P1.9 REVIEW OF THE FEDERAL INTERAGENCY PROCESS USED TO SELECT THE NEW WIND CHILL TEMPERATURE (WCT) INDEX

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1. INTRODUCTION

Over the last several years, there have been many articles published in scientific journals, business journals, and newspapers on the inaccuracy of the wind chill index. Convincing scientific evaluation (Bluestein 1998, Kessler 1993 and 1995, Maarouf and Bitzos 2000, Osczevski 1995 and 2000, Quayle et al. 2000, Quayle and Steadman 1998), as well as public critique, of the current United States (NWS 1992) and Canadian weather services' wind chill indices, which are based on the Siple & Passel (1945) Index, led to the services' decision that an upgrade of the indices was needed. As a result of increasing Federal agencies' concern, the Office of the Federal Coordinator for Meteorological Services and Supporting Research (OFCM) formed a special group during the fall of 2000, called the Joint Action Group for Temperature Indices (JAG/TI), to continue the index discussions, evaluate the existing wind chill formulas and determine if changes were needed. The goal of JAG/TI was to upgrade and standardize the indices used for determining temperature extremes with the first task of the group to evaluate the current wind chill indices. Standardization of the index among the meteorological community is important, so that an accurate and consistent measure is provided and the public safety is ensured.

The Chairperson of the JAG/TI was appointed from the National Oceanic and Atmospheric Administration (NOAA)/National Weather Service (NWS). The JAG/TI representatives and participants were from several U.S. Federal agencies (Department of Defense (DOD) - U.S. Air Force (USAF), U.S. Army Corps of Engineers (USACE)/Engineering Research and Development Center (ERDC)/Cold Regions Research and Engineering Laboratory (CRREL), and U.S. Army Research Institute of Environmental Medicine (USARIEM); Department of Energy (DOE); Department of Commerce - NOAA /NWS; Department of Transportation - Federal Aviation Administration (FAA) and Federal Highway Administration (FHWA); U.S. Department of Agriculture (USDA); and the Federal Emergency Management Agency (FEMA)); Canadian national ministries (Environment Canada (EC)/Meteorological Service of Canada (MSC) and Defence Research and Development Canada/Defence and Civil Institute of Environmental Medicine (DCIEM)); the academic research community (Indiana University-Purdue University in Indianapolis (IUPUI), University of Delaware, and University of Missouri); and the International Society of Biometeorology (ISB).

The Canadian ministries, the academic research community, and the ISB participants were included in the JAG/TI activities because of their involvement in the review of the wind chill models conducted via the EC/MSC sponsored Internet Workshop on Windchill, held the week of April 3, 2000. This Workshop produced comments and discussions from experts and the public around the world which were available for review at the EC/MSC web site for the Workshop. Also participating in the Workshop were representatives from OFCM and NWS and other U.S. professionals.

2. OVERVIEW OF JAG/TI WORK AND RESULTS

Through two workshops held in October 2000 and February 2001, follow-on meetings and email discussions, the JAG/TI reviewed the results of the EC/MSC Internet Workshop, current literature (Bluestein 1998, Kessler 1993 and 1995, Maarouf and Bitzos 2000, Osczevski 1995 and 2000, Quayle et al. 2000, Quayle and Steadman 1998), and invited presentations by E. Kessler, M. Bluestein, R. Schwerdt, R. Quayle, and R. Osczevski. The JAG/TI agreed that the current NWS and MSC methods to determine wind chill overstate the effect of the wind, make people think it feels colder than it really is, and fool the public into thinking they can withstand colder temperatures than reality. In addition, the studies recommended revising the indices because they are too cold, especially at very cold temperatures and high wind speeds, and do not apply well to situations of actual temperatures above freezing. A comparative study of several indices demonstrated that at least three other indices outperform the current NWS and MSC indices, and that these other indices produced consistent results (Quayle et al. 2000). Noted problems with the current NWS and MSC indices include: radiative and convective heat losses were not modeled separately, thermal resistance of the skin was ignored, the assumed skin temperature was too warm, and the wind speed used was measured at a height of 33 feet (10 meters) instead of the average height of a human face (Bluestein 1998, Santee et al. 1994, Schwerdt 1995).

To correct these known problems, the JAG/TI members and participants agreed to have Mr. Randall Osczevski (DCIEM) and Dr. Maurice Bluestein (IUPUI) develop a new Wind Chill Temperature (WCT) Index and base it on their recently published new wind chill models (Bluestein and Zecher 1999, Osczevski 1995 and 2000). The JAG/TI recommended the new model use wind, air temperature, and solar radiation as the environmental factors in the wind chill formula because these environmental parameters appear to have the most influence on wind chill, and are readily available parameters in standard meteorological observations. They also recommended the human face be used for evaluating wind chill impact since it is the part of the body most often exposed to severe winter weather (Osczevski 2000). The JAG/TI agreed to have human studies conducted at the DCIEM Chambers in Canada to validate the new WCT Index. Infrared and heat sensor measurements would be used to measure the volunteers' skin temperature in various environmental conditions which may produce wind chill effects. The OFCM, CRREL and DCIEM agreed to provide the funding for this research and development effort. Transition into the weather services' operations would be

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accomplished by NWS, DOD and MSC using existing resources. The human studies were completed in June 2001. The results were evaluated by Mr. Osczevski and Dr. Bluestein and used to correct their preliminary WCT algorithm. Solar radiation calculations and associated charts could not be completed by the MSC and NWS deadlines for transition and implementation for this winter season, and therefore, the inclusion of the solar radiation effect will be accomplished at a later date.

