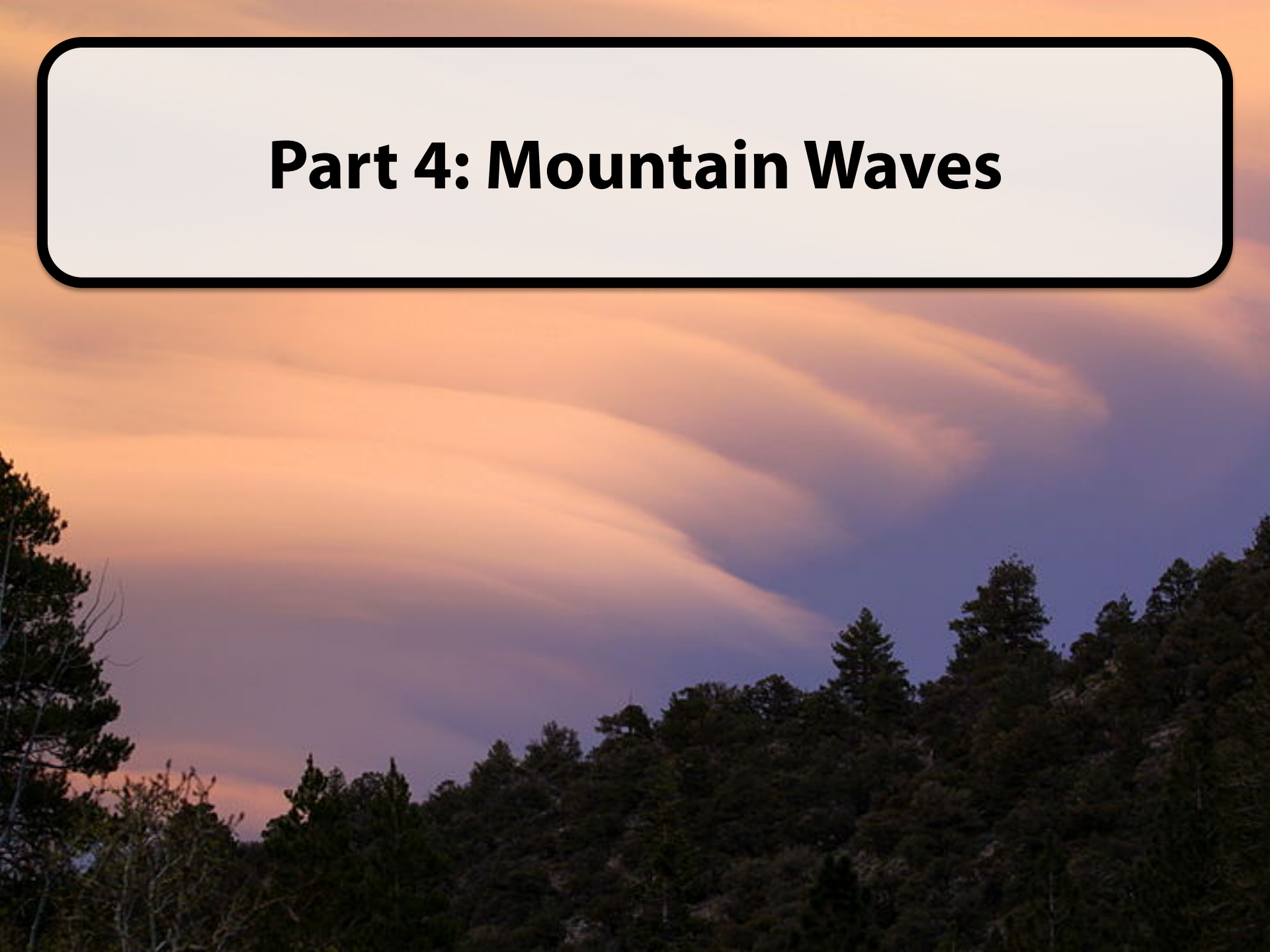
The background of the slide is a vibrant space scene. On the left, a large, dark, textured portion of the Earth is visible, showing the curvature of the planet. The rest of the background is a deep blue space filled with numerous bright, multi-colored stars and nebulae, creating a sense of depth and cosmic wonder. The overall color palette is dominated by blues, from deep navy to bright cyan and white highlights from the stars.

A Rotational View of the Atmosphere

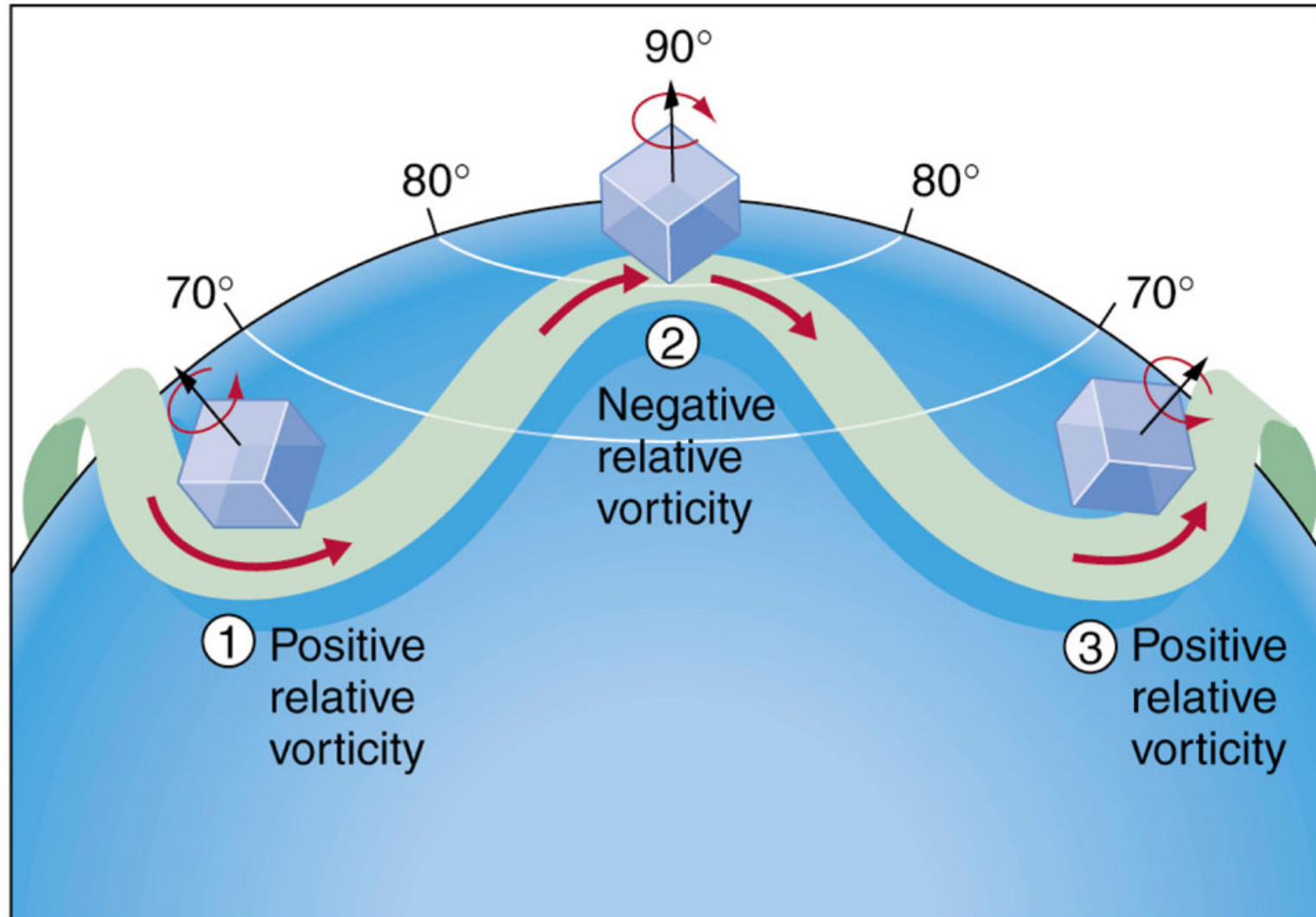
Chapter 4

Paul A. Ullrich
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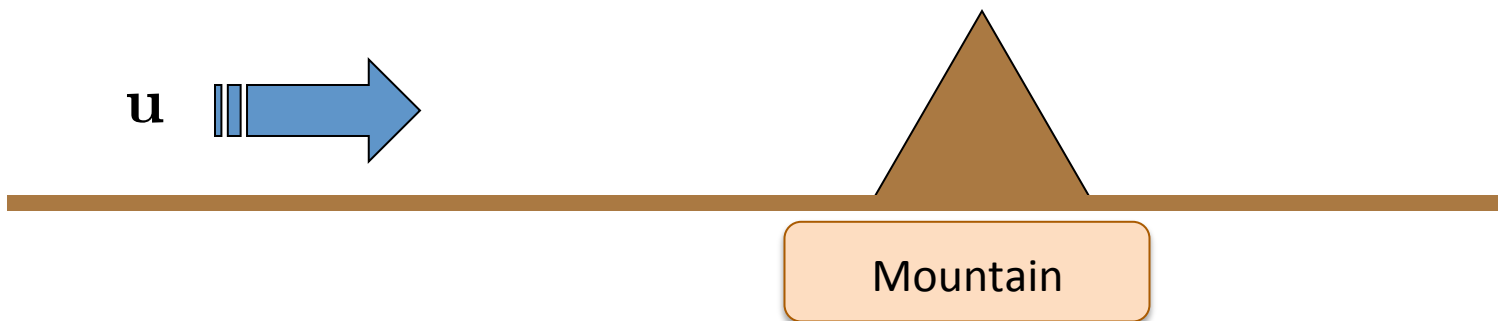
Part 4: Mountain Waves



Question: What might cause this wave-like flow?



Flow Over a Mountain



Potential Vorticity

In a Barotropic Fluid

For a barotropic,
incompressible and
homogeneous fluid:

