Chinook Winds Resemble Water Flowing over a Rock

Winds blowing down from Colorado's Front Range can reach 200 kilometers per hour when the atmosphere behaves like a flowing stream

THE warm winds that come roaring down from the Front Range of the Colorado Rockies once or twice a year are called chinooks. Other mountains have their own winds—the Alpine foehn, the Yugoslavian bora, the Argentine zonda. In the most severe cases of each, a moderate wind blowing up one side of a mountain comes down the other side at speeds as high as 200 kilometers per hour, unroofing houses, toppling power lines, and even overturning trains. Meteorologists struggling to understand this Jekyll to Hyde transformation are focusing on the similarities between such severe winds on the downwind slope of mountains and the flow of water over a rock. This hydraulic approach to a system that normally has no sharply defined upper surface seems to work for both the chinook and the bora despite some differences between the two.

A classic chinook struck on 11 January 1972. Once or twice a year gusts during a chinook will hit 100 kilometers per hour, but in 1972 they approached 200 kilometers per hour. Conveniently enough, the National Center for Atmospheric Research was built in Boulder square in the path of the chinooks, so that Douglas Lilly and Edward Zipser of NCAR were able to fly research aircraft up through the windstorm and record a detailed picture of it. To their surprise, they found that the air flow normally spread throughout the 10-kilometer height of the weather-containing troposphere was squeezed into a surface layer only 2 kilometers thick. Funneled down to such a restricted passage, the winds by necessity had to be faster.

An oft-cited explanation of such winds is that the air is simply falling down the side of the mountain. By this reasoning, air forced to rise by the mountain would accelerate as it fell down the lee side, much like a car coasting down from a mountain crest. But a parcel of air behaves differently from a car because air responds to changes in pressure, so the wind of a chinook not only accelerates down the lee side but also up the windward side. This counterintuitive behavior of air moving over a mountain has its analogs in other everyday phenomena. Air forced over a plane's wing moves faster, a lower pressure appears above the wing than below it, and the plane is lifted. Water flowing over a submerged rock in a stream actually speeds up as the water's surface dips just ahead of the rock. In the case of a mountain, the air flowing toward the crest dips in the form of a wave as the pressure drops and the wind speed increases. This way, the air speeds up (gains kinetic energy) even as it gains potential energy in its trip up the mountain.

The problem is predicting when a chinook will be severe.

The problem for meteorologists has been to explain why, in the case of chinooks, this process is not reversed on the lee side, the low pressure of the wave centered near the crest slowing the air and returning it to its preencounter state. Instead of a return to normal, the air plunges down the lee side to continue its acceleration unrestrained by any wave processes. In fact, a stagnant wedge of turbulent air separates the shallow surface flow from the rest of the atmosphere. Meteorologists took this splitting of the atmosphere into independent layers, despite its normally continuous gradation of properties from bottom to top, to be the key step. Given this decoupling, the already accelerated winds could continue to accelerate without interacting with the overlying air, much as water shoots down the side of a rock without regard to the overlying air.

Researchers have found two ways to negate the wave effects that would otherwise return the air flow to normal. One is wave breaking, as emphasized by Richard Peltier of the University of Toronto and Terry Clark of NCAR. Waves created within the atmosphere downstream from the mountain can become so large that they break, much as an ocean wave breaks. The breaking modifies the wave so as to effectively decouple the lower part of the atmosphere from the upper, leaving the lower part free to fall away and accelerate. Clark and Peltier studied such wave breaking in mathematical models simulating the flow of air over mountainous obstacles. On the basis of these studies, they believe that wave breaking reflects some energy toward the surface that intensifies downslope winds.

Joseph Klemp of NCAR and Dale Durran of the University of Utah simulated the bora of Yugoslavia in their computer model and found that wave breaking there leads to air shooting down the Dinaric Alps. They modeled a particular bora that was intensely observed during the Alpine Experiment (ALPEX) on 15 April 1982. By deleting different aspects of the actual weather conditions in turn, they found that wave breaking produced the high winds that day. In this particular case, the presence of an inversion—the stable layering of warm air over cold—that might tend to act as an upper surface or lid made little difference.

Durran has emphasized a second means of breaking down the mountain wave preventing lee-side acceleration. He argues that if the first-stage acceleration on the windward side raises the wind speed high enough, the wave will not be able to hold its stationary position over the lee side of the mountain. The high winds over the crest will simply blow any wave downstream, eliminating the opportunity for the air to slow on the lee side. It would then be free to fall down the lee slope the way water flowing over a submerged rock suddenly accelerates and drops down the back side of the rock. Like that flow, the downslope winds could shortly return to the state they were in before encountering the obstacle through an abrupt, turbulent jump upwards. That is the hydraulic jump seen in the mound of white water just past the rock.

In simulations of the 1972 chinook, Durran found that the higher wind speeds, called supercritical flow, near the crest removed the wave and provided the first lee-side acceleration. He also found that an inversion was essential to the development of that supercritical flow. Only later did wave breaking play a role, he says. In contrast, Clark and Peltier have cited a case in which supercritical flow appeared without an inversion being present.

Although researchers continue to debate just what triggers a particular episode of severe downslope winds, there is growing agreement that the underlying driving mechanism once triggering occurs resembles hydraulic flow, an explanation that a few years ago seemed too simple for such a complex phenomenon. "The bora, chinook, and water flowing over a rock are fundamentally the same phenomenon," says Durran. Clark will not go quite that far, preferring to emphasize that waves within the atmosphere can never behave exactly like waves on the surface of water. That can lead to some differences from predictions of hydraulic jump theory, he says.

