SUMMARY REPORT OF THE 4TH ARIZONA WEATHER SYMPOSIUM SCOTTSDALE, AZ, JUNE 10–12, 1992

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1. Introduction

The 4th Arizona Weather Symposium, conducted at Scottsdale, Arizona, June 10–12, 1992, was a cooperative effort of private corporations and city, state, and federal governments. Our goal was to improve a wide array of operational services heavily impacted by the weather of the southwestern United States. Our objective was to communicate the most recent research findings and operational knowledge regarding severe weather, flash flooding, lightning, and other local and regional scale weather phenomena. Those participating in the Symposium included meteorologists, hydrologists, climatologists and other earth science professionals from state and county water resource management agencies, local and regional universities, city and state emergency service agencies, power and water utilities, airline services, and environmental consultants, as well as the National Oceanic and Atmospheric Administration (NOAA) and the National Center for Atmospheric Research (NCAR). Forty-three presentations were given in seven sessions: Western Region Forecast Studies and Challenges; Moisture Sources and Advection; Convection and Heavy Precipitation; Flash Flooding, Lightning, and Cloud Physics; Case Studies, Field Projects, and Instrumentation; and Regional and Local Scale Studies. Twenty-nine of the presentations were invited and contributed papers, and fourteen were included in poster sessions. A summary of the Symposium presentations is given below.

2. Western Region Forecast Studies and Challenges

Geoff DiMego, National Meteorological Center (NMC), Camp Springs, Maryland, presented an invited paper on development work in progress to institute the new regional numerical weather prediction model, known as the Eta model. He discussed a regional data assimilation system also under development that will take advantage of new higher spatial and temporal resolution data sets which are available from new technology such as the wind profiler, WSR-88D (Weather Surveillance Radar—1988 Doppler), and ACARS (Aircraft Communication Automatic Reporting System). Geoff also briefly discussed a new personal computer (PC) software package available to forecast offices that will make it possible for them to download and display NMC gridded data on a PC.

Darryl Randerson of the National Weather Service (NWS) Nuclear Support Office, Las Vegas, Nevada, presented a forecast study of a mesoscale convective system (MCS) that developed on August 10, 1981 near Ely, Nevada, and propagated nearly 500 km in 15 h toward Phoenix, Arizona. A large area northeast of Las Vegas, Nevada, received large hail and 3-6 in. of rainfall, creating severe flooding. Darryl found the heaviest weather produced by the MCS was closely associated with the −65°C cloud-top temperature and strong surface convergence. Because of the more complex terrain and vastly different climate regime from the more often studied MCSs found east of the Rocky Mountains, forecasters in the NWS Western Region are challenged to predict the development, intensity, and longevity of MCSs found in their region.

Tim Barker, NWS Western Region Scientific Services Division, Salt Lake City, Utah, presented the meteorology associated with the Awbrey Hall Fire, which occurred in central Oregon on August 4–5, 1990. Tim pointed out that to predict fire behavior properly, weather forecasters need to use full resolution model output and that mesoscale vertical motion fields appeared to have contributed to the "wild fire" character of the event.

Morris Webb, an operational forecaster, at Weather Service Forecast Office (WSFO), Albuquerque, presented his analysis of meteorological events in New Mexico that occurred during the Southwest Area Monsoon Project (SWAMP) of 1990. He showed that New Mexico had a greater percentage of monsoon events than Arizona. Morris showed that within New Mexico the higher terrain of the western counties accumulated the most precipitation from June 14 through

September 26. Morris also showed that there is little correlation between the daily precipitation index (stations reporting precipitation/total reporting stations) and reported severe storms, indicating that verified severe storm reports were biased toward the population centers. He reported several distinct "breaks" or dry spells that lasted for several days during the monsoon of 1990.

3. Moisture Sources and Advection

Gary Wade, National Environmental Satellite, Data, and Information Service (NESDIS), Systems Design and Applications Branch, Madison, Wisconsin presented an invited paper on precipitable water fields derived from VAS (Visible and Infrared Spin Scan Radiometer (VISSR) Atmospheric Sounder) data collected over the southwestern United States. Using data from August 2–3, 1990, he reported there remains much uncertainty about the validity of VAS precipitable water data over the Southwest. Gary continues to investigate its applicability in this region.

