Response to Reviewers' Comments for HESS Discussion Article

Title: A calculation method of unsaturated soil water content based on thermodynamic equilibrium

Author(s): Danhui Su et al.

MS No.: hess-2023-44

MS type: Research article

Dear Referee #2,

We greatly appreciate you providing valuable and constructive comments on our manuscript hess-2023-44. We considered each comment and will revise/improve the manuscript accordingly. The individual comments are replied to below. In the following the reviewer comments are formatted in black font and our responses are in blue.

Based on the assumption of thermodynamic equilibrium, the authors propose an innovative approach to calculate volumetric water content. In general, the manuscript is well written, and could be accepted for publication if the following points can be addressed sufficiently:

Thank you for your encouraging and constructive comments. Your comments are replied to below.

1. The author discussed various issues of using different measurement techniques for measuring soil water content in the introduction. However it is not clear to this reviewer what is the measuring principle of the soil moisture sensors they used. Could the author help to clarify why they choose particularly this sensor?

Thank you for your comments. The soil moisture sensors we used in this study are based on the principle of reflection in the frequency domain to measure soil water content. The measurement is made by launching electromagnetic waves and using the relationship between the velocity of the electromagnetic waves in the soil and the soil water content. We chose this sensor because of its fast and stable testing capability, and acceptable measurement error.

2. One major concern this reviewer has is the wide application of this method to monitor the dynamic change of soil moisture content in the field. Please the author help to add a time series plot to clarify this.

Thank you for your comments. We have added three figures (Figure R1, Figure R2, Figure R3) to illustrate the application of this method for monitoring soil moisture dynamic change in the field. We conducted field monitoring experiments in Wuhan, China. Temperature and humidity sensors were placed at different depths in the soil and samples were taken to test the porosity at the corresponding monitoring depth. The monitoring experiment was then started and continued for one week.

Figure. R1 showed the variation of temperature with time at different depths of the soil. The temperature at all depths had an overall steady decrease during the monitoring period. Temperatures in the shallow part (10-40 cm) had daily fluctuations, and the volatility decreased gradually with the increase in depth. Temperatures at depth (80-100 cm) remained stable with almost no fluctuations.

Figure. R2 showed the variation of relative humidity with time at different depths of the soil. The relative humidity at each depth increased rapidly at the beginning of the experiment, after which it fluctuated from 95% to 100% in the shallow part (10-40 cm) and remained stable at about 100% in the deep part (80-100 cm).

Figure. R3 showed the variation of soil water content at different depths with time. Compared to temperature and relative humidity, soil water content fluctuated insignificantly, having a slight daily variation in the shallow part (0-40 cm) and remaining stable in the deep part (80-100 cm).

The results indicate that the method can be well applied to monitor the dynamic changes of soil water content in the field.

