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A discussion on the paper "Stable isotope mass balance of the Laurentian Great Lakes"

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Outline

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1.Introduction

1.The Laurentian Great Lakes are precious resources for both humans and nature,i.e. hydroelectric power, fisheries, freshwater resources and so on.

2. As of 2014, Lakes Superior, Michigan and Huron are within a 15-year negative lake-level anomaly. Changes in lake levels are driven by sustained imbalances between inputs (direct precipitation, river inflows) and losses (evaporation, river outflows) that change the volume of water retained in each Great Lake.

4.The work uses an alternative approach based on assessment of variations in the relative abundances of the naturally occurring stable isotopes of oxygen (^{18}O) and hydrogen (^{2}H) embedded in the 'heavy' water isotopologues ($^{1}H^{1}H^{18}O$ and $^{1}H^{2}H^{16}O$) to provide residence-time-integrated estimates of net evaporation losses from each of the five North American Great Lakes.

5. Great Lakes evaporation has been estimated in previous studies using a combination of satellite, eddy covariance, and mass balance techniques.This work is Using the stable isotope-based assessment methods to calculate evaporation losses from each Great Lake.

Study area

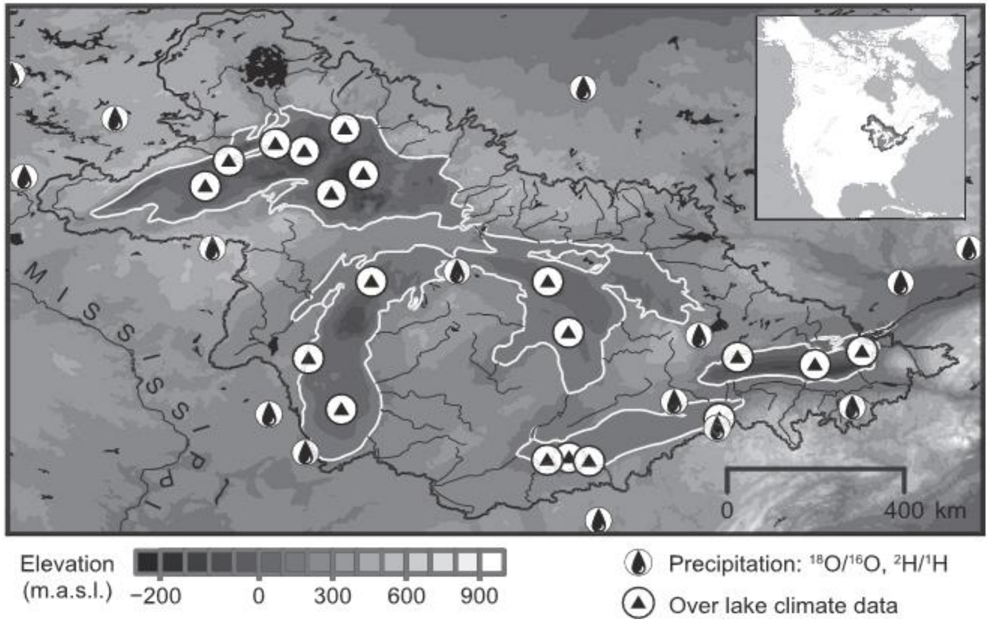


Table .1. Physical characteristics of the North American Great Lakes.

Lake	Lake area (km^2)	Catchment area (km^2)	Lake area ÷ catchment area (%)	Level (m.a.s.l.)	Residence time[a] (years)	Volume (km^3)	Depth (m)	
							Avg.	Max.
Superior	82,000	210,000	39	183.4	173	12,000	147	405
Huron	60,000	193,000	31	176.5	21	3500	59	281
Michigan	58,000	176,000	33	176.5	62	4900	85	229
Erie	26,000	85,000	31	174.1	2.7	480	19	64
Ontario	19,000	80,000	24	74.8	7.5	1600	87	244