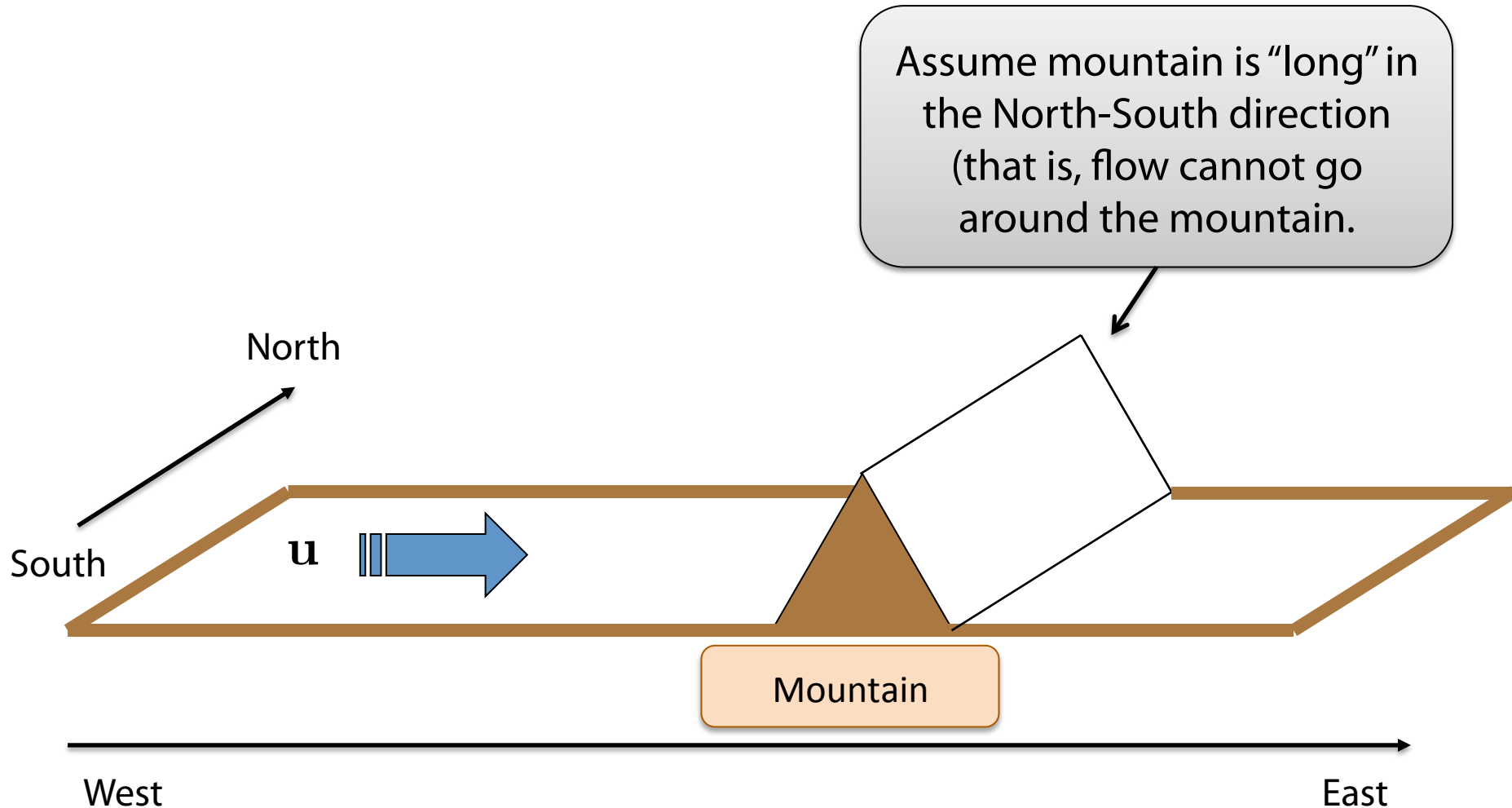
$$\frac{D_h}{Dt} \left[\frac{\zeta_g + f}{h} \right] = 0$$

Definition: The **barotropic potential vorticity** of a fluid column is defined as

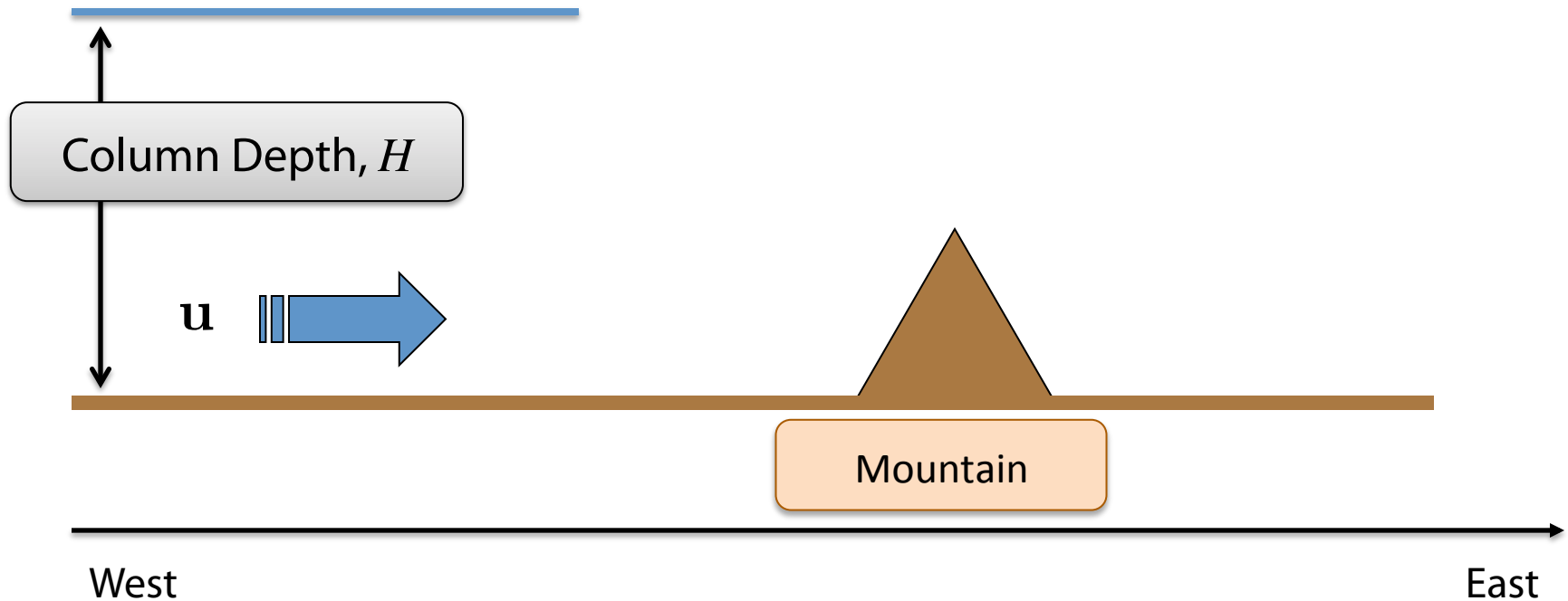
$$PV = \frac{\zeta_g + f}{h}$$

Question: What can barotropic PV tell us about flow over a mountain?

Flow Over a Mountain

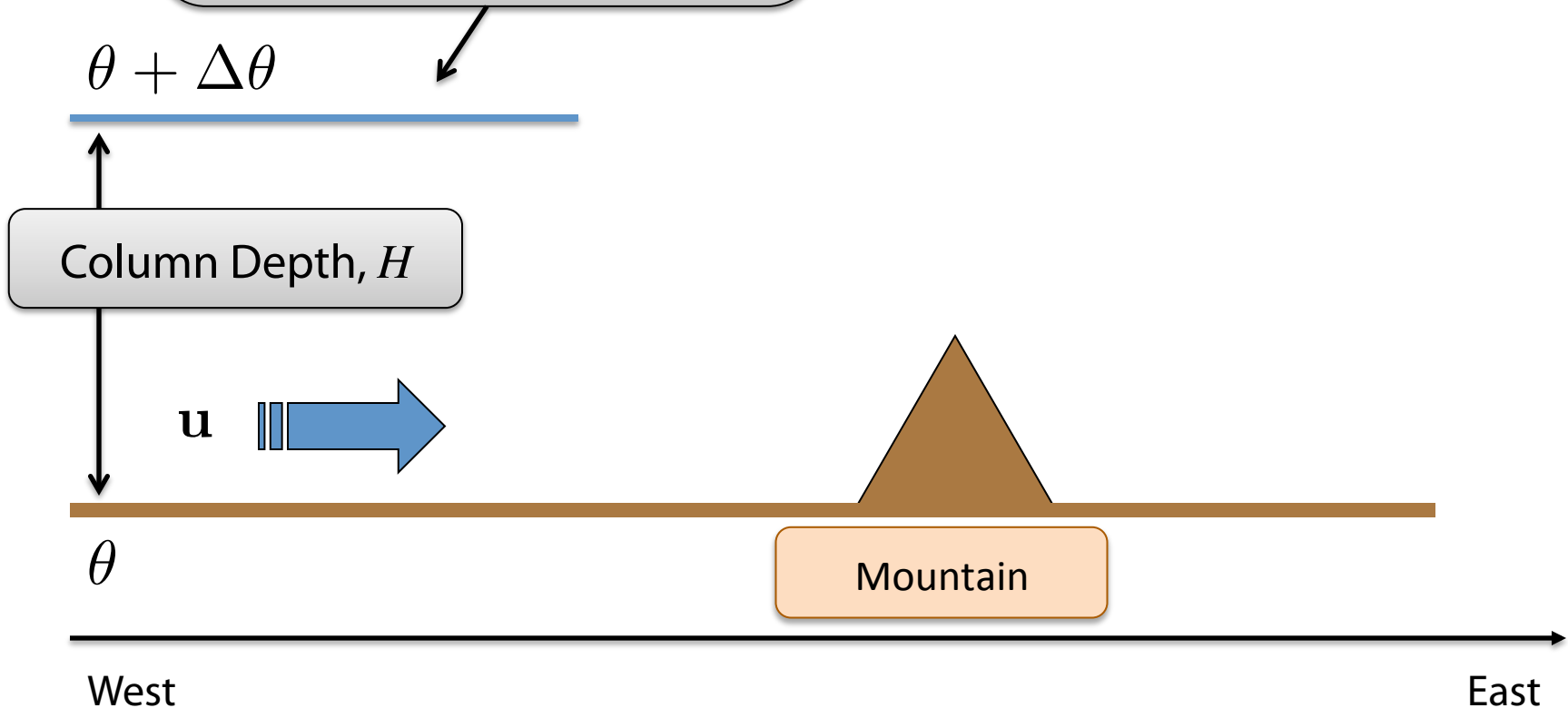


Flow Over a Mountain



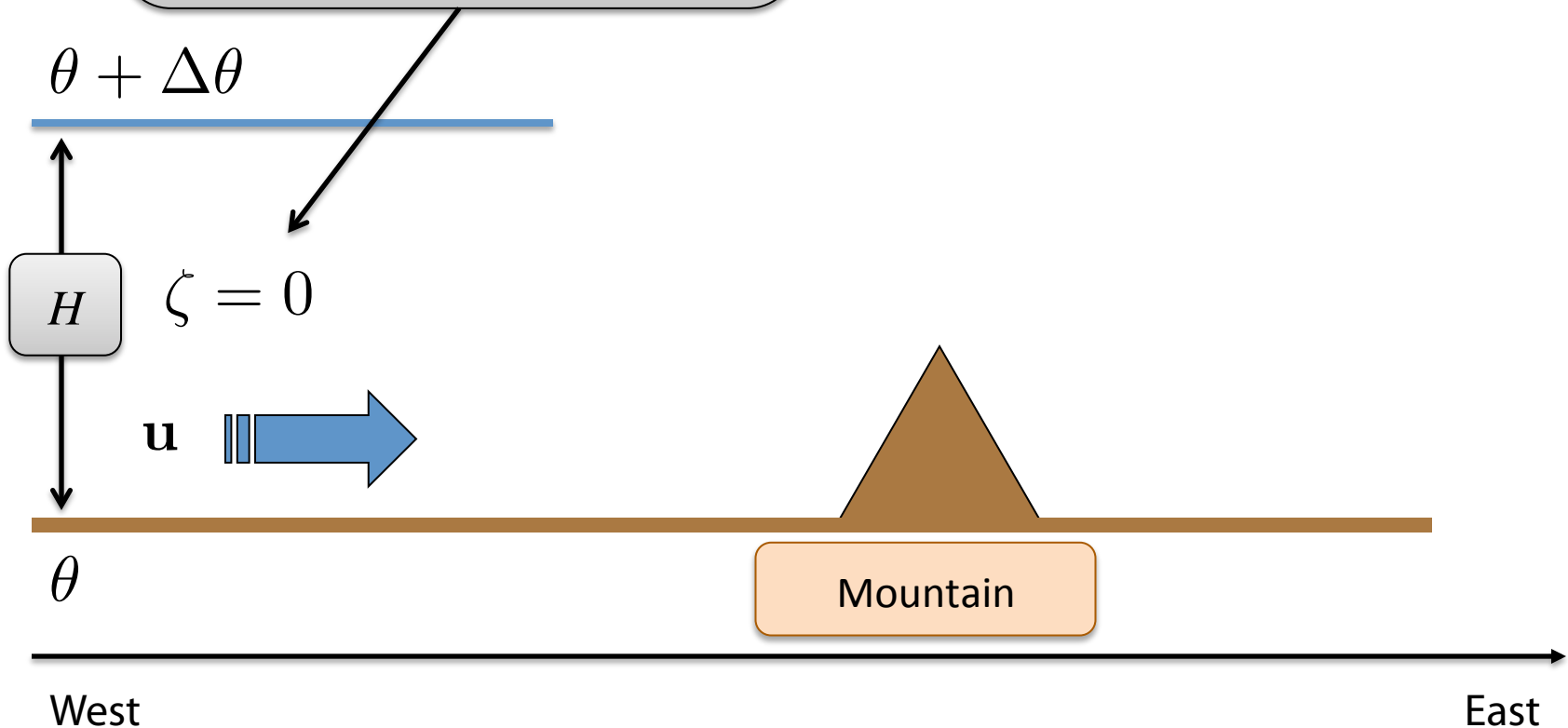
Flow Over a Mountain

Flow is adiabatic so fluid is confined between layers of constant potential temperature.



