

# Warning Operations in Support of the 1996 Centennial Olympic Games



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## ABSTRACT

During the summer of 1996, the National Weather Service (NWS) provided weather support for the Centennial Olympic Games in Atlanta, Georgia. This weather support effort presented many challenges, particularly in the area of providing short-term forecast (watch) and warning support. Topping the list of challenges was working with a customer with different weather information needs than the general public. The needs of the venue and competition management were much more detailed than the NWS traditionally is accustomed to and the thresholds for various phenomena were very low (e.g., warnings for the occurrence of any rain were issued rather than the more traditional NWS severe thunderstorm warning).

This paper discusses many of the challenges faced and met by the Olympic Weather Support Office (OWSO). Details are provided on the weather warning requirements of the Olympic venue and competition management, the watch/warning strategy utilized by the OWSO, and the resulting performance of the office. More than 1200 watches and warnings were issued during the period of Olympic weather support. These bulletins were for phenomena ranging from dew formation and low visibility to lightning and heavy rain. Several emerging technologies were employed for warning operations in the OWSO, including the Warning Decision Support System and the Watch/Warning/Advisory package. These hardware/software solutions appear to have made a positive impact on the performance of the office in meeting the challenges of this unique warning situation.

## 1. Introduction

The 1996 Summer Olympic Games in Atlanta not only challenged athletes with world class competition, but also challenged the National Weather Service (NWS) to provide support to the Games. The challenge for the NWS spanned the entire gamut of weather support operations, from working with a new customer who had new weather information requirements, to the communications media being used. One of the biggest

challenges in supporting the games was conducting warning operations. Traditional NWS warning operations seek to warn the public of severe weather ( $> 1.9$  cm hail,  $> 25$  m s<sup>-1</sup> winds, tornadoes, flooding). However, for the Olympics, the Atlanta Committee for the Olympic Games required notification of the occurrence or prediction of many nonstandard, almost benign by NWS standards, weather phenomena. These nontraditional requirements not only challenged the skills of the meteorologists who manned the Olympic Weather Support Office (OWSO), but also challenged the team of software developers and meteorologists tasked to assemble and integrate the technology tools for the support. This paper discusses the warning requirements of the users, the types of warnings and strategies that were developed and used during the Games, the operational warning methodology, and the software tools that supported the warning operations of the OWSO. Broader operational aspects (including training of the forecasters, products and services, and system infrastructure) of the OWSO are discussed in Rothfusz et al. (1998).

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## 2. Warning requirements

The 1996 Summer Olympic Games consisted of several venues around the state of Georgia. While the majority of the venues were located in the Atlanta metropolitan area, several venues were well removed from Atlanta (Fig. 1). Not only were venues spread geographically across the state of Georgia, which challenged communications, but they were located in different “microclimates,” which challenged the meteorologist’s understanding of the local problems and the technology tools employed to help the meteorologists.

The safety of the spectators and athletes was the primary concern of venue officials. In addition, with many of the world’s best athletes participating in the Olympic Games, Olympic venue officials strived to

provide the athletes and coaches with the best possible “field of play” conditions for their competitions. Knowing about and planning for (or around) inclement weather was necessary to achieve their safety and field of play goals. Thus, venue officials needed to know when the weather would impact their venues, what intensity would be reached and for how long. In addition, they obviously needed to know all this information with adequate lead time.

Table 1 lists the weather phenomena (with warning criteria) for which venue officials required warning or notification. This listing is in addition to the standard NWS severe thunderstorm, tornado, and flash flood warnings. For indoor venues, the primary weather concerns were not for the safety of the athletes and coaches or the condition of the playing field

but rather for spectators outside moving to and from venues. Thus, weather phenomena for indoor venues had much more traditional warning thresholds.

