Environment Canada Environnement Canada

Weather Services

for the 2010 Vancouver Olympic and Paralympic Winter Games

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for the 2010 Vancouver Olympic and Paralympic Winter Games

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Final Report

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1 Executive Summary

The Vancouver 2010 Olympic and Paralympic Winter Games (hereinafter called “2010 Games”) were held in the Vancouver–Whistler region, from February 12-28 and March 12-21. Games organizers faced a wide variety of weather conditions both prior to and during the Games, nearly all of them challenging to venue preparation and competition. Weather posed a significant risk to the integrity of the competition schedule. By strategically using the weather forecasts provided by the weather team, from scales running from seasonal outlooks to now-casts of an hour or less, organizers were able to take action to ensure that all events were completed successfully.

Planning for the task of providing weather services support to Vancouver 2010 began in 2003 with the collection of weather statistics to support the bid. Once the bid was won, the Vancouver Organizing Committee for the Olympic Games (VANOC) almost immediately approached Environment Canada’s (EC’s) Pacific and Yukon Region (PYR) to furnish a proposal to provide a comprehensive weather service to the Games.

Bid members had the support of the Government of Canada (GoC), as the GoC was planning to provide integrated services, including weather, in support of Vancouver 2010.

There are historical precedents for the significant involvement of national meteorological agencies in the Olympics. Governmental agencies were fully responsible for weather services to Torino in 2006, partially responsible for Salt Lake City in 2002 and fully responsible for Nagano in 1998. EC provided the complete package of weather services for the 1988 Winter Olympics in Calgary, and agreed to provide for 2010 on the basis of the 2010 Games’ significant international and national prominence, and in the interests of public safety and security. VANOC agreed with the concept that weather services strictly provided for their sport and related needs would be fully cost-recovered.

There were two main clients for weather services during the 2010 Games: agencies, in particular federal and provincial governmental agencies that were responsible for ubiquitous needs like policing, security and transportation; and VANOC, responsible for sporting and venues. Much of the effort needed to meet the broad meteorological requirements of the community of agencies responsible for delivering the Games in a safe and efficient manner aided in meeting the overall needs of VANOC.

Weather services support for the 2010 Games consisted of three distinct phases: the pre-Olympic-period planning that began in 2004 and carried on to the end of 2006; a program development and implementation phase that ran from 2006 through to 2009; and the 2010 Games themselves.

Phase I was mainly concerned with the planning of the program to provide services, including developing a clear sense of requirements, obtaining the necessary resources to deliver, installing a number of weather observing systems in the venues and throughout the Olympic area, and initiating the recruitment of team forecasters. Venue forecasting offices were planned for each outdoor venue, including offices at the Whistler Sliding Centre; Whistler Creekside, the home of the alpine events; Whistler Olympic Park's ski jump and a separate office for the Nordic and Biathlon events; and at Cypress Mountain, the home of Freestyle, Snowboard and Ski-cross.

In Phase II the focus was on meeting a variety of forecaster training objectives, initiating a research and development program to operate in tandem with the forecast program, and finalizing the Games observing network.

Phase III was both the apex and the conclusion of the program. Comprehensive, accurate and well-used Games-time weather services were provided to a large number of clients and partners including VANOC, federal and provincial agencies, visitors and the public.

2 Weather Services

The successful achievement of the goals for phases II and III was predicated on the successful completion of phase I. Each phase had particular staff, resource and time requirements, and deliverables. There were some activities, like overall project management, coordination and the operation of the observing network (including data management), common to all phases.

2.1 Phase I – Planning

Work in this phase focused on the planning for the initial implementation of the basic infrastructure, including the scoping of requirements for weather observing, personnel, training, communications, technology, research, resources and inter-agency relationships and interdependencies. Significant effort went into the acquisition of resource commitments from the GoC's Treasury Board and VANOC. Estimates of resource requirements were based on expenses incurred in prior Olympics events, especially the Torino Games of 2006 and the Salt Lake City Games of 2002, as we had learned from consultations with our Salt Lake City 2002 colleagues and Torino Organizing Committee 2006 observer visits. For example, initial specifications from VANOC indicated the need for the weather agency to begin preparing detailed climatological studies of the venues as soon as practicable, and resources to initiate this work (mainly through installing venues observing systems) were obtained in 2004. The program planners at EC also realized that a sufficiently long data set (several years' worth) was required to "train" numerical weather prediction models for venue forecasts, and that many of the forecast locations did not have existing or historical weather observing systems.

As new sources of observational data are, in many respects, the foundation of new forecast programs, work on the installation of a network of Olympic automatic weather stations began in late 2004. Early scoping work was completed for the acquisition of advanced remote-sensing equipment, including Doppler weather radar, a wind profiler, and microwave profiling radiometers. Other sensors, including vertically pointing radar instruments, visibility sensors and surface radiometers, were studied.

As we had learned from prior Games, early forecaster training is fundamental to success, and venue forecasting experience is essential. A program of forecaster on-the-job training began in the Whistler alpine venue in January-March of 2006 and continued each winter season, in each venue, until the Games. To increase the level of specific scientific knowledge and training of forecasters selected to work at the Games, a prototype mountain weather forecasting course was developed. It was initially offered in Boulder, Colorado, at the facilities operated by EC's weather training partner, the Consortium for Meteorological Education and Training (COMET), in March 2006, and refined versions of the course were offered in December 2006 and December 2007, also at COMET.

2.2 Phase II – Development and Training

A key component of phase II work was to develop a close liaison with VANOC, sport federation and International Olympic Committee (IOC) officials, and essential federal and provincial agencies, to fully document and prepare to deliver on their needs and requirements. Specialized forecaster workstation and forecast production technology was developed in conjunction with the Ninjo development group, and, initially, with the Canadian Meteorological Centre's (CMC's) Scribe Development Team. Scribe is the main weather forecast production software used by the Meteorological Service of Canada (MSC). Planning was started with EC's Researche en Prévisions Numerique – Numerical Weather Prediction Research Division (RPN) to conduct a research program in numerical weather prediction techniques (NWP) with the aim of producing applications of immense value to venue forecasting, including the downscaling of some elements of high-resolution NWP, particularly precipitation and wind. Discussions on research and development on behalf of the Olympic weather forecasting program led to a suggestion that was rapidly acted on, i.e., to initiate planning for a nowcasting (i.e., very-short-range [0-6 hours] weather forecasting) research development project to be led by scientists with the Cloud Physics and Severe Weather Research Section of the Science and Technology Branch of EC. This project, which became the Science of Nowcasting Olympic Weather for Vancouver 2010 (SNOW-V10), snowballed into a major project that ultimately provided critical support to the Olympic forecasting effort. In a related area, it was arranged to bring some aspects of a World Meteorological Organization (WMO) ongoing research program, the Observing System Research and Predictability Experiment (THORPEX), to BC during the years before the Games. In the winter of 2008, a THORPEX-sponsored western Pacific predictability experiment was conducted over the tropical eastern Pacific with significant participation by 2010 forecasters operating from the Pacific Storm Prediction Centre (PSPC). It promised to bring new meteorological insights to forecasting the weather of the North American west coast, particularly with respect to the effect of tropical cyclone conversion and its modification of the Rossby wave downstream. This phenomenon can produce high-impact weather events along the North American west coast. Indeed, one event occurred in January 2010—a very warm and persistent rainstorm at Cypress Mountain—that posed a significant risk to the Games by melting much of the snow at the venue. This was mitigated at great cost and with great effort by VANOC. In conjunction with THORPEX, a local socio-economic study was planned that would calculate the benefit to the Games' operations of the forecasts produced during the western Pacific predictability experiment that could be extrapolated to 2010.

In 2005 and 2006, discussions were held on forecaster selections. It was decided to undertake an informal but quasi-competitive process within the MSC to select Olympic team forecasters, with two essential attributes deemed necessary for the team: a widespread in-team ability to communicate in both official languages, and significant support from each “home manager.” Prospective members of the team submitted resumes and letters of interest that were vetted by a committee in PYR. Forecasters were selected from each EC forecast office and affiliated Aviation Defence Services forecast offices within MSC, and from the CMC. Two forecasters were also recruited from the private Weather Network, and three forecasters were recruited from adjacent U.S. National Weather Services offices in Seattle, Washington, and Juneau, Alaska. By 2007, Olympic forecast team recruitment and initial training was completed and on-the-job venue forecasting experiences of approximately three weeks duration per forecaster each year were provided to venue forecasters through the winters of 2007 to 2009 at Whistler, the Callaghan Valley and Cypress Mountain. Venue and PSPC Olympic Support Desk forecasters worked sports events of various grades up to and including World Cup events at each venue during the winters of 2007-08 and 2008-09, gaining experience in the weather at the venues and strengthening ties with sporting officials.

In August 2008, a regularly held American Meteorological Society Conference, the Mountain Meteorology Conference, was hosted by EC at Whistler, BC. Immediately following the conference, a four-day workshop and lab sessions focusing on the meteorology of the 2010 venues were held for venue forecasters by MSC Pacific Region, RPN, and Cloud Physics and Severe Weather Research Section staff.

As forecast technology and infrastructure neared completion, a thorough test of the Weather Service System from end to end was undertaken to ensure its functionality and to modify it to adapt to user needs. These tests were carried out during and after key pre-Olympic training events in 2008 and 2009.

In the spring of each year, a full report of actual weather conditions at each venue and an evaluation of forecasts was produced and tabled on our Olympic Family website, www.weatheroffice.pyr.ec.gc.ca/2010, now defunct. These reports are available from the author in CD format upon request.

2.3 Phase III – Execution and Legacy

The final phase was the weather service support during the Olympic Winter Games held February 12-28 and the Paralympics held March 12-21, followed by some decommissioning work thereafter. It included a fully operational weather forecasting system, including dedicated venue forecast products, end-user targeted products, real-time weather forecasts and observed data delivery to the INFO 2010 (the IOC's Games-time information system) data management system (operated by Atos Origin, the worldwide information technology (IT) partner for the Olympic Games), and the provision of real-time information and professional weather advice to the VANOC, IOC, sporting and team officials at the venues and within the Games' Main Operations Centre. Much of the demand was for daily or more frequent outlook scenarios and probabilistic risk assessments, based on current and forecast weather conditions, to assist officials considering the scheduling or rescheduling of sporting or ceremonial events due to the effect of meteorological influences or events. A main forecasting support and guidance unit, the Pacific Weather Centre Olympic Desk (POD), operated on a 24/7 basis during the Games and Paralympics, co-located with the PSPC. As well as providing guidance and coordination to venue forecast teams, the POD acted as the primary source of meteorological support for Essential Federal Services (EFS) agencies and agencies from other levels of government. Operating concurrently was a daily series of teleconferences for forecasters, hosted by SNOW-V10 scientists, to discuss short-term forecasting issues, including nowcasting, model guidance and radar-based nowcasting tools. Forecasting high-impact weather of the day was usually the topic of discussion and SNOW-V10 scientists brought their expertise to bear on the solution.

2.4 Mission Statement

The overall mission of EC's Olympic weather services project (WSP) was to provide comprehensive, high-quality weather-support services to all participants, officials and spectators of the Olympic and Paralympic Winter Games of 2010 and to agencies acting in support of the Games. The project was intended to provide weather forecasts and warnings, observations of

weather conditions, climate information, and advice on weather effects and outlook scenarios necessary to run successful competitions, as well as to promote the efficient operation of the Games and to assist related agencies in meeting their requirements for meteorological information and forecast support. The key responsibilities of the WSP were to ensure that the technical requirements of the international sport federations and the IOC were met and that the specific weather support needs of other agencies were addressed in full.

2.5 Prior Olympics: Weather Support Models

Weather conditions are possibly the single most important uncontrollable element in the successful operation of the outdoor winter sporting events at the Olympic Games. Accurate weather services for the games have therefore proven essential to the organizers and competitors of past winter Olympics. In Nagano in 1998, the scheduling of many of the snow-sport events would have been severely hampered had it not been for the proven reliability of weather forecasts at all venues and the confidence that the competition juries had developed during two years of experience during the test events. In Salt Lake City, the use of a supplementary network of 29 automatic weather stations deployed at selected locations at the outdoor venues allowed for real-time access to weather conditions and important data for local predictions. Weather forecasts and hourly updates during the events played a critical and essential role in both the competition jury deliberations and the race organizing committee's management of resources, workload assignments and, most importantly, the safety of participants. The 2002 Salt Lake City Games employed a dedicated weather support team of 84 people, including 32 professional meteorologists, 34 volunteer weather observers, eight computer and communications experts, and 10 support staff. These individuals provided a continuous 24-hour-a-day service. Weather services for the 2006 Winter Games in Torino relied on approximately 80 weather specialists, with similar ratios to Salt Lake City. Each outdoor sporting venue had its own dedicated weather forecast support office staffed by meteorologists for every day of the Olympics and Paralympics. Within the 2006 Games area there were 50 automatic weather observing stations, augmented by 10 mobile stations deployed to strategic locations at specific venues. Although the 2010 WSP was broadly modelled on the Torino approach, singularly critical lessons, especially on the fusion of science and operations, were learned from Salt Lake City.

