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Cold air drainage: a field experiment

James Levenson
University of Wisconsin-Milwaukee

Paul Matthiae
University of Wisconsin-Milwaukee

COLD AIR DRAINAGE: A Field Experiment

In November 1974, a set of solar radiation studies was undertaken at The University of Wisconsin–Milwaukee Field Station. The exercises were conducted jointly by classes from the Departments of Meteorology and Botany. The Dynamic Meterorlogy class dealt with the 24-hour cycle of radiant energy flows (Miller, *et al.,* 1975) and the Environmental Measurement class examined cold air drainage in an open area near the laboratory.

Cold air drainage is best observed in a hilly topography during clear, calm nights. A cold layer of air forms near the surface of the ground as a result of outgoing radiation. Cold air, being heavier and more dense than warm air, flows to lower ground displacing warmer air (Geiger, 1950). The results are often referred to as "cold air puddles", "frost holes", or "frost pockets".

Cold air drainage is most readily made visible by development of patches of ground fog in low-lying areas. Most of us have experienced a chill when descending a hill or sand dune after dark. Low-lying areas, or potential frost pockets, are of particular interest to the farmer and home gardener. Low areas may anticipate late killing frosts in the spring as well as an early killing frost in the fall. Geiger (1950) described the way in which a railroad embankment located on a gentle slope effectively "dammed" the flow of cold air creating a cold "lake". Gardeners on opposite sides of the embankment must grow different crops and flowers because of the functionally different growing seasons.

Damage to citrus orchards on the Pacific Coast stimulated intensive research efforts to accurately forecast and thwart frosts (Sutton, 1953). One orchard owner constructed a V-shaped wall above his orchard to redirect the flow of cold air to either side as it passed by (Franklin, 1955). The cranberry industry is also extremely liable to severe frost damage. Weather forecasts are closely monitored and if a killing frost is imminent, the entire cranberry bog must be flooded. The severe frost of August 1904, in the Wisconsin cranberry bogs was a decisive event in motivating the Weather Bureau to investigate frost protection (Franklin, 1955).

Some natural communities may be perpetuated by cold air drainage and frost pockets. In northern Wisconsin the larger forest opening appear to be perpetuated by frost action (Levy, 1970). These small openings functionally act as "edge" embedded in the forest matrix. The edge effect provides increased cover as well as providing a broader range of food sources for wildlife. Wildlife utilization of forest pockets was found to be equal to or greater than other types of openings (McCaffery and Creed, 1969). Openings are particularly important in providing overall landscape and habitat diversity.

This study was designed to examine frost pocket and cold air drainage phenomena by monitoring air temperatures at different contour intervals around a depression for a 24-hour period.

MATERIALS AND METHODS

To best demonstrate cold air drainage and the frost pocket phenomena a calm, clear night was needed in which the minimum temperature would reach the freezing point or create frost conditions in the low-lying areas. The experiment began at noon on November 7, 1974.

Thermisters were fastened onto a pole at 0.5, 1, and 2 m. above the ground. An eight-foot length of 1 x 1 inch wood moulding was used as the pole. Holes (0.25 in.) were drilled through the moulding at the respective heights. Thermisters were inserted through the holes so they protruded at least 1 cm. Thermister leads were taped securely to the moulding and labeled appropriately. A telethermometer was used to read thermisters. A plastic ribbon tied to a string and thumb-tacked to the end of the stack acted as a wind direction indicator.

The study area was the broad ravine between the Field Station laboratory and the upland forest. The ravine is approximately 400 feet across and has a maximum relief of 40 feet. Points were located on an east-west and a north-south transect which formed a "T" across the ravine and up the draw (*Fig. 1*). Sample points were placed at natural breaks in the topography at different elevations.

The temperature sensitive telethermometer unit was recalibrated prior to each sampling run. The portable stack of thermistors was carried between sample points. By using a single portable thermister stack we were able to eliminate the errors that would normally be incurred by using different thermisters for each point.

