Hydrol. Earth Syst. Sci. Discuss., 10, C1644–C1647, 2013
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Hydrology and Earth System Sciences
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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

Anonymous Referee #1

Received and published: 12 May 2013

In this article, the maximum strength of the hydrologic cycle is derived analytically based on the thermodynamic properties of the various terrestrial energy fluxes and the Carnot limit. The strength of the hydrologic cycle is quantified by considering the power associated with 'motion' driven by the hydrologic cycle. This is considered to be the sensible heat flux for a vertical analysis of the exchange between the surface and the atmosphere. A separate analysis is performed for the power associated with large-scale circulation between the tropics and the extratropics. The average global sensible and latent heat fluxes associated with the maximum power are then compared to observed value and found to match reasonably well. The sensitivity of the various

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derived power fluxes are studied exhaustively, though the paper would be improved if these sensitivities were related more directly to the difference between the observed and estimated fluxes.

The calculations performed in the paper and the framework presented are novel and important. The article is very comprehensive in scope. Nevertheless, the complexity of the argument coupled to the somewhat non-standard notation can make it difficult to follow the details of the argument and to judge the limiting assumptions used. As a result, most of my comments relate to the presentation and to the support provided for these assumptions. Subject to the minor revisions detailed below, I believe this paper should be published in Hydrology and Earth System Science.

Specific comments:

- The equivalence between the effective velocity used in the drag law in equation 16 and the exchange velocity used in Equation 19 is a major assumption. Please provide some support for why these two velocities should be the same in the turbulent atmospheric boundary layer.
- It is not clear why the various effects listed in the second to last paragraph of page 3200 (lines 10-17, directly beneath Eq. 24) are all accounted for by J_{lh}. In particular, lines 15-16 argue that J_{lh} includes "the work done in lifting water from the surface to the level at which it precipitates". However, in the discussion of power that follows, G_{lh} and G_{lift} are treated separately
- Please explain how the power in Figure 3 is calculated in the manuscript text.
- In deriving equations 31-35, the authors "neglect the dependence of T_s on the heat fluxes in the denominator [of eq. 30]." However, Figure 4 shows that the driving temperature difference, and therefore presumably T_s can vary dramatically as the exchange velocity and convective heat flux change. Please provide

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a more detailed justification of this assumption. Is it just based on the relatively small sensitivity to T_s for T_s near 300 K, or is there a physical reason?

- The observed average energy balance components listed in Table 3 are rather dated, since the Kiehl and Trenberth study was published more than 15 years ago. More recent estimates can be found among others in Stephens G.L et al. An update on Earth's energy balance in light of the latest global observations. *Nature Geoscience* 5, 691–696 (2012) doi:10.1038/ngeo1580. In particular, the listed observed net terrestrial radiation is too high, while the listed latent heat flux is too high.

- Given the large amount of averaging and assumptions used to derive the estimated fluxes in Table 3, I agree with the authors that they match the observed values closely enough to support the interpretation that the hydrologic cycle is operating at least 'near' its maximum limit. However, it is not possible to get any estimate or feeling for how 'near' the limit the cycle is really acting. In order to get a better sense of exactly how near to the limit, it would be useful to see how the observed values of J_{sh} and J_{lh} compare to Figures 4 and 5. That is, it should be possible to calculate an expected exchange velocity based on observations, and to compare its value and the associated power fluxes to those of the maximum. Although it may be hard to partition the observed values into fluxes associated with large-scale circulation and fluxes associated with vertical motion, this could be avoided by simply assuming that the observed sensible and latent heat fluxes are the sum of the horizontal and vertical terms for each. That is, it should be straightforward to create an additional figure that represents the summed fluxes and power of figures 4 and 5, and on which the maximum power value can be compared to that associated with the observed J_{sh} and J_{lh}.

- It is exceedingly difficult to keep track of the meaning of all the different fluxes through the many subscripts and combinations of subscripts used for J. For ex-

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ample,what does the c subscript in Eqtn 28 refer to? I would suggest adding an extra column to Table 3 with definitions of all the different versions of J used, or to use additional variables so that the distinction between different fluxes does not have to be made through similar-looking and ill-defined subscripts.

Minor corrections:

- Page 3201, Line 8: Gamma should be defined as the moist adiabatic lapse rate to avoid confusion.
- Why is $J_{s,net}$ negative in Equation 2 but positive in Equation 1? Is this a typo?
- It may be useful to clarify explicitly somewhere that all forces and fluxes are calculated per unit area
- The variable P is used twice, for both power and precipitation
- The x-axis of both Figures 6 and 7 should be changed to reflect the specific variables that are plotted. The current labels are very confusing.
- What is plotted on the x-axis of the bottom row of Figure 7? Page 3212 suggests it is $J_{in,t} - J_{in,p}$, but that is not the radiative conductance mentioned in the label of the x-axis.

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