

Interactive comment on “Effect of DEM resolution on SWAT outputs of runoff, sediment and nutrients” by S. Lin et al.

S. Lin et al.

jw67@zju.edu.cn

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Dear Reviewer #3,

Thank you very much for your time and critics on our work. Your critics are straightforward and very helpful for our study. Your concerns mainly include the model without calibration, DEM efficient resolution, and DEM interpolation method. By considering your critics, we will improve this study by calibrating each SWAT run, and provide more explanations on the DEM interpolation in the revised version. Following are our specific responses to your critics.

Sincerely,

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The authors

1) My major concern for this paper is the use of an uncalibrated model for the different model runs across different resolutions. First, in general no results with respect to the single runs is shown. How well is the runoff matched with existing observations of flow, how well is the TN matched with measured nitrogen. This has to be shown at least somehow, otherwise we see here only a running a model exercise with one different model parameter.

2) As SWAT is not calibrated and run with its defaults values, it might not be that the default parameters are valid for the given spatial and temporal domain.

3) This is especially important as the curve number for the slope parameter might need to be adjusted with respect to the different resolution used in the paper. The authors identified correctly the change of the slope with respect to the resolution; however this already has been know. The results of the authors are a mixture of effects of DEM resolution as well as the parameters of the uncalibrated model reaction to that, thereby given way to a non linear behavior. In the reviewers opinion, one feasible approach to tackle that problem would be to calibrate the model on data from the first two years using an objective procedure (e.g. use PEST for non linear parameter estimation) for each single resolution; run the model with the calibrated parameter set on all three years and compare the third year results with respect to again the base line run (which also needs to be calibrated). Thereby the interaction effects can be minimized and a 'cleaner' DEM resolution effect be observed.

4)The reviewer ask himself against which parameters and how the model has been calibrated -> Nash-Suthcliff, correlation, discharge measured, TN measured ? If not calibrated at all, this would really be a show stopper as said in Q1.

RE:««««««««

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We will calibrate the baseline run (with original resolution DEM of DLG5m as input) to assess the model parameter errors and the performance of SWAT in the study area.

Calibration for each run was not necessary in this study, because even with the best possible model, calibration for each run at different resolution, model errors solely due to DEM inputs could have not been isolated. Instead of using measured corresponding watershed data, the best possible model predicted value was used to calculate relative difference at different resolutions. This approach could not only isolate the uncertainty in the model due to DEM resolution, but also make the results of watershed delineations or model outputs comparable. Moreover, the objective in SWAT's development was to predict the impact of management on water, sediment and agricultural chemical yields in large ungauged basins (Arnold et al., 1998).

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5) As the watershed contains 96% of forest, the reviewer explicit ask for the validity of the TP results made in the paper. Phosphorus is mainly taken away by plants as well as erosion; erosion in a forest area is almost negligible, and compute by (extended)USLE, so to get that correct is rather questionable. This is valid as well for Fig4c+d.

RE:«««««««««

Base on the model default parameters and the DLG5m original resolution as SWAT inputs, the annual predicted runoff, sediment, TP and TN out of the watershed in 2008 was respectively 2.559 cm³/s, 7140 ton, 27 ton and 269 ton, in which TP was much smaller than TN. (This sentence has been inserted in the result section in the revised version paper.) The results (Figure 4) in the paper are relative difference (not absolute) values with the ones derived from the DLG5m original resolution DEM as benchmarks.

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6) My second major concern is the use/creation of the DEM in general.

6.1. Input DEMs: Starting with the DLG, the question remain how the TIN has been

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produced, which software and which parameters have been used in the generation of the TIN (What is the horizontal and vertical accuracy of the contour lines?).

RE:««««««««

The following paragraph was added/revised in the input data section of original manuscript to address your question:

DLG5m was of 5 m interval contour lines with 3 m maximum vertical error, and was different from ASTER30m and SRTM90m that was grid format. TIN (Triangular Irregular Networks) format DEM was generated from the original contour lines before resampling to different resolution DEMs. Two tools in ArcGIS 3D Analyst Tool set, Create TIN from Features and TIN to Raster, were used for TIN creation and TIN-to-raster conversion respectively. The linear method, which calculates cell values by using linear interpolation of the TIN triangles, was applied in the TIN-to-raster conversion.