Sergio Reyes, Centro de Investigaciones Cientificas y Educacion Superior de Ensenada, Ensenada, Baja California, Mexico, reported on a study of summer water vapor transport over Mexico that identified two source regions and two transport paths for the water vapor. One source is the Atlantic Ocean with transport west through the Gulf of Mexico, and the other is the Pacific Ocean with transport north through the Gulf of California. Sergio showed that the historical contention that moisture transport into Mexico was exclusively from the Atlantic Ocean and Gulf of Mexico may be incorrect. His analysis of the 1978–85 July NMC upper-air data showed a westerly flow component south of Baja California. Thus, during westerly flow regimes moisture is transported into Mexico from the Pacific Ocean. Sergio also showed that during SWAMP 1990 precipitation varied on a 7–8 day cycle as the ITCZ (Intertropical convergence zone) shifted north then retreated southward, allowing tropical moisture to flow north from the Pacific Ocean into Mexico. He theorized that moisture comes from the Atlantic some years and from the Pacific Ocean in other years, especially during El Niño episodes.

Mike Douglas, National Severe Storms Laboratory (NSSL), Norman, Oklahoma, shared results of a study of large-scale monsoon flow and precipitation regimes over southwestern North America. Using historical upper-air data, satellite imagery, and climatological rainfall observations from the United States and Mexico, Mike reported that Arizona and New Mexico experience the fringes of what he suggested be termed the "Mexican Monsoon." He showed a relative summer precipitation maximum extending from the western Mexican state of Sinaloa then north and northeastward into Arizona and New Mexico. In particular, the July rainfall maximum in Mexico lies between the Pacific Ocean and the Continental Divide, and the greatest month-to-month increase in rainfall occurs in June and July. Using a monthly satellite cloud-top temperature climatology, he concluded that monsoon clouds are not the result of the northern migration of the ITCZ, but are distinct from ITCZ clouds.

Don Reinke, Colorado State University, Fort Collins, Colorado, reported on preferred sites for convection over the western third of the United States as derived from visual satellite cloud frequency composites. He discussed some of the difficulties encountered in using the data, such as having to renavigate and remap the data, eliminating terrain, and trying to distinguish clouds from snow or sand. These cloud frequency composites are used to produce high resolution conditional cloud climatologies, which are used in forecasting applications.

4. Convection and Heavy Precipitation

Dave Olson, NMC Forecast Branch, presented an invited paper on the processes and procedures involved in producing a QPF (quantitative precipitation forecast) at NMC. He described an interactive process in which the forecaster consults satellite data, model output, radar data, and observed rainfall data. Dave pointed out that the QPF needs much improvement before it can be used with confidence.

Darren McCollum, NSSL, presented results from a study of 27 severe weather cases that occurred between 1978 and 1990 in Pinal and Maricopa counties of Arizona. Darren showed that the severe weather events could be divided into three distinct groups based on the associated upper atmospheric synoptic scale wave pattern. Type I is characterized by a broad ridge over the central and southwestern United States, southeasterly to easterly flow over northern Mexico and southern Arizona. Type II is characterized by a high amplitude ridge over the Intermountain West and a deepening trough east of the Rocky Mountains, while the Bermuda high is suppressed southward. In Type III, Arizona is on the fringe of deep westerlies at 500 mb and higher. A significant number of severe weather events occur when disturbances in the westerlies interact with low-level "monsoonal" moisture. Future research will focus on the frequency and character of severe weather occurrences associated with each type.

Ken Howard, NSSL, discussed a study using a Satellite Monsoon Index (percentage of infrared [IR] data pixels in Arizona colder than a given threshold temperature), a technique similar to the previously developed TenHarkel Monsoon Index that is based on observed rainfall reports. Ken discussed the relationships between the synoptic scale wave pattern and single monsoon peak days and peaks that occurred over several consecutive days. He showed that single peak days were associated with 500-mb short-wave troughs moving westward through the area, whereas on consecutive peak days, a 500-mb high with high moisture embedded in the circulation was positioned over the region. No significant differences were found using surface data to discriminate which kind of monsoon peak was occurring.

