MPO 503, Lecture 8:
Basin budgets and two-layer exchange flows

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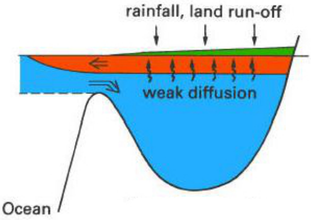
Introduction

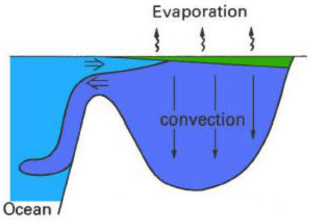
- Basins are regions of enclosed water with a free connection to the open ocean (think of estuaries and semienclosed seas, such as the Mediterranean, Baltic and Red seas);
- Land runoff, precipitation/evaporation and turbulent mixing at the basin induces circulation through the connection (river mouth, strait or sill) in order to maintain the mass and salt balances.

The Gibraltar Strait

Two types of basins

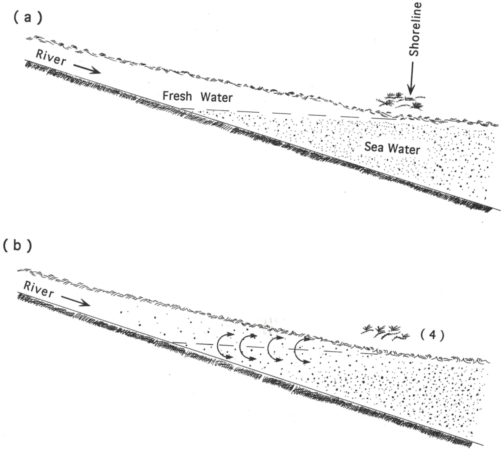
- **Estuarine basins:**
  - Characterized by a gain in freshwater (Evaporation $<$ Precipitation $+$ Land runoff);
  - Fresher water flows OUT at the surface and saltier water flows IN at depth.
- **Evaporative basins:**
  - Characterized by a loss of freshwater (Evaporation $>$ Precipitation $+$ Land runoff);
  - Fresher water flows IN at the surface and saltier water flows OUT at depth.





How the 2-layer flow is maintained?

- Flow in two-layers is a consequence of turbulent mixing;
- By considering the mass and salt budgets over the basin, we can predict the size of the exchange flow between the basin and the open ocean at the connection.



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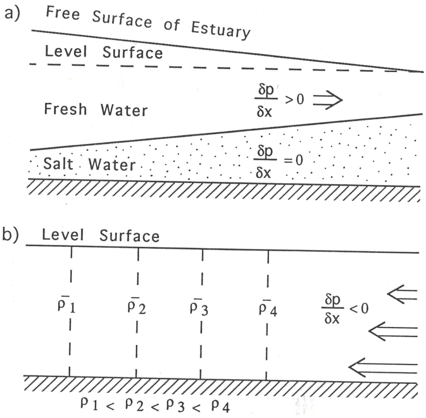

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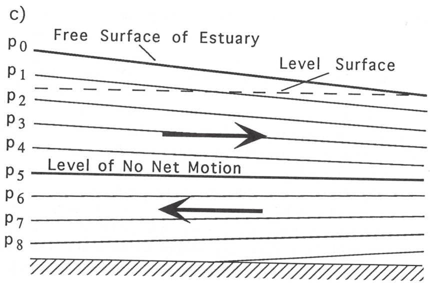

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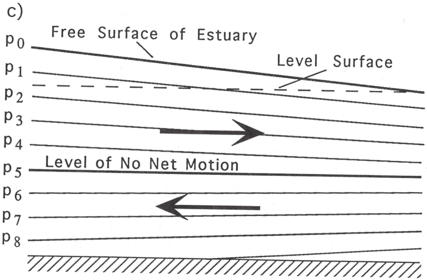
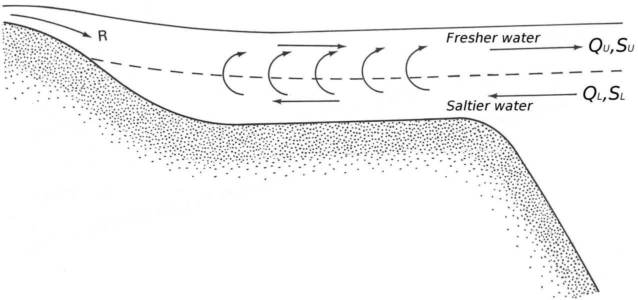


Estuarine basins



- R is the riverine input;
- Q_U and Q_L are the transport of mass at the upper (U) and lower (L) layers;
- S_U and S_L are the salinity of the upper and lower layers.

Estuarine basins

- For a steady circulation, we have that:

$$\begin{cases} Q_U + Q_L = R & \text{Mass conservation} \\ Q_U S_U + Q_L S_L = 0 & \text{Salt conservation} \end{cases}$$

- Solving the system for Q_L and Q_U, we obtain:

$$Q_L = -R\frac{S_U}{(S_L - S_U)}$$

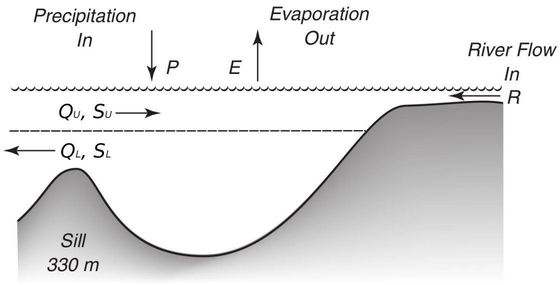
$$Q_U = R\frac{S_L}{(S_L - S_U)}$$

- The relations for Q_L and Q_U are known as *Knudsen relations*.