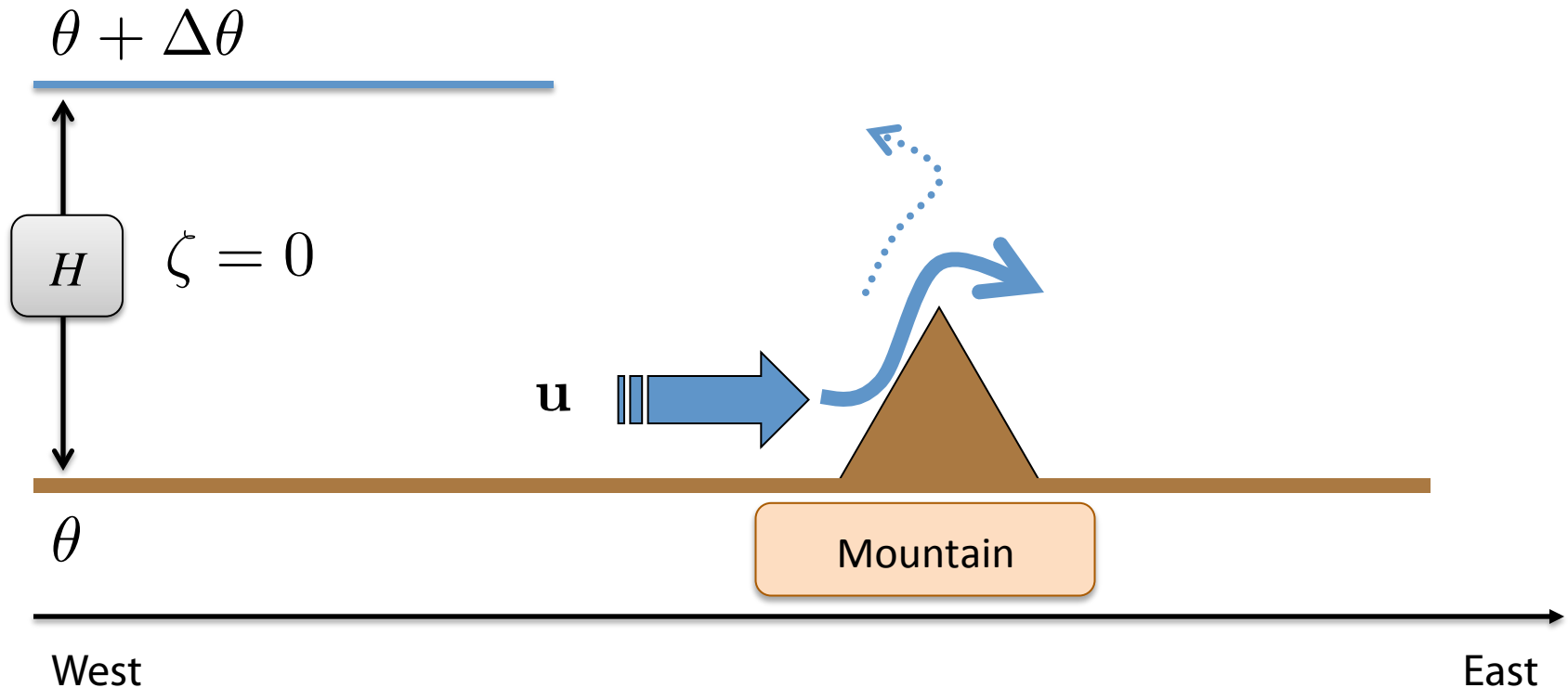
Flow Over a Mountain

Far upstream the flow is purely zonal with no variation in the meridional direction.



Flow Over a Mountain

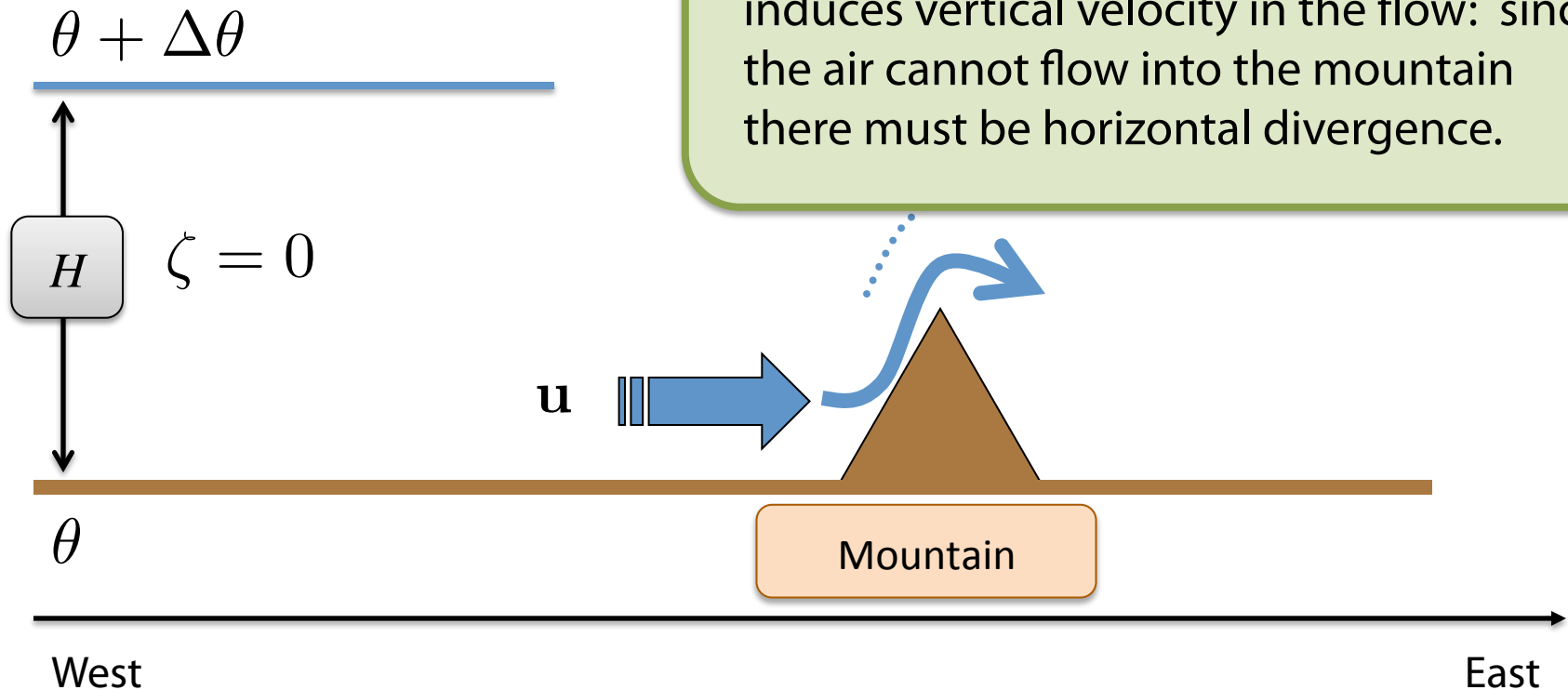
Question: What happens when the wind reaches the mountain?



Flow Over a Mountain

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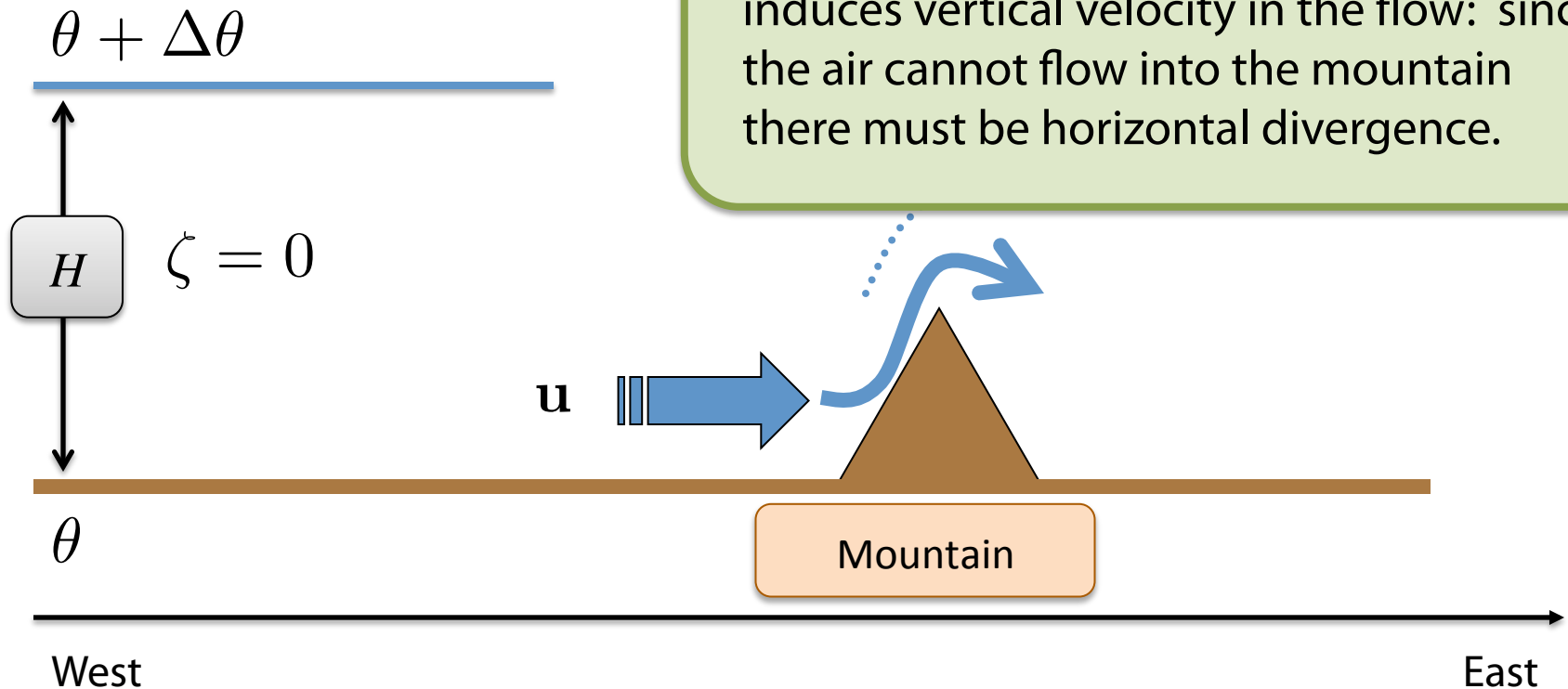
Answer: Air must be lifted. The mountain induces vertical velocity in the flow: since the air cannot flow into the mountain there must be horizontal divergence.



