Water evaporation characterization by its isotopic signatures under controlled conditions

BIRON P.[1], RICHARD P.[1], DELAY F.[2], ACKERER P.[2], DURAND J.L.[3], BARIAC T.[1]

[1] IEES-PARIS, UMR 7618 (CNRS - UPMC - INRA - IRD - UPEC - Université Paris Diderot) , Bât. EGER, Campus de Grignon, 78850 Thiverval-Grignon, France.
[2] LHYGES, UMR 7517 CNRS, EOST / Université de Strasbourg, 1, rue Blessig, 67084 Strasbourg Cedex, France,
[3] UR P3F, INRA, route de Saintes, BP 6, 86600 Lusignan, France.

I. Introduction

• Accurate quantification of evaporation losses from surface water bodies is essential for the validation of hydrological and ecological models.

• Stable isotopes composition of water (liquid and vapor) are increasingly used to estimate these evaporation losses. The signature of water vapor due to evaporation (δ_E) is needed to close the isotopic mass balance but hardly measurable in natural conditions.

• As part of the CNRS-EC2CO-BIOHEFECT program, the evaporation process was studied under controlled conditions and modeled relying upon isotopic mass balance approaches with consideration for isotopic fractionation and interactions with atmospheric moisture.

II. Materials and Methods

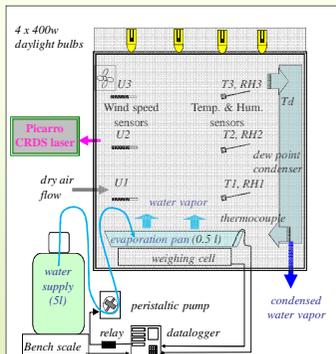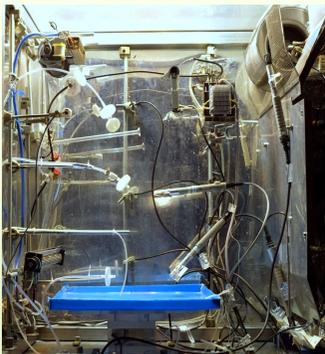

Photo.1: Experimental Device (RUBIC I)
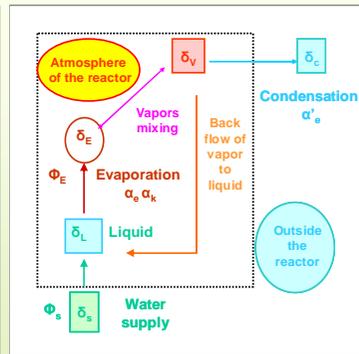

Fig.1: Pan water evaporation experiment

Fig.2: The water exchanges between sources and products

The water cycle and exchanges between the liquid and the vapor in RUBIC-I are represented. All water fluxes and isotopic signatures are measured except δ_E.

The pan (δ_L) is constantly filled up from an external water supply (δ_S) to compensate losses by evaporation (δ_E). The change of phases modifies the respective signatures of the liquid and of the vapor under the effect of fractionations (α_k, α_e). The liquid and vapor phases exchange each other.

The air humidity in the reactor is controlled by the dew point of an air cooler, which condenses the moisture excess. Condensates are collected (δ_c). An additional fractionation occurs (α'_e) in this new phase depending on the condensation temperature. The remaining water vapor is recycled into the chamber.

MIBEC model (*Modèle Isotopique Biogéochimique appliqué à l'Evaporation–Condensation*)

It is based on the coupling of the Craig and Gordon model (1965) with a complete isotopic mass balance equation. It includes the Dansgaard's condensing module and accounts for interactions with the atmospheric moisture.

At steady state (permanent flow):

$$\frac{dV_L}{dt} = \phi_S - \phi_E - \phi_{LS} = 0 \qquad \frac{dV_V}{dt} = \phi_E - \phi_C - \phi_{VS} = 0$$

At isotopic transient state :

$$\delta_L^t = \delta_L^s - (\delta_L^s - \delta_L^0)\, e^{-\left[\frac{(\phi_E + \xi\,\phi_{LS})\,\Delta t}{\xi\,V_L}\right]}$$

$$\delta_E^t = \frac{\delta_L^t - h\,\alpha_e\,\delta_V^t}{\xi}$$

$$\delta_V^t = \delta_V^s - (\delta_V^s - \delta_V^0)\, e^{-\left(\frac{\phi_E\,h\,\alpha_e + \phi_C\,\alpha'_C\,\xi + \phi_{VS}\,\xi}{\xi\,V_V}\right)\Delta t}$$

$$\frac{d(V_L\,\delta_L)}{dt} = \phi_S\,\delta_S - \phi_E\,\delta_E - \phi_{LS}\,\delta_{LS}$$

$$\delta_c^t = \alpha'_e\,\delta_V^t \qquad \xi = \alpha_k\,\alpha_e\,(1-h)$$

$$\frac{d(V_V\,\delta_V)}{dt} = \phi_E\,\delta_E - \phi_C\,\delta_C - \phi_{VS}\,\delta_{VS}$$

