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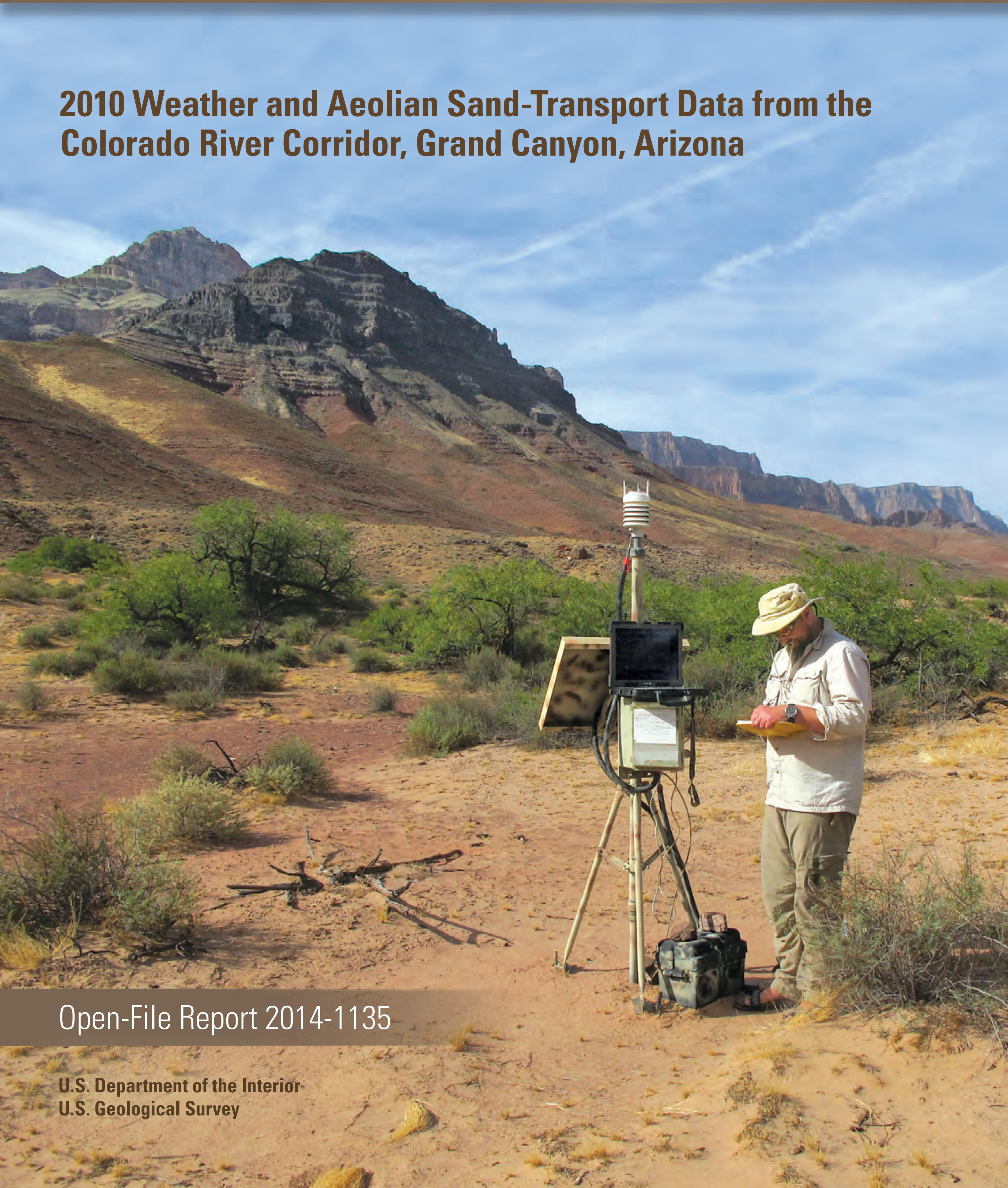
2010 Weather and Aeolian Sand-Transport Data from the Colorado River Corridor, Grand Canyon, Arizona



Open-File Report 2014-1135

U.S. Department of the Interior
U.S. Geological Survey

Cover: Photograph showing USGS employee Joshua Caster downloading weather data in Grand Canyon, Arizona, May 2014. Photograph by Helen Fairley.

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U.S. Geological Survey
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Conversion Factors

SI to Inch/Pound

Multiply	By	To obtain
	Length	
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Flow rate	
meter per second (m/s)	3.281	foot per second (ft/s)
cubic meter per second (m^3/s)	70.07	acre-foot per day (acre-ft/d)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)
	Pressure	
Millibar (mbar)	0.01	pounds per square inch (lbs/in^2)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8\times°C)+32.$$

Abbreviations and Acronyms

BSNE	Big Spring Number Eight
HFE	high-flow experiment
MFS	modern fluvial sourced
RFS	relict fluvial sourced
RH	relative humidity

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Abstract

Measurements of weather parameters and aeolian sand transport were made in 2010 near selected archeological sites in the Colorado River corridor through Grand Canyon, Arizona. Data collected in 2010 indicate event- and seasonal-scale variations in rainfall, wind, temperature, humidity, and barometric pressure. Differences in weather patterns between 2009 and 2010 included a slightly later spring windy season, greater spring precipitation and annual rainfall totals, and a later onset and length of the reduced diurnal barometric-pressure fluctuations commonly associated with summer monsoon conditions. The increase in spring precipitation was consistent with the 2010 spring El Niño conditions compared to the 2009 spring La Niña conditions, whereas the subsequent transition to an El Niño-Southern Oscillation neutral phase appeared to delay the reduction in diurnal barometric fluctuations.

Introduction

This report summarizes high-resolution measurements of wind speed and direction, rainfall, air temperature, barometric pressure, and relative humidity made during calendar year 2010 at weather stations operated by the U.S. Geological Survey Grand Canyon Monitoring and Research Center in the Colorado River corridor in Grand Canyon National Park, Arizona. These stations provide meteorological data for the interior of Grand Canyon that complement daily temperature and rainfall measurements made by the National Park Service near river mile 88 (fig. 1). In addition to meteorological information collected by the weather stations, sand traps deployed near each weather station collect aeolian (windblown) sand from which seasonal sand-transport rates are estimated.

Calendar year 2010 is the fourth consecutive year that weather stations have operated continuously at the same locations in the Colorado River corridor in Grand Canyon National Park. Before 2007, Draut and Rubin (2005, 2006, 2007, 2008) maintained anemometers and tipping bucket rain gages at some of these same locations, as well as at several additional locations in the Colorado River corridor. Following a 1-year hiatus, and in conjunction with a new monitoring and research initiative (Fairley and others, 2007), 9 weather stations and 10 sand traps were installed in 2007 near 7 archaeological sites; 2 additional weather stations and 4 more sets of sand traps were installed in 2008, bringing to 11 and 14 the total number of weather stations and sand traps deployed in Grand Canyon. Previous annual reports documented the data collected in 2007, 2008, and 2009 (Draut and others, 2009a, 2009b, 2010.)

This report follows Draut and Rubin (2008) and Draut (2012) in referring to aeolian sand deposits as belonging to one of two types—modern fluvial sourced (MFS) and relict fluvial sourced (RFS) deposits. The two types of aeolian deposits are distinguishable by their surface characteristics, particularly the abundance of biologic soil crust (Draut, 2012), and are defined by their position relative to modern fluvial sandbars (those that formed at river flows of 1,270 m^3/s or less) that could have provided windblown sand for their formation. MFS dune fields are situated directly downwind of active (postdam) fluvial sandbars and were formed as the wind moved sand inland from those sandbars, creating dune fields. RFS deposits, in contrast, formed as wind reworked sediment from older (pre-dam), high-elevation flood deposits, forming aeolian sand dunes from sediment left by floods that were larger than any post-dam floods. At times, RFS dunes may receive some sand from modern sandbars under certain wind directions; however, the major source of sand for these dunes is older deposits left by floods greater than 1,270 m^3/s.

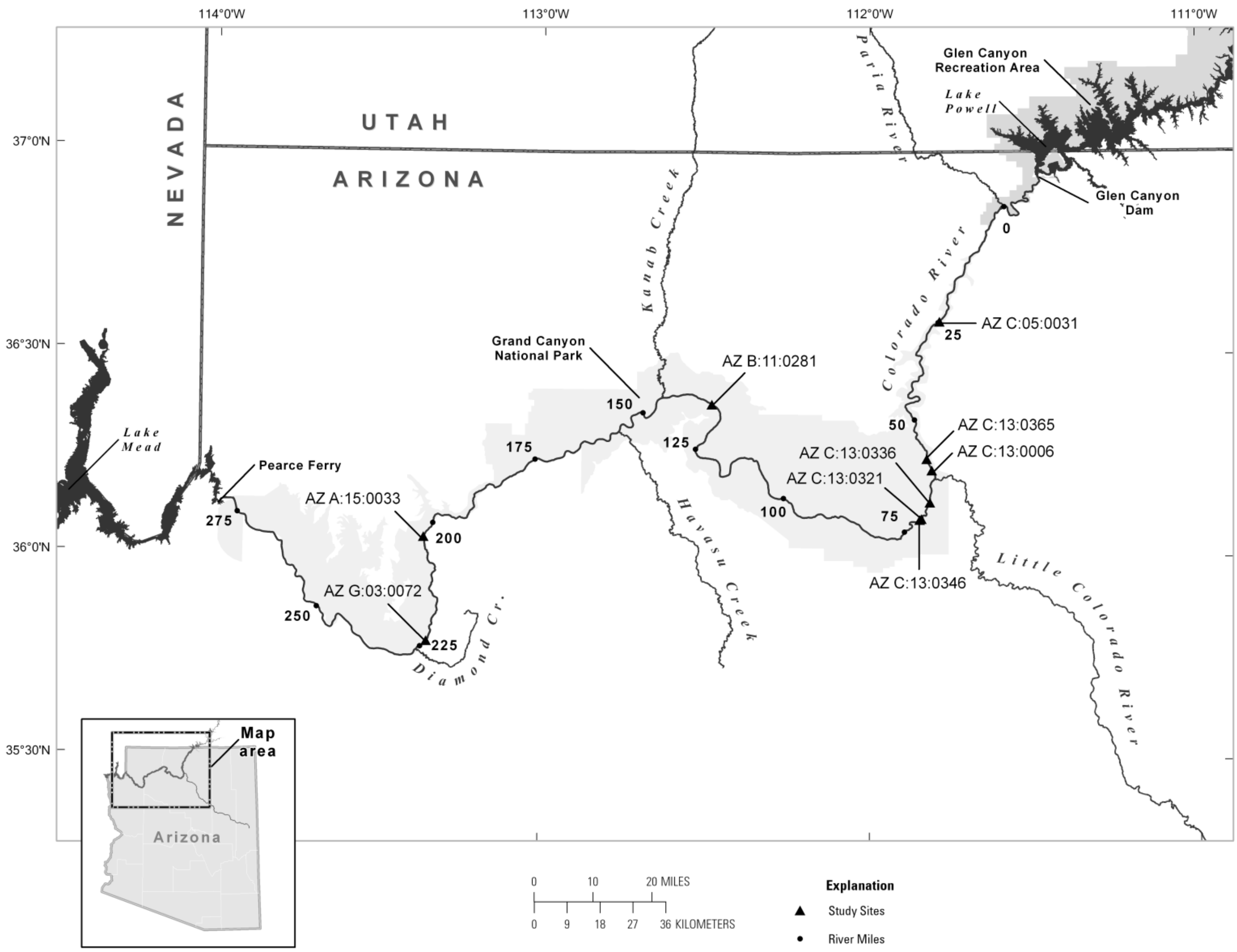

Figure 1. Map showing locations of study sites in Colorado River corridor through Grand Canyon, Arizona. The river reach between Lees Ferry and Little Colorado River is known as Marble Canyon and river miles indicate the distance downstream of Lees Ferry, Arizona.

Project Objectives

The weather data described in this report were collected as part of a larger research effort focused on developing standardized, replicable, quantitative monitoring protocols for measuring ecosystem processes affecting archaeological site stability in the Colorado River corridor of Grand Canyon National Park, Arizona. Methods are being developed, as a part of this larger project, to assess the relation between physical landscape processes, including weather and aeolian sediment transport, and the physical integrity of archeological sites. Objectives specific to the weather monitoring component of this project include

1. Evaluating the utility and practicality of using Vaisala™ transmitters for high-resolution monitoring of local weather conditions in the remote, logistically challenging environment of the inner Grand Canyon;
2. Evaluating the spatial and temporal variability of weather parameters at select sites distributed throughout the Colorado River corridor in Grand Canyon;
3. Evaluating the effects of weather and sediment transport on the physical condition of archaeological sites there; and
4. Applying the methods developed through this project to evaluate the effects of experimental high-flow releases from Glen Canyon Dam on downstream resources, including sandbars, aeolian dunes, and archeologically sensitive areas.

This report is focused primarily on results related to objective 2. Objective 1 was addressed in a previous publication (Draut and others, 2009a), whereas objective 4 was addressed previously by Draut and others (2009b, 2010) and Draut (2012). Objective 3 has been addressed partially in reports by Collins and others (2009, 2012), and is the subject of continuing research.

The physical processes represented by data collected in this study include seasonal weather cycles of wind intensity, humidity, barometric pressure, and precipitation patterns, and individual storm events. High-resolution weather data, when combined with high-resolution topographic surveys, form one basis from which to assess potential or measured effects of Glen Canyon Dam operations on archaeological sites in the Colorado River corridor (Fairley and Sondossi, 2010). Additionally, when compiled into decadal-scale records, weather data such as these can be used to identify regional climatic trends. Given that in recent years the Colorado River Basin has warmed more than other areas of the United States (Saunders and others, 2008), records such as these may prove valuable to a wide range of ecosystem studies.

Methods

Since early 2007, nine instrument stations have operated near seven archeological sites in the Colorado River corridor indicated in figure 1: AZ C:05:0031, AZ C:13:0006, AZ C:13:0336, AZ C:13:0346, AZ B:11:0281, AZ A;15:0033, and AZ G:03:0072. In February 2008, two additional instrument stations were deployed near site AZ C:13:0365 (AZ C:13:0365 L and U), and new sand traps were deployed near AZ C:13:0321 and AZ C:13:0336 (AZ C:13:0336 L) in order to collect data relevant to the March 2008 high-flow experiment (HFE). All these instrument stations continued operating throughout 2010. Each "instrument station" consists of one weather station and one set of sand traps. At sites AZ C:05:0031, AZ C:13:0365, and AZ C:13:0346, two independent instrument stations operate approximately 80 m apart from each other in order to resolve differences in weather and aeolian sand transport that occur at varying elevations and distances from the river. At sites AZ C:13:0336 and AZ G:03:0072, an additional set of sand traps is present approximately 40 m away from the weather station, closer to the river. The names of each station in this report, the locations of the study sites by approximate river mile, the date the instruments were installed, the type of equipment that operated at each site in 2010, and the general setting of each dune field (MFS, RFS, or other type) are shown in table 1.

Table 1. Station names, approximate river miles, equipment deployed at each study site, date at which each station was established, and type of aeolian setting at each study site, Colorado River corridor, Grand Canyon, Arizona.

[Dune field type: MFS, Modern Fluvial Sourced; RFS, Relict Fluvial Sourced; Intermediate, combination of MFS and RFS]

Station name	Approximate river mile	Equipment	Date established	Dune field type
AZ C:05:0031L	25	Weather station, sand traps	2/23/2007	MFS
AZ C:05:0031U	25	Weather station, sand traps	2/23/2007	MFS
AZ C:13:0365L	60	Weather station, sand traps	2/09/2008	MFS
AZ C:13:0365U	60	Weather station, sand traps	2/09/2008	MFS
AZ C:13:0006	60	Weather station, sand traps	2/25/2007	Intermediate
AZ C:13:0336U	65	Weather station, sand traps	2/26/2007	RFS
AZ C:13:0336L	65	Sand traps	2/10/2008	Cobble bar
AZ C:13:0321	70	Sand traps	2/10/2008	MFS
AZ C:13:0346U	70	Weather station, sand traps	2/27/2007	RFS
AZ C:13:0346L	70	Weather station, sand traps	2/27/2007	RFS
AZ B:11:0281	135	Weather station, sand traps	3/04/2007	Intermediate
AZ A:15:0033	203	Weather station, sand traps	3/07/2007	RFS
AZ G:03:0072U	223	Weather station, sand traps	3/08/2007	MFS
AZ G:03:0072L	223	Sand traps	3/08/2007	MFS

Study sites were selected to provide data relevant to monitoring the changing condition and stability of nearby archeological sites where topographic surveys were conducted (Collins and others, 2009, 2012; O'Brien and Pederson, 2009). Instrument stations were deployed near archeological sites (but not near enough to disturb any cultural features or artifacts). Several of the study sites were selected because of their apparent responsiveness to experimental sandbar-building flows in 1996 and 2004 (Draut and Rubin, 2006). These sites were retained for this study in order to extend weather records at these locations and to be able to compare results from previous high-flow experiments (HFEs) with future HFEs. Study sites were distributed along the river corridor between upper Marble Canyon (approximately river mile 25) and the western Grand Canyon (approximately river mile 225) in order to record spatial variations in weather patterns throughout the river corridor (fig. 1).

