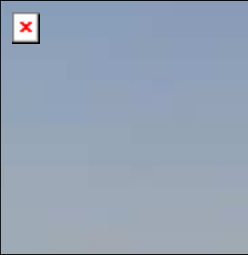
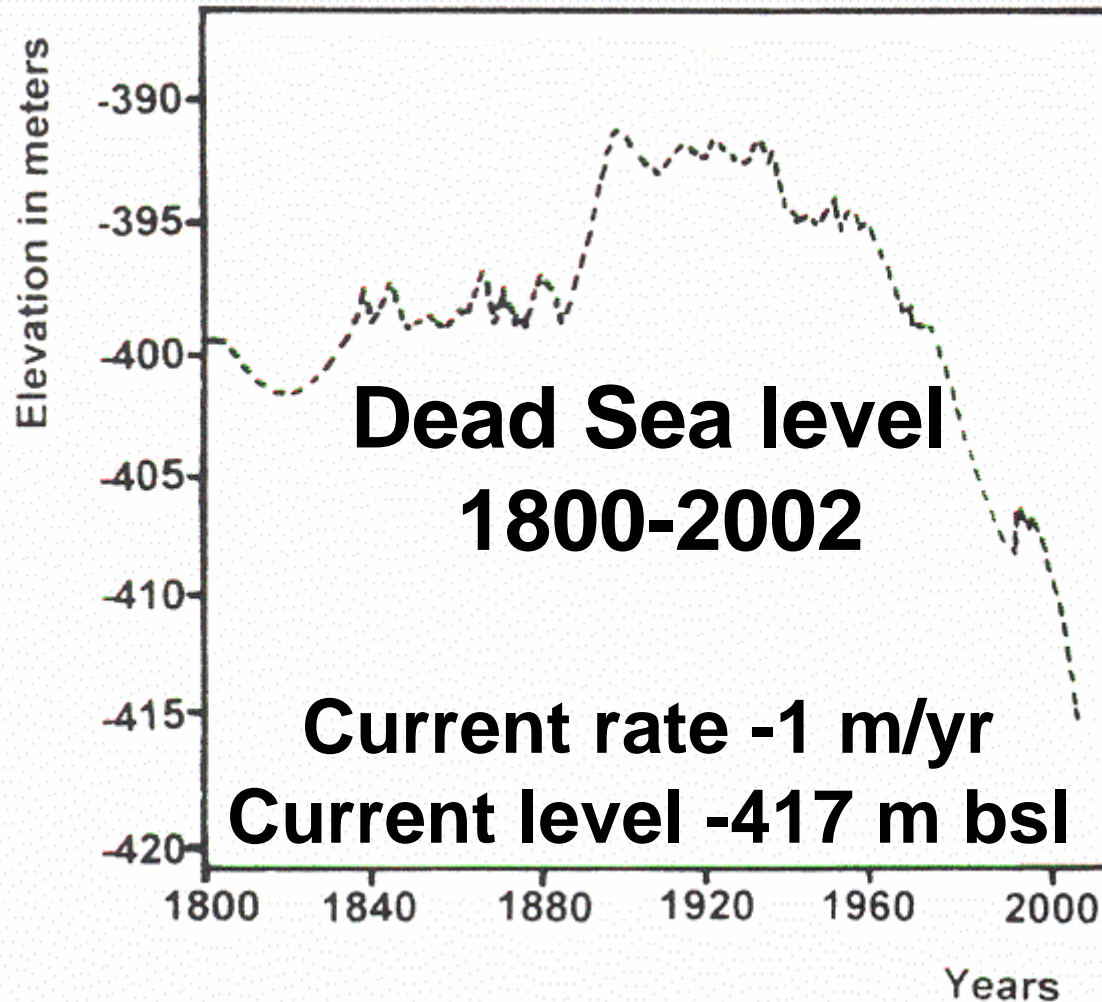


The Dead Sea: mass and energy balances

Nadav Lensky

Geological Survey of Israel





**The DS level drop –
severe
environmental and
ecomnomical
consequences**

- Suggested solutions:**
- 1. Leave as is**
 - 2. Release freshwater**
 - 3. Introduce seawater**

**The consequences (environmental etc.) of
these alternatives are not clear**



Expected results of mixing seawater with the Dead Sea brine:

Change of the Dead Sea composition with time

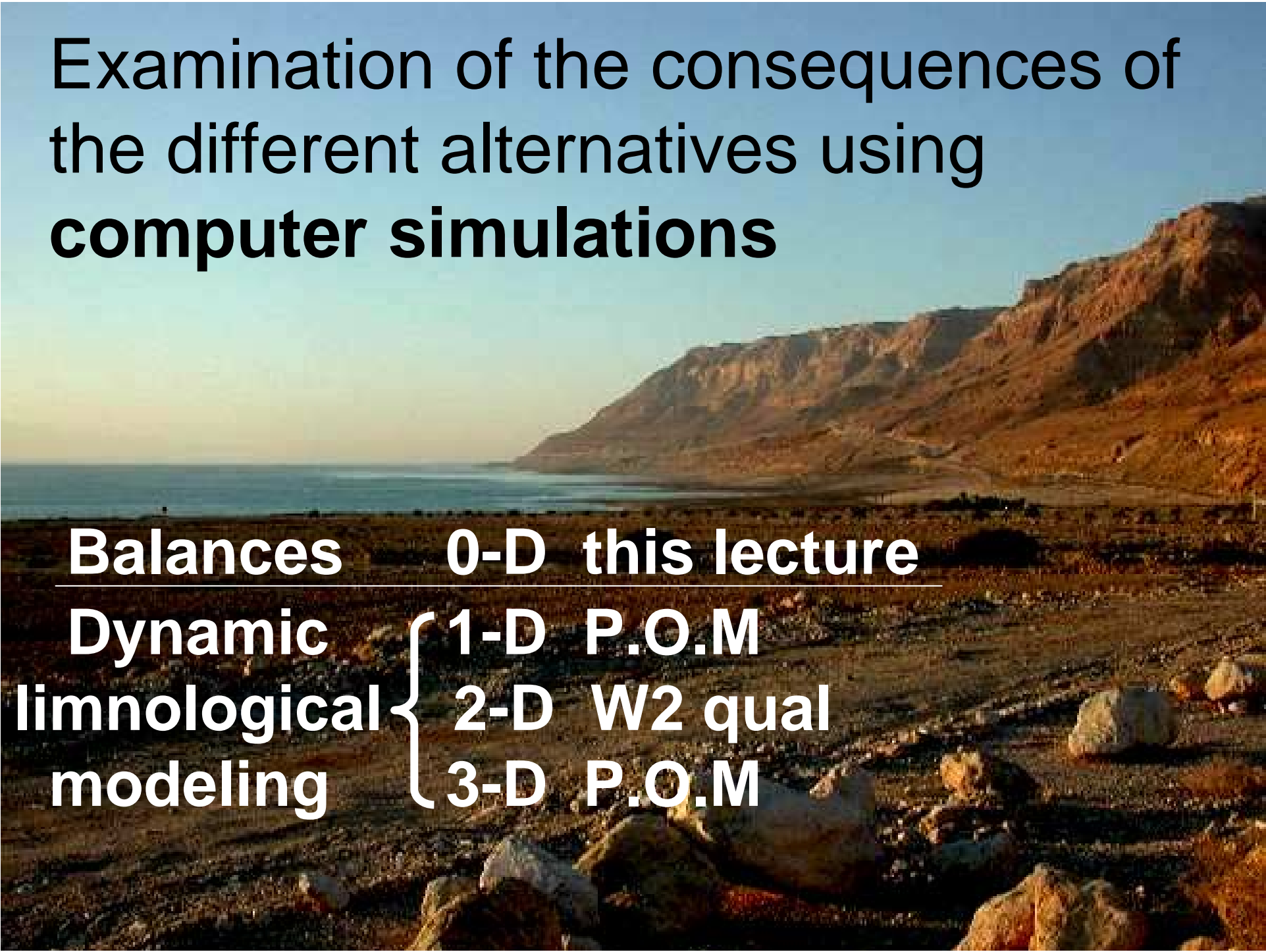
Gypsum precipitation

Dilute upper water layer

Microbial blooming in the upper layer

Reduction conditions in the lower layer

Examination of the consequences of the different alternatives using **computer simulations**



<u>Balances</u>	0-D	this lecture
Dynamic limnological modeling	1-D	P.O.M
	2-D	W2 qual
	3-D	P.O.M

Mass and Energy Balances

Measured data:

(T, P & RH) - air, SW radiation
(T, P & salinity) - water, water level

Salt mass balance

Energy balance

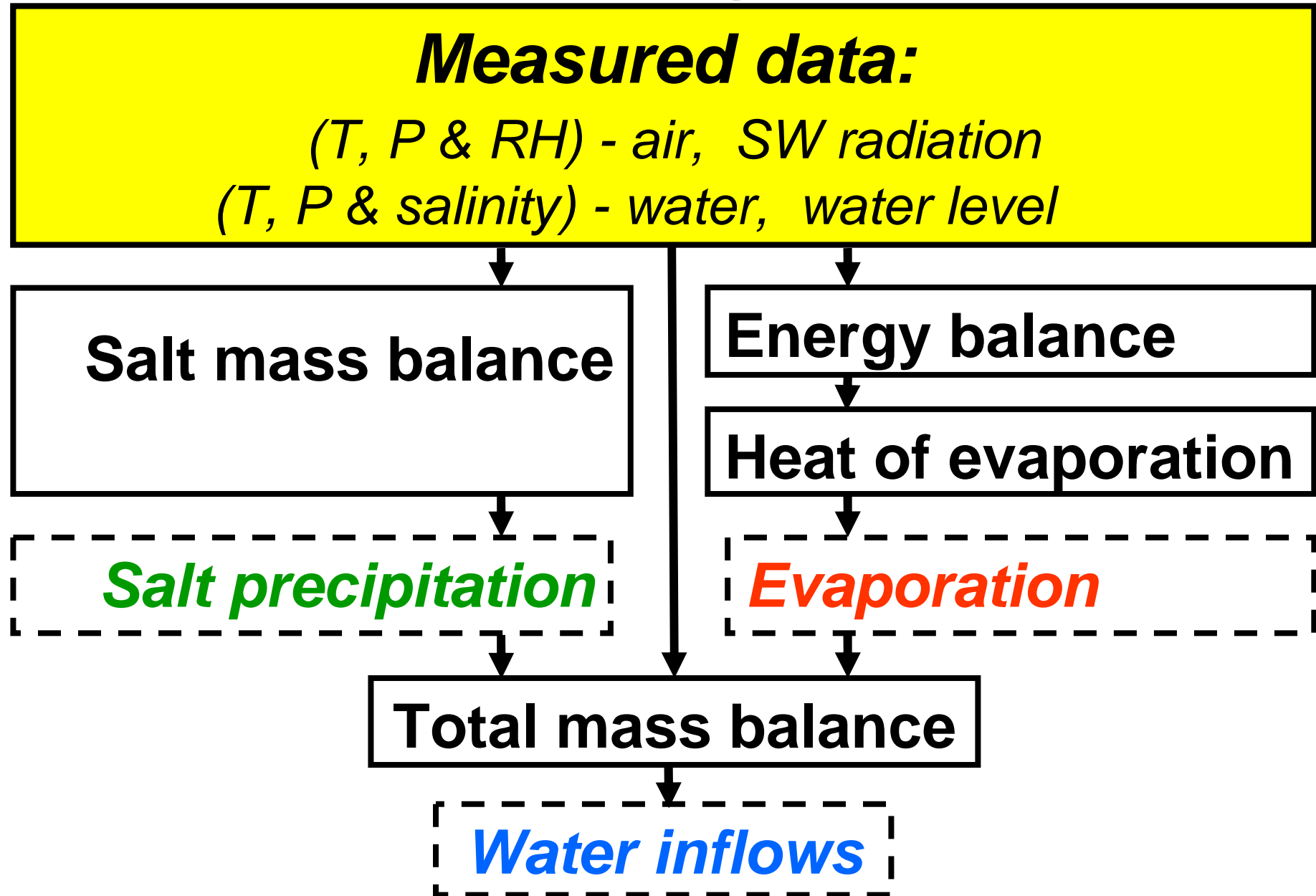
Heat of evaporation

Salt precipitation

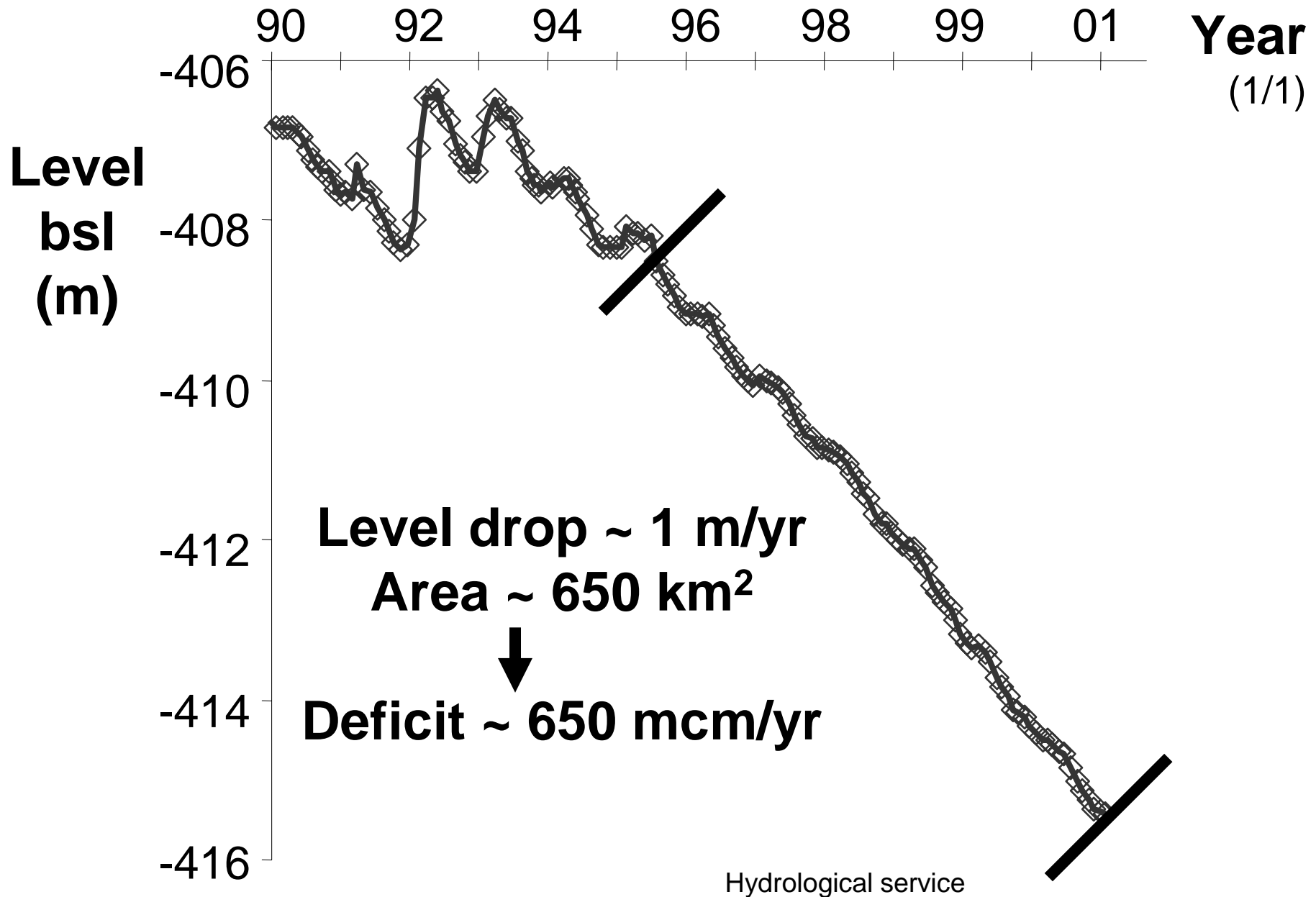
Evaporation

Total mass balance

Water inflows



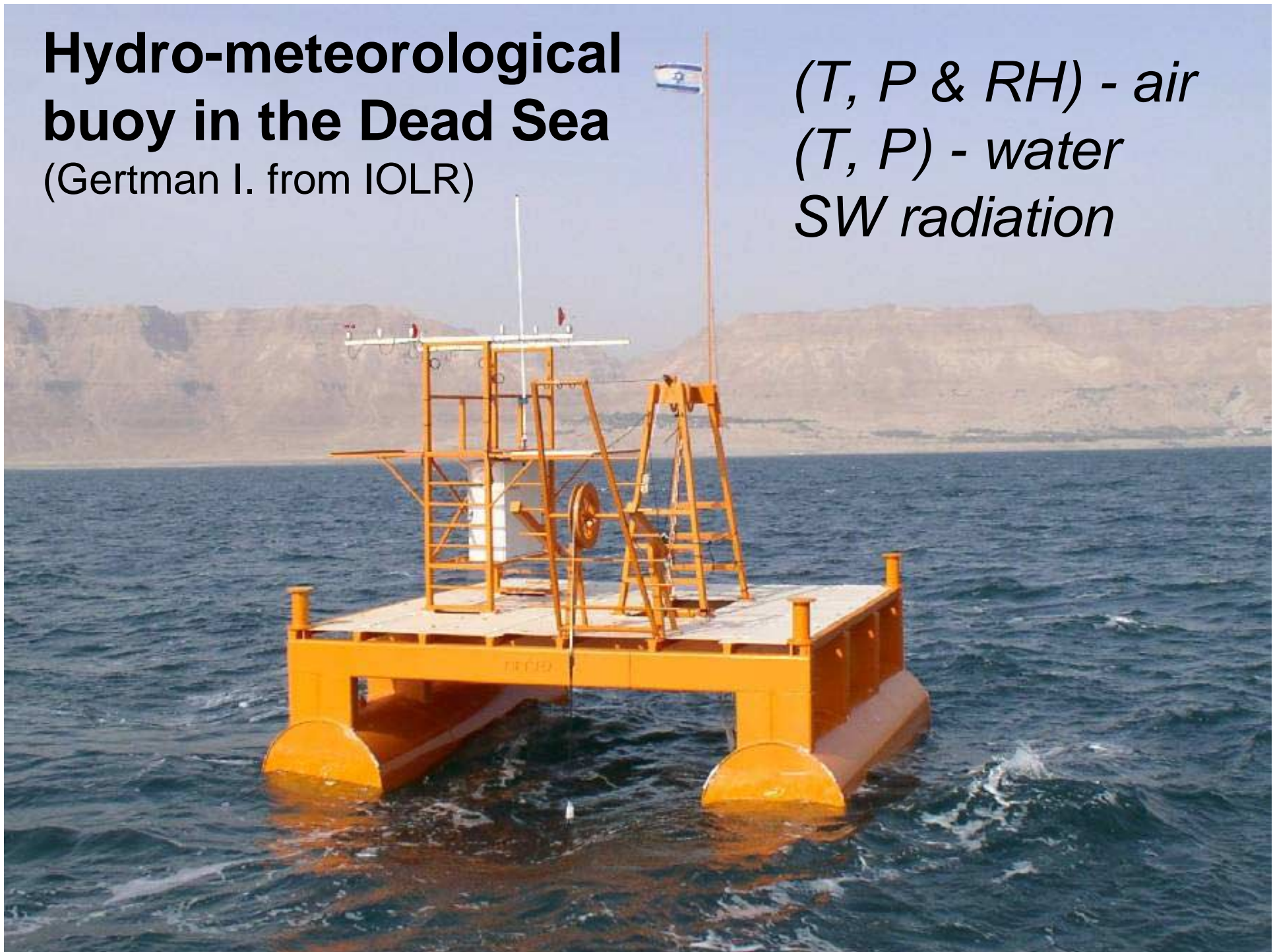
Dead Sea Level (1990-2001)



