by Wendy Wagner

SURFACE TENSION

How temperature sensors can help Olympic ski racers

An insight into competitive ski racing tracks and the methods used to monitor the surface temperature of the snow

Ski racing seems simple at first. The fastest skier from point A to point B wins. However, with continued developments in sport, such as physical training, nutrition, equipment, and technology, more and more athletes run the risk of being helped or hindered by events out of their control. For a ski racer, the speed of his or her skis is a primary concern and can, in certain cases, win or lose medals.

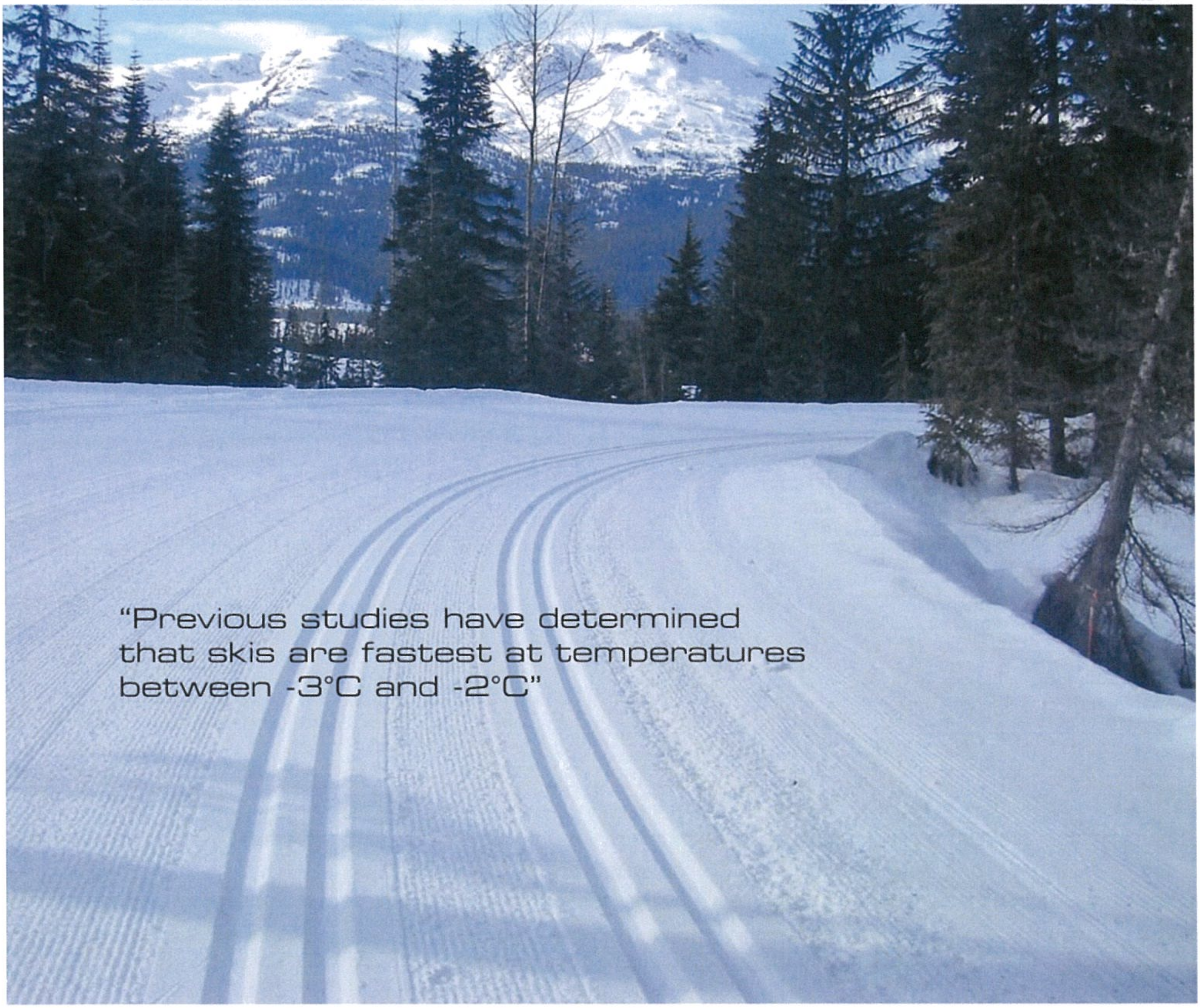
Although ski technicians have studied and experimented with the art of ski waxing and preparation for years, providing athletes with the optimum racing ski is still a challenge. A primary consideration involves applying one of an infinite number of wax and ski base structure combinations between 18 hours and an hour before a race. Competition among waxing technicians often provides for comical and secret waxing tactics. For instance, it's not unusual to switch the packaging between certain waxes and leave decoys out to mislead the other teams at certain events. The bottom line is this: if the snow conditions are incorrectly predicted, then the skis will not perform optimally. So both the skis themselves and the properties of the snow are equally important. The following article examines the methods used to monitor the snow surface on ski racing courses, specifically cross-country ski tracks.