Monitoring Weather Parameters

Specifications of the weather stations were established and fine-tuned during 2007; details of equipment design and modifications made for use in Grand Canyon were discussed by Draut and others (2009a). 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™ multi-parameter weather transmitter, model WXT510/520 with serial data interface SDI-12, is mounted 2 m above ground level. The data logger is a Nexsens™ iSIC logger upgraded to 2 megabytes of 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 BPSX30U model made by BP Solar™, modulated by a SK-6 Morningstar Solar™ 12 VDC, 6A controller. The manufacturer's stated measurement range for wind speed measured by the Vaisala™ WXT510/520 transmitter is 0–60 m/s, with an accuracy of ±0.3 m/s or ±3 percent, whichever is greater, for wind speeds of 0–35 m/s. For wind speeds of 36–60 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 wind-direction accuracy of ±8°. The transmitter has an estimated response time of 250 ms for detecting wind speed and direction. For this study, wind speed and direction are recorded every 4 minutes, with each data record consisting of the 4-minute averaged wind speed, the 4-minute averaged wind direction, and the speed and direction of the highest gust during each 4-minute interval (gust speed measured as 3-second average). A 4-minute interval was selected as the highest resolution that can be used given the capacity of memory in the data loggers and the length of time between data download (often several months).

A pressure sensor on the Vaisala™ WXT510/520 transmitter detects rainfall with a resolution of 0.01 mm and 5 percent accuracy according to the manufacturer. Rainfall is recorded on the data logger at 4-minute intervals as a 4-minute total amount. Air temperature, relative humidity, and barometric pressure are recorded by a separate sensor within the shaded housing of the transmitter. Air temperature from –52 to +60 °C is recorded with an accuracy of ±0.3 °C at 20 °C. Relative humidity (RH) from 0 to 90 percent is measured with an accuracy of ±3 percent, whereas RH from 90 to 100 percent is measured with an accuracy of ±5 percent. The transmitter measures barometric pressure between 600 and 1,100 mbar with an accuracy of ±0.5 mbar at 0–30 °C and ±1 mbar less than 0 °C or greater than 30 °C. 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. Stations were visited for maintenance and data downloading every 12–18 weeks during 2010. All transmitters were replaced during 2009 and 2010 and sent to Vaisala™ for calibration; all were found to have been operating within the manufacturer's stated accuracy ranges during 2010 (Vaisala, 2008; Vaisala, n.d.).

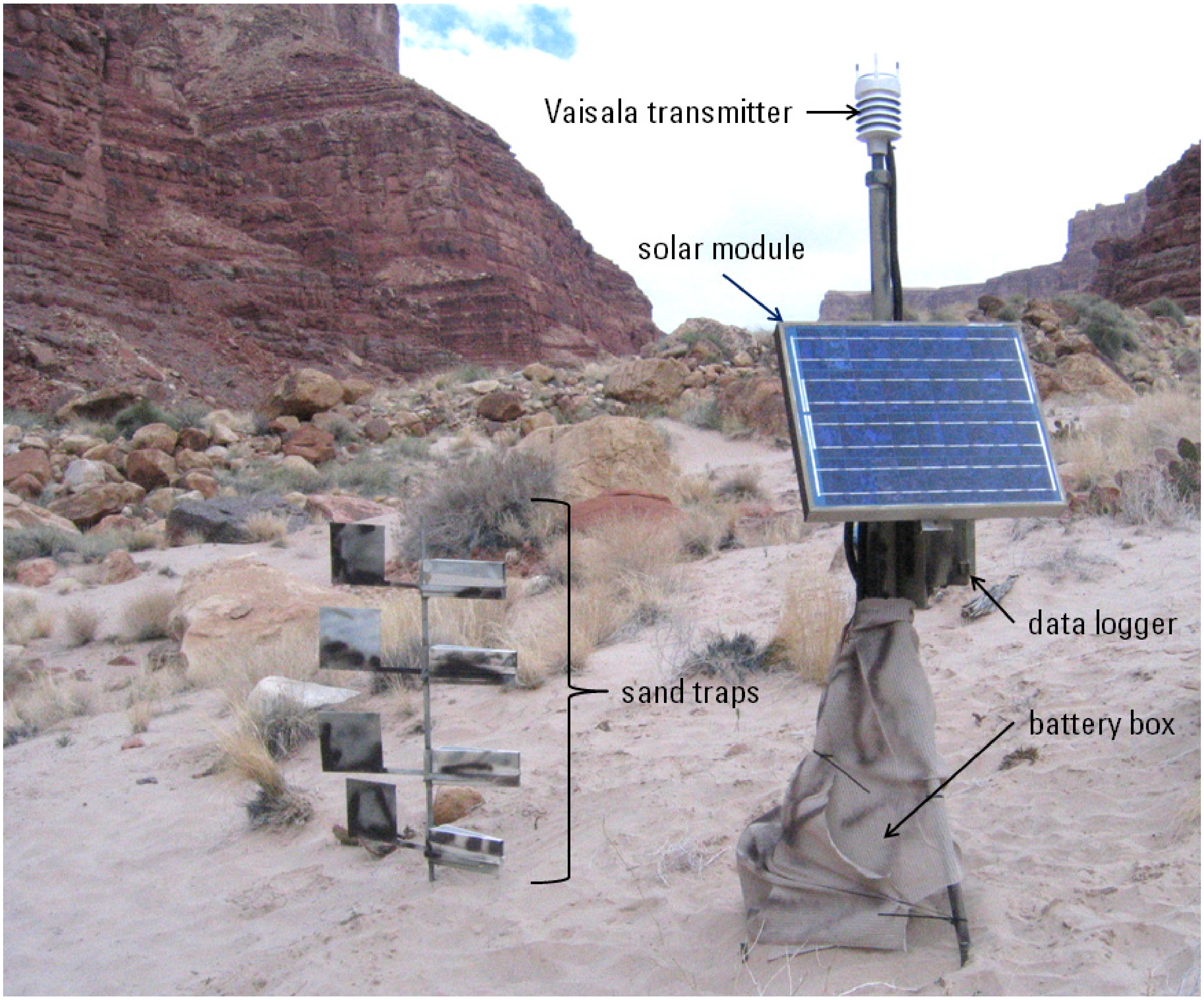

Figure 2. Photograph of instrument station near AZ C:05:0031 L in Grand Canyon, Arizona. The transmitter, data logger, and solar module are mounted on a tripod, and the system is powered by a battery housed in a box on the ground. The pole with four sand traps on it is approximately 3 meters away from the tripod.

Monitoring Aeolian Sediment Transport

Aeolian sediment transport was monitored at each study site using wedge-shaped, galvanized metal “Big Spring Number Eight” (BSNE) passive-sampling sand traps (Fryrear, 1986). Sand traps were emptied during maintenance visits to the instrument stations. To obtain an informative sampling resolution, it generally is necessary to empty sand traps at least once every 12–18 weeks; however, during 2010, some intervals between sand-trap maintenance visits were longer than 18 weeks, reducing the sampling resolution for the aeolian sand-transport measurements. Therefore, sediment-transport measurements were based on cumulative values representing the interval between visits, and were calculated as daily transported mass (in grams per centimeter trap width). Sediment samples were collected from traps in the field and brought back to a laboratory at Northern Arizona University to be weighed. Organic material was removed from the sediment by treating the samples with hydrogen peroxide. Samples were dried overnight in an oven at 80 ºC, allowed to cool in a desiccant chamber, and weighed on a scale with precision to 0.0001 g.

BSNE sand traps in sets of four deployed on a vertical pole were used in this study, with the orifices of the four traps set at heights of 0.1, 0.4, 0.7, and 1.0 m above the ground surface (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 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 one-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. An efficiency range of 70 to 130 percent was used to estimate error in the sand-transport data reported here. This conservative treatment of the data is the best available for the bulk sand-transport data reported here; the exact correspondence between wind velocities and local sand-transport rates is unknown.

To represent the sand-transport potential for a given wind velocity, a proxy variable, *Qp*, was used, which is defined as:

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

where *Qp* is potential sand flux, in cubic meters per cubic second (m^3/s^3),
u is the wind velocity, in meters per second (m/s), and
u_{crit} is the critical threshold of motion (m/s).

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, the *Qp* value for each site over a given time interval serves as a proxy indicating potential for sand transport. *Qp* was calculated for all data points at which u exceeded u_{crit}. The critical threshold of motion is assumed to be 2 m/s based on sediment grain size measured for these study sites and other surficial sediment deposits in the Grand Canyon (Bagnold, 1941; Draut and Rubin, 2005, 2008). For the data points at which u was less than u_{crit}, *Qp* was set equal to zero, indicating that no sand transport would occur. Dominant wind directions causing sand transport then were calculated by using vector sums of *Qp* values from the 4-minute wind measurements. Vector-sum calculations also were 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 generally is sufficiently dry to be mobilized by wind.

Results

Daily rainfall recorded at each weather station during 2010 is shown in table 2 (at back of report). Monthly vector sums of aeolian sand-transport potential at each station are shown in table 3 (at back of report). *Qp* vector sums calculated using all available wind data are shown in table 3*A*, and vector sums for dry conditions are shown in table 3*B*.

Site-Specific Data

The following sections describe the setting of each weather station, any problems with instrument performance, and site-specific findings from 2010. The station numbers reference nearby archeological sites and are presented in geographic order, starting with the farthest-upstream station and proceeding downstream.

Site AZ C:05:0031

Two weather stations operated throughout 2010 in an aeolian dune field on the downstream side of a debris fan at site AZ C:05:0031—one near river level (AZ C:05:0031 L) and one at the upper end of the dune field (AZ C:05:0031 U). Equipment malfunctions did not occur at either weather station in 2010. The dune field between the two weather stations at site AZ C:05:0031 undergoes active sand transport and has moderate vegetation and little biological soil crust (vegetation and biological soil crust were quantified at each study site in 2009; these data are presented in a separate report by Draut (2011). An approximately equal area at the northern (upstream) end of the dune field is relatively inactive, with well-developed biological soil crust and evident deflation of the land surface. Draut and Rubin (2008) identified this dune field as a modern fluvial sourced (MFS) aeolian deposit, based on observations between 2003 and 2006 of net sediment-transport potential from the direction of a river-level sandbar. However, some of the sand in this area apparently was deposited by predam floods and by exceptionally high post-dam flows in 1983, based on its topographic position relative to modeled water-surface elevations (Magirl and others, 2008) and the presence of a penny, dated 1981, found embedded in a fluvial deposit a short distance upstream of the weather station AZ C:05:0031 L. A vector sum of all available wind data from station AZ C:05:0031 L in 2010 yields a net *Qp* magnitude of 43,465 m^3/s^3 from a direction of 246º; using wind data collected only during periods when the sand was estimated to have been dry, a vector sum yields a net *Qp* magnitude of 40,270 m^3/s^3 from a direction of 249º (table 3). These calculations indicate net sand transport generally inland and upstream (fig. 3), with a stronger inland-directed component than was measured at this site in 2009 (net potential sand transport in 2009 was from 215º at station AZ C:05:0031 L; Draut and others, 2009b), although a directional wind plot shows no strong directional component at station AZ C:05:0031 L in 2010 (fig. 4).

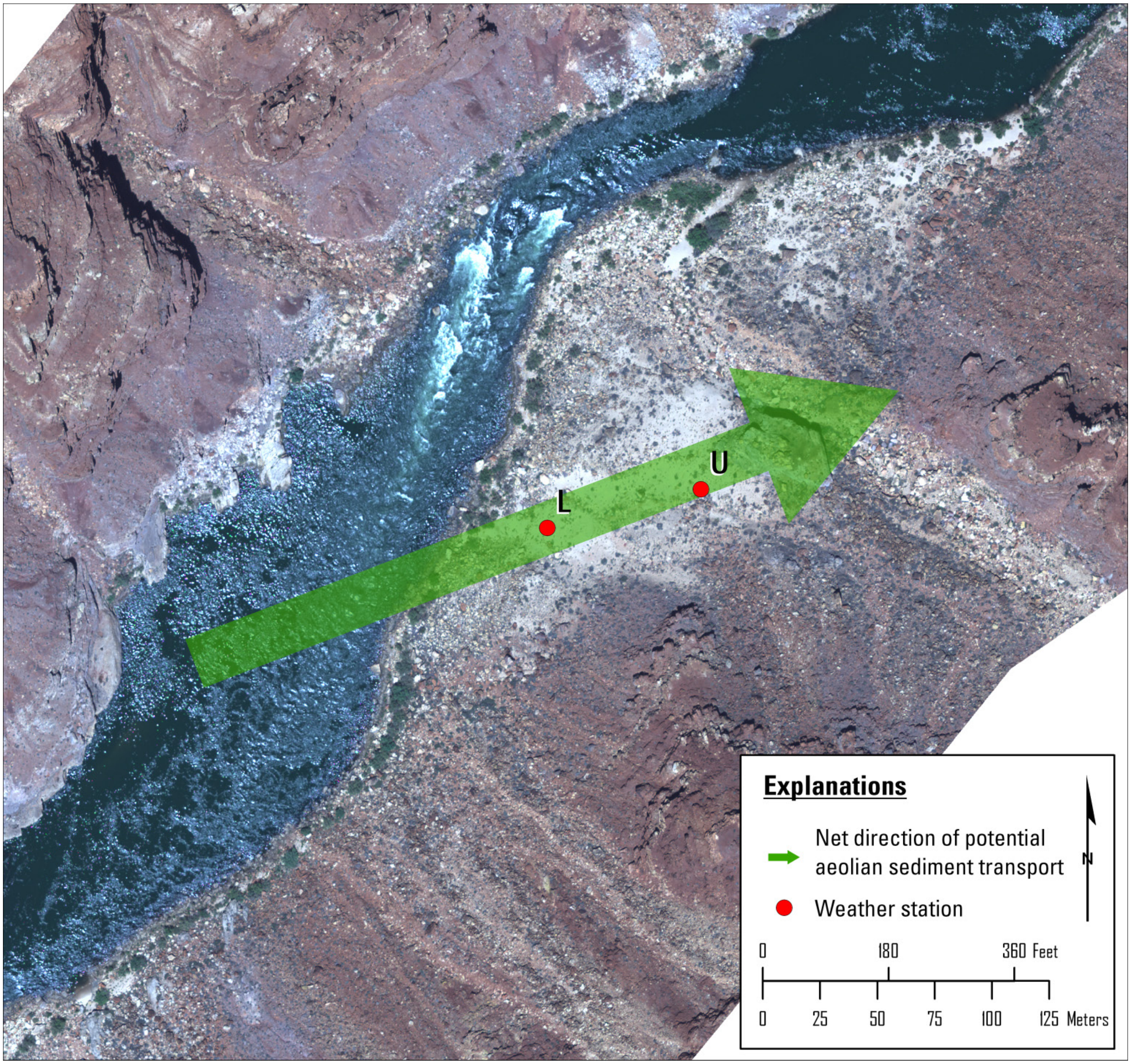

Figure 3. Aerial photograph of the area around site AZ C:05:0031 in Grand Canyon, Arizona. Arrow indicates the net direction of potential aeolian sediment transport measured at AZ C:05:0031 L in 2010. A vector sum of the *Qp* proxy variable (equation 1), calculated using all wind data collected during dry conditions from station AZ C:05:0031 L in 2010, indicates net sediment transport from 246°.

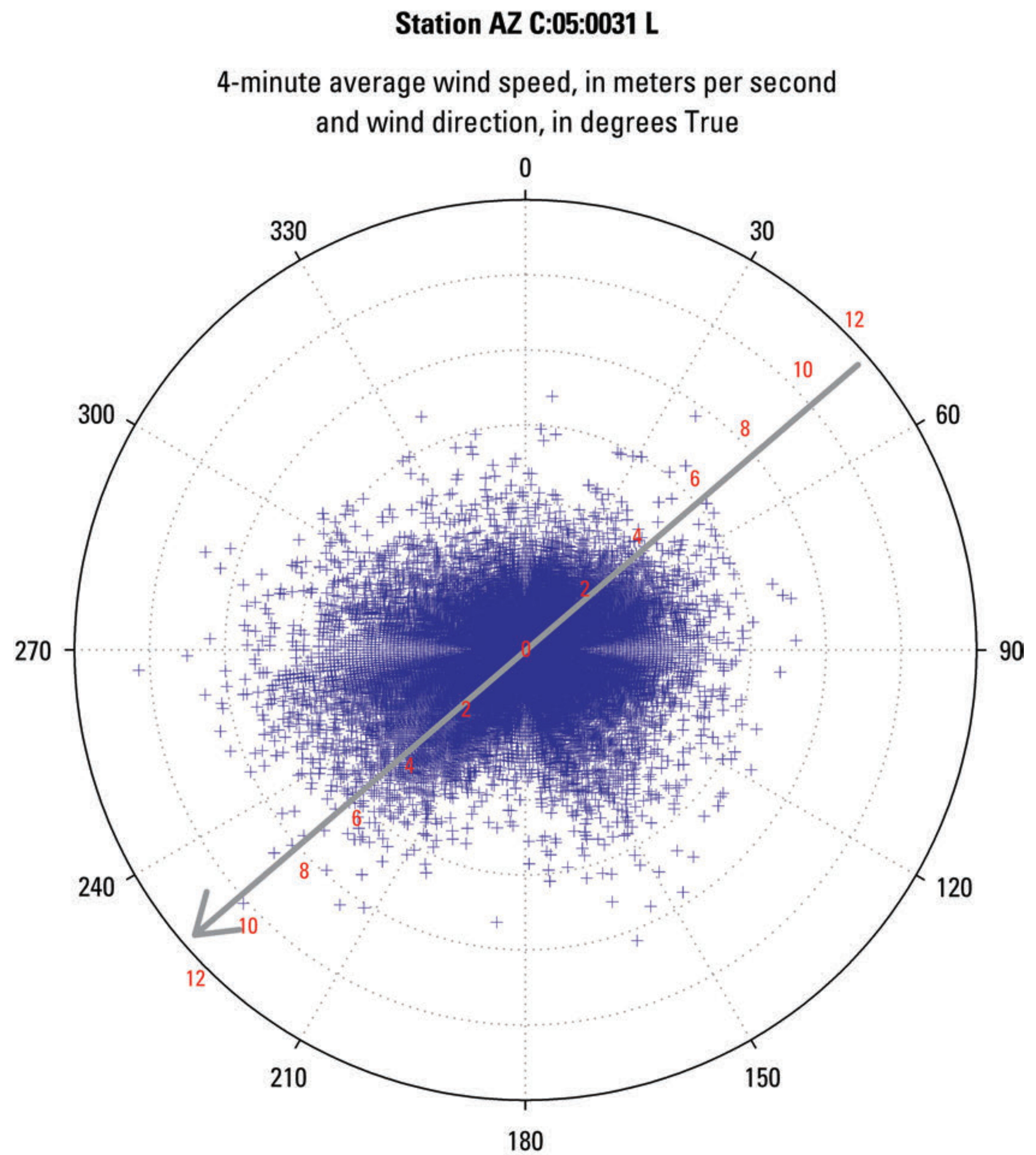

Figure 4. Plot showing magnitude and direction of wind velocity measured at the instrument station AZ C:05:0031 L with 4-minute resolution in Grand Canyon, Arizona, 2010. Magnitude is indicated by the concentric circles, and compass bearing indicates the wind direction. The gray arrow shows the orientation of the river corridor (229°); river flow is toward the southwest.

