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2007 Weather and Aeolian Sand-Transport Data from the Colorado River Corridor, Grand Canyon, Arizona

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2007 Weather and Aeolian Sand-Transport Data from the Colorado River Corridor, Grand Canyon, Arizona

By Amy E. Draut[1], Timothy Andrews[2], Helen C. Fairley[3], and Christopher R. Brown[4]

Abstract

Weather data constitute an integral part of ecosystem monitoring in the Colorado River corridor and are particularly valuable for understanding processes of landscape change that contribute to the stability of archeological sites. Data collected in 2007 are reported from nine weather stations in the Colorado River corridor through Grand Canyon, Ariz. The stations were deployed in February and March 2007 to measure wind speed and direction, rainfall, air temperature, relative humidity, and barometric pressure. Sand traps near each weather station collect windblown sand, from which daily aeolian sand-transport rates are calculated. The data reported here were collected as part of an ongoing study to test and evaluate methods for quantifying processes that affect the physical integrity of archeological sites along the river corridor; as such, these data can be used to identify rainfall events capable of causing gully incision and to predict likely transport pathways for aeolian sand, two landscape processes integral to the preservation of archeological sites. Weather data also have widespread applications to other studies of physical, cultural, and biological resources in Grand Canyon. Aeolian sand-transport data reported here, collected in the year before the March 2008 High-Flow Experiment (HFE) at Glen Canyon Dam, represent baseline data against which the effects of the 2008 HFE on windblown sand will be compared in future reports.

Introduction

In February and March 2007, instrument stations were deployed at seven study sites in the Colorado River corridor, Grand Canyon, Ariz. (fig. 1), to obtain high-resolution records of wind speed and direction, rainfall, air temperature, barometric pressure, and relative humidity. Sand traps deployed near each weather station collect aeolian (windblown) sand, from which daily sand-transport rates are estimated. These stations provide the only meteorological record available from the interior of Grand Canyon, apart from daily temperature and rainfall measurements made by the National Park Service (NPS) at Phantom Ranch, near river mile 88, and rainfall measurements recorded near river mile 60 and near river mile 225 by researchers from Utah State University.[1] Specific weather-measurement technology used in this study is discussed herein, as are problems encountered in applying that technology in the unique environmental conditions of the Grand Canyon backcountry, along with steps that were taken to resolve problems encountered in its application.

These high-resolution records are being applied to study landscape processes at archeological sites in the Colorado River corridor, as one part of an ongoing research and development project by the Grand Canyon Monitoring and Research Center (GCMRC) to develop and implement long-term monitoring protocols for archeological sites in the Colorado River corridor (Fairley and Sondossi, 2008). Rainfall and barometric-pressure records are used to identify localized weather events that can substantially affect the landscape, for example by causing gully incision into sedimentary deposits and associated archeological sites. Quantifying wind velocity and aeolian sediment transport is essential for understanding how the wind moves sediment inland from river-level sandbars; this information can be used to evaluate the potential for sandbar-building river flows (Webb and others, 1999) to increase aeolian sand transport inland toward archeological sites, some of which are preserved by aeolian sand deposits (Thompson and Potochnik, 2000; Fairley, 2005; Draut and others, 2008). In the future, these meteorological records can also be applied to a variety of other physical, cultural, and biological research initiatives in Grand Canyon. Weather records represent environmental parameters important to the Grand Canyon ecosystem and, over time, become the basis from

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[1] Locations in the river corridor are commonly referred to by their distance, in miles, downstream from Lees Ferry, Ariz. (fig. 1). This report follows that convention and uses SI units for other measurements. River miles used here are those provided by the World Wide Web map server operated by the Grand Canyon Monitoring and Research Center: http://www.gcmrc.gov/products/ims, accessed January 31, 2009. However, in keeping with the legal requirement for Federal agencies not to disclose sensitive archeological site locations, river miles cited in this report are approximate.

which regional climatic change can be identified (for example, Saunders and others, 2008).

This report refers to and builds on earlier work by Draut and Rubin (2005, 2006, 2008), wherein wind, rainfall, and aeolian sand transport were measured in the Colorado River corridor between November 2003 and January 2006. This earlier work demonstrates substantial spatial variability in rainfall, with study sites less than 10 km apart receiving annual and event-based rain totals that varied by a factor of two. Wind conditions and sand transport were shown to vary significantly in space and time, with the most aeolian sand transport occurring in dune fields with little vegetation or biologic soil crust; sand-transport rates during the spring windy season (April through early June) were generally 5 to 15 times higher than in other seasons. This report includes data collected at some of the same study sites as in the earlier Draut and Rubin work, but the research focus and technical specifications of the weather stations used in the present study differ from those of Draut and Rubin (2005, 2006, 2008).

Project Objectives

The objectives of the cultural-resource research and development project are to monitor ecosystem processes affecting archeological site stability, including weather parameters and aeolian sediment transport, in the Colorado River corridor through Grand Canyon, Ariz., with sufficient spatial coverage and temporal resolution to document the relationship between physical processes and their effects on the physical integrity of archeological sites. Physical processes represented by the data collected in this study include seasonal weather cycles (for example, of wind intensity and monsoon conditions), and storm events with daily or hourly time scales. The rainfall and aeolian sand-transport rates measured in 2007 and reported here will be used in future reports to evaluate processes responsible for observed landscape change documented at nearby archeological sites using terrestrial lidar and total-station surveys (Collins and Kayen, 2006; Collins and others, 2008).

High-resolution weather data, when combined with high-resolution landscape surveys, form one basis from which to assess potential or measured effects of Glen Canyon Dam operations on some archeological sites in the Colorado River corridor (Draut and Rubin, 2008). For example, data presented in this report will provide a basis for comparison with aeolian sand-transport regimes around the same sites in the year following the March 2008 HFE, which will help to address the question of whether enlarging fluvial sandbars (by high-flow dam operations) increases the amount of sand moved inland by wind toward dunes and archeological sites.

When compiled into decadal-scale records, weather data such as these can also be used to identify regional climatic trends. Given that the Colorado River basin has experienced more warming over recent years than other areas of the United States (Saunders and others, 2008), records such as these should prove highly valuable to a range of ecosystem studies over the coming years.

Methods

Instrument stations were deployed in February and March 2007 near seven archeological sites in the Colorado River corridor indicated on figure 1—AZ C:05:0031, AZ C:13:0006, AZ C:13:0336, AZ C:13:0346, AZ B:11:0281, AZ A;15:033, and AZ G:03:0072. Each instrument station consists of one weather station and one set of sand traps (specifications are discussed below). At AZ C:05:0031 and at AZ C:13:0346, two instrument stations were installed approximately 80 m apart at each site to resolve differences in weather and aeolian sand transport that occur with elevation and distance from the river. At AZ G:03:0072, one additional set of sand traps was deployed approximately 40 m closer to the river than the full instrument station. Table 1 lists all station locations by approximate river mile, along with the equipment operating at each site in 2007 and the names used for each station in this report.

Study sites were chosen to provide data relevant to the condition and stability of nearby archeological sites where intensive topographic surveys were planned (Collins and others, 2008; O'Brien and Pederson, 2008). Instrument stations were deployed in the vicinity of archeological sites but not near enough to disturb any cultural features or artifacts; sites were selected and equipment installed with the approval of and help in the field from NPS archeologists. Several of the study sites were originally chosen by Draut and Rubin because of their apparent responsiveness to experimental sandbar-building flows in 1996 and 2004 (Draut and Rubin, 2006). These sites were retained in the present study to extend weather records at these locations and to be able to compare results from previous experimental flows with future experimental flows, such as the March 2008 HFE. Sites were also selected to be distributed along the river corridor between upper Marble Canyon (approximately river mile 25) and the western canyon (approximately river mile 225) to record spatial variations in weather patterns throughout the river corridor.

Weather Monitoring System Design and Station Specifications

The weather-monitoring component of the GCMRC cultural resources research and development project identified the need for weather-monitoring sensors that (1) collect average wind speed, wind direction, and peak wind gusts with a minimum of moving parts, both to reduce visual impact to Grand Canyon National Park visitors and to reduce the risk of windblown sand hindering equipment performance; (2) collect data reliably over extended time intervals with minimal maintenance; (3) withstand the extreme temperature fluctuations in Grand Canyon; (4) are minimally affected by windblown sediment; (5) utilize sensor(s) that comply with an established meteorological data standard; (6) consume little power at a high sample frequency rate; (7) are stable in strong winds; (8) allow easy replacement of system components; and (9) include a provision for possible future addition of satellite telemetry.

Multiple vendors, sensors, and data-collection platforms were considered for this project, including Campbell Scientific (RAWS™-F), Columbia Weather Systems (Orion LX™ Weather Station), Onset Computers HOBO™ (H21-SYS-A), Roper Associates (RUGID Computer Rug3™ and Vaisala WXT510™), and Fondriest Environmental (Vaisala WXT510™ and NexSens iSIC™ data logger). The Vaisala multiparameter weather transmitter was selected for its ability to measure wind speed and direction, precipitation, temperature, relative humidity, and barometric pressure in a single sensor package that complies with World Meteorological Organization (WMO) meteorological standards and has no moving parts. The WXT510 compares adequately with other independent sensors for the parameters it measures (Dabberdt and others, 2005; Winning and others, 2008). It uses only 8 mA when transmitting data in SDI-12 mode, and 3 mA in idle mode; this sensor's low power consumption is important for applications in remote areas such as Grand Canyon, where power budget is limited. A brief in-house testing interval at GCMRC indicated that building an interface with the Vaisala WXT510 and a Rugid RUG3 RTU data logger was a reasonable task, and thus consideration was given to constructing the entire system in house. Due to time constraints, a decision was made to proceed with the Vaisala WXT510 transmitter through an integrator of this unit; of the two possible companies identified, Fondriest Environmental was chosen on the basis of price and a commitment to deliver the equipment within required time frames.

The total power consumption of each weather station does not exceed 40 mA in any operating mode; each station consumes approximately 11 mA when the WXT510 is transmitting and approximately 6 mA in idle mode. The NexSens iSIC data logger made by Fondriest Environmental is capable of collecting eight weather parameters for approximately 4 months with a 4 minute sampling rate before the 2 MB of memory is full. All system components can withstand temperatures in the range of -20°C to +60°C, and the data logger software provides configuration support for a wide array of popular environmental sensors.

All weather stations used for this study are configured identically and consist of a transmitter and data logger mounted on a tripod (fig. 2). The transmitter, a Vaisala™ multiparameter weather transmitter model WXT510 with serial data interface SDI-12, is mounted at a height of 2 m above ground level. The data logger is a Nexsens™ iSIC logger upgraded to 2 MB memory. The system is powered by an Optima D34/78 deep-cycle 12 V battery (AGM type, 55 Ah) housed in a box on the ground and charged by a south-facing 30-watt, 12 VDC solar panel mounted on the tripod. Solar panels are the BPSX3OU model made by BP Solar, modulated by a SK-6 Morningstar Solar 12 VDC, 6A controller. A center conduit pipe was driven into the ground, placed inside the instrument mast, and coupled tightly to provide excellent stability to the instrument tripod.

The Vaisala WXT510 transmitter uses three ultrasonic sensors to measure wind speed and direction (http://www.vaisala.com/instruments/products/weathermulti-sensor, accessed September 4, 2008). The absence of moving parts provides an advantage to this instrument over traditional spinning-cup anemometers, which may become clogged with windblown sand if installed too near the ground. The manufacturer's stated measurement range for wind speed is 0 to 60 m/s, with accuracy ±0.3 m/s or ±3 percent, whichever is greater, for wind speed 0 to 35 m/s. For wind speed 36 to 60 m/s, accuracy is ±5 percent. The measurement range for wind direction is 360°, with an accuracy of ±3°. We assume an additional 5° margin for error incurred by the user when aligning the transmitter with true North, for a total estimated accuracy range on wind direction of ±8°. The transmitter has an estimated response time of 250 ms for detecting wind speed and direction. We record wind speed and direction at 4-minute intervals, with each data point consisting of the 4-minute averaged wind speed and direction, as well as the speed and direction of the highest gust during each 4-minute interval (gust speed measured as 3-second average). The capability to record the maximum gust speed in each measurement interval was added as an upgrade to the weather stations in April 2007.

A pressure sensor on the Vaisala WXT510 transmitter detects liquid rainfall with resolution of 0.01 mm and 5 percent accuracy according to the manufacturer. Air temperature, relative humidity, and barometric pressure are recorded by a separate sensor within the shaded housing of the WXT510 unit. The measurement range on air temperature is from –52 to +60°C with accuracy at 20°C of ± 0.3°C. Relative humidity (RH) ranges from 0 to 100 percent, with accuracy of ±3 percent within 0 to 90 percent RH and ±5 percent within 90 to 100 percent RH. The sensor measures barometric pressure with a measurement range of 600 to 1,100 mbar, with accuracy of ±0.5 mbar at 0 to 30°C and ±1 mbar below 0°C or above 30°C. Rainfall, temperature, relative humidity, and barometric pressure are recorded on the data logger at 4-minute intervals as 4-minute averages.

Weather stations are camouflaged using paint and burlap to reduce their visibility to Grand Canyon National Park visitors, and are equipped with signs explaining their purpose in the event that visitors approach them. Stations were visited for maintenance and data downloading every 4 to 12 weeks during 2007. Transmitters were replaced in early 2008 and sent to Vaisala for calibration; all were found to have been operating within the manufacturer's stated accuracy ranges during 2007.

Monitoring Aeolian Sediment Transport

Aeolian sediment transport is monitored at each study site using wedge-shaped, galvanized metal "big spring number eight" (BSNE) passive-sampling sand traps (Fryrear, 1986). Sand traps are emptied during maintenance visits to the instrument stations every 4 to 12 weeks. Therefore, sediment-transport measurements are based on cumulative values representing the interval between visits. Sediment samples are collected from traps in the field and brought back to the GCMRC laboratory in Flagstaff, Ariz., to be weighed. Organic material is removed from the sediment by treating the samples with hydrogen peroxide. Samples are then dried overnight in an oven at 80ºC, allowed to cool in a desiccant chamber, and weighed on scale with resolution to 0.0001 g.

This study uses BSNE traps in sets of four deployed on a vertical pole, with the orifices of the four traps set at heights of 0.1, 0.4, 0.7, and 1.0 m above the ground (fig. 2). Each trap is equipped with a vane that turns the trap into the wind. The BSNE design is used widely in agricultural and geologic studies of windblown sediment, in part because its shape allows it to perform nearly isokinetically, causing minimal distortion of air flow at the sampling orifice (Stout and Fryrear, 1989; Nickling and McKenna Neuman, 1997; Zobeck and others, 2003). The sampling orifice measures 5 cm tall by 2 cm wide; air flow enters the trap through the orifice and exits through a 60-mesh screen in the upper surface of the trap. Sediment is retained in the lower half of the trap after falling through a wider (18-mesh) screen. Wind-tunnel studies (Goossens and others, 2000) indicate an efficiency range of 70 to 130 percent for BSNE sand traps for the wind velocities and sediment grain sizes encountered in Grand Canyon. Efficiency less than 100 percent indicates that air flow is directed away from the orifice, such that the trap undersamples windblown sediment, whereas efficiency greater than 100 percent indicates that air flow is directed into the trap, oversampling windblown sediment. We use the efficiency range of 70 to 130 percent to estimate error in the sand-transport data reported here. This almost certainly overestimates the true error margin; however, such conservative treatment of the data is the best available for the bulk sand-transport data reported here because the exact correspondence between wind velocities and local sand-transport rates is unknown.

Aeolian sand-transport rates reported previously by Draut and Rubin (2005, 2006) integrated total sand transport from the ground level up to a height of 1 m based on a curve fitted to the four data points (four sand traps) at each site. That method, which used a five-parameter combined power-law and exponential function to fit a curve to the mass-versus-height data, has been shown to represent vertical sand flux effectively because the amount of sediment transport occurring in the lowermost 1 m generally comprises more than 99 percent of the total sediment transport (Zobeck and Fryrear, 1986; Sterk and Raats, 1996). In this report, we present aeolian sand transport data based on directly measured sand mass. Instead of using the sand collected in traps to fit a five-parameter function and dividing the integrated 0 to 1 m value by the number of days it took for the traps to collect the sand (thus obtaining daily transport rates), we report daily transport rates that are simply the sum of the total sand mass collected in each set of 4 traps divided by the number of days it took for the traps to collect the sand. This method of reporting aeolian sediment transport is directly comparable with the method used by Draut and Rubin (2005, 2006), as shown in figure 3. The method presently used (showing directly measured sand mass) does not estimate the total sand flux occurring in the lowermost 1 m—it does not interpolate sand transport predicted to have passed between the traps. This method has the advantage of being based entirely on the physical sediment samples collected, with no dependence on curve-fitting accuracy.

Results and Discussion

The following section focuses on two different aspects of this study: (1) an evaluation of the suitability of the Vaisala transmitters and Nexsens data loggers and software for collecting the requisite weather data in the remote and logistically challenging setting of the Grand Canyon backcountry, and (2) an evaluation of the weather data.

Assessment of Weather Monitoring Methods and Protocols

Nine weather stations were installed between February 23, 2007, and March 8, 2007. An initial download of data in April 2007 indicated that all hardware (having been calibrated by the manufacturers before deployment) appeared to be functioning properly. In any project using instrumentation, hardware and software difficulties are anticipated; Fondriest Environmental responded quickly to resolve problems that were identified during field operations. Software initially provided by Fondriest included automated data-integrity checks and unit conversions that resulted in slow data downloads. The inability to download data rapidly in the early stages of the project presented a challenge to tightly scheduled river trip itineraries. As a result, download operations were sometimes cancelled before completion or appeared to "hang" without sufficient status information to the user. These problems were amplified when the quantity of stored data caused the data logger memory to approach or exceed its capacity. In October 2007, Fondriest Environmental modified the data logger software to support a faster download algorithm, which somewhat accelerated download capability and provided additional status information during downloads. The download process from NexSens data loggers nevertheless remains significantly slower than from weather data loggers manufactured by other companies (which are incompatible with Vaisala WXT510 transmitters).

The most significant hardware problems encountered in this project were SDI-12 communication board failure on four of the nine original Vaisala WXT510 transmitters, and a memory rollover issue on the NexSens iSIC data logger. The majority of these SDI-12 communications board failures were discovered in late August and early September 2007 and occurred at AZ C:13:0336, AZ C:13:0346 L, AZ C:13:0346 U, and AZ B;11:0281. All of the failed transmitters were promptly repaired or replaced and were recertified by Vaisala. Since then, there has been a significant reduction in the number of failures caused by SDI-12 communications. In a separate instance of equipment malfunction, installation of a LI-COR™ LI-200 pyranometer and a LI-190 quantum sensor to measure solar radiation at AZ C:13:0336 on April 9, 2007, initially appeared to have been successful based on monitoring several data samples before departure. However, the next data download attempt, on August 28, 2007, indicated that valid data collection had ended within 1 hour after the LI-COR sensors were installed. The transmitter was removed when the problem was discovered, and was sent to Vaisala for repair of the SDI-12 board. The weather station at AZ C:13:0336 was rebuilt on September 15, 2007, without the LI-COR sensors. These sensors are listed in the data logger configuration utility as supported instruments, however, their installation factored into a considerable loss of data (April 6, 2007, to September 15, 2007) at that site. The specific cause of failure remains unknown, but improved support documentation and additional testing of this combination of instrumentation warrants attention. At station AZ C:05:0031 L, data collection was interrupted for approximately 6 weeks after a feral goat damaged the equipment (discussed below). Damage was sustained to the solar panel, data logger enclosure, and cables, causing misalignment of the Vaisala transmitter and necessitating a major station overhaul on June 1, 2007.

In mid-September 2007, the data logger memory reached capacity at many of the stations for the first time, and a problem was discovered with the memory rollover function. Attempts to download five of the stations (AZ C:05:0031 U, AZ C:13:0006, AZ C:13:0346 U, AZ A:15:0033, and AZ G:03:0072) produced data records for only the previous 2 days instead of continuous records from the date of the last download, which had occurred about 3 weeks earlier. This issue was ultimately addressed by Fondriest Environmental with a data logger firmware update. Download protocol now includes the disabling of the memory rollover function, clearing the data logger memory during each download, and scheduling future downloads before the data logger memory reaches capacity. The more rapid data download program developed by Fondriest Environmental in October 2007 transfers data in the native Vaisala WXT510 units and thus requires additional postprocessing of the data for proper unit conversion. This is handled more easily in an office setting than in the field.

The potential for downloading data remotely from weather stations was explored in 2007. If feasible, wireless “drive-near” downloads of instrument stations that are working normally could reduce human traffic at weather stations near sensitive archeological sites. Initial trials were encouraging; a low-power Maxstream™ Zigbee radio modem was connected to the data logger serial port inside the data logger fiberglass enclosure on the station at AZ C:13:0006. The Zigbee radio modem was programmed to go into sleep mode until woken by the master radio modem connected to the laptop used for downloads. The “drive-near” download scenario envisioned was to park a raft on shore near the site, send a command to wake up the data logger radio modem from the laptop on the raft, and then download data from the raft through the wireless link. The quick download algorithm accelerated the download process, and increased the viability of a “drive-near” download method. However, because it is always necessary to visit the site to retrieve the sand samples, a “drive-near” download is not presently being used. An automated sand-weighing/recording system would promote and complement a wireless data download system.

Weather and Aeolian Sand Data

Table 2 shows daily rainfall recorded at each weather station during 2007. As discussed above, software problems prevented data collection at several of the stations for extended periods of time, indicated by “N/A” values in table 2.

Figures 4 through 69 show complete high-resolution (4-minute) weather records for all stations, arranged by month and then by weather parameter. Figures 70 through 88 summarize all available weather parameters recorded in 2007, arranged by station and discussed in more detail below. General patterns apparent from figures 4 through 69 include spatial variations in rainfall and other parameters. Rainfall varies considerably throughout the river corridor; the same event can bring significantly more rainfall in some parts of the canyon than in others, particularly from isolated storms in the summer and early fall monsoon season. Software problems that caused disruption in station operation make it difficult to compare monthly or annual rainfall among all of the stations for long intervals of time (table 2). However, it is possible to compare rainfall from certain events among stations in different parts of the canyon. A week of episodic light rain between March 21 and 29, 2007, when all of the weather stations were operational, resulted in broadly similar total rainfall at all sites (14 to 17 mm in Marble Canyon, 14.6 mm at AZ C:13:0336 several miles downstream of the Little Colorado River confluence, 19 to 20 mm at AZ C:13:0346 near river mile 70, and 3 to 8 mm in the central and western canyon (table 2)). At other times, particularly in the summer monsoon season, rainfall shows substantial spatial variability. Widely variable amounts of rain fell within Marble Canyon on the same day; for example, on August 1, 2007, 24 to 28 mm fell at AZ C:05:0031 near river mile 25 while only 1.4 mm fell at AZ C:13:0006 near river mile 60. In the western canyon, stations AZ A:15:0033 and AZ G:03:072 received 0.3 and 2.1 mm that day, respectively (fig. 40). Data such as these can be used to link weather patterns with observations of local landscape change. Gully incision that occurred in sedimentary deposits at AZ G:03:0072 over the summer of 2007, for example (B. Collins, written comm., 2008), is likely attributable to intense rain events in late July, when 32 mm of rain fell on July 29 alone (including 20 mm within 20 minutes), during a week when that site received 67 mm total rainfall (table 2; fig. 34).

Vector sums of aeolian sand-transport potential, listed by month at each station, are shown in table 3. To represent the sand-transport potential for a given wind velocity, we use a proxy variable, *Qp*, which is defined as:

$$Qp = (u - u_{\mathrm{crit}})^3 \quad (1)$$

The relation in equation (1) follows the convention used to construct aeolian-sediment-transport models, such as those of Kawamura (1951) and Lettau and Lettau (1977), but substitutes wind velocity for shear velocity. Although the units of *Qp* (m^3/s^3) do not translate directly to a sand flux, comparison of the spatial and temporal variations in relative *Qp* values yields useful information about sand-transport potential. *Qp* was calculated for all the data points at which the wind velocity (u) exceeded the critical threshold of motion (u_{crit}). The critical threshold of motion is taken to be 2 m/s based on median grain size measured for these study sites and other surficial sediment deposits in Grand Canyon (Bagnold, 1941; see Draut and Rubin, 2005, 2008). For the data points at which $u<u_{\mathrm{crit}}$, *Qp* was set equal to zero, indicating that no sand transport would occur. Dominant wind directions causing sand transport were then calculated by using vector sums of *Qp* values from the 4-minute wind measurements. Vector-sum calculations were also made after eliminating wind measured within 48 hours after a rainfall event, the amount of time (based on field observations at different times of year) after which sand is generally sufficiently dry to be mobilized by wind. *Qp* vector sums for dry conditions are shown in table 3*B*.

High-resolution plots of wind velocities show that wind conditions commonly vary diurnally (for example, fig. 12), as do other weather parameters; wind velocity is typically highest in the afternoon and commonly blows upstream, although wind direction is affected by local topography. Site-specific net potential sediment-transport vectors calculated from the wind data are discussed below. When high-resolution records from all weather stations are compared (figs. 4 through 69), it is apparent that ambient temperature and barometric pressure increase with distance downstream because elevation decreases. Seasonal-scale changes in temperature and barometric pressure are apparent at weather stations that collected data for appropriate lengths of time during 2007 (for example, figs. 73, 75, 85, and 87); barometric pressure displayed the lowest-magnitude daily fluctuations during the months of June, July, and August. Relative humidity, as expected, does show daily fluctuations (responding to air temperature and evapotranspiration cycles of plants) but generally corresponds to local rainfall.

Site-Specific Data

The following sections describe the setting of each weather station, site-specific data-collection problems encountered, and the findings from 2007. The station numbers reference a nearby archeological site and are presented in a geographic order, starting with the farthest upstream station and proceeding downstream.

AZ C:05:0031

Two weather stations were deployed in an aeolian dune field on the downstream side of a debris fan at the AZ C:05:0031 site—one near river level (AZ C:05:0031 L; figs. 70, 71) and one at the upper end of the dune field (AZ C:05:0031 U; figs. 72, 73). These are in approximately the same positions as stations used by Draut and Rubin (2005, 2006). The dune-field area between the two weather stations undergoes active sand transport and has little vegetation or biologic soil crust. An approximately equal area at the north (upstream) end of the dune field is relatively inactive, with well-developed soil crust and evidence of deflation of the land surface. Observations between 2003 and 2006 of sediment transport consistently from the direction of a river-level sandbar led Draut and Rubin (2008) to identify this dune field as a modern fluvial sourced (MFS) aeolian sediment deposit. The sandbar at this site was substantially enlarged by experimental high flows in 1996 and 2004. In the 2005 spring windy season, following the November 2004 controlled flood, aeolian sand transport rates near AZ C:05:0031 L were approximately twice as high as in spring 2004 (Draut and Rubin, 2006).

The weather stations were deployed at AZ C:05:0031 for this study on February 23, 2007. They operated normally until, on April 20, 2007, members of a commercial river trip observed a feral goat damaging station AZ C:05:0031 L. Damage to the instrument tripod and sand traps at AZ C:05:0031 L precludes the use of wind and sand-transport data collected between April 20 and the morning of June 2, when repairs were completed. Temperature, humidity, barometric pressure, and rainfall at AZ C:05:0031 L from the interval between April 20 and June 2 were unaffected by misalignment of the tripod caused by the goat (which offset the recorded wind-direction orientation). Unfortunately, damage to the sand traps by the goat prevented collection of reliable sand samples during the spring windy season in 2007, and so sand-transport rates for the spring before the 2008 HFE cannot be estimated. Station AZ C:05:0031 L operated with no malfunctions for the remainder of 2007.

As observed by Draut and Rubin (2005, 2006), wind velocities are typically higher at station AZ C:05:0031 U than at station AZ C:05:0031 L, attributed to the effects of vegetation at low elevations near river level. Aeolian sand-transport rates measured at AZ C:05:0031 U are correspondingly higher as well (figs. 71, 73). A vector sum of all available wind data from AZ C:05:0031 L in 2007 yields a net *Qp* magnitude of 20,224 m^3/s^3 from a direction of 169º (fig. 70). A vector sum of all available wind data from AZ C:05:0031 U in 2007, which operated from February 23 through the rest of the year with one interruption (from 17:20 on August 23 to 21:04 on September 12), yields a net *Qp* magnitude of 66,680 m^3/s^3 from a direction of 215º (fig. 72; the greater magnitude indicates approximately three times more potential for sand transport at AZ C:05:0031 U than at the lower-elevation station AZ C:05:0031 L). Therefore, wind with velocity high enough to transport sand blew primarily upstream (from the southwest) in the upper part of the dune field in 2007. The vector sum for the year at AZ C:05:0031 L indicates net transport from the southeast, in contrast to annual vector sums calculated for that site from the 2003–2006 data (Draut and Rubin, 2006), which indicated net transport from 244º in those years. Data from AZ C:05:0031 L in 2007 do indicate 5 months when net wind-induced sediment transport would have come from the southwest, however (table 2); the vector sum for 2007 is affected substantially by easterly winds measured in December. If December data are excluded from the calculation, the annual *Qp* vector sum for station AZ C:05:0031 L becomes 21,177 m^3/s^3 from a direction of 228º (southwest).

AZ C:13:0006

One weather station was deployed on February 25, 2007, at AZ C:13:0006 near river mile 60 (figs. 74, 75). The station is on the upstream side (with respect to the Colorado River) of an ephemeral tributary streambed, on a small debris fan. At the instrument site, aeolian sediment is present but is interspersed with rocks and sparse vegetation; areas of open sediment in the vicinity of the weather station and sand traps are largely covered by well developed biologic soil crust. Aeolian sediment-transport rates at AZ C:13:0006 during 2007 were only slightly higher during the spring windy season (and in October) than at other times of year. They were also typically an order of magnitude lower than those observed at AZ C:05:0031 U, which is a more active dune field with little soil crust.

The weather station at AZ C:13:0006 experienced one service interruption between 15:20 on August 26 and 19:04 on September 14 but otherwise operated without malfunction for the remainder of 2007. A vector sum of all available data from the weather station at AZ C:13:0006 in 2007 yields a net *Qp* magnitude of 43,712 m^3/s^3 from a direction of 121º. Net sediment transport from the east-southeast is therefore indicated during 2007, an observation which would be consistent with the fluvial sand deposit at the downstream end of the debris fan serving as a possible source of windblown sand (fig. 74).

AZ C:13:0336

The Palisades (Palisades of the Desert) area, near river mile 65 in eastern Grand Canyon, is characterized by alluvial terraces with local aeolian coppice dunes that are vegetated by grasses and small mesquite trees. The alluvial deposits at Palisades represent multiple episodes of floodplain aggradation by Colorado River floods that predate the closure of Glen Canyon Dam in 1963 (for example, Hereford and others, 1996; Draut and others, 2008). The aeolian dunes at Palisades were interpreted by Draut and Rubin (2008) as relict fluvial sourced (RFS) aeolian deposits that formed by in-place reworking of ancient flood sediment, rather than having been sourced from river-level sandbars within the normal dam-controlled flow range. Alluvial and aeolian deposits are incised by a major gully network (as much as 2 m deep and tens of m wide in places) that drains to the river (Hereford and others, 1993; Thompson and Potochnik, 2000; Hazel and others, 2008). Repeated topographic surveys have shown frequent changes in gully geometry at Palisades, including aggradation in its mouth as a result of high-flow experiments in 1996 and 2004 and episodic erosion attributed to rain events (Yeatts, 1996; Hazel and others, 2008).

One instrument station, AZ C:13:0336 U, was installed at Palisades on February 26, 2007, in approximately the same place as a station used by Draut and Rubin (2005, 2006; figs. 76, 77). This weather station experienced equipment failure caused by installation of a solar radiation sensor (discussed above) and so was not in operation between April 9 and September 15. Although station malfunctions make it difficult to assess the Palisades rainfall record for much of the year, substantial rain events were recorded at AZ C:13:0336 U on September 22 (24 mm over 9 hours, 8.5 mm of which fell within 20 minutes; fig. 46) and in a winter storm from November 30 to December 1, 2007 (another 24 mm; figs. 58 and 64).

A vector sum of all available wind data from AZ C:13:0336 in 2007 yields a net *Qp* magnitude of 149,190 m^3/s^3 from a direction of 94º. This calculation indicating net potential sediment transport from the east is similar to results obtained at Palisades from 2003 to 2006 (Draut and Rubin, 2005, 2006), although the missing data for much of 2007 precludes direct comparison with data from earlier years. Daily aeolian sand-transport rates at AZ C:13:0336 were not measured during the spring windy season because of sand-trap malfunctions; daily transport rates in other times of year were broadly similar to those measured at AZ C:05:0031 (fig. 77), with the highest measured daily transport rates around 1.5 g/cm in July.

AZ C:13:0346

Two instrument stations were deployed near river mile 70 on February 27, 2007 (figs. 78 through 81). This reach of the Colorado River corridor in eastern Grand Canyon is several kilometers wide, is characterized by kilometer-wide meander bends in the river, and is part of the geomorphic region referred to as the Furnace Flats reach by Schmidt and Graf (1987). The station AZ C:13:0346 L is situated within an active dune field that has sparse vegetation, well developed dune forms, and abundant active sediment transport. This weather station experienced multiple equipment failures related to insufficient power supply and operated only between February 27 and March 30 and between August 30 and September 28, although aeolian sand was monitored successfully for most of the year. A vector sum of available wind data from station AZ C:13:0346 L in 2007 yields a net *Qp* magnitude of 109,700 m^3/s^3 from a direction of 250º; these data do not span the spring windy season nor any other substantial length of time. Daily sand-transport rates at AZ C:13:0346 L were highest during the spring windy season (around 8 g/cm; fig. 79) but with a spike in October of comparable magnitude to that in the spring. A similar occurrence of abundant sand transport in October was observed at AZ C:05:0031 (fig. 73); similar increase in sand transport in the fall has not been observed in Grand Canyon in previous years (Draut and Rubin, 2008).

Station AZ C:13:0346 U is situated upstream of AZ C:13:0346 L and slightly farther inland from the river (fig. 80). The land surface in the vicinity of station AZ C:13:0346 U is not an active dune field but a broad, flat landscape with abundant silty material, much of which was apparently derived as distal slope-wash from local Dox Formation bedrock (inferred from its red color). Biologic soil crust is more abundant around AZ C:13:0346 U than around AZ C:13:0346 L. Station AZ C:13:0346 U experienced one interruption in its operation between 05:28 on August 28 and 23:04 on September 17, but otherwise operated normally. A vector sum of all available wind data from AZ C:13:0346 U in 2007 yields a net *Qp* magnitude of 219,940 m^3/s^3 from a direction of 237º. This direction of net potential sediment transport (toward upstream) is consistent with that measured at AZ C:13:0346 L, but is based on a much longer data record than that from AZ C:13:0346 L.

Aeolian sediment-transport rates at AZ C:13:0346 U were, in general, approximately one tenth of those measured at AZ C:13:0346 L. This is likely because biologic soil crust around station AZ C:13:0346 U inhibits entrainment and transport of sand by wind (Leys and Eldridge, 1998; Belnap, 2003; Goossens, 2004) and not because wind velocities are substantially different at the two stations, although with only two months of wind data from AZ C:13:0346 L in 2007 it is not possible to rule out that explanation definitively. Similar to transport rates measured at AZ C:13:0346 L, the daily sand-transport rates at AZ C:13:0346 U were as high or higher in October than they were during the spring windy season in 2007 (approximately 1 g/cm).

AZ B:11:0281

One instrument station was deployed near AZ B:11:0281 in the vicinity of river mile 135 on March 4, 2007 (figs. 82, 83). This station is situated on the upstream side of a small debris fan that formed at the mouth of an ephemeral tributary drainage. The land surface at this site consists of active aeolian dunes with moderate vegetation cover and sparse biologic soil crust; degree of vegetation and soil-crust cover are similar at AZ B:11:0281 to that at Palisades. Inland from the river on its south side, fine-grained sedimentary deposits occur near AZ B:11:0281 that are thought to have settled out of suspension as the river flow ponded behind a large landslide deposit that temporarily dammed the river 3 km downstream at about 20 ka (Huntoon, 2003; R.H. Webb, written comm., 2008).

The weather station at AZ B:11:0281 experienced problems with the SDI-12 board and the logger memory rollover that prevented data collection between 12:52 on April 13 and 08:28 on September 20. A vector sum of the available wind data from the weather station at AZ B:11:0281 in 2007 yields a net *Qp* magnitude of 31,661 m^3/s^3 from a direction of 84º. Daily sand-transport rates were substantially lower at AZ B:11:0281 than at Palisades (which has similar terrain), a fact which we attribute to consistently higher wind speeds at Palisades compared with AZ B:11:0281 during times when both of those stations were collecting data (figs. 77 and 83). The highest rates of sand transport at AZ B:11:0281 occurred during the spring (around 0.3 g/cm), although comparable transport rates were measured in mid-summer. Unlike the conditions measured at AZ C:05:0031 and at AZ C:13:0346, conditions measured at AZ B:11:0281 showed no spike in sand-transport rates in October 2007.

AZ A:15:0033

One instrument station was deployed near archeological site AZ A:15:0033 (figs. 84, 85) on March 7, 2007. The study site includes an aeolian dune field near river level that is covered by moderately dense vegetation. The vegetation has grown on the dune field and on a large river-level sandbar just downstream from the dune field since the 1960s and now covers much of what was previously an open sand area (Draut and Rubin, 2008). Immediately upstream of the weather station, an aeolian dune field shows evidence of deflation, some biologic soil crust, and gully incision. Wind data from 2004 indicated net potential sediment transport at this site oriented toward upstream (Draut and Rubin, 2005). In 2005, however, wind conditions were more complex; although upstream and downstream winds nearly balanced each other, a tertiary wind component from the northeast yielded a vector sum showing net sand flux toward the river (Draut and Rubin, 2006). Collecting longer data records from this site is expected to provide more information about the long-term sediment-transport potential. Additional data will clarify the relative importance of several local sources of windblown sand and thereby lead to a better understanding of whether sandbar-building river flows could enhance windblown sand deposition inland.

The weather station at AZ A:15:0033 experienced one disruption in data collection as a result of a software problem, between 15:00 on September 5 and 09:20 on September 24, 2007, but otherwise operated normally. A vector sum of all available wind data from AZ A:15:0033 in 2007 yields a net *Qp* magnitude of 3,903 m^3/s^3 from a direction of 210º (toward upstream; fig. 84), a result consistent with conditions measured in 2004. Daily sand-transport rates at AZ A:15:0033 were the lowest measured at any study site in 2007 (fig. 85), commonly 0.01 to 0.02 g/cm, attributed to the density of vegetation cover near the instrument station (Bressolier and Thomas, 1977; Buckley, 1987), and were no higher in the spring than at other times of year. This is consistent with the observation that any increase in wind velocity during the “spring windy season” was less pronounced at AZ A:15:0033 than at most other sites (compare figs. 81 and 85).

AZ G:03:0072

On March 8, 2007, one complete instrument station was installed at AZ G:03:0072 (station AZ G:03:0072 U; table 1), as well as one additional set of sand traps (station AZ G:03:0072 L; locations are shown on fig. 86). The study sites are on sedimentary deposits that cover the downstream part of a debris fan. Station AZ G:03:0072 U is in an active aeolian dune field that has sparse vegetation and little to no biologic soil crust. The sand traps at AZ G:03:0072 L are at lower elevation and closer to the river than AZ G:03:0072 U, in an area with some biologic soil crust; moderate to thick vegetation is present between AZ G:03:0072 L and the river (fig. 86).

The weather station at AZ G:03:0072 U experienced one disruption in data collection owing to memory rollover problems, between 17:32 on September 5 and 16:12 on September 26, but otherwise operated normally in 2007. A vector sum of all available wind data from the weather station at AZ G:03:0072 U yields a net *Qp* magnitude of 86,310 m^3/s^3 from a direction of 199° (toward upstream). Daily sand-transport rates measured at AZ G:03:0072 L and AZ G:03:0072 U were similar, though slightly higher at AZ G:03:0072 U, commonly on the order of 0.1 g/cm (figs. 87, 88). Higher sand-transport rates at AZ G:03:0072 U are attributed to the higher elevation above river level and reduced effects of vegetation in the active dune area there. As at AZ A:15:0033, wind velocities and aeolian sediment-transport rates at AZ G:03:0072 were apparently no higher during the spring of 2007 than in other seasons that year.

Implications for Management

Research and development of effective techniques for weather monitoring contribute to the larger goal of detecting landscape change and the processes that cause it, which dictate how long and in what condition archeological material remains preserved in place. Weather data presented here, particularly the rainfall and aeolian sand-transport records, can be used to identify local processes of landscape change that have important implications for the condition of aeolian dune fields and any associated archeological sites. For example, these records indicate rainfall events capable of causing gully incision and can be used to predict likely transport pathways for aeolian sand (on the basis of wind speed and direction vector sums), two landscape processes integral to the preservation of archeological sites. Combined with concurrent high-resolution topographic surveys including ground-based lidar work (Collins and Kayen, 2006; Collins and others, 2008; O'Brien and Pederson, 2008), the data discussed here will be used in future reports to address rates of landscape change at archeological sites and the processes to which landscape change can be attributed.

Such future and ongoing analyses, in turn, provide a basis from which to assess potential or measured effects of Glen Canyon Dam operations on some archeological sites in the Colorado River corridor, especially regarding the importance of aeolian sand (Draut and Rubin, 2008). For example, data presented in this report provide a basis for comparison with aeolian sand-transport regimes around the same sites in the year following the March 2008 HFE, which will help to address the question of whether enlarging fluvial sandbars (by HFE dam operations) increases the amount of sand transported by wind toward inland dunes and archeological sites. These interactions among sandbar size, dam operations such as the 2008 HFE, and landscape change around archeological sites will be explored further in forthcoming publications.

Conclusions

Nine strategically placed instrument stations monitored weather and aeolian sediment transport in the Colorado River corridor through Grand Canyon, Ariz., in 2007. This study is intended to generate high-resolution (4-minute) weather data with sufficient spatial coverage to record physical processes that affect cultural sites (and also physical and biological resources) in the canyon. Although equipment problems affected data collection at several of the stations for part of 2007, enough data of sufficient quality exist to resolve daily and seasonal patterns in wind conditions (including net potential sediment-transport directions), aeolian sand-transport rates, rainfall, temperature, relative humidity, and barometric pressure.

The Grand Canyon backcountry has consistently proven to be a challenging environment for acquiring high-quality data from scientific instruments because of its remoteness, temperature extremes, and windblown sediment. In this project, a Vaisala WXT510 multiparameter weather transmitter was used as the main data acquisition platform to measure average wind speed and direction, maximum gust speed and direction, rainfall, temperature, relative humidity, and barometric pressure. As with any data-acquisition project, it was anticipated that some gaps would occur in the data records as a result of maintenance issues. After some initial difficulties downloading data, an improved algorithm greatly facilitated downloads. Malfunctions with SDI-12 communication boards appears to have been limited to a particular series of transmitters from the original equipment purchase. Resolution of memory rollover problems in the data loggers was accomplished by a firmware update and a change in download protocol.

Maximum benefit of the data logger memory could be achieved by providing a system that allows for logging individual parameters at different sampling intervals. As delivered, our system requires that all weather parameters are sampled and recorded at the same interval. This inflexibility consumes memory inefficiently for parameters of secondary interest. Conceptually, all parameters could still be queried at the smallest interval but only written to memory at varied intervals. This has been suggested to the data logger/software manufacturer (Fondriest Environmental) as a desired program improvement; however, the ability to resolve all weather parameters at the same high resolution has benefits for identifying events such as rapid-onset monsoon storms, indicating a potential trade-off between memory capacity and useful data resolution.

Substantial spatial variation was observed in rainfall throughout the canyon, as well as in wind conditions and seasonal sediment-transport rates. Notably, two study sites in western Grand Canyon (AZ A:15:0033 and AZ G:03:0072) did not show increased aeolian sand transport during spring months, which was observed at sites in the central and eastern canyon during this study and in previous investigations.

Rainfall and aeolian sand-transport data presented here can be used to identify local processes of landscape change that have important implications for the condition of aeolian dune fields and any associated archeological sites. For example, these records indicate rainfall events capable of causing gully incision and can be used to predict likely transport pathways for aeolian sand, two landscape processes integral to the preservation of archeological sites. Combined with concurrent high-resolution topographic surveys including ground-based lidar work (conducted by other researchers), the data discussed here will be used subsequently to address rates of landscape change at archeological sites and the processes that cause it.

Data collected in 2008 are anticipated to provide additional valuable information on weather patterns along the Colorado River corridor and to provide data from the months following the 2008 HFE, against which the 2007 data will be compared in future reports. Compiling longer-term weather records for the Colorado River ecosystem is expected to facilitate other research studies used to define environmental management goals for Grand Canyon National Park.

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Figures

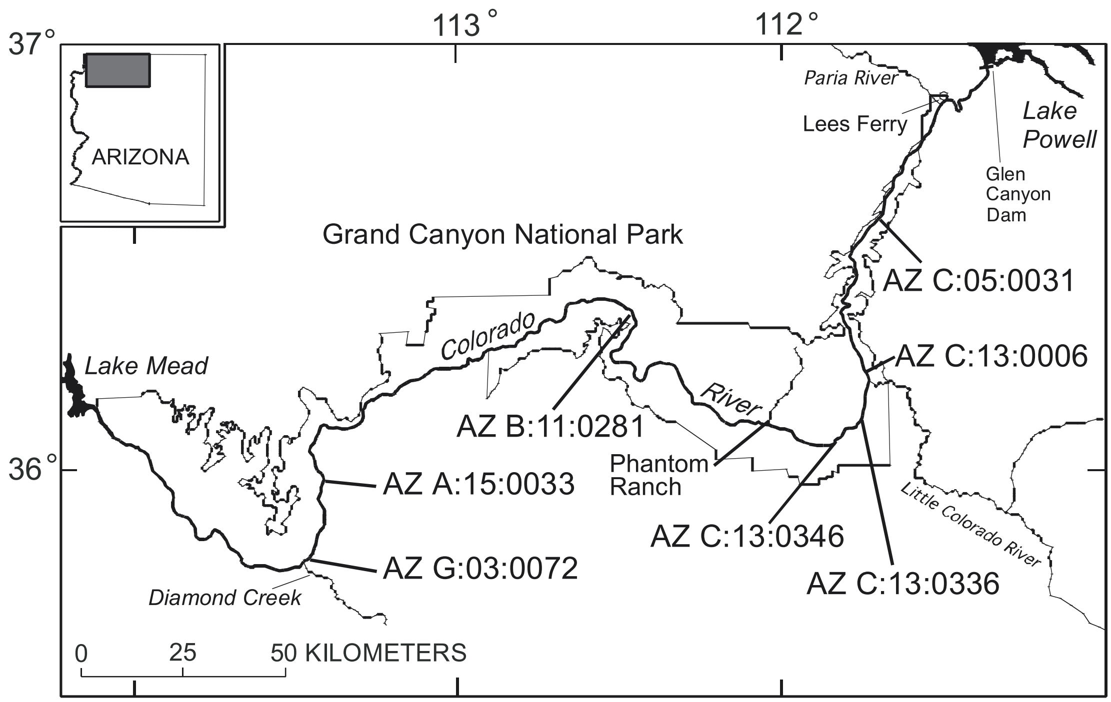

Figure 1. Colorado River corridor through Grand Canyon, Ariz., showing approximate locations of study sites. River reach between Lees Ferry and the Little Colorado River is known as Marble Canyon.

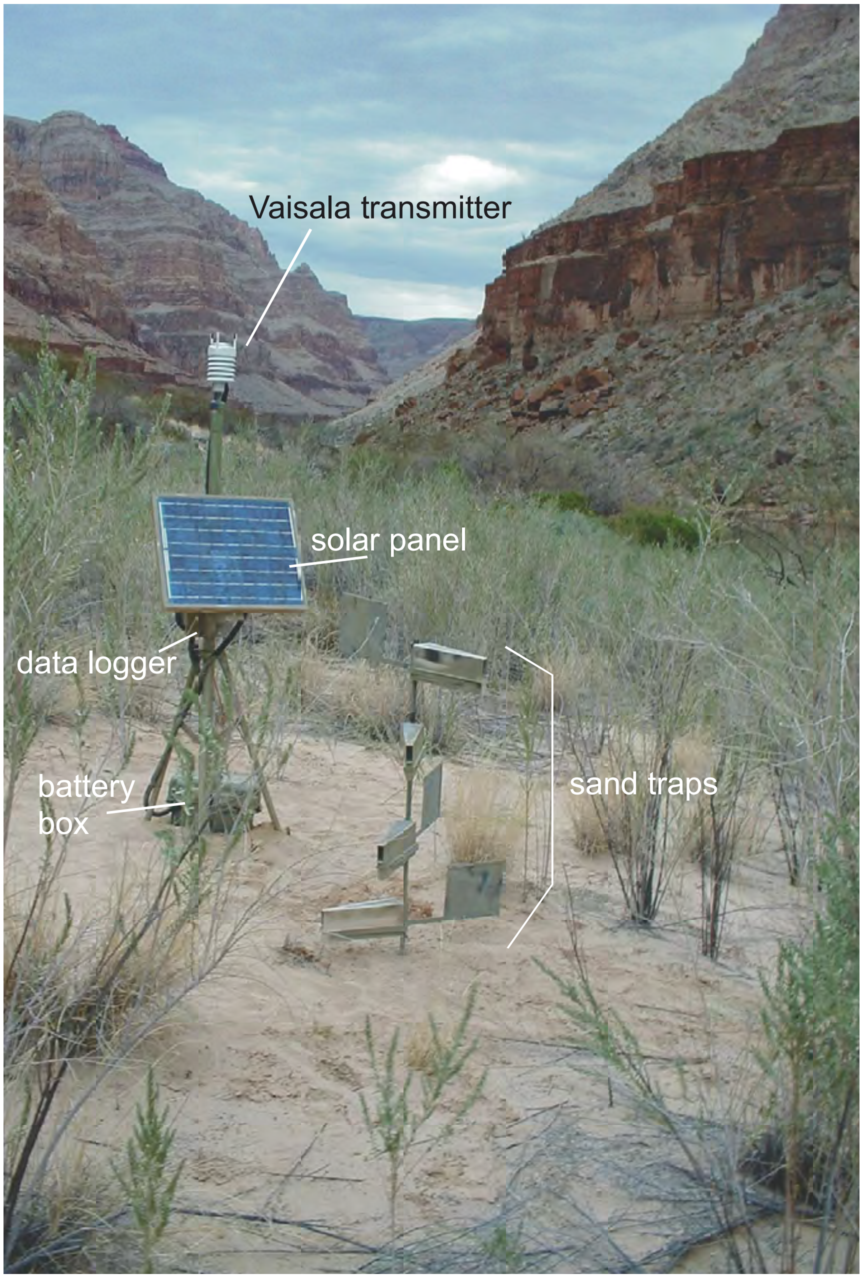

Figure 2. Photograph of instrument station near AZ A:15:0033. The transmitter, data logger, and solar panel are mounted on a tripod (in this photograph, the data logger is behind the solar panel), and the system is powered by a battery housed in a box on the ground. The pole with four sand traps on it is approximately 3 m away from the tripod.