It can be difficult to take accurate measurements on ski racing courses due to the strength and hardness of the snowpack. Racing courses are prepared by mechanically compacting the snow with a groomer. The groomer processes the snow on a daily basis, giving the snowpack enough strength to withstand the expected use. The way the snowpack and snow surface is prepared depends on which event is being held. Alpine or downhill racing courses are much harder and more compact with a snow density of approximately $650kg/m^3$. Nordic or cross-country racing courses are softer with less ice and have a snow density of around $450kg/m^3$ (by comparison, a seasonal undisturbed snowpack is approximately $200\text{-}350kg/m^3$).

Snow has many characteristics that affects ski speed but surface temperature is the focus because it is the main predictor used by wax companies to determine which brand is used. The other factors that govern speed include snow grain type, liquid water content, snow surface roughness, and

Temperature mapping methods used to collect snow surface temperature data along the 2010 Olympic cross-country ski racing courses. A snowmobile was used to carry the instrumentation along the 10km racing tracks.

A section of the 2010 Olympic cross-country ski racing course in the Callaghan Valley, BC. The course was monitored to examine changes in snow surface temperature for the 2010 Winter Olympics.



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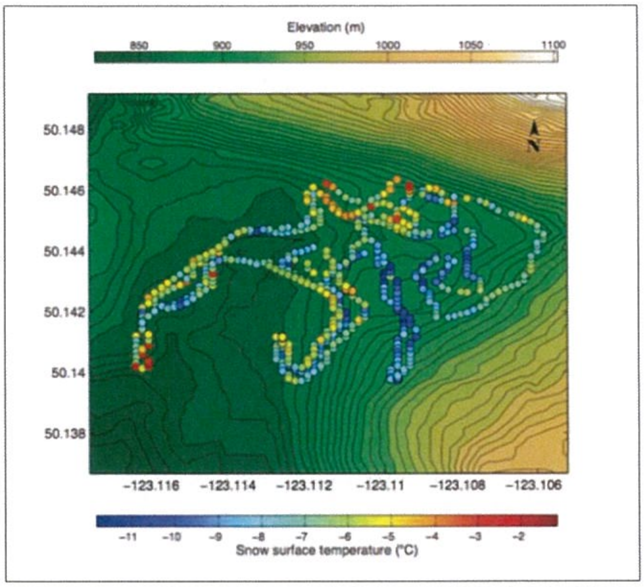
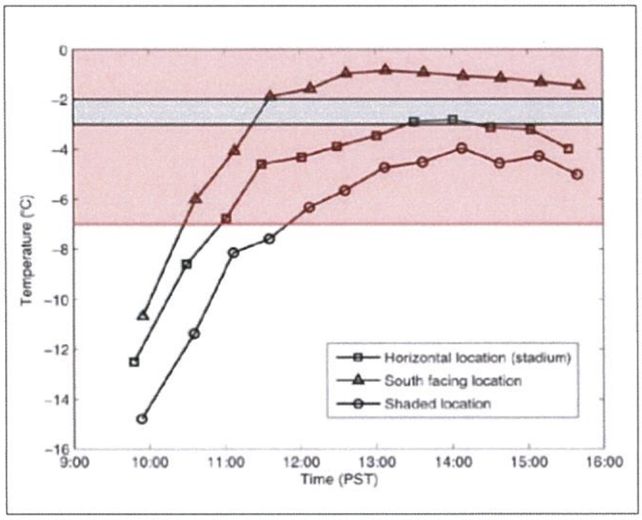


