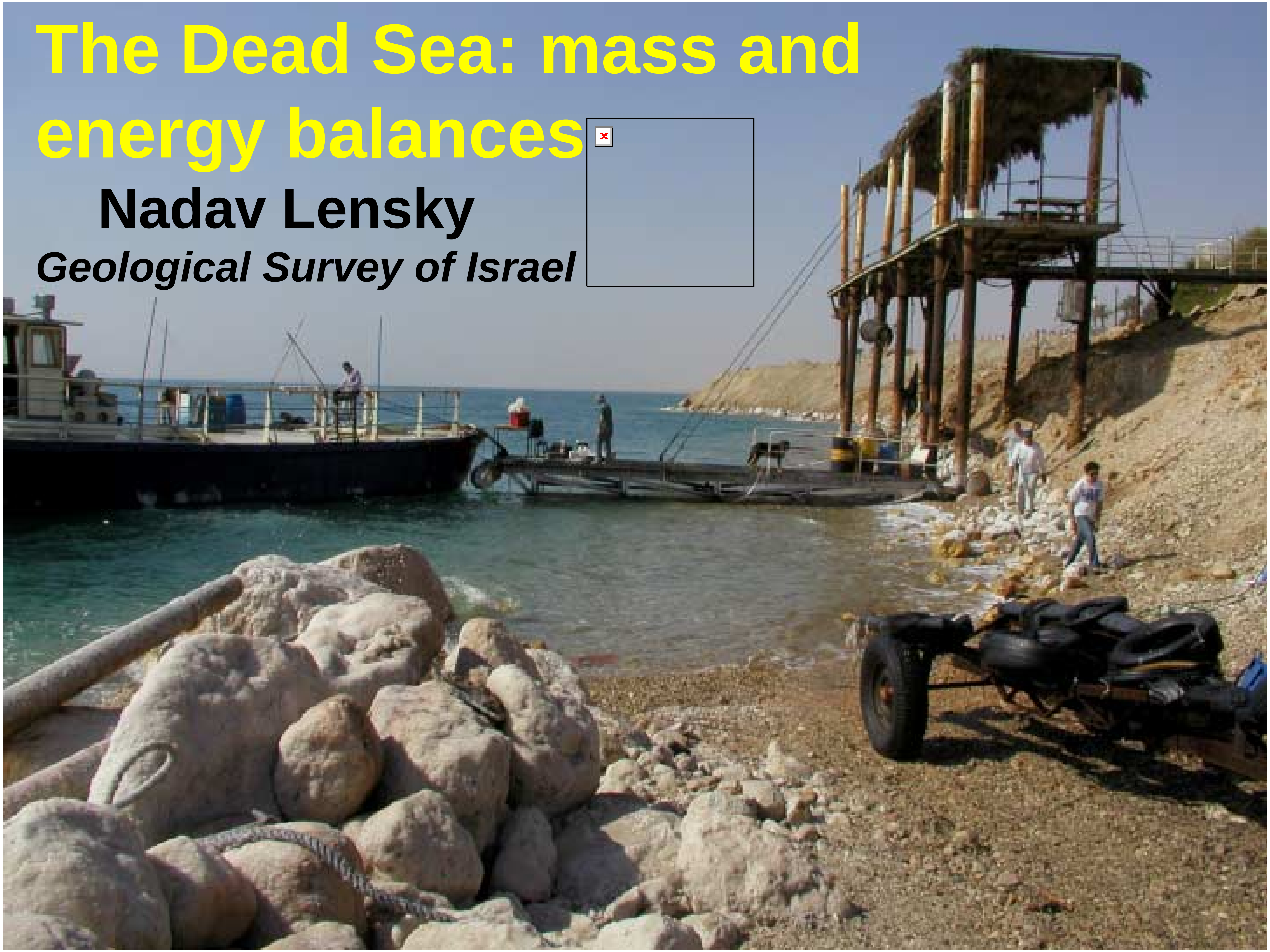
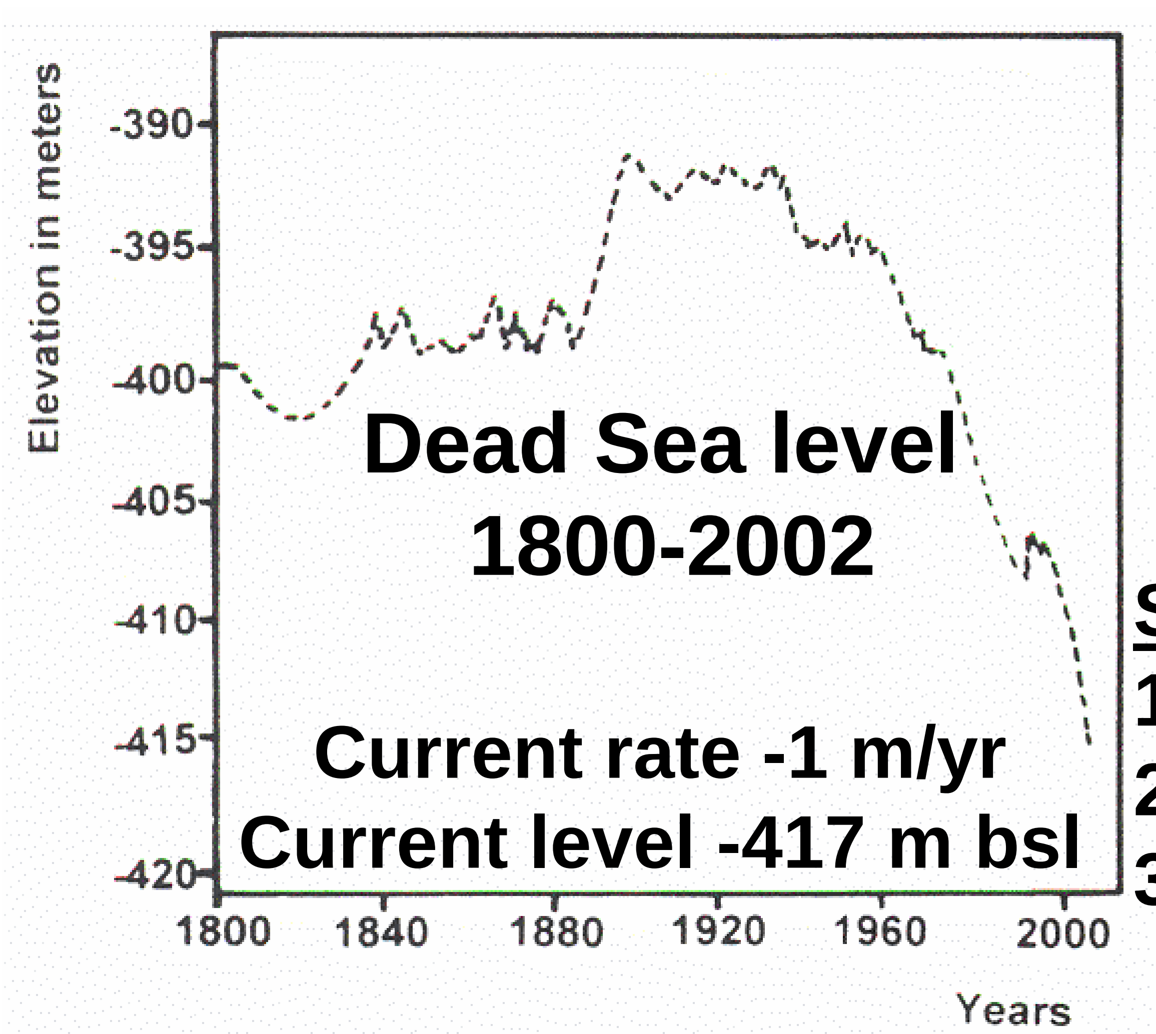
The Dead Sea: mass and energy balances

Nadav Lensky

Geological Survey of Israel





Dead Sea level 1800-2002

Current rate -1 m/yr
Current level -417 m bsl

The DS level drop – severe environmental and ecomnomical consequences

<u>Suggested solutions:</u>

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:

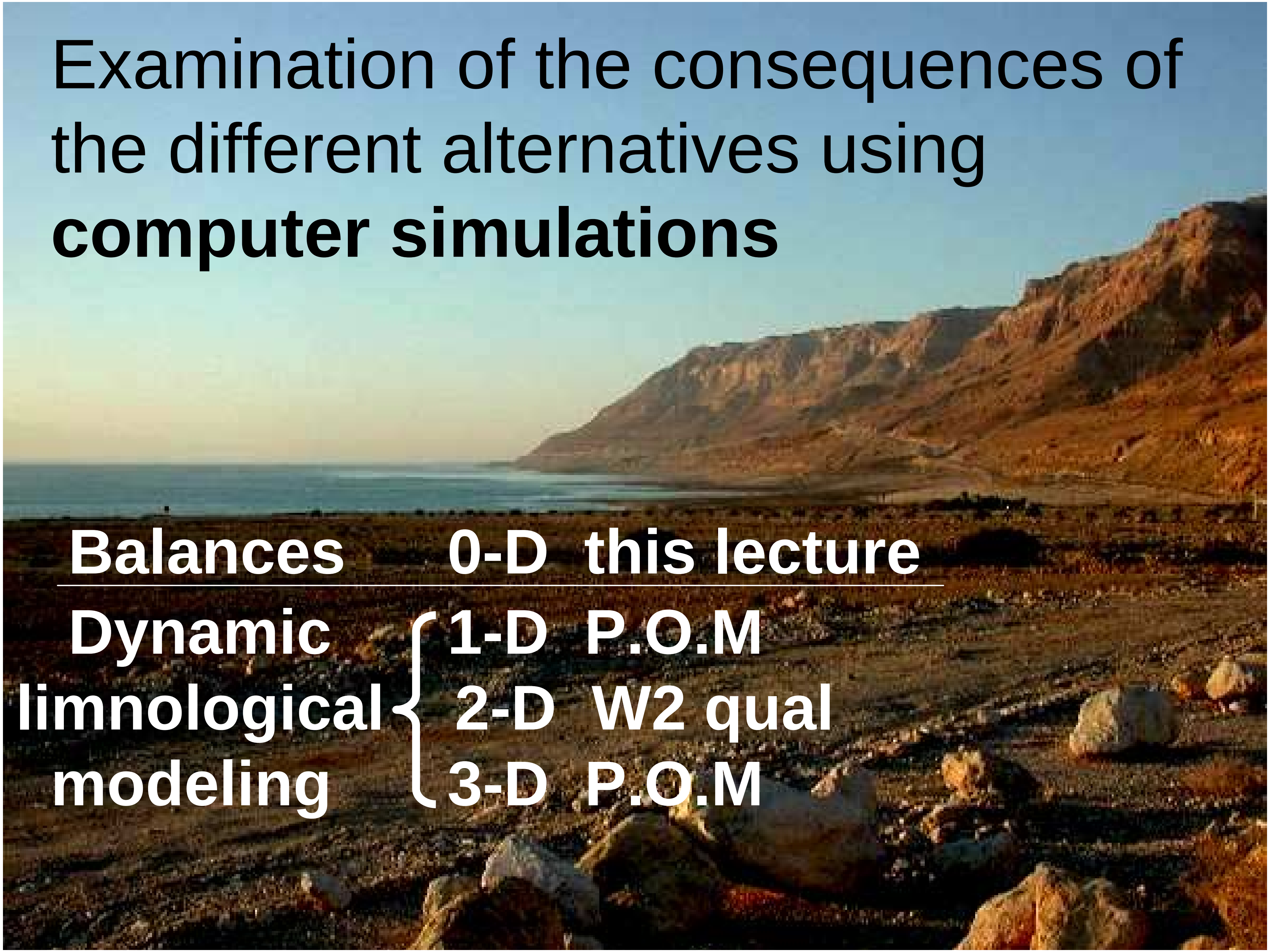
Change of the Dead Sea composition with time