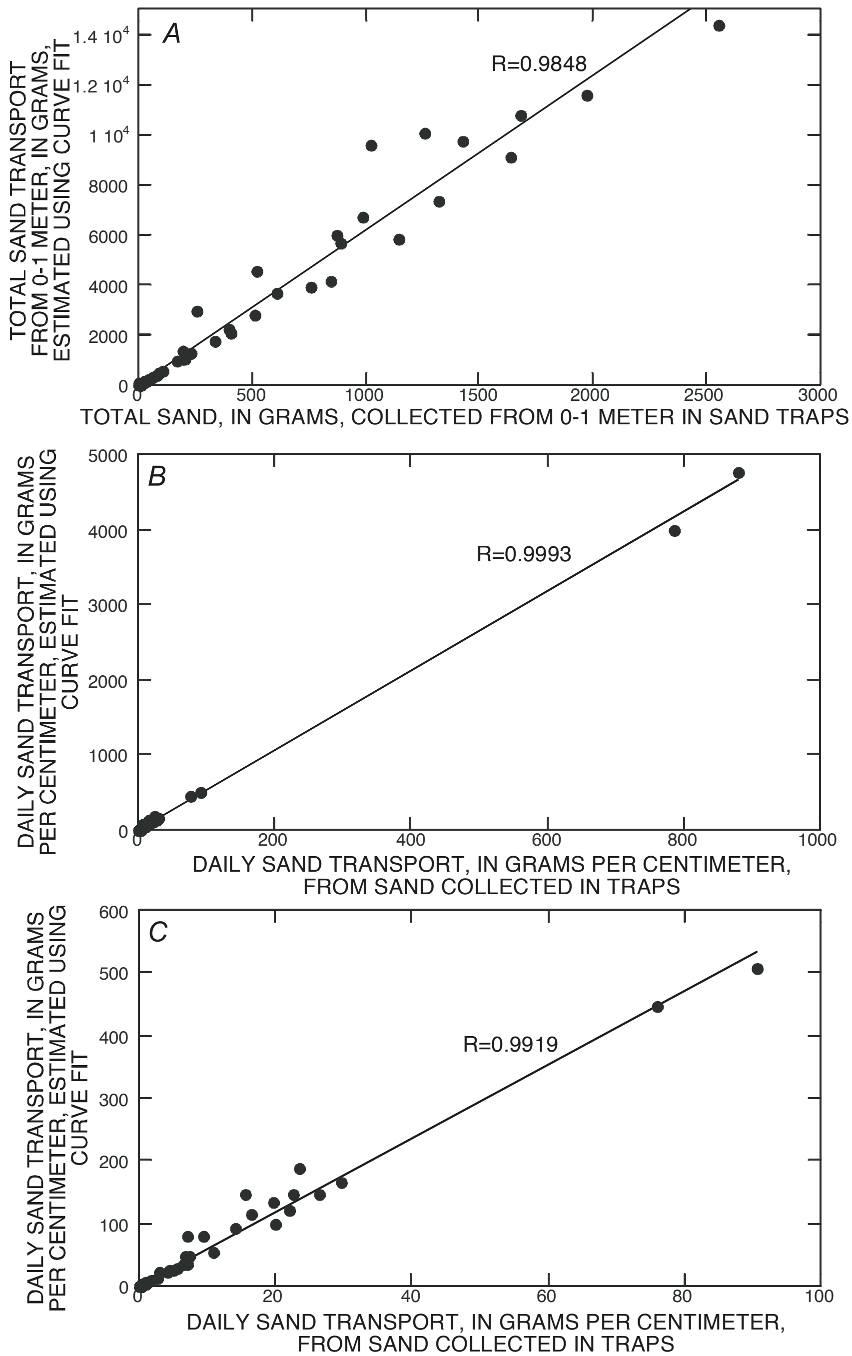

Figure 3. Comparison of methods used by Draut and Rubin (2005, 2006) to report aeolian sand transport with methods used in this report. Data shown were collected by Draut and Rubin between 2003 and 2006. *A*, measured total sand versus estimated total sand flux between the ground surface and 1 m elevation. The estimates were made using a five-parameter combined power-law and exponential function to fit a curve to the mass-versus-height data obtained from weighing sand samples collected in sand traps. *B*, the same data as in A but shown as daily sand-transport rates (dividing the total measured or total estimated sand amounts by the number of days it took for that amount of sand to accumulate in the traps). The two data points showing the highest sand-transport rates were recorded in May 2004 at a site known as Malgosa (near river mile 58) during 2 days of unusually high wind velocities. *C*, the same data as shown in *B*, but omitting the two data points collected at Malgosa in May 2004. In all three plots, correlation coefficients (*R* values) show strong correlation of measured and estimated sand transport (not surprising, given that the estimates were based on curve fits of the measured values). Therefore, sand-transport rates based on directly measured values, as appear in this report, can be compared readily with estimated values presented in earlier reports by Draut and Rubin (2005, 2006).

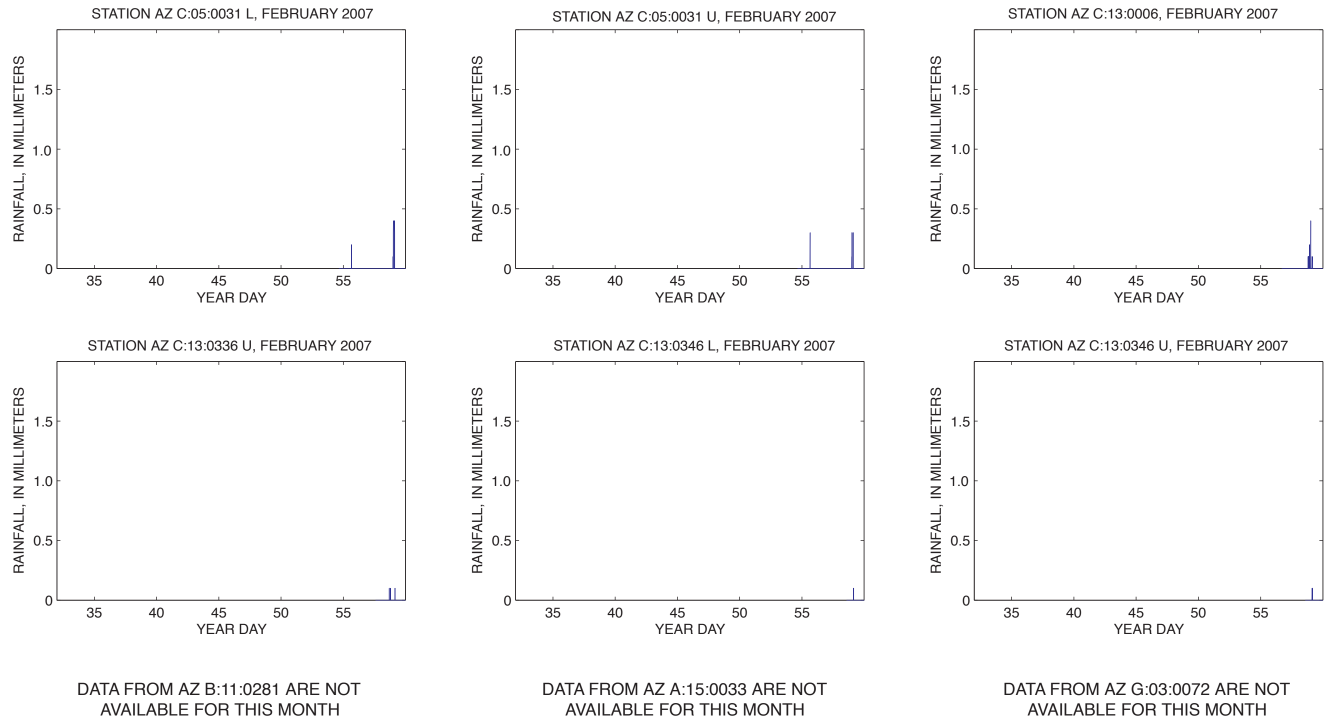

Figure 4. Rainfall measured in February 2007 (year days 32–59) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Data points represent total rainfall in each 4-minute sampling interval.

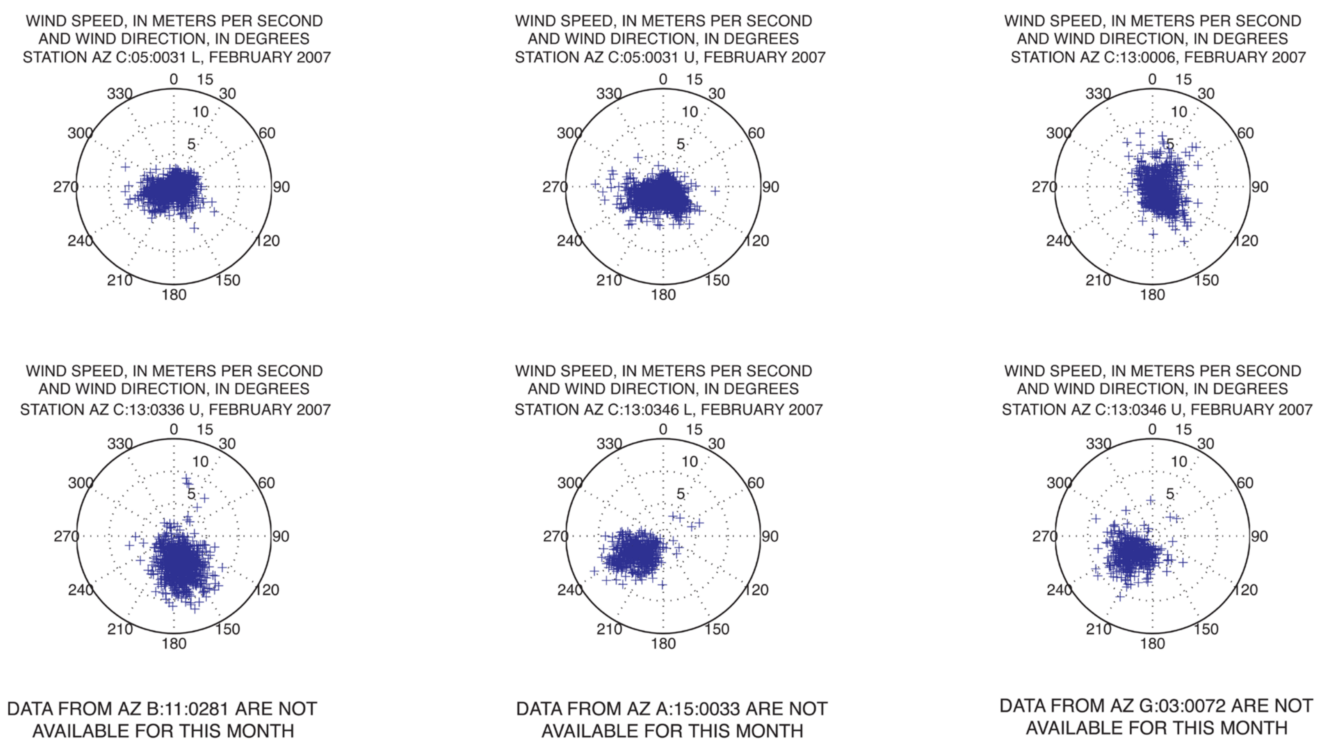

Figure 5. Magnitude and direction of wind velocity measured in February 2007 at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Each data point represents a 4-minute average. Magnitude is indicated by the concentric circles, and compass bearing indicates direction from which the wind came.

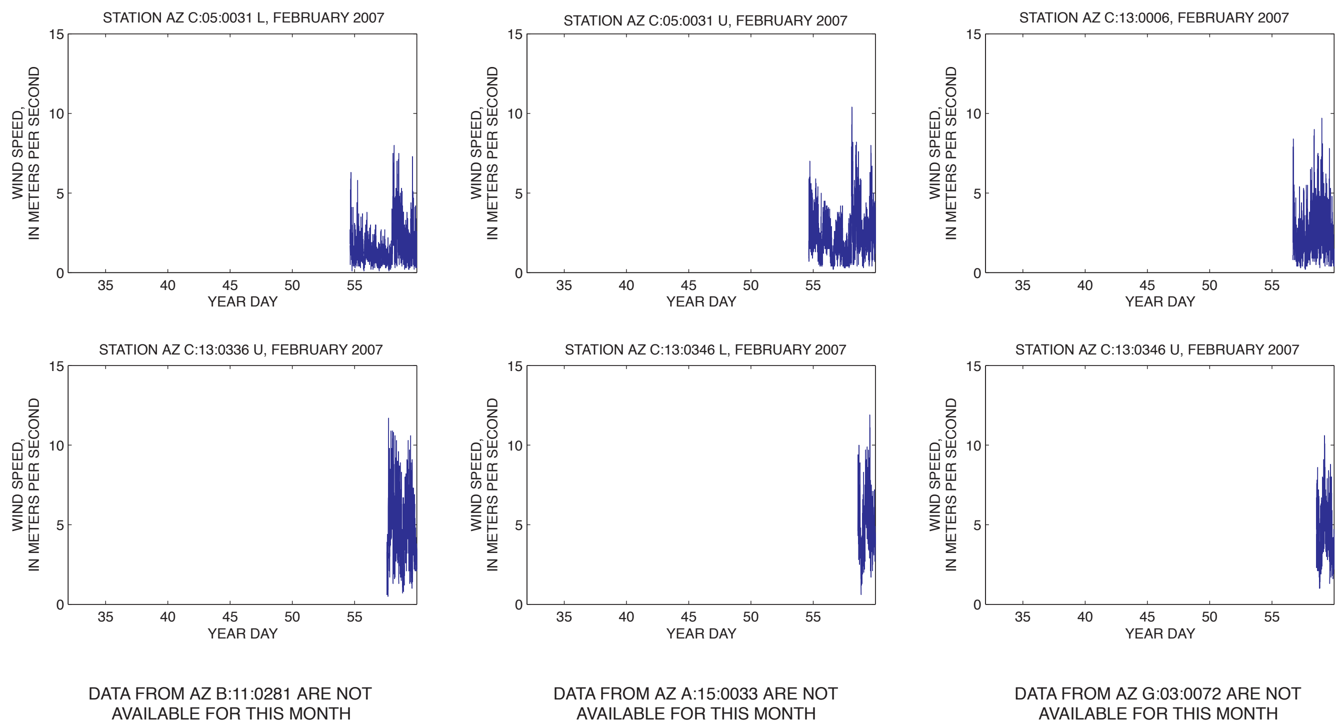

Figure 6. Wind speed measured in February 2007 (year days 32–59) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Data are plotted as values averaged over each 4-minute sampling interval.

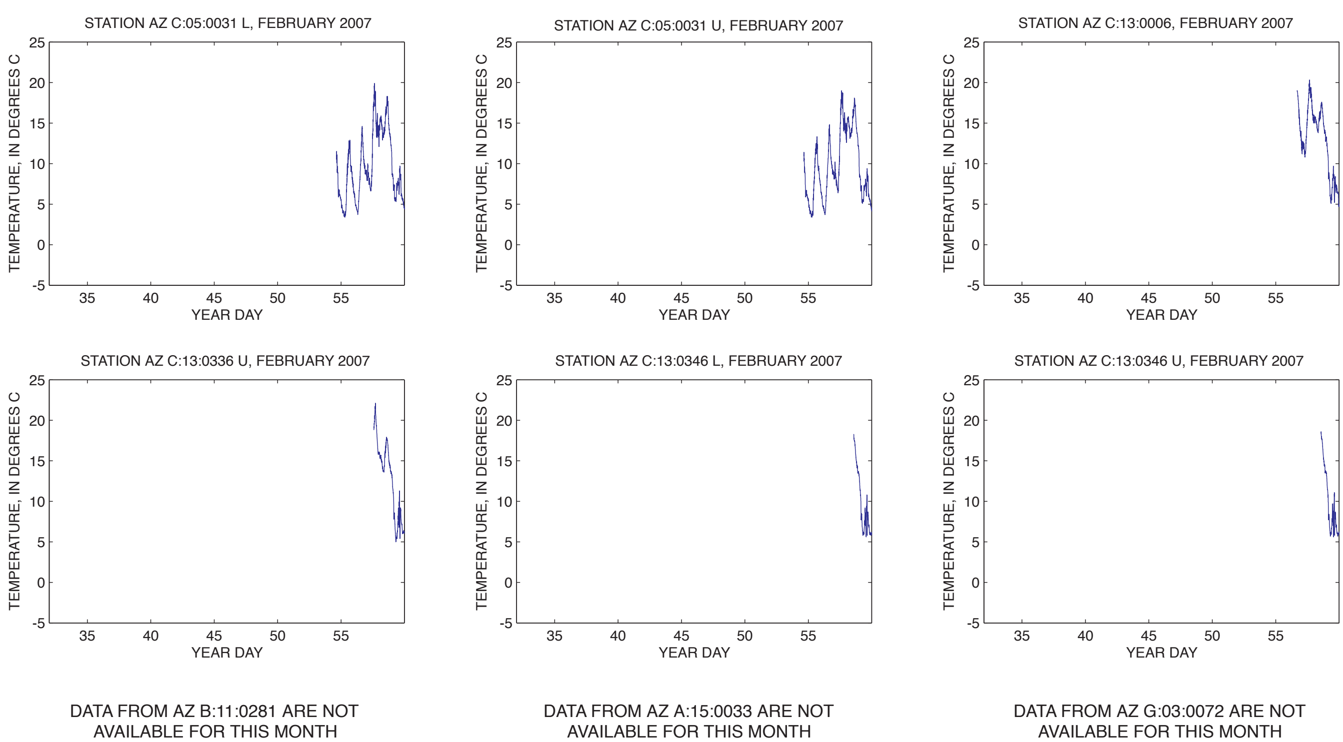

Figure 7. Air temperature measured in February 2007 (year days 32–59) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Data are plotted as values averaged over each 4-minute sampling interval.

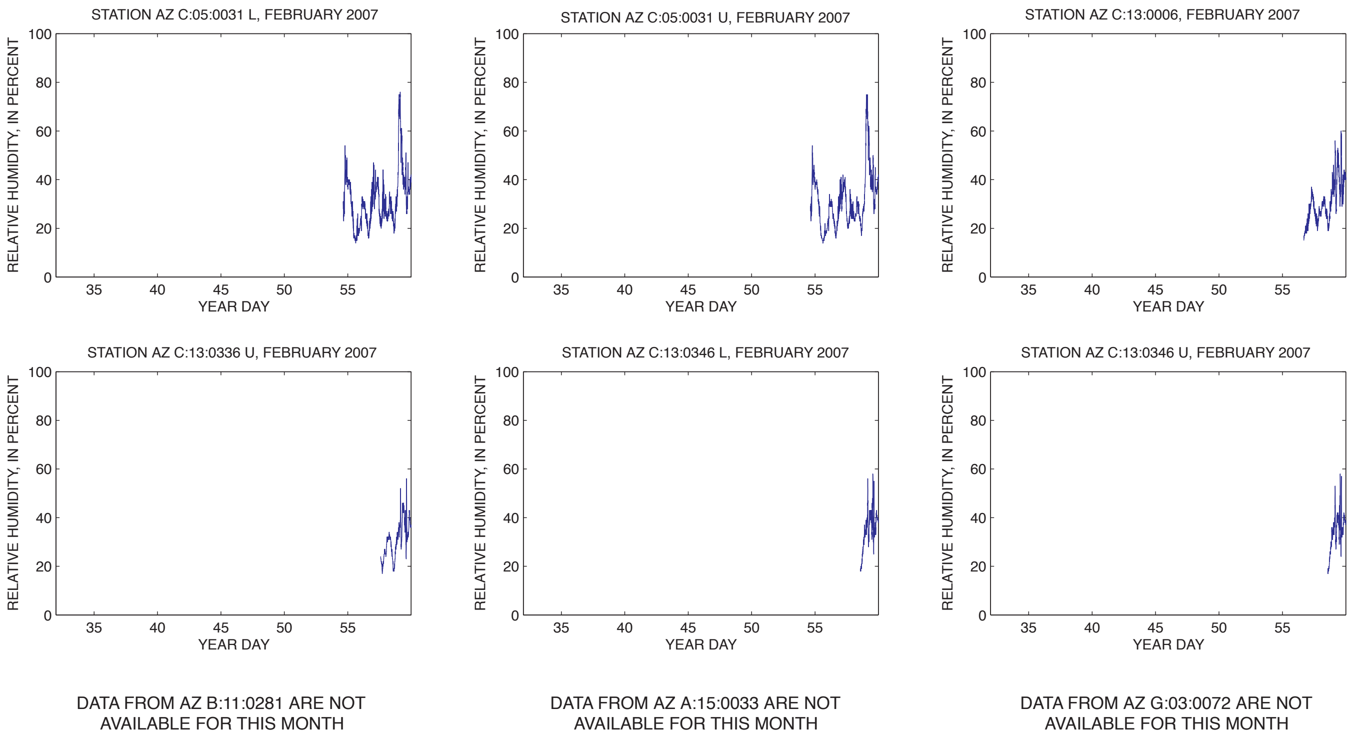

Figure 8. Relative humidity measured in February 2007 (year days 32–59) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Data are plotted as values averaged over each 4-minute sampling interval.

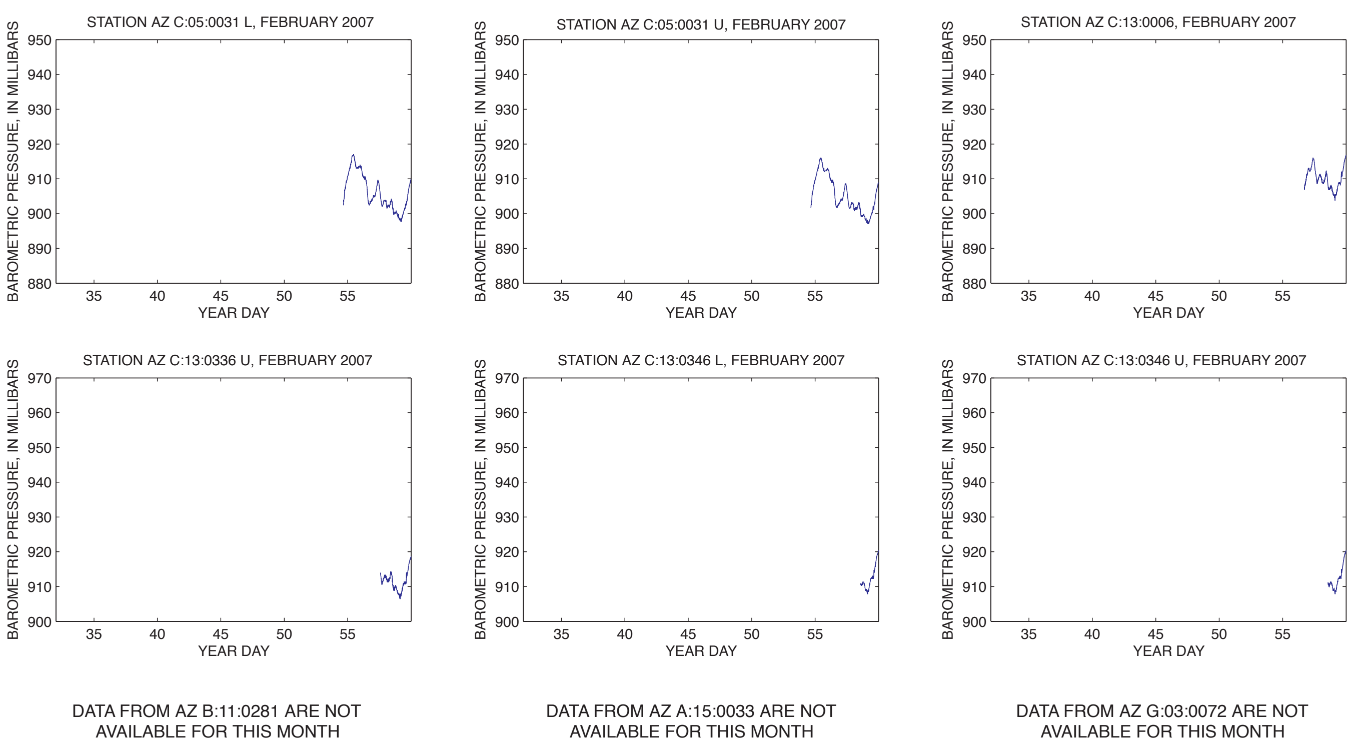

Figure 9. Barometric pressure measured in February 2007 (year days 32–59) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Data are plotted as values averaged over each 4-minute sampling interval.

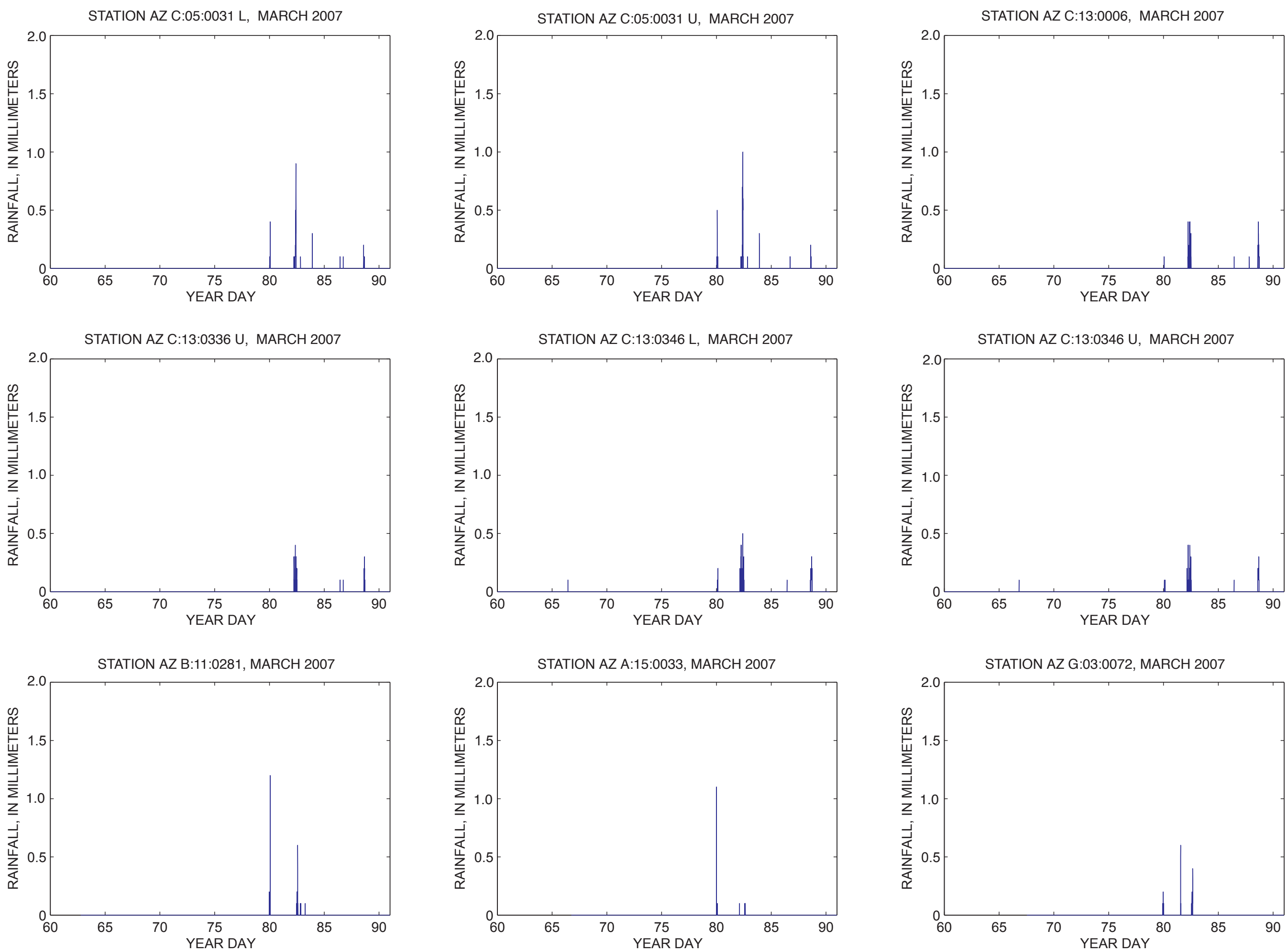

Figure 10. Rainfall measured in March 2007 (year days 60–90) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Data points represent total rainfall in each 4-minute sampling interval.

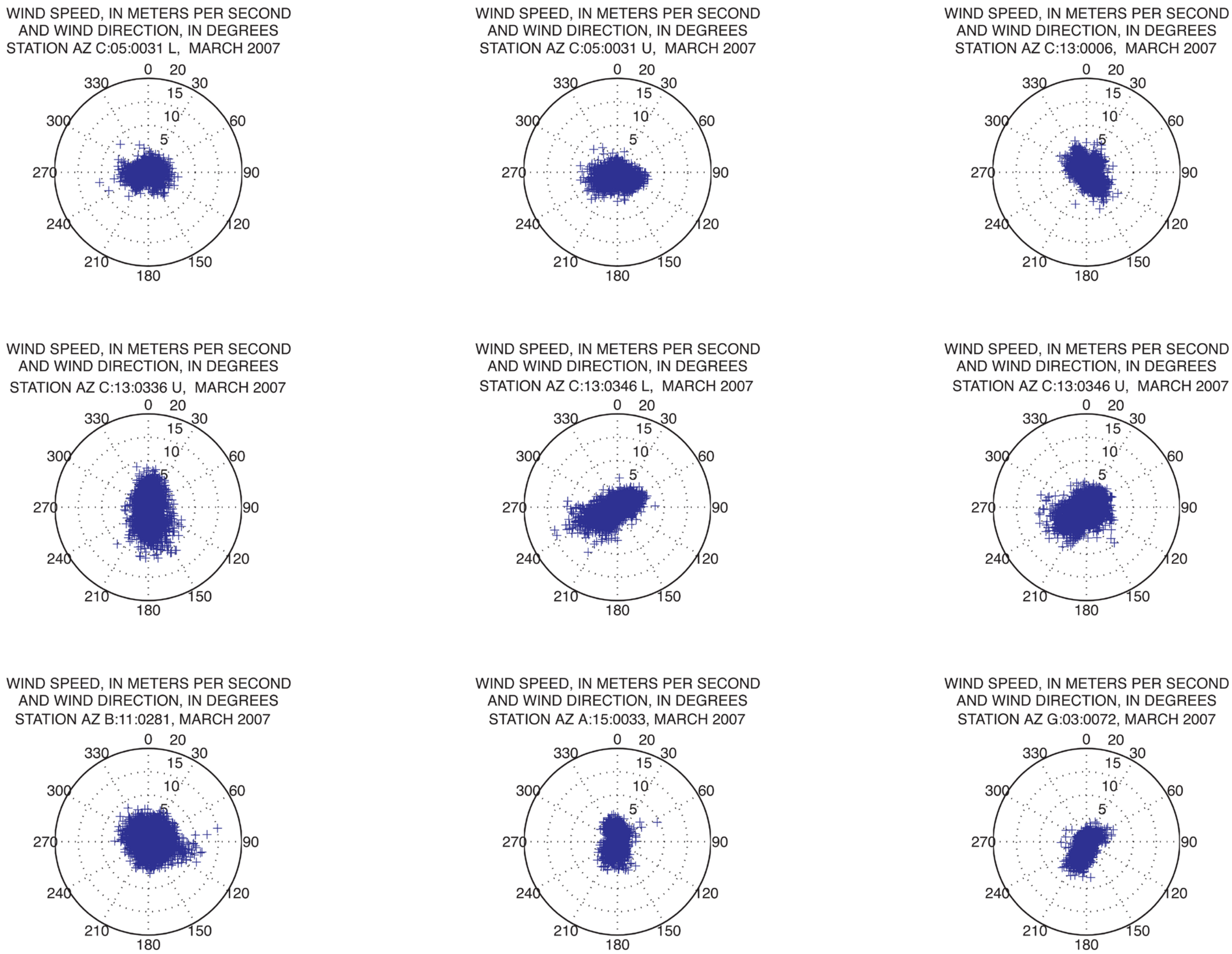

Figure 11. Magnitude and direction of wind velocity measured in March 2007 at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Each data point represents a 4-minute average. Magnitude is indicated by the concentric circles, and compass bearing indicates direction from which the wind came.

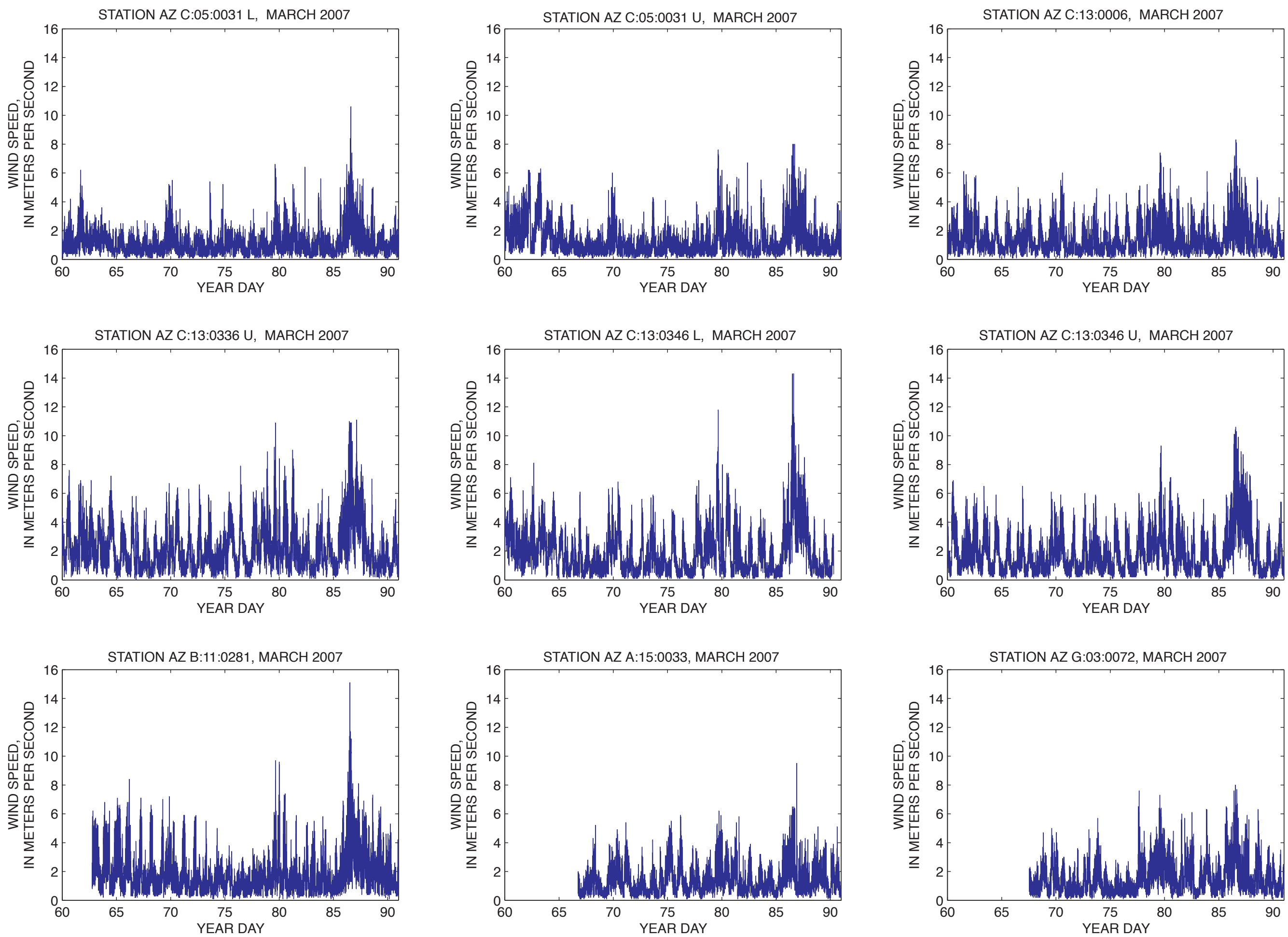

Figure 12. Wind speed measured in March 2007 (year days 60–90) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Data are plotted as values averaged over each 4-minute sampling interval.

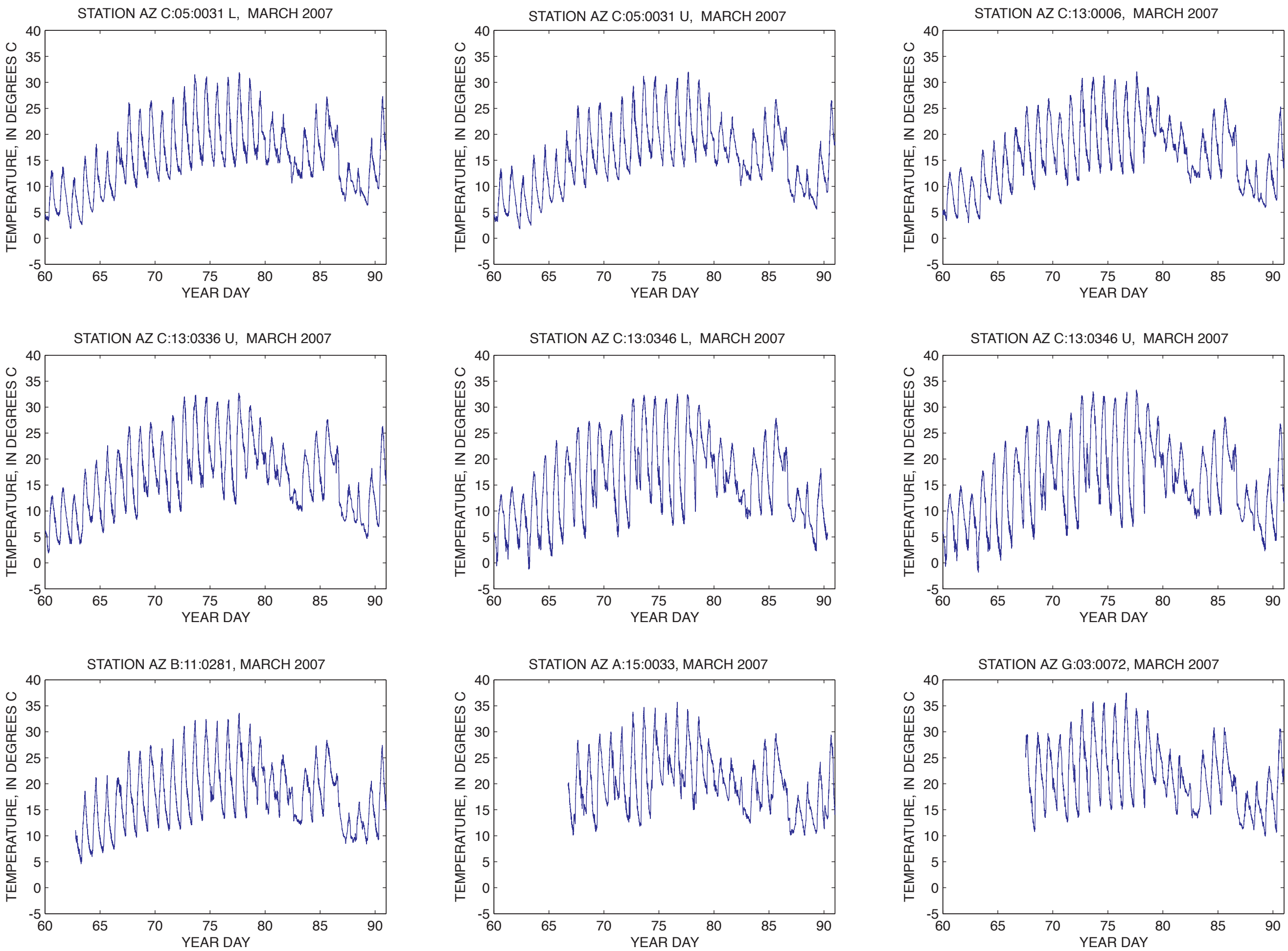

Figure 13. Air temperature measured in March 2007 (year days 60–90) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Data are plotted as values averaged over each 4-minute sampling interval.

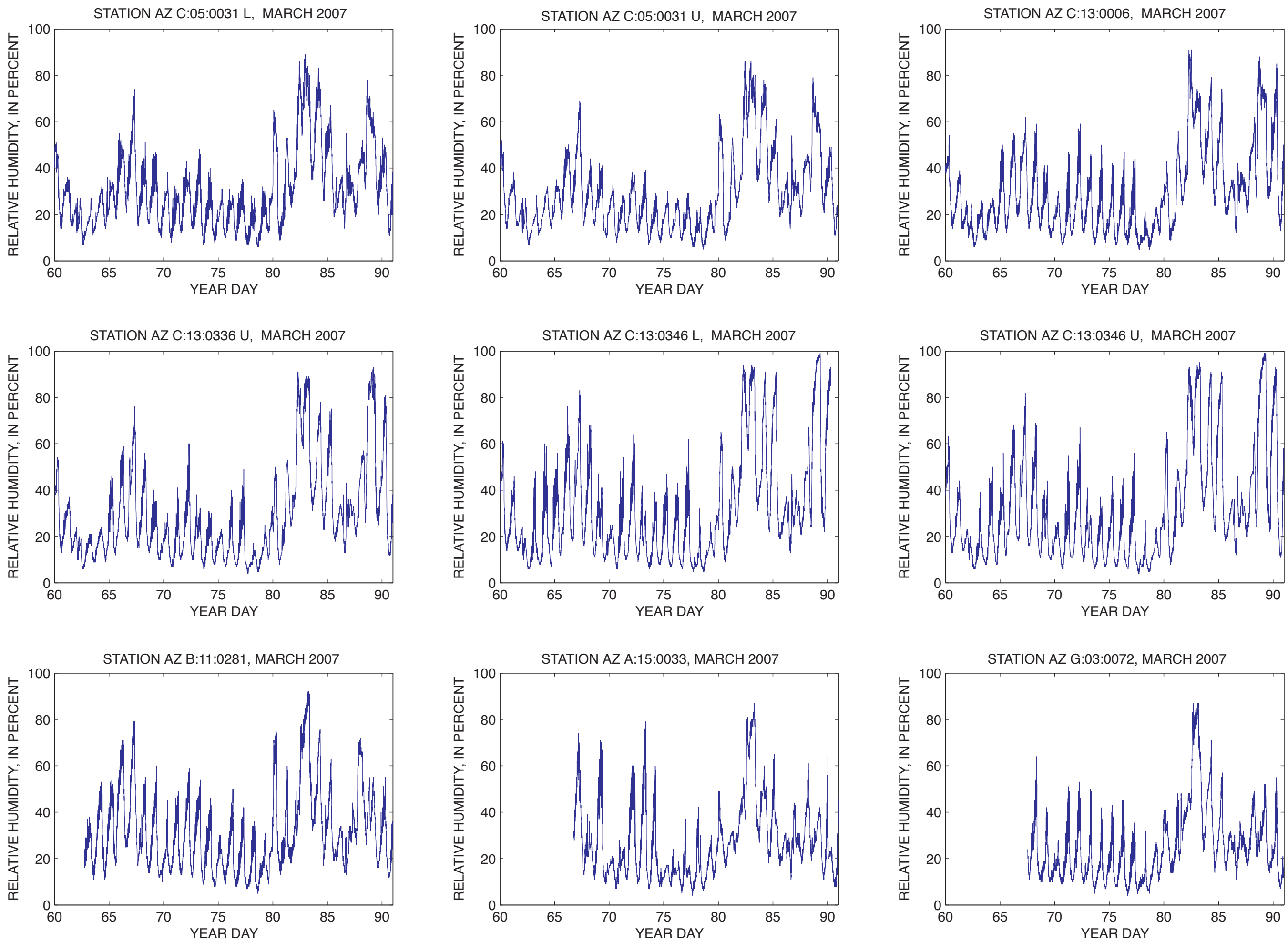

Figure 14. Relative humidity measured in March 2007 (year days 60–90) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Data are plotted as values averaged over each 4-minute sampling interval.

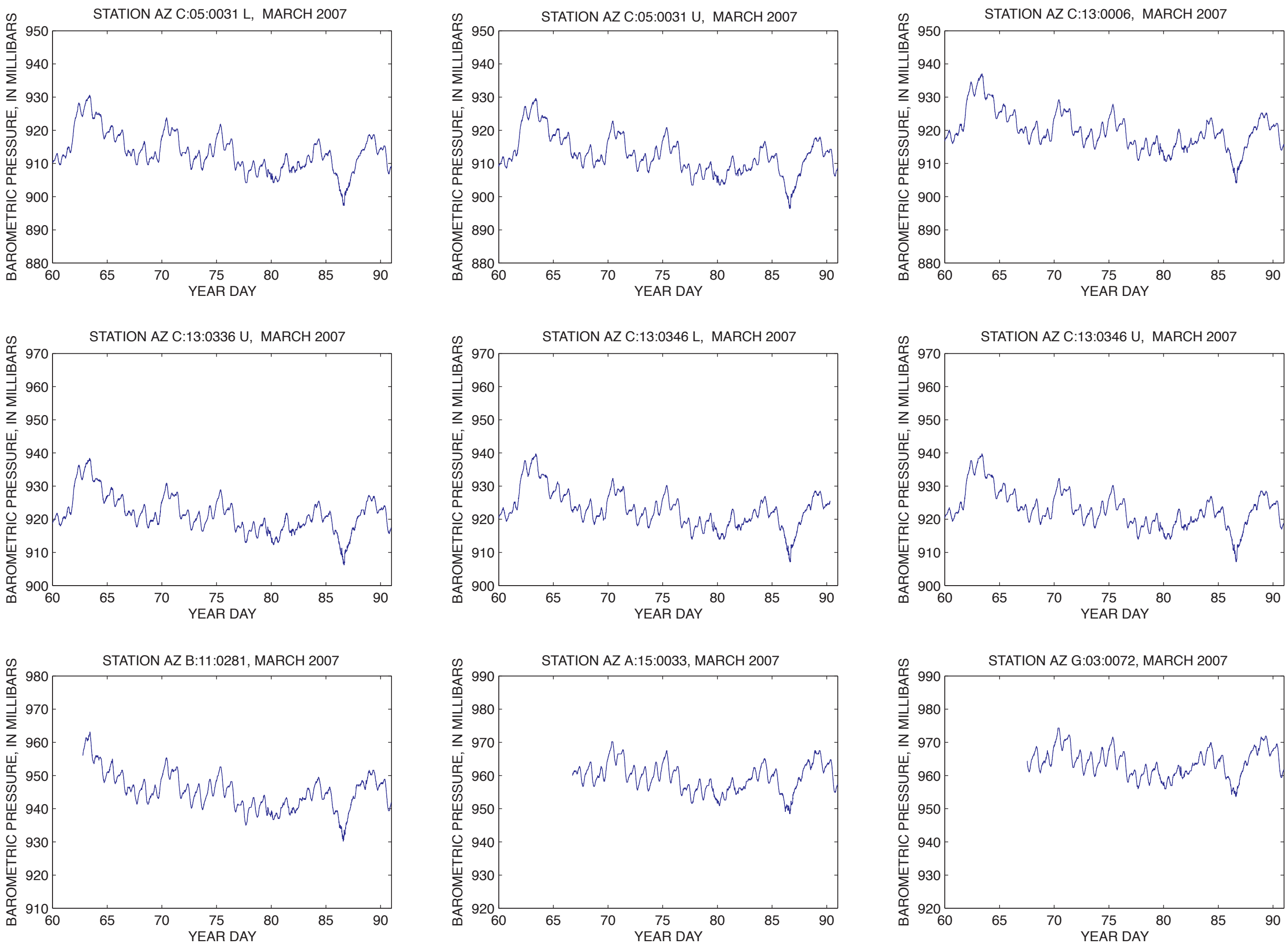

Figure 15. Barometric pressure measured in March 2007 (year days 60–90) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Data are plotted as values averaged over each 4-minute sampling interval.

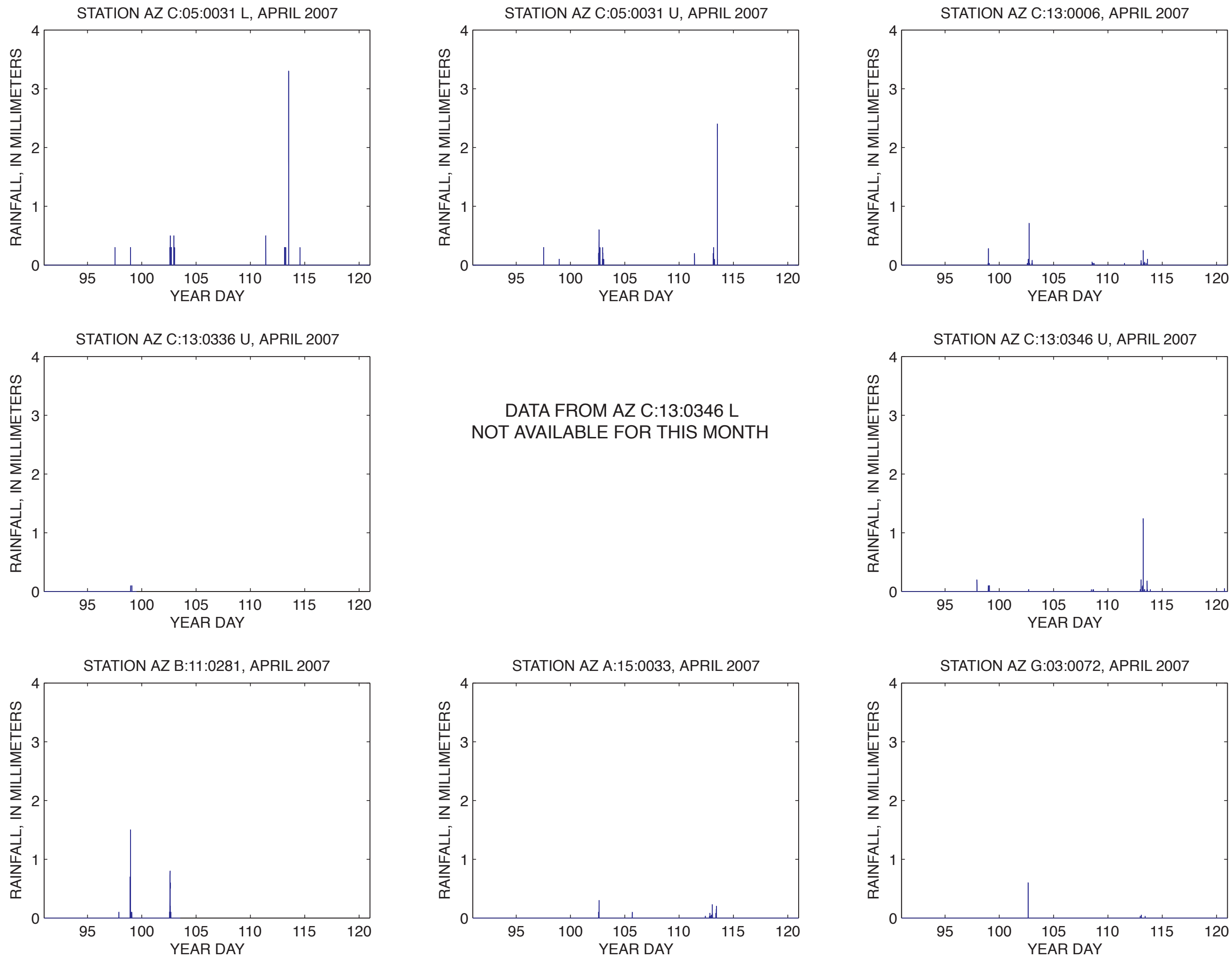

Figure 16. Rainfall measured in April 2007 (year days 91–120) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Data points represent total rainfall in each 4-minute sampling interval.

