OC403/640 : Climate Dynamics   Assignment No. 2

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Problem II.1: Ocean Warming

For changes in the atmosphere's radiation budget over longer than the mixed layer's adjustment timescale, one must take into account how heat enters the ocean interior. It has been popular to model this penetration as vertical diffusion. The IPCC report, for example, bases some transient warming scenarios on a one-dimensional (vertical only) diffusive model, using the following parameters,

Diffusive depth scale (≡ thermocline depth), D = 500m

Vertical diffusivity, k = 0.63 cm^2s^{-1}.

(a) What is the corresponding diffusive timescale of the thermocline?

We know, however, that the thermocline is "ventilated", i.e., it changes its properties by advection of water driven out of the mixed layer through Ekman pumping. A vertical velocity scale is given by the Ekman pumping velocity, w_E ~ 30m/year.

(b) What is the advective timescale of the thermocline?

(c) Comment on the quality of the IPCC's estimate of the ocean's heating timescale.

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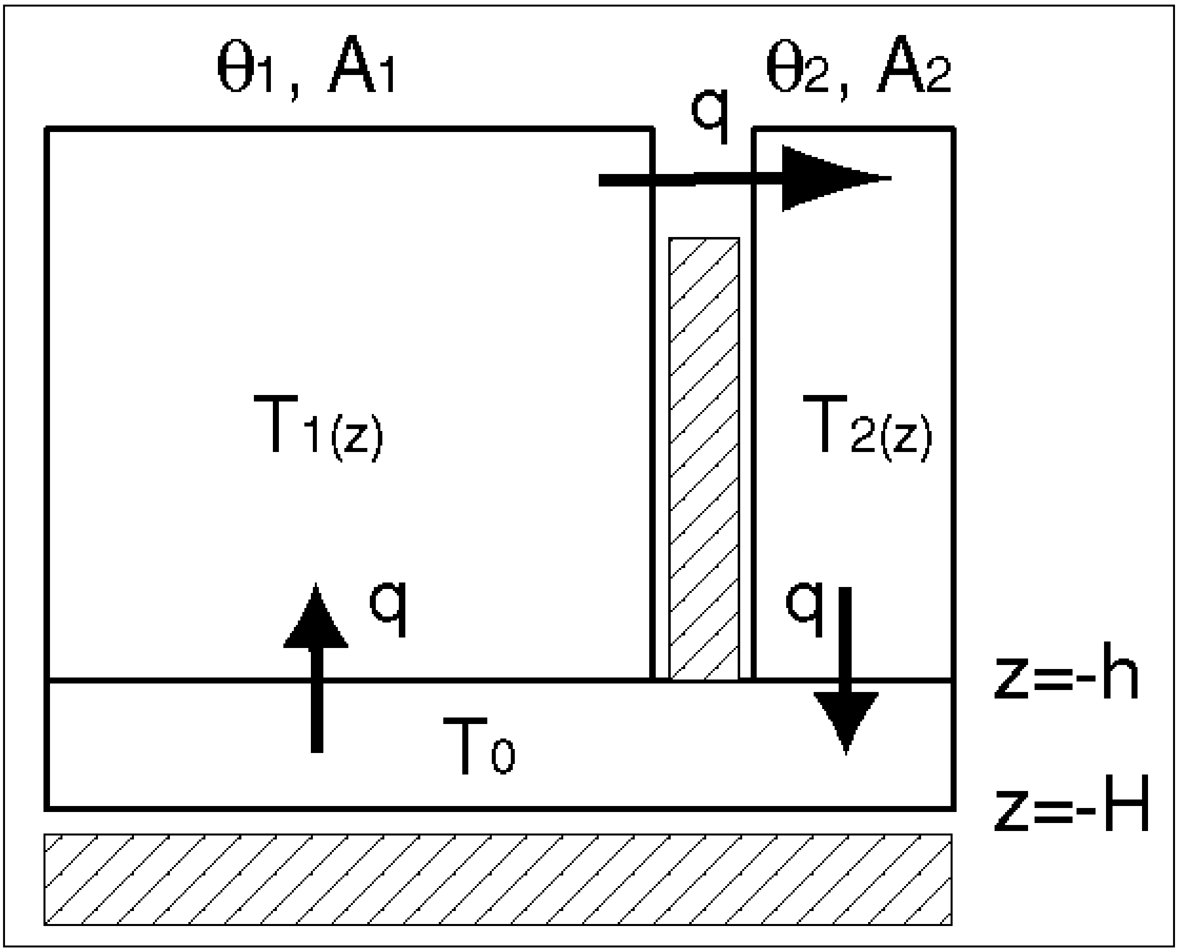
Problem II.2: Surface-Deep Ocean Interaction



Assume that we can describe the interaction between the surface ocean and the abyss as pictured above, through two vertical "pipes" of cross sections A_1 and A_2, respectively. Each pipe has horizontally homogeneous temperature, vertically varying temperature, and fixed surface temperature, θ_i, (i=1,2). The bottom layer is perfectly mixed at temperature T_0, and perfectly insulated below. Pipe 2 ("high latitudes") has very vigorous turbulent vertical mixing, mimicking convection, with diffusivity $k_2 = 10 m^2 s^{-1}$. Pipe 1 has weak turbulent mixing, $k_1 = 10^{-4} m^2 s^{-1}$. The convective "patch" has small area, A_2 =100 km $\times$ 100 km **or** A_2 = 1000 km $\times$ 1000 km (**try both!);** A_1 is about 3×10^{14} m^2. The large-scale flow (thermohaline circulation) is denoted q.

a. Assume first that there is no large-scale flow at all (q=0). Find the steady-state solution, making sure that heat balance holds everywhere, including the deep ocean.
b. Assume now that q = 30 Sv. Use scaling arguments for an analysis of how the solution looks like now (you can try to find the exact solution, but it is not recommended – the algebra is cumbersome).
c. In the light of your results, comment on the frequently encountered statement that "deep convection is narrow because it is more efficient in transferring heat vertically than diffusion, which hence needs a large are to operate over."