Gypsum precipitation

Dilute upper water layer

Microbial blooming in the upper layer

Reduction conditions in the lower layer

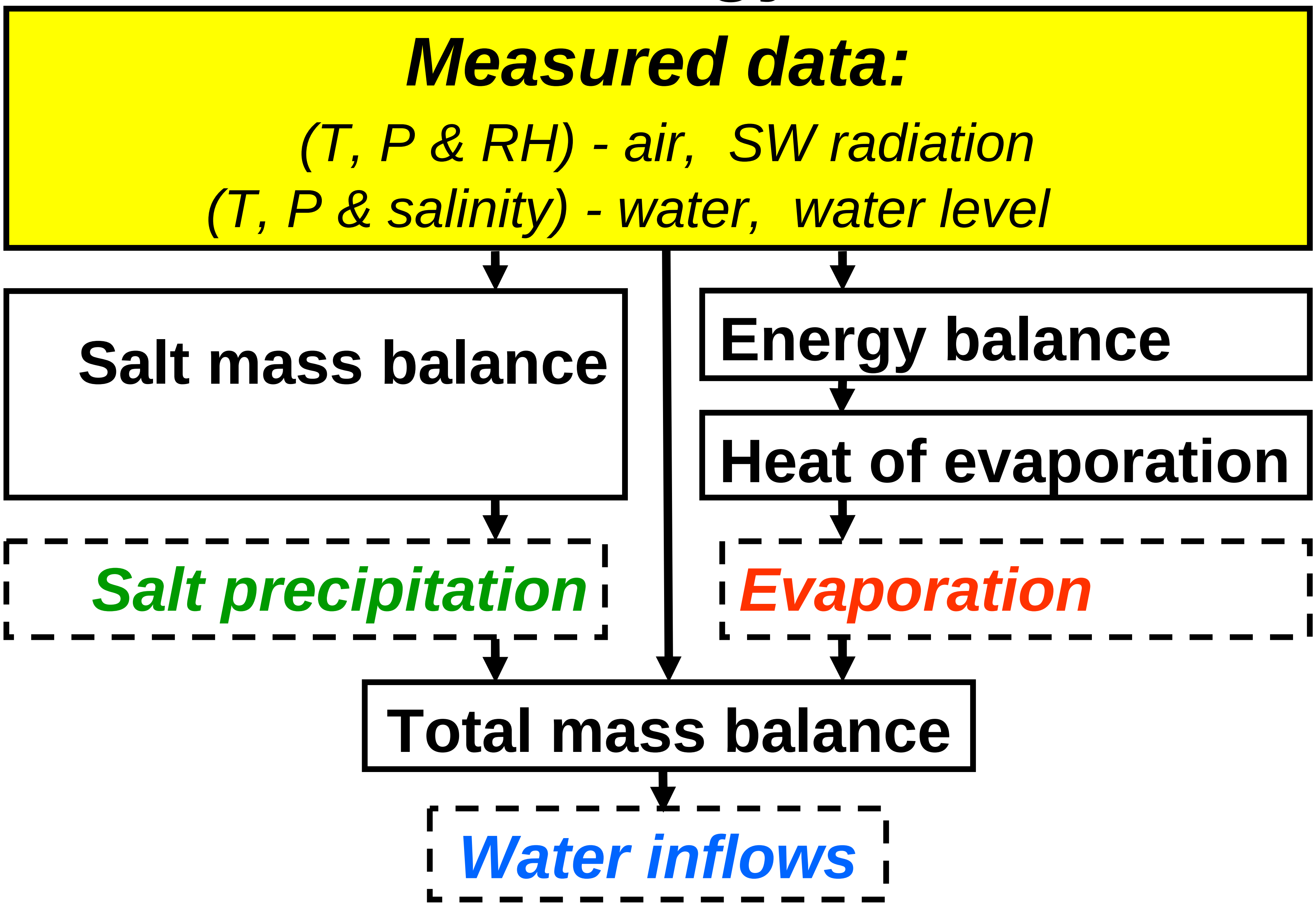


Examination of the consequences of the different alternatives using **computer simulations**

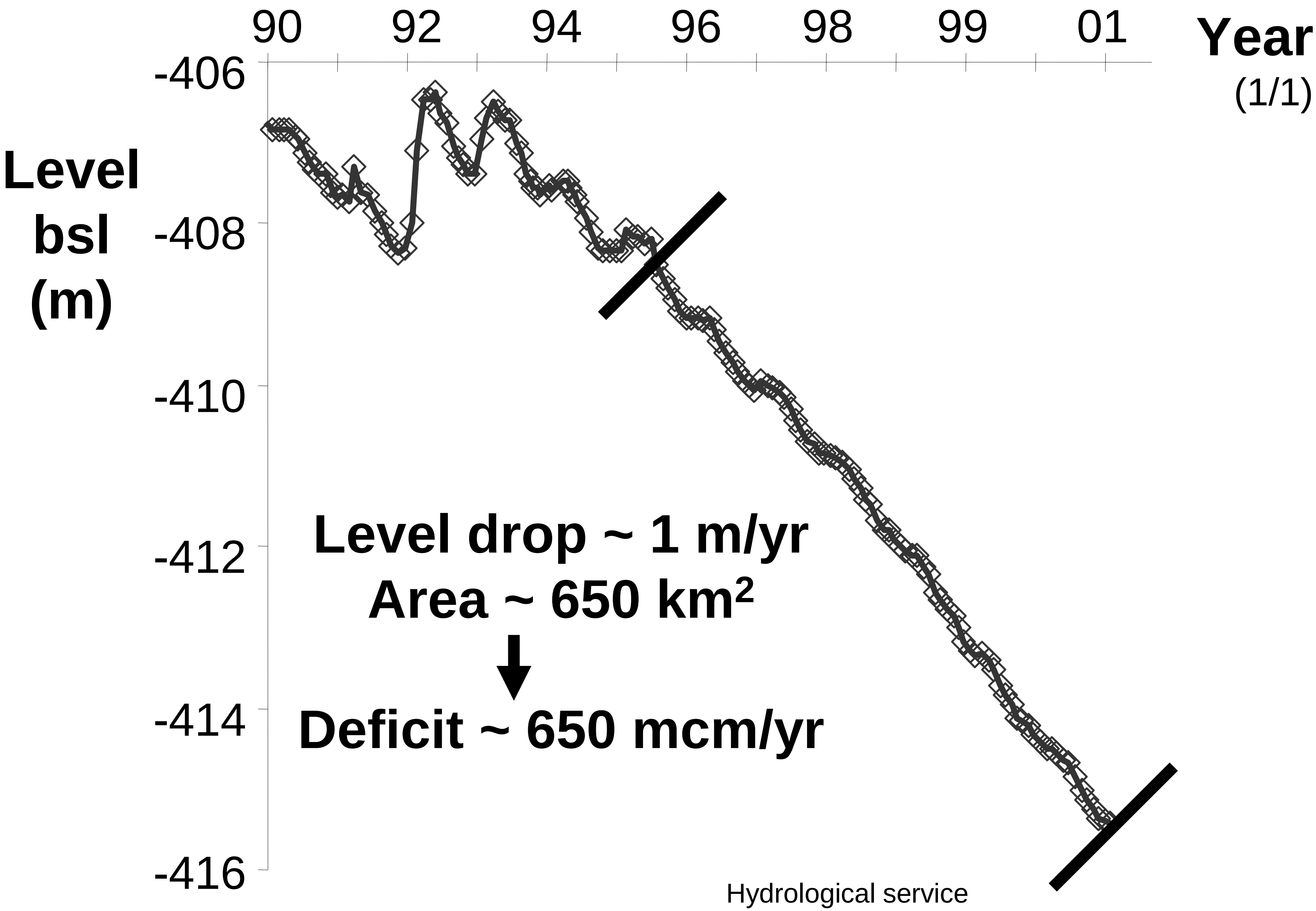
Balances **0-D this lecture**

Dynamic limnological modeling
- **1-D P.O.M**
- **2-D W2 qual**
- **3-D P.O.M**

Mass and Energy Balances



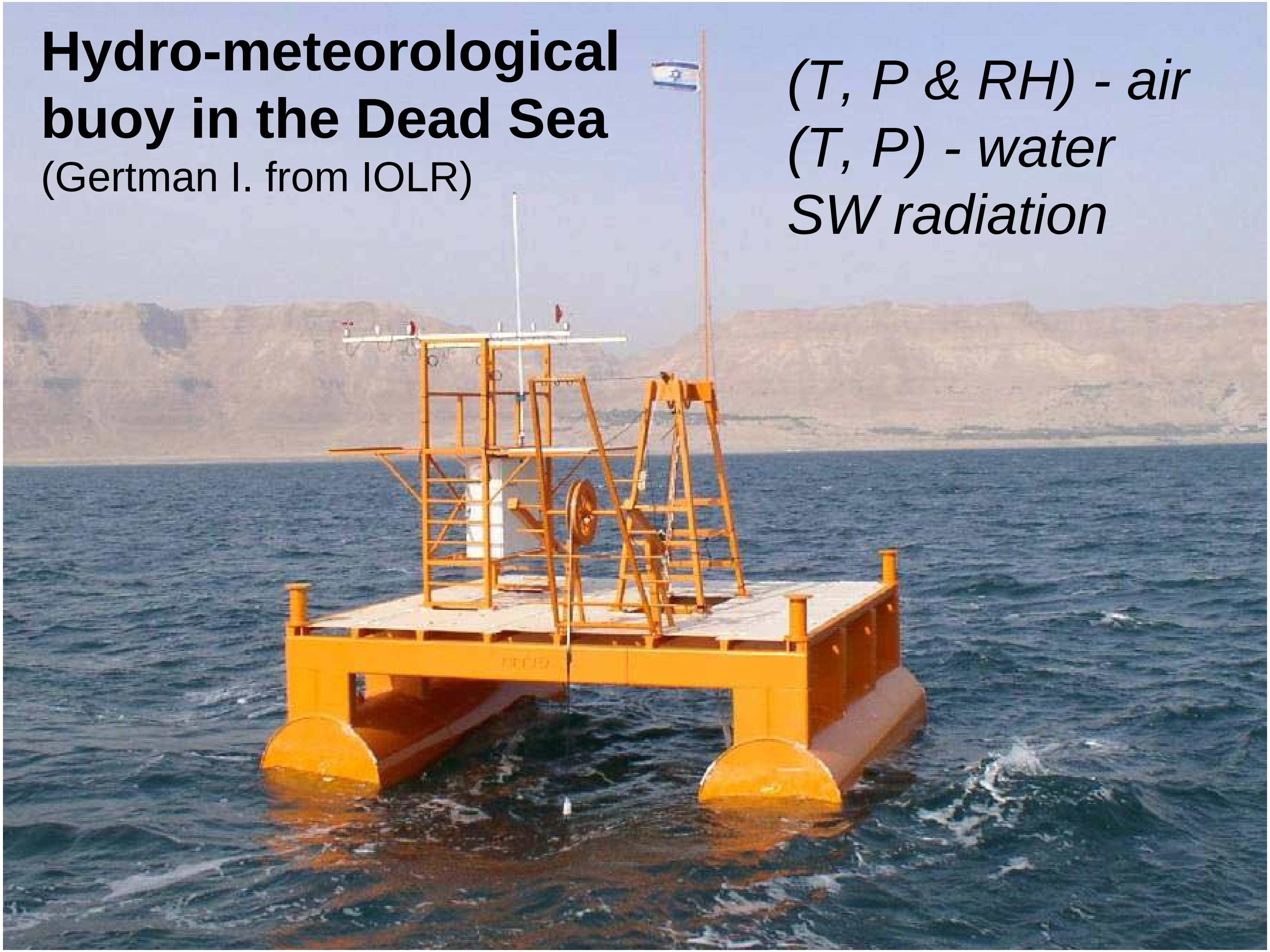
Dead Sea Level (1990-2001)



