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OFCM



OFFICE OF THE FEDERAL COORDINATOR FOR  
METEOROLOGICAL SERVICES AND SUPPORTING RESEARCH

# Report on Wind Chill Temperature and Extreme Heat Indices: Evaluation and Improvement Projects

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**FEDERAL COORDINATOR  
FOR  
METEOROLOGICAL SERVICES AND SUPPORTING RESEARCH**

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**REPORT ON  
  
WIND CHILL TEMPERATURE AND  
EXTREME HEAT INDICES:  
EVALUATION AND IMPROVEMENT PROJECTS**

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## FOREWORD

The Office of the Federal Coordinator for Meteorological Services and Supporting Research (OFCM) is an interdepartmental office established under the Department of Commerce National Oceanic and Atmospheric Administration (NOAA) to ensure the effective use of United States (U.S.) federal meteorological resources by leading the systematic coordination of operational weather requirements, services, and supporting research among the federal agencies. Fifteen federal departments and agencies are currently engaged in meteorological activities and participate in the OFCM's coordination and cooperation infrastructure. In addition to providing a coordinating infrastructure, the OFCM prepares operations plans; conducts studies; responds to special needs, inquiries and investigations; and conducts forums to address national meteorological topics.

Over the last several years, numerous articles on the inaccuracy of the wind chill index were published in scientific journals, business journals, and newspapers. In response to convincing scientific evaluation, as well as public critique, of the current North American wind chill indices, NOAA's National Weather Service and Environment Canada's Meteorological Service of Canada decided to upgrade their wind chill indices and to evaluate the heat indices for possible improvement. They requested assistance in this endeavor from OFCM.

To that end, the OFCM interagency Committee for Environmental Services, Operations and Research Needs formed the Joint Action Group for Temperature Indices (JAG/TI) as the result of discussions on temperature indices at the American Meteorological Society's 12<sup>th</sup> Conference on Applied Climatology, May 8-11, 2000, and during the Environment Canada's Internet Workshop on Windchill, April 3-7, 2000, along with the recommendations and reports of known experts. The JAG/TI was charged with evaluating the existing temperature indices (wind chill and extreme heat) and determining if changes to the operational indices were required.

This OFCM report describes the U.S. and Canadian project to jointly evaluate NOAA's National Weather Service, Environment Canada's Meteorological Service of Canada and U.S. Department of Defense operational temperature indices, to work together on any upgrades and/or replacements, and to implement these changes as necessary.

Samuel P. Williamson  
Federal Coordinator for Meteorological  
Services and Supporting Research



## EXECUTIVE SUMMARY

### REPORT ON

#### WIND CHILL TEMPERATURE AND EXTREME HEAT INDICES: EVALUATION AND IMPROVEMENT PROJECTS

**Introduction.** Over the last several years, there have been many articles on the inaccuracy of the wind chill index which were published in scientific journals, business journals, and newspapers. Convincing scientific evaluation, as well as public critique, of the current United States (U.S.) and Canadian weather services' wind chill indices based on the 1945 Siple & Passel 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's (OFCM) Committee for Environmental Services, Operations and Research Needs (C/ESORN) formed a special group during the summer of 2000 called the Joint Action Group for Temperature Indices (JAG/TI). The JAG/TI's purpose was to evaluate the existing wind chill and extreme heat formulas in light of recent knowledge, 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 focused on the current wind chill temperature indices. Standardization of indices among the meteorological community is important so 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's (NOAA) National Weather Service (NWS). The JAG/TI representatives and participants were from several U.S. federal agencies (U.S. Air Force (USAF), U.S. Army Corps of Engineers (USACE)/Engineer Research and Development Center (ERDC)/Cold Regions Research and Engineering Laboratory (CRREL), U.S. Army Research Institute for Environmental Medicine (USARIEM), Department of Energy (DOE), NOAA (NWS and the National Climatic Data Center (NCDC)), Federal Aviation Administration (FAA), 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 (DRDC, formerly 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 and World Meteorological Organization sponsored Internet Workshop on Windchill, held the week of April 3, 2000. This workshop produced comments and discussions from experts and the public world-wide. The OFCM, NWS and other U.S. professionals also participated in the workshop.

Through a series of workshops held from October 2000 through November 2002 and email discussions, the JAG/TI reviewed research and public comments on wind chill indices, initiated a replacement wind chill index project, and implemented the results for the 2001-2002 winter season. The following is a summary of this work.

**Overview of JAG/TI Work and Results.** The review of the results of the EC/MSI Internet Workshop, current literature (Kessler 1993, 1995; Bluestein 1998; Quayle and Steadman 1998; Maarouf and Bitzos 2000; Osczevski 1995a,b and 2000a,b; Quayle et al. 2000), and invited presentations by subject experts led JAG/TI members to agree that the current NWS and MSI methods to determine wind chill overstated the effect of the wind, made people think it feels colder than it really is, and fooled the public into thinking they could withstand colder temperatures than reality. In addition, the review recommended revising the indices because they were too cold, especially at very cold temperatures and high wind speeds, and they did not apply well to situations of actual temperatures above freezing. A comparative study of several indices demonstrated that at least three other indices outperformed the current NWS and MSI indices, and that these other indices produced consistent results (Quayle et al. 2000). Noted problems with the NWS and MSI indices included: 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 ft (10 m) instead of the average height of a human face (Santee et al. 1994; Schwerdt 1995; Bluestein 1998).

