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On the use of the term 'Evapotranspiration'

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Key Points:

- 'Evapotranspiration' has gained popularity in recent decades and is currently more widely-used than the conventional term 'evaporation'.
- The term 'evapotranspiration' has both a controversial origin and a disputable physical rationale.
- We advocate to preserve the traditional term, 'evaporation', as an umbrella term to refer to the vaporization of water over land.

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Abstract

Evaporation is the phenomenon by which a substance is converted from its liquid into its vapor phase, independently of where it lies in nature. However, language is alive, and just like regular speech, scientific terminology changes. Frequently those changes are grounded on a solid rationale; but sometimes these semantic transitions have a fragile foundation. That is the case with 'evapotranspiration'. A growing generation of scientists have been educated on using this terminology, and are unaware of the historical controversy and physical inconsistency that surrounds it. Here, we present what may appear to some as an esoteric linguistic discussion, yet it was originally triggered by the increasing time some of us have devoted to justifying our word choice to reviewers, editors and peers. By clarifying our arguments for using the term 'evaporation', we also seek to prevent having to revive this discussion every time a new article is submitted, so that we can move directly on to more scientifically relevant matters.

1 Controversial Origin

The term 'evaporation' is of medieval Latin origin, and has been used over the centuries to describe the transition of liquid water into vapor. In the sixteenth century, Bernard Palissy, a Huguenot famous for his diverse contributions to art and science, was among the first to use the term in the vernacular with the specific meaning of vaporization from land, including transpiration (Palissy, 1580; 1957). On the other hand, the first appearances of the term 'evapotranspiration' (in a hyphenated form) date from technical reports in the early 1930s in the United States (see e.g. McEwen, 1934). Only in the late '40s, did the term appear as 'evapotranspiration' for the first time in literature. It was in 1948, when the American geographer and climatologist Charles Thornthwaite presented the notion of (potential) 'evapotranspiration' and an empirical formulation to calculate it (Thornthwaite, 1948). However, the year 1948 did not make it to the hydrology shelves solely due to the work by Thornthwaite. Just three months later, British meteorologist Howard Penman, presented his renowned process-based equation, which would serve as a foundation for hydrological research for decades to come (Penman, 1948). In his lifetime, Howard Penman – as well as most contemporary scientists, such as John Monteith or Charles Priestley – refrained from using the new term, and actively objected to it on the basis of its unnecessary complexity and redundancy. In relation to Thornthwaite's 'potential evapotranspiration', Monteith wrote in Penman's obituary: *'Penman, who found the term clumsy, always referred to 'potential transpiration' himself, and made sure that colleagues followed his example'* (Monteith, 1986). This resistance from the scientific community prevented the term coined by Thornthwaite from gaining momentum during the half a century that followed.

However, recent decades have witnessed an almost exponential gain in popularity in the use of this term (Figure 1). Since the year 2000, 'evapotranspiration' has become more frequent in the scientific literature than 'evaporation' when referring to the integrated land-surface latent heat flux. On the basis of data from the Web of Science, Figure 1 illustrates the number of topical articles in which each of these two terms appears in the title; only publications that use the term 'evaporation' in the broader sense (including plant transpiration) are depicted here. Currently, the number of papers per year using 'evapotranspiration' is nearly triple the traditional counterpart. Interestingly though, the number of scientific articles using the equation by Thornthwaite (1948), which popularized the term 'evapotranspiration', are an order of magnitude lower than those using the contemporaneous 'evaporation' model by Penman (1948). One may conclude that, while Thornthwaite's model barely survived natural selection and now

is only rarely taught in graduate programs, Charles Thornthwaite still won the battle over semantics and nomenclature in the long run.

2 Transpiration is Evaporation

Transpiration involves the change of state of water from liquid to vapor occurring in the stomatal cavities and mesophyll of leaves, hence it is an evaporation process. While the term 'transpiration' in the biology literature is often used to refer to the entire plant hydraulic transport, when it is expressed in $W\ m^{-2}$ (or equivalent water flux), and combined with 'evaporation', it is implied that it refers specifically to the vaporization process. Following that rationale, Figure 2 depicts the total evaporation from land (or terrestrial evaporation) embracing three main fluxes, components or sources: (a) transpiration (evaporation of water from inside the leaves), (b) evaporation from bare soils, and (c) interception loss (evaporation of intercepted precipitation). Moreover, the evaporation from rivers, reservoirs, small lakes etc., may also be considered, as well as the snow and ice sublimation. The term 'sublimation' refers specifically to the direct transition from solid to gas phase (without an intermediary liquid phase); however, the pressure and temperature ranges on Earth imply that ice and snow must melt before evaporating (Jambon-Puillet et al., 2018).

