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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Potential evaporation trends over land between 1983–2008: driven by radiative or turbulent fluxes?" *by* C. Matsoukas et al.

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Reply to Referee 2

We would like to express our thanks to the Referee, because he/she has identified some areas where the paper can be greatly improved. His/her comments and recommendations have been taken into account and our point-by-point reply follows:

"Misleading title"
We agree and have changed the title to "Potential evaporation trends over land between 1983–2008: Driven by radiative fluxes or vapour-pressure deficit?", as suggested.

"The text misrepresents the meaning of Penman's equation"
We understand the Referee's point and we have rewritten the relevant text. Although the phrase "Penman's method" is still used, the text does not imply any more that bulk aerodynamic and energy balance are complete and independent methods, nor that Penman provided an alternative to the two methods above.

"Confusing paragraph"
This is indeed a dense paragraph. The Referee does not mention which is the confusing part, however we made some effort to rewrite it.

"Longwave emission from the surface"
For the radiation transfer model, the skin temperature is not set at the air temperature, but it is given directly as skin temperature from the NCEP/NCAR reanalysis. We have assumed that the skin temperature of the theoretical shallow body of water is the same as the skin temperature of the soil, as given by the NCEP/NCAR reanalysis. This is probably a good approximation, if indeed the body is shallow. The above information is now included in our revised manuscript in Section 2.1.2.
In the Sahara and Arabian Peninsula the skin temperature is larger than the air temperature in the summer months, resulting therefore to positive sensible heat fluxes H. Moreover, $\frac{E_a}{E_r} > 1$, does not mean that H is negative. H is negative if $\frac{E}{E_r} > 1$, (note

the difference of E_a and E in the fractions) because $L \cdot E_r = L \cdot E + H$, with L being the latent heat of evaporation. Therefore, we think that the manuscript does not need to be revised, with respect to this point.

"Stability and the aerodynamic formulae"
We have now included stability corrections from Monin-Obukhov similarity theory in our approach. The E_a values are now quite larger. For example, the global mean of E_a is now 3.2 mm/day, while with the neutral stability assumption it was 2.6 mm/day. E_p is not very sensitive: with stability corrections it is 3.4 mm/day, while with the neutral stability assumption it was 3.3 mm/day. The introduction of Monin-Obukhov theory has not affected significantly neither the E_p trends, nor the main findings of the paper.

"Figure 2c does not make sense to me"
We are grateful to the reviewer for his careful reading and for pointing out this error in our application of Penman's method. We tracked it down to our code, corrected it, and we updated all results where necessary. The cross-correlation between E_a and E_p trends has increased, while the cross-correlation between E_p and E_r trends has decreased. However, E_p trends still follow E_r trends much closer than E_a trends. Note that the interpretation of the results and the conclusions of our study have only minor changes.

"Why not use reanalysis for the calculation of E_r?"
The disadvantage of using reanalysis radiation fluxes, is that they depend strongly on generated clouds through cloud models. This approach introduces uncertainties in GCMs and reanalyses. On the other hand, we use satellite-observed cloud amounts,

optical thicknesses, emissivities, etc., without any need to resort to cloud models. Therefore, on a regional scale, surface radiation analyses products are of limited accuracy, compared to better performing satellite data.

"Why not compare potential evaporation from this analysis to the reanalysis?"
Neither ERA-40 nor ERA Interim provide potential evaporation data, that could be directly comparable to the here calculated E_p. In Fig. 6 two E_p normalized trends are compared, both coming from our methodology. The first is from our radiative transfer model (E_r), and ERA-40 data (VPD, wind, temperatures) used as input to calculate E_a. The other is from the same radiative transfer model (same E_r) but this time ERA-Interim data (VPD, wind, temperatures) used to calculate a different E_a.

"Results contradict observations"
The Referee has a point, when he/she states that the results contradict the observations referenced in the manuscript. However, this is true only because the majority of referenced observations correspond to data before the early 1990s, when dimming was worldwide still prevalent. Things are quite different in the late 90s and in the 2000s. We have added the following paragraph in our paper, which hopefully clarifies this issue.

In the Introduction we highlighted that generally the pan evaporation in observations has been decreasing, while our results so far show a general increase in potential evaporation. This disagreement is based on the fact that the majority of our referenced observations correspond to data before the early 1990s, when dimming was worldwide still prevalent. Things are quite different in the late 1990s, when potential evaporation increased globally, and in the 2000s, when it slightly decreased. Roderick et al. (2009)

compiled pan evaporation trends at various geographic locations and for different time periods in their Table 1. We select from there the trends that extend to 2000 and later, and compare them with the (not necessarily statistically significant) normalized trends of our E_p, in Table 3. This comparison aims to provide a first outlook of our model behaviour and is not meant to be a point-by-point quantitative comparison. We did not go into details such as the exact location of the pans. There are countries with opposing regional trends, but we assigned one trend per country taking into account the geographically prevalent trend. Also, the reported trends correspond to different time frames, so a detailed comparison is impractical. Only two out of seventeen studies do not agree with our results, both of them coming from analysis of only one site: 1) in Turkey, where Roderick et al. (2009) state "This pan was located in an expanding irrigation area", and 2) in Ireland, where we have two studies agreeing and one disagreeing with us. These recent observations extending at least to 2000, tend to correspond geographically with areas where we find decreasing potential evaporation. Our comparison would be more complete if we had a wider coverage including more regions with increasing potential evaporation. However, the large majority of comparisons in Table 3 shows generally good agreement of observational studies with our modelling approach.

Table 3. Qualitative comparison of pan evaporation trends from Table 1 of Roderick et al. (2009) with E_p trends from our study. The first column has units of $\mathrm{mm\,a^{-1}\,a^{-1}}$. $\surd$ in the last column means that the model reproduces the sign of the observed trend, while $\times$ means the opposite.

Slope ($\mathrm{mm\,a^{-2}}$)	Region	Details	Trend sign
-3.0	China	1955–2000, 85 sites	$\surd$
-3.1	China (Yangtze River basin)	1960–2000, 150 sites	$\surd$
-3.9	China	1955–2000, 85 sites	$\surd$
-2.8	China (Yangtze River basin)	1961–2000, 115 sites	$\surd$
-3.2	Australia	1975–2002, 61 sites	$\surd$
-2.5	Australia	1970–2005, 60 sites	$\surd$
-0.7	Australia	1970–2004, 28 sites	$\surd$
-10.5	Thailand	1982–2001, 27 sites	$\surd$
-2.0	New Zealand	∼1970–2000, 19 sites	$\surd$
-4.5	Tibetan Plateau	1966–2003, 75 sites	$\surd$
	Studies with fewer than 10 sites		
-24	Turkey	1979–2001, 1 site	$\times$
-1.0	Canada	∼1965–2000, 4 sites	$\surd$
+13.6	Kuwait	1962–2004, 1 site	$\surd$
+0.6	Ireland	1960–2004, 1 site	$\surd$
-5.1	Ireland	1976–2004, 1 site	$\times$
+0.8	Ireland	1964–2004, 8 sites	$\surd$
+2.1	UK	1957–2005, 1 site	$\surd$

References

Michael L. Roderick, Michael T. Hobbins, and Graham D. Farquhar. Pan evaporation trends and the terrestrial water balance. I. Principles and observations. *Geography Compass*, 3(2):746–760, 2009.