

# Wind Chill and the Wind Chill Index

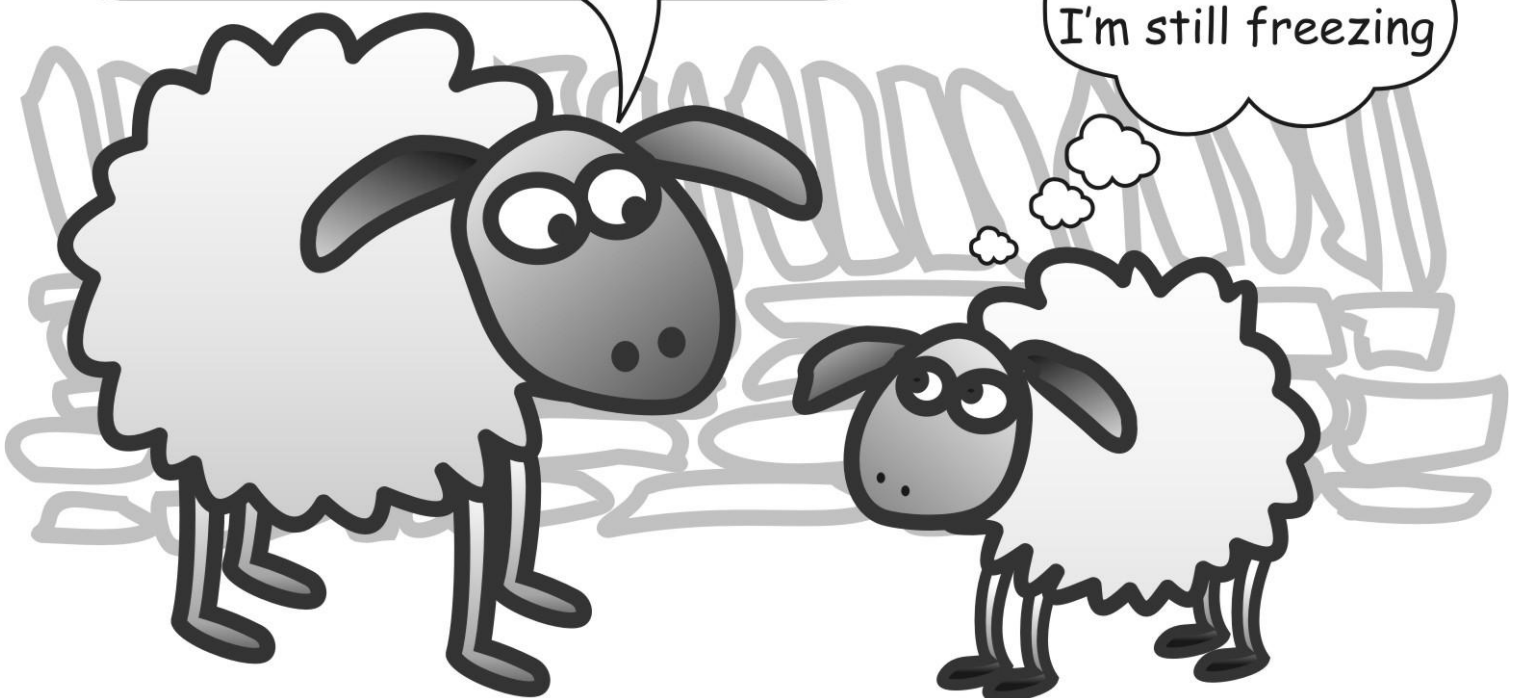
Wayne Naylor

With thanks to James Crompton for editing (improving) the text in Appendix 1.

Look, I've told you before, the reason we're behind this wall is

$$33 - \left( \frac{89.7 \cdot \sqrt{v} + 37.62}{18.97 \cdot \sqrt{r} + 37.62} \right) \cdot (33 - t)$$

Whatever!  
I'm still freezing



## Wind Chill and the Wind Chill Index

### Introduction

The British Association of Snowsports Instructors (BASI) Alpine Manual (p234) defines Wind Chill as, “*The Wind Chill temperature is the equivalent temperature that would produce the same rate of cooling in the absence of a wind*”, there is also a chart displaying various Wind Chills. Both the definition<sup>1</sup> and chart<sup>2</sup> are incorrect. There are other errors in the BASI manual concerning Wind Chill.

This paper will give a correct description of the effect(s) and cover the pathway to the current situation to justify the need for an amendment. It will also give a possible revision of the BASI text, with notes for snowsports instructors.

It is hoped that BASI will use the revision either *verbatim* or as the basis for an amendment.

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It is apparent (and so a good point to start at) that BASI have not understood the causations and effects of Wind-Chill, The Wind-Chill Index or Wind-Chill Equivalent Temperatures. It should be noted that whilst they are related, they are different.

I would suggest that the correct definitions are:

- Wind Chill is the increased rate of cooling of an object down towards the ambient temperature due to the effects of wind.
- The Wind Chill Index is a table containing Wind Chill Equivalent Temperatures which are calculated temperatures equal to the dry bulb air temperature needed to produce the same rate of skin cooling in calm conditions.
  - Wind Chill Equivalent Temperatures are based on the amount of heat that specifically (and only) a human being will lose due to the combined effect of temperature and wind; they could be described as displaying levels of thermal discomfort.

*See Appendix 1 (P 2) for a more concise definition.*

Note – As The Wind Chill Index is based on averages, extrapolations, untested assumptions and some very strange data it is virtually never correct and cannot be (and should not be) relied upon.

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<sup>1</sup> BASI's definition is a misquotation from the BAMS (Bulletin of the American Meteorological Society) paper by Osczevski and Bluestein. By omitting the reference to moisture and radiation (dry bulb) from the quotation BASI's statement no longer gives a correct definition of the effect. Also the Wind-Chill tables are based on calm air, not “the absence of wind”.

<sup>2</sup> The chart is not based on any recognised Wind-Chill formula. Also the chart shows many low wind speeds; wind-chill is not calculated (by either the Old or New formula) for wind speeds of less than 3mph (4.84km).