2.6 VANOC-Environment Canada Relationship

The MSC and its parent federal department, EC, are responsible for operating a national weather and climate monitoring and prediction/warning service for the safety of Canadians and the protection of their property. To fulfill this mandate, the MSC operates an integrated weather observing network that includes automatic weather and climate stations, upper-air measuring stations, weather radars, a lightning detection system, and satellite monitoring facilities. Data from these networks are used in numerical weather prediction models and by professional meteorologists to produce forecasts and warnings. The density of the observing networks and the resolution of the models are at a scale designed to meet the national responsibilities. Smaller-scale predictions, such as those required to support events at an “Olympic scale,” are possible but require a higher density of observing stations, local knowledge, and the application of specialized prediction models that are based on local topography and are capable of simulating local effects. For example, in 1976 for the sailing events associated with the Montreal Olympic Games (held at Kingston, Ontario), and again in 1988 for the Calgary Winter Olympic Games, the MSC entered into a contractual agreement with the Olympic organizing committees to augment existing observing networks in the venues and to provide a dedicated team of weather specialists with local knowledge to support the Games.

To serve the needs of 2010, an initial contract with VANOC concerning the installation and maintenance of main-venue weather observing systems was signed in 2005. As discussed in section 2.6, it was realized early in the planning stage that the density of the existing federal network was too low to permit the more local observations of weather necessary to forecast precise conditions at the venues and to fulfill our weather support responsibilities to Games-supporting agencies. Federal funds were obtained to improve and increase the density of observing systems in the Olympic area and to procure other more advanced weather observing systems. Two further contracts with VANOC for remaining weather services through 2010 (2005-2007 and 2008-2010) were developed to cover the full scope of weather services necessary to fulfill the needs of the Olympic Family.

3 Weather Services Project Management and Administration

The 2010 WSP included planning, organizing, coordinating and managing weather support to all activities related to the 2010 Olympic Winter Games. The Project negotiated and managed a contractual agreement on behalf of the GoC for the provision of specific services to the Olympic Committee and for related public safety services provided by the GoC. While the specialized venue-specific weather data and forecasts were produced for the competition venues, additional information was provided for: related events and activities, such as the opening, closing and medal award ceremonies; ground and air transportation routes to the key venues; security and medical emergency requirements; and media coverage.

Weather services to the 2010 Winter Olympic and Paralympic Games were directed, funded and managed through the 2b3d Outcome Project Plan (OPP), under Al Wallace, Director, MSC PYR. Overall planning and delivery was the responsibility of Chris Doyle, Chief, Weather Services, 2010 Winter Olympic and Paralympic Games.

4 Weather Services Infrastructure

The overall concept of weather support to the 2010 Games included: a 24-hour/day central forecast support office located within the PSPC; five dedicated venue-weather service offices, including two at Whistler/Blackcomb (alpine events and sliding centre), two at the Callaghan Valley (Nordic events and Ski Jump), and one at Cypress Mountain (Snowboard, Freestyle and Aerials); a new network of 21 automated surface outdoor-venue weather observing sites reporting local conditions hourly and more frequently (as often as every minute); and 15 new and upgraded off-venue regional observing systems and other specialized weather observing systems for specific events, for a total of more than 60 new weather observing systems for the Games. Other real-time weather data came from a Doppler radar located adjacent to the Sea-to-Sky highway by the entrance to the Callaghan venue, one wind profiler, a microwave profiling radiometer, an augmented upper-air observing program in the region, a 24-member video camera network installed at the venues through the Sea-to-Sky corridor and Vancouver area, and a large suite of more esoteric instruments provided by SNOW-V10 participants.

Specialized high-resolution forecast models and downscaling methods were developed and run at scales to enable local-scale resolution for local venues. The RPN, co-located with the CMC, was the lead agency for this effort.

Information and forecasts generated from this infrastructure were communicated via INFO 2010 to users in a format and timeliness dictated by the Olympic officials, and through other channels as necessary to related support agencies

Staff at the VANOC Main Operations Centre provided personal briefings to the senior management of VANOC operations and, as required, to IOC. The senior forecaster or delegate at the POD provided personal support to Games EFS agencies, including security and transportation. Additional advice was available as required, including support to other EFS agencies, and in particular the Canada Health Agency. Below is a detailed breakdown of observing systems and the forecast infrastructure that made use of the intensive suite of new observations that became available during phases I and II.

4.1 Surface Monitoring

Planning for the surface monitoring network began in 2004. Installation of a network of five main and two supplementary automatic weather stations at the VANOC outdoor venues was completed during the late winter of 2005, as it was recognized that a sufficiently long period of record was required for the generation of Updateable Model Output Statistics (MOS) for these locations, and to gather a reasonable data set for climatology. VANOC supplied the capital for construction and installation, and paid EC an annual fee to maintain and operate these stations.

Based on an assessment of network characteristics, including a suite of observations and observation density used in prior Olympic Games, a preliminary model of a federally funded observing network was developed. After consultations with the 2010 Scientific Steering Committee in the autumn of 2004 and spring of 2005, a final plan was completed and approved in the summer of 2005. Changes and additions were made as Phase II continued, based on input from international sport federation officials, venue managers, Olympic weather forecasters and eventually SNOW V-10 scientists. The network was named the Olympic Autostation Network.

4.1.1 Venue Weather Observing Sites

Weather observations were being obtained from 21 locations within the five VANOC outdoor venues and on the grounds of one indoor venue (Vancouver Olympic and Paralympic Centre). There were three types of systems at the venues: main, augmented supplementary and supplementary. As the venues were completed, additional supplementary weather observations were installed at each site, based on the nature of the sport and its particular requirements.

Each official weather observing system in Canada has a three- or four-letter identification code, and nearly all of the systems installed for the Games have a code name beginning with the letter “V.” The main V series of surface weather observation stations was equipped similarly to Canada’s modernized reference climate network stations, with real-time communications. Supplementary stations, as required, measured need-relevant subsets of the RCS suite.

Main stations carried the full suite of instrumentation required for Games-time forecasting and climatology, and included sensors to measure:

- Wind speed and direction
- Temperature and humidity
- Precipitation
- Snow depth
- Atmospheric pressure
- Snow temperature

Augmented supplementary stations usually measured:

- Wind speed and direction
- Temperature and humidity
- Snow temperature and/or visibility and/or snow depth

Supplementary stations measured wind speed, direction, temperature and humidity.

Whistler Creekside

Station VOA – Whistler Pig Alley (near the top of the men's downhill) (main).
Station VOH – Whistler High Level – Wind and temperature, at the top of the men's downhill (supplementary).
Station VOL – Whistler Mid Level – Near the lower third of the Olympic downhill run between the Whistler Mountain Low Level and Whistler Mountain High Level automatic weather stations. The men's and women's Olympic downhill runs are on either side of this site (augmented supplementary).
Station VOB – Whistler Creekside – Near the base of the downhill (main).
Station VOT – Whistler Creekside Timing Flats (augmented supplementary).

Sliding Centre

Station VOC – At the NAVCAN compound at Nesters (main) – This station was installed several years before construction of the sliding centre began and was meant to serve as a proxy for the venue until track construction was completed.
Station VOI – This automated system was located at the top of the Sliding Center venue, which is on the Blackcomb Mountain side of the Fitzsimmons Creek valley (main).
Station VON – Base of the sliding centre (supplementary).

Whistler Olympic and Paralympic Park

Station VOD – Callaghan Valley main station.
Station VOF Callaghan Valley Biathlon High Level (augmented supplementary).
Station VOK Callaghan Valley Cross Country High Level (augmented supplementary).
Station VOV – Callaghan Valley Low Level (low elevation point of the Nordic and XC courses) (augmented supplementary).
Station VOW – Callaghan Valley ski jump top (supplementary).
Station VOX – Callaghan Valley ski jump bottom (supplementary).
Station VOY – Callaghan Valley Biathlon (supplementary).

Cypress Mountain

Station VOE – Cypress Bowl North (main).
Station VOG – Cypress Bowl South (supplementary).

Station VOZ – Cypress Bowl Freestyle (supplementary).
Station VWG – Cypress Bowl Grandstand (supplementary). This station was installed a few days before the opening ceremonies and was intended to alert Games' and venue officials to high wind conditions at the somewhat exposed and elevated Half Pipe and Snowboard / Ski Cross venue.
Station VWB – Cypress Bowl Snowboard (supplementary).

City Venues

Station VWC – Vancouver Hillcrest (supplementary).

Image: Weather Station VOC – Whistler Nesters

4.1.2 Federal and other Weather Observing Systems

A total of 15 surface weather stations were installed or upgraded at locations around southwestern British Columbia and Vancouver Island. The series of stations beginning with “W” or “Y” were in operation prior to the bid but were upgraded to meet the Games-time needs. The “V” stations were newly installed for the Olympics. These sites were augmented by other observations available in the Olympic area of southwestern BC from a variety of agencies, including NAV Canada (the Canadian air navigation system operator, also known as NAVCAN), the Coast Guard, the BC ministries of Transportation, Environment and Forests, and Metro Vancouver. In many cases, EC upgraded observing sites owned by other agencies, to meet Olympic needs. This benefitted EC not only by permitting access to more data, but helped the project avoid the lengthy and expensive environmental assessment, permitting and leasing processes required to install weather systems in pristine locations.

Federal Sites

Station WGP – Pemberton
Station WPN – Pemberton remote wind
Station VOP – Powell River
Station WSK – Squamish Airport
Station VOJ – Mount Washington
Station VOM – Port Mellon
Station VOU – Qualicum
Station WWA – West Vancouver
Station WSB – Point Atkinson
Station WHC – Vancouver Harbour
Station YVR – Vancouver International Airport
Station WMM – Pitt Meadows
Station VMO – Richmond Operations Centre (EC)
Station WWK – White Rock
Station VOO – North Cowichan

Other Sites

Operated by the BC Forestry Service
Gwyneth Lake
Toba Camp
D'arcy

Operated by the BC Ministry of Highways
Cayoosh Summit
Brandywine (Sea-to-Sky station)
Tantalus (Sea-to-Sky station)
Eagle Ridge (Sea-to-Sky station)

4.1.3 Monitoring Operations and Maintenance

Surface weather monitoring was the responsibility of the MSC PYR Atmospheric Monitoring Division. An agreement with VANOC provided for the ongoing maintenance and operation of the venue weather observing network.

4.2 Advanced Monitoring

Similar to prior Olympic Games, the Olympics benefitted from a variety of weather-sensing technologies. These technologies were originally evaluated in 2005-06 by the 2010 scientific steering committee. Recommendations were finalized in the spring of 2006 and procurement commenced immediately upon receipt of the final recommendations. Initially, the Doppler weather radar was the first item considered and confirmed. Feasibility studies, including deriving a synthetic look from different elevation scans and locations, were required to ensure that it would have utility even in the complex topography of the Whistler area, and were completed by Cloud Physics and Severe Weather Research Section staff. Advanced monitoring acquisition occurred in two phases: that which was funded by and obtained on behalf of the WSP, and, later, that which was obtained for SNOW-V10.

Advanced Monitoring Equipment Obtained on Behalf of WSP:

4.2.1 Doppler Radar

The MSC's National Radar Program (NRP) and EC's Cloud Physics and Severe Weather Research Section studied options for the construction or procurement of a dual polarized Doppler radar in 2007. A local PYR Atmospheric Monitoring Service project manager was named in early 2007. Prior to this point, the WSP had assisted the NRP in obtaining necessary spares and parts required for both the new radar and for addition to the NRP inventory, through a lengthy process of EC Procurement Review Board submissions and sole-source justifications. Following the appointment of local staff into the project manager position, the tempo of the project increased. Dual polarization was considered for the radar at first but was rejected, because the radar model to be used in Whistler could be polarized only with significant engineering, and it was decided that insufficient time remained both t operationalize a conventional radar and to polarize it.