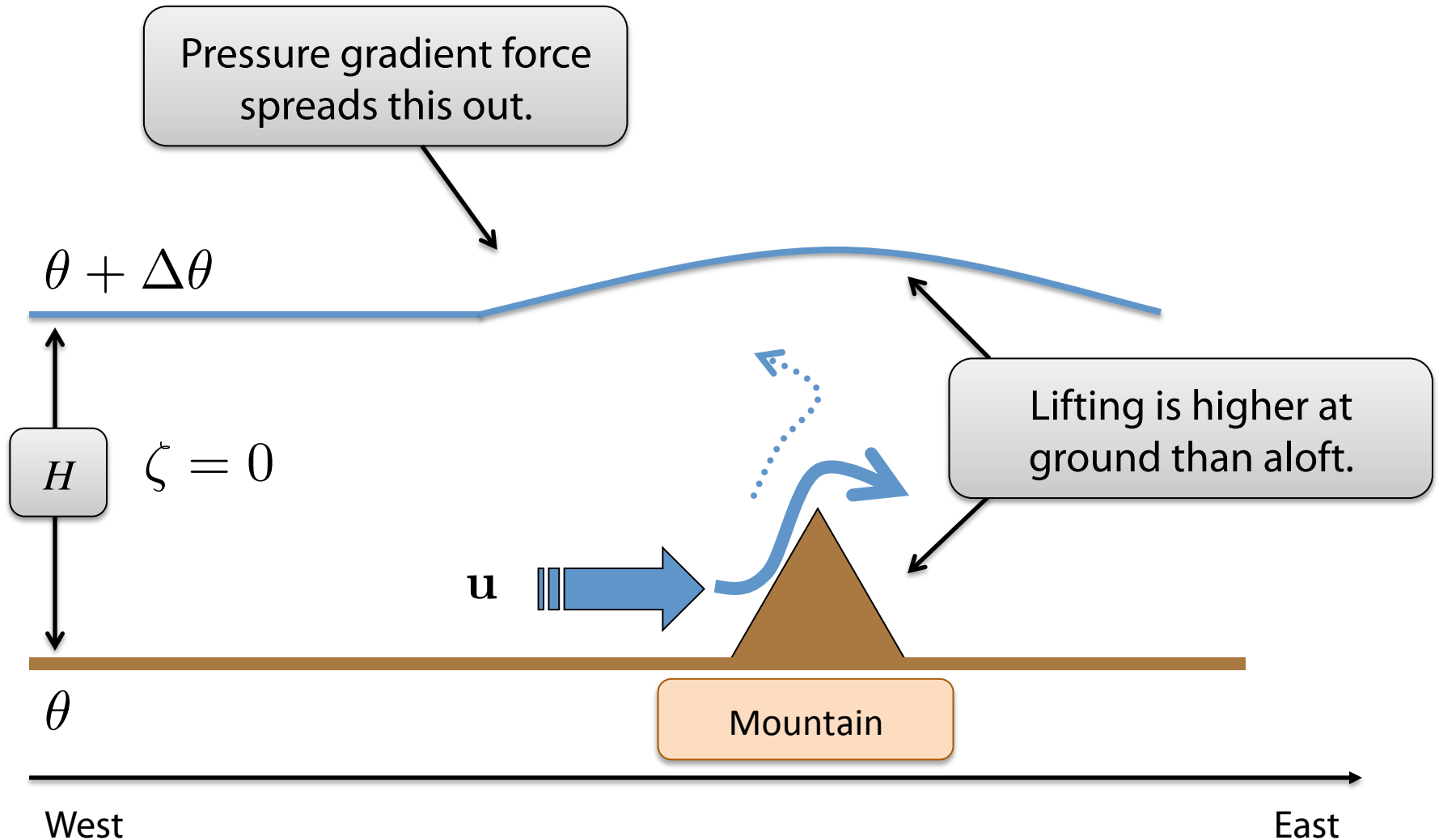
Flow Over a Mountain

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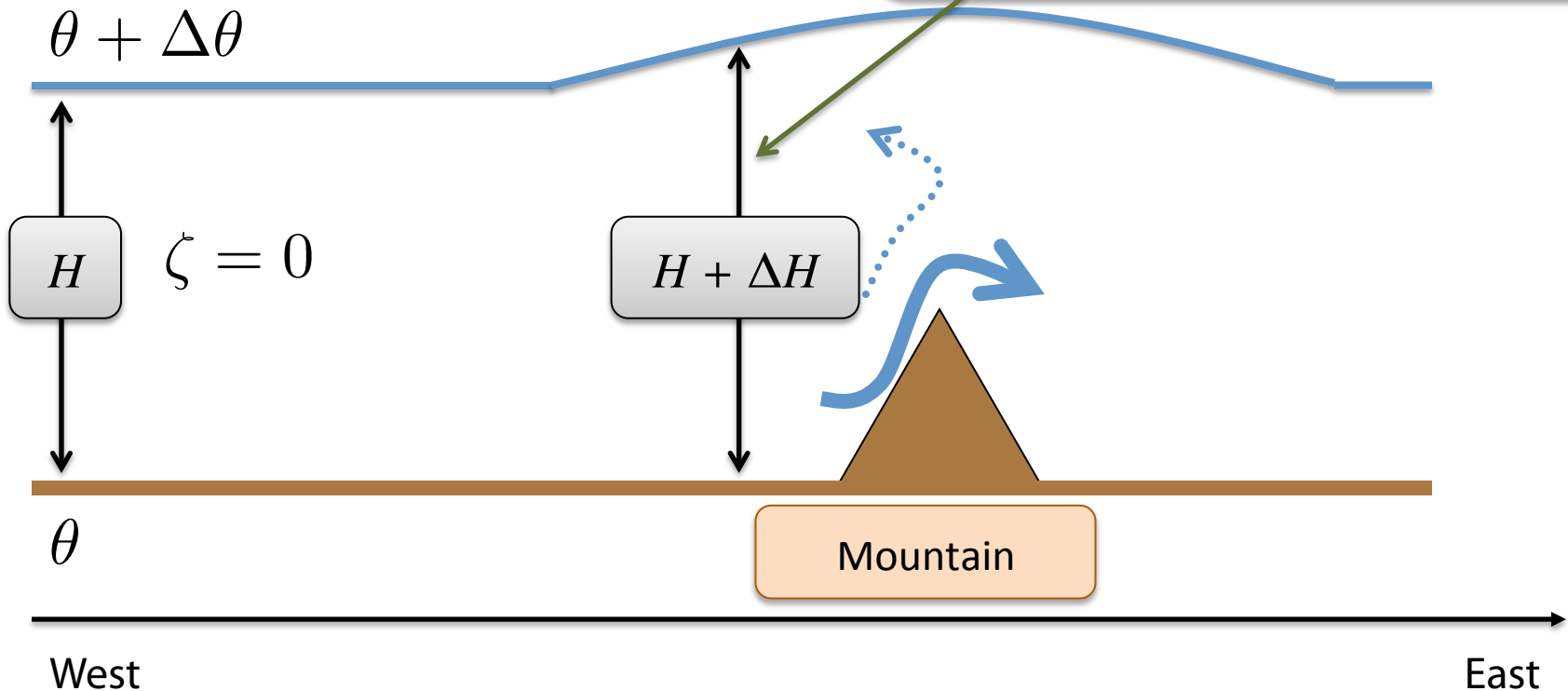
Flow Over a Mountain



