Weather Services, Science Advances, and the Vancouver 2010 Olympic and Paralympic Winter Games

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The Olympics inspire greatness. "Swifter, Higher, Stronger" applies not only to the athletes but sets the tone for everyone associated with the games, including the weather service providers. The Winter Olympic and Paralympic Games of 2010 will be hosted by the city of Vancouver, British Columbia, from 12–28 February and 12–21 March, respectively. Alpine and Nordic events will be held on Whistler Mountain, at the new Whistler Olympic Park in the Callaghan Valley and at Cypress Mountain on the North Shore Mountains just north of the City of Vancouver (Fig.1). The challenges for winter weather forecasting and nowcasting in complex terrain within a coastal region require Olympian efforts and innovations to overcome.

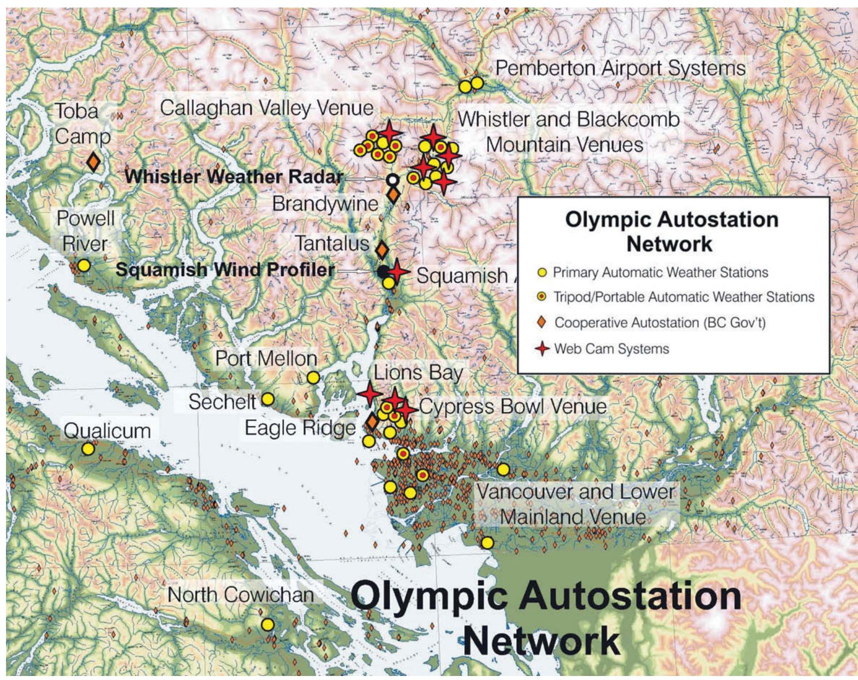

FIG. 1. The forecast domain of the Vancouver 2010 Winter Olympic and Paralympic Games. The map shows the locations of the Olympic Autostation Network (OAN) sites. Including primary, video, and cooperative stations, more than 50 OAN sites have been established. The small diamonds are cellphone tower locations and are not part of the OAN.

The International Olympic Committee (IOC) awarded the games to Vancouver on 2 July 2003. Environment Canada (EC), with its federal mandate to provide weather warning services, was chosen by the Vancouver Organizing Committee (VANOC) to provide weather services specifically to support the safety of the athletes, officials, and spectators and to ensure the fairness of the sporting events. Initial elation of the EC staff assigned to organize the weather support for the games turned to focused and detailed planning as there was an immediate realization of the work required to build the weather support system to meet the essential federal mandate and the needs of the games.

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WARNING AND SPORT MANDATES. The EC team first assembled information on what was accomplished during prior Olympic weather support efforts. Members of the weather teams from the Salt Lake City (2002), Torino (2006), and Beijing (2008) Olympic Games generously shared their insights and experiences and were highly instrumental in setting the scene for what the EC team should expect leading up to and during the 2010 Games. A common theme raised by all of those involved in earlier Olympics forecasting efforts was the challenge and need to determine the requirements of providing essential warning services for large events, in general, and specifically for the events imposed by the IOC, International Sport Federations, and VANOC, and to get an early start on planning for delivery of such pinpoint forecasts.

Weather-related regulations and specifications can be quite detailed for each Olympic and Paralympic event and venue. There is a natural tendency by sports federations and organizing committees to be most comfortable with simply providing what has worked in the past rather than pursuing new approaches. Engaging in detailed, in-depth discussions with organizing committee officials regarding critical weather issues and defining requirements was and continues to be important. The EC team members also immersed themselves in the weather dimensions of high-performance sport and of large, complex public events. For example, the winning margin in downhill ski racing can be 0.01 s over a 2-min event, which represents a less than 0.01% difference between winning and losing.

