CHAPTER 2

SCIENCE REVIEW AND RECOMMENDATIONS

2.1 <u>Introduction</u>. The JAG/TI members agreed to address both the wind chill and heat indices and to evaluate them through workshops, email discussions, and solicitation of recommendations from outside the committee. Five workshops and meetings were held from October 2000 through November 2002. The first workshop was devoted to discussions on the wind chill index, the second devoted to status of the WCTI project and discussions on the heat indices, the third devoted to the review of the human studies and to the finalization of the WCTI, and the fourth a review of the solar radiation calculation and continuation of science review of heat indices. The fifth meeting was held to review further development and/or improvement to the WCTI, and to review possible heat index changes. This chapter presents a summary of the JAG/TI science review, a brief summary of operational programs in the U.S. and Canada, and recommendations and guidance towards the development of a new wind chill temperature and heat index.

2.2 <u>Science Review</u>. The first task of the JAG/TI was to review the results of the EC Internet Workshop, scientific reports and papers on various operational and research indices, the AMS Panel on evaluation of wind chill temperature indices, the results of the 1996 NOAA Heat Wave Workshop, reports on the development of a relative heat factor, and current temperature indices in operations. Descriptions of other indices from European countries and Australia were examined but the group found that it was difficult to directly compare programs outside of the U.S. and Canada to the United States. These differences result in the underlying science in the models. The Europeans work focuses on models which included a complete heat budget, whereas others (e.g., U.S. and Canada) uses simple "facial cooling" models which could provide adequate warning of the effects of wind chill. One possibility was to have two complementary indices: one index based on the properties of the environment and the second follow-on index that tied the temperature to what one should wear using the first equation as input. The group decided to press ahead with the review, summarize the desired indices characteristics, and then analyze the most promising indices as to how they meet these characteristics. This review is presented below.

2.2.1 Summary of EC Internet Workshop on Windchill. The Internet Workshop on Windchill was conducted April 3-7, 2000 and was hosted by the MSC (Maarouf and Goessl 2001). There were six sessions held producing comments and discussions from experts and the public around the world (Windchill Science, Windchill Indices, Current Reporting of Windchill, Communication Issues, International Collaboration, and a last day Panel Discussion). The workshop objectives were to review the science, evaluate the usefulness of the index, discuss the most accurate and acceptable ways of disseminating information and warnings, and to develop recommendations for rigorous experimental research including international harmonization and standards. During this activity, numerous recommendations to upgrade or replace the current commonly used Wind Chill Index were made because this Index tended to be at least 10 degrees Fahrenheit too cold and was used inappropriately for temperatures above freezing. EC determined that the way to move forward was to collaborate with efforts for the adoption of an international program, focus on terminology in the short term, implement program changes in an internationally consistent way, and educate their public on any changes to the existing program.

2.2.2 Osczevski Index. The Osczevski model (Osczevski 1995a,b; Osczevski 2000a,b) is based on facial cooling and was developed at DRDC. DRDC is Canada's center of expertise for research and development in human performance and protection, human-systems integration and operational medicine. The Osczevski wind chill index incorporates the environmental parameters of air temperature, wind, and a solar radiation correction, with heat transfer theory, human comfort and risk of frostbite. DRDC conducted experiments at the testing facilities to determine whether wind chill was a whole body experience or a local cooling effect or a combination. The theory was that cooling was mostly felt on the facial area. For example, if you open an umbrella and shade your face you will feel colder than without the umbrella. One of the devices used to evaluate this theory was a Thermal Manikin Head (TMH) which is a computer-controlled, multi-zone device built to assess the thermal insulation of headgear. Using this device, one can break down the loss of heat from four separate zones (face, crown, back of head, and narrow zone at the contact point of hats). Future development will add a zone for the center of face where most frostbite occurs. The DRDC's testing facilities includes climatic chambers in which clinical trials with the TMH and volunteers are conducted.

2.2.3 Siple and Passel Index. Siple and Passel (1945) conducted an experiment in Antarctica. The data obtained was used to develop their index. The equipment used consisted of water-filled plastic cylinders which were exposed to the cold wind of Antarctica at various temperatures. Siple and Passel recorded the time to freeze the water over a range of temperatures from -9ºC (15.8EF) to -56ºC (-68.8EF) and wind speeds from calm to 43.2 km h^{-1} (12 m s^{-1} or 26.8 mph). The experimental data were scattered, some of the most distant observations were subjectively thrown out, and the best fit line (parabolic) was applied to the remaining data. The extremes of wind were not accounted for or included in the chart. If they were included, the fitted line wouldn't make sense after 50 mph (80.5 km h^{-1} or 22.3 m s^{-1}), since it would imply that the wind chill decreases above 50 mph. Their graph calls the best fit line the cooling rate, but it was really the heat transfer co-efficient. The index was not intended nor should it have been extrapolated beyond a 50 mph wind or Siple's experimental observations. In spite of all this, the index has served the community quite well by getting the public to protect oneself in cold and windy conditions (Maarouf and Bitzos 2000).