2.Methods

20 precipitation collected stations

19 over-lake monitoring stations

75 different depth of sampling

20 surface water sampling----rivers

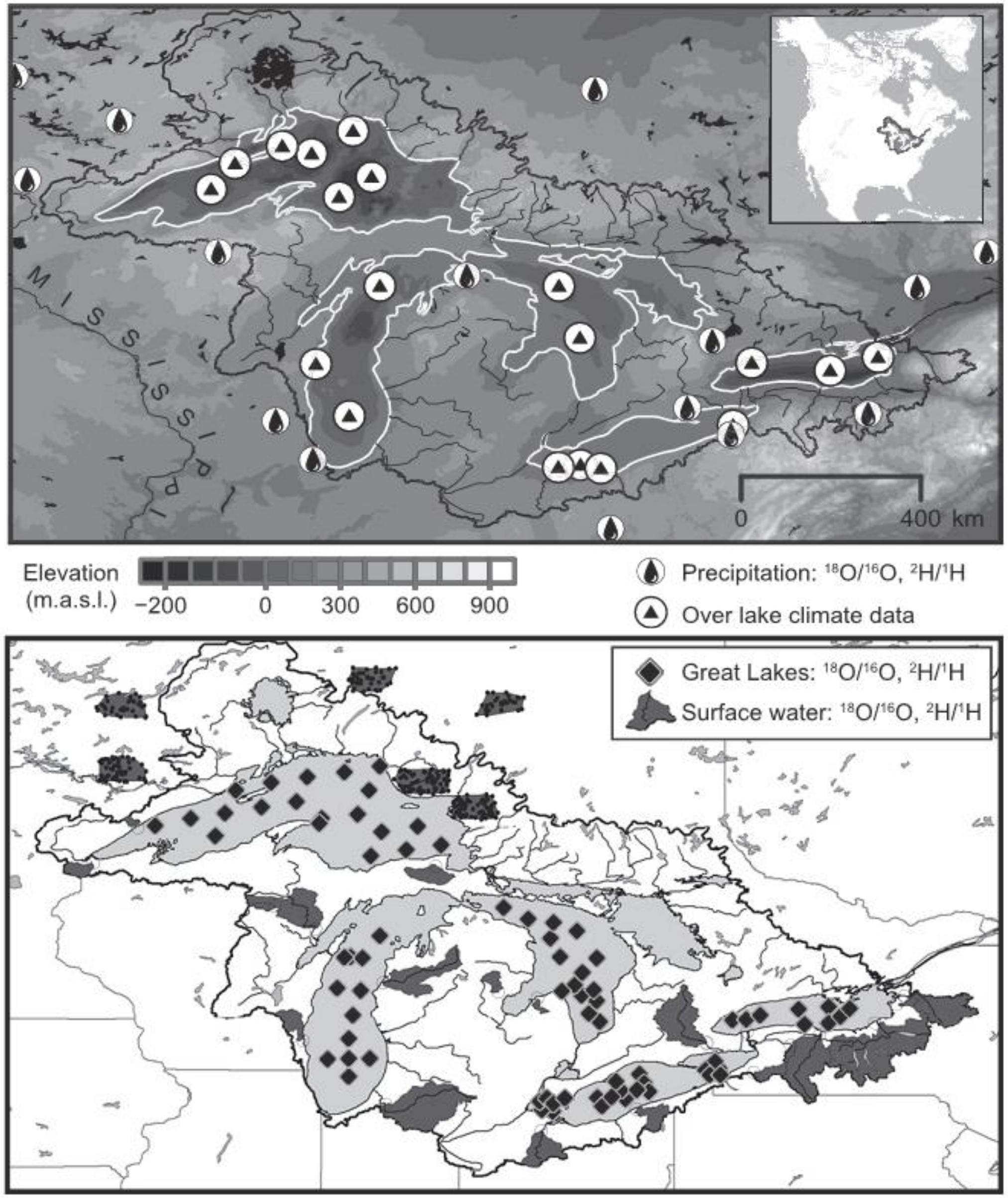


Fig .1. The distribution of monitoring stations and samlpling stations

$$R = {}^{18}O / {}^{16}O \text{ or } {}^{2}H / {}^{1}H$$

$$\delta = [(R_{sample}/R_{V-SMOW}) - 1] \cdot 1000‰$$ Craig (1961)