Researchers had tended to view the bora and chinook as involving different processes because these winds looked so different. The chinook, a warming wind, involves the whole troposphere flowing over the Rockies, while the bora involves a shallow pool of cold air spilling over the Dinaric Alps. But Ronald Smith of Yale University has developed a mathematical description of mountain wave behavior in terms of hydraulic theory that works equally well for both the bora and chinook. When adjusted to a common scale, says Smith, the two bear a strong resemblance, and the same hydraulic theory applies to both.

Parlaying new understanding of the basic mechanism of severe downslope winds into better forecasting will take much more work in computer simulations. Forecasters can already say when conditions will favor a chinook. The problem is predicting when it will be an exceptionally severe one, and that will probably require more details on upstream conditions that lead to the strongest winds. ■ RICHARD A. KERR

ADDITIONAL READING

T. L. Clark and W. R. Peltier, "Critical level reflection and the resonant growth of nonlinear mountain waves," *J. Atmos. Sci.* **41**, 3122 (1984).

D. R. Durran, "Another look at downslope windstorms," *ibid.*, submitted.

J. B. Klemp and D. R. Durran, "Numerical modelling of bora winds," *Meteorol. Atmos. Phys.*, in press.

R. B. Smith, "On severe downslope winds," *J. Atmos. Sci.* **42**, 2597 (1985); "Aerial observations of the Yugoslavian bora," *ibid.*, submitted.

Briefing:

The Tissue Specificity of The Drosophila P Element Is Explained

Introduction of new genes into the fruit fly (*Drosophila melanogaster*) can be readily achieved with the aid of a method that was devised a few years ago by Allan Spradling and Gerald Rubin of the Department of Embryology of the Carnegie Institution of Washington (which is in Baltimore). The method depends on the use of "P elements," segments of DNA that can, under certain conditions, move from place to place in the drosophila genome. Spradling and Rubin took advantage of the P element's ability to integrate into fruit fly DNA and adapted the P element as a vehicle for introducing new genes into that organism. They found that they could in effect cure genetic defects in fruit flies.

The hope was that the element could be developed as a gene transfer vehicle for mammalian cells, too. Attempts to do this proved futile, however, although Spradling and Rubin supplied P element clones to perhaps 100 investigators who wanted to try. Now, Rubin, who moved to the University of California at Berkeley about 2 years ago, and his Berkeley colleagues Frank Laski and Donald Rio have new information about the P element that not only explains its distinctive pattern of activity in the fruit fly but may also account for its failure to work in mammalian cells.*

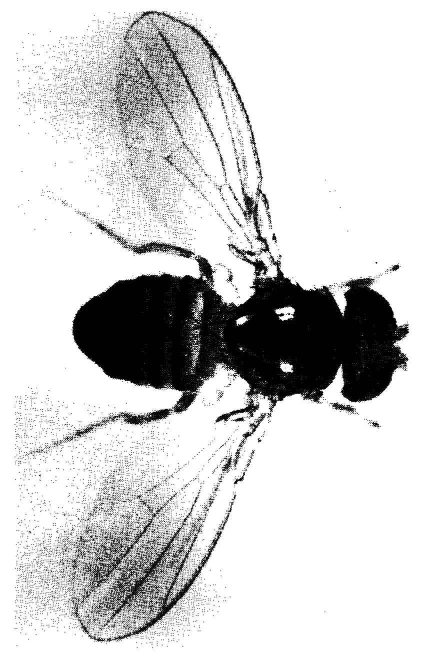
P element movement in drosophila occurs only in the germline cells, which give rise to the sperm and eggs, but not in the somatic tissues. The movement depends on the activity of a "transposase" enzyme that is encoded in the full-size P element.

The question then becomes how germ cells can make active transposase whereas somatic cells cannot. The two types of cells can transcribe the transposase gene into RNA, the Berkeley workers find, but they then process the RNA differently.

Earlier work had shown that the complete P element contains four regions with the potential to code for protein structure. According to Roger Karess who worked with Rubin at Carnegie, all four are needed to make the transposase. They are separated by short, noncoding segments (introns) that would have to be cut out of the original RNA transcript to produce the messenger RNA for the active transposase protein.

*F. A. Laski, D. C. Rio, G. M. Rubin, *Cell* **44**, 7 (1986); D. C. Rio, F. A. Laski, G. M. Rubin, *ibid.*, p. 21.

However, when Laski, Rio, and Rubin examined the mRNA from whole fruit fly embryos, what they found appeared inconsistent with Karess's observations. The intron between the third and fourth coding regions was not spliced out, and thus the fourth coding region would not be represented in the transposase protein. "There was only one logical way out of the contradiction," Rubin explains. "The messenger RNA we were looking at wasn't functional."



Edward Lewis, Caltech

The invaluable fruit fly

To test the hypothesis that the third intron must be removed to produce a functional transposase mRNA, Laski, Rio, and Rubin prepared a mutant P element that was altered so that the third intron could not be spliced out. As expected, this P element worked neither in the somatic nor in the germ cells. Conversely, when the Berkeley workers repeated the transfer with a P element from which the third intron had been precisely removed, this modified element worked in all fruit fly cells.

The Berkeley workers conclude that normally the P element is active in germ cells and inactive in somatic cells because only the germ cells have the ability to remove the third intron.

Rubin, Laski, and Rio do not yet know the basis for the different splicing patterns of transposase mRNA in germ and somatic cells. "There is nothing unusual about the structure of that third intron," Rubin notes. Nevertheless, the results raise the possibility that the P element from which the third intron is removed will work in mammalian cells just as it did in drosophila somatic cells. ■ JEAN L. MARX