2.2.4 Bluestein and Zecher Index. Bluestein and Zecher (1999) developed a new wind chill index based on the Siple and Passel Index. They found that Siple and Passel had not taken into account the resistance of the container used in their experiments. This addition dramatically changed the results of Siple and Passel Index temperatures. It appears that their index had also exaggerated the effect of heat transfer. The new index used a mathematical approach for a full adult head model, with heat loss from the exposed surfaces and temperature and wind considered as the environmental factors. Solar radiation and the effect of light winds on heat transfer from the upwind side of a cylinder were not considered.

2.2.5 Perceived Temperature and the Physiological Equivalent Temperature Indices. Two other indices developed by German scientists were reviewed. Both of these indices incorporated a heat budget model of a standard or average human body to calculate equivalent or perceived temperatures to express thermal comfort. The Perceived Temperature (PT) index

(Jendritzky et al. 2000) is a comfort climate index based on a reference environment related to the public's perception of heat or cold. The Physiological Equivalent Temperature (PET) (Hoeppe 1999) based the calculations of comfort on how indoor temperatures are perceived and the wearing of office work clothes. It enables the public to compare the integral effects of complex thermal conditions outside with their experience indoors. Both models take into account all variables of the thermal environment in a physiological relevant way.

2.2.6 Steadman's Climate Index. The Steadman climate index (Steadman 1994) is a fully clothed body model that accounts for effects of temperature, wind, radiative heat, and relative humidity. The main advantage for the U.S. using the Steadman's index would be that the NWS already uses a modified Steadman's index (which only accounts for temperature and humidity). This would allow the blending together of both heat and cold indices. At the time of the first JAG/TI workshop there was some concern that the algorithms for the Steadman's index were not available since the NWS derived their modified Steadman index from plotting the values and applying a regression analysis to the data (Rothfusz 1990). Subsequently, it was learned that the algorithms could be provided. This would allow more standard atmospheric variables to be included in the future.

2.2.7 Comments and Information From University of Missouri-Columbia. Comments were provided by Dr. Anthony Lupo, University of Missouri-Columbia. Several points were made regarding the development and implementation of a new WCTI. First, more complex models could be used with the advancement of computers. Second, the Steadman model had a few advantages over other indices: more comprehensive, compatible with the current NWS heat index, and it could be easily programmed into existing computer models. Third, base the index on standard bare skin due to the complexities of approximating a clothed model. Also, the whole body should be considered or approximated. Fourth, continue the current NWS practice of warning on extremes because it gets people's attention easier and of using an equivalent or apparent temperature. Fifth and last, continue research in both physiology of human response and in the communication aspects of a thermal environment.

2.2.8 Comparative Study. Quayle et al. (2000) has presented a comparative review of the most common, environmentally based, wind chill indices (Steadman Climate Index, the Bluestein and Zecher Index, the Osczevski (1995b) Index, and the Siple and Passel Index as used by NWS (Rothfusz 1990)). The review demonstrated that the first three indices' values were similar and that all three outperformed the NWS operational index (see Fig. 2-1). The differences between Osczevski's and Bluestein and Zecher's indices were the amount of exposed body part, the inclusion of solar radiation, and how the still conditions are handled. Osczevski's index was a full face model, used a standard person's walking pace for still conditions, and included a set value for radiation, while Bluestein and Zecher's index was a full head model with no solar radiation considered and with still winds equal to 4 mph (6.4 km h^{-1} or 1.8 m s^{-1}). Bluestein and Zecher's model tended to be slightly colder than Osczevski's model, which appeared to be related to solar radiation considerations and the handling of still conditions. Osczevski and other models originally used a wind speed in still conditions set at 4 mph because the standard cup anemometer stopped at this speed and most people tend to be in motion when outside. Steadman's model used a whole body model represented by a cylinder, added more environmental variables, and incorporated clothing assumptions.