## Olympic Venues

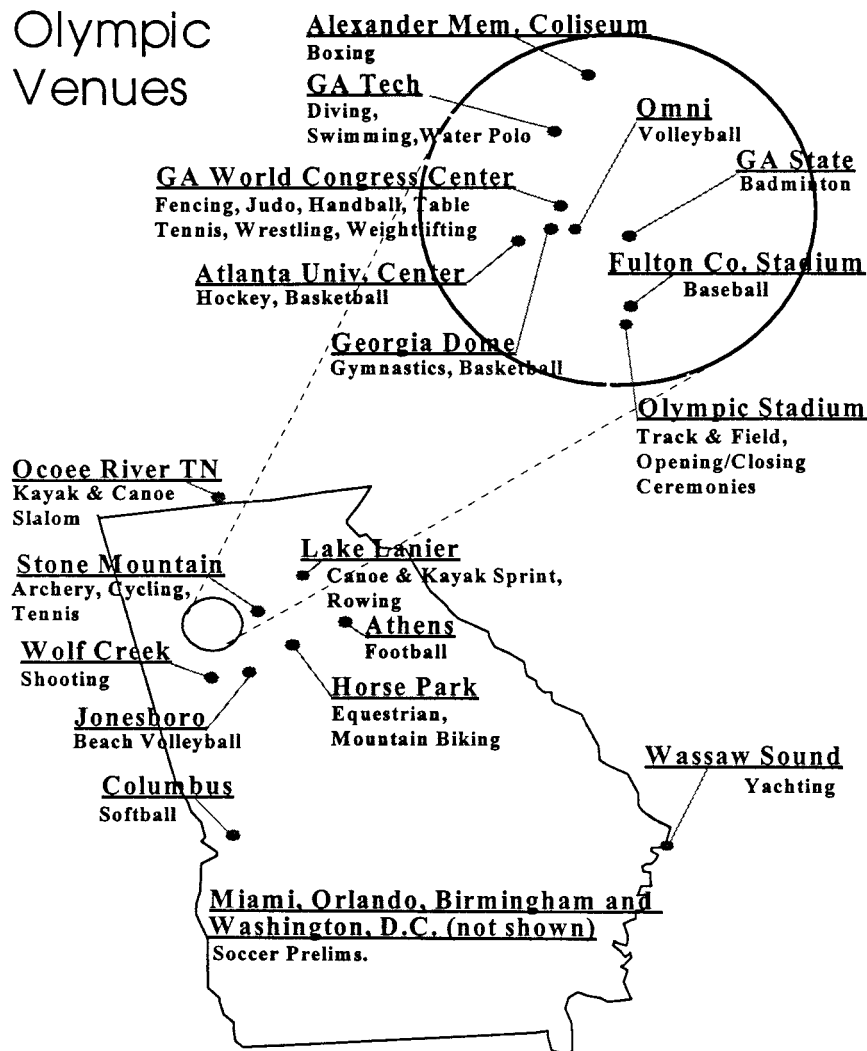


FIG. 1. 1996 Summer Olympic venues. The large ring “blowup” represents the “Olympic Ring” venues. Satellite venues include Washington, DC; Birmingham, AL; Orlando, FL; and Miami, FL.

## 3. Watch/warning strategy

Members of the OWSO staff met with the venue officials to determine what types of weather phenomena were important to their venues and competitions, and also to understand the required frequency and content of weather information for decision making. In an attempt to maintain as much of the traditional NWS strategy and format as possible, so as to lessen the amount of training for both the meteorologists and the customer, the following bulletin types and strategies were chosen.

**Watch:** Issued if there was any potential of an event occurring. A watch was issued to alert venue officials of the possibility of an event. This strategy helped in their

TABLE 1. Weather watch/warning criteria for the 1996 Olympic Games venues.

Watch/warning	Criterion	Venues	Max watch issuance lead time	Max warning issuance lead time	Max statement frequency
Dew formation	T-Td ≤ 5°F	Stone Mtn Cycling	24 h	12 h	1 h
Hail	Any size	All	6 h	As much as possible (AMAP)	15 min
High heat index	HI ≥ 100°F	All	24 h	12 h	1 h
Heavy rain	Rate < 0.03"/min	All (see rain watch/warning)	12 h	AMAP	15 min
Strong wind	> 30 mph (see exceptions at right)	All <i>except</i> : Aquatic Ctr Diving (20) Open/Close Cer. (20) Stone Mtn Cycling (20) Lake Lanier (10)	12 h	AMAP	15 min (convective) 1 h (gradient)
Lightning	Any	All	6 h	AMAP	15 min
Low visibility	≤ 1 mi	AFC Stadium Clark-Atlanta U Morris Brown Open/Close Cer. Road Cycling GIHP Wolf Creek CSG Golden Park	24 h	AMAP	1 h
Rain	Any	AFC Stadium Open/close Cer. Stone Mtn Archery Stone Mtn Tennis Stone Mtn Cycling Atlanta Beach Sanford Stadium	24 h	12 h	15 min
Wind direction change	> 90° in 10 min or less	Olympic Stadium Road Cycling Stone Mtn Cycling Wolf Creek Lake Lanier	12 h	AMAP	15 min (convective) 1 h (synoptic)

contingency planning for each day. Most watches were issued the day before a potential event or the morning before an expected afternoon/evening event.

Warning: Issued if the warning meteorologists believed the event would occur at the venue site.

Statement: Issued as a follow-up to warnings. For the entire lifetime of a warning, a statement was required at least every 15 minutes providing succinct updated information including times of beginning, ending, and how “bad” the event would be.

## 4. Meeting the challenge

With a new customer, new types of warnings and a new set of “issuance” rules, the OWSO had to have efficient and accurate technology tools for making warning decisions, issuing bulletins, and managing the bulletins (i.e., keeping track of what bulletins were in effect, were about to expire, needed an update, etc.). To meet these challenges, the Warning Decision Support System (WDSS), developed by the National Severe Storms Laboratory (NSSL), and the Watch/Warning/Advisory (WWA) package, developed by the NWS Techniques Development Laboratory (TDL), were chosen to serve as the foundation for OWSO warning operations. In addition, several other technology tools were used to support warning operations. All the warning-related tools are discussed below.

### a. Warning Decision Support System (WDSS)

Since 1993, the National Severe Storms Laboratory has developed, enhanced, and tested a prototype Warning Decision Support System in NWS offices across the country as part of actual warning operations. The WDSS consists of severe weather detection and prediction algorithms (e.g., the Hail Detection Algorithm and the Damaging Downburst Prediction and Detection Algorithm), data integration techniques, and an interactive graphical user interface (Johnson et al. 1996). The WDSS was developed to test severe weather detection and prediction algorithms and display concepts in real time, in front of warning meteorologists, to gain feedback on the utility of the WDSS components before these components are transferred to the WSR-88D and the Advanced Weather Interactive Processing System (AWIPS). The positive feedback on the performance and utility of the WDSS in warning operations made it attractive as a technology tool for the OWSO.

