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Hydrology and Earth System Sciences
Discussions

Interactive comment on "Derivation of the mean annual water-energy balance equation based on an Ohms-type approach" *by* X. Shan et al.

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The paper aims for a physically based derivation of the mean water and energy balance equation. The authors use a description of water vapor transfer between catchments and describe the fluxes in a flux gradient approach. Imposing the Budyko hypothesis then yields the well known Mezentsev-Choudhury-Yang equation. I think that a general derivation of the Budyko or the MCY equation is of high interest for hydrological research and thus of interest for HESS. However, one of aims of this paper is a rigorous derivation which reflects hydrological understanding. To be honest, I find it difficult to understand the reasoning which form the basis for the derivation. What I do not understand is the framework of water vapor transfer between catchments (illustrated in the figures). Figure 1 and 2 show a moisture transfer from one catchment to the next

(downwind?) where the input of the next catchment is set by the evaporation of the first. This then leads to their statement that after n catchments there is no water left and E = 0. However, in reality there are also other sources of vapor which can contribute to precipitation in catchment 2 and these are being neglected. So this framework is not intuitive to me. The main derivation is illustrated with figure 3 where 4 different nodes are introduced. With corollary 2 it is stated that the resistance nAB 6= n1 arguing that there are other possible routes between the node Atmosphere A and the catchment node B, namely atmosphere A to atmosphere C to catchment D to catchment B. I did not understand this water transfer between the two catchments. I am also not sure if these assumptions and the ones in stated in section 2.1 are actually relevant for the derivation described in section 3. Therefore I recommend major revisions which should particularly improve the description to enable the reader to better understand how considering hydrological processes lead towards the MCY equation.

Response:

We thank the reviewer very much for taking the time to review our manuscript and for the invaluable comments. And we will carefully revise the manuscript following the comments and suggestions to enable the reader to better understand. I am sorry that we didn't describe the catchment network clearly, especially no detailed description in the figure captions. We will give more detailed explanation in the revised version. As well known, at a long time scale, the water evaporated into atmosphere will be precipitated on land due to water cycle. In our manuscript, we defined the catchment network for water (vapor) transformation and transportation. To define the catchment network, we track the water movement using Lagrangian particle tracking method, i.e. we took the water precipitated into the first catchment as research object and marked it as P1; we focuses on the subsequent transportation and transformation of P1 and all the catchments that the water enters into was defined as the catchment network. Remarkably, for a special catchment of the catchment network, part of precipitation comes from P0 and the rest comes from other sources, and we only studied the former. In Figure 1, Catchments A2,j (j=1, 2, 3, . . .) represent all the catchments that the evaporated water from Catchment 1 can fall down with a form of precipitation, where water vapor has been through once of evaporation-precipitation process from P1; while Catchments A3,j (j=1, 2, 3, . . .) represent the catchments that the evaporated water from Catchments A2,j (j=1, 2, 3, . . .) can fall down with a form of precipitation, where water vapor has been through twice of evaporation-precipitation process from P1. Regarding the precipitation in Catchment 2 as the reviewer concerns, some comes from Catchment 1 and the rest comes from other sources; however, according to the Lagrangian particle tracking method, we only focus on the part from Catchment 1. Also, we can establish the balance equation of only the water from Catchment 1 for Catchment 2, P2 = E2 + R2, where P2 being the precipitation from Catchment 1, E2 and R2 being the evaporation and the runoff from the evaporated water from Catchment 1, respectively. Figure 2 indicates the transportation and transformation of the water P1 according to the Lagrangian particle tracking method. Accordingly, E2 doesn't represent all the evaporation from Catchment 2 but only the part originating from P1 (precipitated and evaporated from Catchment 1). Similarly, E3 only represents the part of evaporation originating from P1. For example, we assumes that P1 = 100 and only focuses on the transportation and transformation for the 100 water. P1 transforms into E1 = 60 and R1 = 40 in Catchment 1; then E1 possibly transforms into E2 = 36 and R2 =24 in Catchment 2. Regarding the water balance of Catchment 2, it is possible that the precipitation is 80 (including 60 from Catchment 1) and the evaporation is 48 (including 36 from E1). Figure 2 will be deleted since Figure 1 has shown the relationship. Regarding Figure 3 (Figure 2 in the revised version), both of the potential of Points A and B (water in liquid) are zero, so we assume the two points directly connected to simplify this catchment network. It neglected the potential differences caused by other factor, such as elevation, temperature. However, the potential difference between the two points equaling zero, which leads to no flux between the points. In this manuscript, the objective of Section 2 is to obtain Equation (18), while that of Section 3 is to yield Equation (25) (equation 23 in the revised version). Then substitution of Equation (25)

into Equation (18) leads to Equation (26) (equation 24 in the revised version).