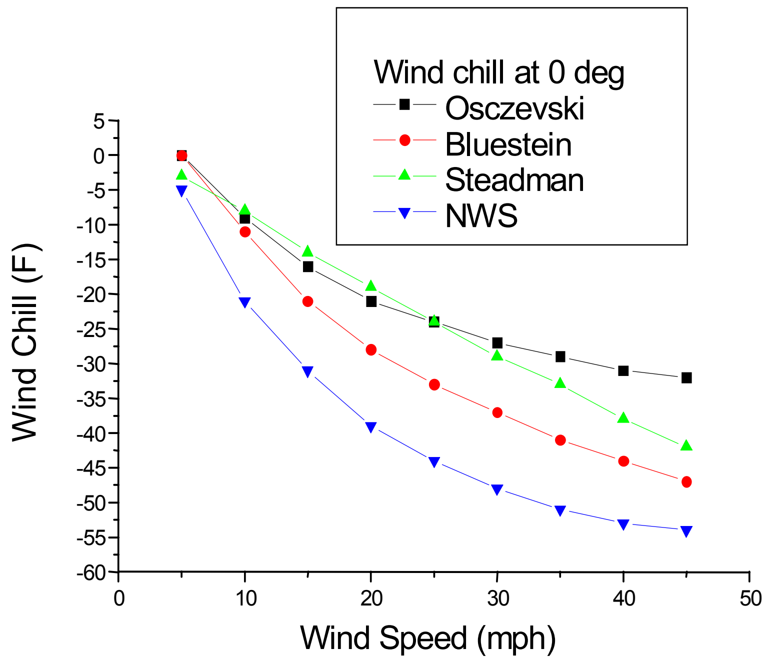

Figure 2-1. The figure shows the differences in the various wind chill equivalent formulations at an air temperature of 0EF (adapted from Quayle et al. 2000).

2.2.9 Comments on upgrading the NWS wind chill program. Schwerdt (1995) evaluated wind chill variations by latitude and region, and on occurrence of frostbite. The report brought out the need to look at injuries occurring outdoors resulting from cold weather and the relation between injury rate and wind chill. Two concerns were discussed: 1) there were no specific NWS standards governing the relation between the onset of frostbite and wind chill, only guidelines for when wind chill is dangerous, and 2) the NWS wind chill index and guidelines needed improvement (NWS 1992). Schwerdt also reported on early 1970's Russian experiments conducted by Adamenko and Khairullin (1972). These were conducted on unprotected human skin under various combinations of wind speed and air temperature, and showed that frostbite can occur at about -10EF (-23.3EC) with wind chill, that acclimation to climate did not change the threshold for frostbite occurrence, and that the higher the wind speed, the faster the skin will freeze with only wind speed varying and no accounting for sunny weather. As a general rule, based on user feedback through the years and the Russian research, the accepted NWS threshold for potentially dangerous wind chill conditions was a wind chill of about -20EF (-28.8EC). This appeared to be a reasonable value overall for the issuance of wind chill warnings, as long as one realized that more positive wind chill values could still cause frostbite on exposed body parts.

2.2.10 U.S. Army Overviews of Temperature Related Research. The U.S. military uses wind chill to provide specific guidance for various cold weather activities. The sources for these guidelines are often undocumented, and may be derived from unofficial, experience-based sources. One example is an Individual Safety Card, GTA 5-8-12 (USA 1999) which included both heat and cold guidance based on indices. The incorporation of this wind chill information into military doctrine made transition to a new wind chill index more difficult and emphasized the need for widespread and frequent public education efforts.

2.2.10.1 U.S. Army Corps of Engineers/Engineering Research and Development Center (ERDC)/Cold Regions Research and Engineering Lab (CRREL). The CRREL was interested in the JAG/TI work as it related to developing cold weather performance factors for soldiers which could be used in models and simulations. DOD was required to run simulations on how material will perform in various environments. CRREL tried to put more human factors into the simulations as decisions were made based on the results of the simulations. This was important because the losses in cold situations outnumber the losses to the enemy. Objective force concepts were dependent on light equipment but soldiers were more susceptible to cold than equipment. The impacts of cold consisted of limited manual dexterity and task efficiency, diminished cognitive functions, and emotional changes. The key was to relate environmental state to body state using heat balance equations. Several historical examples support this idea. Napoleon's army lost two-thirds of its soldiers in the Russian campaign due, in part, to the cold. During the Russian/Finnish conflict, the Russian army was hurt because of the cold. In World War II, Germany invaded Russia but became bogged down and extensively weakened by the winter cold. CRREL has a simplified model which could use the human studies data from DRDC for a benchmark.

2.2.10.2 U.S. Army Research Institute of Environmental Medicine (USARIEM)/ Biophysics and Biomedical Modeling Division. USARIEM interests in the JAG/TI work involve the integration of weather into modeling efforts. USARIEM research areas include the environment, physiology and medicine (hot and cold, complex models, altitude, clothing/biophysics, solar radiation input, and predictive modeling), and occupational health and performance (soldier performance, injury, biomechanics, nutrition, and animal studies). The two USARIEM groups with programs most relevant to weather index issues were the Biophysics and Biomedical Modeling Division (biometeorology, clothing and modeling) and the Thermal and Mountain Medicine Division (heat and cold physiological effects).

Military models were developed for military populations who must conduct operations while exposed to extreme heat or cold conditions. There was a need within the military for models that go beyond heat indices to take into consideration solar radiation input, acclimatization, body size, activity roles, and clothing to predict thermal state. A Heat Strain Decision Aid was developed using complex physiological models to provide guidance for a narrowly focused population. Model outputs included the change in core temperature, maximum exposure time and an optimal work-rest cycle for minimizing heat casualties. Some of the modeling methods applications were linked with a miniature environmental sensor suite to produce a hand-held Heat Stress Monitor. Another product was the MERCURY program that combines heat and cold models and weather data from a grid to predict soldier thermal status, and display it graphically. The Warfighter Physiological Status Monitoring was an entirely different approach that utilizes up to 16 independent sensors to monitor soldier physiological status in real time. Other equipment or facilities available at USARIEM included copper manikins, sectional hand and foot models for measuring clothing insulation, an immersion pool, and weather instrumentation to measure solar radiation.