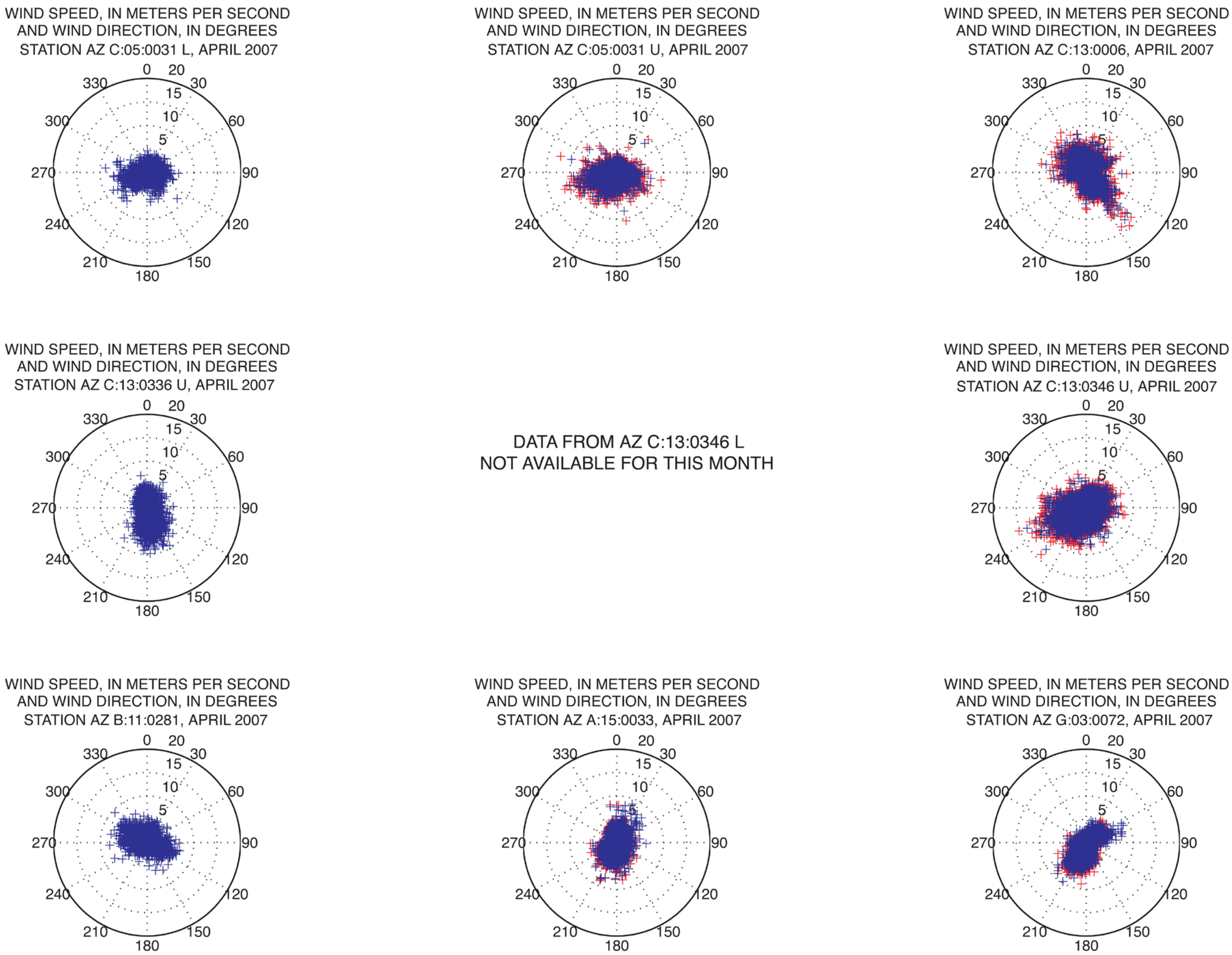

Figure 17. Magnitude and direction of wind velocity measured in April 2007 at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Each blue data point represents a 4-minute average; each red data point represents maximum gust recorded during each 4-minute sampling interval. Magnitude is indicated by the concentric circles, and compass bearing indicates direction from which the wind came.

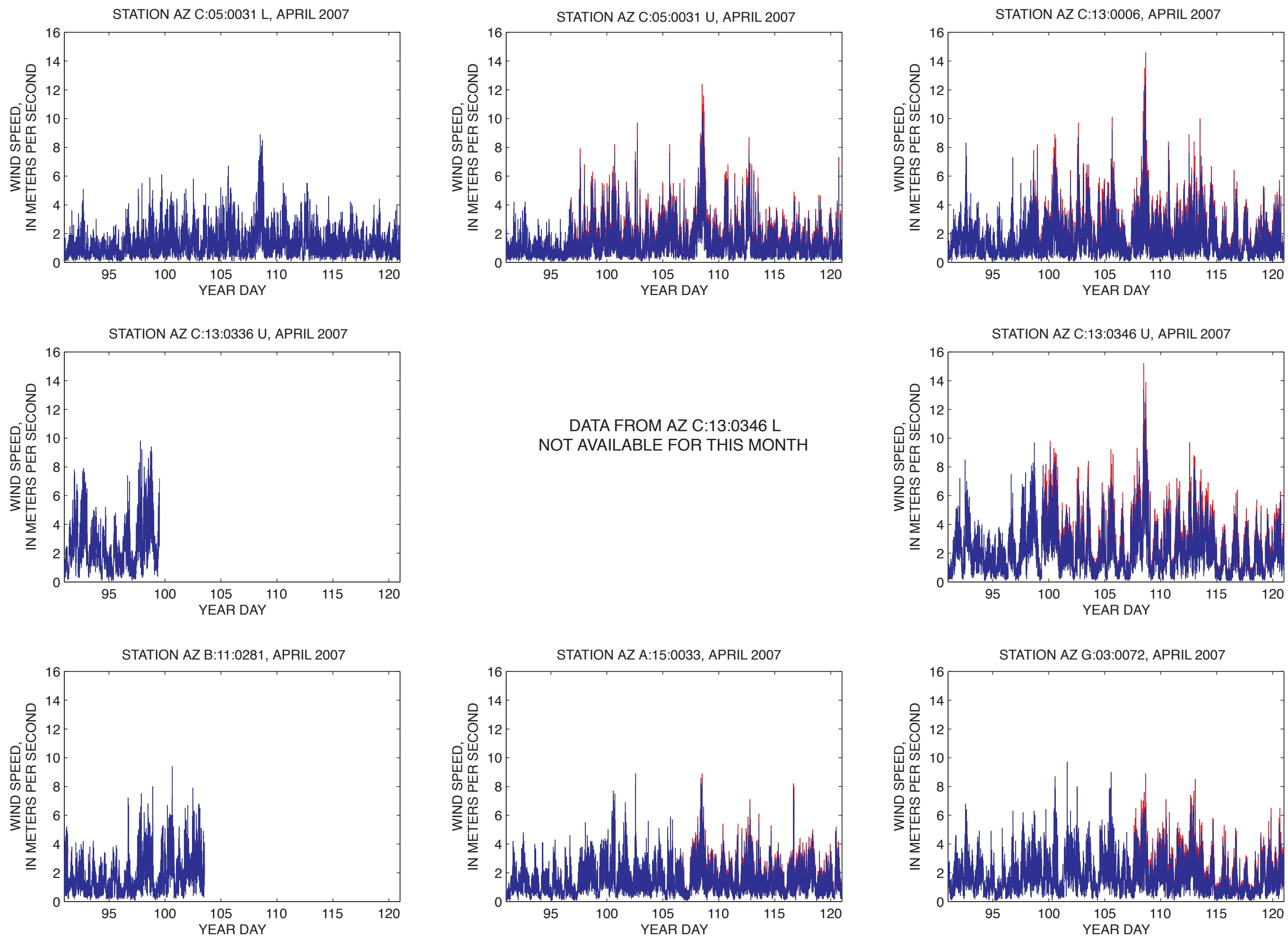

Figure 18. Wind speed measured in April 2007 (year days 91–120) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Blue data are values averaged over each 4-minute sampling interval; red data are maximum gusts recorded during each 4-minute sampling interval. The capability to measure maximum gust was added to weather stations in early April 2007.

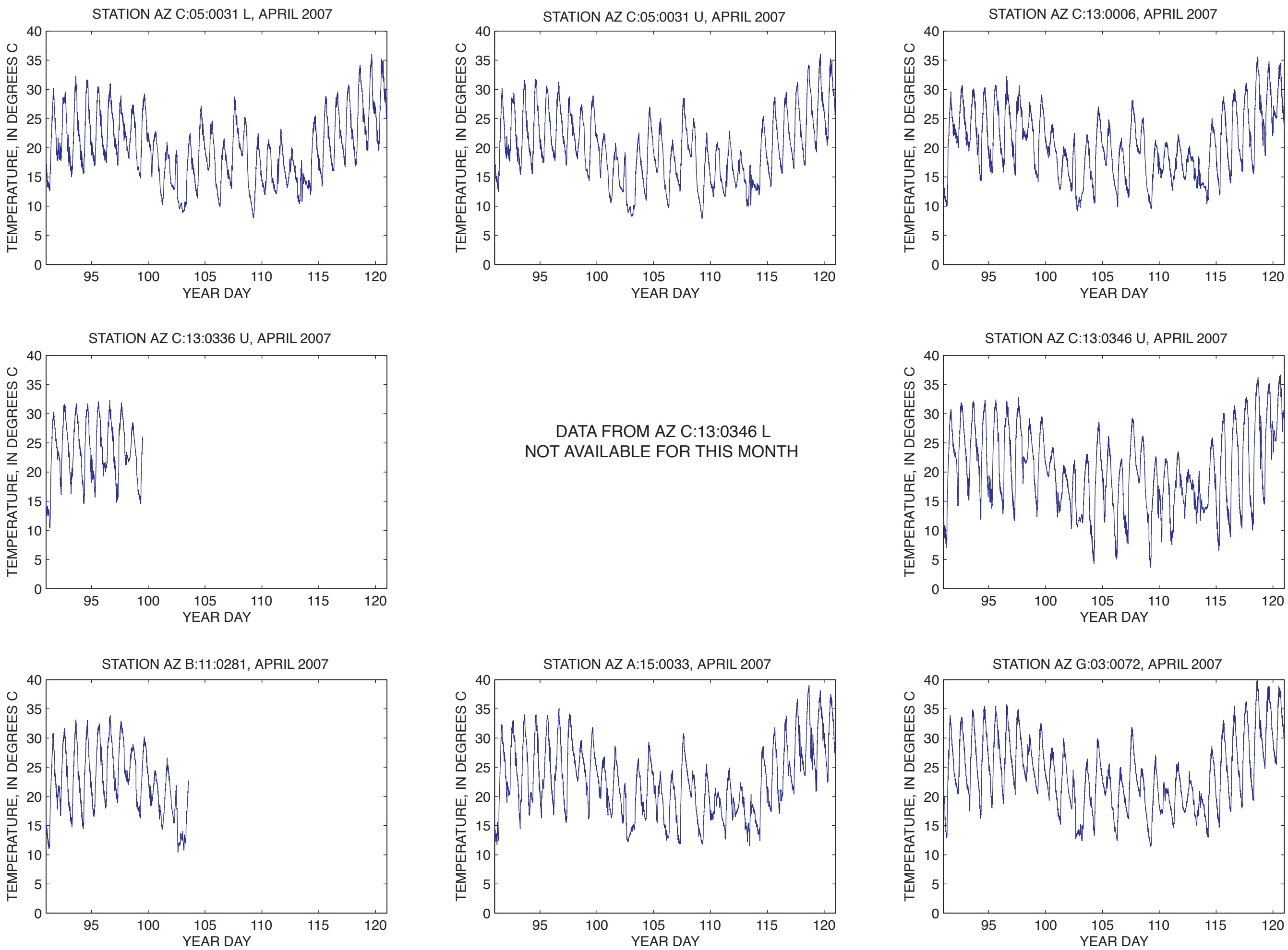

Figure 19. Air temperature measured in April 2007 (year days 91–120) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Data are plotted as values averaged over each 4-minute sampling interval.

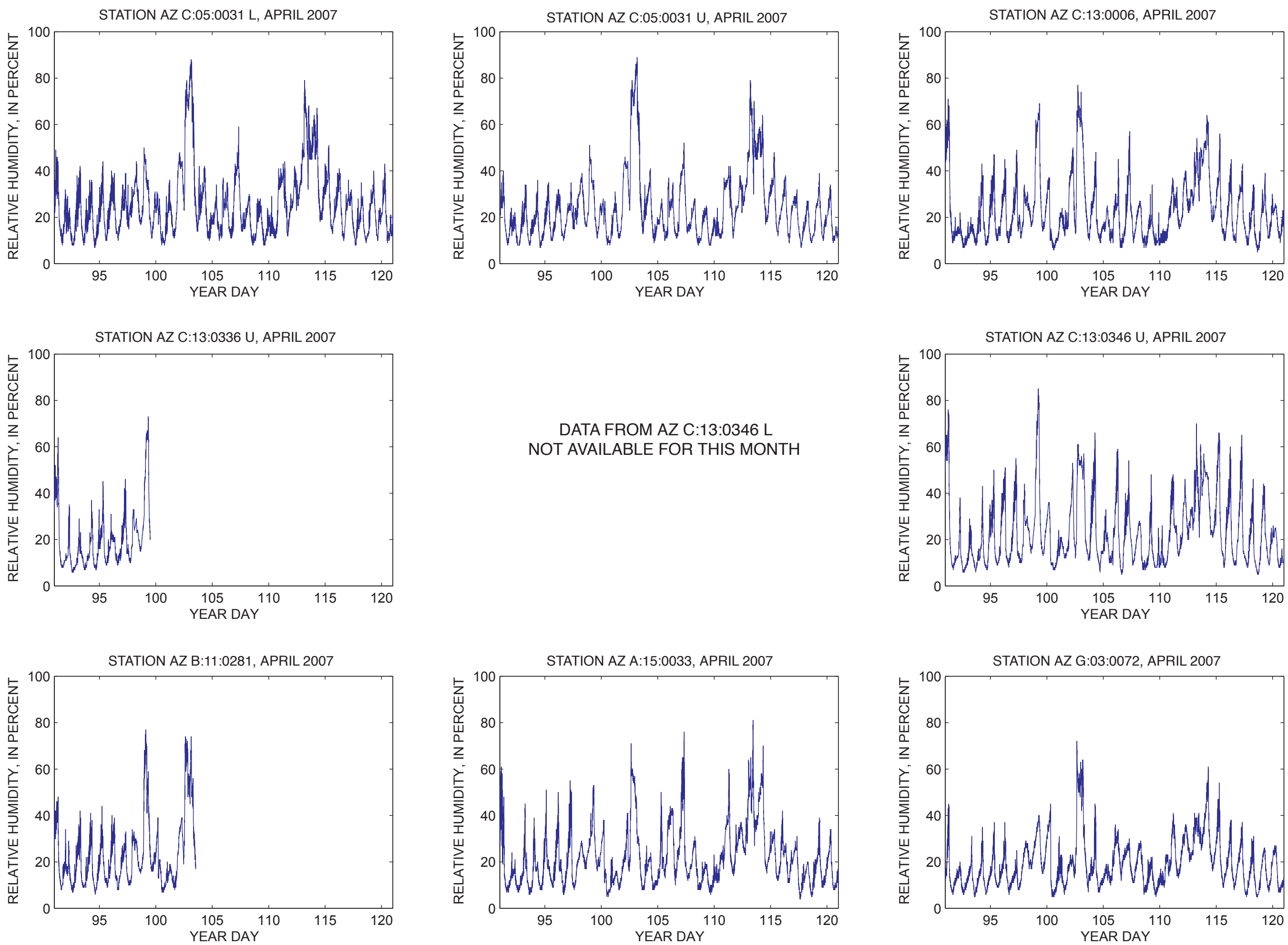

Figure 20. Relative humidity measured in April 2007 (year days 91–120) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Data are plotted as values averaged over each 4-minute sampling interval.

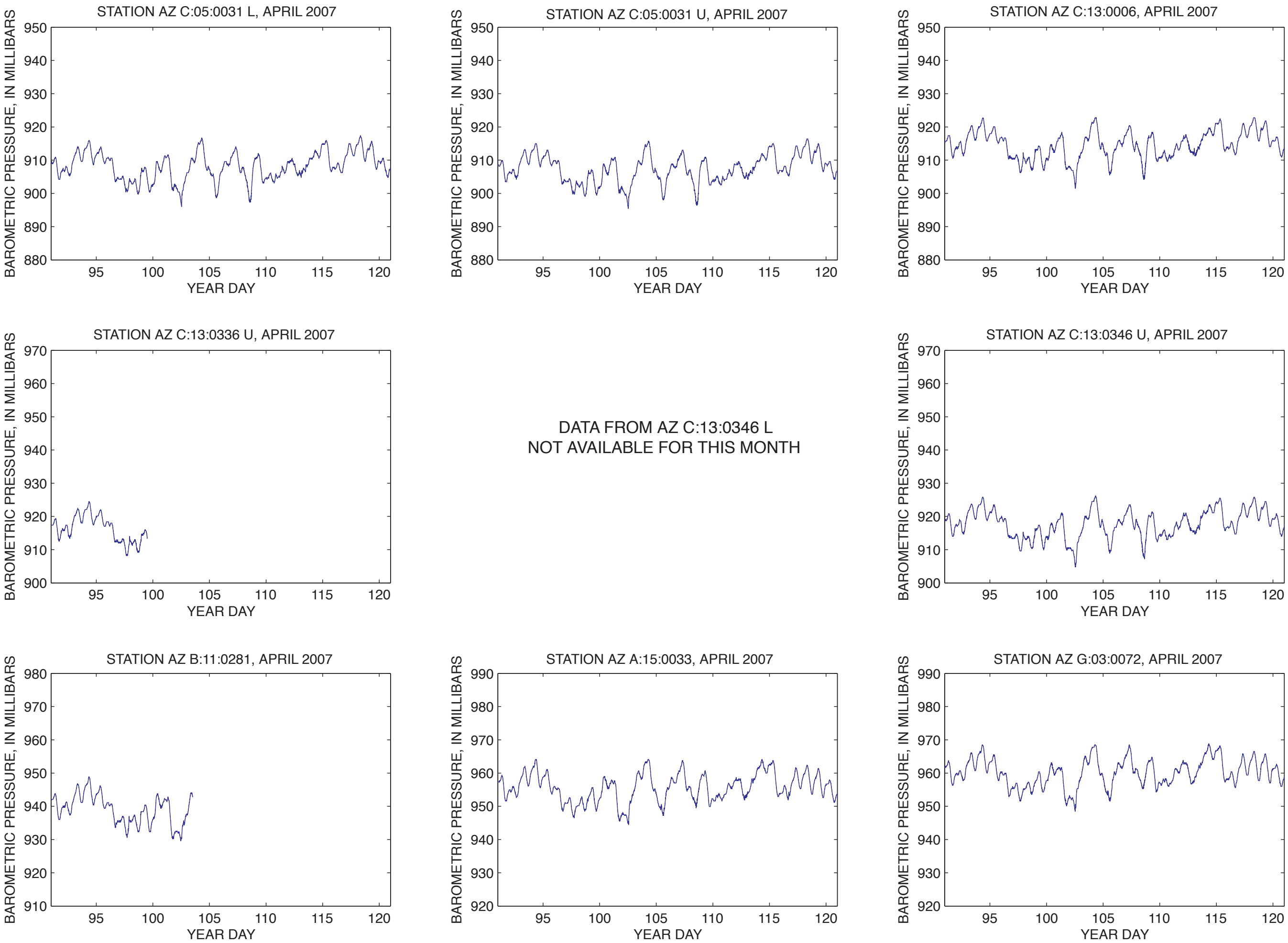

Figure 21. Barometric pressure measured in April 2007 (year days 91–120) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Data are plotted as values averaged over each 4-minute sampling interval.

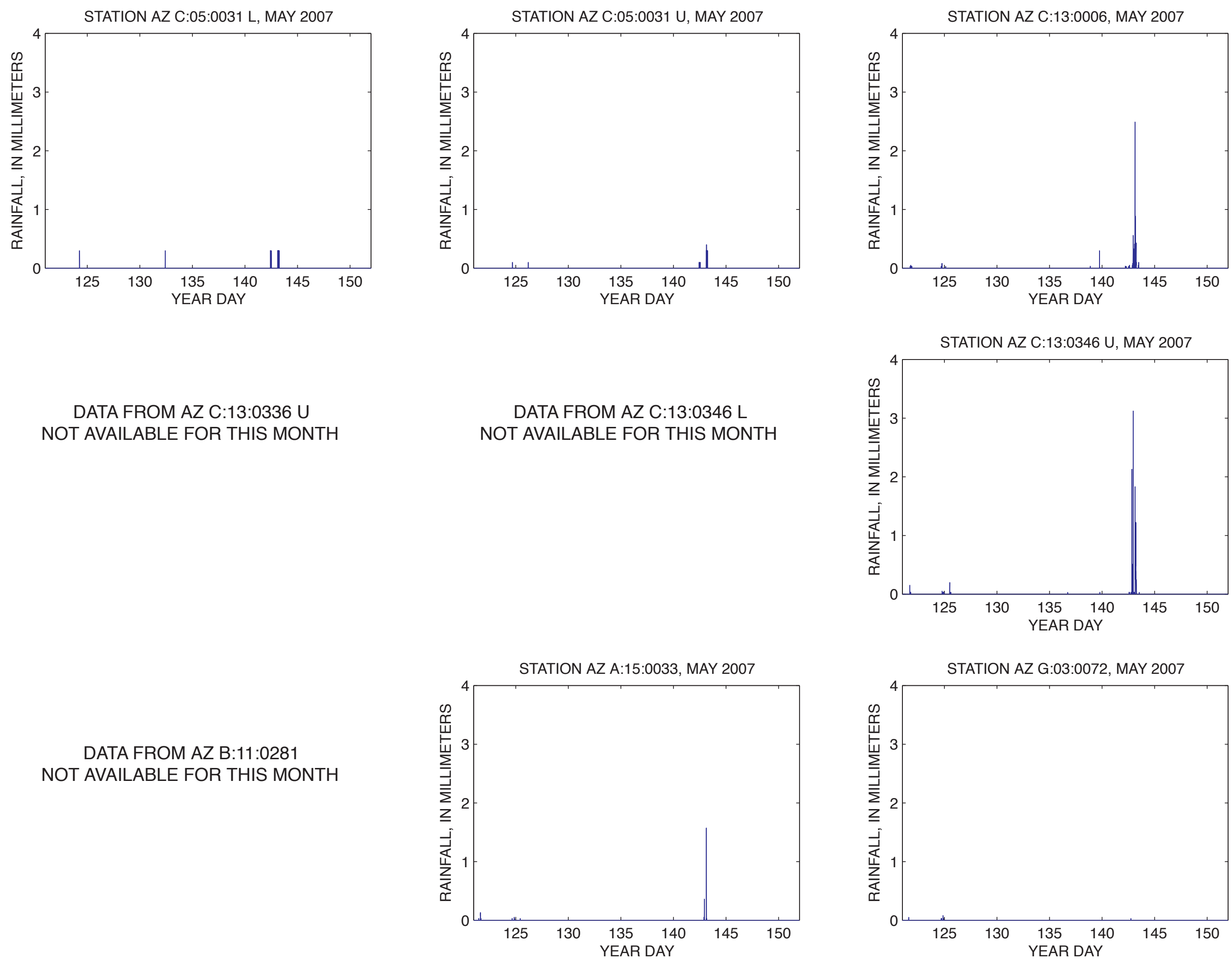

Figure 22. Rainfall measured in May 2007 (year days 121–151) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Data points represent total rainfall in each 4-minute sampling interval.

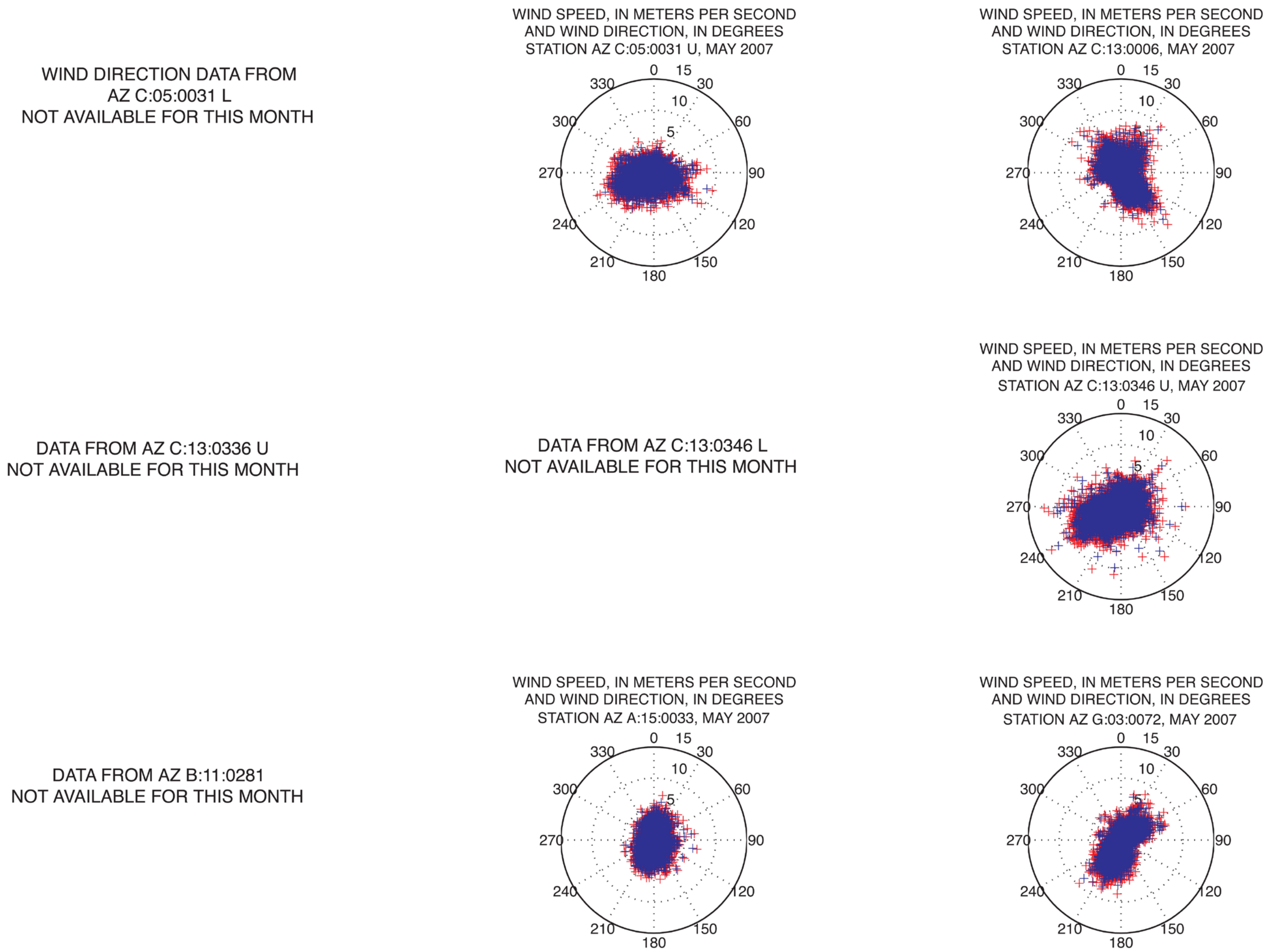

Figure 23. Magnitude and direction of wind velocity measured in May 2007 at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Each blue data point represents a 4-minute average; each red data point represents maximum gust recorded during each 4-minute sampling interval. Magnitude is indicated by the concentric circles, and compass bearing indicates direction from which the wind came.

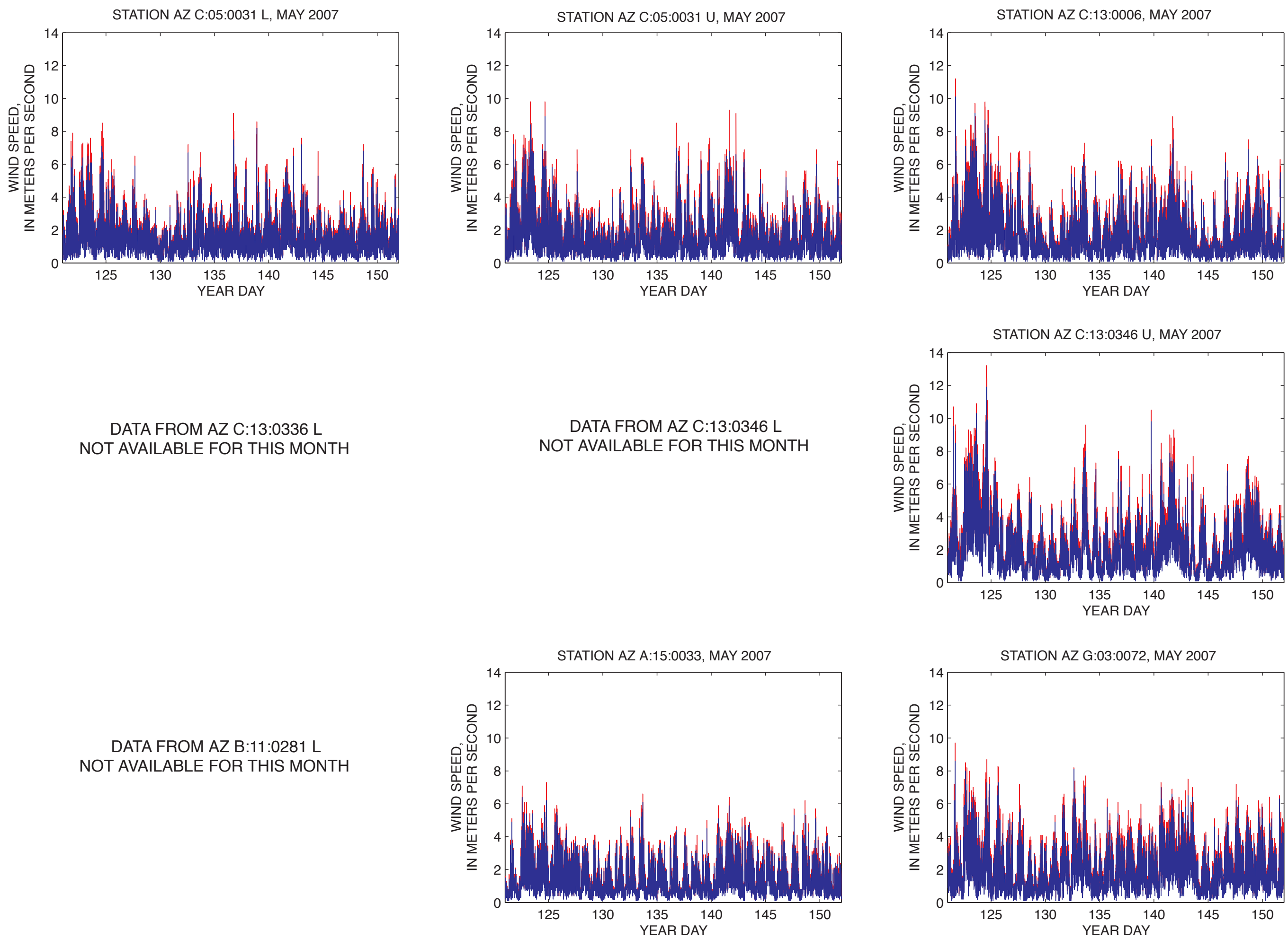

Figure 24. Wind speed measured in May 2007 (year days 121–151) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Blue data are values averaged over each 4-minute sampling interval; red data are maximum gusts recorded during each 4-minute sampling interval.

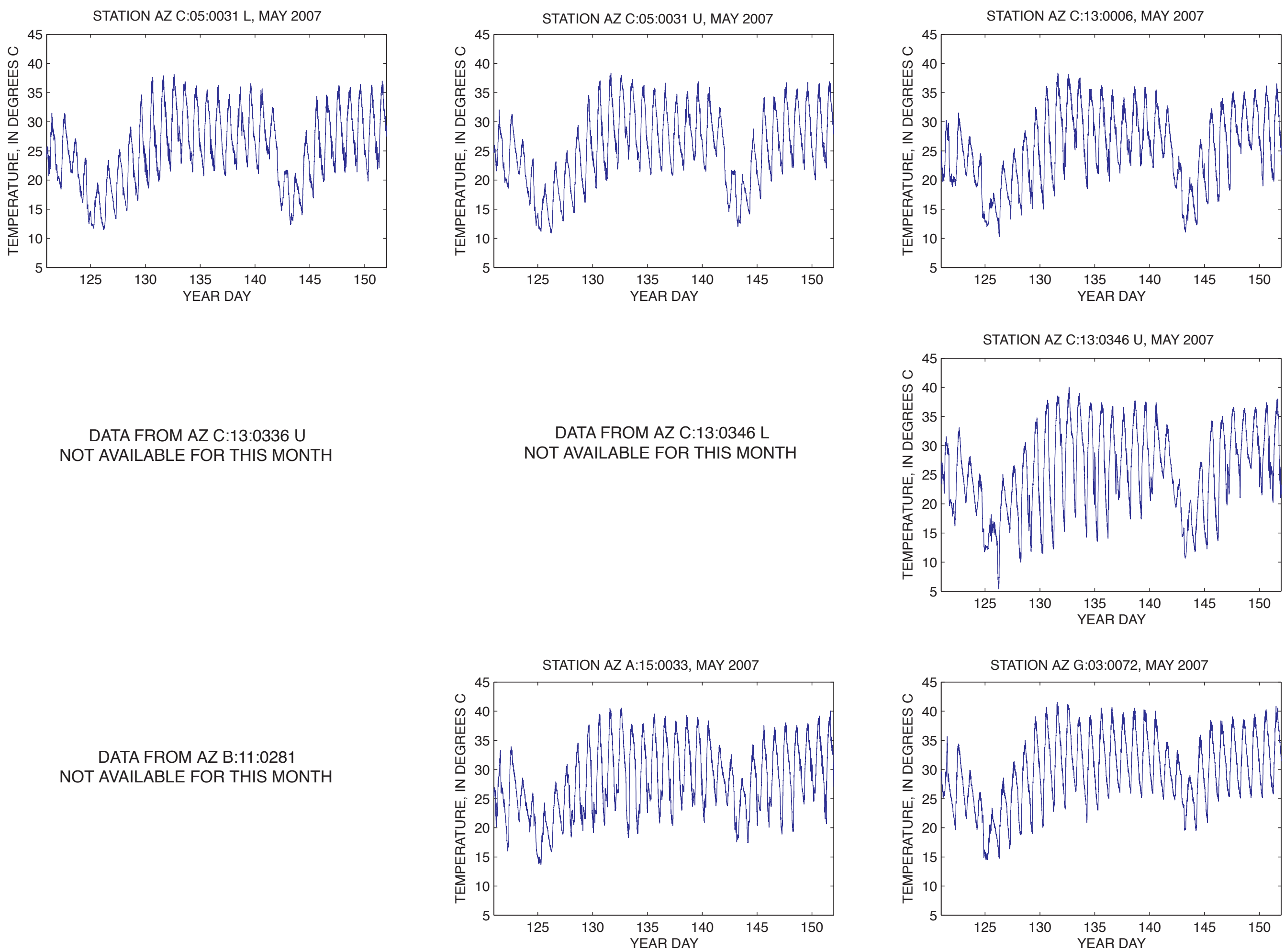

Figure 25. Air temperature measured in May 2007 (year days 121–151) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Data are plotted as values averaged over each 4-minute sampling interval.

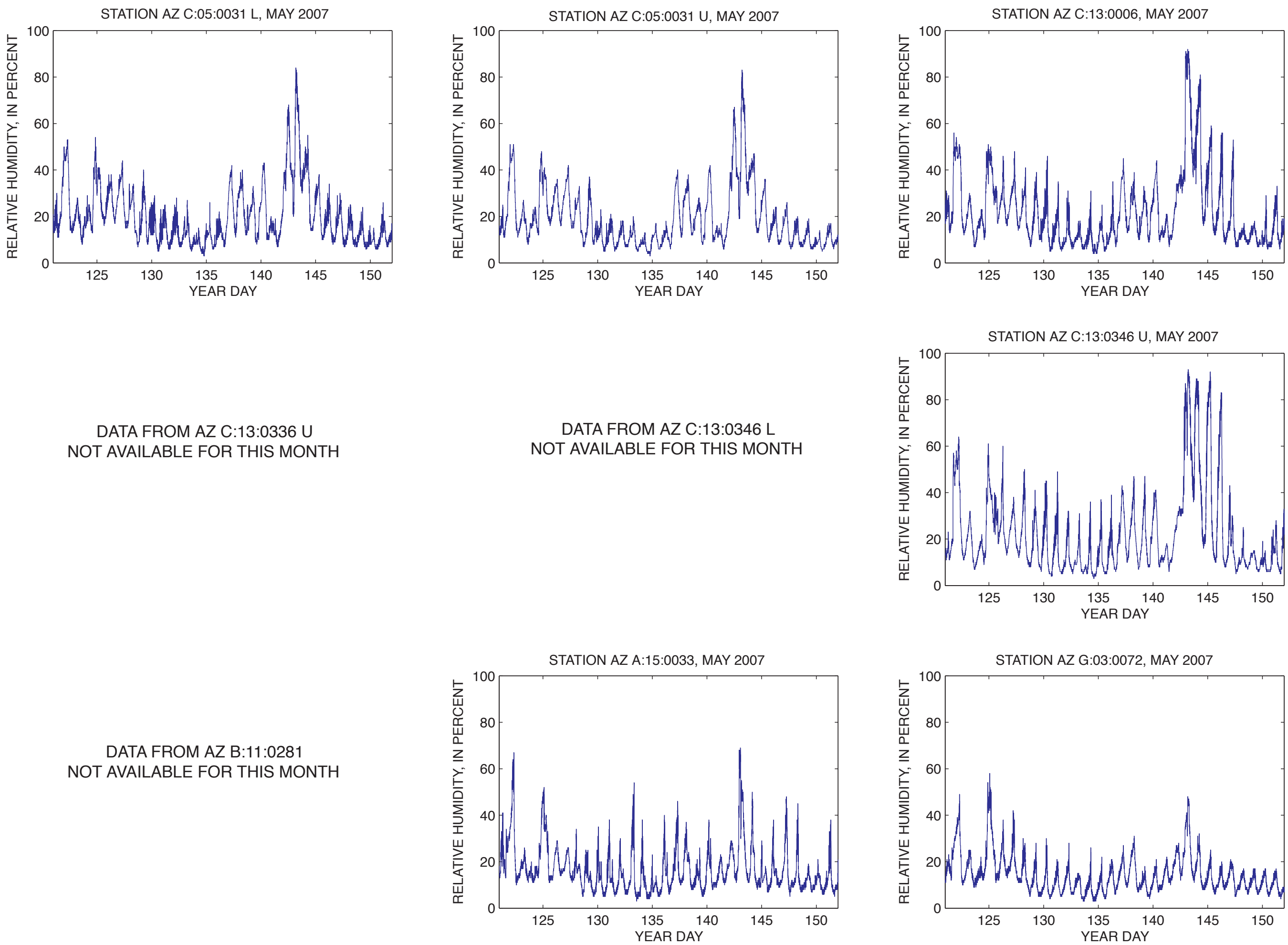

Figure 26. Relative humidity measured in May 2007 (year days 121–151) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Data are plotted as values averaged over each 4-minute sampling interval.

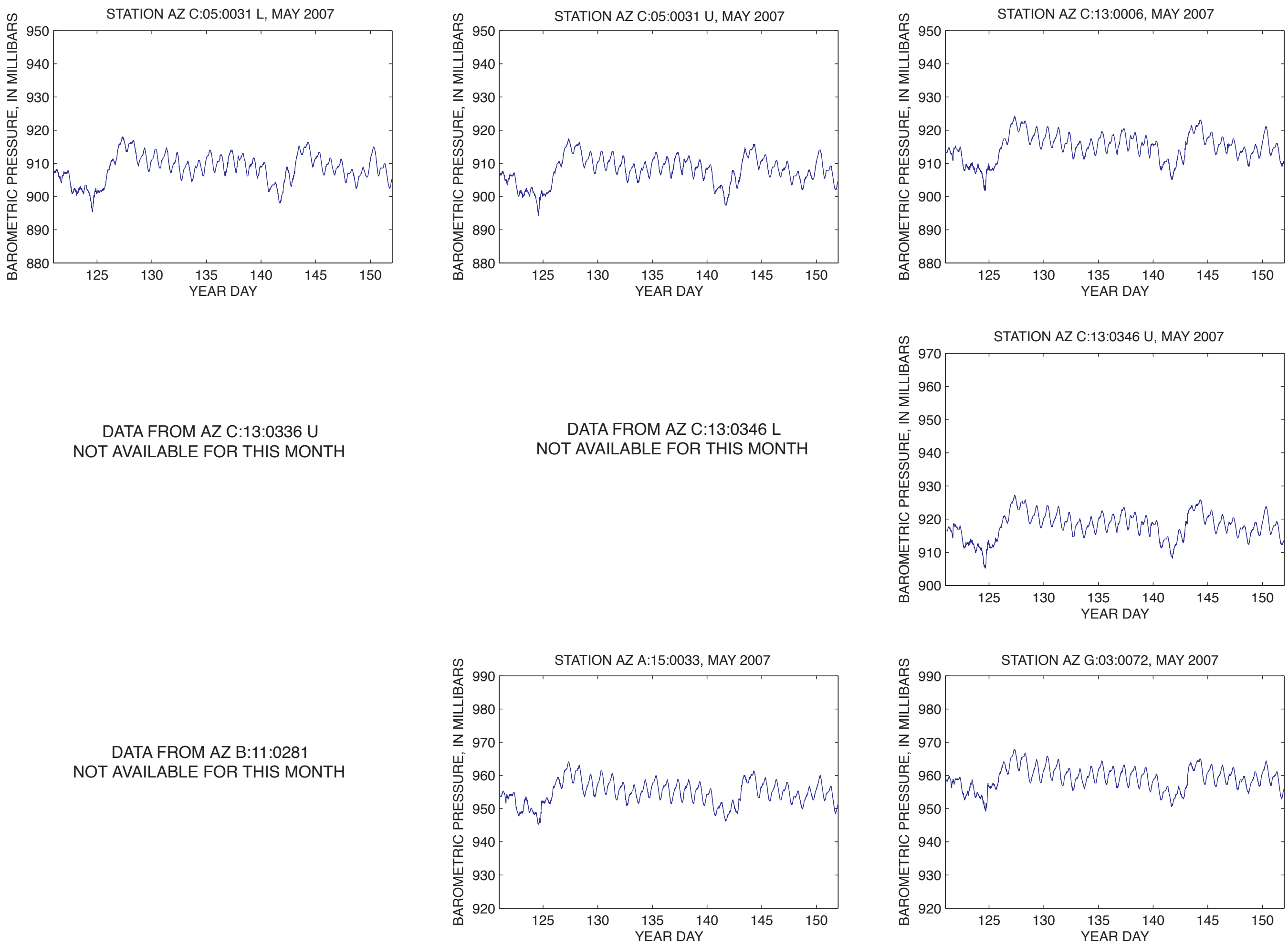

Figure 27. Barometric pressure measured in May 2007 (year days 121–151) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Data are plotted as values averaged over each 4-minute sampling interval.

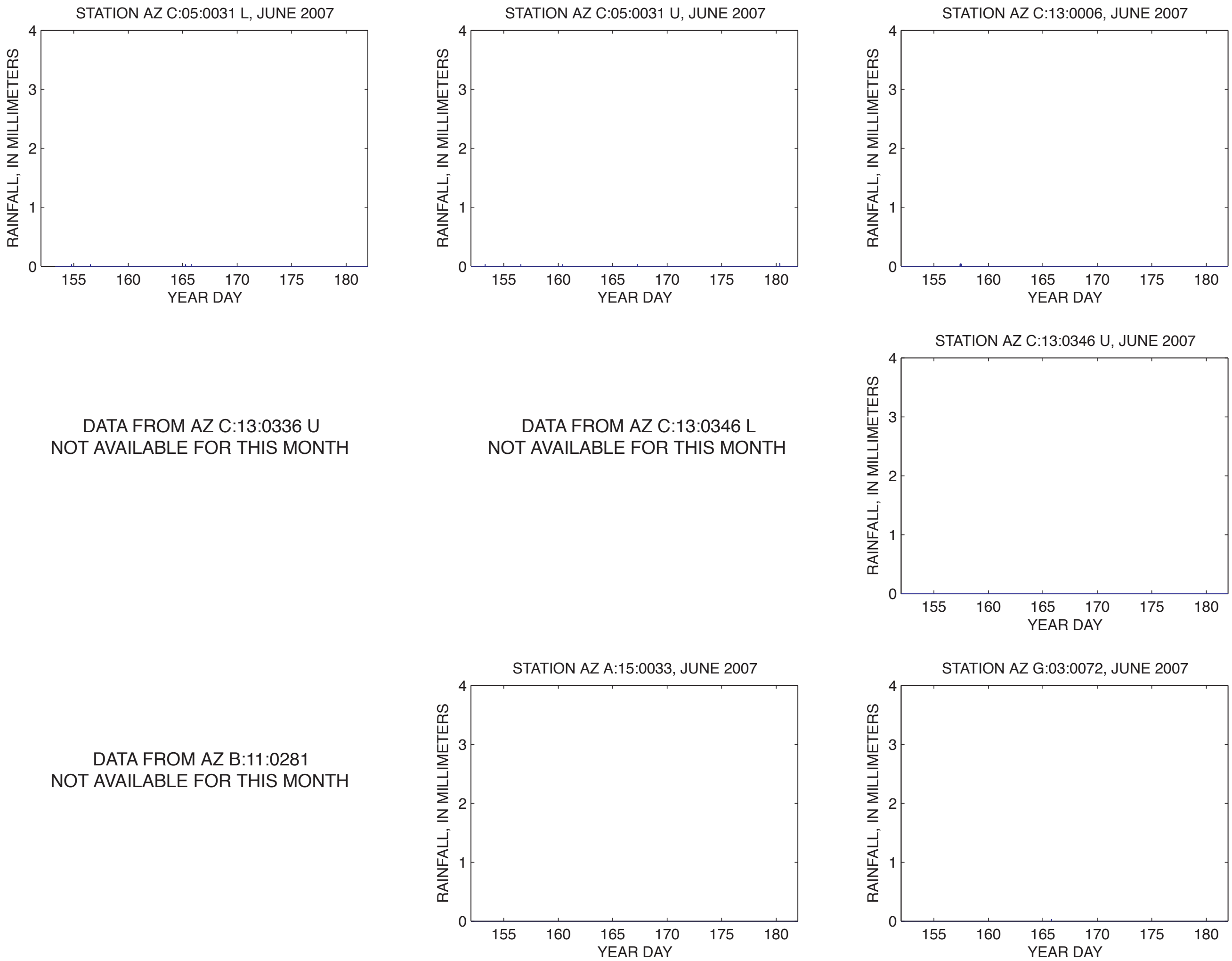

Figure 28. Rainfall measured in June 2007 (year days 152–181) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Data points represent total rainfall in each 4-minute sampling interval.

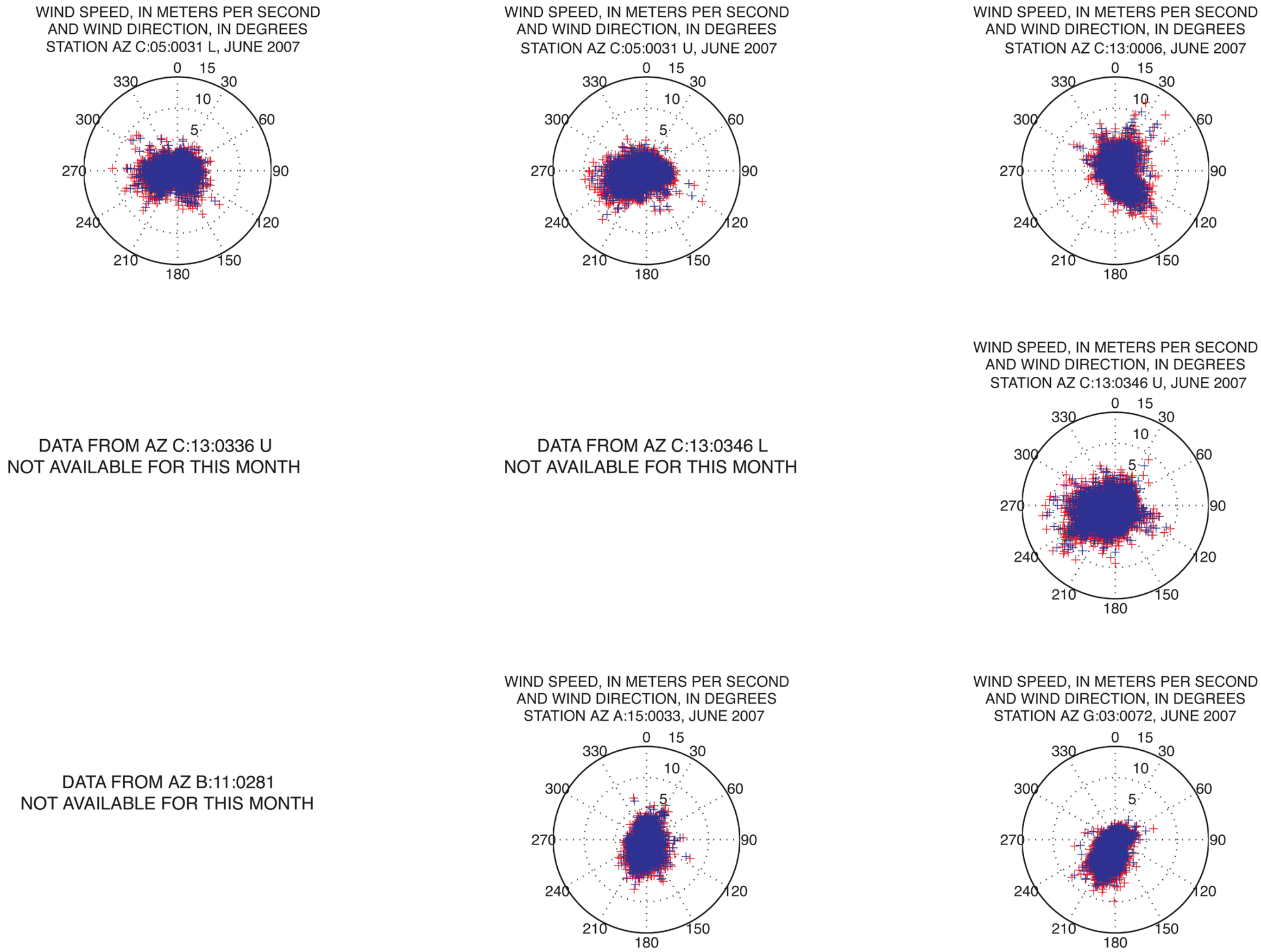

Figure 29. Magnitude and direction of wind velocity measured in June 2007 at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Each blue data point represents a 4-minute average; each red data point represents maximum gust recorded during each 4-minute sampling interval. Magnitude is indicated by the concentric circles, and compass bearing indicates direction from which the wind came.

