

## Cold-air damming

When a cold anticyclone is located to the north of an approximately north-south oriented mountain range in winter, a pool of cold air may become entrenched along the eastern slope and form a cold dome capped by a sloping inversion underneath warm easterly or southeasterly flow. This phenomenon has been observed over the Appalachian Mountains and the Front Range of the Rocky Mountains and is referred to as cold air damming.

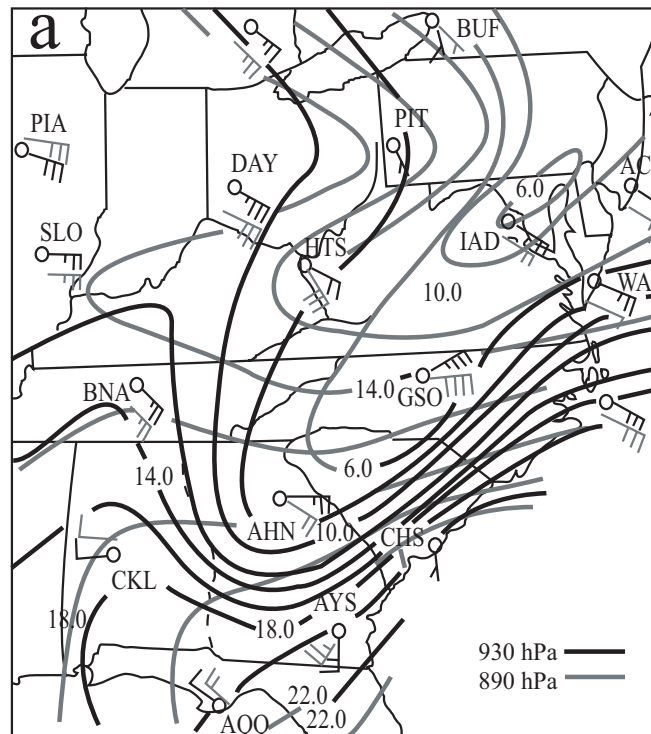
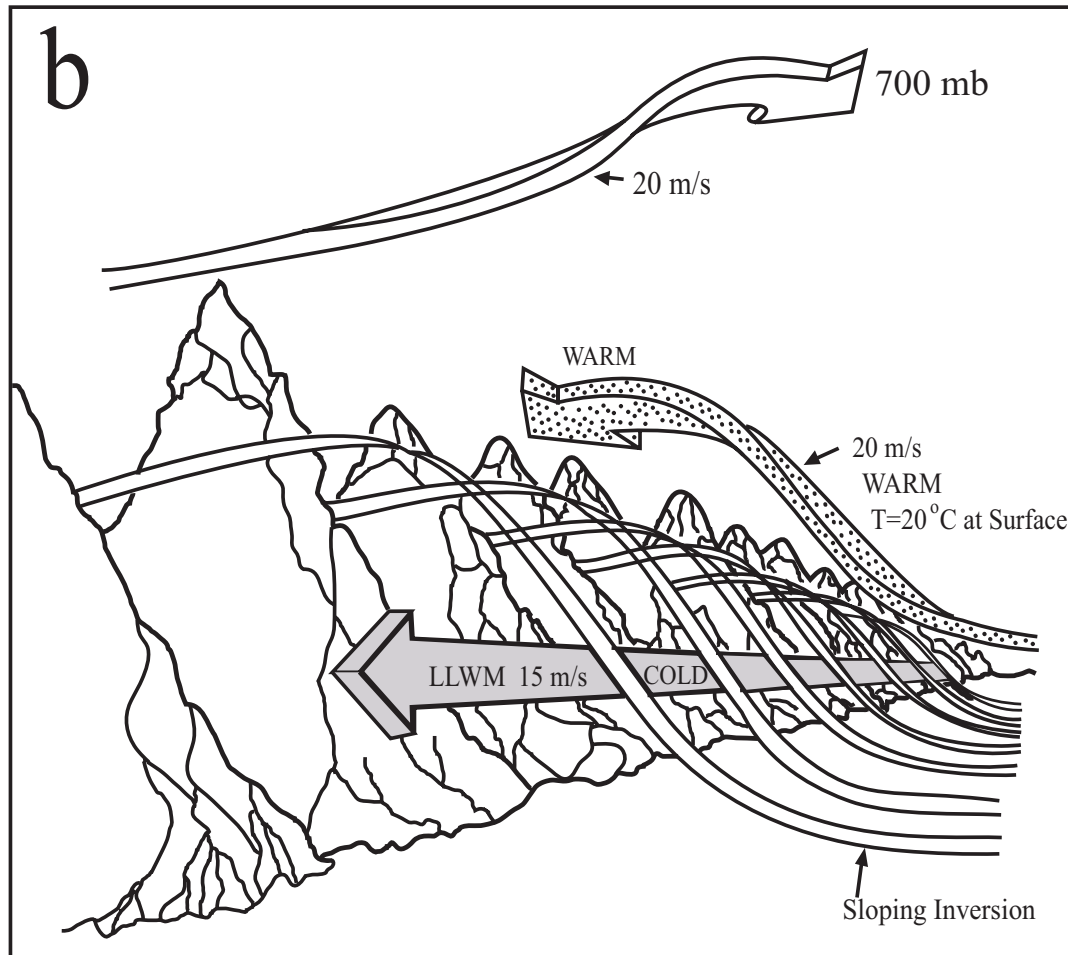


