Notes and Correspondence


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 The observed asymmetry in the land−sea−breeze system is usually attributed to the inequality in the heat transfer for the two situations. While this may well be the major cause, there is an additional reason which is operating in the circulation described in Pearson’s paper.

 In this paper the author shows, by use of a numerical model, that the sea-breeze is expected to be stronger than the land-breeze even if the heat transfer is the same in each case. Under these circumstances, the available potential energy, fluid velocities and mass transport are all larger for the sea-breeze situation. Without detracting from Pearson’s paper, the object of these remarks is to calculate the difference in available potential energies in terms of a simpler model.

 We consider an incompressible fluid with density $\rho_0(z)$, where $z$ is the vertical coordinate, situated in a box of horizontal width $D$. The potential energy of this fluid (per unit length of the box) is given by

 $$ P_0 = D \int_0^H \rho_0(z)gz\,dz, $$

 where $H$ is the depth of the fluid, and the density gradient is assumed to be stable. We now imagine that a region of fluid at the bottom of the box of length $d$ and height $h$ is cooled so that the density is increased uniformly by an amount $\Delta$. The potential energy of this system is then $P_0 + \frac{1}{2} \Delta gdh^2$. If we now rearrange the fluid with this density distribution adiabatically to its new state of dynamical equilibrium, the potential energy of the latter is $P_0 + \frac{1}{2} \Delta gdh^2/dD$. Here we have assumed for simplicity (and without loss of generality to the argument) that $\rho_0(z)$ is constant over the range $0 < z < h$. This situation is a simple model of the forcing appropriate to a land-breeze situation, and the available potential energy in the model for land-breeze motions is $A_L = \frac{1}{2} \Delta gdh^2(1 - d/D)$.

 For the case where the same region of fluid is heated, so that the density is decreased uniformly by an amount $\Delta$ ($\Delta > 0$), the initial potential energy is $P_0 - \frac{1}{2} \Delta gdh^2$. If this density field is then readjusted adiabatically to its new equilibrium distribution, the heated fluid must be ‘slotted in’ to its appropriate level in the density profile $\rho_0(z)$, which will generally be at some height $H_t$ greater than $h$. The potential energy of this ‘final’ density distribution is

 $$ P_0 - \Delta gdh(H_t - \frac{1}{2}d/D) - (\rho_0(0) - \bar{\rho}_0)gdh(H_t - h), $$

 where $\rho_0(0)$ is the initial density in the range $0 < z < h$, and $\bar{\rho}_0$ is the mean initial density over the range $h < z < H_t$. Hence the available potential energy for this sea-breeze situation is given by $A_s = \Delta gdh(H_t - \frac{1}{2}d/D) - (\rho_0(0) - \rho_0)gdh(H_t - h)$.

 Necessarily we will have $H_t > h$ and $0 < \rho_0(0) - \bar{\rho}_0 < \Delta$. If either of these expressions is an equality, $A_s$ is a minimum and equal to $A_L$. The available potential energy for the sea-breeze depends on the initial overlying density distribution, and has that for the equivalent land-breeze as a lower bound. As a representative example, if we take $\rho_0(z)$ to be continuous at $z = h$ and linear above it, we have $\rho_0(0) - \rho_0 = \frac{1}{3} \Delta$, and $A_s = \frac{2}{3} \Delta gdh(H_t - dh/D)$. With $d/D = \frac{1}{2}$, $H_t/h = 2$, this expression gives

 $$ \frac{A_s}{A_L} = \frac{H_t - dh/D}{h(1 - d/D)} = 3, $$

 which is consistent with Pearson’s model.

 Hence the asymmetry in the observed fluid motions is due to a difference in the available potential energy, caused by geometrical asymmetry. Of course, for the complete land−sea−breeze system the heating and cooling are not applied to the same stationary regions of fluid, but the fundamental asymmetry in the system (as illustrated by this simple model) is still present.

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 26 October 1976