Note - The BASI manual also gives some examples of “wind chill temperatures”. There are a number of functions that can be used to obtain the figures given (assuming a round to 0), e.g.  $13.12+0.6215*c-11.37*(t^{0.16})+0.72*c*(t^{0.16})$ . However none of the recognised Wind Chill formulas provide similar results.

## Background (Wind Chill)

It is a widely known that wind has an influence on the rate of cooling, this effect is embodied in Newton's law of cooling – *"The rate of heat loss of a body is proportional to the temperature difference between the body and its surroundings"*. That is, the increasing rate at which an object will cool (chill) is a function of, and proportional to, the wind speed<sup>3</sup>. No wind, however, is required to cool an object. Without protection, a hot bowl of soup (or indeed a person), will eventually cool down to the surrounding ambient temperature<sup>4</sup>. The effect of wind passing over the surface of our unprotected bowl of soup (or person) merely increases the rate of cooling. The reason is simply that the air surrounding the object is warmed by the heat dissipating out of the body. This dissipating heat forms a warm layer around the body, reducing the difference between the body and the environment. Newton's law tells us that this will slow down the rate at which the body will cool. Quite simply, the effect of wind is to remove the warm layer, and so increase the difference between the body and the environment, hastening the rate at which our warm soup (or body), strives towards a point of equilibrium with the surrounding ambient temperature. As a consequence, the rate of cooling speeds up.

Other factors can also speed up the rate of cooling such as water (e.g. rain, melted snow, sweat, etc), as evaporating will also increase the speed at which an object cools. Of course it is possible to cover the object, - placing a lid on our bowl of soup, or donning an insulating layer, traps some of the warm air layer. Again looking at Newton's Law we can see that this will reduce the rate of cooling – as it prevents the wind from dissipating our "warm air blanket".

It should be noted that Wind Chill will cool an object down to the ambient temperature and no further<sup>5</sup>. As an example if a bowl of water at 20c is left outside where the air temperature is 10c but the Wind Chill -10c, the water will only cool down until it reaches 10c, so will not freeze.

## Background (The Wind Chill Index)

A notable early attempt to calculate and define the cooling effect of the wind was attempted by Paul Siple in his PhD dissertation in 1939. During 1941, whilst on the US Army Antarctic Expedition, Siple and the geologist Charles Passel conducted experiments in which they recorded the time it took the water to freeze in a small plastic cylinder which was suspended from a cross on the roof.

A thermometer<sup>6</sup> was suspended in the water with another placed just upwind to measure the ambient temperature. An anemometer<sup>7</sup> was used to detect the wind speed. By recording the time it took the water to freeze (how long it remained at 0° – that is before the water completely crystallised) they were able to calculate the Heat Transfer Coefficient<sup>8</sup> at various winds speeds and temperatures.

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<sup>3</sup> The role played by the 2<sup>nd</sup> Law of Thermodynamics is not covered in this paper.

<sup>4</sup> The Ambient Temperature is a function of the air temperature, radiation, convective heating, etc.

<sup>5</sup> Evaporative cooling by the removal of latent heat (due to molecular phase changes) has never been a part of a formula used to map the cooling effect of wind and temperature so is ignored here.

<sup>6</sup> The thermometer used was a thermhm which is a type of Resistance Thermometer, also known as a Resistance Temperature Detector.

<sup>7</sup> The Robinson Cup Anemometer has four arms with a cup at the end of each. As the wind hits the cups the arms rotate around a central point. The speed of the rotation is dependent upon, and proportional to, the wind speed.

<sup>8</sup> In this case the Heat Transfer Coefficient is simply a function of the wind speed (passing over the body), size and shape of the body and the characteristics of the water in the cylinder.

After the Second World War Siple and Passel published a paper<sup>9</sup> giving details of their experiments. Their paper contained a formula which could be used to produce a calculated air temperature as a function of the actual temperature and wind speed; this would produce the same rate of cooling as would a lower ambient temperature in calm air.

As in a children’s game of Chinese Whispers, the more something is quoted the more it is likely to change. The original Wind Chill formula and tables have been quoted, misquoted (from misquotations), amended (for local conditions), misunderstood (and added to TV weather forecasts), etc. over the years.

For the sake of historical accuracy, here is Siple and Passel’s original formula<sup>10</sup>:

$$(\sqrt{v \times 100} + 10.45 - v (33 - Ta)) = Ko$$

Ko = Atmospheric cooling power (in kg Cal per hour per M<sup>2</sup>) v = wind speed (m per second) Ta = Temp (centigrade).

Using Siple and Passel’s original formula provides the data shown here -

Heat loss coefficient = Energy Loss – kgC/ph<sup>m2</sup> (kilogram calories per hour per square meter of body surface)