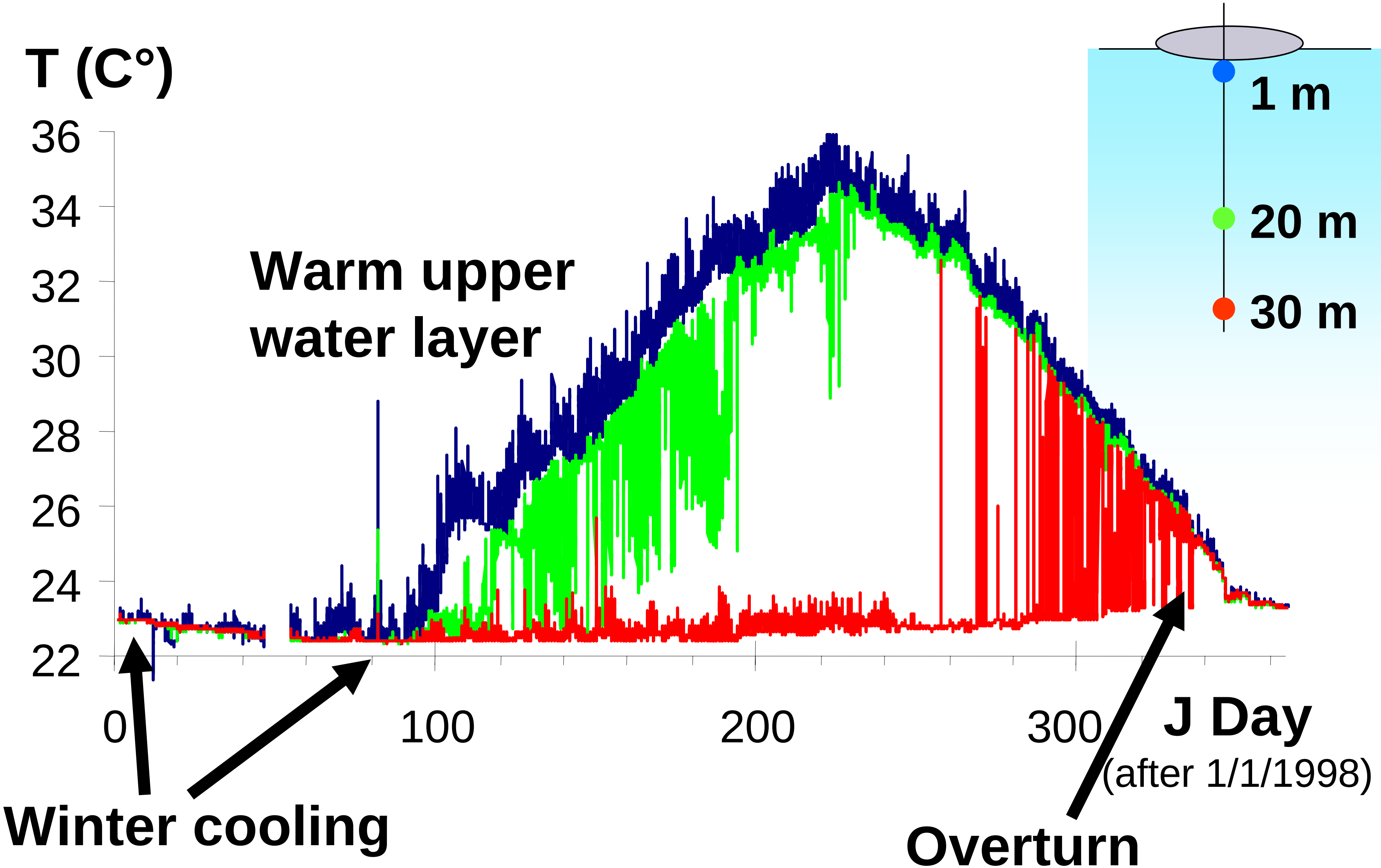
Hydro-meteorological buoy in the Dead Sea

(Gertman I. from IOLR)