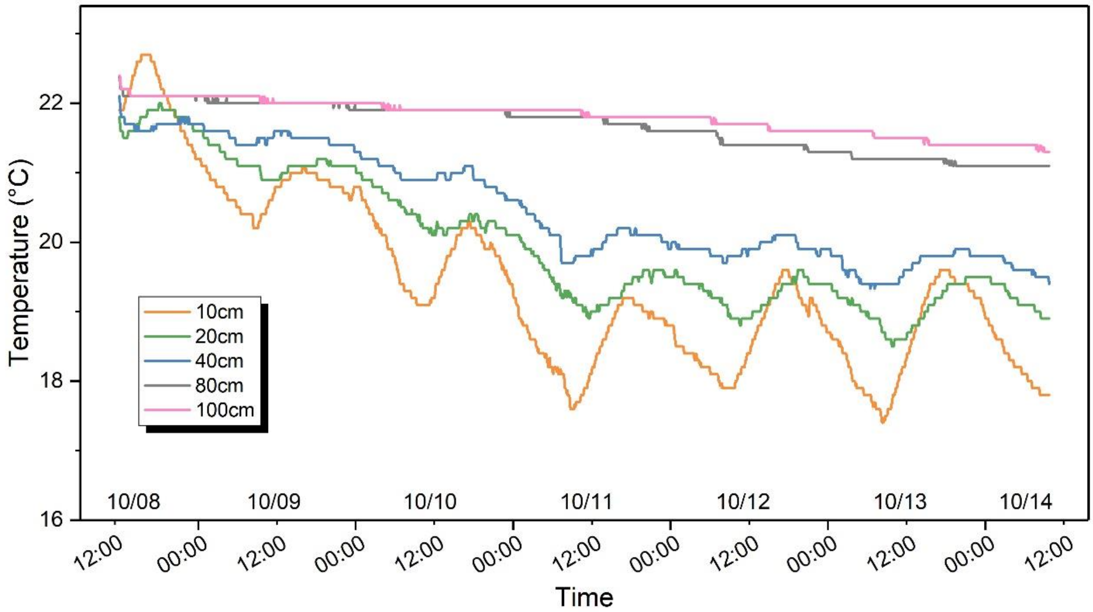

Figure. R1 Variation of temperature with time at different depths of the soil

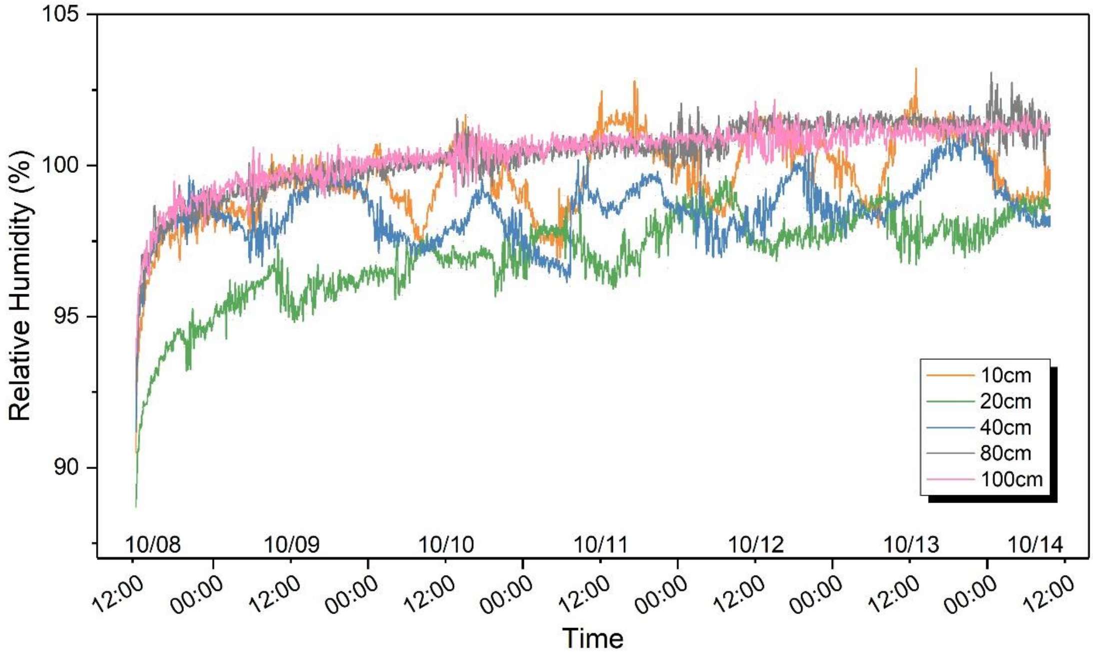

Figure. R2 Variation of relative humidity with time at different depths of the soil

