NOAA Technical Memorandum NWS SR-179

PROVIDING WEATHER SUPPORT FOR THE

1996 SUMMER OLYMPIC GAMES

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Prologue

The 1996 Summer Olympic Games are scheduled to be held in the United States, specifically, in and in proximity to Atlanta, Georgia. A total of 34 venues (including the opening and closing ceremonies) are planned for the Games, and will take place from Friday, July 19, through Sunday, August 4.

On July 14, 1992, the Atlanta Committee for the Olympic Games (ACOG) requested the National Weather Service (NWS) provide meteorological support for the 1996 Olympic Games. On November 30, 1992, the NWS agreed to provide the requested weather support for the Games.

The NWS will be providing support in three broad areas.

- Support will be provided to ensure that adequate warning and forecast services are available to provide for the protection of the athletes and the spectators.

- Support will be provided to satisfy requirements at the various venues for meteorological data to assist ACOG officials in weather contingency planning.

- Meteorological support will be provided to meet the requirements of the various international, federal, state, and local entities which will be providing logistical support to ensure the safe conduct of the Games.

To meet these meteorological support requirements, the NWS plans to operate two Olympic Weather Support Offices (OWSO)—one in the Atlanta area at the new combined weather and river forecast office at Peachtree City, Georgia, and the other in quarters to be provided by the Olympic Committee at Wilmington Island, Georgia.

The two OWSOs will be equipped with some of the latest computer technology available, including Hewlett-Packard and SunSparc Workstations and an IBM Massively Parallel Processor known as an SP2. The workstations will be running the National Centers for Environmental Prediction (NCEP) N-AWIPS software (National Advanced Weather Interactive Processing System); the Local Analysis and Prediction System (LAPS) software supplied by NOAA's Office of Oceanic and Atmospheric Research Forecast Systems Laboratory (FSL); the National Severe Storms Laboratory's new Warning Decision Support System (WDSS), and other specialized software to be developed specifically for Olympic support activities, such as the NWS's Interactive Computer Worded Forecast system. The IBM SP2 will process the Regional Atmospheric Modeling System (RAMS), supplied jointly by the University of Colorado, the National Center for Atmospheric Research (NCAR) and FSL.

Very large volume, high speed communications circuits will supply the two OWSOs with the output of NCEP's high resolution numerical models; and thanks to a special collaborative effort between the NCEP and Cray Research, Inc., some of NCEP's models will be run at very high resolution, especially for the Olympic Games. Also available will be high resolution satellite imagery from GOES-8; wideband data from several of the NWS's new Doppler Weather

Surveillance Radars (WSR-88D); real time lightning data, and frequent meteorological observations from a number of automatic weather observing systems (AOS) which will be operated at selected locations in and around the Atlanta and Savannah areas. Weather warnings, forecasts, and other weather information will be disseminated to the Olympic officials and venues via the Atlanta Committee for the Olympic Games' Info 96 System.

The intent of this overall effort is to supply the 1996 Olympic Games with the best meteorological warning and forecast support possible to ensure the safety of the athletes and spectators, and to showcase, in the international arena, the new technology which will be used throughout the modernized United States National Weather Service.

The papers collected in this technical memorandum were first presented at the American Meteorological Society's 76th Annual Meeting which was held in Atlanta, Georgia, January 29 through February 2, 1996, and are reproduced with permission of the AMS. Specifically, the papers were part of the 12th International Conference on Interactive Processing Systems (IIPS) for Meteorology, Oceanography, and Hydrology and the Conference on Coastal Oceanic and Atmospheric Prediction. The papers give a technical, albeit brief, overview of the technology which is being used in the weather support effort, including hardware, software, and communications arrangements. Also included are papers which describe the training effort being used to prepare the meteorologists who will be doing the forecasting and a paper which describes the strategies and experiences of this major, state-of-the-art weather support effort.

THE OLYMPIC WEATHER SUPPORT SYSTEM

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1. INTRODUCTION

On July 14, 1992, the Atlanta Committee for the Olympic Games (ACOG) formally asked the National Weather Service (NWS) to provide meteorological support for the 1996 Summer Olympic Games. These Games will be held at 34 venues in and near Georgia; taking place July 19 - August 4, 1996. On November 30, 1992, the NWS agreed to provide the requested weather support.

The weather support will be in two broad areas. First, support will be provided to satisfy meteorological data requirements at the various venues and to ensure adequate warning and forecast services are available for the protection of athletes and spectators. Second, support will be provided to meet the requirements of International, Federal, State, and Local entities providing logistical support for the Games.

To meet these requirements, the NWS will operate two support offices in Georgia. The Olympic Weather Support Office (OWSO) is located in the Atlanta area at the collocated Weather Forecast Office (WFO) and River Forecast Center (RFC) in Peachtree City, while the Olympic Marine Weather Support Office (OMWSO) is located in quarters at the Olympic Marina near Savannah.

The technological heart of the Olympic forecasting operations is the Olympic Weather Support System (OWSS), a state-of-the-art, local area network constructed exclusively for operational forecasting. This paper will provide an overview of the goals, hardware, software and data of the OWSS. Companion papers in this volume provide additional details about the components of the OWSS.

2. GOALS OF THE OWSS

Four major goals were identified for the OWSS: Accessibility, integration, intuitiveness and data portability. To meet the needs of forecasters providing Olympic weather support, the OWSS had to have a wide variety of information available quickly (accessibility), on a single, standardized workstation platform (integration), in an easy-to-understand format (intuitiveness) and with output products universally receivable (data portability). Thus, the OWSS was constructed with software and hardware that met these criteria.

2.1 Accessibility

In mid-1994, the NWS provided a questionnaire to the Atlanta Committee for the Olympic Games (ACOG) which was designed to help the NWS identify the weather information needs of its ACOG customers. Evaluating the questionnaire responses also aided in the design of the OWSS, thereby ensuring the system would contain the data and functionality necessary for forecasters to meet the demanding needs of their customers.

The questionnaire respondents had a wide variety of specific weather concerns, many of which were unique to their respective events. Rowing competition officials, for example, are concerned about southeast winds (which would favor competitors in the wind-blocked southeastern rowing lanes), while tennis officials are not concerned about wind direction but are very concerned about any precipitation occurring. Some concerns are common to many respondents, such as high temperatures and high humidities. Lightning is the concern common to all respondents. Despite having both varied and common weather concerns, all respondents indicated a need for weather parameters to be forecast in high temporal resolution; ideally, at three-hour intervals.

In addition, Olympic officials desire immediate notification if certain weather phenomena are expected to affect their activities. The diving competition officials, for example, require notification (e.g., a warning) when surface winds greater than 20 mph (32 kph) are expected.

Given the varied and specific weather concerns of the ACOG customers and their need for high resolution forecasts, the OWSS had to provide rapid access to multiple high-resolution data sets (e.g., radar, satellite, numerical model and observational data). Thus, software and hardware chosen for the OWSS (see sections 3 and 4) were selected for their rapid access to data.

The remote location of the OMWSO in Savannah presents another issue related to data accessibility. Because the OMWSO is located 250 miles (400 km) from the OWSO, high-speed communications had to be established to rapidly provide OMWSO forecasters the data needed from the OWSS data server in Peachtree City.

2.2 Integration

Both Olympic support offices have limited workspace available for operations. The OMWSO, for example, is housed in a 40 foot trailer while the OWSO occupies 225 square feet in the Peachtree City WFO/RFC. Because of the limited space, the OWSS was designed to integrate resources into a common workstation platform. Integration was also crucial to achieving the goal of rapid accessibility to data.

There are eight major software components integrated into the OWSS. They include the National Centers Advanced Weather Interactive Processing System software (N-AWIPS), the Interactive Computer Worded Forecast (ICWF) software, the Warning and Decision Support System (WDSS), the Local Analysis and Prediction System (LAPS), the GEneral Meteorological PAcKage (GEMPAK), the SHARP Workstation for UNIX, the RAMM Advanced Meteorological Satellite Demonstration and Interpretation System (RAMSDIS), and WordPerfect for UNIX. Except for RAMSDIS, which runs on a stand-alone personal computer (PC), all of these programs have been integrated into a UNIX-based, Hewlett-Packard workstation environment. This software is described more fully in Section 3.

2.3 Intuitiveness

The staffs of the OWSO and OMWSO are comprised of NWS meteorologists from across the U.S. and meteorologists from Australia and Canada. Many of these forecasters were unfamiliar with the OWSS software and most had never used it in an operational setting. Also, the unique weather concerns of the Olympic customers necessitated the development of forecast and warning products not typically found in the NWS. Thus, even the most experienced NWS forecasters were forced to spend a good deal of time learning the new products *and* developing an operational routine with the new software. Because of this, it was imperative that the data interpretation and product preparation software on the OWSS be user-friendly and intuitive. This was a crucial need from a training standpoint, as well, since training time was limited (Rothfusz, et al. 1996b)

2.4 Data Portability

The forecast, warning and observational data created on (or collected by) the OWSS are sent to a variety of external users. In 1996, the primary recipient of these products will be a wide-area network called Info '96. Currently under development by ACOG, Info '96 is a network of PCs distributed throughout the Olympic venues and is served by an IBM AS/400. Info '96 will contain weather information, athlete biographies, competition results, transportation schedules, etc. A dedicated line will link the OWSS to Info '96. Although products transmitted to external users will be in textual format (Rothfusz, et al. 1996a; Johnson, et al. 1996a), Info '96 will convert this textual information into easily-understood graphics. For example, forecasts of three-hourly temperatures in text format will be displayed by Info '96 as a 24-hour time series graphic.

Media covering the Olympic Games will have access to all weather information available on Info '96. Other external users, such as the local media and emergency management officials, will acquire the OWSO and OMWSO products via alternate means. For example, a selected set of Olympic weather support information will be provided on the Internet via the World Wide Web, on the Family of Services via a T1 link to the National Centers for Environmental Prediction (NCEP), on the Automation of Field Operations and Services (AFOS) Regional Distribution Circuit via a link with the Peachtree City AFOS, on the NOAA Weather Wire Service (NWWS) via satellite uplink at Peachtree City, and on NOAA Weather Radio via transmitters near Atlanta and Savannah. Given the need to distribute Olympic weather support information to a wide variety of customers, the OWSS software had to produce products universally receivable.

3. SOFTWARE AND DATA FLOW

Forecasts and warnings of high temporal and spatial resolution for each of the venues require observational and forecast data of similar resolution. These data are utilized by the multiple components of the OWSS (Figure 1).

N-AWIPS, developed by the NCEP, provides the capability of generating and displaying meteorological fields from model gridpoint data, satellite data and alphanumeric products available on AFOS and the Family of Services data feed (Rothfusz, et al. 1996a). The models available for display on the OWSS N-AWIPS are shown in Table 1. Satellite imagery available to the OWSS via N-AWIPS (and RAMSDIS, see below) comes from the National Environmental Satellite, Data, and Informations Service (NESDIS) and the National Severe Storms Forecast Center (NSSFC) (Teble 2). GEMPAK programs are used to generate routine products within N-AWIPS and in an interactive mode to create cross-sections of model data, hourly surface plot overlaid on satellite imagery, etc.

The OWSS runs the ICWF software, developed by the Techniques Development Laboratory (TDL) in Silver Spring, MD (Ruth and Peroutka 1993; Rothfusz, et al. 1996a). This software allows forecasters to generate forecast products in various textual formats by manipulating databases initialized with model output statistics (MOS) data, gridpoint values from the Eta-29 model, or values entered by the forecaster on the previous shift. The software generates forecasts in narrative and matrix formats. Most of the routine forecast products prepared for Olympic weather support will be generated using the ICWF software.

WDSS is another component of the OWSS (Johnson, et al. 1996a). Designed by the National Severe Storm Laboratory (NSSL) in Norman, OK, it comprises the next generation of Weather Surveillance Radar - 1988 Doppler (WSR-88D) algorithms. Data are fed to the WDSS via a wide-band link with the Peachtree City WSR-88D radar. This wide-band interface provides base moment data (reflectivity, velocity, and spectrum width) to the WDSS. For the OMWSO in Savannah, base moment data will be available to the WDSS from the Charleston, South Carolina WSR-88D. The WDSS is comprised of a set of algorithms which use the base

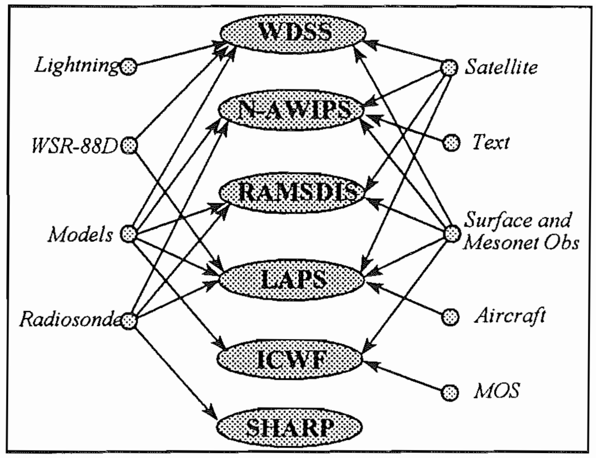

Figure 1. Schematic of OWSS components, data and data flow.

TABLE 1

Model	Run Times (UTC)	Run Extent
Eta-15	03 and 15	36 hrs
Eta-29	00, 03, 12, 15	36 hrs
Eta-48	00 and 12	48 hrs
RUC	3-hourly (00, 03...)	18 hrs
RUC sfc	Hourly	N/A
NGM	00 and 12	48 hrs
RAMS	06	18 hrs
LAPS	Hourly	N/A

TABLE 2

Image	Sector	Source	Destination
GOES-8, 1 km Vis	SE US	NSSFC	RAMSDIS/N-AWIPS
GOES-7, 4 km Vis	US	NESDIS*	N-AWIPS
GOES-8, 4 km Vis	SE US	NESDIS	RAMSDIS/N-AWIPS
GOES-7, 4 km IR	US	NESDIS*	N-AWIPS
GOES-8, 4 km IR	SE US	NESDIS	RAMSDIS/N-AWIPS
GOES-8, 4 km WV	SE US	NSSFC	RAMSDIS/N-AWIPS
GOES-7, 24 km WV	N Hem	NESDIS	RAMSDIS/N-AWIPS
GOES-7, 24 km IR	N Hem	NESDIS	RAMSDIS/N-AWIPS
GOES-8, 10 km Vis	W Atl.	NESDIS*	N-AWIPS

*via NCEP

moment WSR-88D data, satellite data, and real-time lightning data to derive a number of meteorological products (e.g., projected storm movement, probability of storm severity, probability of hail size, mesocyclone detection, tornado vortex signature detection and rainfall accumulation). Output from the algorithms are routed to the HP workstations for display.

LAPS, developed by the Forecast Systems Laboratory (FSL) in Boulder, CO, is a vital component of the OWSS. LAPS is comprised of high-resolution analysis software (Stamus, 1996) and the Regional Atmospheric Modeling System (RAMS) initially developed by Colorado State University (Snook, 1996). The analysis portion of LAPS is run hourly on the OWSS while RAMS is run once daily (see Table 1). Output from both components of LAPS are displayable on N-AWIPS (Johnson, et al. 1996b).

Local and regional data utilized by LAPS come from a variety of sources. Surface observations of standard meteorological variables are obtained hourly from NWS and FAA observation sites, and every 15 minutes from mesonetwork stations maintained by the University of Georgia, the NWS and the Georgia Forestry Service (Garza and Hoogenboom 1996). Finally, LAPS uses upper level data from WSR-88D radars, radiosonde soundings, automated aircraft reports, and satellite data. As a first guess field, LAPS uses the Rapid Update Cycle (RUC) model. It will use the Eta-8 (8 km resolution Eta model) for a first guess field in 1996.

While satellite imagery is available on the HP workstations using the N-AWIPS software, another means of interpreting imagery is via the RAMSDIS (Molenar, et al. 1995). RAMSDIS is designed to run on a Pentium PC and thereby does not meet the integration goal of the OWSS. Nevertheless, the powerful mesoscale forecasting applications of RAMSDIS were considered advantages that outweighed its non-integratability.

The UNIX version of the SHARP Workstation (Hart and Korotky 1991) is also installed on the OWSS. Like its PC-based relative, SHARP for UNIX allows forecasters to interactively adjust sounding information on Skew-T diagrams and hodographs. In addition, multiple soundings can be overlaid for comparison.

WordPerfect 6.0 for UNIX is the primary word processing software of the OWSS. WordPerfect macros were written to streamline the forecast and warning preparation process. To issue a warning, for example, a forecaster initiates a macro and is then led through a series of interactive GUI windows. The selections the forecaster makes in these windows dictate the type, format and recipient of the warning. Once the relevant selections are made, the forecaster simply types the text of the warning and then selects a "Send" button which archives the warning and automatically faxes it to the affected venue. Routine tabular information, such as summaries of current observations, are automatically formatted and faxed using locally-developed software. For Olympics support in 1996, the OWSS macros and programs will be modified to send products to Info '96 via a dedicated communications line, as well as maintaining the capability of faxing the products.

