NOTES AND CORRESPONDENCE

Evaporativity and the Second Stage of Drying of Soil[1]

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This note seeks to clarify the relation between rate of evaporation of water from soil and the prevailing evaporativity. It proposes as a general law that an increase in evaporativity produces an increase in evaporation rate from soil that is losing water by evaporation.

Since evaporativity is, by definition, the capacity of environmental conditions to support evaporation from wet or moist bodies—that is, its "drying power"—the proposed general law might seem obviously true. But Philip (1957) has concluded from a mathematical-physical analysis that actual evaporation rate is independent of the potential evaporation rate, after drying has progressed to the point that actual rate no longer equals the potential rate. Some researchers, among them Gardner and Hillel (1962), have obtained experimental results that seem to support Philip's conclusion. Somewhat akin to this is the conclusion that surface mulches do not significantly retard loss of soil moisture by evaporation after the surface is no longer wet.

The analysis begins with the traditional drying experiment, in which columns of moist or wet soil are subjected to constant drying conditions, and water loss is determined as a function of time. The result is familiar. For a time, the evaporation rate remains constant. Then it begins a continuous decline. For identical columns, the constant-rate period (the first stage of drying) is longer if the initial drying rate is slower. These things can be readily observed even with experimental methods that are not precise, and drying conditions only more or less constant.

The paragraph above alters the traditional statement to have the soil initially moist or wet, and not necessarily saturated. The essential feature of the drying process illustrated by the experiment also remains if the evaporativity is not held constant. The first stage of drying persists as long as the relative humidity of the surface soil is very nearly unity. More precisely, in the first stage of drying,

$$e_0 - e_a \doteq e_s(T_0) - e_a,$$

where e_0 is surface vapor pressure, e_a is vapor pressure in the air and $e_s(T_0)$ is saturated vapor pressure at surface temperature. The abrupt ending of the first stage corresponds to the surface soil becoming dry enough that further drying makes an appreciable decrease in surface relative humidity.

The evaporation rate from soil in the first stage is a useful, though incomplete, measure of evaporativity. Evaporativity is not a simple physical parameter measurable by a single denominate number. In a practical sense, the dimensions of evaporativity must be as many as the different ways evaporating surfaces of interest can respond to changes in drying conditions. Potential evaporation is not a more refined and precise concept to replace that of evaporativity, but a more restricted concept. In the discussion that follows, and in the statement of the general law, reference is made to higher and lower evaporativities and to increases and decreases in evaporativity. This does not mean that we are treating evaporativity as a scalar, or that we really mean potential evaporation. We are assuming that two different soil evaporimeters that would have different evaporation rates with the two evaporativities would change in the same direction, and this distinguishes the higher and the lower evaporativities.

What is the meaning of evaporation rate being dependent on or independent of evaporativity in the second stage of drying? For the concepts to be useful, they must surely refer to whether the course of evaporation rate with time changes or does not change with a change in evaporativity. This matter was put to experimental test in an indoor drying experiment. The lower evaporativity was provided by the general

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laboratory conditions (heated, generally unoccupied, no direct sunlight). The higher evaporativity was provided by adding radiant energy from an incandescent lamp. Two soil columns in insulated boxes were repeatedly interchanged between the two evaporativities. In the second stage of drying, without fail, the evaporation rate increased markedly with a shift to higher evaporativity and decreased markedly with a shift to lower evaporativity.

This single experiment does not establish a general law, of course. Similar results were obtained in an outdoor experiment, where partial shading furnished the lower evaporativity. This, too, does not establish a general law. Our confidence in the validity of the general law is based on its reasonableness, and on the absence of good arguments against it.

The key assumption in Philip's analysis (1957) of the falling rate phase of evaporation is the selection of the boundary condition: constant water content $\theta=\theta_0$ at the surface. This is not specifically justified; it is merely called suitable. For evaporation rate E to be independent of evaporativity in this model, either 1) the surface water content θ_0 must be independent of evaporativity, or 2) the evaporation rate must be independent of surface water content. The second alternative cannot be true. Water content and geopotential are (in this "isothermal" analysis) taken as the only driving potentials for moisture movement in the soil. Therefore, changes of θ_0 must be capable of producing changes in upward rate of water movement at the surface, which equals E. That the surface water content θ_0 is held constant without the influence of any external conditions does not make sense, either. In the more familiar heat conduction problems, a boundary condition of constant surface temperature corresponds to immersion in an ideal heat bath. The ideal heat bath, far from having no effect on surface temperature, holds it in an iron grip.

In summary, it seems clear that soil can never behave as a pure emitter of water vapor. The rate of evaporation from soil must always depend on evaporativity.

REFERENCES

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A Causal Relation for Probabilities in Synoptic Meteorology[1]

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1. Introduction

A network sampling theory, described by the writer (1961, 1964), was used to compute theoretical maximum probabilities of geostrophic wind components, obtained from 24-hr numerical predictions at 500 mb. These probabilities are due to uncertainties of the initial state that occur because no more than a finite number of observations are available for analysis of a continuous field.

A comparison was then made with empirical probabilities. An example is shown in Figs. 1 and 2 for *u* and *v* components, respectively. The theoretical (T) and observed (O) curves are based on 117 sets of wind values each, and represent predictions over North America, 0000 GMT 15 June 1962. Details on the method of construction of these curves can be found in the references above and are referred to in the next section.

The points to be emphasized here are that theoretical and observed probabilities are in good agreement, and that similar agreement has been found in other unpublished predictive studies. Such results suggested that the following comment by Born (1964) might be applicable although he speaks of quantum mechanics: "We have the paradoxical situation that observable events obey laws of chance, but that the probability for these events itself spreads according to laws which are in all essential features causal laws."

To some extent at least, the first half of this statement is borne out by Figs. 1 and 2. For example, small errors are more frequent than large ones, in accord with error theory. And furthermore, the closeness of theoretical and observed curves makes a causal determination of probability seem plausible.

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