10.1 Advances in Mountain Airflow Dynamics

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Questions: Significant progress in understanding the influence of mountains on wind systems has occurred over the last sixty years. The early progress was summarized by Queney et al., (1948), Smith (1979, 1989) and Reiter (1982). More recent advances have been discussed in Blumen (1990), Baines (1995), Wurtele (1996), Whiteman (2000), Smith (2001). This progress has occurred using new tools, including new techniques in numerical modeling and atmospheric observations. There has also been progress in theoretical understanding of mountain airflow. Some of this progress has been step-wise, associated with brief periods of focus on particular controversial questions. A list of thirteen famous questions is given below. Of course this list is not nearly complete. Many other interesting and important questions have been identified and pursued.

1. What is the appropriate upper boundary condition for mountain wave problems in the atmosphere?
2. What is the mechanism of severe downslope winds?
3. How do mountain waves form over complex terrain?
4. What is the mechanism of gravity wave breaking?
5. What is the reason for upstream blocking and deflection?
6. Why does airflow accelerate through mountain gaps?
7. Can mountains produce wakes without potential vorticity generation ?
8. What controls the intensity of orographic precipitation, airflow dynamics or cloud physics?
9. What causes foehn?
10. What is the role of mountain drag and wave momentum flux on the general circulation?
11. What causes lee cyclogenesis?
12. Is there a mountain anti-cyclone in the real atmosphere?
13. What is the relative importance of forcing by mechanical ascent and elevated heating?

In this lecture, we will review a few of these questions, and try to assess the current state of understanding. Brief clues or partial answers are given below.

Answers:

1. The radiation condition for mountain waves, including group velocity ideas, can be used at all boundaries (e.g. Queney, 1948)
2. The severe windstorm mechanism, first simulated numerically by Clark and Peltier (1977), involves a non-linear resonance, related to hydraulic theory. Wind shear and diabatic heating can influence this resonance.
3. Recent theory and observations indicate that non-linear effects and valley stagnation may reduce wave generation over complex terrain and prevent wave reflection.(e.g. Smith et al. 2002)
4. Several different mechanisms may dominate, spilling, cross-rolls, or longitudinal rolls, depending on the details of the stratification (e.g. Lelong and Dunkerton, 1998)
5. Positive pressure anomalies on the windward slope, caused by airflow lifting, can stagnate or deflect the incoming flow. With a strong inversion, flow *acceleration* may be found on the windward slope as the falling inversion creates a favorable pressure gradient. Moisture can strongly influence these processes, by either reducing the effective stratification, or amplifying the density and pressure anomalies through evaporation or melting. (e.g. Smith 1989; Reisner and Smolarkiewicz, 1994)
6. In strong deep-flow cases, horizontal confluence through a gap (sometimes

called the Venturi effect) is minimal. Rather, gap flow accelerates under the influence of the regional mountain induced pressure gradient. In shallow, strongly stable conditions, confluence can be important. (e.g. Pan and Smith, 1999; Sharp, 2003).

7. While mountain waves can occur in the lee-side region, a true wake with eddies requires an violation of the PV conservation law by dissipative processes.(e.g. Schar and Durran, 1997)
8. Both dynamics and cloud physics have first order significance. Dynamical processes include smooth ascent, imbedded convection and triggered deep convection (e.g. Medina and Houze, 2003; Smith and Barstad, 2003)
9. Two foehn mechanisms have been widely discussed: 1) moist ascent and dry descent and 2) upstream blocking and lee-side descent. Recent evidence may link upstream latent heat release and lee-side descent. (e.g. Seibert, 1990, Smith et al., 2003, Doyle and Smith, 2003).
10. Numerous sensitivity tests have shown that wave drag is important. The best documentation may be in the Artic regions with simpler wind profiles (e.g. Duck, 2001). However, even the best mesoscale models have problems estimating the magnitude of the wave momentum flux due to uncertainties in low level blocking and wave breaking. Thus most GCMs use wave drag as a tunable parameter.
11. The causes of lee cyclogenesis were hotly debated in the 1980's, with no clear consensus. Better statistics, models and theories may be required to solve this problem. See Egger (1988)
12. The classical idea of vortex shortening over large mountain ranges has received little observational support, but simple models show it clearly (e.g. Schwierz and Davies, 2003). Observed orographic high pressure anomalies are often due to diurnal or glacial cooling, or uncertainties in reduction to sea level.
13. Climatically, the elevated heating is more important for larger mountains such as the Himalayas of the Andes. Smaller hills may still influence diurnal effects (e.g. Reiter, 1982; Mapes et al, 2003).

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