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



Water temperature at different depths

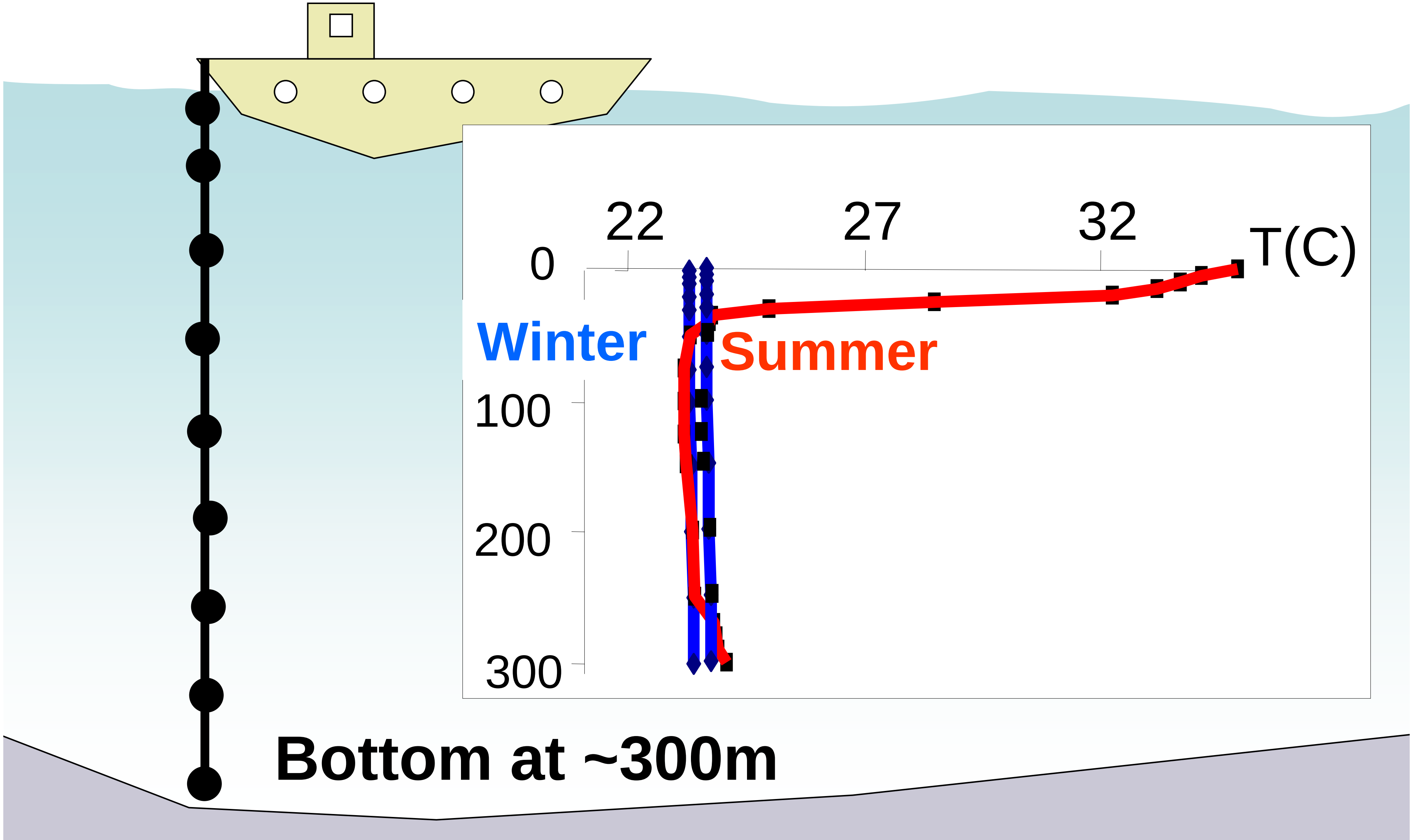


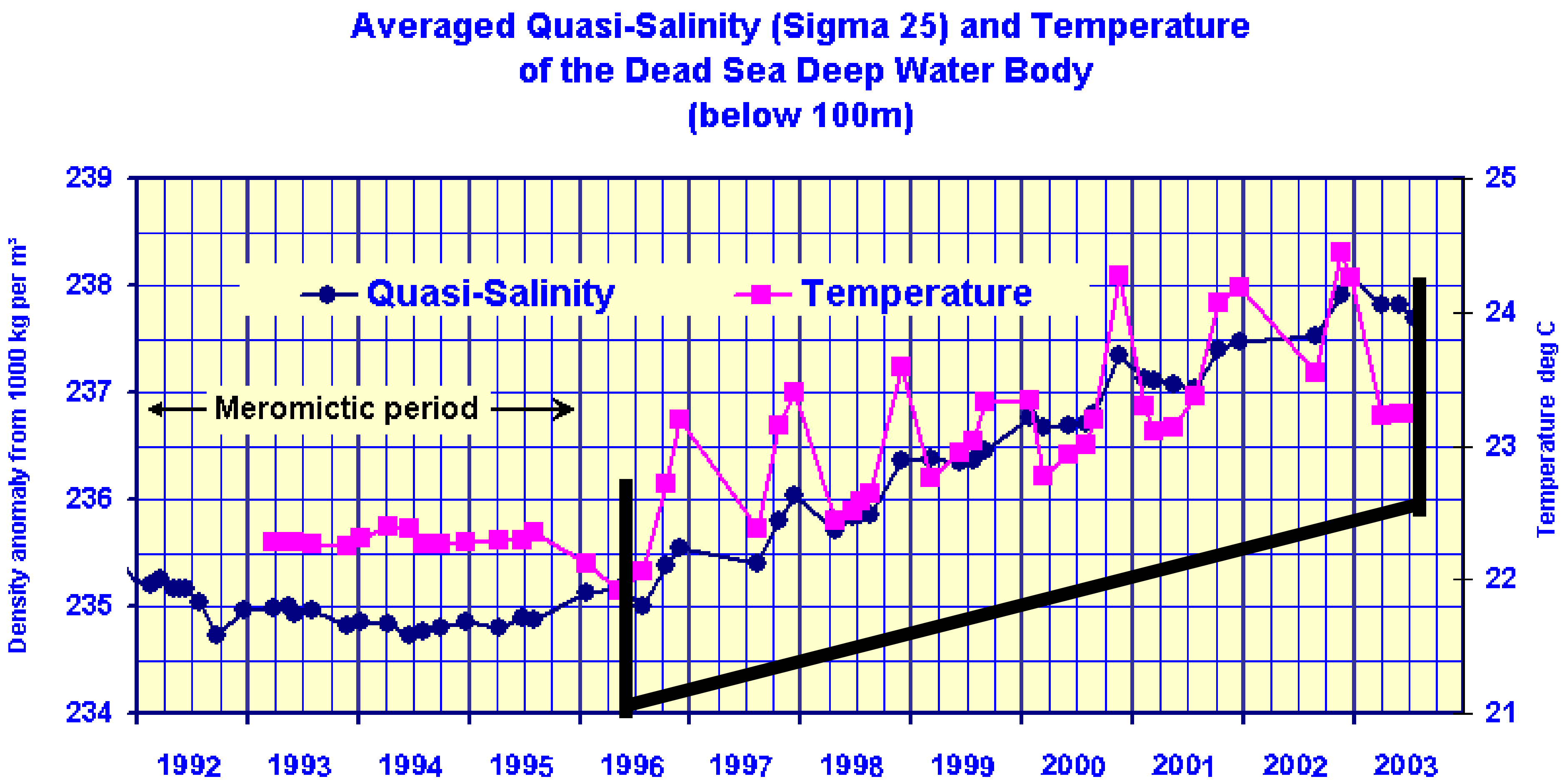
Hydrographycal profiles (T , salinity, ρ)

Every 2 months

Hydrographycal profiles (T , salinity, ρ)

Every 2 months





<u>Measured annual changes</u>:

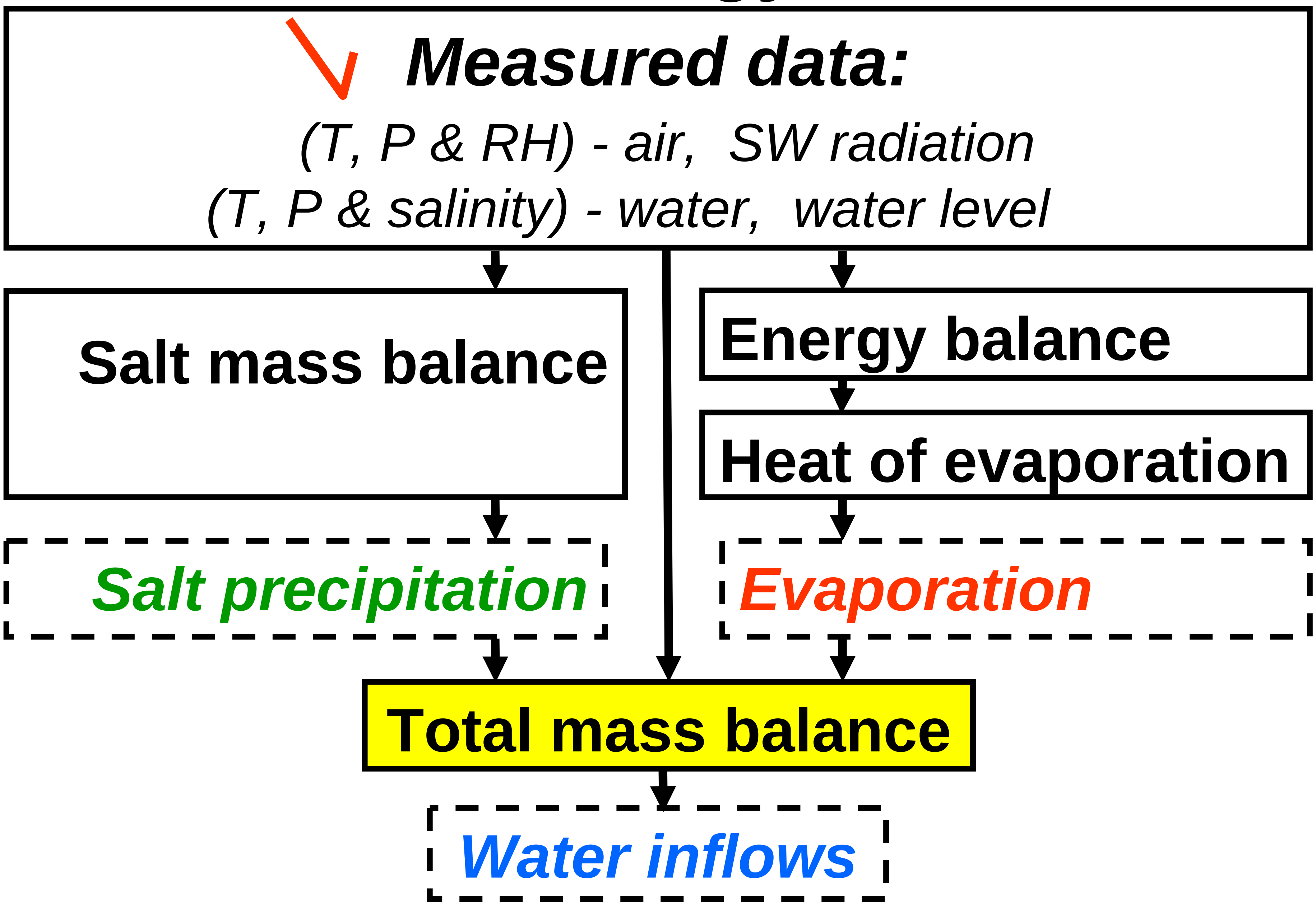
Surface level drop ~ 1 m / yr

Temperature increase ~ 0.2-0.3 °C / yr

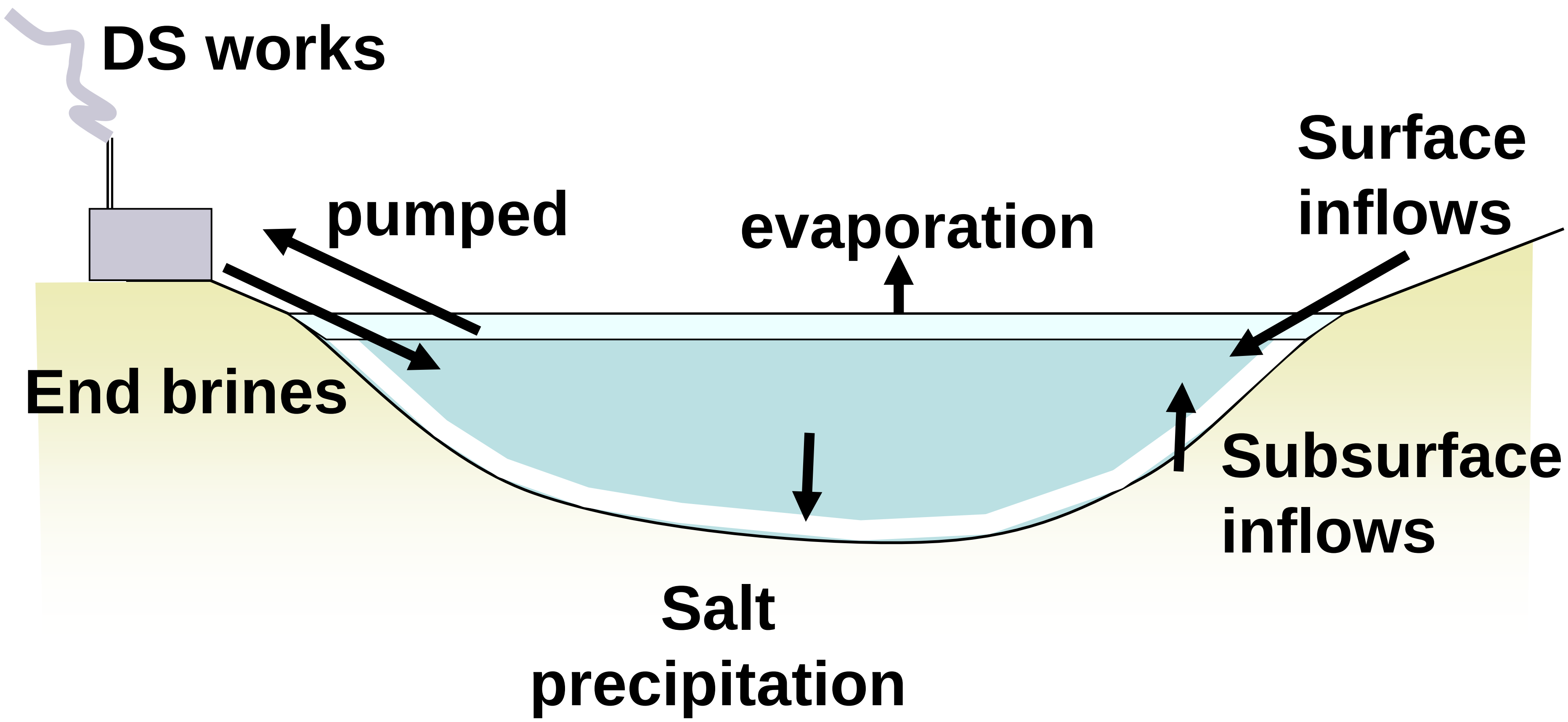
Salinity increase ~ 0.3 g/kg / yr

From IOLR website

Mass and Energy Balances



Total mass balance



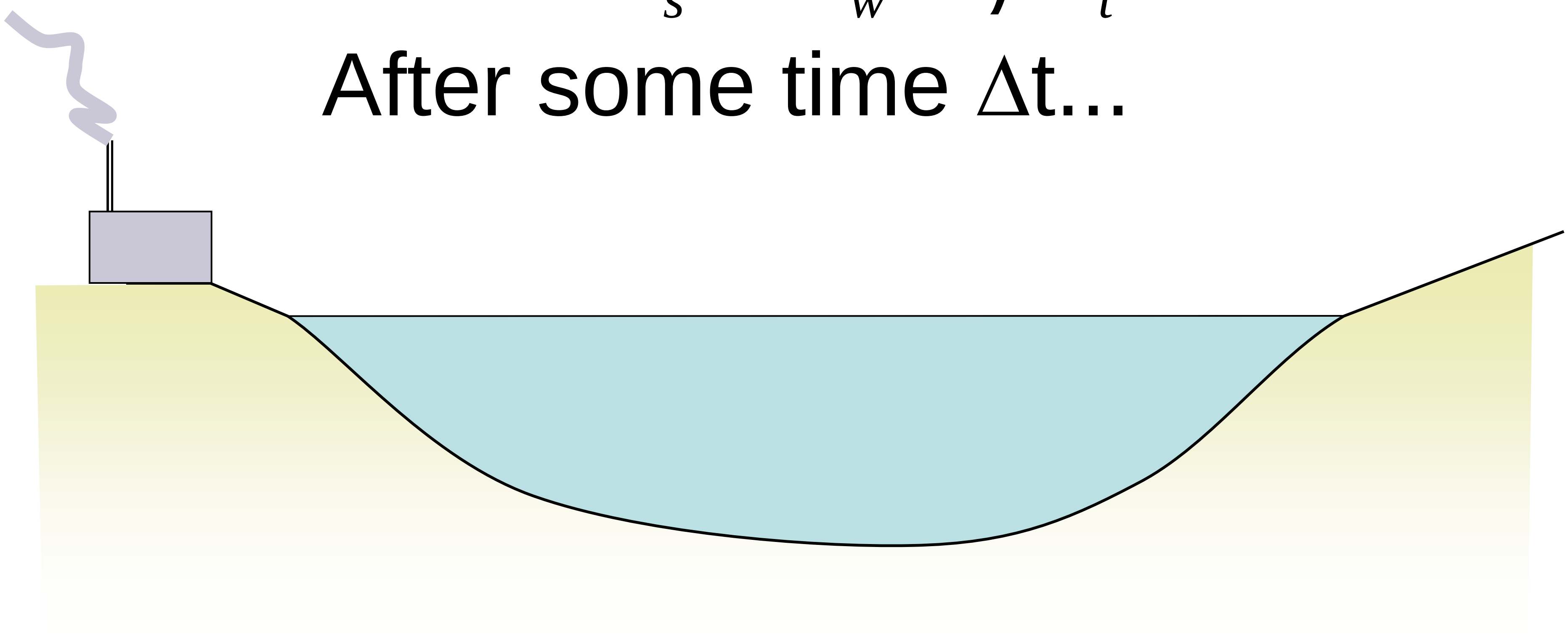
Total mass balance

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...

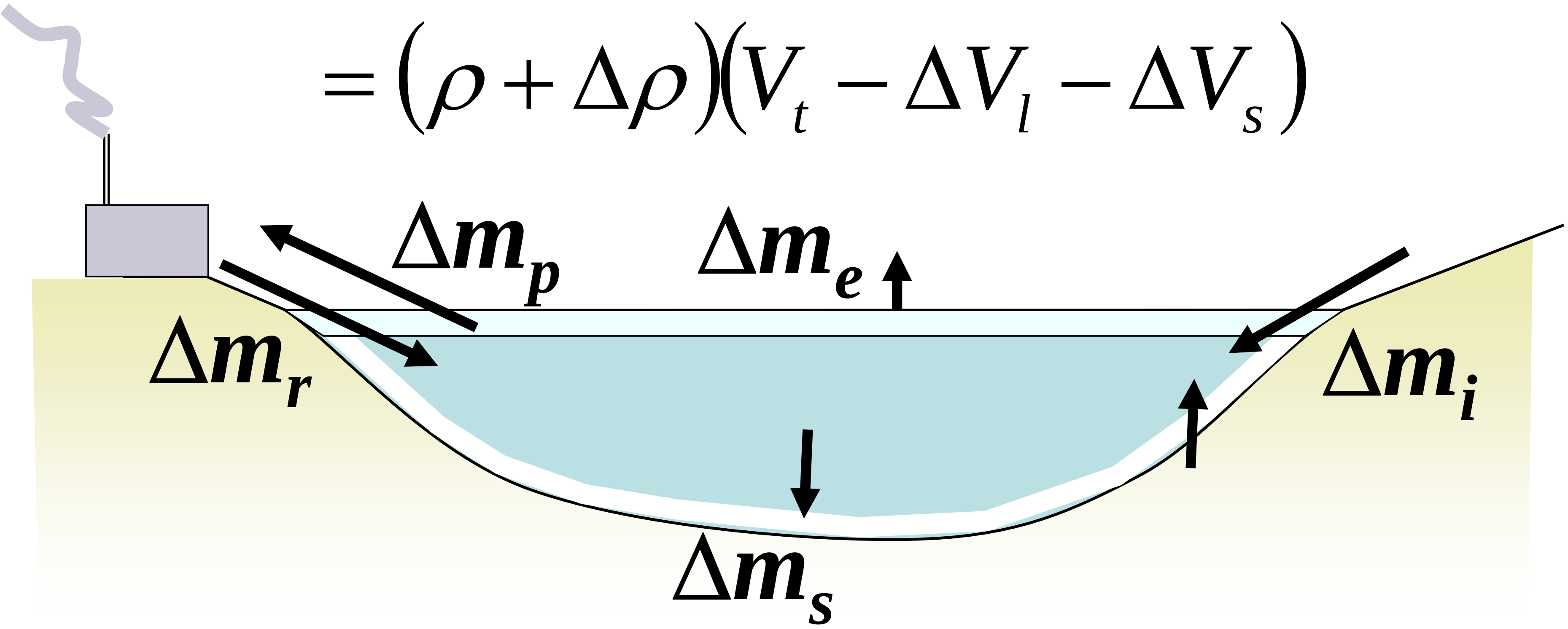


Total mass balance

change during Δt in:
Mass - Δm
Volume – ΔV
Density - Δρ

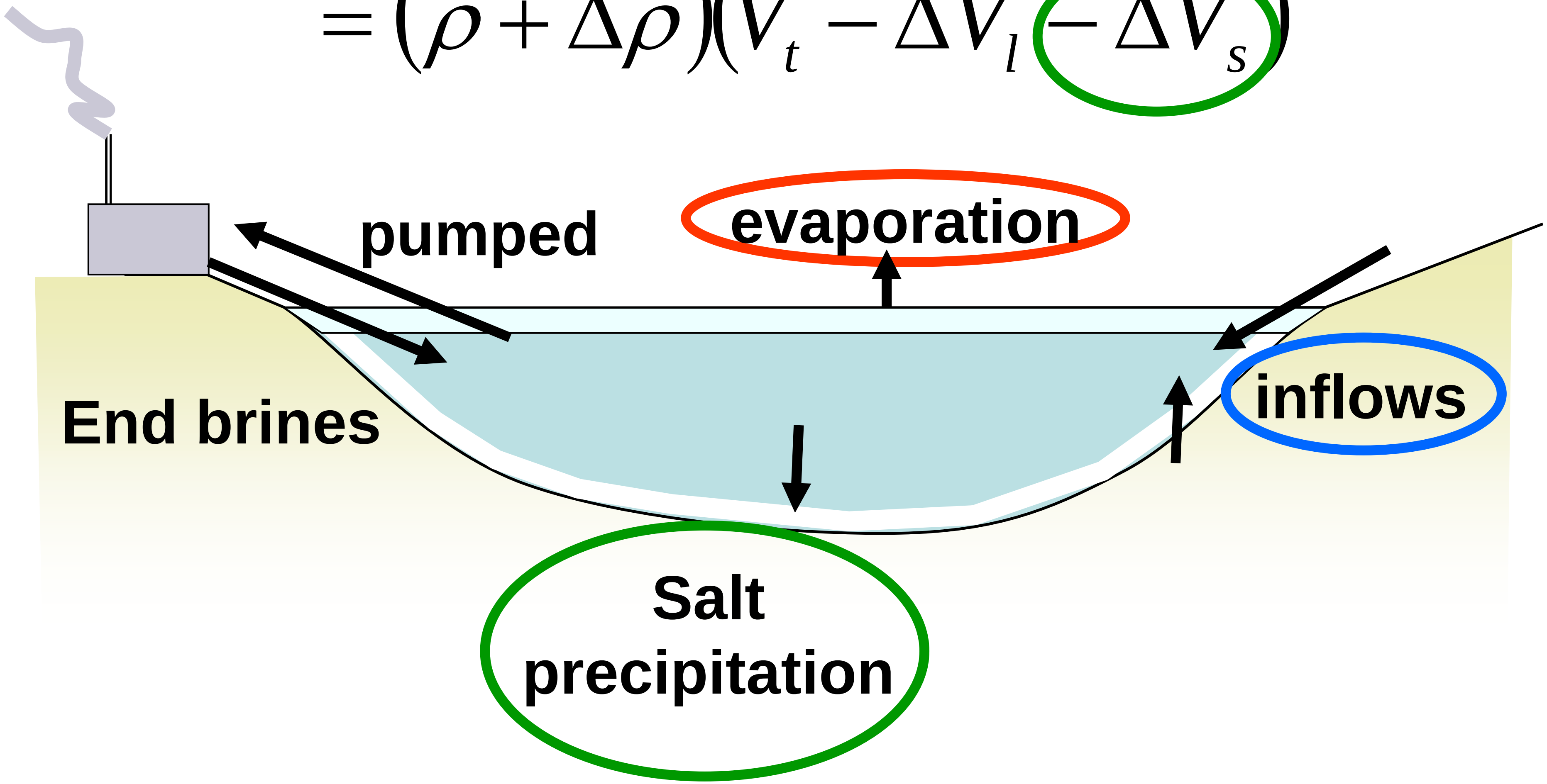
$$m_s + m_w + \Delta m_i - \Delta m_e - \Delta m_s - \Delta m_p + \Delta m_r =$$

