

6B.2 JOINT DEVELOPMENT AND IMPLEMENTATION BY THE UNITED STATES AND CANADA OF A NEW WIND CHILL TEMPERATURE (WCT) INDEX

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1. INTRODUCTION*

The United States (U.S.) National Oceanic and Atmospheric Administration's (NOAA) National Weather Service (NWS) and Environment Canada's (EC) Meteorological Service of Canada (MSC) issue forecasts, warnings and advisories for extreme temperatures that could affect public safety, because their primary concern is the protection of life and property. The U.S. Department of Defense (DOD) also issues warnings on extreme temperatures to the military community. The effects of extreme temperatures are increased by the interaction between temperature and other atmospheric parameters, such as wind and humidity. This interaction led to the development of equivalent temperature or thermal indices which represent the effect of various atmospheric parameters on temperature or energy levels. These indices are used by the forecasters to determine when to advise the public on restricting their behavior or changing their activities. Two types of indices are used by NWS, DOD and MSC: wind chill and extreme heat. Prior to the 2001/2002 winter season, the wind chill index was based on the Siple & Passel Index (Siple and Passel 1945). This paper provides a review of the processes used by the United States and Canada to jointly develop and implement a new Wind Chill Temperature Index (WCTI) for North America.

Scientific evaluation of the Siple and Passel wind chill index led to the weather services' decisions to upgrade their wind chill indices. The NWS requested assistance in this endeavor from the NOAA Office of the Federal Coordinator for Meteorological Services and Supporting Research (OFCM). As a result, OFCM's Committee for Environmental Services, Operations and Research Needs (C/ESORN) established the interagency Joint Action Group for Temperature Indices (JAG/TI) with the purpose of improving the operationally used extreme temperature indices by planning and executing strategies for addressing deficiencies; by reviewing practices and procedures pertaining to the use or development of these indices; and by coordinating any changes to the official indices.

The JAG/TI consists of representatives of several U.S. Federal agencies (U.S. Air Force (USAF), U.S.

Army (USA) Corps of Engineers/Research and Development Center/Cold Regions Research and Engineering Lab (CRREL), USA Research Institute of Environmental Medicine (USARIEM), Department of Energy, NWS, Federal Aviation Administration, Federal Highway Administration, U.S. Department of Agriculture, Health and Human Services/Centers for Disease Control and Prevention (CDC), and the Federal Emergency Management Agency); the Canadian government (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 JAG/TI is chaired by the NWS.

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 Environment Canada (EC) and World Meteorological Organization sponsored Internet Workshop on Windchill, held the week of 3 April 2000. This Workshop produced comments and discussions from experts and the public around the world. The OFCM, NWS and other U.S. professionals also participated in the workshop (Nelson et al. 2002).

2. JAG/TI ACTIONS AND RECOMMENDATIONS

The first goal of the JAG/TI was to upgrade and standardize the index used for determining wind chill impact. Through a series of workshops and email discussions held from October 2000 through January 2002, the JAG/TI reviewed research and public comments on wind chill indices, initiated a replacement wind chill index development project, and implemented the results for the 2001/2002 winter season.

During the first 2 workshops, the group reviewed the EC Internet Workshop's results, current literature (Bluestein 1998; Kessler 1993, 1995; Maarouf and Bitzos 2000; Osczevski 1995a, 2000a; Quayle et al. 2000; Quayle and Steadman 1998), and invited presentations by E. Kessler, M. Bluestein, R. Schwerdt, R. Quayle, and R. Osczevski. JAG/TI members agreed that the NWS and MSC Siple and Passel based methods to determine wind chill overstated the effect of

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the wind, made people think it felt colder than it really was, and gave the impression that a person could withstand colder temperatures than reality. The studies recommended revising the operational indices because the apparent temperatures were too cold, especially at very cold temperatures and high wind speeds, and did not apply well to situations of actual temperatures above freezing. A comparative study of several additional indices demonstrated that at least three other indices outperformed the NWS and MSC indices, and also produced consistent results (Quayle et al. 2000). Noted problems with the NWS and MSC 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 (Bluestein 1998; Santee et al. 1994; Schwerdt 1995). The review of the science also indicated that the human face was the part of the body most often exposed to severe winter weather and, therefore, should be used as the model for evaluating the wind chill impact. During their workshops, the group summarized the desired index characteristics and completed an analysis of how some indices fulfill these characteristics.

