METR 6413

Advanced Mesoscale Meteorology

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Mesoscale, orographically generated vortices in a stable boundary layer

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References:

Bosart, L. F., 1983: Analysis of a California Catalina eddy event. *Mon. Wea. Rev.*, **111**, 1619-1633.

Rasmussen, R. M., P. Smolarkiewicz, and J. Warner, 1989: On the dynamics of Hawaiin cloud bands: Comparison of model results with observations and island climatology. *J. Atmos. Sci.*, **46**, 1589-1608.

Smolarkiewicz, P. K. and R. Rotunno, 1989: Low Froude number flow past three-dimensional obstacles. Part I: Baroclinically generated lee vortices. *J. Atmos. Sci.*, **46**, 1154 - 1164.

A major criticism of the "mixed-layer" theory of the generation of mesoscale vortices in the boundary layer is that observations indicate that the wind profile is not really well mixed. It is not known to what extent the wind profile has to deviate from that of a truly well-mixed layer before "mixed-layer" theory is invalidated. There may be other explanations that can also explain the Denver Cyclone, which do *not* involve the mixed-layer mechansism. Numerical simulations of flow around topography have produced vortices in the absence of a boundary layer (e.g. Smolarkiewicz and Rotunno 1989).

Smolarkiewicz and Rotunno (1989), inspired by simulations of flow around an obstacle, which were intended to represent flow around Hawaii, found that if the Froude number is low, air flows partially over and around a bell-shaped obstacle (we will refer to the virtual obstacle as Mt. Bell, a dead "ringer" for real obstacles) and counter-rotating vortices are produced on the leeward side. Although the Froude number is less than unity at the top of the obstacle, it may be greater than unity along the sides, so flow is only

