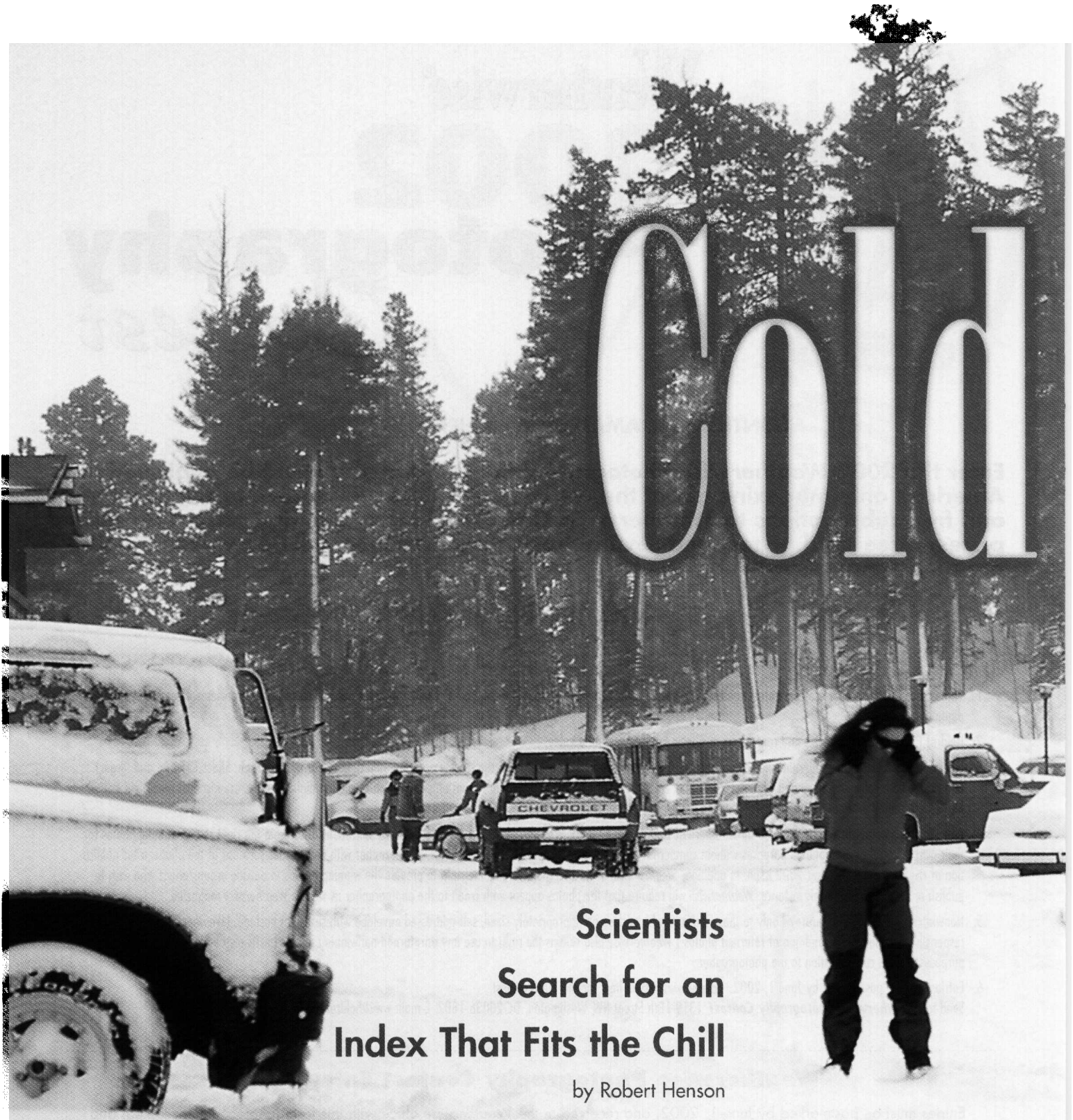

Cold

Scientists Search for an Index That Fits the Chill

by Robert Henson

Putting numbers to human experience is a perilous task. How do you quantify "bone-chilling," "brisk," or "bracing"? The scientists who are updating the flawed but popular wind-chill indices realize what they're up against.

Wind-chill calculations for the U.S. public started in 1973. That year, the National Weather Service (NWS) began to report the equivalent wind-chill temperature, along with the actual air temperature, when conditions warranted. It has long been apparent that the index overestimated the wind's cooling effect on human skin, but nobody was in a rush to fix the problem. Only in the last few years has a surge of research coincided with a critical mass of discontent to make things happen.