		Temperature C'												
		10	5	0	-5	-10	-15	-20	-25	-30	-35	-40	-45	-50
Wind speed (meters per second)	0	240.4	292.6	344.9	397.1	449.4	501.6	553.9	606.1	658.4	710.6	762.9	815.1	867.4
	1	447.4	544.6	641.9	739.1	836.4	933.6	1,030.9	1,128.1	1,225.4	1,322.6	1,419.9	1,517.1	1,614.4
	2	519.6	632.6	745.5	858.5	971.5	1,084.4	1,197.4	1,310.3	1,423.3	1,536.3	1,649.2	1,762.2	1,875.1
	3	569.7	693.6	817.4	941.3	1,065.1	1,189.0	1,312.8	1,436.7	1,560.5	1,684.4	1,808.2	1,932.1	2,056.0
	4	608.4	740.6	872.9	1,005.1	1,137.4	1,269.6	1,401.9	1,534.1	1,666.4	1,798.6	1,930.9	2,063.1	2,195.4
	5	639.6	778.7	917.8	1,056.8	1,195.9	1,334.9	1,474.0	1,613.0	1,752.1	1,891.1	2,030.2	2,169.2	2,308.3
	6	665.7	810.5	955.2	1,099.9	1,244.6	1,389.4	1,534.1	1,678.8	1,823.5	1,968.3	2,113.0	2,257.7	2,402.4
	7	687.9	837.4	986.9	1,136.5	1,286.0	1,435.6	1,585.1	1,734.6	1,884.2	2,033.7	2,183.2	2,332.8	2,482.3
	8	706.9	860.6	1,014.2	1,167.9	1,321.6	1,475.2	1,628.9	1,782.6	1,936.3	2,089.9	2,243.6	2,397.3	2,550.9
	9	723.4	880.6	1,037.9	1,195.1	1,352.4	1,509.6	1,666.9	1,824.1	1,981.4	2,138.6	2,295.9	2,453.1	2,610.4
	10	737.7	898.0	1,058.4	1,218.8	1,379.1	1,539.5	1,699.9	1,860.2	2,020.6	2,180.9	2,341.3	2,501.7	2,662.0
	11	750.2	913.3	1,076.3	1,239.4	1,402.5	1,565.6	1,728.7	1,891.7	2,054.8	2,217.9	2,381.0	2,544.1	2,707.1
	12	761.1	926.5	1,092.0	1,257.5	1,422.9	1,588.4	1,753.8	1,919.3	2,084.7	2,250.2	2,415.6	2,581.1	2,746.6
	13	770.6	938.2	1,105.7	1,273.2	1,440.7	1,608.3	1,775.8	1,943.3	2,110.8	2,278.4	2,445.9	2,613.4	2,781.0
	14	778.9	948.3	1,117.6	1,286.9	1,456.3	1,625.6	1,794.9	1,964.3	2,133.6	2,302.9	2,472.3	2,641.6	2,810.9
	15	786.1	957.0	1,127.9	1,298.8	1,469.7	1,640.6	1,811.5	1,982.4	2,153.3	2,324.2	2,495.1	2,666.0	2,836.9
	16	792.4	964.6	1,136.9	1,309.1	1,481.4	1,653.6	1,825.9	1,998.1	2,170.4	2,342.6	2,514.9	2,687.1	2,859.4
	17	797.7	971.1	1,144.5	1,317.9	1,491.3	1,664.7	1,838.1	2,011.5	2,184.9	2,358.3	2,531.7	2,705.1	2,878.5
	18	802.2	976.5	1,150.9	1,325.3	1,499.7	1,674.1	1,848.4	2,022.8	2,197.2	2,371.6	2,546.0	2,720.4	2,894.7
	19	805.9	981.1	1,156.3	1,331.5	1,506.7	1,681.9	1,857.1	2,032.3	2,207.5	2,382.7	2,557.8	2,733.0	2,908.2
	20	808.9	984.8	1,160.7	1,336.5	1,512.4	1,688.2	1,864.1	2,039.9	2,215.8	2,391.7	2,567.5	2,743.4	2,919.2

Note – the author recalculated the above data 11/08/13 – the rounding functions may alter the results by a max. of 0.05

There are some errors in Siple and Passel’s experiments and calculations:

- They failed to take into account internal resistance to the transportation of heat/energy by convection and conduction inside the body of water.
- They failed to take into account the mechanisms of phase change from liquid to solid.

<sup>9</sup> Measurements of Dry Atmospheric Cooling in Sub-freezing Temperatures, Proceedings of the American Philosophical Society No. 89, 177 (1945)

<sup>10</sup> Proceedings of the American Philosophical Society. No. 89 (1945) page 197

- They failed to take into account the resistance formed by the conduction of heat through the plastic surface of the cylinder.
- That they failed to appreciate that the shape and relative surface area of the water container had an effect on the results.
- The calculations were based on wind speeds recorded at 10m above ground which are significantly higher than at ground level.
- There are other anomalies such as their arbitrary decision to base their research on a wind speed of just over 4 miles an hour, etc.

The main problem with the Wind Chill Index which was based upon the calculation of Siple and Passel was that it over estimated the cooling effect of wind.

In spite of the obvious errors Siple and Passel’s Wind Chill Index was used as the basis for most Wind Chill reports for much of the twentieth century – the most commonly used index being that created by Arnold Court<sup>11</sup>; although this was still based on the 1941 data, and so was still incorrect.

In 1964 Charles Eagan<sup>12</sup> recalculated the effect of Wind Chill to produce Wind Chill Equivalent Temperatures. Unlike Siple and Passel his formula contained a Reference (wind) Speed 1.78m/s (3.98mph) for movement of the subject. This partly solved the obvious difference between the calculated temperatures and the actual perceived temperatures; remember that Siple and Passel’s water container was stationary whereas people (outside) are hardly every completely still.

$$WCET = 33 - \left( \frac{18.97 * \sqrt{v} - v + 37.62}{18.97 * \sqrt{r} + 37.62} \right) * (33 - t)$$

*WCET = Wind Chill Equivalent Temperatures v = wind speed(km) t = ambient air temperature (c’) r=reference speed*

As an example using the Egan formula (above) with a wind speed of 15km/ph and a temperature of -15 we find that, with a Reference Speed of 0mph, the Wind Chill is as -86c, which is obviously wrong. If the Reference Speed is set at 1.78m/s (6.4km) the Wind Chill is -25c, which is becoming more in line with common perception.

A human being does not act (cool) in the same manner as a cylinder of water. The empirical formula created by Siple and Passel was not designed to calculate a “feels like” range of temperatures and so should never have been used as the basis for a table of human thermal discomfort. In fact there are many differences between the way a container of water reacts to temperature and wind and a human being; e.g. humans are thermo regulating (they cool down and heat up as necessary), water freezes at a certain temperature, skin doesn’t have a set temperature as the freezing point is governed by many factors. Skin does not have the same heat transfer coefficient as pyrolin<sup>13</sup>. Etc.

Even when taking into consideration all the differences between the old Wind Chill Index and a Wind Chill Equivalent Temperatures, one major difference looms larger than all the rest: Siple and Passel’s Wind Chill Index is an objective measurement of a physical effect – the rate of cooling of water in certain circumstances,

<sup>11</sup> Professor of Climatology, California State University. Chief Meteorologist, U.S. Antarctic Survey, 1940-41. Etc.