Mr. Osczevski and Dr. Bluestein described their completed WCT Index and algorithm, and the results of the human studies to the JAG/TI at the August 2-3, 2001 meeting at DCIEM in Toronto, Ontario, Canada. The results were discussed by the JAG/TI at the meeting. Following these discussions, the group recommended the Osczevski-Bluestein WCT Index for implementation by NWS, MSC, and DOD who agreed to implement it on November 1, October 3, and tentatively November 1, respectively, for the winter season of 2001-2002.

Specifically, this new model:

- uses wind speed corrected within the equation to a height (5 feet/1.5 meters) that represents the height of an average adult's face;
- is based on a human face model;
- incorporates modern heat transfer theory (heat loss from the body to its surroundings, during cold and breezy/windy days);
- uses a walking speed of 3 miles/hour (4.8 kilometers/hour);
- uses a consistent standard for skin tissue resistance; and
- assumes the worst case scenario for solar radiation (clear night sky).

3. WCT INDEX ALGORITHMS

The initial iterative Osczevski-Bluestein WCT algorithms were submitted to NWS and MSC for transition into their central and forecasters' computers. Subsequently, the weather services asked for non-iterative equations that would best represent the final WCT data points, since iterative procedures overwhelmed their forecasters' computers, and therefore, might jeopardize operational implementation of the new WCT Index. As a result, the researchers ran the model over 800 times with different combinations of wind speed and air temperature, and then performed a multiple regression analysis of the results. The following were the resulting algorithms:

In English units:

$$\mathbf{WCT = 35.74 + 0.6215T - 35.75V^{0.16} + 0.4275TV^{0.16}}$$

Where T is the air temperature in °F and V is the observed wind speed at 33 feet elevation in mph.

In metric units:

$$\mathbf{WCT = 13.12 + 0.6215T - 11.37V^{0.16} + 0.3965TV^{0.16}}$$

Where T is the air temperature in °C and V the observed wind speed at 10m elevation in km/hr.

The equations correct the observed wind speed at 33 feet (10 meters) to the height of the face. For these equations, the wind speed at the level of the face in "calm" conditions is assumed to be 3 mph (4.8 km/hr). As a result, the WCT should equal the air temperature at this "calm" wind speed. These equations were used to prepare the WCT Index charts which were submitted to MSC and NWS for review. On their request, the charts were modified to identify wind chill temperatures that might be expected to produce frostbite on exposed skin in 30 minutes or less, in the most susceptible (95th percentile) of the population, and for a worst case scenario (night time clear). Tables 1 and 2 are the resulting WCT Index charts in degrees Fahrenheit and Celsius, respectively, which were derived from the appropriate WCT equation. If the wind is measured at face level, the wind speed should be multiplied by 1.5 to use the equation or chart.

4. DISCUSSION

Freezing cold injury can occur anytime temperatures (air or surface) fall below freezing (32°F and 0°C). However, the likelihood and severity of injury increases with prolonged exposure to lower temperatures and greater relative wind speed, where wind speed may be a combination of actual wind speed, walking speed, and/or vehicle speed. Wind chill is not just a property of the environmental conditions, but of the faces being cooled by it. Cheek thermal resistance varies considerably among individuals. In the human studies, it varied by more than a factor of two. As a result, cheek temperatures in wind, in general, will differ from person to person.

Individuals will feel different degrees of coldness at the same combination of wind and temperature, since the perception of wind chill depends on the skin temperature. Those with high thermal resistance cheeks will have colder faces than those with lower thermal resistance cheeks. The wind chill equivalent temperature for individuals with high thermal resistance cheeks should be relatively high compared to that of individuals having low thermal resistance cheeks. This is because the wind chill equivalent temperature depends on the heat transfer rate, which in the high thermal resistant individual will be relatively low because of the higher internal thermal resistance.

However, those individuals with low thermal resistance will feel the cold less, because of higher facial skin temperatures. Thus, individuals for whom the wind chill equivalent temperature should be milder, the high thermal resistance group, will perceive the weather to be colder. This apparent paradox calls into question the utility of wind chill equivalent temperatures. In spite of this, once individuals have experienced the range of wind chill, and recalibrated the temperature scale to their own sensations, the scale will be useful to them in that they will know what to expect.