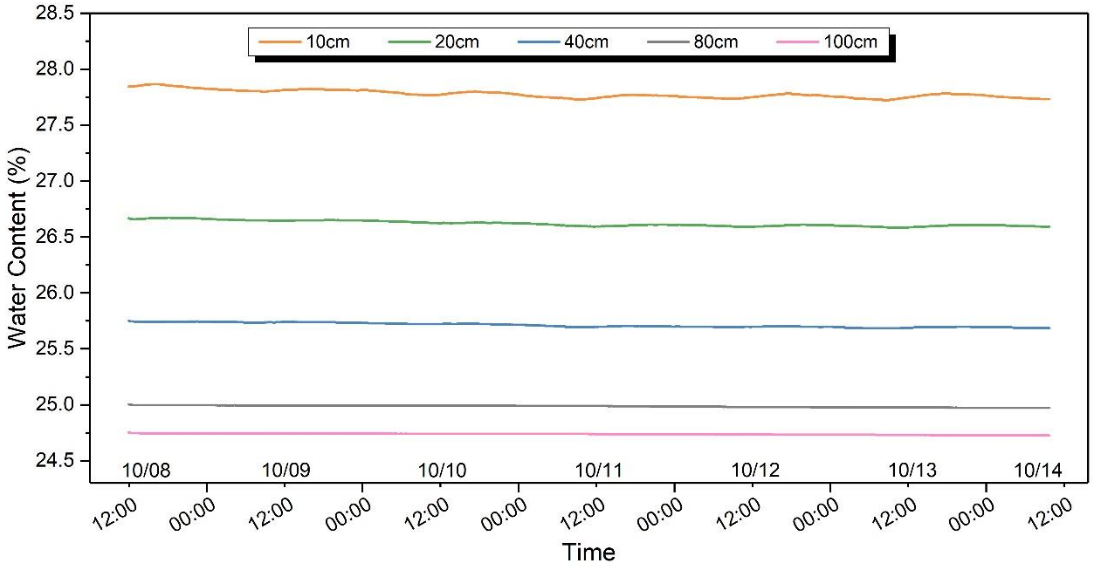

Figure. R3 Variation of soil water content at different depths with time

3. Although the thermodynamic equilibrium conditions exist in the field, it can be frequently interrupted by rainfall events. This reviewer is curious about how this approach could be extended to non-equilibrium conditions, which is more the case in natural environments and the soil moisture of which is more important to be monitored.

Thank you for your comments. This is an important issue because, in the natural environment, thermodynamic equilibrium is relative, specific, temporary, and local, while non-equilibrium is absolute, universal, eternal, and global.
Although natural systems are often in non-equilibrium, our field monitoring data showed that rocks and soils in central and northern China were in near-equilibrium (relative humidity concentrated in the range of 99%-101%) at depths of 10-150 cm, and the water content calculated under these conditions was almost identical to that in equilibrium. Therefore, the water content can also be calculated by this method in near-equilibrium conditions.

4. Although there are supersaturation condition wherein relative humidity will be larger than 100%, I am wondering how this could be the case in the natural environment? Please the authors revisit line 97

Thank you for your comments. There are some important factors influencing the generation of condensation phenomena: temperature, water vapor content, condensation nucleus, etc. At a certain temperature, when the water vapor content exceeds the saturated water vapor content, condensation is theoretically generated, thereby the relative humidity reducing or maintaining at 100%. When there is a lack of condensation nucleus in the air, however, condensation does not occur immediately, and at that time, the relative humidity gradually increases and exceeds 100%. This phenomenon occurs in natural environments such as the atmosphere (Dessler and Sherwood, 2000), soils (Assouline and Kamai, 2019), and rocks (Ho, 1997).

minor technical points

The section 2.2.2 does not consider the impact of osmotic potential, Please the authors help clarify.

Thank you very much for your valuable suggestions. As we all know, water potential is an important parameter that determines the movement of water in unsaturated soils, and it consists of gravitational potential, matrix potential, and osmotic potential. We are very sorry that due to our negligence, the role of the osmotic potential had been omitted from the manuscript. We will add this section in the revised manuscript.

Some minor technical points:

What do you mean by natural density, is it bulk density?

I am very sorry that I was not clear in my words and made you doubt. The natural density in the manuscript means the density of the soil after filling and draining, including soil particles and moisture. I will modify this part in the revised manuscript.

Figure 6, you have two legends both called vapor (and water), please make clear one (column) is for volume ratio, and the other (line) is for volume.

I am very sorry that I made you doubt due to my unclear marking in the figures. In Figure 5 and Figure 6, the column legend indicates the volume ratio of water and vapor, and the line legend indicates the volume of water and vapor. We have made modifications in Figure. R4 and Figure. R5.