Image: Frank Mirecki (construction supervisor) and his radar

Initial operation of the Sea-to-Sky Doppler weather radar (station name: VVO) took place on the afternoon of February 25, 2009, thanks to the signal processing engineering completed by experts at the site. A variety of radar outputs were developed for a range of users, including operational meteorologists and Olympic Broadcasting Services Vancouver (OBSV). Radar was initially accessible through the Science V10 WMO website, then was provided to operational meteorologists on MSC PYR's weather viewer software, thanks to specialists of the PSPC, and was configured and made available for the special Olympic-weather web page planned for EC's national weather website by PYR MSC staff.

4.2.2 Wind Profiler

Approval was granted by the EC Procurement Review Board for the acquisition of a sole-source 915 MHz wind profiler and Radio Acoustic Sounding System (RASS) in 2006. The contract was awarded to Vaisala Inc., and a Vaisala LAP-3000 Lower Atmosphere Wind Profiler was purchased and installed at EC's weather compound at the Squamish Airport.

A wind profiler is a Doppler radar that provides vertical profiles of horizontal wind speed and direction, and vertical wind velocity up to an altitude of 3 km above ground level. The RASS measures virtual temperature profiles up to 1.5 km above ground level. It operates unattended and provides continuous, real-time atmospheric wind and virtual temperature data.

This unit proved to be very useful from the perspective of Games-time forecasting. In certain flow regimes, it provided a roughly half-hour forewarning of precipitation at the Callaghan Valley and Whistler Creekside. It also provided an indication to forecasters of the vertical elevation of the transition of precipitation from snow to rain (the "bright band") and information on wind gustiness and atmospheric stability.

4.2.3 Microwave Profiling Radiometer

A Radiometrics MP-3000A profiling radiometer was acquired in 2007, and after some testing it was installed at the base of the Whistler Creekside venue in the fall of 2008. Profiling radiometers deliver continuous temperature, humidity and water vapour profiles, and, from certain measurements, cloud ceiling can be inferred. Temperature and humidity profiles have comparable accuracy to co-temporal radiosondes, and far better accuracy than radiosondes with 12-hour latency, although inaccuracies in retrievals can occur in heavier precipitation. The radiometer also provides liquid water profiles essential for accurate precipitation forecasting. EC Cloud Physics and Severe Weather Research Section staff worked on developing a suite of forecast tools and indices for optimal nowcasting of cloud, precipitation and fog formation.

4.2.4 Other Observing Technology and Instruments (SNOW-V10)

As outdoor venues are completed, additional weather element sensors necessary to the conduct of sporting events were installed. These included snow surface temperature sensors and digital web cameras, both inside the venues and outside of them at MSC locations where AC power was available. Other, more esoteric sensors were installed for SNOW-V10 in 2008-2010, and these are described in the SNOW-V10 section (section 9).

4.2.5 Augmented Upper Air Program

Using mobile radiosonde tracking equipment, an upper-air observing program was operated in 2009 during the Olympic period of February 12-28 (the dates of the Olympic Winter Games in 2010) and in 2010 during the Games. During the Olympics (and commencing five days before the opening ceremonies), weather balloons were launched four times per day from the MSC Whistler Nesters site and from the Department of National Defence Base Comox on Vancouver Island, about 100 km upstream (to the west of) Whistler. Radiosonde data was assimilated into weather prediction models, but its best use was to give forecasters information on the state of the local atmosphere in the Whistler area, on a relatively frequent basis. Weather balloons were launched twice per day from Whistler and Comox during the Paralympics.

4.3 Forecast Operations

In a manner similar to the Torino 2006 Games, each outdoor venue had an independent weather office staffed with forecasters who prepared highly detailed local forecasts tailored to the sporting event at the venues. These offices were supported by an Olympic weather support centre co-located with the PSPC, i.e., the POD. It operated on a 24/7 basis for 10 days prior to the start of the Games and then throughout the Olympic and Paralympic periods.

4.3.1 Main Olympic Forecasting Centre (POD)

Operating on a 24/7 basis, the main mission of the POD was to coordinate the synoptic perspective of the forecasters in the venues, to prepare forecasts and meteorological information in support of essential federal and other agencies operating in support of Games-related activities, and to provide briefings to officials of Games-supporting agencies, as required. The lead meteorologist for the venue forecast team generally worked on a day-shift

basis from this location. Six additional meteorologists were members of the POD team and provided 24/7 forecast support and venue guidance during the Games and, in 2009, during test events.

4.3.2 VANOC Weather Manager

Operating on an as-required basis during the Games and test events (every day, generally from 0500 until 2300 during Games days and somewhat shorter hours during the Paralympics), the VANOC Weather Manager worked in the VANOC Main Operations Centre. This position was staffed by the Chief Meteorologist for the 2010 Winter Olympics and an assistant weather manager. The mission of the Weather Manager was to meet the needs of VANOC and the sports organizations for meteorological information, generally through routine and ad hoc briefings, and to provide weather-related information to the VANOC executive as well as IOC and sporting officials as required for planning and decision making. Although this was not a forecasting position per se, daily forecasts for snowmaking were produced by the Weather Manager on behalf of VANOC from October 1, 2009, until early January, when that function was taken over by the POD.

4.3.3 Venue Offices

During the pre-Olympic phase of 2006-2009, practicum forecasting in the venues depended on the availability or construction of at least basic shelters at the venues with access to AC power and the Internet. Forecasters worked in various locations, including trailers in the Callaghan Valley, the technical services building above the Roundhouse at Whistler Blackcomb, and the old day lodge at Cypress Mountain. Ultimately, a fixed space at every venue was secured for the period of the Games. Each outdoor venue office was staffed with three meteorologists. Two worked at any one time during the Games and test events; the third rested, or often took the opportunity to view some of the events or take part in some of the social aspects of the Olympics. A minimum of six forecasters were trained for each venue; this helped ensure adequate staffing during the Olympics and Paralympics by providing a contingency for illness or for withdrawal from the team.

4.3.3.1 Whistler Creekside

During practicum years (2006-2009), Whistler Blackcomb provided office space in the Whistler technical services building located within a few hundred metres of the top of the future men's downhill start location. Tranzeo Limited provided a 1-megabyte/second wireless Internet service for access to weather data from EC. At just over 1800 metres above sea level, this office was the highest-elevation forecast centre in Canada. In 2009, forecasters were able to relocate for the "Paralympic period" to trailers placed in the timing flats area of Creekside for test (now "sport") events. In 2010, forecasters worked exclusively in trailers at timing flats, specifically in the jury trailer.

4.3.3.2 Blackcomb Sliding Centre

Prior to the completion of Sliding Centre office space, forecasters worked in their Whistler-area accommodations, using the Internet connectivity provided by either our leased housing or a hotel room. Once construction at the Sliding Centre was completed, forecasters worked out of the track-control building in 2009 and during the Olympic Games.

4.3.3.3 Callaghan XC and Biathlon

Prior to the completion of facilities in 2008, practicum meteorologists worked in their hotel accommodations and went into the Callaghan Valley on a nearly daily basis to observe the local conditions and attempt connectivity to EC via air cards (an endeavour that was not always successful). For the practicum beginning in 2008, and beyond, space was made available in the biathlon building. At Games time, forecasters worked out of a trailer in the cross-country operational area and would provide in-person briefings in the biathlon jury room, when required.

4.3.3.4 Callaghan Ski Jump

Beginning in the winter of 2007-08, a weather working space was established in the ski jump tower, adjacent to Swiss timing and the jury rooms.

4.3.3.5 Cypress Freestyle

Temporary facilities at the venue were used each winter from 2006-07 through 2008-09, often at the freestyle judges building. Cypress Mountain maintained full private-business resort operations and control of the venue until January of 2010, and thus the establishment of a more-or-less permanent weather space was not possible until that time. During the Games, a weather room was set up in the new day lodge, adjacent to the jury spaces.

4.4 Forecast and Data Contingency Arrangements

Several levels of contingency plans and processes were established for Games time—some technological and some carried out by individuals. The ultimate backup for venues was the physical presence of venue forecasters at the venues, although this short-term contingency would be invoked only in the unlikely event of a full communications failure at any particular venue. Due to shared forecast production technology and templates, forecasts for any venue could be prepared from each venue, and all venue forecasts could be prepared, and successfully disseminated to clients, from the POD.

4.4.1 Client Feeds (Dorval)

Bell Canada was the telecommunications provider to VANOC, and so all weather data between the venues and EC moved through the Bell network. Our contingency in the event of a Bell network failure was to have venue forecasters dial into an EC virtual private network, either through a Vancouver node or an Edmonton node in the event of a simultaneous network failure involving Bell and EC in Vancouver. Data for INFO 2010 was backed up by transmission through separate lines from either 401 Burrard (EC Vancouver) or Dorval, Quebec, into the primary and secondary Atos Origin data hubs at VANOC.

4.4.2 Public Forecast Operations (Edmonton)

Scribe files for venue weather forecasts were installed on operational workstations and servers at EC’s Prairie and Alberta Storm Prediction Centre (PASPC) in Edmonton. The home office of two 2010 team members was the PASPC, with one of these forecasters to work the Olympics and the other the Paralympics. Hence, in the event of a catastrophic telecom failure in British Columbia, where both the Bell Games-time network and the separate EC network failed,

forecasts could be produced by an experienced Edmonton-based forecaster for a short period, until either one or both networks were resurrected, or backup help could arrive from Vancouver.

5 Weather Requirements for VANOC

Weather requirements for sport were developed in consultation with VANOC and the international sport federations. Seeking information and requirements from VANOC venue managers and federation officials is a good strategy, because, in our experience, each group separately did not, initially, fully specify the complete set of needs. Indeed, some requirements emerged in the week prior to the opening ceremonies.

5.1 Sport-Specific Forecasts

A variety of sport-specific forecasts were made available to VANOC, the most detailed of which was a tabular forecast with hourly forecasts of weather elements valid for 24 hours. These were produced twice per day at each outdoor venue and once, for each venue, overnight at the POD.

Concurrently, a sport text forecast was produced that provided a synopsis or narrative of the weather of the day for each venue plus detailed 2-day and more general 2-to-5-day forecasts. Generally the same information was provided to INFO 2010 in an Extensible Markup Language (XML) format where short-term detailed and general 5-day weather forecasts were available for each venue.

5.1.1 Forecast Summary for Main Operations Centre (MOC) Operations

At least twice and sometimes three times per day, a forecast briefing was provided by the VANOC Chief Meteorologist during a VANOC MOC functional area debriefing/teleconference. These were normally scheduled as the first item during the debrief and were one or two minutes in duration, with an opportunity for questions afterwards.

5.1.2 Ad Hoc Briefings to VANOC/IOC Executive Committee

When forecast weather conditions posed a significant risk to sport operations during the Games, the Chief Meteorologist was required to attend a VANOC Executive Committee meeting, and provided the forecast to the committee together with an assessment of the uncertainty in the forecast. This happened on three occasions during the Olympics and twice during the Paralympics. On each occasion, significant alterations to the competition schedule were made for one or several venues, sometimes several days in advance of events and, in the case of the Paralympics, up to six days in advance.

5.2 Medical Forecasts

Medical forecast tables (the Battleboard) were generated three times per day for each venue, Whistler and Vancouver, and were produced automatically from forecaster input into general forecast templates. Medical criteria were developed several years prior to Games time in consultation with VANOC staff physicians. This product helped medical staff rapidly assess at a glance (due to its colour-coded elements) the risk of weather-related injuries to athletes and spectators, and any possible upcoming difficulties with surface or medical evacuation (air) transportation. It was sent to a distribution list via email.

5.3 Snowmaking Forecasts

Early-morning snowmaking at Cypress Mountain, December 8, 2009. Credit: Paul Skelton, Manager, Cypress Mountain Venue Operations, Vancouver Organizing Committee for the 2010 Olympic and Paralympic Winter Games.

Special daily forecasts for snowmaking operations were prepared by the MSC's 2010 Weather Services program from October 30, 2009, to January 2, 2010. These forecasts were used by venue staff at Cypress Mountain, Whistler Olympic Park and the Whistler Creekside alpine skiing venues to plan snowmaking operations strategically, and to maximize snowmaking opportunities when optimal temperatures and humidity for snow production were forecast. Regular Olympic venue forecast operations commenced on January 2, 2010.

Feedback on this product indicated that snowmakers successfully incorporated the forecast information into their planning and operations. Indeed, by optimizing snowmaking based on this forecast product, VANOC's Whistler Creekside alpine and Cypress Mountain's sports operations were able to take advantage of almost every snowmaking window at each elevation of the Whistler area and Cypress Mountain Olympic venues. As a result, almost double the minimum snow base was produced in less time than originally planned.

