1. Introduction

The 2002 Winter Olympic and Paralympic Games will be held in the vicinity of Salt Lake City, Utah, during February-March 2002. Approximately 3,500 athletes will compete in 15 sports that will take place at 5 outdoor and 5 indoor venues. A weather support system has been developed to provide weather information to the Salt Lake Olympic Committee (SLOC) staff managing the operation of the Games, athletes, sports officials, public safety and security officials, spectators, and the interested public around the world. Weather support is required beginning several days prior to Opening Ceremonies on 8 February through Closing Ceremonies on 24 February and also for the Paralympics from 7-16 March.

Planning for the weather support system began in 1995, shortly after selection of Salt Lake City (SLC) by the International Olympic Committee (IOC) as the site for the 2002 Games. Early planning for this weather support system was done largely by a few individuals at the University of Utah and the National Weather Service Salt Lake City Weather Forecast Office (NWS SLC WFO). Further development of the system has involved many people at the SLOC, SLC WFO, NWS Western Region Scientific Services Division, the NOAA Cooperative Institute for Regional Prediction (CIRP) in the Department of Meteorology at the University of Utah, and a private sector forecasting group associated with KSL, the local NBC affiliate. Specialized forecast responsibilities involve additional groups, including: U.S. Forest Service Utah Avalanche Center (back country safety); Hill Air Force Base (aviation); NorthWest Weathernet (winter road maintenance), and the Defense Threat Reduction Agency and collaborating federal agencies (security).

Indoor and outdoor venues for the 2002 Winter Olympic and Paralympic Games span a broad area of northern Utah (Fig. 1). Indoor venues are concentrated in the Salt Lake Valley, but one venue is located in Ogden to the north and another is located in Provo to the south. This metropolitan corridor, which spans a distance of 110 km to the west of the Wasatch Mountains, is referred to as the Wasatch Front. The 5 outdoor venues lie on the eastern flanks of the Wasatch Mountains. As a result of the large number of spectators coming to the Winter Olympics, some spectators will travel from accommodations located up to 100 km away from the venues. For example, on the first day of competition (February 9), many spectators will travel across the Wasatch Mountains on Interstate 80 to watch mogul skiiing at Deer Valley (16,000 people), ski jumping at the Utah Olympic Park (22,000), and cross-country skiiing at Soldier Hollow (20,000) (Loomis 2001).

A broad range of weather support activities will be needed to meet the diverse requirements of the Winter Games. These will include area-wide forecasts and warnings, road corridor forecasts for the mountain roads from the Wasatch Front to the venues east of the Wasatch Mountains, highly detailed venue forecasts for the five outdoor venues, and official observations of weather conditions during sports events at the venues,.

2. Weather Effects on Games Activities

Significant weather events have affected all past winter Olympics. For example, weather-related delays for alpine ski events occurred during the 1984 Sarajevo, 1992 Albertville, and 1998 Nagano Games while warm temperatures and high winds affected operations during the 1988 Calgary Games. Weather effects possible during the 2002 Winter Games include delays in sporting events by adverse weather such as heavy snowfall, strong wind, low visibility due to fog or snow, and avalanches. Snow and ice-covered surface streets and highways along the Wasatch Front and over the Wasatch Mountains could delay access to the venues by athletes and spectators. Aviation transportation for security and medical emergency operations may involve flying helicopters in hazardous winter weather over mountainous terrain. The safety, health and comfort of spectators who may be outdoors for several hours could be affected by heavy snow or rain, extreme wind chills, or snow & ice on roads and paths. An extended stable period with cold air trapped in the valleys along the Wasatch Front could lead to poor air quality that may result in respiratory problems for athletes and spectators. Still other activities affected by weather include: snowmaking; construction, safety, and durability of temporary outdoor facilities and displays; outdoor ceremonies and celebrations at the University of Utah (opening and closing), downtown SLC (medal awards), and cities throughout northern Utah; operation of parking lots at venues and transportation hubs; (REPLACE FOLLOWING WITH TEXT AT HOME) and security operations related to accidental or terrorist releases of toxic gases or biological agents.

Weather during the 2002 Winter Olympics and Paralympics will be influenced by a number of factors. Colder and snowier winters in northern Utah usually occur when the jet stream is displaced to the south of its usual position while warmer and drier conditions prevail when the jet is displaced to the north. During the past 2 Olympic periods (February 2000 and 2001), the jet was weak and frequently split into air streams to the north and south of Utah. The net result was wetter than normal conditions during both months while temperatures were above normal in 2000 and near normal in 2001.

Along the Wasatch Front from Ogden to Provo, early morning temperatures are typically below freezing (around -4˚ C in February and -1˚ C in March). Afternoon temperatures are usually above 4˚ C in February and above 10˚ C in March. Typically, about 5 snow storms occur along the Wasatch Front during February with average snowfall during the month around 28 cm. Snow storms are equally likely during the Paralympic Games during March. Stable episodes coupled with heavy fog in the valleys are common, with roughly an 8% chance that fog develops on any particular day in February near the SLC airport.

The mountain valleys to the east of the Wasatch Mountains are at higher elevation than the Wasatch Front. Temperatures tend to be significantly lower in the morning due to cold air pooling in the valleys while afternoon temperatures are similar to those along the Wasatch Front. The number of storms with precipitation falling as snow rather than rain is slightly higher in the mountain valleys than the number along the Wasatch Front with snowfall amounts varying from 28 cm in the Ogden Valley (near the Snowbasin venue) to 41 cm in the Heber Valley (near the Soldier Hollow venue) during February.

The outdoor venues are all located within 50 km of downtown Salt Lake City, Utah. These venues vary in elevation from 2826 m at the top of the Men's Downhill course at Snowbasin to 1670 m at the Cross Country/Biathlon course at Soldier Hollow. There are tremendous variations in the weather and climate at these venues. Snowbasin, for example, averages 193 cm of snowfall during February at the top of the mountain while Soldier Hollow averages only 48 cm during the same period. Winds may exceed 30 m s^{-1} over the ridge tops at the same time that the winds remain less than 5 ms^{-1} at the base of the mountain.

