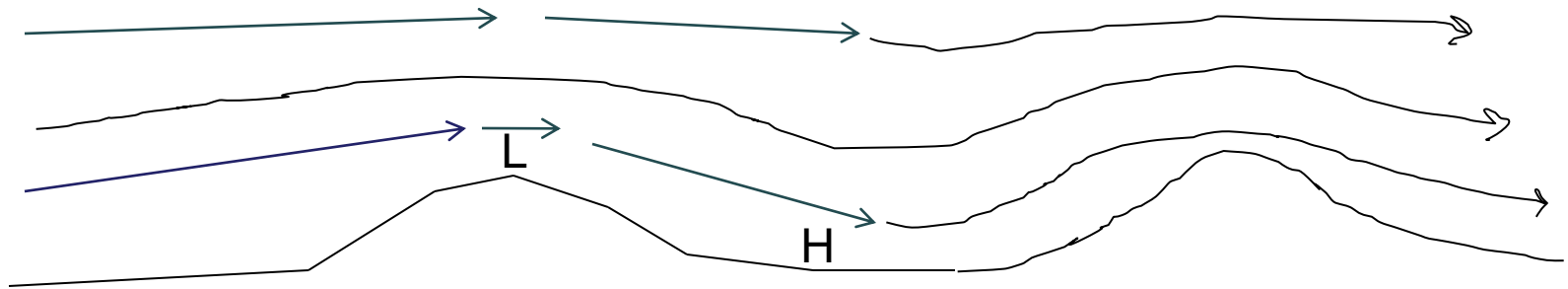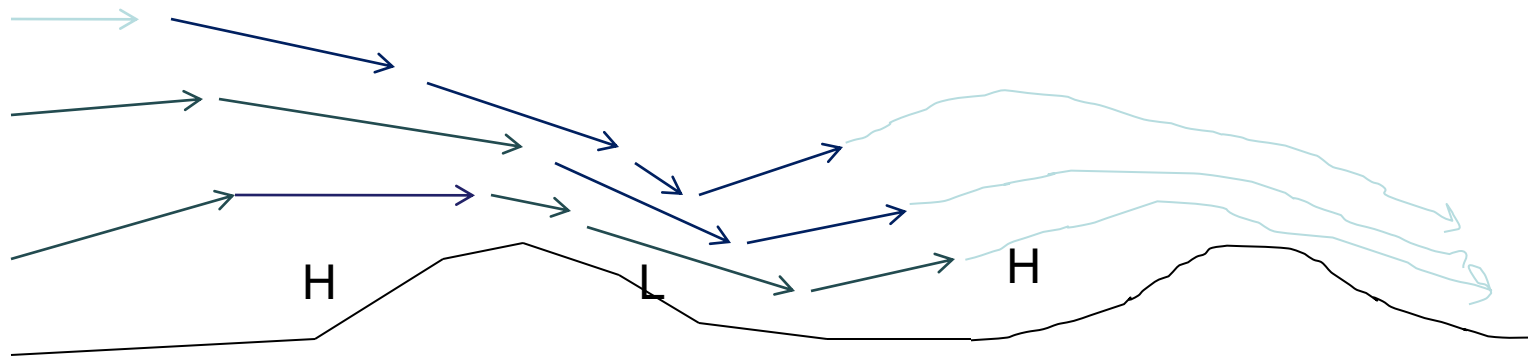# Flow blocking effects

When will air go over a mountain versus being blocked?

- Consider smooth area of flow over a hill

•If the flow is faster over the top of the mountain, PGF and gravity act in opposite directions on the lee side, and we have a supercritical flow situation. Note that the effect of the mountain on the flow will damp out with height.

- Opposite situation

H   L   H

•If the flow is slower approaching the top of the mountain, PGF and gravity act in the same directions on the lee side, and we have a subcritical flow situation. Note that the effect of the mountain is to produce waves that propagate upward and upstream in the atmosphere.

Froude Number

- The Froude number is often used to determine if flow will be supercritical or subcritical.

- Fr=2πU/NL   and if Fr > 1 things are supercritical, and if Fr < 1, subcritical.

- In subcritical cases, flow on lee side of mountain is faster than upwind side, and a hydraulic jump is possible.

Flow blocking

- Consider the special case of a parcel that is JUST able to make it to the ridge top. Then,

- $\frac{1}{2} N^2 h^2 = -1/2 \, (U^2(z_2) - U^2(z_1))$

- Or $N^2 h^2 = U^2(z_1)$ or $U/Nh = 1$

- This U/Nh is a type of Froude number, and this is the inverse of our "nonlinearity factor" Nh/U.

