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Discussions

Interactive comment on "Shift of annual water balance in the Budyko space for a catchment with groundwater dependent evapotranspiration" *by* X.-S. Wang and Y. Zhou

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Wang and Zhou present a reformulation of the traditional Budyko model that accounts for the situation of when actual evaporation is higher than precipitation, due to the contribution of ground water. Under these circumstances, data plot higher than the 'water limit' of the Budyko framework (and hence the evaporative index > 1) and therefore cannot be predicted using the standard Budyko curves. By incorporating a simple soil and ground water bucket model, the authors have derived a new set of curves within the Budyko framework that extend above the water-limit and can capture much of the variability in ground-water-boosted evaporation.

Whilst the authors provide what I think is an effective solution to the problem of the evaporative index (F) being greater than 1, I feel the problem itself is artificial – it is the artefact of a misunderstanding and misapplication of the original Budyko framework. If this is true, which I will attempt to argue, then it calls into question the relevance of this paper as a whole.

Firstly, the main concept underlying Budyko is the effect on surface evaporation of the interplay between the atmospheric supply and demand for water. Which is the same as saying the interplay between the supply of water and the supply of energy. The variables chosen by Budyko in his framework were chosen because they represent water and energy supplies.

Evaporation can't exceed the supply of water or of energy because mass and energy must be conserved. This is axiomatic. The original Budyko was developed using averages from large areas (catchments) and long time periods (long-term averages). Averaged over large areas and over long time periods, the dominant water supply is precipitation (and the dominant energy supply is radiation). So, to represent the supply of water, Budyko used P in his definitions of the aridity and evaporative indices (along with net radiation).

When P isn't the only significant source of water available for evaporation, the Budyko framework needs to be modified to reflect this. So if a location is irrigated, the supply of water is P + irrigation. If ground water is being accessed by vegetation and transpired, the total water supply is P + plant-available-ground water. When the supply of water is greater than P, but only P is used to formulate Budyko, then evaporation can indeed be higher than P, and F can be greater than 1. This occurrence is not a failure or inadequacy of the Budyko framework but a misapplication of it.

Secondly, and somewhat related to the first point, the Budyko framework was developed with the assumption of steady state conditions built into it. If Budyko is applied at non-steady-state, then changes in stored water need to be accounted for. This is important for two reasons 1) when storage changes are large, they need to be accounted for in order to close the water balance; and 2) stored water can contribute to the total supply of water, or can remove water from the supply. When the storage needs filling, some proportion of P will be used in refilling the store and can be effectively removed from the mass of water available for evaporation. Conversely, if the storage is full, or if plants can access the storage, stored water becomes a part of the total evaporable water supply. Hence, at non-steady state, the change in storage and the contribution of stored water to the water supply both need to be accounted for. Failure to do so can result in dubious estimates of evaporation and in high (> 1) estimates of the evaporative index.

My reading of Wang and Zhou's analysis indicates that they have not properly formulated Budyko to account for the effect on total water supply of the known contributions from soil and ground water sources, nor have they accounted for the effect of changes in storage on total water supply.

The authors do discuss the work of Wang (2012) WRR and Chen et al (2013) WRR who both discuss and demonstrate the importance of the concept of effective precipitation (P + dSw) when working at seasonal time scales. Unless I've missed or misunderstood some aspect of this analysis that I'm reviewing, Wang and Zhou have not incorporated the findings of the above two papers into their analyses.

In conclusion, I find that, if this paper is to make a correct and worthwhile contribution to the literature, the authors need to demonstrate that, *when formulated properly*, the standard Budyko model still can't account for the variability in evaporation when soil and ground water stores are contributing to evaporation. If the authors can show that this is in fact the case, then this paper will constitute a very important contribution to the Budyko literature.

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