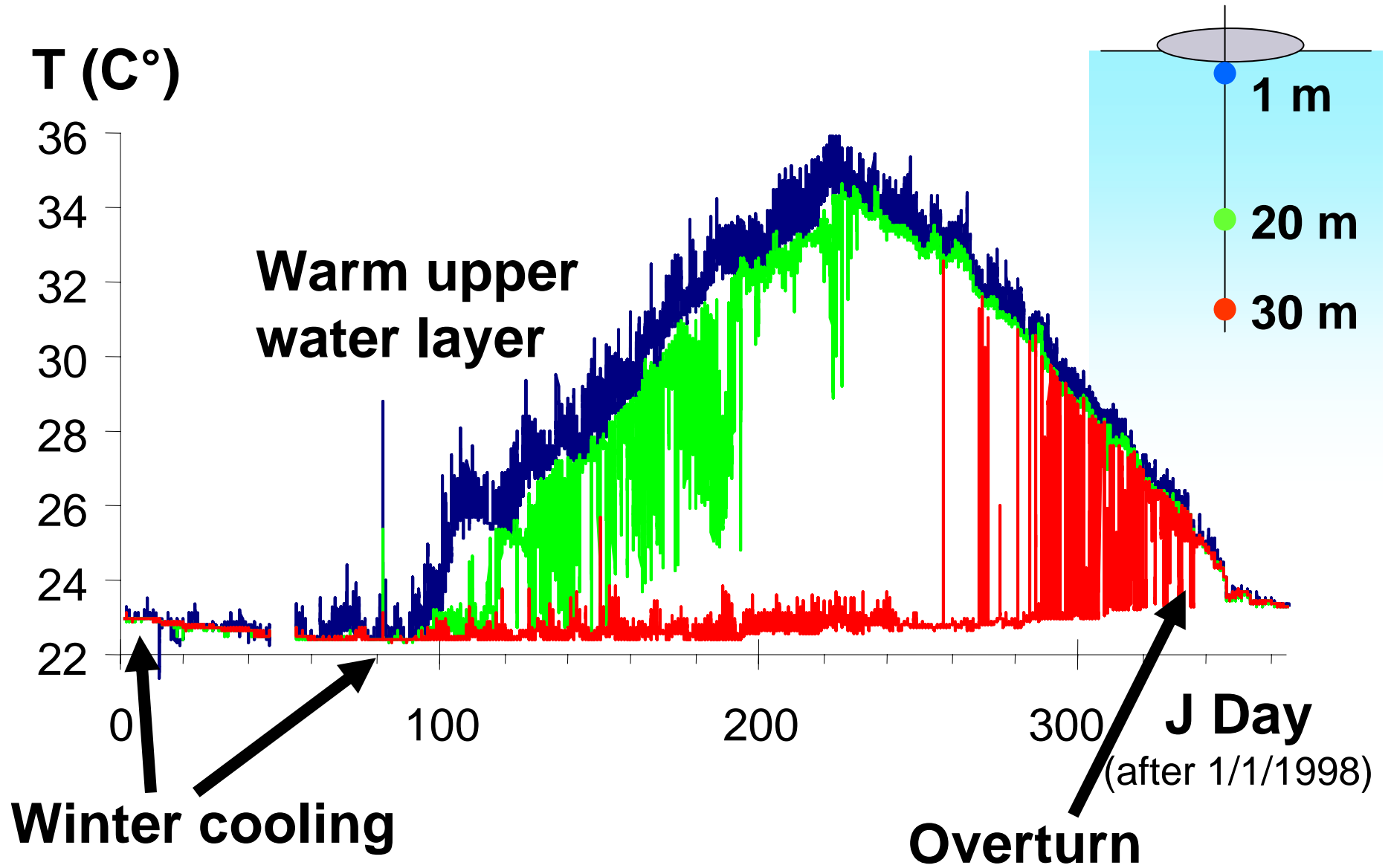
Hydro-meteorological buoy in the Dead Sea

(Gertman I. from IOLR)

(T, P & RH) - air
(T, P) - water
SW radiation



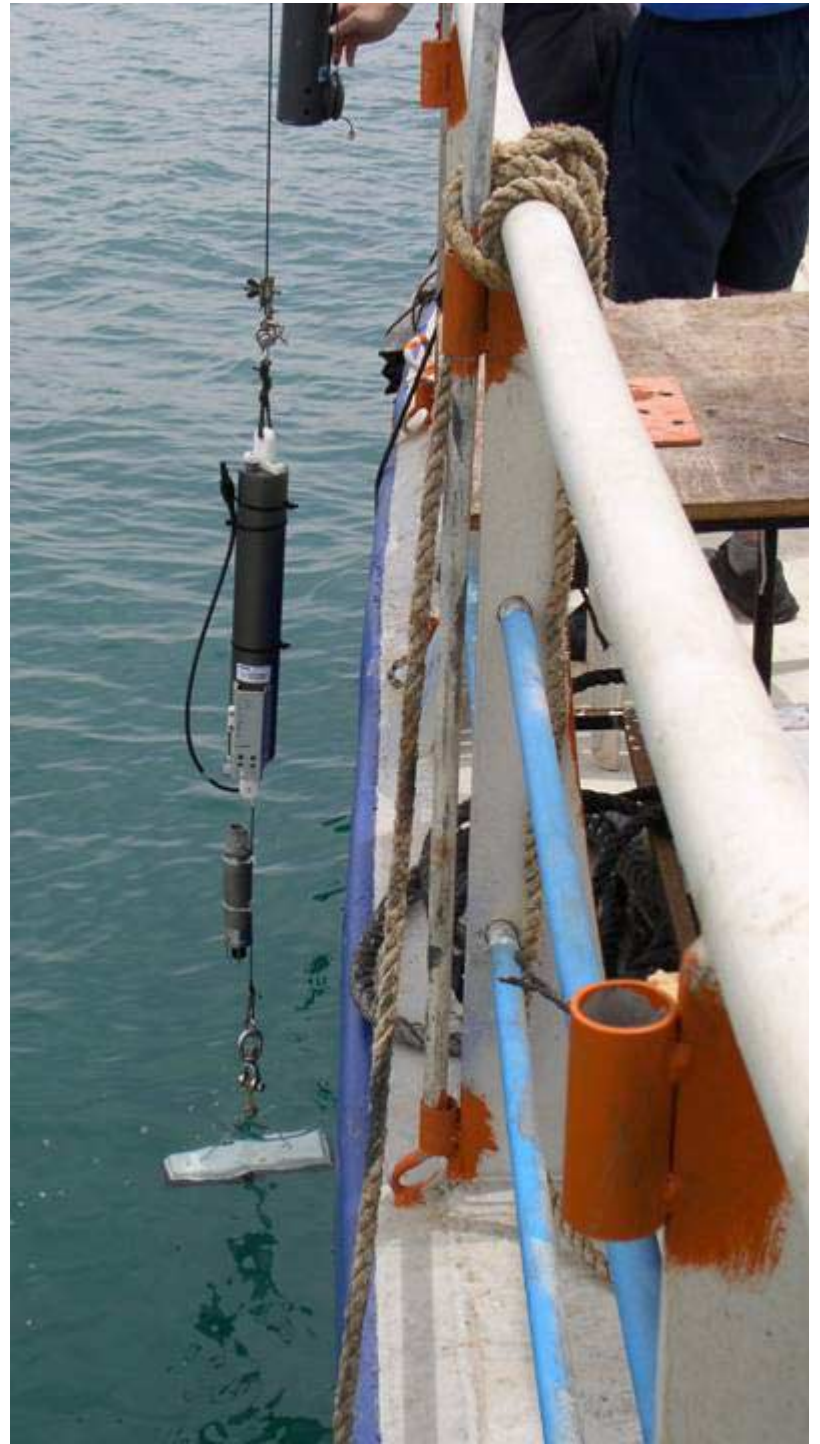
Water temperature at different depths



Hydrographical profiles (T , salinity, ρ)