During the Olympic and Paralympic period, winter storms can usher in a variety of hazardous conditions: low temperatures, heavy snowfall, and high winds are common. Rare arctic air outbreaks have led to record cold temperatures below -18˚ C in the Salt Lake Valley during February. Record snowfall in a 24 hour interval during the Olympic period varies from over 25 cm along the Wasatch Front to over 100 cm in the mountains. Downslope wind storms with winds in excess of 30 m s^{-1} occasionally develop immediately to the west of the Wasatch Range (within a few km of the base of the mountains). For example, the climatological frequency of winds in excess of 20 m

s^{-1} of 8% indicates that strong winds could affect Opening and Closing Ceremonies on the University of Utah campus and strong winds are also possible, for example, at the transportation hub near the mouth of Weber Canyon along Interstate 84.

While every winter during the past 20 years provides examples of adverse conditions that could affect the hosting of the Olympic and Paralympic Games, the conditions observed during February 1986 provide one potentially extreme scenario:

- 12-13 February. A very wet storm along the Wasatch Front and Wasatch Mountains with 60-90 cm of snow in the Mountains. Many naturally released avalanches occurred. On Interstate 80 (the major pass across the Wasatch Mountains), 60 cm of snow fell with blizzard conditions reported.
- 14-17 February. Warm temperatures with heavy rains in the valleys and over the lower slopes of the Wasatch Mountains. Heavy snow at higher elevations led to avalanches and mud slides: a couple of homes were destroyed in the central Wasatch Mountains. A 55 ms^{-1} wind gust was recorded at the Park City Ski Resort (site of Olympic slalom events). The Snowbasin Ski Resort (site of downhill and super giant slalom Olympic events) was closed.
- 18 February. A record high minimum temperature of 11^{o}C for February was observed at the SLC airport. Snowmaking during the period 14-18 February at the Soldier Hollow cross-country venue would have been impossible.
- 19 February. A squall line traversed northern Utah with 54 m s^{-1} gust at the Park City Ski Resort. Morgan County was declared a disaster area as a result of flooding (considerable traffic to the Snowbasin Ski Resort will travel through Morgan County).

3. Organization, Functions, and Staffing

Weather support for the Olympics has been led largely by the host country's primary weather agency. For example, weather support for the 1996 Centennial Olympic Games held in Atlanta, Georgia was led by the NWS (McLaughlin and Rothfusz 1996; Rothfusz et al. 1998) while weather support for the Sydney 2000 Olympic and Paralympic Games was provided by the Australian Bureau of Meteorology. As a result of the complex weather-related needs of the Olympics, many other groups have often become involved in weather support activities; 25 federal and state agencies and commercial firms and 15 components of the National Oceanographic and Atmospheric Administration assisted the NWS Southern Region for the Atlanta Games (McLaughlin and Rothfusz 1996; Powell and Rinard 1998; Snook et al. 1998; Johnson et al. 2000). Olympics have often served as opportunities to showcase new technology and test new forecast techniques (Snook et al. 1998; Keenan et al. 2000).

The weather delays during the 1998 Nagano Winter Olympic Games were greatly mitigated by long-term meteorological planning and development of a sophisticated and detailed forecast system. Meteorological services prior to and during the games were provided by the Japan Weather Association, the largest private weather organization in Japan, under contract from the Nagano Area Organizing Committee.

The organization of the weather support group for the 2002 Winter Games is unique in that it is composed of three core components from the public, private and academic sectors. The public sector is represented by the NWS, the private sector by the KSL venue forecast team, and the academic sector by CIRP. One of our most pressing concerns in using this three-component structure is to facilitate close coordination among the three groups to ensure that consistent forecasts are issued to the athletes, officials, spectators, and SLOC staff managing the Games. In addition, coordination is also required with other agencies and firms that provide specialized forecasts for other Olympic activities, e.g., avalanche, winter road maintenance, aviation, and security.

The NWS team will issue area-wide forecasts, advisories, and warnings, and also major road corridor forecasts. Area-wide forecasts and the road corridor forecasts will be issued twice daily, in the early morning and the late afternoon. Warnings and updated forecasts will be issued at any time that weather conditions warrant.

The KSL venue forecast team will provide detailed forecasts required for the operations of the venues and sporting events for each hour on the first day and three-hourly forecasts for the following two days. These detailed forecasts are made for extremely small areas and specific points at the outdoor venues such as ski jumps, downhill courses, mogul and acrobatic ski runs, bobsleigh and luge tracks, and snow board facilities- all at specific times for each sports event at each venue.

The CIRP team will provide online weather data from over 250 sites in northern Utah and high resolution analyses and forecasts run operationally during the Games. In addition, over 20 undergraduate and graduate student have volunteered, along with other local residents, to assist the venue forecasters and provide supplemental weather observations required for the events. Official manual weather observations are started one hour before each outdoor event begins and continue at 15 minute intervals throughout the event.

The staff during the planning stages consisted of 52 professional meteorologists and other professionals, most of them not full-time. During the Games, the operational staff will be about 25 professionals and 20+ weather aides. The Weather Operations Center (WOC) at the NWS SLC WFO will be open 24 hours every day of the Games, and will be staffed by forecasters from both the NWS and the KSL team. The KSL venue forecasters will be on site from about 4:00 am to

6:00 pm on every event day at their venue. The weather aides will be at outdoor venues from about 6:00 am to 6:00 pm on every event day. The University of Utah team will monitor and troubleshoot the delivery of weather information to SLOC and the forecast team as needed. More detailed discussions of the roles to be played by each of the three core groups follow in sections 4-6.

4. NWS Team Role

The NWS role in support of the 2002 Winter Games is to provide public forecasts and warnings to protect lives and property, in accord with its mission. The NWS forecast team was assembled and practice forecasts were produced during a period of Olympic test events during February-March 2002. The NWS will issue forecasts and warnings at least twice daily, with updates as needed by changing weather conditions. The WOC for the 2002 Winter Games has been established at the NWS SLC WFO. The WOC will be staffed by NWS forecasters who will augment the normal WFO staff and by members of the KSL team. Six NWS forecasters from locations other than SLC were selected; four forecasters will be assigned to the WOC at any given time during the Games. Both NWS and KSL forecasters will be supplied with full data sets and display capabilities on two Advanced Weather Information and Processing Systems (AWIPS) workstations in the WOC.