### b. Watch/Warning/Advisory (WWA) software

The WWA software provides an intuitive method by which forecasters can choose: the phenomenon for which to issue a watch or warning, the valid times of the product, and the areas affected. In addition, WWA manages the watches, warnings, and statements in effect and alerts the user to the need for updates. The WWA software was developed by TDL for “long-fused” warnings such as Winter Storm Warnings as part of the Interactive Computer Worded Forecast now being tested on AWIPS (Ruth et al. 1998). WWA was modified by TDL and the OWSO staff for use in sup-

port of the Olympics. The ability to use WWA and WDSS on the OWSO computing platform and the maturity of WWA made it a perfect fit for the OWSO.

### c. Implementation of WDSS and WWA

Changes to the WDSS and the WWA were necessary due to the uniqueness and frequency of the watches and warnings and pinpoint location requirements. Table 2 provides a brief description of the changes that were required for both the WDSS and WWA to support the OWSO warning operations.

### d. Other OWSO watch/warning tools

In addition to the WDSS and WWA applications, the OWSO utilized several other tools, some of which were software applications and some of which were data sources, as part of its watch/warning operations. These additional tools were primarily used in a “now-casting” role or in watch decision making. These tools included the following:

- the RAMSDIS (Molenar et al. 1996) system;
- surface observations from a mesonet (Garza and Hoogenboom 1997);
- high temporal and spatial resolution analyses from the Local Analysis and Prediction System (LAPS; Snook et al. 1997);
- high temporal and spatial numerical mesoscale models including the Regional Atmospheric Modeling System (RAMS; Snook et al. 1997) and the Eta-10 (Black et al. 1997);
- Interactive Sounding Program for analyzing vertical profiles of wind, temperature, and moisture;
- special 0300 and 1500 UTC soundings from surrounding NWS radiosonde sites; and
- a “mesocast” form that provided meteorologists an integrated look at mesoscale features that could serve as focus mechanisms for convection.

The RAMSDIS system is a PC-based satellite display and interrogation system. The OWSO RAMSDIS was configured to receive *GOES-8* imagery every 15 minutes from the satellite downlink system at the Storm Prediction Center in Kansas City, Missouri. The RAMSDIS also provided satellite data to the LAPS analysis and to the WDSS for displaying and comparing with radar data.

The NWS installed 12 Campbell Scientific surface observing sensors at or near venue sites for the Olympic Games (Garza and Hoogenboom 1997). These sensors along with sensors from the University of Georgia

and the Georgia Forestry Commission composed a mesonet network of surface weather observing platforms. Temperature, relative humidity, wind speed, and wind direction data were collected every 15 minutes from a majority of the mesonet sites.

To better take advantage of the enormous amount of observational data available in the OWSO, an analysis of the data was done every half hour using the analysis capability of the LAPS. The analysis portion of LAPS also served as initial conditions for the prediction portion of LAPS, known as the Regional Atmospheric Modeling System (Snook et al. 1997). The LAPS analysis was run using surface observations (standard NWS sites and mesonet), WSR-88D data,

GOES-8 visible and infrared data, instrumented buoy data (buoys located off the Georgia coast near Savannah), and vertical wind profiler data (located in Savannah) as input. The first-guess estimate of the nonsurface levels was provided by the Rapid Update Cycle. The resulting analysis was on a horizontal grid of  $81 \times 81$  grid points at 8-km resolution. The grid covered all of Georgia, eastern Alabama, southeastern Tennessee, and most of South Carolina. The analysis was updated every half hour. More detailed information on the LAPS configuration and its use for the Olympics can be found in Snook et al. (1997).

In addition to the standard numerical models run by the National Centers for Environmental Prediction

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TABLE 2. Description of modifications that were required for the WDSS and WWA software packages to support warning operations in the Olympic Weather Support Office.

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<b>Required WDSS changes</b>	
Lightning data	The lightning data “overlay” was placed in its own window or image where the data could be viewed as a single data source or as an overlay on other image types (radar reflectivity, visible satellite, etc.).
Venue overlay	Venue locations were added to the maps overlay. These overlays were 5 and 10 n mi rings around the venue sites. These rings provided an immediate reference for noting the location of lightning and storms relative to the venues. Watches and warnings had to be written with references only to venues (and possibly interstate highways), since venue management was typically not from the Atlanta area and only knew the location of venues rather than towns or counties.
Multipanel display	The WDSS display was enhanced with a multipanel display for simultaneously observing radar reflectivities at multiple elevation angles. This provided a means of viewing the reflectivities relative to the freezing level as a possible indicator of the potential of lightning.
Attribute tables	Tabular algorithm information was augmented with a venue location column for quick determination if a storm was affecting a particular venue.
Satellite data	Satellite data (visible, infrared, and water vapor channels) were ingested into the WDSS and displayable side-by-side with the radar data with the same magnification and center point for quick comparison of satellite features and radar echoes.
<b>Required WWA changes</b>	
Venue location selection	The interactive county selection map was deactivated for all counties that did not contain Olympic venues. The county selection map was annotated with venue locations. For counties with multiple venues, a window with all possible venues in that county was displayed and the user could choose which venues to include in the watch or warning.
Database	The WWA database of watch and warning types was augmented to include all the specific Olympic watch and warning types (see Table 1). In addition, since many of the phenomena could occur simultaneously, several pre-determined combinations were also included in the database.  Specialized calls-to-action statements were developed for the watch and warning types that reflected the types of actions that could be expected by athletes, coaches, volunteers, and venue management at the venues.