The forecast took the form of a synopsis or narrative, and included a North American Ensemble Forecast System ensemble meteogram as a point of reference for venue operations staff.

5.4 Torch Relay Forecasts

The Torch Relay (TR) ran from October 30, 2009, until the opening ceremonies on February 12, 2010. Forecasts were provided on a daily basis to on-scene TR officials, almost always by teleconference followed by email. Given that the event covered Canada from coast to coast and into the high Arctic, an extensive amount of coordination with regional EC forecast centres was required. Regional centres provided TR briefings in their geographic area of responsibility, and passed on forecast responsibility to adjacent centres based on the movements of the TR. The main forecast agency, the CMC, provided a graphical, technical forecast product and weather briefing to TR-supporting regional centres on a daily basis as general forecast guidance, with an assessment of the probabilities of severe weather along the route.

6 Weather Requirements for Essential Federal and other Government Services

Weather requirements for essential federal services were developed in consultation with EFS providers. An EFS steering committee, under the auspices of the Canadian Department of Heritage, was established in 2006, with EC as a sitting member. On several occasions, presentations were made to the group on our plans, preparations and weather services

offerings, and feedback was solicited. In the end, the service offerings (weather forecast, data and sources of forecasts and data) satisfied the requirements of our EFS colleagues, because in our planning we had anticipated all of their meteorological needs.

6.1 Briefings to Senior EC and other Government Staff

As part of the operating schedule at the VANOC Main Operations Centre, the Chief Meteorologist provided a weather narrative and a tabular forecast summary every morning to a group of senior EC officials, including the Assistant Deputy Minister of the MSC. This was to keep EC and other levels of government apprised of possible weather effects on the Games time schedule and on the Olympic area. On several occasions, weather briefings were provided to an aide of the Prime Minister.

6.2 Security

Part of the security response to toxic agent weapons involves the modelling of the flow and dispersion of toxics used in a terrorist attack. EC has developed an enhanced capacity to predict the nature of the dispersion of Chemical, Biological, Radiological and Nuclear (CBRN) agents as part of a CBRN Research and Technology Initiative (CRTI). CRTI federal participants included the National Defence Research Establishment, the Office of Critical Infrastructure Protection and Emergency Preparedness, Health Canada, EC, Agriculture and Agri-Food Canada, the Canadian Food Inspection Agency, Fisheries and Oceans Canada, National Research Council Canada, Natural Resources Canada, the Royal Canadian Mounted Police, Public Safety Canada, Atomic Energy of Canada Ltd., the Canada Revenue Agency, the Canadian Nuclear Safety Commission, the Privy Council Office, the Treasury Board Secretariat and the Canadian Security Intelligence Service.

Just prior to and during Games time, the CMC's Environmental Emergency Response Section (EERS) operated a prototype of modelling on an urban scale in Vancouver. This prototype included a Global Environmental Multi-scale Limited Area Model (GEM-LAM) cascade down to a 250-m resolution. The data of this LAM were used to initialize a fluid-dynamic model that simulated the flow through Vancouver at a resolution of approximately 7 m. Various maps were accessible via a website used to display the results. The prototype was run not continuously, but rather on an on-demand and evaluative basis.

A local emergency-response section was established in Vancouver at Games time, comprising lead staff from EC's Emergencies Science and Technology Section. A team of emergency responders was deployed to Vancouver to operate a mobile chemical laboratory and rapid response vehicle for seven weeks, 24 hours per day.

The EC team involved in providing support to the Winter Games was extensive and reflected the cross-departmental support for the security program. EC's team from PYR comprised the Pacific Environmental Science Centre, the regional office of the MSC, the Sustainability Division, the Chief Information Officer Branch, and the Environmental Emergencies Office. Groups outside PYR included the CMC, its Environmental Emergencies Division (Gatineau, Quebec) and the Environmental Emergences offices in the Atlantic, Quebec and Ontario regions.

Within MSC the project lead was the EERS director at CMC.

6.2.1 Security Response Protocol

In the case of an emergency, the EERS would have coordinated efforts with CMC and the POD to provide the best possible forecasts of dispersion and trajectory of toxic agents to on-scene emergency responders, and to assess and identify the agent itself. Two paths were possible, and would likely have been concurrent. In a case where the Vancouver Storm Prediction Centre shift supervisor received the initial notification of an incident, he or she would have informed the shift supervisor at CMC who, in turn, would contact on-call staff of the CMC's EERS. Emergency response staff would run the Canadian Emergency Response Model to predict the expected path and concentration that a toxic plume will take and have over time, and produce output from the more sophisticated models discussed in section 5.1. In the case where notification was received by the local emergency response section, they would have contacted CMC EERS directly and notified the POD to be on standby to provide local weather support information.

Ultimately, simulations of the outcome of terrorist CBRN attacks were modelled and used in planning and contingency scenarios. No CBRN incident occurred during the Games. Nevertheless, one inquiry from the Public Health Agency of Canada regarding sensor alarms at Canada Hockey Place on February 18 was responded to, using wind and temperature data from

the LAM very-high-resolution (1 km) and 250-m resolution model runs. It was determined that nearby fireworks were likely the source of emissions that activated detectors on-site.

6.3 Transportation

General weather forecasts and warnings were produced for the lower mainland and Sea-to-Sky public forecast regions during the Games, as they were in a business-as-usual scenario. Because snow removal and road treatment in BC is the responsibility of municipalities and, in the case of provincial highways, private contactors, these entities generally used private forecasting agencies to develop weather forecast information pertinent to their needs. EC committed through the 2010 weather services project to work with the BC Ministry of Highways, and other ministries with an interest in weather, to ensure that all collected provincial weather data were easily and freely accessible to MSC forecasters. In turn, EC provided the same full and unencumbered access to EC surface weather observations and other environmental data to the Province. On at least one occasion, the BC Ministry of Highways made inquiries regarding a forecast of winter weather conditions on the Sea-to-Sky during the Paralympics. Also, fire weather forecasters working for the BC Ministry of Forests used Olympic Automatic Network weather stations to calculate fire weather indices for the Whistler region during the summers of 2006-2009.

VANOC Transportation, as the operator of a multi-hundred-bus transport system for athletes and spectators at Games time, was an extensive user of the venue forecasts and forecast overview produced by the POD and VANOC MOC forecasters.

6.4 Civil Aviation

Aviation weather services are provided to NAVCAN by EC under contract. Early in the project we contacted NAVCAN to advise them of the considerable demand on their services that would be expected at Games time. Otherwise, the 2010 weather services project supported efforts to provide comprehensive air navigation and aviation weather services to NAVCAN, primarily through the provision of data and in particular a shared network of web cameras along the Sea-to-Sky corridor. Special aviation forecasts for the Games, including Terminal Aerodrome forecasts for Pemberton, Whistler and Squamish, and special Sea-to-Sky corridor route forecasts, were produced by the EC Aviation Forecast Centre West in Edmonton.

7 Weather Services for other Clients

A surprising number of users of weather data for the Games emerged through the project. Universities, in particular, were large users of weather data, especially because the Canadian “Own the Podium” research project depended, to a certain extent, on weather data and records gathered at the venues. One client for a large volume of climatological data and related analyses was the insurance firm that VANOC used to provide event cancellation policies.

7.1 Sport Federations and VANOC-Related Entities

Beginning five years prior to the opening ceremonies, an Olympic Family website was developed as a repository for weather data, analyses, and other meteorological information pertinent to the operations of the Games from the sport and international sport federation perspectives. It was password-protected and accessible only to employees of the MSC and Olympic Family who were provided with the coordinates.

7.2 Media

Services to media ranged from access to surface weather observations to the provision of real-time local weather radar to the delivery of a full suite of weather data, as was done for OBSV. In addition to data and imagery, media were granted generous access to EC staffengaged in developing the weather services project in the years before the Games, as there was considerable media interest in Olympic preparations of all kinds. Section 12 describes the full suite of weather service offerings to media.

8 Forecast Technology Development

The planning philosophy with respect to technology development was to not “reinvent the wheel,” whenever and wherever possible. However, some new technology was necessary to meet the needs of the project after some existing platforms and tools were judged to lack the capability to provide what was required**.**

8.1 Forecaster Workstation Project

It was planned that forecasters, both in the venues and the POD, would use forecast production technology consistent with the technology used in the MSC at large. It was an underlying principle of planning for this project that, whenever possible, technology and general MSC practices would be used by the Olympic forecast team. As a result, the workstation used by the 2010 team was the Ninjo workstation, as is employed by every prediction centre in the MSC (and a number of international [mainly European] national meteorological agencies). Eight workstations were used—one at each outdoor venue forecast office, one in the POD dedicated to Games forecast production, one at the VANOC MOC, and one spare.

8.2 Scribe Development

Consistent with the policy of using MSC technology, it was originally planned to use Scribe to produce all required forecast products for the Games. Scribe is a rules-based expert system for generating weather forecasts from a digital weather element database, and has been used by MSC forecasters for more than a decade.

There were certain modifications to Scribe necessary to produce forecast output to meet the needs of sport events. These included producing hourly point data for the first 24 hours of the forecast period at venues (then every three hours for the subsequent 48 hours), and generating output in XML format.

Unfortunately, after more than one year of development, it became clear that Scribe was not properly configurable to produce the forecast formats and outputs necessary to meet the needs of sport. Scribe was used to produce public venue forecasts for the EC weather website www.weather.gc.ca, but, for sport, a forecast production program (the Q-Device) was developed in-house. Essentially, the Q-device was a spreadsheet that downloaded model data into a

template that forecasters could edit. It was used to produce XML weather forecast data for VANOC's Olympic results and information website, and tabular sports forecasts for venue use.

9 Olympic Weather Research / SNOW-V10

9.1 High Impact Weather (HIW) Research

HIW research, primarily case studies and statistical assessments of the weather at the venues and in the Olympic area and Sea-to-Sky, was conducted by PYR National Laboratory staff under the direction of the Vancouver SPC Science Transfer and Training meteorologist Brad Snyder. Original work by National Laboratory staff included the following:

Ruping Mo et. al: Collision of a Pineapple Express with an Arctic Outbreak over Complex Terrains of British Columbia, Canada – Forecast Challenges and Lessons Learned. Presented at 23rd Conference on Weather Analysis and Forecasting / 19th Conference on Numerical Weather Prediction, Omaha, NE, June 2009.

Ruping Mo et. al: Projecting Winter-Spring Climate in Vancouver from Antecedent ENSO and PDO Signals – Applications to the 2010 Winter Olympics and Paralympics. Presented at the Canadian Meteorological and Oceanographic Society Annual Conference, Winnipeg, MB, June 2010.

9.2 Olympic Team Area and Venue Weather Research

Venue forecaster on-the-job training (practicums) started in the winter of 2006-07. As team members and venue forecasters developed familiarity with their area of responsibility and venue-specific significant weather issues, a number of studies were concluded by team forecasters both for the benefit of team forecasters and for the Olympic Family. These included the following:

Chris Doyle and David Jones. Short Term Weather Patterns of Interest to 2010 Venue Managers. Environment Canada, revised September 2009.

Carl Dierking. Winds in the Callaghan Valley. U.S. National Weather Service, Juneau AK, 2009.

Andrew Teakles. Strong outflow wind events affect the Callaghan Valley Olympic venues. Canadian Meteorological and Oceanographic Society Congress, 2009.

Andrè Giguère et. al. Operational Evaluation of GEM-LAM 2.5 km and 1.0 km Models in view of the Vancouver 2010 Games. Canadian Meteorological and Oceanographic Society Congress, 2009.

9.3 Model Development

The Canadian GEM versions at the global 30-km and regional 15-km resolution were the driving models for semi- and fully-automated forecast production. GEM 2.5 km and a special Olympic GEM 1.0 km were used by the forecasters as guidance and as inputs into the various nowcasting systems developed by SNOW-V10. The 1.0 km was also the database tool that the public could use to generate fully automated point forecasts in the Olympic area from the EC Olympic Weather web page. Model development for 2010 was extensive and complex, involving multiple nested grids of increasingly higher resolution down to 100 m, with validity periods of hours to weeks. RPN is responsible for the research and development of the modelling component of the NWP System for the CMC and the Regional Meteorological Centres of the MSC.