<sup>12</sup> Eagan, C., 1964: The effect of air movement on atmospheric cooling power.

<sup>13</sup> The water filled cylinder used in the Siple and Passel experiments was made of Pryolin which was an early form of plastic.

whereas the Wind Chill Equivalent Temperature is a calculation which aims to tabulate and mirror the subjective perception of cold by a human e.g. how cold does it feel?

During the 60's and 70's the formula was continually updated, with the focus on the face area – this being the area that normally cools first. From the 1970's onwards Wind Chill Equivalent Temperatures were those most frequently quoted in weather reports. E.g. "As the temperature is X and the wind speed is Y, it will feel like Z".

The Wind Chill Equivalent Temperature formula used for the last three decades of the 20<sup>th</sup> century was:

$$wcet = \left( 91.4 - \left( 0.474677 - 0.020425 * (\sqrt{v} + 0.303107) * \sqrt{v} \right) \right) * (91.4 - t)$$

*wcet = Wind Chill Equivalent Temp.*

*v = wind speed(km)*

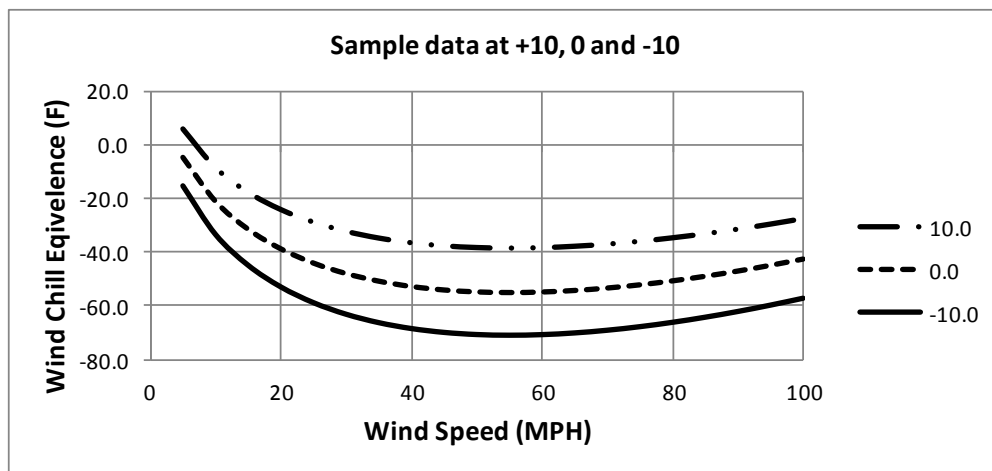
*t = ambient air temperature (c')*

When displayed in table format sample data would be:

		Temp F						
		10	0	-10	-20	-30	-40	-50
Wind MPH	10	-9	-21	-33	-46	-58	-70	-82
	20	-24	-39	-53	-67	-81	-95	-110
	30	-32	-48	-63	-78	-93	-109	-124
	40	-37	-53	-68	-84	-100	-116	-131
	50	-39	-55	-71	-86	-102	-118	-134

Note – the author recalculated the above and below data 11/08/13 – the rounding functions may alter the results by a max. of 0.5

It can be seen that the formula fails above a wind speed of 55.85mph.



## The Current Model

Even with its improvements over the old Wind Chill Indices, the Wind Chill Equivalent Temperature still suffered from flaws in that it did not provide a scientifically valid and simple to understand (to the layman or TV weather reporter) chart of the perception of coldness due to the wind. For this reason, in 2000, a group was formed with the acronym of JAG/TI<sup>14</sup>. JAG/TI was tasked with looking, with a modern perspective, at Wind Chill and of providing a new formula which could be used as a basis of a new Wind Chill Index – this is not the same as Siple and Passel's "Index"; in this case the term "index" means an extrapolated series of values derived from formulae.

JAG/TI also decided to concentrate on the face, as this is area of skin<sup>15</sup> that most people will expose to the elements and is where cold is first perceived. The human face is similar in shape to a cylinder so it was

<sup>14</sup> Joint Action Group for Temperature Indices . The group was formed by the (US) Office of the Federal Coordinator for Meteorological Service and Supporting Research (OFCM). Comprising of personnel from Environment Canada and the U.S. National Weather Service.

<sup>15</sup> In skin there are TRP channels (transient receptor potential) which respond to a small range of temperatures. At these temperatures certain TPR channels open allowing ions to enter into the cell neuron, causing it to become depolarized (producing an action potential). This in turn sends a

possible to mathematically model convective heat loss. They used the forward facing 50° of the cylinder model – which equates to the human cheek area as the basis for the calculations. The cheek area is also the coldest part of the face in normal conditions so provides a “worst case scenario”.

In addition to the cylindrical shape, as a base model they assumed:

- The person would be facing directly into the wind.
  - So the heat loss would be calculated as being at 50° to the wind (as the cheek does not face directly forward but is oblique).
- The person would be in an open space.
  - This would enable them to assume a constant (uninterrupted) wind speed
- The wind speed would be taken as being at 10m above ground and then calibrated to 1.5m
  - Metrological stations normally record speeds at 10m above ground - this is also where Siple and Passel’s water container was - where the wind speeds are considerably higher. 1.5m was assumed to be the average height of a human face.
- The person would be moving at walking speed of 1.34m/s (approx 3mph)
  - This is based on the speed recorded by cameras for people crossing road junctions in the US.

Another assumption, which has a relevance to ski slope users, was the assumption (for modeling purposes) that the air and ground were the same temperature – so radiative loss would be equal to both – of course on a snow covered mountain this is not the case. So any Wind Chill tables that JAG/TI arrived at would not be accurate for a skier.