The results of the review indicated the weather services continue to use the same indices, continue warning the public of environmental dangers, that the indices be tied to a property of the environment, and require the indices to not incorporate a clothing element. The JAG/TI provided the following specific recommendations: correct wind speed to an average adult's face height (5 ft or 1.5 m) based on a human face model; incorporate modern heat transfer theory (heat loss from the body to its surroundings); use a walking speed of 3 mph or 4.8 km/h; use a consistent standard for skin tissue resistance; and initially assume the worst case scenario for solar radiation (clear night sky) with a solar radiation correction to be added later. Based on these recommendations, the JAG/TI members and participants agreed to have Mr. Randall Oszcewski (DCIEM) and Dr. Maurice Bluestein (IUPUI) develop a new WCTI and base it on their recently published new wind chill models (Bluestein and Zecher 1999; Oszcewski 1995b, 2000b).

Assisted by JAG/TI workshops, discussions and funded research, Mr. Oszcewski and Dr. Bluestein developed their new WCTI based on these recommendations. Human studies in a wind and thermal chamber were conducted at DCIEM to verify the accuracy of the new formula (Bluestein and Oszcewski 2002; Ducharme and Brajkiu 2002). The new WCTI makes use of advances in science, technology, and computer modeling to provide a more accurate, understandable, and useful formula for calculating the dangers from winter winds and freezing temperatures. Dr. Bluestein and Mr. Oszcewski presented the results of their work to the JAG/TI on 2 August 2001 for review by the members. Based on this and the discussion at the meeting, the JAG/TI members recommended implementation of the new WCTI by the weather

services for the 2001-2002 winter season (Nelson et al. 2002).

3. WCTI ALGORITHMS

The WCTI algorithm uses observed wind speed at 33 ft (10 m) to generate WCTs corrected to the height of the face. If the wind is measured at face level, the wind speed should be multiplied by 1.5 to use the equation. For these equations, the wind speed at the level of the face in "calm" conditions is assumed to be a walking speed of 3 mph (4.8 km/h). As a result, the WCT should equal the air temperature at this "calm" wind speed. These equations were used to prepare the WCTI charts submitted to MSC, DOD 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 min or less, in the most susceptible (95th percentile) of the population, and for a worst case scenario (nighttime clear). The resulting WCTI charts were given in degrees Fahrenheit and Celsius and were derived from the appropriate WCT algorithm (Nelson et al. 2002). The following are the WCTI algorithms: in English units:

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

where T = air temperature in degrees Fahrenheit and V = wind speed in mph at 33 ft elevation; and in metric units:

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

where T = air temperature in degrees Celsius and V = wind speed in km/hr at 10m elevation.

A preliminary algorithm for time to occurrence of frostbite was also provided to the JAG/TI members and was based on a time-dependent model developed at DCIEM by Mr. Oszcewski and Dr. P. Tikuisis. The frostbite information was used by NWS, DOD, and MSC in their respective WCTI chart, with the understanding that frostbite will not actually occur when the air temperature is above the freezing level. It will take greater than 2 h for frostbite to occur from the freezing level down to 10°F even with high winds of up to 50 mph (Ducharme and Brajkovic 2002). The following is the algorithm for frostbite time (Ft) in minutes and English units:

$$Ft = \left(\left(-24.5 \left(\left(.667 \left(10V \frac{8}{5} \right) + 4.8 \right) \right) + 2111 \right) \left(-4.8 - \left(T_{air} - 32 \right) \frac{5}{9} \right)^{-1.668} \right),$$

where T_{air} = air temperature in degrees Fahrenheit and V = wind speed in mph > 16 measured at 33 ft.

The algorithm for frostbite time (Ft) in minutes and metric units is

$$F_t = \left((-24.5 \left((.667(10V)) + 4.8 \right) + 2111) \right) \left((-4.8 - T_{air})^{-1.668} \right)$$

where T_{air} = air temperature in degrees Celsius and V = wind speed in km/h > 25 measured at 10m.

4. IMPLEMENTATION

From the formation of the JAG/TI in the fall of 2000, all participants were anticipating how their agency could incorporate recommended improvements to their temperature indices as quickly as possible. As a result, the JAG/TI built into their approved advanced research development recommended deadlines for finishing various aspects of the development, including provision of the algorithms and completion of verification and validation. Funding for the project was provided by DCIEM, OFCM, and CRREL. The transition of the new WCTI into operations was handled within the JAG/TI via approved actions and coordinated activities. Notification of the new WCTI was sent by the Federal Coordinator to U. S. Federal agencies in September 2001. The purpose of this memorandum was to officially notify the agencies of the new recommended WCTI, to provide the Index's algorithms and charts, and to provide a summary of the JAG/TI project through an attached executive summary. Subsequent updates and other documentation of the JAG/TI activities and decisions were provided to Federal agencies by their OFCM representatives and through distribution of the JAG/TI meetings' Record of Actions. Canadian authorities were notified by the EC.