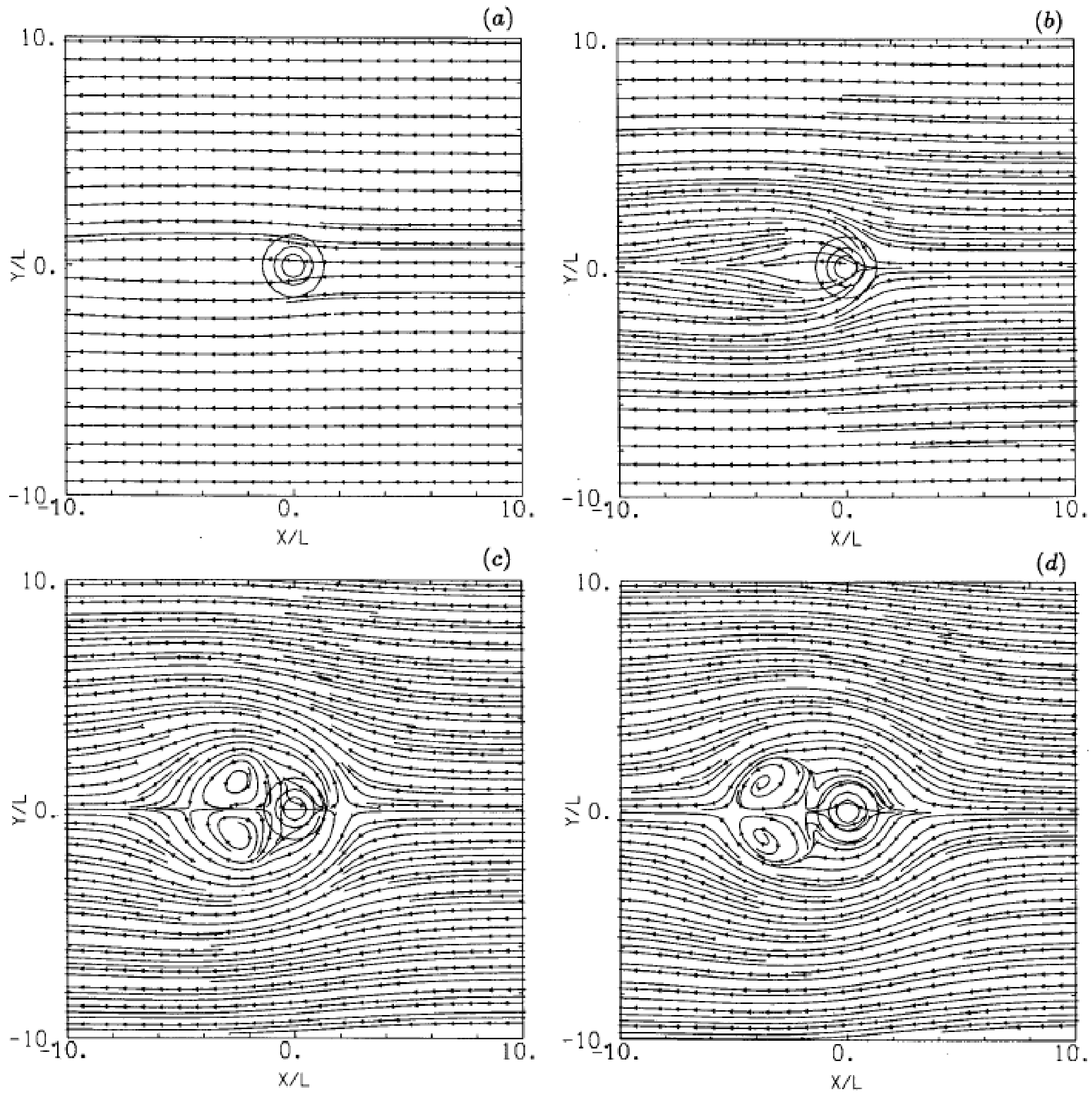

FIG. 1. Steady-state streamlines at the lower surface for Fr = (a) 2.2, (b) 0.66, (c) 0.22, and (d) 0.055. Concentric contours in the center of the domain represent the height of the obstacle with contour interval 0.25 h.

(from Smolarkiewicz and Rotunno 1989)

partially blocked. They found that the vortices were produced baroclinically around the upwind and downwind edges of Mt. Bell, where there is a horizontal potential-temperature gradient; baroclinically generated horizontal vorticity on the upwind side is then diverted around the sides and tilted onto the vertical as air descends in the lee of Mt. Bell. The source of the potential-temperature gradient is the disruption of the environmental potential-temperature field by the flow over Mt. Bell. Air cools adiabatically as it ascends the obstacle, so on the windward side horizontal vorticity is generated along the direction which points normal and to the left of the flow. The vertical-velocity field and potential temperature fields in the vicinity and lee of the mountain are also affected by gravity waves.

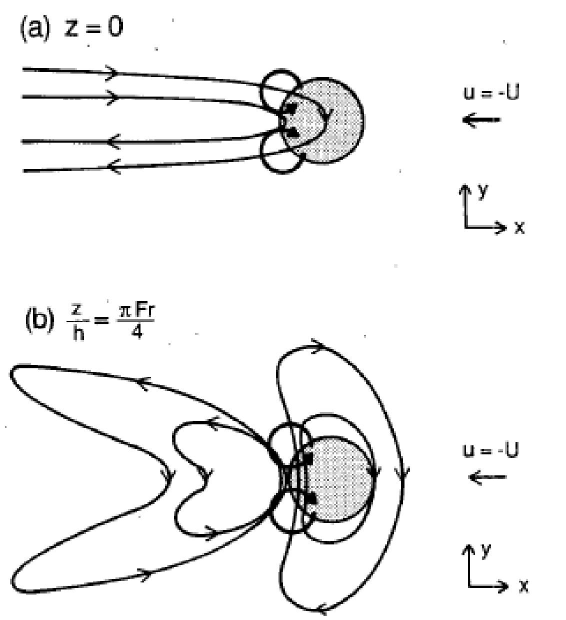

FIG. 6. Vortex lines as deduced from linear theory along with an indication of the sense of the vertical vorticity inferred from the next-higher-order correction to the linear theory at (a) the lower surface and (b) 1/8 of a vertical wavelength aloft.

