High-Resolution Climate Monitoring on a Mountain Island: The Saguaro National Park Pilot Study

Michael A. Crimmins
Department of Geography and Regional Development, The University of Arizona, Tucson, AZ

Abstract—*A pilot project to identify climate monitoring needs within Saguaro National Park began in fall 2003. Nine weather stations were deployed across the complex topography of the park to provide insight into the spatial and temporal patterns of climate within the park management unit. This project will provide a valuable baseline for park management and may highlight unique spatial and temporal patterns that deserve further investigation. Project findings will help dictate long-term climate monitoring strategies for the park and other park units.*

Introduction

Climatic variables are especially important to natural resource management because they are strongly tied to ecosystem function yet are often overlooked in management activities because of inadequate monitoring. Spatial and temporal patterns in precipitation can limit or promote the growth of different plant species, while patterns in temperature can induce mortality in vegetation and wildlife during hard freezes or episodes of excessive heat (Bonan 2002). Current climate monitoring systems within National Parks capture variability at scales too coarse to be relevant to park-level natural resource and ecosystem management decisions. Climate information is integral to many different management activities and needs to be collected at spatial and temporal scales appropriate for a diversity of activities including:

- ***Wildlife studies:*** Predicting amphibian movement patterns based on high-resolution precipitation data.
- ***Hydrological monitoring:*** Addressing water rights issues and maintaining baseflows in critical riparian habitats.
- ***Wildfire management:*** Monitoring spatially explicit fuel moisture conditions and predicting fine fuel accumulations; Analyzing the relationships between post-fire vegetation recovery and climatic variability.
- ***Invasive species management:*** Establishing links between climatically induced disturbances and invasions of non-native species.
- ***Air quality management:*** Monitoring airflow patterns from urban airsheds carrying harmful pollutants; understanding smoke dispersion during prescribed burns for fuel management.
- ***Water quality and channel morphology:*** Characterizing patterns in precipitation with respect to erosion and sedimentation rates in streams.
- ***Education:*** Providing the opportunity for park visitors to learn about the importance of climatic variability on different ecosystem processes and coupled ecosystem-climate monitoring.

Project Background and Design

The Sonoran Desert possesses great habitat diversity due to steep environmental gradients within small geographic areas (Hubbard et al. 2003). The Rincon Mountain District of Saguaro National Park is only 27,000 hectares in size, but contains six biotic communities due to its steep topography. Many programs exist within the park to monitor and inventory wildlife and vegetation, but little has been done to monitor physical environmental parameters in a systematic and long-term manner. This is especially true for climatological variables, which are one of the strongest determinants of the spatial distribution of biological communities within the park.

The present pilot study is an attempt to assess the climatological monitoring needs within a relatively small park with the unique natural resource management challenges posed by the biological diversity found on isolated mountain ranges called sky islands. Since 1994, meteorological data have been collected at two sites within the park boundary. One station is located near the visitor's center at an elevation of 700 meters, while the other is located near the top of the Mica mountain range at 2,500 meters elevation. The lower elevation station is part of the Pima County Department of Environmental Quality (DEQ) air quality monitoring program, and the upper elevation station is part of the National Interagency Fire Center Remote Automated Weather Station (RAWS) program. Each station collects basic meteorological data (wind speed, temperature, relative humidity, precipitation) on an hourly basis, but does so with different sensors and monitoring equipment making long-term comparisons difficult. The two stations' purposes also vary. The Pima DEQ site is focused on air quality monitoring, while the RAWS site is designed for National Fire Danger Rating System (NFDRS) calculations. Each site collects specialized measurements that are not directly comparable. Spatial and temporal patterns of climatological variables relevant to natural resource management activities within the park do exist, but cannot be resolved by the current configuration of meteorological stations within the park.

Nine meteorological stations have been deployed throughout Saguaro National Park-RMD to assess the representativeness of current climate data collection strategies and to explore new ways of integrating climate information into natural resource management decision making. Figure 1 shows the location of meteorological stations within the park deployed for the pilot study as well as the two existing stations (RAWS and Pima County DEQ sites). Each pilot study station collects ten meteorological variables at ten-minute intervals, storing the data in an on-site datalogger. Variables monitored include: air temperature, relative humidity, rainfall, barometric pressure, solar radiation (300-1,100 nm), photosynthetically active radiation (400-700 nm), wind speed, wind direction, soil moisture (10 cm depth), and soil temperature (10 cm depth). Each variable is monitored in compliance with World Meteorological Organization standards (WMO 1983).