They discounted any moisture in the atmosphere or sunlight as they worked with the dry bulb model. So if it is raining or sunny (or any combination of them) any Wind Chill tables that JAG/TI arrived at would not be accurate. Of course the rationale for the dry bulb model was to maintain a constant in their calculations so the logic behind the decision was sound – but it left any resultant calculations open to question.

Many papers<sup>16</sup> and text books refer to evaporative heat loss (via sweating, water on the skin, etc) in connection with Wind Chill. Whilst in the “real world” moisture does in fact increase the cooling effect of wind<sup>17</sup>, it is not used in the JAG/TI calculations, so it can be assumed that once the heat arrives at the surface (of the skin) it will be dissipated by radiation and convection alone.

We can see that the base model for the new wind chill calculation was: for a person who is approx. 5ft 4” tall, walking at 2.99mph in an open field, directly into the wind, on a clear dark night in perfectly dry conditions. For anyone not falling into these bands the new Wind Chill Index would not be accurate.

A Wind Chill Index is simply a chart of how much heat is lost certain conditions and we all experience cold at different levels. One person may describe the conditions as quite chilly but another may feel it as bitterly cold.

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signal to the brain which is interpreted as a feeling of cold at the temperature which that TPR channel responds to. Note – it is actually more complex than this brief description!

<sup>16</sup> Nelson at al. 2002b, Williamson FCM-R19-2003, etc

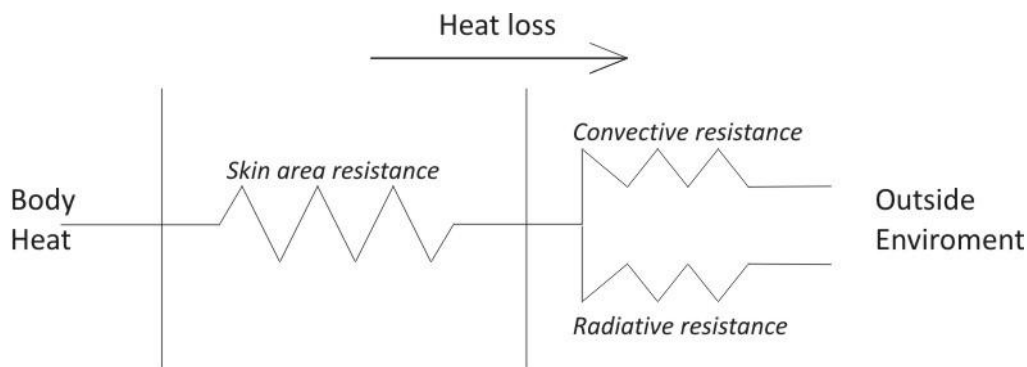
<sup>17</sup> The Australian Wind Chill model includes vapour moisture content; making it more realistic. JAG/TI has said they are contemplating a “wet” wind chill index<sup>17</sup>, for use in marine situations where heavy spray is a major factor in the cooling process.

The perception of cold is subjective. Our perception is based on various factors but predominantly on the difference between our skin temperature and the environment. As the environmental temperature is the same for everyone (in the same place) and our body core temperature is also (approximately) the same, the predominant factor must be on the amount of heat being transferred from our core to the outside. The heat transfer coefficient for each person is different; based upon physiology, metabolic rate, age, thermo-regulation, gender, etc. Consequentially the Wind Chill Index will always be simply a guide to the possible cooling effect of wind; as it is highly unlikely that it will accurately map the chilling effect of wind for an individual.

To be able to use the base model to create a new formula JAG/TI needed to be able define the resistance to heat transfer (from the body to the environment).

A human body creates heat which is transferred outwards by blood circulation and conduction, these form resistances to heat transfer to the skin which is different for each person. The rate at which heat is transmitted outwards (to enable the wind to dissipate it) is of vital importance as this will define how cold it feels to an individual.

If a standard coefficient is used such as  $h = \frac{Q}{A \cdot \Delta T}$  but superimposes fluid for gas the formula still holds. We can assume the "A" (nominally the surface area  $M^2$ ) is the area of skin and this can be described as :-



JAG/TI initially modeled the Wind Chill Equivalence based on studies of a manikin head covered in thermo conducting material. Their preliminary formula was tested during clinical trials during May / June 2001. The trial consisted of twelve volunteers undertaking various tests under laboratory conditions.

During the clinical trials some interesting facts were noticed:

- Physiological differences mean some people perceive cold faster than others; at the same wind speed and temperature.
- Overweight (or simply larger and bulkier) people lose body core heat slower than thin people due to the greater resistance / insulation provided by deeper skin, dermal and lipid layers. As such they are less susceptible to hypothermia. Of course this also means that, as less heat is transported to the skin, their skin cools faster and they are more prone to frostbite. Conversely thinner people are more at risk from hypothermia and less liable to get frostbite.



- Some people (7 of the 12 subjects) were prone to Vaso-Dilation<sup>18</sup> as a physical response to cold meaning they were more prone to hypothermia due to increased heat loss.

Following the trials JAG/TI modified certain aspects of the model:

- It was calibrated to the 95<sup>th</sup> percentile of skin resistance. This means that the formula was based on the 5% of the population (based on the test subjects) with the highest skin resistance – as they are the most at risk from frostbite. The author feels it may be slightly disingenuous to point out this also means that 95% of the population will not feel anything like as cold as the formula predicts.
- As most weather stations anemometers record wind speeds at 10m above ground the model calibrated down to 1.5m as this is the height at which people experience wind.

The final formula produced by JAG/TI was:

$$\text{(Metric) WCET} = 13.12 + 0.6215T - 11.37V^{0.16} + 0.3965TV^{0.16}$$

$$\text{(Imperial) WCET} = 35.74 + 0.6215T - 35.75V^{0.16} + 0.4275TV^{0.16}$$

WCET = Wind Chill Equivalent Temp. V (velocity) = wind speed. T = Temperature

The colours on the new Wind Chill Index are one of the most frequently misunderstood aspects – and are often used by some (?) to add a touch of drama (or scare tactics) to weather reports. JAG/TI produced their Wind Chill Index and included a “time to” frostbite colour scheme. The colours indicate (NOTHING else but) that Wind Chill that may be expected to produce frostbite on an exposed cheek in 30 minutes or less:

- In the most susceptible 5% of the population.
- In a worst case scenario – e.g. walking in an open field, directly into the wind, on a clear night, etc.