- If this is less than 1, then in a 3D case, flow goes around the mountain (lee eddies and vortex shedding occur)
- If 2D, upstream blocking occurs with a dividing streamline $h_c=h(1-Fr)$
- Sample problems where this is important:

  -- air pollution dispersion

  -- cold air damming

Barrier Jets

- Assume we have a background synoptic state that is in geostrophic balance…

$0 = -1/\rho\ \partial p_s/\partial x + fv_{gs}$

$0 = -1/\rho\ \partial p_s/\partial y - fu_{gs}$

Then we can write momentum equations as

$Du/dt = -1/\rho\ \partial p/\partial x + fv = -1/\rho[(\partial p/\partial x)_s + \partial p'/\partial x] + f(v_{gs} + v')$

$Dv/dt = -1/\rho[(\partial p/\partial y)_s + \partial p'/\partial y] - f(u_{gs} + u')$

- We can take advantage of the geostrophic balance of the synoptic state to get:

$Du/dt = -1/\rho(\partial p'/\partial x) + fv'$

$Dv/dt = -1/\rho(\partial p'/\partial y) - fu'$

Consider uniform westerly synoptic flow (i.e. v_{gs} = 0) so all flow is in u direction. Now suppose that we get an accumulation of cold air on one side of the mountain. The initial response is a mesoscale pressure gradient ($\partial p'/\partial x > 0$) that opposes the background flow. As the flow slows down, we get $(u - u_{gs}) < 0$ so that $dv/dt > 0$ and the flow develops a southerly component.

- The southerly wind component is associated with a coriolis force $f(v-v_g)$ which opposes the mesoscale pressure gradient.

- We can eventually reach a balance where the mesoscale PGF is exactly balanced by the Coriolis force acting on the mesoscale flow perturbation:

  $0 = -1/\rho\,\partial p'/\partial x + fv'$ so that a perturbation wind blows **parallel** to the ridge.
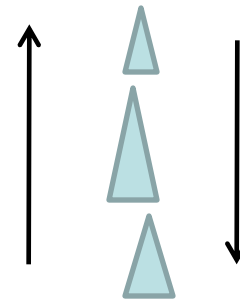
Barrier jets

Linear theory of Trapped Lee Waves

- Scorer divided the atmosphere into layers of different constant ℓ^2 values ($\ell^2=N^2/U^2$)

- If ℓ^2 upper less than lower $\rightarrow$ periodic lee waves develop. This would happen if wind speed increases with height or v. stable layer in lower atmosphere. In this case $k^2 \ll \ell^2$ and waves propagate upward and downstream. When $k^2 > \ell^2$ reflection occurs

Downslope winds and rotors

Higher mountains lead to nonlinear flow and possibly rotor clouds where flow reverses downwind

Downslope windstorms are not fully understood and several theories exist to explain their occurrence.
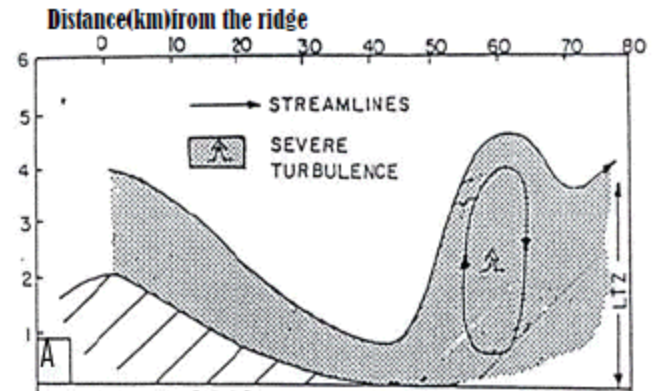
# Downslope Windstorms (more info at http://www.atmos.washington.edu/2008Q4/505/ Lab6_downslope_winds.pdf

- One idea is wave breaking (recall that subcritical flow situations have strong winds on lee side of mtns)

- Hydraulic Jump – midlevel inversion can cause this jump if $Fr = U/(gH)^{0.5} < 1$ but not too small.

- Subcritical to supercritical flow transition over mountain could also create a downslope windstorm
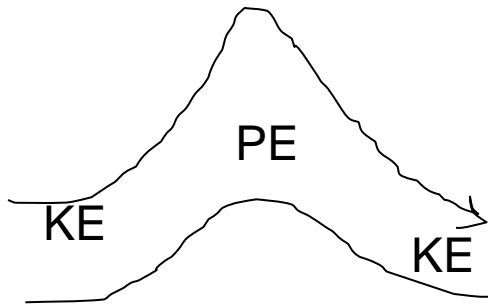
Supercritical has KE convert to PE at mtn top and then back to KE on lee side
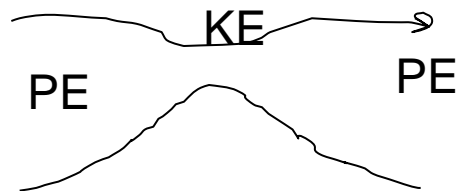
Subcritical has PE convert to KE to go over mountain and then back to PE
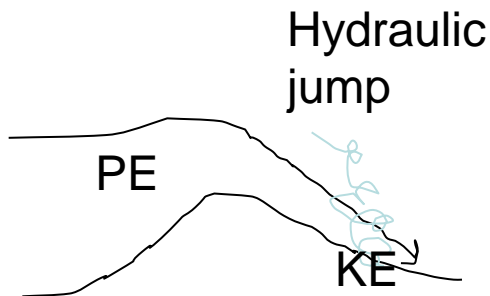
In a transition zone, much stronger winds might occur