The additional NWS forecasters will be responsible for coordinating warnings and forecasts with the KSL forecasters as well as forecasters at the Aviation Security Operations Center (ASOC) at Hill Air Force Base. In addition to this key coordination role, the NWS forecasters will issue a Hazardous Winter Weather Potential product twice each day that focuses on each of the primary transportation corridors connecting the urban Wasatch Front with the mountainous outdoor venues. This product includes expected weather, wind, temperature, wind chill, precipitation type and amount along transportation routes, park and ride lots, and other public areas with large concentrations of people outdoors. Another product includes forecasts of weather, wind, temperature, and snowfall amount for the avalanche starting zones that tower over the highway from Provo to the Soldier Hollow cross country facility. The Utah Department of Transportation will use this forecast as part of their avalanche control operations along with products issued by Northwest Weathernet, a commercial firm that has provided the Department of Transportation with road weather and pavement condition forecasts for several winters. The NWS forecasters also will handle the numerous media inquiries that will otherwise inundate the WFO staff and other members of the weather forecast team.

In addition to routine dissemination, all NWS products will be inserted into the E-Team protected communications system operated by the Utah Olympic Public Safety Command (UOPSC), which is a consortium of local, state, and federal security and safety agencies. The WOC will also operate an FTP server that will provide all local television media equal access to the venue forecasts being produced by the KSL forecast team.

The NWS also has set up AWIPS servers to feed data to the outdoor venues where it is viewed on the FX-Net system. This PC-based system was designed by NOAA's Forecast Systems Laboratory as a vehicle to allow meteorologists to look at the full AWIPS data set on a lower-cost platform fed by narrow-bandwidth communications. Dedicated communications lines were installed by SLOC between the AWIPS servers at NWS Western Region Headquarters and the outdoor venues. In this way, the KSL venue forecasters will have access to all the same data sets as the NWS/KSL forecast teams at the WOC, including the special data sets produced by CIRP. A communications line and FX-Net system has also been installed at the ASOC at Hill Air Force Base so that their aviation forecasters will have access to the same data sets.

5. KSL Venue Forecast Team Role

A team of 13 private sector meteorologists has the responsibility to provide detailed micro-scale weather forecasts for the five outdoor locations. These forecasts will be primarily used by the athletes, sports managers, team captains, venue managers, Olympic officials and on-site spectators. The KSL venue forecast team (under contract with SLOC) was assembled by Mark Eubank, KSL meteorologist, and is composed of meteorologists who either live or have lived in the Salt Lake City area for many years. This team has a combined Utah forecast experience of 247 years. The team consists of retired National Weather Service meteorologists and personnel from six private forecasting companies: WeatherCycles, Inc.; WeatherBank, Inc.; WeatherFacts, Inc.; Meteorological Solutions, Inc.; EM-Assist; and Alta Forecasting.

Four members of the KSL team will work in the WOC located at the SLC WFO while seven other members will be located at the five mountain venues. The WOC has the responsibility to "funnel" the overall weather picture down to the mesoscale. A weather briefing will be conducted each morning between the venue forecasters and the WOC and ASOC forecasters. Mesoscale forecasts will be sent to each venue by the WOC where the venue forecasters will take the forecast to the microscale level. Briefings at the venues will be given routinely 2-3 times a day but more often, if needed. The KSL team director and venue manager will give briefings to Olympic and SLOC officials in SLC at least twice each day and also will provide weather briefings at the Olympic Media Center.

The venue forecast team has been assembled since 1999 and has two winters of on-site forecast experience for pre-Olympic and World Cup testing and training events. Two dress rehearsals have also been held. The venue forecasters will have on-site access to the latest weather observations, graphics and model data using the FX-Net software and also have access to selected weather products over the Internet.   The venue forecasters tested the FX-Net software during the past winter and report great utility and satisfaction. In addition to using the suite of NCEP forecast models, the team will use resources developed by CIRP, including the MesoWest network of surface observations, MM5 model forecasts and Model Output Statistics (MOS) guidance (see section 6).

Weather forecasts for these venues will routinely be issued three times daily at 6:00 a.m., 12:00 p.m., and 6:00 p.m. Updates will be issued as often as needed. For the first 13 hours of each forecast, the predictions will be hourly, then 3 hourly out to 60 hours. Parameters will include: sky cover, precipitation type and amount, air temperature, wind direction, wind speed, wind gusts, wind chill, visibility, humidity, and snow temperature.

6. CIRP Team Role

CIRP helps coordinate the weather support activities provided by the NWS, KSL, and SLOC. CIRP received funding from the U.S. Congress during FY 1998-2001 to help prepare and support the operational forecast responsibilities of the Olympic weather support team. The Olympic weather support project at the University of Utah contributes to the educational, research, and public service missions of the University. Some undergraduate and graduate students will be weather aides collecting weather information at outdoor venues. Others have already contributed to basic and applied research that expands our knowledge of winter weather in complex terrain.

CIRP faculty, staff, and students have contributed to the Olympic effort in four general areas: applied research on winter weather in northern Utah; monitoring current weather conditions in northern Utah and around the West; real-time mesoscale modeling; and direct support activities for the Olympic weather team. Each of these activities are described in greater detail in the following sub-sections.

a. Winter weather in northern Utah

Research has been underway since the creation of CIRP in 1996 to improve the understanding and prediction of atmospheric flows in complex terrain. For example, the Intermountain Precipitation Experiment (IPEX) was held during February 2000 in the vicinity of Salt Lake City to improve the understanding, analysis, and prediction of precipitation over the complex orography of the Intermountain West (see the companion article by Schultz et al. 2002).

A major winter-season forecast challenge for Utah meteorologists and a concern for Winter Games logistics are lake-effect snowstorms produced by the Great Salt Lake. Such snowstorms frequently produce snowfalls of 10-30 cm along the Wasatch Front, and have contributed to lowland storm total accumulations of as much as 130 cm (Carpenter 1993; Slemmer 1998; Steenburgh et al. 2000). Installation of the NWS Weather Surveillance Radar-1988 Doppler (WSR-88D) radar at Promontory Point (KMTX) in 1994, and subsequent development and expansion of MesoWest (see the next sub-section), provided an opportunity for rapid progress in the understanding of Great Salt Lake effect snowstorms prior to the Olympics.

