

Response to Interactive Comment on “Estimation of surface soil moisture and roughness from multi-angular ASAR imagery in the Watershed Allied Telemetry Experimental Research (WATER)” by S. G. Wang et al.

Dear Anonymous Referee #2:

First of all, we greatly appreciate your critical comments and constructive suggestions. We have tried our best to revise our manuscript according to the valuable suggestions. For an easier comprehension, your comments are also reported. We respond below in blue to your comments item-by-item.

General Comments:

Referee #2: ... However, if I am not mistaken, in the paper the authors simply applied a methodology already proposed by Zribe and Dechambre (2002) together with Baghdadi et al. (2006a; 2006b) to field and satellite data collected during the WATER experiment. Therefore, no new methodology was developed by the authors, as it can be supposed reading the abstract and the purposes of the paper. I have not understood if the novelty of this paper is in the determination of equation (11). If so, it should be better highlighted in the corresponding section.

Response: In this manuscript, we used two empirical/semi-empirical relationships alike those ones proposed by Zribe and Dechambre (2002) together with Baghdadi et al. (2006b) to acquire surface roughness. However, we do not think this is just a simple application. What we contribute in this manuscript is that we propose a two-step retrieval scheme to derive soil moisture based on the physical model AIEM, not only over the

course of the deduction of Eq.11, but also for the inversion of soil moisture. This is new.

As we were known, using multi-angular observations could be a promising way to acquire roughness information and Zribe and Dechambre (2002) has developed an empirical relationship. The first difference in our investigation compared to the above report is, as described in P.3376, L.5-7, the AIEM model was used to obtain Eq.11 and the domains of the roughness parameters were expanded during the simulations and calculation. At this stage, the obtained roughness could be more comparable to natural surface situation and is more reliable. In the revised manuscript, we have restated this point by adding a sentence in P.3380, L.12 (conclusion section) in front of ‘An evaluation...River Basin’ to highlight this aspect. In addition, the other difference from Zribe and Dechambre (2002) and Baghdadi et al. (2006a; 2006b) is that we used an iterative algorithm based on the AIEM during the inversion step as described in P. 3373, L.1-6, this could be more promising than empirical means to obtain soil moisture. The above two points are our main concerns.

In order to better emphasis our new contribution of the proposed two-step retrieval scheme, other modifications have been made in abstract section (P.3366, L.9) by adding ‘...by using a two-step retrieval scheme...’ after ‘...ASAR images’. Secondly, in P.3370, L.5, we modified this sentence with ‘...The strategy is a two-step retrieval scheme which consisting of semi-empirical...’. And finally, in conclusions (section 4), we also modified the first sentence in the second paragraph (P.3380, L.8) with ‘This investigation presented in the paper proposed a two-step retrieval strategy to estimate surface roughness and soil moisture...’ in the revised manuscript.

Referee #2: The presentation of the results in terms of soil moisture retrieval is very short. For instance, why was the validation performed for only sites D and E if measurements were conducted at five sites (A-E)? The comparison was made for each measurement point. How many soil moisture measurements were carried out? Which is the spatial resolution of ASAR images?

Response: As we have declared at the end of the section 2.3 (P.3373, L.24-26), the problem of land salinization in experimental sites A, B and C is severe. As the following picture shows (Fig.1 in next page in this response), not only saline-alkali solutes are inside soil columns, but for most areas in these three sites, there is a shell layer with several centimeters thickness composed by saline-alkali materials onto soil surfaces. Thus, it is desirable to know whether SAR pulse can really detect soils information since the radar signals would be greatly impacted by this salt layer. At present, we did not accomplish a proper dielectric constant model and find out the feedbacks of SAR signals for this kind of salinity soil. Hence in this manuscript, we did not perform the roughness and soil moisture estimation and subsequent comparison for sites A, B and C but only at sites D and E although in situ measurements were conducted in all of the five sites. For this point, the sentence in section 3.2 (P.3377, L.14) has been modified with ‘Due to strong salinization in the study area described at the section 2.3 and sensitivities on media permittivity of radar signals, it is questionable whether SAR pulse could penetrate the salt layer and really detect soils information. Appropriate dielectric constant model and the feedbacks of SAR signals to this kind of soil, although not the focus of this article, are under developing and assessing in terms of lab experiments and our further field campaigns. Therefore, roughness and soil moisture estimation were not performed at sites A, B, and C but only for sites D and E. In addition, roughness results could not be validated because in situ roughness measurements were not conducted at sites D and E due to vegetation obstacles. As shown in Fig.7, soil moisture estimates without eliminating vegetation effect are also used for comparison...’. We think by adding these words can help readers know why soil moisture validation were performed only for sites D and E.