The total annual rainfall measured at station AZ C:05:0031 L in 2010 was 369.2 mm (table 2), more than three times the amount measured there in 2009; cumulative rainfall data for this station are shown in figure 5. All weather parameters and sand transport measured at station AZ C:05:0031 L in 2010 are summarized in figures 6 and 7, with 2009 data shown for comparison.

A vector sum of all available wind data from station AZ C:05:0031 U (approximately 80 m inland and uphill of station AZ C:05:0031 L) in 2010 yields a net *Qp* magnitude of 149,490 m^3/s^3 from a direction of 245º; using wind data collected only during periods when the sand is estimated to have been dry, a vector sum yields a net *Qp* magnitude of 107,740 m^3/s^3 from a direction of 246º (fig. 8). These calculations indicate net sand transport generally inland and upstream, although, like at the lower station, the directional wind plot (fig. 9) still shows no strong directional component at station AZ C:05:0031 U.

Total annual rainfall measured at station AZ C:05:0031 U in 2010 was 275.9 mm (table 2); cumulative rainfall data for this station are shown in figure 10. All weather parameters and sand transport measured at station AZ C:05:0031 U in 2010 are summarized in figures 11 and 12, with 2009 data shown for comparison.

Wind velocities typically are higher at station AZ C:05:0031 U than at station AZ C:05:0031 L, which is attributed to lower vegetation densities at the upper site. Aeolian sand-transport rates measured at station AZ C:05:0031 U also are correspondingly higher than at station AZ C:05:0031 L (figs. 6, 11). At both the upper and lower stations, the highest sand-transport rates in 2010 occurred in the spring, which is commonly observed in Grand Canyon (Draut and Rubin, 2005, 2006; Draut and others, 2009a, 2009b), although the highest wind speeds in 2010 were observed somewhat later (April–May) than in 2009 (in 2009, the windiest season, evaluated by visual inspection of the 4-minute-averaged wind data plots, was uncharacteristically early and spanned March–April). At both stations, aeolian sand-transport rates were somewhat higher in spring 2010 than in spring 2009—by approximately 30 percent—even given the error margin assigned to these data (figs. 6, 11).

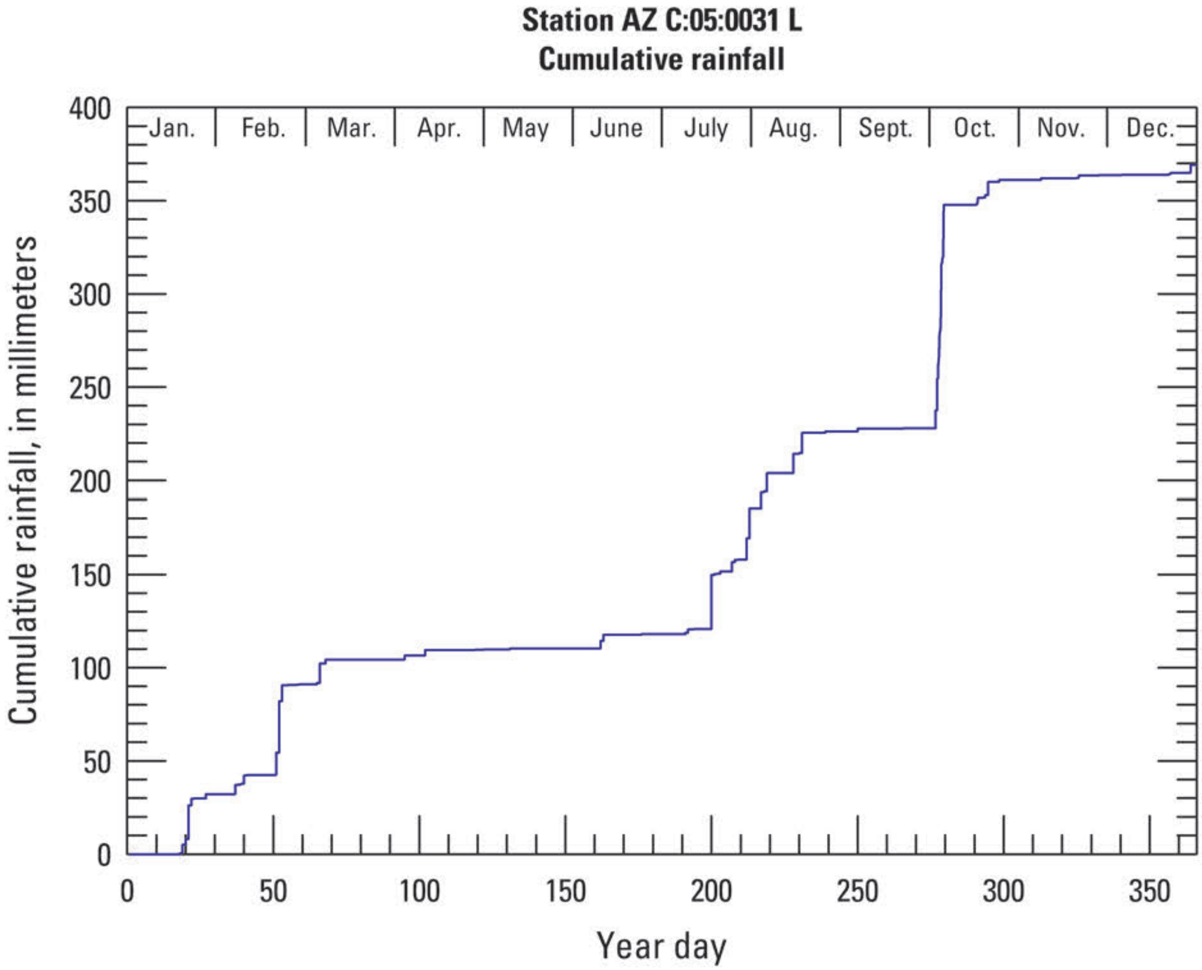

Figure 5. Plot showing cumulative rainfall recorded at station AZ C:05:0031 L compiled from data collected at 4-minute resolution in Grand Canyon, Arizona, 2010.

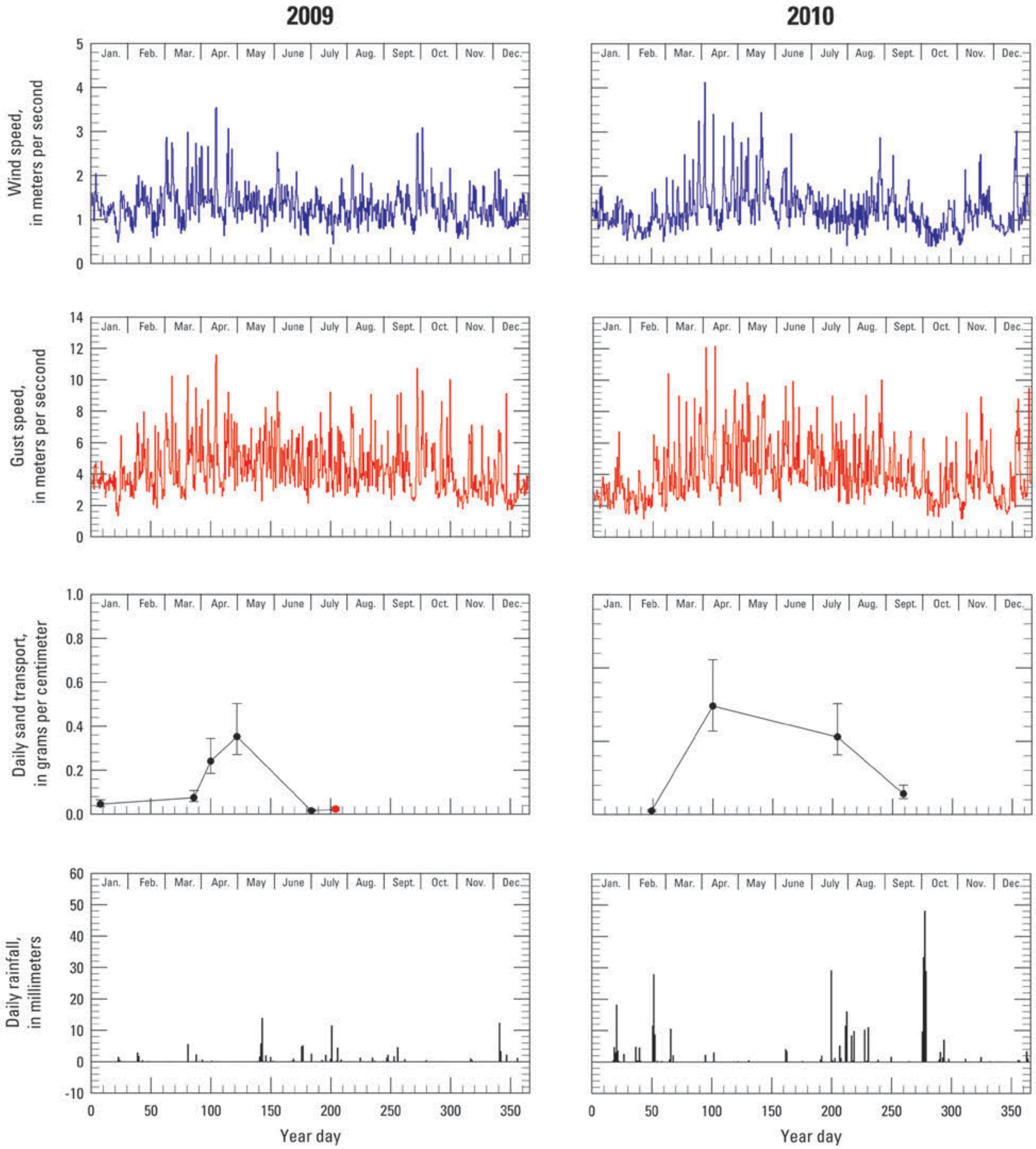

Figure 6. Plots showing wind, aeolian sand-transport, and rainfall data collected at the instrument station AZ C:05:0031 L in Grand Canyon, Arizona, 2009–10. Wind speed is presented as diurnal average values, using daytime (0600–1800 hours) and nighttime (1800–0600 hours) averages of data collected at 4-minute intervals. Gust speed is shown as maximum values that occurred during each diurnal interval. Daily sand transport is plotted in grams, normalized to a width of 1 centimeter. To obtain these values, total sand mass collected from four traps during each maintenance visit was divided by the number of days since the trap had last been emptied. Rainfall is plotted as daily (24-hour) totals.

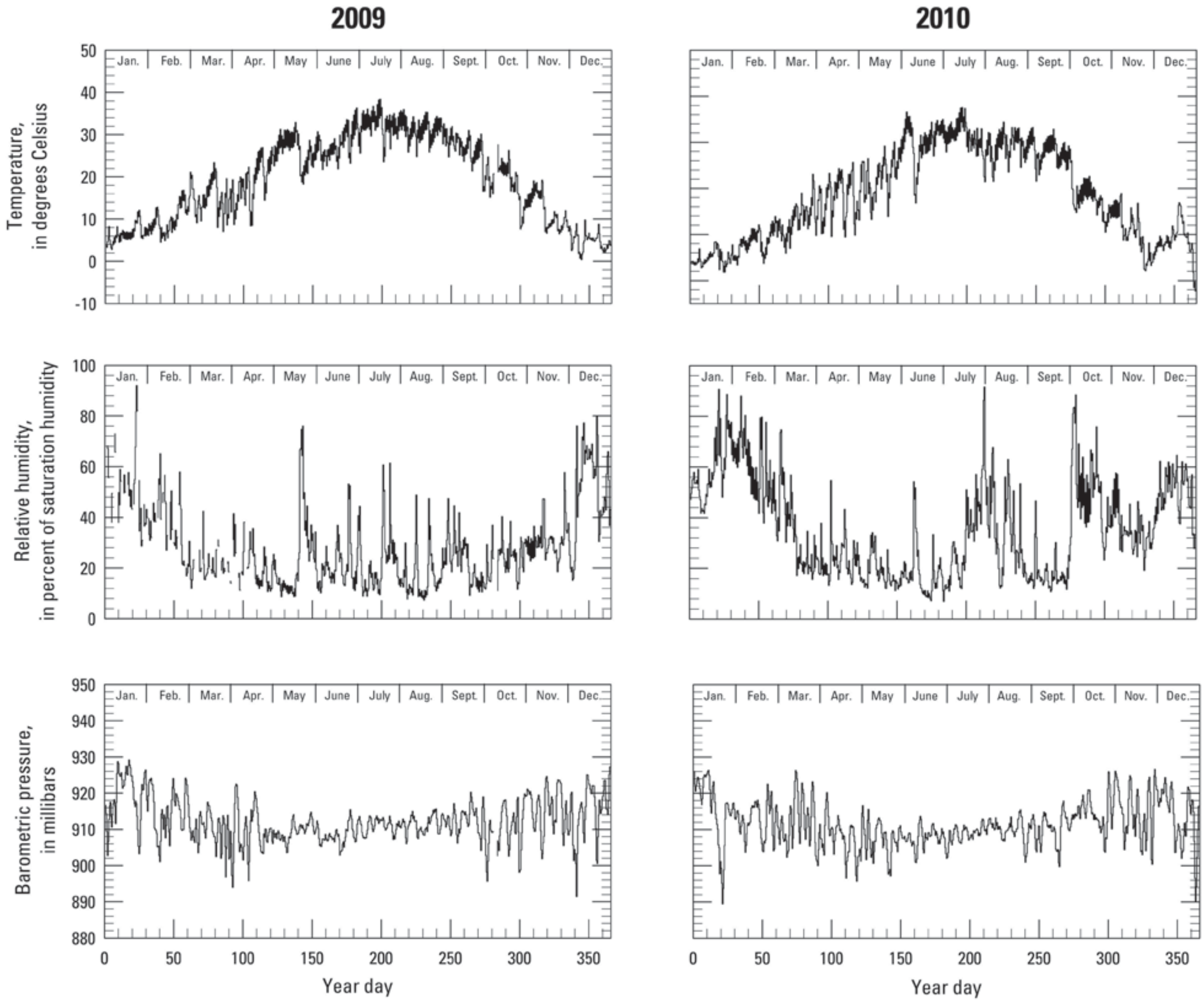

Figure 7. Plots showing temperature, relative humidity, and barometric pressure data collected at instrument station AZ C:05:0031 L in Grand Canyon, Arizona, 2009–10. All parameters are plotted as diurnal averages (defined using 0600–1800 and 1800–0600 hours).

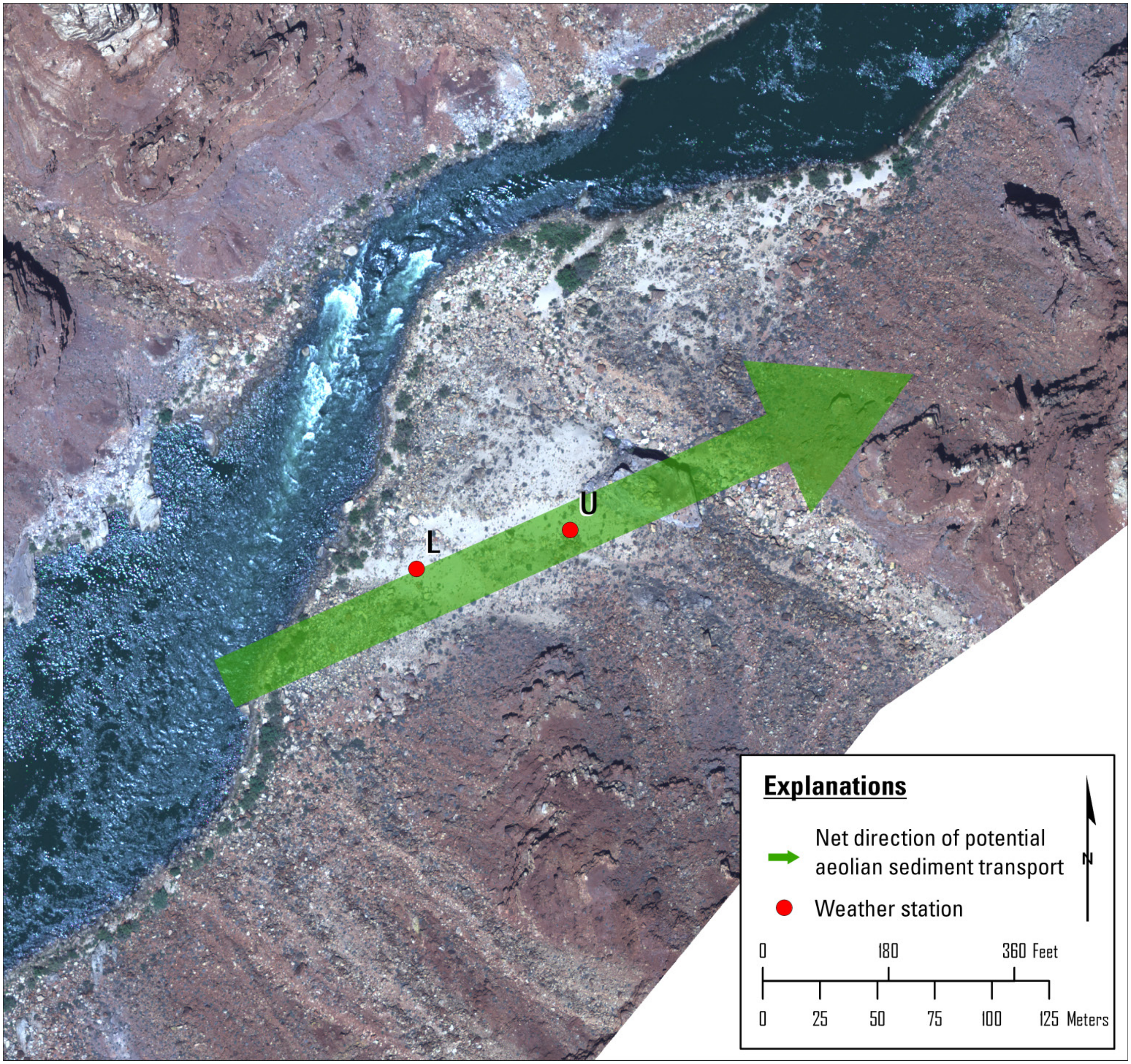

Figure 8. Aerial photograph showing area around site AZ C:05:0031 in Grand Canyon, Arizona. Arrow indicates the net direction of potential aeolian sediment transport measured at AZ C:05:0031 U in 2010. A vector sum of the *Qp* proxy variable (equation 1), calculated using all the wind data collected during dry conditions from station AZ C:05:0031 U in 2010, indicates net sediment transport from 245°.