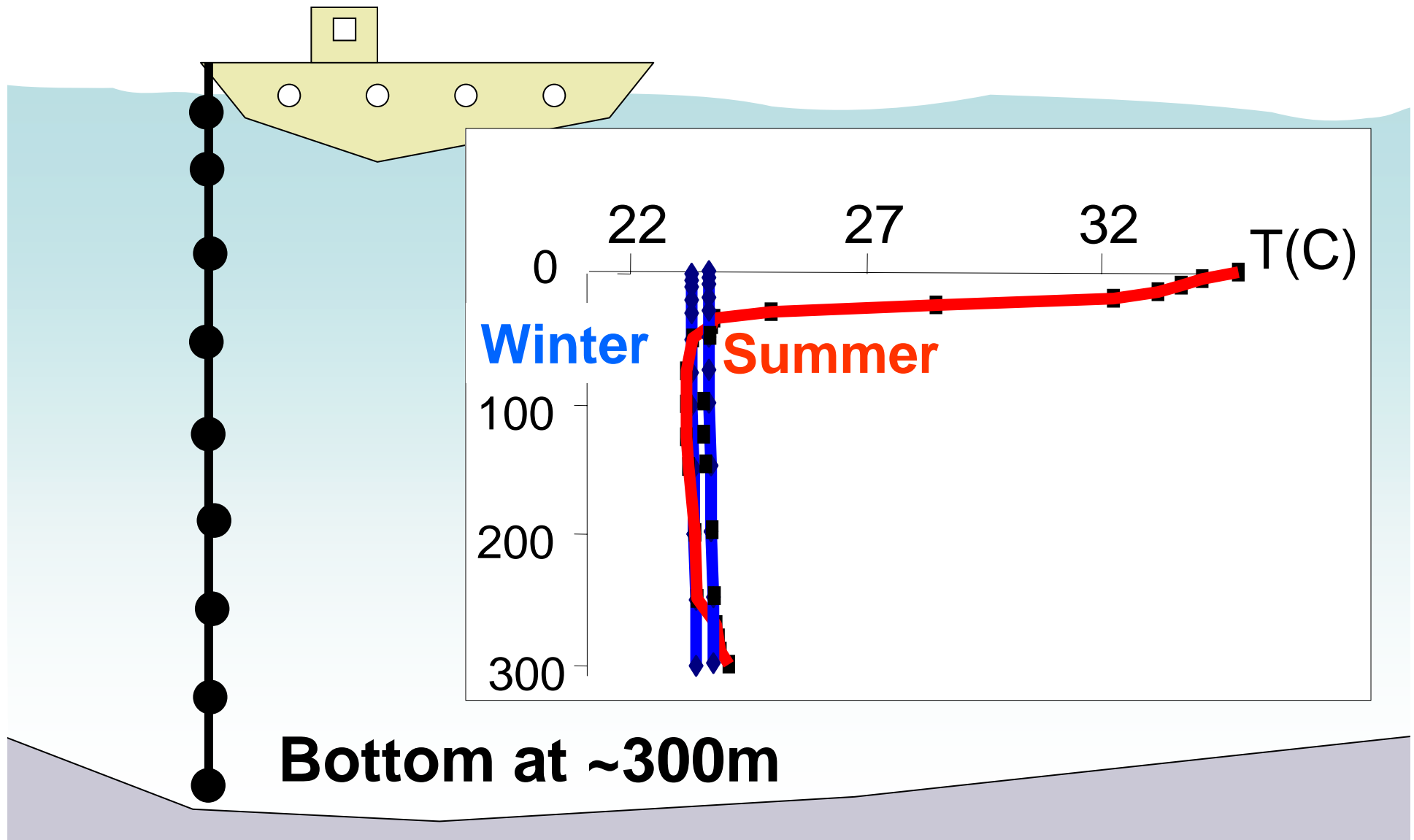
Every 2 months



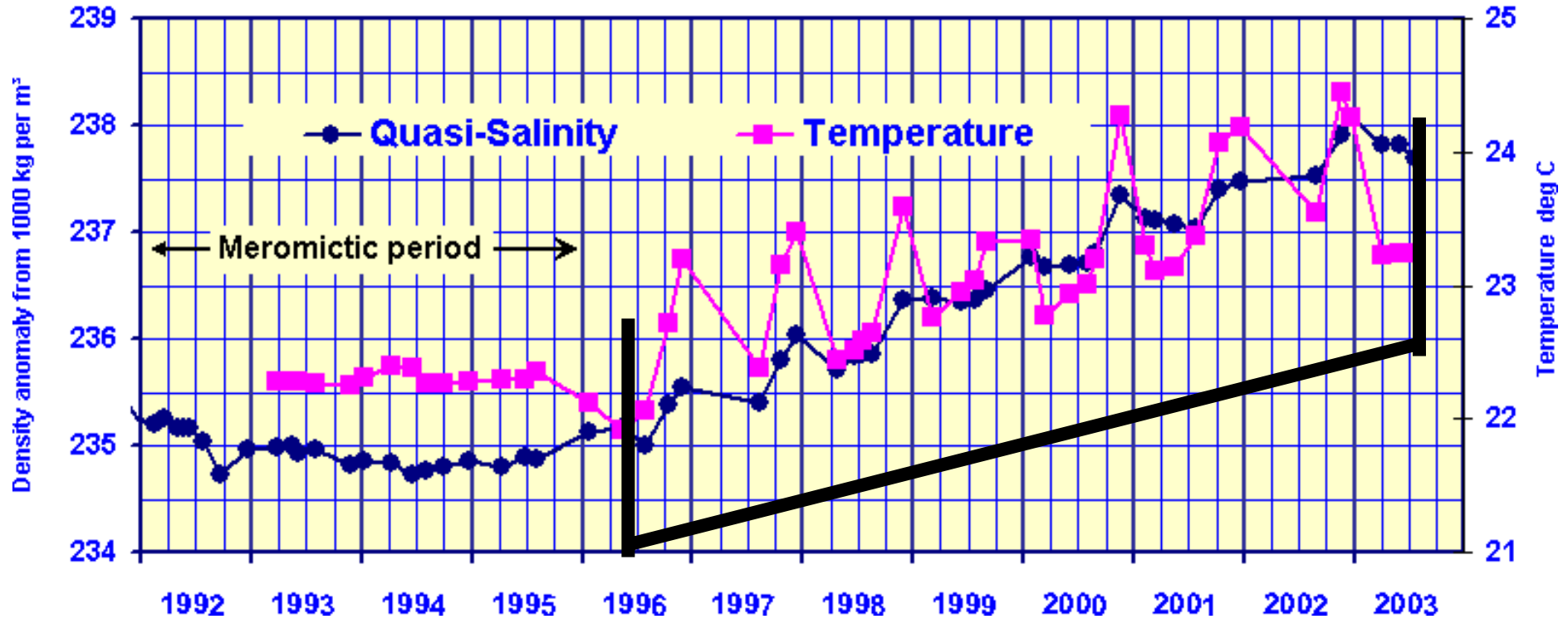


Hydrographical profiles (T , salinity, ρ)

Every 2 months



**Averaged Quasi-Salinity (Sigma 25) and Temperature
of the Dead Sea Deep Water Body
(below 100m)**



Measured annual changes:

Surface level drop ~ 1 m / yr

Temperature increase ~ 0.2-0.3 °C / yr

Salinity increase ~ 0.3 g/kg / yr

Mass and Energy Balances

✓ **Measured data:**

(T, P & RH) - air, SW radiation

(T, P & salinity) - water, water level

Salt mass balance

Energy balance

Heat of evaporation

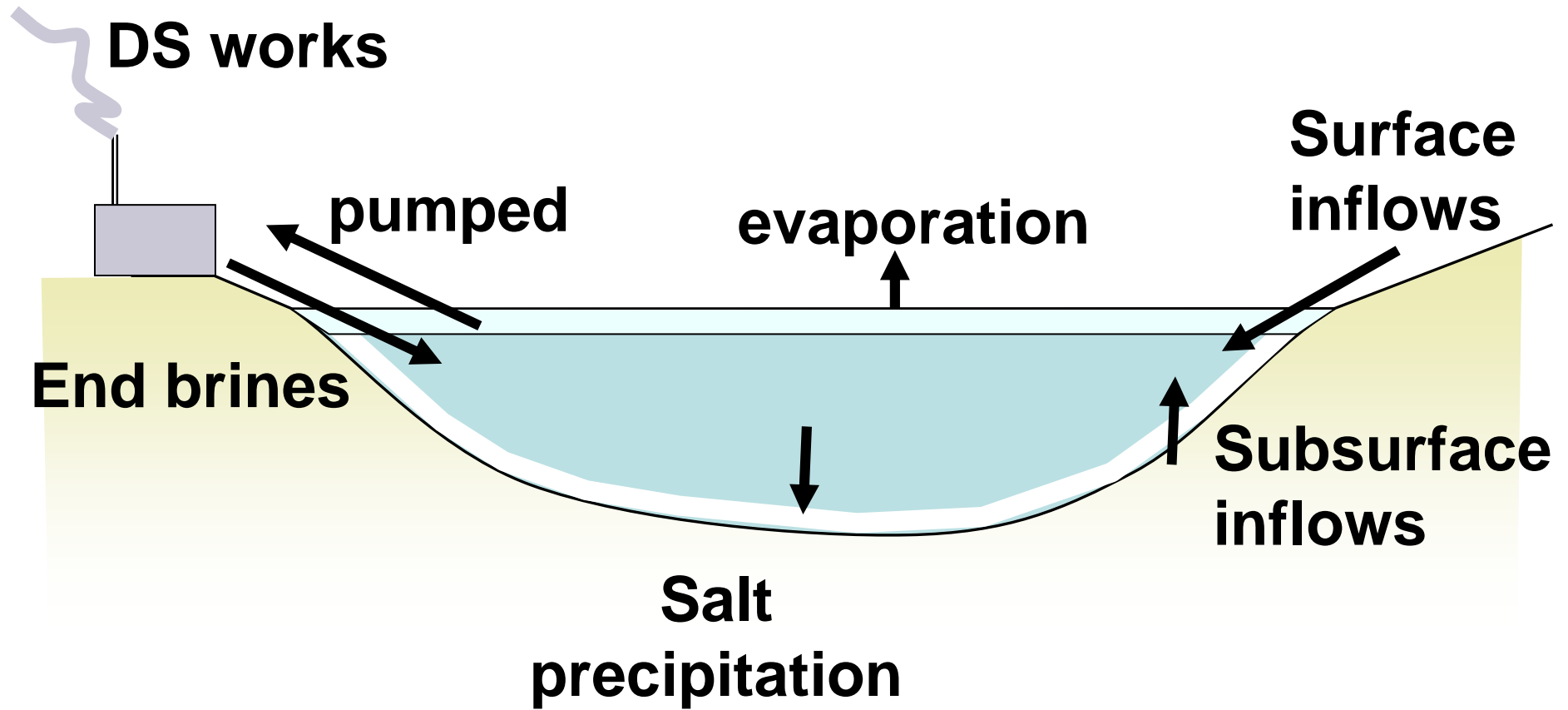
Salt precipitation

Evaporation

Total mass balance

Water inflows

Total mass balance



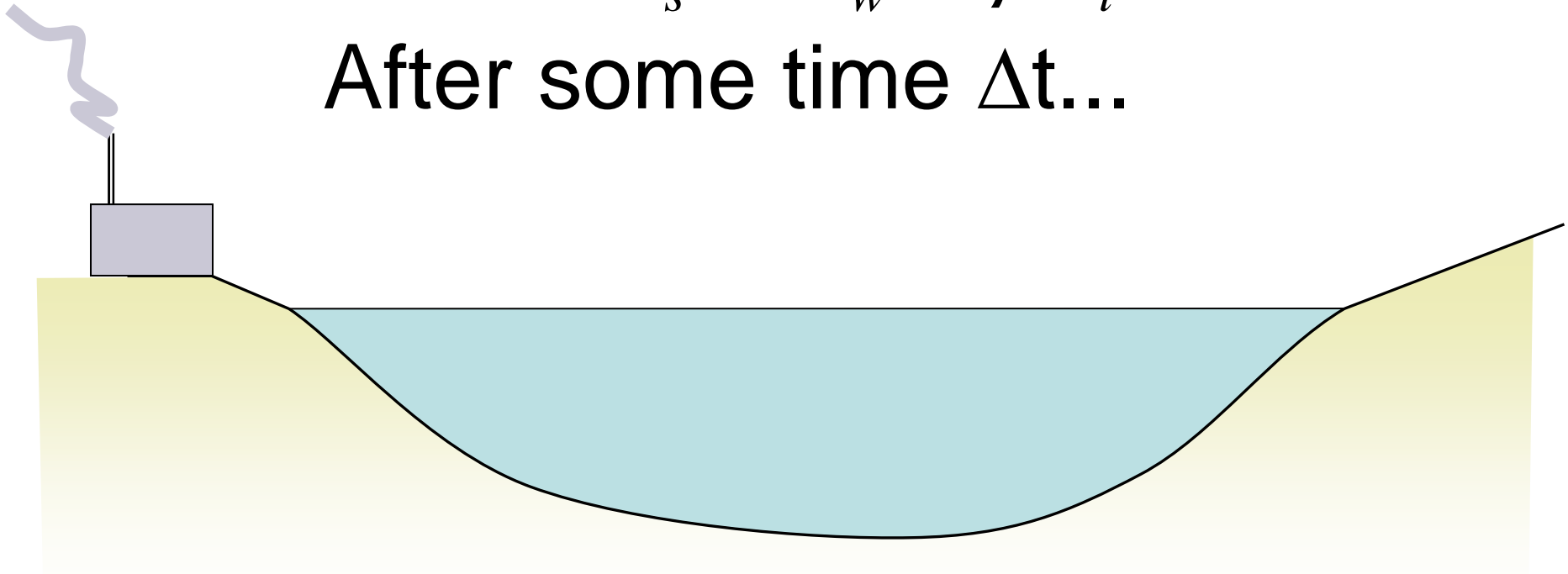
Total mass balance

At a given time:

Mass of water + mass of salts = total mass of brine

$$m_s + m_w = \rho V_t$$

After some time Δt ...