In sampling the thermister stack was held vertically at arms length and the thermisters were orientated away from the body and out of the direct sunlight. At each sampling period, sky condition, wind direction and other pertinent meteorological phenomena were recorded. Each sampling run required approximately 20 minutes. A continuous record at one point was provided by a recording hygrothermograph placed at the bottom of the ravine *(Fig. 1)*.

RESULTS AND DISCUSSION

The results of the 24-hour temperature monitoring illustrate the frost pocket phenomena very dramatically. The east slope (west-facing, points A, B, & C) stayed consistently warmer than the west slope until the sun dipped behind the upland forest at approximately 16:00. Then the temperature at the bottom of the ravine (point C) began plunging rapidly and remained considerably colder than the surrounding upland. By 21:00, an inversion had developed with the temperatures at 2m greater than at 0.5m in the ravine. Between 1:00 and

3:00, the temperature of the air at the bottom of the ravine was uniform for at least a 2m depth. Sub-freezing temperatures were first recorded at point C at 3:00. The cold air continued to enter the ravine until the size of the frost pocket had swelled to include points B, D, F, and G. Point C stayed significantly colder than the surrounding upland with a 4.5°C (8°F) differential at the 2m height at 5:30. One could readily feel the temperature change while going from point A (3°C) down to point C (-1.5°C) and up to point E (2°C). It is little wonder why warnings for frost in low-lying areas are given!

Shortly after sunrise, the sun had sufficiently warmed the west slope and the bottom of the ravine to destroy the inversion. As the day progressed, the bottom of the ravine went to the opposite temperature extreme and became the warmest region. It is noteworthy that points C and D had a maximum temperature range of 24°C (43°F) while the upland points (A & E) ranged 20° and 19°, respectively. The 4-5°C (7-9°F) difference creates a harsher environment for temperature sensitive organisms.

The exercise was a decided success with a minimal amount of equipment and cost. Temperature change could actually be sensed by the students and backed up by the equipment. Understanding the dynamics of the atmosphere is an essential part of an overall understanding of the environment and the stresses to which organisms must respond. As an exercise in environmental measurements, or in microclimatology, the drainage of cold air into a valley merits study because of the serious consequences it may have on crops, or even human health if a pollution source is involved.