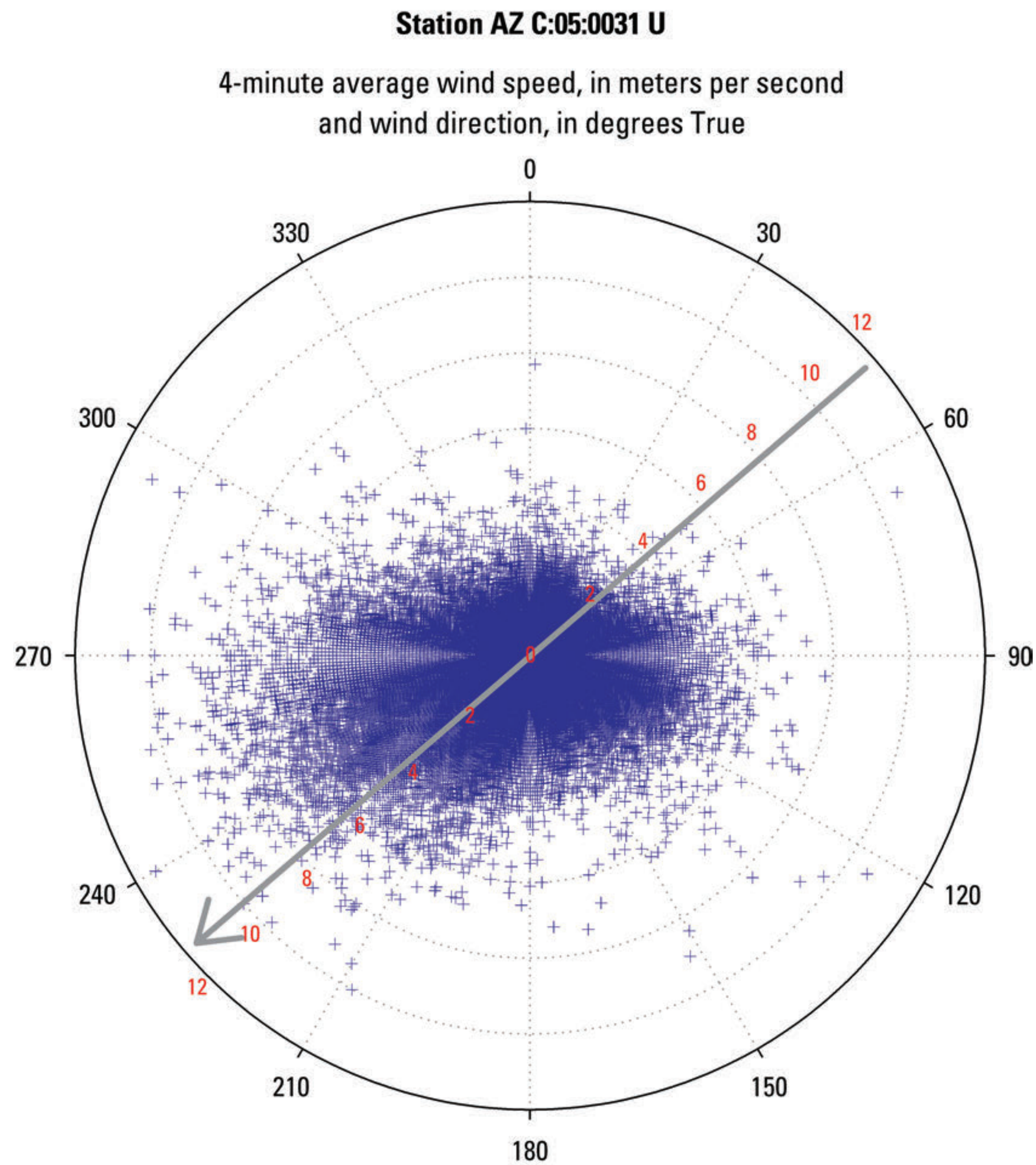

Figure 9. Plot showing magnitude and direction of wind velocity measured at the instrument station AZ C:05:0031 U with 4-minute resolution in Grand Canyon, Arizona, 2010. Magnitude is indicated by the concentric circles, and compass bearing indicates the wind direction. The gray arrow shows the orientation of the river corridor (229°); river flow is toward the southwest.

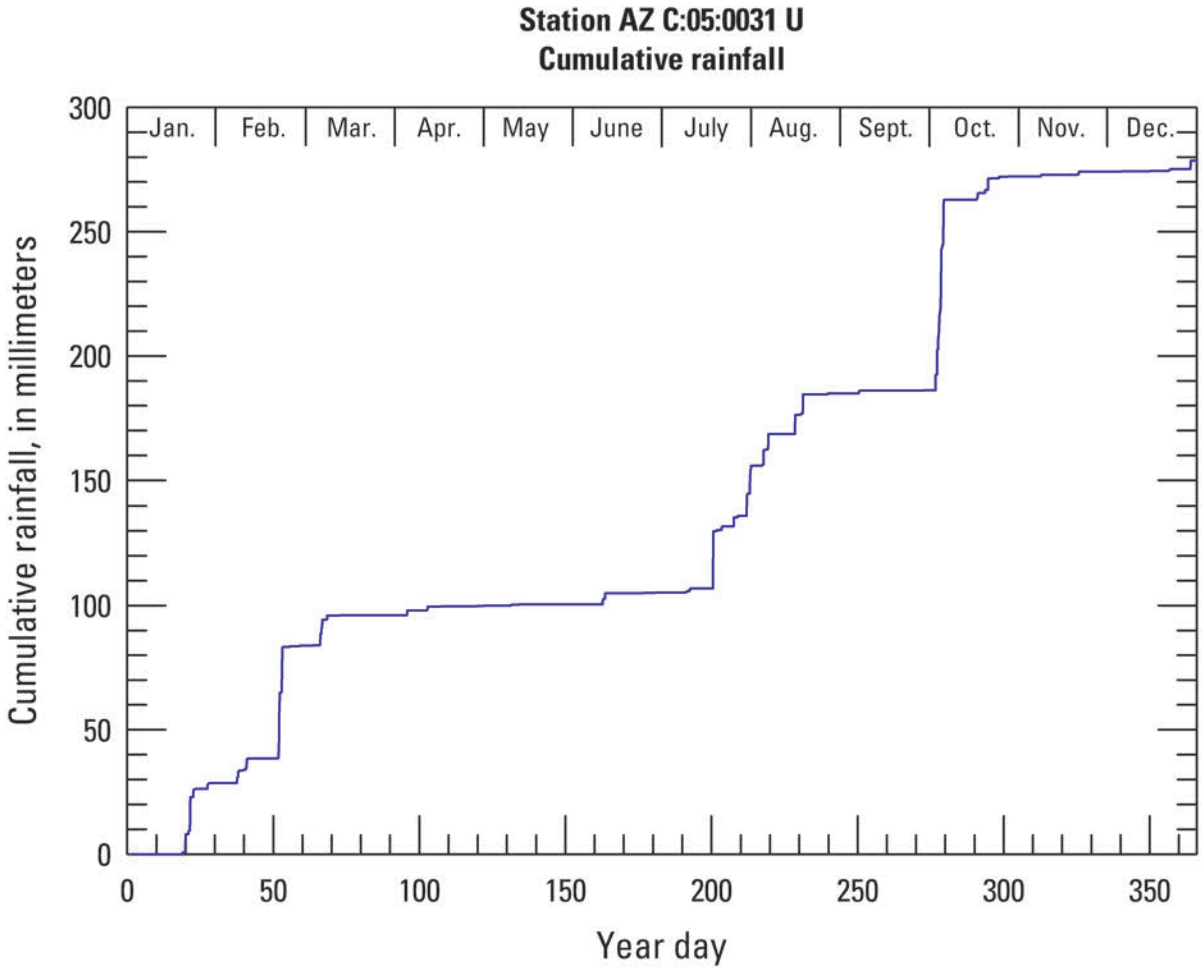

Figure 10. Plot showing cumulative rainfall recorded at station AZ C:05:0031 U compiled from data collected at 4-minute resolution in Grand Canyon, Arizona, 2010.

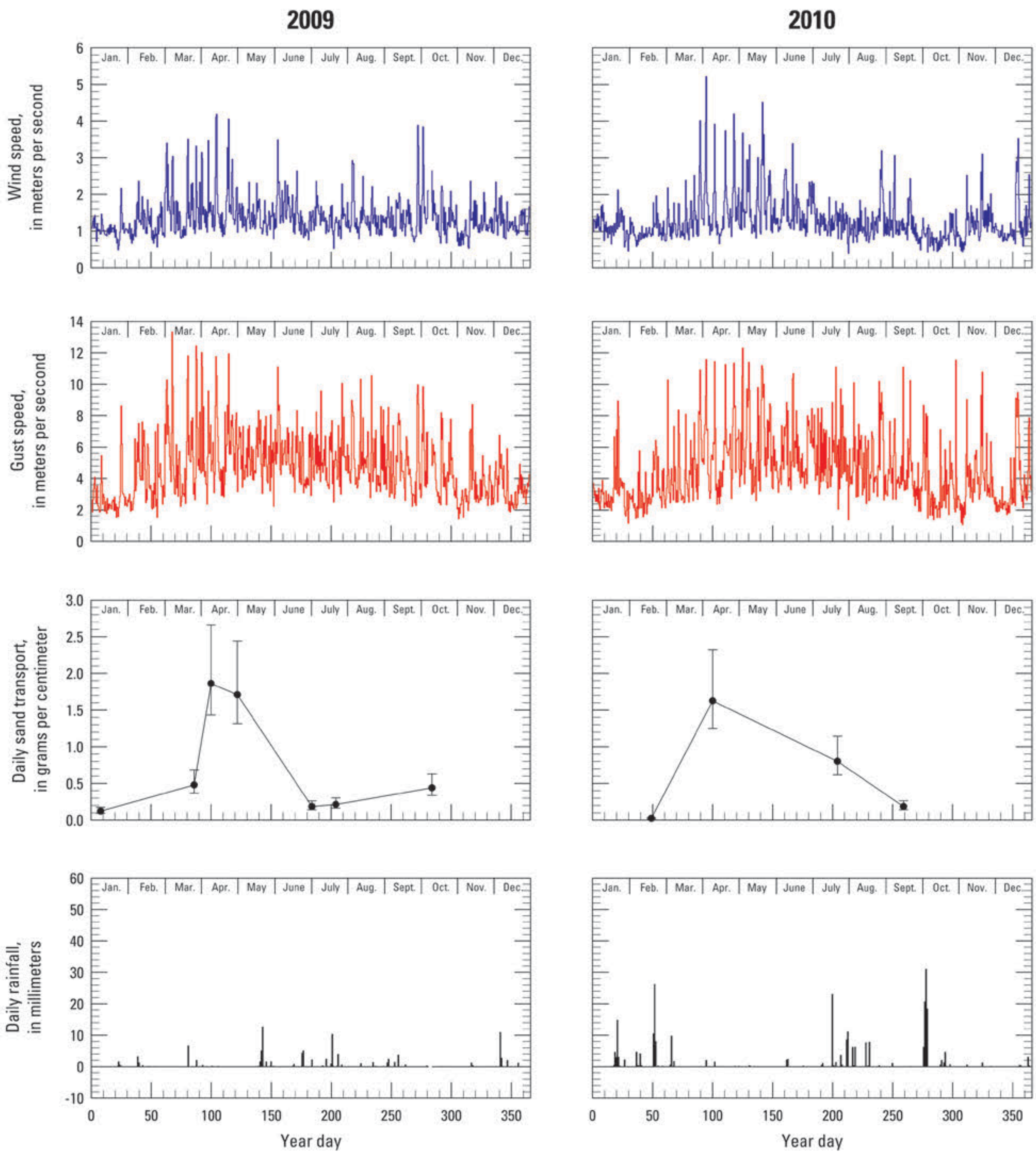

Figure 11. Plots showing wind, aeolian sand-transport, and rainfall data collected at the instrument station AZ C:05:0031 U in Grand Canyon, Arizona, 2009–10. Wind speed is presented as diurnal average values, using daytime (0600–1800 hours) and nighttime (1800–0600 hours) averages of data collected at 4-minute intervals. Gust speed is shown as maximum values that occurred during each diurnal interval. Daily sand transport is plotted in grams, normalized to a width of 1 centimeter. To obtain these values, total sand mass collected from four traps during each maintenance visit was divided by the number of days since the trap had last been emptied. Rainfall is plotted as daily (24-hour) totals.

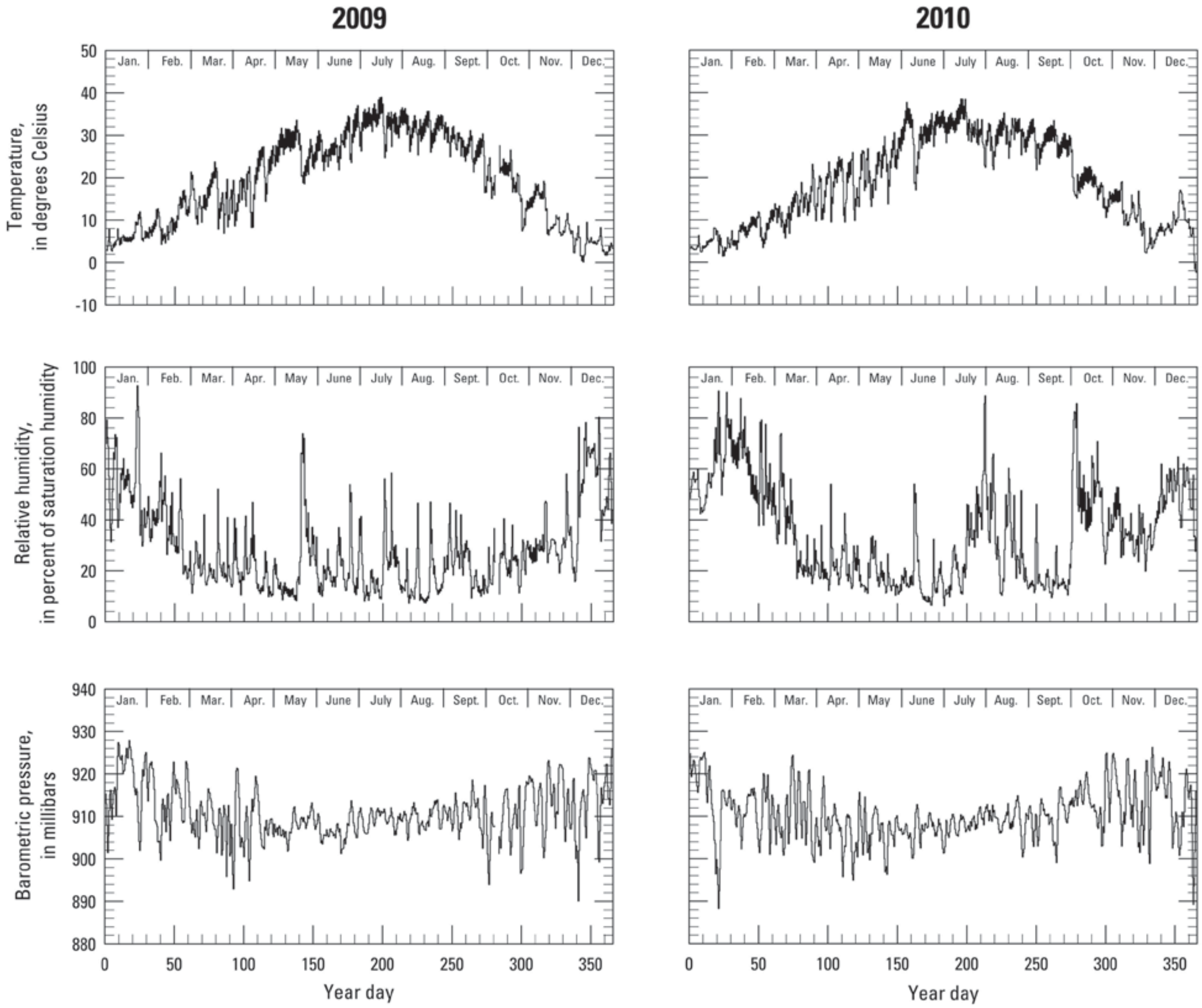

Figure 12. Plots showing temperature, relative humidity, and barometric pressure data collected at instrument station AZ C:05:0031 U in Grand Canyon, Arizona, 2009–10. All parameters are plotted as diurnal averages (defined using 0600–1800 and 1800–0600 hours).