This winter, the United States and Canada unveiled a new wind-chill index to replace the various indices previously used in both countries.

Further revisions are pending, based on variables other than wind (sunshine, for instance). At the same time, an international group is developing a single index that will convey perceived comfort in both heat and cold (see sidebar "An Index for All Seasons" on page 16).

What's New and Different?

People familiar with the old wind-chill index have no doubt noticed that the new one has less bite than before. In many cases, the difference between the actual and equivalent temperature is now only about half as much as before.

The original index was created by two men working in the lonely, months-long Antarctic night while World War II raged half a world

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An Index for All Seasons

Americans are used to switching between the wind-chill index in winter and the heat index in summer. Both are temperature-based scales that attempt to indicate perceived human comfort levels. The wind-chill index combines temperature and wind while the heat index combines temperature and humidity. The International Society of Biometeorology is leading the charge to develop a single, "continuous spectrum" index that would cover both heat and cold throughout the year.

AccuWeather has already done that. The Pennsylvania-based firm has a U.S. patent pending for its RealFeel Temperature, which premiered in 1999 on the company's Web site <www.accuweather.com>. According to Joel N. Myers, AccuWeather founder and president, the scale incorporates the effects of eight variables: temperature, wind, humidity, solar intensity, cloud cover, precipitation, atmospheric pressure, and elevation. The exact formula is proprietary, and thus not released publicly. The current and predicted RealFeel temperature for every ZIP code in the United States, each Postal Code in Canada, and tens of thousands of other locations around the world are available on their Web site. "One of the most widespread uses is by school systems determining whether to have recess or not," says Myers.

"I'm glad if human reactions to heat and cold are drawing more interest," says Robert Steadman, an Australian environmental scientist who has done pioneering work on thermal indices. The goal is a time-honored one. Dozens of such scales were produced over the first half of the twentieth century before the field narrowed. Even the French tower builder Gustav Eiffel once created a temperature/humidity scale, according to Steadman.

—*Robert Henson*

away. Geographer Paul Siple and geologist Charles Passel placed a series of water-filled plastic cylinders in varying polar conditions and measured how long the water took to freeze.

By 1945, Siple and Passel had published a set of numbers expressing heat loss as a function of temperature and wind speed. The data weren't calculated as equivalent temperatures but as numbers corresponding to the amount of energy lost from the surface of the cylinder. Although they weren't always included, the units were kilocalories per hour per square meter of surface area. For example, a temperature of -10°F and a station-measured wind speed of 13 m.p.h. would produce a wind chill of 1600.

Using a number without units—rather than a wind-chill "temperature"—isn't such a bad idea, says Randall Osczevski. An environmental physicist with Canada's Defence and Civil Institute for Environmental Medicine, he's one of the key members of the U.S./Canada wind-chill team. "The wind-chill index has always been burdened unnecessarily with units," says Osczevski, who notes that in 1958 Siple acknowledged his regret at having released the index with units in the first place. "At first you don't know what 1600 feels like, but once you've experienced it you know what to expect next time you hear that number." In that spirit, the Meteorological Service of Canada is lopping off the Celsius symbol from the new wind-chill index so people are less inclined to interpret it as a pseudotemperature.

It wasn't until 1973 that the NWS converted the Siple-Passel results into equivalent temperature. For the first time, the U.S. public had a quick way to judge how much colder it might feel in a stiff winter wind than on a calm day. The new index may have raised the public's awareness, but critics soon claimed that this new awareness was distorted.

One of the corrections made recently was fairly straightforward. Official wind measurements are taken at a height of 10 meters (about 33 feet). However, the wind at face level (roughly five feet) is only about two-thirds as strong. The new index brings the perceived wind down accordingly, thus reducing the wind-chill effect. The new index also slightly lowers the minimum speed for wind-chill calculation from 4 to 3 m.p.h. This was to more closely match the typical walking speed of a person—the speed at which she or he encounters the air even when it's completely calm.

Of course, a plastic cylinder isn't a person. Siple and Passel didn't correct their data for the insulating effects of plastic. They also assumed that human skin would remain near 91°F, no matter how strong the wind and how cold the air. Frostbite victims can verify that skin cools in a matter of minutes. Most people experience discomfort, if not pain, when their skin cools to about 50°F, and wind can easily bring skin to that point. One study of people in still air at 23°F found that facial skin cooled to about 81°F in about three minutes. With a 20 m.p.h. wind, the same three minutes can bring parts of the face all the way down to the 50°F pain threshold.

