Easterly Flow over a Topographic Barrier

Yaoxuan Zeng[1], Jiacheng Wu[1], Hang Luo[1], Siyuan Shen[1] and Ji Nie[1]

[1]Department of Atmospheric and Oceanic Sciences, School of Physics, Peking University, 100871, Beijing, China

Correspondence: Yaoxuan Zeng (yxzeng@pku.edu.cn);

Jiacheng Wu (1600011451@pku.edu.cn);

Ji Nie (jinie@pku.edu.cn)

Abstract: The schematic of easterly flow over a topographic barrier in the influential textbook of *An Introduction to Dynamic Meteorology (5th Edition*, Fig. 4.12) is misleading. To demonstrate this point, we present numerical simulations of Lagrangian trajectories in an idealized setting. We also provide some suggestions about modifying this schematic at the end.

In the discussion of westerly and easterly flows over a topographic barrier in *An Introduction to Dynamic Meteorology (5th Edition)*, it states the westerly flow can generate Rossby wave patterns, while the easterly flow will end with a straight streamline (Fig. 1a, c). We find the argument for the easterly flow is confusing. We carried out simulations based on Eq. (4.39) in the book (see Method). The simulation of the westerly flow matches well with the schematic (Fig. 1a-b). However, the simulation of the easterly flow is quite different from the schematic (Fig. 1c-d).

For the easterly flow, when it goes northward, the increase of the planetary vorticity can be balanced by the decrease of the relative vorticity. The absolute vorticity can be conserved, so the flow can curve northward for a long distance (Fig 1d). As a result, a disturbance in the meridional motion will be amplified in the case of easterly flow instead of “damping out away from the barrier” as mentioned in the book. The simulated trajectory resembles the schematic only if the particle's meridional velocity is 0 the top of the barrier (figure not shown), which is a specific situation. A detailed argument about the trajectories of easterlies flow in a f/beta plane is discussed in *Motion of a Free Particle on a Beta-Plane* by Cushman-Roisin (1982), which is consistent with the idealized simulations here. Given the wide uses of the textbook in dynamic meteorology courses, the misleading schematic and argument about easterly Flow over topographic barrier might be revised in the future edition of the textbook.

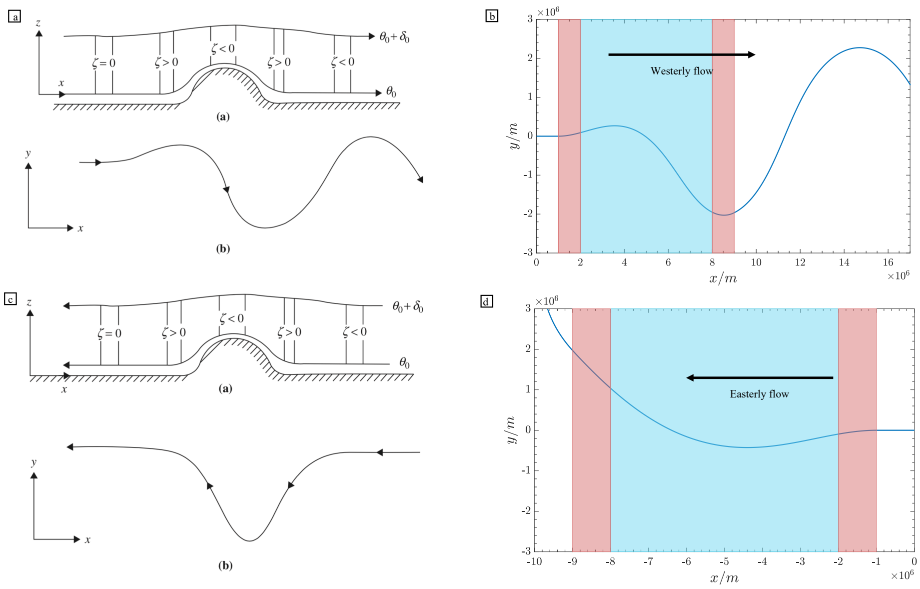

Figure 1: Sketches in *An Introduction to Dynamic Meteorology (4th Edition)* and our simulation results. (a) and (c): sketches for westerly/easterly flow over a topographic barrier in the book, respectively. (b) and (d): our simulation results for westerly/easterly flow over a topographic barrier, respectively. In (b) and (d), blue shading indicates the perturbation range of bottom topography and red shading indicates the perturbation range at the top of the air column.

Methods: We use the shallow-water potential vorticity equation $\frac{d}{dt}\left(\frac{\zeta+f}{h}\right)=0$ to simulate the flow over a topographic barrier. $\zeta(x,y)$ can be calculated by $f(x,y)$ and $h(x,y)$. $f(x,y)$ and $h(x,y)$ are known before simulation. If we assume that the magnitude of the velocity to be constant, then $\zeta(x,y)$ will only change the direction of the velocity. This change can be calculated by $\Delta\theta=\zeta\Delta t$. With assumptions above, the trajectory line can be simulated.

We simulate a westerly/easterly flow with a constant velocity of 100m/s. The planetary radius is 6371km, the rotation rate is 86400 s, the initial latitude is 40°N and the initial height of the air column is 10km. We set both cosine patterns perturbation to the bottom topography and the top of the air column:

$$h_t = H_t \cos\left(\frac{x-x_c}{L_t}\cdot\pi\right) + H_0 \tag{1}$$

$$h_b = H_b \cos\left(\frac{x-x_c}{L_b}\cdot\pi\right) \tag{2}$$

where h_t and h_b are the height of the top and bottom of the air column, respectively. $H_t = 5km$ and $H_b = 2km$ are the amplitude of the perturbation at the top and bottom, respectively. $L_t = 8000km$ and $L_b = 6000km$ are the horizontal range of the perturbation at the top and bottom, respectively. x_c is the center of the perturbation, and $H_0 = 10km$ is the initial thickness of the air column.

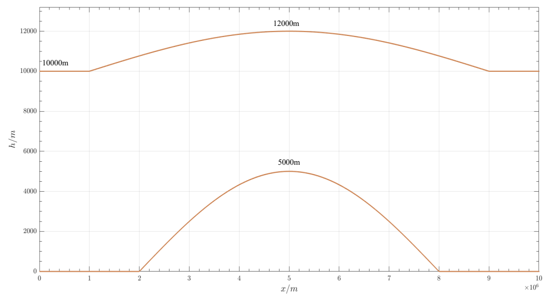

Figure 2: Bottom and top perturbation of the air parcel.