GMWL: $$\delta^2 H = 8 \cdot \delta^{18} O + 10$$

$$d\text{-}excess = \delta^2 H - 8 \cdot \delta^{18} O$$

3.Isotope Results

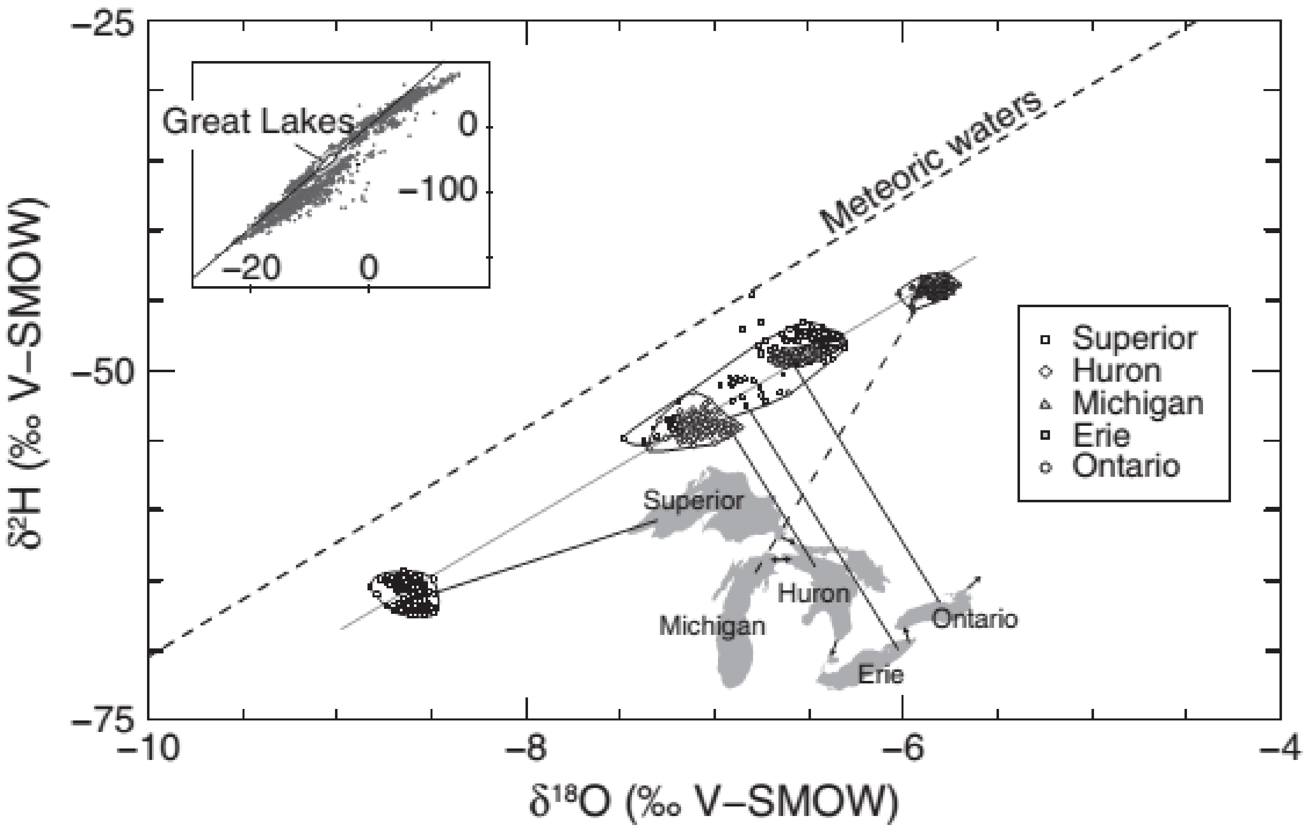
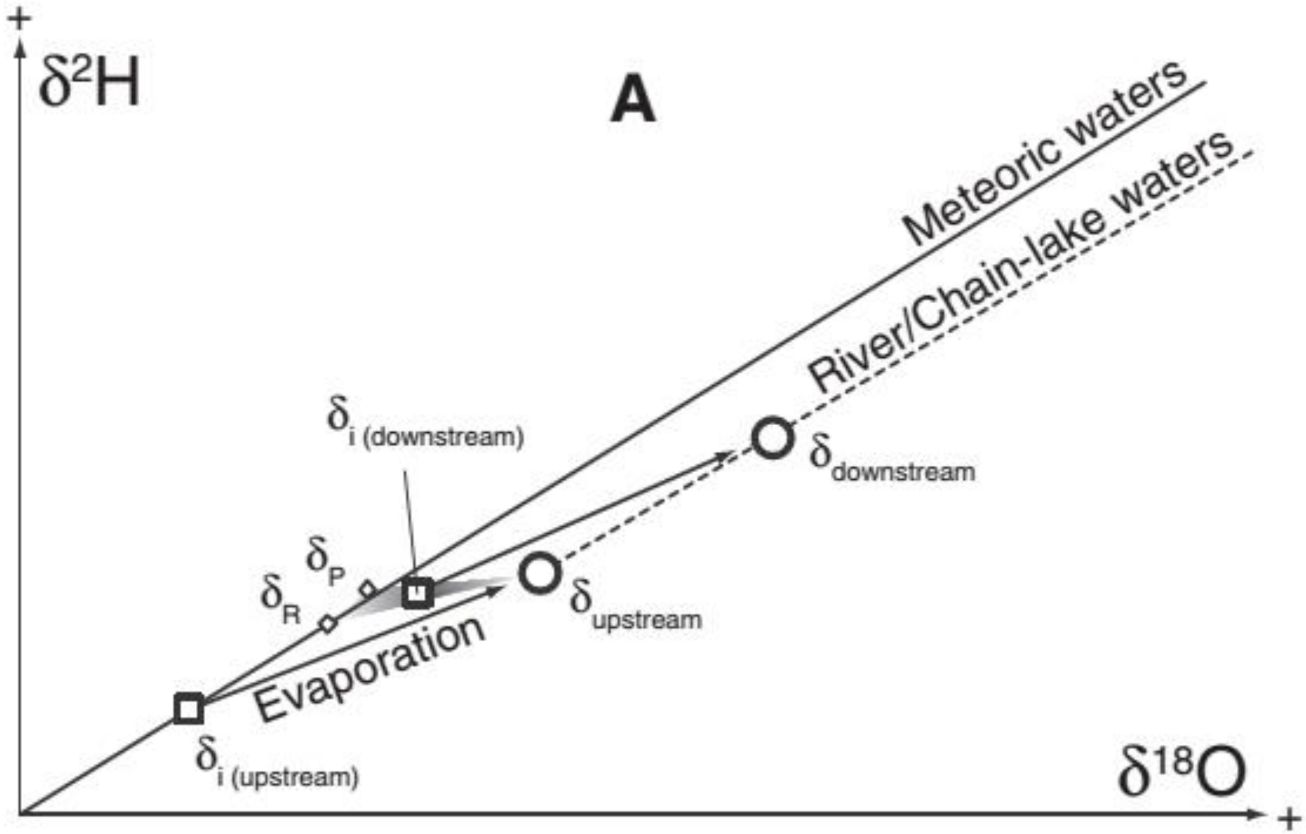


Fig .2. Isotopic composition of the waters of the Great Lakes

GLWL: $\delta^2H = 8.0\delta^{18}O + 3.2 (R^2 = 0.98)$.