4. HARDWARE CONFIGURATION

The OWSS LAN at the OWSO in Peachtree City consists of two HP 755 workstations; three HP 715 workstations; a SUN SparcStation 5 and SUN SparcStation 20 for WDSS; and Pentium PCs for RAMSDIS and mesonetwork data ingest. All workstations are networked via an Alantec hub utilizing 10BaseT technology. Two T1's provide wide-area-network (WAN) connectivity to NCEP and Georgia Tech University. For the 1995 test events, three HP 715s at the OMWSO in Savannah were connected to the OWSS network via Gandolf bridges providing 8:1 compression over a 56 Kbaud circuit.

At the center of the OWSS LAN resides an HP 755 server responsible for the collection and distribution of all data. The server contains a 99 MHz RISC processor, 128 MB of RAM, four 2-gigabyte (GB) Fast-Wide SCSI drives, a CD-ROM SCSI drive, a 4 mm DAT internal tape drive and an 8 mm external tape drive. Software running on the server includes HP-UX 9.05, a local data manager (LDM), a communications link to AFOS called AFOSCOM, data reformatting software, LAPS, GEMPAK scripts, data archival scripts, the WordPerfect license server and the INFORMIX database engine for the ICWF.

Data arrive at the server from several sources (see Figure 2). Most data are sent to the OWSS via file transfer protocol (ftp). Family Of Services data are received from NCEP via LDM. Local mesonetwork surface data are collected by an OS/2-based Pentium PC.

About seven GB of disk space is allotted for storage of all data. That was found to be insufficient during the 1995 test events, so an additional 18 GB of storage will be in place in 1996, of which 9 GB will be added to the server.

Upon receiving data, the server initiates a series of scripts that reformat the data for use by other applications (see Fig. 1). Unfortunately, no messaging system is in place to notify the server of a file's arrival. Therefore, files are assumed to arrive in a timely manner or else UNIX cron jobs constantly poll the file system for the existence of needed files. Neither method is desirable. Assuming a file will arrive by a certain time introduces system delays and/or problems when that file is late. Polling for data consumes the server's resources. A more efficient method using the LDM is being devised for 1996.

All raw and processed data are archived before they are removed. An external 8 mm SCSI tape drive and 2

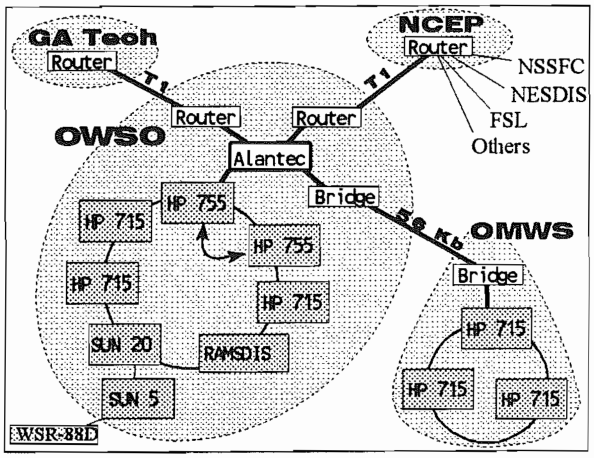

Figure 2. Schematic of the 1995 configuration of the OWSS, including links to the NCEP, Georgia Tech, and the OMWSO in Savannah. The double-headed arrow in the OWSO domain (large oval) represents mirroring between the primary and backup servers.

GB SCSI disk drive are connected to the server for that purpose. Due to the volume of data, archiving takes place every four hours. An archive script uses the UNIX cpio command to copy the previous four hours of data to a temporary directory. That directory is then "tarred" to a file that is compressed and stored on tape. An archive tape contains six four-hour cycles separated by end-of-file markers. A log containing a list of the archived files is created for each four-hour cycle and is stored on disk. Eight hours (two cycles) of data are kept on the disk to allow for recovery in the event of a full tape.

With all that is expected of the server, a second HP 755 was added as a backup in case the primary server fails. This backup server is nearly identical to the primary server. It runs a Perl mirroring script that monitors the primary server's data directories for changes and initiates ftp transfers in the event that those directories differ. Under normal operations, the backup server is the main Network File System (NFS) server for the HP 715 workstations of the OWSS. The N-AWIPS, WordPerfect and ICWF directories are exported for use by those workstations. In the event of the backup server failing, the 715s can switch to the primary server for applications and data.

The mirroring software is reasonably easy to install and is extremely versatile. It has options available for just about any situation that could arise. For example, when moving AFOS data, the time identifier of the original file must be maintained for N-AWIPS to work properly. Conversely, when receiving files from the NCEP, maintaining the original time stamp means that the data won't be archived. The mirror script can handle both situations. Also, the control over what does and does not get mirrored is easy to set up and modify.

On the negative side, mirroring is not efficient at maintaining directories that contain many small files. In fact, mirroring software can move ten one-MB satellite images faster than it can move ten 50 *byte* text files. The delay is caused by the comparison of the directories. When disk space is at a premium, delays of an hour or more have occurred. In times of high data traffic, data may never get mirrored.

The three HP 715s are used as X-workstations. They contain an 80 MHz RISC processor, 64 MB of RAM, a 2 GB internal SCSI disk drive and an external 4 mm DAT tape drive. One HP 715 is the mail hub and provides printer support; another runs the Domain Name Service.

The connection between the NCEP and the OWSO is a dedicated T1. Because of router incompatibilities, PPP protocol is used. The routers in the OWSO connect to an Alantec hub which is the backbone of the entire OWSS network. A second T1 circuit exists between Georgia Tech and the OWSS for the use by the WFO and RFC. Also, a 56 Kbaud circuit connects OWSS to the LAN at the OMWSO in Savannah.

The OMWSO LAN is comprised of three HP 715s networked via a 3Com 10BaseT hub. After initial tests, it was determined that the 56 Kbaud circuit between the OWSO and the OMWSO provided insufficient bandwidth. A pair of Gandolf bridges increased the data transfer from approximately 6 Kbytes/sec to 12 Kbytes/sec. Even with the improved transfer rate, it became evident that a T1 line would be needed to support the OMWSO operations in 1996.

Server responsibilities at the OMWSO are handled by an HP 715 with an 80 MHz RISC processor, 64 MB of RAM, an internal 2 GB SCSI drive, three external 2 GB SCSI drives and an external 4 mm DAT tape drive. Due to the limited bandwidth of the 56 Kbaud circuit and the limited processing power of an HP 715, the OMWSO server mirrored only limited data from the OWSO server during the 1995 test events.

5. SUMMARY

The Olympic Weather Support System has been developed in response to the high-resolution weather forecast and warning needs identified by officials associated with the 1996 Summer Olympic Games. The needs of these customers - and the needs of the forecasters supporting them - dictated that the hardware, software and data of the OWSS must be fast (accessible), integrated, intuitive, and portable. For the most part, these goals have been achieved by utilizing powerful off-the-shelf hardware and state-of-the-art software, much of which was developed by agencies of the National Oceanic and Atmospheric Administration (NOAA). Specifically, the software of the OWSS was developed by NCEP (developers of N-AWIPS), TDL (ICWF), NSSL (WDSS), FSL (LAPS), CIRA (RAMSDIS), and the support staff of the OWSO in Peachtree City, Georgia. The hardware and communications have been configured for the OWSS with the help of NCEP, NSSL, the Mountain Administrative Support Center (MASC) and the Southern Region Headquarters of the NWS.

The OWSS represents the first integrated, operational implementation of many of its components. By providing rapid access to observational, satellite, radar, local- and remotely-run model data (all of which are at high-resolution); and by giving forecasters more time to spend evaluating weather information rather than creating products, the OWSS gives a glimpse of the future (AWIPS-era) operational forecasting environment of the National Weather Service.

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The Integration of Diverse Environmental Data Collection Systems Used In Support of the 1996 Olympic Games

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1. INTRODUCTION

Weather support for the 1996 Olympic Games will be provided by the National Weather Service (NWS) through two "weather offices"; the Olympic Weather Support Office (OWSO), located within the combined NWS Weather Service Forecast Office and River Forecast Center (NWSFO/RFC) located in Peachtree City, GA, and the Olympic Marine Weather Support Office (OMWSO), located at the Olympic Marina near Savannah, GA. Both of these offices will be equipped with state-of-the-art computer workstations and software to be used in running the latest technologically advanced analysis and forecasting numerical models, such as the Local Analysis and Prediction System (LAPS) and the Regional Atmospheric Modeling System (RAMS) (Johnson, et al. 1996). Basic to the success of this venture is the amount and quality of data that can be made available and fed into these high-resolution models.

The Atlanta Committee for the Olympic Games (ACOG) has indicated that it will be also important and vital to officials, athletes, and spectators to have surface atmospheric conditions, such as temperature, wind speed and direction, and humidity available on a real-time basis at the numerous venue sites. The data will be provided through ACOG's information system, INFO '96 to venue management officials, sports officials, coaches, and athletes, and broadcast to numerous hotels in the area (McLaughlin., et al. 1996). These and other requirements made known to the NWS reinforced the need to have a dense meso-network of observing sites that would also include monitoring at or near many Olympic venues.

2. SURFACE WEATHER MONITORING SITES

The surface weather parameters to be used by most models will be temperature, moisture content (in the form of humidity, dewpoint temperature, etc.), wind speed and direction, rainfall information, and atmospheric pressure. Also of use, but not necessarily essential, to the models, will be information on soil temperature, solar radiation, and atmospheric pollutants. To provide these surface data, a myriad of automated meteorological observation systems in Georgia and the surrounding states will be accessed. While some systems existed prior to this olympic effort, there had never been a concerted effort to bring together as many differing systems as will be interrogated during the 1996 Summer Olympic Games.

2.1 NWS Observations Sites

The NWS has numerous offices and/or associated Automated Surface Observation Systems (ASOS) that will be accessed at 15-minute intervals during the 1996 Summer Olympic Games. ASOS sites in Georgia include those in Atlanta, Fulton County (west Atlanta), DeKalb (north Atlanta), Peachtree City, Cartersville, Gainesville, Athens, Augusta, Macon, Savannah, Brunswick, Alma, and Albany. Also being polled will be: in Florida, Jacksonville, Tallahassee, and Marianna; in Alabama, Dothan, Montgomery, Birmingham, Anniston, and Huntsville; in Tennessee, Chattanooga; and in South Carolina, Charleston, Columbia, and Greer.

The ASOS units measure atmospheric parameters, or "weather", that passes through a sensor array. The set of data is then collected over a specified time to provide what is considered a representative observation of conditions within a three- to five-mile area. Due to the algorithms involved, the parameters are sampled in the following manner : temperature (deg F) is the one-minute average, processed every five minutes; the wind's processing interval is every 2 minutes; and the pressure is processed every 1 minute.

2.2 University of Georgia Observation Sites

Traditionally, the NWS has been responsible for collection of weather data. However, various agencies have specific needs for weather data that could include either additional weather variables, more frequent monitoring, different sampling heights, and others. In Georgia, the University of Georgia, through its' College of Agriculture's Department of Biological and Agricultural Engineering, has implemented one of the largest automated weather station networks in the state (Hoogenboom, G. 1996).

The Georgia Automated Environmental Monitoring Network (AEMN) was begun in 1991 (Hoogenboom, et al. 1991). During the first year, four weather stations were installed at branch research stations spread across the state of Georgia. The AEMN currently has 20 automated weather stations and three more will be added during the Fall of 1995. Moreover, in response to a request from the National Weather Service in 1993, the UGA bought and installed eight additional units to be used specifically in support of the 1996 Summer Olympic Games.

The weather stations of the AEMN are based on the CR10 unit manufactured by Campbell-Scientific, Inc. Each station monitors air temperature, relative humidity, wind speed, wind direction, solar radiation, precipitation, and soil temperature at 2, 4, and 8 inches. The station is powered by a 12-volt battery that is recharged every day through a solar panel. For communication, each station has a dedicated telephone line and modem (one unit has a cellular phone connection).

The AEMN units are normally programmed to have the sensors scanned at one-minute intervals and then obtain an average or total for each hour. The daily extremes (for temperature highs and low, precipitation totals, etc) are calculated at midnight.

The NWS has asked the University of Georgia to adjust the scanning interval for the sensors and the averaging interval of the data to meet the requirements of the highly sophisticated models that will be used by the OWSO and the OMWSO. The access to the twenty-eight (28) units in the state will be made from the forecast offices in 15-minute intervals.

2.3 Forestry Commission Observation Sites

The Georgia Forestry Commission has been producing automated forecasts based on raw model data since the late 1980s. The forecasts must be augmented with information on fuel moisture, evaporation, and other pertinent data. To meet these needs the Commission began establishing a network throughout the state of Georgia in 1988. Presently, it has 22 weather monitoring units. These automated stations are very similar to the ones used by the University of Georgia and differ only in the sampling interval and the method of polling.

The Georgia Forestry Commission agreed, in 1994, to assist the National Weather Service in its support of the Olympics by allowing the NWS to access the stations through its' central computer in Dry Branch, GA. Because of the need for extremely frequent interrogation (every 15 minutes), the agreement is being reviewed to permit cost recovery due to the increased number of long-distance calls made by the Forestry Commission.

The supplemental automated stations will bring the total number of accessed units in the state to over 60.

2.4 Additional Environmental Monitoring Sites

The Local Analysis and Prediction System (LAPS), developed by the Forecast Systems Laboratory in Boulder, CO, is designed to use all data available to a field office. This includes data from ASOS and local meso-network sites. For the 1996 Summer Olympic Games, the domain used by LAPS, will include Georgia, most of South Carolina, and portions of North Carolina, Tennessee, Alabama, and Florida (Johnson, et al. 1996). As a result, additional surface weather data is needed from those states surrounding Georgia.

Agreements have been reached with the South Carolina Forestry Commission, the Alabama university system, and other agencies, to permit the National Weather Service's OWSO and OMWSO access the necessary data to support the models.

3. INTERROGATION OF DATA

Because of the insatiability of the models for data, the meso-networks have been modified to produce information on temperature, wind, pressure, precipitation, and humidity at 15-minute intervals. This could conceivably provide a problem area due to the amount of time required to interrogate a single unit. Assuming a successful dialup attempt taking about 15 seconds and adding to that another 30 to 45 seconds of interrogation, it should take close to a minute per station. If one computer were used for this process, it would be 45 to 60 minutes to complete the interrogation of 60 units. It is for this reason that it is extremely important to have multiple computers completing this function.

At this time, the Georgia Forestry Commission has agreed to interrogate their units along with the South Carolina stations. The National Weather Service's OWSO will employ two to three computers to interrogate the rest. Using this system, the data should be available to the numerical models in 15-minute intervals as required.

4. QUALITY CONTROL

Quality control on the data being provided falls into two categories: primary and secondary. The primary responsibility for quality control falls on the agency owning and maintaining the equipment. Each agency has set in place procedures to interrogate the equipment daily and check the consistency/quality of the data by either visual means or using software to compare each station to nearby stations. If a parameter appears to be outside of a certain interval (say, for temperature, +/-5 degrees), that station will be flagged. A person then checks to see if the difference is being caused by a local condition, such as a thunderstorm, or whether the instrumentation is indeed in error.

For the period covering the Olympic Games, a secondary source of quality control will be used. The OWSO is developing software to flag any incoming data that may appear to be outside the scope of the prevailing conditions in the area. These suspect data will be reviewed before allowed to enter into the models for processing.

8. SUMMARY

The National Weather Service, in cooperation with the University of Georgia, the Georgia Forestry Commission, the South Carolina Forestry Commission, the Alabama University system, and others, and through its' OWSO, will have available the largest surface weather information that has ever been used by weather numerical models in the southeastern U.S. The amount of data will help insure not only very detailed analysis charts but also help fill the needs of the additional forecasting models as well.

The "legacy" left behind by this olympic effort will be noticed in the tremendous amount of data that are being archived in CD-ROMs. These data will be available for studies involving convection, etc., and should prove to be of great importance in defining climatological boundaries as well. It may also provide an impetus in convincing others to develop similar networks that will improve weather services to the community.

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WEATHER INFORMATION DISPLAY, ANALYSIS AND PRODUCT GENERATION TOOLS USED IN SUPPORT OF THE 1996 SUMMER OLYMPIC GAMES: DAILY FORECASTS

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1. INTRODUCTION

In support of the 1996 Olympic Games, the National Weather Service (NWS) is assembling weather information systems for use by forecasters in the Olympic Weather Support Office (OWSO) in Peachtree City, Georgia and the Olympic Marine Weather Support Office (OMWSO) in Savannah, Georgia. (Hereafter, both offices will be referred to as OWSOs.) Tools available to these forecasters include weather data displays, forecast generation systems, warning decision systems, and locally-run mesoscale models.

This paper will discuss the use of the National Centers Advanced Weather Interactive Processing System (N-AWIPS) and the Interactive Computer Worded Forecast (ICWF) software (Ruth and Peroutka 1993) in producing high-resolution, site-specific forecasts in support of the 1996 Olympic Games. This relatively new software was tested operationally during the summer of 1995 so that forecasters would learn how to use it and so that software problems could be worked out well in advance of the Olympic Games.