James Levenson
Department of Botany

Paul Matthiae
Field Station

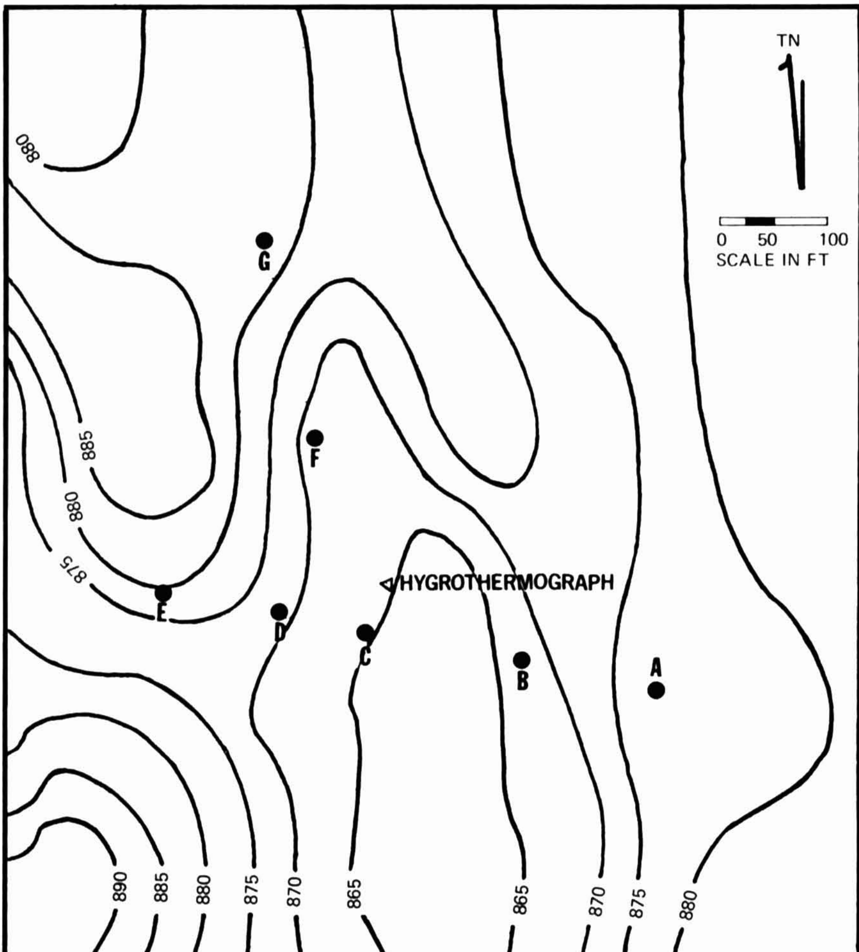
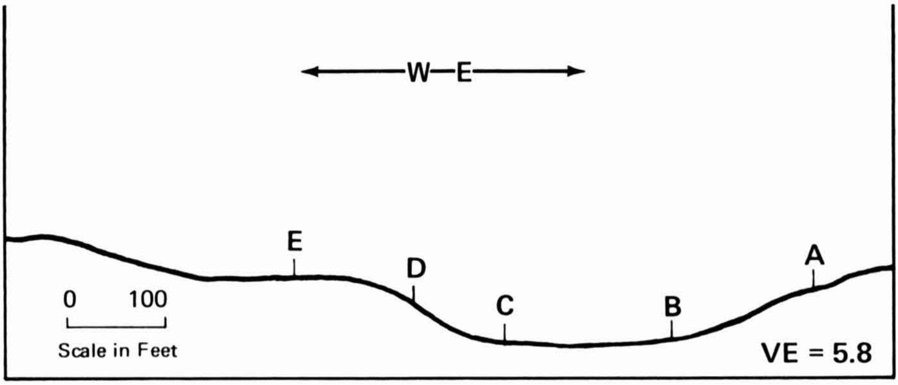
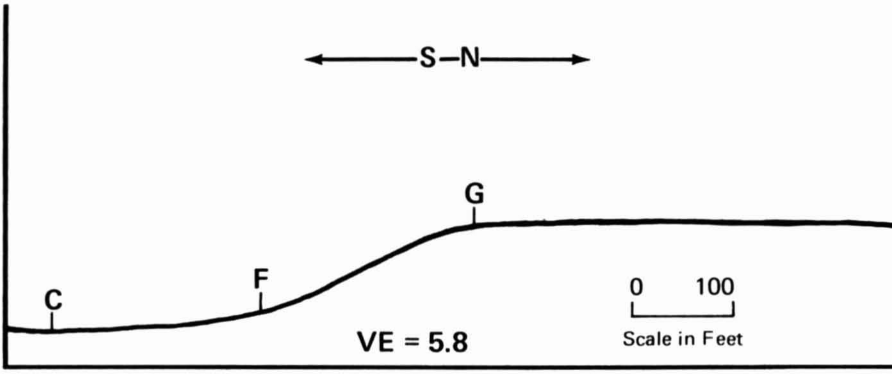


Fig. 1 Topographic representation of the ravine at the Field Station. The seven sample sites are indicated alphabetically.