The fact that transpiration implies vaporization of water should suffice to end this semantic debate. However, the topical literature summarized in Figure 1 suggests that the term 'evapotranspiration' is tempting to use and hard to resist. Hence, in the following we clarify this point further. The redundancy of the term lies in the fact that 'transpiration' should already be included in the 'evapo' part of the term. A reasonable analogy can be drawn on the input side of the hydrological balance: although not yet coined in the literature, a term like '*precipisnowfall*' would be equally redundant – yet, if repeated often enough, it would start to sound just fine. While most scientists are aware of the lack of logic surrounding 'evapotranspiration', they consciously choose to use this terminology under the argument that transpiration is a separate physiological process regulated by vegetation. Yet, this argument seems hard to sustain, since the uniqueness of transpiration does not negate the fact that it is, in the end, an evaporation process. Moreover, one could also add that the plant's physiological responses that control stomatal conductance remain largely influenced by meteorological and environmental conditions. This is suggested by the success of stomatal conductance models that are purely (e.g., Jarvis, 1976) or partly (e.g., Ball et al., 1987; Medlyn, 2011) based on atmospheric and/or soil moisture data. In fact, transpiration and bare-soil evaporation share most drivers, and tend to be highly correlated to each other, especially in energy-limited regions; the same is not true for interception loss (see Figure 3).'

It must be noted that we fully advocate the independent study of both the biological (transpiration) and non-biological (soil evaporation and interception) 'losses' of water into the atmosphere. Their separate understanding is crucial for agricultural sciences and food production, and essential if we are to unravel the connection between the hydrological and carbon cycles (Shuttleworth and Wallace, 1985). As most instrumentation techniques are unable to measure these components individually, the exploration of new means to parse them out is paramount (Stoy et al., 2019). However, we believe that lumping these fluxes within the compound term 'evapotranspiration' does not facilitate steering the focus to transpiration, bare

soil evaporation and interception loss independently. This point was clearly argued by Savenije (2004), who advocated the need to move beyond the study of the bulk flux.

3 What about Interception?

The scientific literature is inconclusive and inconsistent in regards to whether the term 'evapotranspiration' incorporates or not the flux of interception loss. For instance, the Food and Agriculture Organization (FAO) refers to 'evapotranspiration' as the '*combination of two separate processes, whereby water is lost on the one hand from the soil surface by evaporation, and on the other hand from the crop by transpiration*' (Allen et al., 1998). However, the importance of rainfall interception in forests cannot be overstated; and at continental scales, it is arguably of similar magnitude to soil evaporation (Figure 2) – i.e. 10–20% of the total latent heat flux over land (Miralles et al., 2011; Wei et al., 2017). From a water management point of view, interception represents a net 'loss' of water for ecosystems, in the sense that it comprises a fraction of precipitation that does not reach the ground and is thus not available for biological uptake or societal use. Its consideration, both independently and as a component of terrestrial evaporation, is therefore of prime importance.

Even if one were to take the charitable view that 'evapotranspiration' does in fact embrace all three fluxes in Figure 2, the unique nature of interception loss in terms of its physical characteristics, drivers, timing and isotopic composition must be emphasized. Interception loss is mainly driven by precipitation and vegetation properties, with the vaporization of intercepted water occurring at rates that appear unconstrained by net radiation, often exceeding daytime rates of transpiration even at nighttime (Pearce and Rowe, 1980). On the basis of satellite-based model estimates (Martens et al., 2017), Figure 3 shows that the correlation between transpiration and soil evaporation is high, especially in Northern Hemisphere energy-limited regions, while interception loss tends to follow different patterns in terms of seasonality and interannual variability. This uniqueness of interception dynamics puts the need to single out transpiration into serious question. Would the term '*evapointerception*' be in fact more justified? The truth is that the invention and usage of any compound term is both largely arbitrary and unnecessary. Using artificially composed terminologies will not enhance our understanding of these individual components.

4 Conclusions

From the above, it can be concluded that we would favor rendering the term 'evapotranspiration' obsolete on purely physical science grounds. Nonetheless, we acknowledge that 'evapotranspiration' can sometimes be illustrative during the active growing season at the field scales of agriculture, when sublimation is nonexistent, and as long as interception loss is lumped together with bare soil evaporation. However, intentional users of the term should be mindful of its limitations. The term is meaningless, and even misleading, in the presence of abundant rains, when interception loss represents a large fraction of the evaporative flux; also in the presence of open-water bodies, and during wintertime in the many regions of the world covered with snow and ice.