2. USER NEEDS

Officials of the Atlanta Committee for the Olympic Games (ACOG) will be the primary recipients of weather information supplied by the OWSOs. These officials have expressed a need for high temporal resolution forecasts of weather phenomena that would adversely affect their respective sporting venues. In addition, this forecast information must be relayed to these external users via Info '96, a wide-area information network to be used during the Olympic Games. Thus, the data must be transmitted in a specific format usable by Info '96.

Given the varied weather concerns of the ACOG officials, their need for high-resolution forecasts and the portability of data to Info '96; the OWSS had to provide the forecasters rapid access to multiple high-resolution data sets and easy formatting of standardized, high-resolution forecast products. The two software packages chosen to help meet these goals were N-AWIPS and the ICWF. (See Rothfusz, et al. [1996] for more information on the OWSS and user needs.)

3. N-AWIPS

N-AWIPS is comprised of software that ingests, analyzes, displays and integrates various types of hydrometeorological data. These data types include numerical model, surface, upper-air, satellite, radar and text data. N-AWIPS runs on Unix workstations that support X-Windows and Motif. The N-AWIPS software is being developed within the NWS, by the National Centers for Environmental Prediction (NCEP), formerly the National Meteorological Center (NMC).

N-AWIPS includes the General Meteorological PAcKage, (GEMPAK) software and a set of graphical user interface (GUI) programs. The GEMPAK software provides much of the N-AWIPS core capabilities including data decoding, data analysis, navigation and display capabilities. GEMPAK includes a comprehensive set of meteorological parameter calculations for surface, upper-air, and gridded data. Multiple map projections are supported and data can be displayed by user-defined geographic regions. Satellite and radar imagery may be subsetted and displayed with graphic overlays (e.g., geography, contours, etc.). Graphics and imagery can be animated and color enhanced.

The N-AWIPS GUI programs provide an easy-to-use interface to some of the GEMPAK capabilities. These programs include the AFOS emulator; NSAT; NTRANS; and NWX.

The AFOS emulator displays graphics and text products from the AFOS data feed. A Motif graphical user interface controls the program functions. The AFOS emulator provides a means for the forecasters to view standard NWS products available on the AFOS circuit. Originally developed at the River Forecast Center in Tulsa, OK, it has been enhanced and integrated with the N-AWIPS software. In addition to standard AFOS products, data from the Georgia mesonetwork (Garza and Hoogenboom 1996) were added to the list of products displayable on the AFOS emulator.

NSAT displays and animates satellite imagery. A Motif graphical user interface is used to control the program functions. NSAT loads the latest sequence of satellite images into memory for display. The program has the option to automatically update an animation sequence as images become available in the data base. Images may be color enhanced and geographical/political boundaries and latitude/longitude lines of varying resolutions may be overlaid on images. Remapped or images in the native satellite projection can be displayed. The program supports a variable number of lines and pixels in the image files. The image data are sampled to properly fill the display window.

Some satellite data are provided to NSAT by NCEP. Additional data are supplied to RAMSDIS (Molenar, et al. 1995) by the National Environmental Satellite Data Information Service (NESDIS) and the National Severe Storms Forecast Center (NSSFC). These data are, in turn, converted into a format usable by NSAT.

NTRANS displays and animates N-AWIPS graphics metafiles. The program is primarily used to display model fields generated by the N-AWIPS and GEMPAK software. NTRANS allows the selection of graphical products from a set of metafiles stored in the database. Metafiles are generally listed by model and contain groups of products, usually forecast sequences that may be selected for display. For example, a metafile group could be the 500mb height and vorticity fields for all available analysis and forecast times. Selection of a metafile group loads the entire product sequence for display and animation. The display window can be subdivided into panels to allow comparison of different model fields, different model runs, or different model start times. OWSO forecasters also make use of the X-Windows environment by opening multiple windows displaying different model data and quickly switching between the windows to compare the data.

NTRANS is the feature of N-AWIPS used most frequently by OWSO forecasters. Although it took a while to modify metafiles developed by NMC so they would be applicable to the unique forecasting challenges of the OWSOs, the modified metafile images were particularly valuable due to the speed of display and ready access to multiple numerical models. Models available to OWSO forecasters via NTRANS include the NGM, Eta, Eta-29 (29 km resolution), Eta-15 (15 km resolution), RUC, and RAMS (Snook 1996).

NWX displays NWS text products. A graphical method is used to select the products to be displayed. Text products that can be represented at individual locations, e.g., MOS data, are plotted as markers on a map. The text products are displayed in a text window by clicking on the desired location with the cursor mouse. The program allows selecting data by station or state. Different map regions and zooming are available options. Although NWX was not used in the testing phase of Olympic weather support during the summer of 1995, it is planned for use during the Olympics support in 1996.

4. SPECIAL GEMPAK SCRIPTS

Model, satellite, surface observation and upper-air observation datasets are maintained in GEMPAK format. These data are processed automatically upon arrival for display within NTRANS. These automatic processes (scripts) are a part of the N-AWIPS software and are a combination of GEMPAK routines and UNIX C-shell programming. The primary modifications made to these scripts were to handle special datasets (e.g., the Georgia mesonet data) and to make changes to the geographical domain of the final graphics products (e.g., the Eta-29 domain was reduced to the southeast U.S. for the NTRANS display).

In addition, the GEMPAK data sets can be accessed interactively via scripts. These scripts were originally designed to be UNIX command-line scripts where arguments could be supplied interactively. However, a simple GUI was developed for these scripts because most Olympic Weather Support forecasters were not familiar with UNIX, GEMPAK or the N-AWIPS software; and because the amount of time for training on the use of the interactive scripts was limited.

The interactive scripts provide the user with an opportunity to look at the GEMPAK data sets in ways that are not common to NWS operations. For instance, the automatic processes do not produce vertical cross-sections of model data because predefined cross-sections will not always meet the user's needs. Thus, a method to interactively choose the meteorological parameters and the location of the cross-section is preferred.

The GUI utilized for the interactive scripts is a simple menu listing of the scripts and a series of cascading menus for each type of script. The menu is activated by a right mouse click in the HP-VUE X-Windows manager. The interactive scripts available to the Olympic Weather Support forecasters were:

- Cross-sections of model data from the Eta, NGM, Eta-29, RUC, RAMS and LAPS analysis.
- Skew-T sounding plots and relevant index calculations for surrounding upper-air sites.
- Overlays of upper-air observations on satellite imagery.
- Overlays of surface observations on satellite imagery
- RUC model surface analyses every hour.

These represent only a small sample of the interactive GEMPAK scripts available as part of N-AWIPS. Additional scripts are being added to the GUI for Olympic Weather Support in 1996.

The conversion of the interactive scripts required removing some of the flexibility for use in an operational setting. The command-line scripts allow enough flexibility to produce any number of combinations of plots. However, for the OWSO, it was assumed that the user would want to look at the most recent cycle of a particular model; the user would want to look at the most recent satellite information; when combining data sources, the user would want to look at data from nearly the same times; and the user would want to look at data only in the states in and around the forecast area.

5. ICWF

The ICWF is a family of techniques that enables forecasters to interactively prepare digital forecasts of weather elements from which routinely-issued products can be automatically composed and formatted. Forecasters use the ICWF to generate forecast products at several WFOs, and it is the primary technique for preparing routine forecasts at the OWSOs. These techniques allow forecasters to concentrate on the meteorology of the situation by relieving them of the need to type products in different formats. The common database used to generate these products also allows for more consistent forecasts over time and among products, and for easier monitoring and maintenance of those forecasts.

Three steps characterize the ICWF process. First, ingest programs initialize forecast grids from various guidance sources as these data arrive. Second, interactive programs allow the forecaster to modify gridded forecasts and venue forecasts. Third, product generation programs use the values stored in the digital database to produce a variety of forecasts.

5.1 *The Digital Forecast Database*

The ICWF stores the digital forecasts produced by the OWSOs in a single relational database. This database resides in the Peachtree City office, and forecasters at both sites use it. The data tables that hold the digital forecasts dedicate one row to forecasts produced by the OWSO and another for OMWSO forecasts. This arrangement has several advantages. OWSO forecasters can provide backup services to the OMWSO by selecting the appropriate database row. Data from the two rows are merged each time the ICWF matrix-editing program is invoked so forecasters can view the latest forecast data entered by both sites. Storing the forecasts side-by-side makes it possible to write software that checks the two sets of digital forecasts for consistency.

The ICWF stores its digital forecasts in two forms--grids and matrices. ICWF grids are regular arrays of 35 x 35 data points spread over a Lambert Conformal projection with a nominal spacing of 19 kilometers. Grids are defined for each hour from 0000 or 1200 UTC model cycle time to 192 hours for ten weather elements. The Digital Forecast Matrices (DFMs) used to support the Olympics contain 22 weather elements specified at 57 time projections. Time projections are three hours apart beginning at model start time. One DFM is allocated to each of the ten Olympic venues.

Table 1 lists the weather elements used in an Olympic DFM. Notice these DFMs contain only one precipitation type where other ICWF DFMs allow three. The forecast wind gust is included explicitly in the Olympic DFM; other versions of the ICWF infer wind gust information from the wind speed and an inflation factor. The Olympic DFM contains wave and current information that support marine events and a "raw" ultraviolet index (see below).

5.2 *Initializing the Digital Forecast Database*

Forecasters using the ICWF choose to initialize their digital database from a variety of sources. The previous forecast is one option. Olympic forecasters have two other options, Model Output Statistics (MOS) and forecasts from the meso-Eta model.

Like other versions of the ICWF, the MOS initialization is based on the Nested Grid (NGM) and Medium Range (MRF) model runs. To initialize the ICWF grids from station-based MOS, a station-to-

TABLE 1

Max/Min Temperature
Temperature
Dew Point
Total Opaque Sky Cover
12-hour Probability of Precipitation
Thunderstorm Probability
Thunderstorm Intensity
Precipitation Amount
Wind Direction
Wind Speed
Wind Gust
Obstructions to Vision
Precipitation Type
3- Hour Precipitation Probability
Precipitation Intensity
Wave Height
Wave Direction
Wave Period
Ocean Current Speed
Ocean Current Direction
Raw Ultraviolet Index

gridpoint map had to be devised. When ICWF was installed on the OWSS, each gridpoint was assigned a weighted average of up to three MOS forecast stations. The station (or stations) to be assigned to each grid point were determined first by proximity to the MOS forecast stations. Then similarity of climatology was used in deciding how much weight to assign each MOS station.

Another part of installing the ICWF was to assign an average maximum and minimum temperature for five-day periods to each venue. These normals were determined by using daily average high and low temperatures from NWS first-order stations and using "constructed" daily average high and low temperatures from cooperative observer stations where only monthly normals are available. These average temperatures are then used by ICWF when generating forecast text to determine descriptive terms which may be used with the forecast high and low temperatures. Forecast temperatures are compared to various thresholds, the departure from the normal temperature, the departure from the previous day's temperature, and forecaster-selectable detail levels to incorporate adjectives such as "hot," "warm," "cold" or "cool" into the text where appropriate (Kosarick, et al. 1992).

The Olympic DFM needs several elements for which MOS provides no guidance--especially the marine elements. In these cases, the ingest programs use the latest observed value to initialize the fields, making a persistence forecast. If an observation is not available, a site-defined standard value is selected.

An additional source of initialization data is the NCEP's Eta-29 model. Special algorithms post-process the model output to generate fields that can initialize the ICWF database.

5.3 *Forecaster Modification of the Digital Forecast Database*

Forecasters at the OWSOs manipulate the digital forecasts with ICWF programs in ways that differ little from other ICWF sites. Forecasters can edit selected grid fields by:

- Drawing, erasing, and modifying contours.
- Assigning, incrementing, translating, and smoothing values at collections of grid points.
- "Freehand" assigning, incrementing, and smoothing of values under the cursor.

Forecasters choose to display the grid field they are editing as an image, a grid of values, or a field of contours. Forecasters can also display related grid fields for reference. When grid editing is done, the gridded forecasts update the DFMs.

Forecasters edit the details of the digital forecast using the ICWF matrix editor. They view, enter, and modify DFMs for each cluster of venues. For continuous weather elements, the editor provides the capability to increment and decrement the matrix values. For categorical weather elements, the editor provides the capability to step through the applicable categories for each element. Related matrix values are automatically modified to enforce meteorological consistency among related elements (e. g., temperature and dew point).

A set of editing tools provides techniques to copy highlighted blocks of values matrix to matrix, perform "global" tasks for all matrices at all time projections, and perform a set of locally defined quality control checks. Special display windows provide the forecaster with additional information relevant to the matrix currently being modified. One such window displays a row of station model plots for the matrix currently under the cursor. Another window allows the forecaster to consider the current forecast in relation to the previous official forecast, MOS guidance or Eta guidance.

5.4 *Generating Products from the Digital Forecast Database*

TDL developed the programs that generate the Olympic product suite specifically for this application, although the underlying code borrows heavily from previous ICWF development. The ICWF generates two types of products for the Olympics - text and tabular. Text generating software produces forecasts that are similar to NWS Zone Forecasts. These products use 12-hour periods labeled "TODAY," "TONIGHT," etc. The tabular products contain forecasts for most of the weather elements every three hours. The digital forecasts for thunderstorms, weather, and obstruction to vision are summarized into two fields named "significant weather 1" and "significant weather 2" (see Table 2).

TABLE 2

EDT	12	15	18	21
POP 3HR	60	60	40	40
MN (F)	72			
MN (C)	22			
MX (F)	84			
MX (C)	29			
TEMP (F)	81	83	78	75
TEMP (C) 27	28	26	24	
RH	66	62	70	83
HEAT INDX F	85	87	82	79
HEAT INDX C	29	31	28	26
WIND DIR	E	SE	SE	SE
WIND SPD MPH	18	18	16	16
WIND SPD KTS	16	16	14	14
WIND SPD KPH	29	29	26	26
WIND GST MPH	30	25	25	20
WIND GST KTS	26	22	22	17
WIND GST KPH	48	40	40	32
CLOUDS	BK	BK	BK	OV
SIG WX 1 40	40	40	40	
SIG WX 2 00	00	00	00	
UVI	4	1		

5.5 *Ultraviolet Index*

The ICWF allows the forecaster to generate tabular forecasts which contain three-hourly forecasts of the Ultraviolet Index (UVI) (Long, et al. 1995). The NWS Climate Analysis Center issues UVI forecasts daily, but these forecasts are valid for local solar noon and represent the influences of cloud cover as forecast by MOS. The ICWF ingest routines remove these MOS-based cloud influences and store a "raw" UVI into the DFMs. Product generation routines use this raw UVI, apply factors for sun angle and forecaster's cloud forecast, and generate UVI forecasts for every three hours during the daytime.

6. FORECAST OPERATIONS

To ensure consistency between the OWSO forecasts and those of the NWSFO during the test events in 1995, daily weather discussions were held. In addition, the AFOS emulator within N-AWIPS gave the OWSO forecasters the ability to read AFOS text and maintain consistency between forecast products. The forecaster would then evaluate model and satellite data using NTRANS and NSAT, respectively, to formulate a forecast. The ICWF would then be used to create the forecast.

Three different forecast products were issued throughout the day. Per ACOG's needs, forecasts were issued for the present day (Today's Forecast), the next day (Tomorrow's Forecast), and the three days after that (Day 3 - 5 Forecast). Each forecast period ran from midnight to midnight. Since each forecast type was sent separately at one hour intervals, the forecaster had ample time to put considerable detail (and thought) into each of the three products.

The Olympics version of the ICWF was specially designed to generate forecasts products of the three types needed by ACOG. Once ICWF generates tabular and text products for each venue, the appropriate output files are merged using WordPerfect macros. Final editing of these merged files is accomplished with WordPerfect. The forecast product in its final form is then faxed automatically to the venue via WordPerfect.

7. FUTURE ENHANCEMENTS

Unfortunately, the Info '96 system was not available for testing during the summer of 1995. When Info '96 becomes operational, it will have the capability of displaying past, present and forecast weather information by a user-friendly GUI. This information will be displayed in text and graphical format, with the graphical information (e.g., time series plots and meteograms) generated directly from the tabular data created by the ICWF.

For the ICWF, numerous improvements are planned. Sometime in 1996, output fields from NCEP's Eta-8 (8 km resolution) model will replace the Eta-29 initialization.

Also, OWSS workstations use an X-windows display system configured to use eight bits of color information. This means the color table for any one display can hold no more than 256 colors. If a forecaster runs ICWF and N-AWIPS simultaneously, this color limit is exceeded. In this case, the first program invoked will run properly while the second fails. TDL is developing techniques that address this problem by remapping the color table when the window focus shifts from one application to another.

TDL is developing two other enhancements that will benefit both Olympic weather support and future NWS requirements. The first is automated coordination of the DFMs. The situation in Georgia is novel; three forecasters (WFO, OWSO, and OMWSO) will be generating digital forecasts for neighboring areas. Software will be developed which will compare these forecasts for coordination and report on any problems noted. Forecast coordination of this sort will become more important to the NWS as the number of field offices increases. The second ICWF enhancement will be the generation of a text forecast with six-hour resolution. Forecast periods for text products will run from 0000-0600, 0600-1200, 1200-1800, and 1800-2400 EDT.

Finally, N-AWIPS is continuously undergoing development by the NCEP. The OWSS will receive software updates as they become available. At the local level, NWX will be fully implemented thereby reducing the need for the AFOS emulator. This will give forecasters more convenient access to textual data.