Steenburgh et al. (2000), Steenburgh and Onton (2001), and Onton and Steenburgh (2001) described the large-scale characteristics and mesoscale structure of Great Salt Lake-effect snowstorms. These studies have shown that although the Great Salt Lake is relatively small in scale compared to the Great Lakes, and is surrounded by dramatic vertical relief, it is capable of inducing thermally driven circulations and, in some cases, banded precipitation structures (e.g., mid-lake bands) similar to those observed in lake-effect regions of the eastern United States and Canada. They also found that GSL-effect precipitation usually develops at night, is most organized and intense at night and during the early morning hours, and weakens or dissipates during the afternoon. These characteristics appear to be related to the modulation of lake/land breezes and overlake convergence/divergence by the diurnal cycle, and their identification has proven valuable for operational short-range weather prediction.

Efforts to improve the prediction of Great Salt Lake-effect snowstorms have also included the installation of MesoWest observing sites over and around the Great Salt Lake, including two sites that provide real-time lake temperature observations (Gunnison and Hat Islands; see Fig. 3). Prior to the installation of these stations, real-time lake-temperature observations were not available to operational forecasters (Carpenter 1993). Derived products for monitoring lake-effect events have also been developed. Finally, mesoscale modeling systems at NCEP and CIRP (see section 6c) have provided forecasters with numerical model guidance capable of producing Great Salt Lake-effect snowstorms, although the skill and utility of these modeling systems for lake-effect storms has yet to be validated.

b. MesoWest and SnowNet

A number of weather networks were operational in northern Utah when the Winter Olympics were awarded to Salt Lake City in 1995. Work was underway at that time by forecasters at the SLC WFO and researchers at the University of Utah to collect the observations from those networks for use in weather forecasting and research. Nonetheless, it was recognized that additional collaboration with SLOC, commercial firms, and local, state, and federal agencies was necessary in order to support the weather needs of the games organizers, athletes, and weather forecast team. Since documentation of weather conditions prior to the Olympics was required for planning and during the Olympics for operations, additional weather sensors and weather stations were required at venues and other key locations in northern Utah. Since 1996, weather equipment has been installed cooperatively by SLOC, CIRP, the NWS, the Utah Department of Transportation, and the commercial firms and state agencies managing the outdoor olympic venues. Portable weather stations manufactured by Campbell Scientific, Inc. that were deployed by the NWS Southern Region for the 1996 Atlanta Summer Games were made available to the NWS Western Region after the summer games were completed. In addition during 1996, the NWS Western Region and the National Severe Storms Laboratory started a research project in the vicinity of Salt Lake City designed to validate WSR-88D radar algorithms in regions of complex terrain that included deployment of weather equipment at eight locations (4 along the Wasatch Front and 4 at Olympic venues).

A unique partnership has evolved since 1996 within the government, commercial, and research communities to share weather information in northern Utah and throughout the western United States. Initially referred to as the Utah Mesonet, this larger program has been called MesoWest since January 2000 and is discussed in greater detail in the companion article by Horel et al. (2002). During February-March 2002, weather observations will be available from over 278 locations in the northern Utah region shown in Fig. 2. These weather stations are owned and operated by 15 commercial firms, 8 local and state agencies, and 9 federal agencies. For the western United States as a whole, MesoWest is dominated by the large federal networks that support primarily the aviation, fire weather, and water resource communities. In northern Utah, we have worked closely with the private sector and local and state agencies that play a significant role by operating weather stations for a variety of specific purposes, including: water resource management, air quality monitoring, winter road maintenance, equipment development, agriculture, ski area operations, and emergency management.

Weather data are collected at 5-60 minute intervals via ethernet, phone, cellular phone, radio, satellite, and meteor burst technologies. As part of a combined effort of the SLC WFO and CIRP, the WFO operates 4 computers to collect weather observations by phone and radio from Campbell Scientific weather stations deployed by commercial firms and government agencies. This collection effort is called SnowNet and radio base stations are maintained at the Promontory Point WSR-88D radar site, Farnsworth Peak, and Olympics Sports Park to provide radio coverage across the Great Salt Lake, along the Wasatch Front, and at the Sports Park venue, respectively (Fig. 2).

As part of SnowNet activities, weather observations are collected from 27 sites at the 5 outdoor Olympic venues (Fig. 3): Snowbasin Ski Area (downhill, combined downhill and slalom, and super-G slalom), Olympic Sports Park (bobsleigh, luge, skeleton, ski jumping, and nordic combined), Soldier Hollow (cross-country, biathlon, and nordic combined), Park City Mountain Resort (giant slalom, snowboarding parallel, and snowboarding halfpipe), and Deer Valley Resort (slalom, freestyle moguls, and freestyle aerials). All weather stations report wind, temperature and relative humidity, while at least one station at each venue has additional liquid equivalent precipitation, snow depth, and pressure sensors. Weather stations are also located in close proximity to all of the indoor venues that stretch from Ogden to Provo along the Wasatch Front (see Fig. 2).

In support of the helicopter and other aviation traffic into landing zones at the outdoor venues, the U. S. Air Force will deploy Tactical Meteorological Observing System (TMOS) portable weather stations near the Snowbasin, Olympic Park, Park City, and Soldier Hollow outdoor venues as well as at one location to the west of the mountain pass between Salt Lake City and Park City (see Fig. 2). TMOS provides continuous reports of wind, temperature, moisture, ceiling, visibility, liquid equivalent precipitation, and present weather.

As a means to integrate the surface observations in northern Utah for use in nowcasting and forecast verification, surface analyses of temperature, wind, and relative humidity are generated on a 1-km horizontal grid every 15 minutes (Lazarus et al. 2002). These analyses are made available, along with the surface observations, via the Internet to all potential users as well as distributed via LDM for use in AWIPS at the SLC WFO and FX-Net at the outdoor venues.