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6.2. Input DEMs: GDEM is known to have severe artifacts (sinks and artificial mountains) due to the DEM merging process (I would assume that the figure1 e and f have been swapped and that we see some serious artifacts in the hill shade). How have artifacts been treated? Sink filling, breaching? The effective resolution of the DEM is in the range of 90-120m due to the missing ortho rectification of the single scenes (see Literature). How does that influence the results? BTW, the GDEM dems have been created from the Band 3N and Band 3B!!! (see Reuter et al, 2009, A FIRST ASSESSMENT OF ASTER GDEM TILES FOR ABSOLUTE ACCURACY, RELATIVE ACCURACY AND TERRAIN PARAMETERS, IEEE IGARSS 2009, Cape Town)

RE:««««««««

Based on the evaluation of Reuter et al. (2009), the current GDEM product is not fit for terrain analysis purposes at 30 m resolution for its artifacts. That conclusion was based on the assumption that the five study titles were representatives of the current

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GDEM product. While in our study area, more serious artifacts in the hill shade can be seen in SRTM than ASTER GDEM. That indicates that less anomalies and artifacts is possible in some tiles of ASTER GDEM.

Before watershed delineation, Sink Filling (Tarboton et al., 1991) was applied in each DEM. ArcSWAT integrates ArcGIS Spatial Analyst tools, which include Hydrology tools such as Sink Filling, in watershed delineation.

It is interesting to investigate the artifact impact on environmental models. We did not quantify the DEM vertical and horizontal accuracies in detail and we did not investigate how grid size aggregation will influence those accuracies. We will conduct further study on this regards. Without quantifying the artifacts variation on different DEMs, we cannot assess the artifacts influence on SWAT predicted outputs. Nonetheless, as showed in the Fig. 4, SWAT predicted TN and TP decreased on DEM grid size, while runoff and sediment did not show clear difference between varied grid sizes. Therefore, ASTER GDEM in the resolution range of 90-120m does not guarantee better performance of SWAT than resolution 30 m. As no turn-point of the predicted outputs has been identified, an absolute difference of the predicted accuracy and accuracy threshold are necessary in the further study to recognize the ‘effective’ resolution.

The source band of ASTER GDEM has been corrected.

Reference:

Tarboton D. G., R. L. Bras, I. Rodriguez–Iturbe. 1991. On the Extraction of Channel Networks from Digital Elevation Data. *Hydrological Processes*. 5: 81-100.

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6.3. Interpolation routines: As data from the CSI and NASA server are in geographic projection, the reviewer wonders how the interpolation has been performed specifically for the SRTM 90m resolution results. Results in Figure 4c+d are showing quite some outliers from the almost linear decrease with resolution with see for SRTM/DLG/GDEM.

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RE:««««««««

The flowing paragraph has been added to the text to correct this problem: The Interpolation process was done in ArcGIS Destop. The spatial references for SRTM and ASTER GDEM are both WGS 1984. Before the DEMs were resampled (by the Re-sample tool in ArcToolbox) to different resolutions independently, the original DEMs were project (by the Project tool in ArcToolbox) to UTM 50 Zone with 30 m and 90 m as grid size for ASTER GDEM and SRTM respectively.

The linear decrease in Figure 4c+d is contributed by linear decrease of slope, as discussed in the text.

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Related to that is the question what the effective scale from your terrain is? At which frequency do you observe the river/ridge network. This might also help to explain why we see the strongly varying results in Fig 3b. A possible assumption is that the specific frequency is around 30 (small scale) or 80-90m as the RE minimizes there. However, the strongly varying results for GDEM are a complete puzzle.

RE: ««««««««

About the effective scale, please see our response to your Comment 6.2. To compare the derived river/ridge networks with the field survey, one will be helpful to investigate the DEM content and is worth further study.

The reach slope variation of relative difference of DLG5m, ASTER30m, and DLG90m is 14.1%, 20.8%, and 7.3% respectively (Table 1). The reach slope might be an indicator of ASTER GDEM artifacts, but to get that conclusion we need more observations. In this study, the reach slope variation of SRTM90m (7.3%) is only almost half of the one of DLG5m (14.1%). If the reach slope was the indicator of artifacts, the artifacts in SRTM90m are less than those of DLG5m. Obviously that is not true.