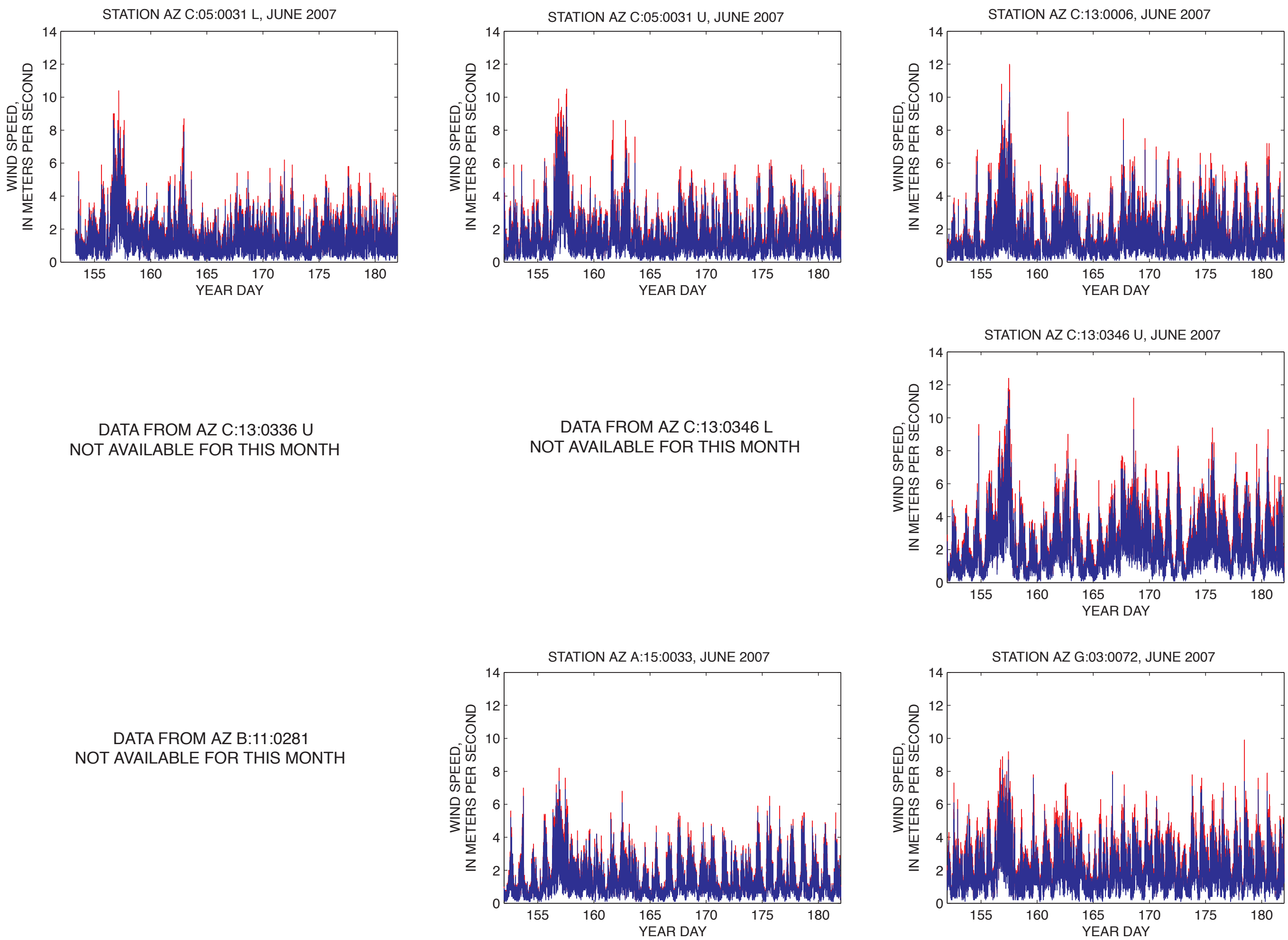

Figure 30. Wind speed measured in June 2007 (year days 152–181) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Blue data are values averaged over each 4-minute sampling interval; red data are maximum gusts recorded during each 4-minute sampling interval.

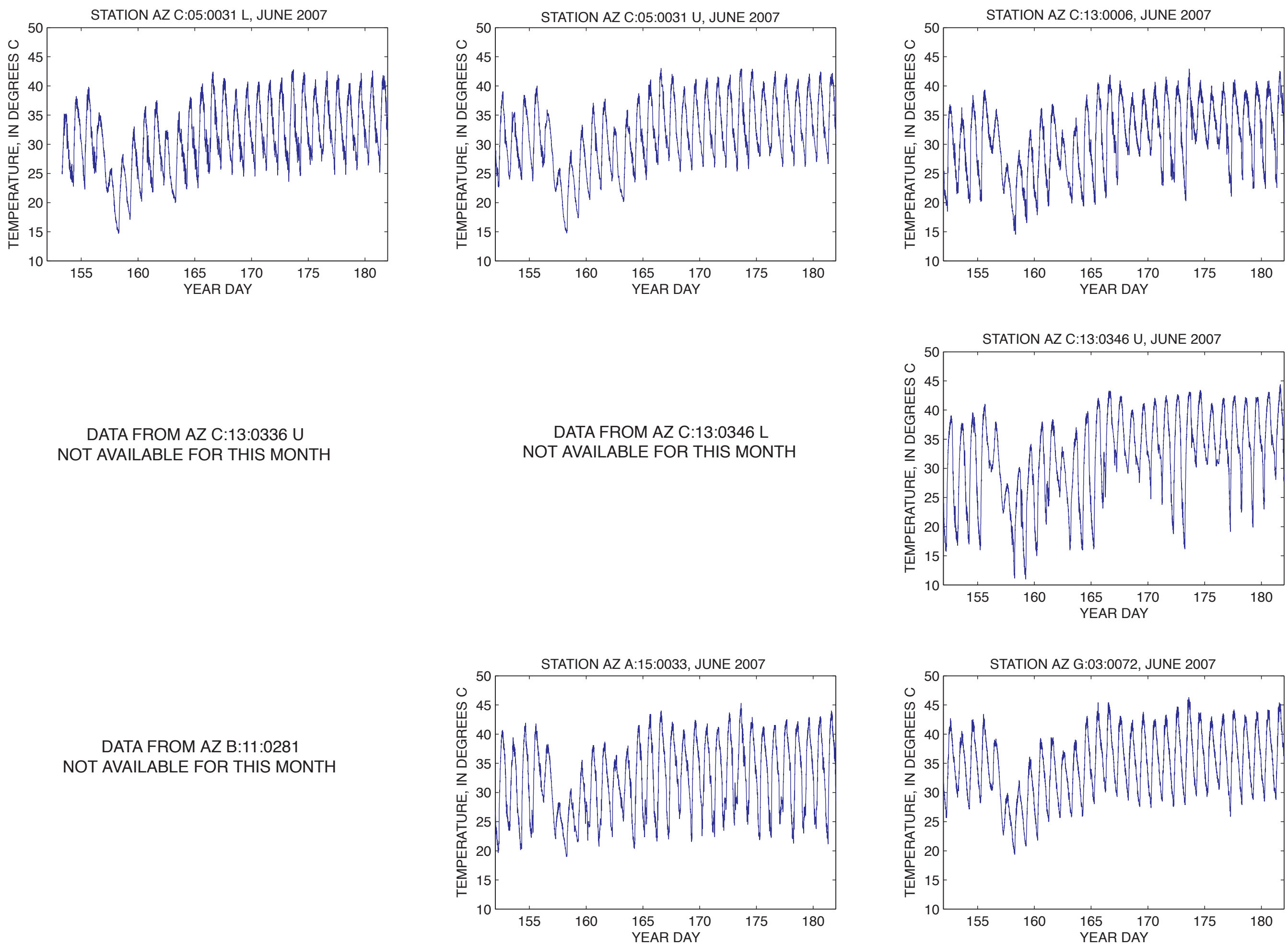

Figure 31. Air temperature measured in June 2007 (year days 152–181) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Data are plotted as values averaged over each 4-minute sampling interval.

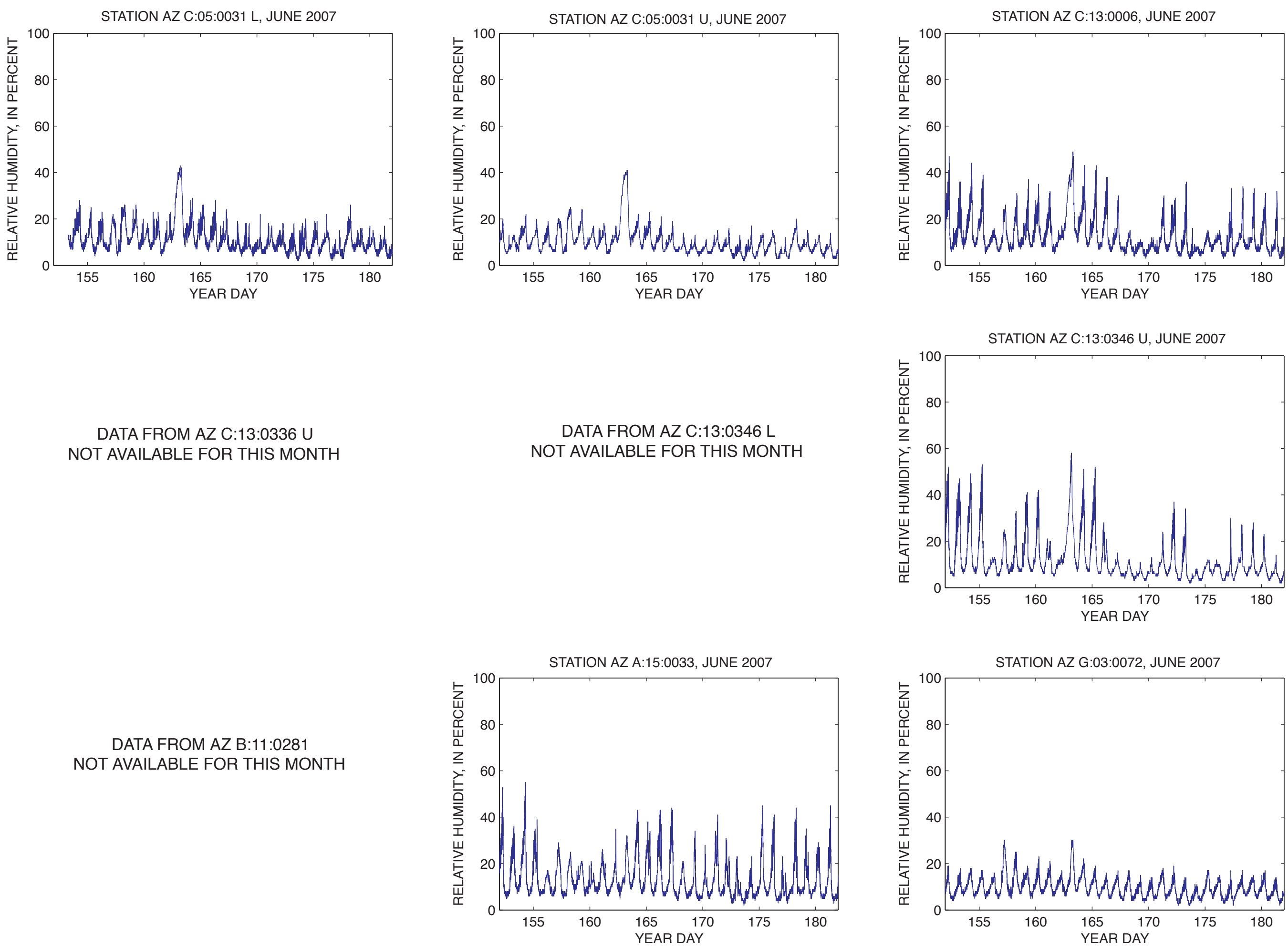

Figure 32. Relative humidity measured in June 2007 (year days 152–181) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Data are plotted as values averaged over each 4-minute sampling interval.

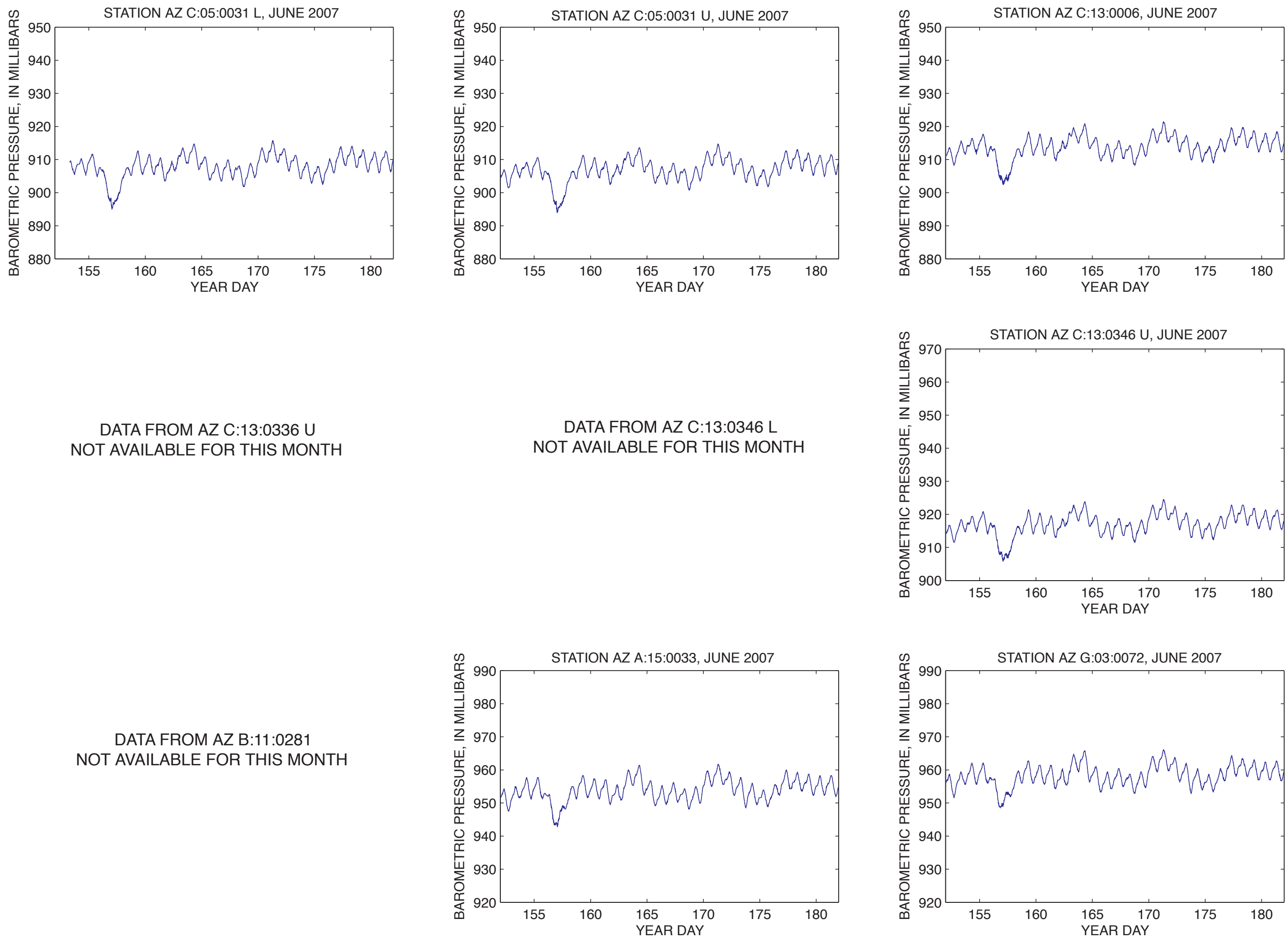

Figure 33. Barometric pressure measured in June 2007 (year days 152–181) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Data are plotted as values averaged over each 4-minute sampling interval.

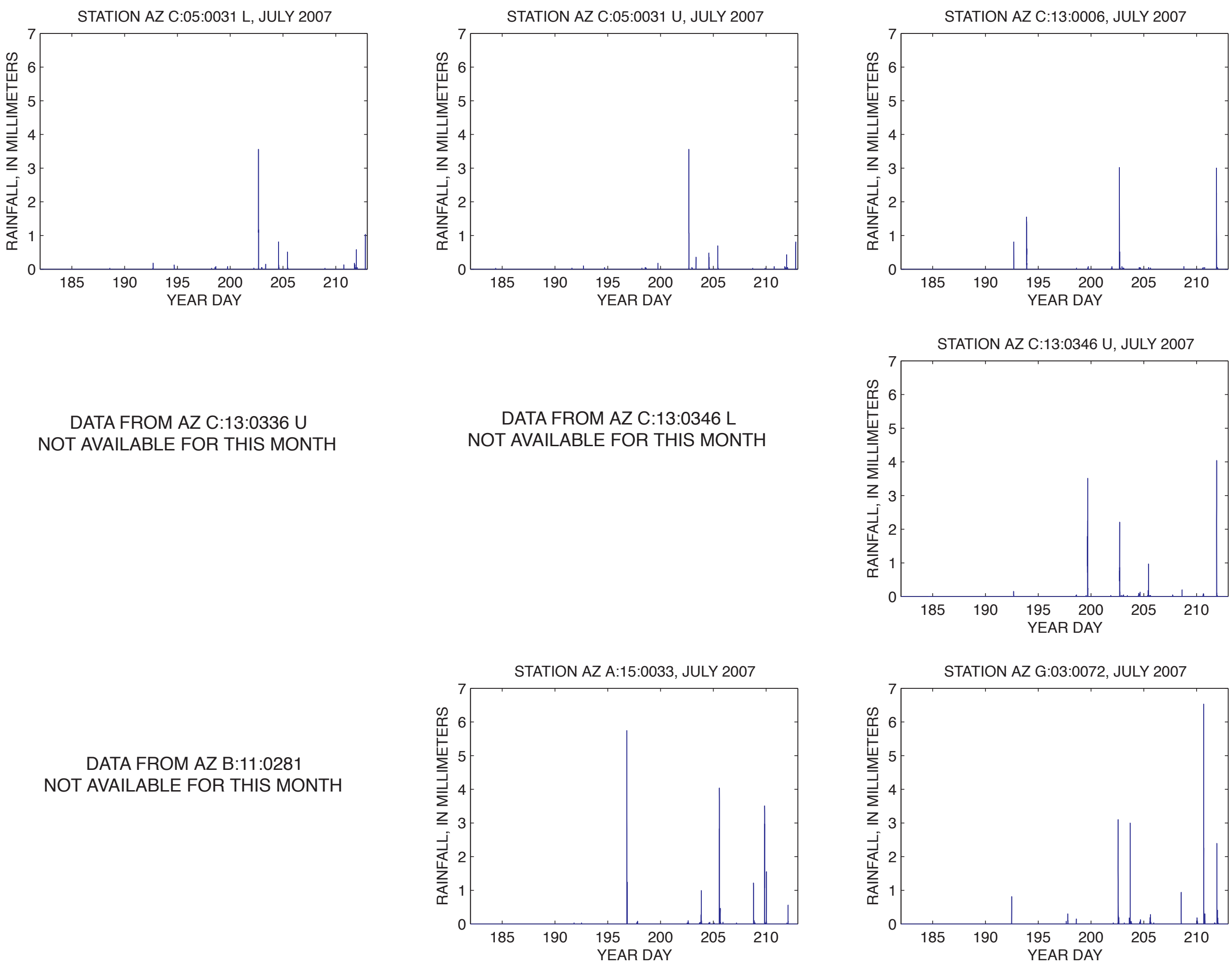

Figure 34. Rainfall measured in July 2007 (year days 182–212) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Data points represent total rainfall in each 4-minute sampling interval.

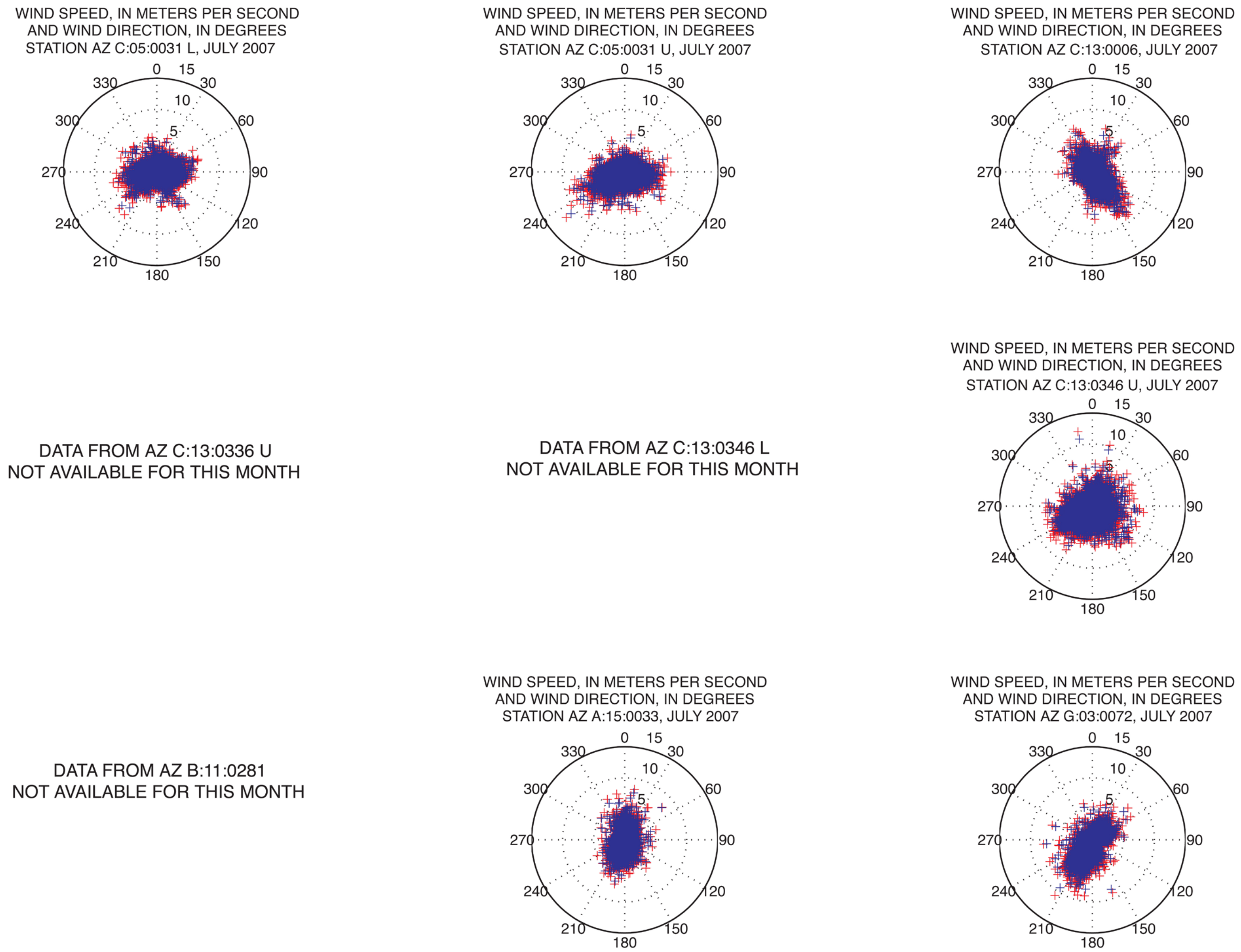

Figure 35. Magnitude and direction of wind velocity measured in July 2007 at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Each blue data point represents a 4-minute average; each red data point represents maximum gust recorded during each 4-minute sampling interval. Magnitude is indicated by the concentric circles, and compass bearing indicates direction from which the wind came.

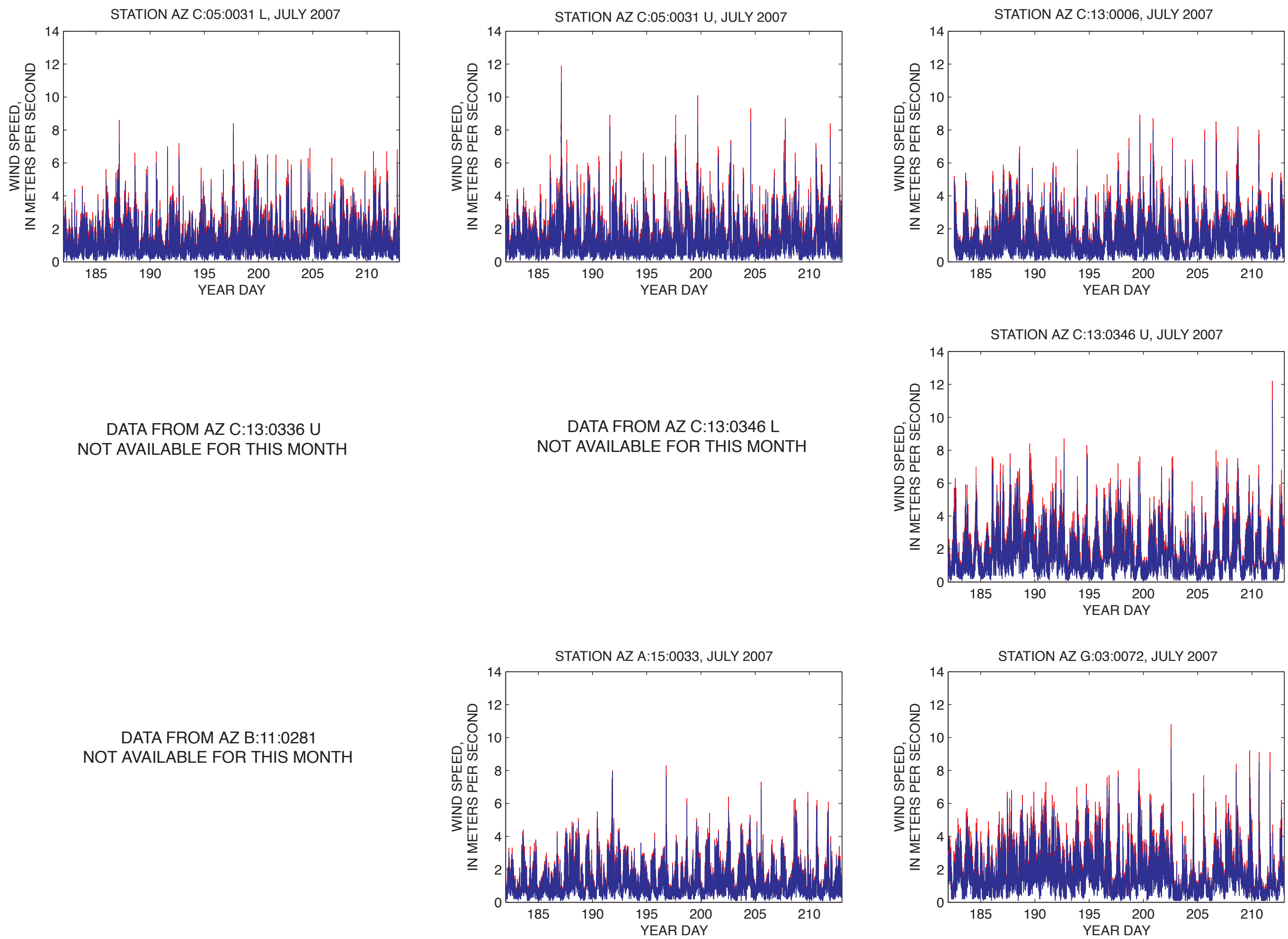

Figure 36. Wind speed measured in July 2007 (year days 182–212) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Blue data are values averaged over each 4-minute sampling interval; red data are maximum gusts recorded during each 4-minute sampling interval.

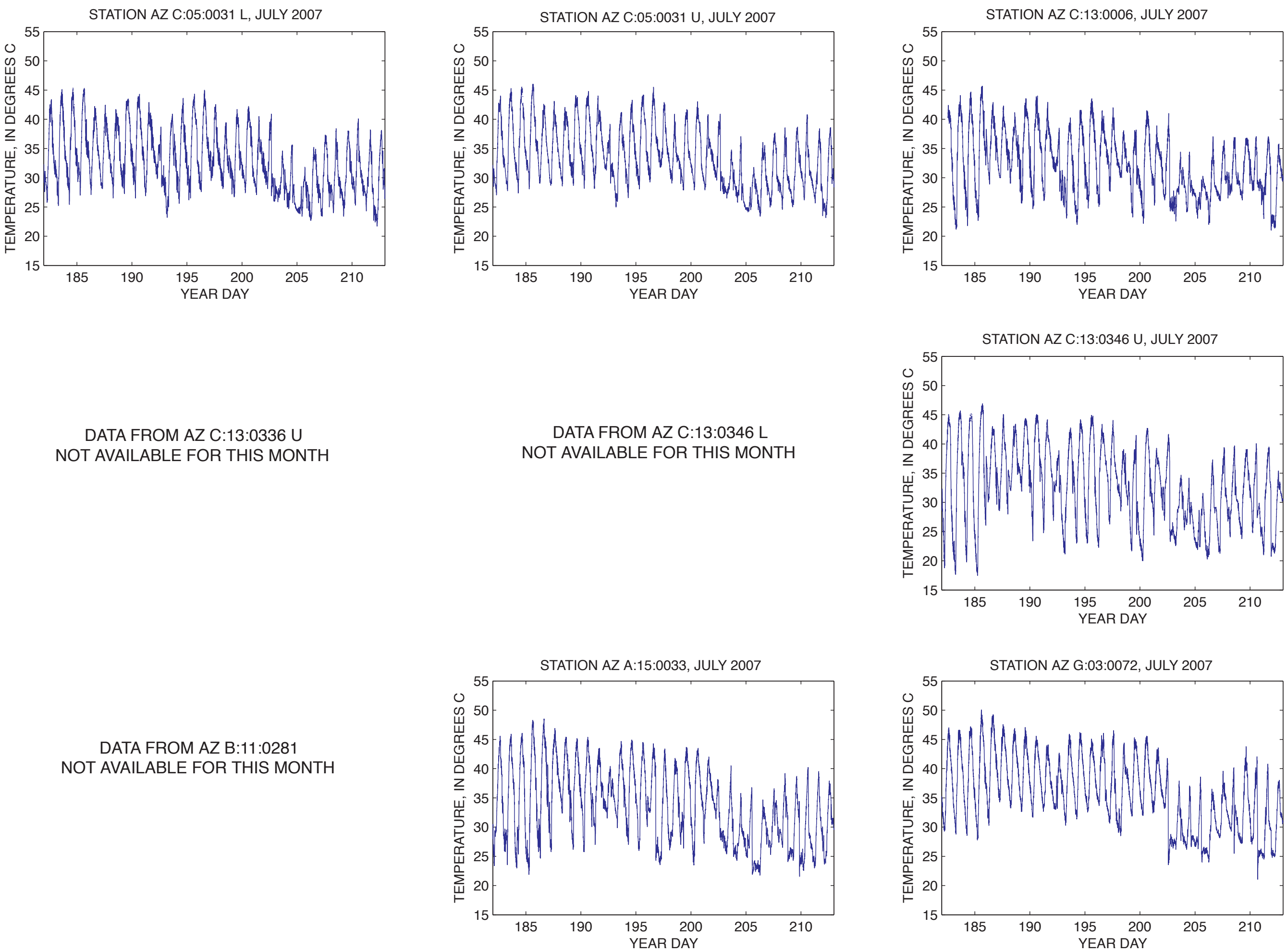

Figure 37. Air temperature measured in July 2007 (year days 182–212) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Data are plotted as values averaged over each 4-minute sampling interval.

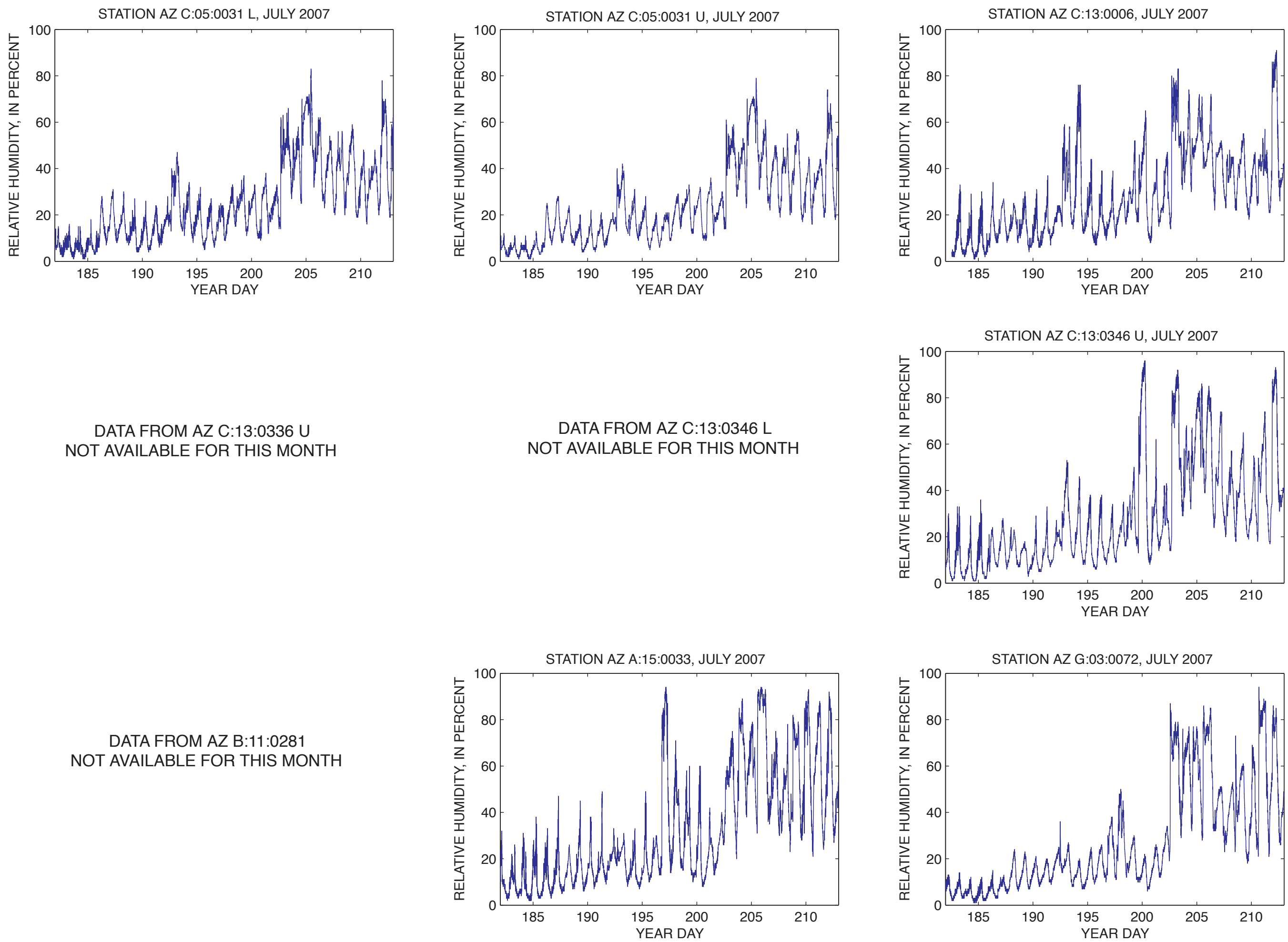

Figure 38. Relative humidity measured in July 2007 (year days 182–212) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Data are plotted as values averaged over each 4-minute sampling interval.

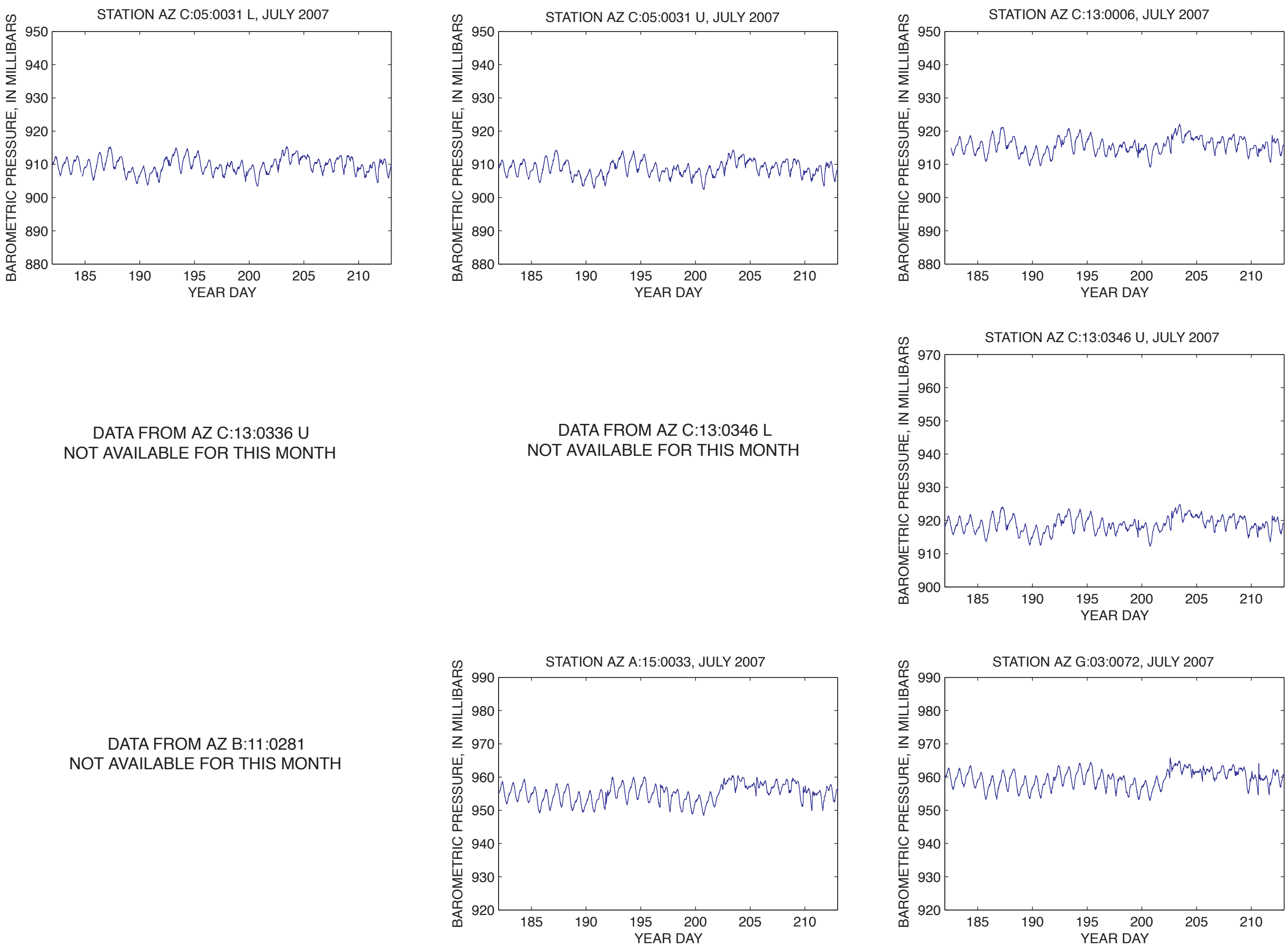

Figure 39. Barometric pressure measured in July 2007 (year days 182–212) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Data are plotted as values averaged over each 4-minute sampling interval.

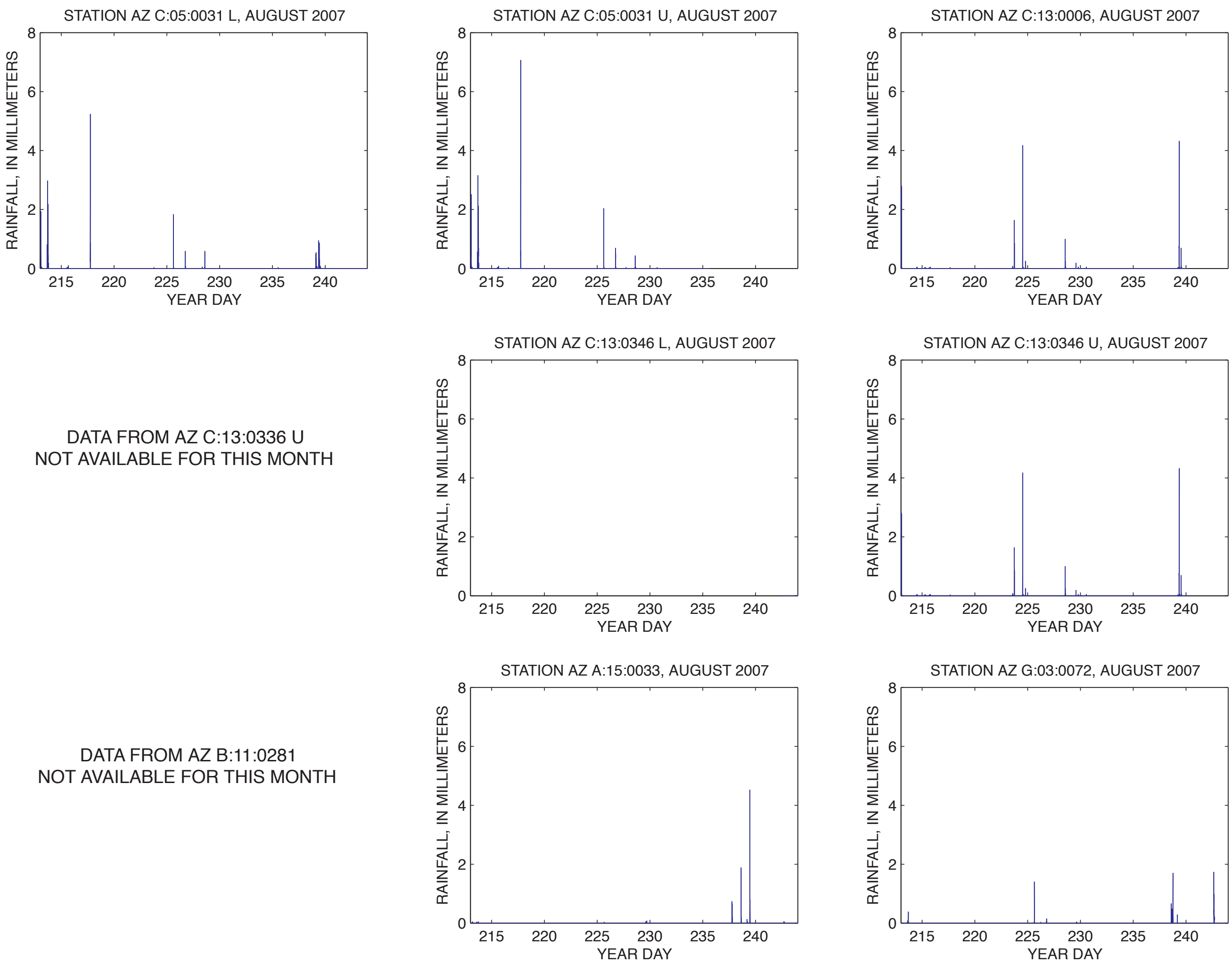

Figure 40. Rainfall measured in August 2007 (year days 213–243) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Data points represent total rainfall in each 4-minute sampling interval.

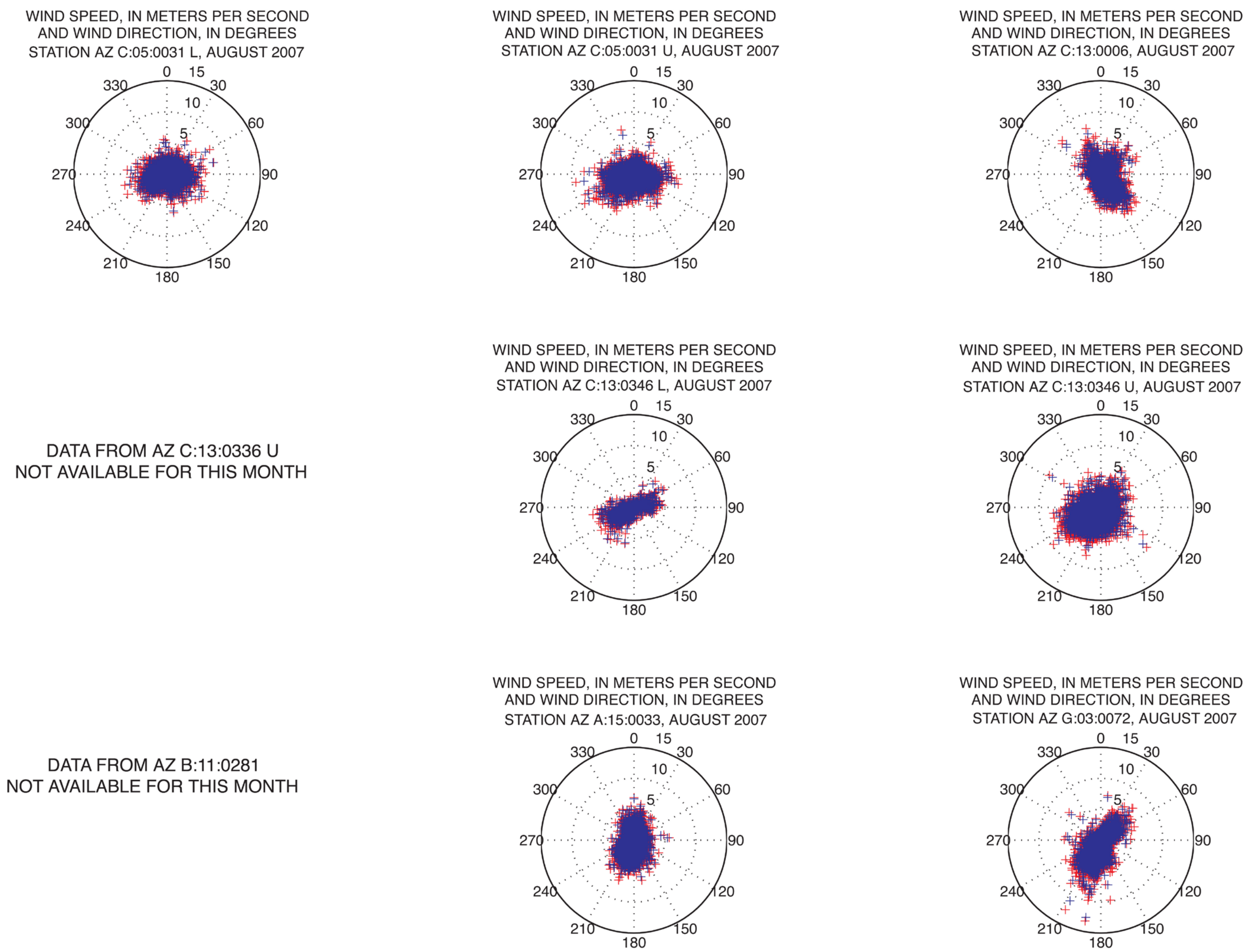

Figure 41. Magnitude and direction of wind velocity measured in August 2007 at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Each blue data point represents a 4-minute average; each red data point represents maximum gust recorded during each 4-minute sampling interval. Magnitude is indicated by the concentric circles, and compass bearing indicates direction from which the wind came.

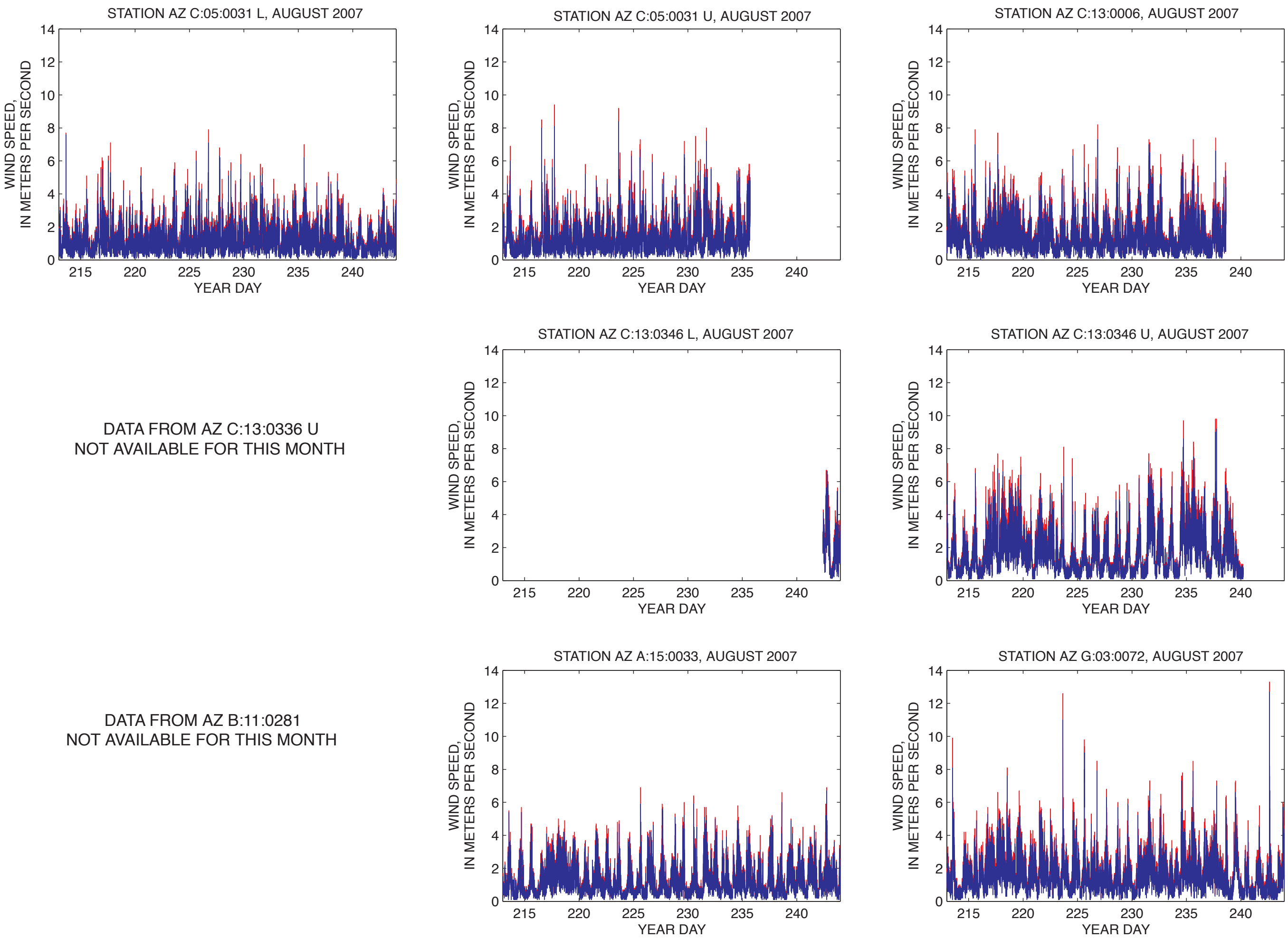

Figure 42. Wind speed measured in August 2007 (year days 213–243) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Blue data are values averaged over each 4-minute sampling interval; red data are maximum gusts recorded during each 4-minute sampling interval.