$$= (\rho + \Delta\rho)(V_t - \Delta V_l - \Delta V_s)$$

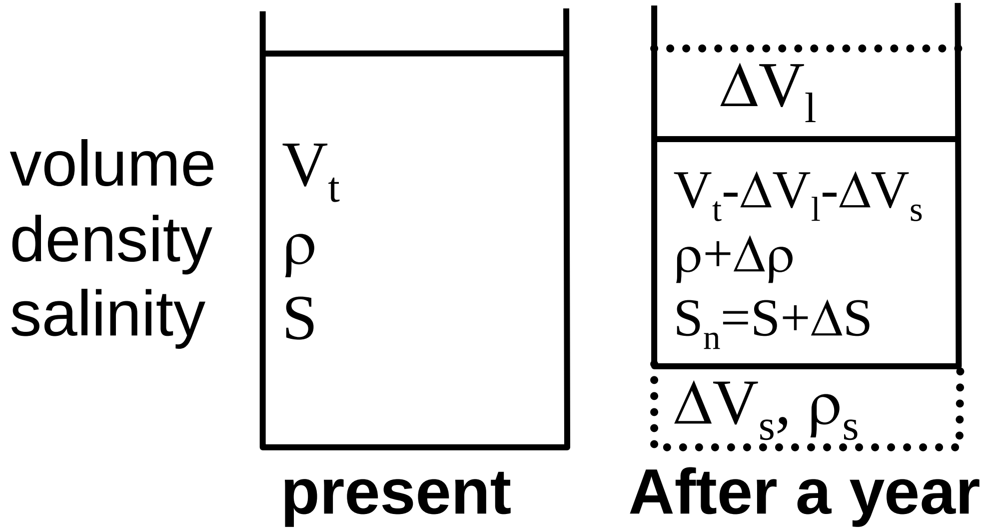


Total mass balance

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



Salt mass balance



After Δt - a year

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

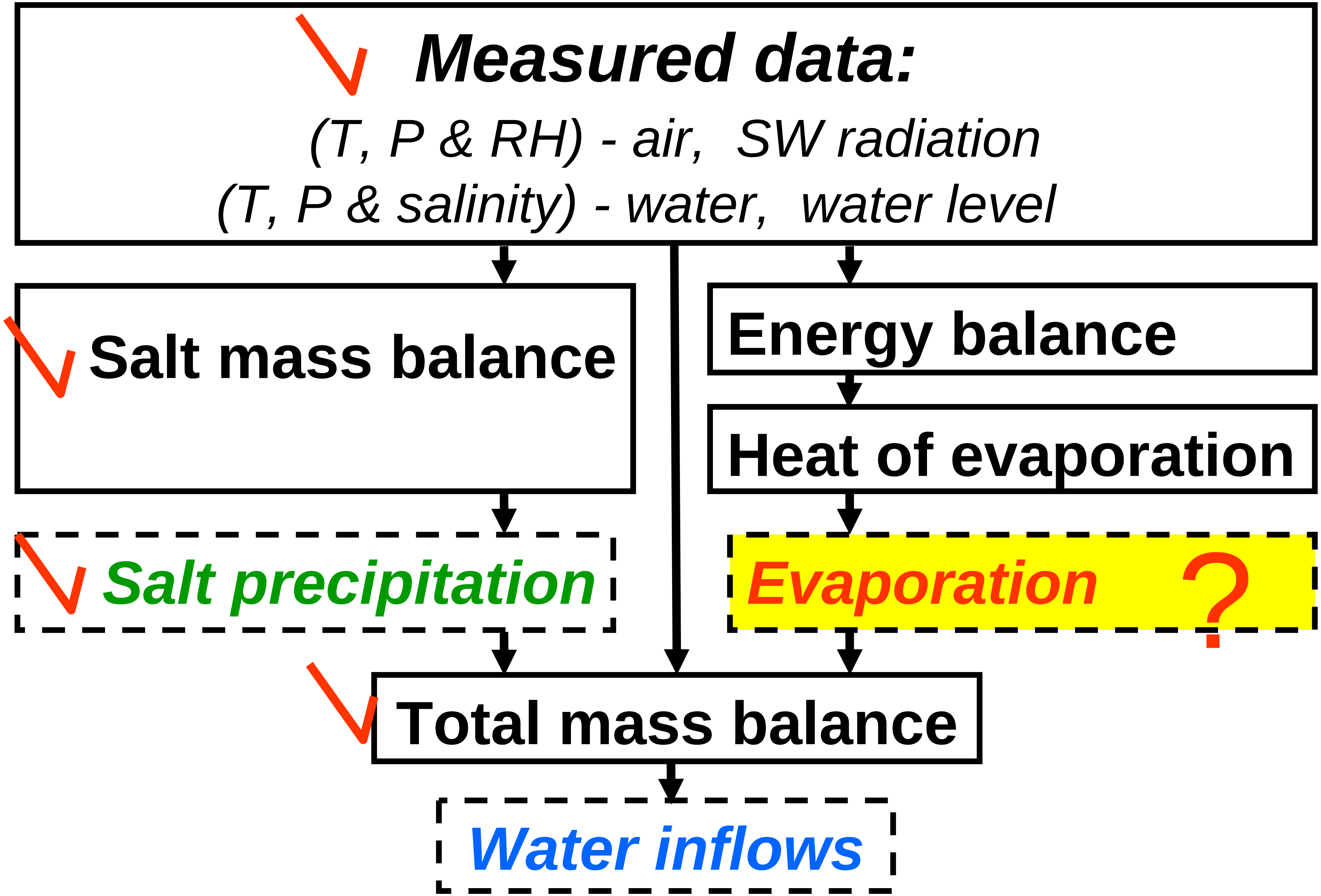
salt precipitation ~0.1 m/yr

<u>2 unknowns remain:</u>

Freshwater inflows ΔV_i

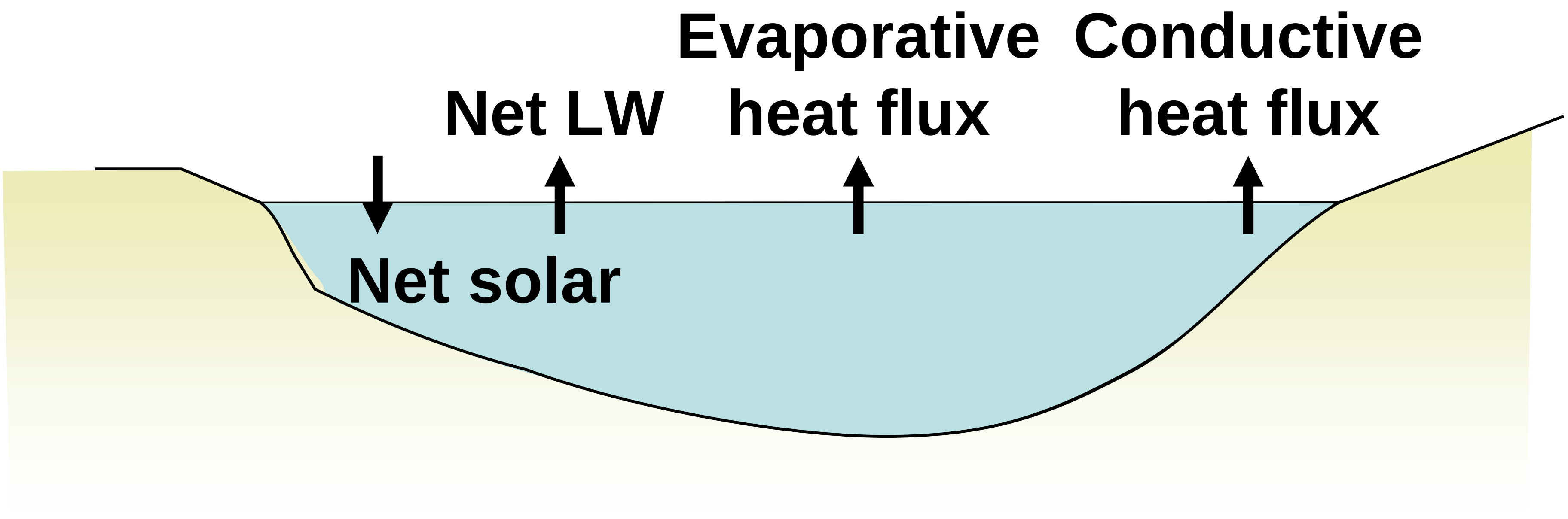
Evaporation ΔV_e

Mass and Energy Balances



Energy balance

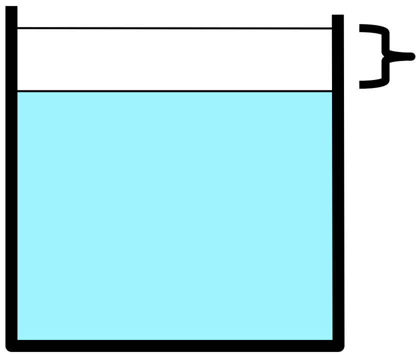
Net heat flux $Q_n = Q_{SN} - Q_{LW} - Q_e - Q_C$



Heat of evaporation (Bowen 1926)

