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Hydrology and Earth System Sciences
Discussions

Interactive comment on "Separating the effects of changes in land cover and climate: a hydro-meteorological analysis of the past 60 yr in Saxony, Germany" *by* M. Renner et al.

M. Renner et al.

mrenner@bgc-jena.mpg.de

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1 Justification of the separation method

The reviewer rightly asks for further explanations and discussion of the separation method:

The paper is well written except the assumption of the method. "The orthogonality assumption states that the climate change direction is perpendicular to the aridity index line on (q0, f0)." This is the foundation of the devel- oped method.

More discussion or reasoning needs to be added for this assumption. For example, what is the basis that the climate change direction is perpendicular to the aridity index line on (q0, f0)? Why not perpendicular to the aridity index line on (q1, f1)? If the Budyko-type equation is plotted in the f-q space, will it be perpendicular to the equal E0/P lines? The assumption is based on the "symmetry of water or energy limitation" (such as lines 13-15 on page 8542; lines 19-20 on page 8543). The "symmetry" is not clear and needs to be explained explicitly.

Our aim was to provide a simple geometrical approximation of climate and land surface change effects on E_T using the water - energy partitioning plot ($E_T/E_0 \sim E_T/P$ space). This extents the framework of Tomer and Schilling (2009) who use this plot to distinguish climate from land surface changes. In their framework climate effects are assumed to alter both the water- and the energy partitioning ratios by the same magnitude but opposite signs, hence $\Delta(E_T/E_0) = -\Delta(E_T/P)$. Land surface changes are assumed to shift $\Delta(E_T/E_0) = \Delta(E_T/P)$.

Their framework implies (i) that climate changes are orthogonal to land surface changes within the $E_T/E_0 \sim E_T/P$ space and (ii) the impacts of climate and land surface changes are independent of the catchments climate (E_0/P) and catchment response (E_T). Renner et al. (2012) discuss their framework and Renner and Bernhofer (2012) show for semi-arid basins in the US, that the aridity alters the change directions in the water - energy partitioning plot.

In this manuscript we explicitly take the climate dependence of the change directions into account, by defining that land surface changes are changes in E_T with a fixed aridity index. In the water - energy partitioning plot the land surface change direction is determined by the inverse of the aridity index P/E_0.

While the land surface change direction is clearly defined in this concept, the climatic change direction needs further assumptions. Here, we simply adopted the orthogonality assumption of the Tomer and Schilling (2009) framework. This has the following implications:

(i) we inherently assume that climatic impacts are independent of the catchment response (E_T). Hence, at any point along a constant aridity index a line with the slope of P/E_0 the climate change direction simply is $-E_0/P$, see Illustration in Fig. 1.

(ii) However, when E_T is close to a limitation ($E_T/P \rightarrow 1$ or $E_T/E_0 \rightarrow 1$) then this assumption violates the first principles of mass and energy conservation.

(iii) Hence, accounting for water- or energy limitation implies that the catchment response must be taken into account. As Yang et al. (2008) show this yields the Mezentsev (1955) or Choudhury (1999) parametric Budyko functions.

(iv) As illustrated in Fig.2 the Choudhury equation only yields a orthogonal response of climate to land surface changes when the catchment parameter is set to $n = 2$ which is identical to the classic Pike (1964) equation. Other classic Budyko curves (Schreiber, 1904; Ol'Dekop, 1911; Budyko, 1948) are similar but yield not exactly orthogonal responses of E_T to climate. Also note, that the climate elasticity studies of Dooge (1992) and Arora (2002) use the slope at a given aridity index of these classic Budyko functions. Hence, these studies derive the climatic sensitivity also independently of the actual catchment response. At higher n (or E_T) the Choudhury curve is more bent towards the limits, whereas at $n < 1$ the curve bends towards ($E_T/P \rightarrow 0$ or $E_T/E_0 \rightarrow 0$). To our knowledge, however, there exists no empirical evidence of these mathematically derived sensitivities of E_T to changes in climate, when below the negative diagonal.

(v) While the results for the case study presented in the manuscript are similar to the use of the Choudhury equation using the Wang and Hejazi (2011) separation framework (see also Fig. 4), the presented geometrical separation method has the benefit that it does not require a Budyko type of function for application.

1.1 Discrete approximation

... what is the basis that the climate change direction is perpendicular to the aridity index line on (q0, f0)? Why not perpendicular to the aridity index line on (q1, f1)?

The reviewers question points to a problem which is not discussed in the manuscript. He rightly points out that it is somewhat arbitrary if the lines should be perpendicular in point (q0,f0) or point (q1,f1). Or more generally, how do we get from point (q0,f0) to (q1,f1)?

The problem is that we treat the differences within the non-linear $E_T/E_0 \sim E_T/P$ space as discrete differences (just as Wang and Hejazi (2011)). If the differences would be infinitesimally small than it would make no difference at all at which point we assume orthogonality. So, ideally we might use an integral of these small changes. For the geometrical approach this would yield a circle equation with origin in at (0,0) and a radius defined by the point in the diagram.