Flow Over a Mountain

$$\frac{D_h}{Dt} \left[\frac{\zeta_g + f}{h} \right] = 0$$

Observe: By conservation of PV, ζ must increase here

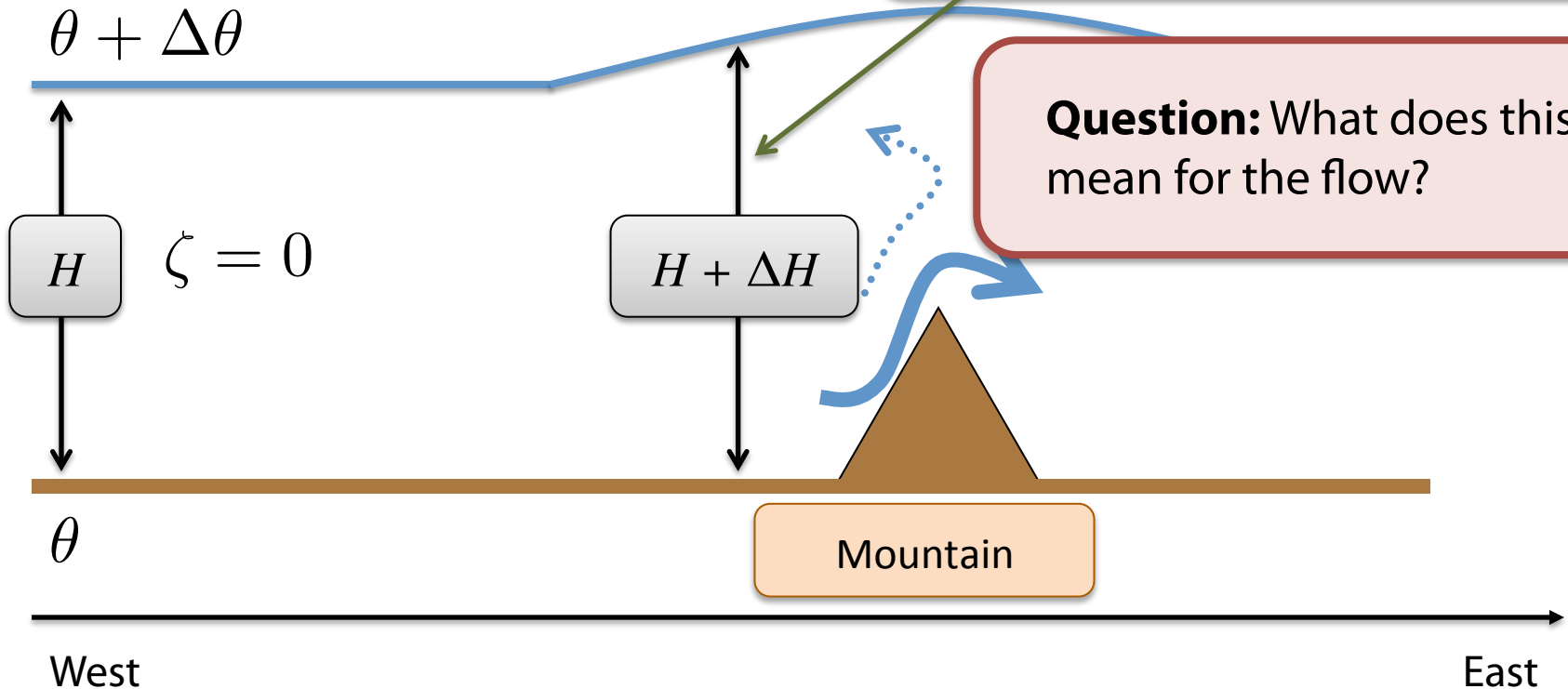


Flow Over a Mountain

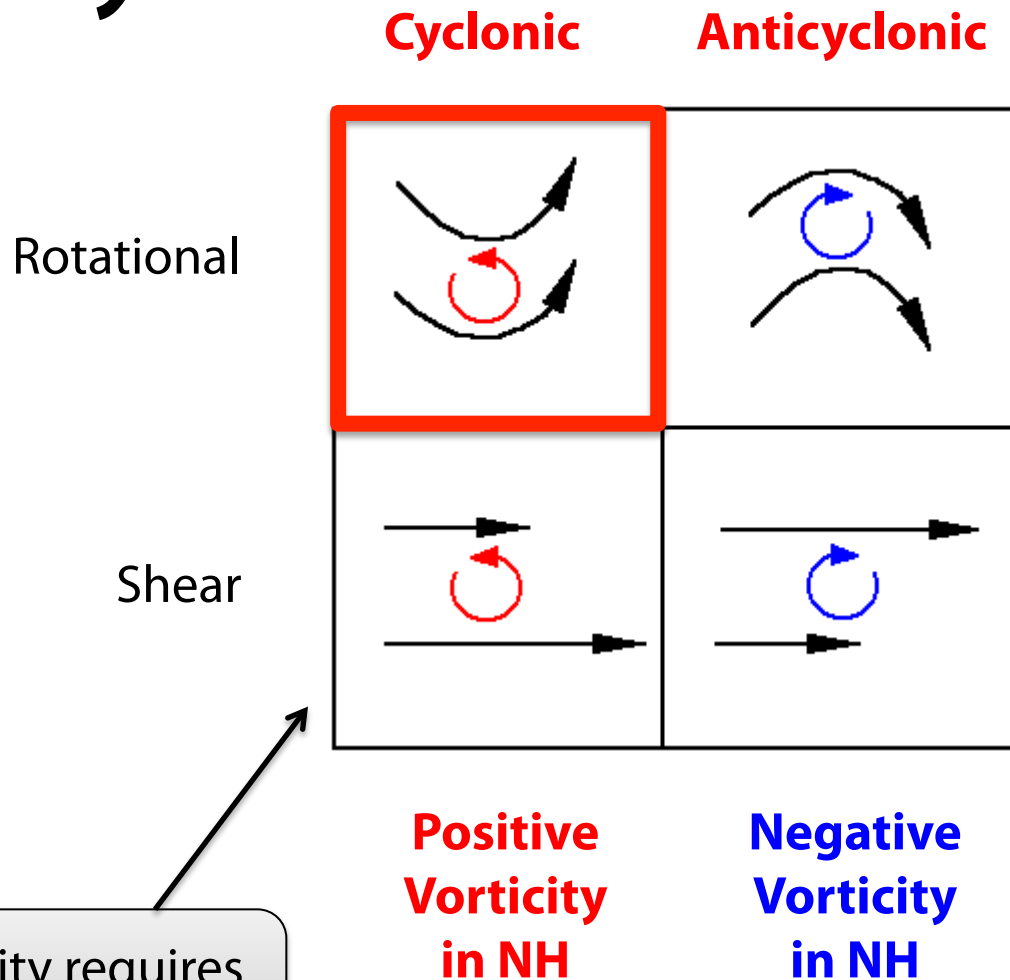
$$\frac{D_h}{Dt} \left[\frac{\zeta_g + f}{h} \right] = 0$$

Observe: By conservation of PV, ζ must increase here

Question: What does this mean for the flow?



Vorticity

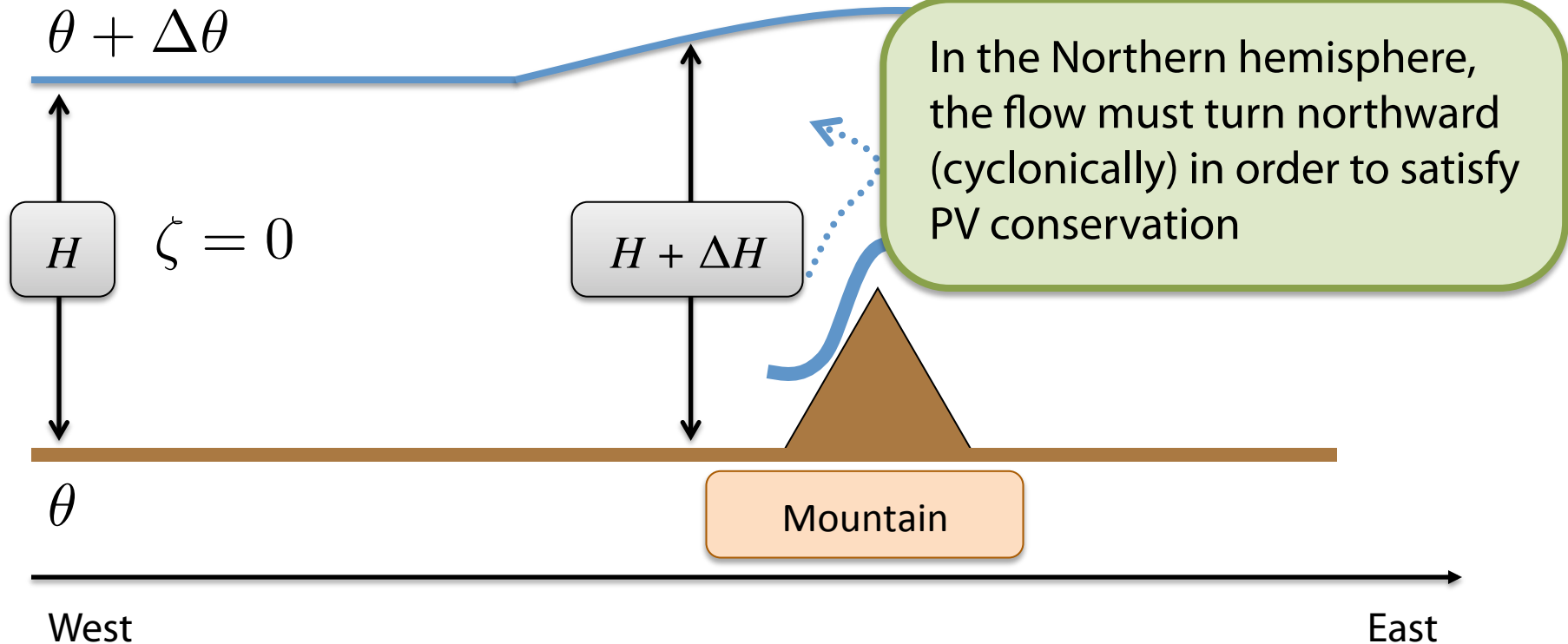


Shear vorticity requires meridional asymmetry

Flow Over a Mountain

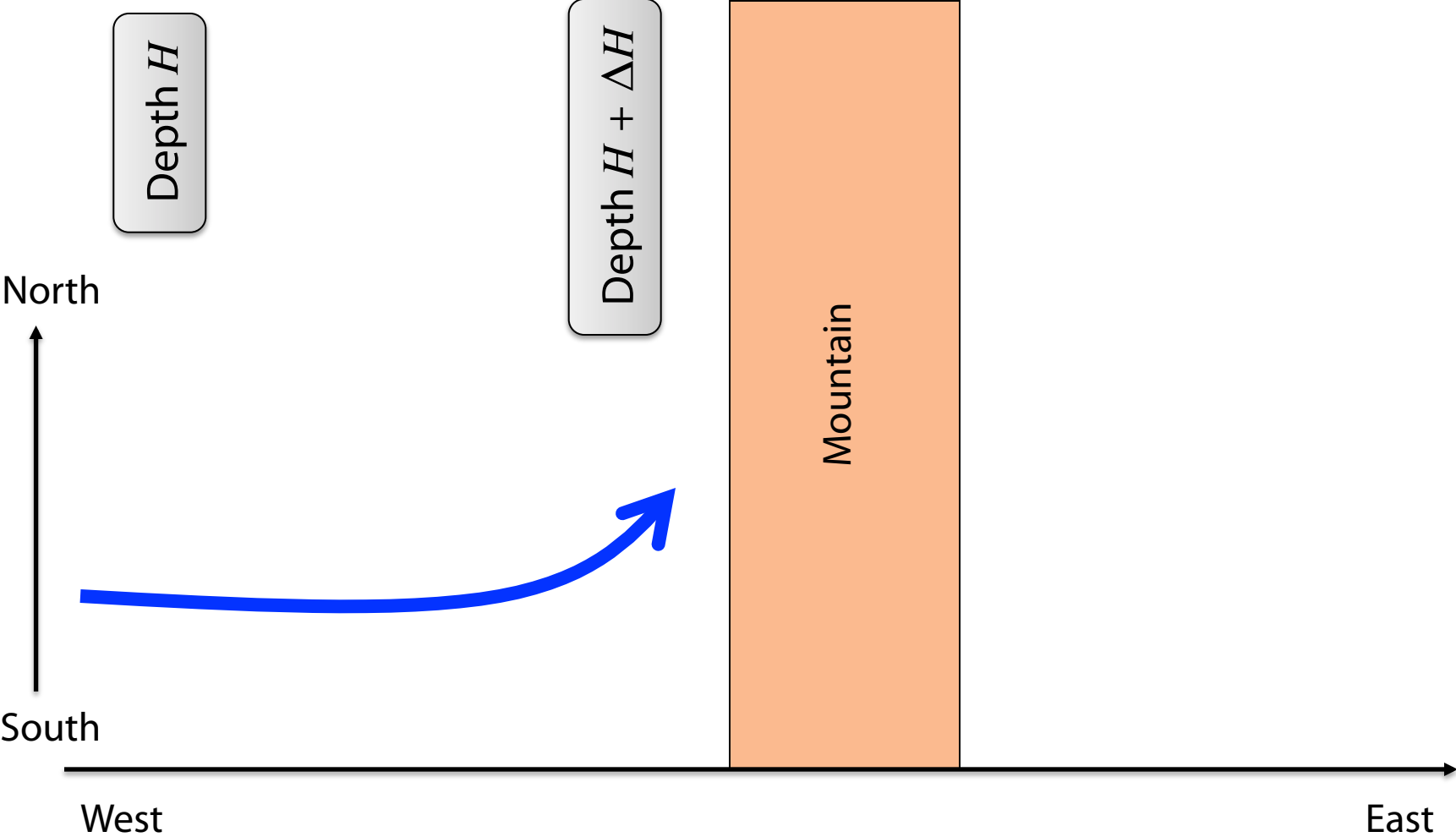
Question: What happens to air as it hits the mountain?

By conservation of PV, ζ must increase here.