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(NCEP), two high-resolution mesoscale models were run in support of the Olympics to provide additional information to the forecast process. The Eta-10 was run at the Cray Research facility in Eagan, Minnesota, and at the NCEP. The domain of the Eta-10 was roughly the eastern half of the United States. The model was run at 0300 and 1500 UTC daily during the Olympic Games out to 45 h in 3-h increments. The RAMS was run at the OWSO at both 8- and 2-km horizontal resolution with the same domain as LAPS for the 8-km resolution and a movable domain for the 2-km resolution. The RAMS model was run every day every 3 hours from 0600 to 2100 UTC. The model runs generally ran to 14 or 15 hours before the next model run would start. [See Snook et al. (1997) for more information on the implementation and use of RAMS during the Olympics and Black et al. (1997) for more information on the implementation and use of the Eta-10 during the Olympics.]

The NWS radiosonde sites, in states surrounding Georgia, made special 0300 and 1500 UTC radiosonde releases. These soundings were used as part of the initial conditions for the Eta-10 model. In addition, a 1600 UTC sounding was taken each day during the games at Peachtree City, Georgia (site of the OWSO), for a better “convective potential” examination than the 1200 UTC sounding typically offers.

There is no clear-cut line where forecast operations end and warning/watch operations begin. To assist in moving downscale from the standard forecast package to mesoscale watch/warning operations, the OWSO developed a mesocast form (Fig. 2) to be filled out by the mesoanalyst. The purpose of the form was to document key mesoscale features (cloud boundaries, wind shift lines, fog shadows, precipitation footprints, existing radar echoes, etc.) and to make a one-hour forecast of radar echoes, lightning, winds > 10, > 20, and > 30 mph and RH > 90%. This form was an attempt to focus all the mesoscale data sources (surface observations, radar, satellite, etc.) into one form for a comprehensive look at the situation.

## 5. Watch/warning operations

Peak staffing at the OWSO centered around the daily convective potential (Rothfusz et al. 1998). Two, two-person teams dedicated to mesoscale operations were scheduled daily from 1400 to 2200 EDT. Each team was comprised of one person doing mesoanalysis (completing the mesocast form with the aid of

LAPS) and observational data while the other person interpreted the WDSS and issued warnings with the WWA. Watch/warning decisions were made jointly by the team members. Each team was responsible for either north or south venues (Fig. 1) as shown below.

<b>North Team Venues</b>	<b>South Team Venues</b>
Ocoee	Olympic Ring
Lake Lanier	Atlanta Beach
Athens	Wolf Creek
Stone Mountain	Columbus
Georgia International Horse Park	

Note that the yachting venue, Wassaw Sound, was the responsibility of the Olympic Marine Weather Support Office (Powell and Rinard 1998).

### a. Mesocasts

Mesoscale forecasts or “mesocasts” were prepared by the mesoanalysts every two hours from 0600 LT until noon and then hourly until 2100 LT. Although this form was not distributed externally, it was used as a tool for constantly and consistently monitoring mesoscale phenomena.

A special form with three base maps was developed for this purpose (Fig. 2). The first map, known as the “Key Mesoscale Features Map” (Fig. 2, upper left), documented, for an extended period, those areas that might support convective initiation. Peripheries of areas where fog dissipated in the morning, rain fell the previous day, or clouds were prevalent, were noted as possible locations for convective initiation. In addition, wind shifts and strong gradients of moisture and temperature were indicated on the form.

The First Echo and One-Hour Precipitation Mesocast Map (Fig. 2, upper right) was used to indicate the prediction of the onset and subsequent movement of convection/precipitation. The location and time of first echoes (> 20 dBZ) were indicated by identifying a block of four counties in which echoes were expected to form and by labeling the expected initiation time. The forecasters utilized all available observational data sources, model forecasts, experience, and understanding to make these forecasts with no particular formula or method. There was no attempt to verify these forecasts. The forecasts were simply a useful means by which the forecasters could document their thoughts for others in the OWSO to see and use as a guide for the coming hour(s).

Finally, the One-Hour Nonprecipitation Mesocast Map (Fig. 2, lower right) was used to indicate the forecast position of key weather features important to Olympic venues (Table 1).

*b. Watches, warnings, and updates*

All OWSO watches, warnings, and statements were issued with the WWA. Any standard NWS watches and warnings (e.g., severe weather, tornado, and flash flood) issued by the NWSFOs or national centers that had watch/warning responsibility for the Olympic venue areas were “passed through” to the OWSO customers. WWA was configured to “reissue” these products and it was the responsibility of the OWSO forecasters to monitor NWSFO, National Hurricane Center, and Storm Prediction Center activities for their original issuance.

