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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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The purpose of this note is to evaluate the effect of large-scale motion due to spatial differences in radiative surface heating on the partitioning of surface heat fluxes. In the model of convective exchange in Kleidon and Renner (2013), we set up a model in which the surface heat fluxes are driven by local buoyancy only that results from the radiative heating at the surface (section 3.2). However, horizontal gradients in radiative heating provide additional means to generate motion, and this motion was not accounted for in the model of vertical exchange. What we do here is to explore the effect of horizontal motion on the partitioning within the surface energy balance in

a simplified way.

To do so, we extend the parameterizations of the turbulent heat fluxes for convection by adding a contribution to vertical exchange (eqns. (19) and (23) in Kleidon and Renner (2013)):

$$J_{sh,c} = c_p \rho (v + v_h)(T_h - T_c) \tag{1}$$

and

$$J_{lh,c} = c_p \rho (v + v_h) \frac{s}{\gamma} (T_h - T_c) \tag{2}$$

For simplicity, we express the additional contribution by large-scale motion as being proportional to the vertical exchange, so that

$$v_h = f_h v \tag{3}$$

With this modification, the surface energy balance yields a somewhat different expression for the temperature difference, $T_s - T_a$ (cf. eqn. 29):

$$T_s - T_a = \frac{J_{in,s}}{k_r + c_p \rho v (1 + f_h)(1 + s/\gamma)} \tag{4}$$

Using the expression for v_{opt} (eqn. 32), we then obtain for the partitioning of heat fluxes

$$J_{s,a} = \frac{2}{2 + f_h} \frac{J_{in,s}}{2} \tag{5}$$

$$J_{sh,c,opt} = \frac{2 + 2f_h}{2 + f_h} \frac{\gamma}{\gamma + s} \frac{J_{in,s}}{2} \tag{6}$$

and

$$J_{lh,c,opt} = \frac{2 + 2f_h}{2 + f_h} \frac{s}{\gamma + s} \frac{J_{in,s}}{2} \tag{7}$$

These expressions are essentially the same as before (cf. eqns. (32) and (33)), except for a shift from radiative to convective cooling since the net radiative cooling, $J_{s,a}$, is reduced by a factor of $2/(2+f_h)$, while the turbulent fluxes are enhanced by a factor of $(2+2f_h)/(2+f_h)$.

Given that the power for large-scale motion is maximized at an exchange velocity that is essentially of the same magnitude as the vertical exchange velocity (cf. Figs. 4 and 5), the contribution of large-scale motion is probably of similar magnitude as the locally generated motion, so that $f_h \approx 1$. With this value for f_h, $2/(2+f_h) = 2/3 = 0.67$ and $(2+2f_h)/(2+f_h) = 4/3 = 1.33$. This enhancement factor of the turbulent heat fluxes is very close in value to the empirically derived Priestley Taylor coefficient of 1.26 (Priestley and Taylor, 1972), which is typically used in empirical estimates of potential evaporation.

The modified estimates of the surface energy partitioning is shown in Table 1. With the effect of horizontal motion ($f_h = 1$), the partitioning is improved and closer to the recent estimate from observations by Stephens et al. (2012). To compare this effect to spatial differences in radiative forcing, another estimate was performed in which the flux partitioning at the surface were computed separately for tropical and extratropical regions and then averaged (Table 2), using the relative forcing as in section 3.3 of Kleidon and Renner (2013). This estimate shows that the spatial differences in radiative forcing mostly average out and show little effect on the partitioning of absorbed solar radiation into radiative vs. turbulent cooling at the global scale. This insensitivity is reasonable, because the fluxes are mostly proportional to the absorption of solar radiation, $J_{in,s}$. This aspect would, however, need to be further explored in more spatial and temporal detail.

Nevertheless, it would seem that it is primarily the effect of large-scale motion that results from horizontal differences in radiative heating which enhances turbulent exchange at the surface at the expense of net radiative cooling. This effect shifts the partitioning away from a $1/2$ that would result if turbulent exchange was generated by local effects only. This interpretation is consistent with the general interpretation of potential evaporation (Penman, 1948) in which potential evaporation is seen as the combined contribution of local radiative heating and a dryness term associated with atmospheric motion.

Table 1. Comparison of the modified estimate of surface energy partitioning to recent global estimates by Stephens et al. (2012). All estimates are given as global means in units of W m^{-2}.

heat flux	$f_h = 0$	$f_h = 1$	Stephens et al. (2012)
absorption of solar radiation, $J_{in,s}$	165	165	165 ± 6
net emission of terrestrial radiation, $J_{s,a}$	83	55	52 ± 7
sensible heat flux, $J_{sh,c}$	30	41	23 ± 3
latent heat flux, $J_{lh,c}$	52	69	88 ± 10

Table 2. Evaluation of the effect of spatial differences in absorption of solar radiation in the tropics and extratropics on the global estimate. For the estimate, it was assumed that the surface temperatures in the tropics and the extratropics were 303 K and 273 K, respectively.

heat flux	$f_h = 0$			$f_h = 1$		
	tropics	extratropics	global	tropics	extratropics	global
absorption of solar radiation, $J_{in,s}$	198	132	165	198	132	165
net emission of terrestrial radiation, $J_{s,a}$	99	66	83	66	44	55
sensible heat flux, $J_{sh,c}$	20	39	30	27	53	40
latent heat flux, $J_{lh,c}$	79	27	53	105	35	70

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