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

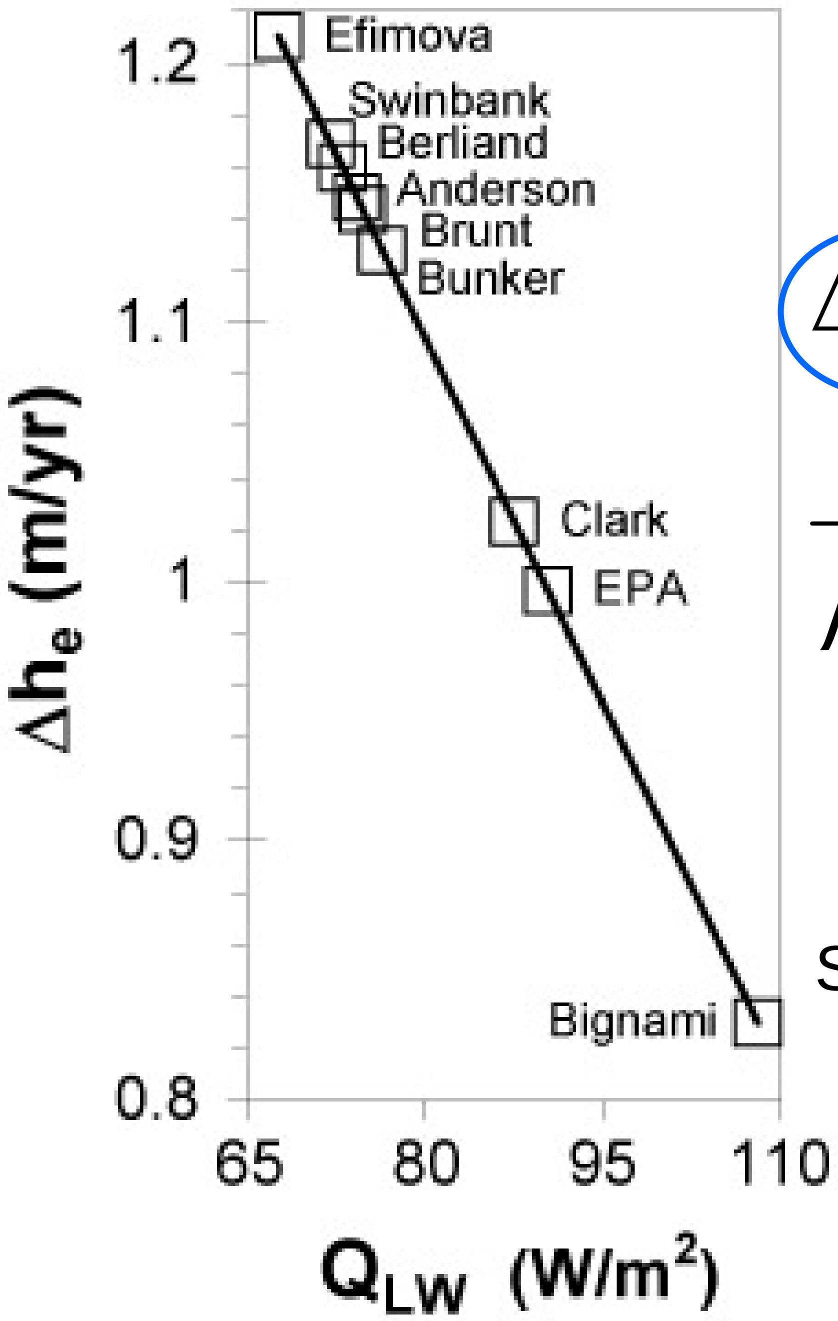
From heat to rate of evaporation



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

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

Le - latent heat



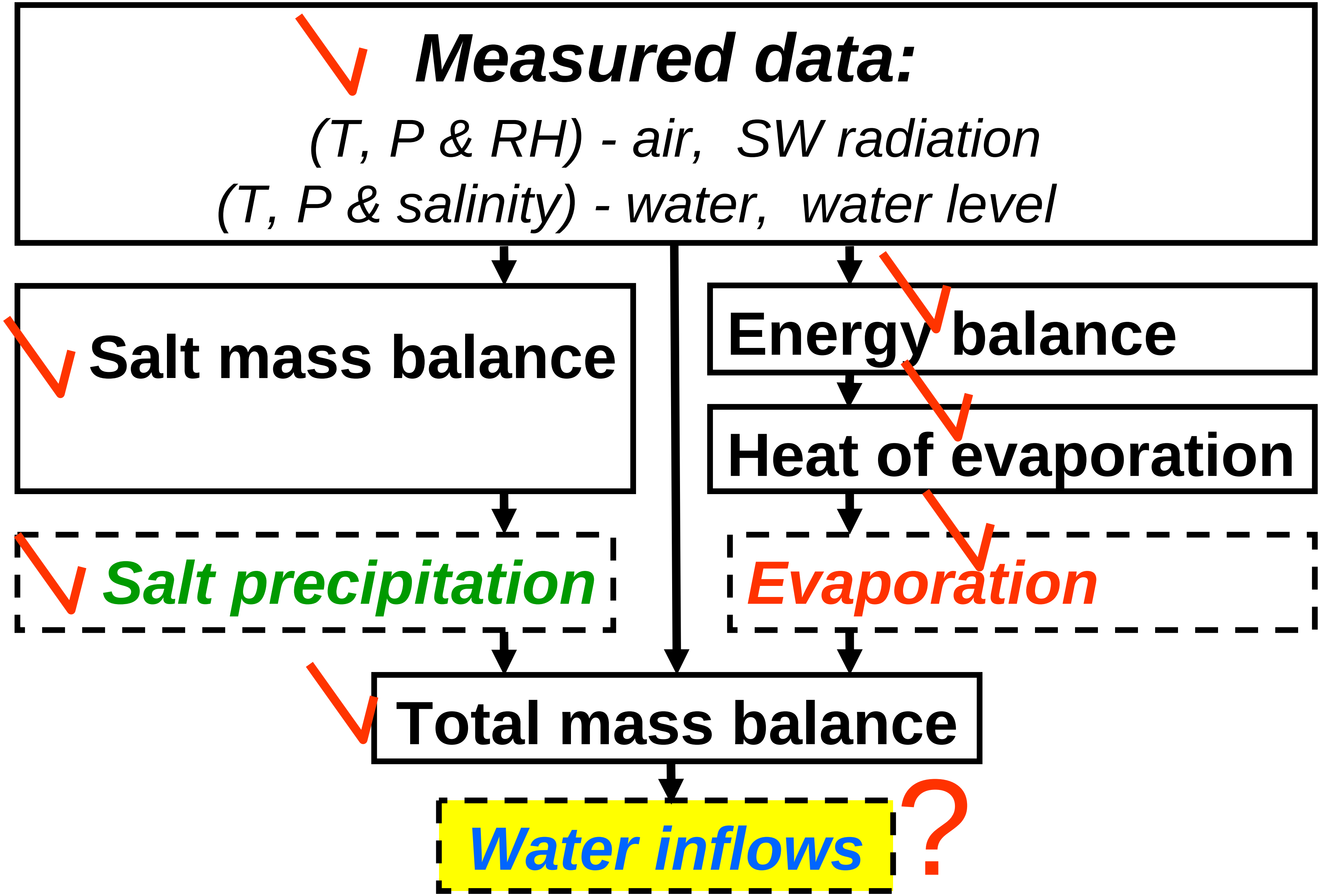
Evaporation rate vs. Q_{LW}

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

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

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

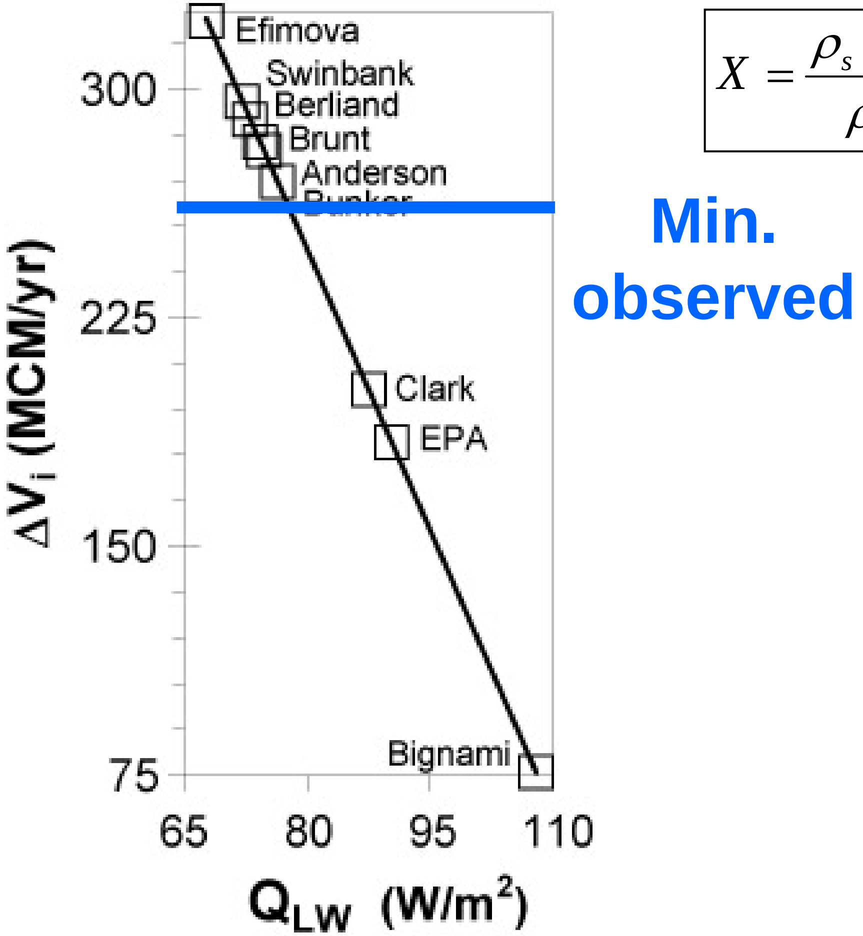
Mass and Energy Balances



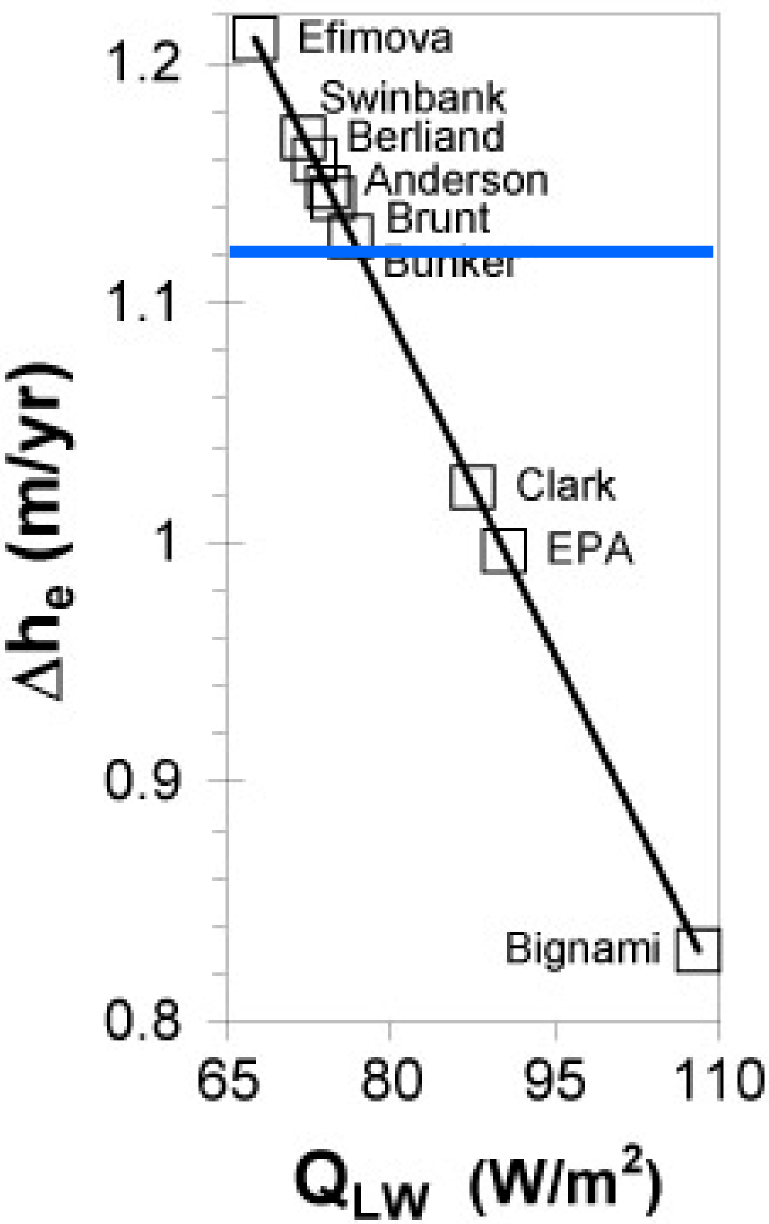
Energy and mass balances

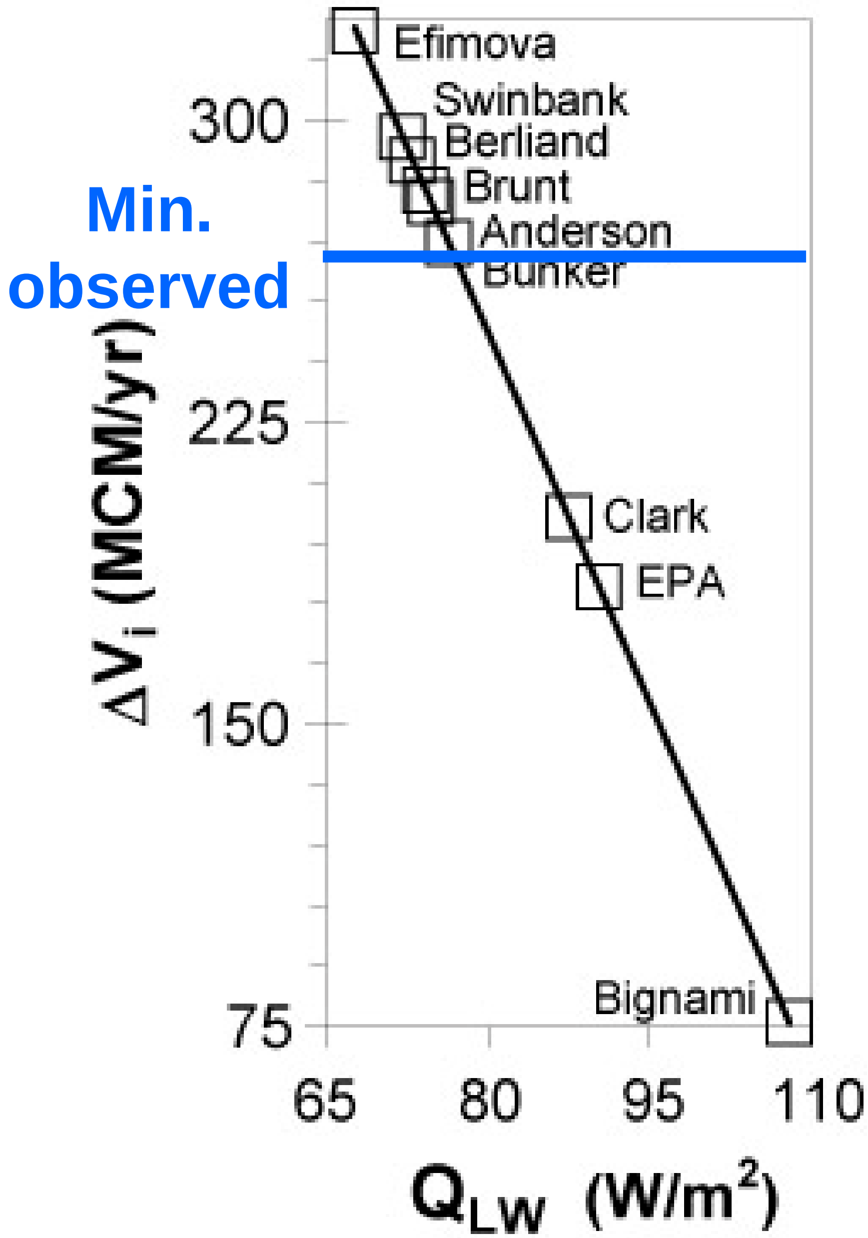
$$\Delta V_i = \Delta t \frac{A}{\rho L_e} \frac{Q_{SN} - Q_{LW} - \rho C_p h_t \Delta T / \Delta t}{1 + c_b (T_s - T_a)/(e_s - e_a)} + X$$