Total mass balance

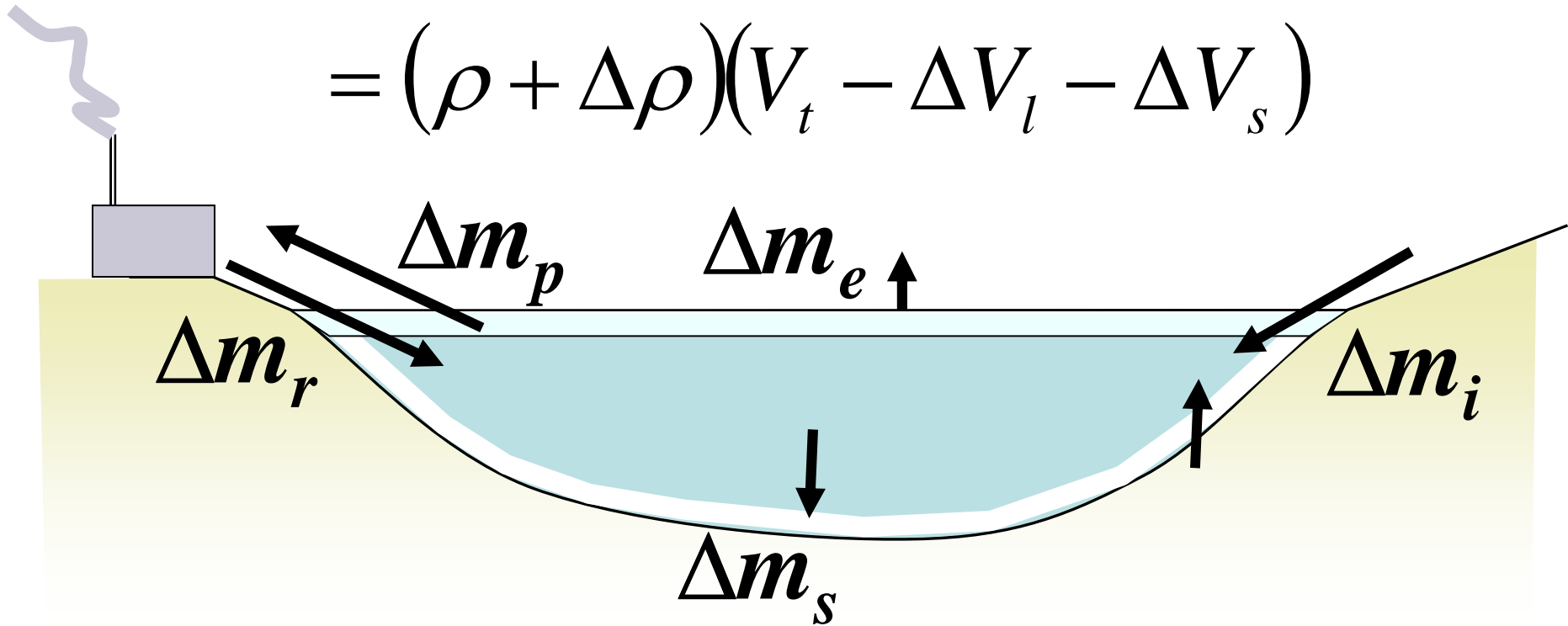
change during Δt in:

Mass - Δm

Volume - ΔV

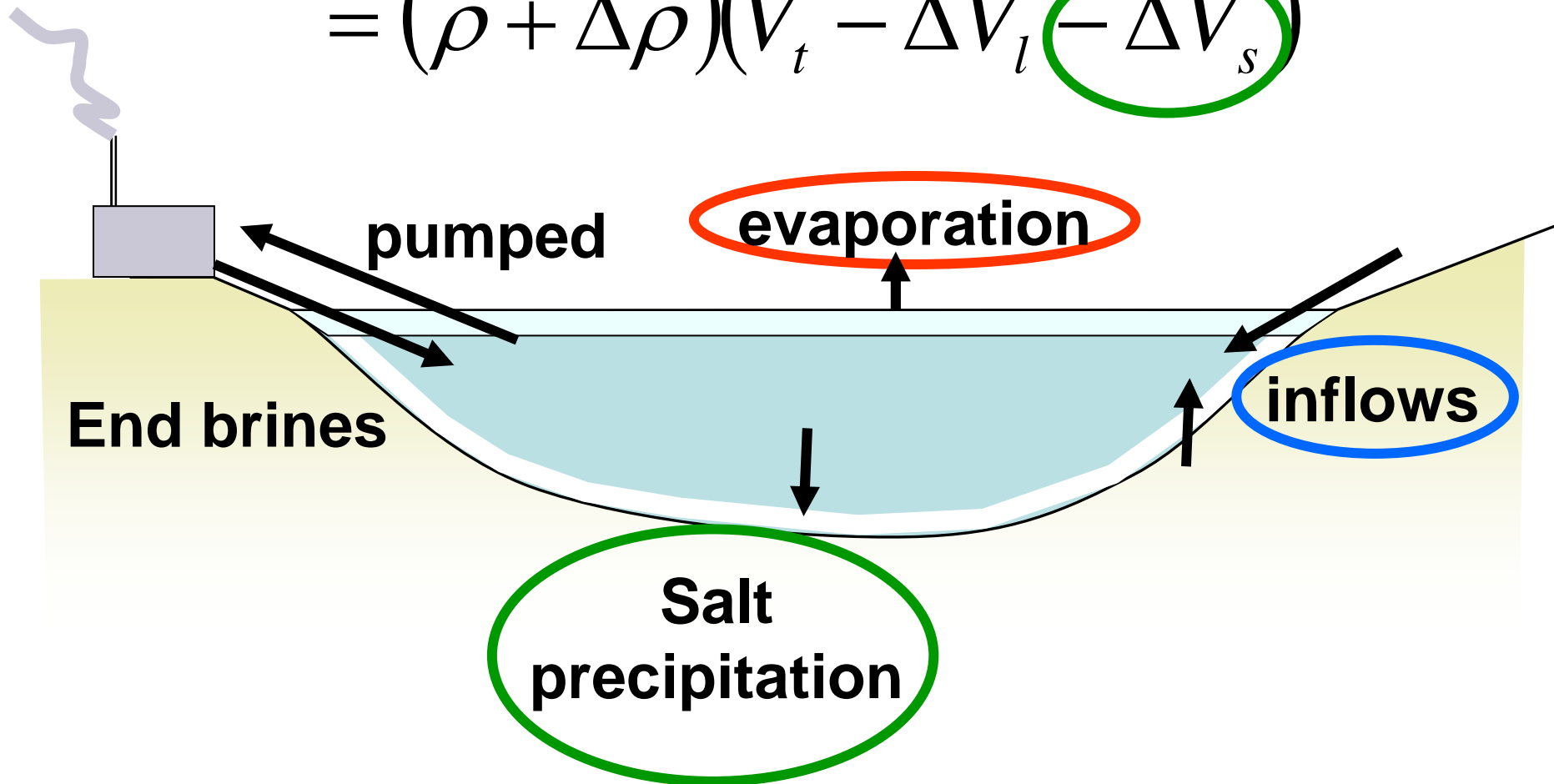
Density - $\Delta \rho$

$$m_s + m_w + \Delta m_i - \Delta m_e - \Delta m_s - \Delta m_p + \Delta m_r =$$
$$= (\rho + \Delta \rho)(V_t - \Delta V_l - \Delta V_s)$$

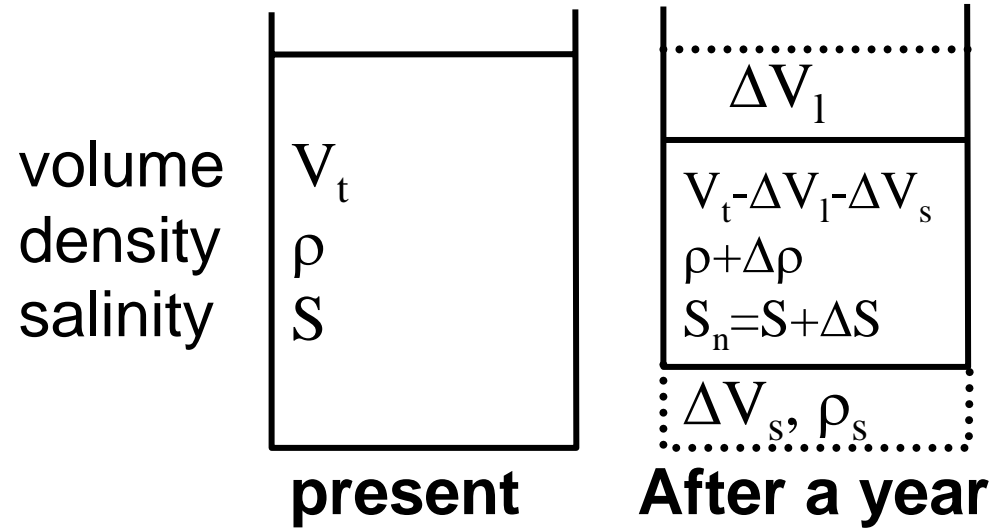


Total mass balance

$$m_s + m_w + \Delta m_i - \Delta m_e - \Delta m_s - \Delta m_p + \Delta m_r =$$
$$= (\rho + \Delta\rho)(V_t - \Delta V_l - \Delta V_s)$$



Salt mass balance



After Δt - a year

$$\Delta V_s = \frac{(S + \Delta S)(\rho \Delta V_l - \Delta \rho V_t) - \Delta S V_t \rho + S_r \rho_r \Delta V_r - S \rho \Delta V_p}{\rho_s - S_n \rho}$$