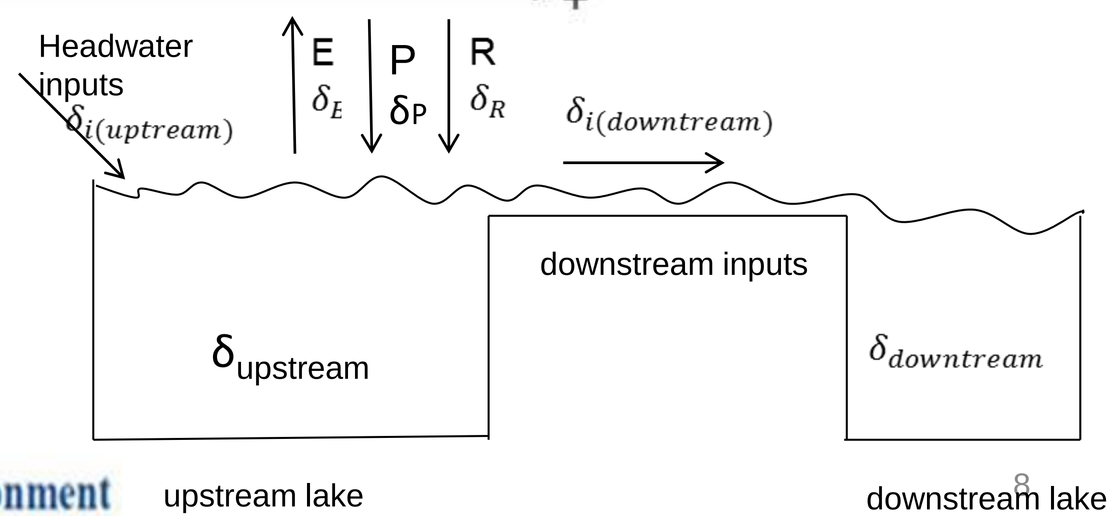


Fig .3. The $\delta^{18}O$ and $\delta^{2}H$ values of an evaporating chain lake system.

Table 2

$\delta^{18}O$, $\delta^{2}H$ and *d-excess* mean values and one standard deviation (s.d.) of North American Great Lake waters (expressed in units of ‰).

Lake	Sampling	n	$\delta^{2}H$	1 s.d. $\delta^{2}H$	$\delta^{18}O$	1 s.d. $\delta^{18}O$	*d-excess*	1 s.d. *d-excess*
Superior	Spring	80	−66.3	0.8	−8.60	0.06	2.5	1.0
	Summer	60	−65.0	0.3	−8.66	0.06	4.2	0.6
	Average		−65.8	0.9	−8.62	0.07	3.2	1.2
Huron	Spring	60	−54.4	0.4	−7.05	0.10	2.1	0.7
	Summer	45	−53.4	0.6	−7.09	0.06	3.4	0.7
	Average		−53.9	0.7	−7.06	0.09	2.6	1.0
Michigan	Spring	44	−44.2	0.3	−5.83	0.06	2.5	0.5
	Summer	36	−44.2	0.6	−5.84	0.07	2.5	0.6
	Average		−44.2	0.5	−5.83	0.06	2.5	0.6
Erie	Spring	63	−49.9	2.8	−6.69	0.37	3.6	0.8
	Summer	63	−48.7	1.6	−6.60	0.15	4.1	1.1
	Average		−49.3	2.3	−6.64	0.29	3.8	1.0
Ontario	Spring	36	−49.1	0.2	−6.62	0.04	3.8	0.4
	Summer	27	−49.0	0.4	−6.51	0.08	3.1	0.4
	Average		−49.1	0.3	−6.57	0.08	3.5	0.5