Site AZ C:13:0365

Two instrument stations, situated in approximately the same locations as those used at this site by Draut and Rubin (2008), have operated near site AZ C:13:0365 since February 2008. The area around site AZ C:13:0365 includes an active aeolian dune field on the downstream side of a side canyon and an associated debris fan; sand-transport rates in this dune field were higher than those measured at any other site by Draut and Rubin (2008). Dune morphology at site AZ C:13:0365 includes north-facing slip faces, consistent with northward dune migration; this morphology combined with dominantly south-southeast winds identify this site as a modern fluvial sourced (MFS) dune field whose primary sediment source is a fluvial sandbar immediately upwind of the dune field. A second sandbar, across the river and approximately 200 m downstream, also provides sediment to the dune field near site AZ C:13:0365 (Draut and Rubin, 2008).

A vector sum of all wind data from station AZ C:13:0365 L in 2010 yields a net *Qp* magnitude of 72,645 m^3/s^3 from a direction of 171º; using wind data collected only during periods when the sand is estimated to have been dry, a vector sum yields a net *Qp* magnitude of 50,596 m^3/s^3 from a direction of 170º (table 3). These calculations indicate net sand transport toward the north-northwest (fig. 13), although the directional wind plot (fig. 14) shows that substantial transport from the north-northwest also can occur at station AZ C:13:0365 L. This is consistent with net potential sand transport measured from 2003 to 2006 and in 2008 and 2009 at this site (Draut and Rubin, 2008; Draut and others, 2009b).

Total rainfall measured at station AZ C:13:0365 L was 421.3 mm (table 2), much higher than in 2009; cumulative rainfall during 2010 at this station is plotted in figure 15. All weather parameters and sand transport measured at station AZ C:13:0365 L in 2010 are summarized in figures 16 and 17. Sand-transport rates were highest at station AZ C:13:0365 L during late winter 2010 (fig. 16) and were lower in spring 2010 than in spring 2009.

A vector sum of all available wind data from station AZ C:13:0365 U (approximately 50 m inland and uphill of station AZ C:13:0365 L) in 2010 yields a net *Qp* magnitude of 1,500,600 m^3/s^3 from a direction of 154º; using wind data collected only when the sand is estimated to have been dry, a vector sum yields a net *Qp* magnitude of 730,990 m^3/s^3 from a direction of 154º (table 3). These calculations indicate net sand transport generally toward upstream (fig. 18), with higher wind speeds and a stronger southeasterly directional component than at the lower-elevation station AZ C:13:0365 L, although strong northwest winds also are present at times (fig. 19). The wind velocities and dominant direction from the southeast at station AZ C:13:0365 U are consistent with wind conditions measured at this site between 2003 and 2006 (Draut and Rubin, 2008) and in 2008 and 2009 (Draut and others, 2009b).

Total rainfall measured in 2009 was 354.8 mm (table 2) at station AZ C:13:0365 U; cumulative rainfall at this site is plotted in figure 20. All weather parameters and sand transport measured at AZ C:13:0365 U in 2010 are summarized in figures 21 and 22. Sand-transport rates measured during the spring windy season at station AZ C:13:0365 U in 2010 cannot be compared directly with those in 2009, owing to sand-trap malfunctions in early spring 2010 that allowed only minimum transport values to be estimated for 2010 (Draut and others, 2009b).

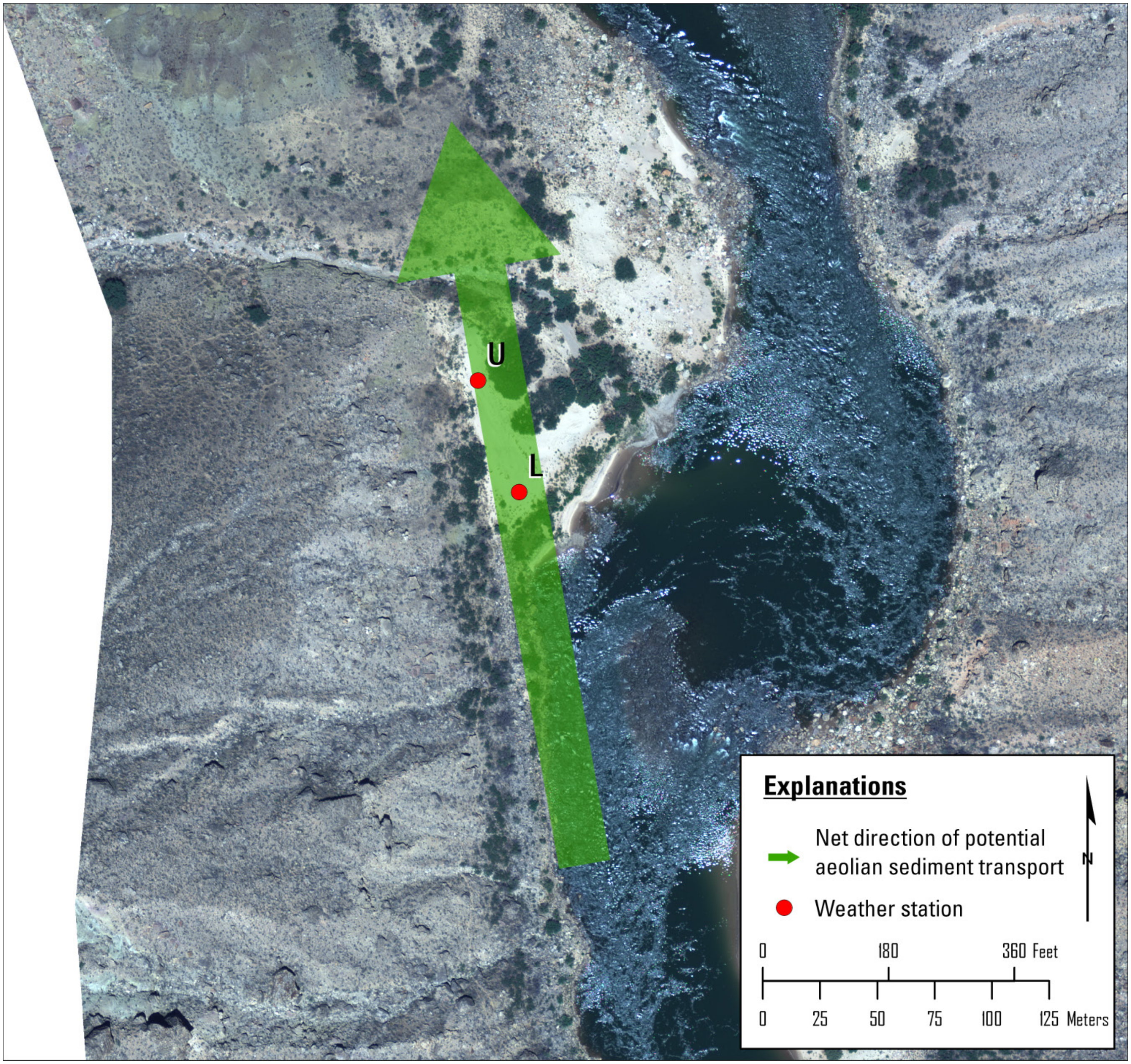

Figure 13. Aerial photograph showing area around site AZ C:13:0365 in Grand Canyon, Arizona. Arrow indicates the net direction of potential aeolian sediment transport measured at AZ C:13:0365 L in 2010. A vector sum of the *Qp* proxy variable (equation 1), calculated using all the wind data collected during dry conditions from AZ C:13:0365 L in 2010, indicates net sediment transport from 171°.

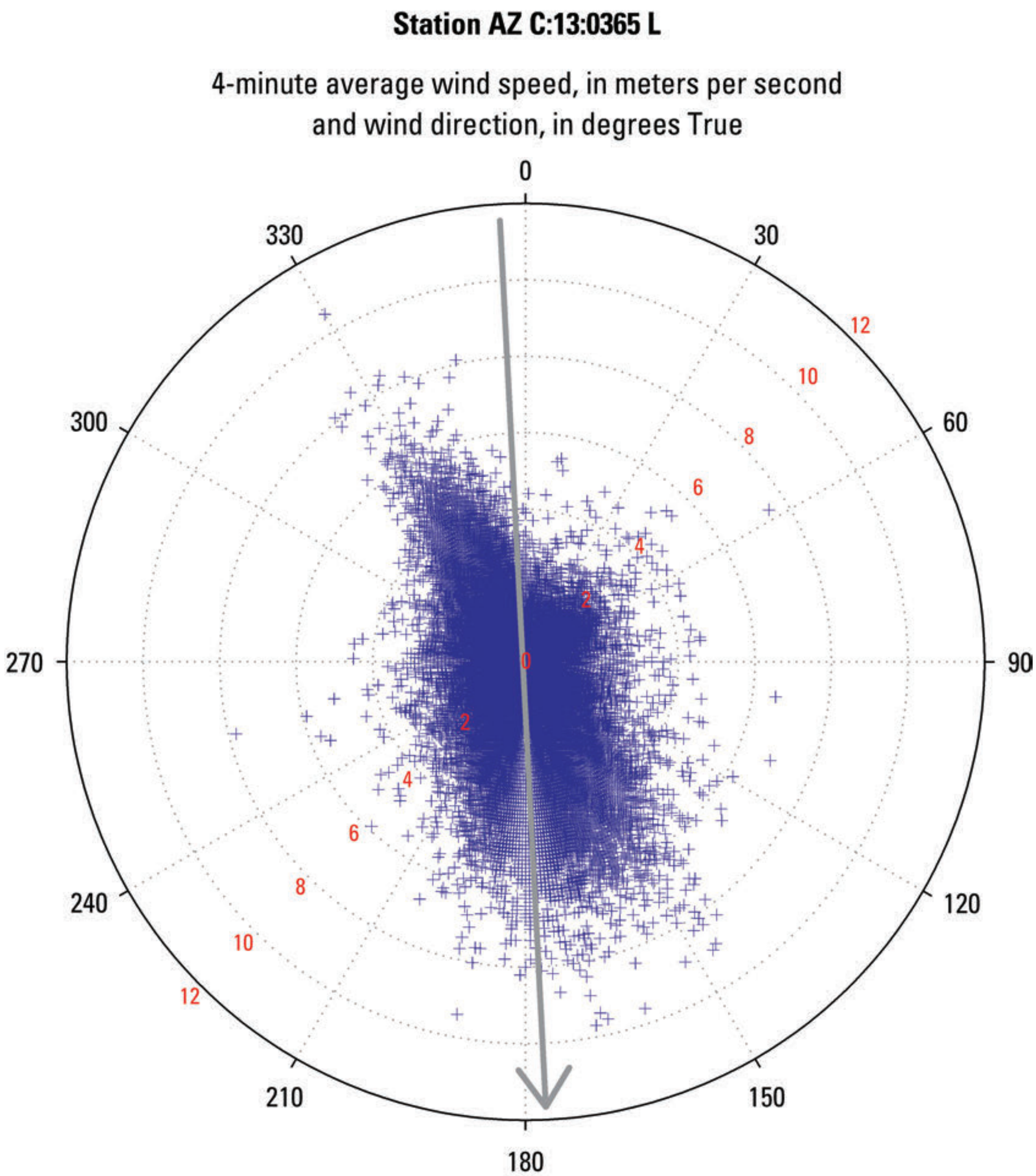

Figure 14. Plot showing magnitude and direction of wind velocity measured at the instrument station AZ C:13:0365 L with 4-minute resolution in Grand Canyon, Arizona, 2010. Magnitude is indicated by the concentric circles, and compass bearing indicates the wind direction. The gray arrow shows the orientation of the river corridor (177°); river flow is toward the south.

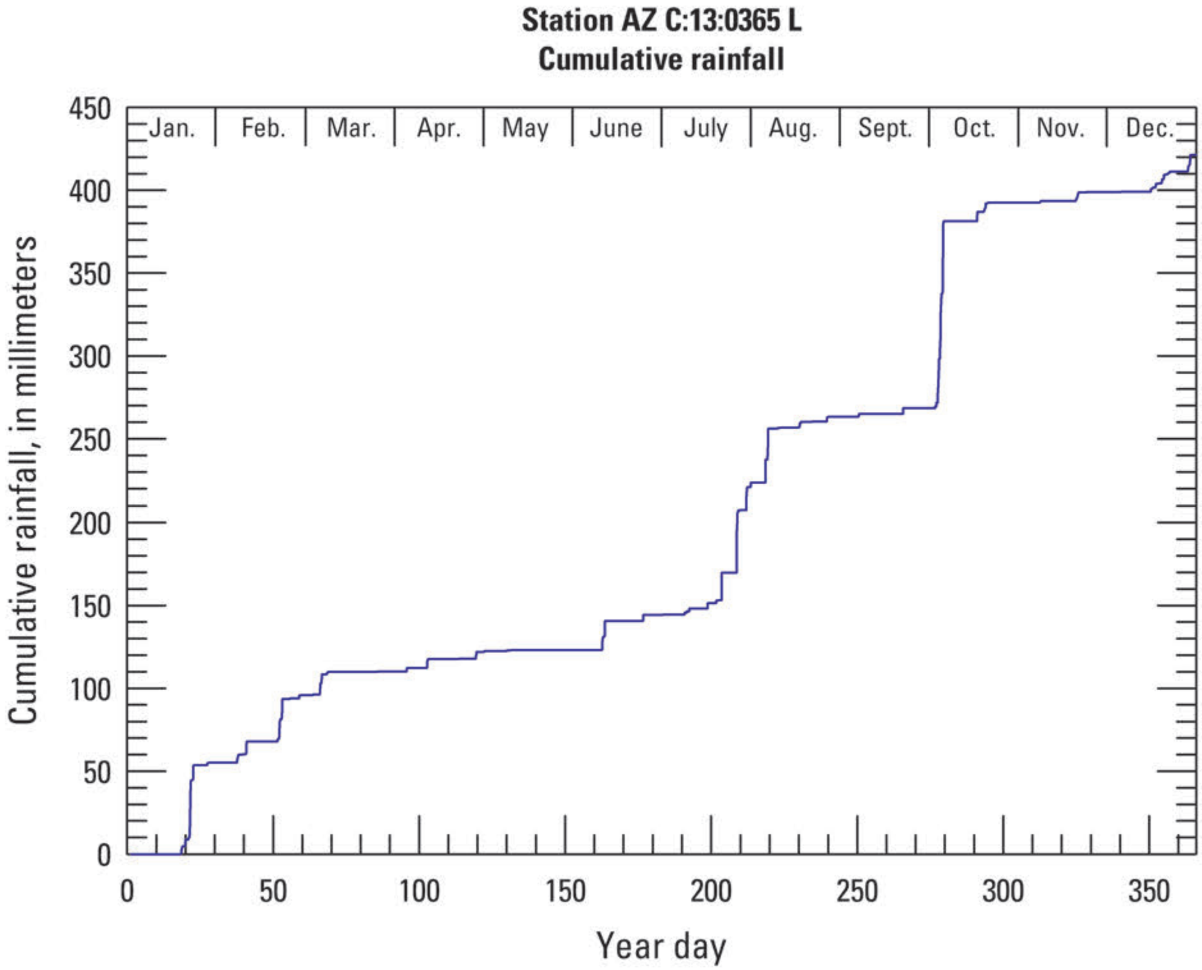

Figure 15. Plot showing cumulative rainfall recorded at station AZ C:13:0365 L compiled from data collected at 4-minute resolution in Grand Canyon, Arizona, 2010.