Further remarks:

abstract: "homogeneity assumption" should be described more specific to the paper End of abstract, L15: There is no conclusion provided. Please explain what your results imply.

Response:

Thanks a lot. The homogeneity assumption indicated that the generalized flux has the same form for both water vapor transportation and chase transformation, or precipitation and potential evaporation have an equalized effect on evaporation. The results may imply that the homogeneity needs further test or the Budyko hypothesis should be non-homogeneity. We will give more clear explanation in the revised version, and the revised text as given as: "The Budyko hypothesis has been widely used to describe precipitation partitioning at the catchment scale. Many empirical and analytical formulas have been proposed to describe the Budyko hypothesis. Based on dimensional analysis and mathematic reasoning, previous studies have given an analytical derivation, i.e., the Mezentsev-Choudhury-Yang (MCY) equation. However, few hydrological processes are involved in the derivation. Therefore, this study firstly defined a catchment network to describe water vapor transformation and transportation using the Lagrangian particle tracking method; and then defined the generalized flux of water vapor, which can be expressed as the ratio of potential difference with resistance. Furthermore, this study gave a new derivation of the Budyko hypothesis based on an analogy of the Ohms-type approach and the homogeneity assumption, i.e., the generalized flux has the same form for both water vapor transportation and chase transformation, and in other words, precipitation and potential evaporation have an equalized effect on evaporation. The derived equation has the same form as the MCY equation but has a more physical explanation than the mathematic reasoning proposed in previous studies. In addition, this study suggested a more general expression E=P(b+kE0)/(P^n+(b+kE0)^n)^(1/n) under conditions without the homogeneity constraint, where E, E0 and P are evaporation, potential evaporation and precipitation, respectively, and n, k and b are constants. Setting b to 0, E=(kE0*P)/(P^n+(kE0)^n)^(1/n) can be obtained, which was proposed by Zhou et al. (2015). It is the MCY equation when b = 0 and k =1."

P5L2-5: it is unclear why this is mentioned here

Response:

In the original manuscript, we tried to interpret the generalized function by giving some examples. However, we found that it isn't suitable for this section and prepared to move it into discussion section.

P6L18: Garrison 2017 not in bibliography

Response:

I am sorry for our carelessness and will revise it in the revised version.

P8L10: φ(E0) = ; while φ = E/P on L27 ; unclear why the symbols is used for different meanings

Response:

It was caused by our carelessness. We will use the different symbols in the revised version.

P9L1: ". . . the MCY function is the best function among . . ." a) best in which respect and b) why is it the best?

Response:

Zhou et al. (2015) concludes "Based on the form and properties, Mezentsev-Choudhury-Yang's function is a better one among the existing Budyko functions to describe the water-energy balance in the two-dimensional state space (E0/P, E/P)"

(Zhou, S., B. Yu, Y. Huang, and G. Wang (2015), The complementary relationship and generation of the Budyko functions,Geophys. Res. Lett., 42, 1781–1790,doi:10.1002/2015GL063511). In this manuscript, we found only MCY equation satisfies Equation (18). Therefore we speculate that it is a best form. It is only a speculation. We will remove it in the revised version.

P14: There are two Zhou et al., 2015 indicate in the text to which you are referencing to

Response:

We will revise them in the revised version.

Figure 3 and in text: I recommend to use a different symbol for water vapor than P which is precipitation. It may be also useful to consider physical units of the quantities within the derivation.

Response:

Thanks a lot. We will use a different symbol (V) and do more analysis on the physical units in the revised version. The unites of fluxes (P, E, E0) are mm/a. We will emphasize the units within the derivation in the revised version.

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