The goal for this pilot study was to capture the spatial and temporal variability in climatic patterns potentially relevant to specific natural resource management needs and to identify long-term monitoring strategies that could be applied at other parks. Four stations were located at regular intervals (300-500 m) along a drainage to complement existing hydrological studies and to capture the climatic component of the topographic-environmental gradient. Three stations at the top of Mica Mountain were spaced to assess the importance of aspect and spatial variability over the upper elevation regions of a sky-island. One of these stations was placed adjacent to the existing RAWS to compare data acquisition strategies (variables, sampling interval, sensor placement). The two remaining stations were located near the summit of Rincon Peak and in the saddle between Rincon Peak and Mica Mountain to assess the spatial variability in climatological variables between two adjacent peaks. Site information, including ecological community type, for each station appears in table 1.

These stations are located with respect to existing Saguaro National Park monitoring programs including wildlife monitoring, water quality monitoring, and fuel/post-fire vegetation recovery monitoring. New monitoring programs are also being instituted in conjunction with the weather station network. Vegetation monitoring plots have been established near each station and are being sampled at a high frequency (monthly to seasonally) to compliment the high-temporal resolution climate data. Evaluating links in species composition, phenology, and plant reproductive cycles to high-resolution climate variability will provide insight into ecosystem function and help to better inform resource management decisions.

Preliminary Results

Stations were installed during the period of September 2003 through May 2004, resulting in different periods of record for each station at the writing of this paper. A preliminary examination of data from several stations demonstrates that distinct climatic patterns exist over short distances within the park. Air temperature data from four stations for a 7-day period in late March and early April of 2004 are presented to illustrate climatic variability within the monitoring network (figure 2). The approach of a vigorous low-pressure system and subsequent cold frontal passage transitioned the entire Southwest United States from exceptionally warm and dry conditions to cold and wet. The month of March 2004 was the warmest March on record for many locations in southern Arizona including the city of Tucson (NWS 2004). Early spring growth of annuals and budding on trees were noted during field visits in March to several of the weather station sites, including high elevation sites. The passage of the cold front on April 1, 2004, dropped temperatures over 10 ^{o}C in just a few hours. The upper elevation site (RAWSDN, 2,417 m) recorded below freezing temperatures for over 30 hours after the frontal passage. The lower elevation sites (MADRAN, SHIDAG, and GRASHA) also recorded substantial drops in temperature, but none fell below freezing.

This type of climatic variability is probably not uncommon at each of these sites. Each of these stations is located at sites representing different ecological community types with different long-term climatic regimes. What is unclear is how flora and fauna are responding to climatic variability at short time scales. Subsequent vegetation sampling and wildlife monitoring may show that the period of freezing at higher elevations impacted certain plant and animal species in unexpected ways, while lower elevation species were not impacted. Ecosystem dynamics are driven in part by short duration, high intensity climate variability as well as the slower changes brought on by lower frequency variability (e.g., global warming) (IPCC 2001). Understanding how ecosystems respond to high frequency climate variability (e.g., short duration, extreme events) is necessary to properly manage natural resources in a changing climate. For example, accounting for a late season freeze can provide crucial information on live versus dead fine fuel availability for early summer wildfires.

Examination of wind speed and direction data over the same period further illustrates the spatial variability of climatic variables within the 27,000 hectare park boundary. Wind roses for the same four stations discussed previously are plotted in figure 3. Each wind rose depicts the frequency of occurrence of winds in 16 direction sectors (every 22.5 degrees) and 6 wind speed classes using 1,009 wind observations over the seven day period from March 30 through April 5, 2004.

Each wind rose in figure 3 has one dominant direction with the highest frequency of occurrence and interestingly is a different direction at each site. The MADRAN and SHIDAG sites have a higher frequency of northerly and northwesterly wind observations, while GRASHA and RAWSDN have more northeasterly to southeasterly observations. MADRAN, SHIDAG, and GRASHA are located along a drainage that is most likely influencing dominant wind directions. The dominance of easterly winds at GRASHA and northerly winds at SHIDAG and MADRAN suggests that cold air drainage flows are occurring during the evening hours. Plotting wind roses for evening hours (9 PM LST to 5AM LST) only (not shown) confirms that over 45% of evening wind observations are northerly (MADRAN and SHIDAG) or easterly (GRASHA) consistent with an air flow pattern that follows the drainage along which they are located. The highest elevation station (RAWSDN) is at the top