Rob Fovell, University of California at Los Angeles (UCLA), reported on his work with two-dimensional fluid dynamic models. He discussed the influence of vertical shear of the environmental wind on thunderstorm updraft behavior. He showed that as shear depth increased toward 6 km (level of maximum buoyancy), storm strength increased; whereas, above 6 km strength increased very little with continued increase in shear. He also reported the model indicated that the periodicity of updrafts in a multicell storm is a function of shear depth. When the shear depth was less than 2.5 km, the interval between successive updrafts was chaotic. With shear depth at 2.5 km, updraft production occurred at 15-min intervals, whereas with shear depth at 5 km, updraft production occurred at 30-min intervals. Rob suggested that the difference between the 15-min and 30-min periodicities may be the result of the transition from forced to free convection as a parcel rises above the level of free convection.

5. Flash Flooding, Lightning, and Cloud Physics

Tom Dulong, an operational forecaster at WSFO Denver, reported on a case of heavy rain and hail that occurred in southwest Denver on May 28, 1991. He showed that flash flooding occurred coincident with a strong equivalent potential temperature gradient, conforming to one of the Maddox models for flash flooding/heavy rain situations.

Irv Watson, NSSL, presented statistics on interannual cloud-to-ground (CG) lightning activity for the southwestern United States and on diurnal CG activity in Arizona. Irv compared synoptic patterns for eight bursts in monsoon CG activity and five breaks in monsoon CG activity from 1985 through 1990. He found that during burst periods the flow was from all directions except the west, with moisture at all levels. During the break periods, west winds did occur, constant pressure surface heights were lower, and the atmosphere was drier and cooler at 500 mb and above. Irv also reported that breaks lasted three to four days and occurred three to four times during the monsoon season.

Roelof Bruintjes, NCAR and University of Arizona (U of A), Tucson, Arizona, presented an overview of the research being conducted by NCAR and U of A to determine the feasibility of increasing snowfall along the Mogollon Rim. A three-dimensional, anelastic fluid dynamic model is being run to simulate field conditions and study wind flow, possible transport and diffusion of seeding material, and the sequence of microphysical processes within a seeded cloud. The model simulated gravity waves with 3-5 ms^{-1} updrafts produced downstream of mountain peaks. In addition, model simulations showed that precipitation is formed on the upstream side of mountain ridge lines. Measurements collected by aircraft, balloon soundings, and wind profilers showed that indeed gravity waves and precipitation formed as the model simulated. Observations also showed that gravity waves vanished when wind flow is more than 30 deg from normal to the ridge line.

Ed Ellison, White Sands Missile Range (WSMR), New Mexico, discussed localized heavy rain and the resulting flash flood near WSMR on August 13, 1991. He suggested that a back-door cold front triggered the severe storms and flooding. Peak rainfall was in excess of 6 in.

6. Case Studies, Field Projects, and Instrumentation

Don Burgess, WSR-88D Operational Support Facility, Norman, Oklahoma, provided an overview of the computational and data processing power of the new WSR-88D. He also discussed the various meteorological and hydrological algorithms within the system that produce products derived from the base data. Don pointed out that hydrologic applications of the WSR-88D, such as derived rainfall estimates over instrumented watersheds, compare favorably with the ground-truth measurements. However, some factors like evaporation below the beam, low-precipitation storms with high hail reflectivities, rainfall overestimates due to the bright band, and inaccuracies in the radar reflectivity vs. rainfall relationship can lead to errors, which the forecaster must understand.

Diana Bartels, NSSL, presented P-3 airborne Doppler radar data collected in a MCS to the south and southeast of Phoenix on August 2, 1990. Although its structure and circulations were much different than those observed in large central United States systems, the MCS generated strong winds, small hail, and heavy rains, as well as an organized outflow that was tracked all the way to the Colorado River Valley. The outflow was noteworthy because it produced the coolest temperature at Phoenix (76°F) during SWAMP.