After the science review, the group initiated the research activity, solicited funding support, and established a time line for delivery of the new WCTI. As the project progressed, the group approved adjustments to this time line, monitored the research activity, conducted ongoing coordination with the researchers and funding agencies, and reviewed project reports by the researchers. The final form of the WCTI algorithm was required by the NWS and MSC no later than the beginning of August 2001 in order to have it correctly inserted into their forecast centers' and forecast offices' computer software and to finish developing forecaster and public education packages before the 2001-2002 season began. In addition, NWS was required to issue a public information statement on the planned implementation at least 60 days in advance of the implementation. DOD also required it by August so they could complete their internal coordination with the various military branches' medical and operational hierarchy. The recommendation to move ahead with adoption of the new WCTI was reached at the August 2001 meeting. Each weather service then implemented the new WCTI and frostbite equation according to their agency's procedures.

The JAG/TI assisted this process with the development of educational packages by arranging for the DCIEM human studies to be filmed by CRREL. Copies of the film were provided to the weather services and OFCM. In addition, Mr. Mulherin and Dr.

Phetteplace of CRREL created a poster on the WCTI implementation which was distributed to the JAG/TI participants for their use in publicizing the WCTI change. MSC also provided their educational package on CDROM and video tapes to NWS and OFCM along with additional pictures of the human studies tests. The JAG/TI members were interviewed for television reports and articles on the new index that appeared in various newspapers across the nation and in professional journals such as "Weatherwise".

Through C/ESORN, the JAG/TI composed several documents on the WCTI project to assist in the public and Federal agencies education process, including an executive summary, papers for professional meetings, media talking points, and point papers. The C/ESORN JAG/TI posted their executive summary on the web site under Special Projects at: <http://www.ofcm.gov>.

In addition, the Centers for Disease Control and Prevention (CDC) was contacted to update their web site to reflect the new WCTI. CDC agreed and established a link to the NWS wind chill web site. The Office of Safety and Health Administration was also contacted to invite them to participate in future JAG/TI meetings and activities, and to update their manuals, handbooks, and relevant web sites to reflect the new WCTI. They have agreed to participate in the group activities and will look into making any necessary updates.

4.1 NWS Implementation

The NWS implemented the new WCTI on 1 November 2001 (Tew et al. 2002). The implementation process involved three key steps: the Advanced Weather Interactive Processing Systems (AWIPS) implementation, operations integration and public education. In order to begin the WCTI Implementation process, the new WCTI algorithm was first inserted into AWIPS. The AWIPS programs and products that use it are: the Hourly Weather Roundup; the Interactive Forecast Preparation System products; and the Display 2-Dimensions application. The WCTI algorithm with frostbite thresholds was released to all 121 NWS Weather Forecast Offices in October 2001. The AWIPS software changes were transmitted to each WFO through a maintenance release by the Office of Operational Services, and the installation was monitored by the Network Control Facility. The installation was completed at all sites before the 1 November 2001 implementation date.

Operations integration required changing warning and advisory threshold values and updating national and regional policy documents to reflect the changes. Threshold values are used in Wind Chill Outlooks, Wind Chill Watches, Wind Chill Warnings and Wind Chill Advisories to decide when to provide the public advance notice of dangerous or life threatening wind chill conditions.

During August 2001, NWS developed an extensive education effort to inform their customers and partners about the new WCTI and their WCTI Chart with frostbite times shaded. They established the NWS Wind Chill

web page, which included this new chart and a wind chill calculator. They also updated the NWS Winter Storm Brochure, organized mailings and seminars targeting local media, emergency managers, city and school officials, and participated in interviews. This resulted in numerous wind chill articles published in newspapers and magazines. On 2 September 2001, NWS issued a public information statement to inform the public of the upcoming change to the NWS wind chill program. The NWS Wind Chill Index web site is located at <http://www.nws.noaa.gov/om/windchill>.

4.2 MSC Implementation

The MSC began using the new WCTI in their forecasts on 2 October 2001 (Shaykewich et al. 2002), but did not have the formal implementation ceremony until 30 October 2001. The formal implementation ceremony took place at the DCIEM site of the human trials and was attended by most major media networks in Canada. The algorithm was incorporated into the winter guidance and into the Scribe auto-generated forecast bulletin preparation program before the start of the use of the new index. MSC wrote a short Standard Operating Procedure document for use by the forecasters, available upon start-up. It included national guidance on format and terminology as well as on climate region specific thresholds for reporting on wind chill for inclusion in a forecast and for the issuance of warnings. The initial notice was issued by mid-August 2001. MSC worked with several media outlets during the human studies and afterward to help publicize the change and educate their public. As part of the media coverage and from the filming of the studies, Discovery Channel and The Weather Network in Canada broadcast two hours of interviews, views of the equipment used in the studies, human studies, and the results of the studies.