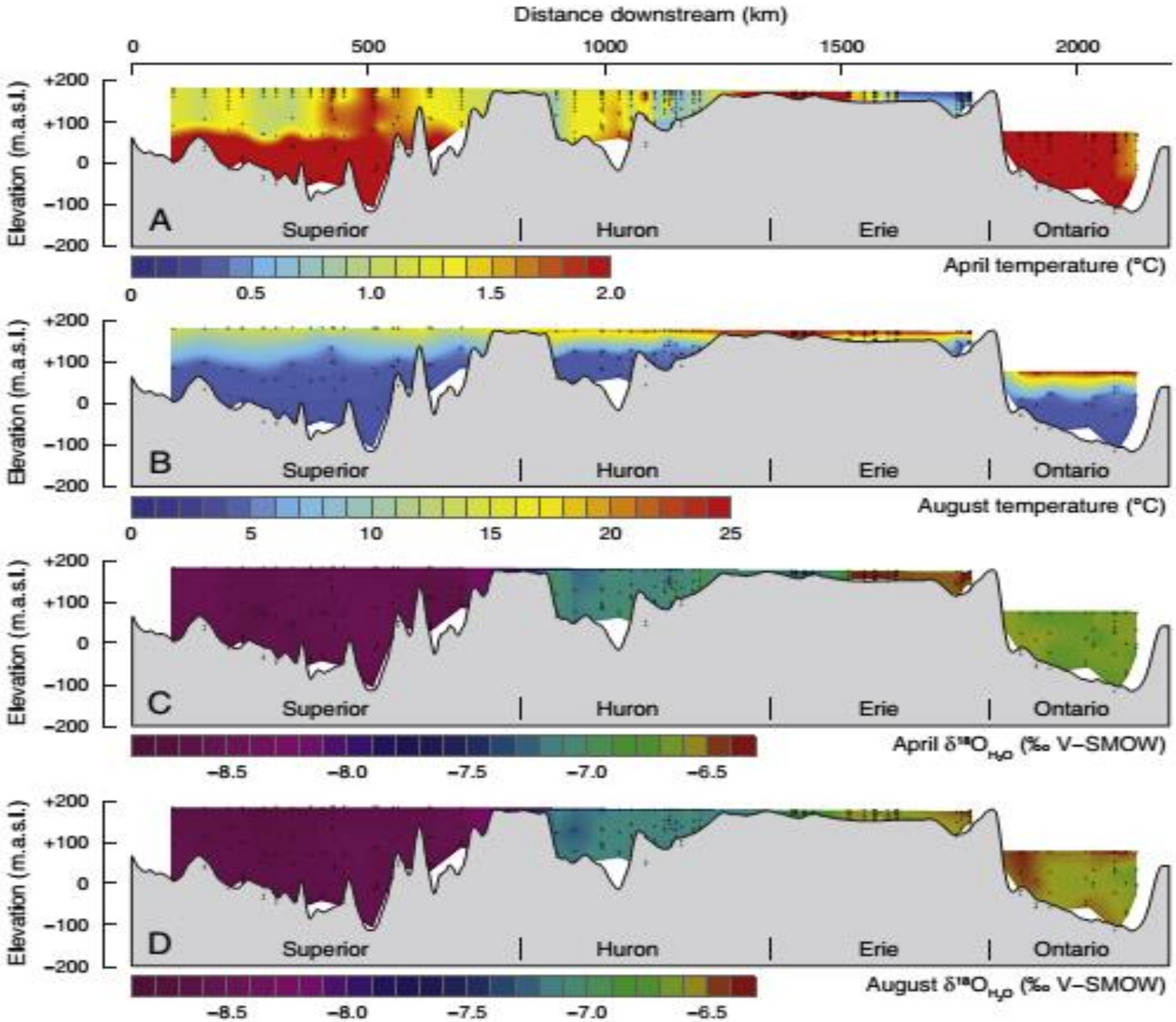
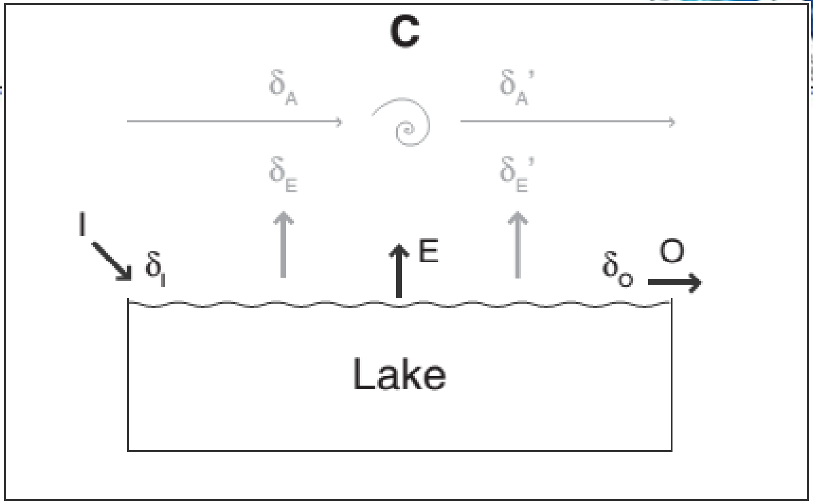


Fig .4. Temperature and $\delta^{18}O$ profiles of Superior, Huron, Erie, and Ontario in April (A, C) and August (B, D) 2007

4.Calculation



$$\frac{dV}{dt} = I - O - E \qquad (1)$$

$$\delta_L \frac{dV}{dt} + V\frac{d\delta_L}{dt} = \delta_I I - \delta_O O - \delta_E E \qquad (2)$$

$$E = O \cdot \frac{\delta_I - \delta_L}{\delta_E - \delta_I}. \qquad (3)$$

$$I = U + P + R \qquad (4)$$

$$\delta_I = \frac{U\delta_U + P\delta_P + R\delta_R}{U + P + R} \qquad (5)$$

$$\delta_{P(aw)} = \frac{\sum_{i=1}^{12} \delta_{P(i)} P_i}{\sum_{i=1}^{12} P_i}$$

$$\delta_{R(fw)} = \frac{\sum_{i=1}^{12} \delta_{R(i)} R_i}{\sum_{i=1}^{12} R_i} \qquad (6)$$

Gridded data

Gridded data resource:
monthly 10′ by 10′ global gridded estimates

$\delta_{P(BW)}$

Dependent linear equation:
$\delta^{18}O_{P(BW)}$=1.154· $\delta^{18}O_{means}$+1.16 (R^2=0.59)

Measured values

New localized gridded dataset:
$\delta^{18}O$ and $\delta^{2}H$ values of precipitation Specifically for the Grate Lakes region

Direct precipitation
δ_P
River inputs
δ_R

Craig and Gordon model

$$\delta_E = \frac{(\delta_L - [\alpha_{l\text{-}v^*} - 1])/\alpha_{l\text{-}v^*} - h\delta_A - (C_k[1-h])}{1 - h + (C_k[1-h])} \quad (7)$$

δ_L	isotope composition of a Great Lake
δ_A	isotopic composition of the overlying atmosphere
h	relative humidity
$\alpha_{l\text{-}v}*$	equilibrium liquid–vapor fractionation factor
C_k	kinetic fractionation constant