Mike Franjevic, an operational forecaster at WSFO Phoenix, and Norm Hoffmann, Area Manager, WSFO San Francisco, reported on the development and interaction between the WSFO Phoenix and the Arizona Thunderstorm Chase (AZTC) Program. The AZTC program began in 1989 as a cooperative effort between the WSFO Phoenix and Arizona State University (ASU), Office of Climatology. Mike highlighted that the AZTC provides the WSFO with trained mobile observers who gather and transmit information concerning thunderstorm conditions within the Phoenix metropolitan area in real-time during the monsoon. AZTC information can lead to severe storm warnings or verify the presence of severe weather in the area, thereby aiding in the warning verification process. Students who make up the team receive innovative field experience in observing and forecasting monsoonal thunderstorms, as well as in collecting and assessing research data sets. Norm expanded on the work of the AZTC. He described a particular case in which two AZTC chase vans provided high-quality near real-time observations of a July severe thunderstorm to the forecast office as the storm moved through Phoenix.

John Gaynor, NOAA, Wave Propagation Laboratory, Boulder, Colorado, reported on the US Environmental Protection Agency sponsored Project MOHAVE (Measurement of Haze and Visual Effects), which was designed to monitor the effect of emissions from the Mohave Power Plant in Laughlin, Nevada, on visibility in the Grand Canyon. The study took place from January 11–February 20, 1992. Five wind profilers, two equipped with RASS (radio acoustic sounding system) for measuring temperature, were used. Definitive results are not yet available, however, persistent low-level northerly flow down the Mohave Valley is driven by the Great Basin cold surface high pressure. It may be possible that this low-level flow could transport pollution and eventually mix it into the southerly flow component aloft, resulting in a plume that spreads toward the Grand Canyon.

7. Regional and Local Scale Studies

Andy Negri, National Aeronautics and Space Administration (NASA), Goddard Space Flight Center, Greenbelt, Maryland, presented research on the regional rainfall climatology of southwestern North America using SSM/I (Special Sensor Microwave/Imager) and IR satellite sensor data. He presented precipitation estimates from IR, passive microwave, and a combined IR/microwave technique. Andy showed that a preferred area for afternoon and evening convection was found between 500 m and 2000 m elevation of the western slopes of the Sierra Madre Occidental. A morning maximum was identified off the Mexican coast south of Mazatlan. Another maximum was found along the Mogollon Rim of Arizona. The SSM/I passive microwave radiometer data are more useful than the IR data. The IR data are often contaminated by high altitude, non-precipating cirrus, which does not affect the SSM/I sensor. But, since the SSM/I instrument is carried on a polar orbiting satellite, its temporal resolution is much poorer than Geostrationary Observational Environmental Satellite (GOES) IR. A combination of these data and techniques seems to work well, since IR has higher temporal resolution and SSM/I has better physics.

Dave Whiteman, Battelle Pacific Northwest Laboratories, Richland, Washington, presented another aspect of wintertime visibility studies in the Grand Canyon and Colorado Plateau. He found that under undisturbed clear sky conditions in wintertime, diurnal circulations within the basin arise from slope and valley wind systems that form on the sloping sides and interior plateaus of the basin. One of these wind systems circulates between Lake Powell and the Grand Canyon. With weak synoptic flow conditions, these circulations produce a deep pool of cold air over the Lake Powell basin that can stagnate under a temperature inversion. Dave showed that a convective boundary layer develops over the floor of the basin during the day, but sensible heat fluxes are normally insufficient to break the inversion. Usually the inversion is only broken by passing wintertime synoptic-scale storms, which allow the basin to be ventilated.

Joe Sutherland, Salt River Project (SRP), Phoenix, Arizona, presented an overview of a comprehensive air quality and meteorological study conducted from January through March 1990 to determine the impact of the Navajo Generating Station, situated northeast of the Grand Canyon near Page, Arizona, on visibilities within Grand Canyon National Park. Extensive meteorological measurements were made with a large surface network and frequent upper-air soundings. Wind measurements were made at Phantom Ranch on the canyon floor, Hopi Point on the south rim, and Indian Gardens halfway between the south rim and the canyon floor. Joe showed that because of the east-west orientation of the canyon, preponderance of bare rock, and low wintertime sun angle, the canyon is characterized by a thermally active south-facing canyon wall (north wall) and a thermally quiet north-facing wall (south wall). This generates a nearly neutral stability because of the cross-canyon mixing of air. No organized up-river or down-river air flow was found.