Facing Up to the Cold

Faces are especially important in the wind-chill world because they're the part of the body most likely to be left exposed when icy winds are at

their worst. "The face is a very important part of the human thermoregulatory system," says Osczevski. "Some people believe the brain is cooled separately from the rest of the body and the face serves as its radiator. To use a *Star Trek* term, it's the 'forward sensor array' of the body."

Osczevski and a U.S. researcher found themselves modeling heads in different ways to get at the effect of cold winds on people. Osczevski built a mannequinlike head to test the insulation of military helmets. Meanwhile, Maurice Bluestein used a computer-based approach at Indiana University–Purdue University Indianapolis, where he's affiliated with the mechanical engineering technology department. Bluestein devised a cylindrical human head inside a computer model.

The actual cylinder used by Siple and Passel in Antarctica "was never meant to represent a body part," says Bluestein. His computer model included all three modes of heat transfer: convection (heat exchanged through tiny, swirling eddies around one's skin), radiation (heat emitted by one's body), and conduction (heat transferred through the skin).

Several years later, Osczevski and Bluestein put their heads together, so to speak, on behalf of a newly formed project to unite and improve the U.S. and Canadian wind-chill indices. While the United States had relied on a single index, Canadian indices varied by region. Manitoba is one of the few places that used the original Siple-Passel index, so people knew to watch for frostbite if the index climbed above, say, 1600. Other parts of Canada used an equivalent temperature much like that used by the NWS.

An Internet workshop arranged by Environment Canada in the spring of 2000 brought together experts from around the world to hash out the merits and pitfalls of wind-chill measurement. Shortly thereafter, the U.S. Office of the Federal Coordinator for Meteorological Services and Supporting Research (OFCM) organized the Joint Action Group for Temperature Indices (JAG/TI). Its development work has been funded and sponsored by agencies from both countries. According to coordinator Cynthia Nelson, OFCM, "The JAG/TI agreed that the [then-current] methods to determine wind chill overstate the effect of the wind." In other words, people accustomed to a -40°F wind chill might underestimate how dangerous an actual temperature of -40°F can be.

Osczevski and Bluestein were tapped by the JAG/TI to pool their research and to meet with other experts who had devised cold-weather indices of their own. Much of what the two scientists already knew was in sync with the JAG/TI research, but there was still work to be done. For instance, how well would the data from artificial heads and computer models match the actual human experience?

To answer that question, Osczevski's lab in Toronto put 12 volunteers through chilly paces in a wind tunnel. A forest of sensors attached to the subjects' bodies kept track of skin and internal temperatures moment by moment as the subjects exercised or stood still in a variety of temperatures and wind speeds. For ethical rea-

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Canadian volunteers endure a series of wind-chill tests in a refrigerated wind tunnel. The volunteers walked or stood still in a variety of temperatures and wind speeds and also withstood occasional splashes of water to the face (top). The tests were part of a study conducted at the Defence and Civil Institute of Environmental Medicine (DCIEM) that helped scientists determine the new wind-chill index.

BRUCE W. ANDERS/*WEATHERWISE* PHOTO CONTEST

Wind Chill on the Web

NOAA
<www.noaanews.noaa.gov/stories/s800.htm>

OFCM
<www.ofcm.gov/homepage/text/spc_proj.htm>

Environment Canada
<www.msc.ec.gc.ca/windchill/index_e.cfm>

DCIEM
<www.drdc-rddc.dnd.ca/newsevents/backgrounders/011030chill_e.html>

People familiar with the old wind-chill index have likely noticed that the new one has less "bite" than before. The old index was especially inaccurate at high wind speeds.

sons, the volunteers couldn't be subjected to cold severe enough to produce frostbite.

"The trials made me realize the real sensation of wind chill," reported volunteer Pierre Tourigny (of the Meteorological Service of Canada), who took a series of 90-minute walks in a wind tunnel, one each at 50, 32, and 14°F. Each walk featured three half-hour intervals with progressively stronger wind (4.5, 12.5, and 18 m.p.h.). A fourth walk at 50°F included a one-second splash of water in the face every 15 seconds.

Tourigny found that, while his face felt the chill with each ramp-up of wind, at 14°F "my body began to adapt and the feeling of cold subsided. After 15 minutes, there was not much difference compared with the lower wind speed. Clearly, it seems there is a biological mechanism that fights cold, and a good one at that." Both the modeling and the human tests showed that the old wind-chill index was especially overdone at high wind speeds, in line with Tourigny's experience. (In fact, Siple and Passel had never done any testing at wind speeds above 27 m.p.h.)