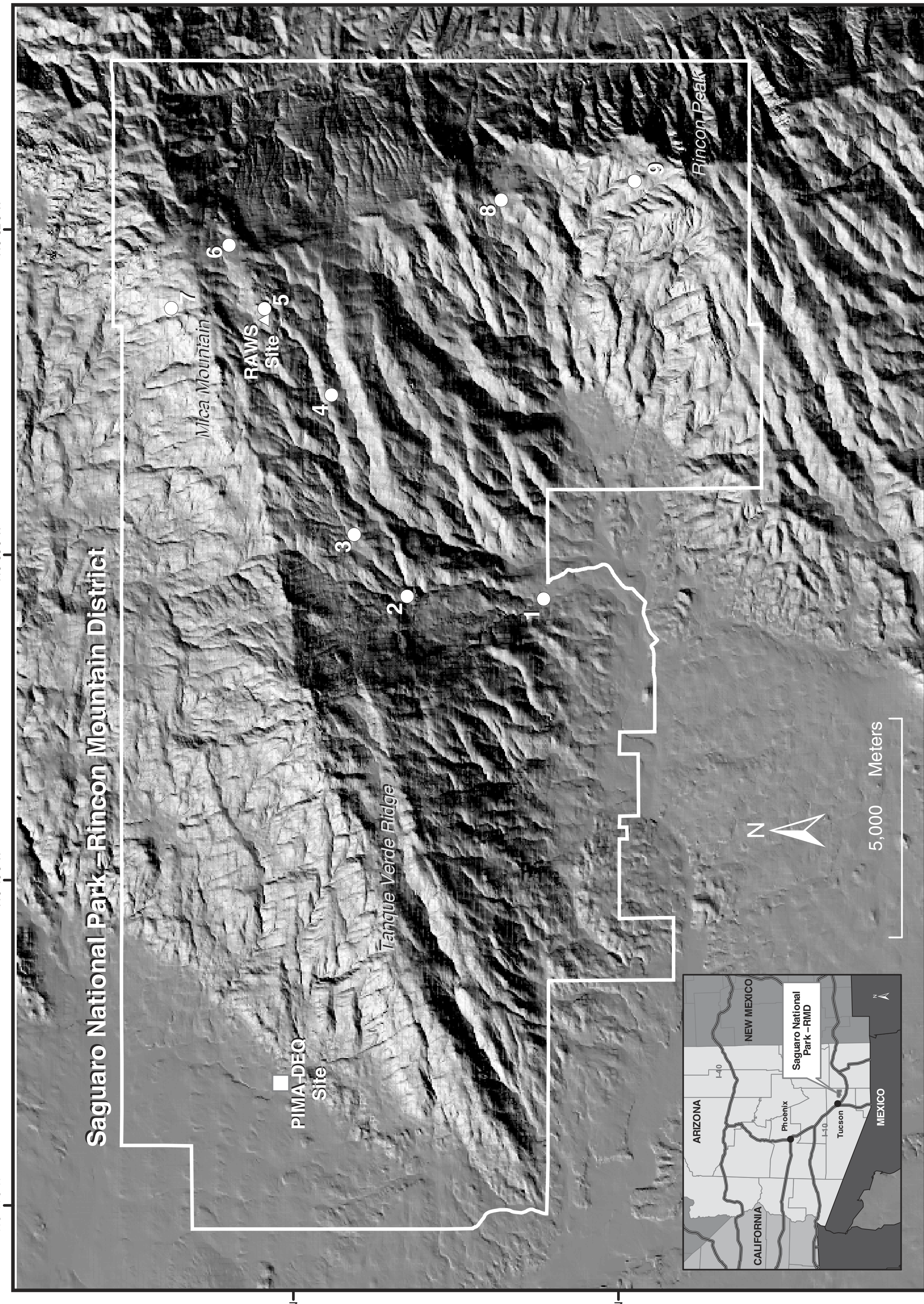

Figure 1—Weather station locations in Saguaro National Park-RMD. Refer to table 1 for station names and site information.

Table 1—Weather station site characteristics.

Station	Name	Elevation	Aspect	Ecotone/community type	Site installation
1	MADRAN	1,052 m (3,450 ft)	S	Upper Sonoran Desert Scrub	September 2003
2	SHIDAG	1,402 m (4,599 ft)	S	Madrean Evergreen Woodland/Chaparral	December 2003
3	GRASHA	1,670 m (5,500 ft)	Level	Madrean Evergreen Woodland	February 2004
4	MANZAN	1,980 m (6,500 ft)	S	Pinyon/Juniper Woodland	May 2004
5	RAWSDN	2,417 m (7,929 ft)	S	Ponderosa Pine Forest	February 2004
6	MICMEA	2,325 m (7,627 ft)	Level	Ponderosa Pine Forest/Open Meadow	March 2004
7	NORSLO	2,430 m (7,972 ft)	N	Mixed Conifer Forest	March 2004
8	HAPVAL	1,923 m (6,309 ft)	W	Pinyon/Juniper Woodland	May 2004
9	RINPEA	2166 m (7,106 ft)	N	Mixed Conifer Forest	May 2004