Warren Blier, UCLA, presented results of a study on the monthly and season variations of California wintertime precipitation. Wintertime monthly mean precipitation data from 1931 to 1988 were used. Correlations between the extreme wet and dry months, climatological 500-mb heights, and surface pressure fields were completed. Essentially, when a long-wave ridge is positioned over the state, the weather is dry. When the ridge is positioned well off the coast and west-southwest winds prevail at the surface, California experiences it wettest weather.

Luis Farfan, a graduate student at the U of A, reported on a climatological study of propagating and stationary mesoscale convective systems observed in southwestern North America during SWAMP 1990. Luis showed that of the 27 MCSs studied, 16 were the propagating type and 11 were stationary. Most of the MCSs formed along the west slope of the Sierra Madre Occidental and propagated to the west, southwest, or south. The research documented a tendency for middle-level vortices to form in the long-lived MCSs. Eight of the 27 MCSs left behind "residual" vortices. Of the eight vortices, seven were formed within stationary MCSs. The mean radius of the vortices was 88 km.

Jack Hales, National Severe Storms Forecast Center (NSSFC), Kansas City, Missouri, presented an invited paper on the role of the unique topography of the southern California coastal region in favorably enhancing the environment for the development of high values of helicity. Jack's theory was that this topographically induced helicity contributes to the high incidence of tornadoes. The region, which includes Orange County and Los Angeles County, experienced 38 tornadoes from 1977 to early 1992. None of the tornadoes resulted in fatalities, but several inflicted considerable damage and some injuries. Most of the tornadoes formed several hours after the passage of a cold front. The atmosphere was characterized by small CAPE (convective available potential energy), large helicity, an onshore flow of moist air at low-levels, and dry air aloft.

Ray Lougeay, State University of New York, Geneseo, New York, reported on research he has been conducting with the ASU Department of Geography. Ray discussed the use of Landsat thematic mapper image data coupled with a ground-level network of automated meteorological stations and special microclimatic energy budget observations to assess ambient surface and near surface temperatures associated with various land uses in Phoenix, Arizona. He showed a large range of apparent surface temperatures. The maps of land use he showed were generated from classification and analysis of the Landsat thematic mapper data. This and future work are targeted toward assessing the magnitude of inadvertent climate modification that may result from proposed land use development over the next few decades.

Bill Hall, NCAR, showed results from three-dimensional nested grid model simulations of the January 9, 1989 severe windstorm over the Front Range of the Colorado Rockies. The model employs a 10-km grid with an interior nested grid resolution of 1 km. Rawinsonde observations from Craig, Colorado, were used to initialize the model. Bill showed that the model indicated a breaking of small-scale, upper-atmospheric waves. These waves were thought to be the cause of strong, gusty, surface winds as downslope flow was observed along the Front Range. A jump-type front with updrafts as strong as 30 m s^{-1} developed in the model simulation along the leading edge of downslope flow.

Shawn Bennett, NSSL, presented the final paper, on the four-dimensional structure of the Phoenix heat island. The horizontal, vertical, and temporal structures of heat island were discussed. Because the Phoenix metropolitan area sprawls throughout the Valley of the Sun (Salt River Valley), the corresponding heat island also spreads from Glendale in the northwest toward Mesa in the southeast. Shawn proposed the term "heat archipelago" to describe the chain of heat islands linked across the valley. He showed that the peak intensity of the heat island ocurred between 2300 and 0100 MST. Surface air temperature during peak intensity ranged from 85°F to 100°F, and the coolest temperatures were in the vicinity of irrigated, lush vegetation. Cross-sections through the heat island revealed a distinct urban boundary layer about 600 m deep with a well-mixed layer evident to about 3000 m. Mixing ratios in the urban boundary layer were about 13–14 g kg^{-1} (40%–60% rh), and mixing ratios in the well-mixed layer were about 10–11 g kg^{-1}. Future research plans include modeling the intensity of the Phoenix heat archipelago 10, 20, or even 30 years into the future.

8. Poster Session

A poster and demonstration session was held Thursday evening, June 11. The NSSL mobile research laboratory was shown and a sounding launch demonstrated. Alongside the NSSL mobile laboratory, the ASU AZTC exhibited its chase van. Thirteen papers were presented by graduate students, operational forecasters, and research meteorologists. A description of those papers follows.

