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Hydrology and Earth System Sciences Discussions

Interactive comment on "The COsmic-ray Soil Moisture Interaction Code (COSMIC) for use in data assimilation" *by* J. Shuttleworth et al.

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In the following, author responses are given after each comment

Responses to Anonymous Referee #1

Received and published: 5 March 2013 Review:

Title: The COsmic-ray Soil Moisture Interaction Code (COSMIC) for use in data assimilation.

Authors: Shuttleworth, Rosolem, Zreda, and Franz

The paper introduces a simple, physically-based and computationally efficient model

(COSMIC) to predict above-ground fast neutron flux as a function of the soil moisture profile. The simple model is verified against the existing Monte Carlo N-Particle eXtended (MCNPX) model that includes process-level descriptions of neutron transfer and is therefore computationally demanding and, unlike the newly developed COSMIC model, not suitable for use in a soil moisture data assimilation system. The authors demonstrate that estimates of above-ground neutron fluxes from COSMIC match very well with those obtained from MCNPX, although they are not necessarily a perfect match against in situ measurements of neutron fluxes when model inputs are based on in situ soil moisture measurements. Nevertheless, the authors further demonstrate for a single site that COSMIC can be used as an efficient observation operator in a soil moisture assimilation system.

The manuscript is well written and of high relevance to HESS readers. The COSMIC model evaluation part of the paper can be published more or less as is. The data assimilation example, however, requires more substantial edits so that readers get a better sense of what exactly was done. Since these edits are meant mostly for clarification and should not change the results of the paper I recommend publication of the paper after MINOR revisions following the comments outlined below. Major comment:

The description of the data assimilation example in section 5 needs to provide much more detail. What assimilation method was used? Which model variables were updated (control vector)? What were the model and observation error inputs? What is the skill of the soil moisture estimates in each layer (as opposed to the vertically averaged time series shown in Fig 9, with metrics in Table 2)?

RESPONSE: The description of the data assimilation example given in the revised manuscript has been significantly extended to give additional information and additional discussion of the results, but without destroying the primary focus and overall balance of the paper, see page 8, line 320 to page 11 line 467 in the revised manuscript.

Minor comments:

p1098, line 19: typo: replace "soilis" with "soil is"

This typographic error was not present in the submitted manuscript, rather picked up when the manuscript was transposed on to the EGU website and this error was not noticed when the latter type-set version was reviewed. It remains absent in the revised manuscript.

p1100, line 8: are "(a) and (b)" the same as "1." and "2." in lines 16 and 18 of page 1099?

This typographic error was not present in the submitted manuscript, rather picked up when the manuscript was transposed on to the EGU website when the labels (a) and (b) were transposed to "1" and "2" and this error was not noticed when the latter type-set version was reviewed. The inconsistency remains absent in the revised manuscript.

p1101, line 2 (and many other places): Use SI unit "g" instead of "gm" throughout the paper.

"gm" has been changed to "g" throughout the new submitted manuscript.

p1104, line 5 and Figure 4: Why is the wettest profile chosen to be uniform at 0.4 m3/m3? Shouldn't this depend on the porosity at a given site?

In practice the wettest profile possible at each specific site will indeed depend on the porosity, but for consistency during parameter optimization at many sites a fixed set of hypothetical profiles was defined and applied, with one of the criteria used during optimization then weighted towards individual site conditions (specifically, the Mean Absolute Error between the above-ground fast neutron counts calculated using the COSMIC model and the equivalent counts calculated by MCNPX weighted by the probability density function of soil moisture historically observed at each site), see page 5 line 205 to page 6 line 209 in the revised manuscript.

p1106, line 23: change "alpha and L_3" to "L_3 and alpha" (that is, use the order in which the two are used in lines 22 and 24.

The suggested alteration was made in the revised manuscript, see page 7 line 259.

p1108, line 23: typo: replace "thefast" with "the fast"

This typographic error was not present in the submitted manuscript, rather picked up when the manuscript was transposed on to the EGU website and this error was not noticed when the latter type-set version was reviewed. It remains absent in the revised manuscript.