c. Real-time mesoscale modeling

CIRP mesoscale modeling activities for the 2002 Winter Olympics have involved providing twice-daily real-time model guidance to Olympic and NWS forecasters at the Salt Lake and Elko Forecast Offices for more than three years prior to the games. These activities have allowed for validation and hands-on use of the modeling system by Olympic forecasters, and the development of MOS equations that provide point-specific forecasts for Olympic venues and other weather sensitive location. The modeling system is known as the Intermountain Weather Forecast System (IWFS) and is based on the non-hydrostatic Penn State/NCAR MM5 version 3 (Grell et al. 1995). Since July 1998, IWFS has featured an outer domain with 36-km grid spacing that covers the western United States and a nested domain with 12-km grid spacing that covers Utah and portions of adjacent states. The 12-km domain was expanded and a 4-km grid spacing nest was added during summer 2001 and used by Olympic forecasters for several months prior to the Winter Games (Fig. 4). Initial and lateral boundary conditions are provided by the NCEP Eta model, although a second simulation is run, but available at a later time, using the NCEP Aviation model. Since June 2001, a version of ADAS (see previous sub-section) has been used to incorporate MesoWest observations into the near-surface initial conditions. Prior to September 2000, the IWFS was run on an SGI Origin 2000 (using 16 195- Mhz R10000 processors) maintained by the University of Utah Center for High Performance Computing (CHPC). Since September 2000, it has run on a CHPC-maintained Linux cluster. Using 16 1.3-GHz Advanced Micro Devices (AMD) Athlon processors, a 36-h forecast with all three domains requires 90 min to complete. As a result, 0000 UTC (1200 UTC) model output is typically available to forecasters by 0400 (1600 UTC). Hourly model output is converted to netCDF and ingested into AWIPS systems at the NWS Western Region Headquarters and SLC WFO. Forecasters at outdoor Olympic venues access model output using FX-Net. Model products can also be accessed by Olympic forecasters and the public at http://www.met.utah.edu/olympics. MM5-based model output statistics (MM5-MOS) provide hourly forecasts of temperature, dewpoint, wind speed, and wind direction at the outdoor venues and other weather sensitive locations (Table 1). At venues with substantial variability in surface weather conditions, MM5- MOS is available for multiple observing sites. MM5-MOS was used by Olympic forecasters during test events held during the 2000-2001 winter season, and was upgraded during summer 2001 using a three-year period of observations and forecasts. MM5-MOS can be accessed from the web page listed above.

d. SLOC Support Activities

CIRP faculty and staff have worked closely with the SLOC to develop weather resources required for Olympic planning and operations. Weather observations at outdoor venues and all other MesoWest locations from January 1, 1997 to the present are available over the Internet at www.met.utah.edu/olympics. This information has been used extensively during the test events and for planning. Using long-term records at the Salt Lake City, Hill Air Force, and Provo airports, climatologies during the Olympic and Paralympic periods for the occurrence of rain, snow, fog, high winds, and extreme cold temperature have also been determined.

Considerable effort has been required to develop software to route weather information to the SLOC computer networks while maintaining secure networking for all organizations. The Info 2002 computer system has been designed by SLOC for the athletes, Olympic organizers, and media while SLOC and MSNBC will jointly develop the official public internet site for the Winter Games (http://www.saltlake2002.com).

As summarized schematically in Fig. 5, weather reports from automated weather stations at the venues are collected routinely as part of SnowNet. The automated weather observations are also accessed manually on a personal computer operated by a weather aide at the venue. Supplemental information (e.g., sky condition or snow temperature) required by SLOC is collected by weather volunteers before, during, and after competition, entered into a spreadsheet, and transmitted automatically to the SLC WFO. Forecasts issued by the venue forecasters are also transmitted automatically to the WFO. These reports (along with all requested NWS products such as zone forecasts, advisories, watches and warnings, and transportation corridor forecasts) are then processed and transferred automatically to the SLOC Central Repository System for use by the Info 2002 and public web site.

Specialized research and development has also been undertaken in support of the sporting events. For example, Fig. 6 shows a thermal map of the snow temperature along the cross-country course at Soldier Hollow based upon a portable IR sensor system. On this cold morning after several days of clear skies, the snow temperature varied from -20^{o}C to -10^{o}C depending upon terrain aspect and the age of the snow. This information can be used to determine the optimum type of wax to use during competition.

7. Legacy

The states that comprise the Intermountain West are undergoing significant population increases and the economic losses from winter snowstorms in this region are high (Schultz et al. 2002). The weather support infrastructure developed for the Winter Olympics will have long-term benefits to the public throughout the Intermountain West. The improved tools (MesoWest, ADAS, and IWFS) will be in place to monitor and predict storms throughout the Intermountain West during all seasons. The experience gained from the application of these tools by skilled NWS and private forecasters will prove invaluable to suggest further improvements for operational and research models. In addition, the ongoing research related to lake-effect snowstorms and orographic precipitation will help to improve the understanding of winter weather in complex terrain. Improved understanding benefits not only Olympic forecasts, but other weather prediction activities over northern Utah, including public forecasts and warnings by the NWS and avalanche prediction by the Utah Department of Transportation and Utah Avalanche Center.

The value of the dense network of surface observations in northern Utah that are a part of MesoWest has already been demonstrated for other research applications. For example, the Department of Energy Vertical Transport and Mixing (VTMX) experiment was held in the Salt Lake Valley during October 2000 in part as a result of the existing infrastructure that is supported by government agencies and commercial firms (Doran et al. 2002). Additional field programs are likely to occur in this region as a result of the many scientific questions arising from the complex air flow over the Wasatch Front valleys, Great Salt Lake, and adjacent mountains. The comprehensive data sets collected during the Olympics, IPEX, VTMX, and future field programs will be invaluable to study mountain weather processes.

Ackowledgments: ...

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MM5 MOS Predicted Weather Conditions for PARK CITY MUN G.C. (SNOWNET), UT
Lat/Lon/Elev= 40.66/ −111.52/6354.99 ft