L = liquid, V = vapor, S = source water, E = evaporation, LS = liquid sampling, C = condensation, VS = vapor sampling, δ_L^s = steady state (liquid), δ_V^s = steady state (vapor), h = relative humidity, α_e = equilibrium fractionation factor between liquid water and vapor, α_C = equilibrium fractionation factor between vapor and liquid water (condensates), α_k = kinetic fractionation factor associated with diffusion in the air laminar layer above the liquid interface

The RUBIC I reactor allows:
1. Regulation of the microclimate (air temperature and humidity) . 2 Calculation of mass balance (evaporation, condensation) 3. Isotopic sampling in both liquid and vapor phases.
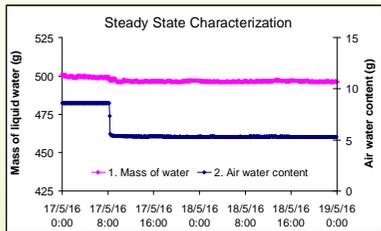
III. Results and Discussion

Fig.3: Steady state characterization

1- It is shown that the pan water evaporates in steady-state conditions throughout the experiment. The mass of water in the reservoir (500 g) does not vary using a peristaltic pump controlled by a bench scale (Fig.1). Losses by evaporation are immediately compensated by water supply.
2- The plot shows two periods with different air water content. On May 17 at 8:00 am we deliberately lowered the humidity set point to observe its consequences on evaporation and isotopic signatures. For each period, air humidity is constant with the meaning that withdrawn fluxes of condensed water vapor from the chamber exactly balance evaporation fluxes.
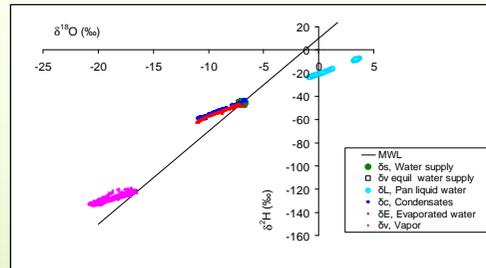

Fig.4: Relationship between isotopic water tracers

Relationships between δ^2H and $\delta^{18}O$ of different pools in RUBIC I: Meteoric Water Line (MWL), source water, pan water, condensates, reactor water vapor, vapor from pan evaporation, vapor in isotopic equilibrium with source water.
The intercept between MWL and the evaporation line (liquid phase) gives the signature of the source water before evaporation (liquid initial step). The intercept between MWL and the evaporation line (vapor phase) gives the signature of the vapor in equilibrium with the source water (vapor final step).
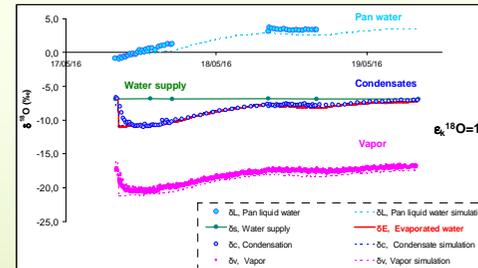

Fig.5: Time courses of the isotopic compositions

It summarizes the evolution of the $\delta^{18}O$ isotopic signatures of the different phases after the decrease of air humidity setpoint.
- Top plot, the pan water (in light blue) is enriched in heavy isotopes due to evaporation.
- Middle plot, the signature of the condensed water (dark blue circles) by the dew point chiller as well as the vapor simulated by the MIBEC model (red line).

This vapor escapes from the pan before it mixes with the ambient vapor of the reactor. In green, the water supply.
- Down plot, more depleted with reference to the liquid, the ambient vapor measured by the CRDS Picarro laser and that simulated by MIBEC.
The isotopic compositions of the different water phases are destabilized by the change in the humidity set point. It takes two days to find a new steady state. This is achieved when the signature of the condensates overlaps that of the water supply.

The simulations of the MIBEC model are in excellent agreement with measured values. The modeling helped us to define the value of the kinetic fractionation in the climatic conditions prescribed in RUBIC-I. It was made possible to show that the signature of the vapor coming from the pan water was similar to that of the condensates.

IV. Conclusion

▪ By using the model we were able to estimate the signature of δ_E ▪ MIBEC model sensitivity calculations still needed ▪ Applications to the plants (signatures of leaf water and transpired vapor) are envisioned
▪ MIBEC model needs for improvements and settings for dealing with unsteady water regimes as they occur under natural conditions at different scales

References: **Craig H. & Gordon L.i., (1965)**: Deuterium and oxygen-18 variations in the ocean and the marine atmosphere. in: E. Tongiorgi (Editor), Proc. *Conf. on Stable Isotopes in Oceanographic Studies and Paleo-temperatures*, Spoleto, 9-130. ; **Dansgaard W (1964)**:- Stable isotopes in precipitation. *Tellus*, 16, 4, 436-468 ; **Gibson JJ., Edwards T. W. D. and Prowse, T. D. (1996)**:- Development and validation of an isotopic method fot estimating lake evaporation. *Hydrol. Processes*, 10, 1369-1382 ; **Majoube M. (1971)**:- Fractionnement en oxygène-18 et en deutérium entre l'eau et sa vapeur. *J. Chim. Phys.*, 68, 1423-1436.