Fig 6 (a) and (b), x-axis labels in graphic: replace "rho_dry" with "rho_s" for consistency with symbol for bulk density used elsewhere

The suggested alteration was made to this figure 6 in the revised manuscript.

Fig 8 caption: There are lines in the graphic that are not discussed in the caption. The caption needs to be expanded to include those additional lines and shading

These lines are now described in the Fig 8 caption in the revised manuscript.

âĂČ Responses to Anonymous Referee #2 Received and published: 6 March 2013 Review of The COsmic-ray Soil Moisture Interaction Code (COSMIC) for use in data assimilation by Shuttleworth et al.

General comments:

A new simplified model able to simulate the response of the cosmic-ray neutron intensity to soil moisture profiles is presented (COSMIC). The main added value of the COSMIC is the high computing time efficiency. A comparison with a more complex model is performed and the 6 parameters (3 of them are site-specific) of COSMIC are determined for a number of sites. Then, the COSMIC model is used as an observation operator coupled with a land surface model in a land data assimilation system. This is a very interesting paper presenting a pragmatic way to use a new and promising measurement technique for water resource evaluation. This is fully consistent with the scope of HESS. However, the data assimilation part is not sufficiently well described to be convincing. It should be either removed or filled out. Moreover, the modelling assumptions made in section 2 should be better explained/justified.

Recommendation: major revisions.

RESPONSE: The description of the data assimilation example given in the revised manuscript has been significantly extended to give additional information and additional discussion of the results, but without destroying the primary focus and overall balance of the paper, see page 8, line 321 to page 11 line 445 in the revised manuscript.

In fact the description of this simple model is already simple in the text. In practice the primary call for additional explanation by the referee seems to be for justification of the assumption of exponential decay of the neutron fluxes, which he/she raises as particular comment two below. The response for better explanation/justification of modeling assumptions is therefore given there.

Particular comments:

- P. 1100, L. 8: do you mean (1) and (2) ?

This typographic error was not present in the submitted manuscript, rather picked up when the manuscript was transposed on to the EGU website when the labels (a) and (b) were transposed to "1" and "2" and this error was not noticed when the latter type-set version was reviewed. The inconsistency remains absent in the revised manuscript.

- P. 1100, L. 25 and P. 1102, L. 2: any reason to think that the reduction with depth is exponential in the real world?

Yes. In fact the assumption of an exponential reduction controlled by the amount of mass through which neutron fluxes pass is consistent with physical intuition, but the fact that the MCNPX simulations in fact calculate such an exponential reduction perhaps gives more categorical evidence for this assumption. Consequently we have included

a short sentence in the text stating this point to justify the assumption, see Page 3 lines 95-97

- P. 1101, L. 2, L. 10, and P. 1102, L. 8: “units of gm per unit area” ? Unclear. Do you mean “g cm-2” as in Table 1 ? Using units of “kg m-2” could be more convenient.

"gm per unit area" has been replaced by "g cm-2" throughout the text. (It is traditional to use grams and centimeters [rather than kg and m] in the literature describing neutron attenuation.)

- P. 1104, L. 2 (and elsewhere in the text): please replace “gm cm-2” by “g cm-2”, or (even better) “162 gm cm-2” by “1620 kg m-2”.

"gm per cm-2" has been replaced by "g cm-2" throughout the text. (It is traditional to use grams and centimeters [rather than kg and m] in the literature describing neutron attenuation.)

- P. 1104: why does the nature of the data used to optimize the parameters varies from one occasion (L. 9, COSMOS observations) to another (L. 20, MCNPX model)?

To explain this more clearly, the relevant paragraph (page 5 lines 164-179) has been rewritten as follows.

