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School of Resources, Environment and Society, Australian National University, Canberra, Australia

Evaporation trends

E. T. Linacre

With 2 Figures

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Summary

Lake-evaporation rates Eo around the world have been deduced in three ways, using land-based data. The estimates indicate generally *decreasing* rates of 0.08, 0.13 and 0.05 mm/day per decade respectively, i.e. of the order of 0.1 mm/d · dec. One method of estimation involves a simplified version of the Penman evaporation formula, which shows that the reduction of Eo is due chiefly to the general lessening of solar radiation at the surface. In consequence of the decline of Eo, a two-regime model of the evaporation from land surfaces shows that there has been a *decrease* in the rate of actual evaporation from land surfaces Ea also, at places where rainfall exceeds Ep, the rate of water loss from a US Class-A pan evaporimeter. This implies increased runoff there. On the other hand, there is a slight *increase* of Ea in drier seasons and places, which are more common, implying a little more soil moisture.

1. Introduction

The ground's moisture-content which governs agricultural productivity depends on the difference between the rainfall and surface evaporation, both of which may be affected by global warming. You might expect evaporation to *increase* as a result of the temperature rise (e.g. Rind et al., 1990; Robock et al., 2000). However, it will be shown that the observed reduction of solar-radiation intensities is more important, so that in certain circumstances the rate of evaporation from land surfaces Ea is actually *decreasing*.

Evaporation from a land surface is not easy to measure, outside experiments in small areas with sophisticated equipment. It can readily be inferred only over large areas and long periods of time, as in the following example. The annual evaporation across the Mississippi River basin is the difference of 637 mm/annum (i.e. 1.7 mm/day, on average) between the spatial average annual rainfall (835 mm/annum) and the net river outflow (Milly and Dunne, 2001). Likewise in catchments along the east of the USA, evaporation rates are between 0.5–2.7 mm/d (Huntington, 2002). The difference between rainfalls onto the world's continents and river-flows from them indicate a mean rate of evaporation of 1.6 mm/d (Dai and Trenberth, 2002), reckoning on the average rainfall on the land as about 2.4 mm/d (Chen et al., 2002).

An alternative way of regarding land-surface evaporation Ea is based on the concept of the 'lake-evaporation rate' Eo (Linacre and Geerts, 1997, p. 86). This is the rate of evaporation from a (hypothetical) large lake in precisely the same climatic environment as that of the region in question (Thornthwaite, 1948; Morton, 1969;

Brutsaert and Stricker, 1979). It will be shown that the actual evaporation rate Ea is related to Eo.

2. Estimation of the lake-evaporation rate Eo

The rate Eo is independent of vegetation or ground wetness, and serves as a convenient index of the 'evaporative demand' of a particular climate. It is nowadays calculated by the evaporation formula of Penman (1948; Morton, 1969; Stanhill, 1976; Linacre, 1992; Allen et al., 1998), which is based on the balance of energy flows at the lake's surface over some specified period, such as a day. The useful accuracy of the Penman formula and derivatives from it has already been discussed by Linacre (1993a, p. 240) and is reviewed more broadly in the Appendix.

Calculations from Penman's formula for 65 widely different places in China and Tibet show a deceleration of the rate of evaporation Eo during 1954–1993 by 0.08 mm/day per decade (Thomas, 2000). (Hereafter, these units are abbreviated to mm/d · dec. One such unit is equivalent to an annual change of evaporation rate by 36.5 mm/annum, i.e. 36.5 mm/a^2) A second estimate of the characteristic decline of Eo can be derived from changes of pan evaporation, as discussed below. A third figure involves a linear version of Penman's formula, which has the advantage of showing the relative importance of each of the causes of the change. We shall see that all three methods produce qualitatively similar results.

3. Pan-evaporation evidence on the change of the lake-evaporation rate Eo

Relevant to any current alteration of lake-evaporation rates Eo are the reports of a general reduction of evaporation rates Ep from open pans of water (Peterson et al., 1995; Brutsaert and Parlange, 1998; Lawrimore and Peterson, 2000; Roderick and Farquhar, 2002). Alongside these reports is a well-established proportionality between Ep and figures for Eo given by the Penman formula (Linacre, 1994; from data of Stanhill, 1976). The range of Stanhill's data is wide, with Penman-formula monthly-mean evaporation rates from 0.5 mm/d (corresponding to cold, still, moist and dark conditions) to more than 8 mm/d, where the weather is warm, windy, dry and sunny. The ratio Eo/Ep for a U.S. Class-A pan evaporimeter is about 0.7 when the pan-evaporation rate is less than about 7 mm/d, falling to about 0.6 when it is 12 mm/d, for instance.

Various reports show a decline in pan-evaporation rates. Peterson et al. (1995) found that Ep in each five-month warm season in western USA fell during 1950–1995 by 97 mm, i.e. by 0.14 mm/d · dec (i.e. 97/[30 × 5 × 4.5]). Golubev et al. (2001) reported falls by 1.8–8.9% per decade (with a median of 2.6% per decade) in eight of 12 regions in the USA and Russia. Thus the median reduction rate was around 0.13 mm/d · dec, assuming pan-evaporation rates like those in Table 1, i.e. around 5 mm/d. In the Mississippi River basin the estimated decrease of warm-season pan evaporation

Table 1. The average daily precipitation P and decadal-average pan-evaporation rates Ep at places in Australia (from data supplied by the Canberra office of the Australian Bureau of Meteorology)

Place	Period	Rainfall P: mm/d	Pan evaporation Ep: mm/d		
			1971–80	1981–90	1991–00
Darwin 12° S	Dec.–March	12.2	6.70	6.57	6.24
	April–Nov.	1.5	7.87	7.59	7.11
	year	5.1	7.48	7.25	6.82
Alice Springs 25° S	year	0.9	7.80	8.13	9.16
Canberra 35° S	year	1.7	4.53	4.77	4.48
Strathgordon 43° S	year	6.8	2.11*	1.92	2.16

* 1975–1980