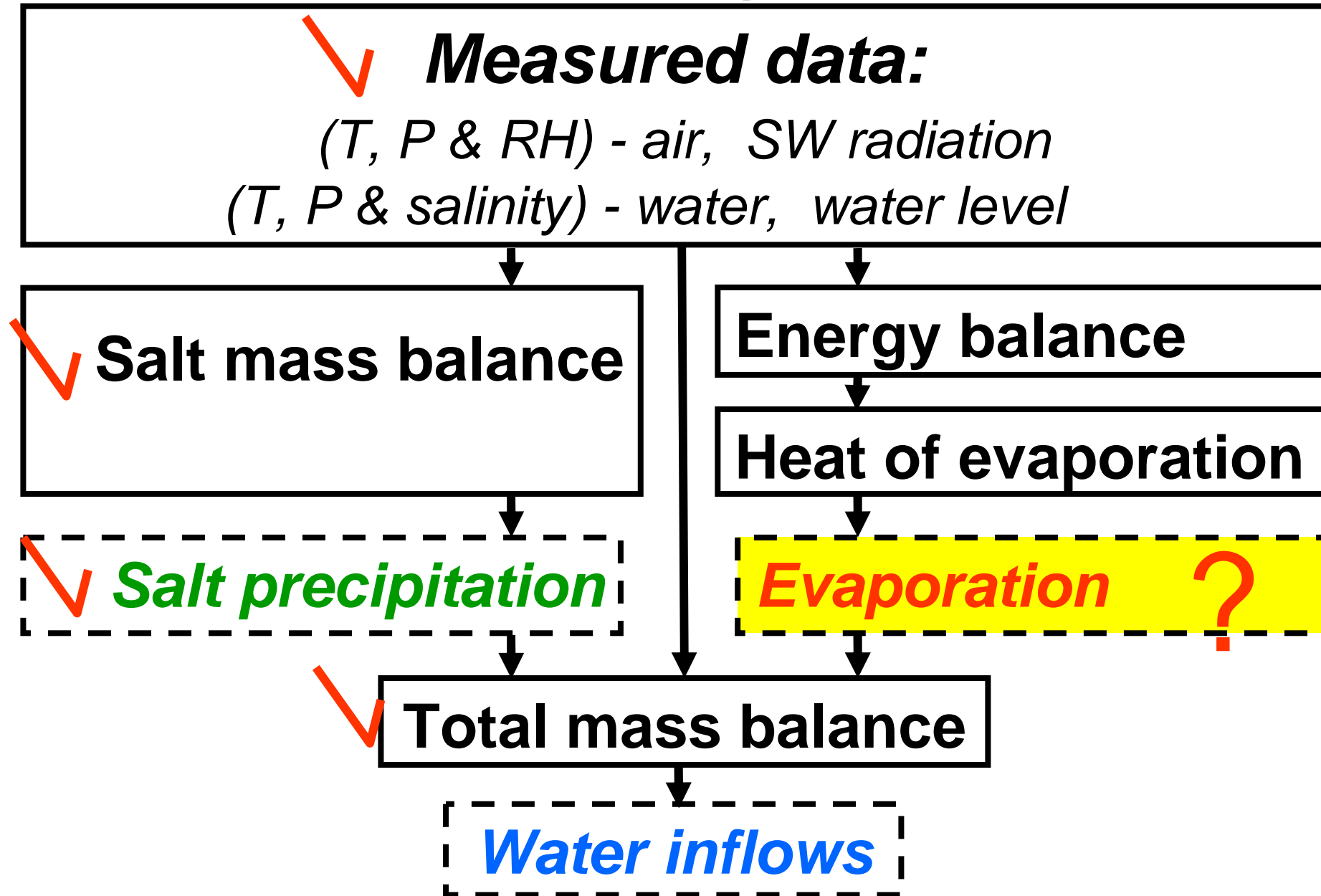
salt
precipitation
~0.1 m/yr

2 unknowns remain:

Freshwater inflows ΔV_i

Evaporation ΔV_e

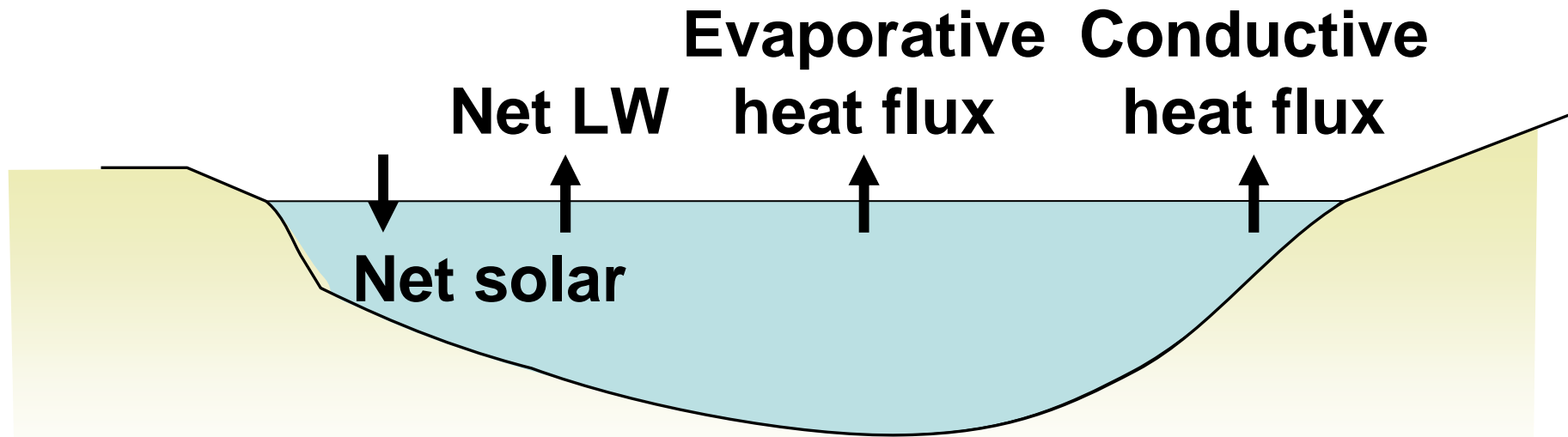
Mass and Energy Balances



Energy balance

Net heat flux

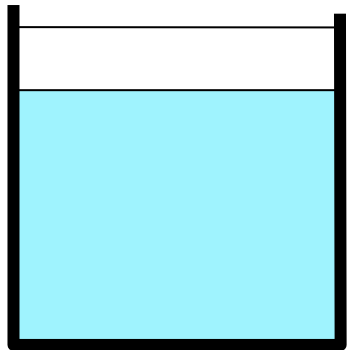
$$Q_n = Q_{SN} - Q_{LW} - Q_e - Q_c$$



Heat of evaporation (Bowen 1926)