For all nonstandard Olympic weather products, the WWA would automatically include information relating to the nature of the watch, warning, or update statement. OWSO forecasters added a discussion section for each product. Forecasters were required to include the following information in all discussion sections:

- 1) the expected onset time of the phenomenon,
- 2) the expected intensity of the phenomenon, and
- 3) the expected end time of the phenomenon.

When warnings had been issued, or when activity for which a watch had been issued approached warning criteria, updates or Weather Status Statements were issued as frequently as every 10 minutes. OWSO support of pre-Olympic events demonstrated that statements issued as frequently as every 10 minutes were necessary when a warning for a convective phenomenon was in effect to keep

the competition and venue management abreast of changes. Over 1200 updates were issued during the support of the Olympics (7 July–4 August 1996). WWA’s ability to advise forecasters as to when follow up statements were due was a tremendous asset. Table 1 lists the variety of venue-specific watches and warnings that were required of the OWSO and the planned frequency of updates.

*c. Verification of watches and warnings*

Great care was taken by the OWSO staff to determine if watches and warnings verified. A watch/warning verification log was maintained by the mesoanalysts. A watch or warning verified if the phenomenon was

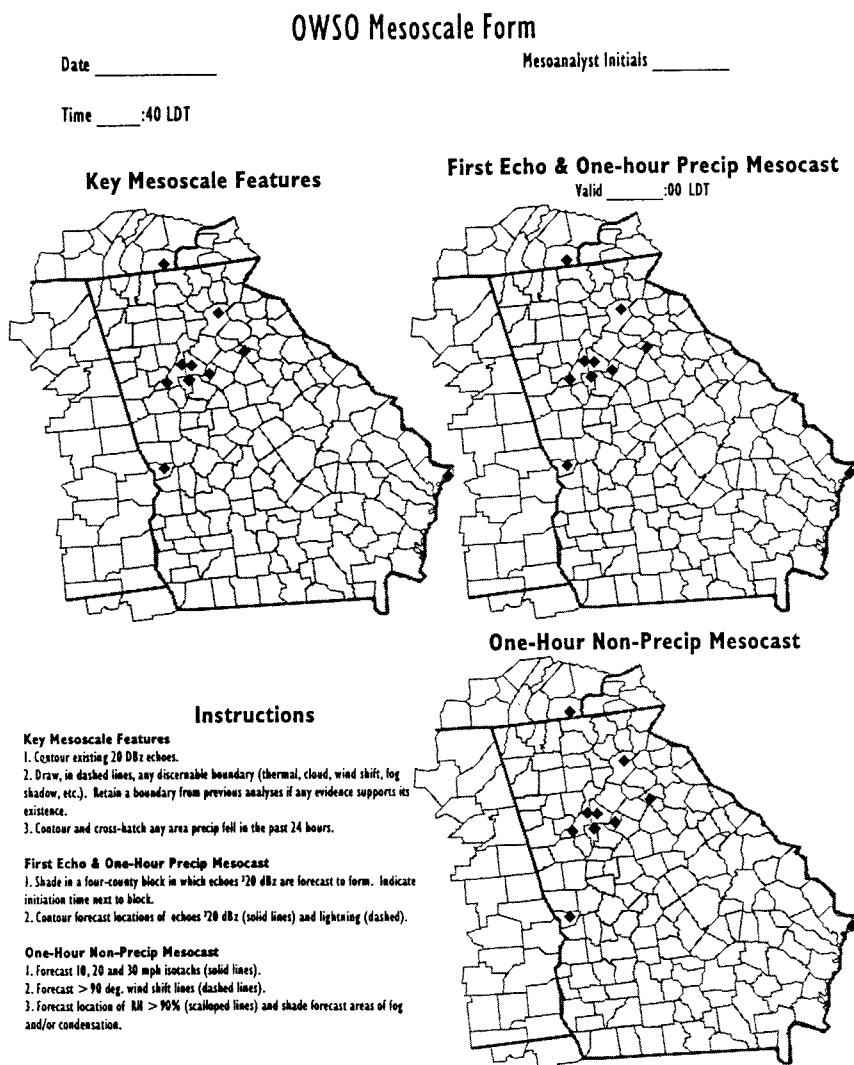


FIG. 2. Mesocast form used in support of the 1996 Olympic Games. Upper-left map is for denoting key mesoscale features, such as boundaries (thermal, cloud, wind shift, fog shadow, etc.). The upper-right map is for first echo and 1-h precipitation mesocast. The lower-right map is for 1-hour nonprecipitation mesocast (wind speeds, direction, RH).

confirmed at the venue site. Warnings for multiple phenomena were verified for each phenomenon at each venue. For example, a lightning and heavy rain warning issued for Atlanta Beach and Wolf Creek constituted four warnings. The existence of lightning alone would only verify the lightning portion of the warning (one verification for each venue). Heavy rain would have had to have been verified separately for each venue.