Flow Over a Mountain

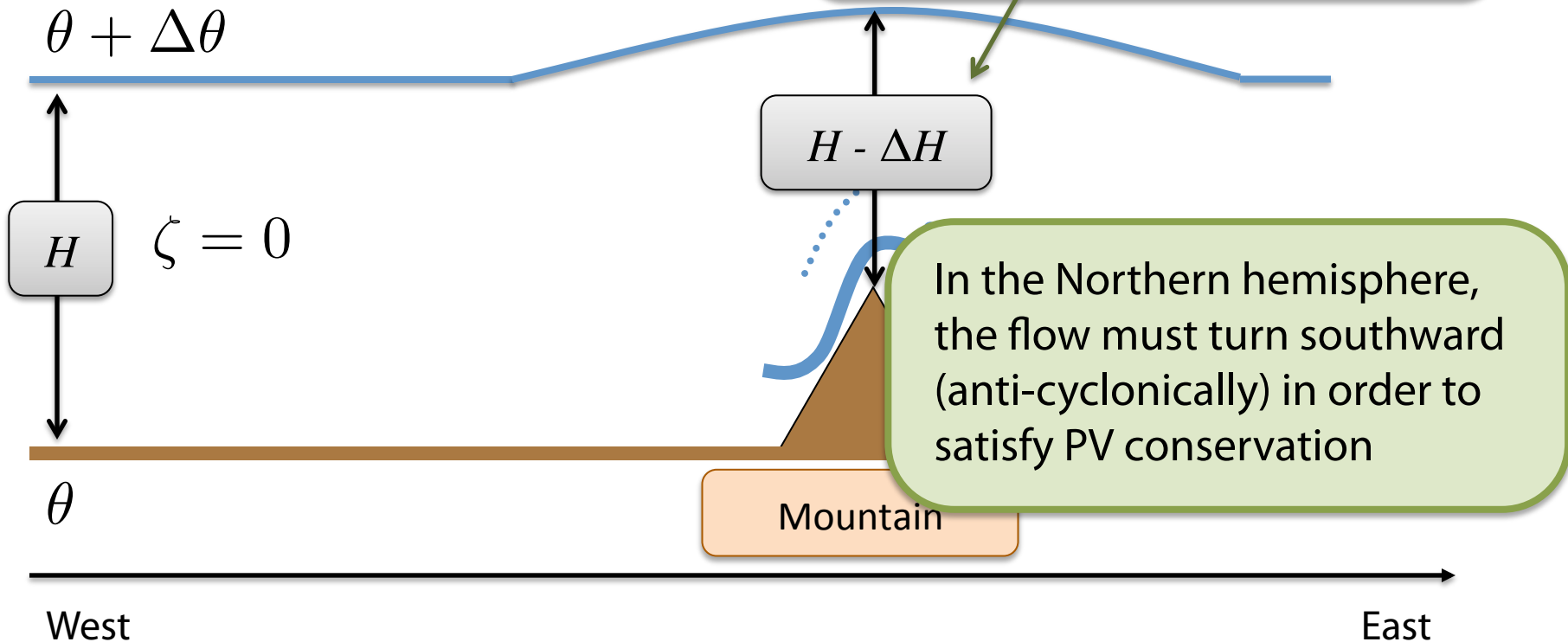
Looking down from above



Flow Over a Mountain

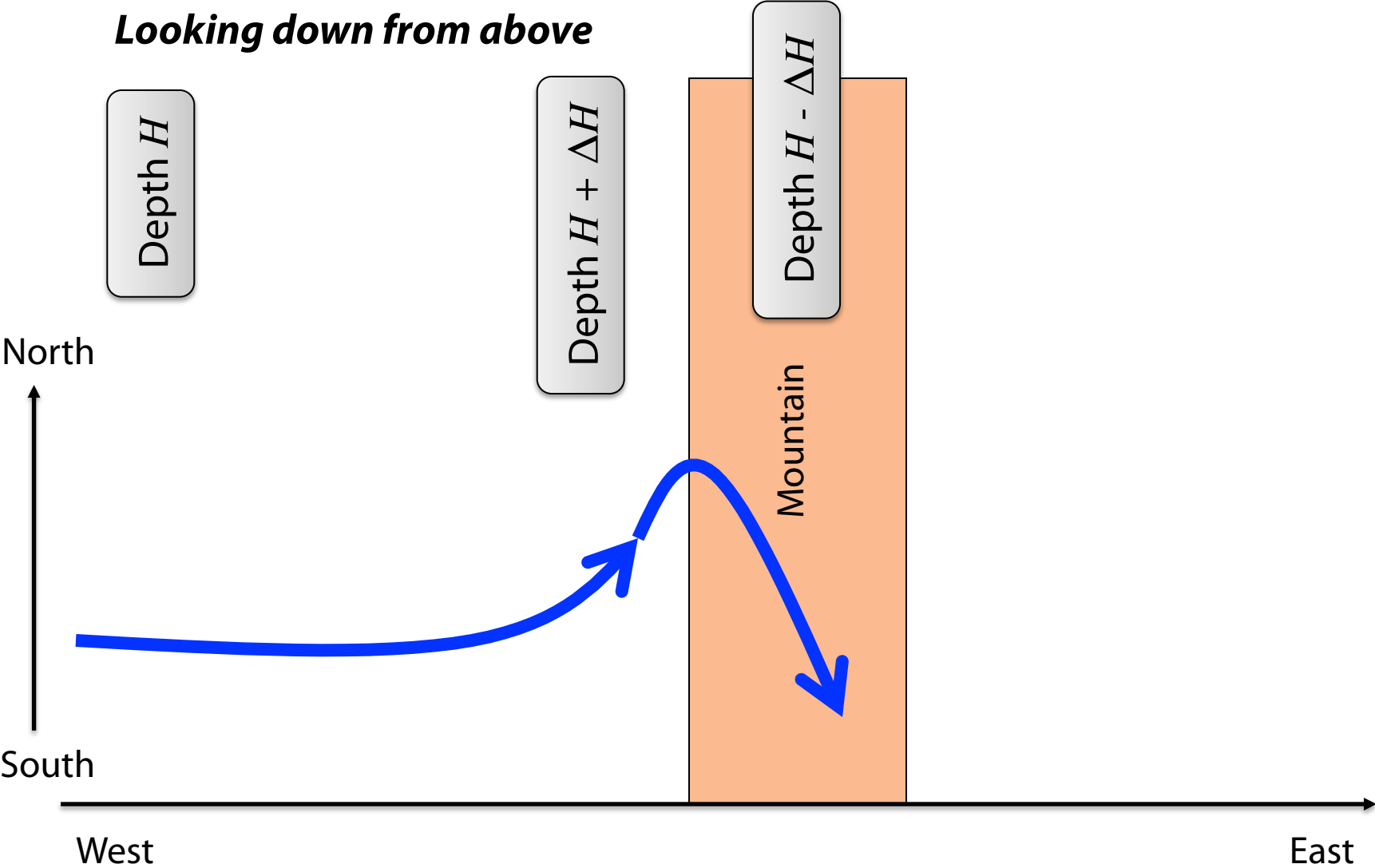
$$\frac{D_h}{Dt} \left[\frac{\zeta_g + f}{h} \right] = 0$$

Observe: By conservation of PV, ζ must decrease here



Flow Over a Mountain

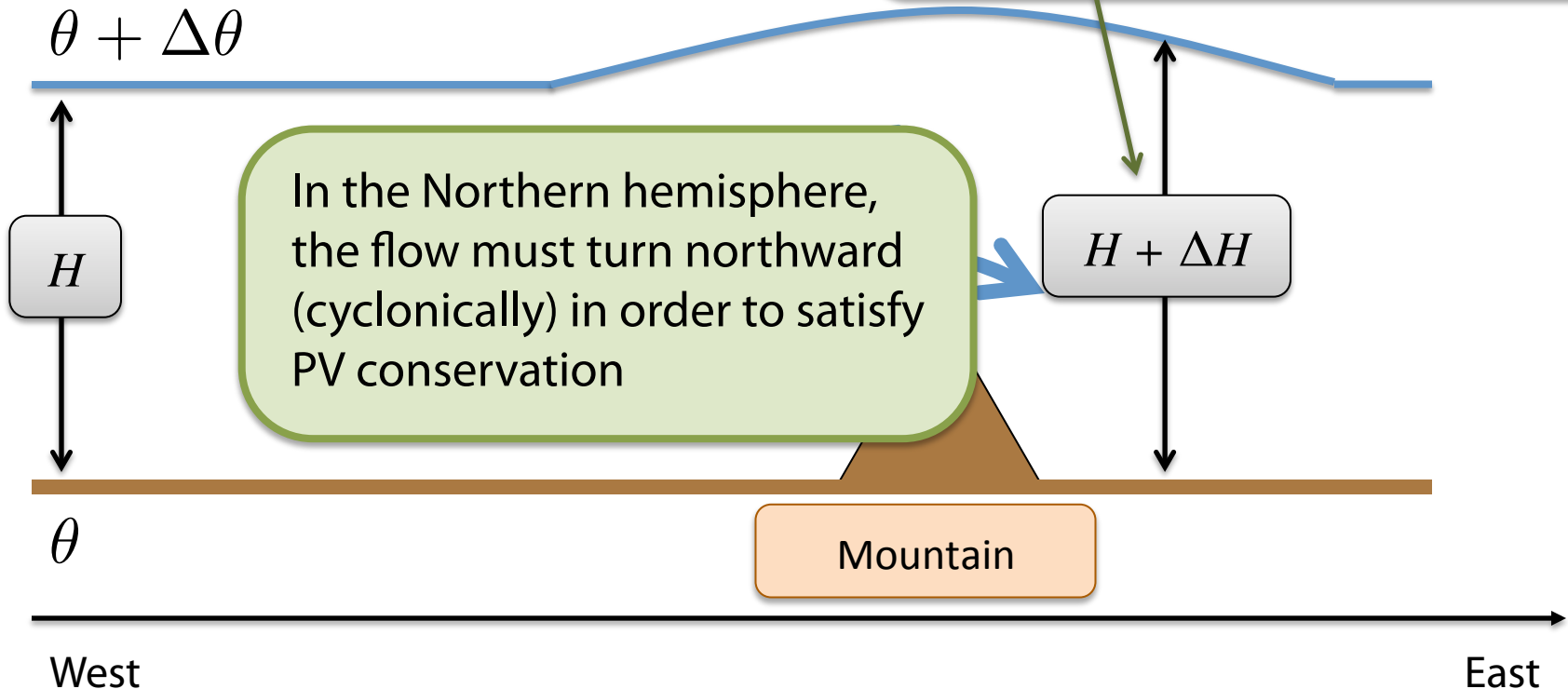
Looking down from above



Flow Over a Mountain

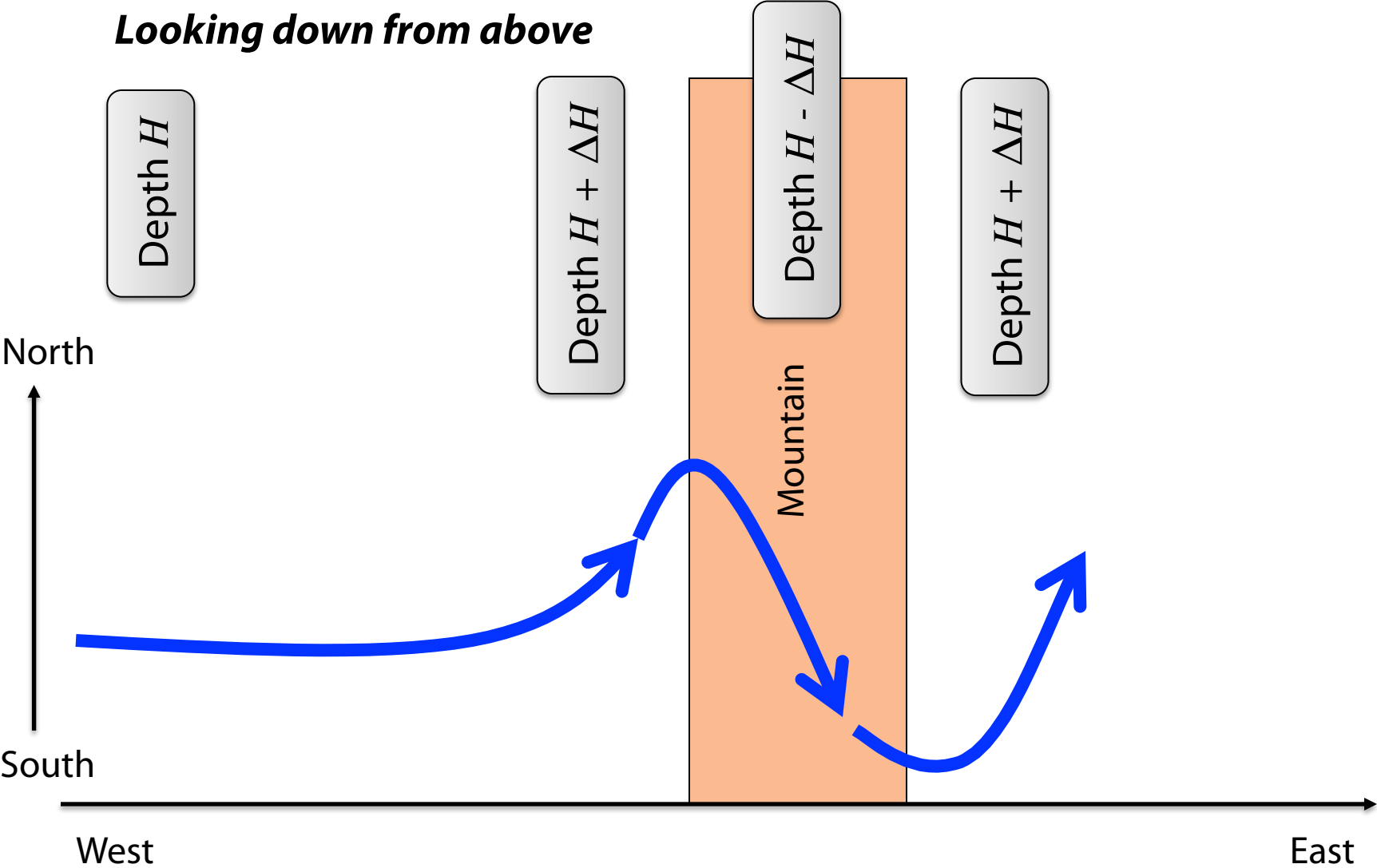
$$\frac{D_h}{Dt} \left[\frac{\zeta_g + f}{h} \right] = 0$$