(from Smolarkiewicz and Rotunno 1989)

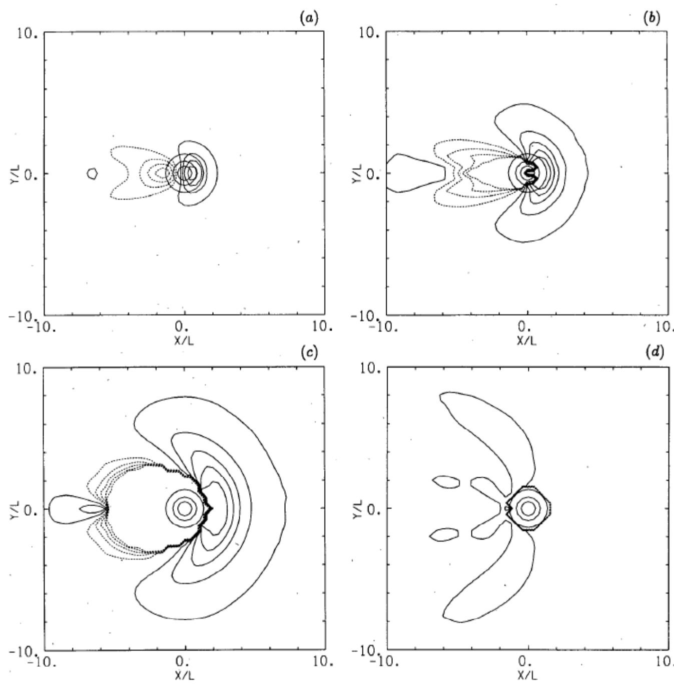

FIG. 2. Displacement field of the isentropic surface with undisturbed height $z/h = \pi\ \mathrm{Fr}/4$ for (a) Fr = 2.2; contour interval, $10^{-4}\ h$, (b) Fr = 0.66; contour interval, $5 \times 10^{-5}\ h$, and (c) Fr = 0.22; contour interval, $1\frac{2}{3} \times 10^{-5}\ h$. In (d) the surface originating at $z/h = 9\pi\ \mathrm{Fr}/8$ is displayed for the experiment with Fr = 0.055; contour interval, $8\frac{1}{3} \times 10^{-6}\ h$. Dashed contour lines indicate negative displacement and zero contour lines are not shown.