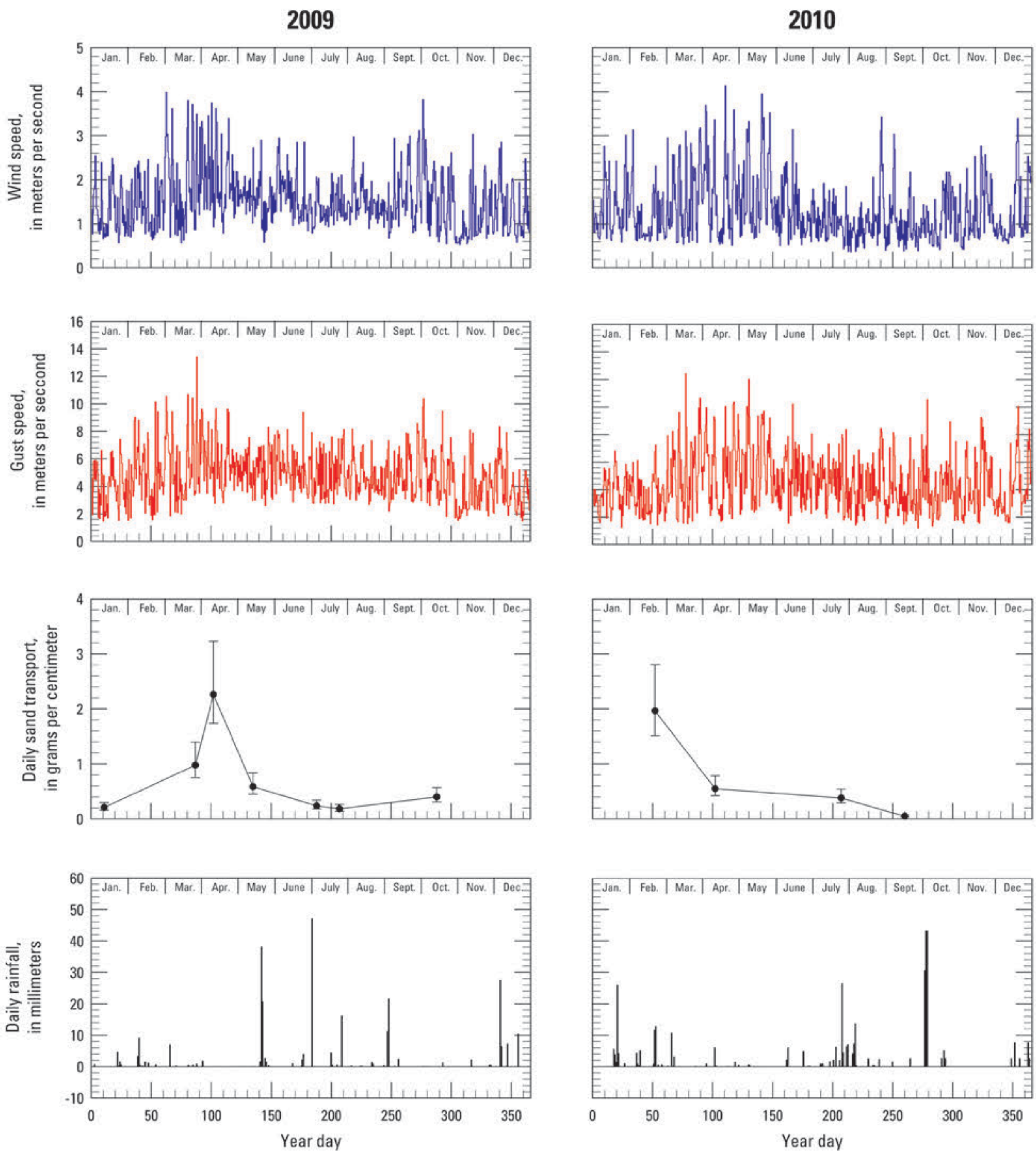

Figure 16. Plots showing wind, aeolian sand-transport, and rainfall data collected at the instrument station AZ C:13:0365 L, in Grand Canyon, Arizona, 2009–10. Wind speed is presented as diurnal average values, using daytime (0600–1800 hours) and nighttime (1800–0600 hours) averages of data collected at 4-minute intervals. Gust speed is shown as maximum values that occurred during each diurnal interval. Daily sand transport is plotted in grams, normalized to a width of 1 centimeter. To obtain these values, total sand mass collected from four traps during each maintenance visit was divided by the number of days since the trap had last been emptied. Rainfall is plotted as daily (24-hour) totals.

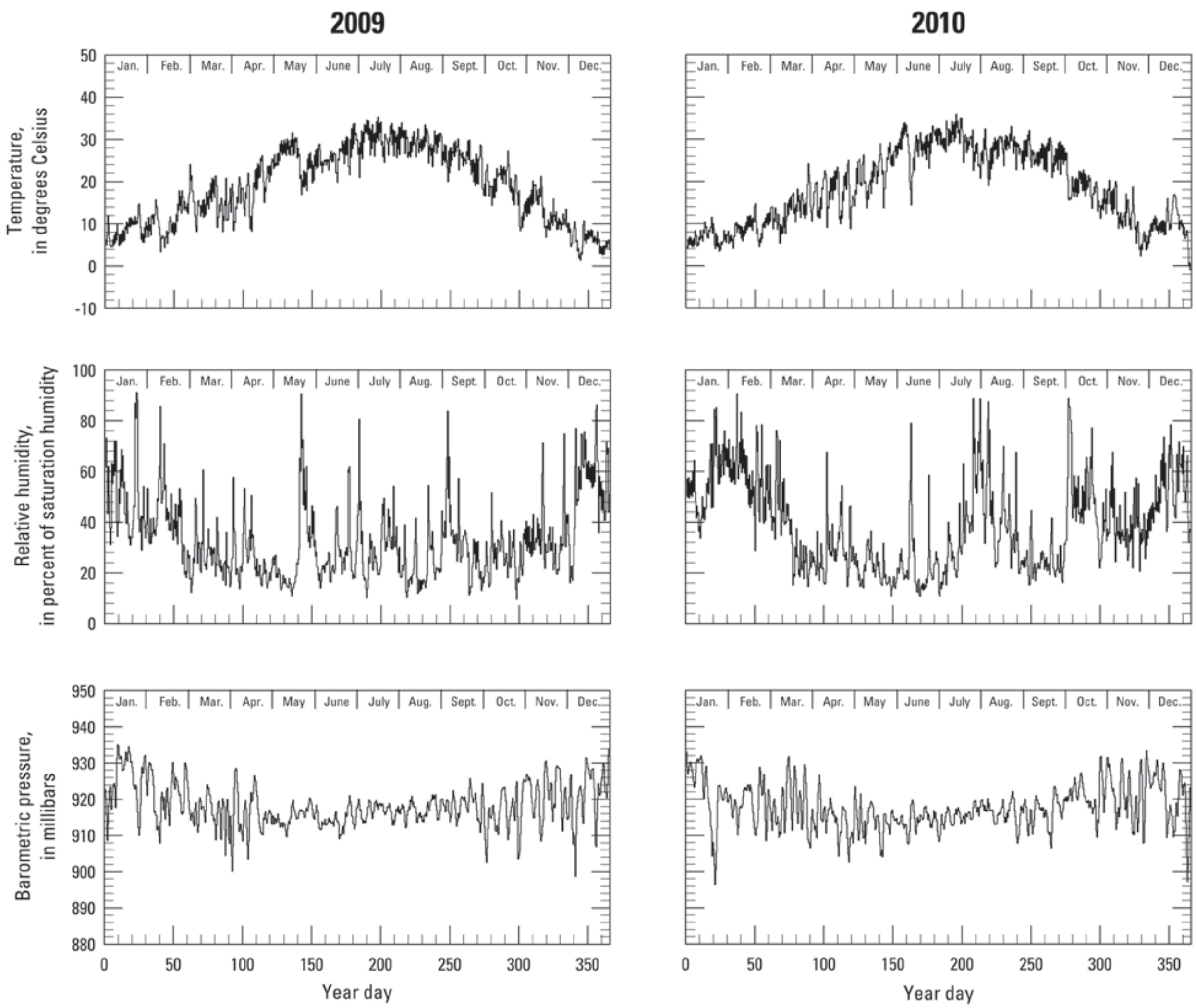

Figure 17. Plots showing temperature, relative humidity, and barometric pressure data collected at instrument station AZ C:13:0365 L, in Grand Canyon, Arizona, 2009–10. All parameters are plotted as diurnal averages (defined using 0600–1800 and 1800–0600 hours).

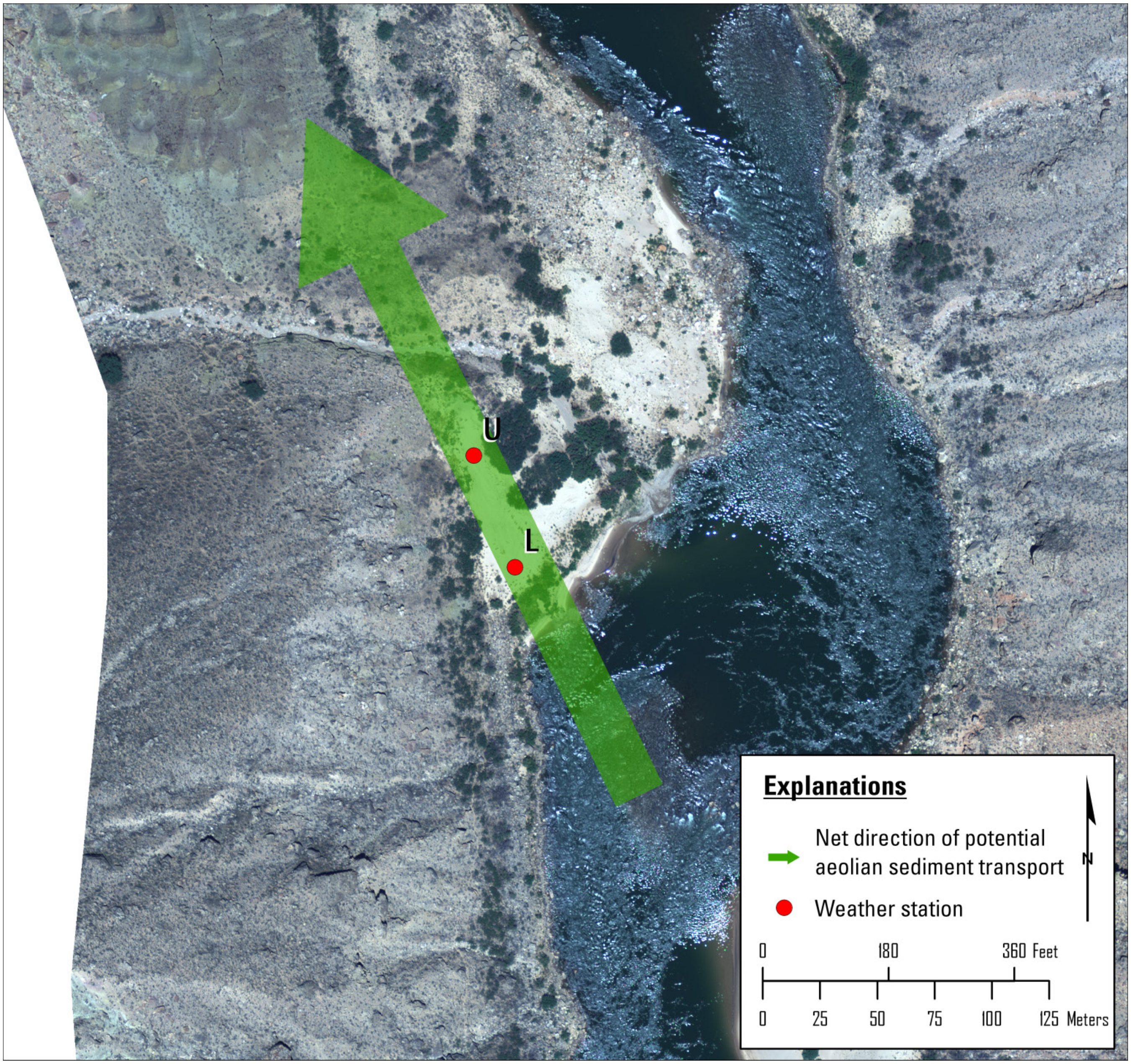

Figure 18. Aerial photograph of the area around site AZ C:13:0365 in Grand Canyon, Arizona. Arrow indicates the net direction of potential aeolian sediment transport measured at AZ C:13:0365 U in 2010. A vector sum of the *Qp* proxy variable (equation 1), calculated using all the wind data collected during dry conditions from AZ C:13:0365 U in 2010, indicates net sediment transport from 154°.

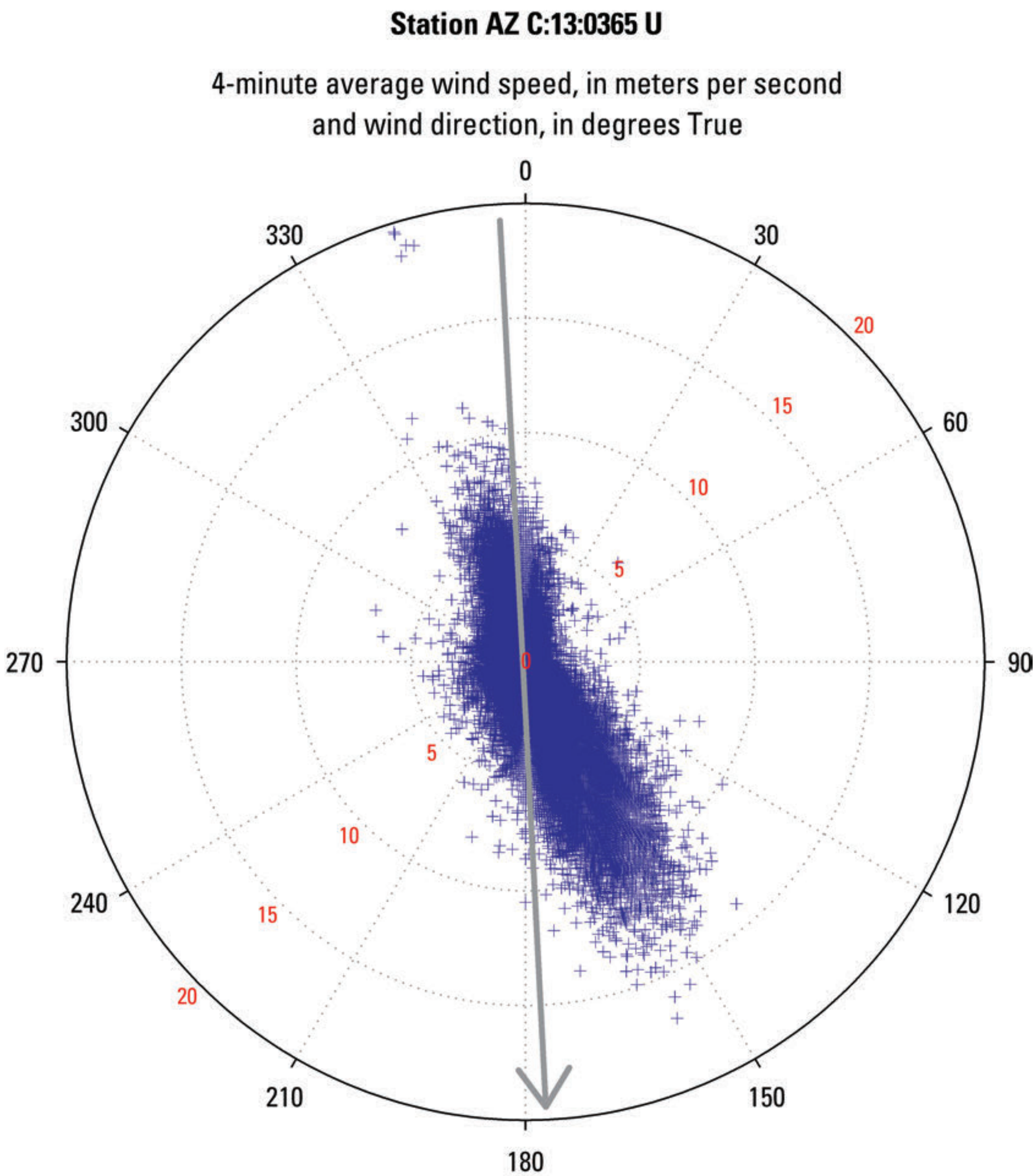

Figure 19. Plot showing magnitude and direction of wind velocity measured at the instrument station AZ C:13:0365 U with 4-minute resolution in Grand Canyon, Arizona, 2010. Magnitude is indicated by the concentric circles, and compass bearing indicates the wind direction. The gray arrow shows the orientation of the river corridor (177°); river flow is toward the south.

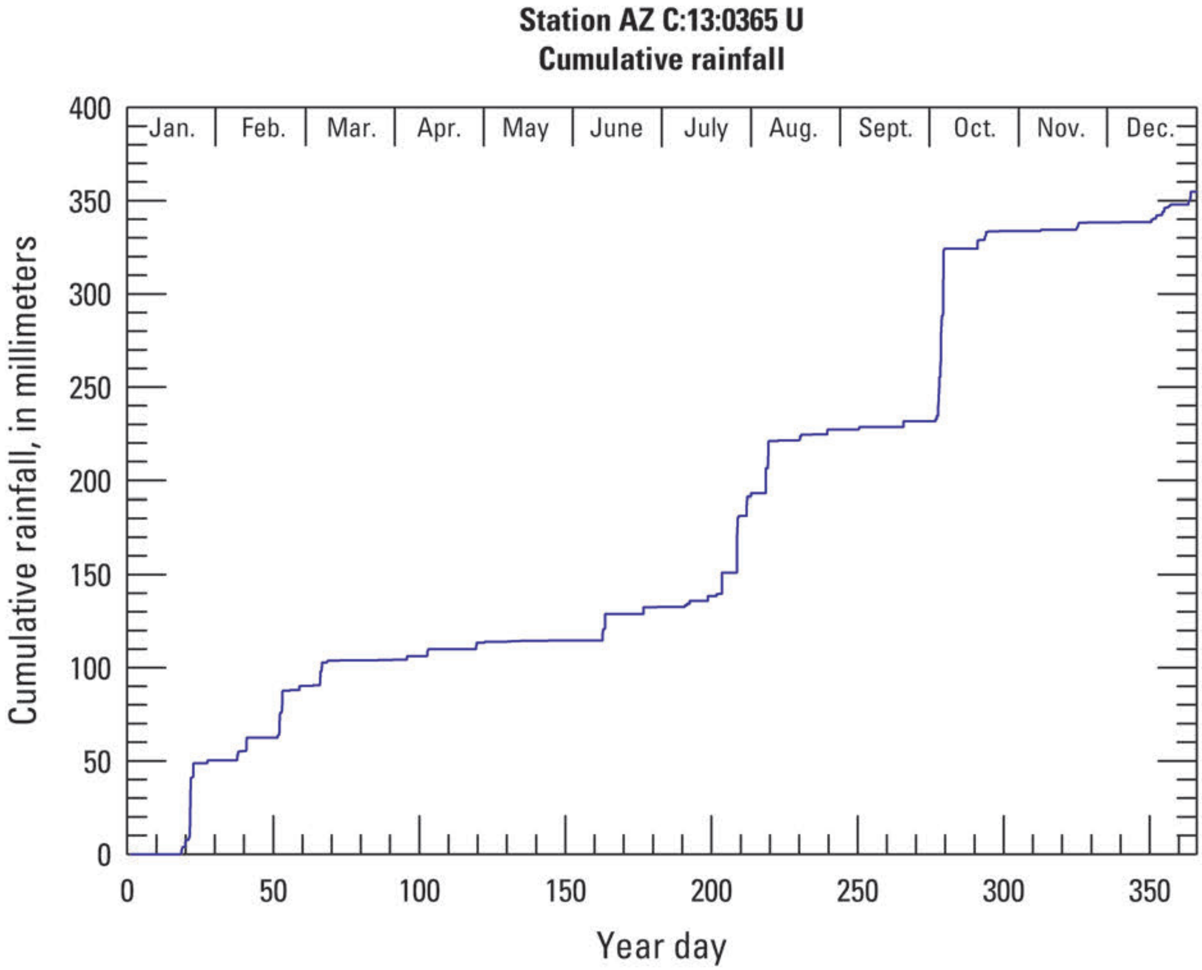

Figure 20. Plot showing cumulative rainfall recorded at station AZ C:13:0365 U compiled from data collected at 4-minute resolution in Grand Canyon, Arizona, 2010.