Temperature map generated on February 21, 2009, showing changes in snow surface temperature along the 2010 Olympic racing courses. The sunny areas, in red, are approaching 0°C, while the shaded locations, in blue, are around -10°C. These temperature variances can significantly affect ski speed



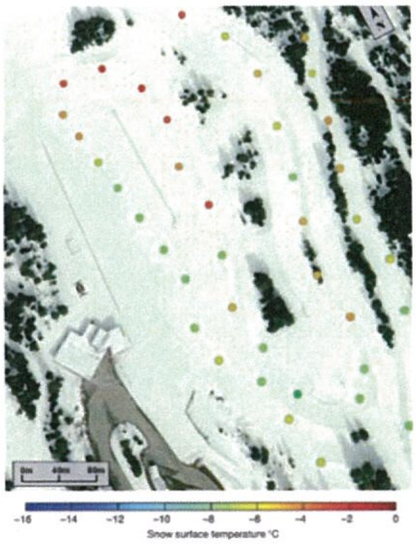
Graph examining snow surface temperature at three critical points on the 2010 Olympic course: stadium, warmest location (south facing slope) and coldest location (continually shaded area) on February 20, 2009. Shaded in gray is the temperature range where research shows skis have minimum friction with the snow surface. Shaded in red are regions where small changes in surface temperature can have large changes in ski friction and ski speed. These spatial and temporal gradients can affect race ski preparation

hardness. Therefore, accurately measuring snow surface temperatures at racing events becomes crucial. But predicting these surface conditions depends largely on local weather systems, which contributes to the complexity of ski preparation.

Ski system instruments

The most commonly used instruments by waxing technicians at Olympic level are digital probe thermometers and infrared sensors. There are concerns with this approach, however. For example, simple probe thermometers can be placed at depths of up to around 10cm, but different readings may occur if a near-surface temperature gradient exists. Also, infrared sensors with various emissivities can result in erroneous measurements. As a result, there is no standard way of measuring snow temperature among the ski racing and wax company community.

For two winters prior to the 2010 Olympic Winter Games, snow data was collected on the Olympic cross-country ski racing courses at the Whistler Olympic Park in the Callaghan Valley near Whistler, British Columbia, Canada. Snow surface temperatures, subsurface temperatures, near-surface air temperatures, and vertical profiles of the snowpack were collected. This information was used to help the Vancouver Olympic weather support team monitor snow surface temperatures during



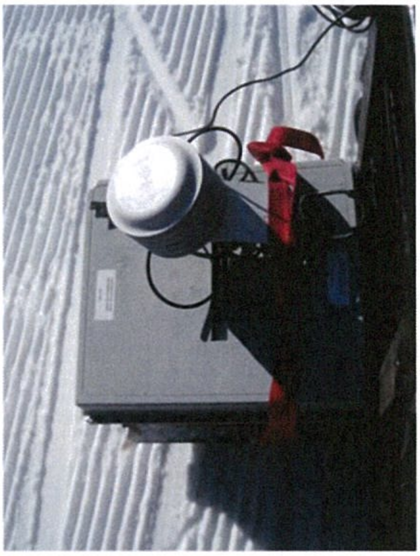
Snow surface temperatures collected in the 2010 Olympic cross-country stadium at 11:15 PST on February 19, 2008

the Games. After the Olympics, in February and March 2010, more snow temperature monitoring experiments were made at Mountain Dell, Utah.

For the Whistler Olympic Park study in February 2008 and 2009, snow surface temperature was monitored using an Everest Interscience Inc series 4000.4G infrared temperature sensor with a viewing angle of 4°. The accuracy of this sensor is ±0.5°C and it has a linear response over the range of interest. The infrared sensor was calibrated daily using a cup of iced water. Post study, a correction was made to the data after some readings showed snow surface temperatures above 0°C in areas where the snow was wet, with wet grains visible. Infrared sensor emissivity was initially set at 0.98, then corrected for an emissivity of 0.99.

To map the temperatures along the course a technique was used that was developed by John Horel at the University of Utah to assist in the weather support effort at the 2002 Olympic Winter Games. The infrared sensor and a GPS unit were connected to a Campbell Scientific CR-10X datalogger. The instrumentation was housed in a watertight enclosure and attached to the side of a snowmobile. A 5cm diameter hole was cut in the bottom of the enclosure to expose the infrared sensor to the snow below. The infrared sensor was mounted 20cm above the surface so it could measure the course undisturbed by the snowmobile.