Bob Maddox, NSSL, presented an overview of the 1990 SWAMP program in Arizona. Dan Blumberg, ASU Department of Geography, contributed his study of seasonal and diurnal wind variations in the Phoenix metropolitan area as measured by the Phoenix Real-time Instrumentation for Surface Meteorological Studies (PRISMS). Matthew Stoll, ASU Department of Geography, offered his work on the surface emissivity calibration of remotely sensed thermal imagery in an urban environment. Mark Hubble and Kristine Kosnik, ASU Office of Climatology, shared their experiment to study the isolated effects of different instrument shelter designs on the measurement of ambient air temperature. Herbert Verville, Sandra Brazel, Anthony Brazel, and Steve Calderon, ASU Office of Climatology, presented a description of the PRISMS network. Norman Hoffman, Area Manager, WSFO San Francisco, contributed his analysis of a severe dust storm and its devastating effects along the Interstate 5 freeway in the San Joaquin Valley, California. Shawn Bennett, NSSL, Jon Skindlov, SRP, Ken Howard, NSSL, and Dean Edwards, SRP, contributed their study of the process of applying weather prediction to the forecasting of SRP hourly energy demand over a 24-h period. Diana Bartels, NSSL, presented her research on the middle-level circulations associated with MCSs observed during SWAMP. Rodger Brown, NSSL, discussed dual-Doppler observations of the flow in the wake of a developing severe storm updraft. Les Colin, WSFO Boise, described the process of spatial interpolation of unequally distributed data. Mike Douglas, NSSL, showed his analysis of the low-level jet observed in the northern Gulf of California. Darren McCollum and Bob Maddox, NSSL, contributed a case study of severe storm outbreak on July 23–24, 1990. Paul Ostapuk, SRP, described his technique for forecasting monsoon precipitation on the Colorado Plateau using a single-station climatological index. Ken Howard and Bob Maddox, NSSL, presented an overview of convective cloud-top temperatures as observed in southwestern North America by GOES IR during the summers of 1989, 1990, and 1991.

9. Future Plans

We feel that those who attended the 4th Arizona Weather Symposium were stimulated by the exchange of ideas and experiences. Southwestern North America has a unique and challenging climate, one unlike any other region on the continent. Continued improvement in our understanding and forecasting of the weather phenomena that occur in this environment can be enhanced by gatherings like the Arizona Weather Symposium, which seeks to build bridges to transfer research and development into an improved quality of products and operations. We hope that this process will continue. The 5th Arizona Weather Symposium is tentatively being planned for the spring of 1994.

Authors

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Rodger Brown is a research meteorologist at the National Severe Storms Laboratory, a position he has held since 1970. He received a Bachelor of Science in Earth Science from Antioch College, a Master of Science in Meteorology from the University of Chicago, and a Doctor of Philosophy in Meteorology from the University of Oklahoma. During the 1970s, he was part of the research team that documented the potential of Doppler radar for improving the accuracy and timeliness of severe storm and tornado warnings (leading to NEXt generation RADar or WSR-88D). More recently, he has been using Doppler radar to study the morphology and evolution of thunderstorms from their nonsevere to severe stages. He is also involved with the preparation of WSR-88D training materials.

Jon Skindlov, a senior staff scientist in the Water Resources Management department of the Salt River Project (SRP), a public water and power utility in Phoenix, Arizona is involved in short, medium, and long-range weather forecasting for reservoir and power operations. His research areas at SRP cover urban climate, global climate change, winter precipitation enhancement, and regional and local scale convective systems. He received a Bachelor of Arts in physics from St. Olaf College in 1968, studied meteorology at San Jose State University, received a Master of Arts in geography from Ohio University in 1984, and a PhD in climatology from the University of Delaware in 1992.

David Carpenter is the Deputy Meteorologist in Charge of the National Weather Service Forecast Office in Phoenix, Arizona. Prior to WSFO Phoenix, David worked for the NWS in Salt Lake City and New Orleans, and for NSSL in Norman, Oklahoma. He received the Bachelor of Science degree in Meteorology from the University of Oklahoma in 1978. His primary interests are mesoscale meteorology and operational forecasting.

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