Direct calculations of :-  $WCET = 35.74 + 0.6215T - 35.75V^{0.16} + 0.4275TV^{0.16}$

		Temp C												
		-9	5	0	-5	-10	-15	-20	-25	-30	-35	-40	-45	-50
KM/PH	63	-21.5	-2.0	-8.9	-15.9	-22.9	-29.8	-36.8	-43.7	-50.7	-57.6	-64.6	-71.5	-78.5
	15	-15.5	1.7	-4.4	-10.6	-16.7	-22.9	-29.1	-35.2	-41.4	-47.6	-53.7	-59.9	-66.1
	20	-16.6	1.1	-5.2	-11.6	-17.9	-24.2	-30.5	-36.8	-43.1	-49.4	-55.7	-62.0	-68.3
	25	-17.5	0.5	-5.9	-12.3	-18.8	-25.2	-31.6	-38.0	-44.5	-50.9	-57.3	-63.7	-70.2
	30	-18.2	0.1	-6.5	-13.0	-19.5	-26.0	-32.6	-39.1	-45.6	-52.1	-58.7	-65.2	-71.7
	35	-18.9	-0.4	-7.0	-13.6	-20.2	-26.8	-33.4	-40.0	-46.6	-53.2	-59.8	-66.4	-73.1
	40	-19.4	-9.4	-13.0	-16.6	-20.1	-23.7	-27.3	-30.9	-34.5	-38.0	-41.6	-45.2	-48.8
	45	-19.9	-1.0	-7.8	-14.5	-21.3	-28.0	-34.8	-41.5	-48.3	-55.1	-61.8	-68.6	-75.3
	50	-20.4	-1.3	-8.1	-15.0	-21.8	-28.6	-35.4	-42.2	-49.0	-55.8	-62.7	-69.5	-76.3
	55	-20.8	-1.6	-8.5	-15.3	-22.2	-29.1	-36.0	-42.8	-49.7	-56.6	-63.4	-70.3	-77.2
	60	-21.2	-1.8	-8.8	-15.7	-22.6	-29.5	-36.5	-43.4	-50.3	-57.2	-64.2	-71.1	-78.0

Frostbite may occur within 30 mins

<sup>18</sup> Vaso-Dilation – when the skin falls below a certain temperature the capillaries open to heat the skin for a short time. Each time the skin cools the process is repeated, dissipating body heat quicker.

Direct calculations of :-  $WCET = 13.12 + 0.6215T - 11.37V^{0.16} + 0.3965TV^{0.16}$

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

Frostbite may occur within 30 mins

The above was amended in 2002<sup>19</sup> to:-

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

Frostbite may occur in:      30 mins      10 mins.      5 mins.

Note – the author recalculated the above data (3 charts) 11/08/13 – the rounding functions may alter the results by a max. of 0.05 (1<sup>st</sup> chart) and 0.5 (2<sup>nd</sup> and 3<sup>rd</sup> charts).

### Conclusion

The new formula for the Wind Chill Index is a major improvement over that which was based on the Siple and Passel calculations. However it is still confusing to the public (and TV weather reporters) as it does not mirror perception. It is not (as the UK met office states) a “feels like”<sup>20</sup> temperature – this would only be the case in a nudist colony (populated by perfectly cylindrically shaped people), although it continues to be promoted as such.

It is applicable in only a few extremely specific circumstances and for a small section of society. It is highly unlikely that one of the 5% of the population (being 5ft 4” tall), with the least resistance to wind chill, would find themselves walking directly into the wind, through an open field, on a dry night – but if they did then the Wind Chill Index may come in handy.

<sup>19</sup> Mark Tew et al. Implementation of a new Wind Chill Index.

<sup>20</sup> www.metoffice.gov.uk/learning/wind/wind-chill-factor

As a method of raising awareness of the combined dangers of wind and cold the Wind Chill Index does help. However as it is not sufficiently understood by the public or educators it should only be used as a very loose guide.

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## Appendix (1)

Currently the BASI Alpine Manual (P 234) has this to say regarding Wind Chill

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In the same way that a fan cools you in summer, wind increases the rate at which your body loses heat. This adds to the effects of altitude, and can make even a sunny winter's day an ordeal for all but the best equipped. The wind chill temperature is the equivalent temperature that would produce the same rate of cooling in the absence of a wind. For example in Figure 8.5, if the actual air temperature is  $-5^{\circ}\text{C}$ , a 25km/hr (15mph) wind produces a wind chill equivalent of  $-20^{\circ}\text{C}$ . If the actual temperature is already down at  $-15^{\circ}\text{C}$ , a 50km/hr (30mph) wind gives a wind chill of  $-38^{\circ}\text{C}$ . In other words, wind chill can have a dramatic effect on our comfort and safety and that of our clients.

To interpret Figure 8.5, place a ruler to link the actual (thermometer reading) air temperature and the wind speed. Where it crosses the diagonal wind chill line, read off the equivalent wind chill temperature.

The actual relationship is rather complex. As a guide, the lower the still air temperature (as indicated on a thermometer), the greater the effect of wind chill. Also, the stronger the wind, the greater the wind chill factor. This holds for wind speeds up to around 50km/hr (30mph). Above this wind speed, relatively little further cooling occurs. It should be borne in mind that these effects do not simply occur in windy conditions. Even on a still day, skiers create their own wind chill by their rate of travel through the air. Descending at 30km/hr (20mph) has the same effect as standing still in a 30km/hr wind. The same applies when riding lifts – modern chairlifts travel at speeds of up to 15km/hr and can cause considerable wind chill on a cold day.

Finally, remember that wind speed generally increases with altitude. The wind is roughly 2-3 times stronger per 1000m of ascent. It may seem calm in the valley, while a strong wind is blowing higher up the mountain. On a clear day, look out for the tell tale signs such as spindrift blowing off exposed ridges, the speed at which clouds are moving or lenticular clouds (lens shaped or flying saucers).