Time/Date(Local)	Temperature (f)	Dewpoint (f)	Relative Humidity (%)	Wind Speed (mph)	Wind Direction	Raw Model 1−hour Accumulated Precip (in)	Raw−Model Total Accum. Precip (in)
09:00 am Aug 20 2001	67.8	45.3	49.2	0.6	SW ↗ (215)	0.04	0.09
10:00 am Aug 20 2001	70.1	45.9	46.5	1.0	SW ↗ (228)	0.03	0.11
11:00 am Aug 20 2001	73.5	45.5	40.1	1.3	SW ↗ (227)	0.01	0.12
12:00 pm Aug 20 2001	75.1	45.7	35.4	1.5	SW ↗ (230)	0.01	0.14
01:00 pm Aug 20 2001	75.4	46.9	39.3	1.6	SW ↗ (215)	0.01	0.14
02:00 pm Aug 20 2001	76.2	46.6	38.8	1.5	SW ↗ (222)	0.00	0.15
03:00 pm Aug 20 2001	76.1	46.3	36.7	1.6	SW ↗ (235)	0.02	0.16
04:00 pm Aug 20 2001	70.3	47.0	51.5	1.0	SW ↗ (211)	0.10	0.26
05:00 pm Aug 20 2001	61.2	48.2	75.0	0.9	SW ↗ (203)	0.11	0.37
06:00 pm Aug 20 2001	50.3	49.4	100.0	0.9	S ↑ (197)	0.11	0.48
07:00 pm Aug 20 2001	54.5	47.9	92.1	0.8	S ↑ (192)	0.07	0.55
08:00 pm Aug 20 2001	59.3	46.7	69.8	0.6	S ↑ (191)	0.01	0.56
09:00 pm Aug 20 2001	61.0	46.8	65.4	0.7	SW ↗ (206)	0.00	0.56
10:00 pm Aug 20 2001	60.0	45.2	63.5	1.1	SW ↗ (222)	0.00	0.56
11:00 pm Aug 20 2001	56.8	44.5	71.0	1.0	SW ↗ (223)	0.00	0.56
12:00 am Aug 21 2001	54.3	45.0	79.8	0.8	S ↑ (202)	0.00	0.56
01:00 am Aug 21 2001	53.8	46.3	80.1	0.6	S ↑ (200)	0.00	0.56
02:00 am Aug 21 2001	54.1	47.3	78.4	0.4	S ↑ (191)	0.00	0.56
03:00 am Aug 21 2001	53.3	48.4	80.0	0.1	S ↑ (158)	0.00	0.56
04:00 am Aug 21 2001	53.1	47.3	80.6	0.0	S ↑ (164)	0.00	0.56
05:00 am Aug 21 2001	52.7	46.7	81.2	0.0	SE ↖ (129)	0.00	0.56
06:00 am Aug 21 2001	52.5	43.2	76.2	0.1	SW ↗ (217)	0.00	0.57
07:00 am Aug 21 2001	55.4	47.3	68.5	0.0	S ↑ (160)	0.01	0.57
08:00 am Aug 21 2001	57.7	44.6	66.8	0.3	S ↑ (201)	0.01	0.58
09:00 am Aug 21 2001	61.9	45.5	54.7	0.4	S ↑ (193)	0.01	0.58
10:00 am Aug 21 2001	66.3	43.4	44.4	0.7	SW ↗ (207)	0.01	0.59
11:00 am Aug 21 2001	69.7	40.3	36.0	1.0	SW ↗ (209)	0.00	0.59
12:00 pm Aug 21 2001	71.6	39.2	37.2	1.2	SW ↗ (214)	0.00	0.59
01:00 pm Aug 21 2001	74.0	39.2	31.6	1.6	SW ↗ (217)	0.00	0.59
02:00 pm Aug 21 2001	75.0	39.5	30.2	1.6	SW ↗ (219)	0.00	0.59
03:00 pm Aug 21 2001	76.8	38.0	28.4	1.8	SW ↗ (216)	0.00	0.59
04:00 pm Aug 21 2001	75.7	35.3	27.0	1.7	SW ↗ (213)	0.00	0.59
05:00 pm Aug 21 2001	74.3	34.0	27.2	1.5	SW ↗ (210)	0.00	0.59
06:00 pm Aug 21 2001	72.2	32.6	27.4	1.5	SW ↗ (208)	0.00	0.59

Table 1. Sample MM5 MOS ouput ...

Figure 1. Locations of Olympic venues (numbers 1-10) and the sports at those venues (icons). Opening and Closing Ceremonies (11), Medals Plaza (12), and the Salt Lake City International Airport (13) are shown as well as icons for locations of Park and Ride sites. Outdoor venues are Snowbasin Ski Area (2); Utah Olympic Park (6); Park City Mountain Resort (7); Deer Valley Resort (8); and Soldier Hollow (9). Figure courtesy of the Salt Lake City Corporation.