Public safety considerations are also very important. Safely hosting thousands of spectators in a winter alpine environment and transporting them along the Sea-to-Sky Highway between Vancouver and Whistler will be highly dependent on the weather. EC planners have built observing capacity and focused forecaster training on meeting the meteorological needs of emergency responders as well as transportation system operators.

FORECAST REQUIREMENTS. The overall Olympic weather service requirements include forecasts out to 5 days with 6-h resolution, forecasts out to 72 h with 3-h resolution, predictions out to 24 h with 1-h resolution, and nowcasts for specific venues of about 15-min resolution out to 2 h. The teams and officials need detailed information on temperature, wind, visibility, and precipitation at venues. Predicting precipitation phase and amounts will be a significant and challenging issue at many of the venues. The seasonal snowfall at Whistler Mountain in the vicinity of the downhill events is measured at 1,650 m above sea level (ASL) and is about 1,000 cm yr^{-1}, while the average temperature and precipitation in the valley during the months of February and March are −0.3° and 2.3°C, and 60.3 mm of rain/66.8 cm of snow and 54.0 mm of rain/45.4 cm of snow, respectively. Since Whistler Valley is located near 600 m ASL and the top of the downhill is near 1800 m ASL, skiers often experience sunshine and high winds at the top of the run and descend through fog/low clouds and snow that changes to rain by the time they reach the bottom. In addition, there are about 30 days when the high-alpine area is shut down for strong winds. So, the EC weather team faces forecasting issues associated with high winds, low visibility, and precipitation type and intensity that are strongly affected by elevation at this and other sites.

FORECAST AND NOWCASTING CHALLENGES. A considerable challenge is to make measurements on the appropriate nowcasting time scales with sufficient accuracy in alpine environments. There are many automated snow gauges but they all have their limitations and can suffer from such issues as wind effects, capping, and sensor failure due to heavy snowfall, to name a few. The causes of low visibility (fog, low clouds, and precipitation on mountains) are extremely complex, making forecasting and nowcasting challenges significant. Warnings, nowcasts, and forecasts, as identified as requirements for the 2010 Games, have not been previously done in winter by EC in this specific coastal/marine and mountain environment. Previously, the only routine observations for Whistler were from the valley floor at about 600 m ASL. Some venue forecasts are in another valley and between 600 and 1,800 m in elevation.

One example of a low-visibility forecasting challenge is a midcloud phenomenon affectionately called Harvey's cloud, named after a local resident who resided for a time on the mountain at about the 1,200-m level. This cloud forms as southerly moist air rises along the Creekside slope of Whistler Mountain, condenses at Raven's Nest (~1,200-m level), and then expands outward and in the vertical. Depending on many factors, it may never get to the village side of the ridge. This cloud can be very thick and is located near the top half of the Alpine downhill course. It has postponed and delayed downhill ski competitions in the past.

Another example is a fog/low cloud event at the Cypress venue (freestyle events) on the North Shore Mountains of Vancouver. The Cypress venue is located in a col, or pass, between two rounded mountain peaks that are aligned approximately southwest–northeast. In northwest flow, a minicyclone can set up and the flow can wrap around the two mountain peaks and come around from the south or southwest, or it can advect through the col from the northwest, both of which create visibility problems. The challenge is to anticipate when the setup might occur and which mechanism is operating, and predict the event in a timely manner. These phenomena were not known to forecasters before the project began.

Fig. 2. Custom automatic winter weather stations, such as this, were built to meet the needs of the specialized conditions in a coastal complex terrain environment. They have been placed in both valley and slope-side locations. The photo shows a high-capacity snow gauge, an acoustic snow-depth sensor, a temperature/pressure/humidity unit, solar panels, wind sensor, cellular internet protocol antenna, and data logger.

INSTRUMENTATION AND FORECAST DEVELOPMENT. The aforementioned requirements and challenges led to the development of an innovative forecasting system and team of operational forecasters and scientists. A first step was to obtain observations at the expected venue and event locations to gain familiarity with the weather at each, and compile statistics to be used for model output statistics (MOS), which requires several years of data. Fifty custom surface observing stations had to be designed, constructed, and installed. Figure 1 shows the locations of these Olympic Autostation Network (OAN) stations. The instruments at each station are situated on an elevated platform (Fig. 2) high enough to keep them above the seasonal snowpack (about 3–6 m). Solar panels provide power since they are in remote locations without access to AC power. Due to the region's heavy snowfall, large-capacity buckets are used in the catchment snow gauge to reduce the maintenance visit requirements. Cellular internet protocol telecommunications are utilized to transmit the data. In this remote complex-terrain environment, the stations are confined to existing roads, which limits their spatial coverage. Another significant issue is that site availability is dependent upon the Olympic construction schedule and OAN Stations may be required to move due to changes in site design or due to aesthetics as determined by VANOC.

