RC1

General comments The paper presents soil moisture data observations covering 20 years (and for some of the data even longer) measured at different soil depths and at a high temporal resolution. Soil moisture was measured at several locations in a large lysimeter on a landfill. The long and more or less continuous soil moisture observations with a high temporal resolution cover different climatic conditions and make the study valuable. This allows analyzing soil moisture development in the soil horizon under different climatic conditions over several years, including very dry conditions. The structure of the manuscript is clear and concise. Despite this wealth of data, I have severe concerns that the way the data are presented and discussed misses important aspects. The discussion and interpretaion remains rather vague and should go into more detail. The manuscript requires a major revision. My suggestions are listed below:

Specific comments

1. The manuscript does not provide basic information on factors that have substantial influence on soil water movement and evapotranspiration. Please provide these information in the study site description, and also use these additional data in the interpretation and discussion of your results (e.g. by applying an analysis of variance) a) The data stem from two large lysimeters installed at a landfill. This makes a very specific case study, since the soil layers have been build up artificially. This specific case is not discussed in the paper, but it seems as if the landfill cover can be compared to surrounding non-artificial soil or landscapes. Unfortunately, there is no presentation of the soil profile(s) of the two lysimeters and no description of soil properties, like texture, bulk density, pore volume, pF values and so on. I assume that the cover of the landfill has to meet specific requirements, and I would expect that information on soil properties therefore are available. I recommend including a table with information on soil properties (in different depths or discretized by the layer type, e.g. recultivation layer, drainage layer etc.) in the site description, and along with that, a figure of the soil profile with indications of compaction horizons or other information which are specific to that soil.

More Information on the lysimeters was added to the manuscript along with the available information on vegetation and soil properties. We added cross sections of both lysimeters. The cover was built as an alternative landfill cover not following or using any of the approved sealing systems at the time. Therefore the lysimeter was built to prove the proper functioning of the sealing system.

b) Along with missing information on soil properties, there is no description of the vegetation cover of the landfill (if there is a cover, or is it bare soil / something else?). If the two lysimeters have the same (vegetation) cover type, the effects on evaporation, transpiration and drainage are likely comparable. The second lysimeter was implemented later than the first one. Are there changes in the (vegetation) cover between the two? Please add this information in the study site description, and also consider it in the further discussion and interpretation of results.

We agree that comprehensive information on used materials is important in interpreting results. Unfortunately, detailed properties of the soil are not available. The major point of the monitoring program and reason for building of the lysimeters has been and still is the proper functioning of the landfill cover to stop water from percolating through the landfill itself. The material used as recultivation layer was only of minor importance

during construction. Overall the soil is very heterogeneous, containing clay, sand and even larger rocks.
We added available information on vegetation to the manuscript. Both lysimeters have the same vegetation cover consisting of grass and weeds. Unfortunately, not much information on soil properties and the establishment and past development of a grass cover is available.
c) A photo might be helpful to give the reader an idea of the site
We agree, photo added:

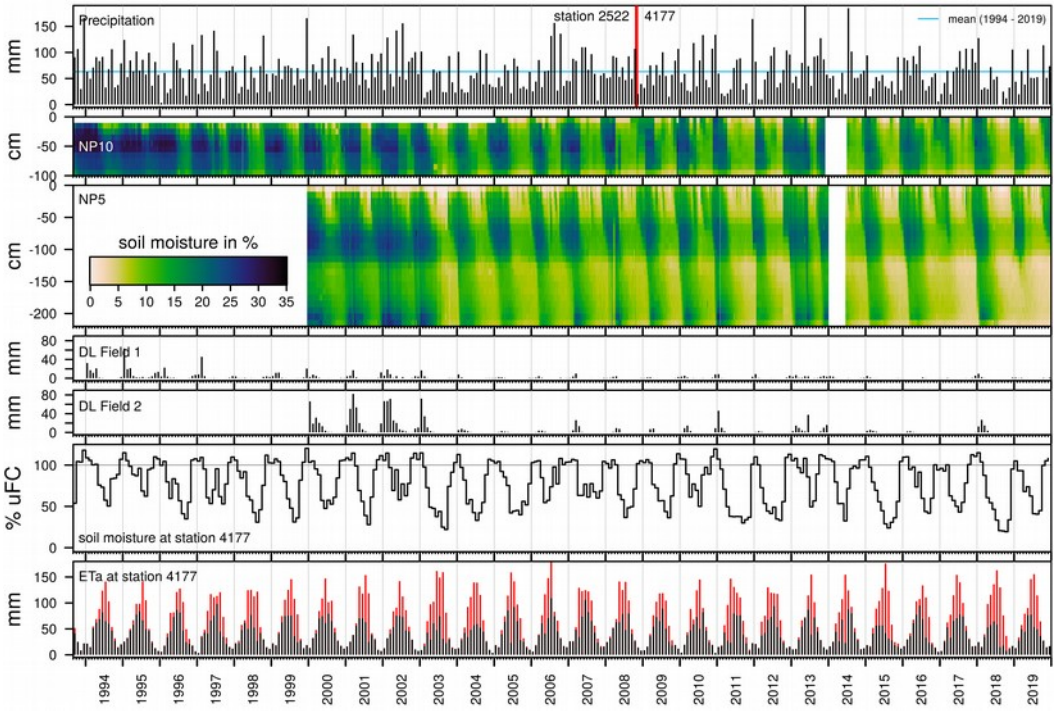
2. Information on mean annual and monthly precipitation and temperature at the study site or in its vicinity (e.g. from DWD station data) is missing. Since the authors discuss the effects of the very warm and dry summer 2003 on subsequent soil moisture, it would help the reader to see some information on average conditions and on the deviation from long-term averages during the observation period. Please add a table and/or figure with mean annual and mean monthly precipitation and temperature at least, and indicate the deviation from these average conditions during your observation period. You may also consider to highlight years with very strong deviations (e.g. very warm/cold, wet/dry).
We added a figure showing annual precipitation and mean annual temperatures to the manuscript. These data are sourced from the DWD.
3. The methods section (3.3. Theory and calculations) is very brief. Especially the Bayesian change point detection should be explained in more detail. Please also add a reference to the software you used for calculating the linear regression models.
We explained the Bayesian changepoint detection in more detail and added a reference to the lm-function (R Core Team, 2020) used to calculate the linear models.
4. Comparison of soil moisture measurements with modelled uFC: a) When using the (modelled) usable field capacity (uFC) provided by DWD I wonder why you did not try to make these data more comparable to the volumetric soil moisture measurements from the two lysimeters. This could either be done by converting the modelled uFC into volumetric soil moisture making use of the soil properties (in particular pF values, pore volume) these calculations are based on - as far as these information are provided along with the modelled uFC data. Or do it the other way round and calculate uFC at the soil moisture sampling points based on the volumetric soil moisture content and the soil properties (e.g. layer specific pF values) of the soil layers of the two lysimeters. This touches the above-mentioned missing information on soil properties. b) A discussion on how well modelled uFC can be compared with soil moisture measurements at the the lysimeters is missing. Presumably, the modelled uFC is based on non-artifical soils,

but soil moisture observations at the two lysimeters represent conditions in an ‘artificial’ soil layer. Please include a more detailed discussion here, or skip the modelled uFC data, if the soil properties on which the calculations are based are not comparable the conditions at the lysimeters.

The soil parameters used to model uFC data are different to the soil used in the lysimeter. Comparison of modeled and measured values is not possible quantitatively. However, as noted in the manuscript, they share similar temporal distribution patterns. We added information on the soil and boundary conditions used in the model to the manuscript.

5. Presentation of results: Figure 2 (discussed chapter 4) is hard to read and the information might therefore not reach the reader. Since there is many data ‘squeezed’ into this figure I find it hard to read or to really compare the different NP measurements. It is particularly difficult for the NP data of Field 1. Can think of another way of presenting the data, or (this goes more to the Editor) place this figure in landscape format? It might also be worth to plot it in a different way, e.g. calculate the difference from average for each depth increment over the entire observation period for each pixel/time step. I suggest to remove the map with modelled uFC at the bottom of Fig. 2 completely, or to move it to the appendix.

As suggested we moved the modeled uFC to the appendix. The Figure containing all measured soil moisture data was also moved to the Appendix and replaced by a figure showing selected soil moisture at two measurement points, along with the requested discharge (measured at lysimeter), precipitation and evapotranspiration (measured by the DWD) data. We hope the reduced amount of data helps readability.



L. 149: explain climatic conditions 2003 (dry and hot summer in the study region) – this can be accompanied or underlined by further general information on climate characteristics at the study site over the study period (see also #2 of my general comments above)

A figure showing annual precipitation and temperatures was added and a description of exceptional years given in section 2 “Study site” of the manuscript.