2.2.11 NWS National Centers for Environmental Prediction (NCEP), Climate Prediction Center's (CPC) Excessive Heat Index and Forecast. A new NWS heat index and forecast product was implemented in June 2000. It was originally designed to give the likelihood for occurrence of a heat wave (defined as three hot days out of five with a daily average heat index of 85EF (29.4EC). The heat index is a simple regression model based on the warm end of the Steadman apparent temperature scale and uses temperature and humidity observations. As a starting point, CPC decided to use the 500 hPa height and 850 hPa temperature forecasts as predictors in the excessive heat forecast model. CPC has skill in forecasting 500 hPa heights and 850 hPa temperatures in the 6 to 10 day time frame and some skill in the 8 to 14 day time frame. In addition, the Medium Range Forecast (MRF) model ensembles, consisting of 20 runs or members of the model, are also heavily used in the regression model. The ensemble member results are combined to produce a smooth mean field. The biggest flaw of ensembles appears to be the result of excess smoothing which reduced the amplitude of the response. The regression model did reasonably well on predicting the phase of an event and CPC was able to follow most events, although the amplitudes were insufficient. The Texas heat wave of 2000 was not well captured because it was mainly a surface event with the drought and lack of soil moisture enhancing the heat wave effects. CPC has a soil moisture data set to train the model, and the future intent will be to improve the model with this training set by adding soil moisture as a predictor. In addition, there were some persistent biases that showed up in the MRF which were corrected by the addition of a Kalman filter. The main CPC product sent to the WFOs has been the probability field of a heat wave occurring in the 6 to 10 day window, which gave a forecast of the highest expected heat wave. This product appeared to be difficult for the public and some meteorologists to understand and to relate to the physical world. Another more user-friendly product on CPC's web site was obtained from contouring the probability product to show a maximum value of the heat index product. This was depicted on a U.S. chart as apparent temperatures and shaded. Individual stations could be selected to get temperature values, observations and climate values. Directly distributed to WFOs, the U.S. Threats Assessment depicted potential threats as highlighted areas on U.S. maps and included heat waves. These forecasts were prepared every day with the weekend product fully automatic and the remainder of the week the forecasts had human intervention. These heat index products were discontinued in mid-fall 2000, and CPC worked over the winter to improve them based on the information and data collected during the summer of 2000. These products are now regularly procuded by CPC daily from May through September.

2.2.12 Development of a Universal Relative Comfort Index. At the University of Delaware with funding from NOAA's National Environmental Satellite, Data, and Information Service (NESDIS) National Climatic Data Center (NCDC), several graduate students are working on a relative comfort index, where relative relates to accounting for different locations. The work is based on the Weather Stress Index (WSI) developed by Kalkstein and Valimont (1986) where apparent temperature varied from mean apparent temperature and was adapted to regional applications. The new relative comfort index is based on Steadman's Apparent Temperature (AT)

Index, regional temperature means, and prolonged exposure or consecutive day effect. It represents the percent difference from the mean conditions. The imbedded heat index uses Steadman's updated algorithms (Steadman 1999) for this project. A daily stress value is calculated. The model uses U.S. Surface Airways reports which have wind speed, temperature, dew point temperature, and information to calculate solar radiation. This comfort index incorporates: consecutive day effect, maximum and minimum AT, mean cloud cover (10 a.m. to 6 p.m.), cooling degree days, and 30 years of data at 240 first order stations. This research is focused on the summer/high heat application to various locations. A winter side will be worked on later and will represent the opposite end of the index. Possible applications are for the NCDC climate atlas, public health initiatives, and problems related to animal stress.

At the first workshop, Ms. Jill Derby Watts (University of Delaware) presented an overview of her Master's thesis work on developing a new relative comfort index (Watts and Kalkstein 2002). The WSI used 40 years of data, the results were smoothed, and the real-time data was compared to the mean temperature. The relative results were presented as a percent of real-time temperature compared to the mean temperature. Comparative evaluations of the WSI's summer and winter algorithms, Steadman's outdoors and with sun (year around) algorithm, and the current NWS index have been completed. Comparisons showed the NWS index had noticeably different results from the rest of the indices. For instance, NWS did not appear to handle the situation well when cold temperatures existed and/or when the wind was calm. All the results appeared to agree during the afternoon in the summer. The new relative index will include using a daily mean relative stress value to account for several hours of exposure/day, which will cause an adverse effect. This should help account for consecutive days impact on regular human health. Incorporation of the cooling degree-day aspect was also done since the amount of cloud cover impacts both day and night temperatures. Possible applications for this work include the development of a U.S. comfort index climatology which could be presented as a climate atlas and would have values for all first order weather stations across the United States. It would account for means, variances, and temporal and spatial differences. Another area the index could be used for was within the public health sector as implementation information for health warnings and advisories.