Fig. 1 Soil salinity in the experimental sites

As the nested sampling strategy shows in the discussion manuscript (P.3391, Fig.2), at each experiment site, 49 soil moisture measurements were performed.

Forty five measurements were involved in the soil moisture validation for each ES and the other 4 were discarded. The reason is the quantities of these 4 soil moisture sampling are obviously irrational, which probably caused by improper sampling implementation. To clarify this point, in P.3377, L.17, we added a sentence 'For each ES, 45 points of in situ measurements were used to validate the estimates from SAR imagery...' before 'The results showed that for site D,....' in the revised manuscript.

The original resolution of ASAR APP product we acquired is $15\text{m} \times 15\text{m}$, after image-to-image co-registration based on the ETM+ image, the resolution of the imagery used in the estimation of roughness and soil moisture is $30\text{m} \times 30\text{m}$. In the revised

manuscript, we have added a sentence at P.3375, L.16, which is ‘After image processes, the resolution of the imagery used for the estimation of roughness and soil moisture is 30 m × 30 m.’ before ‘Figure 3 illustrates the subsets....’.

Referee #2: By reading section 3.1, it seems that surface roughness measurements are not needed because the standard deviation and the correlation length of surface roughness can be obtained only by the knowledge of the difference in backscattering coefficient of two images acquired with different incidence angle. Are in situ surface roughness measurements used for the calibration of equation (13)?

Response: The in situ measurements of surface roughness were not involved in the calibration of Eq. 13. The parameters used to form this equation were referenced from Baghdadi et al. (2006b) since this investigation includes lots of SAR and in situ observations to obtain the statistical coefficients. Álvarez-Mozos et al. (2008) also reported that the calibration is promising. Thus, as described in P.3376, L.19-27, we used those coefficients provided by Baghdadi et al. (2006b) dependent on the configuration of acquisition SAR imagery (i.e., incidence angle, polarization, and frequency).

Besides, our original motivation is to evaluate the calibration since acquiring of the effective correlation length would be helpful to reduce one unknown surface parameter and derive soil moisture subsequently. Another purpose to carry the roughness field measurements is to collect necessary data for developing microwave transfer model and validating soil moisture and roughness estimates. However, our field campaigns did not collect sufficient observations (including SAR data and in situ measurements) to further evaluate the validity of those coefficients summarized by Baghdadi et al. (2006b). Hence, it is also one of our next aims to better estimating soil moisture in future researches conducted in the Heihe River Basin.

Referee #2: Moreover, why is the vegetation effect corrected only using parameter values taken from literature? I suppose that these parameters have a strong influence on the

retrieved soil moisture therefore, why an attempt to calibrate these parameters was not carried out by using as benchmark the in situ observed soil moisture values?

Response: We agree with the referee, vegetation parameters are very significant for the correction. Actually, we attempted to observe the behaviors of canopy layer to the backscattering coefficients in experiments designs. Unfortunately, due to limited recourses, there are no proper controllable SAR observations (such as ground based scatterometer) for the vegetations grown in this area during this period. Moreover, measurements of plant properties and underlying soils are also insufficient. Thus, we used the parameters form literatures as an alternative. That's why we summarized in the error analysis part (section 3.3, P.3378, L.8-16) that dedicated measurements of vegetation parameters are indeed desired. It is anticipate that the estimation accuracy of soil moisture can be improved by carrying more sophisticated vegetation measurements in our future field experiments in this river basin.

For revision, the paragraph begins at P.3374, L.26 in section 2.4 has been modified with 'As for the parameters used in the water cloud model, vegetation water content was measured only at site E on 18 June 2008. It was already the closest date when radar images for the same experimental area were collected. Unfortunately, due to limited resources, both controllable SAR observations and necessary in situ measurements on canopy properties which could be very helpful to the calibration of coefficients A and b in water cloud model were not obtained for the vegetation grown here during this period. Therefore, the vwc at site D was inferred on the basis of local growing status and constants A and b were not able to be calibrated at this stage. Thus, their estimates were mainly referenced from Bindlish and Barros (2001)....' in the revised manuscript.

Referee #2: Another important drawback of the paper is related to the total absence of a comparison of the obtained results with those previously published in the scientific literature. If SAR images should be used to retrieve soil moisture operationally, a better assessment of their performance over different regions and by using different algorithms should be clearly assessed. In fact, the accuracy obtained in this study ($RMSE < 0.06$

$\text{cm}^3\text{cm}^{-3}$) could be not sufficient for many applications.

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Response: We agree with the referee, many literatures reported that the RMSE of soil moisture estimation is around $0.04 \text{ cm}^3\text{cm}^{-3}$, or even smaller. Actually, one of our motivations is to explore and evaluate an operational methodology to estimate soil moisture since the main advantage of this two-step retrieval scheme is based solely on SAR imagery. As you have mentioned, it's just a case study which need to be broaden the application and may not be a so called operational method up to now, but it's really our goal. Thereby, we will evaluate this method for more landscapes over different regions in further.

