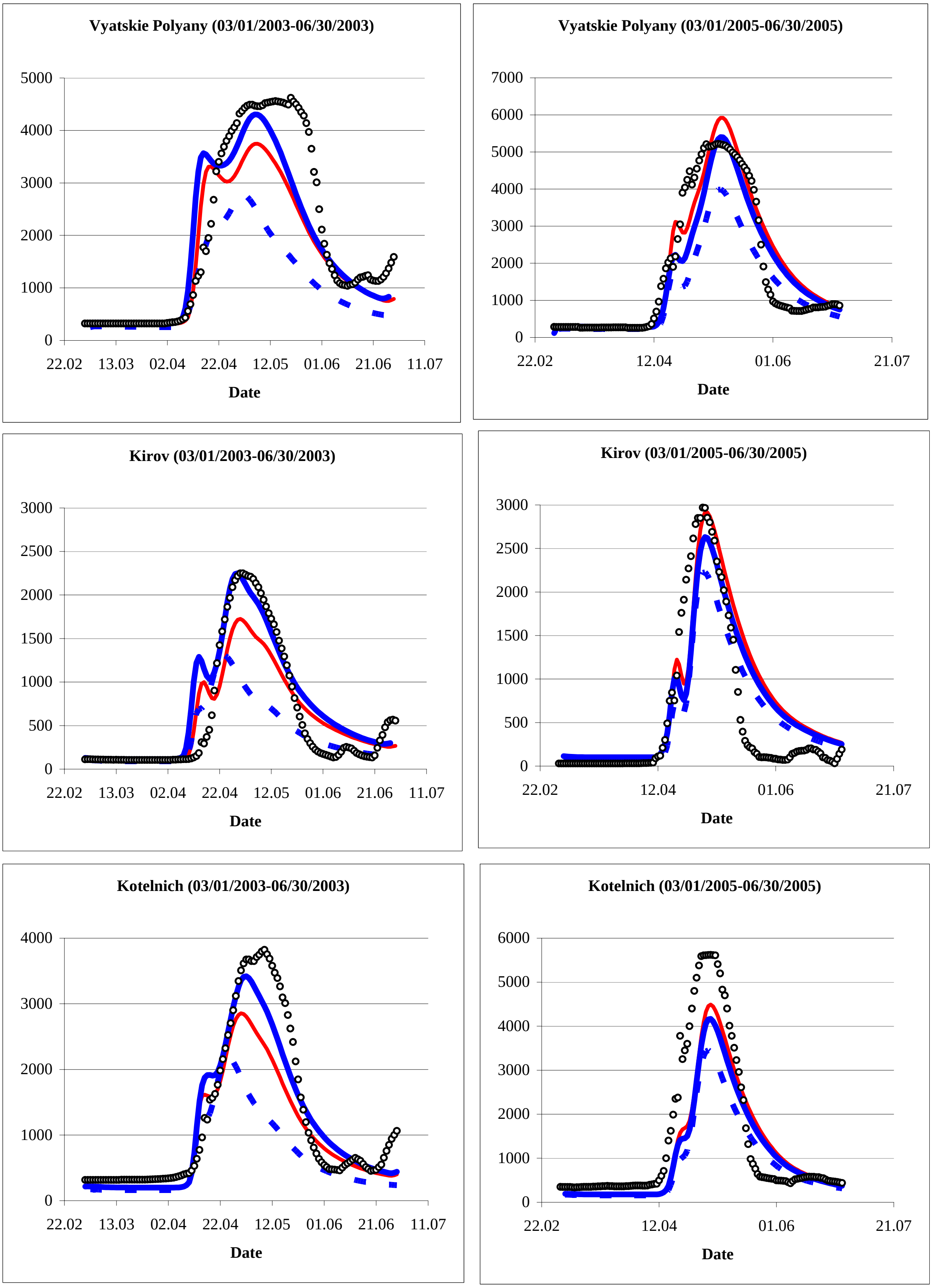

Fig. 12. Observed (circles) and calculated (lines) hydrographs of the Vyatka river:
red line – calculated with satellite data
blue lines – calculated without satellite data (continues line - data of 19 meterological stations are used, dashed line – data of 4 meteorological stations are used)

5. I recommend the removal of all mentions of the word “assimilation” or “assimililate”…

We have removed all mentions of the word “assimilation” from the revised text.

A more appropriate title might be something like: “Characterization of snowpack and runoff using models and remote sensing measurements”.

According to the suggestion of the reviewer we have changed the title. The revised title is **“Use of satellite-derived data for characterization of snow cover and simulation of snowmelt runoff through a distributed physically based model of runoff generation”**

Minor comments

1. p. 5508, Line 18: “physical based” should be “physically based”

Corrected

2. p. 5009, Line 20: Cite something peer-reviewed on AMSR accuracy, in addition to or instead of the internal NASA report; the internal report accuracy is not adequate, here.

The paper Dong, J.; Walker, J.P.; Houser, P.R. Factors affecting remotely sensed snow water equivalent uncertainty. *Remote Sensing of Environment* 2005, *97*, 68-82 is referred additionally.

3. Section 5 title is grammatically incorrect and confusing: “Using spatial snow characteristics into the distributed model of runoff generation of the Vyatka River basin” Please reword.

Corrected

4. Figure 8: not legible

Improved