2.2.12.1 Effects of Temperature on Livestock. During the second workshop, Ms. Katrina Frank reported on another aspect of this research effort at the University of Delaware. Her graduate study was looking at the effects of extreme temperatures on livestock production. Live stock managers and agricultural experts noted that animal food intake was affected by extremes of heat and cold. The relationship between air temperature and livestock production was well established. There was a zone where the animals were comfortable and thresholds where production began to decline. This can be quantified because the animals will not produce as much milk or eggs and their eating patterns change when the environment changes. Temperature, relative humidity, wind, number of consecutive days, available shade, and precipitation were taken into account when determining how much food would be eaten and converted to growth or production by animals. For instance, at -10EF (-23.3EC) ranchers needed to add 7 to 8 lbs (3.2-3.6 kg) of hay per cow and 4 to 5 lbs (1.8-2.3 kg) of grain per cow to fill their energy needs to maintain body weight. If the threshold was wrongly predicted, there would be either feed consumed when not needed resulting in additional costs or not enough feed resulting in weight loss or decrease in production of milk or eggs. Both would result in decreased profits for the owner. To limit feed waste, the rancher needed to decrease the amount of feed because the cattle eat less during extreme heat conditions and increase feed during extreme cold conditions to maintain cattle weight. Another aspect considered was the animals' hair or feathers which can provide insolation. The condition of the cow's hair needed to be evaluated, which was also a function of exposure to the environment, especially wind and precipitation. In general, state agriculture departments develop food intake tables that use the NWS wind chill and heat index output, a percentage adjustment for the environment, and adjustments for hair condition to determine the recommended food amount per day for animals such as cows. The project was based on developing a comprehensive means to accommodate all the factors in a table or index that is easily applied by the livestock manager. Another reason that livestock managers needed to know the temperature extremes would be for the transport of animals, where one was more concerned about mortality issues.

2.2.13 NOAA Heat Wave Workshop, September 18-19, 1996. The JAG/TI reviewed the action items and proceedings from the NOAA Heat Wave Workshop of September 18-19, 1996 (Adams 1997). The workshop was held as a result of the Chicago heat wave and was co-sponsored by the CDC and the EPA. One of the purposes of this workshop was to discuss what had occurred during the 1995 Chicago heat wave, which killed 465 people, and to outline steps to help prevent that type of high mortality from occurring in future heat waves. This included developing a better warning system for heat waves; suggesting state and local intervention programs, such as the provision of shelters and assistance to the elderly and others by health officials and emergency managers; and meteorologists, health professionals, and others conducting research into identifying the pertinent environment, medical and social factors. As a result of the workshop, NWS has loosened operational application of weather service procedures, developed local criteria for the WFOs, and produced some informational brochures on extreme heat safety. The overall policy recommendations have not been accomplished, including the establishment of a task force. One encouraging aspect is the reorganization of NWS Headquarters, which resulted in more personnel to address this program and other types of policy issues. The new CPC product is in partial answer to the research recommendations (see section 2.3.3.1). Funding was still being sought for the recommended comparison work that University of Delaware and the NWS wanted to conduct. The changing or updating of the NWS heat index was not a part of this workshop's discussions. The workshop focus was on improving the types of public warnings and public response. The JAG/TI Canadian participants pointed out that there were no Canadian cities that suffered a heat wave at the same time as Chicago. The biggest difference between Chicago and nearby Canadian cities was the nighttime cooling in the Canadian cities that was not experienced in Chicago.

2.3 Descriptions of NWS and MSC Operational Programs.

2.3.1 NWS Wind Chill Program. Prior to November 2001, the NWS index was based on the work of Siple and Passel who conducted heat loss rate research in the Antarctic immediately prior to World War II (Siple and Passel 1945). As a result of their research, Siple and Passel developed the basic empirical formula used for determining the wind chill index. In 1973, the NWS adopted this formula to produce a wind chill index for alerting the public of possible hazardous conditions. This index used the rate of body cooling based on cooling of water, did not account for sun or the lack thereof, and used the wind velocity at 10 m (33 ft) height. The NWS basic policy for producing wind chill warnings and advisories was described in their Operations Manual (NWS 1992) under Winter Weather Warnings Chapter C-42. Current NWS policy on wind chill products can be found at the following web site: http://www.nws.noaa.gov/directives. It provided the worst case criteria for wind chill warnings and referred to Regional NWS Operations Manuals for specifics of how the program is implemented in the field. Each NWS Region established a modified set of criteria for warnings based on regional and local consideration.

Wind chill warnings and advisories were used to alert the public of dangerous or life-threatening wind chill conditions. A Wind Chill Warning was issued when WCTs become life threatening. A Wind Chill Advisory was issued when WCTs become dangerous and, if caution is not exercised, could lead to life-threatening situations. Issuance criteria of Wind Chill Warnings and Wind Chill Advisories were locally defined.