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

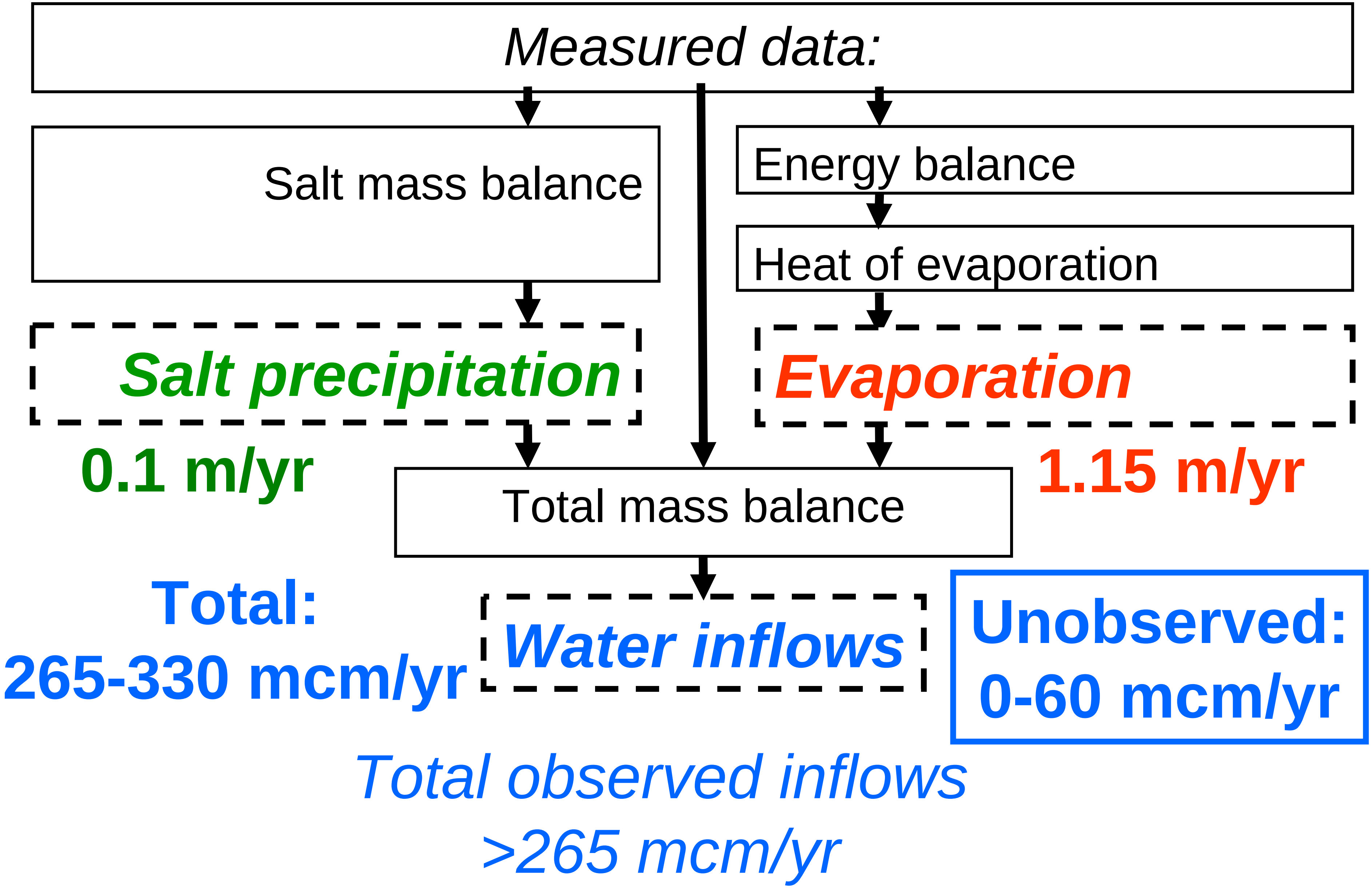


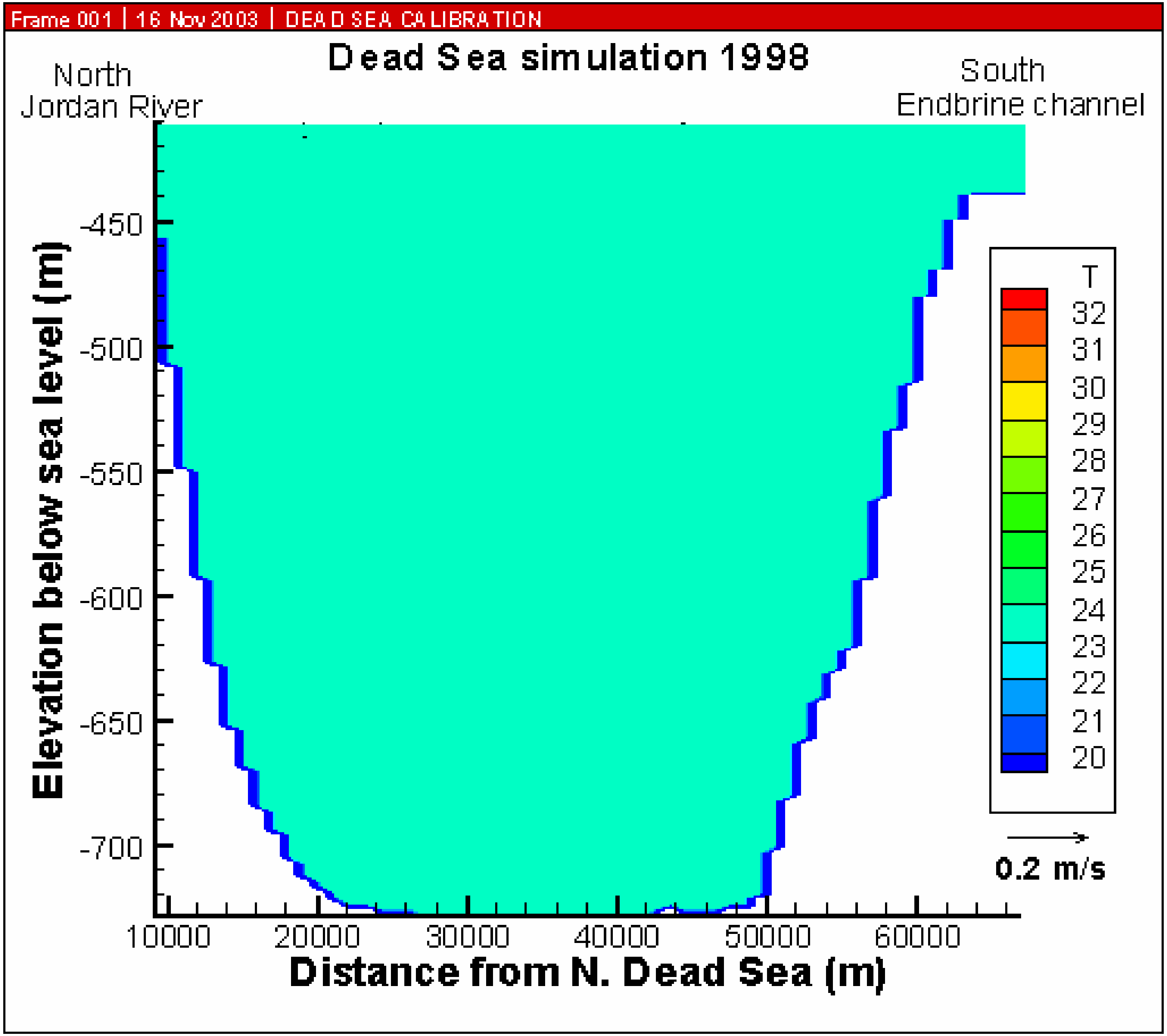
Rate of evaporation and inflows vs. Q_{LW}





Summary


Measured data:
Salt mass balance
Energy balance
Heat of evaporation
Salt precipitation
Evaporation
0.1 m/yr
1.15 m/yr
Total mass balance
Total:
265-330 mcm/yr
Water inflows
Unobserved:
0-60 mcm/yr
Total observed inflows
>265 mcm/yr


Frame 001 | 16 Nov 2003 | DEAD SEA CALIBRATION
Dead Sea simulation 1998
North
Jordan River
South
Endbrine channel
Elevation below sea level (m)
-450
-500
-550
-600
-650
-700
10000
20000
30000
40000
50000
60000
Distance from N. Dead Sea (m)
T
32
31
30
29
28
27
26
25
24
23
22
21
20
0.2 m/s


Thank you…