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Discussions

Interactive comment on "Thermodynamic limits of hydrologic cycling within the Earth system: concepts, estimates and implications" *by* A. Kleidon and M. Renner

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This is an extremely valuable paper, providing a quite different perspective on evaporation and moisture circulation in the hydrological cycle, derived from energetic principles. I welcome it very much and I think the paper will have a lot of impact. From detailed reading I have a couple of comments/questions, a few suggestions and also I found some minor mistakes. I look forward to the replies to my comments and I hope the authors will benefit from my suggestions.

General remarks/comments:

1). I still have a problem with the loose treatment of the second law of thermodynamics. In Lines 6-15 on page 3193 it is implied that:

$TdS = dQ$, where $dQ/dt = J_{net}$.

Yet, as also stated in Kleidon et al. (2013), $Q = TS$ and hence:

$dQ = TdS + SdT$

What has happened to this second term SdT, which we see nowhere in the derivations? Is it maybe replaced by the term D included in (1)? Does D represents SdT/dt?

2). The two balances (vertical and horizontal) are global, not distinguishing between continents and sea. The vertical balance is for the entire Earth. I am wondering what spatial heterogeneity does, since the equations are not linear. Would the optimum exchange velocity in Fig. 4 (now about 2 mm/s) be different as a result of spatial heterogeneity or longitudinal variation? And similarly for Figure 5, would the difference between ocean and land lead to a different optimum (also at about 2 mm/s)? The authors deal with this issue in section 4, but I am not sure if this is the same thing.

3). It is not clear to me how the horizontal and the vertical balances are coupled. The authors consider them independently. However, I presume that the sum of (9) and (15) would be the total entropy production. Should that not be equal to σ in (2)? Now the two systems are optimized independently, but would a combination of the two systems lead to another optimum?

4). It is nice to see that indeed the general evaporation equation is obtained, as in (35). This equation is very close to the Penman equation (commonly used in hydrology), where we use the sum of the net radiation reaching the surface and the turbulent wind energy. If we would want to equate the two equations then we obtain the following expression:

$$J_{net} = R_N + \frac{c_p \rho_a}{s r_a}(e_s - e_a) = R_N + J_{turb}$$

whereby :

$$R_N = (1 - r)R_C - R_B$$

where r is the albedo, R_C is the net incoming short wave radiation at the surface and R_B is the net outgoing long wave radiation from the surface. R_C is calculated by an empirical formula. For an average climate it is given by:

$$R_C = (0.25 + 0.5n/N)J_{in,s}$$

where n/N is the proportion of sunshine on an average day. If this n/N=0.5, then

$$R_C = 0.5J_{in,s}$$

Hence:

$$J_{net} = 0.5J_{in,s} + (J_{turb} - 0.5rJ_{in,s} - R_B)$$

If the term between brackets cancels out (meaning that the energy required for wind-driven evaporation is equal to half the reflected incoming radiation and the outgoing long wave radiation), then we have the same result. Since the turbulence is generated by the energy reflected from the surface, this looks plausible.

5). Regarding the derivations in 2.3, I have a few issues:

1. I think that (16) is not the "momentum" balance, but the balance of forces per unit area. The unit is [N/m^2].

2. Next, to derive (17), it is said that the forces are multiplied by the velocity to obtain the equation for kinetic "energy". First, I think it should be kinetic "power per unit area" rather then energy. Second, I think that the power is obtained by integration, and not by multiplication. Hence I suspect that the last term of (17) should be divided by 3, and that (18) should contain 3 between the brackets. Of course this does not change the argument, but it may have an impact on the magnitudes (if I am right).

Minor corrections:

P3200, L4: the unit is 65 Pa/K

P3205, L9: it should read that "1/(1-x) =appr. 1+x for small values of x" (not 1-x). Also I think q_{sat} should be e_{sat}.

P3213, L7: remove "the"

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 10, 3187, 2013.