HILLS ARE THERMAL PRODUCERS

by PAUL B. MACCREADY, JR.

A glider pilot's principal task is trying to figure out where the next upcurrent may be found. Local topography can always give him a clue: observations of cumulus cloud appearance, cloud shadow areas, smoke columns, dust devils, etc., can yield even better information, but these are often absent. The following discussion concerns the role of topography in causing thermals to be more common, stronger, and higher over mountains than over adjacent lower elevations.

Hills or mountains help produce thermal upcurrents both because of their height and because of their slopes. The slope effects are extremely important but they are simple and need not be discussed here in detail. The mechanical slope effect is that wind being forced to blow up the slope helps start and localize thermals. The heating slope effect is that the air on slopes can be heated more than the air on horizontal surfaces (since the sun is rarely directly overhead, some slopes rather than horizontal will be more perpendicular to its rays; in addition, the heat per unit area on steep slopes is concentrated over a small horizontal area).

The altitude effect of a hill as a thermal producer is simply that in mid-day the mountain top air is warmer than valley air would be if it were raised to the same height. Since dry air cools and heats at 5.5°F/1,000 ft. as it ascends and descends, all these temperature comparisons should be made at a particular elevation—it is conventional to use "potential temperature" for this purpose, this being the temperature the air would be if lowered to a pressure of 1,000 millibars, corresponding to an elevation near sea level. If the temperature of a mountain station is 5.5°F/1,000 ft. cooler than a nearby valley station, both would have the same potential temperature and a thermal could start at either and reach about the same height and strength. Since the sun's heating of mountains is similar to that in valleys, in mid-afternoon there is a tendency for the two areas to reach somewhat similar temperatures, closer than this 5.5°F/1,000 ft. figure, and so on then the mountain has the warmer potential temperature.

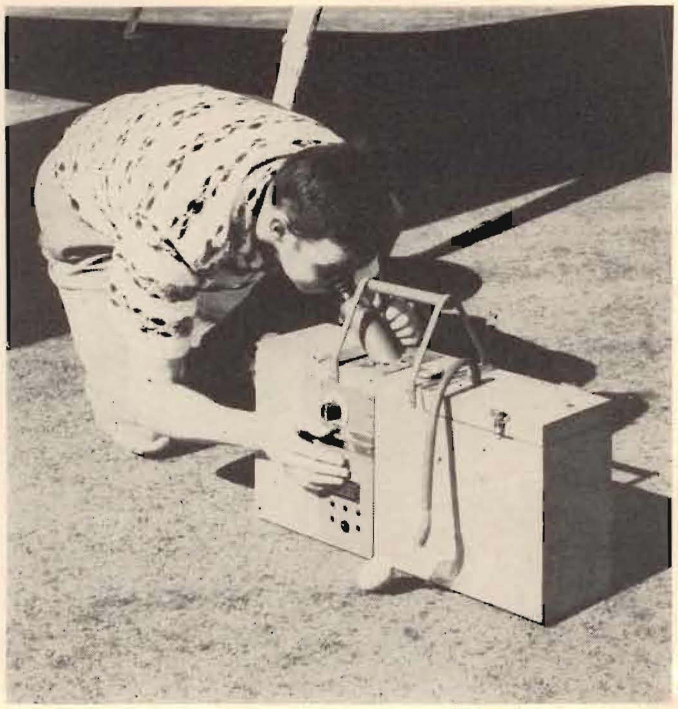

Photo: U. S. Forest Service

Soaring-Scientist Dr. Paul B. MacCready, Jr., makes a nuclei count with this machine which he uses in connection with his cloud-seeding operations.

Consider a typical case with the valley at 2,000 feet and the mountain 4,000 feet higher. The valley temperature is 69°F, meaning a potential temperature of 80°F, and the mountain top temperature is 53°F, corresponding to a potential temperature of 86°F. At any given level, air rising from the valley would be 6°F cooler than air rising from the mountain. The central core of a thermal may be only 1°F or 2°F warmer than the surrounding air. Since such a small temperature excess can power a thermal, obviously the 6°F excess due to the mountain will mean that hill thermals are far more likely than valley thermals (assuming, of course, that the general instability of the air is such that thermals can be produced).

The hill effect is very pronounced during the start of convection each day. Then the only upcurrents are to be found over slopes. Later in the day when surface temperatures have risen much higher there may be thermals from both hill and valley, with most and the biggest originating over hills. When the clouds grow so large that they receive most of their power from the instability in their upper portions they become less related to ground conditions. If clouds shield the sun the temperature of air near the surface can drop rapidly, enough to overcome the hill's temperature advantage.

Some figures showing the magnitude of the hill effect are obtained from U. S. Forest Service records by comparing temperatures from mountain top lookout stations in Montana and Idaho with temperatures from nearby valley stations. The maximum potential temperature difference was about 3°F/1,000 ft., and the average value was about 1.5°F/1,000 ft. Some microclimatological measurements in the mountains of Scotland gave an average difference of 1°F/1,000 ft.[2]

When average cumulus clouds exist, not only their tops but also their bases are higher over mountains. The height of the cloud base can be calculated by knowing the moisture content and temperature of the surface air rising into it. If the moisture content is the same in valleys and on hill tops, then the warmer potential temperature of mountain-caused thermals means that the condensation level will be higher. For the example cited earlier of a 2,000-foot valley at 69°F and a 6,000-foot elevation mountain with a temperature of 53°F, the mountain cumulus cloud would have a base about 1,300 feet higher than the valley cumulus cloud. Actually the moisture content is usually a little less on mountain tops than in valleys, and the variation in

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