Some individuals have leveled criticism at the previous wind chill equivalent temperature scale because the cold equivalent temperatures do not feel the same as a real temperature of that magnitude in still air that they have experienced previously. This criticism will probably still be heard, because the new scale was not derived for their faces, but for the faces of the 95th percentile of cheek thermal resistance. Incidentally, while the population with high thermal resistance is at greater risk of frostbite, they are at lower risk for hypothermia.

Several cautions apply to the use of the Osczevski-Bluestein WCT model and tables. The exact effect of cold exposure due to wind chill on an individual will vary depending on the type and level of activity; length of exposure; moderating effects of clothing, partial shelter from the wind, and/or solar radiation; and overall physical state of the individual. The model was not designed to determine hypothermia effects since it is based on facial cooling, not on the whole body's temperature cooling. Frostbite will not occur when the air temperature (T) is above freezing (T>32°F or 0°C). In addition, wind chill does not apply to inanimate objects. The only effect that wind will have on inanimate objects is to shorten the time to cool to the actual air temperature.

5. FUTURE

It is expected that this new WCT Index will be periodically reviewed and upgraded as additional human data becomes available and as science progresses. The following are several areas that will be pursued by OFCM's JAG/TI over the next several years.

A detailed description of the time to frostbite for various sets of conditions is forthcoming, based on a time-dependent model being developed at DCIEM by researchers, including Dr. P. Tikuisis, an internationally recognized expert in the prediction of body cooling and survival times in cold conditions.

The JAG/TI agreed to delay incorporation of solar radiation effects to allow the researchers to finish determining the correct adjustments for solar radiation (i.e., the impact of sun) for a variety of conditions, including day time clear, day time cloudy, and night

time cloudy. The tentative operational implementation is expected to be the winter season of 2002-2003.

The JAG/TI agreed to fully document their WCT Index project by producing an OFCM report, tentatively set to be published in the November/December 2001 time frame.

The JAG/TI will next focus on addressing standardization of the extreme heat indices of both the United States and Canada, moving towards a North American standard, and if possible, an international standard. This process will be in collaboration with a commission of international experts that was brought together by ISB, known as ISB Commission 6. Its purpose is to build on the EC/MSC Windchill Internet Workshop discussions and recommendations towards an internationally accepted Universal Thermal Climate Index (UTCI). The JAG/TI, NWS, MSC, and U.S. academia, as well as other well respected experts on thermal indices and pertinent country representatives, are participating in the on-going Commission 6 meetings and email discussions. Commission 6 has set a goal to produce an UTCI within the next 3 years.

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Table 2. The new Wind Chill Temperature (WCT) Index chart and equation, with T = Air Temperature in °C and V = Observed Wind Speed in km/h at 10m elevation, which is corrected to 1.5 meters elevation via the equation

Temperature (°C)

Wind Speed (km/h) at 10 meters	0	-5	-10	-15	-20	-25	-30	-35	-40	-45	-50
Calm											
5	-2	-7	-13	-19	-24	**-30**	**-36**	**-41**	**-47**	**-53**	**-58**
10	-3	-9	-15	-21	-27	**-33**	**-39**	**-45**	**-51**	**-57**	**-63**
15	-4	-11	-17	-23	**-29**	**-35**	**-41**	**-48**	**-54**	**-60**	**-66**
20	-5	-12	-18	-24	**-30**	**-37**	**-43**	**-49**	**-56**	**-62**	**-68**
25	-6	-12	-19	–25	**-32**	**-38**	**-44**	**-51**	**-57**	**-64**	**-70**
30	-6	-13	-20	-26	**-33**	**-39**	**-46**	**-52**	**-59**	**-65**	**-72**
35	-7	-14	-20	-27	**-33**	**-40**	**-47**	**-53**	**-60**	**-66**	**-73**
40	-7	-14	-21	-27	**-34**	**-41**	**-48**	**-54**	**-61**	**-68**	**-74**
45	-8	-15	-21	–28	**-35**	**-42**	**-48**	**-55**	**-62**	**-69**	**-75**
50	-8	-15	-22	-29	**-35**	**-42**	**-49**	**-56**	**-63**	**-69**	**-76**
55	-8	-15	-22	**-29**	**-36**	**-43**	**-50**	**-57**	**-63**	**-70**	**-77**
60	-9	-16	-23	**-30**	**-36**	**-43**	**-50**	**-57**	**-64**	**-71**	**-78**

Frostbite may occur in 30 minutes or less

WCT (°C) =13.12 + 0.6215T – 11.37$V^{0.16}$ + 0.3965T$V^{0.16}$

Table 1. The new Wind Chill Temperature (WCT) Index chart and equation, with T = Air Temperature in °F and V = Wind Speed in mph at 33 feet elevation, which is corrected to 5 feet elevation via the equation.

Temperature (°F)

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

Frostbite may occur in 30 minutes or less

WCT (°F) = 35.74 + 0.6215T - 35.75$V^{0.16}$ + 0.4275T$V^{0.16}$