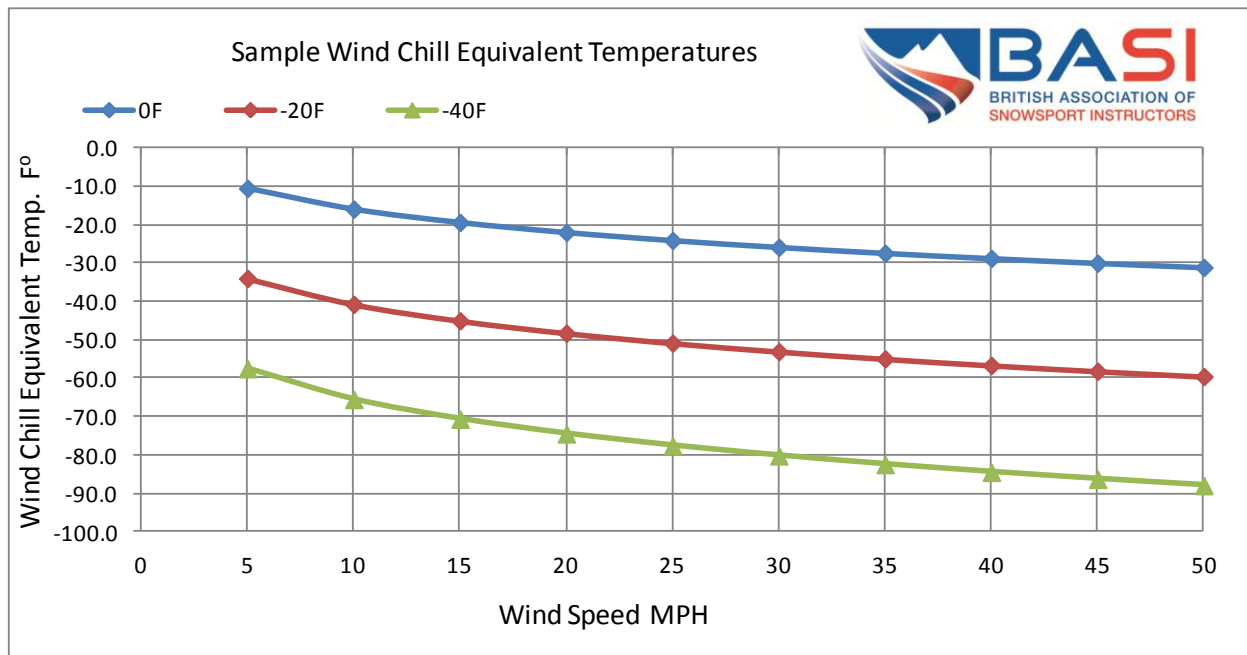
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A suggestion for a revision is shown below.

Wind chill can have a dramatic effect on our comfort and safety and that of our clients. It can make even a sunny winter's day an ordeal for all but the best equipped. In the same way that a fan cools you in summer, wind increases the rate at which your body loses heat.

Wind removes warm air surrounding you, allowing the ambient (colder) air to come into contact with your skin, which is then cooled. As this process continues your body attempts to regulate heat loss by transporting more heat to the cold areas. Unless action is taken – for example by shielding from the wind or descending into warmer air – serious problems can occur as the wind will continue to dissipate body heat.

A number of formulas have been created for calculating the rate of cooling based on temperature and wind speed, the most recent in 2001. The results are normally displayed in an index (table).



The Wind Chill Index is a table containing a number of Wind Chill Equivalent Temperatures. These are calculated temperatures equal to the dry air temperature needed to produce the same rate of skin cooling in calm conditions. It presents a worst case scenario and can be a useful guide when explaining to students that it is not just the air temperature that will make them cold.

Wind Chill Equivalent Temperatures



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

NB. The formula is calibrated for flat open areas, without sunlight (at night) and a height of 1.5m/5ft. For example, exposed skin cools at the same rate in calm air (3mph / 4.8km) with a temperature of -15F as it would if the air temperature was +5F and the wind speed was 20mph.

The best protection from wind chill effects is windproof clothing. As a snowsport instructor you will probably be wearing high quality clothing but you should bear in mind that your students' clothing may not be as thermally efficient as yours, as such they may be more susceptible to wind chill.

There are situations when you (and your students) can cool down faster due to the combined effects of wind and temperature, such as riding an open chair, or waiting in a windy location.

There are simple methods you can use to reduce your students' discomfort due to Wind Chill.

- Be on time for the start of your lessons.
- In inclement weather try to meet your class in a sheltered area (whenever possible).
- When you stop with your students, ensure they are stood with their backs to the wind (cold is perceived initially by exposed skin, normally the face).
- As such, encourage your students to use a scarf/buff to cover their face in strong winds.
- Above all ensure they are dressed appropriately for the prevailing conditions.

Finally, remember that wind speed tends to increase with altitude. It may seem calm in the valley, while a strong wind is blowing higher up the mountain. On a clear day, look out for tell tale signs such as spindrift blowing off exposed ridges, the speed at which clouds are moving or lenticular clouds (lens shaped or flying saucers).

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## Appendix (2)

If the public do not understand the concept of Wind Chill, the question must be asked, why not?

At its basic level Wind Chill is an extremely simple concept; the wind blows and it cools you down. The public aren't interested in the physics behind the effect nor are they interested in calculations required to provide them with information. In an ideal world, there is no reason why this topic should not be simple to grasp.

Of course this is ignoring political correctness and the desire that some people in the academic world have to justify their grant budgets. These, combined with some over enthusiastic government press officers, have combined to mystify what should be a simple idea.

Whether Wind Chill Equivalent Temperatures should even be mentioned in weather reports is for others to discuss.

So where did the misinformation and confusion come from?

The public at large obtain all of their information about the weather from government meteorological departments, either directly via their websites, or indirectly from broadcasters who include it within their schedules.