8. SUMMARY

The customer's (ACOG's) demand for high temporal resolution forecasts in a format easily transferrable to its own database system (called Info '96) necessitated the use of both N-AWIPS and the ICWF. N-AWIPS, created by the NCEP, gives forecasters the ability to quickly evaluate numerical model data in resolutions and formats heretofore unavailable in standard NWS forecast offices. Then, the ICWF, created by TDL, gives forecasters the ability to create high-resolution forecasts in multiple formats with minimum effort. Thus, the pairing of N-AWIPS and the ICWF makes for an extremely effective set of tools for forecasting at the resolution required in support of the Olympic Games.

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TRAINING FORECASTERS ON THE USE OF NEW WEATHER TECHNOLOGY IN SUPPORT OF THE 1996 SUMMER OLYMPIC GAMES

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1. INTRODUCTION

In support of the 1996 Summer Olympic Games, the National Weather Service (NWS) is assembling weather information systems for use by forecasters in the Olympic Weather Support Office (OWSO) in Peachtree City, Georgia and the Olympic Marine Weather Support Office (OMWSO) in Savannah, Georgia. The tools available to these forecasters will include weather data displays, forecast generation systems, warning decision systems, locally- and remotely-run mesoscale numerical models, etc. Most of these tools have seen some operational use and testing, but only on limited bases. Thus, most OWSO forecasters have had little or no operational experience with the new technology. A comprehensive training program was deemed critical to the overall success of the Olympics weather support effort.

This paper will describe planned and existing elements of the Olympics weather support training program. Issues related to training on the use of new technology will be emphasized. The elements described will include standard training approaches such as videos and lectures, but particular attention will be focused on a unique, on-line, forecast performance support system called Coach.

2. THE TRAINING CHALLENGE

The mission statement of the OWSOs states: *The National Weather Service will dedicate the world's best meteorological science, skill, service and technology to keep the 1996 Summer Olympic Games weatherwise and weathersafe.* Implicit in this statement is an onerous training challenge. It is one thing to bring the world's best technology into an operational forecasting setting, it is an entirely different (and more difficult) issue to train forecasters to fully exploit the technology. Other issues not related to technology pose additional training challenges. Examples include training on forecasting weather in the Southeast, local geography, and the unique weather support needs of the 1996 Summer Olympic Games.

At the root of the technology-related training challenge lies the fact that most forecasters have had limited exposure to the state-of-the-art software available on UNIX-based systems such as the Olympics Weather Support System (OWSS) (Rothfusz, et al. 1996). While most NWS forecasters use PC-based software such as PC-GRIDDS (Petersen 1992) and WordPerfect, such programs are not systematically supported by the NWS and their use is inconsistent throughout the agency. Therefore, data interpretation and product preparation in NWS forecast offices are typically accomplished via a combination of personal computers (PC) and the Automation of Field Operations and Services (AFOS), an RDOS-based system developed in the 1970s.

Of the 25 forecasters selected to participate in the Olympic weather support for 1996, 19 will staff the OWSO and the remaining 6 will staff the OMWSO. While the majority of these forecasters are NWS employees from around the U.S., four are forecasters with the Canadian Atmosphere and Environment Service and two are with the Australian Bureau of Meteorology. Naturally, these forecasters all have varied backgrounds. In addition, the two Olympic weather support offices have decidedly different responsibilities. The OMWSO, for example, provides marine weather forecasting support to the sailing competitions near Savannah. The OWSO, on the other hand, provides weather support to competition venues from the mountains of southeast Tennessee to the plains of southwest Georgia. The varied backgrounds of the forecasters and the differing emphases of their respective offices further compound the training challenge.

Finally, the time allotted for centralized training is limited. Since the Olympic support forecasters hail from the U.S., Australia and Canada, any extended centralized training program would be cost-prohibitive. Thus, what centralized training could be accomplished - and there was some - had to be quick and effective.

3. 1995 TRAINING

For about six weeks in the summer of 1995, the Atlanta Committee for the Olympic Games (ACOG) hosted a series of international sport competitions known as the Atlanta Sports Festival '95. The competitions were held at most of the venues to be used in 1996, including an international sailing regatta near Savannah. This festival, commonly called the "test events," provided an opportunity for the NWS to test technology and practices slated for use during the 1996 Games. It was also an excellent opportunity to train forecasters. Thus, each forecaster received one week of training in Georgia during the summer of 1995.

Prior to their arrival for training, OWSO and OMWSO forecasters were given a training video and a supplementary training binder called *The Forecaster's Guide*. The training video was created solely to familiarize forecasters with the OWSS and its component programs. Footage for the video was provided by the organizations (and for the software) shown in Table 1. Where possible, the video was shot simultaneously with two cameras - one showing the instructor and the other displaying a close-up of the monitor. The two videos were then edited for final production. *The Forecaster's Guide* contained material supplementary to the video, including user's manuals, relevant technical articles, etc. Forecasters were required to view the video and read the material prior to receiving centralized training.

All Olympic support forecasters (and ten alternates) received five days of training in Georgia. The training consisted of two to three hours of orientation, one day of classroom instruction and then four days of on-the-job-training (OJT) when forecasts and warnings were provided to the Atlanta Sports Festival '95. Forecasters were scheduled three at a time for five-day training tours. This spread the training over six weeks so that weather support could be provided during the Festival. In the classroom sessions, training was limited to the basics (e.g., the "knobology") of the various OWSS component software. Most of the operational experience was expected to be gained during OJT.

The OJT in the OWSO differed slightly from that in the OMWSO. Upon receiving their classroom instruction at Peachtree City, OMWSO forecasters travelled to Savannah where they received one-half day of training and orientation from the preceding team before that team departed. Continuity was maintained by the MIC and a systems administrator. Marine forecasting and boating/sailing experience were key factors used in selection of the OMWSO forecasters. With such experience, there was a basic understanding of marine weather; thus, no time was needed to train the staff on the critical needs of the mariner.

TABLE 1

Organization	**Software/System**
National Centers for Environmental Prediction (NCEP)	National Centers Advanced Weather Interactive Processing System (N-AWIPS)
Techniques Development Laboratory (TDL)	Interactive Computer Worded Forecast (ICWF)
National Severe Storms Laboratory (NSSL)	Warning Decision Support System (WDSS)
Forecast Systems Laboratory (FSL)	Local Analysis and Prediction System (LAPS)

During their time at Savannah, OMWSO forecasters were given the opportunity to work in all areas of the support program, e.g., forecasting, briefing, observing on the weather boat, and working in the venue operations areas. When possible, most forecast decisions and problem solving were done on a team basis using the vast experience of the forecasters.

After OWSO (Peachtree City) forecasters received their one-day classroom training, each spent one day "shadowing" a forecaster from the preceding crew before assuming support responsibilities for three days. On the last day of a forecaster's training, he/she was shadowed by a forecaster from the next crew. This shadow forecasting approach proved particularly effective in helping trainees learn the technology quickly. As a shadow forecaster, they could learn from the mistakes of their predecessors who learned from their predecessors, and so on. Primary trainers frequently monitored these interactions to ensure that erroneous information would not be propagated.

4. WORLD WIDE WEB HOMEPAGE

While they are away from the OWSO and OMWSO, updating the forecasters on new developments and keeping their newly-acquired skills tuned present additional training challenges. To meet these challenges, a World Wide Web (WWW) homepage has been developed. The objectives of the homepage are to:

- Provide information on changes and upgrades to the OWSS.
- Provide results of interesting cases from 1995.
- Provide results of studies done especially for the Olympic weather support (e.g., lightning climatology).
- Provide examples of new data types that will be available during the forecasters stay in 1996.

5. PERFORMANCE SUPPORT SYSTEM

A performance support system (PSS) provides people with the support they need to perform a job competently *while they are performing it.* Typically, such systems are computer-based (Gery 1991) and are utilized by professionals in technical sciences such as medicine. Information provided by the PSS comes in the form of "granules" that are application-focused and that provide guidance on how to proceed in a particular situation. These granules consist of focused training and case studies, rather than simple "help" files.

Malcom (1992) shows that the quality of an employee's performance when using a PSS is unrelated to the individual's experience level. This makes the PSS concept particularly attractive for the Olympic support effort due to the varied backgrounds of the forecasters and the significant learning curves they must quickly achieve.

Imagine, for example, that an Olympics forecaster is confronted with a potential convective downburst event, but he/she is not familiar with the critical downburst-indicative thresholds from WDSS, especially those typical for north Georgia. The forecaster will likely revert to routine procedures used on his/her radar at home (if, in fact, he/she has ever faced such an event). Since significant weather events have a major impact on society, forecasters should undoubtedly use the most appropriate skills and tools for those critical situations rather than those that are most comfortable. With a PSS at hand, the harried Olympic forecaster would be trained on how to use WDSS to detect downbursts in Georgia *at the moment these skills were needed.*

A PSS is being developed for Olympics weather support. Known colloquially as "Coach," the PSS will be driven by MOSAIC software such as that used in homepage applications. MOSAIC provides links to related subjects via hypertext - a characteristic which lends itself perfectly to a PSS like Coach. Since many potential training "granules" such as job sheets, case studies and data examples already exist for many of the OWSS components, they can be easily incorporated into Coach. Coach will also provide access to a database designed to provide immediate forecasting experience in certain weather situations. The following paragraphs describe how this tool is being developed.

While the OWSO forecasters were working shifts in support of the summer test events, they created their own contributions to Coach's development. Each time a forecast "package" was issued, the forecaster responsible for that package was required to make entries into a WordPerfect file called *The Forecaster's Journal.* The required entries were:

1. A brief description of the synoptic setting.
2. A brief description of the mesoscale setting.
3. A brief description of the forecast problem of the day.
4. A paragraph or two summarizing the rationale behind the forecast issued.

The next day, each forecaster was required to evaluate the previous day's forecast and enter descriptions of what was forecast well and what could have been forecast better. This "post-mortem" evaluation included descriptions of which model(s) handled the situation the best (or worst), what data provided good (or poor) insight into the forecast problem of the day, and any other observations that might someday benefit another forecaster in a similar situation.

Documenting both the forecast rationale and the post-event observations is the key to turning *Journal* entries into long-term forecasting aides available on Coach. Prior to the 1996 Summer Games, all *Journal* entries will be edited and entered into a database. A MOSAIC GUI will access the database and prompt the user for selection of general descriptors of the synoptic pattern, mesoscale pattern and forecast problem of the day. Based on the selections made, the appropriate forecast rationale and post-event observations (made by OWSO forecasters in 1995) will be displayed along with relevant model, satellite, and/or observational data, if available. Used in real time, forecasters will gain the benefit of someone else's experience in a similar situation (provided the weather situations are similar). At a minimum, this approach will give forecasters the ability to compare their formative forecast rationale with that of someone who worked a similar meteorological situation and witnessed first-hand the strengths and weaknesses of their rationale in that situation. Ideally, then, the "real-time" forecaster could modify his/her thinking and/or data evaluation based upon the "experience" imparted by Coach.

To our knowledge, such an approach has never been tried operationally in the NWS. Naturally, there will be issues to resolve before Coach moves from concept to operational tool. Nevertheless, we feel the resources are available for an early prototype to be operational by the summer of 1996.

6. SUMMARY

The challenges typically associated with training forecasters on state-of-the-art technology are compounded for the Olympics support project due to the widely-varied meteorological, technological, geographical and operational backgrounds of the forecasters. The training provided to these forecasters in 1995 went a long way toward meeting the challenges by using tried-and-true training methodologies such as video tapes, classroom lectures and on-the-job training. To assist forecasters in 1996, however, a performance support system (called Coach) is being developed. Coach will use MOSAIC applications to give forecasters quick access to valuable lessons learned by forecasters who have faced similar meteorological situations. Although never before tried operationally, the concept behind Coach is appealing and will be tested thoroughly during the 1996 Summer Olympic Games.

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MEETING WEATHER INFORMATION NEEDS OF THE 1996 SUMMER OLYMPIC GAMES: STRATEGIES, EXPERIENCES AND OBSERVATIONS

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1. INTRODUCTION

On July 14, 1992, the Atlanta Committee for the Olympic Games (ACOG) formally requested the National Weather Service (NWS) to provide meteorological support for the 1996 Summer Olympic Games. On November 30, 1992, Dr. Elbert W. Friday Jr., Assistant Administrator for Weather Services, and Director of the National Weather Service, wrote to the ACOG agreeing to have the NWS provide the requested support.

Weather support for the 1996 Olympic Games began as early as 1989, however, well before the commitment to support the Games was formalized. In preparing their proposal to host the Games, the Atlanta Organizing Committee (AOC), later known as ACOG, approached the NWS Forecast Office (NWSFO) in Atlanta, Georgia seeking climatological information. After Atlanta was awarded the right to host the Games, the Atlanta NWSFO assisted ACOG with a variety of weather support issues. For example, ACOG's concern about the site of the equestrian event led to NWS collaboration with the University of Georgia in installing automated meteorological observing systems around the state.

2. STRATEGIES

Early in the planning process, it became apparent that providing weather support to the '96 Games, would showcase much of the new weather-related technology being developed in the United States, and demonstrate a number of new weather forecast and warning techniques which could benefit the American people as a whole. In that spirit, the following mission statement was adopted: *The National Weather Service will dedicate the world's best meteorological science, skill, service, and technology to keep the '96 Summer Olympic Games weatherwise and weathersafe.*

To satisfy the meteorological support requirements specified by the customers, and to accomplish the stated mission, two state-of-the-art Olympic Weather Support Offices (OWSOs) were established; the main OWSO is located at the combined NWS weather and river forecast office (NWSFO/RFC) in Peachtree City, GA., approximately 35 mi (56 km) southwest of downtown Atlanta. A second OWSO, the Olympic Marine Weather Support Office (OMWSO), is located 200 mi (320 km) to the southeast at the Olympic Marina near Savannah.

2.1 *Staffing*

Early plans called for staffing the OWSO at Peachtree City with a Meteorologist In Charge (MIC) and fifteen forecasters. Likewise, the planning for the OMWSO called for an MIC and five forecasters. What was not anticipated in the early planning stages, was the need for additional support staff. Subsequently, a system administrator position was added to the staff at the main OWSO, and a part time system administrator was added to the OMWSO. In addition, a Science and Operations Officer (SOO) and a technical support person were added to the staff at the main OWSO.

The MICs coordinate with external users such as ACOG, develop strategies to provide products and services to external users, and serve as the project's general managers. The system administrator assembles the hardware and manages the flow and storage of data. The SOO focuses on the operational application of new science and technology; training the forecasters; and the quality of data, numerical models, and software available on the OWSS. The technical support person contributes to studies, assists in evaluating model biases, creates operationally-suitable model output graphics, and addresses other programming issues on the OWSS.

2.2 *Technology - Workstations*

The OWSOs need to be equipped with state-of-the-art computer workstations and software. Initially, AWIPS, the NWS's Advanced Weather Interactive Processing System, was the technology of choice. The first prototypes of the AWIPS were scheduled to be delivered in the 1996 time frame. As the AWIPS development schedule began to slip, it soon became apparent that this was not a viable option. Even if the program had remained on schedule, a delivery date in 1996 would have given insufficient time for tailoring the system to meet the Olympic weather support requirements.

About this time, the National Centers for Environmental Prediction (NCEP, formerly the National Meteorological Center - NMC) suggested consideration of the N-AWIPS software which was already being used operationally at the NCEP. The N-AWIPS software is designed to enable forecasters to display and interact with model output and satellite data. N-AWIPS was ultimately chosen for use as the foundation applications software of the Olympic Weather Support System (OWSS). Since the N-AWIPS software is designed to run on Hewlett-Packard 755 and 715 workstations, the HPs became the workstations of choice for the OWSS. After studying the service requirements, and estimating the maximum number of forecasters who would be needing to access a workstation at any given time, a decision was made to equip the OWSO with two HP 755s and three HP 715s; the OMWSO with three HP 715s.

2.3 *Other Technology*

One of the challenging forecast problems in providing weather support for the Olympic Games is the need to provide high resolution forecasts, both spatially and temporally. The Forecast Systems Laboratory's (FSL) Local Analysis and Prediction System (LAPS), which incorporates a high resolution surface analysis procedure as well as the University of Colorado's Regional Atmospheric Modeling System (RAMS), was chosen to assist in meeting this requirement. The decision to use the LAPS resulted in additional hardware requirements. While the output of the LAPS can be displayed on the HP workstations, timely running of the RAMS requires far more CPU power than the HPs can provide. Fortunately, the IBM Corporation has offered to loan a "high-end" parallel processing computer to meet the high speed requirement. The IBM computer will be installed at the OWSO to run the RAMS, which will produce a 24- hour forecast on a 4 km (possibly 2 km) grid within approximately 60 minutes of the time the model run is initiated. In order to provide the necessary initialization fields and boundary conditions for the RAMS, the NCEP will provide data from the Rapid Update Cycle (RUC) and output from special high resolution runs of the Eta model.