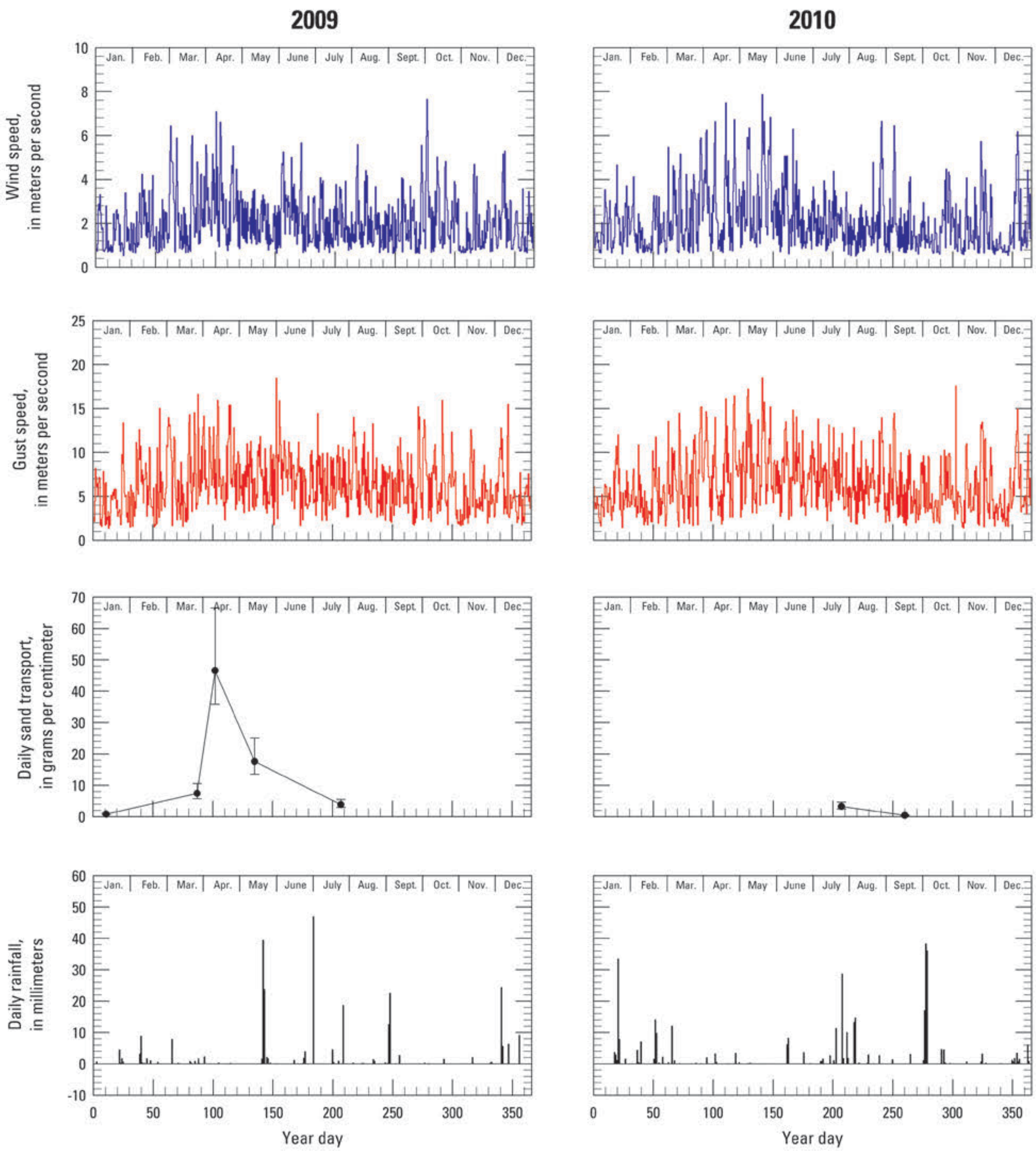

Figure 21. Plots showing wind, aeolian sand-transport, and rainfall data collected at the instrument station AZ C:13:0365 U in Grand Canyon, Arizona, 2009–10. Wind speed (blue plot) is presented as diurnal average values, using daytime (0600–1800 hours) and nighttime (1800–0600 hours) averages of data collected at 4-minute intervals. Gust speed (red plot) is shown as maximum values that occurred during each diurnal interval. Daily sand transport is plotted in grams, normalized to a width of 1 centimeter. To obtain these values, total sand mass collected from four traps during each maintenance visit was divided by the number of days since the trap had last been emptied. Rainfall is plotted as daily (24-hour) totals.

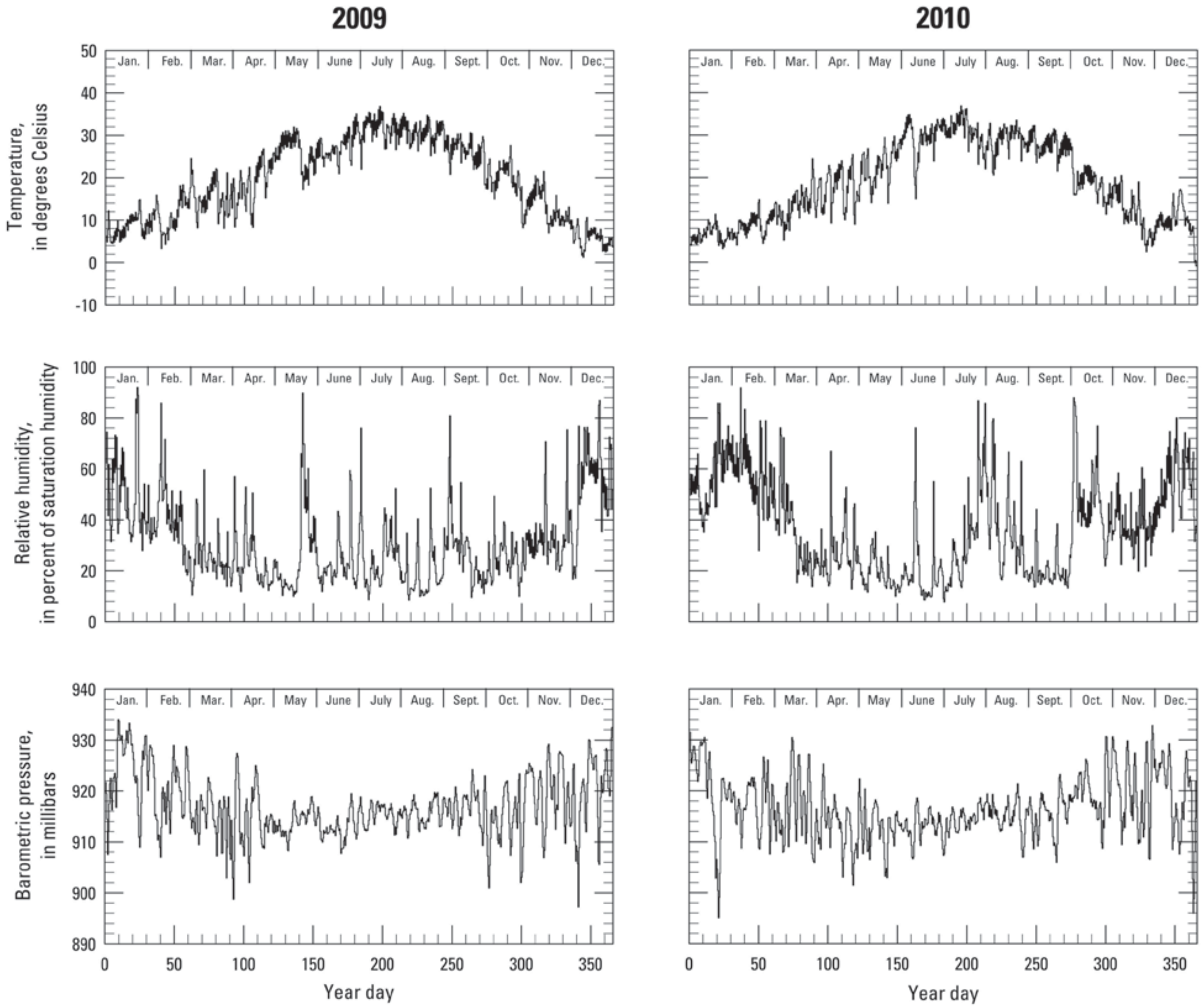

Figure 22. Plots showing temperature, relative humidity, and barometric pressure data collected at instrument station AZ C:13:0365 U in Grand Canyon, Arizona, 2009–10. All parameters are plotted as diurnal averages (defined using 0600–1800 and 1800–0600 hours).

Site AZ C:13:0006

The instrument station near site AZ C:13:0006 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 near the weather station and sand traps are largely covered by well-developed biological soil crust.

A vector sum of all wind data from the weather station at AZ C:13:0006 in 2009 yields a net *Qp* magnitude of 100,400 m^3/s^3 from a direction of 131º; using data only from when the sand is estimated to have been dry, a vector sum yields a net *Qp* magnitude of 63,431 m^3/s^3 from a direction of 129º (table 3). These calculations indicate net sand transport generally toward upstream (fig. 23). Wind speed and direction measured at site AZ C:13:0006 in 2010 are plotted in figure 24. Cumulative rainfall data are shown in figure 25; the 2010 annual rainfall total at this site was 360.1 mm (table 2). All weather parameters and sand transport measured at site AZ C:13:0006 in 2010 are summarized in figures 26 and 27.

Although wind from other directions is not uncommon around site AZ C:13:0006 (fig. 24), net potential sediment transport from the east-southeast was indicated during 2010, similar to conditions measured at this site between 2007 and 2009 (Draut and others, 2009a, 2009b). Net sand transport from the southeast 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. 24); however, sand-transport rates measured in 2010 were no higher than in 2007–2009 and, even after the 2008 HFE, these rates remain substantially lower than in more active dune fields such as that at site AZ C:13:0365, with the measured daily flux at site AZ C:13:0006 consistently less than 0.1 g/cm (fig. 26). As discussed by Draut and others (2009b), the low sand-transport rates measured at the instrument station (approximately 20 m laterally away from and 5 m vertically below the archeological site) likely do not accurately represent aeolian processes acting on the cultural site. However, in order to avoid disturbing the archeological site, sand traps cannot be deployed directly in the area where Collins and others (2009) used remote-sensing lidar equipment to record aeolian sand deposition at site AZ C:13:0006. Therefore, links among HFE sand deposition, aeolian sand transport, and inflation-deflation at archeological site AZ C:13:0006 may not be characterized accurately using the data collected by this study. It is likely that a large part, perhaps even most, of the windblown sand moving upstream (north-northwest) from the fluvial deposit at the downstream side of this debris fan is trapped by the tributary channel and does not travel as far as the archaeological site or the AZ C:13:0006 weather station.

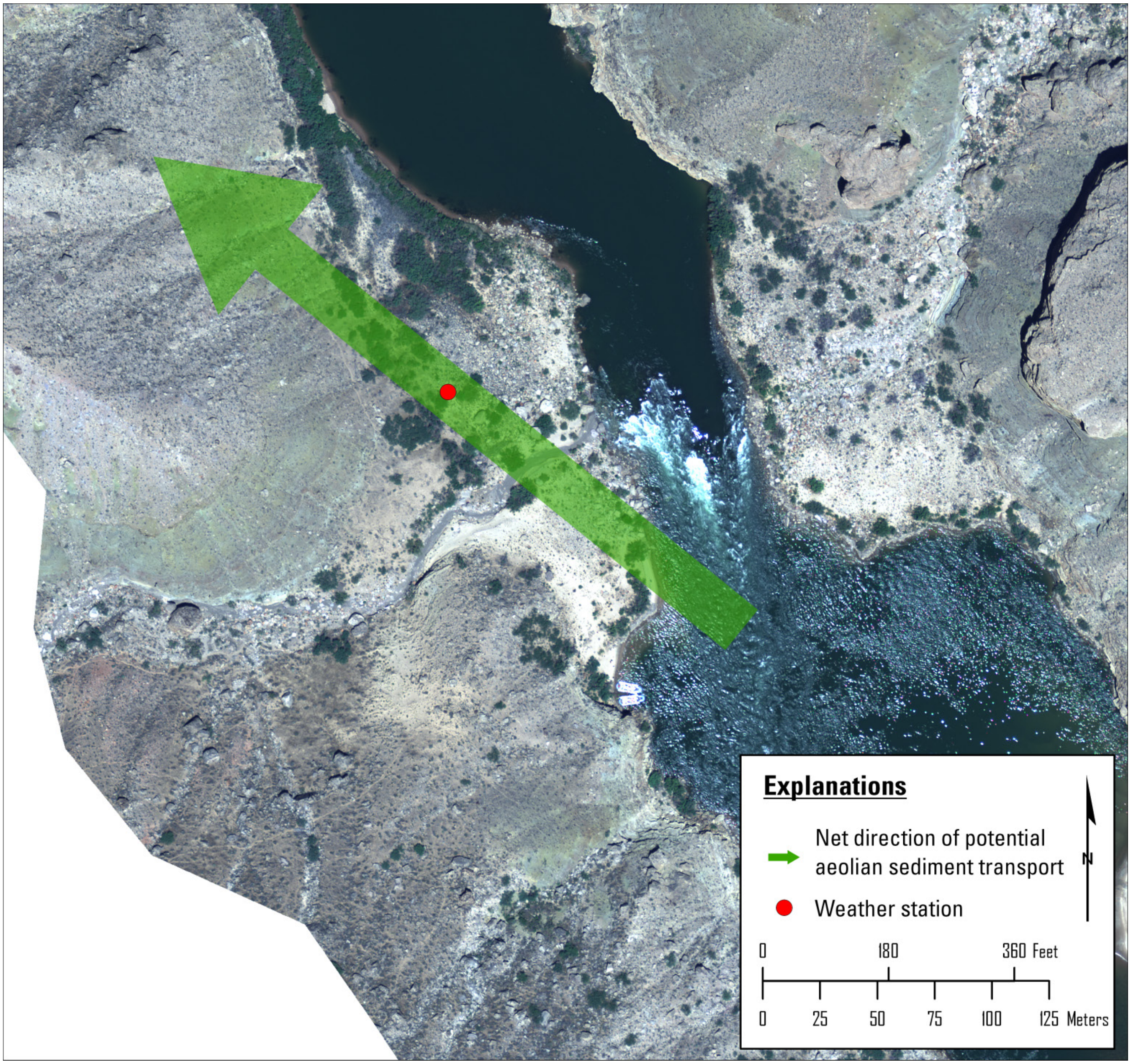

Figure 23. Aerial photograph of the area around site AZ C:13:0006 in Grand Canyon, Arizona. Arrow indicates the net direction of potential aeolian sediment transport measured at AZ C:13:0006 in 2010. A vector sum of the Qp proxy variable (equation 1), calculated using all the wind data collected during dry conditions from AZ C:13:0006 in 2010, indicates net sediment transport from 131°.