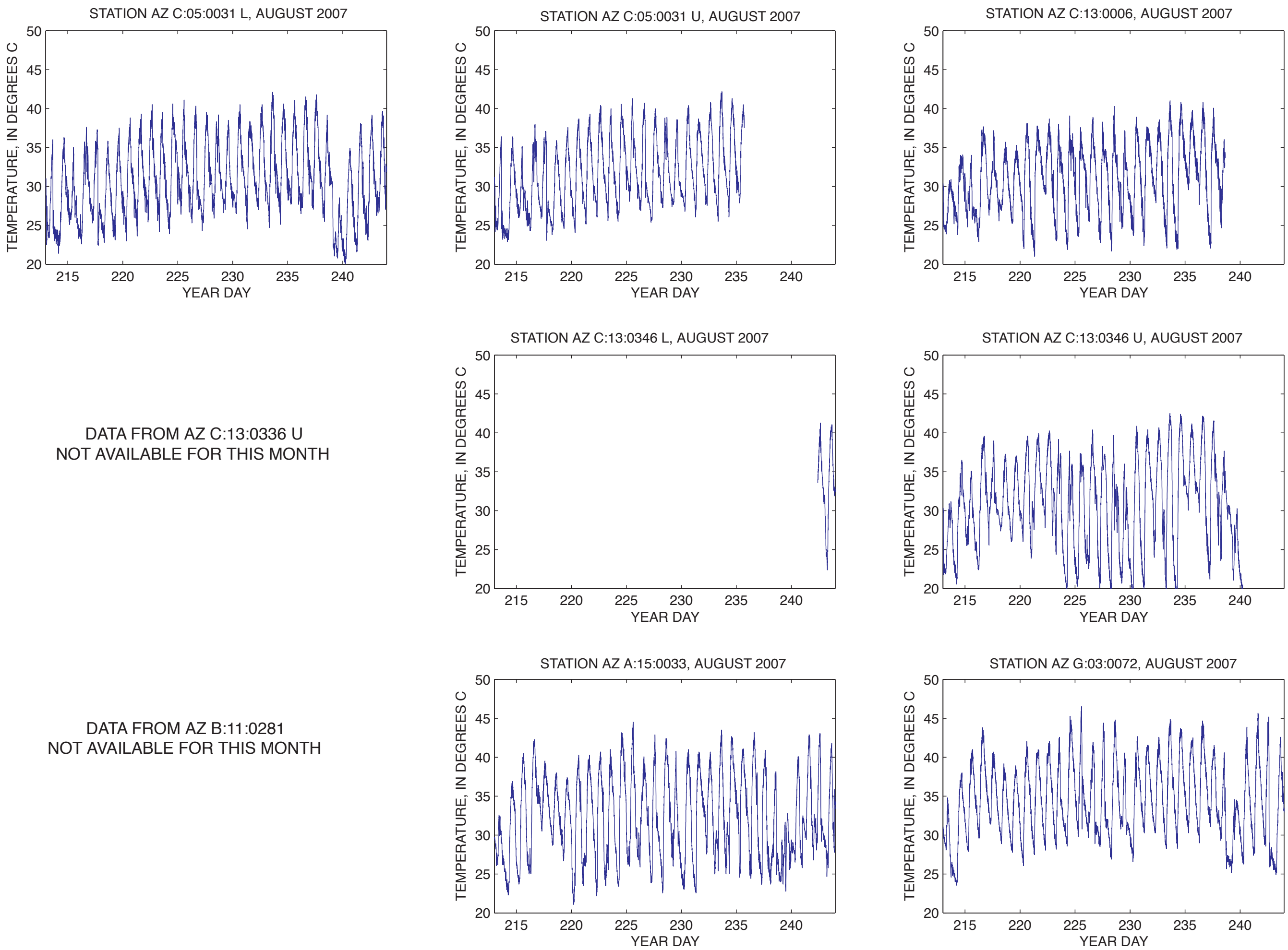

Figure 43. Air temperature measured in August 2007 (year days 213–243) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Data are plotted as values averaged over each 4-minute sampling interval.

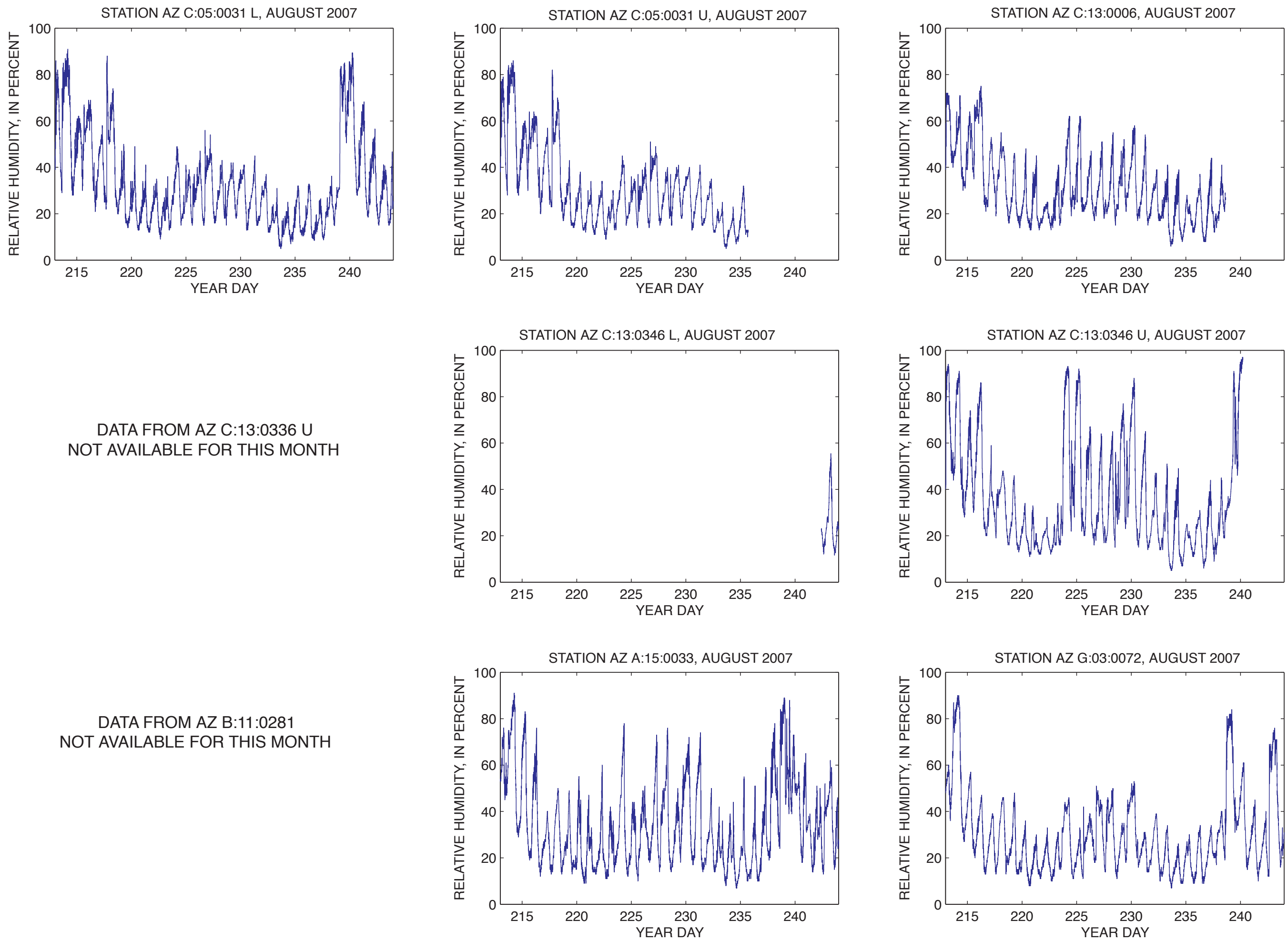

Figure 44. Relative humidity measured in August 2007 (year days 213–243) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Data are plotted as values averaged over each 4-minute sampling interval.

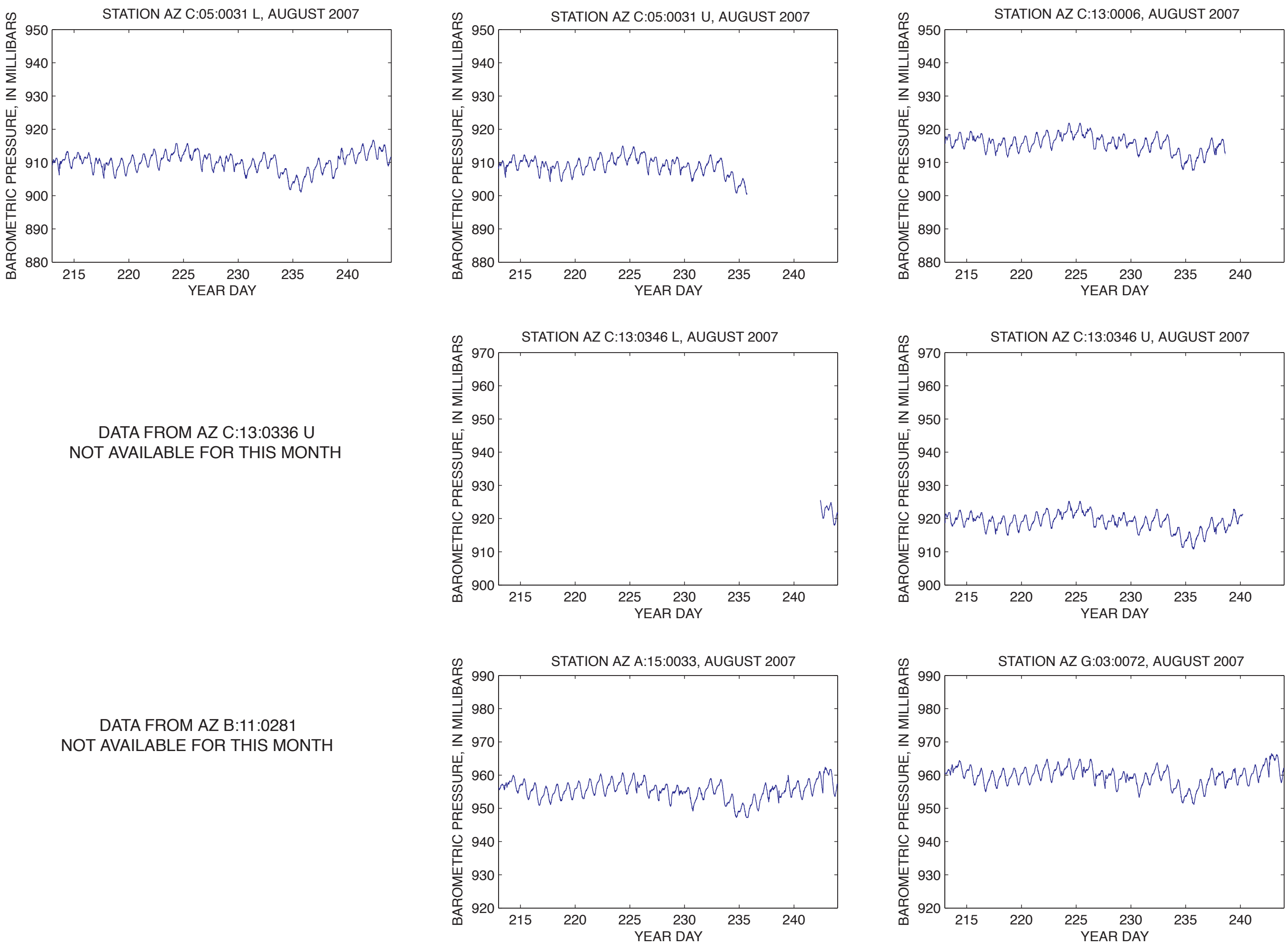

Figure 45. Barometric pressure measured in August 2007 (year days 213–243) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Data are plotted as values averaged over each 4-minute sampling interval.

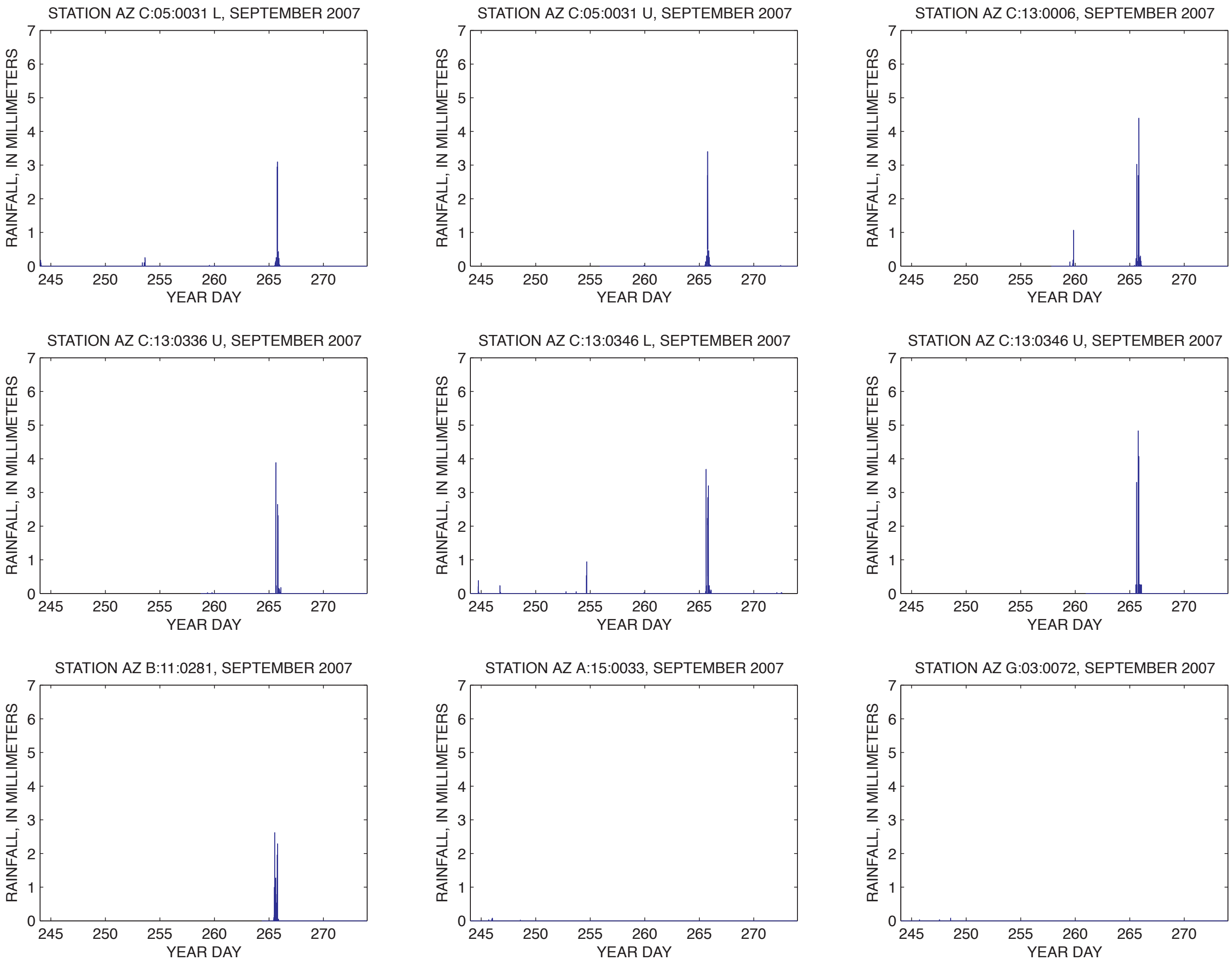

Figure 46. Rainfall measured in September 2007 (year days 244–273) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Data points represent total rainfall in each 4-minute sampling interval.

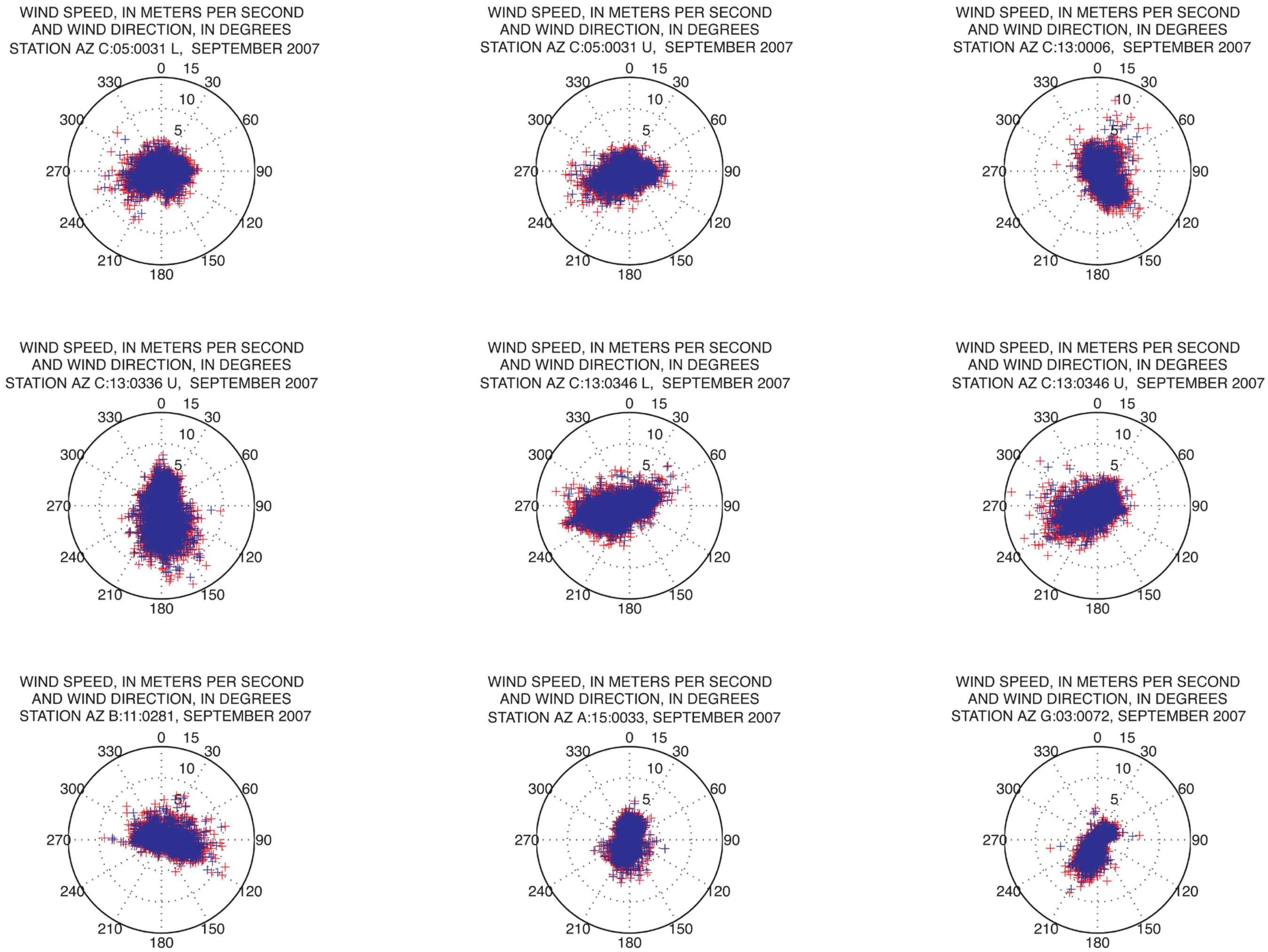

Figure 47. Magnitude and direction of wind velocity measured in September 2007 at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Each blue data point represents a 4-minute average; each red data point represents maximum gust recorded during each 4-minute sampling interval. Magnitude is indicated by the concentric circles, and compass bearing indicates direction from which the wind came.

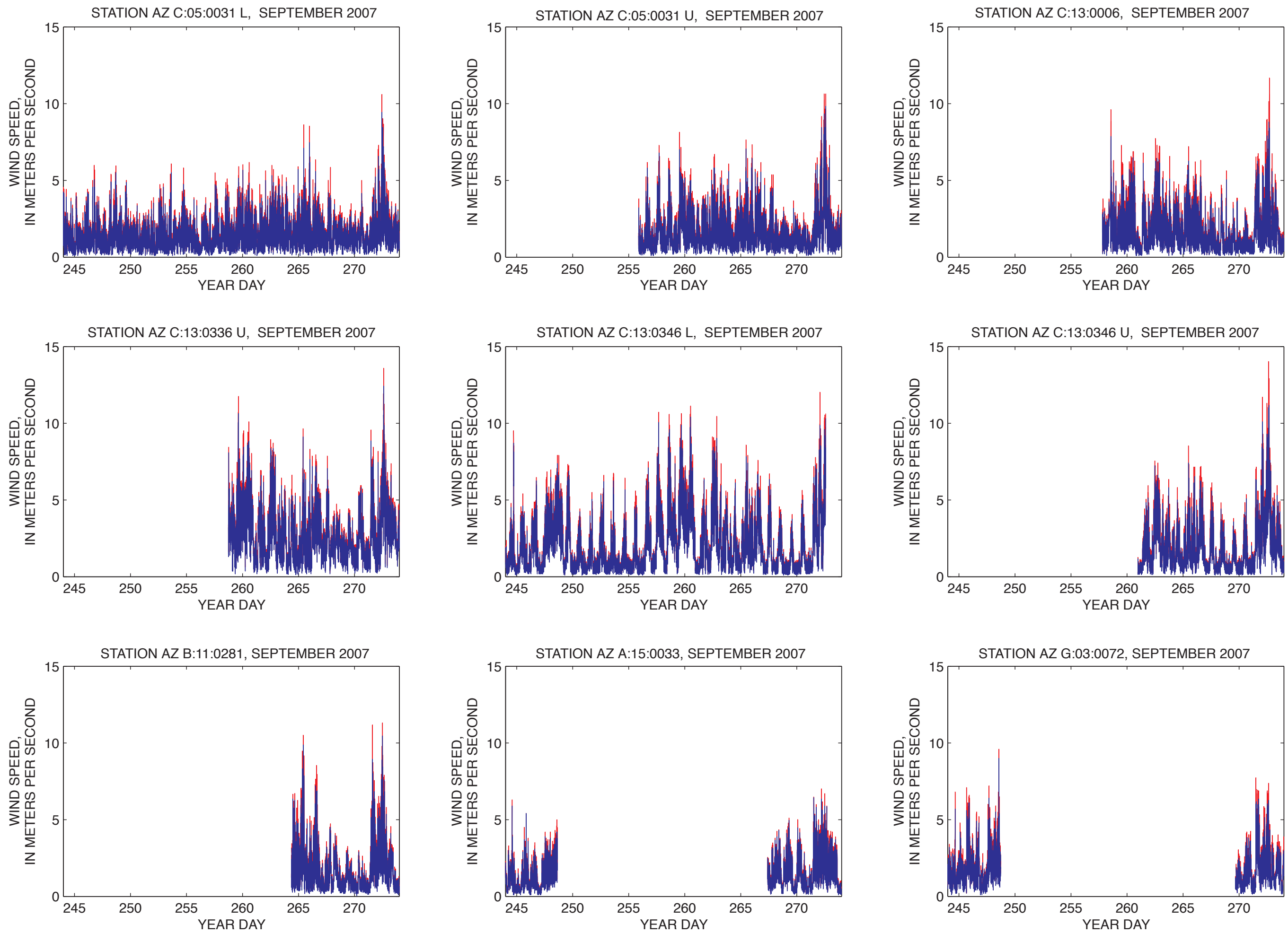

Figure 48. Wind speed measured in September 2007 (year days 244–273) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Blue data are values averaged over each 4-minute sampling interval; red data are maximum gusts recorded during each 4-minute sampling interval.

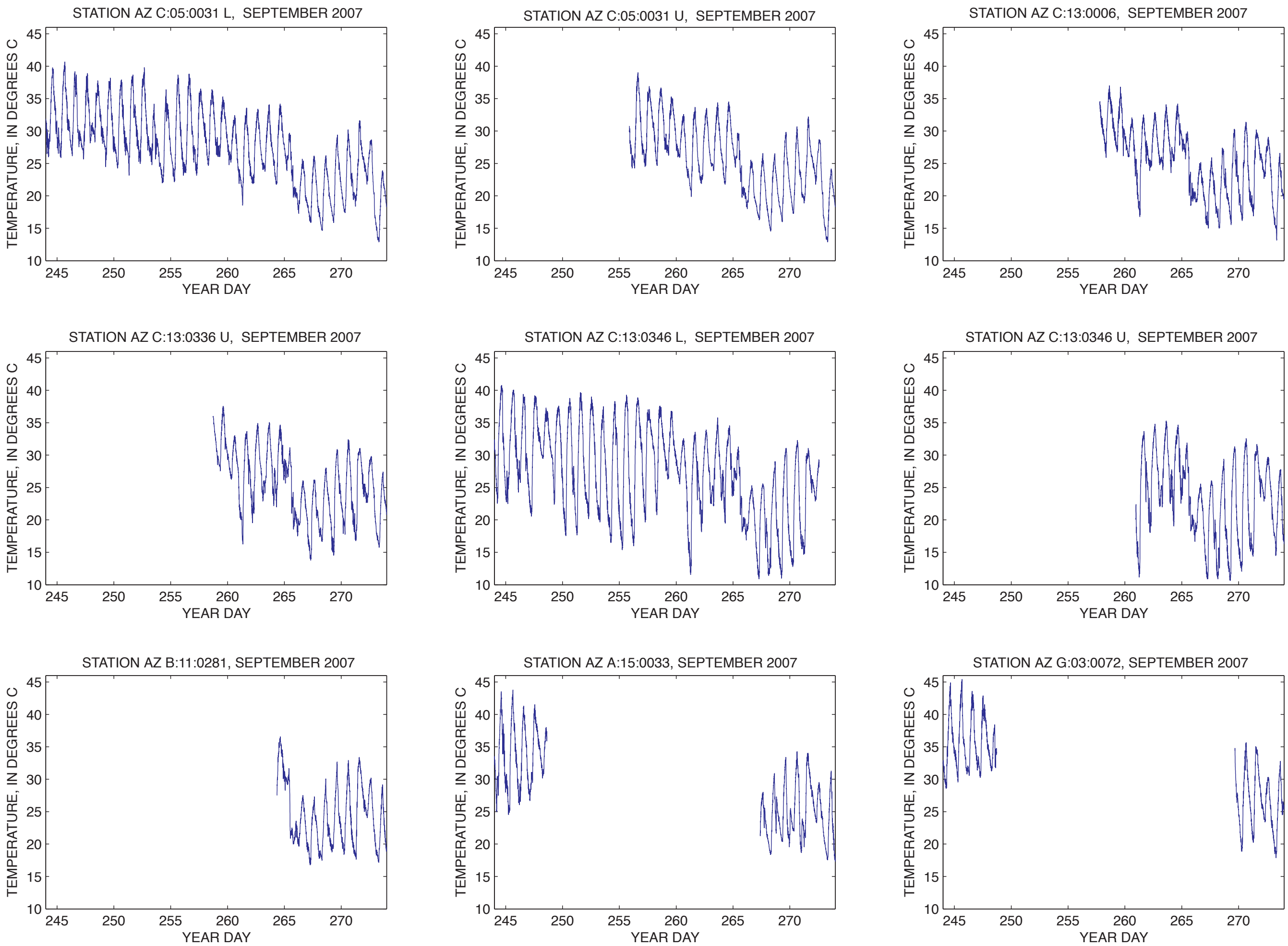

Figure 49. Air temperature measured in September 2007 (year days 244–273) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Data are plotted as values averaged over each 4-minute sampling interval.

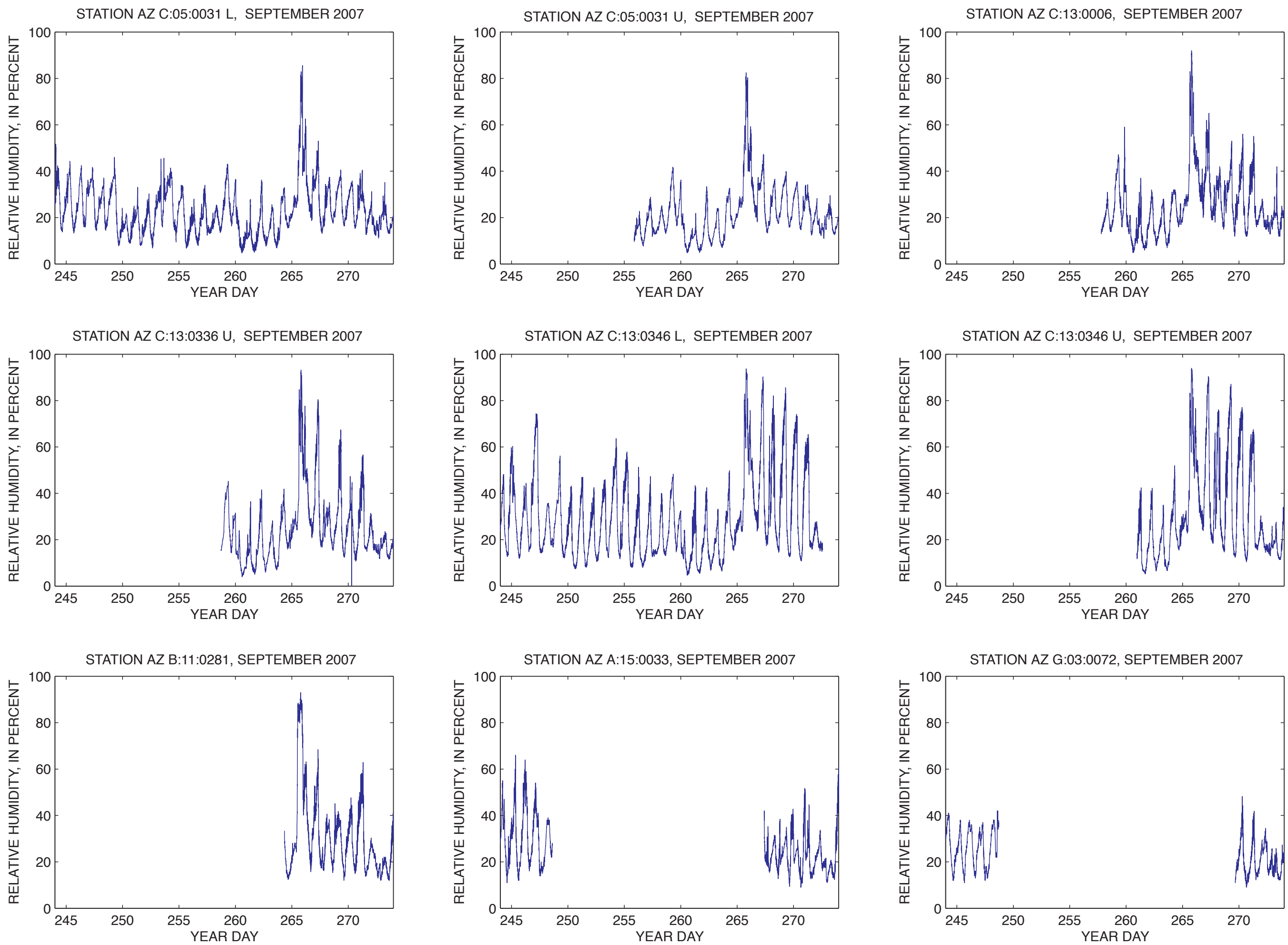

Figure 50. Relative humidity measured in September 2007 (year days 244–273) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Data are plotted as values averaged over each 4-minute sampling interval.

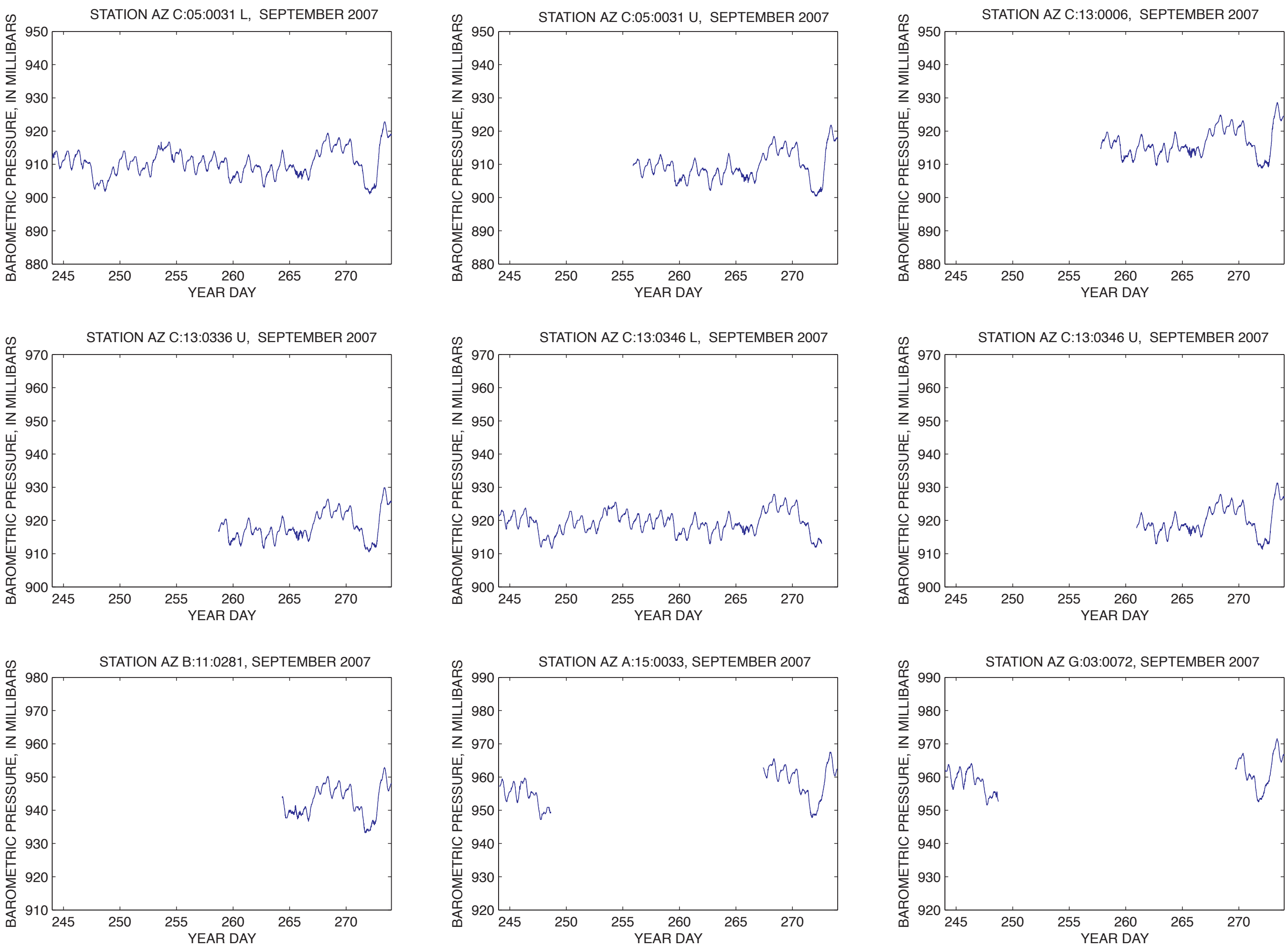

Figure 51. Barometric pressure measured in September 2007 (year days 244–273) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Data are plotted as values averaged over each 4-minute sampling interval.

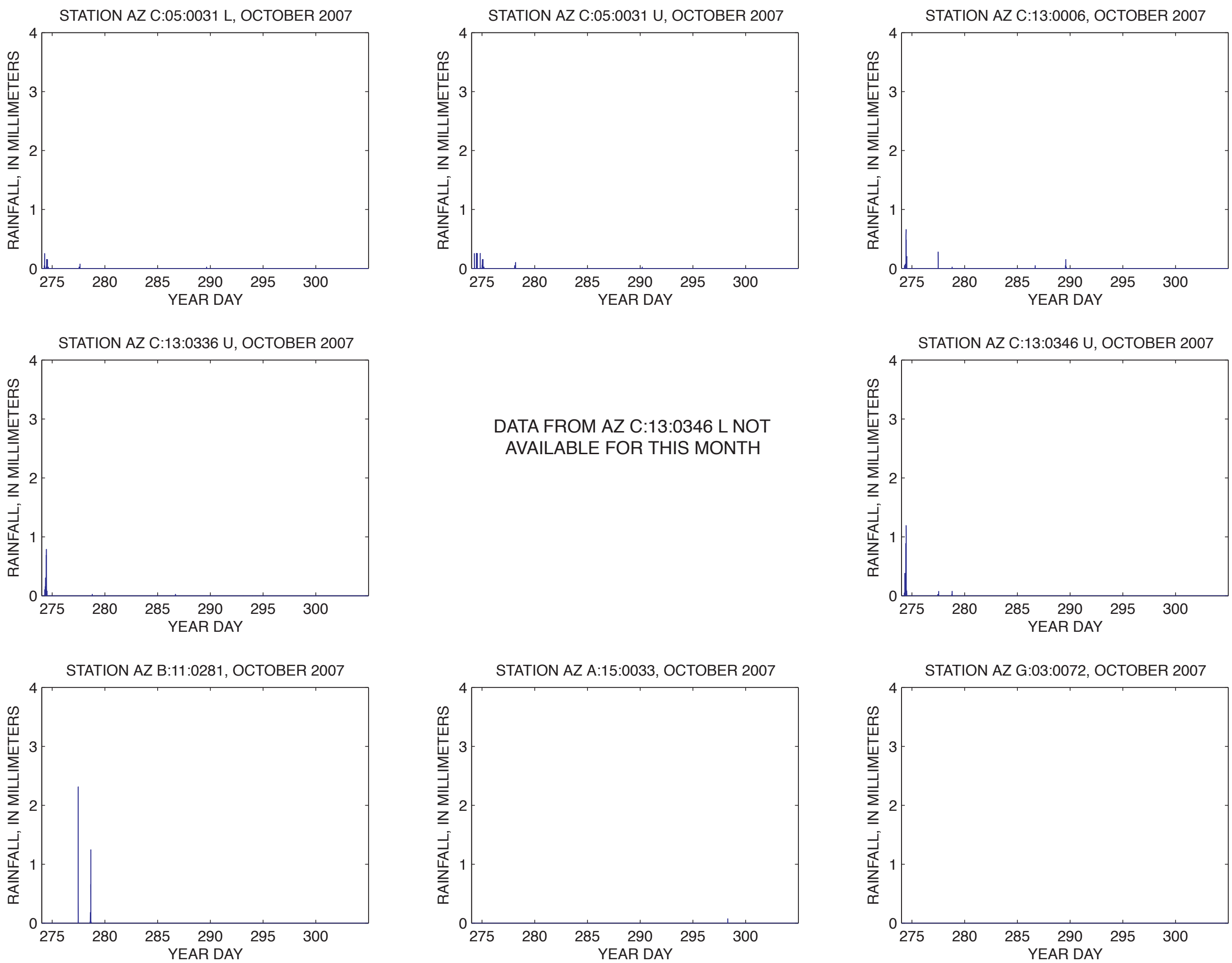

Figure 52. Rainfall measured in October 2007 (year days 274–304) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Data points represent total rainfall in each 4-minute sampling interval.

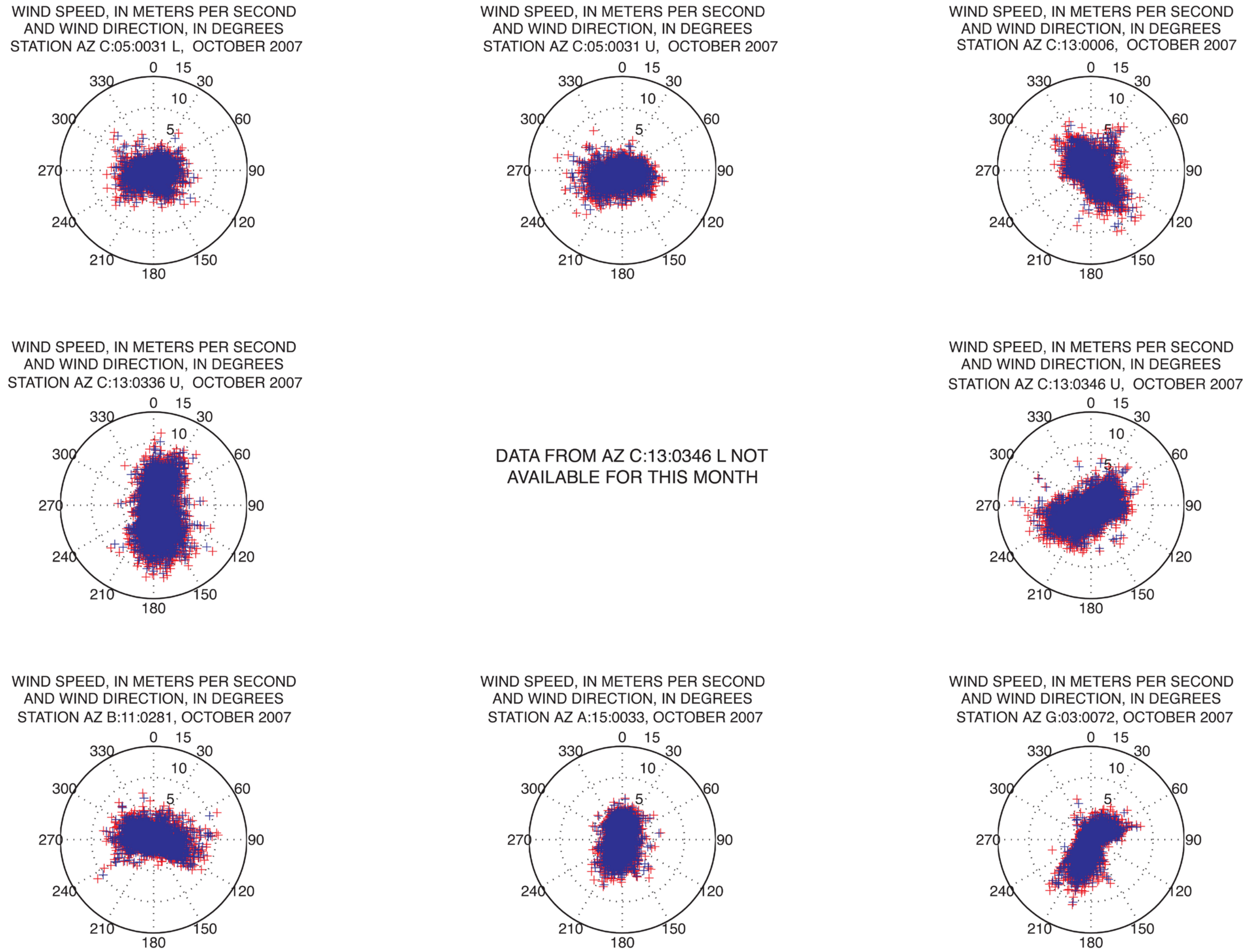

Figure 53. Magnitude and direction of wind velocity measured in October 2007 at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Each blue data point represents a 4-minute average; each red data point represents maximum gust recorded during each 4-minute sampling interval. Magnitude is indicated by the concentric circles, and compass bearing indicates direction from which the wind came.

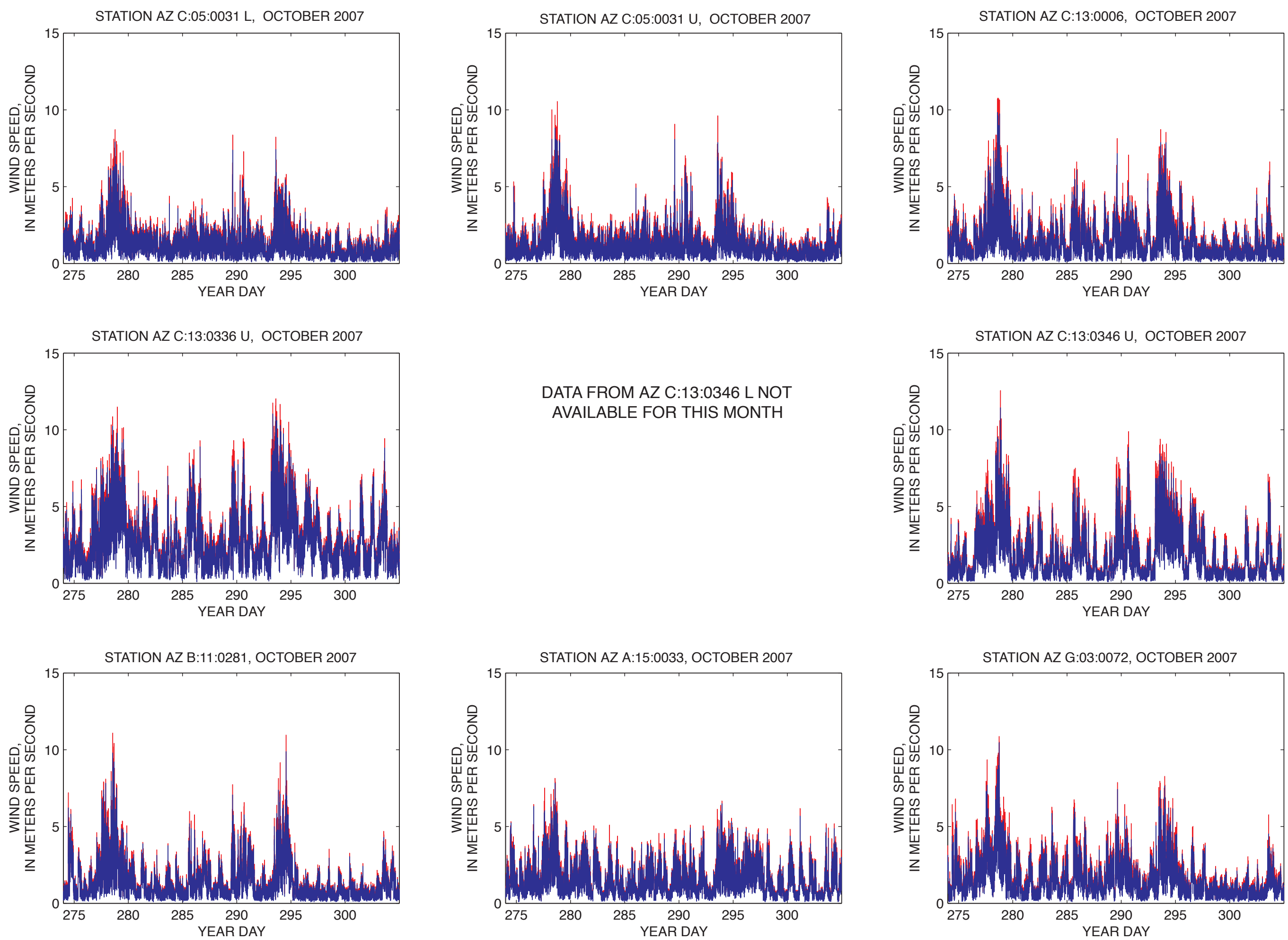

Figure 54. Wind speed measured in October 2007 (year days 274–304) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Blue data are values averaged over each 4-minute sampling interval; red data are maximum gusts recorded during each 4-minute sampling interval.

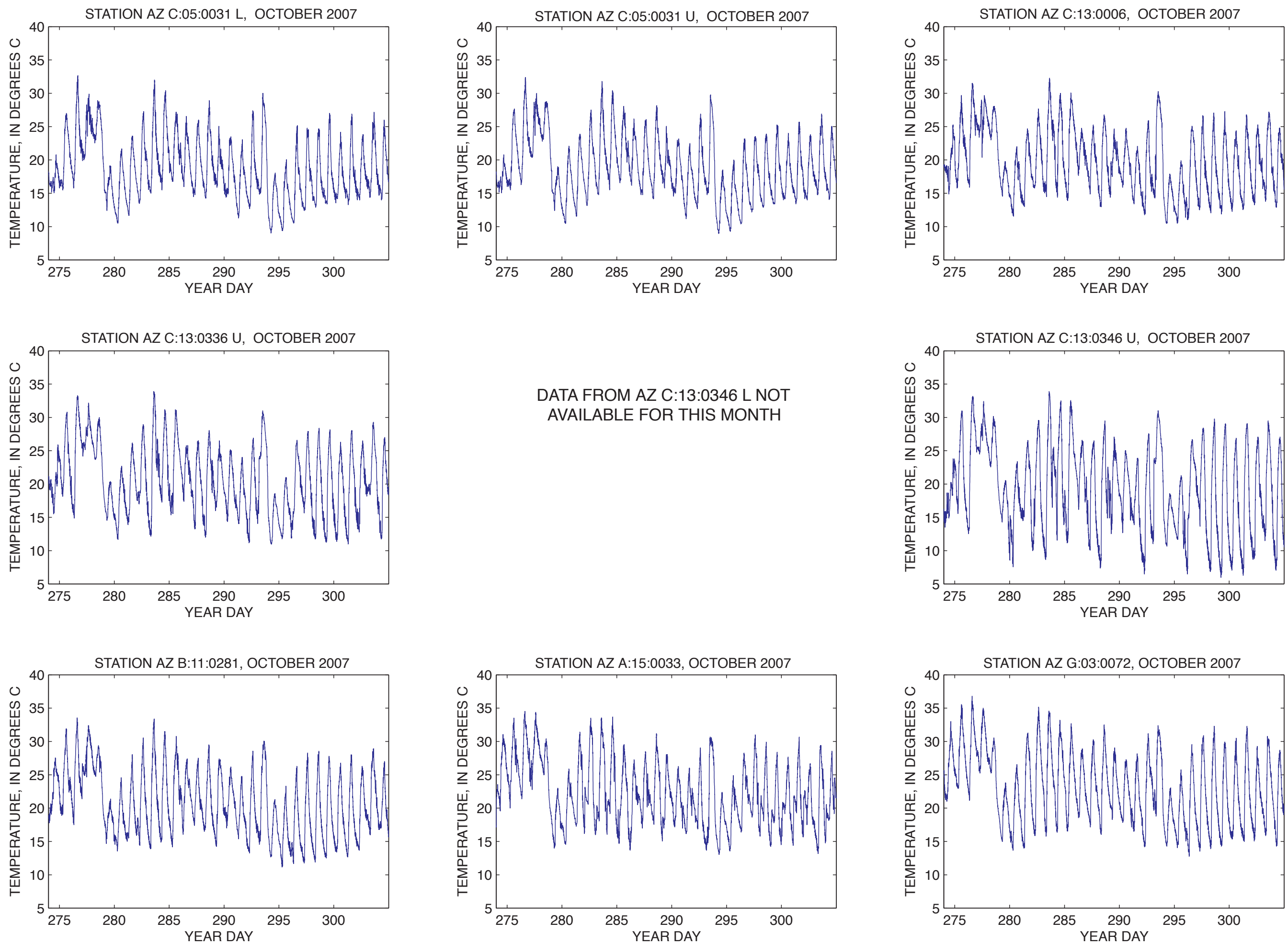

Figure 55. Air temperature measured in October 2007 (year days 274–304) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Data are plotted as values averaged over each 4-minute sampling interval.

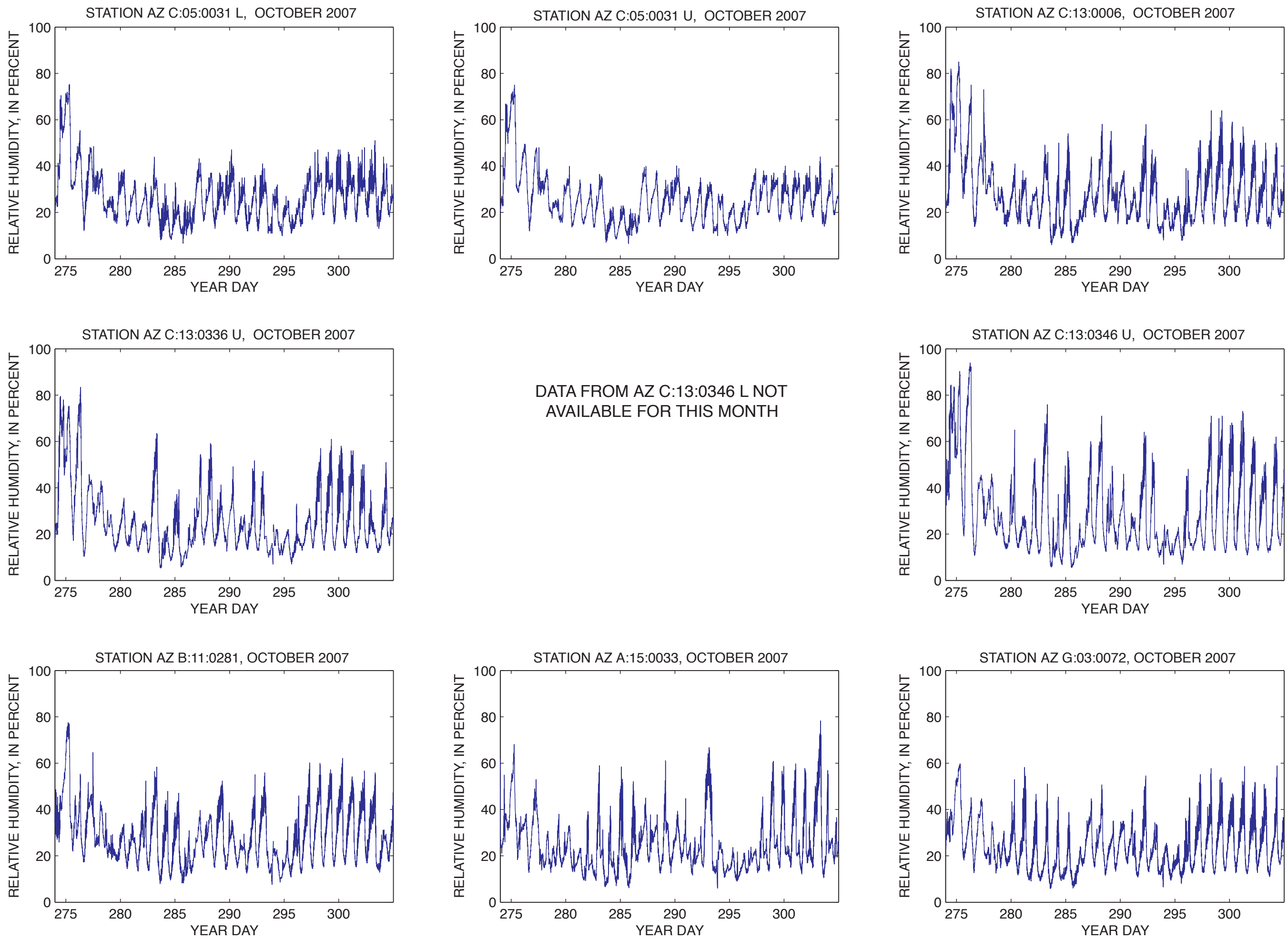

Figure 56. Relative humidity measured in October 2007 (year days 274–304) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Data are plotted as values averaged over each 4-minute sampling interval.