With N-AWIPS, LAPS, the high resolution Eta, and access to other guidance products from the NCEP, the Olympic weather support forecasters will have a solid set of meteorological data to use as a basis for formulating forecast products; however, three critical capabilities were missing. First, the OWSOs will require the capability to ingest and display a full suite of high resolution WSR-88D data from radars providing coverage over the Olympic venues. The N-AWIPS software will not have that capability. Second, the N-AWIPS does not have the capability to display satellite imagery in the specialized manner needed at the OWSOs. Third, still lacking was the technology needed to assist the forecasters in physically generating the forecast products. Software developed by the National Severe Storms Laboratory (NSSL) solved the first problem.

The NSSL is operationally testing new algorithms to be used with the WSR-88D radar. A new set of algorithms, along with an innovative display capability, incorporates WSR-88D data and real time lightning strike information to produce various products designed to assist the forecaster in making warning decisions. This system is known as the Warning Decision Support System (WDSS).

The NSSL was eager to test the WDSS in the environment found in the southeast U.S., and offered use of the system as part of the OWSS. The offer was accepted at once; however, use of the WDSS required additional hardware. The WDSS needs access to WSR-88D wideband data.. The WDSS uses a Sun SparcStation 5 to ingest these data, and a Sun SparcStation 20 to process the data and generate the algorithm output. Accordingly, the two needed Sun SparcStations have been provided to the OWSO, accessing data from the Peachtree City WSR-88D. Since the WDSS capability is needed at the OMWSO, a second set of Sun SparcStations will be required. The OMWSO WDSS will access the Charleston, SC, WSR-88D, which is the closest radar to the yachting venue.

To solve the problem of satellite imagery needs, the RAMM Advanced Meteorological Satellite Demonstration and Interpretation System (RAMSDIS) was chosen (Molenar, et al. 1995). The RAMSDIS provides the forecaster with a full suite of satellite products. Coverage can be tailored to meet the local needs, and the system provides many interactive capabilities, as well. Once again, the decision to use this technology created an additional hardware requirement. The RAMSDIS is PC-based. Consequently, a Pentium PC with expanded RAM and hard disk capacity was procured for each Olympic weather support office..

Finally, the NWS's Techniques Development Laboratory (TDL) was approached to explore the possibility of obtaining help regarding the problem of reducing workload associated with the physical aspect of forecast preparation. The TDL was immediately receptive, and agreed to devote resources necessary to adjust their Interactive Computer Worded Forecast (ICWF) software to meet the OWSO's needs. For once, the decision to incorporate yet another specially-developed software in the OWSO operations did not result in a requirement for additional hardware. The ICWF is being developed to run on the same type of HP workstations which run the N-AWIPS software. Nevertheless, some additional software was required, since the ICWF requires a database management program known as INFORMIX.

2.4 *Olympic Mesonet*

The high-resolution numerical models being provided by NCEP and FSL need high-resolution observations if they are to be properly initialized. Additionally, marine observations are needed for the yachting venue, where none currently exist. Much of the surface data required to meet these needs will come from automated meteorological observation systems already in place in Georgia and surrounding states (Garza and Hoogenboom, 1996). Most of these systems are manufactured by Campbell Scientific, Inc.

The University of Georgia operates over 25 systems, primarily in support of agricultural research projects, and has installed additional systems in support of the 1996 Games. The Georgia and South Carolina Forestry Commissions each operate a network of similar systems in support of their respective fire weather programs. The state of Alabama, through its Auburn University agricultural program, has a network of sensors, as well. All of these organizations agreed to allow access to their data. Furthermore, during the period of operational support, all have agreed to program their systems to provide observations at 15-minute intervals. Finally, the NWS has procured 14 of these automated systems to install at some of the Olympic venues. These will also provide observations on a 15-minute interval during the period of operational support.

To enhance upper air observations, six NWS upper-air sounding locations in the southeast United States will take soundings 4 times a day, instead of the normal 2 soundings per day, during the period of operational weather support in 1996.

The only permanent marine observation site near the yachting venue area is the National Data Buoy Center's (NDBC) C-MAN platform at Savannah Light, located about eight miles (12.8 km) northeast of the venue. To supplement this observation, NDBC is deploying several 3-meter data buoys. The buoys contain the standard package of wind, wave, and temperature sensors. One of these buoys has been equipped to measure ocean currents. During the summer of 1994, one buoy was deployed; while during a sailing regatta in the summer of 1995, two buoys were in place. Plans are being developed to deploy a third buoy during the 1996 Olympics. The buoys provide observations 24 hours/day and, along with data from the Savannah Light C-MAN, have already provided sufficient data to prepare a limited summer climatology of the yachting venue for use by Olympic officials and competitors. Since the standard hourly buoy observations are not frequent enough to support the high resolution forecasts required, NDBC has devised a line-of-sight radio transmission capability which will permit the collection of an observation every ten minutes from one of the buoys. To supplement the buoy observations, a series of Campbell Scientific automated weather stations have been installed at selected locations along the coast. Observations from these sites will be collected every 15 minutes.

2.5 *Internal Communications*

Clearly, a number of high speed communication circuits are needed to acquire the large (and frequent) files of numerical model output, satellite imagery, and WSR-88D radar data. Consequently, a T1 line between the OWSO and the NCEP, and a T1 line between the OWSO and the Georgia Tech Research Institute (for access to the Internet), have been installed. Gridded model output arrives at the OWSO via the T1 to the NCEP, and RAMSDIS satellite imagery arrives via the T1 connected to the Internet. Data from the Charleston WSR-88D will be transmitted via a T1 line installed between the radar and the OMWSO. Since the Peachtree City WSR-88D is collocated with the OWSO, the wideband link with the WDSS is made directly. A fourth T1 line will connect the OWSO and the OMWSO. Data from the Olympic mesonet will be collected utilizing normal voice grade phone lines.

3. MULTI-PARTY COLLABORATIONS

Much of the technology being used in providing weather support to the '96 Games does not currently exist in the operational environment of the NWS. It is either still under development in various laboratories, or it is awaiting the arrival of sufficient computer capability at field offices to allow its incorporation into NWS operations. Consequently, if the OWSOs are to be successfully established, collaboration with a number of diverse organizations is essential.

The National Centers for Environmental Prediction are providing the OWSO with their N-AWIPS software (Rothfusz, et al. 1996b), assisting in configuring the OWSS's communications network, and setting up critical security measures. The NCEP is also providing special guidance support by running high resolution versions of the Eta model tailored for the Olympic weather support effort (Johnson, et al. 1996b).

The Forecast Systems Laboratory of the National Oceanic and Atmospheric Administration's (NOAA) Office of Oceanic and Atmospheric Research (OAR) and the University of Colorado are providing the LAPS and RAMS software (Snook 1996; Stamus 1996). FSL is also providing staff resources to tailor the LAPS and RAMS for use in Georgia, and to assist the OWSO in forecasting using the system. The FSL is collaborating closely with the NCEP, since the NCEP is providing the data fields necessary to initialize the LAPS.

The National Severe Storms Laboratory, also a part of OAR, is providing its WDSS (Johnson, et al. 1996a), and a scientist to serve as the SOO of the OWSO.

The Techniques Development Laboratory of the Office of Systems Development at NWS Headquarters is providing its ICWF software (Kosarick, et al. 1992; Ruth and Peroutka, et al. 1993) and is providing the staff resources to configure the software for Olympic weather support. TDL is also collaborating with NCEP in developing techniques to allow the ICWF to initialize on model gridpoint data and model output statistics.

When it was time to assemble and configure the hardware and communications of the OWSS, the support of system architects, computer security experts and electronics technicians from NCEP, NWS Southern Region Headquarters, the Mountain Administrative Support Center, and the Peachtree City NWSO/RFC was invaluable.

Many others are collaborating as well. Cray Research, Inc. is providing access to a C90 "super-computer" to enable NCEP to run the high resolution Eta model. IBM is loaning a high-end parallel processing computer to enable FSL to run the RAMS at the OWSO in Peachtree City. The University of Georgia and the Georgia Forestry Commission are providing access to their automated meteorological observing systems positioned throughout Georgia (Garza and Hoogenboom 1996). Florida State University and Texas A&M University are conducting meteorological studies. The National Environmental Satellite, Data and Information Service (NESDIS) and the National Severe Storms Forecast Center (NSSFC) are assisting with special satellite imagery. The NDBC is providing specially-designed data buoys strategically positioned to support the weather support for the yachting venue. Finally, NOAA Public Affairs is providing assistance with telling the story of the Olympic Weather Support Project.

In keeping with the Olympic Charter's fundamental principal of "creating international goodwill", the NWS is also collaborating with the Australian Bureau of Meteorology and the Canadian Atmospheric Environment Service. Both are providing assistance to the project.

In many ways, the degree of collaboration taking place between researchers and operational personnel, between national and field offices, between the public and private sector, and in the international arena is unprecedented and speaks highly of the professionalism of everyone involved in the project.

4. OPERATIONS PREPARATION

The success of the OWSS's development (thus far) can be attributed to factors common to any successful project, specifically: Starting the project early, getting philosophical and fiduciary commitment from superiors, identifying outstanding support people and giving those people the tools they need to get the job done.

While interactions with ACOG began as early as 1989, preparations for the day-to-day forecasting support did not begin in earnest until mid-1994 when the major goals for the OWSS were established (Rothfusz, et al. 1996a). These goals were vitally important to defining the hardware, software, personnel and funding necessary to create the OWSS and all it supports. Commitment from DOC, NOAA, and NWS administrators was critical to the meeting these goals.

Once the personnel were in place, hardware, communications and software testing took place routinely throughout late 1994 and early 1995, especially as new systems were installed. The 1995 U.S. National Rowing Championship held in north Georgia in mid-July provided an excellent opportunity to test some the systems.

As news circulated of the NWS's participation in Olympic weather support, private- and public-sector organizations began approaching the NWS with offers of products and services in exchange for being considered official sponsors of the Olympic Games. Most of these organizations were not aware that the right to be called an "official sponsor" comes with sponsorship fee in the millions of dollars. Nevertheless, some products and services were still offered. While it was tempting to accept all offers, the need to control the OWSS development necessitated a freeze on the software and hardware in early 1995. No other major additions were made to the system after May 1, 1995.

5. TEST EVENTS EXPERIENCES

The Atlanta Sports Festival '95 (also known as the "test events") was a series of sporting events conducted by ACOG during the summer of 1995. These events were held at some of the Olympic venues in preparation for the 1996 Games. To fully test the support concepts of the OWSOs, forecasters selected to provide weather support in 1996 were assembled in Peachtree City and Savannah to receive training and provide the weather support to these test events.

5.1 *OWSO*

Overall, the test event operations were successful and *absolutely necessary*. With so many new concepts being implemented as part of the OWSS, a thorough test of the software, hardware and communications were needed prior to the highly-visible Olympics in 1996. The testing took place in conjunction with the training of the forecasters in the summer of 1995 (Rothfusz, et al. 1996c).

While the system performed well on the whole, there were difficulties. For example, as the volume of data grew throughout the test events, disk space became scarce. Although early estimates of file sizes were reasonably accurate, the LAN server "mirroring" feature implemented late in the OWSS's development stage effectively cut the available disk space in half (Rothfusz, et al. 1996a). Faxing information to ACOG venue communications centers was not without its share of problems either. Busy signals and disconnected fax machines were rare problems but they did occur. Steps are being taken to implement more reliable communications in 1996.

Since some of the software was being implemented operationally for the first time, errors in the programs (bugs) invariably appeared. Feedback from trainees documented these bugs and most were corrected by the developers in a timely fashion.

The training for forecasters was a valuable portion of the test event support. Thirty-seven forecasters received one week of training. By the third or fourth day of the training, most forecasters were performing well with the new technology - an indication that a major goal of the OWSS (intuitiveness) had been met. The crowning operational achievement of the OWSO support happened on 3 August 1995 when a line of near-severe thunderstorms moved across the Georgia Tech Aquatic Center while swimming competitions were occurring. A warning for lightning and strong winds was issued 45 minutes in advance of the storm reaching the venue. This gave the officials ample time to move spectators and athletes into protected areas. Winds of 40 mph (64 kph) and frequent lightning strikes occurred at the venue. The venue officials were grateful for the support.

5.2 *OMWSO*

As is the case with most field operations, flexibility was the key to successfully providing weather support to the international regatta held during the summer of 1995. For the test events in 1995, a 56 Kbaud dedicated line was installed between the OWSO in Peachtree City, and the OMWSO at the Olympic marina. All non-local data for the OMWSO system was received via this line. Within 24 hours of beginning operations, it became clear the 56 Kbaud line was insufficient to meet the data ingest requirements of the OMWSO. A T1 line will be needed between the OWSO and the OMWSO during the support period in 1996.

There was one scare when, as a result of beach erosion caused by swells emanating from Hurricane Erin, one of the automated weather observation stations was almost washed away. However, quick action on the part of personnel of the OMWSO in relocating the equipment to higher ground averted a costly loss.

6. SUMMARY

Providing weather support services for the 1996 Summer Olympic Games has afforded the National Weather Service a unique opportunity to showcase new weather-related technology developed in the United States, and to operationally test new weather forecast and warning techniques. To take full advantage of this opportunity, the NWS has constructed an Olympic Weather Support System comprised of cutting-edge weather-related technologies. During the design and implementation of the Olympic Weather Support System, an unprecedented level of collaboration has taken place among the research and operational meteorological communities, between the public and private sector, and among research, operational, and administrative levels within the NWS itself. The spirit of cooperation and collaboration which has occurred among these diverse entities will stand as one of the legacies of the Olympic Weather Support Project.

Finally, the extraordinary degree of professionalism exhibited by many key people involved in the effort must not go unrecognized. These individuals have devoted skills, abilities and their own time to ensure the success of the Project. Because of their contributions, not only will the '96 Games be kept weatherwise and weathersafe, but the American people as a whole will benefit from improved weather warning and forecast services for years to come. That achievement will stand as the grand legacy of the Olympic Weather Support Project of the National Weather Service.

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STUDIES OF THE GEORGIA COAST SEA BREEZE - AN OLYMPIC SUPPORT ACTIVITY

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1. INTRODUCTION

The 1996 Olympic Regatta will be held in the waters off Savannah, Georgia from July 19 through August 4, 1996. The sailing venue is located in the Wassaw Sound and off Williamson Island (Figure 1).

The sea breeze that develops along Georgia's barrier islands is unique because of the complex coastal terrain. The coastal area is complex maze of salt water swamps and marshes with many embedded small rivers and streams. Compounding that, there is also a seven foot tidal surge that further changes the complexity of the coastal terrain. The marshes are alternatingly dry or awash and the there is typically 50 to 100 meters of additional beachline exposed or covered by the changing tides.

The goal of this project is to model the sea breeze in this area with an emphasis on the seaward extent of the circulation. It is this seldom studied portion of the sea breeze circulation that will be the most influential on the Olympic Regatta.

2. MODEL STUDY

The PSU/NCAR MM5 model (Grell *et al*, 1994) is being used to simulate the sea breeze.

2.1 Setup

Current plans call for several runs with various synoptic scale forcing. Inputs will range from a calm initialization, both on shore and off shore flow, and along shore flows. Also, at least one run will be done using real data for initialization using a day with an observed strong sea breeze development.

The grid scale resolution for the model runs will also be varied. An example model domain is shown in Figure 2. The larger domain has 12 km resolution and the smaller domain has 4 km. Experiments are planned with resolutions as fine as 1 - 2 km.

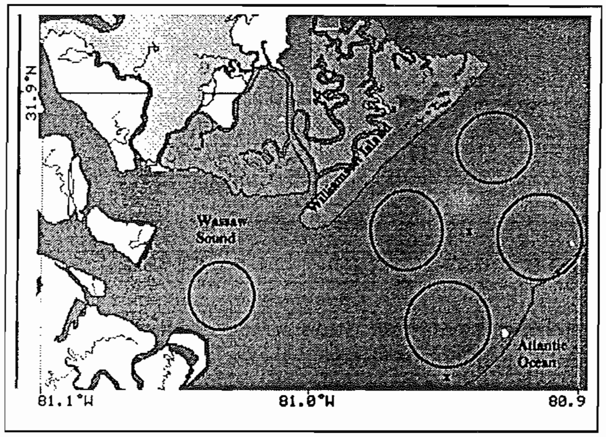

Figure 1. Sailing venue for the 1996 Olympic Regatta with race courses indicated. Buoy locations denoted by an X.

2.2 Output

Model output will be used to develop an understanding of the development of the sea breeze circulation in the presence of complex coastal terrain. The goal is to obtain a working knowledge of the onset, development, intensity, duration, and decay of the seaward component of the sea breeze

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circulation. Results from the simulations will be presented.

2.3 Verification

Model output verification will be done using local observations from the land areas included in the domain (Savannah, GA (SAV), Hunter Army Airfield, GA (SVN), and Hilton Head, SC). Additional land observations are available from the Georgia Mesonet. Seaward observations are available from two NOAA buoys located in the sailing venue and from the Savannah Light buoy, north of the race courses.

3. ACKNOWLEDGMENTS

This study is being funded in part by the UCAR Comet Program and the Florida State University Computing Center and with support from the National Weather Service Southern Region.