This step would complicate the approach and the differences are small (see also Fig.4) compared to the overall changes and the detection thereof (changes in E_T, P, E_0).

1.2 Symmetry of forcing variables

The assumption is based on the "symmetry of water or energy limitation" (such as lines 13-15 on page 8542; lines 19-20 on page 8543). The "symmetry" is not clear and needs to be explained explicitly.

With "symmetry" we refer to the effect when the limitation of whether water (P) or energy (E_0) on E_T is equally strong. For example, the limits proposed by Budyko imply a symmetry of the limits: $E_T = min(P, E_0)$. Further, we term a Budyko function symmetric if

$$E_T/P = f(E_0/P), \quad E_T/E_0 = g(P/E_0) \quad 1/f = g \tag{1}$$

This is true for Choudhury (1999) equation (including Pike (1964)). But this is not true for the equations of Schreiber, Oldekop and Budyko. See also the illustration in Fig. 3.

The orthogonality assumption (yielding a circle equation when integrated over $d(E_0/P)$ in the $E_T/E_0 \sim E_T/P$ space) is symmetric in that sense.

1.3 Comparison of separation estimates

With respect to our case study, the attributed land surface changes in E_T are fairly similar with a $R^2 > 0.99$, when compared with the Wang and Hejazi (2011) method. In the scatterplot of Fig. 4 we use the data of the decadal anomalies shown in Fig.7 of the manuscript. So our assumption that the catchment response depends on the present climate condition but not on the actual catchment response hardly affects the separation results for the hydro-climatic conditions in Saxony.

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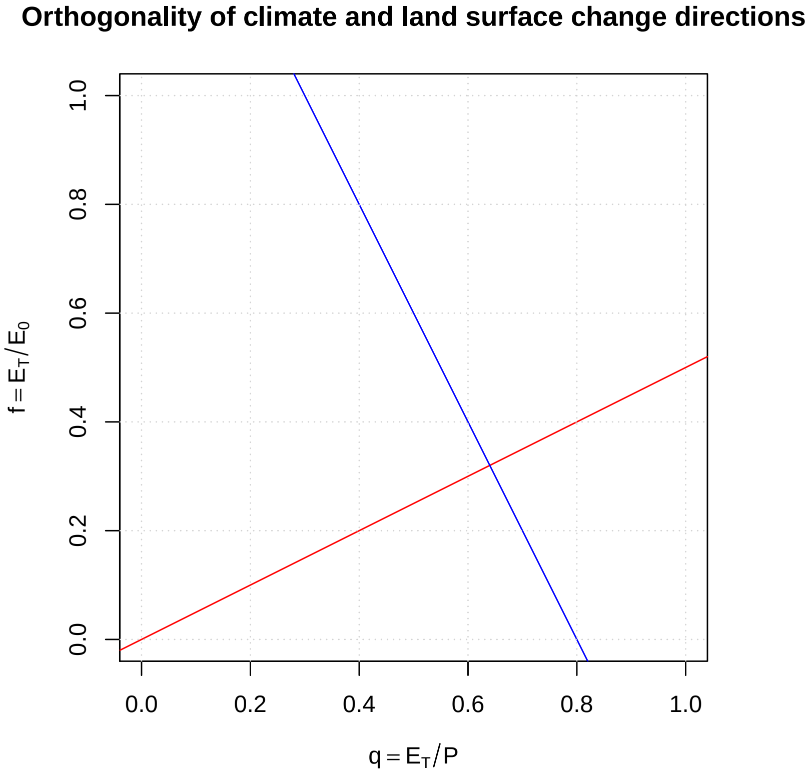

Fig. 1. Water energy partitioning plot showing a line of fixed aridity E0/P = 2 (slope is P/E0 = 1/2) and the orthogonal climatic change direction (blue) with a slope of -E0/P = -2.

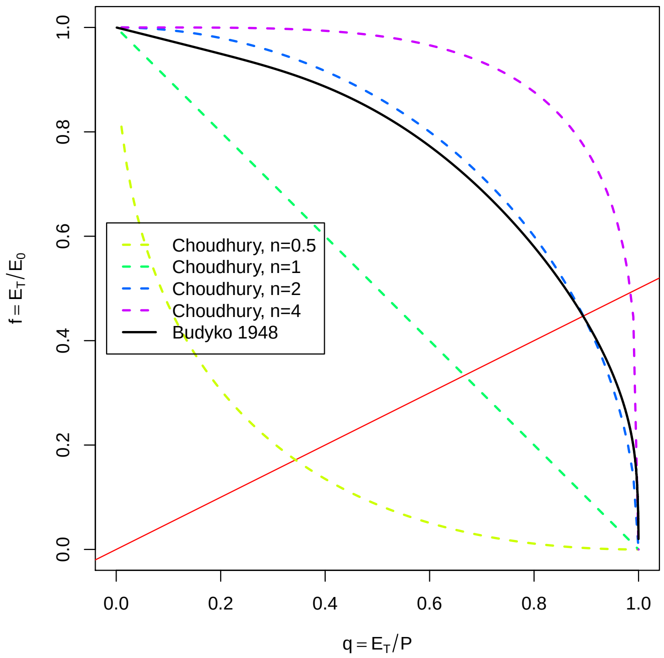

Fig. 2. Mapping of the Budyko curve (black) and different Choudhury functions for n ... 0.5,1,2,4 into the water energy partitioning plot.