The forecasters were encouraged to use all available resources in determining whether or not a watch/warning verified or if an unwarned event occurred. This usually involved calling the Venue Communications Center (VCC) and questioning the venue management about the events that transpired. These calls typically took place during the duration of the warning or shortly after the expiration of the warning. If some observational data (e.g., radar data, surface observation) were received that indicated the possibility of an unwarned event, a call to the VCC was made to verify the conditions. A few warnings were verified by off-duty forecasters watching a competition on television while still others were verified by observational data (e.g., a mesonet observation of a 30 mph gust at a venue site would verify a high wind warning, and a lightning strike in the NLDN data stream within 5 n mi of the venue would verify a lightning warning). A correct hit was credited for a watch or warning if the warned for event occurred during the valid time of the warning, otherwise, the watch or warning was declared a false alarm.

The final verification statistics are shown in Tables 3 and 4. Table 3 provides the statistics for watches issued during the period 7 July–4 August 1996. A total of 571 watches were issued during the period with the majority being for lightning (210), heavy rain (181), and high heat indices (59). The high FAR is indicative of the type of criteria used to issue watches. The philosophy was to minimize the risk of catching the customer off guard to a potential weather situation. Even if only the slightest chance existed for a phenomenon to occur, a watch was issued. A state of readiness was accomplished at the VCCs with the issuance of a watch. The greatest success (CSI) for watches was the issuance of watches for lightning (38%).

Table 4 provides the statistics for warnings issued during the period 7 July–4 August 1996. A total of 663 warnings were issued during the period with the majority being for lightning (228), light rain (237), and heavy rain (125). Success rates for warnings were between 60% and 70% for these most frequent phenomenon. The reasons behind these successes are discussed

below in section 6. The most difficult phenomena to warn for were wind direction changes and dew formation. The reasons behind these failures are discussed below in section 6.

## 6. Discussion of challenges

Most of the watches and warnings issued during the Olympics had much lower thresholds than that for which the NWS traditionally issues watches and warnings. These thresholds were put into place because of the need to not only protect life and property but to provide weather information that could affect an athletic competition. Alerting the customer to the occurrence of these lower threshold phenomena was scientifically and technically challenging. Some of these challenges were addressed by supplying forecasters with high temporal and spatial resolution observations and forecasts. In addition, the tools available to the forecasters made the examination of these data efficient and effective. However, as the statistics show, there was room for improvement.

### *a. Lightning*

Lightning was the weather phenomenon most feared by venue and competition management. It can be quite daunting to have 100 000 spectators in an open-air stadium and have lightning in the vicinity. While lightning is an obvious concern for outdoor venues, the indoor venue management had to manage crowds outside their venues and the occurrence of lightning impacted this crowd management. Lightning warnings were considered successful if thunder was heard at the venue or if a lightning strike was indicated in the NLDN data stream within 5 n mi of the venue during the valid time of the warning.

Lightning accounted for 31% of all the warnings and 37% of all the watches issued by the OWSO. The 72% probability of detection (POD) for lightning watches and 83% POD for lightning warnings indicates good skill at recognizing the factors that lead to the occurrence of lightning. However, the false alarm ratio of 25% for warnings and 55% for watches indicates a significant amount of uncertainty in these factors.

For lightning watches, forecasters looked for all the factors that are generally considered for thunderstorm development (instability, moisture, lift). If thunderstorms were even a slight possibility, a lightning watch was issued. Thus a high FAR for lightning is not surprising.



For lightning warnings, the forecasters were forced to rely more on the tools that were at their disposal rather than relying on a generally accepted method. The tools included the 15-minute *GOES-8* satellite data (via RAMSDIS) the WSR-88D data and displays (via WDSS), the LAPS analyses, and the surface mesonet data. Warnings for lightning were most often triggered by existing thunderstorms anticipated to move over the venue of interest. The less frequent and more difficult situation was forecasting the onset of lightning from clouds that either did not yet exist or had been detected by the radar for no more than a few minutes. For the first few days of the Olympic weather support, the forecasters examined WSR-88D data looking for reflectivity echoes located near the freezing level (Hondl and Eilts 1994) by using the multipanel display in the WDSS. This technique was determined to be unreliable for the summertime Georgia environment and led to too many false alarms. Forecasters began using storm top above 20 000 ft as a predictor which seemed to work better. There is obvious room for improvement in finding better predictors for the onset of lightning and more research is needed in this area.

#### *b. Heavy and light rain*

While most venues were primarily concerned about heavy rain, some venues were concerned about the occurrence of any rain (these venues were outdoor venues with playing fields that could be hazardous for competition). As with lightning, issuing a watch for heavy or light rain was essentially an extension of developing a forecast with heavy or light rain in the 24-hour forecast. However, with the warnings there were two modes or types of scenarios: 1) issuing a warning for existing precipitation that was expected to move over the venue(s) of interest, and 2) issuing a warning for developing precipitation in the vicinity of the venue(s).

For heavy and light rain warnings of the first type, the use of the looping capability (of radar reflectivity) of the WDSS and the track forecast feature of the Storm Cell Identification and Tracking Algorithm (Johnson et al. 1998) was sufficient to provide enough information to the forecasters on whether existing precipitation would move over the venue(s) of interest. These warnings were generally valid only for 30–45 minutes and thus the extrapolation of existing motions worked sufficiently well. For events of the second type, the use of the WDSS multipanel display and

the RAMSDIS satellite display provided the most insight into precipitation development. The biggest challenge was in determining both if the radar echo or clouds seen on satellite would develop precipitation and, if so, how long formation would take. Traditionally, NWS forecasters do not have to concern themselves with whether or not a cloud or low reflectivity radar echo will produce any precipitation, rather they have to be more concerned with more substantial storms and whether or not they will produce very heavy rain, damaging winds, hail, or tornadoes. Thus, being concerned with the other end of the spectrum was a challenge for the OWSO forecasters. Even so, the forecasters were quite successful in the both watches and warnings for heavy and light rain. The use of data integration and convective initiation tools (e.g., Wilson and Mueller 1993) would likely have been tremendously useful for these situations.