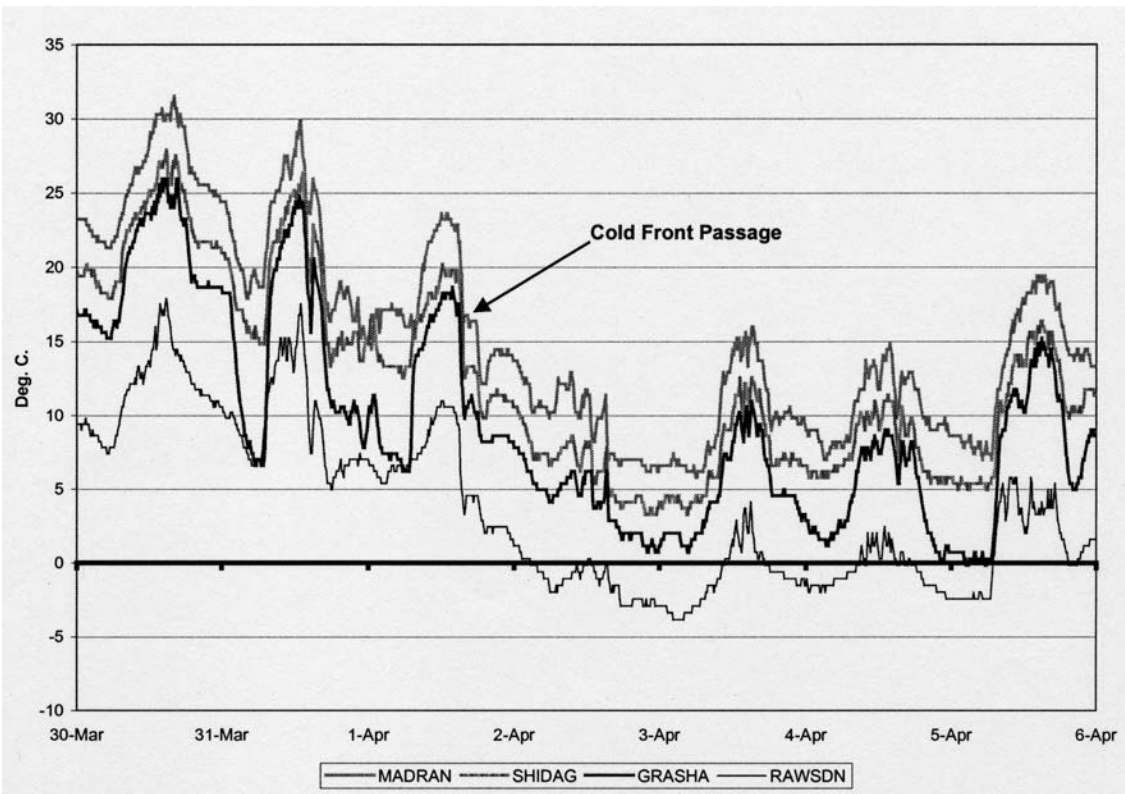

Figure 2—Air temperature data from four stations for the period of March 30 through April 5, 2004.

of this drainage. Wind observations at this ridge-top location are less influenced by local drainage flows, capturing wind variability more dominated by synoptic influences (passing low and high pressure systems).

These differences in wind regimes have direct relevance to park management decisions, specifically wildfire and fuels management. Hypothetically, if a prescribed burn for fuels reduction was scheduled during our seven-day analysis period at upper elevations, the existing RAWS site would indicate that winds were primarily out of the east-southeast. The additional climate monitoring stations show that wind flow patterns are much more complex and variable beyond the RAWS site. Smoke from the prescribed burn could actually be drawn down drainages into low-lying communities outside the park boundary. The management of smoke from prescribed fires could be substantially enhanced with the additional climate