After they finished tweaking the new index based on the human tests, Bluestein and Osczevski blocked out parts of their new chart to signify the potential for frostbite on skin after more than 30 minutes of exposure (see the new wind-chill chart on the opposite page). A margin of error is built in: the calculations are based on the 5 percent of the public whose facial skin is the most thermally resistant. That means it's harder for the body to export its internal heat to the surface. Thus, the skin can get cold more quickly, even though the person doesn't necessarily feel cold inside, leaving the skin at greater risk for frostbite.

A Work in Progress

Although the new U.S./Canada wind-chill index is in the midst of its first season, the JAG/TI is already working on adding other factors that have nothing to do with the wind itself. Sunshine has a profound effect on how cold the air feels. Working in nonstop darkness, Siple and Passel couldn't take this into account. Even at night, an overcast sky radiates just enough heat to make a tiny difference in how we perceive a given temperature.

The JAG/TI is planning to add these variables next winter, which means the wind-chill values will vary somewhat based on the amount of cloudiness and the time of day. Since the corrections already in place were expected to make the biggest difference in wind-chill values, the United States and Canada decided to go ahead with the 2001–02 debut rather than wait for the added research needed for sunshine and cloudiness factors.

If the wind-chill gurus had infinite time and money, they could add a myriad of other ingredients to the recipe. Relative humidity in itself doesn't seem to make much difference to the perception of cold—the new index assumes 50 percent relative humidity—but if drizzle or other perceptible moisture reaches the skin, it's a different story. In his recent experiments, Osczevski found that "if your skin is wet, it can easily double the heat loss." Altitude also makes a difference, but not in a straightforward way. The less-dense air reduces convection effects, but altitude allows for more intense solar radiation and, in general, colder air temperatures. "It's a complicated matter," says Bluestein.

No matter what the formula for wind chill, people experience cold in their own way. Some cold-accustomed Coloradans wear shorts in the same below-freezing air that sends visiting Southerners into parkas. When Charles Darwin visited Tierra del Fuego at the tip of Patagonia, he found a woman nursing her baby in an open boat as snowflakes swirled around them.

New Wind-Chill Chart

Wind (m.p.h.)

Temperature (°F)	Calm	5	10	15	20	25	30	35	40	45	50	55	60
40	36	34	32	30	29	28	28	27	26	26	25	25
35	31	27	25	24	23	22	21	20	19	19	18	17
30	25	21	19	17	16	15	14	13	12	12	11	10
25	19	15	13	11	9	8	7	6	5	4	4	3
20	13	9	6	4	3	1	0	-1	-2	-3	-3	-4
15	7	3	0	-2	-4	-5	-7	-8	-9	-10	-11	-11
10	1	-4	-7	-9	-11	-12	-14	-15	-16	-17	-18	-19
5	-5	-10	-13	-15	-17	-19	-21	-22	-23	-24	-25	-26
0	-11	-16	-19	-22	-24	-26	-27	-29	-30	-31	-32	-33
-5	-16	-22	-26	-29	-31	-33	-34	-36	-37	-38	-39	-40
-10	-22	-28	-32	-35	-37	-39	-41	-43	-44	-45	-46	-48
-15	-28	-35	-39	-42	-44	-46	-48	-50	-51	-52	-54	-55
-20	-34	-41	-45	-48	-51	-53	-55	-57	-58	-60	-61	-62
-25	-40	-47	-51	-55	-58	-60	-62	-64	-65	-67	-68	-69
-30	-46	-53	-58	-61	-64	-67	-69	-71	-72	-74	-75	-76
-35	-52	-59	-64	-68	-71	-73	-76	-78	-79	-81	-82	-84
-40	-57	-66	-71	-74	-78	-80	-82	-84	-86	-88	-89	-91
-45	-63	-72	-77	-81	-84	-87	-89	-91	-93	-95	-97	-98

Frostbite Times

■ 30 minutes ■ 10 minutes ■ 5 minutes

$$\text{Wind Chill (°F)} = 35.74 + 0.6215T - 35.75(V^{0.16}) + 0.4275T(V^{0.16})$$

Where T = Air Temperature (°F)
V = Wind Speed (m.p.h.)

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In some people—especially those acclimated to severe cold—blood vessels near the skin open and close periodically, bringing pulses of heat to the surface that help keep frostbite at bay. The body's heat budget has to stay balanced, though, so the dilation of blood vessels tends to lower the core body temperature. In contrast, a panicked hiker may get severe frostbite even as his or her body temperature soars above normal from miles of walking.

As Osczevski muses, when it comes to cold and human beings, "it's not a nice, simple package, that's for sure." At least there's one thing we know: Wind chill alone can never make a dry object colder than the air temperature. In other words, even a wind chill of 10°F won't give you frostbite (or freeze your car's radiator) if the air temperature remains above 32°F. □