C_k

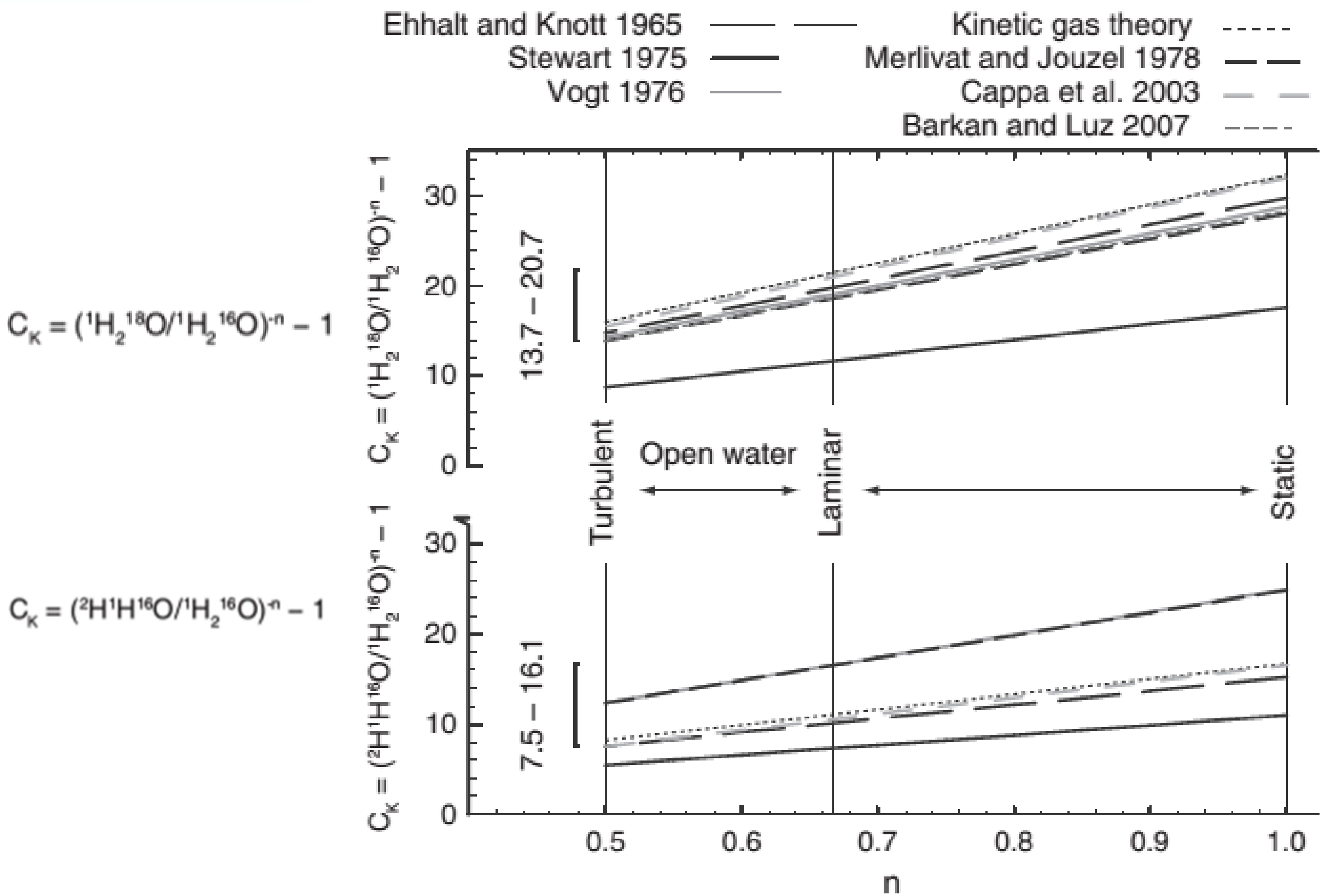
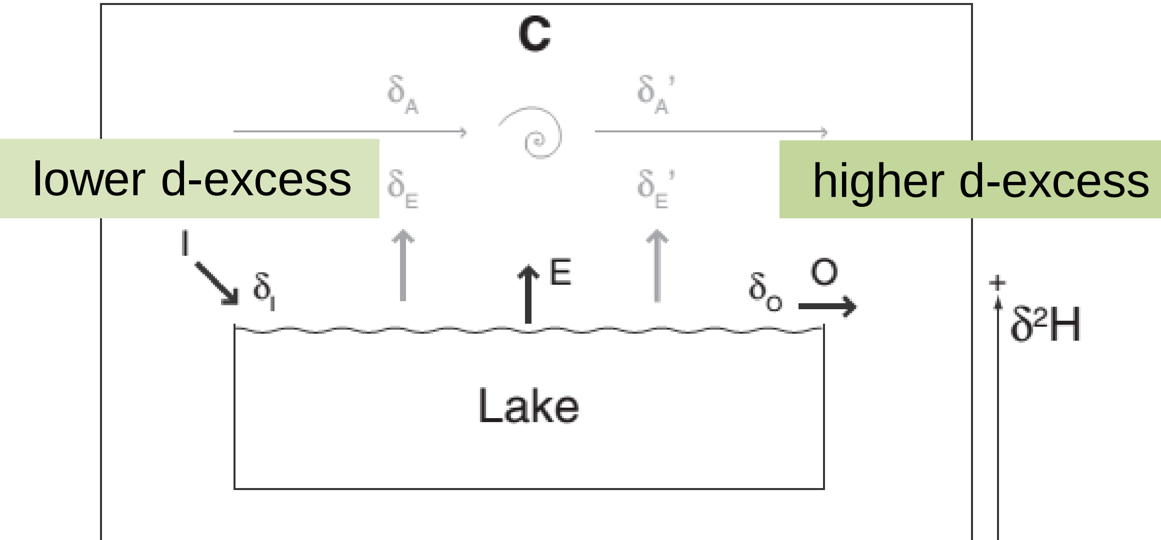
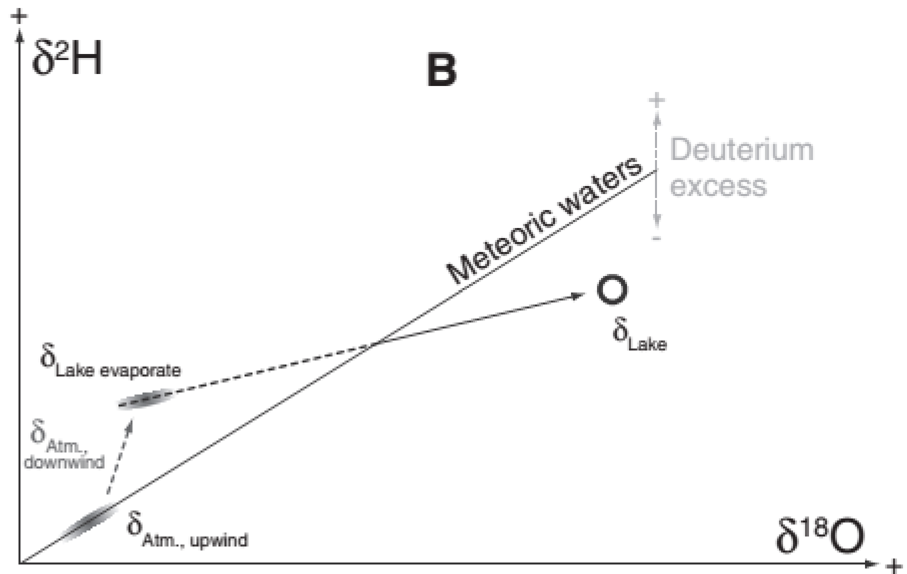


