



Discussion Forum

The Australian National Committee for Earth Systems Science held a workshop of experts dedicated to the question in this title. They found that available data do not yet support the frequently repeated assumption that global warming increases evaporative demand on the land, an assumption that continues to be common, for instance in the IPCC 4th Assessment Report, Summary for Policy Makers.

Evaporative demand: Does it increase with global warming?

It may seem counterintuitive, but the overwhelming body of data from pan evaporimeters and estimated lake evaporation rates averaged over large regions in numerous countries in both hemispheres show decadal trend-lines, fitted through the inter-annual variability, of declining rates of unconstrained free-water evaporation since the early 1970s (when measurements began). This is despite the warming of the lower atmosphere during that period. Although there is considerable spatial and temporal variation in annual pan evaporation, on average the evaporation rate from such 1.2 m diameter pans of water (Figure 1) has been declining by about 2–4 mm per year since the 1970s in many regions, e.g. USA, former Soviet Union, China, India, Thailand, Australia, New Zealand and Canada. The rate of decline for lakes since the 1950s has been similar. After reviewing the evidence for this phenomenon, the workshop addressed why this might be, what significance it has for evaporative demand on the vegetation in the area of the pan evaporimeters during global warming, and what implications the observation have for our understanding of the global hydrological cycle and its representation in global climate models (GCMs).

Why is it so? Is it an artifact of the pan evaporimeter methodology? It was concluded that only one of the known artifacts of pan evaporimeters (as a measure of lake or wet-vegetation evaporation) could cause a decline in readings over several decades. That was the Australian practice of retrofitting bird-guards at various dates for the different pans. However, applying the 7% correction for



Figure 1. A Class A Pan Evaporimeter run by the Australian Bureau of Meteorology at Canberra Airport.

the bird-guard effect from the dates of installation did not alter the conclusion much that Australian annual pan evaporation rates have been in long term decline by about 3 mm per year.

Complementary relationship

An important effect in water-limited (arid) environments but not wet ones (Figure 2), is the so-called “complementary relationship” in which, during times of lower rainfall, pan evaporation rates tend to be higher than during wetter periods. This is because when rainfall is high, the atmosphere is moist and also cloudiness is often high, leading to lower insolation. Thus a primary cause of inter-annual variation in individual pan evaporation in the more arid areas is a sometimes complementary variation in local rainfall. On the other hand, after this correlation is stripped out of the data, there remains the downward long-term trend in the area-averaged record that is unrelated to long term change in precipitation, in for example, Australia, China and New Zealand. What this means is that in periods of drought, evaporative demand can be relatively high despite the long term trend of decline in potential evaporation. Thus, if for a particular area, global warming shifted spatial and temporal patterns of climate causing an increase in the frequency of droughts (offset by increased rainfall elsewhere), for that droughty area, potential evaporation could increase, not because of the directly enhanced greenhouse warming, but because of the changed local weather (less cloud, less rain, and higher air temperature than via just the enhanced greenhouse warming alone) that global warming engendered via atmospheric circulation changes. Unfortunately distinguishing whether a drought event at a specific location is part of normal long term variability or is attributable to greenhouse gas (GHG) induced global warming is not possible for any one event. That is why when discussing the impact of global warming on potential evaporation it is only meaningful to consider long term spatially averaged trends.

What increases the evaporation rates?

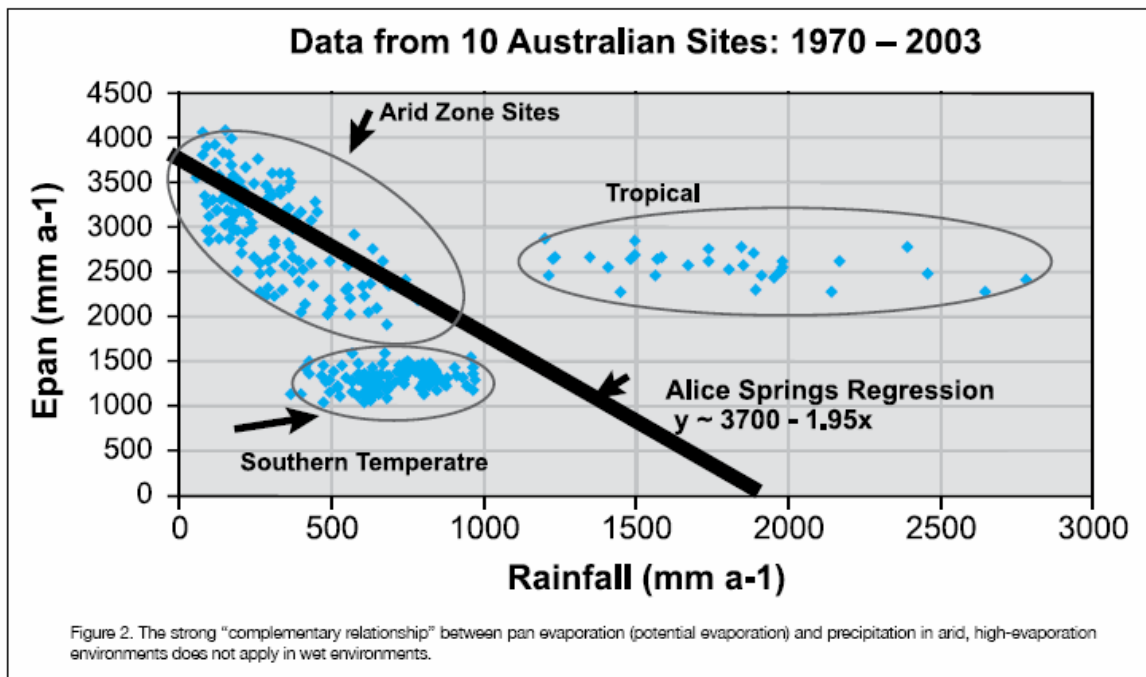
That it is typically hotter by day during a drought owing to less cloudiness, fosters the intuitive perception that hotter conditions cause high evaporation rates. However, it is not high temperature that increases evaporation rates, it is the low vapour pressure deficit that can go with high temperature that increases evaporative demand. Thus if *all else is equal*, warmer conditions do increase evaporative demand via increased atmospheric Vapour Pressure Deficit (VPD). But, with temperature increases attributable to increased atmospheric concentrations