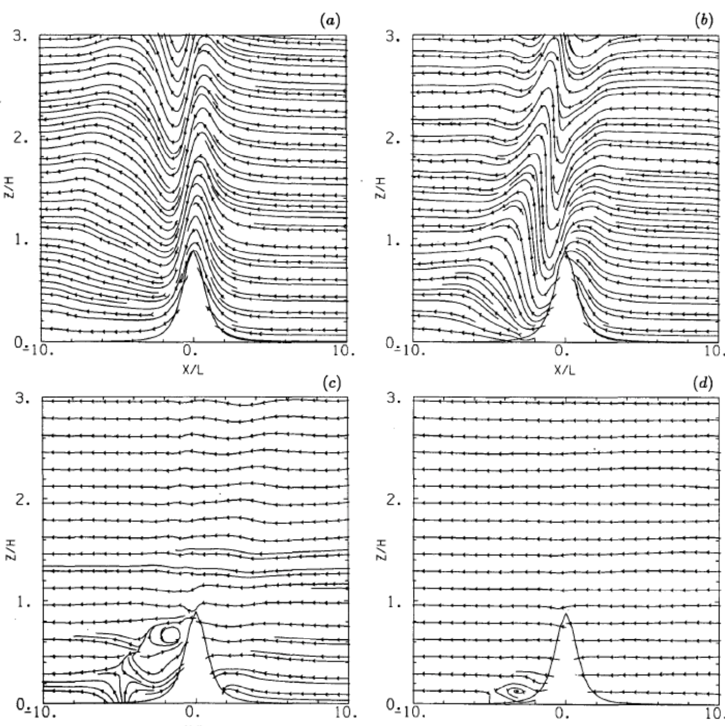

FIG. 3. Steady-state streamlines in vertical cross section through the center plane for Fr = (a) 2.2, (b) 0.66, (c) 0.22, and (d) 0.055.

(from Smolarkiewicz and Rotunno 1989)

Actual vortices in the lee of the Hawaii are seen in the figure below.

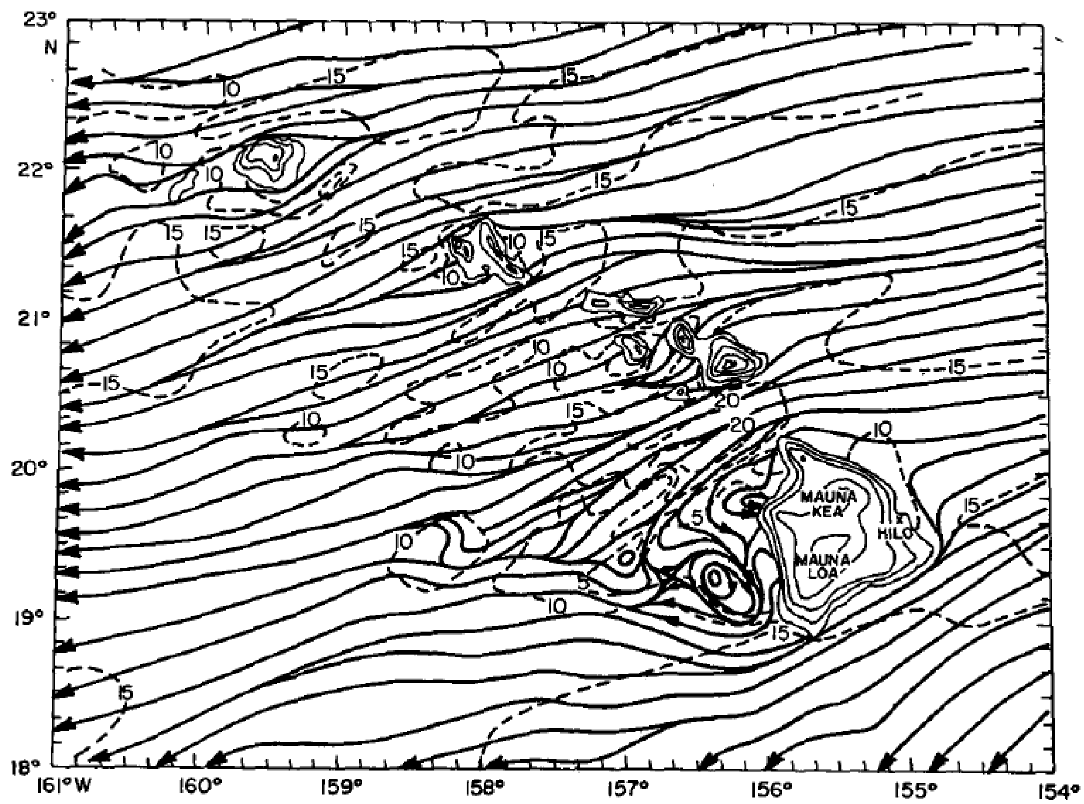

FIG. 2. Mean resultant surface winds during tradewind conditions for the Hawaiian Archipelago, wind speed in knots (Courtesy of C. S. Ramage, University of Hawaii).

(from Rasmussen et al. 1989)

Mesoscale vortices have also been observed offshore from Los Angeles, in the lee of mountains to the east.