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6.4. Interpolation routines: The question remains open how and by using which software the different meshes have been generated. What was the reason to choose these specific series?

RE:««««««««

The flowing paragraph has been added to the text to clear this problem:

All the DEMs needed to be resampled to different resolutions, including 5 m, 10 m, 20 m, 30 m, 40 m, 60 m, 80 m, 90 m, 100 m, 120 m, and 140 m, where 5 m, 30 m, and 90 m was the original resolution for DLG5m, ASTER30m, and SRTM90m respectively. Except for the original resolutions, the resample resolution series is based on a 2 ratio progress in small scale and 20 m interval in large scale to get 2-3 sample points between or after original resolutions. The resample method was bilinear interpolation. The Interpolation process was done in ArcGIS Destop. The spatial references for SRTM and ASTER GDEM are both WGS 1984. Before the DEMs were resampled (by the Resample tool in ArcToolbox) to different resolutions independently, the original DEMs were project (by the Project tool in ArcToolbox) to UTM 50 Zone with 30 m and 90 m as grid size for ASTER GDEM and SRTM respectively.

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6.5. Interpolation routines: The reviewer wonders what the information content of a 5m DEM out of a 90m DEM is? Can you please comment on that. If the authors would have used some downscaling procedure using auxiliary data (streamnetwork, satellite data), they might have observed a bit different results. (see Hengl et al, 2008)

RE:««««««««

As shown in the study of Hengl et al. (2008), there is indeed a benefit of using auxiliary maps that can help us generate more realistic DEMs (especially considering the hydrological features). Except for that, other methods to derive DEM, such as ANU-DEM (contour-specific interpolator), Kriging, and PEM4PIT (Grimaldi et al., 2007), can

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improve the DEM accuracy too. To observe the DEM accuracies derived from different methods is interesting and we will think about it in the further study. The interpolation routines (bilinear interpolation, TIN-based method for DLG) applied in this study are common. We explicitly investigated the variations of SWAT predicted outputs on different resolution and source of DEM, rather than information contents of DEMs themselves. Therefore, we cannot get the conclusion of how a 5m DEM is out of a 90m DEM so far without further study, while the result has already indicated that when re-sampling DEM to a coarser resolution, SWAT predicted lower outputs of TPs, TNs, and sediments. Runoffs were not sensitive to resample resolution. At original resolution, SWAT outputs with SRTM90m as input was underestimated by 0.8% in runoff, 3.0% in sediment, 18.3% in TP, and 8.0% in TN (Table 1), comparing with the outputs with DLG5m as input. This quantifies how DLG5m is out of SRTM90m with respect to the SWAT outputs.

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7)With respect to the results reported in Table 1, why is the variance of RE of the field slope length always zero. This can not be, if the other parameter change as they do.

RE:<<<<<<<<

When resampling to coarser resolution, Field slope lengths derived from ASTER30m and SRTM90m keep constant, while field slope length derived from DLG5m increases with pauses and reaches to the maximum values, which are the same as ones derived from ASTER30m and SRTM90m, and are larger than the minimum value by 66.7% of base value (DLG5m 5 m). The field slope values of subbasins assigned by GIS interface were not continual. Field slope length values of subbasins derived ASTER30m and SRTM90m at any resample scale were all assigned to 15.2 m in this study. But for DLG5m, 9.1 m was assigned to all subbasins derived from DEMs with resolution in range of [5 m, 20 m], but 9.1 m was to some subbasins and 15.2 m for others in range of [30 m, 80 m], and 15.2 m to all subbasins in range of [90 m, 140 m], which resulted

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in the intermittent increase of average field slope length with larger resample grid size. The values assigned to field slope length of subbasins by GIS interface ArcSWAT were depended on subbasin slopes, no matter what the DEM data sources, areas of subbasins and resample grid sizes were and where the subbasins were. In this study, field slope lengths were 15.2 m for all subbasins with slopes in range of [34.2%, 57.9%], and 9.1 m in rang of [58.5%, 82.2%]. Steeper the subbasin slopes were, shorter the subbasin field slope lengths were, but it should be noticed that there was a maximum of field slope length for each specific slope and support practice to the corresponding sediment loss. Therefore it was possible that the field slope length kept constant if the slope varied in a small range in ArcSWAT.