Figure: The 930 hPa height (in m, dark solid) and 890 hPa potential temperature ( $^{\circ}\text{C}$ , grey solid) fields valid at 1200 UTC 22 March 1985. Winds are in  $\text{ms}^{-1}$  with one full barb and one pennant representing  $5 \text{ ms}^{-1}$  and  $25 \text{ ms}^{-1}$ , respectively.

The above figure shows the surface geopotential temperature field at 1200 UTC 22 March 1985 at the mature phase of a cold-air damming event that occurred to the east of the U.S. Appalachian Mountains.

- In the initiation phase, a surface low pressure system moved from the Great Lakes northeastward and the trailing anticyclone moved southeastward to central New York.
- The cold, dry air was then advected by the northeasterly flow associated with the anticyclone.
- The air parcels ascending the mountain slopes experienced adiabatic cooling and formed a *cold dome*, while those over the ocean were subjected to differential heating when they crossed the Gulf Stream toward the land.
- At the mature phase, the surface anticyclone remained relatively stationary in New York and the cold air was advected southward along the mountain slopes within the cold dome.



Conceptual model of a mature cold-air damming event. LLWM stands for low-level wind maximum. (Adapted after Bell and Bosart 1988)

A conceptual model of the cold-air damming occurred to the east of the Appalachian Mountains at the mature phase.

- The low-level wind (LLWM in the figure) moved southward at a speed of about  $15 \text{ ms}^{-1}$  within the cold dome.
- The cold dome was capped by an inversion and an easterly or southeasterly flow associated with strong warm advection into the warm air existed above the dome.
- Moving further aloft to 700 mb, the wind flows from south or southwest associated with the advancing short-wave trough west of the Appalachians.

The cold-air damming process can be divided into the initiation and mature phases.

- During the initiation phase, the low-level easterly flow adjusts to the mountain-induced high pressure and develops a northerly *barrier jet* along the eastern slope of the mountain range, similar to that shown in the first figure except for the basic flow direction.
- Because the upper-level flow is from the southwest, it provides a cap for the low-level flow to climb over to the west side of the mountain.
- In the mean time, a cold dome develops over the eastern slope due to the cold air supplied by the northerly barrier jet, adiabatic cooling is associated with the upslope flow, and/or the evaporative cooling.
- In the mature stage, the frictional force plays an essential role in establishing the steady-state flow with the cold dome (Xu et al. 1996). See next figures.
- It was found that the cold dome shrinks as the Froude number ( $U/Nh$ ) increases or, to a minor degree, as the *Ekman number* ( $\nu/(fh^2)$ ), where  $\nu$  is the coefficient of eddy viscosity) decreases and/or the upstream inflow veers from northeasterly to southeasterly.
- The northerly barrier jet speed increases as the Ekman number decreases and/or the upstream inflow turns from southeasterly to northeasterly or, to a lesser degree, as the Froude number decreases.