Observe: By conservation of PV, ζ must again increase here



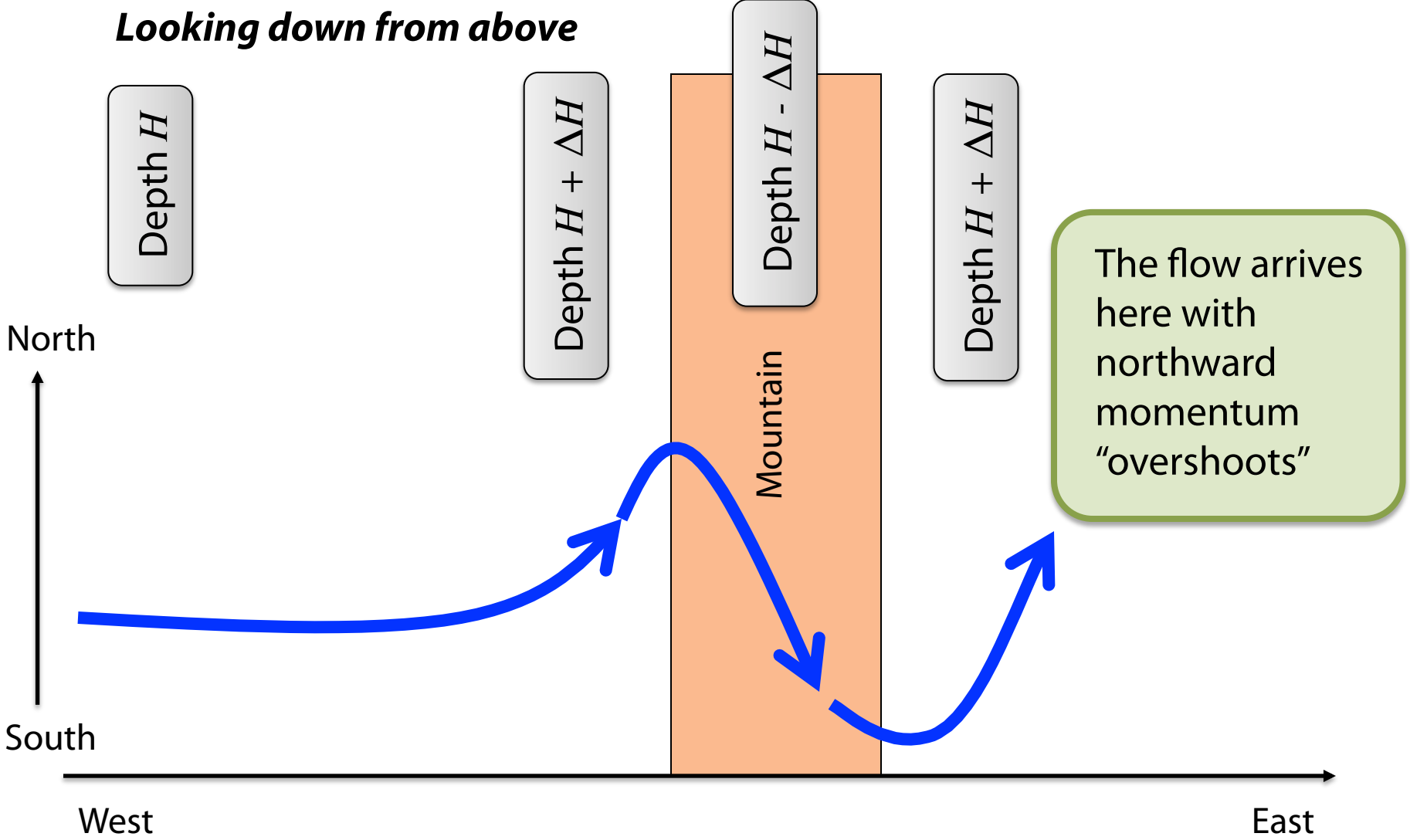
Flow Over a Mountain

Looking down from above



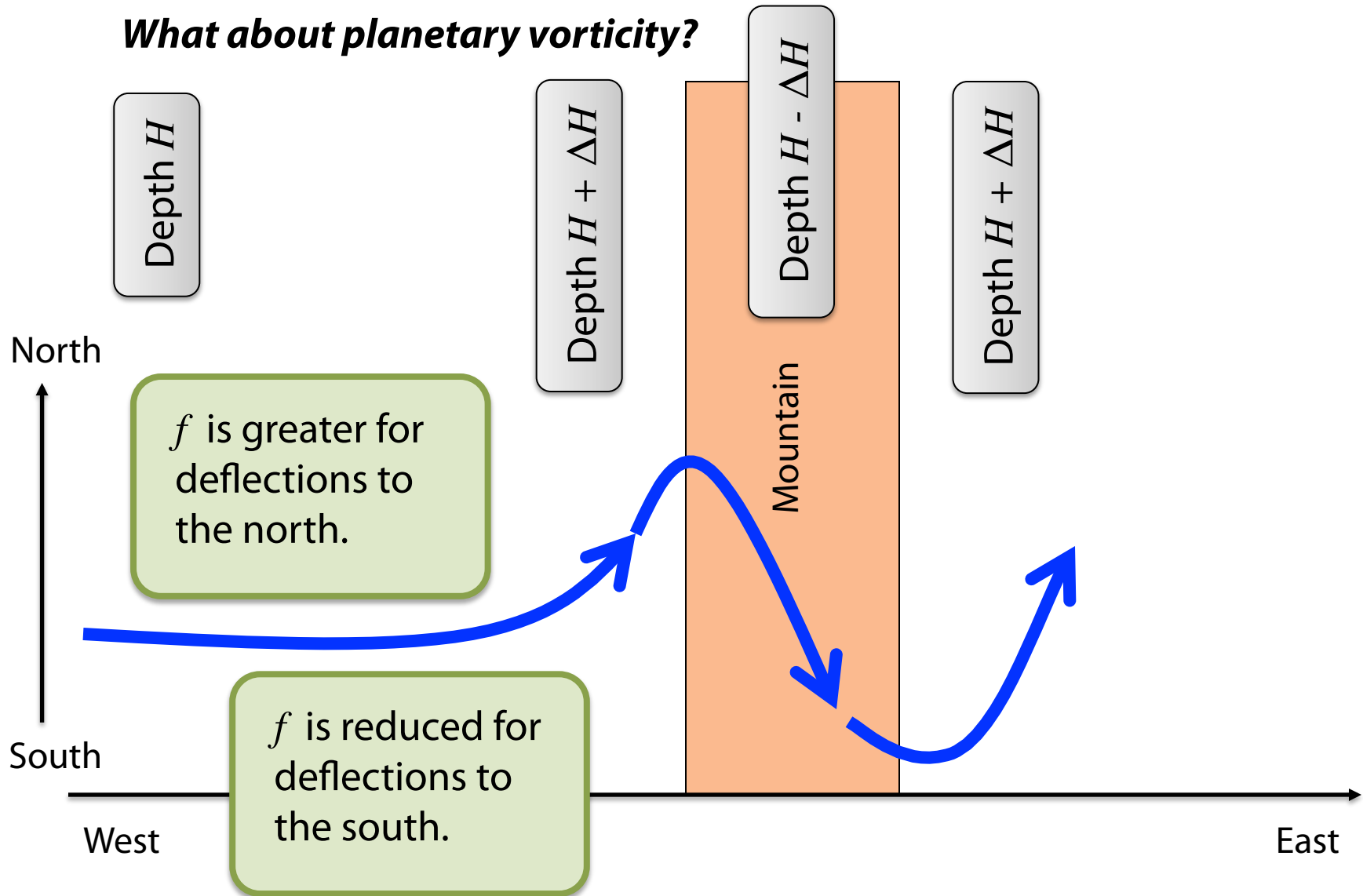
Flow Over a Mountain

Looking down from above



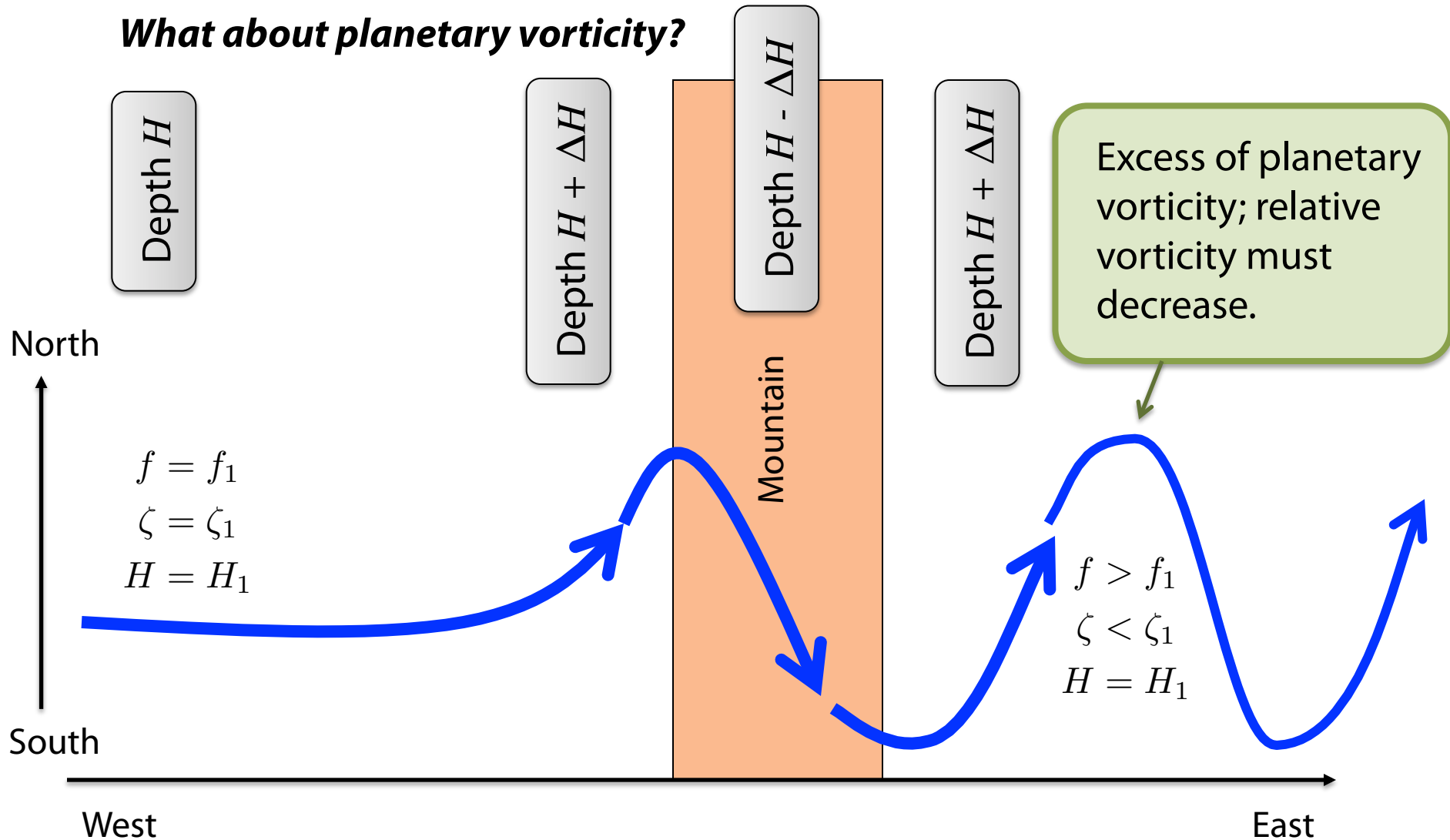
Flow Over a Mountain

What about planetary vorticity?