9.3.1 Forecaster Tools

Numerous forecaster tools, based on GEM 2.5 and GEM 1.0, were produced for Olympic forecasters. These included prognostic tephigram, time series, cross-section, and others that were suggested by operational staff. RPN's forecaster tool development was aided by CMC's A and P division staff, both locally in Vancouver and in Dorval, Quebec.

9.3.2 NWP Development

Certain improvements to GEM 2.5, including explicit physics, were implemented prior to 2009 when a "frozen" operational version of the model was maintained for the use of forecasters.

9.3.3 Downscaling

Very-high-resolution (100 m) downscaling of certain model-weather-element outputs was made available for venues and other locations for 2010 forecast purposes. RPN led research and development efforts for the production of downscaled forecast predictions.

9.3.4 Regional Ensemble Prediction System (REPS)

Ensemble forecasting is a numerical prediction method that is used to attempt to generate a spectrum of the possible future states of a dynamical system, like weather. Ensemble members were derived from the limited-area version of the Canadian GEM model at 33-km horizontal resolution over North America. It was operationalized for the Vancouver 2010 Olympic and Paralympic Winter Games area, and produced ensemble products such as EPS-grams (meteograms) and probability charts for Olympic venues and related sites.

9.3.5 Nowcasting Project (SNOW-V10)

The nowcasting project used a variety of data sources, data integration and management techniques, and forecast production methodologies, to improve very-short-range (0-6–hour) forecasts of ambient weather in the Olympic area. This was a large national and international research demonstration project sanctioned by the WMO's World Weather Research Programme (WWRP), a first for the Olympic Winter Games. It involved significant collaboration between researchers and meteorologists, both in the development of scientific objectives in the formative stage and in operational outputs at Games time. Nowcasting observations were used in routine nowcast and short-range forecast production in the Olympic area during the Games.

9.3.6 Snow Surface Temperature (SST) Forecasting

EC planned to produce forecasts of SST for all venues. These fields were produced using the downscaling approaches noted in 9.3.3. Prior to the development of the forecast, the WSP supported research and development on snow surface temperatures in the Whistler Olympic Park venue through a contract with a graduate student from the University of Utah. The university had pioneered, for the Salt Lake City 2002 Games, the production of a course-length forecast of SST based on the development of a climatology that was based on the thermal mapping of the course in various ambient meteorological conditions. We used the student's work, in the form of a written research report, to provide background information and training on the topic for venue meteorologists. Although snow surface temperature forecasts were available at Games time for all venues, they were not part of the suite of weather elements required by VANOC.

9.4 Climate Research and Reporting

The Olympic area was rather sparse in terms of data sites and long-term records of weather and climate observations. This prompted the early installation of venue weather systems wherever possible. Some long-term data sets, particularly for Whistler-Blackcomb, were available and were of use, but were inadequate for the variety of data ultimately required by the project and its clients.

9.4.1 Routine Climate Reporting

Observations at VANOC and other Olympic Autostation Network (OAN) sites have been archived, both nationally and in the PSPC regional archive. This allowed routine access to climate data as is currently available on the Environment Canada weather website's "Historical Weather" link, and enabled climate research.

9.4.1.1 Routine Internal Reports

Internal climate reports, generally dealing (in great detail) with the specific weather record at the outdoor venues and the potential weather effects on the competition schedule, were prepared on behalf of VANOC for each of the Olympic periods of 2005 through 2009 and for Games time. These and some derivatives were used for forecaster education and training, and were a resource for a variety of users, including insurance companies, VANOC transportation, scientific researchers and the media.

9.4.1.2 Routine IOC and International Sport Federation Requirements

IOC and sport federation requirements for routine climate data at the venues were prepared for these clients as part of regular reporting to VANOC. Some of these data were also included in information handbooks and packages for team officials and athletes.

9.4.1.3 Special Studies

To rule out (in anticipation of related questions) the effect of climate change on the Games, a 30-year climatology of alpine-elevation temperatures from the U.S. National Weather Service radiosonde data base from Quileute, Washington, was produced in 2006. This study indicated

an average temperature increase through the 1975-2005 period, at about 3000 metres above sea level, of about 0.4°C per decade, allowing us to reasonably discount the effects of climate change on an event planned for five years into the future.

VANOC's insurers required an in-depth assessment of historical snowpack conditions for venue insurance, and were provided with one in 2009. Studies were also conducted on the solar climatology of the venues, snow water-equivalent ratios, and statistical assessments of observed venue weather parameters for data quality control and instrument location planning. The City of Vancouver received a probabilistic climatology of severe weather risk at Games time, and venue officials at Cypress Mountain requested and received an analysis of the probability of winds above certain thresholds for the Cypress grandstand. In addition, we completed several studies in 2009 in an effort to determine the El-Niño Southern Oscillation (ENSO) phase during the Olympic Period.

9.5 WWRP and THORPEX

The Observing System Research and Predictability Experiment (THORPEX) is an international research initiative that is part of an overall coordinating programme, the WMO's WWRP. THORPEX is intended to accelerate improvements in the accuracy of 1-to-14-day weather forecasts for the benefit of society and the economy. It builds upon ongoing advances within the basic-research and operational-forecasting communities, and will make progress by enhancing international collaboration between these communities and with users of forecast products. In cooperation with other THORPEX agencies and scientists, weather experiments were planned to coincide with the pre-Games period and the Winter Olympic Games, in areas ranging from data assimilation to socio-economic impacts.

9.5.1 T-PARC 2008-09

From early summer 2008 until late March 2009, an international THORPEX experiment, the Pacific-Asian Regional Campaign (PARC), was conducted. PARC was designed to be conducted in two phases, i.e., summer and winter. The main intent of PARC is to improve our understanding of the earlier stages of typhoons from genesis to recurvature, because an improved knowledge of the tropical cyclone to extratropical transition (ET) is essential to understanding and predicting the downstream impacts over North America. PARC is therefore

unique, with a dual emphasis on the shorter-range dynamics and forecast problems of one region and the resulting medium-range dynamics and forecast problems of a downstream region (the west coast of North America). To put this into perspective, historical downstream events since 2005 have included two record floods (one in BC and the other in Oregon/Washington), and California forest fires. All of these events were major disasters on the west coast and were relatively poorly predicted in the medium range. Accurate short-range predictions (< 3 days) of aspects of the life cycle of a tropical cyclone near the east Asian coast will mean an increased likelihood of accurate medium-range predictions (3-10 day) of floods, widespread severe weather outbreaks and damaging extratropical cyclones downstream over North America.

From the 2010 perspective, increasing our understanding of ET was a critical activity. Heavy rains in January of 2005, resulting from a synergy of tropical energy and the Rossby wave, obliterated much of the local snowpack below 1800 m. It did not recover to near-normal levels for the remainder of the winter. In retrospect, this was an event with some predictability in the scale of a week or more. Advance notice of similar events in the weeks prior to the 2010 Olympics was useful for planning and mitigation. In fact, good forecasts of particularly wet and mild episodes made in mid-January 2010 helped inform VANOC's strategies for preserving the Cypress Mountain venue.

Canadian participation in the summer phase of PARC has so far been limited to model data assimilation and some data assimilation experiments.

9.5.2 Winter-Phase TPARC and 2010 Winter Storms Reconnaissance Project

PARC 2008-09 continued beyond the ET phase into the late winter of 2008-09, and involved increasing the density of weather observations on the east Asian mainland and over the western and central North Pacific. EC contributed funding to supply Roshydromet (the Russian National Hydrometeorological Service) with 600 extra radiosondes and related supplies. National Oceanic and Atmospheric Administration (NOAA) G-IV aircraft and U.S. Air Force winter storms reconnaissance C-130 aircraft conducted near-daily weather reconnaissance and targeted "dropsonde" flights over Japanese and adjacent and north-central Pacific waters in the January-March period of 2009. Targeting missions were planned by a group of meteorologists, including Olympic team forecasters at the PSPC. They used an advanced data-targeting system through project access to real-time European Centre for Medium-Range Weather Forecasts (ECMWF)

forecast products for the North Pacific. Normally, ECMWF products are available only to European consortium members (not Canada).

Although invited to participate in a similar process during the winter of 2009-10, POD participation was minimal due to workload. Nevertheless, researchers and NOAA meteorologists kept the Olympic period in mind during the winter storms reconnaissance project, and several missions were undertaken to help improve forecasts for the Games.

9.5.3 Research and Forecast Demonstration Projects

Research and forecast demonstration projects (RDP/FDP) are an essential part of the WWRP and are intended to confirm, by objective measures, the enhanced prediction capabilities gained through improved understanding and/or the utilization of enabling technologies. FDP proposals are expected to outline the aim and method of demonstrating improved prediction capability and indicate the extent to which a number of qualifying attributes are present. The following attributes describe the objectives of FDPs within the overall WWRP:

- to address forecasts of weather of international applicability, with emphasis on high-impact weather;
- to articulate and meet clear evaluation protocols;
- to meet the expectation of success and level of support available;
- to produce a clear advance on current local or global operational practices;
- to produce forecasts that can be provided in real-time and forecast information that can be communicated for user utilization and subsequent impact evaluation.

RDPs do not generally produce operational, real-time outputs or products. Although outputs were not guaranteed by SNOW-V10, many were in fact provided, and therefore the nature of the project was a synthesis of FDP and RDP.

Olympic Games have become inspirations for WWRP-sanctioned forecast demonstration projects, beginning with Sydney (2000) and followed by Athens (2004), Beijing (2008) and Vancouver (2010). Many FDP technologies were deployed for the winter of 2009 to allow the development of nowcast and improved forecasting approaches, and to give forecasters experience with some of the systems involved.

10 Forecaster Training and Development

The outdoor venues of the 2010 Winter Olympic and Paralympic Games were located in complex mountainous terrain, which made forecasting very difficult, for several reasons. First, the location and relief of mountains has a significant effect on how and where storms and other meteorological phenomena develop and evolve, making weather highly localized. Second, there are few observations taken in mountainous areas, because good observing sites are difficult to access. Third, existing stations tend to be representative of only a small area due to the complexity of the terrain. For these and other reasons and based on the experiences of prior Games, it was ascertained that specialized training and direct venue forecasting experiences were necessary precursors to the success of the forecasting project for 2010.

10.1 Venue On-the-Job-Training (the Practicum)

Based on our discussions with planners from prior Olympics, and our understanding that the microclimates and micro-meteorology of the venues were not well understood, it was decided very early in the planning phase to enable forecasters destined to work at the venues to obtain some in situ forecasting experience prior to Games time, and to bolster their level of knowledge and understanding of complex-terrain wintertime forecasting. Training was envisaged as three-phased: theoretical classroom training; workshops and simulators to increase both theoretical and tacit (“experiential”) knowledge; and practical, in situ forecasting periods at venues (the practicums).

From January 2006 until the end of March 2007, EC meteorologists destined for work during the Games began on-the-job training at Whistler, based initially on three-week rotations in the venues. Their office, courtesy of Intrawest and VANOC, was located in the technical services building at 1860-metres elevation, just above the Whistler Village gondola. From that location, forecasters produced forecasts for Whistler, and from the village, forecasters produced

forecasts for the Callaghan Valley and the Sliding Centre. On occasion, meteorologists would snowmobile and snowshoe into the Callaghan venue to do some on-site weather familiarization. By the winter of 2007-08, indoor office spaces at the venues were located for meteorologists at each venue, including Cypress Mountain.

Besides gaining an understanding of weather patterns at venues, forecasters were able during their practicum periods to interact with venue and sporting officials and to develop a deeper understanding of the weather-related aspects of each venue's sporting events. This proved to be an invaluable dimension of the practicum experience, because, by Games time, forecasters were clearly experts in their field and had earned the confidence of the venue and sporting officials they had worked with in the preceding years.

10.2 Mountain Weather Course

Building upon a cooperative arrangement between the MSC and COMET, a residence course on mountain weather was developed in 2005. This inaugural one-week course on mountain meteorology was held in the COMET classroom from March 20-24, 2006. The objectives of this course were primarily twofold: to provide operational forecasters with exposure to current research and theory from experts in the field of mountain meteorology, and to provide training for forecasters involved in the 2010 Winter Olympics. The course was also offered in December 2006 and December 2007.

10.3 Conferences and Workshops

Conferences and workshops pertinent to Olympic weather services and training were identified on an annual basis and assessed for suitability.

Other training forums for Olympic forecasting staff included the following:

- 12th Conference on Mountain Meteorology, August 28-September 1, 2006, Santa Fe, New Mexico (attended with two Olympics presentations made).
- 13th Cyclone Workshop, Asilomar Conference Center, October 22-27, 2006, Monterey, California (attended by two Olympics meteorologists).
- The Pacific Northwest Weather Workshop, March 2-3, 2007, Seattle, Washington (attended with presentation made).