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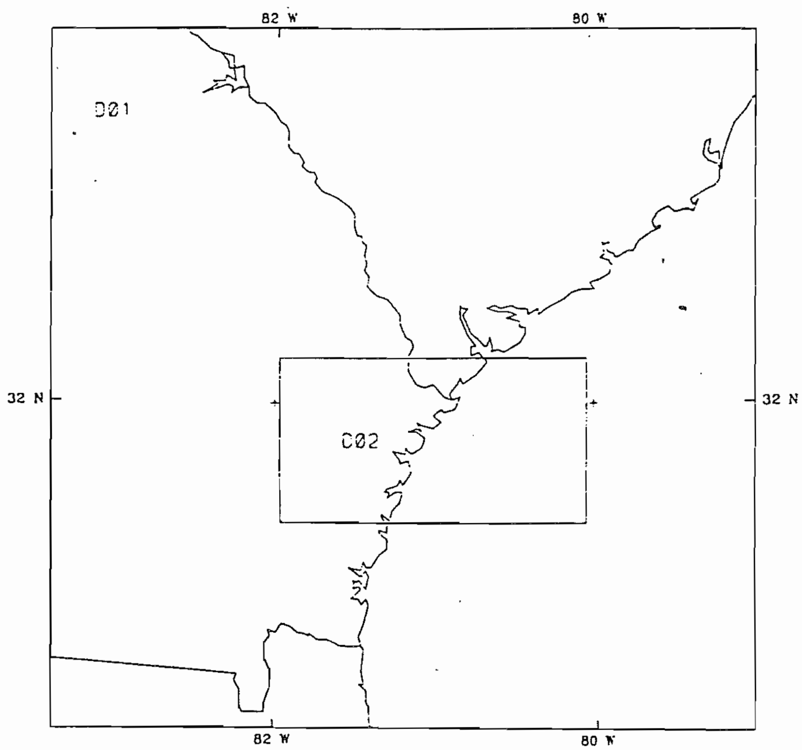

Figure 2. Example MM5 nested domains. Domain DO1 has 12 km resolution and D02 has 4 km resolution.

MARINE WEATHER SUPPORT DURING THE 1996 OLYMPIC GAMES

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1. INTRODUCTION

The National Weather Service (NWS) is in the process of developing a unique office to support the yachting events off Savannah, Georgia during the 1996 Olympic Games. The Marine Olympic Support Forecast Center (MOSFC), while using the same technology as its sister office, the Olympic Support Forecast Center (OSFC), is unique as it supports only one Olympic venue -- yachting. Besides the normal suite of weather forecast and warning products, the MOSFC will also address coastal and oceanographic concerns as coastal sea/land breeze, tides, currents and waves -- and of course, as shown in the summer of 1995, the threat of a hurricane.

To accept this challenge, the NWS has selected and trained a special group of marine meteorologists, expanded the surface weather monitoring stations along the coast to include weather buoys, made plans to tie the MOSFC into the WSR-88D Doppler radar coverage from Charleston, South Carolina, developed communications between itself and OSFC and thus into the Olympics Info '96 information system and have placed the MOSFC office directly within the Olympic Marina to ensure availability to respond directly to the needs of the venue managers and competitors.

2. DEVELOPMENT OF THE MOSFC PROGRAM

The early stated goal of the MOSFC was to respond to the weather forecast and warning needs of the Olympic venue management and the yachting competitors. This goal, and the NWS mission statement of "...dedicating the world's best meteorological science, skill, service and technology to keep the 1996 Summer Olympic Games weatherwise and weathersafe" became the mandate of the MOSFC.

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2.1 *Forecast Staff*

The forecast team of the MOSFC will be made up of 5 NWS forecasters plus a meteorologist-in-charge. In addition, a forecaster each from the Canadian Atmosphere and Environment Service and the Australian Bureau of Meteorology will supplement the team. NWS forecasters were, among things, selected to the team based upon their marine forecasting experience, their boating and sailing experience and their ability to work as a team player in a high tech computer environment. With forecasters scattered literally over the country and indeed, the world, an early training program was devised (Rothfusz, et al., 1996c).

2.2 *Expansion of Local Surface Observations*

To provide model and forecast support for a yachting venue area of about 50 square miles (~90 sq km), a meso-network of observations needed to be established. Existing inland airport observations and a single National Data Buoy Center (NDBC) Savannah Light C-MAN platform (SVLS1) off the mouth of the Savannah River just north of the venue area were supplemented by land based and weather buoy observation platforms.

Portable surface weather monitoring stations were placed at several key coastal locations near the yachting venue area by the NWS and the University of Georgia's Department of Biological and Agricultural Engineering (Garza, et al., 1996). In a effort to make such observations representative to exposed coastal conditions, such monitoring stations were sometimes put in environmental jeopardy. Such was the case with the station on Williamson Island at the northern entrance to Wassaw Sound just ashore of the yachting venues. It twice had to be moved to safety in late July and early August as the island dissolved around its location as a result of high tides, large waves and hurricane Erin.

To supplement the land based observations and Savannah Light, it was thought essential to add observations from weather buoys installed by NDBC. One buoy was placed near the center of the offshore sailing area during the summer of 1994 and two buoys were placed (in the center and south of the venue) during the summer of 1995. These buoys provided a climate data base and supported an international regatta in 1995. These buoys provide hourly wind, wave, pressure and temperature (air and water) observations via satellite through normal NWS communication means. Ocean current data are observed and transmitted from one buoy. Plans are being evaluated to put a third buoy in the shallow waters of Wassaw Sound during the 1996 Olympic Games.

Since it was felt that hourly data were not frequent enough for our mesoscale needs, NDBC devised a line-of-sight system that provides buoy data directly to MOSFC at the Olympic Marina every 10 minutes. The hardware and software were tested and evaluated during the summer 1995 regatta and will be operational in 1996.

2.3 *WSR-88D Doppler Radar*

The city of Savannah and the Olympic yachting venue fall under the umbrella of the WSR-88D Doppler weather radar to be located south of Charleston, South Carolina. This radar is scheduled to become operational during spring of 1996 and will be used by the MOSFC staff to support the 1996 Olympic yachting events. MOSFC will have a direct link with the Charleston 88D and will use the Warning and Decision Support System (WDSS) developed by the National Severe Storm Laboratory (NSSL) in Norman, Oklahoma. WDSS was successfully used during the summer of 1995 by the OSFC during Olympic test events (Rothfusz, et al., 1996a).

2.4 *Test Event*

During late July and early August, 1995, a year before the 1996 Summer Olympic Games, MOSFC forecasters provided operational weather support to a international regatta in much the same way we plan to support the Olympics. This opportunity not only provided the regatta needed support but gave MOSFC forecasters and the support team at Peachtree City (site of the Atlanta Weather Forecast Office, River Forecast Center and OSFC) experience in testing forecast procedures, equipment and communications. The OSFC was concurrently running a similar exercise. This event provided an opportunity to identify weakness and strengths in the MOSFC and NWS Olympic support program and gave us a year to rectify and correct our procedures as needed.

2.5 *Local Climate Study*

A preliminary climate study of coastal Savannah was developed that proved to be a favorite of the venue management and the foreign competitors. It included information from the weather buoys, Savannah Light C-MAN, coastal stations, lightning strike probabilities, hurricane risk probabilities, and brief discussions on land/sea breezes, thunderstorms, NOAA Weather Radio, tides and currents (Powell, et al., 1966). Without such information, foreign competitors had often misleading climatology of the area to work with. A final report is scheduled for release during the spring of 1996.

2.6 *MOSFC on Location*

One of the obvious success stories learned from last summer was the decision to place the MOSFC within the Olympic Marina in order to directly provide support to the venue. As a result, each day of the regatta, separate morning weather briefings were provided to venue management, venue officials and to the competitors including team meteorologists, captains and individual athletics. Such briefings set the stage for the days activities and on two occasions, resulted in cancellation of the days competitions due to unfavorable conditions. During the day, MOSFC was available to venue management to discuss weather related problems. To ensure equal treatment, the MOSFC was closed to competing teams during the day until after the sailing completions were finished. After that, the MOSFC was open to all for opportunities to discuss the days weather conditions -- forecasters and competitors learned a lot from such exchanges.

During the day, a forecaster was normally assigned to Williamson Island -- a staging area for sailing events or onboard a daily provided weather boat able to transverse the venue area. Such on scene contacts enabled the forecaster to observe directly the effects of the environment on the competitors and the venue. Communications were maintained with these forecasters and the MOSFC via cellular telephone.

3 PAST AND FUTURE

The MOSFC was developed as part of a larger NWS effort to support the 1996 Olympic Summer Games. A forecast staff has been selected and trained and provided operational experience, an extensive surface observation network including weather data buoys reporting every 10 minutes has been tested, special atmospheric and oceanic models and delivery systems have been tested and, perhaps, most important (as told to me by several U.S. and foreign team officials), the MOSFC presence and capabilities have been favorably presented to the international yachting community. They (and MOSFC) are looking forward to our return and support during the 1996 Summer Olympic Yachting Venue.

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DEVELOPING A COMPREHENSIVE CLIMATOLOGICAL PUBLICATION FOR USE BY PARTICIPANTS DURING THE 1996 OLYMPIC YACHTING EVENTS

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1. INTRODUCTION

In support of the 1996 Summer Olympic yachting events, the National Weather Service is obtaining comprehensive weather information from various sources to be used in compiling a useful climatological summary for all participants. The data included in the publication, to be titled "BACKGROUND CLIMATOLOGICAL, METEOROLOGICAL, AND OCEANOGRAPHIC INFORMATION FOR THE 1996 OLYMPIC GAMES SAILING EVENTS," should serve to assist officials of the Atlanta Committee for the Olympic Games in Savannah, the sailing crews, and other participants from around the world better prepare for events.

Marine buoys from the National Ocean Survey, Automated Surface Observations Systems (ASOS) from the National Weather Service, remote Automated Environmental Monitoring Units from the University of Georgia, the Georgia Forestry Commission, the South Carolina Forestry Commission, the U.S. Fish and Wildlife Service, as well as other sources, have been used in compiling the climatological publication. The preliminary version , published in June, 1995, was distributed to, and was well received by, participants, venue managers, and sports managers at the 1995 summer regatta in Savannah, GA (Rinard, et al. 1996)

2. EXISTING PUBLICATIONS

2.1 *Surface Data From Land Stations*

In 1984, the Summer Olympic Games were held in the Los Angeles, CA area. The yachting event took place just off Long Beach. The southern coast of California was populated and the climate conditions were well-known and documented. The climate publication that was formulated contained a variety of information from existing sources, including buoys, many coastal weather reporting stations, and even the large locally-supported meso-network in the Los Angeles basin.

In Savannah, there existed a problem of compiling a comprehensive climatological publication due to the lack of a dense weather reporting network. The National Weather Service has had a Weather Service Office in Savannah but that is located at the airport, some 18 miles away from the site of the yachting venue. The Army has also had a weather station at the Hunter Army Airfield but this is an inland facility about 15 miles away from the race site. The Skidaway Institute (a part of the University Of Georgia) has maintained a presence on the Willmington River for quite some time but maintained information on ocean currents for the area. For these reasons, it was felt early on (around 1991) that additional instrumentation would be needed to develop the climatological information that is deemed vital to the participants of the yachting event.

2.2 *Other Land-based Weather Data*

In 1993, the National Weather Service asked the University of Georgia to supply a weather monitoring unit (referred to as a Campbell-Scientific unit) to be used in the Savannah area in support of the 1996 Olympic Games sailing events. This C-S unit was installed in the early summer of 1994 in Williamson Island, which is a small sandy strip of land that has been building up just south of Tybee Island. This "spit" of land has, on occasion, disappeared due to erosion caused by heavy swells during the passage of hurricanes to the east of the coastline. However, this is the area where barges will be anchored during the events. These barges will serve as the "headquarters" to officials overseeing the daily races.

The C-S unit supplied by the UGA proved to be extremely useful not only for gathering climatological information but in providing real-time weather data during the regattas held in the race area during this past summer. In addition to the Williamson Island weather monitoring unit, additional stations were installed early in the summer of 1995. One was installed at the Skidaway Institute on the Willmington River. Institute personnel proved invaluable in assisting the installation of the unit on the pier. This particular station provides excellent readings for the participants moving from the Olympic Village to the starting area near the mouth of the river.

The National Weather Service also installed another weather monitoring station during the early summer of 1995 at the Coast Guard site at Fort Pulaski at the northern tip of Tybee Island. These three units have proved to be incredibly useful for real-time data as well as for developing the climatological data base for the 1996 yachting events.

2.3 *Buoy and Marine Data*

Savannah was truly a data-sparse area in regards to marine weather . The only permanent marine observation site along the coast near Savannah has been the National Data Buoy Center's C-MAN platform at the Savannah Light, which is located about 10 miles northeast of the mouth of the Willmington River. No other sources of marine weather information have been available other than that. In 1994, the NDBC agreed to supplement this observation with buoy observations. There was one buoy deployed during that year and another was added during the 1995 sailing regatta. These buoys provide observations continuously 24 hours-a-day and can be polled from the OMWSO at any time (McLaughlin, 1996).

3.0 SUPPLEMENTAL INFORMATION

3.1 *Lightning Information*

A survey of weather needs was conducted in 1994 to determine what elements the participants, venue management officials, and others held as important to the success of the event. Information on lightning was deemed as crucial to the safety of all concerned.

Two Texas A&M researchers, Dr. Richard Orville and Eric Livingston, agreed to provide an analysis of the lightning climatology to be included in the NWS climatological publication. Comments from the 1995 regatta participants have verified that this type of information is indeed invaluable.

3.2 *Hurricane Climatology*

The threat of a hurricane in the coast along Savannah during July and early August is minimal, according to climatology. Information on this was obtained from the National Hurricane Center in Miami, Florida , and has been included in the prepublication. Most of the statistics derived came directly from the NHC's HURRISK program, which was run for Wassaw Sound which is the area where the races will be held.

4.0 FINAL PUBLICATION

A final publication will be available by the Spring of 1996 for the participants from each country, venue management personnel, and the general public. Information will be greatly enhanced by additional monitoring units being placed all along the Georgia coast. For example, another C-S unit was placed by the National Weather Service in Harris Neck, GA about 30 miles south of the venue location. Other stations include one maintained by the U.S. Fish and Wildlife Service at the Savannah National Wildlife Refuge just northwest of Savannah and one owned by the Georgia Forestry Commission near Brunswick, about 70 miles south of the race area, will help keep track of sea breeze conditions and/or development of convection along the coast.

5.0 SUMMARY

Forecasting for the 1996 Olympic Games sailing events will offer quite a challenge to meteorologists assigned to that venue. Having as much climatological data as possible will greatly enhance the participants' familiarity with the area -- an area where little or no climate information had been available in the past. The publication in early 1996 of information that will include temperature, wind speed and direction, tides, wave conditions, lightning climatology, and sunrise and sunset data will make that publication a much sought after item.

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WIND FORECASTING FOR THE SAILING EVENTS OF THE SUMMER OLYMPIC GAMES

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1. INTRODUCTION

The Yachting (Sailing) competition for the 1996 Olympic Summer Games will be held in the Vicinity of Wassaw Sound, on the Atlantic Ocean southeast of Savannah Georgia. The competition will take place in 10 classes of small boats and will involve a total of several hundred competitors and team personnel. Because of the large number of competitors, the location of the competition several miles from the major launch venue, and the length of time needed to conduct races, sailing athletes, officials and spectators will be the most weather-exposed group taking part in the olympics. Hence the National Oceanic and Atmospheric Administration's (NOAA) National Weather Service (NWS) committed to provide a Marine Olympic Weather Support Office on the site of the sailing venue.

Forecasting wind conditions for the yachting events of the Olympic summer games will require using sophisticated mesoscale atmospheric numerical models together with the knowledge of a staff of meteorologists with considerable marine forecasting and sailing experience. With the exception of specialized private forecast services similar to that provided for the America's Cup competition, mesoscale models are not normally used to provide detailed, hour-by-hour, local area wind forecasts; hence the models will need to be evaluated against climatology and persistence to determine whether they demonstrate skill. Since the forecast team comprises individuals from several states outside the venue area and includes members from Canada and Australia, it is important that the forecast team become familiar with the local conditions expected for the olympics. The Marine Olympic Weather Forecast Center will be issuing forecasts and briefings to the athletes and coaches of all participating nations in addition to race officials and venue managers. As shown by Powell (1993), information on the atmospheric and oceanographic climate of the competition venue will assist these users with precompetition planning and training. Climatology suggests that the sea breeze will be the dominant wind pattern during the competition. In order to learn more about the expected oceanic and atmospheric conditions, as well as sea breeze development and evolution off Savannah, a study was initiated using observations collected in the summer of 1994 by a special olympic buoy deployed by the National Weather Service (NWS) within one of the race courses and by an automatic weather station sited by the University of Georgia on a barrier island adjacent to another of the race courses. These data were compared to nine years of measurements collected from 1985-1993 at the NWS Savannah Light Coastal Marine Automated Network (C-MAN) platform located roughly 22 km offshore.