The sensor was positioned normally with an unimpeded view of the snow surface. Using a snowmobile enabled them to cover all of the 2010 Olympic cross-country courses in a reasonable time. Driving at 10-15km/h and recording temperatures every five seconds, they covered the courses in 35-45 minutes,



Close-up view of the watertight instrumentation enclosure. This was attached to the side of a snowmobile and housed an infrared sensor, GPS, and datalogger. It also had an air temperature and relative humidity sensor on top

The author generating a temperature map along the 2.4km representative course using the instrumentation. The equipment was inside a backpack and the infrared sensor held out to the side

The author collecting snow grains on the Mountain Dell cross-country ski course in Utah to record and photograph grain type. Marked with the pink flags are locations where iButtons are logging snow temperature approximately one centimeter under the surface

resulting in a good illustration of spatial variability. When skies were clear, there were temperature variances of over 10°C from one point on the course to another. As one would expect, the warmer areas were on exposed southerly slopes and the colder areas were in the shaded stretches of the course.

Time changes

It is important to know the temperature shifts along the length of the racing tracks, and also to examine changes that take place during the day. It was unrealistic to try and map the entire 10km course every 30 minutes, so a representative course was determined.

This shorter track was 2.4km long and included the warmest and coldest points, which were determined by checking the initial temperature maps. A snowmobile was not available so the author placed the instruments, datalogger, and battery in a backpack and skied the shortened course over a day. The infrared sensor was attached to a handle and held out to the side. Care was taken to hold the sensor normal to, and approximately 75 cm above, the snow surface, and to keep skis and other equipment out of the field of view. The author had to reduce speed on the downhill sections to sample them adequately. Using this method 12 temperature maps were generated every 30 minutes between ~10:00 PST and ~16:00 PST. This enabled the team to examine temporal changes at key points on the course.

Since cross-country ski races can last up to two hours, it is important to assess future snow surface conditions during the race. Point measurements were taken to monitor changes throughout the day in the 2010 Olympic cross-country stadium. Surface temperature was measured with the infrared sensor described earlier, while subsurface temperature was measured using an Omega TJ180 – CP16 thermistor at a depth of 10cm. Air temperature and relative humidity were measured with a Campbell Scientific CS500 sensor. During the collection period sunny skies prevailed, which led to large changes in temperature being recorded. On February 17, 2009, there was an increase in surface temperature of more than 15°C, while the subsurface temperature increased by about 7°C.

Performance changes

Previous studies have determined that skis are fastest at temperatures between -3°C and -2°C. Additionally, at temperatures just above and below this range (-7°C to -3°C and -2°C to 0°C) ski speed becomes sensitive to small changes in surface temperature. These differences become important during the race when the surface temperature shifts from one range to another on the course.

By using these temperatures as reference points, one can see how common it is, particularly on clear days, for the snow surface to fluctuate between ranges. During the winter of 2010 at Mountain Dell, Utah, more experimental methods of monitoring snow surface temperature were used. Cross-country skis typically ride on the top 1–2cm of snow, so measuring temperatures along the course just under the surface was tried using iButtons. The iButtons (Maxim DS1922L) are watch battery-sized temperature sensors/dataloggers. These small sensors were placed about a centimeter below the snow surface at predetermined points on the Mountain Dell course, an advantage being that they can be set several days before the event. It was found that the iButtons absorbed solar energy, which resulted in warmer temperatures (above 0°C) being observed when the snow surface was exposed to the sun.

A reflective coating (Labsphere 6080) was applied to the iButtons which limited solar absorption but did not completely eliminate it. Data collected and analyzed using iButtons may prove useful in the future, particularly during persistent weather patterns, but just how practical or applicable these techniques are for waxing technicians has yet to be determined.

In conclusion, snow surface temperatures can vary widely along a race course during an event. These changes in temperature are difficult to predict, which is why choosing the right wax and preparing the best ski are complex issues. In some cases, where conditions vary significantly over time and location, an optimal wax is often below par from the racer's perspective. Nevertheless, all aspects of ski racing will continue to evolve, with the fastest skiers continuing to win. ▮

Wendy Wagner is a post-graduate researcher with the US Army Cold Regions Research and Engineering Laboratory at the University of Utah's Department of Atmospheric Sciences