During August 2001, MSC worked on training, more detailed talking points, information for outreach, possible questions and answers, climatology, and the relation of the old index to the new index. MSC also produced educational products for children, updated brochures, and wallet cards to reflect the new WCTI. These were distributed widely and made available via their web site. MSC developed an extensive web site which provides information on the wind chill index, including the scientific basis, the April 2000 EC Internet Workshop documents, the update process, an on-line downloadable wind chill calculator, equations for the WCTI and frostbite times, educational documents, charts and tables, fact sheet, and links to other JAG/TI agencies. Their web site address is: <http://www.msc.ec.gc.ca/education/windchill>.

4.3 DOD Implementation

The USAF and USA began implementation of the new WCTI and Minutes to Frostbite equation at worldwide locations on 1 November 2001. The USAF Director of Weather, Policy Division issued an announcement to USAF and USA units on 17 October

2001. The USA Office of Surgeon General sent additional guidance to USA units on 17 December 2001. Subsequently, the information on the new WCTI and frostbite was publicized, distributed, adapted for use, included in models and weather systems, and references and publications were updated. Articles were released by the USAF Weather Agency Office of Public Affairs to the *Air Force News* on 26 October 2001 and appeared on Air Force Radio News on 29 October 2001. The new index was introduced by several other media through safety articles, disaster preparedness briefs, and internal newsletters. The new index was also available for downloading at several military web sites. For worldwide adoption of WCTI and Minutes to Frostbite information, an additional eight charts were created in metric units, corrected for the different wind measuring heights (5, 15, and 33 ft), and extended the equations from wind 45 mph to 60 mph. The new charts were completed in January 2002 and distributed shortly thereafter to both the military and JAG/TI members.

Automating the new WCTI and Minutes to Frostbite equations into Air Force Weather systems will be accomplished as new versions of software are created, such as the inclusion of the new index in the software upgrade to the USAF Weather's forecast display work station, the New Tactical Forecast System. Weather models will also be updated with the WCTI as visualization output is programmed. As identified or reviewed, military publications will include the new WCTI and Minutes to Frostbite information. The USAF Surgeon General plans to include the information in the Air Force Pamphlet 48-151, *Thermal Injury*. The USARIEM has incorporated the new information into their update of the Technical Note: *Sustaining Health and Performance in Cold Weather Operations*, published in October 2001.

The United States Navy (USN) and United States Marine Corps (USMC) implementations were coordinated by the Commander, Naval Meteorology and Oceanography Command (CNMOC). CNMOC forwarded the new WCTI to its Fleet Meteorological and Oceanographic (METOC) Offices and Regional Centers in November 2001. Since that time, copies of the WCTI were posted on the CNMOC Operational Support Web. In addition, the WCTI will be incorporated in the next version of the Automated Surface Observing System software release. Finally, an article on the change to the WCTI was published in the bi-monthly CNMOC News.

The USMC also incorporated the WCTI in support of USMC operations worldwide during November 2001. The USMC METOC personnel introduced the new index to all the warfighting commands of the Marine Air Ground Task Force (MAGTF). The new index was also made available for downloading at several USMC military web sites. The WCTI will be included as a new requirement into automated observing and recording weather systems as new versions of the software are fielded. References to the wind chill in the USMC publications will be updated when identified or reviewed, as is planned for the Marine Corps Warfighting

Publication, MAGTF Meteorological and Oceanographic Support 3-35.7.

5. FUTURE

It is expected that this new WCTI will be periodically reviewed and upgraded as science progresses. Research and development is already planned to continue for implementing solar radiation effects and the frostbite model. The JAG/TI had agreed to delay incorporation of solar radiation effects to allow the researchers to finish determining the correct adjustments for solar radiation for a variety of conditions, including day time clear, day time cloudy, and night time cloudy. Full analysis of the human studies will be used by DCIEM 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.

The International Society of Biometeorology Commission 6 is intending to build on the EC/MSC Internet Workshop discussions and recommendations towards an internationally accepted Universal Thermal Climate Index (UTCI). The JAG/TI members, EC/MSC, and U.S. academia, as well as other experts on thermal indices and pertinent country representatives, will be participating in the ongoing Commission's meetings and discussions. The ISB Commission 6 has set a goal to produce a UTCI within 3 years.

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