To provide areal and vertical coverage of precipitation and wind, a Doppler weather radar was installed at the confluence of three important valleys—those that contain the Alpine venue, the Nordic venue, and the highway route from Squamish to Whistler. It was configured for local coverage (less than 60 km) using short pulses (0.65 μs, 125-m range bins) to mitigate the effects of ground and mountain clutter. Scanning requirements differ from those typically used for general weather operations, since low-level azimuthal scanning is blocked by nearby terrain. A special scan strategy was created in which more elevation scans (in azimuthal scanning mode) than normal are collected in the 11°–15° elevation angles and very few (3) low-level scans are used below 10°, since the radar beam generally clears the terrain above 12°. An example of the utility of the radar is shown in Fig. 3.

In deep valleys, there can be a separation of the trapped valley air with the overriding system air, and monitoring this is important to understanding the weather at the scales required. This separation is usually identified by inversions, which are often measured just below the 1,800-m level. To acquire detailed observations of the transitional environment, a pressure, temperature, humidity (PTU) sensor was installed on one of the Village Gondolas on Whistler Mountain (Fig. 4). It moves up the side of the mountain from 600 to 1,800 m, and under normal operating conditions the gondola travels at 4 m s^{-1}, making the round trip in about 40 min. The PTU sensor creates about 14 temperature soundings per day as the gondola traverses vertical and horizontal distances of about 1.2 and 4.5 km, respectively. Since the inversion can cap the low-level rising air and associated clouds, monitoring it will help with nowcasting the evolution of visibility and precipitation along the mountain slope.

ENHANCING THE FORECAST PROGRAM. Given the requirements to forecast and nowcast in this environment, an enhanced observational, training, and research program was needed to understand

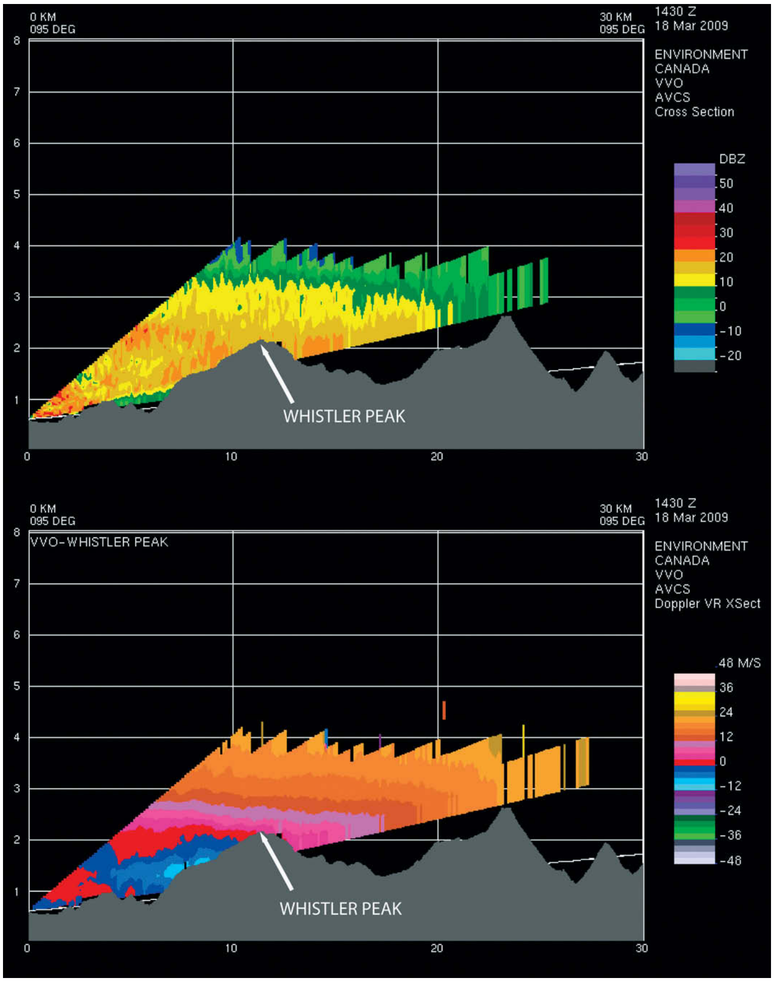

Fig. 3. A range-height indicator (RHI) display of (top) reflectivity and (bottom) radial velocity, taken toward Whistler Peak (at ~12-km range), showing the rich structure of the shallow downslope blocking winds (blue colors are radial velocities toward the radar) along Whistler Mountain. In this situation, moderate to heavy precipitation falls on the slope and not at the crest of the mountain.

and provide the physical insights into the regional phenomena and their prediction.