2.3.2 MSC Windchill Program. The Canadian Windchill Index was also based on the Siple and Passel (1945) Index. The wind chill program was established in the late 1970's. The index values were reported in units of W m^{-2}. Using this Index, MSC produced forecasts and issued warnings on wind chill dangers. Their warning criteria also varied by region.

With Canadian Ministerial commitment to review the wind chill program, EC's objective was to reconcile clients' needs for information with the science. MSC decided to review the basic science on wind chill temperature determination and to communicate with the public through a public opinion survey. This survey showed how the public used the information and what were their concerns. This review was compiled and published by MSC before the Internet Workshop (Maarouf and Bitzos 2000). MSC determined that the science information would be obtained by doing a literature review, a science assessment, physiological assessment, working groups, and workshops. MSC was unable to do clinical tests because funds were not yet available. National and MSC working groups were formed to work on the review of science. As mentioned earlier, the MSC sponsored a one week Internet Workshop on Windchill in April 2000 that was very successful. The workshop continued the review of the science, evaluated the usefulness of the index, discussed the most accurate and acceptable ways of disseminating information and warnings, and worked towards recommendations for rigorous experimental research and international harmonization and standards. Progress on these recommendations were constrained by budgetary restrictions, cross-border compatibility concerns, and the formation of a special commission to look at the issues of thermal indices. MSC determined the way to move forward was to collaborate with efforts for the adoption of a renewed international program, focus on terminology in the short term, and implement program changes in an internationally consistent way.

2.3.3 Excessive Heat Programs. The heat wave that Chicago experienced in 1995 resulted in more than 400 human deaths (Adams 1997). Although there did not appear to be any major problems identified with the present heat indices in U.S. or Canada, these two North American indices do not result in the same values for the same conditions, which is confusing for the public. In addition, the NWS WFOs have identified wind as a parameter that makes a difference, and therefore, should be an additional factor in determining the AT during extreme heat instances. Another major reason for upgrading the heat index would be to replace old technology with better scientifically based equations that used more of the known affecting parameters. Public pressure to upgrade the heat index is not prevelant at this time, but could occur if there was another severe heat wave episode like the 1995 heat wave in Chicago. This situation allows for the slow movement on updating the heat index to ensure that a better, improved index would be adopted.

2.3.3.1 NWS Program. NWS issues outlooks, watches and warnings using a version of Steadman's index (Steadman 1979a,b), represented as a table called the NWS Heat Index. The last incorporated update to this table and to the NWS operational program was in 1992. NWS WFOs' computers use a NWS derived regression algorithm (Rothfusz 1990) to approximate the table. The derived algorithm appears to be unstable at the lower end and it doesn't take into account the number of days that the excessive heat existed, cool nighttime temperatures, and regional acclimation. A table on the NWS web site describes the NWS Heat Index. In the NWS Operations Manual, there are descriptions of the effects of extreme heat, effects of humidity and the minimum criteria for issuing advisories and warnings. An Advisory is issued when the daytime high AT reaches 105EF (40.6EC) or above with nighttime lows at or above 80EF (26.7EC). A Warning is issued under extreme conditions, exceeding those conditions for an advisory. The specific values or thresholds are determined by the NWS Regional Headquarters. Two NWS regions do not issue advisories and warnings: Pacific and Alaska Regions. Eastern, Southern, Western and Central Regions issue advisories and warnings, and each Region sets regional criteria to accommodate any adjustments. These criteria are used by the WFOs to decide whether or not to issue a heat advisory.

The NWS extreme heat forecast guidance product was first officially issued during the summer of 2000 by the CPC. It was developed from a training set of observed data, a linear regression fit of 500 hPa heights and 850 hPa temperature fields, and approximated algorithms of the NWS Heat Index (modified Steadman's Apparent Temperature Index). This was combined with NCEP's MRF model and the MRF ensemble model output to produce a prediction of apparent temperatures. CPC found the following problems with the product: the MRF ensembles were not very good at forecasting extremes (tends to under forecast), the training data were not good or complete (needs soil moisture), and the linear regression fit was unstable. CPC added soil moisture, replaced the regression fit with the use of 1000-500 mb thickness, 1000-850 hPa thickness, and 1000 hPa height fields, used Steadman's Index table instead of approximate algorithms, and improved the look of the products by the 2001 summer season.

2.3.3.2 MSC's Humidex. The Canadian heat index, Humidex, has been used for about 22 years. Humidex uses temperature and relative humidity to determine how hot the weather feels to any person. The reports are in degrees Celsius and considered significant if the temperature are greater than 30EC (86EF) and the Humidex value is greater than 40EC (104EF). In addition, a scale of discomfort splits the Humidex from 29º to 54ºC (84.2 to 129.2EF) into several discomfort levels. In general, the Humidex values tend to be higher than the U.S.' heat index values, except at the extreme end, where they tended to be slightly lower. Excessive heat advisories are issued by the MSC in only two provinces, Ontario and Quebec.