- 22nd Conference on Weather Analysis and Forecasting / 18th Conference on Numerical Weather Prediction, June 25-29, 2007, Park City, Utah (attended by two meteorologists).
- Canadian Oceanographic and Meteorological Society Annual Congress, May 28-June 1, 2007, St. John's, Newfoundland (attended by several team meteorologists).
- The May 2008 Canadian Meteorological and Oceanographic Society (CMOS) Congress in Kelowna, British Columbia, with three Olympic weather papers in two sessions.
- The January 2008 American Meteorological Society (AMS) annual meeting in New Orleans, Louisiana. Several papers on Olympic weather preparations were given in different conferences.
- Whistler, in July of 2008, hosted the AMS Conference on Mountain Meteorology, with seven Olympics-related presentations, followed by a four-day AMS/COMET/MSC–sponsored mountain weather workshop, attended by the majority of Olympic team forecasters.
- A special Olympic session was held at the January 2009 AMS annual meeting in Phoenix, Arizona, with nine presentations in three conferences (one special Olympics session in the 25th Conference on International Interactive Information and Processing Systems (IIPS) for Meteorology, Oceanography, and Hydrology featured five presentations).
- A four-poster session was offered at the 2009 CMOS Congress in Halifax, Nova Scotia.
- In 2010, two papers and three posters were presented on various Olympic topics at the May CMOS Congress in Ottawa.
- A special Olympics session featuring eight presentations was made at the AMS 14th Conference on Mountain Meteorology, August-September 2010, Lake Tahoe, California.

11 Telecommunications and Weather Data

There were two main communications and data streams for 2010: those that served internal clients (EC forecasters) and those that served external clients (VANOC and the public).

11.1 Internal EC Telecommunications

No specialized communications methods, equipment or data management protocols were used in Games-related internal communications. Extensive use was made of WebEx for team briefings.

11.1.1 Routine Weather Data

Routine weather data (observations, imagery, radar reflectivity and velocities, etc.) were made available through existing EC data transmission networks, and made accessible through forecaster workstation technology.

11.1.1.1 Codecon Modifications and 15-minute Data Sets

EC used decoding software (Codecon) to transform surface weather observations into various formats that can be used by our variety of users. In most cases, weather stations are polled hourly and weather observations are processed in accordance with WMO standards for weather observations. A few modifications to Codecon were required to meet the needs of VANOC, SNOW-V10 and the team forecasters. These included the following:

- 15-minute rather than hourly observations
- Special 1-minute observations (for the use of SNOW-V10)
- A parameter measuring the short-term variability of the wind
- A parameter measuring the instantaneous maximum wind in a 15-minute interval
- A data element containing snow depth

The process by which these necessary Codecon modifications were made was complex and time-consuming. Special software had to be written to repair some data, and care was required to ensure that the standard climatological data set was not contaminated by observations recorded under the “Olympic rules.”

11.1.2 Olympic Weather Wiki

Information for the benefit of some EC users of 2010 weather services and the forecast team was made available through an internal (to EC) Wiki page. Observations, analytical tools and meteorological data from area surface and other observations were accessible through the Department's intranet. In addition to real-time weather information, data, research, forecaster blog submissions and publications pertinent to the 2010 weather project were be published on the site.

11.1.3 SNOW-V10 Website

Data, observations and inter-model comparison data were published on an internal SNOW-V10 website accessible to V10 study members and forecast team members.

Researchers and forecasters were able to access real-time one-minute observations from the surface observing network, a variety of radar nowcasting tools, meteograms that would overlay various resolutions of model output on top of real-time observations, and a wealth of other data.

11.2 Data for Games Clients

Atos Origin is the IT firm that has a contract with the IOC to provide turnkey IT systems for Olympic Games through 2020. It has, as its primary responsibility, IT consulting, systems integration, operations management, information security and software applications development for the Olympic Games. One system that is integral to this is the Information Diffusion System (IDS), which relays results and athlete information to the Olympic Family, the media and TV viewers.

11.2.1.1 Weather Information through INFO 2010

At the heart of the IOC IDS was INFO 2010, an intranet that was available to accredited media and the many thousands of members of the Olympic Family. It featured 50 000 pages of information in English and French. Weather information from EC observing and forecast systems was provided to Atos Origin in XML format. Atos Origin has predefined methodologies for meteorological information display and appearance. So, the ultimate responsibility for EC was to provide weather forecast and observation data in an acceptable format. Data and

forecasts were prepared at venues, converted to the required XML with the “Q-Device” (see below), transmitted to the data centre at CMC in Montreal, and retransmitted to Atos Origin on a direct line from CMC to Vancouver. A backup router and data line were activated at Games time for contingency purposes.

11.2.1.2 Q-Device

Scribe is a Canadian forecast production tool that allows meteorologists to make adjustments to merge model forecast data with current observations, and to alter elements where error is perceived, within an editable weather elements matrix. This matrix is then automatically converted into a variety of weather forecast products.

It was originally intended that Scribe would create all weather products for the Games. However, extensive testing in 2007 and 2008 indicated that it could not be successfully modified to generate properly formatted XML output as required by Atos Origin for INFO 2010. Hence, the Q-Device was developed for this purpose. It has the following attributes:

- Is a web-based interface with an editable spreadsheet of forecast weather elements with a 1-hour time interval for the first 30 hours and three hourly time-steps for Hour 33 to Day 7
- Imports high-resolution (GEM 1.0 km) model data as an initial guess with an option to load the 2.5-km, 15-km regional and global model data sets
- Generates products for INFO 2010, venue operations (sports tabular forecast), and VANOC Medical
- Meets current Atos XML specifications

Data and forecasts were prepared at venues on the Q-Device, converted to the required XML, transmitted to EC’s data centre at CMC in Montreal, and retransmitted to Atos on a direct line from CMC to Vancouver. A backup router and data line were activated at Games time for contingency purposes.

11.2.1.3 Olympic Broadcasting Services Vancouver (OBSV)

OBSV was the Olympic broadcaster in Vancouver. EC prepared satellite, weather radar, and current conditions data for OBSV. Whistler radar and satellite imagery was prepared with high-definition (HD) resolution.

11.2.1.4 Olympic Family Website

Very early in the project, EC developed a password-protected website for the benefit of forecasters and Olympic Family, where real-time Olympic weather data, weather studies, and annual Games-time climatological reports could be posted and accessed. Each station's real-time and historical data could be accessed at a click, and lines were provided to existing EC satellite and radar products.

11.3 Data for the Public

As is common in recent Olympics, EC developed a specialized web page for Olympic weather within its main weather website.

11.3.1 Weatheroffice Public Olympic Weather Web Page

Produced in English and French, the main Weatheroffice public web page provided access to simple graphical and detailed text forecasts for all Olympic venues and for locations in the Olympic area, as well as climatological information and real-time satellite/radar imagery.

11.3.1.1 Street-Level Forecasts (SLFs)

This clickable graphical interface produced meteograms of a number of forecast weather variables for any location within the SLF domain, with a 1-hour temporal resolution, valid for 24 hours. It was driven by output from the 1-km resolution Olympic GEM weather model. This prototype service was discontinued after the Games.

11.3.1.2 Media Web

EC ran a password-protected site for media at Games time, permitting access to weather observations and forecasts, plus a special, daily, 3-4–minute streaming media “weather of the day” video which provided a news-like visual presentation of weather in the Olympic area, focusing on high-impact weather and effects on the public. Nearly all of these briefings were also placed on YouTube for public access and were designed to be used both pre- and post-Olympics. For example, the February 10, 2010 Vancouver 2010 Daily Weather Briefing can be viewed at http://www.youtube.com/watch?v=hE3srRa1fyk&feature=channel.

11.3.1.3 EC YouTube

EC Communications produced a number of YouTube videos, providing the public with access to the considerable background information on the weather of the Olympic area.

Weather During the Olympic Period:

http://www.youtube.com/watch?v=GkiVDBtdplo

2010 Weather Services:

http://www.youtube.com/watch?v=P7YCc6pZelY

Weather FAQ - **Whistler Temperature Inversion**:
http://www.youtube.com/watch?v=t1pJnwaLZRo&feature=related

Weather FAQ - **Harvey’s Cloud**:
http://www.youtube.com/watch?v=rAMZLuEFs2o&feature=channel

Weather FAQ - **Major Snowstorms on the South Coast of British Columbia**:
http://www.youtube.com/watch?v=bax5UCGAPcw&feature=related

12 Decommissioning and Legacy

Since funding was obtained from Treasury Board on the basis of weather services to the Olympics, legacy capital installations are relatively few. It was not intended that the substantial upgrades to the observing system installed and operated for the Games would survive beyond the Olympics. Nevertheless, the door was left open to shared-cost and fully-cost-recovered agreements to maintain a number of systems, both within the venues and outside. Negotiations on a number of such agreements have been concluded.

12.1 Legacy Agreements for VANOC Surface Weather Observing Instruments

On behalf of VANOC, EC operated seven semi-permanent platform-type (not portable) weather stations in the outdoor venues. With one exception, VANOC retained no interest in these instruments following the conclusion of the Paralympics. The ownership of the four stations installed at the Whistler Blackcomb resort was transferred to the resort operator after the Games. Legacy agreements to operate two weather stations will be concluded with the Whistler Legacies Society (the entity responsible for the maintenance and use of post-Games venues in the Whistler area). The main station at Whistler Olympic Park and at the top of the Sliding Centre will continue to operate indefinitely, and data will be available on EC's public weather website. Of the two platforms at Cypress, one (inside the venue) was disposed of privately by VANOC. The other has been dismantled by EC.

In addition, an instrument located in the NAVCAN compound at Nesters, in Whistler, has been retained and is being operated by EC following NAVCAN's grant to EC of a permanent lease-hold.

12.2 Legacy and Decommissioning of Federal Observing Instruments

One surface weather installation at Mount Washington was fully decommissioned in the summer of 2010. Maintaining year-round operations for this site would be prohibitively expensive due to its relative remoteness and high elevation. Other sites (Port Mellon, Sechelt, Powell River, Qualicum and North Cowichan) continue to operate, and licence and operating agreements have been negotiated.

The Whistler radar was decommissioned on August 31, 2010. As the municipality agreed to take ownership of the compound and structure, the only remaining work was to remove the radome and mechanical and electrical components of the radar. The radome was transferred to the Department of National Defence and the remaining components were redeployed into the national program. The tower is enjoying a new life as a zip-line platform in Whistler.

The profiling radiometer has been deployed to EC's Science and Technology Branch, where it will be used in a number of planned experiments during the next few years.

The Squamish wind profiler will remain on-site and will operate indefinitely.

12.3 Legacy of Training and Experience

A rich human legacy of experience in the forecasting of winter weather conditions in the alpine area of southwestern BC, and in complex terrain, is just one of the long-term benefits of the MSC's participation in the Games. Other areas have benefited greatly from participation in PARC 2008 and the SNOW-V10 period in 2009-10, including NWP modelling and model outputs, forecaster training (from the establishment of a complex-terrain forecasting module based on the Mountain Weather Course), and the meteorological research and development community. Members of the public and the media have benefited from experimental services offerings.

12.4 Legacy of Science and Forecast Innovation

From a very early stage, the 2010 Olympic Winter Games were seen by EC as an opportunity to leverage investments in Olympic weather forecasting in order to improve the national weather prediction program through research and development. Two major research and development directions emerged: the first was to improve numerical weather prediction for the Games, and the second was to improve the science and technology of nowcasting.

12.4.1 Model Development

Venue forecasts are essentially point forecasts (i.e., forecasts predicting weather at a specific point in time and place), although the venues are not precisely points. Outdoor venues are small geographically but have significant elevation changes within. Hence, it was understood that higher-resolution models would be necessary to accurately reflect real weather conditions at the venues, and that some model outputs would be required that would provide information salient to sports operations—not necessarily the kind of weather data routinely produced for the benefit of the public. A plan was therefore developed to significantly increase the vertical and horizontal resolution of the NWP suite available for the Games, and to develop some very-high-resolution forecasts using computationally efficient downscaling methods. These model innovations have to a certain extent already been integrated into the national prediction program, and have formed the basis of NWP of Games-time operations for the Pan Am Games taking place in Toronto in the summer of 2015.

