Dear Editor and Reviewers:

Thank you very much for your review on our manuscript. Your constructive comments and suggestions are very important and useful to improve our work and brush up the manuscript.

According to all the comments, the paper was thoroughly revised with point-to-point response. Meanwhile, some errors and deficiencies have been also revised through our self-check process and proofread service. The key changes are marked with red color. The detailed responses are listed in the following. We hope these revisions can satisfy your requirements and meet with your approval for final publication in HESS.

Best regards,

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Reply to Referee #3

In this manuscript, authors developed a precipitation downscaling method based on a fine soil moisture product. It's an interesting topic to improve the spatial details of satellite-based precipitation. My comments are as follows:

(1) As shown in figure 1, changes of soil moisture $\frac{ds(t)}{dt}$ significantly lagged behind precipitation events, but the authors didn't consider this scenario.

Ans.: Thanks a lot for your good comment. As a common knowledge, the difference between soil moisture observations at current and previous time steps can be used to estimate precipitation at current time. However, it is an important issue in this estimation that the changes of soil moisture at different depth lag behind precipitation events with different extents. According to the artificial rainfall-runoff experiment of Song et al. (2020), the results showed that this relationship can be improved by increasing the temporal aggregation interval. The performance improvement with the increase of aggregation intervals is in line with earlier findings at daily scale (Brocca et al. 2014; Brocca et al. 2016). Thus, the lagged response of soil moisture to precipitation can be ignored in the downscaling process of this study. We clarified this point in the revised version.

"Although there is a lagging effect of the changes in soil moisture to precipitation, the rainfall runoff experiment conducted by Song et al. (2020) further confirmed this effect becomes small with the increase of the temporal aggregation interval and its impact is relatively small at daily time scale (Brocca et al., 2016b)"

Refs:

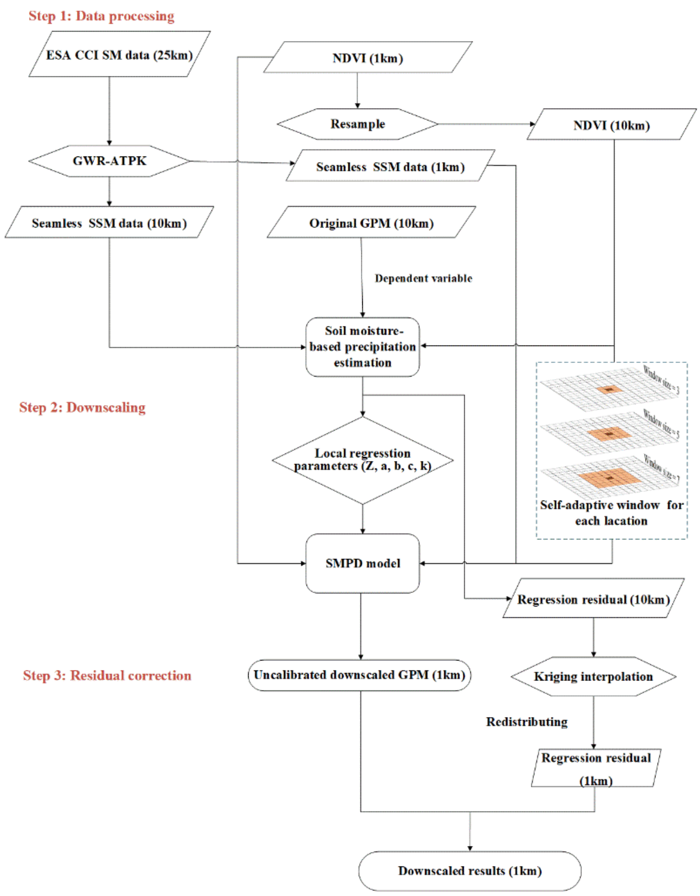
Brocca, L., Ciabatta, L., Massari, C., Moramarco, T., Hahn, S., Hasenauer, S., Kidd, R., Dorigo, W., Wagner, W., & Levizzani, V. (2014). Soil as a natural rain gauge: Estimating global rainfall from satellite soil moisture data. *Journal of Geophysical Research: Atmospheres*, *119*, 5128-5141

Brocca, L., Pellarin, T., Crow, W.T., Ciabatta, L., Massari, C., Ryu, D., Su, C.H., Rüdiger, C., & Kerr, Y. (2016). Rainfall estimation by inverting SMOS soil moisture estimates: A comparison of different methods over Australia. *Journal of Geophysical Research: Atmospheres*, *121*, 12,062-012,079

Song, S., Brocca, L., Wang, W., & Cui, W. (2020). Testing the potential of soil moisture observations to estimate rainfall in a soil tank experiment. *Journal of Hydrology, 581*, 124368

(2) Methodology: to facilitate the description, I suggest adding an algorithm flowchart.