of GHG, all else is not equal. As Arrhenius, and all greenhouse effect modellers since have supported, the magnitude of GHG warming is associated with increased atmospheric humidity consistent with the principle behind the Clausius-Clapeyron relationship. This leads to approximately constant globally averaged relative humidity involving increases in absolute atmospheric humidity but only a small increase in the VPD. In fact, about half of the modelled greenhouse warming derives from the long-wave radiation absorption by the assumed increased water vapour content of the atmosphere. Thus with that central feedback in GHG forcing considered alone, we would not expect a large change in evaporative demand with greenhouse warming. So why are inter-decadal declines in potential evaporation rates being widely observed?

In fact, about half of the modelled greenhouse warming derives from the long-wave radiation absorption by the assumed increased water vapour content of the atmosphere.

The physics of evaporation from a free land-locked water, or fully hydrated vegetation, surface has been accurately expressed in the Penman Equation, which combines the net radiation-driven and aerodynamically-driven components of evaporation into a single relationship. In that highly successful formulation, evaporation from a free water surface, like an evaporation pan, mostly depends on three drivers: atmospheric vapour pressure deficit, wind speed, and net radiation load on the wet surface. The temperature of the evaporating surface is eliminated when the radiation and aerodynamic components are combined in the derivation of the Penman Equation. The workshop devoted much time to evaluating these three possibilities for the observed decline in pan evaporation. It was not resolved except that all three drivers have shown trends with different contributions in different places. Vapour pressure deficit sometimes shows a declining trend commensurate with the daily temperature range declining as night minimum temperatures have increased faster than daytime maxima.

Widespread dimming of incident solar radiation was discussed and seemed to be at least partly responsible for the decline in pan evaporation at many sites. But solar dimming may have ceased in the 1990s and may have started to re-brighten over large areas of the Earth since then, though the evidence for that is mixed. Average wind speeds have varied over the last decades as global warming proceeded too. No consistent cause of the declining pan evaporation rates, applicable everywhere, was identified at the workshop but work has continued since then.



How to define potential evaporation

There are different ways that “potential evaporation” can be conceptualised and defined. The Penman equation implicitly permits the evaporating surface temperature to float with the evaporative cooling, which is the appropriate approach when the impact of evaporative demand on actual evaporation from vegetation is of interest. This is what is needed for studying the impact of climate change on primary productivity, e.g. agricultural production. Under that assumption the actual evaporation rate of a fully wetted vegetation surface is equal to the potential evaporation – adding more water causes no increase in actual evaporation. As the soil dries, actual evaporation declines towards the rate at which the vegetated non-saturated soil can supply water to the air and plant processes. In the intermediate moist zone of soil wetness, between wet and dry, actual evaporation is determined by both the evaporative demand and the soil moisture availability for evaporation. The latter depends on several things including soil type, litter-mulch, rooting depth, root extension rates into moist soil under plant water deficits, and plant stomatal response to evaporative demand and leaf surface temperature. A low evaporative demand, *sensu* Penman, can be equivalent to a wetter soil insofar as plant growth is concerned.

A second way to conceptualise potential evaporation is to adopt a fixed evaporating surface temperature equal to near-surface air temperature rather than

allowing it to float with evaporation rate. While this is not the case in the real world where increased evaporation decreases the surface temperature by evaporative cooling, it is the way that GCMs have usually been programmed to predict “potential evaporation” using the Dalton Equation that does not take the changed energy balance into account but uses the saturated vapour pressure at surface temperature (assumed to be equal to near surface air temperature without any evaporative cooling effect) to drive calculated evaporation. This could perhaps be one reason for a GCM to predict that global warming will increase the “potential evaporation”.

Proceedings of the workshop with extended abstracts of the 13 papers presented and a detailed review of the conclusions of the meeting, including primary literature references, can be found as a PDF at the Australian Academy of Sciences website: www.science.org.au/natcoms/pan-evap.pdf.

Roger M. Gifford
CSIRO Plant Industry
Canberra, AUSTRALIA
E-mail: roger.gifford@csiro.au

Michael Roderick
E-mail: Michael.Roderick@anu.edu.au

Graham D. Farquhar
E-mail: graham.farquhar@anu.edu.au

Both at:
Research School of Biological Sciences
Australian National University
Canberra, AUSTRALIA

