



THE EVAPORATION PAN TECHNIQUE REVISITED: OLD THEORY AND A NEW APPLICATION FOR TIME-WEIGHTED SYNOPTIC TRACING OF THE ISOTOPIC COMPOSITION OF ATMOSPHERIC VAPOUR

Reliable and consistent characterization of the stable isotope composition of atmospheric water vapour and its temporal variability are important prerequisites to the wider application of isotope mass balance methods in atmospheric and water balance studies, at scales ranging from the typical atmospheric general circulation model (GCM) grid-square domain down to and including field-based studies conducted in small watersheds or at points near the ground surface. Precipitation sampling conducted within the WMO/IAEA Global Network for Isotopes in Precipitation (GNIP) and affiliated national networks has made significant contributions to our understanding of temporal and spatial variations in the isotopic composition of atmospheric moisture using the equilibrium assumption, i.e., that the isotope distribution in precipitation is an "equilibrium proxy" for that in vapour, based on assumed temperature-dependent equilibrium isotope exchange effects. However, because precipitation predominantly occurs as discrete events separated in time, especially in arid or seasonally-arid climates, liquid-phase sampling may not provide a good time-weighted estimate of vapour-phase isotopic composition, nor does it provide information on changes occurring between precipitation events. This is further complicated by uncertainty in the relation between cloud temperature and climatological temperature, which is difficult to ascertain without specific knowledge of the atmospheric boundary layer structure. Conversely, improved understanding of the isotopic relations between precipitation and vapour could potentially provide important hydroclimatological insight, for example yielding clues about the nature and causes of variations in the slope of local evaporation lines in $\delta^{18}\text{O}$ - $\delta^2\text{H}$ space, or providing information for evaluation of atmospheric feedback or throughput in coupled evaporative systems (e.g. Gat and Bowser 1991).

Routine sampling of atmospheric water vapour using cryogenic traps has not been widely adopted in field studies, primarily due to logistical constraints, and it has rarely been integrated within precipitation sampling networks. Moreover, field-based sampling campaigns are commonly of rather limited duration, yielding short-term data sets that may have limited applicability at water balance time-scales or may be poorly suited for meaningful comparison with records of precipitation isotope composition. Challenges also exist to design efficient trapping systems, because of the potential for fractionation arising from incomplete vapour recovery.

Field work in remote areas of continental northern

Canada, an arid region that is typically characterized by 15-20% wetland area because of underlying permafrost, has prompted development of a new approach for characterizing the isotopic composition of vapour-phase atmospheric moisture and its variability. The method employs conventional evaporation pans and is especially suitable for use in water balance studies of lakes at local to regional scales. Due to the pronounced seasonality of precipitation, proportionately large snowmelt input and short thaw season, lakes in the region rarely attain isotopic steady state, but instead often display systematic seasonal enrichments and spatial trends that are strongly dependent on the shifting isotopic composition of local atmospheric vapour.

Intensive experiments (Gibson *et al.* 1999) have demonstrated that five- to ten-day flux-weighted records of the stable isotope content of ambient atmospheric vapour can be obtained through careful monitoring of the isotope and mass budgets of evaporation pans, coupled with the well-known layered resistance model of Craig and Gordon (1965). This conclusion is reinforced by successful use of pan-derived vapour $\delta^{18}\text{O}$ and $\delta^2\text{H}$ values in a detailed isotope-mass balance analysis of a small lake at Lupin, Nunavut, which yielded evaporation rates in close agreement ($\pm 10\%$) with results based on Bowen ratio energy balance and aerodynamic profile calculations (Gibson *et al.* 1996a,b).

Previous evaporation pan experiments mainly focused on investigation of isotope exchange parameters using relatively small pans sensitive to rapid changes in ambient conditions (e.g. Gat 1970; Welhan and Fritz 1977; Allison *et al.* 1979; Allison and Leaney 1982). In contrast, the new approach utilizes standard class-A pans, which have sufficient volume (220 l) to buffer short-term transient variations in atmospheric conditions, justifying the assumption of constant kinetic isotopic fractionation effects in concert with precisely measured temperature and relative humidity to derive vapour isotopic composition.

A major strength of the method is that pan-derived vapour isotopic compositions are naturally flux-weighted, as represented in the Craig and Gordon (1965) model, and can thus be applied directly to isotope mass-balance analysis of nearby lakes. Fortunately, although the use of kinetic isotope effects that are inherently dependent on the turbulence regime of the boundary layer is a potential weakness,

this factor seems to be remarkably uniform on synoptic time scales or, alternatively, it can be indexed on the basis of other routinely measured climatological data.

As an example, Figure 1 shows a comparison of pan-derived atmospheric vapour $\delta^{18}\text{O}$ and $\delta^2\text{H}$ at the Lupin study site with data obtained from cryogenically trapped vapour during the daytime and calculated vapour $\delta^{18}\text{O}$ and $\delta^2\text{H}$ assuming isotopic equilibrium with discrete occurrences of precipitation. The pan-derived values clearly provide comparable records of temporal changes in atmospheric moisture $\delta^{18}\text{O}$ and $\delta^2\text{H}$. Note that the daytime vapour-trap estimates are biased relative to the daily pan-derived estimates because of the influence of vapour from local lakes and tundra bryophytes.

The results suggest that isotopic sampling of existing, conventionally operated class-A evaporation pans could offer a straightforward and cost-effective solution to the problem of documenting the shifting isotopic distribution in atmospheric moisture. The method could provide continuously-weighted records of vapour $\delta^{18}\text{O}$ and $\delta^2\text{H}$ for use in isotope-climate research, which would be of partic-

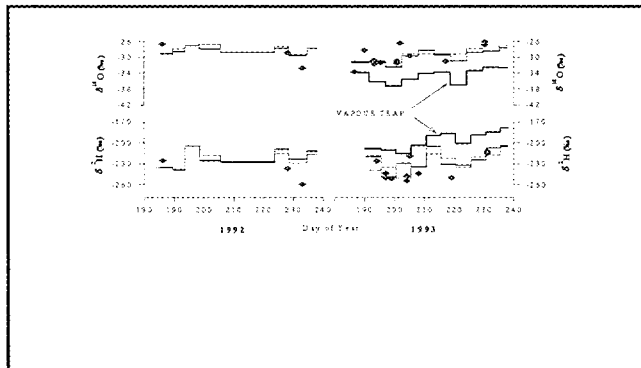


Figure 1. Time-series of step-wise atmospheric vapour $\delta^{18}\text{O}$ and $\delta^2\text{H}$ values derived from class-A pans (solid lines), average of moisture collected daily in vapour trap at height of 6-m over tundra (bold lines), and estimates of vapour $\delta^{18}\text{O}$ and $\delta^2\text{H}$ based on the assumption of isotopic equilibrium with discrete occurrences of precipitation (diamonds). (See Gibson *et al.* 1999.)

ular value for stations receiving little or highly variable precipitation. As studies in Canada have shown, such data are applicable in hydrometeorological studies at various spatial and temporal scales. Significant potential also exists for incorporation into major international hydrosience initiatives, like the ongoing continental-scale regional hydrologic studies within the Global Energy and Water Cycle Experiment (GEWEX), as well as being a resource for validation of the global isotope field as depicted by atmospheric GCMs field as depicted by atmospheric GCMs.

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