Ans.: Thanks a lot for your suggestion. We have added an algorithm flowchart in the methodology section, shown as follows:



(3) Is the air temperature (Ta) in *eq*. 4 time varying? The air temperature can be assumed to be the same in a small extent, but the temporal variation in temperature is inevitable and cannot be ignored.

Ans.: Thanks a lot for your comment. In *Eq*. 4, we consider that the T_a of each day is the same in a small extent. Thus, the term with the second brackets of Eq. 4 is simplified to a coefficient *c* (Eq. 2 as follows). Meanwhile, the coefficient *c* value is time-dependent, showing similar temporal variation feature as T_a.

$$e(t) = a\left(1-e^{-bVI}\right)\left(m\Big/\left(1+e^{-(T_a-d)/p}\right)+f\right) \tag{1}$$

$$C = a\left(m\Big/\left(1+e^{-(T_a-d)/p}\right)+f\right) \tag{2}$$

We have clarified this process in the revised version.

(4) The description of the residual correction in 3.2.3 (particularly for *eq*. 9 and *eq*. 10 is rather ambiguous and please check *eq*. 9 again.

Ans.: Thanks for your comments. In the residual correction part, it is divided into two steps. First, the coarse resolution residual is interpolated by kriging interpolation method to obtain the high-resolution residual. Then, to meet the requirement of value preservation in the downscaling process, the kriging residuals should be corrected by redistributing it to each fine-resolution pixel *i*. That is, the ratio of the i^{th} high-resolution residual pixel in the j^{th} coarse-resolution cell to the sum of the precipitation in the j^{th} coarse pixel is used as the weight, and the residual is multiplied by the λ_{ij}, the kriging residuals were redistributed to each fine resolution pixel *i* to obtain the residual after value preservation. We have checked and modified this part, shown in section 3.2.3.

(5) In section 3.3, the i in $eq.$ 12 − 14 stands for station but in figure 7 the i seems stands for the sampling time/number.

Ans.: Thanks for your comments. We modified this expression, i in $eq.$ 12 − 14 stands for i^{th} time scale. In figure 7, all these indicators are calculated based on the comparison between the original precipitation estimates and downscaled precipitation estimates for all gauged-based stations from 2016 to 2018 periods, while *i* represents the i^{th} daily time scale, and the frequency statistics plot represents the frequency statistics of the index values for all evaluated sites rain gauge stations. We have added explanations to these terms in the revised manuscript.

(6) Section 4.1: Does the soil moisture-based precipitation estimation model used in section 4.1 contain the residual correction?

Ans.: The soil moisture-based precipitation estimation model used in section 4.1 does not contain the residual correction. First, we analyzed the soil moisture-based precipitation estimation model derivation process in Section 3.1 Then, Before the downscaling process, to evaluate the performance of the soil moisture-based precipitation estimation model based on the calibrated estimation model in Eq. 7. The mean value of the daily CCs and RMSEs during the period of 2016–2018 and their standard deviation (STD) by comparing the precipitation estimated with the proposed estimation model and the original GPM precipitation product was shown in Fig.4.

(7) Line 296 – 303: This paragraph can be combined in the section of method.

Ans.: Thanks for your suggestion. We are aware that this is the content of the downscaling method section, which has been combined with the methodology section 3.2.

(8) Please provide additional explanation to the meaning of the points shown in Figures 6 and 9, and provide a description of how to obtain the statistical metric (also for table 1 and table 2), since they contain both temporal and spatial information.

Ans.: Thanks for your comments. According to the formulas in section 3.3, Figures 6 and 9 (Figure 7 and 10 in the revised manuscript) sequentially show the scatter density plot of the original precipitation product and the downscaled precipitation data against in-situ observations from 1027 stations with the evaluation statistics (POD, FAR, CSI, R, RMSE and BIAS), at the daily and monthly scales during the period from 2016 to 2018.

Table 1 is the validation of the downscaled precipitation data, original GPM precipitation data with the daily precipitation measured by the selected stations at each month from 2016 to 2018. Table 2 represents the validation results at different precipitation density intervals for original and downscaled GPM products from 2016 to 2018 at daily scale. We provided additional explanation and description of the meaning of the figures and tables.