2. JULY-AUGUST MEAN CONDITIONS

The typical wind behavior is shown in Figures 1 through 6 and consists of a weak offshore south westerly that decreases to a minimum between 10 and 11 am local time and then backs steadily while increasing to 12-14 kts from the south-southeast by 4 pm. The wind climate of the marine waters surrounding Wassaw Sound is represented in the following set of wind traces from the NOAA National Data Buoy Center (NDBC) Olympic Buoy, the University of Georgia College of Biological and Environmental Sciences mesonet site at Williamson Island, and the Savannah Light C-MAN station (Fig. 1). These data have been

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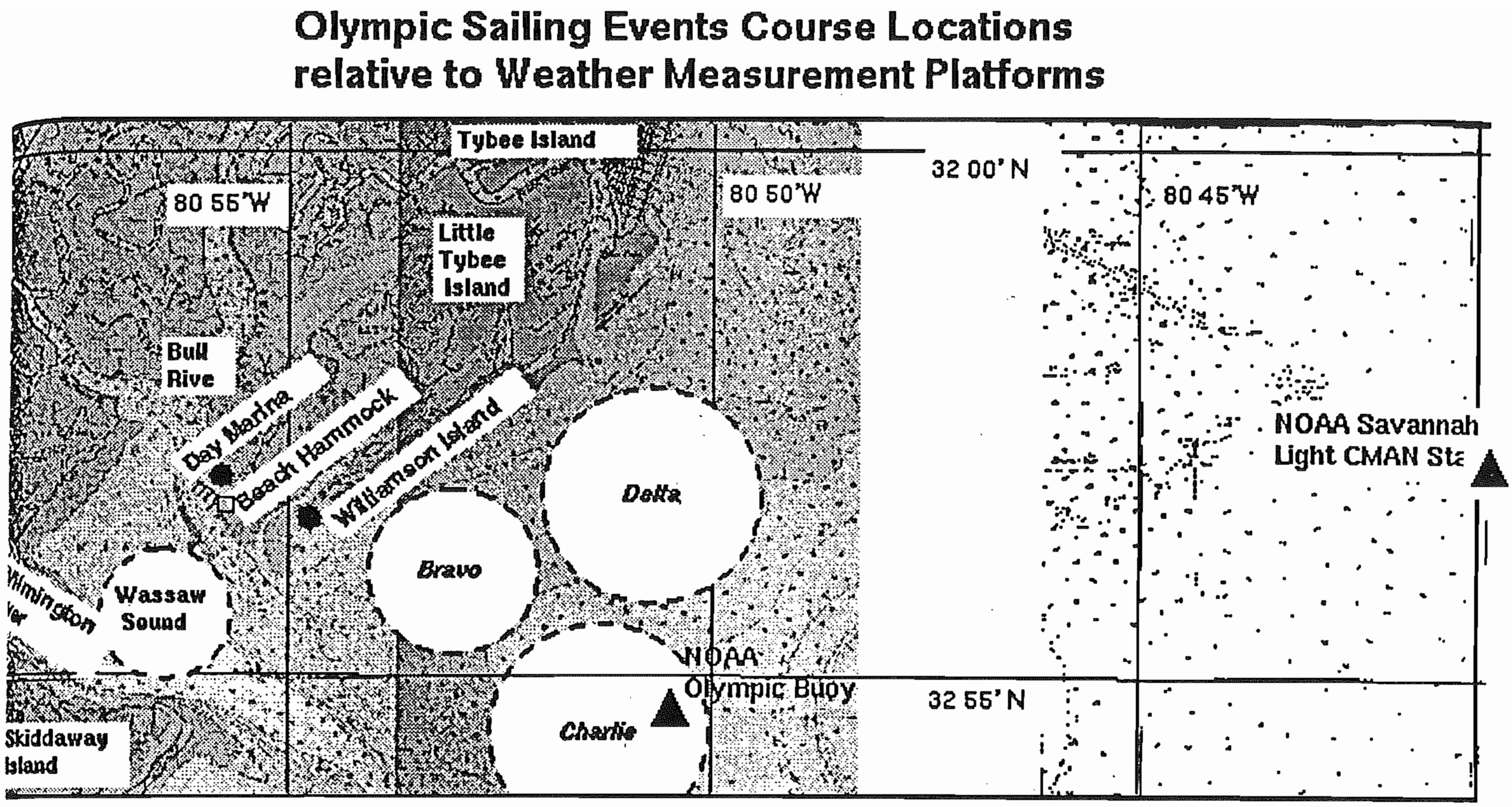

Figure 1 Location of Summer olympic race courses relative to NOAA and University of Georgia Observing platforms during 1994.

adjusted to a common height of 10 meters above sea level. The data from the Olympic buoy (Fig. 2) consist of consecutive or "continuous" 10 minute averages. The data from Williamson Island (Fig. 3) consist of one hour averages. The Williamson Island data were plotted on a slightly different time axis which has been shifted over for comparison to the other plots. The data from the Coastal- Marine Automated Network (C-MAN) station at Savannah Light (SVLS1, Fig. 3) consist of 2 minute averages transmitted each hour. All times on the plots refer to Eastern Daylight Time which is Greenwich or Universal Coordinated Time (UTC) minus 4 hours. Note that the Olympic buoy and WIlliamson Island data were not available before 1994 but the Savannah Light data go back to 1985. The plots show the relative amount of time the wind blew with a given speed and direction as a series of gray squares. The darker the squares at a particular hour, the greater the percentage of time that the wind blew with that speed or direction. In this type of plot you get a feeling for the variability of the wind in each location. The dark lines on the plot are the mean values of wind speed and direction for each hour. Note that these lines do not give a true indication of predominant wind direction where there is large amount of variation.

All plots show evidence of the sea breeze-land breeze circulation. The Olympic buoy and Williamson Island both show minima in the wind speed of less than 10 kts at 10-11 am local time. Savannah Light (SVLS1) shows a later wind minimum at 1 pm which suggests a later sea breeze due to its location further (22 km) offshore. The sea breeze onset occurs shortly after this wind

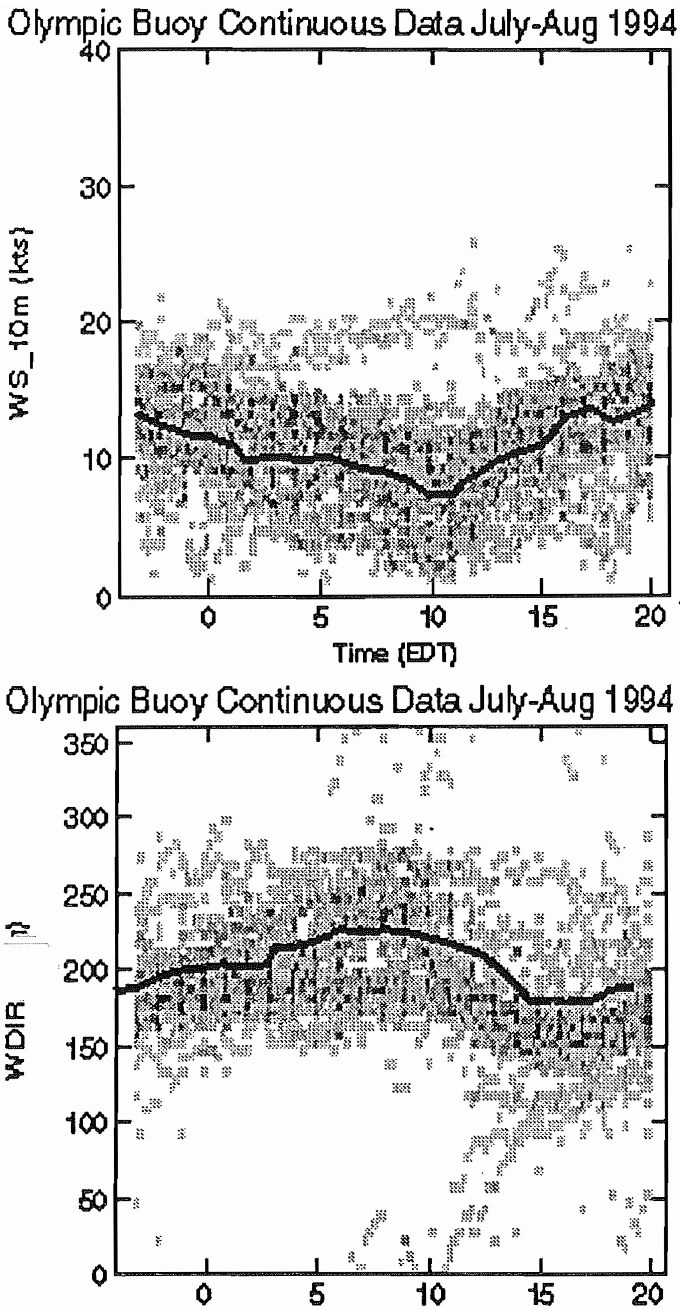

Figure 2. Observation frequency plot of Wind speed (upper, kts) and wind direction (lower, degrees) as a function of local time. More frequent observations are indicated by darker shading.

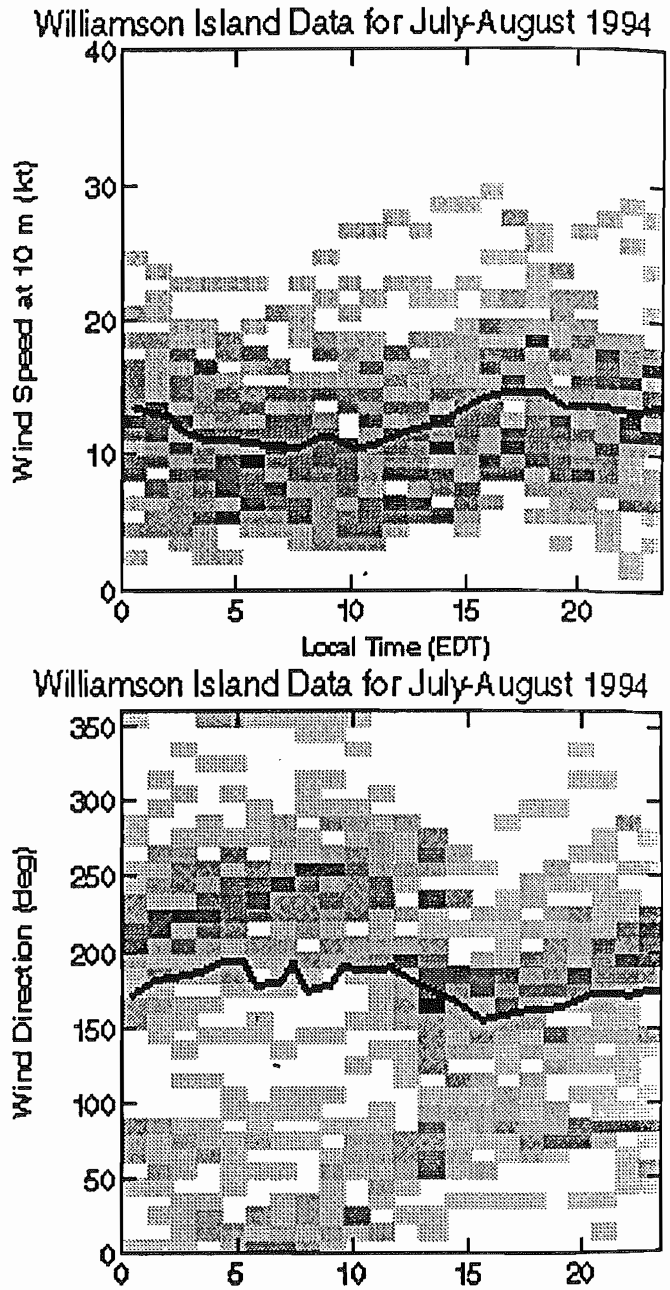

Figure 3. As in Fig. 2 but for Williamson Island.

speed minimum and is evident as a gradually increasing and backing (wind shifting counter clockwise) wind. The backing in direction is caused by a mixing of the background flow with the sea breeze. As the sea breeze circulation strengthens, the wind direction turns progressively towards a direction perpendicular to the coastline. Once the sea breeze direction is reached, the background flow is completely removed from the surface and the wind will veer with time under influence of the Coriolis force. The maximum wind at the Olympic buoy and Williamson Island

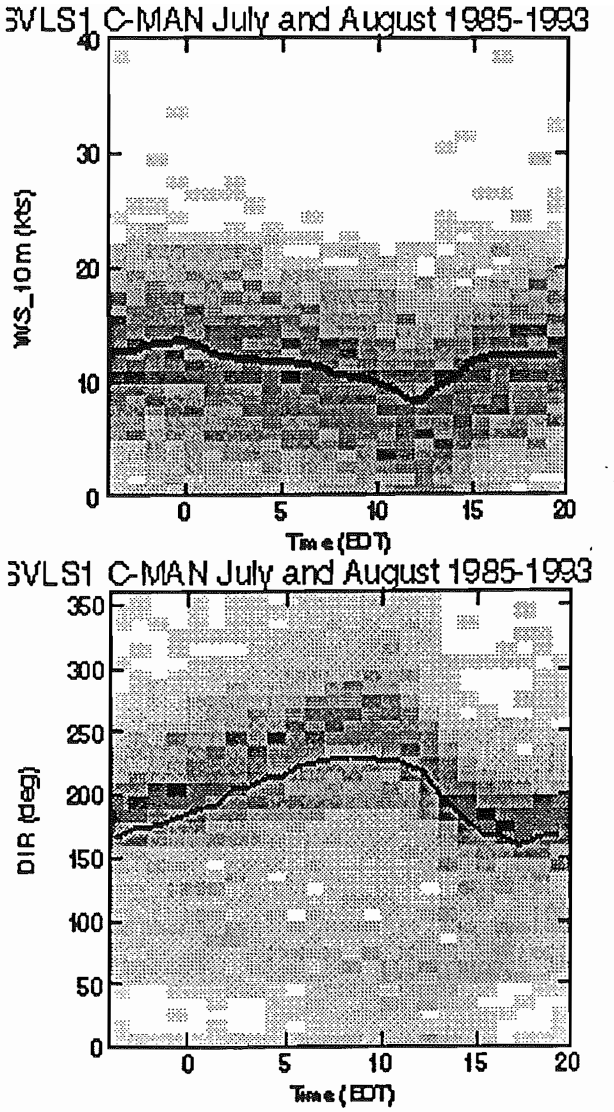

Figure 4. As in Fig. 2 but for C-MAN station SVLS1 (Savannah Light).

reaches 12-15 kts late in the afternoon between 4 and 5 pm at which time the wind direction reaches a bearing of 155-165 degrees. At Savannah Light further offshore, this maximum occurs later near 6-7pm and is slightly weaker. Williamson Island's coastal location shows more variability in the wind. If the wind direction is from the north or northeast in the morning hours, there is a tendency for the wind direction to veer with time as the sea breeze develops. During the early evening hours, the sea breeze begins to veer with time and continues veering while gradually transforming into an offshore land breeze after midnight.

Winds in excess of 20 kts in the morning and evening hours are generally associated with thunderstorm activity. Occasionally the afternoon sea breeze can reach speeds of this strength when inland heating is higher than normal and the background flow (prior to generation of the sea breeze) is slightly offshore or parallel to the coastline. A flow parallel to the coastline is believed to help maintain a large land-sea temperature and is consistent with observations of stronger sea breeze activity on the southeast Florida coast during southerly flow (Burpee 1979).

3. SEA BREEZE CHARACTERISTICS

During the olympics, forecasters will be attempting to forecast conditions in the vicinity of Wassaw Sound using the olympic buoy for verification. Since there appear to be differences in the timing of the sea breeze between SVLS1 and the olympic buoy, the July 1994 olympic buoy data were examined in further detail with supplemental information from the Savannah National Weather Service Office and the tide and current tables published by the National Ocean Service. A one month record is certainly not an ideal length for a study to help formulate forecast guidelines, but was chosen as a pilot study to help identify important characteristics of the sea breeze as a function of background weather conditions. The background conditions include mean high pressure ridge position, the propensity for thunderstorms, the amount of inland heating relative to the air temperature over the ocean, and the tidal cycle.