2.4 <u>Science Review Results</u>. After reviewing the NWS operational requirements, the JAG/TI members determined that the federal government's responsibility was to address temperature extremes and safety, not necessarily what clothing the public should wear or for public comfort.

2.4.1 WCTI. The most important function of a wind chill program was to address safety and cover the most extreme situations (bare skin). Comfort factors could also be considered, but as a secondary function. This led to a wind chill index that would be based on environmental factors as the prime scientific input to the index algorithm. The results of the comparison studies led the JAG/TI members to agree that the NWS Wind Chill Index produced wind chill temperatures that were too cold, creating a false sense of actual air temperatures in nearly windless conditions by the public. The JAG/TI members and participants agreed that a new WCTI should be science-based by addressing proper heat transfer aspects, including appropriate environmental parameters, and be easily explainable to the public. This has been accomplished in many of the existing indices, including Osczevski, Bluestein and Zecher, the PT, and the PET indices. Although more comprehensive by taking into account many more environmental factors, Steadman's model included varying aspects of how one is clothed and used a full average body model, which added complexity to the model. Osczevski's and Bluestein and Zecher's indices both use a bare skin model while the other models use a standard clothed human body model. For the comfort factor, the PT and PET models might work, if clothing amounts were precisely defined and could vary, and other parameters were easily turned on and off. These physiological models assume an average or standard body. This could cause a problem resulting from the physiology of a body, since it changes from person to person and depends on size, shape, weight, circulation factors, etc. On the other hand, the JAG/TI decided that a face didn't vary much from one individual to the next and was a sensitive "instrument" that would normally be exposed, with the most cold felt on the face. With the use of the face model, one didn't have to account for clothing nor need to define a "standard" human. Other threshold temperatures, including those above freezing, were also considered important. Some temperatures were used to determine when to open homeless shelters because of concerns about hypothermia (e.g. Tampa, FL used a wind chill temperature of 44EF (6.7EC)), and others were used by power companies to determine the public's need for additional power. The workshop participants suggested these uses may be better addressed by ISB C6 development.

The group summarized the desired index characteristics in Table 2.1. They also completed an analysis of how some indices fulfill these index characteristics. There were other indices and studies mentioned (e.g. Israel and Russia) which were not included, because full descriptions of them were not readily available to the workshop participants. The JAG/TI members and participants recommended that U.S. and Canada use the same indices. Next, the group agreed that the primary use of the index was to provide warnings to the public about potentially harmful temperatures. With public safety the paramount goal, public comfort would be next consideration on the list.

For wind chill, the overall consensus of the JAG/TI was that the operational Siple and Passel (1945) based wind chill indices used by NWS and MSC should be revised as the first task because the indices generate values that are too cold, especially at cold temperatures and high wind speeds. After detailed discussion of each index, the group decided to recommend a combination of Bluestein and Zecher's (1999) and Osczevski's (1995 a,b) indices, with an addition of a solar radiation calculation, for the replacement WCTI**.**

2.4.2 Heat index. The JAG/TI members agreed there did not appear to be any major problems identified with the present heat indices in U.S. and Canada. The major reason for upgrading the heat index is to replace old technology with better scientifically based equations that use more of the known affecting parameters and to have the U.S. and Canada use the same index. Two areas that need to be addressed are: 1) these two North American indices did not result in the same values for the same conditions, which was confusing for the public, and 2) the NWS WFOs identified wind as a parameter that makes a difference, and therefore, should be added as another environmental parameter. Public pressure to upgrade the heat index was not present at the time, but could occur if there was another heat wave episode like the 1995 heat wave in Chicago. This current situation allowed for the slow movement on updating the heat index to ensure that a better, improved index would be adopted.

Although the JAG/TI members recommended waiting for the results of the ISB C6 discussions on a UTCI before making judgment on heat index improvements or replacement, a preliminary evaluation of indices was completed. The following were recommended to be included as input to the heat index: solar radiation (based on cloud cover and type, latitude and longitude), temperature, humidity, and wind. Precipitation is another parameter to consider but it was not in some of the indices. Soil moisture will be added to the numerical weather forecast model of apparent temperatures from satellite observations but was not currently considered appropriate for the index. How many days extreme heat has existed and whether or not there are cooling nights need to be taken into account, since the effects of a heat wave are not instantaneous but cumulative. Another variable shown to be important was the time of occurrence within the season. This may be related to acclimatization or mortality. The JAG/TI members thought that acclimatization might be hard to incorporate as part of an index, but including this as a forecaster adaption may be possible. There were also differences from the European weather services on how to address the problem (comfort and extremes/safety) and between instantaneous and cumulative values. For instance, the wind chill value is instantaneous and the extreme heat value is cumulative, but for both of these, the weather services in Canada and U.S. warn on the extremes that could affect public safety. Tentatively, the JAG/TI members agreed to the following heat index characteristics:

- the index should be capable of regional adaption by the forecaster and acclimatization may be possible;
- smog would not be a component, but kept separate;
- the output should be temperature based in degrees C or F;

Table 2-1. Summary of index characteristics recommended by the JAG/TI.