Characteristics of the transport

- So, for $(S_L - S_U) > 0$, the lower layer flow has opposite sign to the upper layer;
- Note that mixing reduces $(S_L - S_U)$ and increases $(Q_L + Q_U)$ along the estuary. By measuring salinity profiles in different coordinates along the estuarine channel we can quantify the mixing that occurs in the zone between the profiles;
- Also, note that near the ocean $(S_L - S_U)$ will be smaller and hence the fluxes will be larger;
- The along-estuary difference in the inflowing water, Q_L, must equal the amount of water mixed vertically into the upper layer.

Evaporative basins



- The net evaporation E_{net} is equal to difference between the loss of freshwater due to evaporation (E) and the input by land runoff (R) and precipitation (P): $E_{net} = E - P - R$;
- Q_U and Q_L are the transport of mass at the upper (U) and lower (L) layers;
- S_U and S_L is the salinity of the upper and lower layers.

Evaporative basins

- Analogously to the estuarine basin case, we have:

$$\begin{cases} Q_U + Q_L = E_{net} & \text{Mass conservation} \\ Q_U S_U + Q_L S_L = 0 & \text{Salt conservation} \end{cases}$$

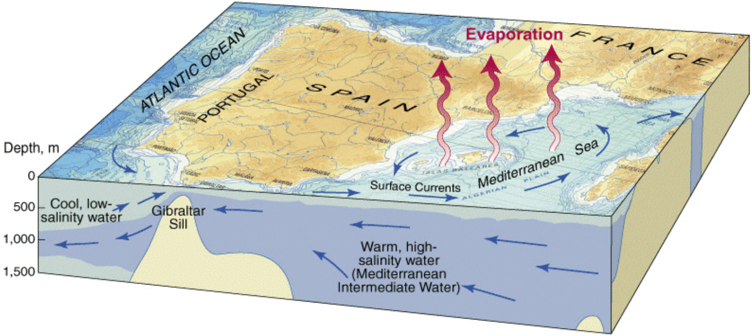
- Solving for Q_L and Q_U, we obtain:

$$Q_L = -E_{net} \frac{S_U}{(S_L - S_U)}$$

$$Q_U = E_{net} \frac{S_L}{(S_L - S_U)}$$

- Now, let's use the Knudsen relations to estimate the Q_L and Q_U exchanged between the Atlantic ocean and the Mediterranean sea across the Gibraltar Strait.

Exchange flow across the Gibraltar Strait



- Net evaporation (E_{net}) ~ 0.8 m.year^{-1} $\times$ 2.5 $\times$ 10^{12} m^2 $= 0.55 \times 10^5$ m^{3}s^{-1}, ~ 0.05 Sv;
- Upper layer salinity (S_U) = 36.15;
- Lower layer salinity (S_L) = 37.9.

Exchange flow across the Gibraltar Strait

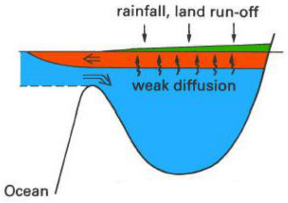
- $Q_L = -E_{net}\dfrac{S_U}{(S_L - S_U)} = -0.55\times 10^5 \times \dfrac{36.15}{1.75} = 1.14\times 10^6 \mathrm{m}^3\mathrm{s}^{-1}, \sim 1$ Sv;
- $Q_U = E_{net}\dfrac{S_L}{(S_L - S_U)} = 0.55\times 10^5 \times \dfrac{37.90}{1.75} = 1.19\times 10^6 \mathrm{m}^3\mathrm{s}^{-1}, \sim 1$ Sv;
- Note that, because $(S_L - S_U)$ is small, the inflow/outflow transports are 20$\times$ larger than the net loss of mass due to evaporation on the Mediterranean basin.

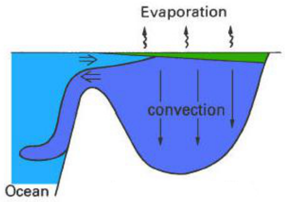
Exchange flow across the Gibraltar Strait

- Practical problems:
  - Estimating the net evaporation;
  - Deciding on where/how to measure S_U, S_L;
  - Sensivity of fluxes to the accuracy of E_{net}, $S_U + S_L$;
- Nevertheless, any reasonable estimates of E_{net} and salinity for the Mediterranean yields transports across the Gibraltar Strait of 0.5 - 2.0 Sv.

Physical differences between estuarine and evaporative basins

- **Estuarine basins (e.g. Baltic, Black):**
    - Stagnant deep water. Deep water is anoxic because it is not ventilated. A thin surface layer of fresh water is separated from the stagnant, deep water by a sharp halocine.
- **Evaporative basins (e.g. Med, Red):**
    - Has vigorous deep water circulation driven by buoyancy loss from net evaporation at the surface. Waters sink or connect to form deep water.





Thank you!