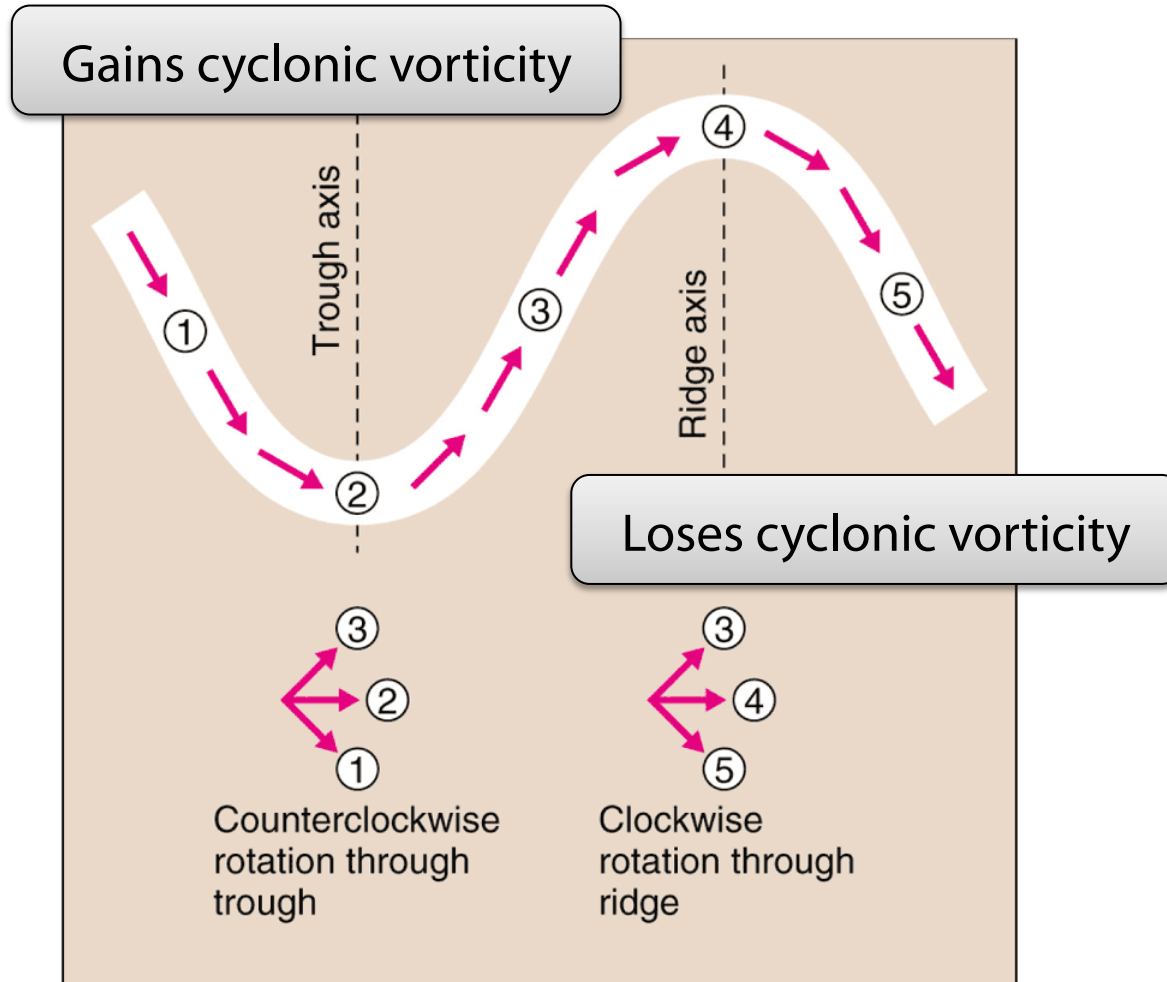


Flow Over a Mountain

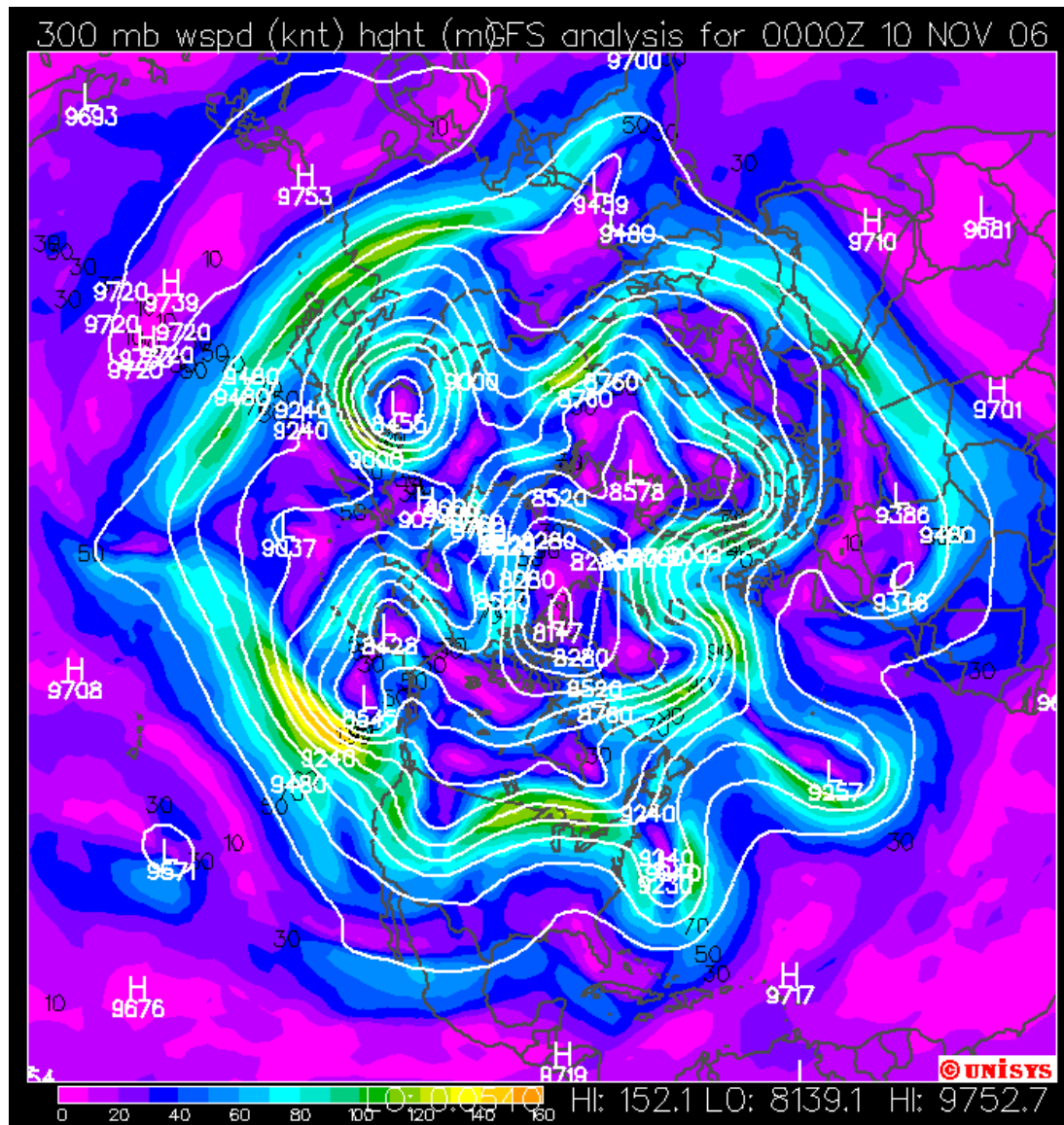
What about planetary vorticity?



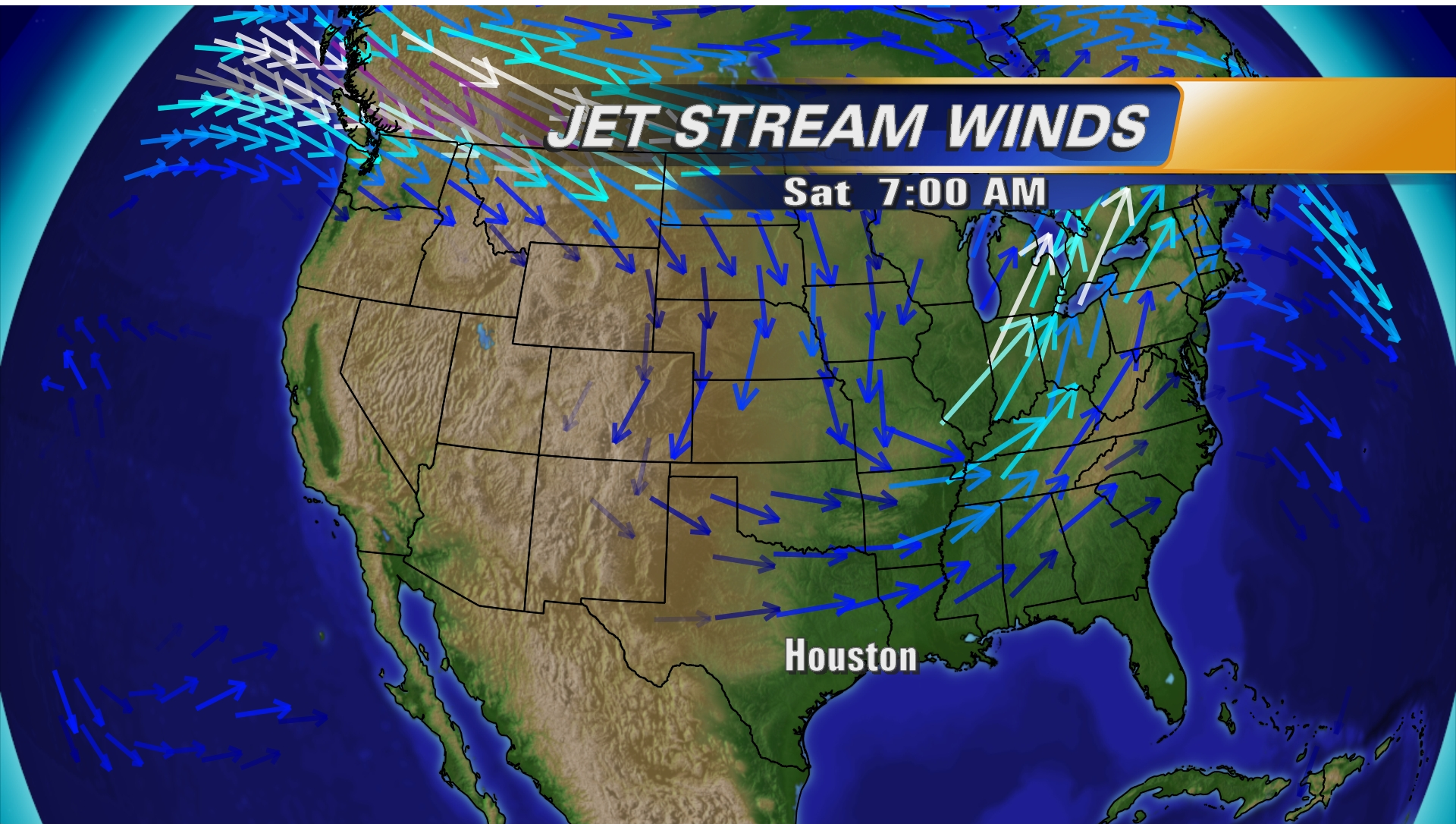
Atmospheric Waves



Atmospheric Waves



"Alberta Clipper"



Flow Over a Mountain

Question: What if the flow is from the East?