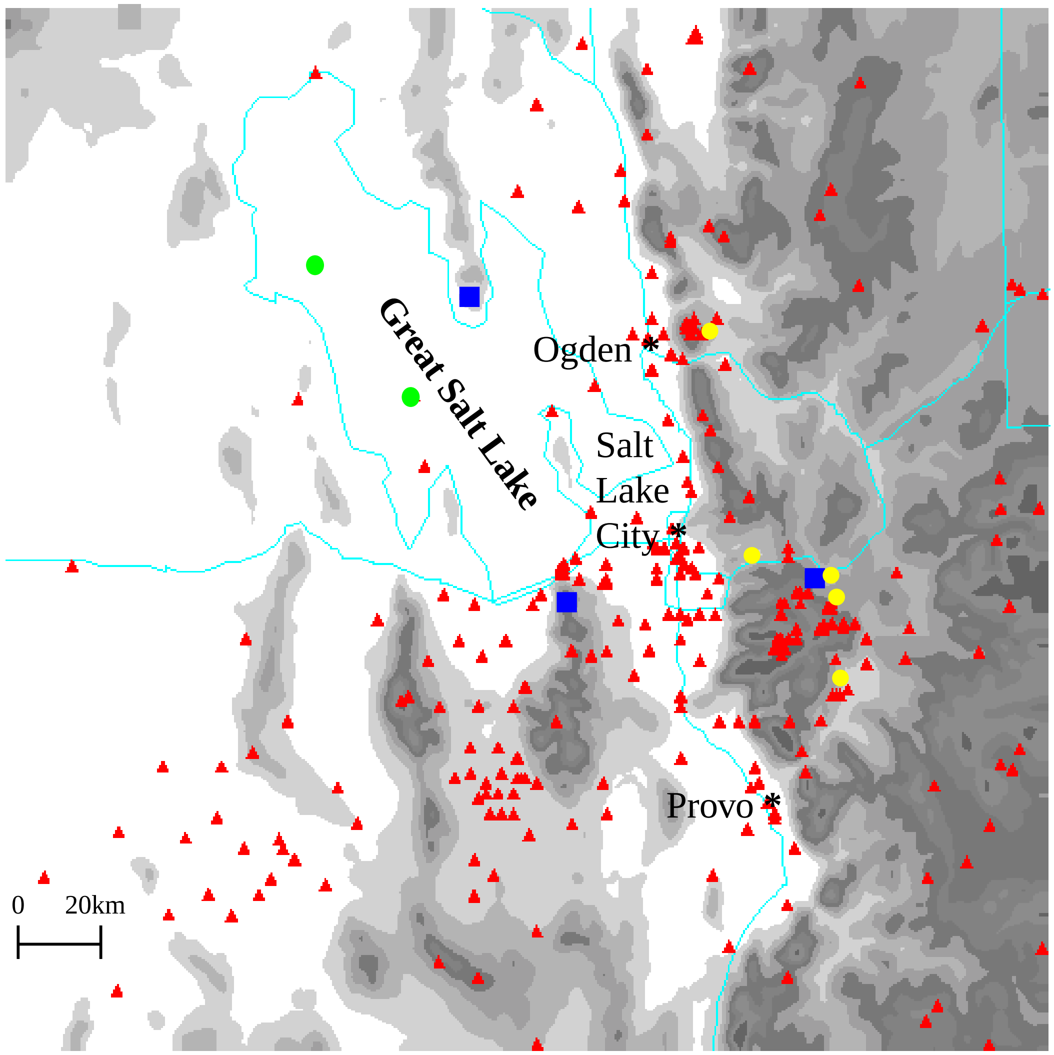


Figure 2. Locations (red triangles) of 278 weather stations in the vicinity of Salt Lake City that are available for the 2002 Winter Olympic Games. Successively darker shading denotes higher terrain. Blue squares denote weather stations that collect weather information from other remote weather stations by radio and which are maintained as part of SnowNet by the NOAA Cooperative Institute for Regional Prediction. Green circles denote locations where temperature of the Great Salt Lake is monitored while yellow circles denote locations of TMOS stations.

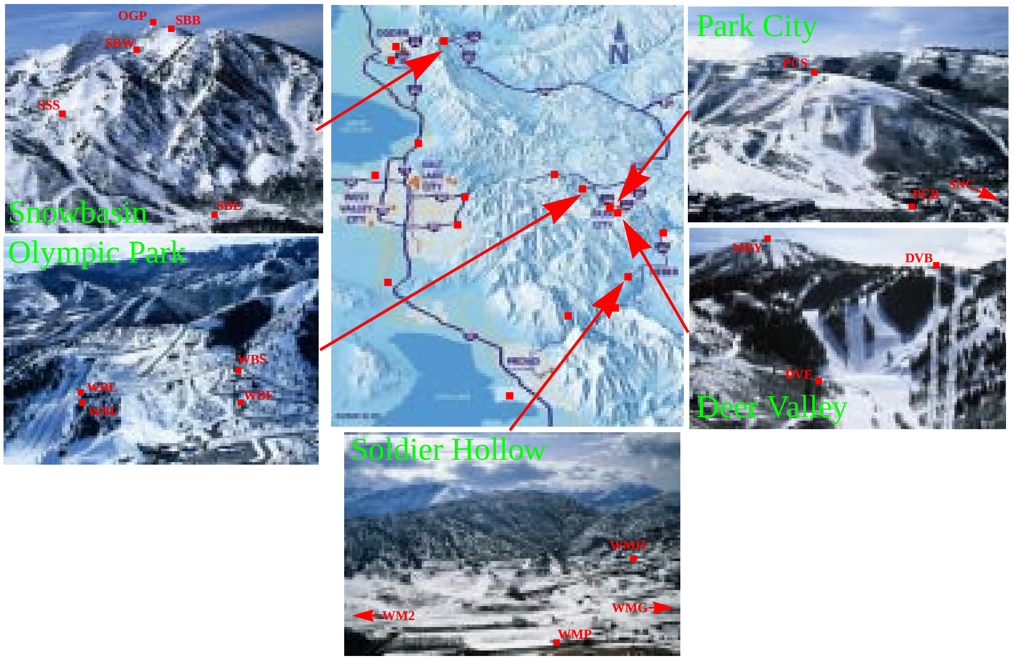
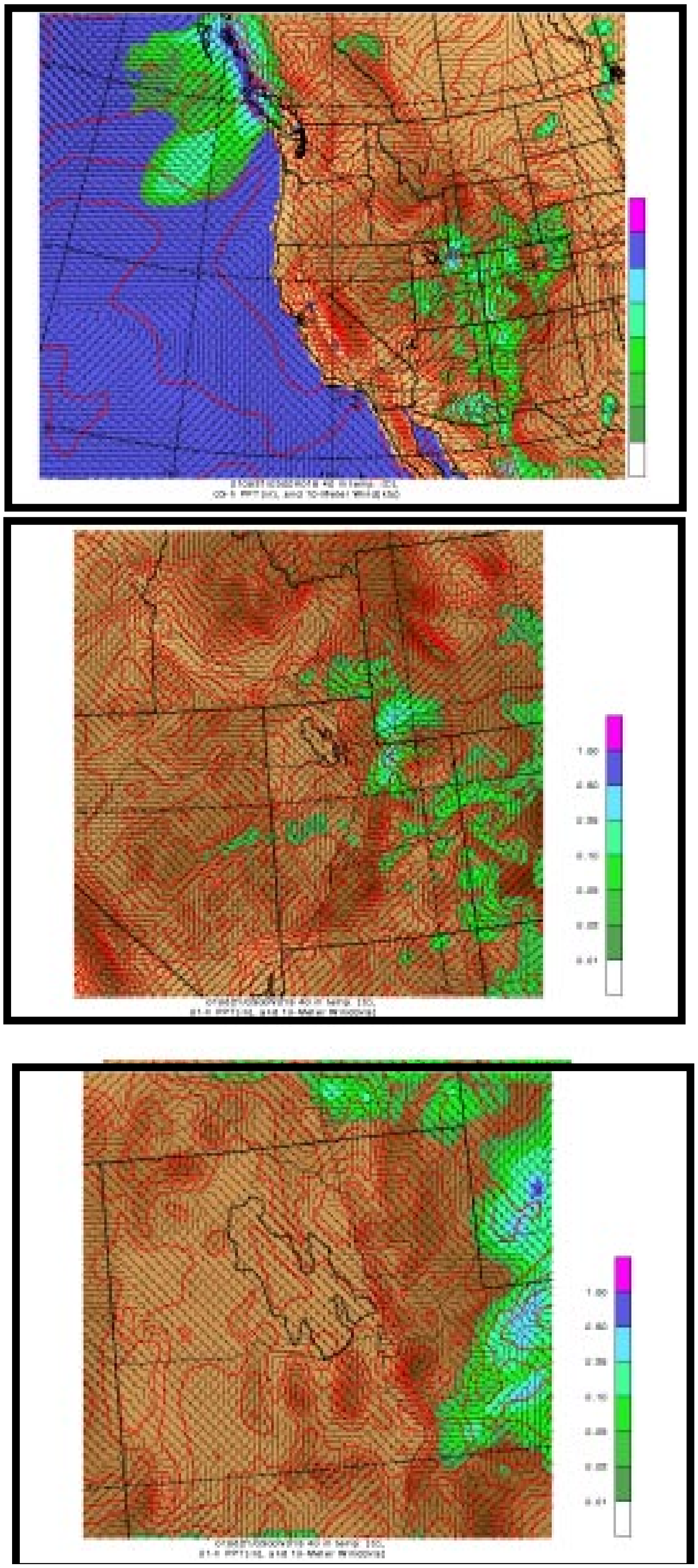


