

The author's answers are indicated in red color, as well as old text passages. New text passages are indicated in green color.

The paper explores methods to estimate subsurface soil moisture from surface soil moisture based on in-situ observations in cold mountainous areas since 2013. This variable is important for different scientific and applied topics. Authors explored the availability of three methods and applied the exponential filter method to the SMAP product. Research showed the improvement of profile soil moisture estimations in the mountainous. Many useful data, figures, and results were shown in the manuscript. I recommend a minor revision.

Response:

Thank you for your positive comments.

General comments: The paper is well written, and the results are well presented. Bibliography very exhaustive. The analyzed dataset is interesting, and the results can be useful to improve the estimation of subsurface soil moisture and could be potentially useful for hydrological modelling. The results show that the combination of exponential filter method and satellite surface product can improve the estimation of profile soil moisture, and the availability of the area-generalized T_{opt} in the cold mountainous areas. Related researches in high mountain ranges are limited around the world. Therefore, the presented results add new knowledge on those relevant hydrologic topics.

Response:

Thank you for your positive comments. We also think that our work can provide a useful reference for studies in high mountainous areas.

1. Line 111, The half-hourly measurements were averaged to obtain daily SM values that will be used for the estimation of subsurface SM, which cover up the response of soil moisture to precipitation in a day if it's a rainstorm in where are a big soil porosity.

Response:

Yes. In this study, the soil moisture data was averaged from half-hourly scale to daily scale, and we neglect short-term effects of rainstorms on the soil moisture dynamics. The exponential filter (ExpF) method assumes that the water flux between two layers is proportional to the difference in soil moisture and that the temporal characteristics of soil moisture can be represented by one parameter (T , time characteristic length) (Albergel et al., 2008; Ceballos et al., 2005). This simplification of the ExpF method ignores the complex relationship between the surface and profile soil moisture during rainstorm events (e.g. Tian et al., 2019). Thus, the ExpF method is typically used at the daily time scale (e.g. Albergel et al., 2008; Ceballos et al., 2005; Ford et al., 2014; Wang et al., 2017).

2. Figure 12, please explain this figure in detail about the temporal variation of soil moisture. It's obvious that SM increased in August. You can link the impact of climate change to moisture source

and so on.

Response:

We have explained the figure in detail in the revised manuscript (Line 355-360).

The temporal variation of profile SWI, surface SWI, and precipitation are shown in Fig. S10. Results showed that the temporal variation of profile SM corresponded well with the precipitation. It increased from May (with mean value of 0.27) to September (0.533), then decreased to October (0.304). Profile SWI_{SMAP} was lower than surface SWI_{SMAP} from May to August, while profile SWI_{SMAP} was higher than surface SWI_{SMAP} from September to October. This is attributed to the higher sensitivity of surface SM dynamics to precipitation and evapotranspiration (ET). During September and October, decreased precipitation and increased ET caused the faster decrease of surface SM compared to profile SM.

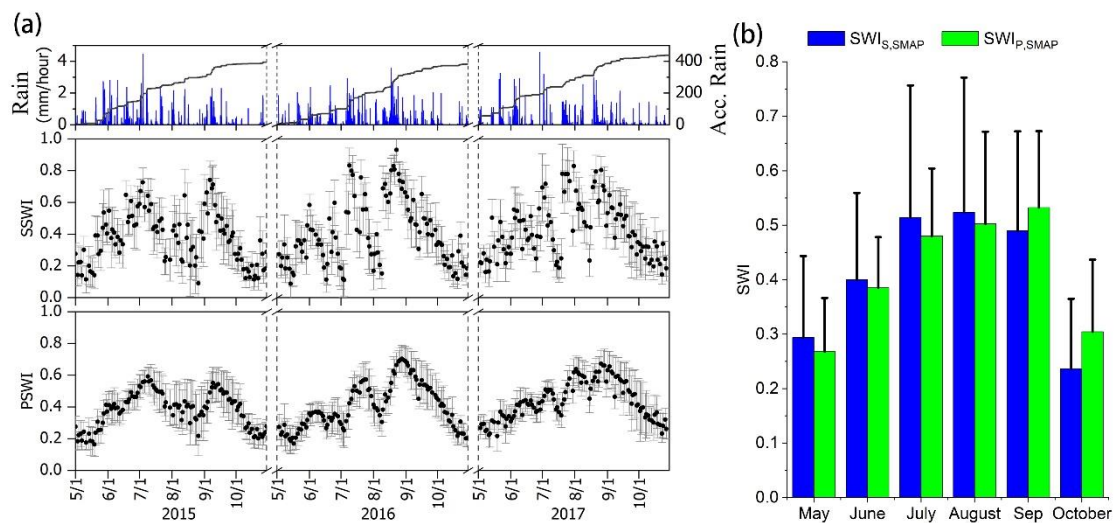


Fig. S10 (a) the temporal variation of precipitation, SSWI and PSWI, and (b) the comparison (bar represents the mean value and error bar means the standard deviation) of the monthly SSWI and PSWI during the growing seasons of 2015-2017.