Fig .5. Calculation of kinetic fractionation constants (Ck) for $\delta^{18}O$ (upper) and $\delta^{2}H$ (lower) for the liquid–vapor phase.



$$\delta_{A'} = (1-x)\delta_A + x\delta_E \qquad (8)$$



$$\delta_{E'} = \frac{(\delta_L - [\alpha_{L\text{-}V} * -1])/\alpha_{L\text{-}V} * h\delta_{A'} - (C_k[1-h])}{1-h+(C_k[1-h])} \qquad (9)$$

Fig .6. The impact of lake evaporate on the isotopic composition of the downwind atmosphere overlying a lake surface.

5.Discussion

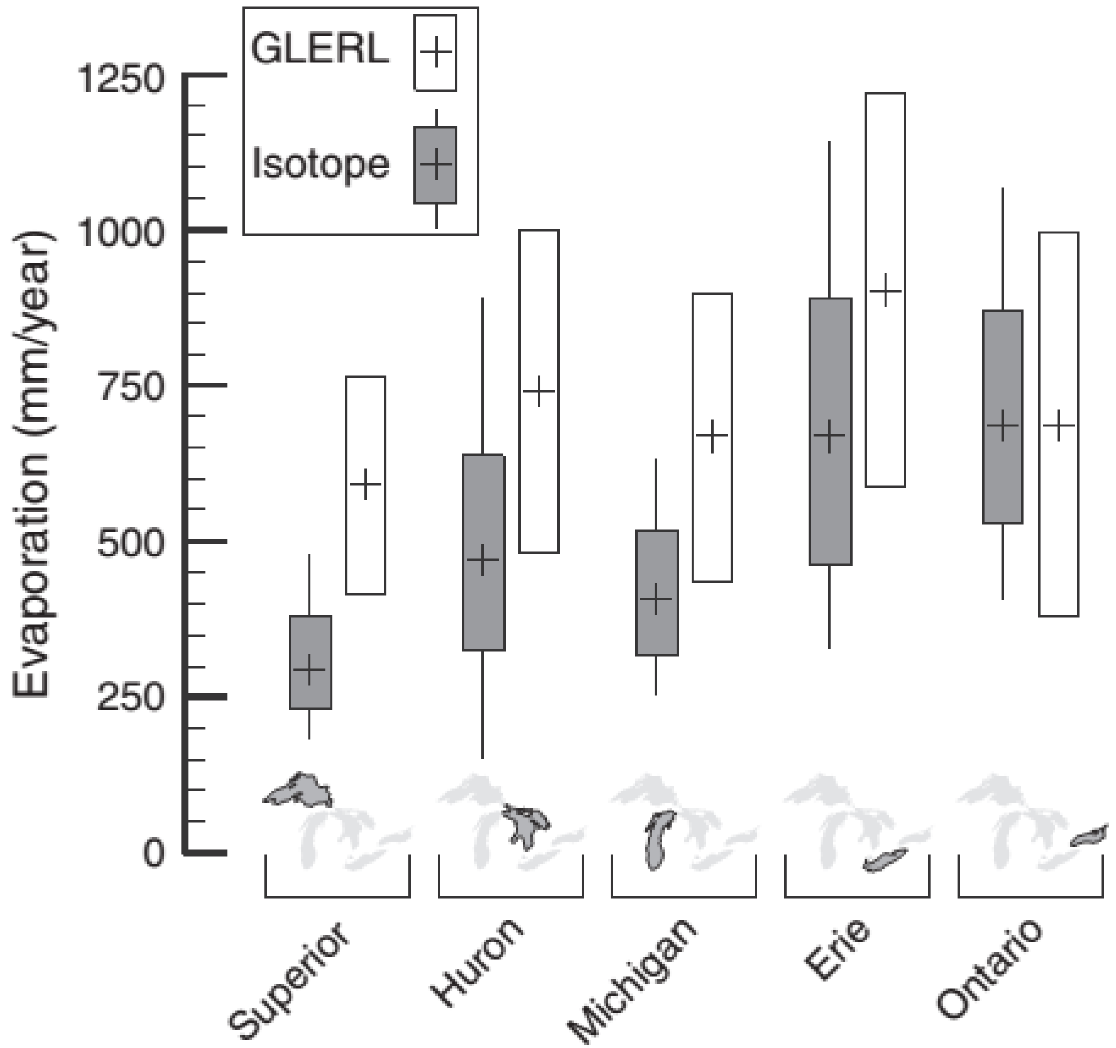


Fig .7. Isotope mass balance (gray boxes) and evaporation estimates from GLERL for the five Great Lakes.

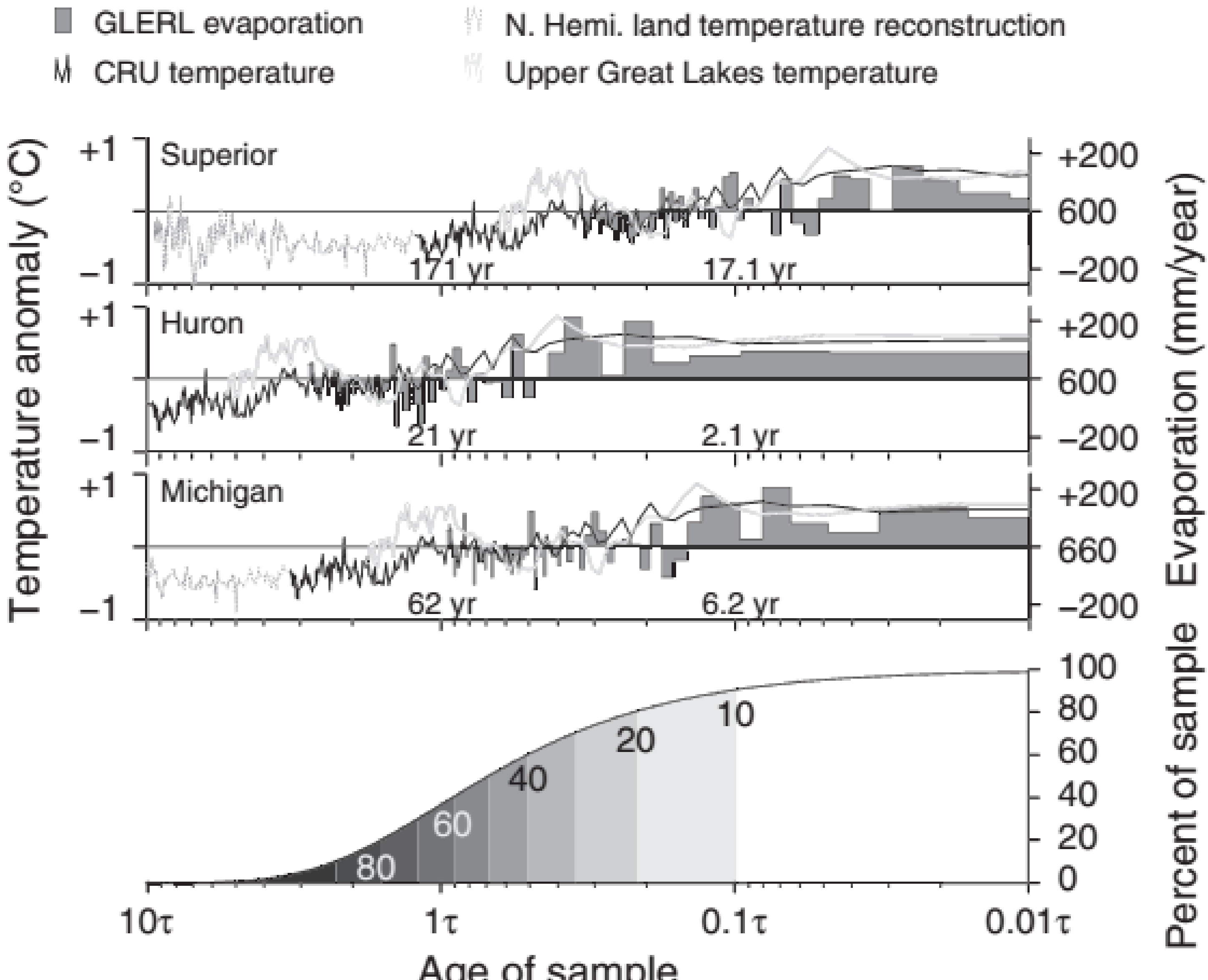


Fig .8. Great Lakes annual modeled evaporation rate GLERL (gray bars) and atmospheric temperature anomaly.

6.Summary

1. The distribution of isotope compositions of precipitation in the Great Lakes is parallel to, but offset below, the Global Meteoric Water Line, which attributed to combined effects of evaporative enrichment, precipitation and runoff .

2. New dataset to a stable-isotope-based evaporation model that explicitly incorporates downwind lake effects, including humidity build-up and changes to the isotope composition of atmospheric vapor.

3. For Superior, the Calculated evaporation is less than previous estimates, because this isotope mass balabce method do not reflect present hydroclimatological conditions as long water residence time preserves the "memory" of a cooler past climate.

Thank you