The following figures are from Xu et al (1996, JAS).

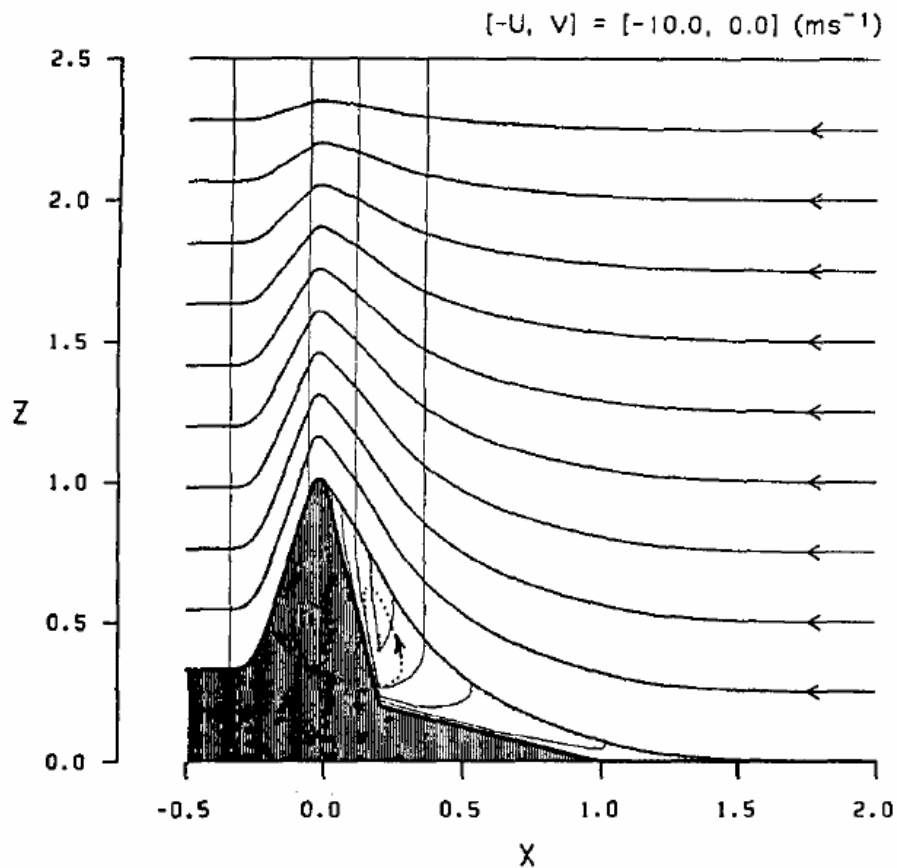


FIG. 10. The internal flow structure for the solution with an Appalachian-type mountain profile. The parameter settings are as in Fig. 5, but with fixed  $Fr = 0.5$ . The streamline  $\psi$  contours are thick solid and drawn every 0.25 (dimensional  $2500 \text{ m}^2 \text{ s}^{-1}$ ). The mountain-parallel wind  $v$  contours are thin solid and drawn every 0.25 (dimensional  $2.5 \text{ m s}^{-1}$ ) and the maximum intensity of the mountain-parallel jet in the cold dome is 1.14 ( $11.4 \text{ m s}^{-1}$ ). The secondary transverse circulation in the cold dome is very weak and shown by dashed streamline contours every 0.001.