Meteorological Parameters		Exposed body / clothes	Other model considerations	Requirements (in order of importance)	Operations	Research & Development
temperature	at human height (hh); Heat-temps. for both day and night	amount of time exposed; Heat - number of consecutive days and cooling nights	Based on heat transfer theory	1. Extremes - public safety; heat stroke, frostbite, death	Cold: Interim O and B&Z combination Heat: See what ISB recommends	Cold: add radiation Heat: add wind and radiation calculations
wind	wind speed adjusted to hh	skin/body temperature is greater than or equal to air temperature	Regional criteria or thresholds	2. Comfort - what to wear, stay inside, find shelter	one index, if possible, but could have more than one with a transition or buffer zone between heat and wind chill	Continue tests and development of national and regional criteria
humidity	for heat it is major effect For wind chill a lesser effect	steady state conditions assumed and defined	product = apparent/ equivalent/perceived temperature in degrees C and/or F; forecast of apparent temperature	3. forecast for steady state conditions for worst case; range of use if not continuous	Cold: Temp and Wind Heat: Maintain current operations until decide how to use ISB recommendations.	add radiation, clouds; R& D for hypothermia, precipitation, soil moisture
solar radiation	use cloud cover and type, latitude, and longitude	WCT - no clothing, covering of face Heat- Not sure how to handle	WCT-combine O and B&Z indices; Heat-Participate in and rely on recommendation of the ISB Commission 6	4. Common units for Canada and U.S. - degrees preferred	Plan upgrade of both countries for the same cold and heat season with cold first (Oct/Nov 2001)	time of occurrence within the season
precipitation	let forecaster add for now	time of occurrence within the season - include as forecaster adaption	understandable by forecasters and users	Did not decide on whether to address hypothermia. No stated requirement.	If change, must educate public and other users about new index and how to use	Develop public education; determine need for hypothermia warnings
soil moisture	heat/address in FCST only (CPC)					

- consecutive high temperature days and cooling nights should be considered;
- temperature, humidity, solar radiation, and wind speed should be included as input;
- a simple heat index chart for use by local forecasters and the public is preferred, with possibly a more complicated version for the numerical weather forecast product;
- for now, no soil moisture and precipitation should be used as input to the index, although the NWS CPC is planning to use soil moisture in their forecast model; and
- proper air mass handling and turbidity should be part of the NWP forecast model guidance products, but not as input to the index used by the forecaster.

2.5 <u>Wind Chill Temperature (WCT) Advanced Development Guidance.</u> The JAG/TI members agreed to the following recommendations for the advanced development of WCTI:

- The new wind chill index should be based on an algorithm that was scientifically defendable, reasonable, understandable, and simple; on obtaining its basic input from existing environmental observations; on experimental data and not human comfort; and on heat budget theory. This index could be used by others as input to "comfort" indices that included clothing concerns. Associating the wind chill index with the environment allows a step further into the interpretation of human comfort.
- Having an internationally agreed upon index was preferable, but at least there should be an agreement between the U.S. and Canada on using a common index. The group recommended that the output should be the same in both Canada and the U.S., and be an equivalent temperature. In addition, the members recommended that both countries switch to the new index at the same time. This consistency aspect was seen as important for the U.S. and Canada because of the movement of the public between the two countries.
- At the initial stage, wind, air temperature, and solar radiation should be the environmental factors used. As further research progresses on how to handle other environmental parameters, the results could be incorporated into this simple index.
- The uncovered frontal cylinder or face should be used to represent the bare skin human model, since it represented the worst case and tended to be uncovered. The nose, chin and ears were the most likely parts of the body to feel the cold and freeze first.
- The Bluestein and Zecher and Osczevski indices should be combined and should include the addition of a radiation calculation. In addition, DRDC has a testing facility where testing of a new index algorithm could be accomplished, if funding is

available. These scientists agreed to work together on developing a common wind chill index. Their indices were recommended for the following reasons:

< were the closest to the environment;

< made the least assumptions;

< were based on bare skin that is exposed first;

< could be operational in a relatively short period of time;

< did not depend on body characteristics;

< could be implemented anywhere;

< used parameters that are available in standard environmental observations;

< could have a radiation calculation added scientifically; and

< were reasonably simple and could be explained to and understood by the public.

- The output product should be an equivalent or AT in both degrees Fahrenheit and Celsius, with warnings issued for extremes only. Limited user surveys in the U.S. on wind chill index information and more extensive surveys in Canada favored the use of equivalent or apparent temperatures and warning on extremes.

- Public education should be conducted prior to and after the implementation of the new index. This education should stress that this change to the current index was an improvement on the old index and incorporated more information.