Five research sites along the slope of Whistler Mountain were established as well as an upstream wind profiler site at Squamish (Fig. 4). Three of these sites coincided with the OAN stations; two sites were established at Cypress Mountain. No sites were established at the Nordic venues (Callaghan Valley) due to the lack of AC power, though there are significant weather forecasting issues there. The research stations were designed to study winter and alpine precipitation, wind, and visibility processes and not specifically to provide weather services. Besides conventional observations, some additional specialized measurements of such quantities as drop sizes and their distributions, visibility, and vertical profiles of reflectivity and Doppler spectrum, wind, and temperature were collected.

Relative to prior Olympic weather support programs, EC's training of its forecasting team was unprecedented. In addition to forecasters already assigned to Vancouver, forecasters were "borrowed" from EC offices across the country, U.S. National Weather Service offices, and the private Canadian Weather Network. A specialized residence training course on wintertime mountain weather was developed for all forecasters in conjunction with the University Corporation for Atmospheric Research (UCAR) Cooperative Program for Operational Meteorology, Education and Training (COMET). This residence course was offered three times prior to 2008. EC also cosponsored, with the AMS, the Mountain Weather Workshop held 5–8 August 2008 at Whistler. In addition, a weather-event simulation training course combining new research and operational products and case studies provided a final tune-up for the forecasters. The training courses and workshops created unique learning opportunities to bridge the gaps between research, development, and forecasting related to mountain meteorology.

To gain in situ experience, forecasters were dispatched from January through March in 2006–09 to the venues to observe local conditions, formulate conceptual models of local weather, and prepare forecasts. Forecasters participated in "test" events such as Canadian championships and World Cups that gave them the opportunity to establish relationships with the venue and competition officials and to see, firsthand, how forecast information was used during an event. This helped to develop and refine a mutual understanding of the venue and sport requirements.

ADVANCING THE SCIENCE. Advances in numerical weather prediction modeling by EC to support the weather forecasting team were necessary and included local-area modeling at 2.5- and 1-km scales with enhanced double-moment microphysics, updated numerics for greater efficiency, higher update cycles than normal, plus an offline downscaling surface model running at 100 m. Behind the scenes, significant changes were required to the data collection, the processing and product generation, and the visualization systems. A significant benefit is that these changes will leave a legacy for rapid technology development and transfer into the national prediction system.

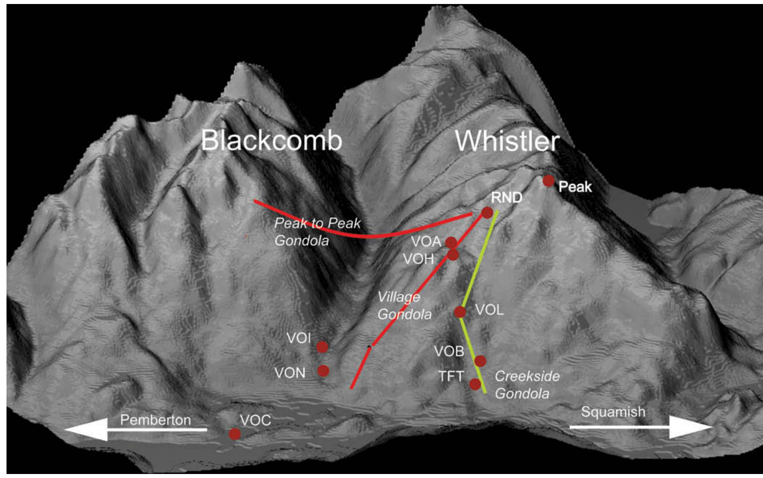

Fig. 4. A schematic of the locations of the OAN and SNOW-V10 measurement sites in the Whistler area (red dots). The background is a shaded smoothed rendering of a 3-arc-second digital elevation model looking toward the southeast. The red lines indicate the gondolas that are instrumented with meteorological sensors. The stations with the 3-letter identifier are OAN sites, with V referring to Vancouver and O to Olympic, and various letters assigned to differentiate between them. Most are in situ surface sites with both basic and advanced sensors, although VOC denotes the upper-air site located in the valley where the official Whistler weather observations are made. TFT is the vertical remote sensing site at Timing Flats at the bottom of the downhill venue, RND refers to the Roundhouse for the gondola system, and Peak is an air-quality research site. Whistler Mountain reports snow accumulation from VOA.