TIME (CST)	Temperature (°C) - 0.5m height					Temperature (°C) - 2m height				
	A	B	C	D	E	A	B	C	D	E
13:30	21.0	23.0	22.0	21.0	20.0	19.0	19.1	20.0	18.5	18.3
14:30	20:0	21.0	19.5	18.3	18.2	18.5	19.0	17.8	17.5	17.0
15:30	18.2	16.0	14.2	14.0	13.9	14.8	14.0	13.5	13.2	13.0
16:30	10.2	10.0	7.5	8.2	8.9	9.3	9.0	7.3	8.0	8.5
17:30	6.7	4.5	2.2	2.4	4.1	6.2	4.7	1.8	3.7	5.1
18:30	5.0	3.7	1.5	2.5	3.0	5.0	2.6	1.6	2.0	3.0
21:00	6.0	3.8	1.9	3.5	6.9	5.9	4.3	2.5	4.9	5.1
23:00	5.0	3.5	1.8	2.0	2.8	5.0	3.5	2.0	3.0	3.3
1:00	4.2	2.2	0.8	1.5	2.0	4.8	2.4	2.2	2.2	2.5
3:00	3.5	1.2	-0.9	1.2	1.2	2.0	1.1	-1.1	0.4	1.1
5:30	2.0	0.0	-1.9	0.0	1.0	3.0	0.0	-1.5	0.0	2.0
6:30	1.0	-1.0	-2.0	-2.1	-0.2	1.2	-1.0	-2.0	-1.5	1.0
7:30	5.0	4.1	4.0	4.5	6.0	5.2	5.0	5.0	5.8	6.9
8:30	6.0	8.0	9.5	9.0	10.0	7.0	7.5	10.0	12.5	12.5
9:30	10.7	11.9	12.9	12.9	13.2	10.9	12.0	12.0	12.5	12.9
10:30	12.8	13.7	14.8	15.2	15.7	12.7	13.0	13.5	14.2	15.4
11:30	16.0	15.1	16.8	15.2	16.3	14.9	15.5	15.7	14.7	15.0
12:30	16.5	16.5	16.5	17.0	16.8	14.5	15.0	14.9	15.5	14.9

Table 1 A cross-section of the ravine along the east-west transect. The location of the sample sites are indicated alphabetically. Temperatures are listed in degree Celsius at 0.5 and 2m levels for each site.



TIME (CST)	Temperature (°C) 0.5m height			Temperature (°C) 1m height			Temperature (°C) 2m height		
	C	F	G	C	F	G	C	F	G
13:30	22.0	21.0	20.0	21.0	19.9	19.0	20.0	19.0	18.5
14:30	19.5	18.0	17.0	18.8	18.0	17.0	17.8	17.0	16.5
15:30	14.2	13.8	13.0	14.0	13.2	12.9	13.5	13.0	12.7
16:30	7.5	8.1	8.0	7.3	7.9	7.8	7.3	7.9	7.9
17:30	2.2	2.0	4.5	2.0	2.4	5.2	1.8	3.0	6.1
18:30	1.5	2.0	3.0	1.0	1.0	2.0	1.6	2.2	2.5
21:00	1.9	4.7	6.2	2.2	2.8	4.9	2.5	3.8	5.4
23:00	1.8	1.8	3.5	1.2	1.9	3.8	2.0	2.1	4.0
1:00	0.8	1.2	3.5	2.3	2.3	4.3	2.2	2.4	4.3
3:00	-0.9	0.8	2.1	-1.3	-0.5	1.1	-1.1	0.4	1.7
5:30	-1.9	-1.0	1.0	-2.1	-1.0	0.3	-1.5	0.9	1.5
6:30	-2.0	-2.0	-0.5	-2.5	-1.0	-0.1	-2.0	-0.5	0.0
7:30	4.0	6.5	7.0	4.9	7.2	7.0	5.0	7.0	6.9
8:30	9.5	11.5	11.5	10.0	12.0	11.5	10.0	11.5	10.5
9:30	12.9	14.0	13.8	12.9	14.4	14.0	12.0	13.0	13.0
10:30	14.8	16.0	14.5	15.0	15.5	13.1	13.5	15.0	12.9
11:30	16.8	16.0	15.7	16.1	15.8	15.0	15.7	14.8	13.9
12:30	16.5	16.0	15.9	15.9	15.5	15.3	14.9	14.5	14.8

Table 2 A long-section of the ravine along the north-south transect. The location of the sample sites are indicated alphabetically. Temperatures are listed in degrees Celsius at .05, 1, and 2m levels for each site.

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