However, we understand that at this stage it would be delusional to expect the total abandonment of the terminology. Therefore, this communication is neither a manifesto to disown the term, nor is it an attempt to impose our terminology of choice on anyone. Others already embarked on that noble quest in the past, evidently with limited success in light of the

data shown in Figure 1. Savenije (2004), in particular, aimed to make '*evapotranspiration disappear from the hydrological jargon*' on the basis of its apparent neglect of interception, combatively urging to retain the conventional term, 'evaporation'. Almost two decades later, the term 'evapotranspiration' has become rooted into our scientific literature to a point that even experts in the topic sometimes believe that one has misspoken or miswritten when one intentionally avoids its use. That spread leads nowadays to frequent misunderstandings when the term 'evaporation' is used to refer to the bulk flux of water evaporated over land. To avoid those misunderstandings, the term 'latent heat flux' may be used instead; however, in hydrological sciences, there is often a need to express this flux in water volume units. In those cases, we advocate for clarifying on its first use that the term 'evaporation' refers to the bulk flux of water, including transpiration.

Finally, we believe that we have outlined a clear rationale for resisting this linguistic transition, by presenting a solid and physically-based argument on why the choice for the more correct and simpler term, 'evaporation', deserves not only to be respected, but also to be encouraged.

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Data availability

Data used in Figure 1 were extracted from Web of Science <https://www.webofknowledge.com/>. Figure 3 were freely downloaded from <https://www.gleam.eu/>.

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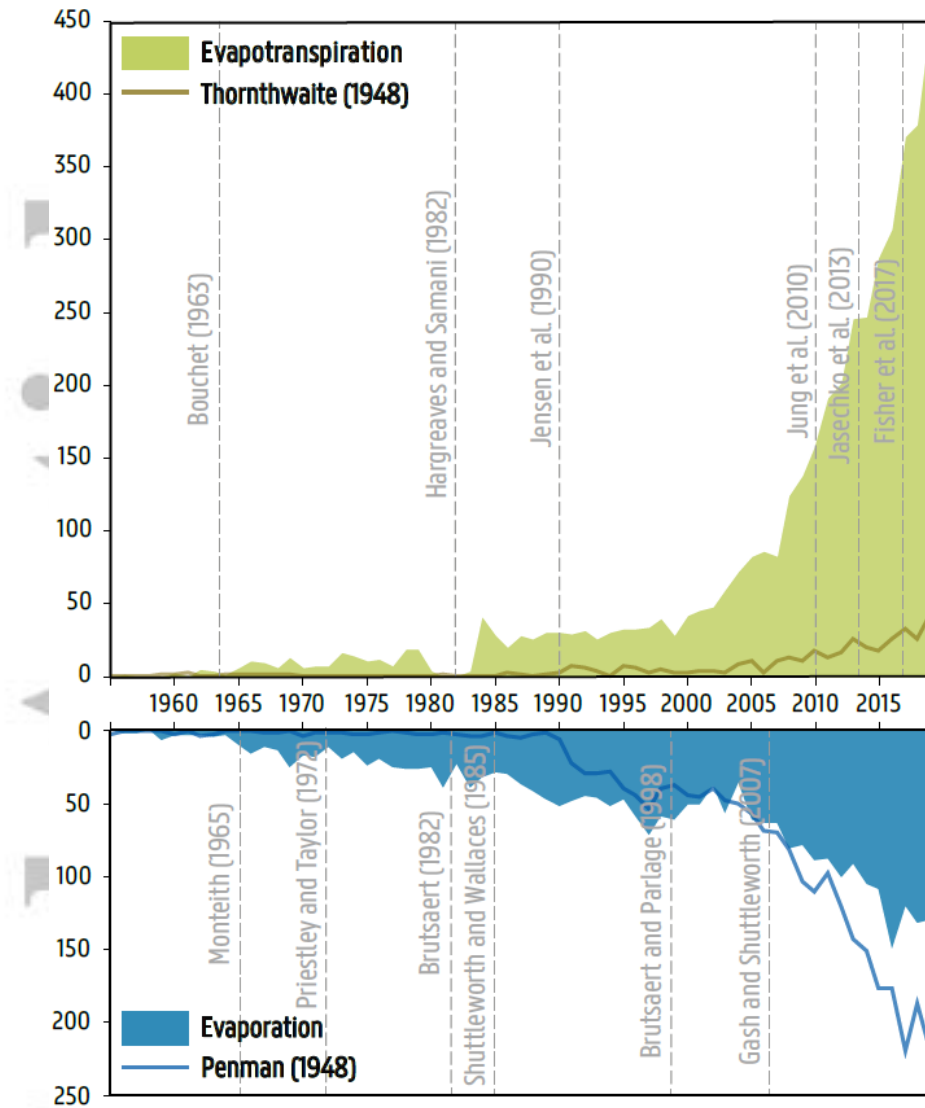


Figure 1. Published articles using the term 'evapotranspiration' (top) or 'evaporation' (bottom) in the title to refer to the integrated land-surface latent heat flux. The top figure also illustrates the number of articles making use of the model by Thornthwaite (1948) that popularized the term 'evapotranspiration', together with other benchmark articles that used this terminology. The bottom figure shows the number of articles that use the model by Penman (1948), together with other seminal papers that used 'evaporation' instead. Data extracted from the Web of Science.