Specific comments: Line number are related to the authors' line numbers.

3. Line 14, 'statistical' replace with 'multiple'.

Response:

We have changed it. (Line 14)

4. Line 15, 'an' replace with 'its'.

Response:

We have changed it. (Line 14)

5. Line 15, '15' and '25' replace with '10-20' and '20-30', respectively.

Response:

We have changed it. (Line 21)

6. Line 25, 'with' replace with 'by'.

Response:

We have changed it. (Line 22)

7. Line 26, please rewrite this sentence. I would prefer to 'the ExpF method was applied to estimate profile soil moisture using the satellite soil moisture product'.

Response:

We have changed it. (Line 23-24)

8. Line 27, the first 'to' replace with 'with'.

Response:

We have changed it. (Line 25)

9. Line 33, please insert 'as' before 'an'.

Response:

We have changed it. (Line 31)

10. Line 36, 'included' replace with 'include'.

Response:

We have changed it. (Line 34)

11. Line 41, 'provide' replace with 'provides'.

Response:

We have changed it. (Line 40)

12. Line 48, 'from 0 to 60 cm depth' replace with '(from 0 to 60 cm depth)'.

Response:

As the cross-correlation analysis is not connected to the further analysis, we have deleted the part related to the cross-correlation analysis in the revised manuscript.

13. Line 56, please delete 'that'.

Response:

We have changed it. (Line 50)

14. Line 59, 'are' replace with 'is'.

Response:

We have changed it. (Line 54)

15. Line 60, 'have' replace with 'has'.

Response:

We have changed it. (Line 54)

16. Line 61, 'on' replace with 'about'.

Response:

We have rewritten the sentence. (Line 56-57)

The exponential filter (ExpF) method belongs to the semi-empirical modeling approaches and relies on a two-layer SM balance equation (Wagner et al., 1999).

17. Line 73-74, please re-write this sentence 'In the absence of large scale networks of in situ SM observations in mountainous areas'.

Response:

We have changed it. (Line 67)

In the absence of large-scale in-situ SM observations networks of mountainous areas

18. Line 84, delete 'which is'.

Response:

We have changed it. (Line 78)

19. Line 106, please put the reference 'Zhang et al., 2017b' at the end of the sentence.

Response:

We have changed it. (Line 100)

20. Line 107, '(González-Zamora et al., 2016)' replace with 'González-Zamora et al. (2016)'.

Response:

We have changed it. (Line 101)

21. Line 109, 'data set' replace with 'dataset'.

Response:

We have changed it. (Line 103)

22. Line 118, delete the 'and' after 'bulk density'.

Response:

We have changed it. (Line 102)

23. Line 123, I think you use the SMAP products of 2015-2017 in your research, not only 2015-2016.

Response:

We have changed the '2015-2016' to '2015-2017'. (Line 117)

24. Line 118, delete 'and' after 'bulk density'.

Response:

We have changed it. (Line 102)

25. Line 155, 'tn-1' replace with 'tn-1'.

Response:

We have changed it. (Line 146)

26. Line 166, delete ',' before 'The ANN'.

Response:

We have changed it. (Line 157)

27. Line 167, delete 'of' after 'training'.

Response:

We have changed it. (Line 164)

28. Line 177, I think the equation (6) is incorrect, please correct it.

Response:

We have changed it. (Line 172-173)

$$\hat{\Delta} = K_0 + K_1 \cdot \theta_1 + K_2 \cdot \theta_1^2 + K_3 \cdot \theta_1^3$$

(6)

Where $\hat{\Delta}$ is the predicted difference between surface and subsurface SM, and K_i ($i=0,1,2,3$) are parameters.

29. Line 190, please unify the 'lag time' and 'Lag time', I think it's better to use the term 'Lag time'.

Response:

As the response for comment 12, we have deleted the contents about the cross-correlation analysis. Thus, the Lag time was also deleted in the revised manuscript.

30. Line 193, 'from 0-70 cm' replace with '(from 0-70 cm)'.

Response:

We have deleted this part.