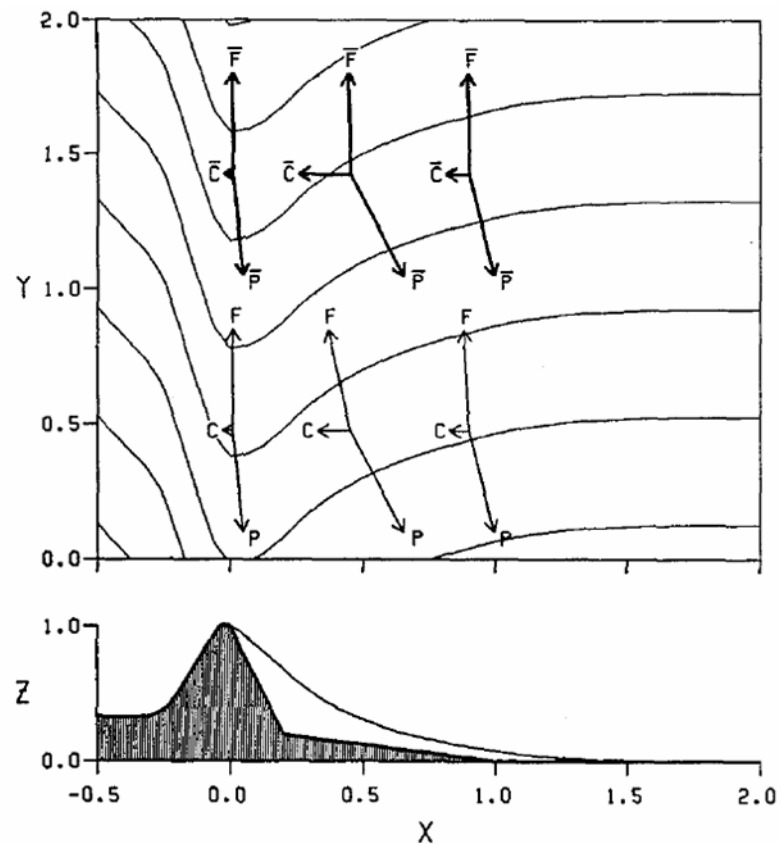


FIG. 12. Sea level pressure (computed by assuming that the cold air occupies the mountain volume above the sea level), vertically-averaged force balance (thick arrows in the upper row) in the cold dome, and force balance (thin arrows in the lower row) at the anemometer level ( $15 \text{ m}$  above the ground  $Hh_0$ ) for the solution in Fig. 10. The pressure contours are drawn every 0.4 (dimensional  $2 \text{ mb}$ ). The vertically-averaged Coriolis force, pressure gradient, and frictional force [see (5.2)] are labeled  $\bar{C}$ ,  $\bar{P}$ , and  $\bar{F}$ , respectively. The Coriolis force, pressure gradient, and frictional force at the anemometer level are labeled  $C$ ,  $P$ , and  $F$ , respectively. The mountain-parallel (along  $y$ ) components for  $\bar{P}$ ,  $\bar{F}$ ,  $P$  and  $F$  are all of unit length; i.e.,  $fU = 10^{-3} \text{ m s}^{-2}$ . The mountain profile and cold dome are also shown for reference in the lower panel.