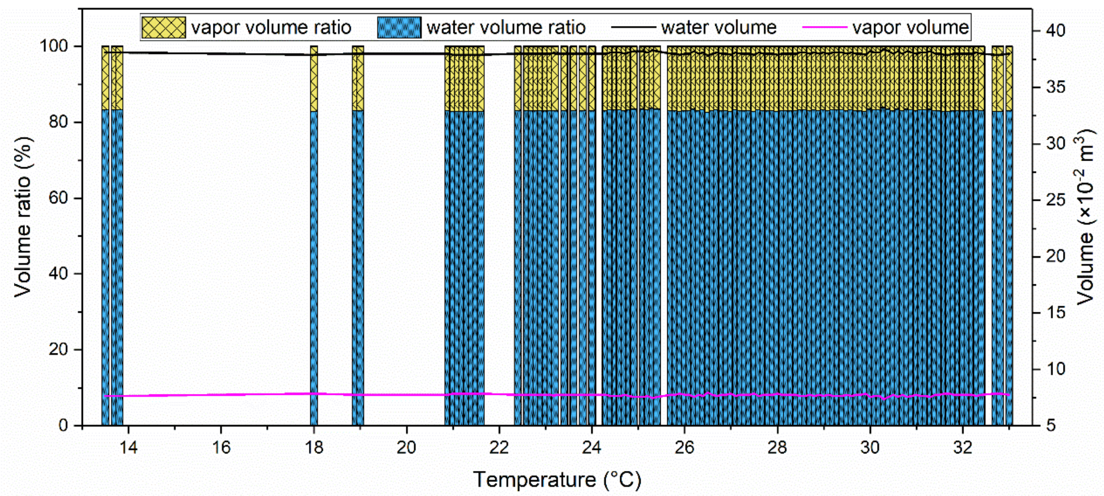

Figure. R4 Variation of the volume of water and vapor with temperature in medium sand

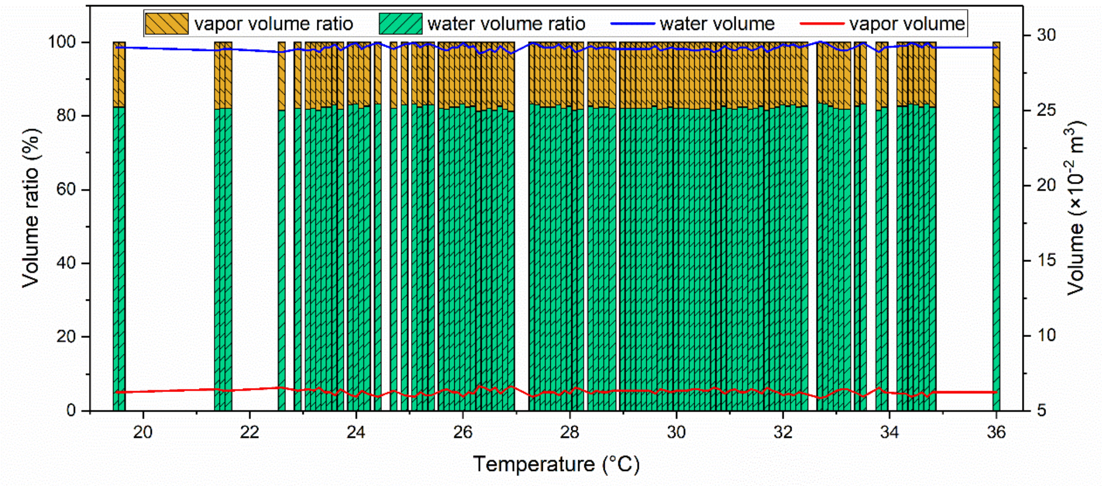

Figure. R5 Variation of the volume of water and vapor with temperature in fine sand

Reference

Assouline, S., Kamai, T., 2019. Liquid and Vapor Water in Vadose Zone Profiles Above Deep Aquifers in Hyper-Arid Environments. Water Resour Res, 55(5): 3619-3631. DOI:https://doi.org/10.1029/2018WR024435

Dessler, A.E., Sherwood, S.C., 2000. Simulations of tropical upper tropospheric humidity. Journal of Geophysical Research: Atmospheres, 105(D15): 20155-20163. DOI:https://doi.org/10.1029/2000JD900231

Ho, C.K., 1997. Evaporation of pendant water droplets in fractures. Water Resour Res, 33(12): 2665-2671. DOI:https://doi.org/10.1029/97WR02489