31. Line 204, add ', 'respectively at the end.

Response:

We have deleted this part.

32. Line 211, I think you mean that 'no significant linear correlations' rather than 'no linear correlations'.

Response:

We have deleted this part.

33. Line 216, delete 'have' after 'may'.

Response:

We have deleted this part.

34. Line 250, 'season' replace with 'seasons'.

Response:

We have changed it. (Line 213)

35. Line 270, insert 'ranging' before 'from'.

Response:

We have changed it. (Line 231)

36. Line 280, please insert 'layer' before both the '3' and '4'.

Response:

We have changed it. (Line 240)

37. Line 285, 'Topt' replace with ' T_{opt} '.

Response:

Fig. 5 has been changed and merged with Fig. 4 into a new figure in the revised manuscript. (Fig. 4, Line 213)

38. Line 300, 'suggest' replace with 'suggests'.

Response:

As suggested by referee 2, the correlation between ln-transformed LAI and precipitation is significant (Pearson's $R=0.80$, $P<0.01$). Furthermore, we tested the partial correlation analysis of the ln-transformed LAI, precipitation and T_{opt} . The results showed that the relationships between ln-transformed LAI and T_{opt} are nonsignificant under the control of precipitation. Meanwhile, the relationships between precipitation and T_{opt} under the control of ln-transformed LAI are not valid for all layers. Thus, this section about the control factors of T_{opt} is not convincing.

Furthermore, as the control factors and regression of T_{opt} are not applied to the further estimation of subsurface soil moisture from the SMAP_L3 product, this part is not important for the manuscript. Therefore, we have deleted the section on the control factors and regression of T_{opt} in the revised manuscript.

39. Line 310, I think it is negative correlations from Fig. 6.

Response:

As the response for comment 38, this part has been deleted in the revised manuscript.

40. Line 356, 'Topt' replace with ' T_{opt} '.

Response:

We have changed it. (Line 255)

41. Line 380, insert 'were shown' before both 'in supplementary' and 'in Fig.11'.

Response:

We have changed it. (Line 281)

42. Line 380, 'researches' replace with 'research'.

Response:

We have changed it. (Line 286)

43. Line 420, 'T_{opt}' replace with 'T_{opt}'.

Response:

We have changed it. (Line 303)

44. Line 421, insert 'profile SWI' before 'estimation'.

Response:

This sentence has been deleted in the revised manuscript as we have rewritten the paragraph (Line 300-306)

For the estimation of subsurface soil moisture from the SMAP_L3 surface product, the site-specific T_{opt} was calculated based on the best match between SMAP estimations and in-situ observations in terms of NSE. The median values of T_{opt} for the layers 2, 3, 4, 5 and profile are 7 days, 12 days, 22 days, 35 days and 10 days, respectively. The subsurface SWI estimated from the combination of SMAP surface soil moisture with the ExpF method (with the median values of T_{opt}) were compared with the in-situ observations. A comparison of the subsurface SWI time series for different layers at each station are provided in Fig. S3- S7. Fig.7 shows the scatter plot between measured and predicted SWI, and the performance metrics are summarized in Table 4.

45. Line 430, 'season' replace with 'seasons'.

Response:

We have changed it. (Line 308)

46. Line 444, 'soil profile moisture' replace with 'profile soil moisture'.

Response:

We have changed it. (Line 344)

47. Line 447, 'SMAP-L4' replace with 'SMAP_L4'.

Response:

We have changed it. (Line 347)

48. Line 485, insert 'The' before 'main findings'.

Response:

We have changed it. (Line 374)

Reference:

Albergel C, Rüdiger C, Pellarin T et al. From near-surface to root-zone soil moisture using an exponential filter: an assessment of the method based on in-situ observations and model simulations. *Hydrology and Earth System Sciences*, 2008, 12(6): 1323-1337.

Ceballos A, Scipal K, Wagner W, Martinez-Fernandez J. Validation of ERS scatterometer-derived soil moisture data in the central part of the Duero Basin, Spain. *Hydrological Processes*, 2005, 19(8): 1549-1566.

Ford T W, Harris E, Quiring S M. Estimating root zone soil moisture using near-surface observations from SMOS. *Hydrology and Earth System Sciences*, 2014, 18(1): 139-154.

Wang T, Franz T E, You J, Shulski M D, Ray C. Evaluating controls of soil properties and climatic conditions on the use of an exponential filter for converting near surface to root zone soil moisture contents. *Journal of Hydrology*, 2017, 548: 683-696.