12.4.2 Legacy of SNOW V-10

The main focus of SNOW-V10 was to improve our ability to produce nowcasts of high-impact winter weather over complex terrain in association with the 2010 Olympic and Paralympic Winter Games. The enhanced observing network developed for the Olympics was augmented by special research equipment. Similarly, research numerical forecast models, based on operational models, were developed for the Olympic area. The nowcasts produced during the Olympics have been evaluated for their accuracy in real time, and their usefulness to users. A special issue of the *Journal of Pure and Applied Geophysics* published in December 2012 highlighted, through 17 peer-reviewed articles, Games-time weather services including scientific innovations, performance statistics and utility. As part of the project, articles have been and will be written describing the activities and results, and training workshops were conducted to transfer relevant knowledge to the venue forecast teams and will be provided to other participant national meteorological agencies. Workshops and training were provided in 2010, 2011 and 2012 to Roshydromet, the Russian national weather service. It is responsible for weather services to the 2014 Olympic Winter Games to be held in Sochi, Russia.

12.5 Valuation Study

The THORPEX Societal and Economic Research and Applications (SERA) group promotes four themes concerning forecast utility:

1. predicting hazardous weather impacts and communicating uncertainty;
2. user-relevant verification;
3. the use and economic value of forecasts in decision making; and
4. developing decision-support systems and applications.

All were relevant to greater or lesser extents during the Games; what THORPEX T-PARC provided was an opportunity to not only begin the generation of metrics that would allow the calculation of value to the end user (in this case, venue operators and the sport department of VANOC), but also to calculate the value of the extra weather observations taken during T-PARC that augmented the data set normally assimilated into each NWP cycle. As it turns out, this is a complex and ambitious endeavour, and preliminary results are not expected until 2012. At that point we expect to have developed a calculus of the economic value to the Olympics of weather forecasts.

During the T-PARC experiments of 2008-09 and NOAA winter storm reconnaissance mission of 2009-10, POD forecasters were given the opportunity to participate in targeting mission planning. This involved the use of advanced targeting software and models developed by the ECMWF.

12.6 Services Legacy

EC operated an innovative and ambitious program of service offerings to Canadians and media at Games time, including the Olympics Weatheroffice web page, the SLF prototype, and a foray into social media with YouTube briefing materials.

13 Communications and Media

The 2010 Olympic and Paralympic Winter Games benefitted from a significant investment by the GoC, of which weather services was a nominally small but highly “visible” component. Games planners should be aware of the degree of coordination that will be required between staff in the local venue area and with the departmental executive. On several occasions the Minister of the Environment made highly public references to the weather services program, and its importance to the smooth operation of the Olympic Games. Local and Headquarters communications staff managed several ministerial press conferences, to announce such news as the operation of our new weather radar in Whistler and, later, the launch of the EC Olympics Weatheroffice website.

13.1 Information for Stakeholders and Media

In anticipation of significant demand for information, EC Communications built a portfolio of reference materials and FAQs in 2008 and 2009. Fact sheets were prepared on the effect of El Niño, EC’s investments in weather science and technology, the training and development of forecasters, and sustainability. As well, the unit began development of in-house video materials sharing the same topics. In anticipation of repeat questions from media, Communications worked with the MSC to develop media lines well before the Games. This allowed us to respond almost immediately to media requests on the 17 most popular or likely topics. Adding to this advantage was having special authority to manage media requests in the Olympic region (rather than Ottawa) during Games time. This, along with having our spokespeople already present in

BC, meant fewer delays in arranging and delivering media interviews. Where other departments could not respond to requests within a 24- or 48-hour time period, EC spokespeople were responding to weather services media questions often within the hour.

13.1.1 Pre-Games

In general, media interest was sporadic in the 2005-2008 period. Occasionally, stories were printed by local and international media, generally regarding EC's preparations for weather services during the Games and about the weather expected at Games time. Early on, we devised a policy regarding responding to media inquiries. In general, if questions from media pertained to weather effects on sporting events, we referred these to VANOC Communications. Inquiries regarding our preparations or general weather conditions for the area were dealt with by EC staff (a number of whom were designated as official spokespeople), or delegated experts in the case of inquiries on specialized topics like el Niño or other climate phenomena.
Media interest increased in July/August 2008 when EC hosted an AMS Conference on Mountain Meteorology and a venue forecaster workshop, both in Whistler. After a short lull, national and international media inquiries began to steadily rise in the early fall of 2009 after forecasts of a significant el Niño were produced by the U.S. Climate Prediction Centre and corroborated by EC's seasonal forecasts. Significant projects, such as a Discovery Channel episode on EC's preparations for forecasting the weather of the 2010 Winter Games (part of a special series "Science and the Games") and requests for field interviews with forecast team members, were managed by EC Communications in a "gatekeeper" role. Communications staff assigned as "gatekeepers" assessed each request for its potential benefit to EC, and prioritized their response on that basis.

Media questions to EC regarding the weather effects on the field of play/sport were directed to VANOC Communications, whereas questions regarding general weather conditions in the Olympic area, venue forecasts or venue climatology were dealt with by EC spokespeople.

13.2 Games Time

The protocol that EC developed regarding spokespeople and topics worked relatively well. Designated MSC spokespersons, the EC executive in charge of the Weather Services Project, and the VANOC Chief Meteorologist engaged in dozens of media interviews, especially during the month prior to Games time, with multiple international print, television, radio and Internet media outlets. Generally, VANOC sports officials responded directly to questions regarding the effect of weather on the fields of play; the meteorologists confined themselves to discussing the forecast and current conditions. Weather conditions were less than ideal in January 2010, with significant venue remediation and restoration required at Cypress Mountain. On a number of occasions just prior to the beginning of the Games and during the first week, reporters asked venue meteorologists, during briefings with team coaches and captains, to speculate on the effect of weather on the competition schedule. Our meteorologists were trained to direct these inquires to sport officials at the venue, or to the Chief Meteorologist, who would route the media to VANOC Communications.

13.3 Communications Lessons Learned

As we were warned by our Salt Lake City predecessors, media interest, infrequent at first, ramped up exponentially in the six months prior to the Opening Ceremonies. The experience of EC Communications can be summarized as follows:

What was Accomplished?

- It is estimated that EC's weather-related messages reached approximately 400 million people around the world.
- EC's priorities for 2009-10 were reflected in the communications tools and tactics employed for the 2010 Winter Games.
- EC was a leading organization inside the GoC and among external partners.

What Worked

- Leveraging the Games to build partnerships and create communications opportunities that aren't normally available to EC.
- Leveraging our weather services role to create new media opportunities in order to promote the Department.

- Developing content for a variety of platforms to ensure our messages were available to the widest possible audience.
- Implementing a regional approach to media relations during Games time, including the development of continuously updated media lines and a spokesperson book.
- Streamlining approvals to expedite project timelines.

What Didn't Work

- The EC 2010 Working Group was poorly attended and was discontinued when proven unnecessary.
- Building our online presence around canada2010.gc.ca and not weatheroffice.gc.ca.

Communications Lessons Learned

- The best time to communicate about departmental priorities and accomplishments is before the event, particularly the weeks immediately before its start, in order to gain maximum exposure.
- While it is fruitful to cultivate a relationship with the organization responsible for coordinating the GoC's umbrella communications approach, important aspects of EC's communications strategy should not rely on this other organization.
- Consult extensively when drafting a communications plan, to ensure all aspects of the Department are represented, and then synthesize that information into focused, simple objectives that can be transparently carried out.
- Identify the approvals required at the outset.
- Look beyond ministerial announcements and create as many opportunities to promote the Department as possible.
- Weather services will play an integral role in any major outdoor event in Canada. Use this to help build a close relationship with the lead organization responsible for the event, and leverage that relationship into opportunities for the Department.

In the winter of 2009, the IOC identified weather as the biggest risk to the 2010 Winter Games. As it turned out, given the effects of a well-forecast El Niño, the weather (particularly the lack of snow on Cypress Mountain) was the main news story at the start of Games.

13.4 Media Interest by the Numbers

EC maximized public awareness of its weather forecasting expertise in several ways. Anticipating the weather story as early as 2008, Communications partnered with the regional MSC Client Services group to develop a series of Weather FAQ videos. These videos answered frequently asked questions about prominent local weather phenomena, and profiled our contributions to Games weather services. They were distributed to media at the launch of EC's dedicated 2010 Games weather website, weatheroffice.gc.ca/2010 (January 28), and to patrons at the Geological Survey of Canada Bookstore. The videos were placed on EC's YouTube page, with links to the videos created for ec.gc.ca and canada2010.gc.ca. VANOC asked for the videos to be played on screens inside each Games venue. Total audience reach for these activities was estimated at between 3000 and 900 000.[1]

Another way that EC maximized public awareness of its weather forecasting expertise was by adopting a special approach to media relations during Games time. Starting in 2008, Communications provided advice to MSC on its development of a "single point" of media access for weather information during Games time. This approach eventually evolved into a management system that saw Communications, MSC's Weather Preparedness Meteorologists, and PSPC staff working together to expedite responses to fact-based weather inquiries.

As a result of this organization and collaboration, EC managed more than 100 media requests on weather topics during Games time. The total reach of this coverage was greater than 161 000 000[2] people worldwide. Anecdotal evidence also suggests that this unique approach to Games-time media relations was recognized by various media attending the 2010 Winter Games. Departmental employees handling calls from media outlets were informed by some media that EC's media relations approach was considered impressive.

EC also made two ministerial announcements in relation to our weather forecasting role, which helped demonstrate our expertise in this area. On March 27, 2009, the Minister announced that the final piece of weather monitoring equipment for the Games, a Doppler radar, had been installed, and that EC was officially ready for the Games. More than 20 members of the Vancouver media attended this event. On January 28, 2010, the Minister announced the launch of weatheroffice.gc.ca/2010, a "one-stop shop" for public information about weather pertaining

[1] Note: MSC's confirmed YouTube traffic was 3000; VANOC's indoor venue attendance was 900 000. VANOC could not confirm at which venue and on what days the videos were played.
[2] Source: This figure only includes known newspaper and magazine circulations, television audience figures and website traffic. **Actual reach was likely 400-500 million people**.

to Games venues. Once again, more than 20 media attended. Both of these announcements took place inside EC offices at 401 Burrard in Vancouver, and featured photo opportunities within the PSPC.

Challenges

Weatheroffice.gc.ca is one of the most visited websites in Canada, and was identified early as a significant tool that EC could use to promote its weather services role for the 2010 Winter Games. Weatheroffice.gc.ca/2010 was a popular site, but could have been better used as a communications tool. Although there were constraints to the communications placement and messaging within the web templates, better planning of the web content at the beginning could have addressed these issues.

EC Communications supported the development of the weatheroffice.gc.ca/2010 website. This site was designed to become the public's "one-stop-shop" for weather information about the Games, including historical weather data, current weather conditions for the outdoor venues, and links to other sites detailing EC's 2010 Winter Games role. The site was live from September 2009 until March 2010, and generated more than 1.3 million page views.

A second challenge was the timing of the launch to promote the website. Weatheroffice.gc.ca/2010 went live in September 2009 and generated a media inquiry on its first day of public availability. However, promotional efforts were delayed until after an official announcement took place. Scheduling such an event was difficult. Given the scheduling challenges, much of the outreach and awareness-building that had been planned and envisioned for the fall of 2009 and winter of 2010 could not be accomplished until the announcement was made on January 28, 2010. With only two weeks remaining prior to the Games, the window of opportunity to promote the site was not only significantly limited, but also one that required EC to compete in an exceptionally crowded marketplace of entities pursuing Games-related coverage and exposure.

13.5 SNOW-V10 and Media

SNOW-V10 received significant international media coverage of its meteorological research at the 2010 Olympic Games, including coverage in Britain and the U.S.—such as an article in the *Wall Street Journal*, a story in *Popular Mechanics*, and an online article on physorg.com. In addition, an interview was provided to the *New York Times* and a radio station in Hamilton, Ontario. The most extensive coverage of SNOW-V10 was on the Canadian Discovery Channel, where a nine-minute episode of *Daily Planet* was broadcast on February 5, featuring EC Senior Cloud Physics Research Scientist George Isaac. The original broadcast reached an audience of 300 000 viewers in Canada.

14 Financial Notes

EC provided multi-year support to the WSP for the 2010 Winter Olympic Games, through an $8.4-million GoC commitment. Support for the MSC started in 2004-05 and continued through 2010-11. Funding approval was tied to the safety and security aspects of the Games. Multi-year resources were targeted to the installation and operation of weather monitoring systems, research to improve predictability and develop forecast tools, provision of service, and the provision of forecasts and warnings for the public and federal/provincial agencies.