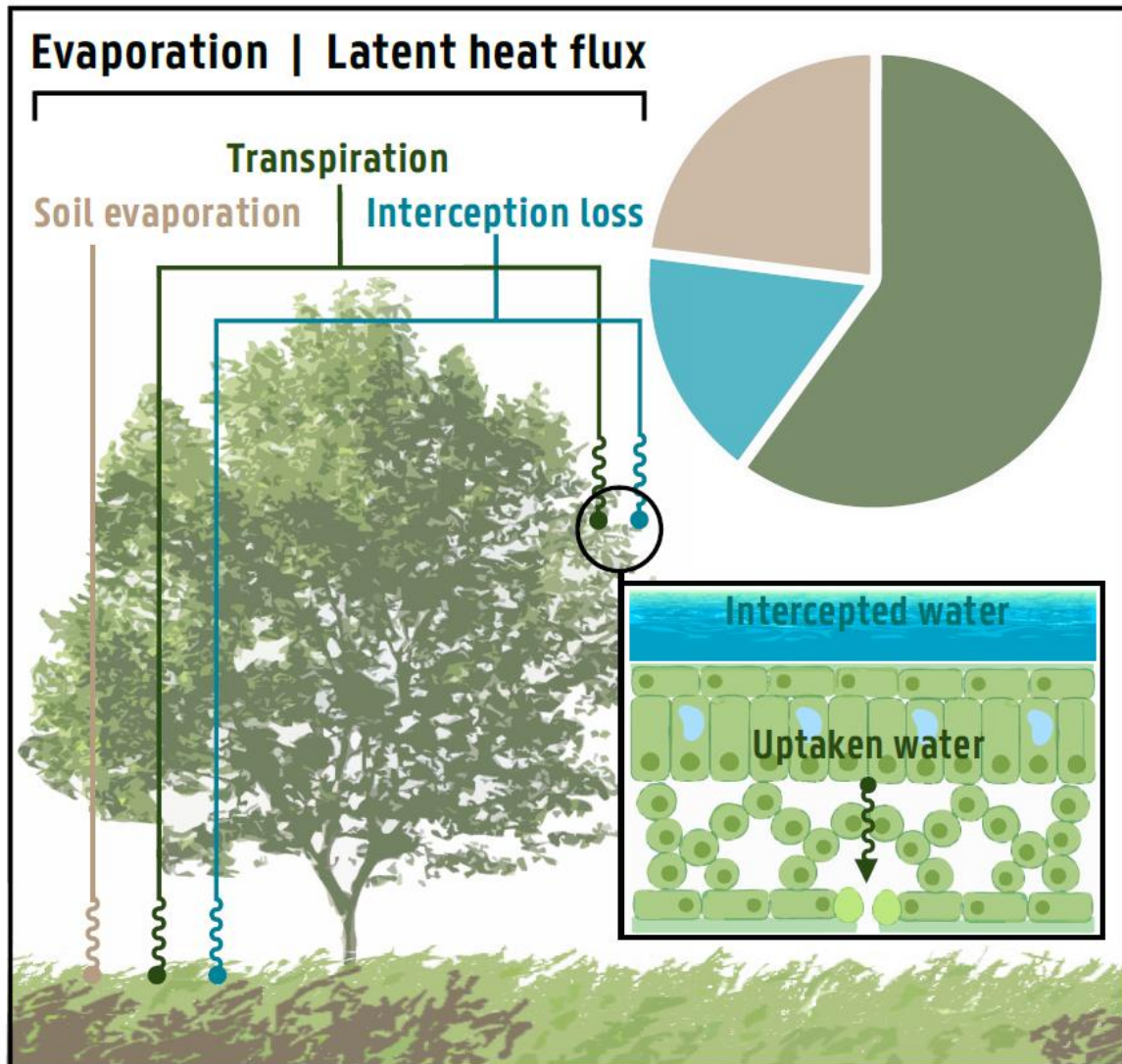


Figure 2. Main components of land evaporation. The pie-chart indicates the approximated contribution by each of these three components globally, based on data from Wei et al. (2017). The bottom illustration shows a cross section of a wet leaf, with evaporation occurring inside the leaf (transpiration) and on its surface (interception loss). Note that the snow and ice sublimation, and the evaporation from water bodies (rivers, reservoirs, small lakes, etc.) should also be considered as separate components when appropriate, and that the interception loss is not restricted to leaves only.