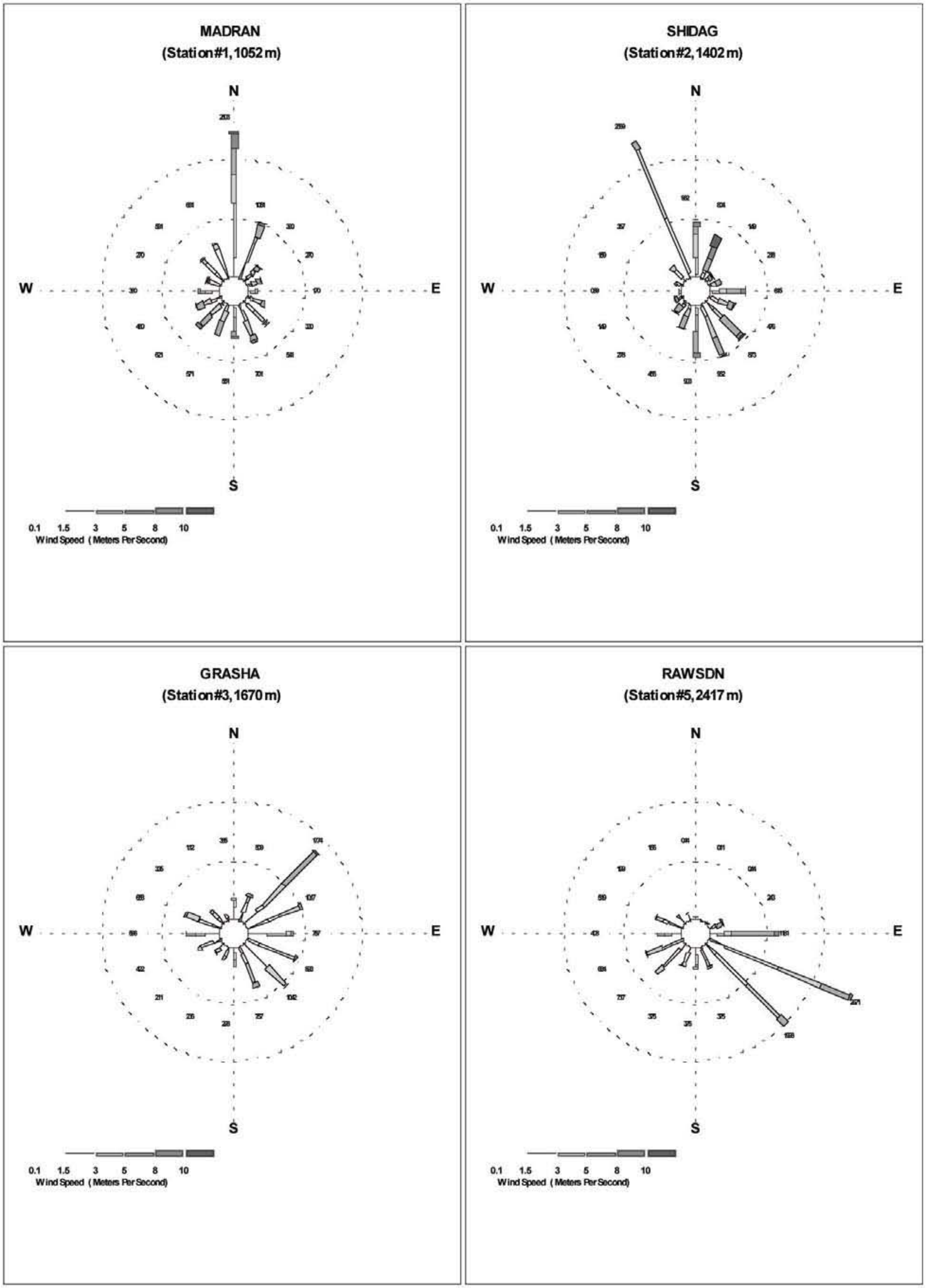

Figure 3—Wind rose diagrams for four stations for the period of March 30 through April 5, 2004. Numbers around petals show relative frequency in percent of total observations. Calm observations were excluded from analysis.

information provided by the monitoring network. As more data are collected, a more complete picture of wind flow pattern variability (daily, monthly, seasonally) will be developed. A high-resolution climatology of all meteorological variables could benefit all aspects of wildfire management including suppression efforts and fuels reduction activities.

Conclusion

Mountain areas are the focus of increasing attention with respect to global change and ecosystem management (Fagre et al. 2003; Diaz 2003). More holistic monitoring systems and approaches that include climate monitoring at appropriate scales (time and space) will be needed to properly manage natural resources and gauge ecosystem changes. Preliminary results from the pilot study at Saguaro National Park demonstrate that the collection of high-resolution climate information can highlight spatial and temporal patterns in climatic variability important for sound management decisions.

Acknowledgments

Special thanks to Nina Chambers, Andy Hubbard, and Theresa Mau-Crimmins for reviewing this manuscript. Additional thanks to Jeff McGovern, Kristen Beaupre, Amy Tendick, Dennis Crimmins, and Jim Nunnold for technical and field support. Support for this project was provided by the Sonoran Institute and the Sonoran Desert Network of the National Park Service Inventory and Monitoring Program.

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