Occurrence of precipitation was verified by the forecasters calling the VCC and questioning the venue management about the nature of the precipitation and by rainfall measurements at the mesonet sites located at venues. On occasion, precipitation occurrence was verified by radar observation of precipitation at a venue.

#### *c. Wind speed*

Table 1 shows that most venues were concerned with wind speeds greater than 30 mph, but several were concerned with wind speeds greater than 20 mph and one with wind speeds greater than 10 mph. The weather pattern in Georgia during the summer of 1996 was dominated by a high pressure system that was not conducive to wide-spread high wind events. Thus, the concern over winds greater than 30 mph was limited to thunderstorm situations and their resulting outflow. These events were generally not difficult for the forecasters to determine. Watches for high winds were generally handled similar to lightning; with a forecast of thunderstorms, a watch for high winds was issued. In general, warnings for high winds were always issued when a thunderstorm was expected to move over or very near the venue(s) of interest.

The 20-mph criteria was similar to the 30-mph criteria. Winds in Georgia during the summer typically do not exceed 20 mph except in thunderstorm situations. The biggest warning challenge for wind speeds was at Lake Lanier (Fig. 1), site of the rowing competition. With a watch/warning criteria of wind speeds greater than 10 mph, this venue received the majority of the 32 wind warnings and 41 wind watches. The

watches were generally issued when forecast models were forecasting surface winds greater than 7 mph. Forecasters relied heavily on the surface mesonet station near the Lake Lanier venue for wind warnings at the venue. However, the siting of the mesonet station was not optimal for this purpose. The mesonet station had to be located on a ridge above the rowing site on the lake. Thus, using the mesonet station to make warning decisions for the Lake Lanier venue was difficult. This required more of a reliance on communication with the venue site about the wind conditions.

Tables 3 and 4 show that the wind watches had a low (23%) POD and high FAR (85%). However, the warnings were more successful, 73% POD and 50% FAR. The lack of success for the watches is due to the lack of spatial resolution in the forecast models and thus the ability to predict the small variations in the wind field that were needed to discern the need for a watch. The better success with the warnings is likely due to the high resolution of the observational sensors (radar, satellite, and surface mesonet), but the rather high FAR is likely due to not high enough resolution in the surface mesonet for detecting the detailed features of the thunderstorm outflows and sampling limitations of the WSR-88D.

#### d. Wind direction

No wind direction change watches were issued during the period 7 July–4 August 1996. A 90° wind direction change was the criteria and forecasters had to rely (for watches) heavily on the mesoscale forecast models to predict deep convection. With the wind direction change being an issue at only five venues, forecasters had to either trust the forecast models explicitly about the timing and location of deep convection or only issue watches for more obvious events (such as fronts). Only three wind direction change warnings were issued, none of which verified. Two events actually occurred that went unwarned. It is apparent that the scale of the phenomenon that occurred was much smaller than the resolution of the observational tools in place.

#### e. Heat index

Summer in Georgia can be quite hot and humid and thus the heat index can be quite high at times. Competition and venue management alike were concerned about the health and safety of the athletes, spectators, and workers. Heat index was chosen as the measure for which to gauge heat stress and thus watches and warnings were issued for events with

TABLE 3. Probability of Detection (POD), False Alarm Ratio (FAR), and Critical Success Index (CSI) for the various phenomenon for which *watches* were issued during the Olympics.

Phenomenon (verified events)	POD	FAR	CSI
Lightning (95)	72%	55%	38%
Heavy rain (58)	74%	68%	29%
Light rain (38)	51%	51%	27%
Wind speed (6)	23%	85%	10%
Wind direction change (0)	—	—	—
Heat index < 100°F (29)	91%	51%	47%
Visibility > 1 mi (0)	0%	—	—
Dew formation (2)	22%	33%	20%
Hail (any size) (0)	0%	—	—
Total (228)	64%	60%	33%

TABLE 4. Probability of Detection (POD), False Alarm Ratio (FAR), and Critical Success Index (CSI) for the various phenomenon for which *warnings* were issued during the Olympics.

Phenomenon (verified events)	POD	FAR	CSI
Lightning (155)	83%	25%	65%
Heavy rain (78)	93%	38%	60%
Light rain (170)	96%	28%	70%
Wind speed (16)	73%	50%	38%
Wind direction change (0)	0%	100%	0%
Heat index > 100°F (29)	94%	29%	67%
Visibility < 1 mi (3)	100%	0%	100%
Dew formation (6)	100%	54%	46%
Hail (any size) (0)	0%	100%	0%
Total (457)	89%	31%	64%

a heat index greater than 100°F. There were 59 watches and 41 warnings issued for high heat index. Forecasting for this phenomenon was much more traditional and the additional tools available to the forecasters appear to have been helpful for predicting these events as shown by the high POD and low FAR numbers for both watches and warnings (Tables 3 and 4). However, it is difficult to truly determine if the additional tools made an improvement because the NWS does not traditionally issue watches and warnings for heat index.