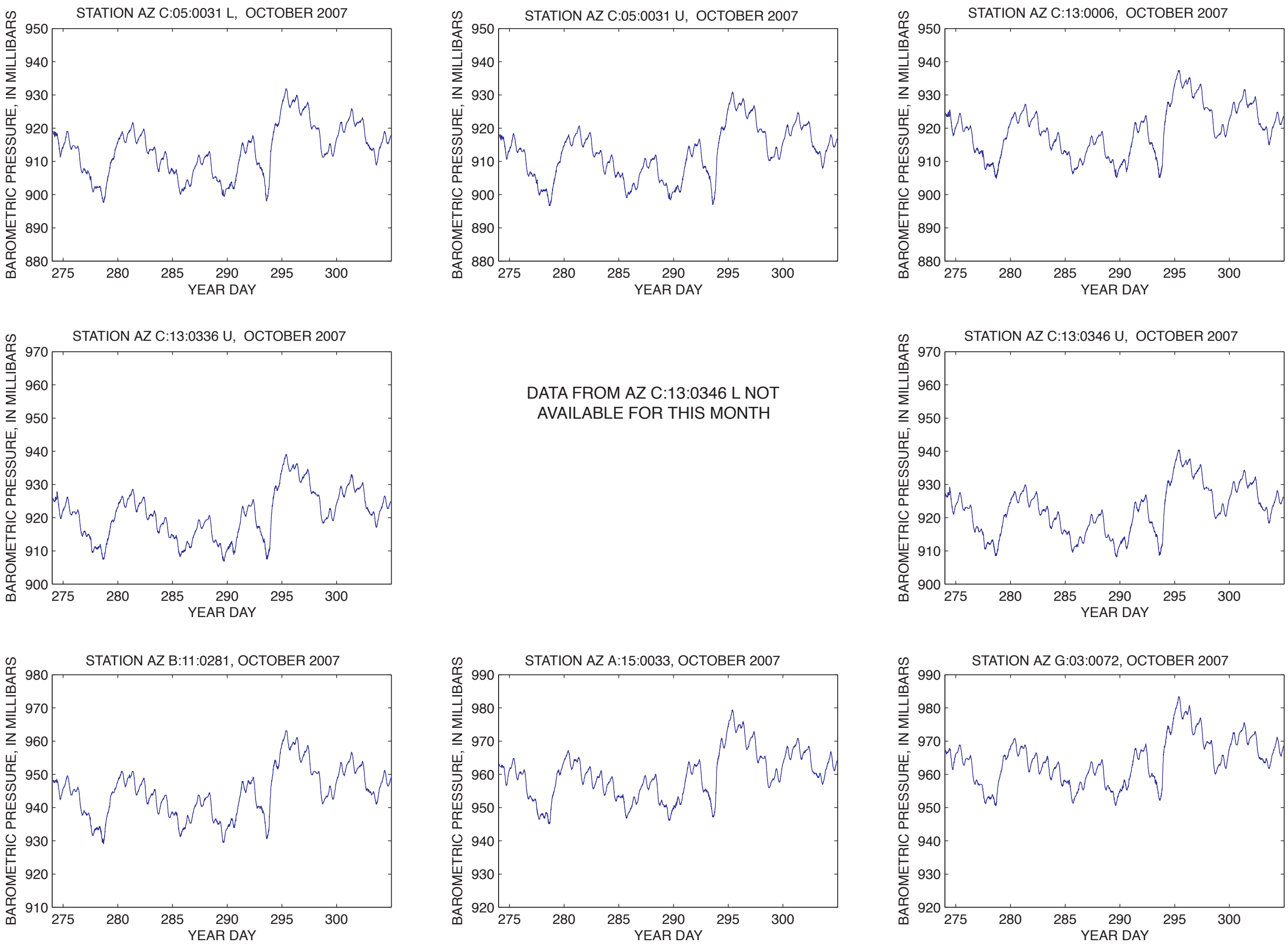

Figure 57. Barometric pressure measured in October 2007 (year days 274–304) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Data are plotted as values averaged over each 4-minute sampling interval.

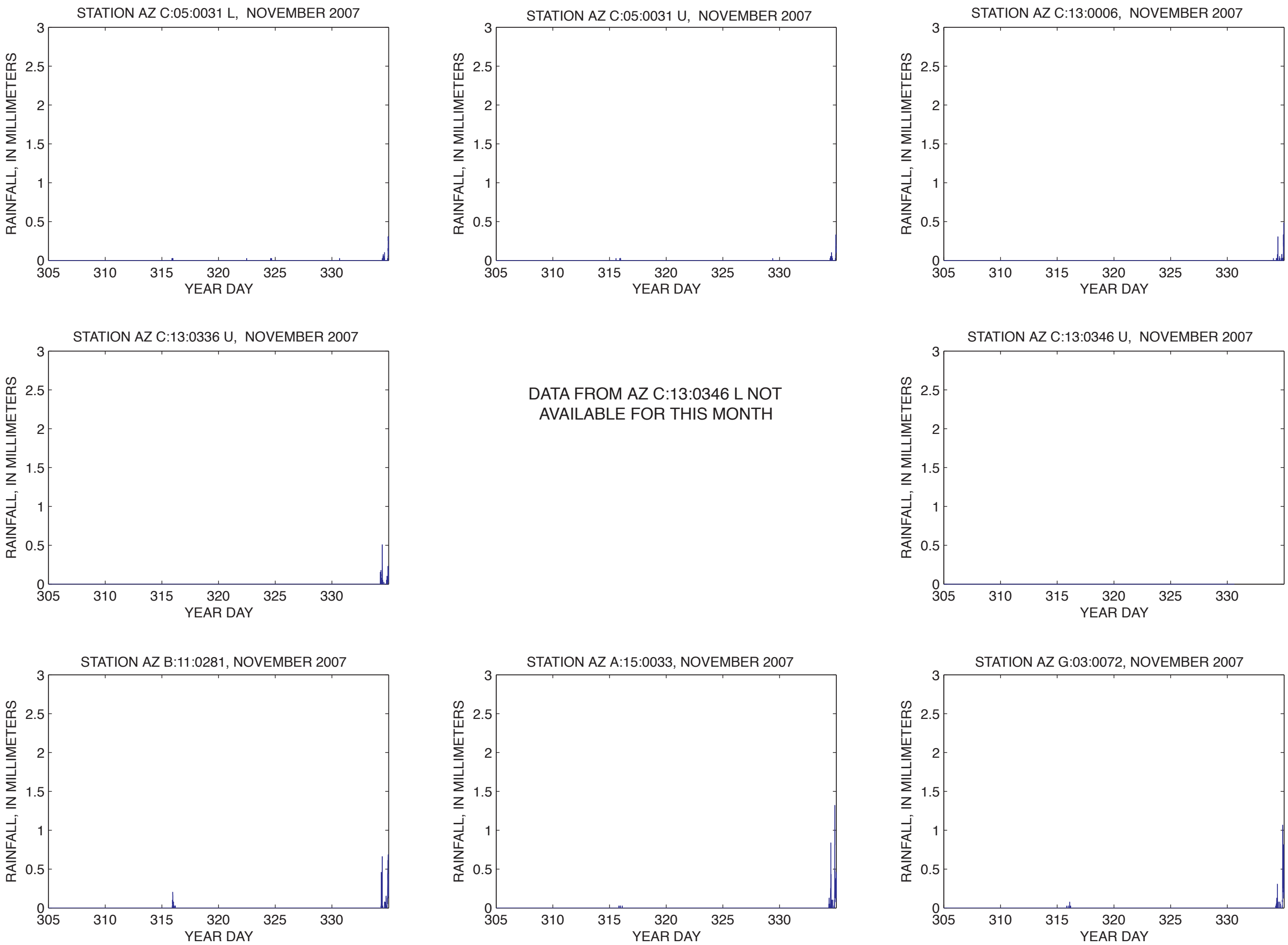

Figure 58. Rainfall measured in November 2007 (year days 305–334) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Data points represent total rainfall in each 4-minute sampling interval.

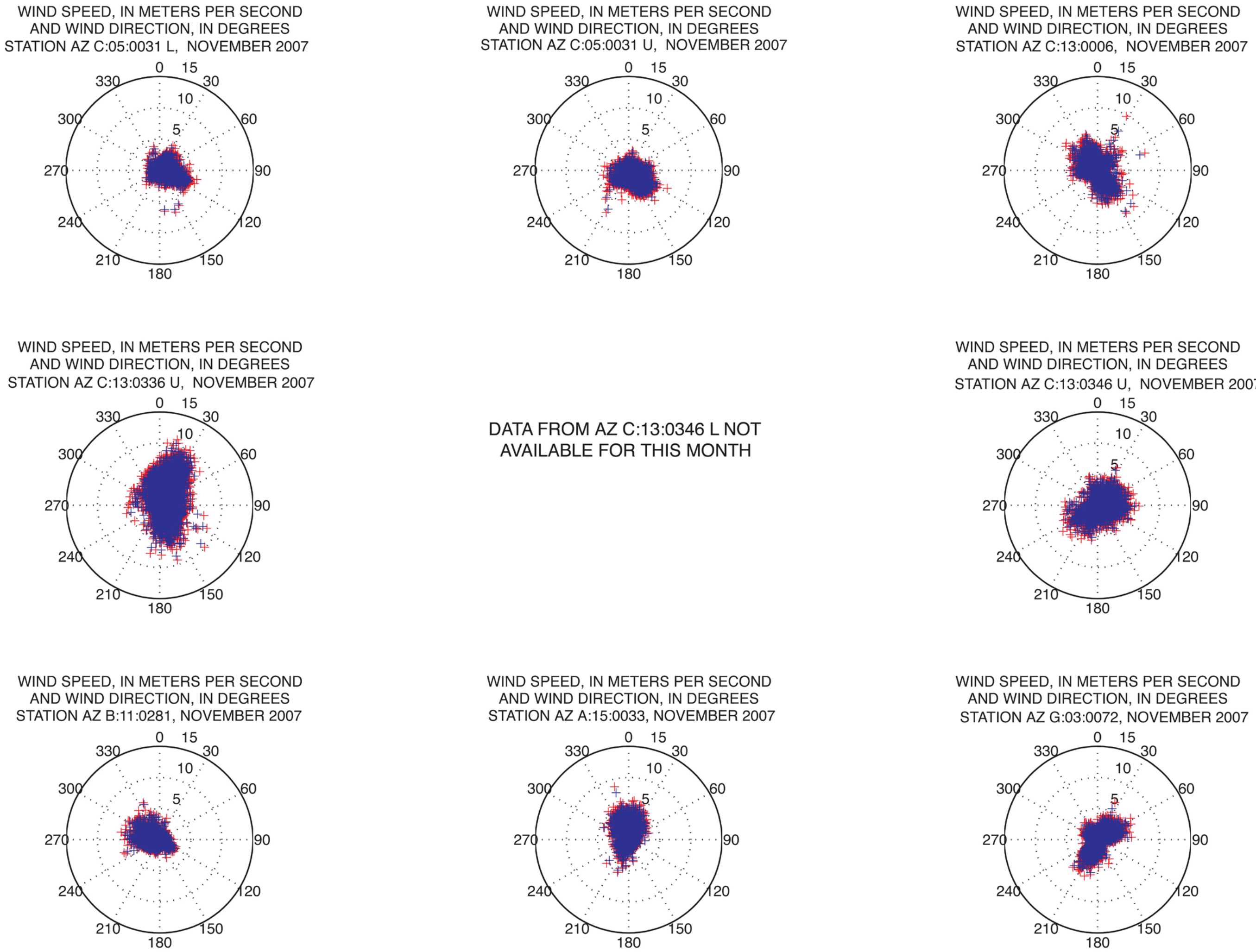

Figure 59. Magnitude and direction of wind velocity measured in November 2007 at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Each blue data point represents a 4-minute average; each red data point represents maximum gust recorded during each 4-minute sampling interval. Magnitude is indicated by the concentric circles, and compass bearing indicates direction from which the wind came.

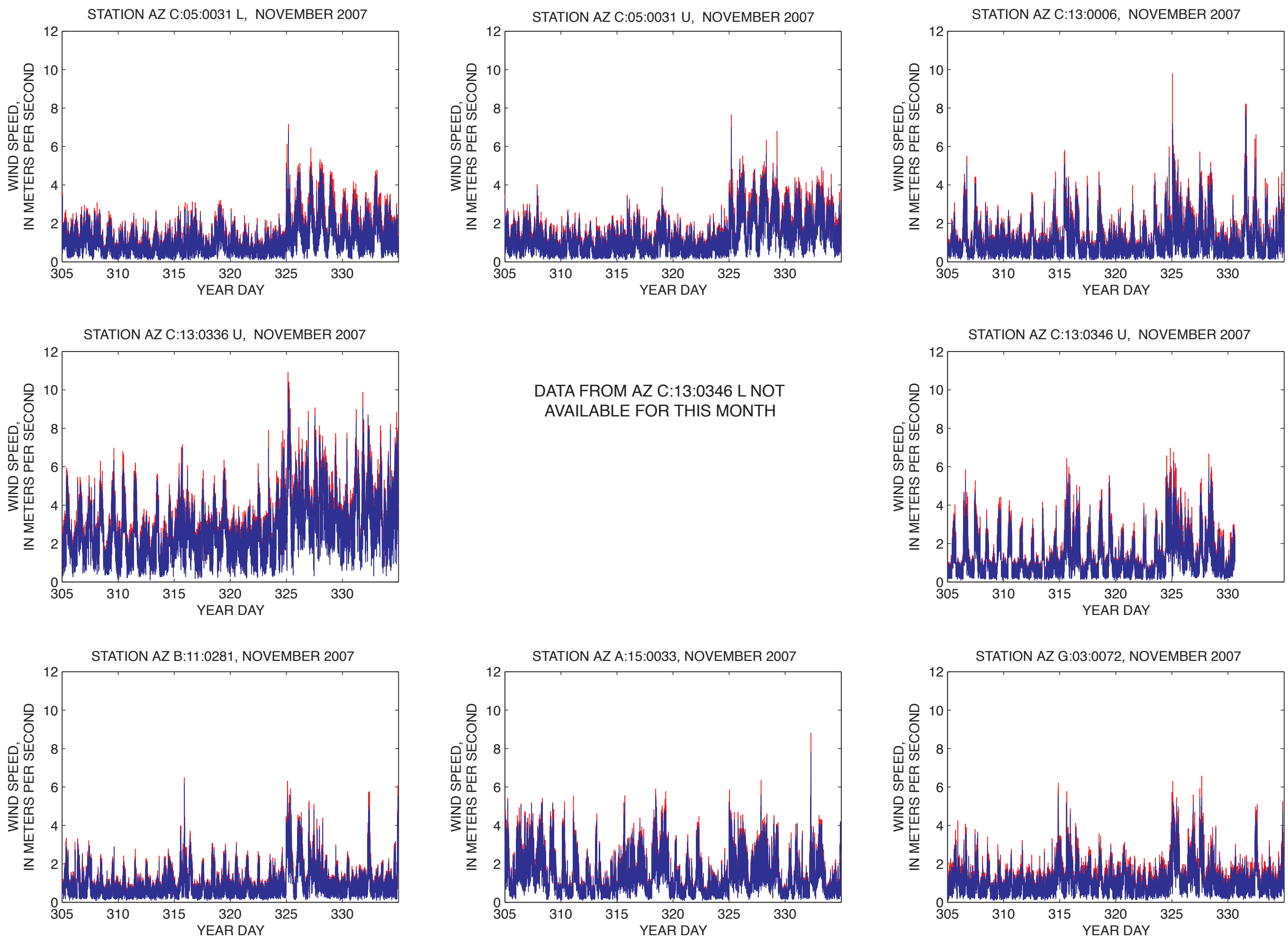

Figure 60. Wind speed measured in November 2007 (year days 305–334) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Blue data are values averaged over each 4-minute sampling interval; red data are maximum gusts recorded during each 4-minute sampling interval.

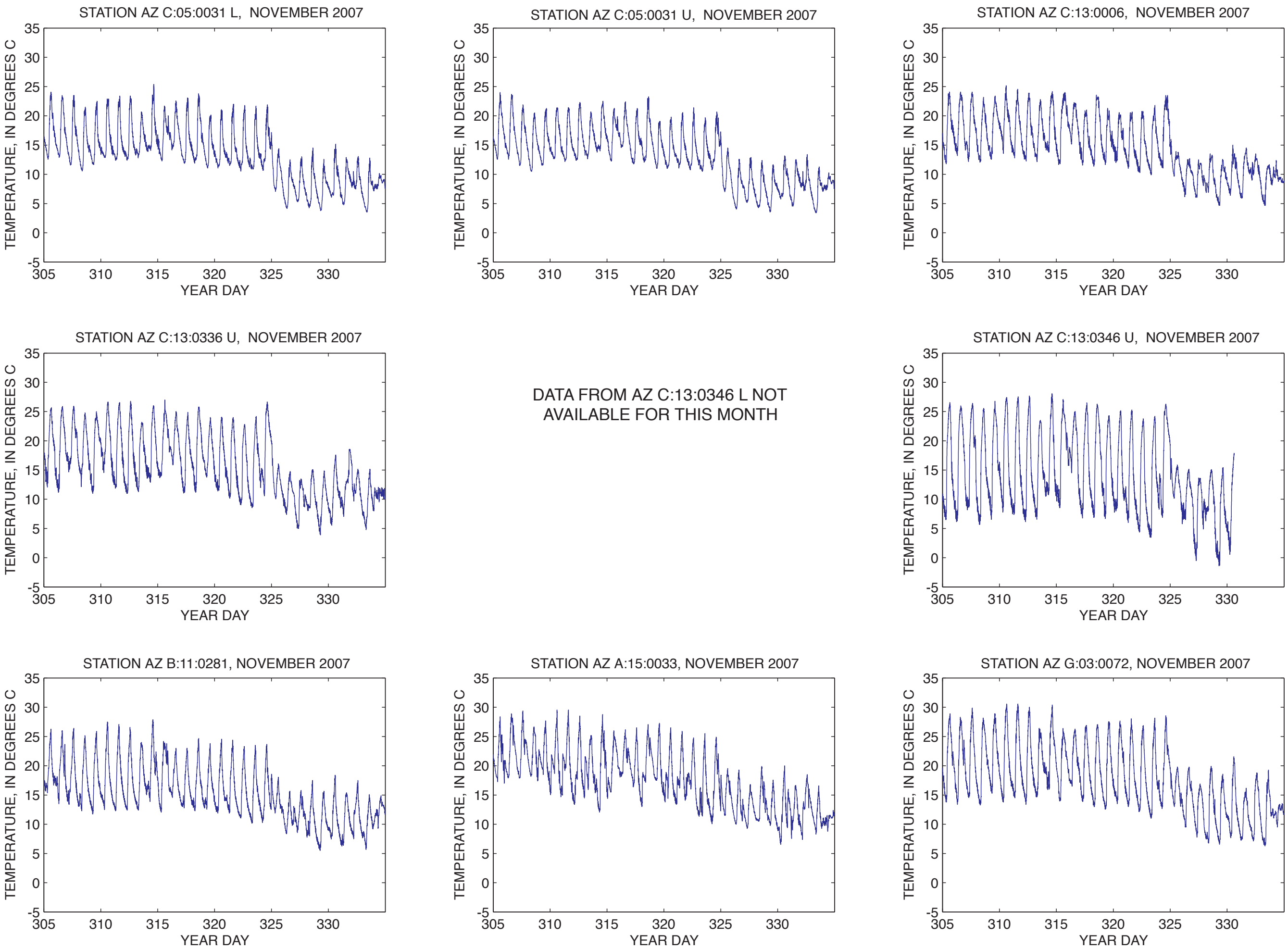

Figure 61. Air temperature measured in November 2007 (year days 305–334) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Data are plotted as values averaged over each 4-minute sampling interval.

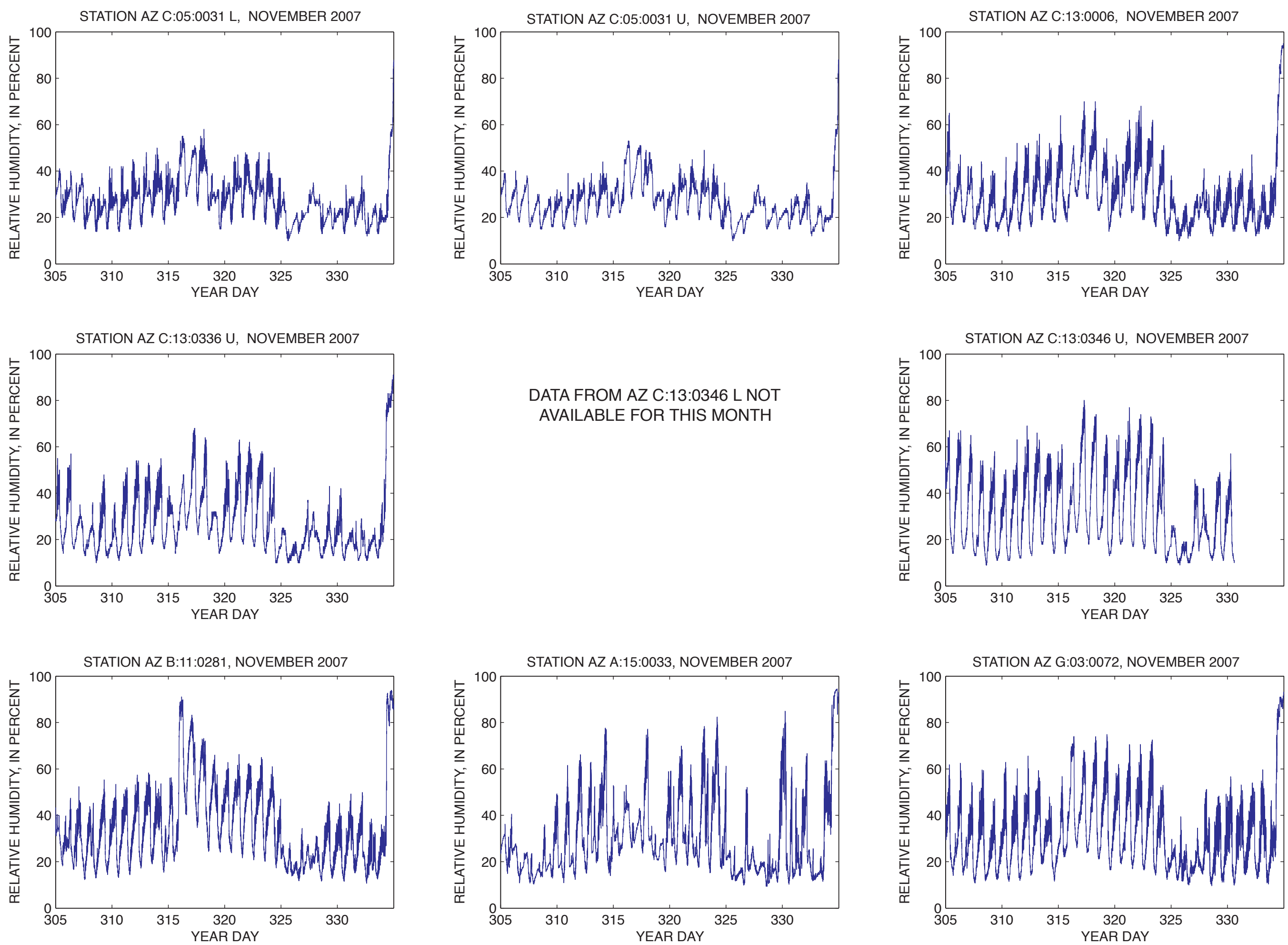

Figure 62. Relative humidity measured in November 2007 (year days 305–334) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Data are plotted as values averaged over each 4-minute sampling interval.

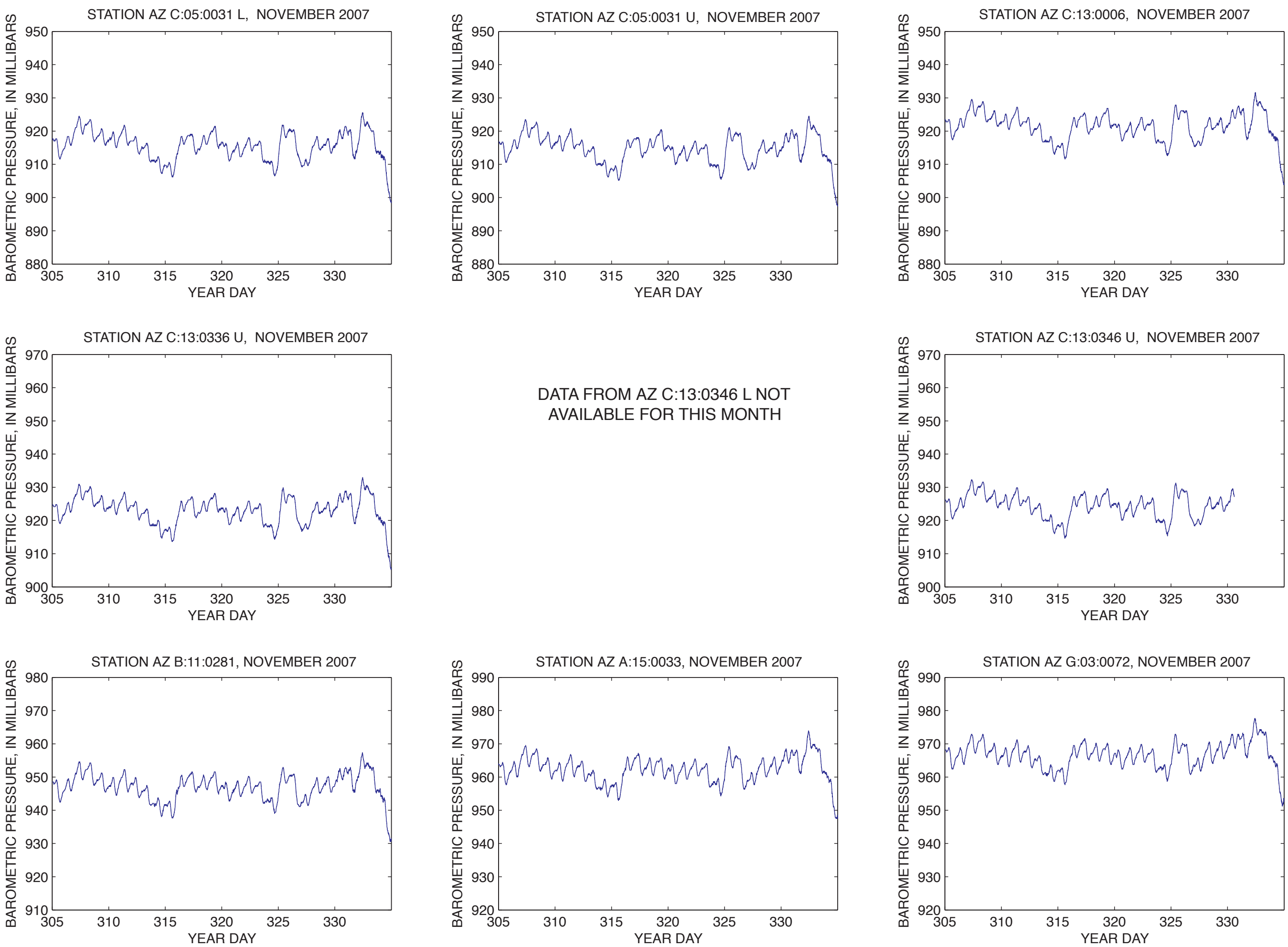

Figure 63. Barometric pressure measured in November 2007 (year days 305–334) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Data are plotted as values averaged over each 4-minute sampling interval.

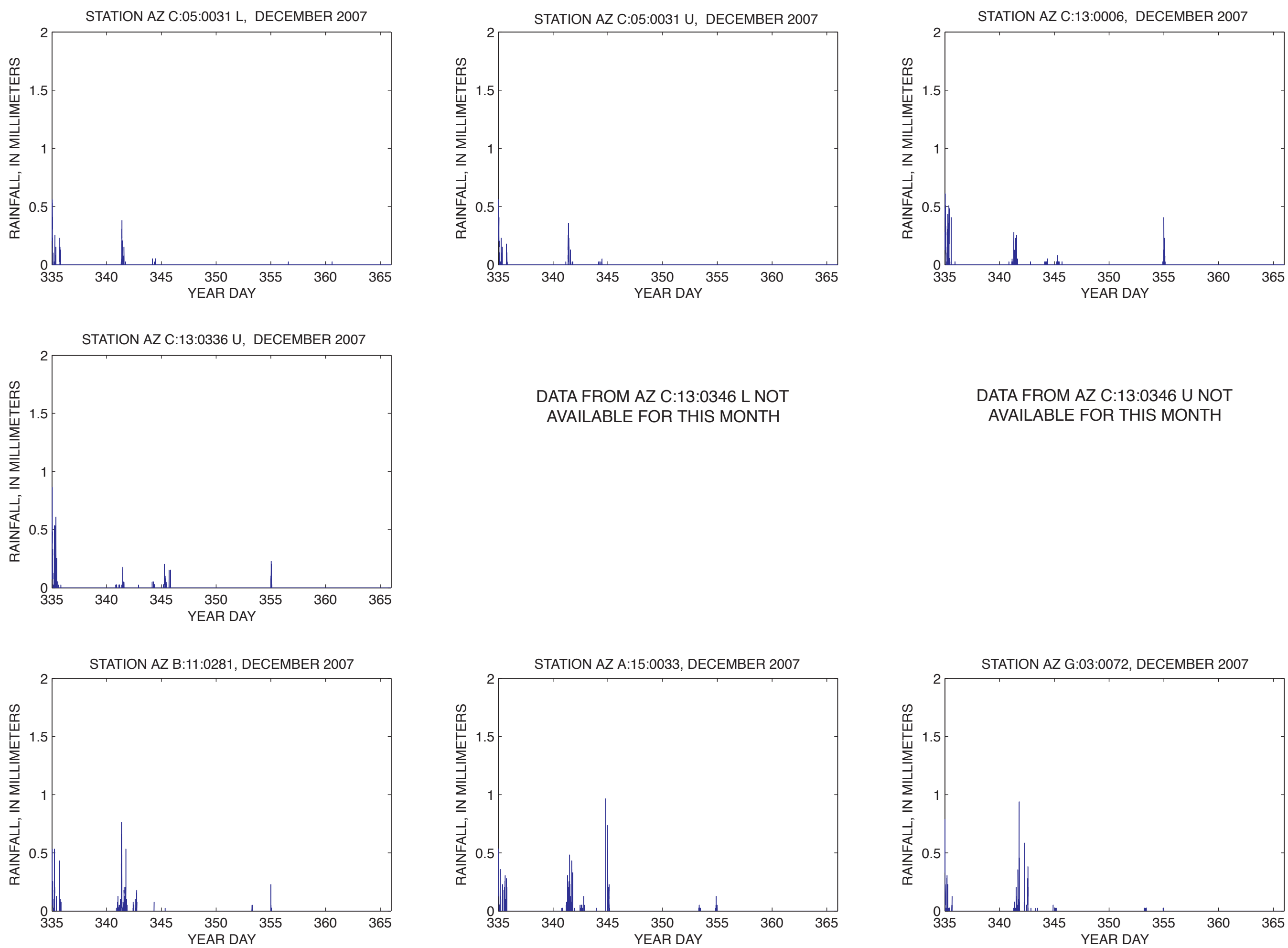

Figure 64. Rainfall measured in December 2007 (year days 335–365) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Data points represent total rainfall in each 4-minute sampling interval.

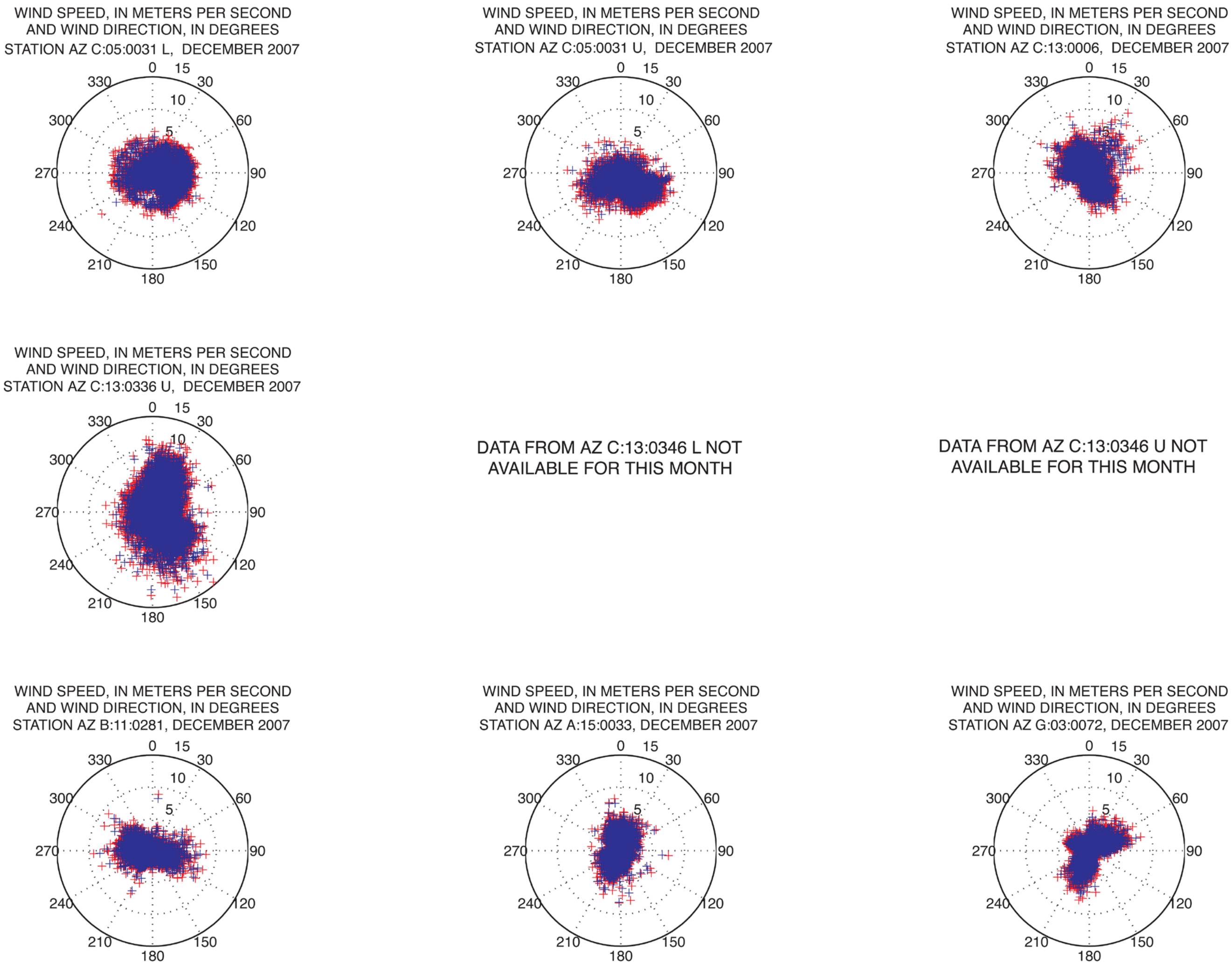

Figure 65. Magnitude and direction of wind velocity measured in December 2007 at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Each blue data point represents a 4-minute average; each red data point represents maximum gust recorded during each 4-minute sampling interval. Magnitude is indicated by the concentric circles, and compass bearing indicates direction from which the wind came.

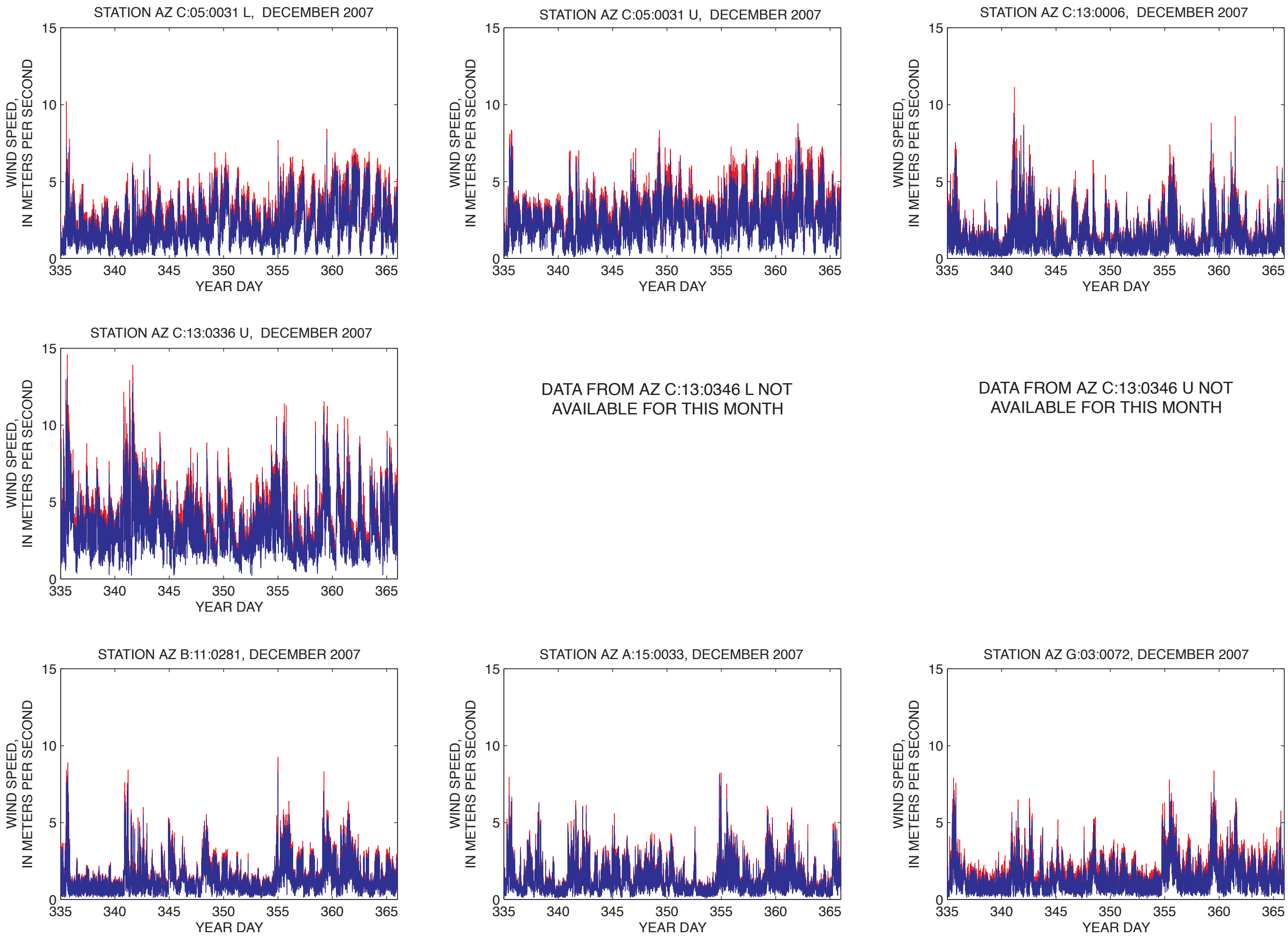

Figure 66. Wind speed measured in December 2007 (year days 335–365) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Blue data are values averaged over each 4-minute sampling interval; red data are maximum gusts recorded during each 4-minute sampling interval.

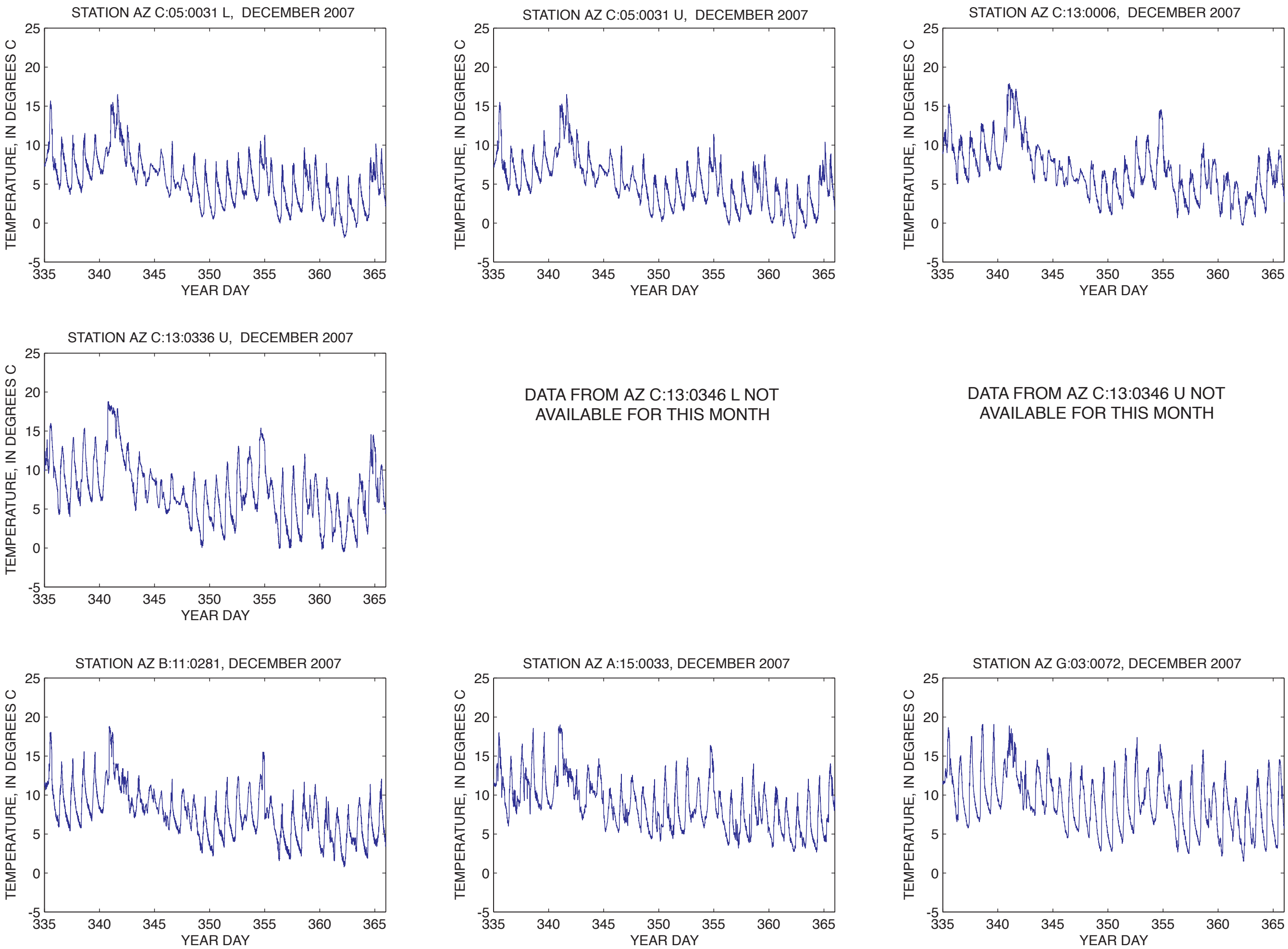

Figure 67. Air temperature measured in December 2007 (year days 335–365) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Data are plotted as values averaged over each 4-minute sampling interval.

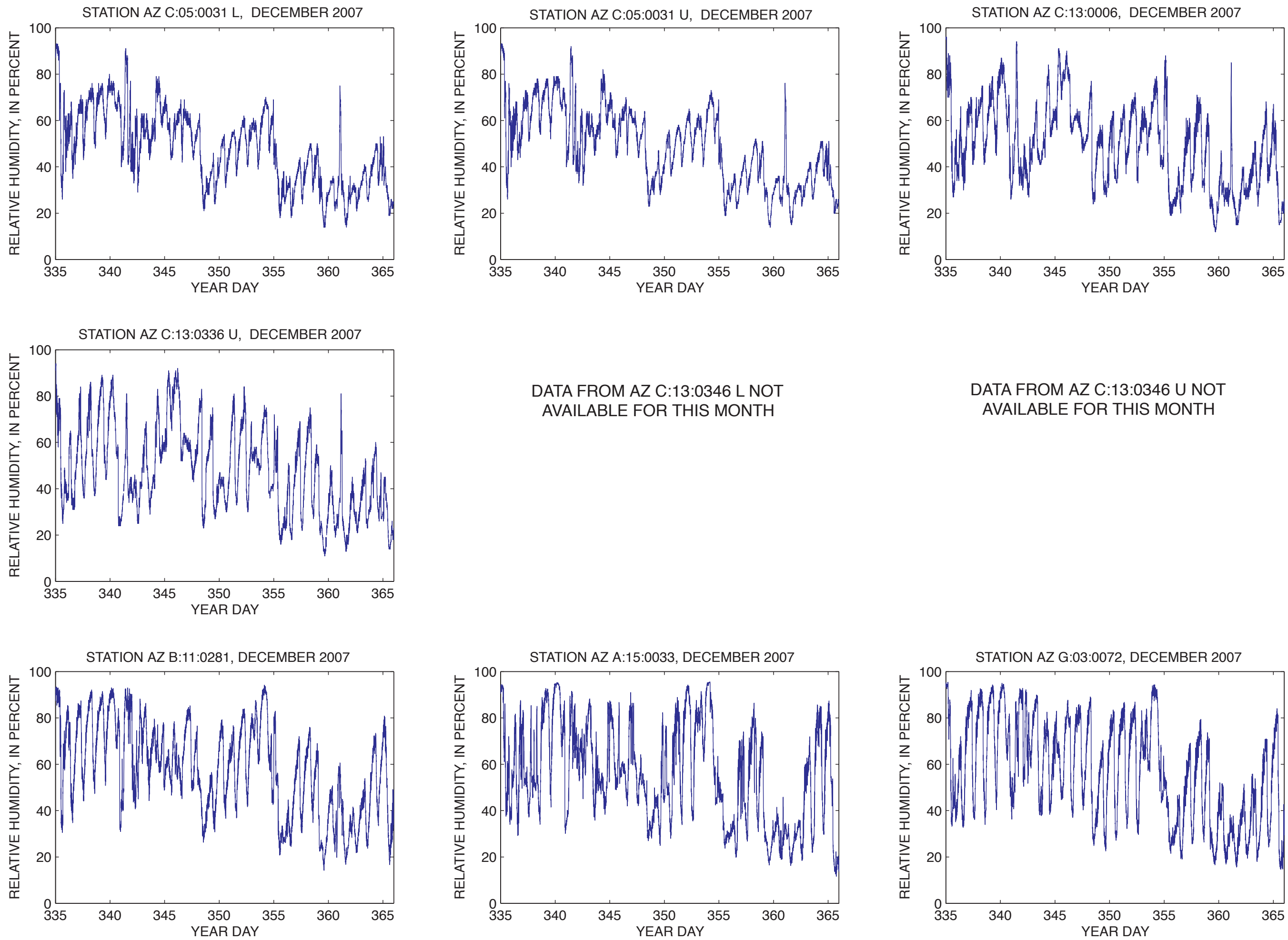

Figure 68. Relative humidity measured in December 2007 (year days 335–365) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Data are plotted as values averaged over each 4-minute sampling interval.

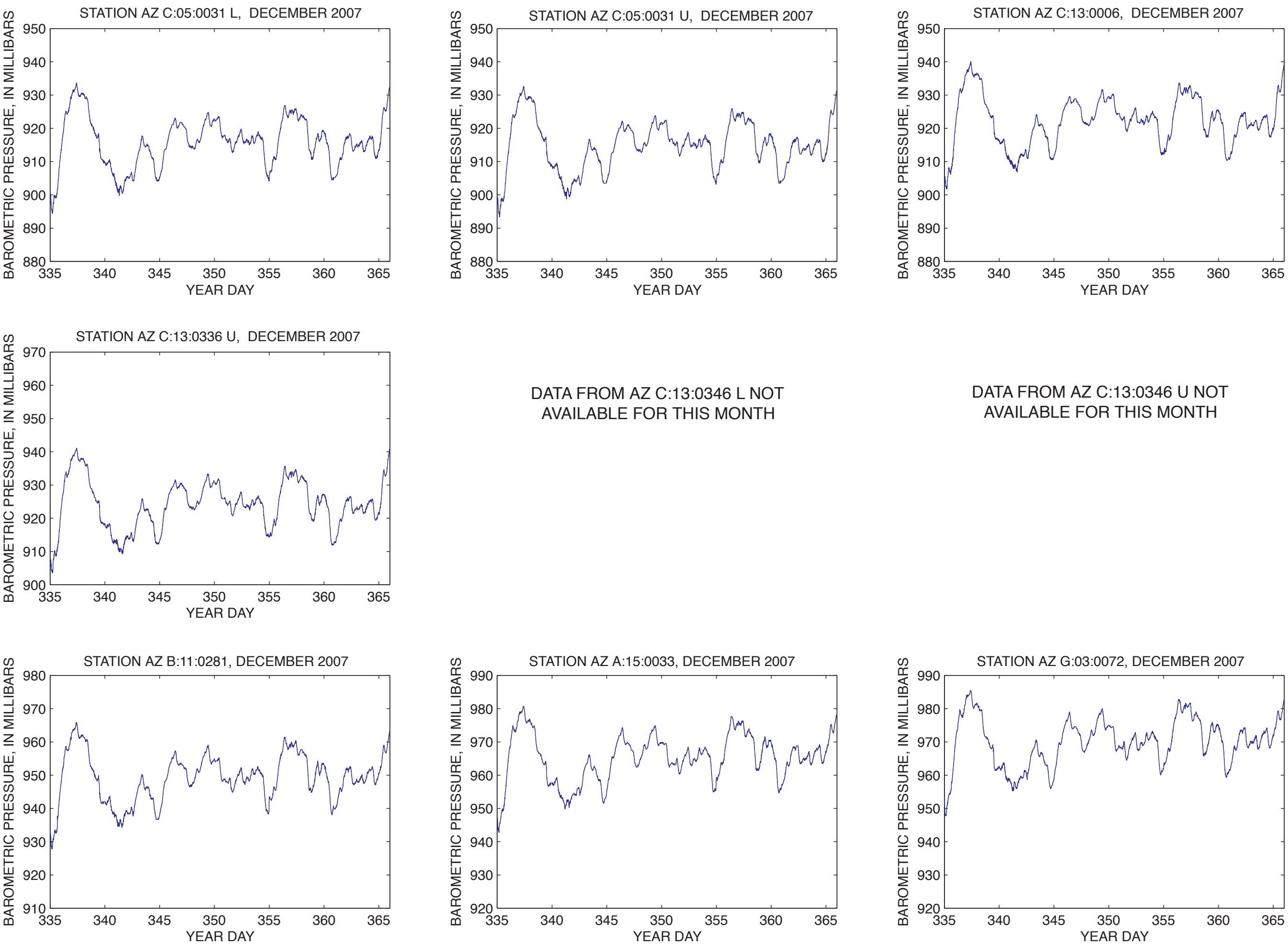

Figure 69. Barometric pressure measured in December 2007 (year days 335–365) at weather stations in the Colorado River corridor, Grand Canyon, Ariz. Data are plotted as values averaged over each 4-minute sampling interval.