To correct these known problems, the JAG/TI members and participants agreed to have IUPUI and DRDC develop a new wind chill temperature (WCT) index (WCTI) based on their recently published new wind chill models. The new model used wind, air temperature, and solar radiation as the environmental factors in the wind chill formula and used the human face for evaluating wind chill impact since it is the part of the body most often exposed to severe winter weather. The JAG/TI also agreed to have human studies conducted at the DRDC facilities in Canada to help verify the new WCTI. Infrared and heat sensor measurements were used to measure the skin temperature of human subjects in various environmental conditions which may produce wind chill effects. The OFCM, CRREL and DRDC provided the funding for this research and development of the new wind chill index. Transition into the weather services' operations was accomplished with NWS and MSI existing resources. The human studies were completed in June 2001 and the results used to correct the preliminary WCTI algorithm. Solar radiation calculations and associated charts could not be completed by the MSI and NWS deadlines for transition and implementation for the winter season 2001/2002.

The completed WCTI algorithm and the results of the human studies were presented to the JAG/TI at the August 2-3, 2001, meeting at DRDC in Toronto, Canada. The group recommended the new WCTI for implementation by NWS, MSI and DOD. NWS and MSI agreed to and did implement it on November 1 and October 31, respectively, for the winter season of 2001-2002. DOD also agreed to implement beginning in November. These agencies also asked for threshold values for frostbite, which could be added to their web sites. During September and October 2001, DRDC continued their frostbite research, used the human studies' results to develop threshold values for "time to frostbite," and subsequently provided the data to the JAG/TI members to be included in the WCTI.

Specifically, the new WCTI:

- uses wind speed corrected to a height (5 ft or 1.5 m) 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 mph (4.8 km h<sup>-1</sup> or 1.3 m s<sup>-1</sup>);
- uses a consistent standard for skin tissue resistance; and
- assumes the worst case scenario for solar radiation (clear night sky).

**WCT Index Algorithms.** The initial iterative WCT algorithms were submitted to the 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, would have jeopardized operational implementation of the new WCTI. 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, 
$$\text{WCTI} = 35.74 + 0.6215T - 35.75V^{0.16} + 0.4275TV^{0.16}$$
where T is the air temperature in °F and V the wind speed in mph at 33 ft elevation.

In metric units, 
$$\text{WCTI} = 13.12 + 0.6215T - 11.37V^{0.16} + 0.3965TV^{0.16}$$
where T is the air temperature in °C and V the wind speed in km h<sup>-1</sup> at 10 m elevation.

The equations use observed wind speed at 33 ft (10 m) to generate WCT corrected 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 the walking speed of 3 mph (4.8 km h<sup>-1</sup> or 1.3 m s<sup>-1</sup>). As a result, the WCT should equal the air temperature at this “calm” wind speed. These equations were used to prepare the WCTI charts. On the request of MSC and NWS, the charts were modified to identify wind chill temperatures that might be expected to produce frostbite on exposed skin in 30 min or less, in the most susceptible (95<sup>th</sup> percentile) of the population, and for a worst case scenario (night time clear). The resulting WCTI charts were given in degrees Fahrenheit (EF; NWS) and Celsius (EC; MSC) and 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.

**Future.** It is expected that the new WCTI will be periodically reviewed and upgraded as science progresses. The following are several areas that will be pursued by JAG/TI. 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. For the WCTI, research and development will continue for the solar radiation and frostbite models. Full analysis of the human studies will be used to refine the frostbite model. In addition, the marine spray part of the studies will be evaluated for possible application of the WCTI for maritime warnings.

JAG/TI will continue to focus on addressing standardization of the heat indices of both U.S. 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 were brought

together by the International Society of Biometeorology (ISB) for the development of a Universal Thermal Climate Index (UTCI), known as ISB Commission 6 (ISB C6). Its purpose is to build on the EC/MSC Internet Workshop discussions and recommendations towards an internationally accepted UTCI. The JAG/TI members, EC/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 ISB C6's meetings and discussions. ISB C6 has set a goal to produce a UTCI within two to three years.

## ACKNOWLEDGMENTS

The Joint Action Group for Temperature Indices (JAG/TI) is a subgroup of the Committee for Environmental Services, Operations and Research Needs (C/ESORN), under the Office of the Federal Coordinator's Interdepartmental Committee for Meteorological Services and Supporting Research. In August 2000, this Group was charged with evaluating the existing temperature indices for wind chill and extreme heat. The group determined that changes to the indices were needed, and then coordinated and implemented a new Wind Chill Temperature Index (WCTI). The following scientists and engineers' contributions to the JAG/TI work are gratefully acknowledged:

- Ms. Esther Atkins, National Oceanic and Atmospheric Administration (NOAA), National Weather Service (NWS), Silver Spring, Maryland (former Chairperson, JAG/TI)
- Mr. Myron Berger, NOAA, NWS, Silver Spring, Maryland
- Dr. Maurice Bluestein, Purdue School of Engineering and Technology, Indiana University-Purdue University at Indianapolis, Indiana
- Dr. Michel Ducharme, Defence Research and Development Canada (DRDC) , Defence and Civil Institute of Environmental Medicine, Toronto, Ontario, Canada
- Ms. Katrina Frank, Center for Climatic Research, University of Delaware, Newark, Delaware
- Dr. Edwin Kessler, University of Oklahoma, Norman, Oklahoma
- Dr. Anthony Lupo, Department of Soil and Atmospheric Science, University of Missouri, Columbia, Missouri
- Mr. Abdel Maarouf, EC, MSC and Co-Chairman of the International Society of Biometeorology Commission 6, Toronto, Ontario, Canada
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