Government meteorological departments (like all tax payer funded institutions) suffer from the scourge of political correctness. In the context of weather forecasting this manifests itself as a dumbing down of the information to (in the minds of the PC brigade) make it understandable. In doing so however the information is altered to such an extent that the recipient (the public) is actually misinformed.

As an example, whilst an association such as BASI can be excused for their errors concerning Wind Chill, it is, to say the least, slightly disconcerting to read that the UK Met Office's definition of Wind Chill is "*the apparent temperature felt by warm blooded creatures, primarily humans, during cold and windy conditions*"<sup>21</sup>. This is obviously total rubbish as a (cold blooded) slug is affected by Wind Chill even on a warm summer day, as would be an *Al Fresco* bowl of soup.

The almost universal misunderstanding regarding Wind Chill is a prime example of an "*argumentum ad populum*" (paraphrased as "if everyone says it, it must be true"). The public at large will, wrongly, assume that their met office or TV weather reporters, who frequently and incorrectly use the supposed Wind Chill to add weight to their dire predictions, are knowledgeable about their subject and are passing on correct information. In fact it would be difficult to argue against their pronouncements (who can argue with the Met. Office about the weather?) Given that it is extremely difficult to find an educated opposing argument; as virtually all websites and text books continually misquote studies on the subject. It can be seen that the confusion surrounding Wind Chill is a prime example of forecasters, authors, broadcasters and teachers being taught incorrectly and then passing on their "knowledge". And so the confusion continues, "*Argumentum ad populum*" indeed.

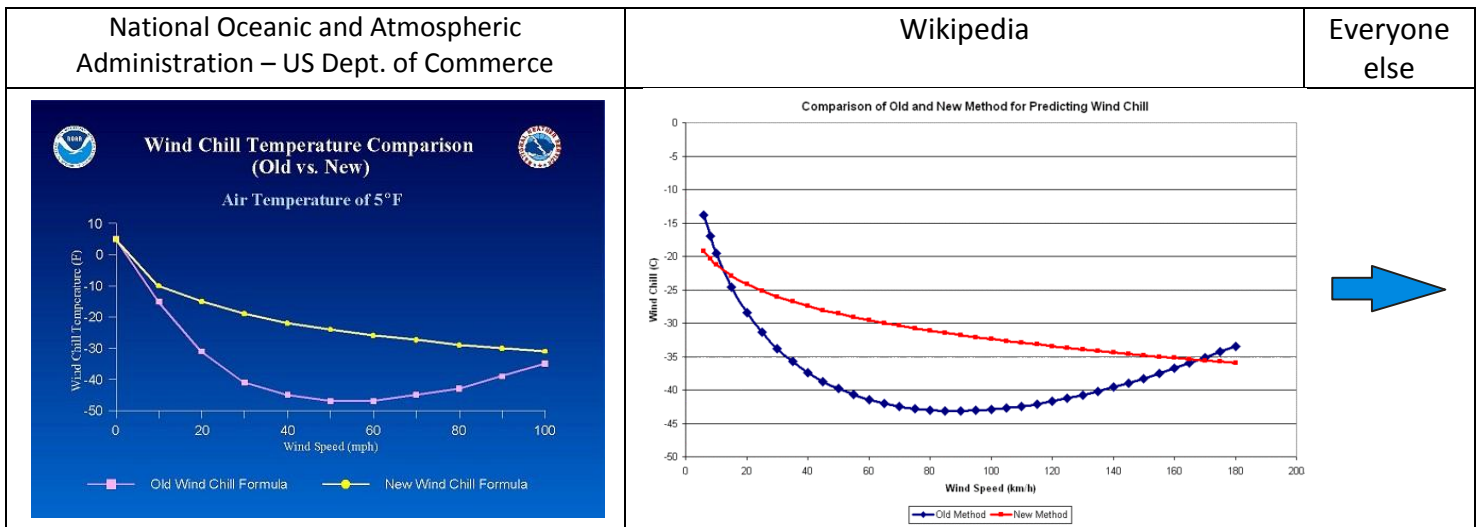
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<sup>21</sup> [www.metoffice.gov.uk/about-us/help/weather-faq](http://www.metoffice.gov.uk/about-us/help/weather-faq)

Occasionally a Met. Office press office will push out some information which may be used by academics to justify their research. Of course the academics will recognise that the information is incorrect, but still allow its dissemination. Whilst this type of thing can be expected in the Global Warming (academic) Industry; shouldn't the weather forecast be sacrosanct? Obviously not.

When data is supplied by a government (scientific) department it is usually taken as read that it is correct. A problem arises when the information is simply not true. How are the public meant to know this?

As an example. To point out the benefits of the New Formula for obtaining Wind Chill Equivalent Temperatures - and justify the large financial grants required to obtain the data – the US government (met office) placed a simple to understand graphic on their website. This graphic displayed that without doubt the old system was wrong and that the new system was (basically) much better. The fact that the graphic used data that was simply made up didn't seem to bother them.



The two graphics display the obvious failures of the Siple and Passel formula and this would be acceptable if the claimed errors were true, but they are not. Both graphics display data that simply was not, anywhere, in the original paper. To suggest that the Wind Chill will go down as the wind increase is ridiculous. The data required to create the graphics has been extrapolated (made up) from the 1945 paper by someone attempting to prove a point. Siple and Passel's formula formed an inverse parabola and the index they produced simply did not show any wind speeds above 20mph<sup>22</sup> – but it does make the graphic look more interesting and, let's face it, who is going to argue with NOAA and the US government. *Argumentum ad populum*? As shown above the information supplied by the US Government has now been taken up by other (seemingly independently verified) websites, such as Wikipedia. From here it continues to flow outwards.

The simple answer to the question "why doesn't the public understand Wind Chill" is that the information they are given concerning the topic is frequently incorrect and, occasionally, obfuscated.

<sup>22</sup> Proceedings of the American Philosophical Society No. 89, 177 (1945) pages 189 / 190  
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