### *Gap flow*

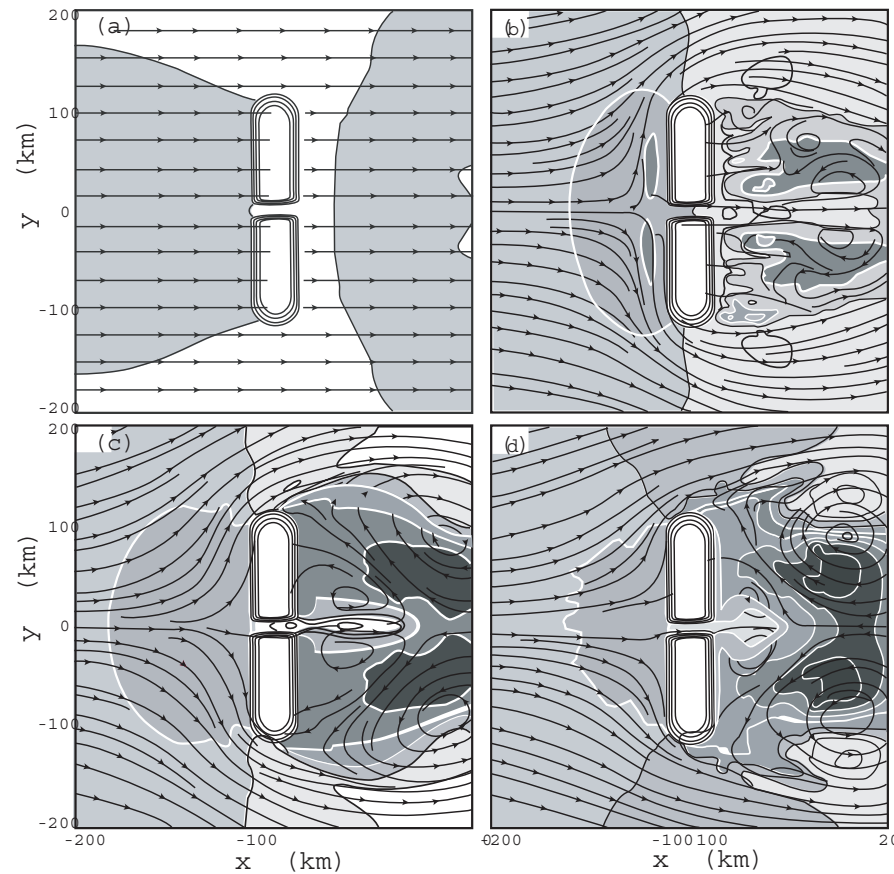
When a low-level wind passes through a gap in a mountain barrier or a channel between two mountain ranges, it can develop into a strong wind due to the acceleration associated with the pressure gradient force across the barrier or along the channel.

- *Gap flows* are found in many different places in the world, such as the Rhine Valley of the Alps, Senj of the Dinaric Alps, Independence, California, in the Sierra Nevada, and Boulder, Colorado, on the lee side of the Rockies (Mayr 2005).
- Gap flows occurring in the atmosphere are also known as mountain-gap wind, jet-effect wind or canyon wind.
- The significant pressure gradient is often established by (a) the geostrophically balanced pressure gradient associated with the synoptic-scale flow and/or (b) the low-level temperature differences in the air masses on each side of the mountains.

Based on Froude number ( $F = U / Nh$ ), three gap-flow regimes can be identified:

- (1) linear regime (large  $F$ ): with insignificant enhancement of the gap flow;
- (2) mountain wave regime (mid-range  $F$ ): with large increases in the mass flux and wind speed within the exit region due to downward transport of mountain wave momentum above the lee slopes, and where the highest wind occurs near the exit region of the gap; and
- (3) upstream-blocking regime (small  $F$ ): where the largest increase in the along-gap mass flux occurs in the entrance region due to lateral convergence (Gaberšek and Durran 2004).

Gap flows are also influenced by frictional effects which imply that: (1) the flow is much slower, (2) the flow accelerates through the gap and upper part of the mountain slope, (3) the gap jet extends far downstream, (4) the slope flow separates, but not the gap flow; and (5) the highest winds occur along the gap (Zängl 2002).



Horizontal streamlines and normalized perturbation velocity  $(u - U)/U$  at  $z = 300$  m and  $Ut/a = 40$ , for flow over a ridge with a gap when the Froude number  $(U/Nh)$  equals (a) 4.0, (b) 0.72, (c) 0.36, and (d) 0.2. The contour interval is 0.5; dark (light) shading corresponds to negative (positive) values. Terrain contours are every 300 m. (From Gaberšek and Durran 2004)