$$Q_e = \frac{Q_{SN} - Q_{LW} - Q_n}{1 + c_b (T_s - T_a) / (e_s - e_a)}$$

From heat to rate of evaporation

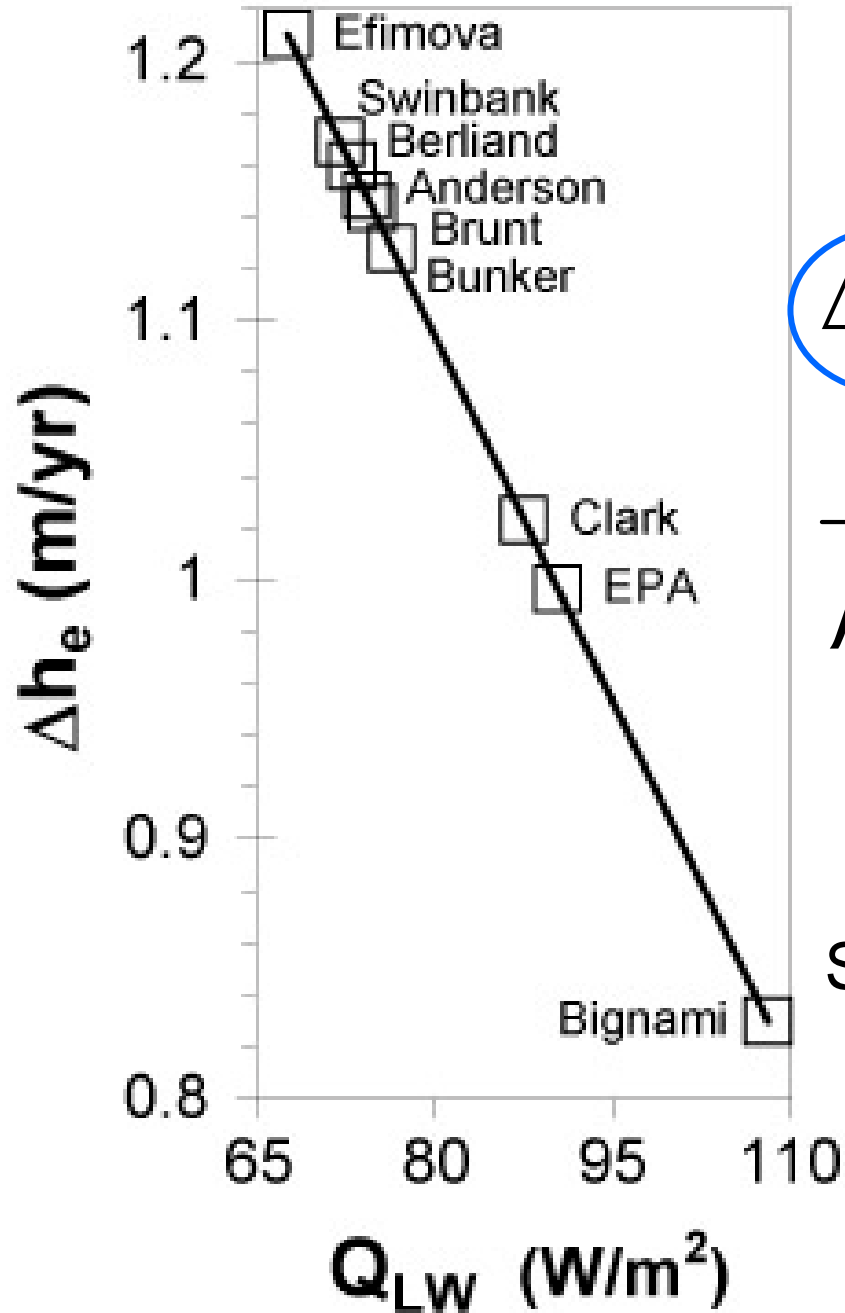


$$\Delta h_e = \frac{\Delta V_e}{A}$$

$$\Delta h_e = \Delta t \frac{Q_e}{\rho L_e}$$

L_e - latent heat

Evaporation rate vs. Q_{LW}

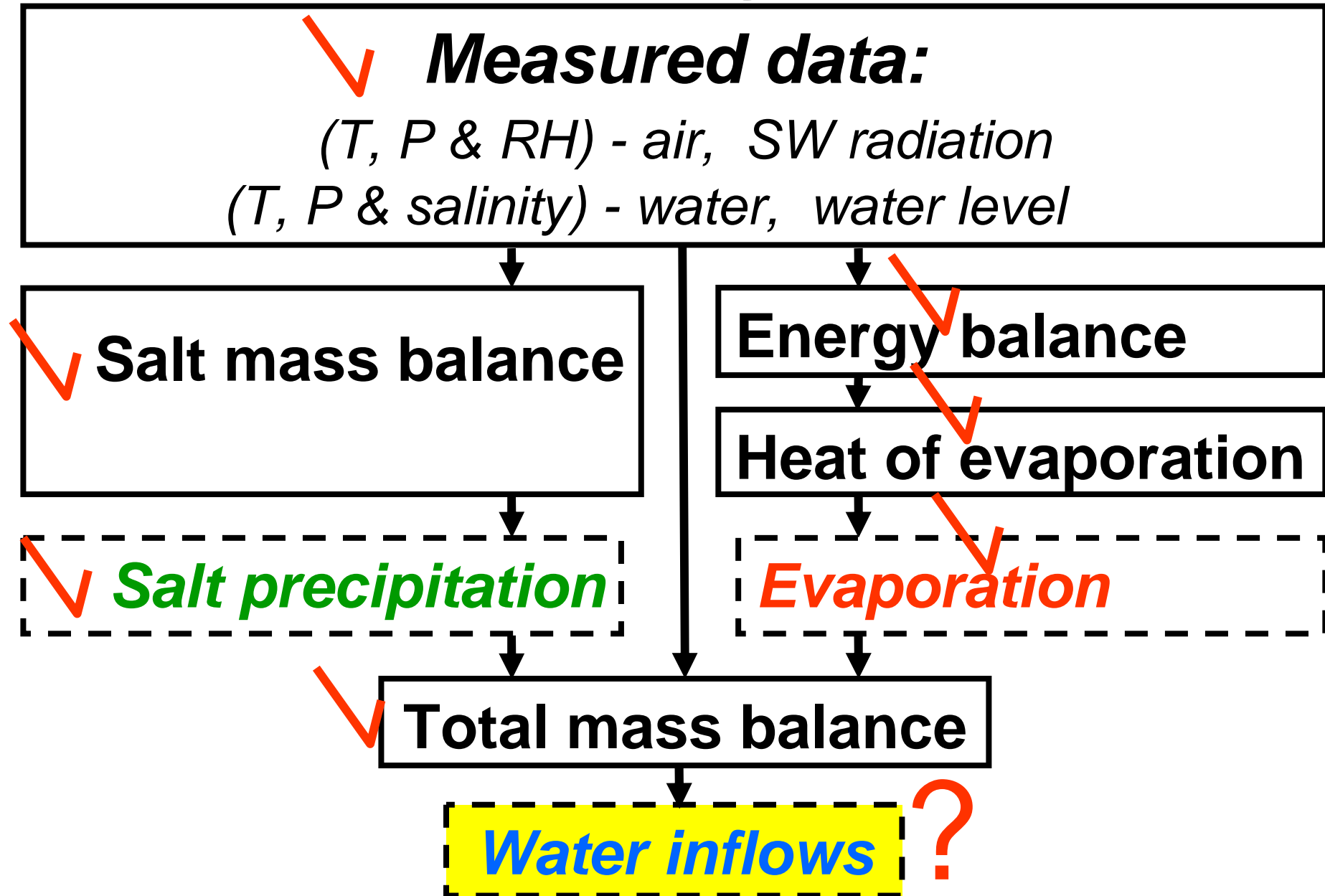


$$\Delta h_e = \frac{\Delta t}{\rho L_e} \frac{Q_{SN} - Q_{LW} - Q_n}{1 + c_b (T_s - T_a) / (e_s - e_a)}$$

Stanhill (1994): **1.05 m/yr**

Salameh & El-Naser (2000): **2 m/yr**

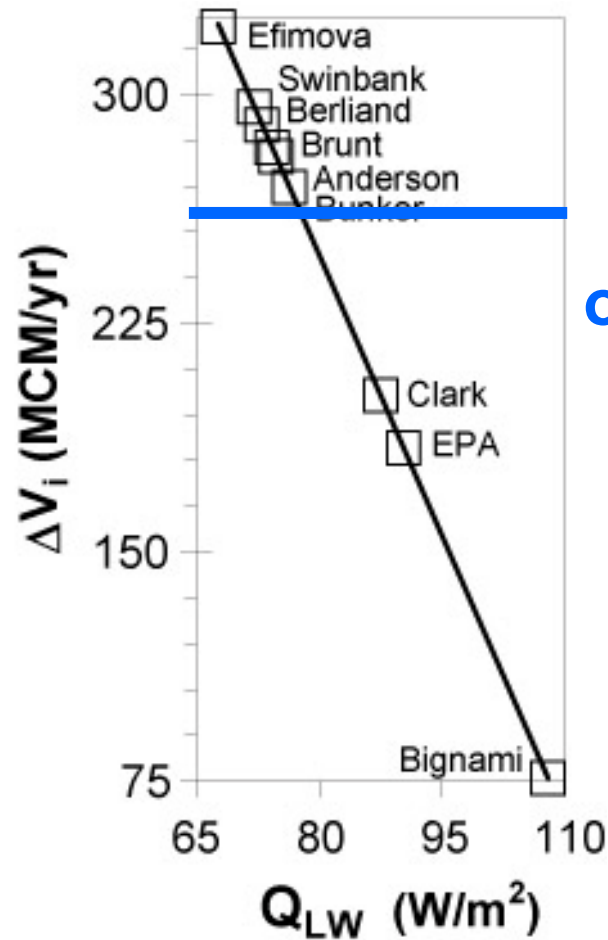
Mass and Energy Balances



Energy and mass balances

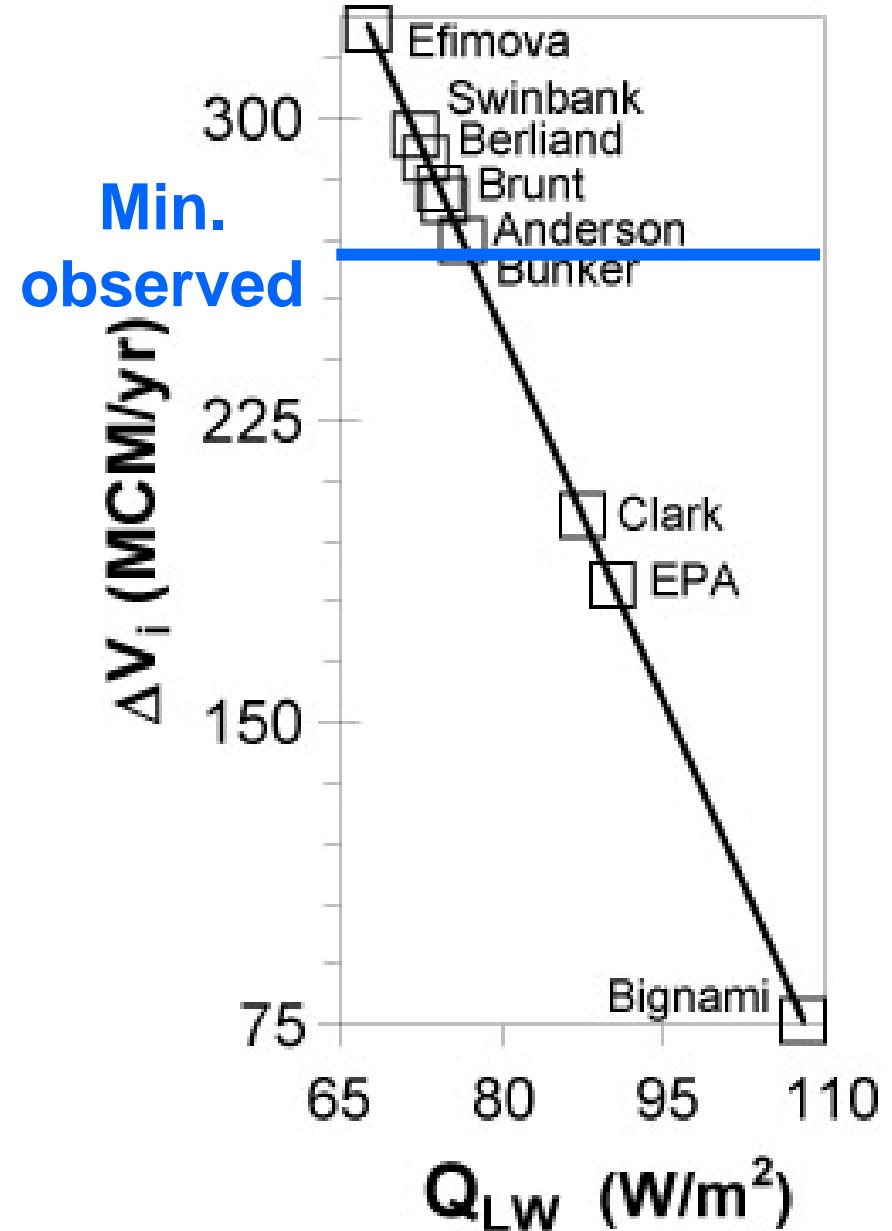
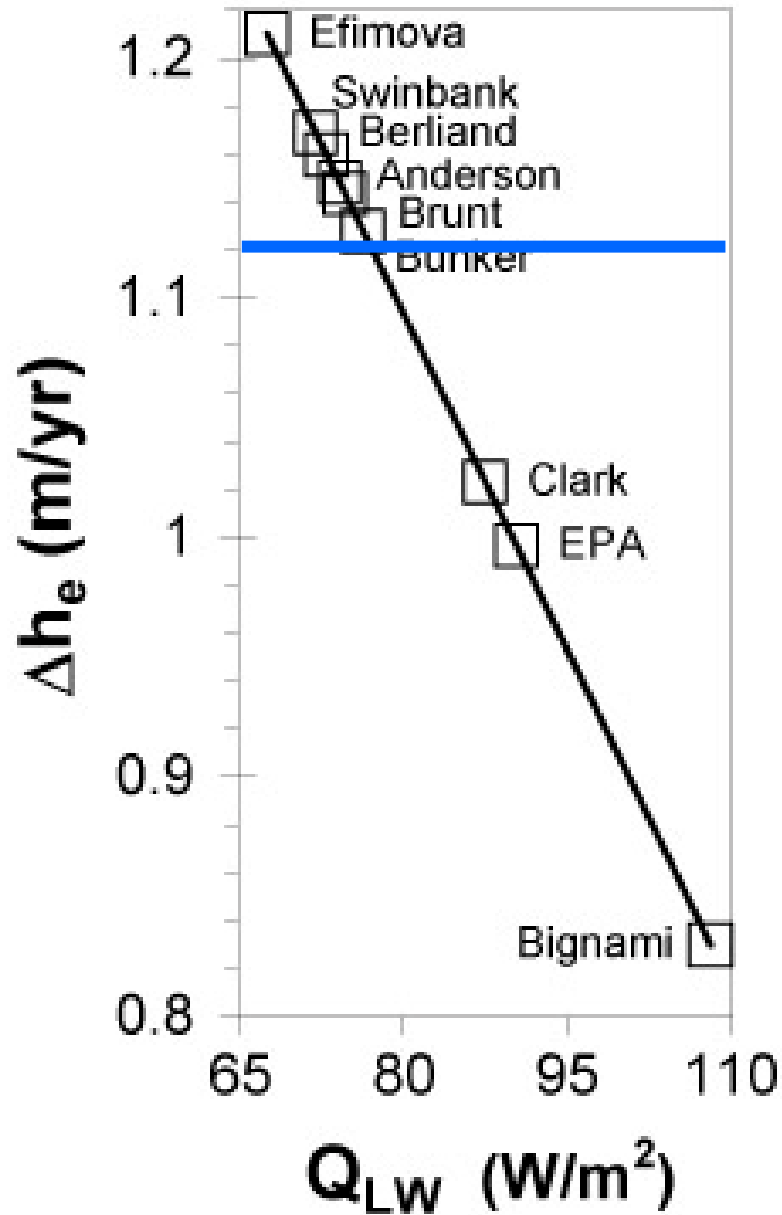
$$\Delta V_i = \Delta t \frac{A}{\rho L_e} \frac{Q_{SN} - Q_{LW} - \rho C_p h_t \Delta T / \Delta t}{1 + c_b (T_s - T_a) / (e_s - e_a)} + X$$