L. 161 – 165: give a more detailed description on soil properties, and discuss the effects of soil compaction. Could a compaction horizon result in a capillary barrier in the soil layer? How would that effect soil water movement?

Additional information added to section 2 of the manuscript.

Usually a capillary layer is formed by a fine material on top of a coarse material with a sharp contact. This sharp contact is not present within the compacted layer (porosity follows a gradient). The sharp contact with the layer on top is inverse to the one usually found within a capillary barrier (lower capillary forces in top layer due to higher porosity).

L. 193 – 199: please provide a more in-depth discussion in this paragraph on potential effects of soil compaction and why moisture patterns at some depths are more persistent than in other depth. E.g. continuously ‘wet’ conditions at approx. 100 cm in field 2 or at roughly 150 – 200 cm at field 1; why are there drier conditions in a small area above 150 cm at field 1).

added an explanation to this section regarding different compaction and soil material used during construction.

L. 203 – 206: In this paragraph you argue that the shorter observation period in field 2 is reason why the observed decrease in soil moisture is not significant. I wonder if this is the only way of interpreting this result. A) When looking at Fig. 5 there seems to be a change in the direction of soil moisture change at approx. 70 cm at field 2. This might also correspond to the rooting depth (in case vegetation is present), resulting in a quick recycling of precipitation via root water uptake / evapotranspiration which does not allow percolation to deeper soil layers. B) A compaction layer might further impede percolation. C) The different soil depths of field 1 and 2 and the different duration since the lysimeters have been installed, resulting effects on soil properties and (vegetation) cover should be discussed, too.

It certainly is not the only way of interpreting this result. There might be a correlation between rooting depth of plants with quick recycling of water in the upper soil and different trend in moisture change in deeper soil layers. However, both lysimeters have similar vegetation and thus should show similar results. It seems more likely that this effect is caused by the length of time series and differing compaction/differing material in both lysimeters.

L. 209 – 212: please provide a more detailed discussion on the reasons for the observed reductions in soil moisture (e.g. in the context of precipitation / temperature regimes). Why is the reduction in the lowest part of the soil profile most pronounced from January – May in field 2, and why is it not obvious in field 1?

We added a more detailed discussion and the precipitation data to the manuscript. Highest absolute moisture is observed during these month at the mentioned lower part in Field 2 at the beginning of the time series (largest seasonal amplitude). Maximum values of soil moisture are affected more by drying of the soil. Reduction is not obvious in Field 1 because depth of the soil in the lysimeter is less.

Figure 7, time series decomposition: this analysis is valuable to detect trend changes. As with Figure 2 I am concerned that, with the amount of data, the figure is still readable. As suggested before, it might be worthwhile to test different colour schemes, or highlight particularly relevant results.

We moved this figure to the appendix and replaced it with a figure showing only a selection of the results at two measurement points, greatly reducing the amount of data that is presented. Furthermore, to familiarize the reader with the results of the model, an example of model results is presented in an additional figure as a “more traditional” line graph and a discussion added.

L. 262: it is the first time in the manuscript that re-wetting from groundwater is mentioned. Are the lysimeters connected to the groundwater in this specific setting on a landfill? If so, please also describe this in the study site description

Lysimeters are not connected to the groundwater. Both lysimeters are constructed using plastic sealing liners at the sides and the bottom.

L. 270: which soil properties do you think of? Please include that in more detail in this paragraph

These could be any of the properties that are related to moisture transport and retention in the soil.

Added some examples for these soil properties to the manuscript: “(water retention, preferential flow paths, hydraulic conductivity, soil structure, etc.)”

Technical comments:

Chapter 1

L. 27-28: which were the effects of El Nino? Please explain the results of the cited studies (Solander, Kolusu) in more detail (1-2 sentences) or skip it

Added short explanation of main findings: “The 2015-2016 El Niño event is associated with extreme drought and groundwater storage declines in Southafrica while at the same time in east African countries south of the equator an increase in precipitation and groundwater recharge was recorded (Kolusu et al. 2019). Similarly, Solander et al. (2020) found evidence for both, increase (eastern Africa) and decrease (northern Amazon basin, the maritime regions of southeastern Asia, Indonesia, New Guinea) in soil moisture storage depending on location.”