*f. Visibility*

Visibility was one of the more obscure phenomena requiring prediction during the Olympics. The NWS does traditionally issue public advisories and forecasts for dense fog. Only in aviation forecasts is there a need to be concerned about the density of the fog. The forecasters at the OWSO were asked to forecast and issue watches and warnings for situations with visibility less than 1 mi. In general, the forecasters were forecasting conditions of RH of > 95% and attempting to equate the RH with a visibility. The two visibility watches that were issued did not verify. The three visibility warnings issued all verified.

*g. Dew formation*

Dew formation was likely the most challenging phenomenon to forecast during the Olympic Weather Support effort. Watches and warnings for dew were required at the velodrome (a banked oval cycling track). Any moisture on the track created hazardous conditions for practices and competitions. For issuing watches, forecasters relied on model forecasts of temperature and moisture as well as the previous day's observations. For issuing warnings, forecasters relied more on the observations of dewpoint and temperature from the mesonet sensors at the venue site. Unfortunately, the mesonet unit could not be sited optimally and thus the usefulness of the temperature and dewpoint were limited. Confirmation of the formation of dew was critical for determining the reliability of the sensors and for determining the measured temperature/dewpoint spread at which dew actually formed. During the early morning and late evening hours, frequent calls were made to the venue site to confirm the moisture conditions on the track. These reports were compared to the mesonet sensor readings for calibrating the sensors. It took several days for the forecasters to gain understanding about what conditions/readings resulted in dew formation on the track.

In general, watches for dew formation were not issued. The warnings became the standard bulletin for alerting the users. Thirteen dew formation warnings were issued with a POD of 100% and a FAR of 54%.

## 7. Observations and recommendations

In supporting the 1996 Summer Olympic Games, the National Weather Service undertook a tremendous challenge of assembling cutting-edge technology, working with a new customer and forecasting and warning for low threshold weather phenomena. However, the experience was a bona fide success by all accounts from the participants, the customers, and the resulting watches and warning statistics. The experience provided insight into the needs, concerns, and issues of the NWS office of the future and for similar support efforts.

Watch/warning operations within the Olympic Weather Support Office included using new technology tools and methods to 1) issue new types of warnings, 2) provide more frequent information, 3) provide point watches and warnings for venues rather than area (county based) watches and warnings, and 4) provide specific information about a situation. Several recommendations and observations about OWSO watch/warning operations may benefit future NWS operations support efforts, as follows.

- The practice of issuing follow-up statements rapidly—as often as every 10 minutes during thunderstorms—until the weather episode ended made the warning program particularly successful. This impacted the operational workload, but software like WWA minimized the impact. Olympic officials commented that the continuous stream of post-warning statements made them feel that their interests were truly being tended. The ratio of statements to warnings was over 2:1. It is recommended that a similar practice be adopted for standard NWS warning operations.
- Customers were especially pleased with the three required elements in the discussion section of each watch, warning, and statement: When the event would start, how bad it would get, and when it would end. It is recommended that such information be included in all NWS bulletins and short-term forecasts.
- During the early days of the Olympic weather support verification statistics were not as good as one would have hoped. This was likely due to some un-

familiarity with the technology and the forecast domain (only two of the forecast staff were from NWS forecast offices in the southeast United States). However, overall warning verification statistics of the OWSO showed POD and FAR scores declined (to 0.89 and 0.31, respectively) and the CSI improved to 0.64 during the period of support. The decrease in POD scores was likely due to a reduction in “broad-brush” warnings. The decrease in FAR scores, on the other hand, was probably evidence of forecasters’ increased skill with the new technology. Forecasters were in general agreement that the scores would only improve with more experience with the new technology. It is recommended that all watch/warning verification statistics be evaluated over a period of time before, during, and following the introduction of new technology to determine if the new technology had an impact on the results.

- Forecasters used the WDSS multipanel display to locate the existence of 10 dBZ or more of radar reflectivity above the freezing level as a potential indicator of lightning. This proved to be unreliable. Although forecasters eventually discovered a better predictor (storm top above 20 000 ft) more research is needed for “forecasting” lightning on the 10–15-minute timescale.
- With the watch/warning criteria thresholds so much lower than the standard NWS criteria, it was often necessary to look for the existence of first echo, and, depending on the stability of the atmosphere, decide on whether or not to issue a warning. Waiting for a storm to show up as an identified storm cell (via the Storm Cell Identification and Tracking algorithm) was often too late. Among other tools, WDSS’s multipanel display of several elevation angles at the same time was useful in these situations.
- The mesocast form became an integral part of the mesoscale forecast operations. It helped forecasters track and focus their thoughts on possible mesoscale forcing mechanisms. It is recommended that a similar device for tracking mesoscale features—even for long periods of time—be devised for NWS operations. Such a device could be in paper format, but tools (software) that integrate data and provide guidance on convective initiation should be the ultimate goal (e.g., the Autonowcaster; Wilson and Mueller 1993). It is recommended that the NWS take action to provide these types of tools in their operational systems.

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