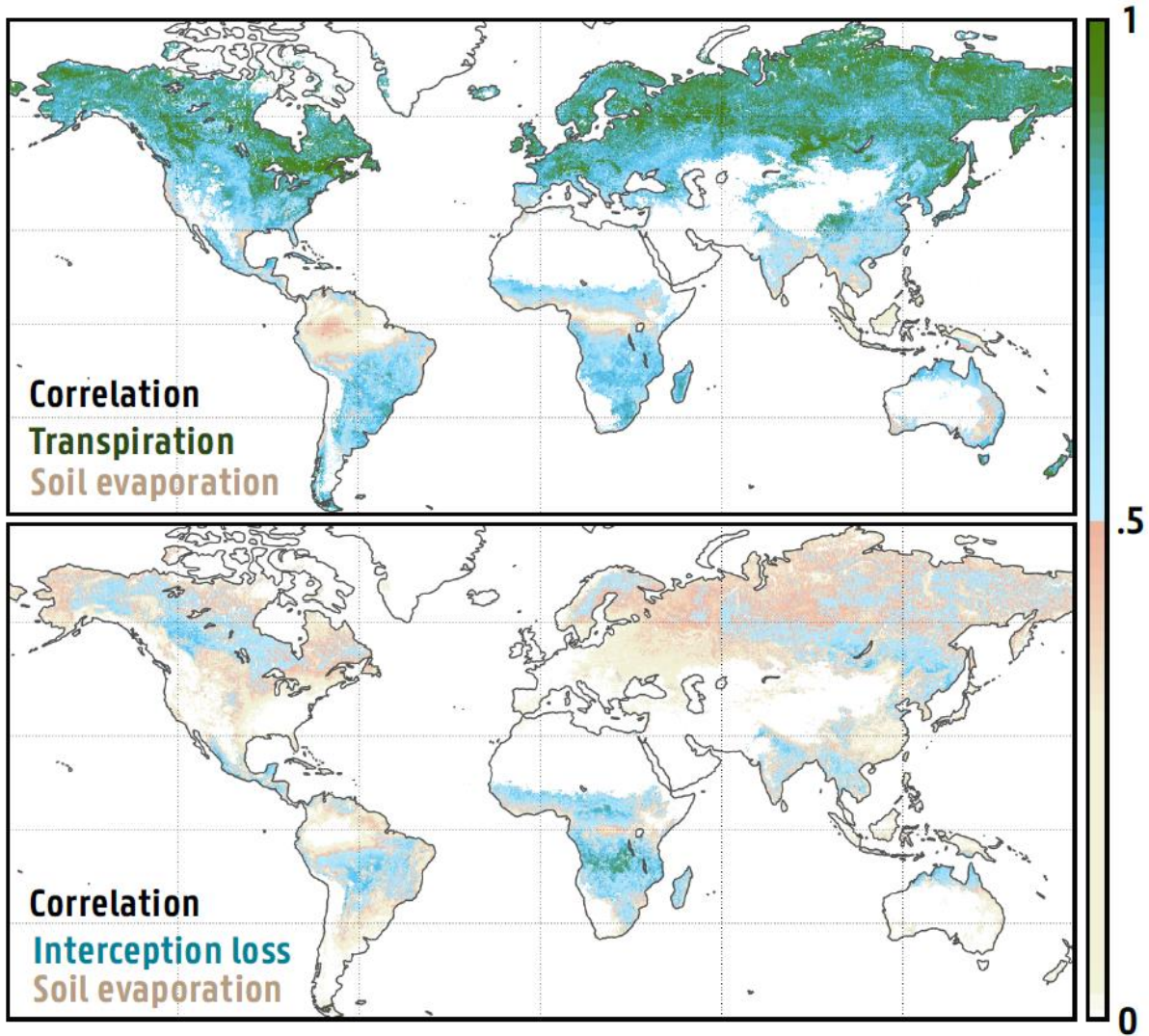


Figure 3. Correlation between land evaporation components. (top) Transpiration and soil evaporation. (bottom) Interception loss and soil evaporation. Derived from satellite-based model estimates spanning the period 1980–2019 at daily temporal scale – interception loss is limited to tall canopy interception (Martens et al., 2017).