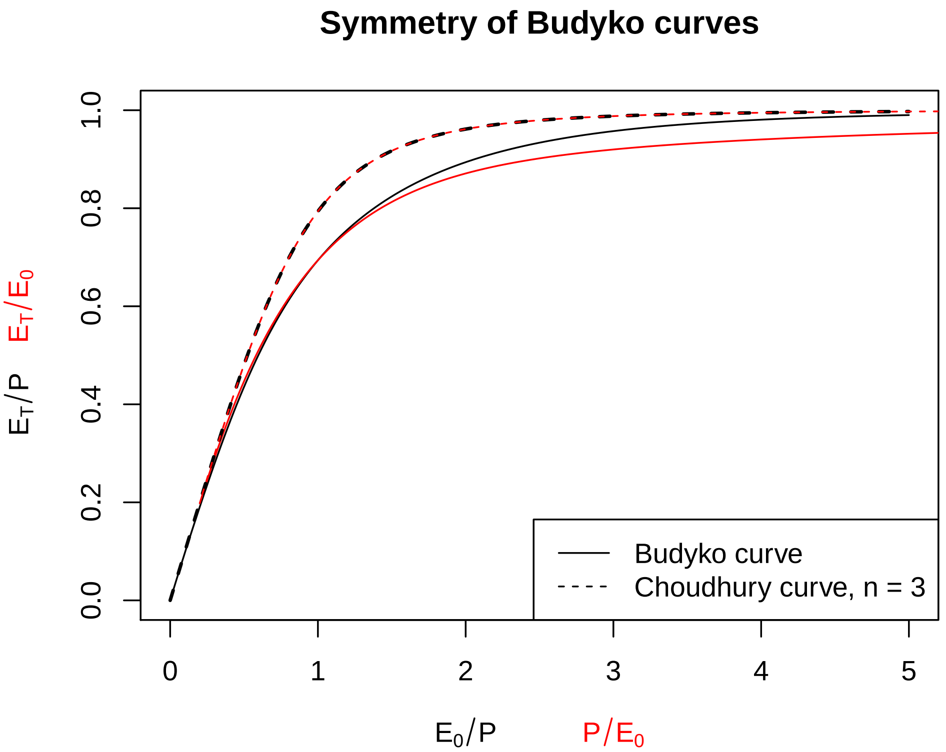

Fig. 3. Budyko space plot of the Budyko (lines) and Choudhury curves (dashed) for both, ET/P vs. E0/P (black) and ET/E0 vs. P/E0 (red).

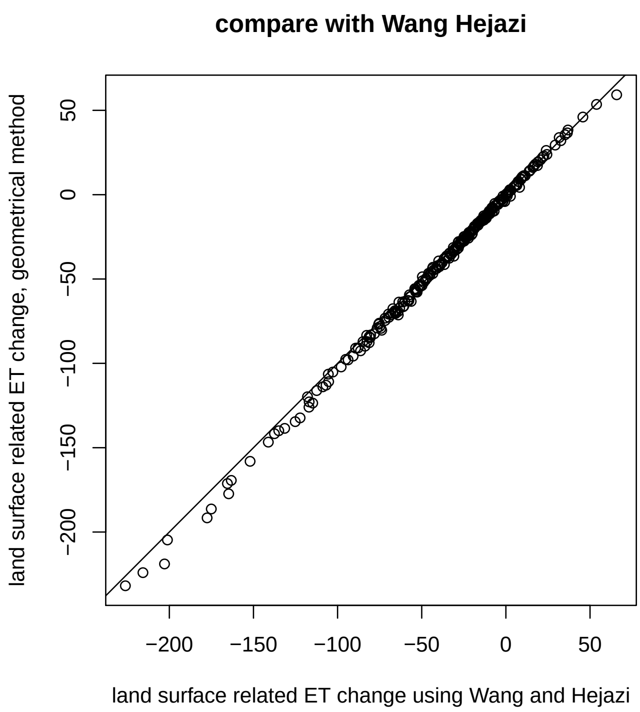

Fig. 4. Comparison of the estimated land surface change impact with the method of Wang and Hejazi (2011) for all basins in mm/yr.