15 Lessons Learned, Recommendations and Legacy

Nearly six years of WSP development invariably allowed for a number of blind alleys and errors that we generally rectified before the Opening Ceremonies, although not, at times, having first suffered probably avoidable delays and setbacks. Having gone through the process, the 2010 WSP management team offers the following suggestions for future Games' weather service planners:

15.1 Accommodations and Logistics

Since forecaster training for the Games began in the winter of 2005-06 and continued every winter prior to 2010, venue forecaster accommodation and, at times, technician's accommodation (such as for test events), was required at or near the venues. Accommodation at Games time for federal employees used a centralized approach, with all accommodations arranged and reserved by the Royal Canadian Mounted Police. However, since MSC

forecasters needed to be practicing in venues well before the arrival of the rest of the GoC, EC needed to obtain much of its accommodations through private seasonal leases with Whistler-area homeowners, which we maintained for several years prior to the Games and during the Games (although at significantly higher prices during the Games than the practicum periods). We recommend this approach for the weather services team, as it offers the benefit of security of tenure and helps the team's management avoid dealing with the considerable uncertainty of place and location that results from having to depend on another agency to satisfy needs. Forecasters work very long hours at Games time and they need quiet and accessible accommodation, close to their working venues. It is also very helpful to have high-speed Internet access in their accommodations, so they can self-brief before going into work and can respond to telephone requests off-hours.

Technicians can be more remotely located than the forecasters, as they are likely to be more mobile (with their own vehicles). However, team management must ensure that technical staff are granted easy access to venues through the early procurement of a few vehicle access and parking passes, and that proper accreditation is prepared for technicians. The number of accredited technical staff can be kept to a relatively small number as, at Games time, they would be required only in the event of an observing system failure. We obtained technician access through a number of "second-part passes," but these were awkward and, at each venue, technical staff developed informal agreements with venue managers to permit easier accessibility.

15.2 Planning and Management Support

Weather services planning for 2010 began at the conclusion of the Olympic bid. The structure of the team was very flattened, with the Chief Meteorologist in the role of developing an integrated plan for weather services, and negotiating with other managers in other areas of EC for the services and staff necessary to deliver on the plan. The executive in charge of the project generally had an information-gathering role in the initial stages, which transformed into an oversight and senior management reporting role in the few years prior to the Games. Since the WSP was designed to meet the needs both of VANOC and of the federal agencies that provided services at Games time, there were a considerable number of cross-cutting issues that required coordination. For example, the design of the Olympic weather observing network needed to take into account not only meeting the requirement for specific weather data at the venues, as

required by the various international sport federations, but also had to be designed to permit better analyses of current weather patterns over the entire Olympic area as an aid to the quality of the overall forecasting program. It became clear early on that the central coordination role of the Chief Meteorologist was the most significant and important dimension of the job.

There were a large number of key relationships that were made, facilitated and/or maintained by the Chief Meteorologist. These included, on the government and partners side, the following:

- SNOW V-10
- EC Chief Information Officer Branch (CIOB)
- EC MSC Atmospheric Monitoring Division (in PYR and PNR)
- EC Communications
- EC senior managers
- Team forecasters
- CMC Operations
- CMC Environmental Emergency Response
- The Essential Federal Services Committee (government-wide)
- Local researchers and developers
- The 2010 internal and external weather website developers
- EC MSC Services
- Procurement Review Board
- Public Works and Government Services Canada
- The U.S. National Weather Service
- The Weather Network
- The Pacific Storm Prediction Centre
- EC Legal (contracts and intellectual property).

At VANOC, the Chief Meteorologist developed and maintained relationships with the following entities:

- Sport Department
- Medical Department
- Transport Department

- IT Department
- Atos Origin
- International sport federations
- Sport Production
- Venue Management and Operations
- Official Observers
- Legal Services

Communications were coordinated through the Chief Meteorologist in order to simplify the flow of information and to make connections only where necessary. In some cases, initial connections consisted simply of introductions, and letting the two or more parties follow up to complete their task. Other connections required significant participation, direction and, at times, intervention. The main reason for this structure, however, was that VANOC Sport Services insisted that the Chief Meteorologist be the sole point of contact for all meteorological issues. This provided “one-stop shopping” for the Olympic Games Organizing Committee, and simplified their planning and sourcing of resources and meteorological support.

As workload increased, the Chief Meteorologist developed dozens of connections and productive relationships (ultimately there were more than 240 individuals in EC working on the project). It would have been useful to have a full-time dedicated administrative assistant as early as three full years before the Opening Ceremonies. By early 2009, as the urgent need for administrative support became obvious, much of that role was taken on by the administrative support staff of the Regional Director.

15.3 IT Contracting and Atos Origin

Atos Origin’s weather data requirements were met by preparing relatively simple in-house software to translate forecast and observation templates into a version of XML that met the format requirements of INFO 2010. Originally it was planned that the conversion of EC data formats into appropriate XML could be completed automatically using the national forecast program’s Scribe database and some built-in XML output functionality that was part of Scribe’s capabilities. Despite considerable investment in time and effort, it was determined by 2008 that Scribe was not capable of producing weather data that could be successfully ingested by INFO. This was a significant setback, as Scribe was intended, consistent with its design, to be the

basis of all forecast production at Games time. To fill the gap, the Q-Device was built, tested and deployed by December 2009. Although the Q-Device worked as intended, it added a few layers of complexity to forecast production. Firstly, forecasters need to become familiar with the operations of the Q-Device in the year prior to the Games, and although this was adequate, given more time, some additional development would likely have been achieved on the basis of forecaster input and evaluation. The Q-Device was somewhat awkward to edit, and this issue could not be rectified in time for the Opening Ceremonies. We recommend that early in their planning period, the Sochi weather team examine the specifications for weather data and forecasts available from Atos Origin and prepare their software solution well in advance. Ideally, all forecasts—for INFO, sport and the public—can be based on a single forecast and observation database, as was our original intention.

15.4 Weather Observations

A number of weather observation innovations were introduced at Games time. These include a higher-than-usual observation reporting period (every 15 minutes for the main network and 1 minute for the SNOW-V10 systems). New data sets were introduced: some to meet the needs of the international sport federations (snow surface temperature) and some to improve forecast quality (15-minute speed and directional variability of the wind, and 15-minute instantaneous peak wind). In addition, a comprehensive network of webcams, both at the venues and along the Sea-to-Sky corridor, was installed prior to the Games. These observing-system innovations proved to be exceptionally useful to the venue meteorologists and ultimately the clients.

Because our approach to weather observation was, with few exceptions, full automation, we could not derive a satisfactory solution to develop a sky condition observation for INFO, as it requires. Sky conditions are measured and classified by human observers. The available automatic equipment generally provides observed data along a line and not with the 360-degree three-dimensional perspective provided by a trained observer. To compensate for this, venue forecasters produced observed sky condition data every hour while at the venues, and manually entered the data into the Q-Device. During shutdown hours, forecasters at the POD provided venue sky condition observations to INFO by evaluating webcam, satellite and other data sets at and over each venue, and then creating a synthetic observation. For the purposes of INFO this worked satisfactorily.

15.5 Legacy of Science

Weather services for the Games represent a considerable investment in money and human resources. As part of the original planning philosophy, it was intended that EC would leverage investments made in advancing the state-of-the-art in weather forecasting for the eventual benefit of the entire national forecasting program. This has come to immediate fruition in a number of areas. Firstly, 1-km resolution NWP guidance for public forecast areas is now routinely available in the Pacific region, although not yet across the country. This is a significant advance from the 2.5-km guidance available prior to the Games and represents a rate of progress some 3-5 years ahead of the schedule of model innovations planned prior to the Olympics. The nationally available 2.5-km variant of the GEM will be extensively modified in the near future based on lessons learned from the Games-time prototypes, and eventually national use of the 1.0-km model will be expanded, depending on computational resources.

For the time being, SNOW-V10 research continues, although its website (with a large number of forecaster tools), is now offline. Accessibility to high-resolution models, SNOW-V10 nowcasting tools and the additional wind profiler and Whistler radar observations has created a wealth of data on local conditions and led to the discovery of explanations for weather phenomena never previously observed or perceived in models, such as the “Cypress Chinook.” This occurs when a series of large-scale events create an easterly flow over the North Shore Mountains, and can lead to rapid snowpack depletion through melt and wind-driven sublimation. It can also create damaging down-slope winds in the southern portion of the Sea-to-Sky corridor, a phenomenon for which, until our new tools were available, we did not have a satisfactory physical explanation. “Blocked flows,” where wind is diverted by topography in situations with precipitation, were for the first time clearly visible on experimental Doppler radar wind and reflectivity imagery. These situations in the past have led to significant snowstorms that were under-forecast or not forecast at all; the SNOW-V10 technology has greatly improved our likelihood of detecting these phenomena and improving the forecast result.

15.6 Forecaster Experience and the Introduction of New Technologies

Perhaps the most significant feedback from forecasters was not about their access to new sets of data and forecaster tools, but about the personal gratification and satisfaction they derived by working closely with venue managers as well as sport and international sport federation officials

on day-to-day weather forecasts that could and did affect the competition schedule. The new technologies significantly improved their personal confidence in the forecasts they prepared, and they were able to communicate those forecasts and the uncertainty therein in a manner that enabled venue officials to make decisive and timely decisions. Having SNOW-V10 and model experts on hand at the POD also contributed significantly to the success of forecasts, especially during periods where particular radar or model expertise was required to help clarify some forecaster uncertainty.

15.7 Probabilistic Forecasts and Client Utility

In general, weather forecasts contain an element of uncertainty, and these are communicated using different methods. In Canada, the most overt measure of uncertainty is in the probability of precipitation (POP) part of a public forecast, usually expressed as a percentage. The POP is meant to provide information on the likelihood of precipitation in the venue or public forecast area during the period of the forecast. This simple sort of uncertainty statement is, however, not reflective of the much more sophisticated probability data prepared for the Games in 2010. We developed regional ensemble models at high resolution that produced forecast uncertainty information explicitly. However, these Games did not generally benefit from the ensemble approach. There is a controversy in the meteorological and social communications literature on how to communicate uncertainty data in weather forecasts, and we did not resolve this issue for the 2010 Games.

One area where uncertainty information was significantly communicated was in the snowmaking forecasts prepared for the mountain venues prior to the Games. As discussed in section 5.3, both an ensemble forecast graphic and a narrative to discuss its contents were provided to venues and other users on a daily basis between November 2009 and January 2010. Anecdotally, this was used by venue managers to decide on snowmaking locations, elevations and workforce deployments, sometimes days in advance depending on the degree of confidence expressed in the narrative and discernible from the graphic. Although complex compared to POP, clients seemed to grasp the essentials of these forecasts and put them to very good use. For example, not a single opportunity to make snow at Cypress was missed in the months that the forecasts were produced, although there were a few occasions when snowmaking was unsuccessful when it was attempted during periods of borderline forecast conditions.

Several very significant multiple-day adjustments were made to the competition schedule during the Olympics and especially during the Paralympics. These were based on long term (3-7 day) forecasts and derived principally with the help of the North American Ensemble Forecast System.

Sochi 2014 and Pyeongchang 2018 should investigate opportunities to communicate a larger fraction of weather forecast information in probabilistic forms. A good place to start evaluating the concept may be http://www.meted.ucar.edu/nwp/prob_v_determ. This is a probabilistic forecasting educational module, prepared by our training partner for the Games, COMET.

15.8 Services and Communications Legacy

EC's initial steps into social media proved successful and demonstrated the utility of the Internet for disseminating useful information to the public and media. Other approaches involving a broader social-media marketing approach should be assessed for 2014. The Weatheroffice Olympic web pages and SLF prototype were well received, but would have benefited from a much earlier introduction—at least one year before the Opening Ceremonies rather than the two months as occurred.

16 Summary

Successful weather services for the Vancouver 2010 Games relied, in the final analysis, on an all-of-MSC (indeed much of EC) effort. Meteorological Operations, Monitoring, Science, Services, IT, Administrative and Communications staff at all levels participated in the Games; 240 in total throughout the development of the program. The goodwill we received and relied on in Vancouver from all parts of the organization made it possible for us to be proud of our efforts when the last medal was awarded and the athletes went home.

Standing, foreground: Trevor Smith, Lead Forecaster for the Olympic Weather Team, at the Montreal, 2009, Olympic Weather Workshop.
Chris Doyle, Environment Canada, Vancouver, November 2012.

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