Additionally updated reference Solander, 2019 from discussion article to published version Solander 2020.

L. 30-36: you could state which measurement type is used

Added measurement type used in this study to the introduction

L. 44-46: rearrange order of sentences (e.g. start with second sentence in this paragraph

Sentences rearranged

L. 55 ‘with regard’ instead of ‘in regard’ Please check and correct where necessary throughout the manuscript: - ‘depth’ and ‘depths’ - ‘In depht’ vs. ‘in-depth’ - ‘at depth of’ vs. ‘at a depth of’

Changed to “with regard”. Also checked throughout the manuscript and corrected several other instances.

Chapter 2

Include information on soil properties (at least those that are most relevant for soil moisture movement/storage), (vegetation) cover of the landfill, and climate characteristics

Added information on vegetation to the manuscript. Unfortunately not much information on soil properties and the establishment and past development of a grass cover is available.

Explain why the two lysimeters have different soil depths

Added an explanation for different soil depth in the two lysimeter fields to the manuscript. Results from the first lysimeter suggested a stronger recultivation layer better protects the mineral clay liner from drying out and thus improves long term stability of the system.

L. 78: add year '. . .being taken in December 2000' / '.. in December of that year'

added "of that year" to the manuscript

Chapter 3

Are there more neutron probe measurement points in the lysimeters (since NP numbers start with 3, and if so, why was that data not used

There are more measurement points in Field 2. As mentioned no measurements were taken at these points. Due to settling of the cover material after construction, some of the steel pipes were bent and are not usable for measurements.

L. 90: when was Field 2 constructed?

As mentioned in the section about the study site Field 2 was constructed in 2000. Added "(December 2000)" to the manuscript.

L. 122 – 127: could you please explain more clearly what you did here?

We added another figure to make this more clear.

L. 134 – 137: please describe in more detail the Bayesian change point detection and time series decomposition: how is it done and which information does it provide?

Added more information on Bayesian changepoint detection

Chapter 4

L. 141: please indicate the mentioned clay layer in Fig. 2

In accordance with a previous comment to reduce the amount of information we changed Fig. 2. It now only includes the recultivation layer.

L. 155 – 157: it is hard to see the discussed results in the Figure in its current form (see #5 in general comments)

changed figure

L. 157: change '. . .the missing occurrence. . .' into a less complicated sentence

changed

L. 160: delete 'or so'

deleted "or so"

L. 168: delete duplicate 'the bottom of'

deleted "of the bottom"

L. 170: depending on the DWD station, there is an annual cycle of uFC at 60 cm depth, so I would not call it 'minimal'

As suggested by reviewer 2, we added an indication to the boundary condition used at the bottom of the model defined as a constant water content. So annual cycle in soil moisture at the model bottom should not be very high.

L. 171: 'at a depth'

added "a", new sentence is "… is only minimal at a depth of 60 cm."

L. 172-173: Why is there a clear change in modelled uFC already after 2001, but for the soil moisture measurements this is only visible after 2003?

because we moved the time series of depth dependent usable field capacities to the appendix we removed these lines from the results and discussion section.

L. 177: add 'and a mean time series from all sampling points at field 2 are shown'

added to the manuscript according to suggestion.

L. 178 and 183: change 'in the individual time series' to 'in the time series of NP at 170

cm’
changed in both lines as suggested
L. 190: change ‘could be observed’ to ‘soil moisture decreases by 0.34 % . . .’
Changed sentence accordingly
Figure 3: even with a good colour printer it is difficult to discern the colours representing the different years in the polar coordinate system. I suggest to try out other colour or gray scale palettes, or you just highlight very dry or very wet years.
The main reason to show data in a ploar coordinate system was to highlight the seasonal asymmetry (the opening of the nautilus representing fast re wetting). The offset from the center illustrates seasonal dynamics. Different years under dry and wet conditions can be discerned by looking at the traditional time series plot.
L. 202: change end of sentence to ‘are indicated by a marker’
end of sentence changed accordingly
L. 208: I would not use ‘bias’ in this case, since the differences are not artefacts
bias replaced by “push” in the manuscript.
L. 215 – 218: please discuss in more detail why less water is percolating during winter in recent years
This is a direct consequence of the reduced soil moisture. We added percolation data to the manuscript.
L. 226: typo in the DWD station code?
2935 changed to correct code 3925
L. 228: ‘increase’ instead of ‘increases’
changed