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Reach slope of GDEM is also interesting as this is the only parameter and the only time where the range of the RE is larger than the usually twice as high DLG5 RE range. Is that an indicator for the artifacts in the GDEM ?

RE:««««««««««

The subbasin slopes decreased on larger resample grid sizes, while the reach slopes were calculated by the relative altitude deviation of two cells on edge of each reach in subbasins. Therefore, both positions and elevations of the reach edges contributed to the reach slope. The larger deviation of reach slope derived from ASTER GDEM did indicate the difference between ASTER GDEM and other two DEMs (SRTM, DLG).

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The variance as a parameter does not really tell a lot as it might change with the Mean of the parameter, is there another parameter like Standard error more useful in reporting the change of SWAT output with respect to DEMs resolution.

RE:««««««««««

The variance in Table 1 is the variance of the ‘standardized’ relative difference (%),

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which is defined as equation (1) and is comparable between different variables.

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Smaller detailed points to be fixed.

Fig4 , a+b The reviewer suggests that you change/break the Y-scale so some results can be visualized. For the current display, nothing is to be seen (ntbs) there. Fig3 c+d (ntbs). Fig2 a+c. (d as well)

RE:««««««««

Actually one of the authors holds the same opinion with the reviewer. On the other hand, another author insists that the same scale is necessary for comparison between the four variances in the same figure. We will think about scaling down the Y-axis to keep the information as much as possible.

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P4422L25 IMHO, SWAT2005 does adjust for CN, you have to specify it before inputing the management file.

RE:««««««««

We are aware that the CN value can be specified and the default value is only suitable in USA. For a purpose of comparison, the default value was applied for the CN as well as other parameters such as the management.

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Table 1, column 5 can be removed as it only contains ZEROS.

Table 1, rename Remax-min to Var(Re) or Range

RE:««««««««

Will be renamed in our revised version.

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»»»»»»»»> Rework all figure and table titles, so they are understandable from the figure text alone. Fig1 title replace 'shaped terrain' with 'hillshade'

RE:««««««««

The figure and table titles are rewritten as follow: Fig.. (a) Location of the Xiekengxi River watershed (81.7 km²); (b) estimated stream networks derived from different DEMs (ASTER30m and SRTM90m were resampled to the same resolution 5 m as DLG5m for comparison); (c) stream networks zooming in on the rectangle of b; e, hillshades derived from original resolution DEMs: (d) DLG5m, (e) ASTER30m, and (f) SRTM90m.

Fig. 2. Watershed topographic characteristics derived from DEMs vary with DEM resolutions. The benchmarks of relative differences (RDs) are the values derived from the finest DEM (DLG5m). Lines between data points are cubic interpreting trend lines. The field slope length is the mean value of mean subbasin field slope lengths derived by ArcSWAT interface.

Fig. 3. Estimated stream network characteristics derived from DEMs vary with DEM resolutions. The benchmarks of relative differences (RDs) are the values derived from the finest DEM (DLG5m). Lines between data points are cubic interpreting trend lines. The reach length, reach slope, reach width, and reach depth is the mean value of subbasin values derived by ArcSWAT interface.

Fig. 4. SWAT predicted outputs vary with DEM inputs of different resolutions. The benchmarks of relative differences (RDs) are the values derived from the finest DEM (DLG5m). Lines between data points are cubic interpreting trend lines. The runoff, sediment, TP, and TN is the predicted value at watershed outlets.

Table 1. The effects of DEM resolution on watershed delineations and SWAT predicted outputs.

Note: VariationRD: the relative difference (RD) variation (maximum - minimum) due to

resampled resolutions. R_Doriginal: R_D at original resolution. The field slope length, reach length, reach slope, reach width, reach depth is the mean value of subbasin ones derived by ArcSWAT interface. The runoff, sediment, TP, and TN is the predicted value at watershed outlets.

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Fig1 e+f swapped figures ?

RE:««««««««

No. We have checked it again and no error found. It is possible that artifacts in some tiles of SRTM are more than the one of ASTER GDEM in the same location.

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P4415L22 rename ASTER30m in ASTER 1 arc second, SRTM90m into SRTM 3 arc second. There is no Version 4 of SRTM, the latest released version from NASA is version 2, CIATs version numbering for the release is V4.1 to be correct !!!

RE:««««««««

Version 4 has been corrected to Version 4.1.

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Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 7, 4411, 2010.

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