$$X = \frac{\rho_s - \rho}{\rho_w} \Delta V_s - \frac{\rho}{\rho_w} (\Delta V_l - \Delta V_p) + \frac{\Delta \rho}{\rho_w} V_t - \frac{\rho_r}{\rho_w} \Delta V_r$$

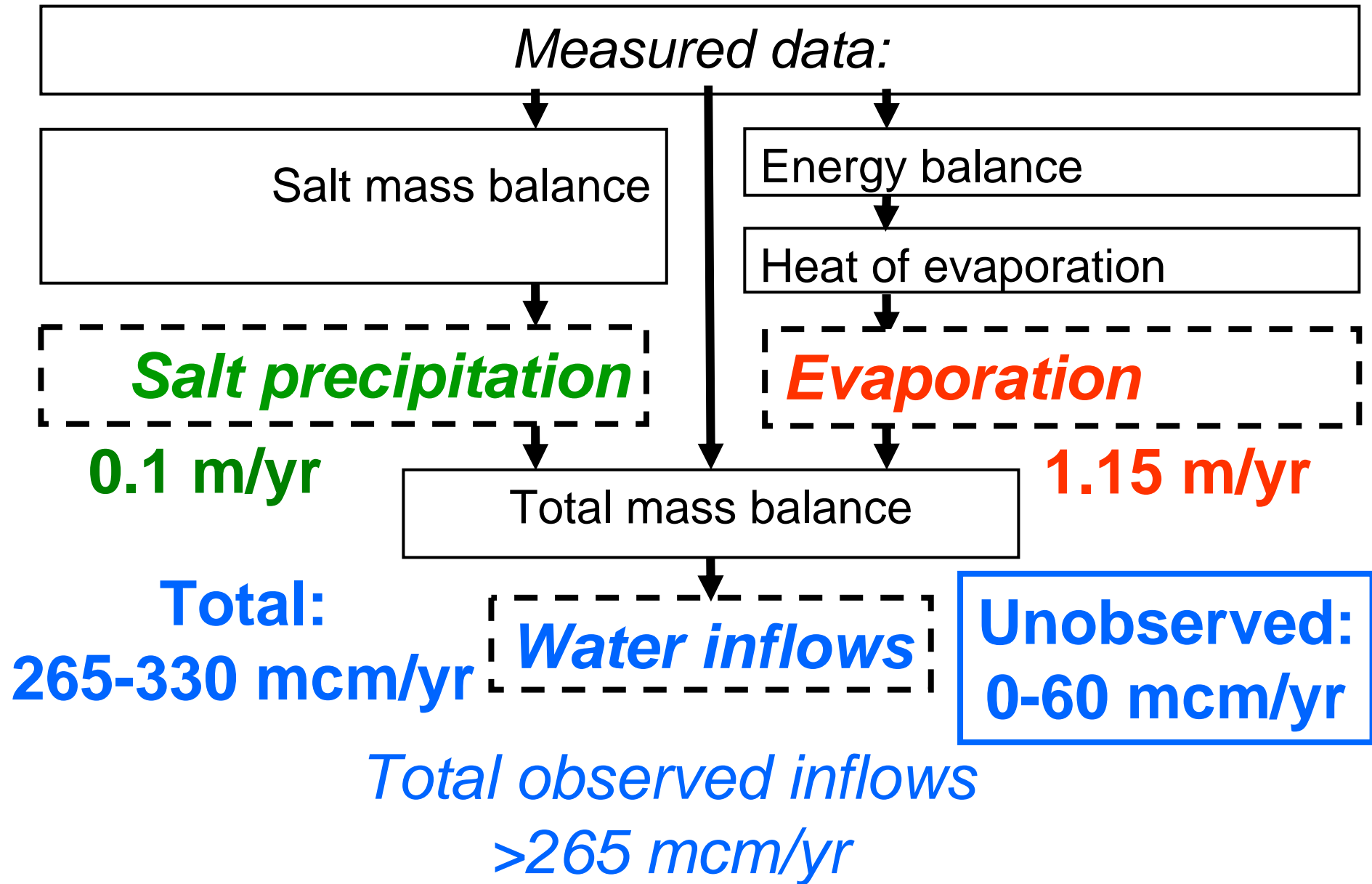


**Min.
observed**

Rate of evaporation and inflows vs. Q_{LW}



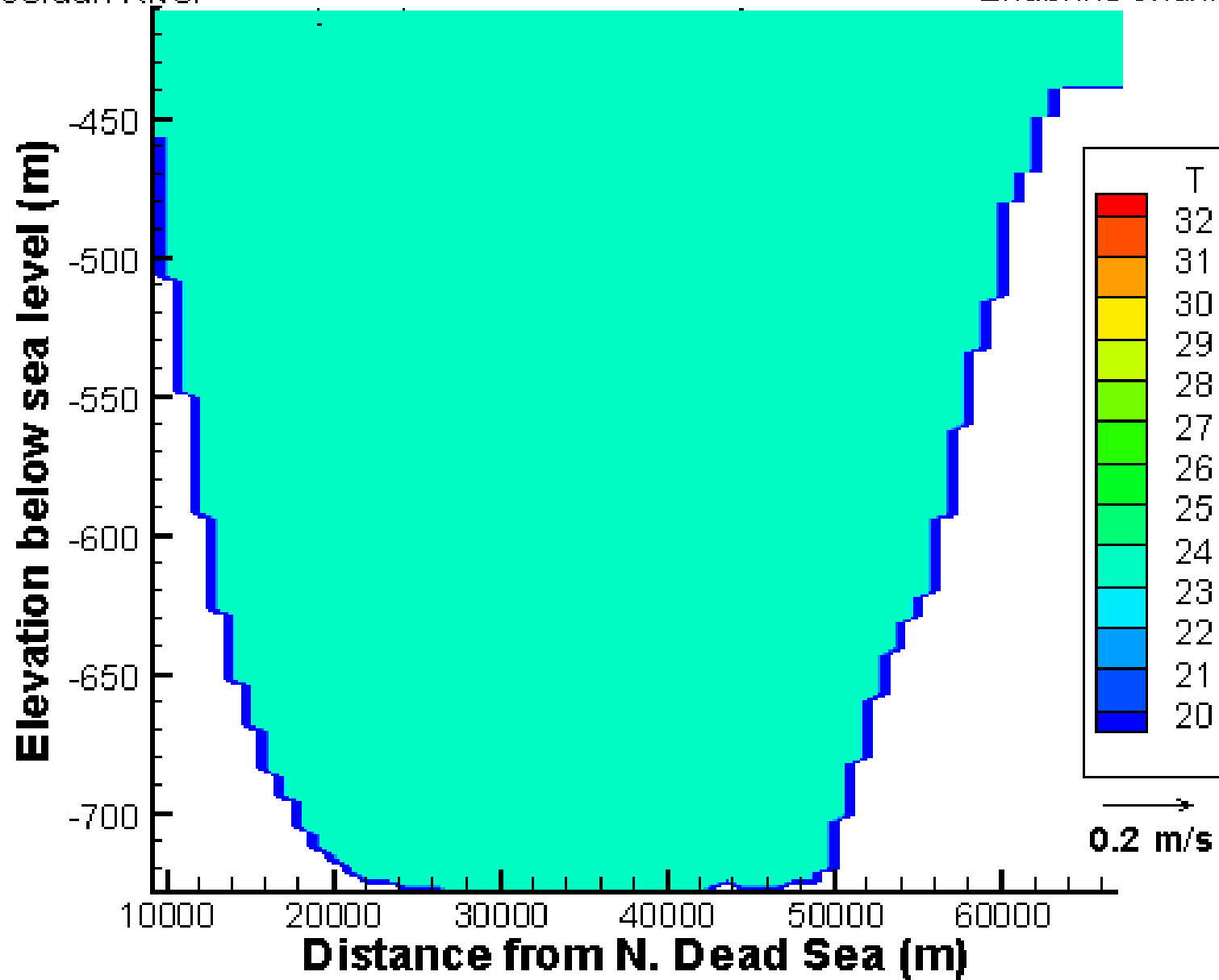
Summary



Dead Sea simulation 1998

North
Jordan River

South
Endbrine channel



Thank you...