As described in section 3.4 (P.3378, L.18-P.3379, L.26), we were quite aware that the errors of the estimation can be attributed to the presence of vegetation, the empirical deduction of surface roughness, the difference in sensing depths between SAR and TDR probe measurements, and the impact of the saline-alkali soils on SAR signals. As we have responded above and analyzed in section 3.3 and 3.4 in the manuscript, correction of vegetation effect is critical but we did not perform vegetation parameters calibration owing to lack of sufficient canopy measurements. We also would like to assess the difference of perceivable depth between SAR observation and TDR probe detection, since this point may be an important error source in arid region. Moreover, developing a proper dielectric model and evaluating the feedbacks of SAR signals for saline soils in this study area is an interesting issue and still going on. We suppose if all these issues can be well addressed, the accuracy can be improved.

For revision, firstly, we have replaced the word 'operational' by 'effective' and modified this sentence in P.3370, L.2 with 'The objective of this paper is to develop and evaluate an effective method that explores surface roughness based...'. Second, in P.3380, L.8, the sentence here has been modified with 'This paper proposed a promising method to simultaneously acquire surface roughness and soil moisture estimates without auxiliary information...'. And, for the sentence in last paragraph (P.3381, L.1), it has been modified with 'Potential future works in this area should expend the applications of the

proposed method over other study regions. Besides, some state-of-the-art tools can be dependent...’ in the revised manuscript.

Specific Comments/ Technical Corrections:

Referee #2: P3366, L9-14: The sentence is not clear at this point because the terminology is not yet been defined (roughness slope, roughness parameters). Please modify the sentence.

Response: Thanks for your suggestion and we have modified those sentences in P.3366, L.8-14 with ‘...This study aims to directly obtain surface roughness parameters (standard deviation of surface height σ and correlation length cl) along with soil moisture from multi-angular ASAR images by using a two-step retrieval scheme. The method firstly used a semi-empirical relationship that connects the roughness slope, Z_s ($Z_s = \sigma^2 / cl$) and the difference in backscattering coefficient ($\Delta\sigma$) from ASAR data in different incidence angles, in combination with an optimal calibration form consisting of two roughness parameters (σ and cl), to estimate the roughness parameters. The deduced roughness was then used...’ in the revised manuscript.

Referee #2: P3367, L2-4: I disagree with the authors about the fact that coarse resolution satellite sensor can not be employed at the catchment scale. Several contributions using these type of information for rainfall-runoff model calibration (Parajka et al., 2006, 2009), for the assessment of the reliability of modeled soil moisture (Sinclair and Pegram, 2010) and to improve runoff prediction (Crow et al., 2005; Brocca et al., 2010) were already published in the scientific literature.

Response: Thanks for the provision of additional references, we have read these papers and got some new ideas. For the revision, this point has been modified with ‘...It is well

known that space-borne passive systems possess the advantage of high revisit capacity, however, the spatial resolution of passive microwave remote sensing is very coarse. On the contrary, SAR sensors have the capability to provide...’ in the revised manuscript.

Referee #2: P3368, L5-9: The expressions of the two linear relations can be also removed from the Introduction section.

Response: These two expressions have been deleted in the revised manuscript.

Referee #2: P3371, L10: "... and more applicable..." to modify with "... and applicable...".

Response: Thanks for your suggestion and this sentence has been modified with "... and applicable...".

Referee #2: P3371, L12: In equation (7) the symbol F_{pq} is not defined.

Response: The symbol F_{pq} denotes the complementary field coefficient and we have added this definition in the revised manuscript.

Referee #2: P3372, L15-18: The sentence is not clear and should be revised.

Response: This sentence has been modified with ‘...Soil texture and land surface correlation function type can be measured in field and assumed as a priori information. Thereby, the remained three unknown surface parameters are soil moisture m_v , standard deviation of surface height σ and correlation length $cl...$ ’ in the revised manuscript.

Referee #2: P3375, L12: What does it mean "after calibration". Please specify if different filters or different size were used.

Response: Here, 'calibration' means radiometric calibration, the purpose of this process is to convert the DN value from amplitude to backscattering coefficient, and to rectify the radiometric errors caused by the difference of observations between near and far range beams. The sentence in P.3375, L.12 has been modified with 'After radiometric calibration,...' in the revised manuscript.

How to do noise filter depends on the speckles on the imagery. For this purpose, we have tested different combinations of filters and sizes, eventually, we chose the enhanced Lee filter with 5×5 window size. The criterias for the selection of filters and sizes are by sight check and comparing the statistical mean, range and standard deviation of the backscatter coefficients. The bigger window size is, the smoother image we obtained. Smaller window size could keep details and edges on the image while it often can not reduce speckles effectively. Different filters also lead to different process results, by inspection of the processed images and comparing the statistical indexes, we thought enhanced Lee filter with 5×5 window size was more fit for acquired images.