The mean flow over the marine area during the morning daylight hours is indicative of the high pressure ridge associated with the Bermuda High. In general the ridge is positioned to the south over central or north Florida; it's position may modulate northward or southward in response to low pressure systems moving across Canada and associated cold fronts and trailing highs affecting the northeastern U.S. or westward moving tropical systems beneath it to the south. . The high is accompanied by a subsidence inversion which should be strengthened by morning radiative cooling and which should help to concentrate the sea breeze circulation. Southwesterly flow is parallel to the coastline orientation of Tybee, Williamson, and Skidaway Islands. With morning flow from this direction the forecaster needs to determine the likely progression of the subsequent sea breeze. Wind data collected at the Olympic buoy during July of 1994 were examined for sea breeze dependence on the extent of inland heating during disturbed and undisturbed conditions. A thunderstorm observation at Savannah International Airport (over 20 miles inland) was designated as a "disturbed" day and inland heating was defined according to the difference between air temperature at the olympic buoy and the airport maximum daily air temperature. During undisturbed days with weak (less than 6 C difference) inland heating (Fig. 5) the sea breeze begins at noon (as suggested by the time subsequent to the wind speed minima) and peak speed is reached at 4 pm with a range of 6-15 kts. The sea breeze begins with a wind direction of 190-200 deg and gradually backs to 160 degrees by 5 pm. The morning wind direction from the south suggests that the ridge is positioned north of the

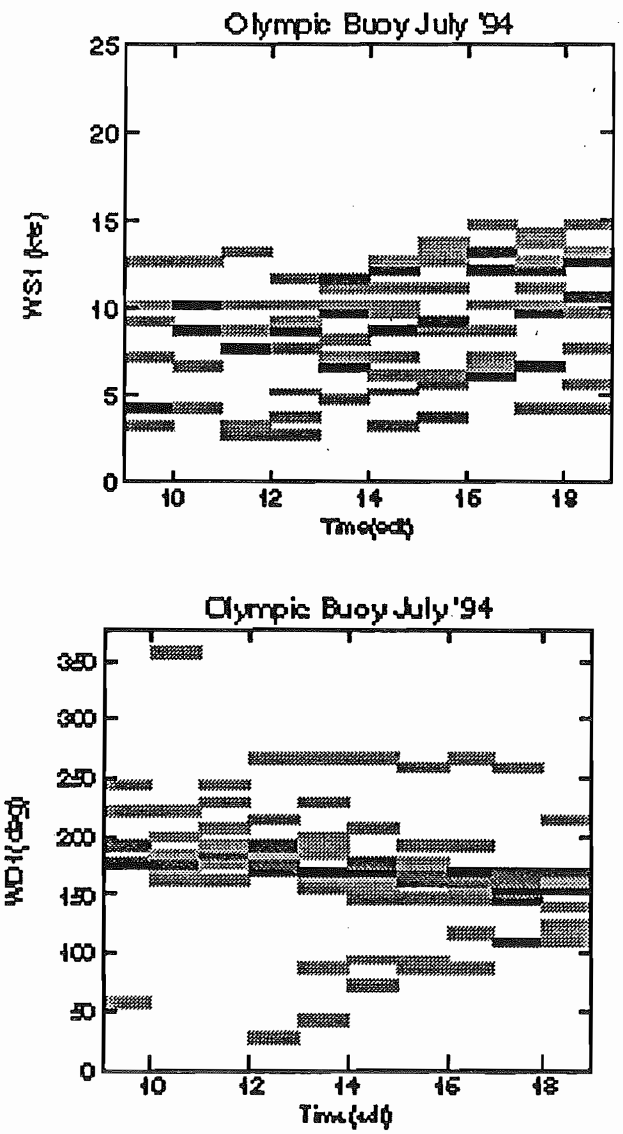

Figure 5. As in Fig. 2 but for the Olympic buoy during July 1994 on undisturbed days with weak inland heating.

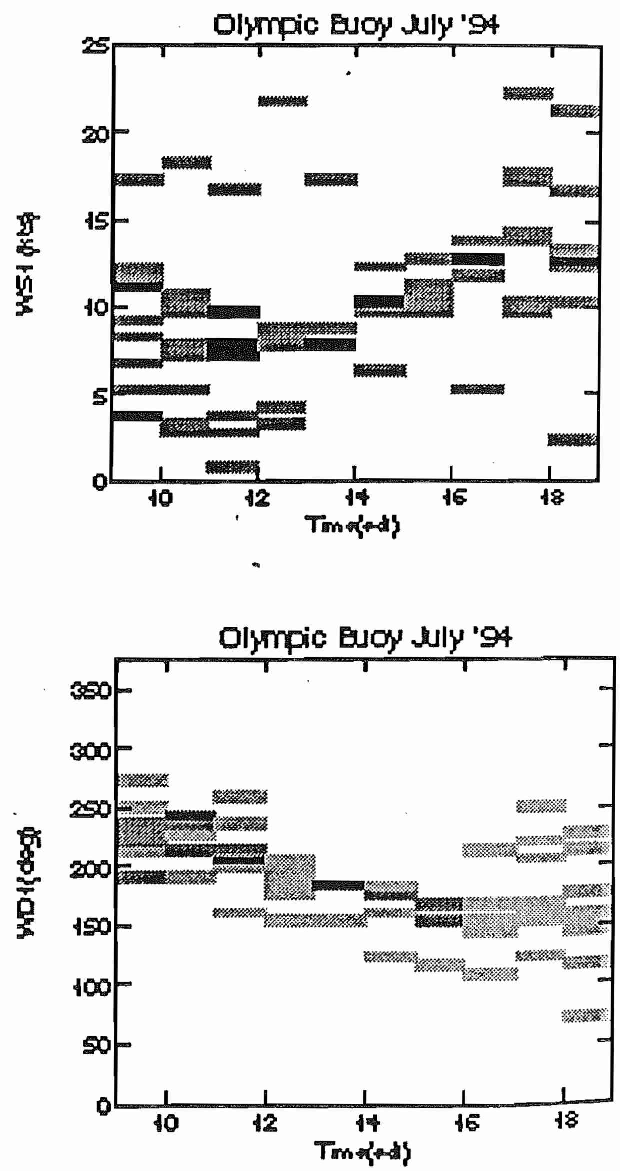

Figure 6. As in Fig. 2 but for the Olympic buoy during July 1994 on disturbed days with strong inland heating.

competition venue. Subsidence associated with the ridge is likely responsible for suppressed thunderstorm activity.

On disturbed days with strong inland heating (Fig.6, temperature difference of 6-9 C), the sea breeze begins at 11 am and increases to speeds of 10-15 kts with a peak 5pm. Disturbed conditions appear to be associated with with more southwesterly winds in the morning that shift to 190-200 at noon and then continue to back to 150 degrees by 5 pm. Southwesterly winds in the morning are consistent with a ridge position to the south of the competition venue. Occasionally winds can pick up to 20-25 kts in the late afternoon and these conditions include directions associated with the sea breeze (180) and with thunderstorm outflows (230).

On undisturbed days with strong inland heating (Fig. 7) the sea breeze begins at 11am or noon and winds increase steadily to 10-15 kts by 4 pm. The wind direction in the morning is generally from the west or southwest initially and then backs to 180-200 during the onset of the sea breeze. The sea breeze influence then causes the wind to continue backing to 150-160 by 4 pm. The morning wind direction also suggests a ridge positioned to the south but there is much variability with some cases from the southeast. A higher percentage of west winds may be indicative of the ridge to the south extending well into the Gulf of Mexico. Comparing Figs. 5 and 7, for undisturbed

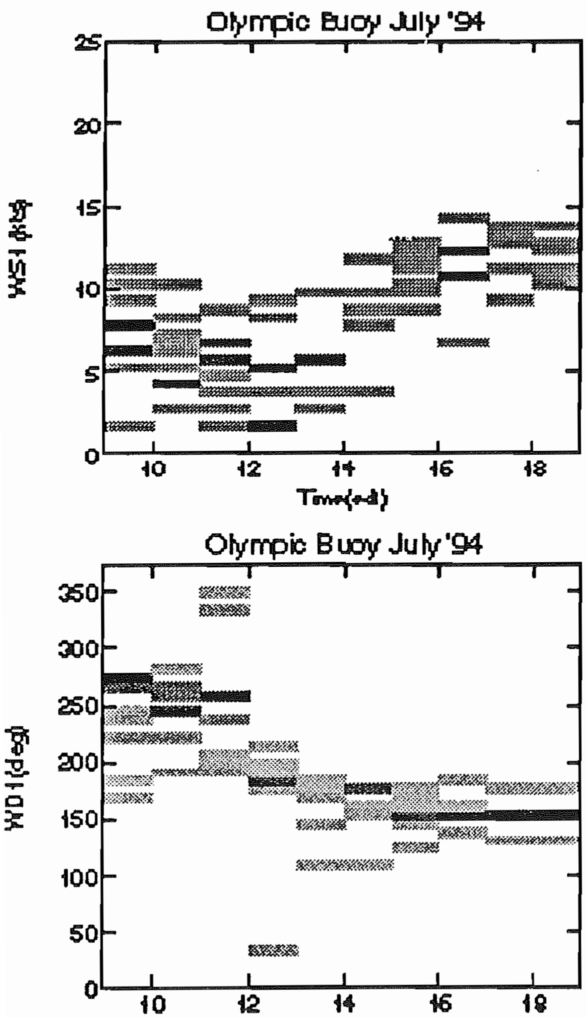

Figure 7. As in Fig. 2 but for the Olympic buoy during July 1994 on undisturbed days with strong inland heating.

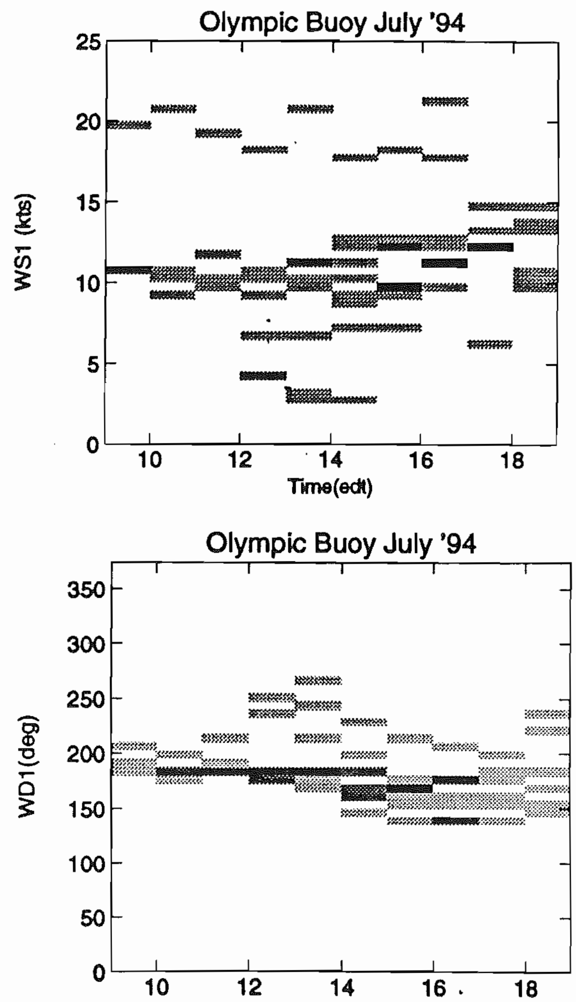

Figure 8. As in Fig. 2 but for the Olympic buoy during July 1994 on disturbed days with weak inland heating.

conditions it is not obvious that stronger inland heating contributes to a stronger sea breeze.

On disturbed days with weak inland heating (Fig. 8) it is more difficult to identify a clear wind minimum associated with the sea breeze and winds in excess of 20 kts occurred on July 27 and 28 for several hours. The wind direction in the morning is south and gradually backs towards 150 by 4 pm. These conditions probably occur when subtropical troughs form on the bottom side of the high associated with easterly wave interactions or when upper level cold lows are in the vicinity.

The data of July 1994 suggest that disturbed conditions are a pre-requisite for strong winds in excess of 20 kts. This is more clear in plots (Fig. 9) of wind speed vs. wind direction. Between 9am and 7 pm local time, the highest winds under undisturbed conditions are less than 15 kts and generally with wind directions between 150 and 180. During disturbed conditions, winds of 15-23 kts can occur from these same directions, but also from offshore directions of 230-270. Enhanced wind speeds from sea breeze directions may be inflow to developing inland thunderstorms while the offshore directions suggest downdrafts.

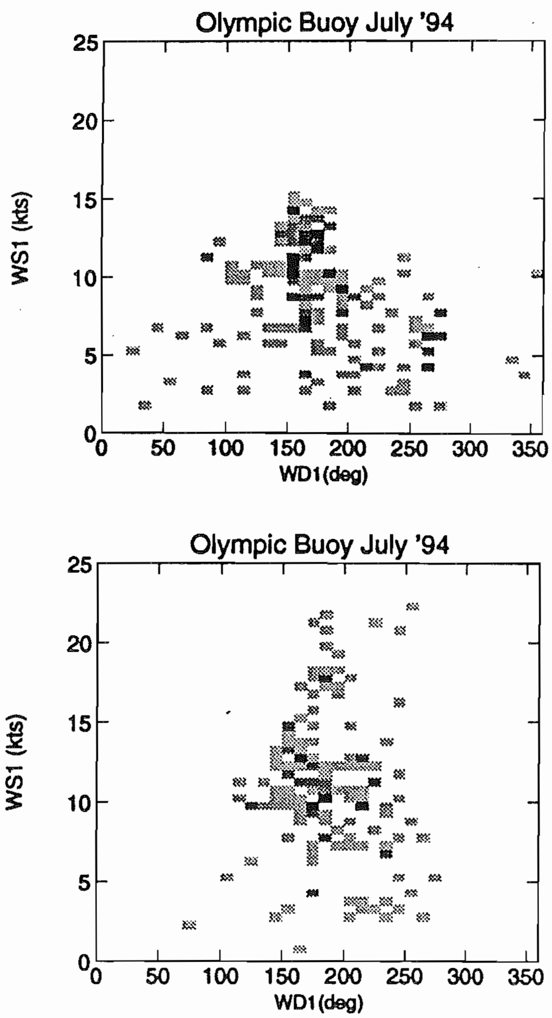

Figure 9. Wind speed vs. direction observation frequency plot for the Olympic buoy during July 1994 for hours 9am-7pm local on undisturbed (upper) and disturbed (lower) days .

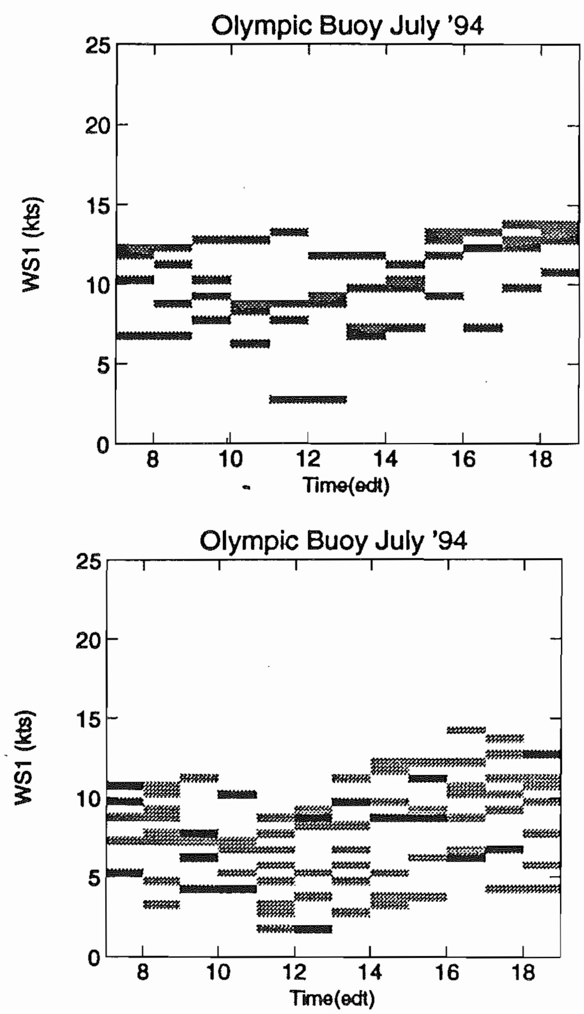

Figure 10. Wind speed vs. time observation frequency plot for the Olympic buoy during July 1994 on undisturbed days for low tide in morning 7-11 am (upper) and high tide in morning (lower).

4. SEA BREEZE RELATIONSHIP TO TIDAL CYCLE

Many sailors believe that the time of onset and ultimate strength of the sea breeze is related to the tidal cycle. One line of reasoning suggests that a low tide in the morning uncovers vast marsh land and mud flats with high emissivity characteristics which then heat relatively quickly, thereby enhancing latent heat flux and the land-sea temperature difference. The enhanced temperature difference and increased humidity would then assist the sea breeze to form earlier and stronger. Another argument suggests that the sea breeze initiation is assisted by an incoming or flood tide that follows the low morning tide. Studies described by Simpson (1994) provide conflicting evidence. One study suggests that a high tide in early morning hours is preferable because flats and marsh will then be uncovered at the time corresponding to maximum heating. Another finds that a flooded marsh or mud flats will act as the sea, allowing the land-sea temperature difference to be maximized "inland" of the coastline. Perhaps low tide in the morning is important for the early part of the heating and moistening cycle and then, once the sea breeze becomes established, a flooding tide will help the maximum temperature gradient to progress inland more rapidly than an ebbing tide. The July 1994 wind data were plotted for low time in morning (Fig. 9) and high tide in morning (Fig. 10) as a function of time for undisturbed conditions. Although the data set is extremely small for studying this question, there is no obvious relationship apparent in the plots.

5. CONCLUSIONS

The olympic buoy data for July 1994 in conjunction with climatological information measurements collected for Savannah have helped to identify factors that influence the sea breeze in the vicinity of Wassaw Sound. Data for August of 1994 and July and August of 1995 will be added to this study to help formulate forecast guidelines to use during the olympics.

It is apparent that key parameters for forecasting the sea breeze are the position of the high pressure ridge and the tendency for disturbed conditions leading to thunderstorm development. More data are required to determine whether the tidal cycle is relevant to the sea breeze onset time and intensity. Further study is also needed to determine sea breeze dependence on inversion strength and whether the available numerical weather prediction models display skill in forecasting the sea breeze.

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