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THE EFFECT OF WIND AND TEMPERATURE ON HUMANS

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Working with the formula in WSOM Chapter C-42, it can be shown that the wind chill index (T_{WC}) is computed via the equation:

$$T_{WC} = 0.0817\ (3.46\ V^{0.5} + 5.81 - 0.25\ V)(T - 91.4) + 91.4$$

where V is the wind speed in knots and T is the temperature in degrees Fahrenheit. A fair question to ask is "what exactly does the wind chill represent?"

Antarctic explorers Paul Siple and Charles Passel measured the time required for 250 grams of water in a plastic container to freeze under various weather conditions. Not surprisingly, they found that the principal factors involved were the initial temperature of the water and the diffusion rate of heat from the container to the atmosphere. This rate is determined by the wind speed and the air temperature.

In a 1949 paper, Siple and Passel (Measurements of Dry Atmospheric Cooling in Subfreezing Temperatures, Proc. Amer. Phil. Soc., 89, 177-199) empirically related these data to the rate of heat loss of exposed human skin. They derived curves of constant heat loss as a function of temperature and wind speed by assuming that the skin temperature is maintained at 91.4°F, and not explicitly considering heat production by the body (i.e., the metabolic rate). Their formulas show that a high temperature with fast winds can produce the same amount of cooling as a much lower temperature with nearly calm conditions. The wind chill index (T_{WC}) is obtained from these curves. T_{WC} is defined as the theoretical temperature that would have to occur in conjunction with a 4 mph wind to produce the same amount of body cooling as is caused by the observed conditions.

Thus, the wind chill index is an effort to tell the public "how cold" it will seem. It gives an indication of what kind of clothes will be necessary to prevent body heat loss during outdoor activities. However, it does not really tell us when it is dangerous to be outside, i.e., when we are susceptible to frostbite.

This topic was explored by two Russian meteorologists, Ademenko and Khairullin (Evaluation of Conditions Under Which Unprotected Parts of the Human Body May Freeze in Urban Air During Winter, Bound. Layer Meteor., 2, 510-518) during the winters of 1967 and 1968. They instrumented the cheeks, noses and earlobes of about 40 people whose age ranged between 19 and 35 and had them walk slowly around out of doors. People of both sexes were used. Experiments were conducted in four different cities with temperatures ranging from 50°F to -40°F and winds varying from calm to 29 knots.

The temperatures of the various facial parts were found to be related to the wind and air temperature by the the following least squares formula:

$$T_{cheek} = 0.4\ T - 4.3\ V^{0.5} + 53.4$$
$$T_{nose} = 0.4\ T - 4.3\ V^{0.5} + 49.6$$
$$T_{ear} = 0.4\ T - 4.3\ V^{0.5} + 40.8.$$

The last term in these equations arises from the amount of heat contained in the blood supplied to the various portions of the face. More blood flows to the cheek than the ear and it stays warmer. Since freezing requires the skin temperature to be to 32°F or colder, these temperatures, not the more commonly given wind chill index, indicate when there is a danger of frost bite.

Averaging these three equations together, gives an approximate temperature for the face after a half hour to an hour of slow walking will be:

$$T_{face} = 0.4\ T - 4.3\ V^{0.5} + 47.9.$$

For still air, the air temperature has to drop to a -39.8°F before the face temperature will reach freezing. However, for a rather light 10 knot wind, a temperature of -5.8°F (T_{wc} of -21.8°F) can cause frostbite during a short stroll.

It must be noted that neither the skin temperature formulas nor the wind chill formula considers either radiation or humidity. Obviously direct sunshine provides significant heating to the body. High humidities produce cooler effective temperatures because moist air has both a greater heat capacity and a greater thermal conductivity than dry air. Thus, cold moist air is harder on the body than cold dry air. However, the moisture content of very cold air is fortunately quite small and this is typically a minor effect.

Physical fitness and personal acclimation to cold weather has very little to do with facial freezing. In fact, some of the Russian data was collected using residents of Noril'sk in north central Siberia (about 69°N) where winters are more extreme than those found in the contiguous United States. The guideline for issuing wind chill advisories when T_{wc} is -35°F or less is, in actuality, rather conservative. Freezing of exposed skin, in periods of about a half an hour, is a real threat even when the wind chill is warmer than the -35° threshold.