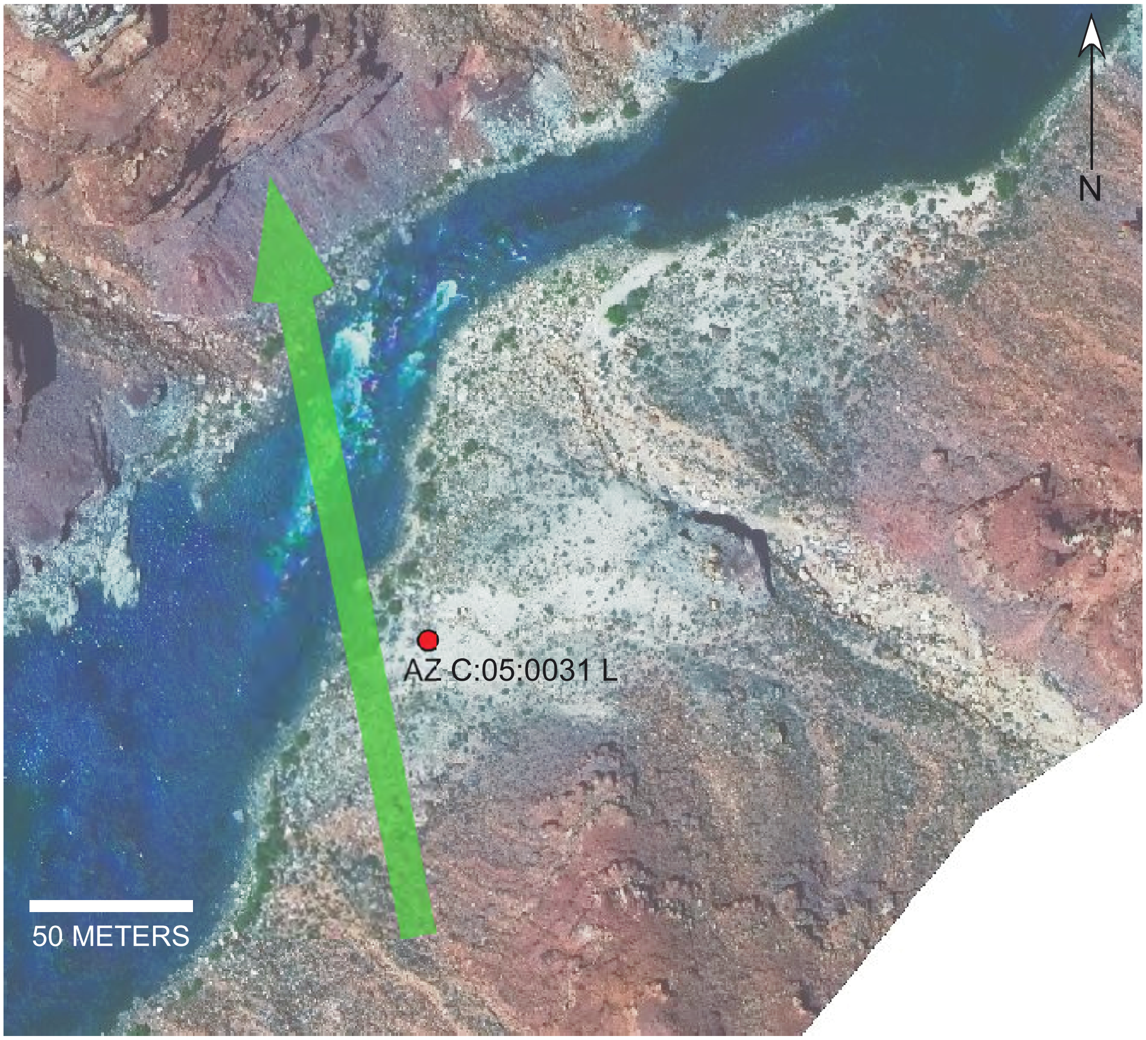

Figure 70. Aerial photograph of the area around the instrument station AZ C:05:0031 L, in Grand Canyon, Ariz., with arrow indicating net direction of potential aeolian sediment transport. A vector sum of the *Qp* proxy variable (equation 1), calculated using all available wind data from AZ C:05:0031 L in 2007, indicates net sediment transport from 169 degrees.

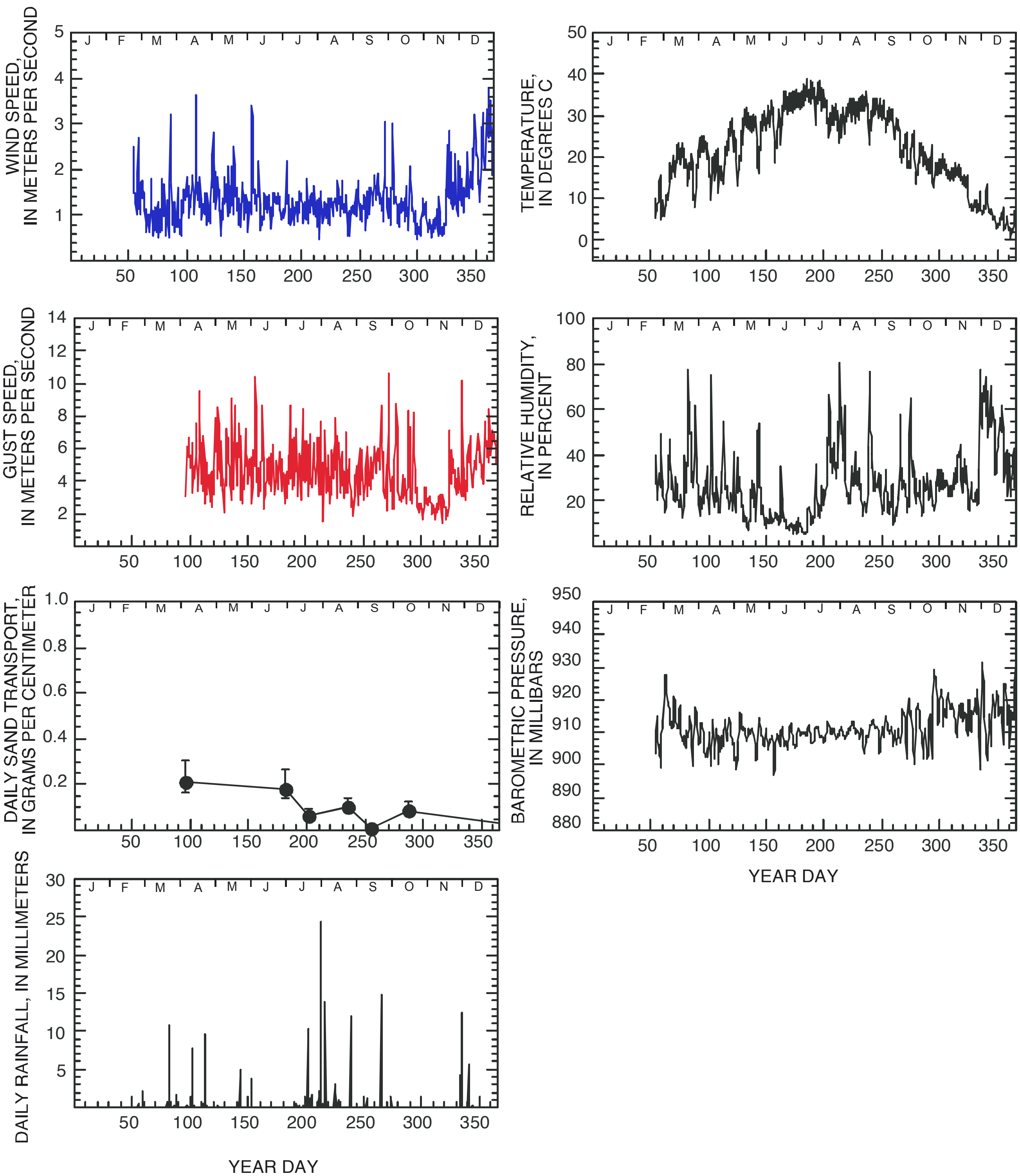

Figure 71. Wind, rainfall, temperature, humidity, barometric pressure, and aeolian sand-transport data collected at the instrument station AZ C:05:0031 L in the Colorado River corridor, Grand Canyon, Ariz., in 2007. Daily sand transport is plotted in grams, normalized to a width of 1 cm. To obtain these values, total sand mass collected from four traps during each maintenance visit was divided by number of days since traps had last been emptied. Wind speed (blue plot), temperature, humidity, and barometric pressure are presented as diurnal average values, using daytime (0600–1800 h) and nighttime (1800–0600 h) averages of data collected at 4-minute intervals. Gust speed (red plot) is shown as maximum values that occurred during each diurnal interval.

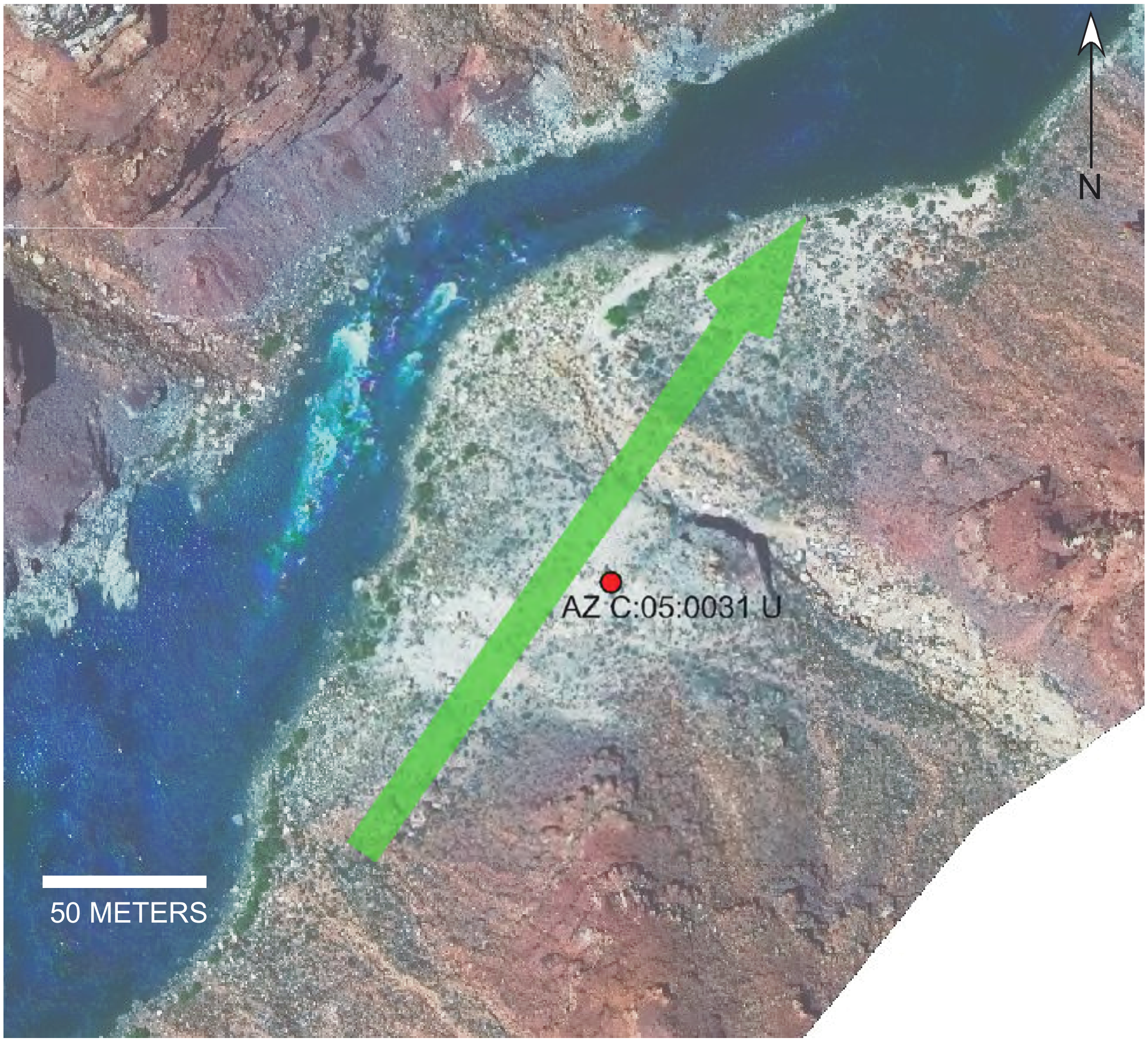

Figure 72. Aerial photograph of the area around the instrument station AZ C:05:0031 U, in Grand Canyon, Ariz., with arrow indicating net direction of potential aeolian sediment transport. A vector sum of the *Qp* proxy variable (equation 1), calculated using all available wind data from AZ C:05:0031 U in 2007, indicates net sediment transport from 215 degrees.

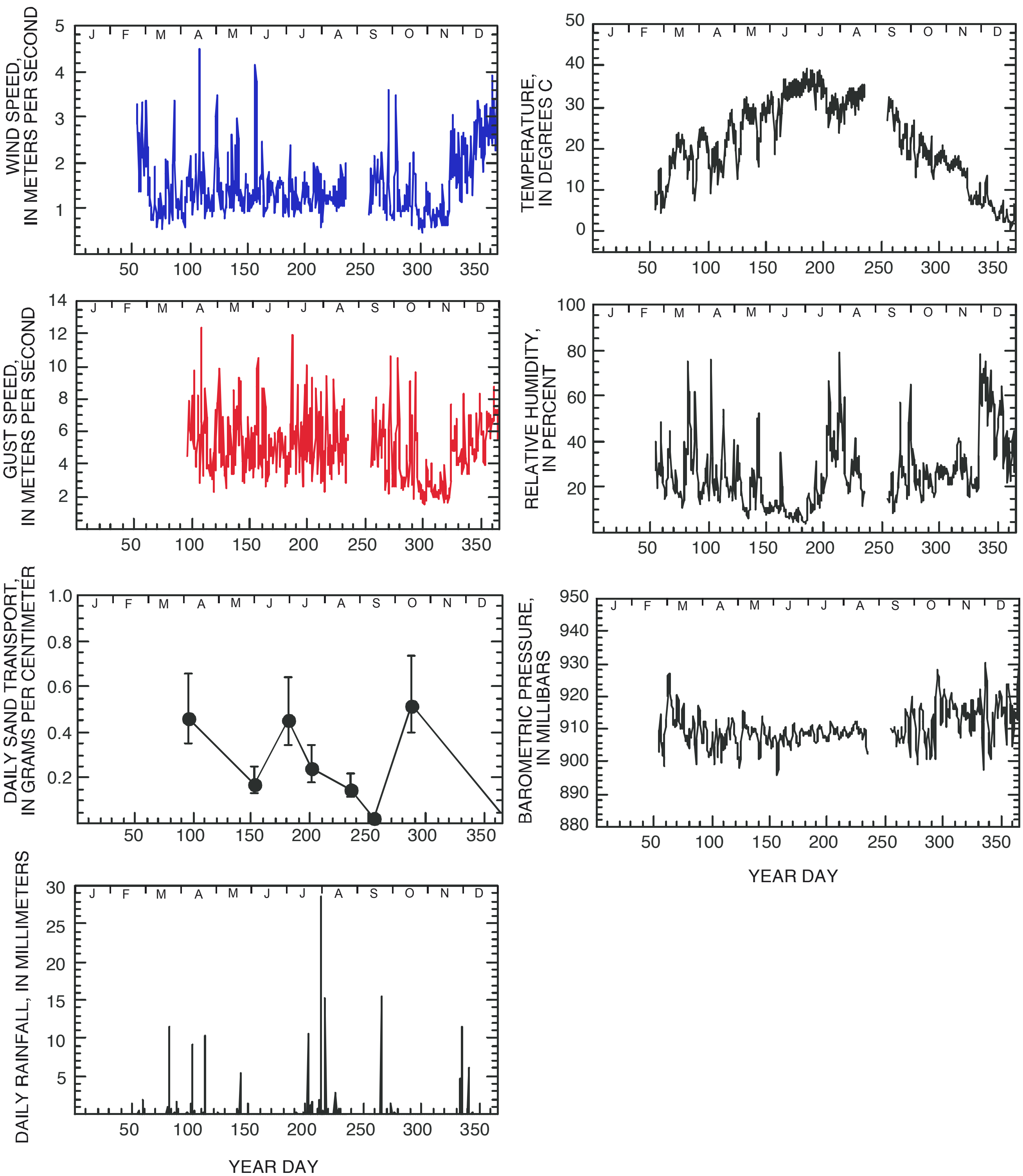

Figure 73. Wind, rainfall, temperature, humidity, barometric pressure, and aeolian sand-transport data collected at the instrument station AZ C:05:0031 U in the Colorado River corridor, Grand Canyon, Ariz., in 2007. Daily sand transport is plotted in grams, normalized to a width of 1 cm. To obtain these values, total sand mass collected from four traps during each maintenance visit was divided by number of days since traps had last been emptied. Wind speed (blue plot), temperature, humidity, and barometric pressure are presented as diurnal average values, using daytime (0600–1800 h) and nighttime (1800–0600 h) averages of data collected at 4-minute intervals. Gust speed (red plot) is shown as maximum values that occurred during each diurnal interval.

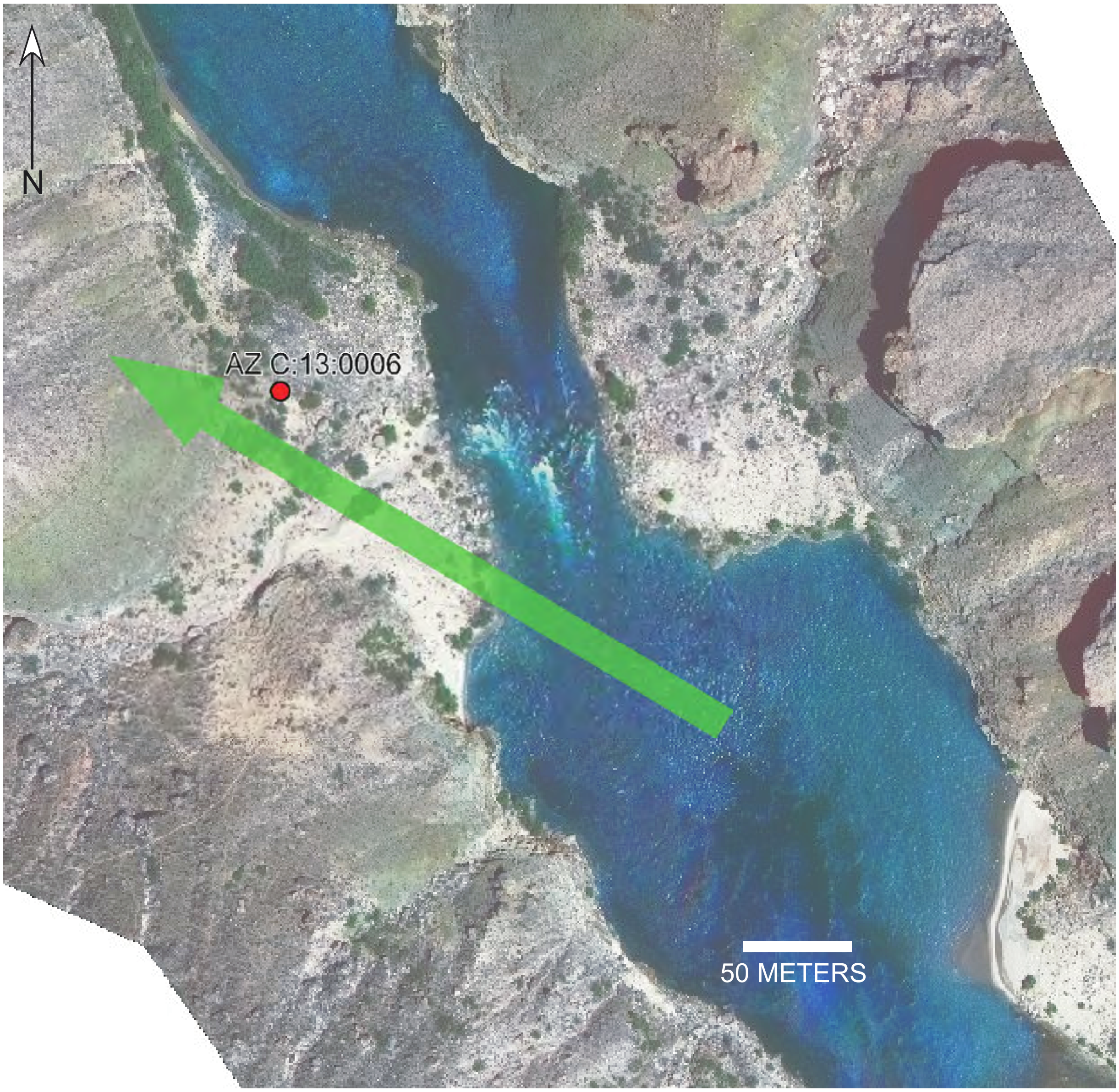

Figure 74. Aerial photograph of the area around the instrument station AZ C:13:0006, in Grand Canyon, Ariz., with arrow indicating net direction of potential aeolian sediment transport. A vector sum of the *Qp* proxy variable (equation 1), calculated using all available wind data from AZ C:13:0006 in 2007, indicates net sediment transport from 121 degrees.

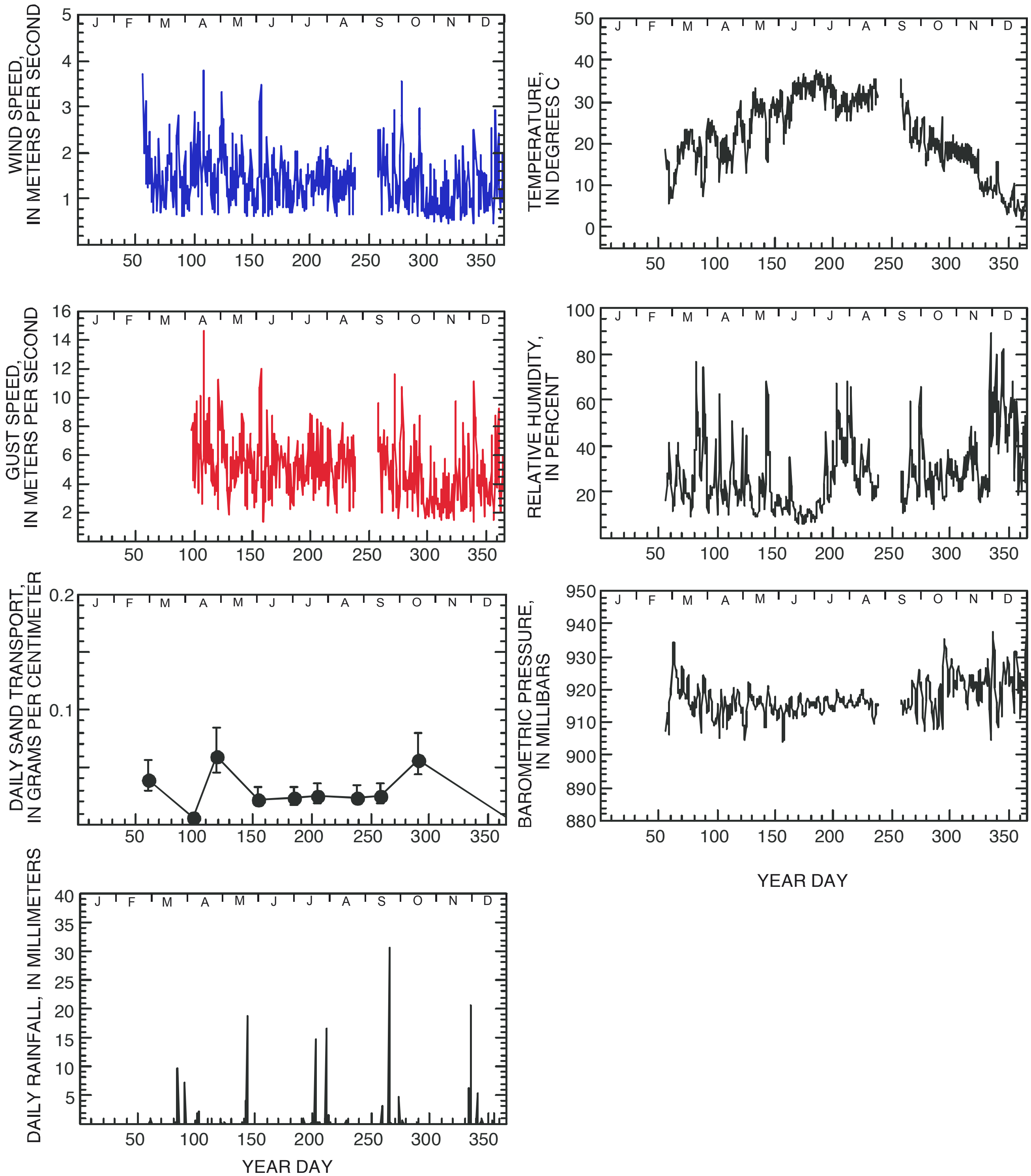

Figure 75. Wind, rainfall, temperature, humidity, barometric pressure, and aeolian sand-transport data collected at the instrument station near AZ C:13:0006 in the Colorado River corridor, Grand Canyon, Ariz., in 2007. Daily sand transport is plotted in grams, normalized to a width of 1 cm. To obtain these values, total sand mass collected from four traps during each maintenance visit was divided by number of days since traps had last been emptied. Wind speed (blue plot), temperature, humidity, and barometric pressure are presented as diurnal average values, using daytime (0600–1800 h) and nighttime (1800–0600 h) averages of data collected at 4-minute intervals. Gust speed (red plot) is shown as maximum values that occurred during each diurnal interval.

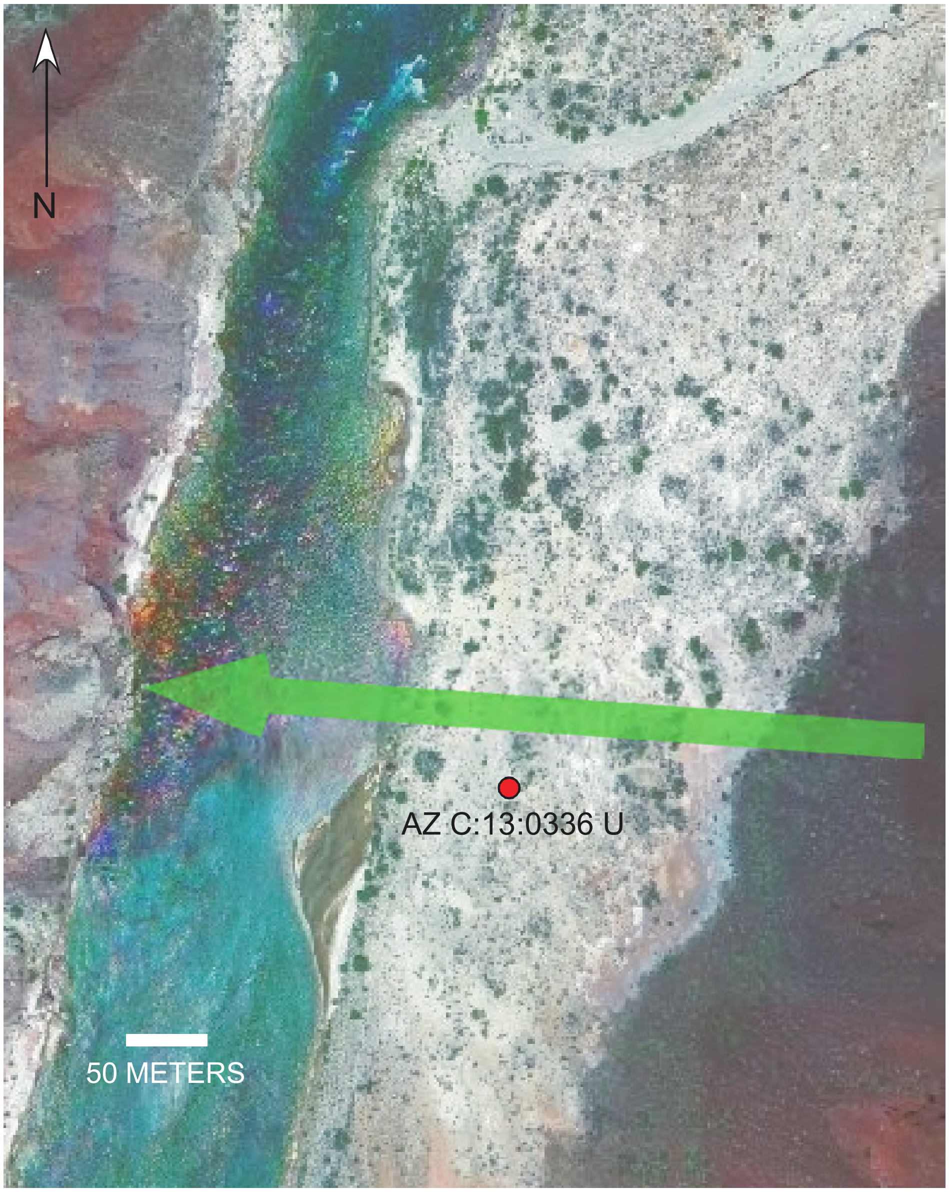

Figure 76. Aerial photograph of the area around AZ C:13:0336, in Grand Canyon, Ariz., with arrow indicating net direction of potential aeolian sediment transport. A vector sum of the *Qp* proxy variable (equation 1), calculated using all available wind data from AZ C:13:0336 U in 2007, indicates net sediment transport from 94 degrees.

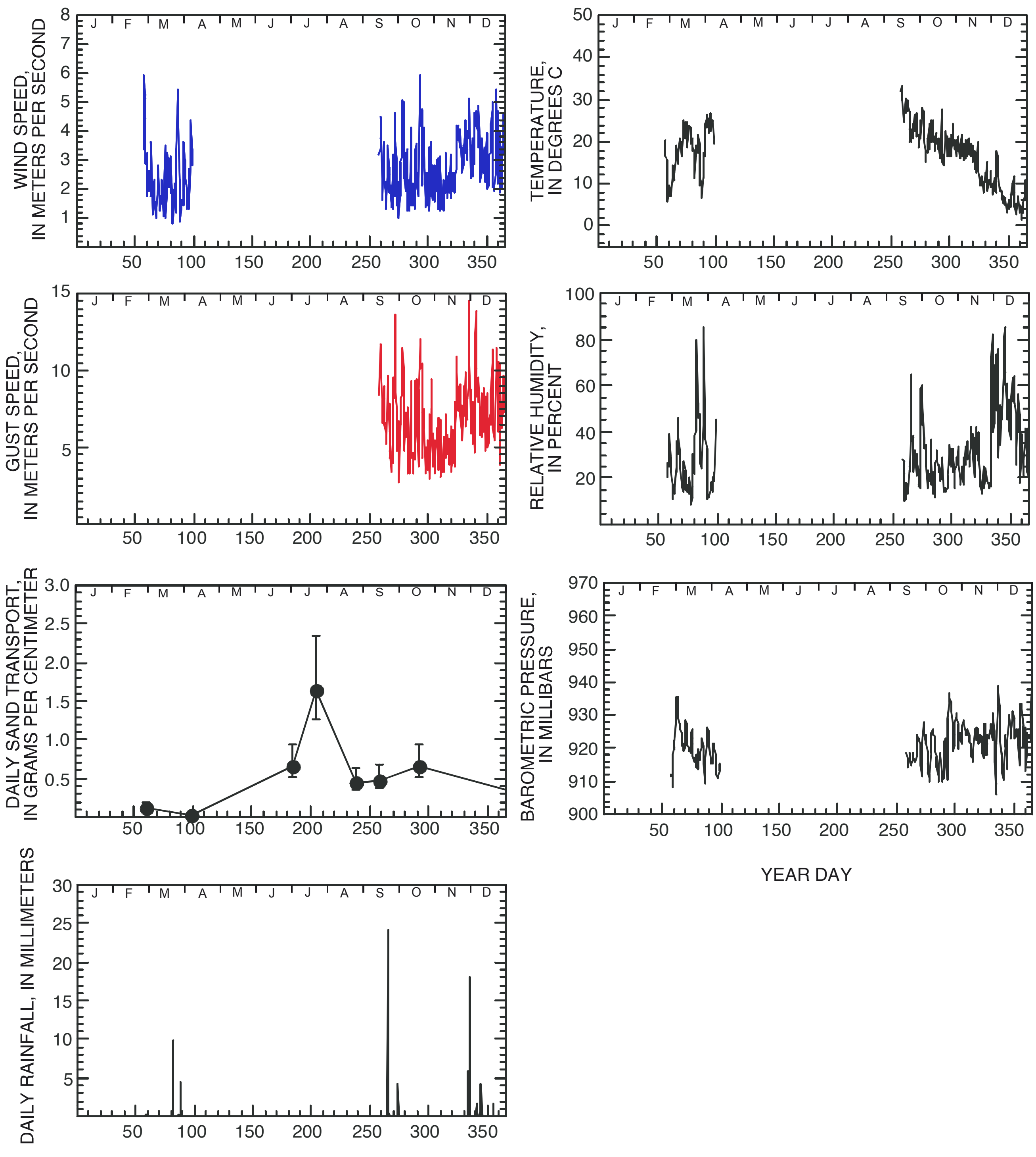

Figure 77. Wind, rainfall, temperature, humidity, barometric pressure, and aeolian sand-transport data collected at the instrument station AZ C:13:0336 U in the Colorado River corridor, Grand Canyon, Ariz., in 2007. Daily sand transport is plotted in grams, normalized to a width of 1 cm. To obtain these values, total sand mass collected from four traps during each maintenance visit was divided by number of days since traps had last been emptied. Wind speed (blue plot), temperature, humidity, and barometric pressure are presented as diurnal average values, using daytime (0600–1800 h) and nighttime (1800–0600 h) averages of data collected at 4-minute intervals. Gust speed (red plot) is shown as maximum values that occurred during each diurnal interval.

Figure 78. Aerial photograph of the area around the instrument station AZ C:13:0346 L, in Grand Canyon, Ariz., with arrow indicating net direction of potential aeolian sediment transport. A vector sum of the *Qp* proxy variable (equation 1), calculated using all available wind data from AZ C:13:0346 L in 2007, indicates net sediment transport from 250 degrees.

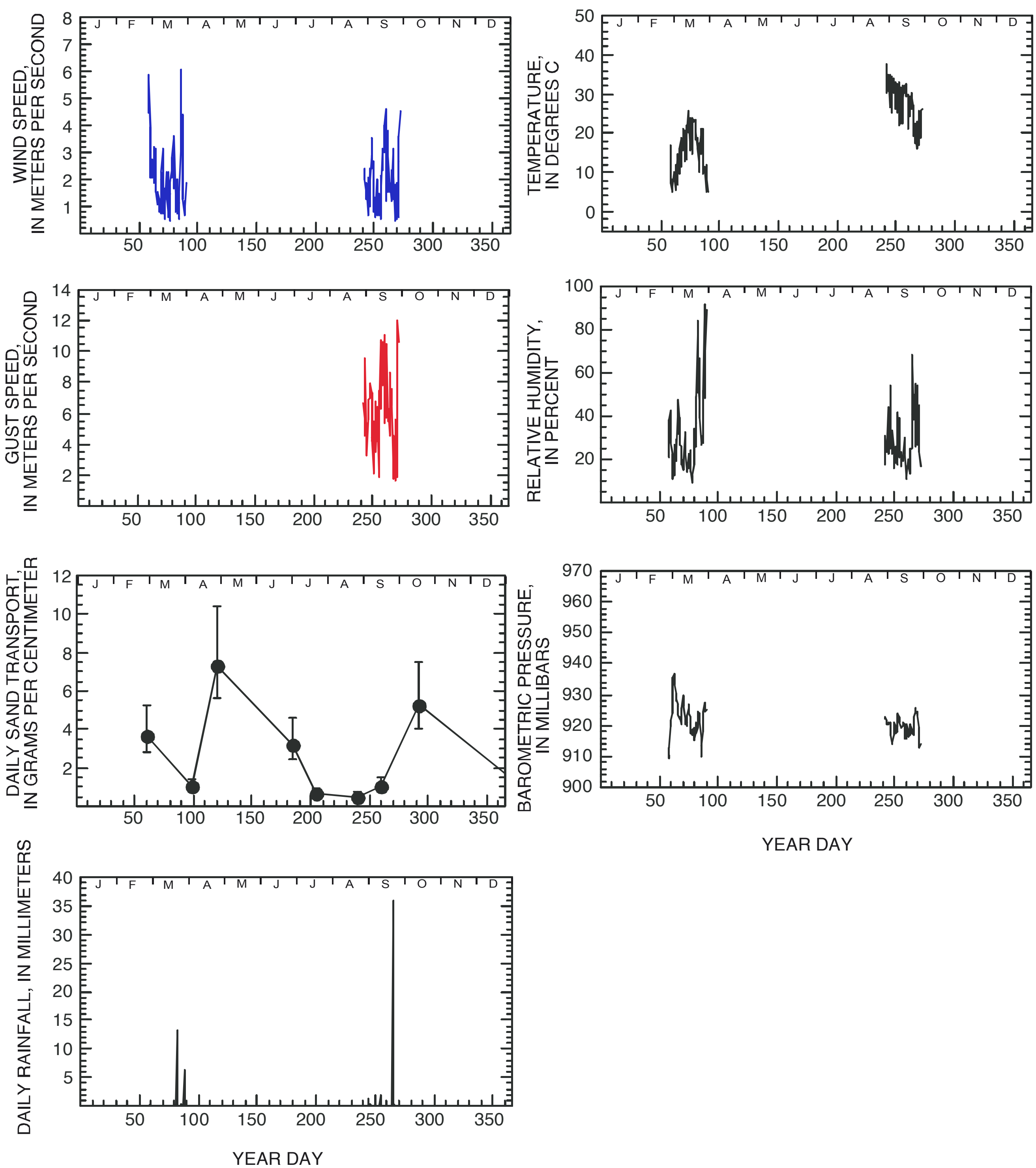

Figure 79. Wind, rainfall, temperature, humidity, barometric pressure, and aeolian sand-transport data collected at the instrument station AZ C:13:0346 L in the Colorado River corridor, Grand Canyon, Ariz., in 2007. Daily sand transport is plotted in grams, normalized to a width of 1 cm. To obtain these values, total sand mass collected from four traps during each maintenance visit was divided by number of days since traps had last been emptied. Wind speed (blue plot), temperature, humidity, and barometric pressure are presented as diurnal average values, using daytime (0600–1800 h) and nighttime (1800–0600 h) averages of data collected at 4-minute intervals. Gust speed (red plot) is shown as maximum values that occurred during each diurnal interval.

Figure 80. Aerial photograph of the area around the instrument station AZ C:13:0346 U, in Grand Canyon, Ariz., with arrow indicating net direction of potential aeolian sediment transport. A vector sum of the *Qp* proxy variable (equation 1), calculated using all available wind data from AZ C:13:0346 U in 2007, indicates net sediment transport from 237 degrees.

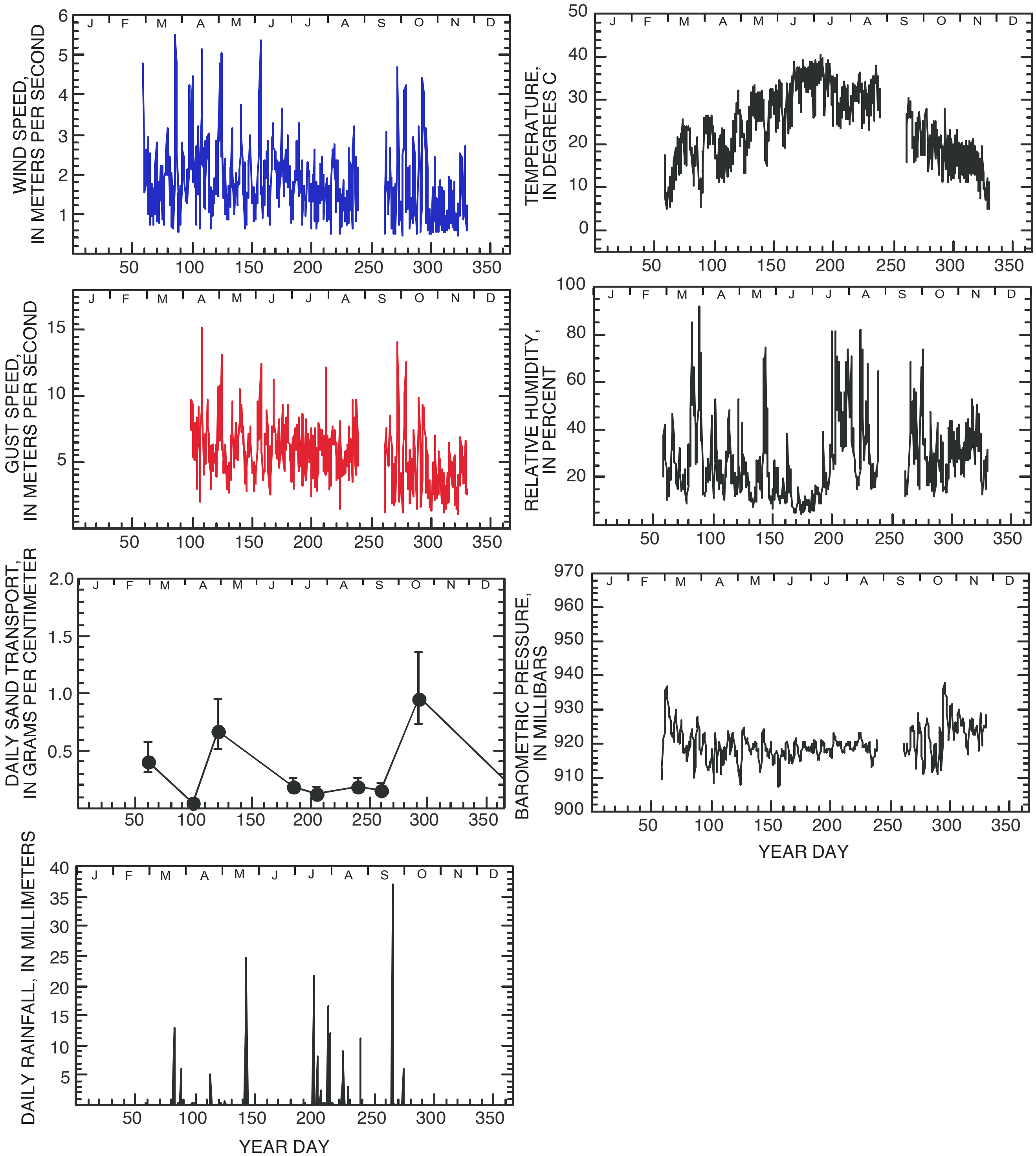

Figure 81. Wind, rainfall, temperature, humidity, barometric pressure, and aeolian sand-transport data collected at the instrument station AZ C:13:0346 U in the Colorado River corridor, Grand Canyon, Ariz., in 2007. Daily sand transport is plotted in grams, normalized to a width of 1 cm. To obtain these values, total sand mass collected from four traps during each maintenance visit was divided by number of days since traps had last been emptied. Wind speed (blue plot), temperature, humidity, and barometric pressure are presented as diurnal average values, using daytime (0600–1800 h) and nighttime (1800–0600 h) averages of data collected at 4-minute intervals. Gust speed (red plot) is shown as maximum values that occurred during each diurnal interval.

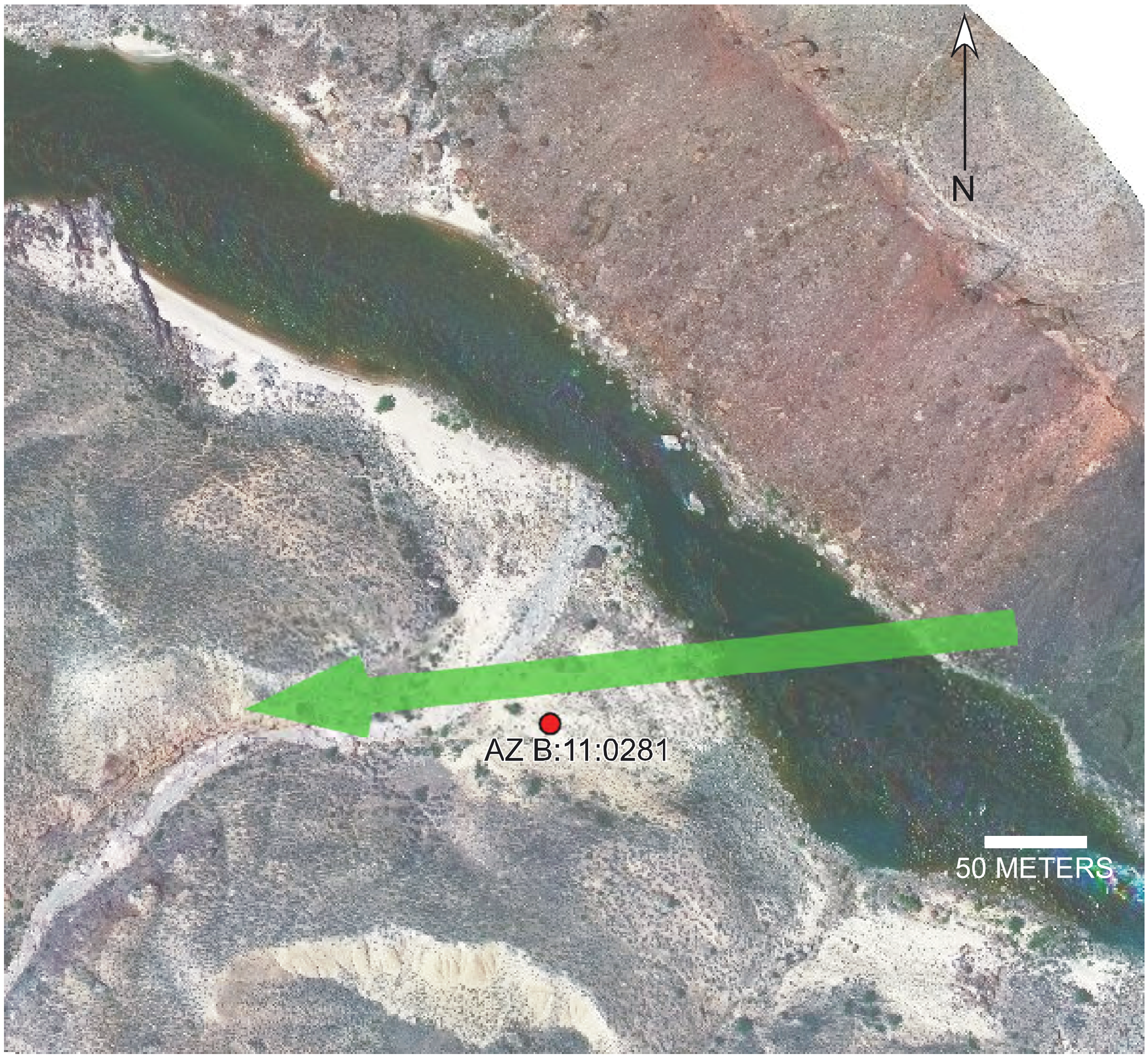

Figure 82. Aerial photograph of the area around the instrument station near AZ B:11:0281, in Grand Canyon, Ariz., with arrow indicating net direction of potential aeolian sediment transport. A vector sum of the *Qp* proxy variable (equation 1), calculated using all available wind data from AZ B:11:0281 in 2007, indicates net sediment transport from 84 degrees.

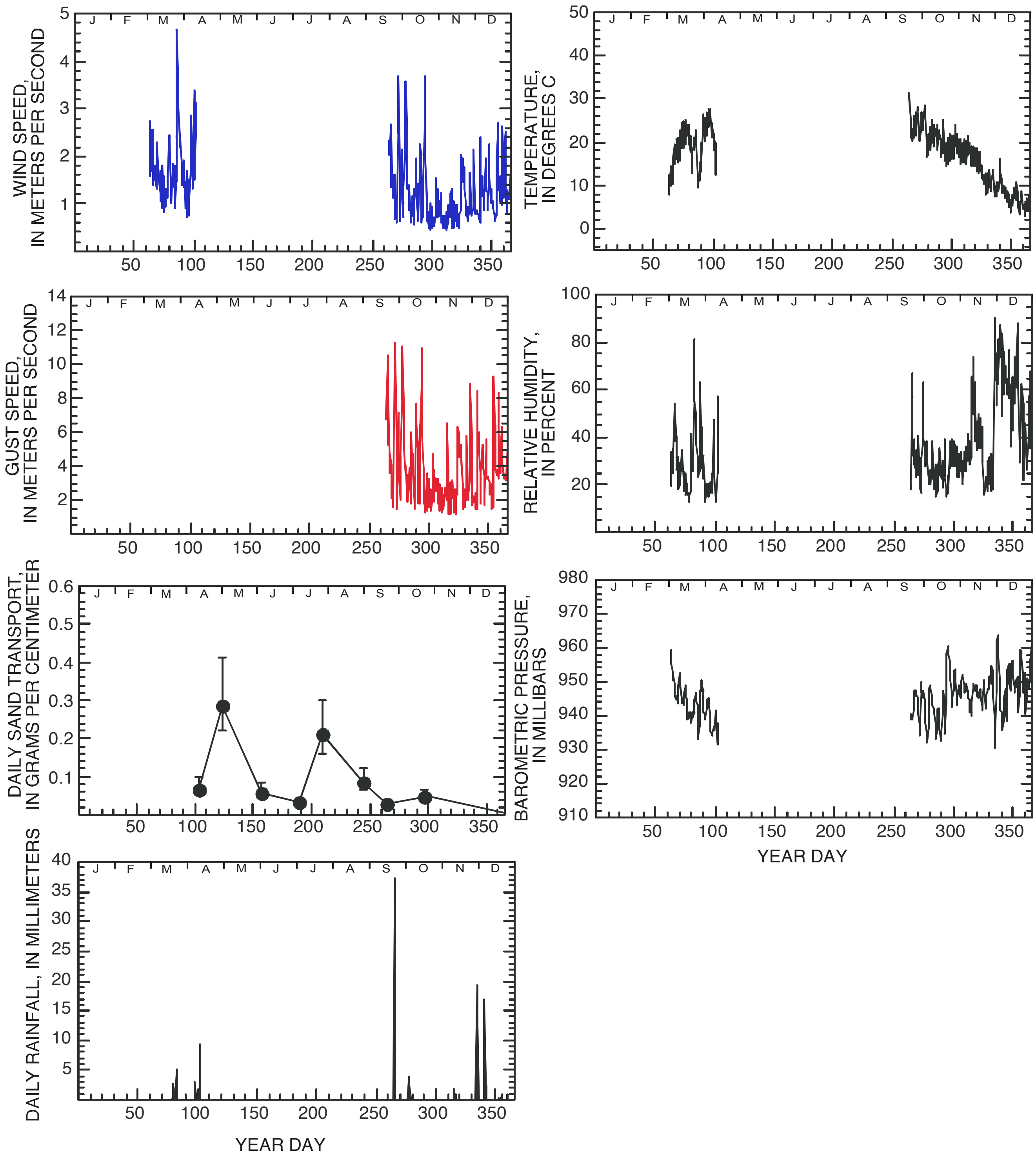

Figure 83. Wind, rainfall, temperature, humidity, barometric pressure, and aeolian sand-transport data collected at the instrument station near AZ B:11:0281 in the Colorado River corridor, Grand Canyon, Ariz., in 2007. Daily sand transport is plotted in grams, normalized to a width of 1 cm. To obtain these values, total sand mass collected from four traps during each maintenance visit was divided by number of days since traps had last been emptied. Wind speed (blue plot), temperature, humidity, and barometric pressure are presented as diurnal average values, using daytime (0600–1800 h) and nighttime (1800–0600 h) averages of data collected at 4-minute intervals. Gust speed (red plot) is shown as maximum values that occurred during each diurnal interval.