Referee #2: P3376, L1: "..., it was found..." By who? Please add a reference.

Response: The reference Zribe and Dechambre (2002) has been added here in the revised manuscript.

Referee #2: P3376, L6-8: Again, it was found by who? Does it refer to in situ measurements carried out in this study?

Response: Yes, it refers to in situ measurements carried out in sites A, B and C in this study. The sentence in P.3376, L.8-10 has been modified with '... $0.2 \text{ cm}^3 \text{ cm}^{-3}$. From the analysis of in situ roughness measurements (Table 2), the correlation function type is found to be fit for the exponential one.' in the revised manuscript.

Referee #2: P3376, L21: The relationship provided by Baghdadi et al. (2006b) was

obtained from simulated data or from in situ observations? Please specify. How this relationship behaves considering in situ observation of surface roughness conducted in this study?

Response: The calibration presented by Baghdadi et al. (2006b) was based on a large experimental database consisting of SAR images and in situ measurements (soil moisture and roughness), and it is an extension of Baghdadi et al. (2002, 2004).

(N. Baghdadi, C. King, A. Chanzy and J.P. Wigneron "An empirical calibration of the integral equation model based on SAR data, soil moisture and surface roughness measurement over bare soils," International Journal of Remote Sensing, vol. 23, no. 20, pp. 4325-4340, 2002;

N. Baghdadi, I. Gherboudj, M. Zribi, M. Sahebi, C. King and F. Bonn. "Semi-empirical calibration of the IEM backscattering model using radar images and moisture and roughness field measurements," International Journal of Remote Sensing, vol. 20, no. 18, pp. 3593-3623, 2004.).

In the revised manuscript, we have modified the sentences in P.3376, L.19-20 with 'Additionally, on the basis of various SAR instrumental configurations and abundant in situ measurements, Baghdadi et al. (2006b) has deduced the calibrated correlation length from SAR images and found a statistical relationship between σ and cl , which is...'

Since in situ roughness measurements have been carried only in sites A, B, and C and roughness estimation were performed in sites D and E, we did not compare the roughness behaviors.

Referee #2: P3377, L9-10: Please add a land use map to visualize the pattern of vegetated areas.

Response: Thanks for your suggestion and we have added a land use map to visualize the pattern of vegetated areas in the revised manuscript.

Referee #2: P3378, L22: Please specify the characteristics of the TDR probes used in the study. It is quite strange to have portable TDR measurements for a layer depth of only 5 cm.

Response: The TDRs used in the field campaigns are Steven TDR and Delta TDR. The former one is composed of POGO portable soil sensor, Steven Hydraprobe, and PDA. The latter one includes a HH2 portable datalogger and a Theta Probe (type: ML2). The length of the probes of both two sensors are about 5 cm, thus the detection depth we described here is also around 5 cm.

Referee #2: P3379, L1-7: I have not understood if the coefficients in equation (12) were taken from Baghdadi et al. (2006b) or from in situ measurements performed in this study.

Response: The coefficients used in Eq. 12 were referenced from Baghdadi et al. (2006b). Because the above research obtained a parameterization of the calibration parameter for SAR sensors in C band with HH and VV polarizations at different incidence angles, and this calibration enabled a good generation of effective correlation length. Thus, we chose proper values of those coefficients dependent on the configuration of acquired images provided by Baghdadi et al. (2006b) as described in section 3.1 (P. 3376, L. 23-26).

Here, we have modified the sentences in P.3379, L.4-7 with ‘...In spite of the fact that a large quantity of images and corresponding in situ measurements were involved in the deduction of the coefficients used in Eq. (12) presented by Baghdadi et al. (2006b), it is conceivable that this empirical relationship could contribute more or less errors when it is deployed in our study environment.’ in the revised manuscript.

Referee #2: P3379, L23: Results are reported only for sites D and E whereas strong salinization is present only on sites A, B and C, for which no result is shown.

Response: The strong salinization is a quite severe problem for land use in this area, and the farmers living there are really suffering from it. During the field works, they asked us whether it can be mended or not. We think this question is hard to answer. For soil moisture retrieval, as we have responded above, the salinization issue is complicated and need to be well addressed. Now, we are developing the dielectric model and evaluating the impacts of saline soils and salt-alkali layer on the SAR signals. If we could obtain proper algorithms, it is anticipated that we could properly estimate the roughness and soil moisture for the soils in sites A, B and C. However, it is not available at present. Besides, by doing these explorations, it can also be helpful to soil maintenance that would be more benefit for social activities and human beings.