Figure 3. Locations of the 5 outdoor Olympic venues and the MesoWest 3-letter identifiers of the weather stations in the vicinity of the competition areas. (A total of 29 weather stations are deployed at the outdoor venues; some lie outside the competition areas.)

Figure 4. ...



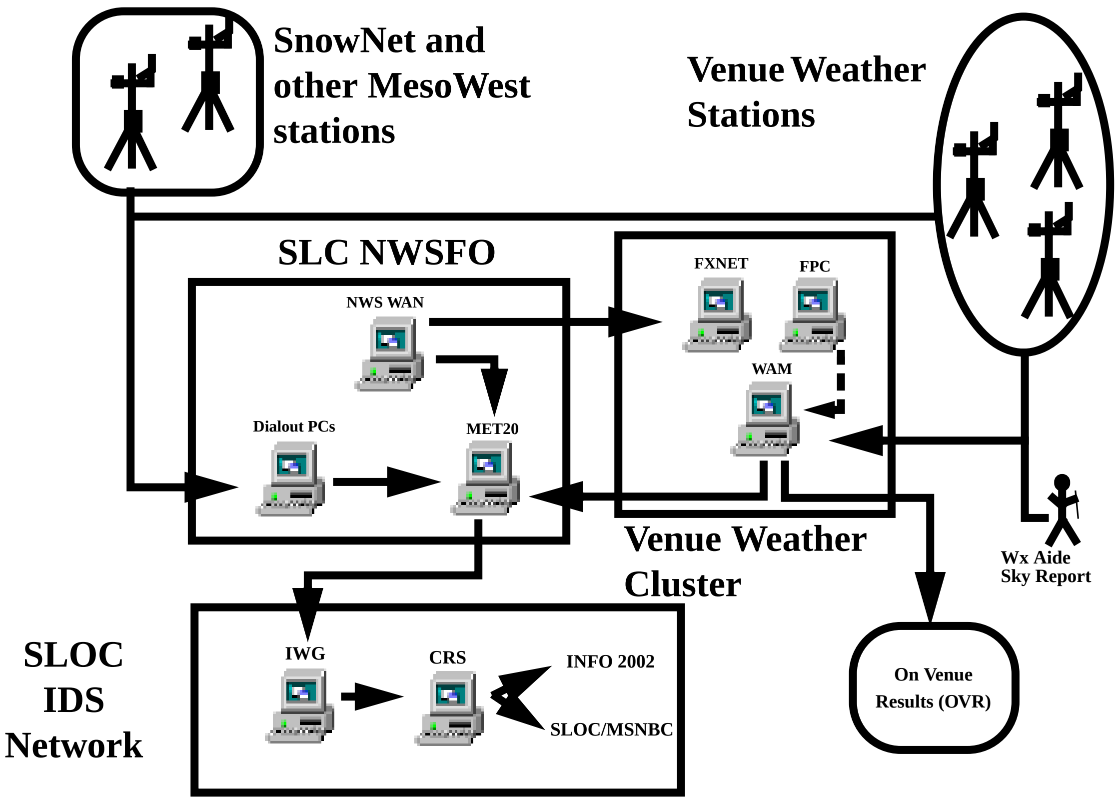


Figure 5. Schematic depiction of the flow of weather information between the venues, weather forecast operations center, and the Salt Lake Olympic Committee computer networks.

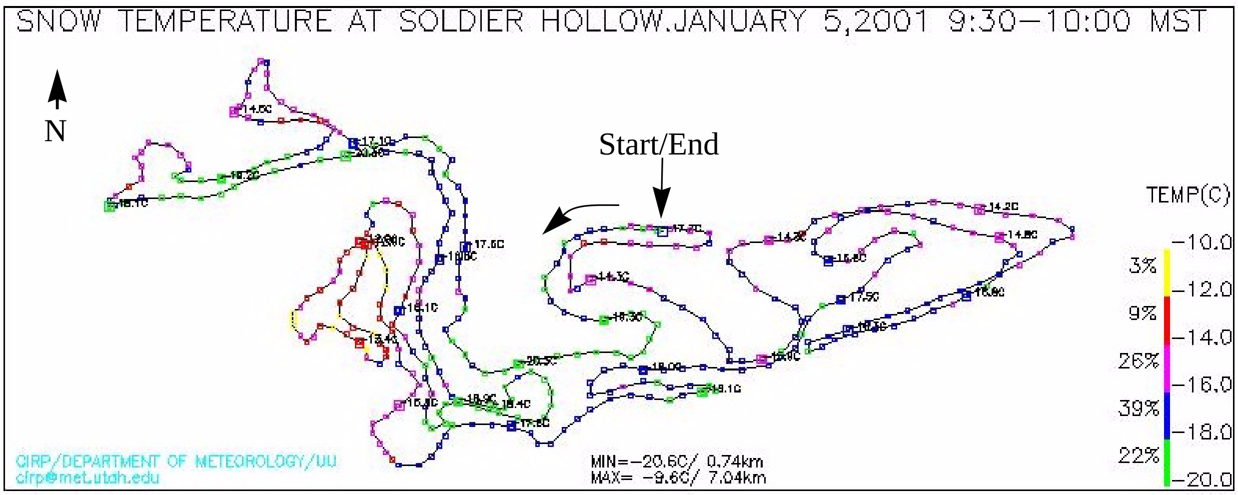


Figure 6. Snow temperature (^oC) along the 25 km cross-country course on 5 January 2001.