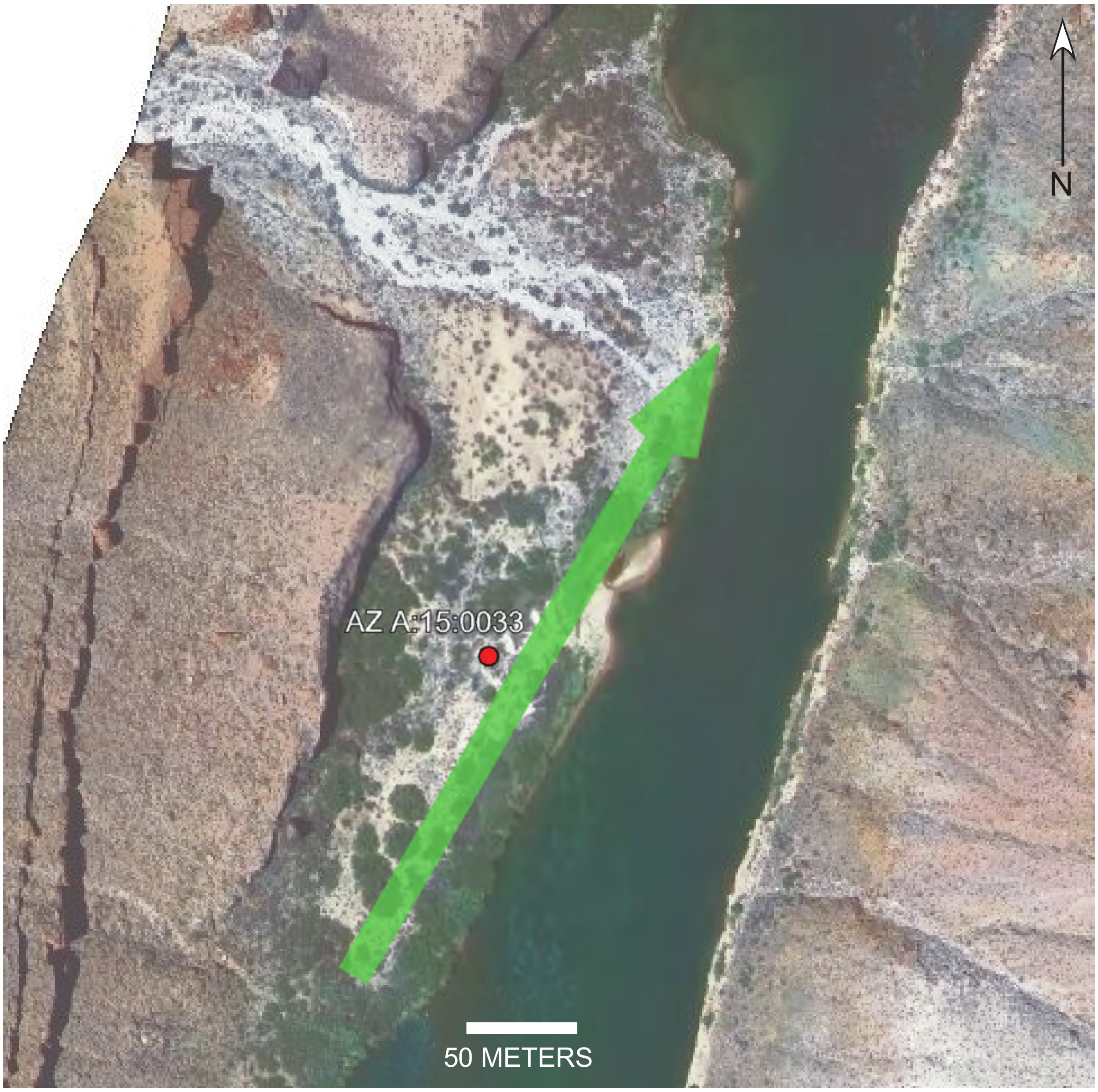

Figure 84. Aerial photograph of the area around the instrument station near AZ A:15:0033, in Grand Canyon, Ariz., with arrow indicating net direction of potential aeolian sediment transport. A vector sum of the *Qp* proxy variable (equation 1), calculated using all available wind data from AZ A:15:0033 in 2007, indicates net sediment transport from 210 degrees.

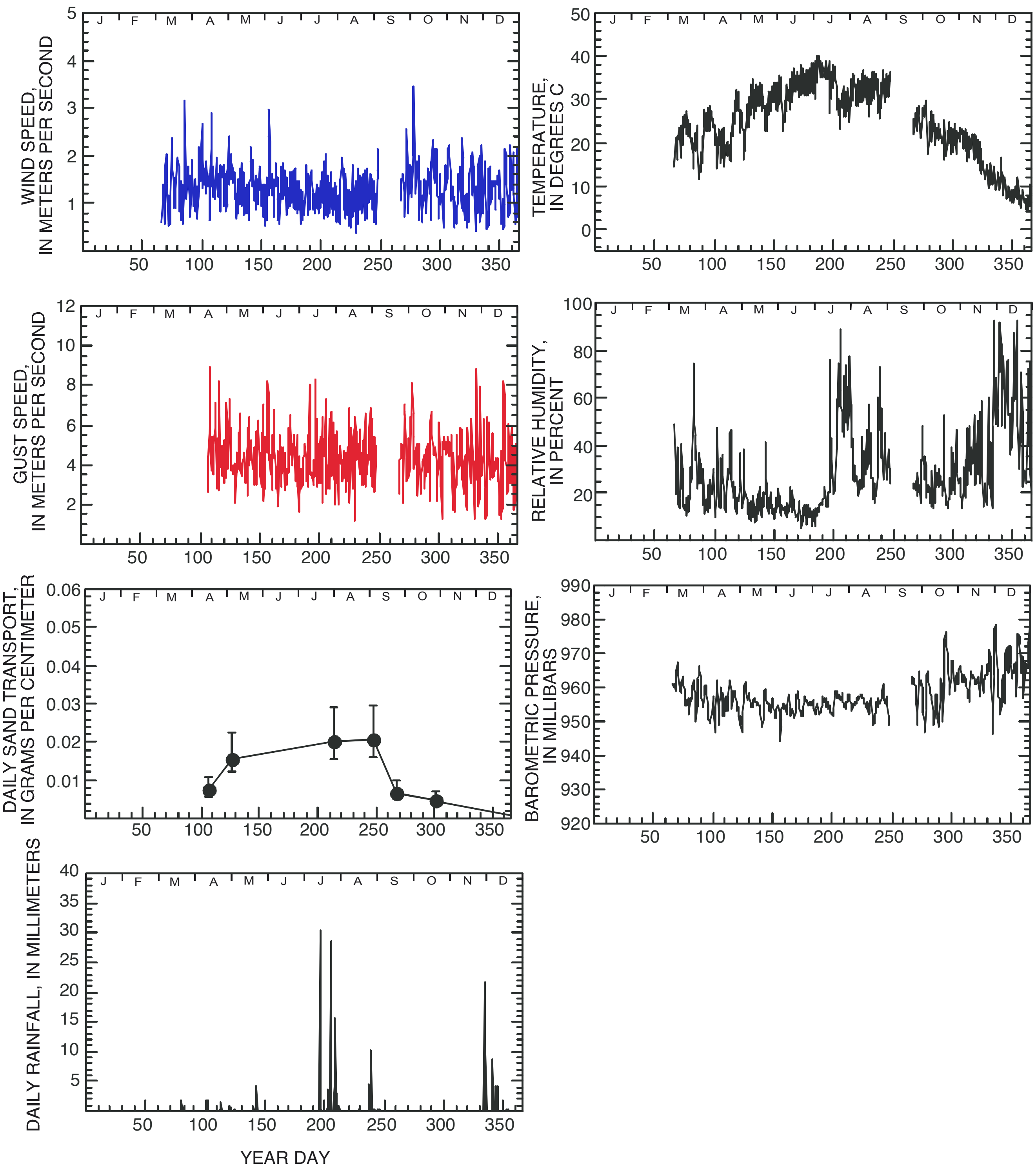

Figure 85. Wind, rainfall, temperature, humidity, barometric pressure, and aeolian sand-transport data collected at the instrument station near AZ A:15:0033 in the Colorado River corridor, Grand Canyon, Ariz., in 2007. Daily sand transport is plotted in grams, normalized to a width of 1 cm. To obtain these values, total sand mass collected from four traps during each maintenance visit was divided by number of days since traps had last been emptied. Wind speed (blue plot), temperature, humidity, and barometric pressure are presented as diurnal average values, using daytime (0600–1800 h) and nighttime (1800–0600 h) averages of data collected at 4-minute intervals. Gust speed (red plot) is shown as maximum values that occurred during each diurnal interval.

Figure 86. Aerial photograph of the area around the instrument station near AZ G:03:0072, in Grand Canyon, Ariz., with arrow indicating net direction of potential aeolian sediment transport. A vector sum of the *Qp* proxy variable (equation 1), calculated using all available wind data from AZ G:03:0072 U in 2007, indicates net sediment transport from 199 degrees.

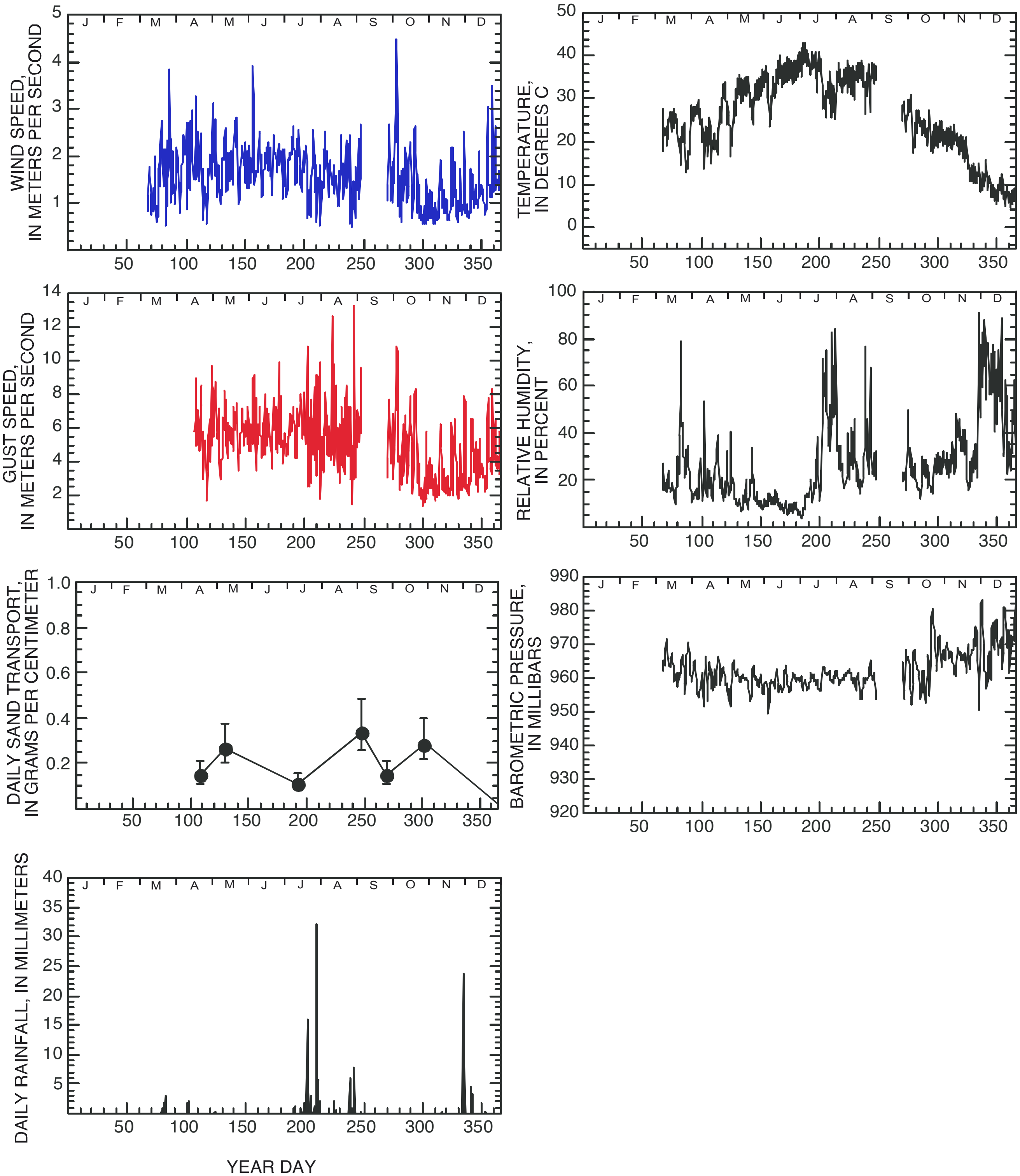

Figure 87. Wind, rainfall, temperature, humidity, barometric pressure, and aeolian sand-transport data collected at the instrument station AZ G:03:0072 U in the Colorado River corridor, Grand Canyon, Ariz., in 2007. Daily sand transport is plotted in grams, normalized to a width of 1 cm. To obtain these values, total sand mass collected from four traps during each maintenance visit was divided by number of days since traps had last been emptied. Wind speed (blue plot), temperature, humidity, and barometric pressure are presented as diurnal average values, using daytime (0600–1800 h) and nighttime (1800–0600 h) averages of data collected at 4-minute intervals. Gust speed (red plot) is shown as maximum values that occurred during each diurnal interval.

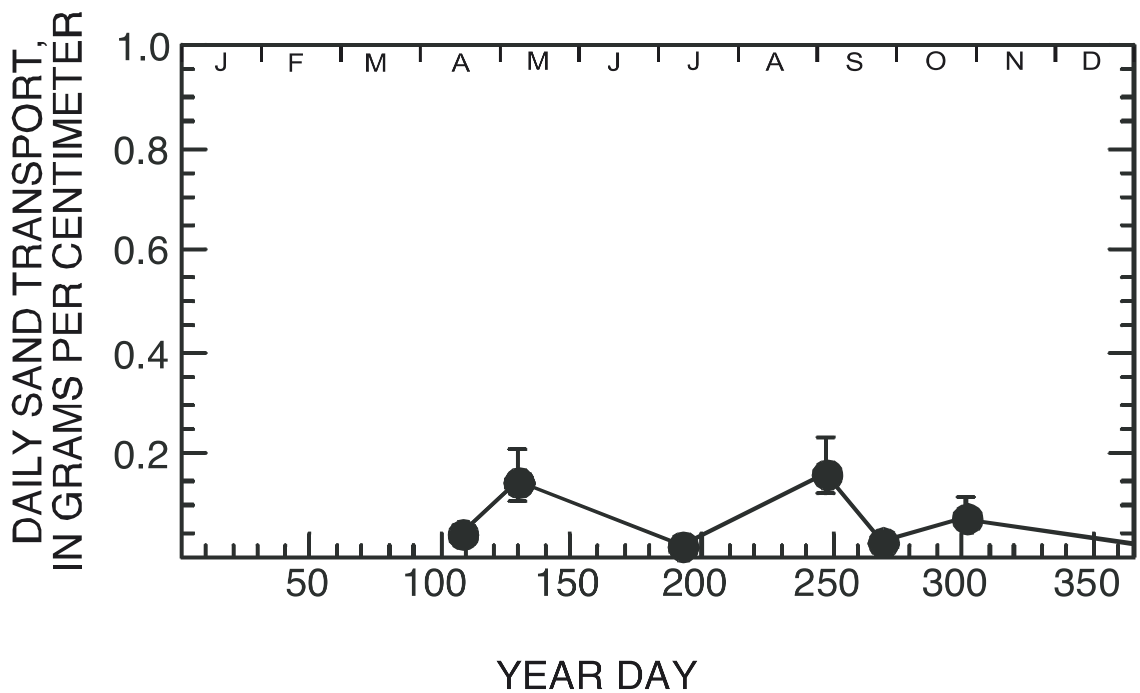

Figure 88. Aeolian sand-transport data collected at the instrument station AZ G:03:0072 L in the Colorado River corridor, Grand Canyon, Ariz., in 2007. Daily sand transport is plotted in grams, normalized to a width of 1 cm. To obtain these values, total sand mass collected from four traps during each maintenance visit was divided by number of days since traps had last been emptied.

Tables

Table 1. Approximate river miles, station names, abbreviations, and equipment deployed at each study site.

Approximate River Mile	Station Name	Equipment
25	AZ C:05:0031 L	weather station, sand traps
25	AZ C:05:0031 U	weather station, sand traps
60	AZ C:13:0006	weather station, sand traps
65	AZ C:13:0336 U	weather station, sand traps
70	AZ C:13:0346 L	weather station, sand traps
70	AZ C:13:0346 U	weather station, sand traps
135	AZ B:11:0281	weather station, sand traps
203	AZ A:15:0033	weather station, sand traps
223	AZ G:03:0072 L	sand traps
223	AZ G:03:0072 U	weather station, sand traps

Table 2. Total rainfall, in mm, recorded daily at each of the weather stations.

[N/A indicates that the station did not collect data that day]

Date	AZ C:05:0031 L	AZ C:05:0031 U	AZ C:13:0006	AZ C:13:0336 U	AZ C:13:0346 L	AZ C:13:0346 U	AZ B:11:0281	AZ A:15:0033	AZ G:03:0072	Year Day
2/23/2007	0	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	54
2/24/2007	0.5	0.4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	55
2/25/2007	0	0	0	N/A	N/A	N/A	N/A	N/A	N/A	56
2/26/2007	0	0	0	0	N/A	N/A	N/A	N/A	N/A	57
2/27/2007	0.1	0.1	0.5	0.3	0	0	N/A	N/A	N/A	58
2/28/2007	2.1	1.9	0.8	0.2	0.3	0.3	N/A	N/A	N/A	59
3/1/2007	0	0	0	0	0	0	N/A	N/A	N/A	60
3/2/2007	0	0	0	0	0	0	N/A	N/A	N/A	61
3/3/2007	0	0	0	0	0	0	N/A	N/A	N/A	62
3/4/2007	0	0	0	0	0	0	0	N/A	N/A	63
3/5/2007	0	0	0	0	0	0	0	N/A	N/A	64
3/6/2007	0	0	0	0	0	0	0	N/A	N/A	65
3/7/2007	0	0	0	0	0.1	0.1	0	0	N/A	66
3/8/2007	0	0	0	0	0	0	0	0	0	67
3/9/2007	0	0	0	0	0	0	0	0	0	68
3/10/2007	0	0	0	0	0	0	0	0	0	69
3/11/2007	0	0	0	0	0	0	0	0	0	70
3/12/2007	0	0	0	0	0	0	0	0	0	71
3/13/2007	0	0	0	0	0	0	0	0	0	72
3/14/2007	0	0	0	0	0	0	0	0	0	73
3/15/2007	0	0	0	0	0	0	0	0	0	74
3/16/2007	0	0	0	0	0	0	0	0	0	75
3/17/2007	0	0	0	0	0	0	0	0	0	76
3/18/2007	0	0	0	0	0	0	0	0	0	77
3/19/2007	0	0	0	0	0	0	0	0	0	78
3/20/2007	0	0	0	0	0	0	0.4	0	0.7	79
3/21/2007	0.8	1.0	0	0	0.3	0.2	2.7	1.7	0.2	80
3/22/2007	0	0	0	0	0	0	0	0	1.7	81
3/23/2007	10.7	11.5	9.7	9.8	13.2	12.8	5.0	1.0	2.9	82
3/24/2007	0.8	0.8	0	0	0	0	0.1	0	0	83
3/25/2007	0	0	0	0	0	0	0	0	0	84

Table 2. Total rainfall, in mm, recorded daily at each of the weather stations. N/A indicates that the station did not collect data that day.—Continued

Date	AZ C:05:0031 L	AZ C:05:0031 U	AZ C:13:0006	AZ C:13:0336 U	AZ C:13:0346 L	AZ C:13:0346 U	AZ B:11:0281	AZ A:15:0033	AZ G:03:0072	Year Day
3/26/2007	0	0	0	0	0	0	0	0	0	85
3/27/2007	0.2	0.2	0.1	0.3	0.2	0.2	0	0	0	86
3/28/2007	0	0	0.1	0	0	0	0	0	0	87
3/29/2007	1.6	1.6	7.1	4.5	6.4	6.0	0	0	0	88
3/30/2007	0	0	0	0	0	0	0	0	0	89
3/31/2007	0	0	0	0	N/A	0	0	0	0	90
4/1/2007	0	0	0	0	N/A	0	0	0	0	91
4/2/2007	0	0	0	0	N/A	0	0	0	0	92
4/3/2007	0	0	0	0	N/A	0	0	0	0	93
4/4/2007	0	0	0	0	N/A	0	0	0	0	94
4/5/2007	0	0	0	0	N/A	0	0	0	0	95
4/6/2007	0	0	0	0	N/A	0	0	0	0	96
4/7/2007	0.33	0.36	0	0	N/A	0.4	0.1	0	0	97
4/8/2007	0.13	0.15	0.06	0.1	N/A	0.2	2.9	0	0	98
4/9/2007	0	0	0.54	0.1	N/A	0.3	0.2	0	0	99
4/10/2007	0	0	0	N/A	N/A	0	0	0	0	100
4/11/2007	0	0.02	0	N/A	N/A	0	0	0	0	101
4/12/2007	7.65	9.12	2.16	N/A	N/A	0.15	9.4	1.9	2.2	102
4/13/2007	0.28	0.46	0.17	N/A	N/A	0	N/A	0	0	103
4/14/2007	0	0	0	N/A	N/A	0	N/A	0	0	104
4/15/2007	0	0	0	N/A	N/A	0	N/A	0.1	0	105
4/16/2007	0	0	0	N/A	N/A	0	N/A	0	0	106
4/17/2007	0	0	0	N/A	N/A	0	N/A	0	0	107
4/18/2007	0.02	0	0.14	N/A	N/A	0.09	N/A	0	0	108
4/19/2007	0	0	0	N/A	N/A	0	N/A	0	0	109
4/20/2007	0.05	0.02	0	N/A	N/A	0	N/A	0	0	110
4/21/2007	0.41	0.33	0.03	N/A	N/A	0	N/A	0	0	111
4/22/2007	0.03	0	0	N/A	N/A	0.03	N/A	0.43	0.03	112
4/23/2007	9.65	10.42	0.9	N/A	N/A	5.26	N/A	1.42	0.08	113
4/24/2007	0.28	0	0	N/A	N/A	0	N/A	0	0	114
4/25/2007	0	0	0	N/A	N/A	0	N/A	0	0	115
4/26/2007	0	0	0	N/A	N/A	0	N/A	0	0	116

Table 2. Total rainfall, in mm, recorded daily at each of the weather stations. N/A indicates that the station did not collect data that day.—Continued

Date	AZ C:05:0031 L	AZ C:05:0031 U	AZ C:13:0006	AZ C:13:0336 U	AZ C:13:0346 L	AZ C:13:0346 U	AZ B:11:0281	AZ A:15:0033	AZ G:03:0072	Year Day
4/27/2007	0.02	0	0	N/A	N/A	0	N/A	0	0	117
4/28/2007	0	0	0	N/A	N/A	0	N/A	0	0	118
4/29/2007	0	0	0	N/A	N/A	0	N/A	0	0	119
4/30/2007	0	0	0	N/A	N/A	0.1	N/A	0	0	120
5/1/2007	0.03	0.05	0.2	N/A	N/A	0.37	N/A	0.51	0.13	121
5/2/2007	0	0	0	N/A	N/A	0	N/A	0	0	122
5/3/2007	0	0	0	N/A	N/A	0	N/A	0	0	123
5/4/2007	0.18	0.15	0.25	N/A	N/A	0.29	N/A	0.17	0.41	124
5/5/2007	0	0	0.03	N/A	N/A	0.48	N/A	0.03	0	125
5/6/2007	0	0.05	0	N/A	N/A	0	N/A	0	0	126
5/7/2007	0	0	0	N/A	N/A	0	N/A	0	0	127
5/8/2007	0	0	0	N/A	N/A	0	N/A	0	0	128
5/9/2007	0	0	0	N/A	N/A	0	N/A	0	0	129
5/10/2007	0.05	0	0	N/A	N/A	0	N/A	0	0	130
5/11/2007	0.05	0	0	N/A	N/A	0	N/A	0	0	131
5/12/2007	0.02	0	0	N/A	N/A	0	N/A	0	0	132
5/13/2007	0	0	0	N/A	N/A	0	N/A	0	0	133
5/14/2007	0	0	0	N/A	N/A	0	N/A	0	0	134
5/15/2007	0	0	0	N/A	N/A	0	N/A	0	0	135
5/16/2007	0	0	0	N/A	N/A	0.06	N/A	0	0	136
5/17/2007	0.05	0	0	N/A	N/A	0	N/A	0	0	137
5/18/2007	0	0	0.06	N/A	N/A	0	N/A	0	0	138
5/19/2007	0	0	0.46	N/A	N/A	0.03	N/A	0	0	139
5/20/2007	0	0	0	N/A	N/A	0	N/A	0	0	140
5/21/2007	0	0	0	N/A	N/A	0	N/A	0	0	141
5/22/2007	0.56	0.51	3.96	N/A	N/A	14.37	N/A	0.84	0.03	142
5/23/2007	5.03	5.33	18.74	N/A	N/A	24.80	N/A	4.18	0	143
5/24/2007	0	0	0	N/A	N/A	0	N/A	0	0	144
5/25/2007	0	0	0	N/A	N/A	0	N/A	0	0	145
5/26/2007	0	0	0	N/A	N/A	0	N/A	0	0	146
5/27/2007	0	0	0	N/A	N/A	0	N/A	0	0	147

Table 2. Total rainfall, in mm, recorded daily at each of the weather stations. N/A indicates that the station did not collect data that day.—Continued

Date	AZ C:05:0031 L	AZ C:05:0031 U	AZ C:13:0006	AZ C:13:0336 U	AZ C:13:0346 L	AZ C:13:0346 U	AZ B:11:0281	AZ A:15:0033	AZ G:03:0072	Year Day
5/28/2007	0	0	0	N/A	N/A	0	N/A	0	0	148
5/29/2007	0	0	0	N/A	N/A	0	N/A	0	0	149
5/30/2007	0	0	0	N/A	N/A	0	N/A	0	0	150
5/31/2007	0.05	0	0	N/A	N/A	0	N/A	0	0	151
6/1/2007	0	0	0	N/A	N/A	0	N/A	0	0	152
6/2/2007	0	0.03	0	N/A	N/A	0	N/A	0	0	153
6/3/2007	0.03	0	0	N/A	N/A	0	N/A	0	0	154
6/4/2007	0	0	0	N/A	N/A	0	N/A	0	0	155
6/5/2007	0.03	0.03	0	N/A	N/A	0	N/A	0	0	156
6/6/2007	0	0	0.11	N/A	N/A	0.03	N/A	0	0	157
6/7/2007	0	0	0	N/A	N/A	0	N/A	0	0	158
6/8/2007	0	0	0	N/A	N/A	0	N/A	0	0	159
6/9/2007	0	0.03	0	N/A	N/A	0	N/A	0	0	160
6/10/2007	0	0	0	N/A	N/A	0	N/A	0	0	161
6/11/2007	0	0	1.07	N/A	N/A	0	N/A	0	0	162
6/12/2007	0	0	0	N/A	N/A	0	N/A	0	0	163
6/13/2007	0	0	0	N/A	N/A	0	N/A	0	0	164
6/14/2007	0.06	0	0	N/A	N/A	0	N/A	0	0.03	165
6/15/2007	0	0	0	N/A	N/A	0	N/A	0	0	166
6/16/2007	0	0.03	0	N/A	N/A	0	N/A	0	0	167
6/17/2007	0	0	0	N/A	N/A	0	N/A	0	0	168
6/18/2007	0	0	0	N/A	N/A	0	N/A	0	0	169
6/19/2007	0	0	0	N/A	N/A	0	N/A	0	0	170
6/20/2007	0	0	0	N/A	N/A	0	N/A	0	0	171
6/21/2007	0	0	0	N/A	N/A	0	N/A	0	0	172
6/22/2007	0	0	0	N/A	N/A	0	N/A	0	0	173
6/23/2007	0	0	0	N/A	N/A	0	N/A	0	0	174
6/24/2007	0	0	0	N/A	N/A	0	N/A	0	0	175
6/25/2007	0	0	0	N/A	N/A	0	N/A	0	0	176
6/26/2007	0	0	0	N/A	N/A	0	N/A	0	0	177
6/27/2007	0	0	0	N/A	N/A	0	N/A	0	0	178

Table 2. Total rainfall, in mm, recorded daily at each of the weather stations. N/A indicates that the station did not collect data that day.—Continued

Date	AZ C:05:0031 L	AZ C:05:0031 U	AZ C:13:0006	AZ C:13:0336 U	AZ C:13:0346 L	AZ C:13:0346 U	AZ B:11:0281	AZ A:15:0033	AZ G:03:0072	Year Day
6/28/2007	0	0	0	N/A	N/A	0	N/A	0	0	179
6/29/2007	0	0.05	0	N/A	N/A	0	N/A	0	0	180
6/30/2007	0	0	0	N/A	N/A	0	N/A	0	0	181
7/1/2007	0	0	0	N/A	N/A	0	N/A	0	0	182
7/2/2007	0	0	0	N/A	N/A	0	N/A	0	0	183
7/3/2007	0	0.03	0	N/A	N/A	0	N/A	0	0	184
7/4/2007	0	0	0	N/A	N/A	0	N/A	0	0	185
7/5/2007	0	0	0	N/A	N/A	0	N/A	0	0	186
7/6/2007	0	0	0	N/A	N/A	0	N/A	0	0	187
7/7/2007	0.03	0	0	N/A	N/A	0	N/A	0	0	188
7/8/2007	0	0	0	N/A	N/A	0	N/A	0	0	189
7/9/2007	0	0	0	N/A	N/A	0	N/A	0	0	190
7/10/2007	0	0.03	0	N/A	N/A	0	N/A	0.03	0	191
7/11/2007	0.49	0.29	0	N/A	N/A	0.32	N/A	0.03	1.24	192
7/12/2007	0	0	8.37	N/A	N/A	0	N/A	0	0	193
7/13/2007	0.16	0.08	0	N/A	N/A	0	N/A	0	0	194
7/14/2007	0	0	0	N/A	N/A	0	N/A	0	0	195
7/15/2007	0	0	0	N/A	N/A	0	N/A	30.28	0	196
7/16/2007	0	0	0	N/A	N/A	0	N/A	0.28	0.99	197
7/17/2007	0.26	0.23	0.03	N/A	N/A	0.08	N/A	0	0.15	198
7/18/2007	0.18	0.23	0.38	N/A	N/A	21.62	N/A	0	0	199
7/19/2007	0	0	0	N/A	N/A	0	N/A	0	0	200
7/20/2007	0	0	0.17	N/A	N/A	0.03	N/A	0	0	201
7/21/2007	10.32	10.55	14.63	N/A	N/A	8.2	N/A	0.53	15.87	202
7/22/2007	0.33	0.42	0.06	N/A	N/A	0.2	N/A	3.62	5.12	203
7/23/2007	1.10	1.25	0.19	N/A	N/A	0.83	N/A	0.34	1.15	204
7/24/2007	1.62	1.62	0.3	N/A	N/A	2.27	N/A	28.48	2.92	205
7/25/2007	0	0	0	N/A	N/A	0	N/A	0	0	206
7/26/2007	0	0	0	N/A	N/A	0.2	N/A	0.03	0	207
7/27/2007	0.03	0.03	0.11	N/A	N/A	0.26	N/A	4.44	1.07	208
7/28/2007	0	0.03	0	N/A	N/A	0	N/A	15.6	0	209

Table 2. Total rainfall, in mm, recorded daily at each of the weather stations. N/A indicates that the station did not collect data that day.—Continued

Date	AZ C:05:0031 L	AZ C:05:0031 U	AZ C:13:0006	AZ C:13:0336 U	AZ C:13:0346 L	AZ C:13:0346 U	AZ B:11:0281	AZ A:15:0033	AZ G:03:0072	Year Day
7/29/2007	0.13	0.13	0.16	N/A	N/A	0.46	N/A	2.90	32.17	210
7/30/2007	1.39	1.20	16.51	N/A	N/A	16.56	N/A	0.09	5.62	211
7/31/2007	2.14	1.95	0.06	N/A	N/A	0	N/A	0.93	0.47	212
8/1/2007	24.42	28.57	1.44	N/A	N/A	11.92	N/A	0.31	2.12	213
8/2/2007	0	0	0	N/A	N/A	0.19	N/A	0	0	214
8/3/2007	0.54	0.53	0.34	N/A	N/A	0.17	N/A	0	0	215
8/4/2007	0	0.03	0	N/A	N/A	0	N/A	0	0	216
8/5/2007	13.89	15.23	0	N/A	N/A	0.03	N/A	0	0	217
8/6/2007	0	0	0	N/A	N/A	0	N/A	0	0	218
8/7/2007	0	0	0	N/A	N/A	0	N/A	0	0	219
8/8/2007	0	0	0	N/A	N/A	0	N/A	0	0	220
8/9/2007	0	0	0	N/A	N/A	0	N/A	0	0	221
8/10/2007	0	0	0	N/A	N/A	0	N/A	0	0	222
8/11/2007	0.03	0	0.03	N/A	N/A	3.83	N/A	0	0	223
8/12/2007	0	0	0.06	N/A	N/A	9.15	N/A	0	0	224
8/13/2007	3.05	2.88	0	N/A	N/A	0	N/A	0.03	2.25	225
8/14/2007	1.95	2.65	0	N/A	N/A	0	N/A	0	0.56	226
8/15/2007	0	0.03	0	N/A	N/A	0	N/A	0	0	227
8/16/2007	0.94	0.62	0.53	N/A	N/A	3.1	N/A	0	0	228
8/17/2007	0	0	0	N/A	N/A	0.59	N/A	0.51	0.09	229
8/18/2007	0	0.03	0	N/A	N/A	0.05	N/A	0	0	230
8/19/2007	0	0	0	N/A	N/A	0	N/A	0	0	231
8/20/2007	0	0	0	N/A	N/A	0	N/A	0	0	232
8/21/2007	0	0	0	N/A	N/A	0	N/A	0	0	233
8/22/2007	0	0	0	N/A	N/A	0	N/A	0	0	234
8/23/2007	0.03	N/A	0	N/A	N/A	0	N/A	0	0	235
8/24/2007	0	N/A	0	N/A	N/A	0	N/A	0	0	236
8/25/2007	0	N/A	0	N/A	N/A	0	N/A	4.38	0	237
8/26/2007	0	N/A	0	N/A	N/A	0	N/A	3.45	5.96	238
8/27/2007	12.1	N/A	N/A	N/A	N/A	11.02	N/A	10.34	0.56	239
8/28/2007	0	N/A	N/A	N/A	N/A	N/A	N/A	0	0	240

Table 2. Total rainfall, in mm, recorded daily at each of the weather stations. N/A indicates that the station did not collect data that day.—Continued

Date	AZ C:05:0031 L	AZ C:05:0031 U	AZ C:13:0006	AZ C:13:0336 U	AZ C:13:0346 L	AZ C:13:0346 U	AZ B:11:0281	AZ A:15:0033	AZ G:03:0072	Year Day
8/29/2007	0	N/A	N/A	N/A	N/A	N/A	N/A	0	0	241
8/30/2007	0	N/A	N/A	N/A	0	N/A	N/A	0.23	7.84	242
8/31/2007	0	N/A	N/A	N/A	0	N/A	N/A	0	0	243
9/1/2007	0.46	N/A	N/A	N/A	1.42	N/A	N/A	0	0	244
9/2/2007	0	N/A	N/A	N/A	0	N/A	N/A	0.27	0.03	245
9/3/2007	0	N/A	N/A	N/A	0.36	N/A	N/A	0.33	0	246
9/4/2007	0	N/A	N/A	N/A	0	N/A	N/A	0	0.03	247
9/5/2007	0	N/A	N/A	N/A	0	N/A	N/A	0.03	0.19	248
9/6/2007	0	N/A	N/A	N/A	0	N/A	N/A	N/A	N/A	249
9/7/2007	0	N/A	N/A	N/A	0	N/A	N/A	N/A	N/A	250
9/8/2007	0	N/A	N/A	N/A	0	N/A	N/A	N/A	N/A	251
9/9/2007	0	N/A	N/A	N/A	0.08	N/A	N/A	N/A	N/A	252
9/10/2007	1.14	N/A	N/A	N/A	0.05	N/A	N/A	N/A	N/A	253
9/11/2007	0	N/A	N/A	N/A	1.78	N/A	N/A	N/A	N/A	254
9/12/2007	0	N/A	N/A	N/A	0	N/A	N/A	N/A	N/A	255
9/13/2007	0	N/A	N/A	N/A	0	N/A	N/A	N/A	N/A	256
9/14/2007	0	N/A	N/A	N/A	0	N/A	N/A	N/A	N/A	257
9/15/2007	0	N/A	N/A	N/A	0	N/A	N/A	N/A	N/A	258
9/16/2007	0.03	0.03	3.00	0.08	0.03	N/A	N/A	N/A	N/A	259
9/17/2007	0.03	0	0	0	0	N/A	N/A	N/A	N/A	260
9/18/2007	0	0	0	0	0	0	N/A	N/A	N/A	261
9/19/2007	0	0	0	0	0	0	N/A	N/A	N/A	262
9/20/2007	0	0	0	0	0	0	N/A	N/A	N/A	263
9/21/2007	0	0	0	0	0	0	0	N/A	N/A	264
9/22/2007	14.68	15.44	30.68	24.16	35.86	36.88	37.44	N/A	N/A	265
9/23/2007	0.03	0.05	0.41	0.51	0.46	0.43	2.69	N/A	N/A	266
9/24/2007	0	0	0	0	0	0	0	0	N/A	267
9/25/2007	0	0	0	0	0	0	0	0	N/A	268
9/26/2007	0	0	0	0	0	0.03	0	0	N/A	269
9/27/2007	0	0	0	0	0	0	0	0	0	270
9/28/2007	0	0	0	0	0	0	0	0	0	271

Table 2. Total rainfall, in mm, recorded daily at each of the weather stations. N/A indicates that the station did not collect data that day.—Continued

Date	AZ C:05:0031 L	AZ C:05:0031 U	AZ C:13:0006	AZ C:13:0336 U	AZ C:13:0346 L	AZ C:13:0346 U	AZ B:11:0281	AZ A:15:0033	AZ G:03:0072	Year Day
9/29/2007	0	0.03	0	0	0.08	0	0	0	0	272
9/30/2007	0	0	0	0	N/A	0	0	0	0	273
10/1/2007	1.42	1.40	4.60	4.24	N/A	6.05	0	0	0	274
10/2/2007	0	0	0	0	N/A	0	0	0	0	275
10/3/2007	0	0	0	0	N/A	0	0	0	0	276
10/4/2007	0.13	0.15	0.64	0	N/A	0.10	0	0	0	277
10/5/2007	0	0	0.03	0.05	N/A	0.10	0	0	0	278
10/6/2007	0	0	0	0	N/A	0	0	0	0	279
10/7/2007	0	0	0	0	N/A	0	0	0	0	280
10/8/2007	0	0	0	0	N/A	0	0	0	0	281
10/9/2007	0	0	0	0	N/A	0	0	0	0	282
10/10/2007	0	0	0	0	N/A	0	0	0	0	283
10/11/2007	0	0	0	0	N/A	0	0	0	0	284
10/12/2007	0	0	0	0	N/A	0	0	0	0	285
10/13/2007	0	0	0.05	0.03	N/A	0	0	0	0	286
10/14/2007	0	0	0	0	N/A	0	0	0	0	287
10/15/2007	0	0	0	0	N/A	0	0	0	0	288
10/16/2007	0.03	0.03	0.36	0	N/A	0	0	0	0	289
10/17/2007	0	0	0	0	N/A	0	0	0	0	290
10/18/2007	0	0	0	0	N/A	0	0	0	0	291
10/19/2007	0	0	0	0	N/A	0	0	0	0	292
10/20/2007	0	0	0	0	N/A	0	0	0	0	293
10/21/2007	0	0	0	0	N/A	0	0	0	0	294
10/22/2007	0	0	0	0	N/A	0	0	0	0	295
10/23/2007	0	0	0	0	N/A	0	0	0	0	296
10/24/2007	0	0	0	0	N/A	0	0	0	0	297
10/25/2007	0	0	0	0	N/A	0	0	0.08	0	298
10/26/2007	0	0	0	0	N/A	0	0	0	0	299
10/27/2007	0	0	0	0	N/A	0	0	0	0	300
10/28/2007	0	0	0	0	N/A	0	0	0	0	301
10/29/2007	0	0	0	0	N/A	0	0	0	0	302

Table 2. Total rainfall, in mm, recorded daily at each of the weather stations. N/A indicates that the station did not collect data that day.—Continued

Date	AZ C:05:0031 L	AZ C:05:0031 U	AZ C:13:0006	AZ C:13:0336 U	AZ C:13:0346 L	AZ C:13:0346 U	AZ B:11:0281	AZ A:15:0033	AZ G:03:0072	Year Day
10/30/2007	0	0	0	0	N/A	0	0	0	0	303
10/31/2007	0	0	0	0	N/A	0	0	0	0	304
11/1/2007	0	0	0	0	N/A	0	0	0	0	305
11/2/2007	0	0	0	0	N/A	0	0	0	0	306
11/3/2007	0	0	0	0	N/A	0	0	0	0	307
11/4/2007	0	0	0	0	N/A	0	0	0	0	308
11/5/2007	0	0	0	0	N/A	0	0	0	0	309
11/6/2007	0	0	0	0	N/A	0	0	0	0	310
11/7/2007	0	0	0	0	N/A	0	0	0	0	311
11/8/2007	0	0	0	0	N/A	0	0	0	0	312
11/9/2007	0	0	0	0	N/A	0	0	0	0	313
11/10/2007	0	0	0	0	N/A	0	0	0	0	314
11/11/2007	0.08	0.10	0	0	N/A	0	1.68	0.13	0.05	315
11/12/2007	0	0	0	0	N/A	0	0.89	0.03	0.33	316
11/13/2007	0	0	0	0	N/A	0	0	0	0	317
11/14/2007	0	0	0	0	N/A	0	0	0	0	318
11/15/2007	0	0	0	0	N/A	0	0	0	0	319
11/16/2007	0	0	0	0	N/A	0	0	0	0	320
11/17/2007	0	0	0	0	N/A	0	0	0	0	321
11/18/2007	0.03	0	0	0	N/A	0	0	0	0	322
11/19/2007	0	0	0	0	N/A	0	0	0	0	323
11/20/2007	0.05	0	0	0	N/A	0	0	0	0	324
11/21/2007	0	0	0	0	N/A	0	0	0	0	325
11/22/2007	0	0	0	0	N/A	0	0	0	0	326
11/23/2007	0	0	0	0	N/A	0	0	0	0	327
11/24/2007	0	0	0	0	N/A	0	0	0	0	328
11/25/2007	0	0.03	0	0	N/A	0	0	0	0	329
11/26/2007	0.03	0	0	0	N/A	0	0	0	0	330
11/27/2007	0	0	0	0	N/A	N/A	0	0	0	331
11/28/2007	0	0	0	0	N/A	N/A	0	0	0	332
11/29/2007	0	0	0	0	N/A	N/A	0	0	0	333

Table 2. Total rainfall, in mm, recorded daily at each of the weather stations. N/A indicates that the station did not collect data that day.—Continued

Date	AZ C:05:0031 L	AZ C:05:0031 U	AZ C:13:0006	AZ C:13:0336 U	AZ C:13:0346 L	AZ C:13:0346 U	AZ B:11:0281	AZ A:15:0033	AZ G:03:0072	Year Day
11/30/2007	4.32	4.67	6.40	5.87	N/A	N/A	19.41	21.64	23.85	334
12/1/2007	12.32	11.43	20.50	18.01	N/A	N/A	14.43	12.45	11.71	335
12/2/2007	0	0	0	0	N/A	N/A	0	0	0	336
12/3/2007	0	0	0	0	N/A	N/A	0	0	0	337
12/4/2007	0	0	0	0	N/A	N/A	0	0	0	338
12/5/2007	0	0	0	0	N/A	N/A	0	0	0	339
12/6/2007	0	0	0.03	0.23	N/A	N/A	0.03	0.13	0	340
12/7/2007	5.61	6.02	5.26	1.63	N/A	N/A	16.89	8.71	4.60	341
12/8/2007	0	0	0.03	0.03	N/A	N/A	2.34	0.76	3.45	342
12/9/2007	0	0	0	0	N/A	N/A	0	0.03	0.05	343
12/10/2007	0.25	0.30	0.66	0.61	N/A	N/A	0.15	4.32	0.10	344
12/11/2007	0	0	1.04	4.19	N/A	N/A	0.03	4.09	0.08	345
12/12/2007	0	0	0	0	N/A	N/A	0	0	0	346
12/13/2007	0	0	0	0	N/A	N/A	0	0	0	347
12/14/2007	0	0	0	0	N/A	N/A	0	0	0	348
12/15/2007	0	0	0	0	N/A	N/A	0	0	0	349
12/16/2007	0	0	0	0	N/A	N/A	0	0	0	350
12/17/2007	0	0	0	0	N/A	N/A	0	0	0	351
12/18/2007	0	0	0	0	N/A	N/A	0	0	0	352
12/19/2007	0	0	0	0	N/A	N/A	0.28	0.20	0.18	353
12/20/2007	0	0	0.51	0	N/A	N/A	0	0.41	0.08	354
12/21/2007	0	0	1.96	1.57	N/A	N/A	0.89	0	0	355
12/22/2007	0.03	0	0	0	N/A	N/A	0	0	0	356
12/23/2007	0	0	0	0	N/A	N/A	0	0	0	357
12/24/2007	0	0	0	0	N/A	N/A	0	0	0	358
12/25/2007	0	0	0	0	N/A	N/A	0	0	0	359
12/26/2007	0.03	0	0	0	N/A	N/A	0	0	0	360
12/27/2007	0	0	0	0	N/A	N/A	0	0	0	361
12/28/2007	0	0	0	0	N/A	N/A	0	0	0	362
12/29/2007	0	0	0	0	N/A	N/A	0	0	0	363
12/30/2007	0	0	0	0	N/A	N/A	0	0	0	364
12/31/2007	0	0	0	0	N/A	N/A	0	0	0	365

Table 3. Vector sums of the sediment-transport proxy variable, *Qp* (equation 1), by month for each weather station.

[Vector sums are reported as the magnitude of *Qp* (in m3 s-3) followed by the direction from which this net transport would occur, in degrees. *A*, vector sums for all months at all stations where mostly complete months of data are available (February 2007 is omitted because at most only a few days of data were available from each station for that month). These calculations were made irrespective of rain events. B, vector sums re-calculated using wind data only from time when sand is assumed to have been dry enough to transport sand. These calculations (in *B*) omit wind data collected within 48 hours after a rain event]

A

Station	Mar-07	Apr-07	May-07	Jun-07	Jul-07	Aug-07	Sep-07	Oct-07	Nov-07	Dec-07
AZ C:05:0031 L	2688, 248	3257, 230	N/A	10486, 236	895, 183	648, 118	3807, 242	1798, 227	2280, 115	20599, 106
AZ C:05:0031 U	5842, 205	10776, 240	10159, 238	13349, 245	5787, 227	2711, 232	9818, 247	6847, 239	2426, 141	23070, 142
AZ C:13:0006	2488, 119	8691, 130	5916, 122	7347, 106	5038, 141	3336, 137	5689, 120	7114, 133	404, 73	3593, 11
AZ C:13:0336 U	32815, 163	N/A	N/A	N/A	N/A	N/A	42638, 169	43170, 142	65778, 24	85762, 65
AZ C:13:0346 L	52684, 243	N/A	N/A	N/A	N/A	N/A	57720, 256	N/A	N/A	N/A
AZ C:13:0346 U	33718, 230	47626, 237	36936, 241	41134, 242	6798, 215	11475, 232	18850, 250	25787, 236	1207, 101	N/A
AZ B:11:0281	25108, 86	3724, 310	N/A	N/A	N/A	N/A	8998, 97	3597, 97	1336, 292	1967, 274
AZ A:15:0033	430, 214	662, 138	1051, 172	3385, 185	165, 339	1140, 198	763, 195	1284, 215	3559, 354	1077, 346
AZ G:03:0072	9210, 201	11197, 195	10795, 195	17360, 205	12327, 206	9801, 201	4017, 204	13665, 198	452, 101	2585, 67

B

Station	Mar-07	Apr-07	May-07	Jun-07	Jul-07	Aug-07	Sep-07	Oct-07	Nov-07	Dec-07
AZ C:05:0031 L	553, 234	3231, 238	N/A	3254, 249	639, 209	231, 221	3086, 245	579, 160	1605, 111	14827, 101
AZ C:05:0031 U	4022, 199	9099, 245	10136, 242	3067, 250	3169, 225	1089, 231	5800, 248	1649, 215	2224, 141	22585, 135
AZ C:13:0006	714, 87	4333, 120	3135, 114	7539, 136	1685, 142	2305, 135	4324, 115	1592, 6	408, 76	1792, 314
AZ C:13:0336 U	4554, 100	N/A	N/A	N/A	N/A	N/A	23428, 168	29218, 129	59415, 23	65954, 34
AZ C:13:0346 L	11017, 245	N/A	N/A	N/A	N/A	N/A	34561, 256	N/A	N/A	N/A
AZ C:13:0346 U	5925, 233	13524, 241	18301, 241	32412, 242	3937, 204	6621, 232	17598, 251	11643, 225	1207, 101	N/A
AZ B:11:0281	21376, 83	1471, 312	N/A	N/A	N/A	N/A	7620, 96	3269, 269	1247, 294	2859, 273
AZ A:15:0033	384, 199	583, 139	971, 175	3385, 185	85, 230	848, 200	848, 192	1330, 213	3479, 353	1400, 1
AZ G:03:0072	7825, 200	11312, 197	9497, 203	16333, 203	6096, 207	6237, 203	1199, 207	13665, 198	459, 94	2585, 67

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