With the science of winter nowcasting in complex terrain in its infancy, a WMO/World Weather Research Program (WWRP)/Nowcast Working Group Research Development Project was initiated, called the Science of Nowcasting Olympic Weather-Vancouver 2010, or SNOW-V10 for short. The project takes advantage not only of the enhanced and unique datasets created by observations leading up to and during the Olympic Games, but also promotes scientific research and development into winter weather nowcasting science and systems. The focus of the science is in the 0–6-h time frame of wind, temperature, precipitation intensity, precipitation phase, and visibility. Participating organizations/countries include ZAMG[1]/Austria with the INCA system; University of Basel/Switzerland with fog modeling; University of Bonn/Germany with fog/low cloud modeling; FMI/Finland with precipitation typing; Weather Decision Technologies/U.S.A. with energy balance column modeling; NCAR/U.S.A. with the WSDDM nowcasting system; NSSL/U.S.A. with the NO-XERES dual-pol X-Band Doppler radar; Chinese Academy of Meteorological Science/China with the GRAPES/SWIFT nowcasting system; the Centre for Australian Climate and Weather Research/Australia with their STEPS system; and EC/Canada's CAN-NOW. This collaborative science project follows the successful Beijing 2008, MAP, MAP D-Phase, and Sydney 2000 WWRP projects, which arguably are the most effective ways to leave a long-term technology transfer legacy.

Monitor the weather conditions prior to and during the 2010 Olympic and Paralympic Games online at www.weatheroffice.gc.ca/2010.

OVERSEEING ALL THE NEW INFORMATION. With the diversity and rapid deployment of the technological and science innovations and new services, a commensurate change in the concept of forecast operations was required. A new forecast-support position, called the Pacific Olympic Desk

[1] ZAMG refers to the ZentralAnstalt fur Meteorolgie and Geodynamik. INCA is Integrated Nowcasting through Comprehensive Analysis. FMI is the Finnish Meteorological Institute. WSDDM is the Winter Support to Deicing Decision Making. NO-XERES is the NOAA X-band radar for Environmental Research. GRAPES/SWIFT is the Global/Regional Assimilation and Prediction System/Severe Weather Integrated Forecasting Tools. STEPS is Short Term Ensemble Precipitation System. CAN-NOW is Canadian Airport Nowcasting. MAP is the Mountain Alpine Project, and MAP D-Phase is the Mountain Alpine Project-Demonstration Phase.

(POD), was created by EC within its Pacific Storm Prediction Centre (PSPC) in Vancouver to monitor the new observations and products and to alert the venue forecasters, the meteorologists at the Olympic Committee offices, and the regular forecasters at PSPC to significant changes in the nowcast products or in the weather as indicated by the new sensors. This position is staffed by Olympic forecasters. Various nowcasting systems specialists, including those from the WWRP SNOW-V10 project, provide expert interpretation of the nowcast products and new sensor data. Some will be physically colocated at PSPC and some will participate remotely through Web meeting technology.

CONCLUDING REMARKS. Readying a venue for the Olympics is a high-profile project with a very firm deadline that requires very strong motivation to complete on time. It inspires innovation, collaboration, new science, new technology, and new forecast services. It requires rapid training and technology transfer that would never have occurred in such a short time frame under ordinary circumstances. There has been a significant and innovative upgrade to the observation program integrating both in situ and remote sensing data in complex terrain and at high time resolutions. Numerical weather prediction programs have gone to finer scales, with improved physics and innovative surface modeling approaches. Investing in the training of the venue and support forecasters both meets the short-term needs of the Olympics and improves the skills of the people who will bring this experience back to their home offices. Adding a research and international development program will result in an additional long-term legacy, as will the program to accelerate development of NWP at fine scales.

Key insights into microscale weather, from microcyclones, to microclouds, to the impact of rotor clouds on the ski jump, to articulating end users' requirements, have already been realized. The foresight of a healthy respect for the challenges, an ambitious vision, and a collaborative approach have been the catalysts for the innovations and insights that support the forecasting efforts for the Vancouver 2010 Winter Olympic and Paralympic Games and, equally importantly, the legacies in science, education, technology, understanding, and operations that will spread far beyond these Olympian events.

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FOR FURTHER READING

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