Because L2 and L4 relate to attenuation by water alone, their values are independent of the soil chemistry of the site and they can be determined by substituting pure water for dry soil in MCNPX and COSMIC calculations. A simulation with MCNPX was made with pure water substituting for soil, and an exponential function then fitted to the calculated reduction in high energy neutrons with depth calculated by MCNPX for pure water to determine L2. The original San Pedro site was then selected for determining L4 and the required value of the parameter N first defined at this site. This was accomplished by first optimizing the values of all remaining four COSMIC parameters (N, α, L3, L4) at this site, with L2 given as previously discussed and L1 computed directly from MCNPX, in a similar manner to that described below. Once N is determined, COSMIC is configured to simulate pure water, and the parameter L4 is fine-tuned to match the same neutron count obtained directly from MCNPX at the San Pedro site (after appropriate scaling using the F term described in the last paragraph of this section and shown in Table 1). Notice that for pure water simulations, the terms associated with parameters a, L1, and L3 no longer appear in Eq. 5. Based on these pure water simulation comparisons, the values of L2 and L4 were set to 129.1 and 3.16 g cm-2 at all COSMOS sites.

- P. 1105, Table 1: the bulk density and lattice water content may vary considerably from one soil horizon to another. At which depth were these quantities determined/measured ?

The 108 soil samples for which bulk density and water content were determined at each site were made at depths of 5, 10, 15, 20, 25, and 30 cm and the average values of these measurements used to specify the (assumed uniform) soil represented in COSMIC and MCNPX.

- P. 1109: What do you mean by “assimilation” ? How is soil moisture modelled in NOAH ? Optimization of parameters of the land surface model (e.g. soil depth) ? Sequential correction of state variables ? In this case, did you match the observations with the model before assimilation ? Are other variables simulated by the model improved such as evapotranspiration or drainage ? How could COSMIC be implemented in a completely new site ? Does one need to measure the bulk density ? At which depth ?

See the response relating to data assimilation given above.

- P. 1122: units of L3 in Fig. 6 ?

The units are now included in this figure. âĂČ Responses to Comment #1 by L Brocca (luca.brocca@irpi.cnr.it)

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Comment

Reading the title, I have been suddenly very interested by the topic of the paper as I believe that the capability of cosmic-ray method to obtain area-average soil moisture at the large scale could provide a significant added-value for soil moisture assimilation in land surface or rainfall-runoff models. I quickly went throughout the paper for looking at the results of the soil moisture assimilation into the Noah land surface model. Unfortunately, I found the description of the data assimilation results to be not good as expected. I am fully aware that the main purpose of the paper is to describe the new physically-based COSMIC model for interpreting quickly modelled soil moisture proïn ÌÍAles in terms of the above-ground fast neutron count. However, two major prob- lems in the description of the data assimilation results have to be surely addressed in C23 the paper.

Firstly, the method used for assimilating the cosmic-ray data into the land surface model is not described at all. Which is the data assimilation technique used? pre/post- processing of the data is made? Secondly, the improving of the Noah simulations after the assimilation of the COSMOS probe count is limited to the elimination of the BIAS between modelled and observed data. However, it is well-known that the im- provements related to the assimilation of soil moisture data (and not only) have to be evaluated not in terms of BIAS reduction but for reducing the random errors between model and observations. For instance, see the detailed and clear discussion in Draper et al. (2011) or in Yilmaz and Crow (2013).

I suggest addressing these two aspects for allowing the reader to understand (and evaluate) the data assimilation part of the paper.

References Draper, C., Mahfouf, J.-F., Calvet, J.-C., Martin, E., and Wagner, W.: Assimilation of ASCAT near-surface soil moisture into the SIM hydrological model over France, Hydrol. Earth Syst. Sci., 15, 3829-3841, doi:10.5194/hess-15-3829-2011, 2011. Yilmaz, M.T., and Crow, W.T.: The optimality of potential rescaling approaches in land data assimilation, in press, Journal of Hydrometeorology, doi:10.1175/JHM-D-12- 052.1, 2012.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 10, 1097, 2013

RESPONSE: The description of the data assimilation example given in the revised manuscript has been significantly extended to give additional information and additional discussion of the results, but without destroying the primary focus and overall balance of the paper, see page 8, line 321 to page 11 line 445 in the revised manuscript.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 10, 1097, 2013.