Book: Dynamical Oceanography
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Chapter: 2, Exercise: 2.5: Mediterranean Outflow
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Consider a flow over a sill such as that in the Gibraltar Strait. West of the sill, the water has a salinity $S_a = 36.2$ ppt and east of the sill (in the Mediterranean basin), the salinity is $S_b = 38.4$ ppt. The volume flux of the surface transport of the Atlantic to Mediterranean is Q_a, and the reverse transport at depth has a volume flux of Q_b (both in Sv).

a. Derive that

$$Q_a + Q_b = 0$$

$$Q_a S_a + Q_b S_b = -(E - P) A S_0$$

where S_0 is a mean salinity in the Mediterranean basin.

The above equations are based on the peculiar yet often used approximation that the effect of $E-P$ may be represented by a 'virtual salt flux' $F_S = (E - P)AS_0$, where S_0 is a reference salinity. In this approximation there is *no* freshwater transport through the ocean surface. Hence the volume change of the Mediterranean is determined solely by the transports through the Gribraltar Strait. When Q_a is the volume flux of surface water (positive eastward) and Q_b that of the flow at depth (also positive eastward) then it follows by continuity that $Q_a + Q_b = 0$. The salt leaving the Mediterranean basin is $-Q_b S_b$ while the salt entering the basin is $Q_a + (E - P)AS_0$. A balance of salt over the Mediterranean basin then gives

$$Q_a S_a + Q_b S_b = -(E - P) A S_0$$

To illustrate the peculiarity of the approximation, let us suppose for a moment that we did not use the (unphysical) 'virtual salt flux' to account for the effect of $E - P$. In that case continuity would require

$$Q_a + Q_b = (E - P) A$$

There would be no transport of salt through the ocean surface, but only advection through Gibraltar Strait:

$$Q_a S_a + Q_b S_b = 0$$

Although this set of equations is essentially different from those in the book, their solution is very similar (try!).

Assume that the difference between evaporation E and precipitation P is about 1 m/year over the Mediterranean basin. This basin has an area of about $A = 2.5 \times 10^{12}$ m^2.

b. Determine Q_a and Q_b for the Mediterranean outflow and compare the result to values in the literature.

With $Q_b = -Q_a$ in the salt balance under a., we can solve for Q_a and find

$$Q_a = -\frac{(E - P) A S_0}{S_a - S_b}$$

and hence we find

$$Q_a = -Q_b = \frac{2.5 \times 10^{12} \times 35 \times 1 \times \frac{1}{3600 \times 24 \times 365}}{2.2} \approx 1.3 \text{ Sv}$$

which is in quite good agreement with estimates from observations.