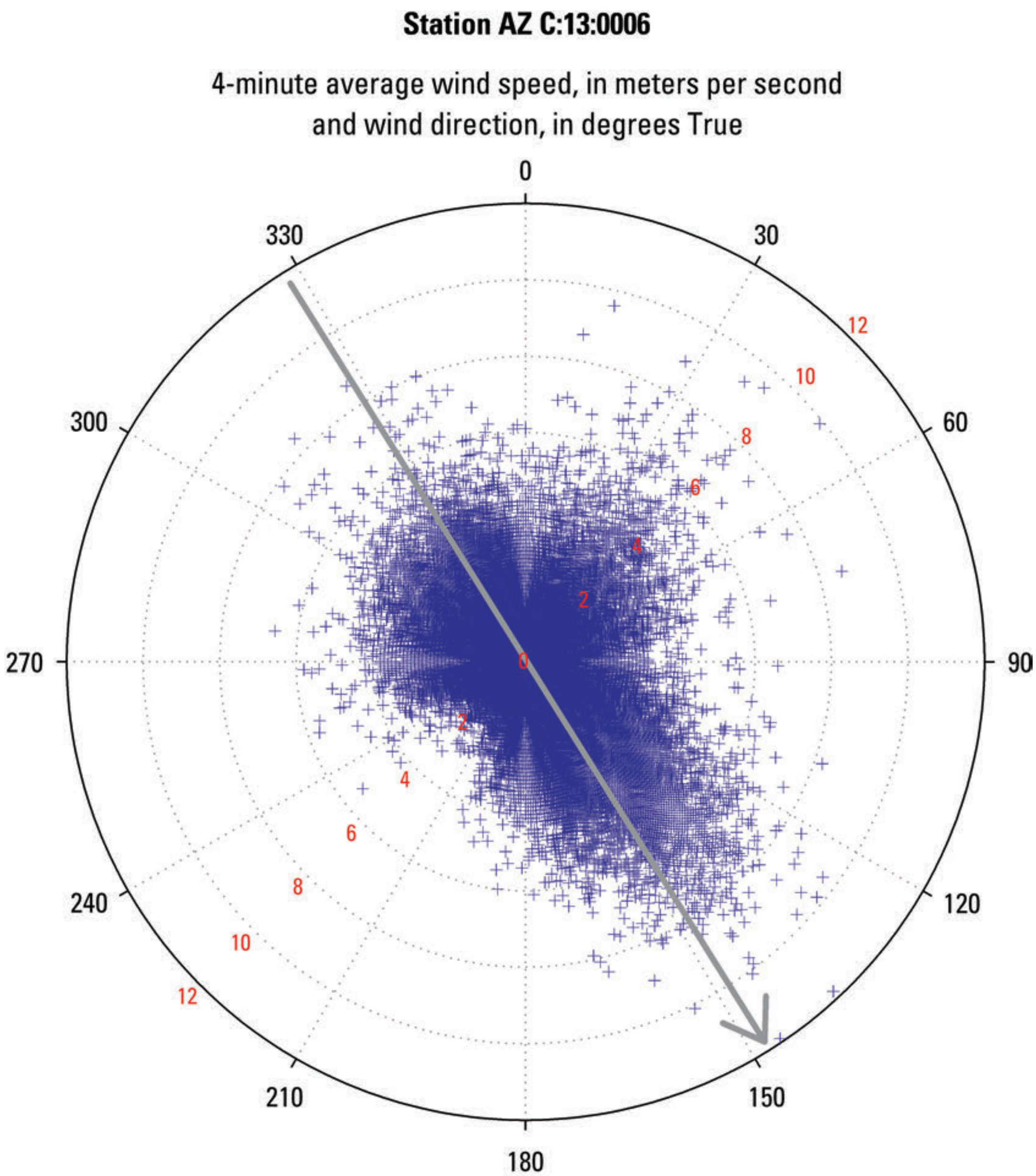

Figure 24. Plot showing magnitude and direction of wind velocity measured at the instrument station AZ C:13:0006 with 4-minute resolution in Grand Canyon, Arizona, 2010. Magnitude is indicated by the concentric circles, and compass bearing indicates the wind direction. The gray arrow shows the orientation of the river corridor (148°); river flow is toward the south.

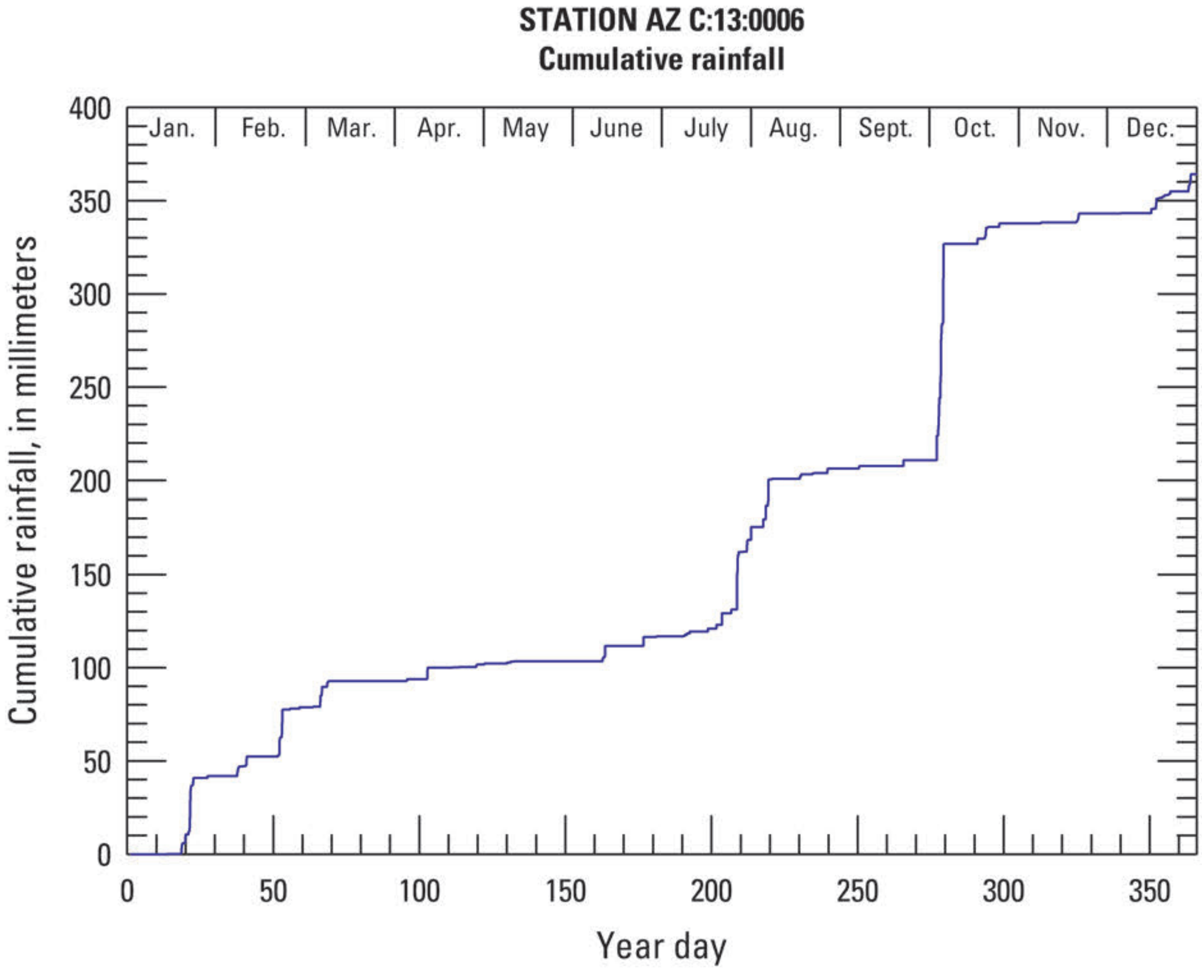

Figure 25. Plot showing cumulative rainfall recorded at site AZ C:13:0006 compiled from data collected at 4-minute resolution in Grand Canyon, Arizona, 2010.

Site AZ C:13:0336

The Palisades area in eastern Grand Canyon is near the start of a relatively open stretch of the river corridor that is referred to as the Furnace Flats by Schmidt and Graf (1990). The local area is characterized by alluvial terraces capped by aeolian coppice dunes that are vegetated by grasses and small mesquite trees. The alluvial deposits in the immediate vicinity of this site represent multiple episodes of floodplain aggradation by Colorado River floods that predate the completion of Glen Canyon Dam in 1963 (Hereford and others, 1993, 1996; Draut and others, 2008). Aeolian coppice dunes at Palisades were interpreted by Hereford and others (1993) and Draut and Rubin (2008) as relict fluvial sourced (RFS) aeolian deposits that formed by in-place reworking of older flood sediment, rather than having been recently sourced from river-level sandbars within the normal dam-controlled flow range. Alluvial and aeolian deposits are incised by a major gully network 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 HFEs in 1996 and 2004 and episodic erosion attributed to rain events (Yeatts, 1996; Hazel and others, 2008). The sandbar nearest to site AZ C:13:0336 increased substantially in area and volume as a result of the March 2008 HFE (Draut and others, 2009b). Although subsequent flow fluctuations caused cutbank retreat that eroded the sandbar through the latter part of 2008 (Draut and others, 2009b), by mid-2010 a substantial sandbar was still present and was being colonized by tamarisk and other vegetation.

One weather station and one set of sand traps operate at station AZ C:13:0336 U (fig. 28). Since February 2008, one additional set of sand traps has collected windblown sand at a site referred to as AZ C:13:0336 L, on a cobble bar riverward of AZ C:13:0336 U (fig. 28). The AZ C:13:0336 L study site is approximately 50 m upstream of where a single set of sand traps was used by Draut and Rubin (2008) to study sand transport near river level following the 2004 HFE.

Wind speed and direction measured at station AZ C:13:0336 U in 2010 are plotted in figure 29. Cumulative rainfall data are shown in figure 30. The 2010 annual rainfall total at this site was 325.8 mm (table 2). All weather parameters and sand transport measured at station AZ C:13:0336 U, and sand transport measured at station AZ C:13:0336 L, in 2010 are summarized in figures 31 and 32, with 2009 data shown for comparison.

Net potential sediment transport from the southeast was indicated at station AZ C:13:0336 U during 2010 (fig. 28), similar to conditions measured at this site in previous years (Draut and Rubin, 2008; Draut and others, 2009a, 2009b). A vector sum of wind data from the weather station at AZ C:13:0336 U in 2010 yields a net Qp magnitude of 907,640 m^3/s^3 from a direction of 148°; using wind data collected only when the sand is estimated to have been dry, a vector sum yields a net Qp magnitude of 533,990 m^3/s^3 from a direction of 147° (table 3). The highest wind speeds in 2010 were observed later (April–May) than in 2009; in 2009, the windiest season was uncharacteristically early and spanned March–April (by visual inspection of 4-minute-averaged wind-speed data; fig. 31). Sand-transport rates measured at station AZ C:13:0336 U in 2010 were limited in scope, owing to sand-trap malfunction, and cannot be compared directly with those measured in 2009. Sediment-transport rates measured on the cobble bar near river level (station AZ C:13:0336 L) generally were less than one-twentieth as great as those within the dune field (station AZ C:13:0336 U; fig. 31).

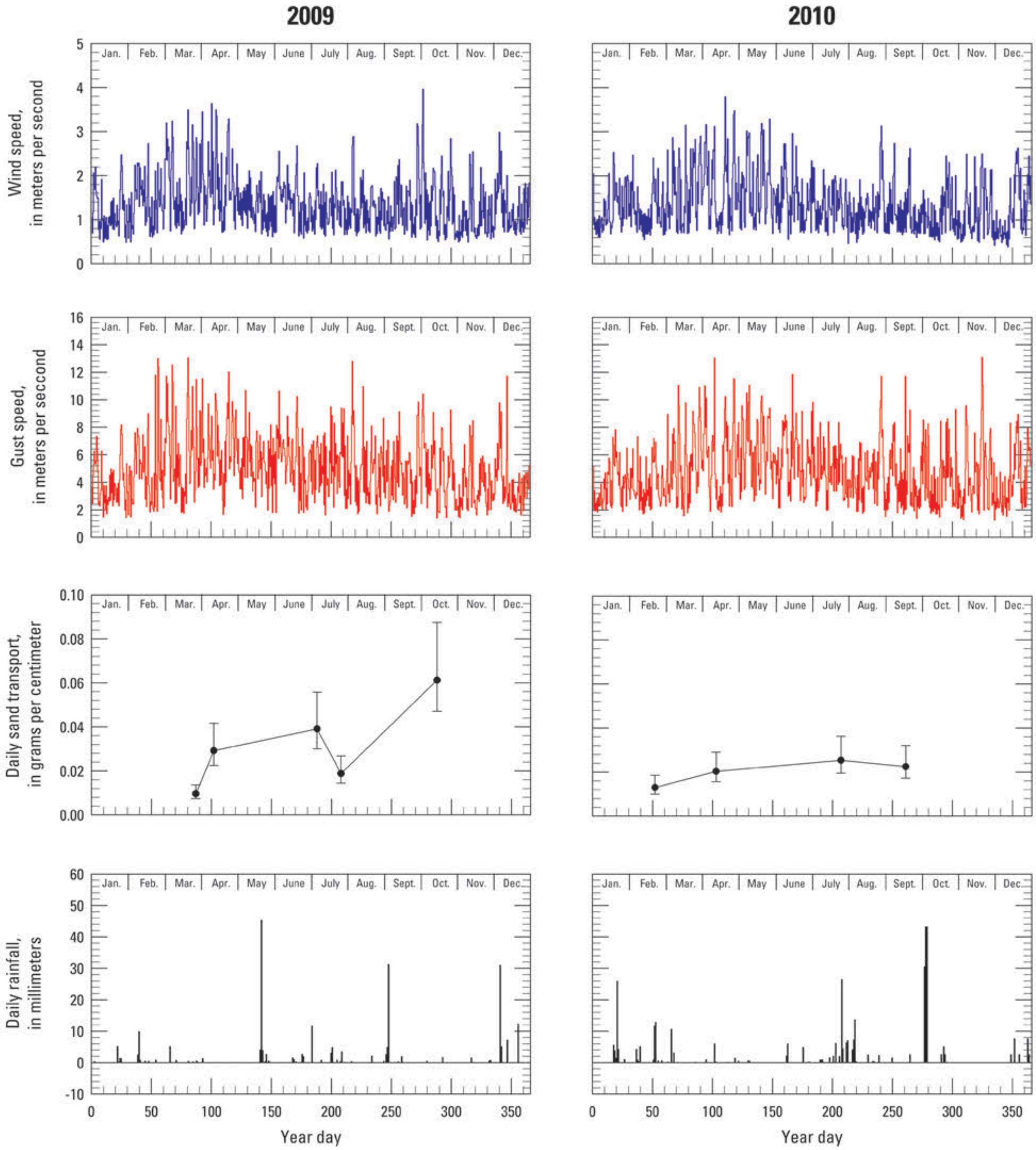

Figure 26. Plots showing wind, aeolian sand-transport, and rainfall data collected at the instrument station AZ C:13:0006 in Grand Canyon, Arizona, 2009–10. Wind speed is presented as diurnal average values, using daytime (0600–1800 hours) and nighttime (1800–0600 hours) averages of data collected at 4-minute intervals. Gust speed is shown as maximum values that occurred during each diurnal interval. Daily sand transport is plotted in grams, normalized to a width of 1 centimeter. To obtain these values, total sand mass collected from four traps during each maintenance visit was divided by the number of days since the trap had last been emptied. Rainfall is plotted as daily (24-hour) totals.

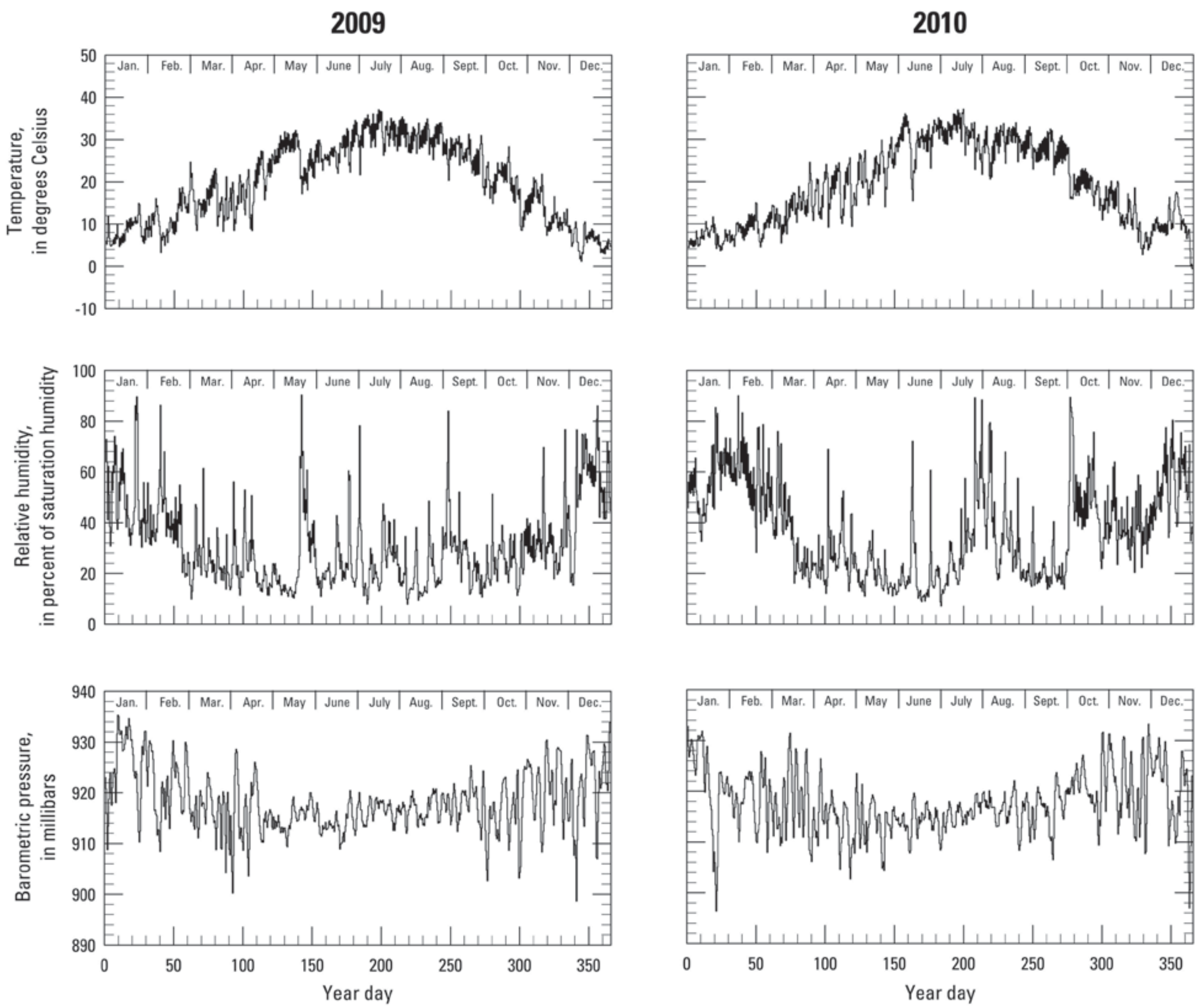

Figure 27. Plots showing temperature, relative humidity, and barometric pressure data collected at instrument station AZ C:13:0006 in Grand Canyon, Arizona, 2009–10. All parameters are plotted as diurnal averages (defined using 0600-1800 and 1800-0600 hours).

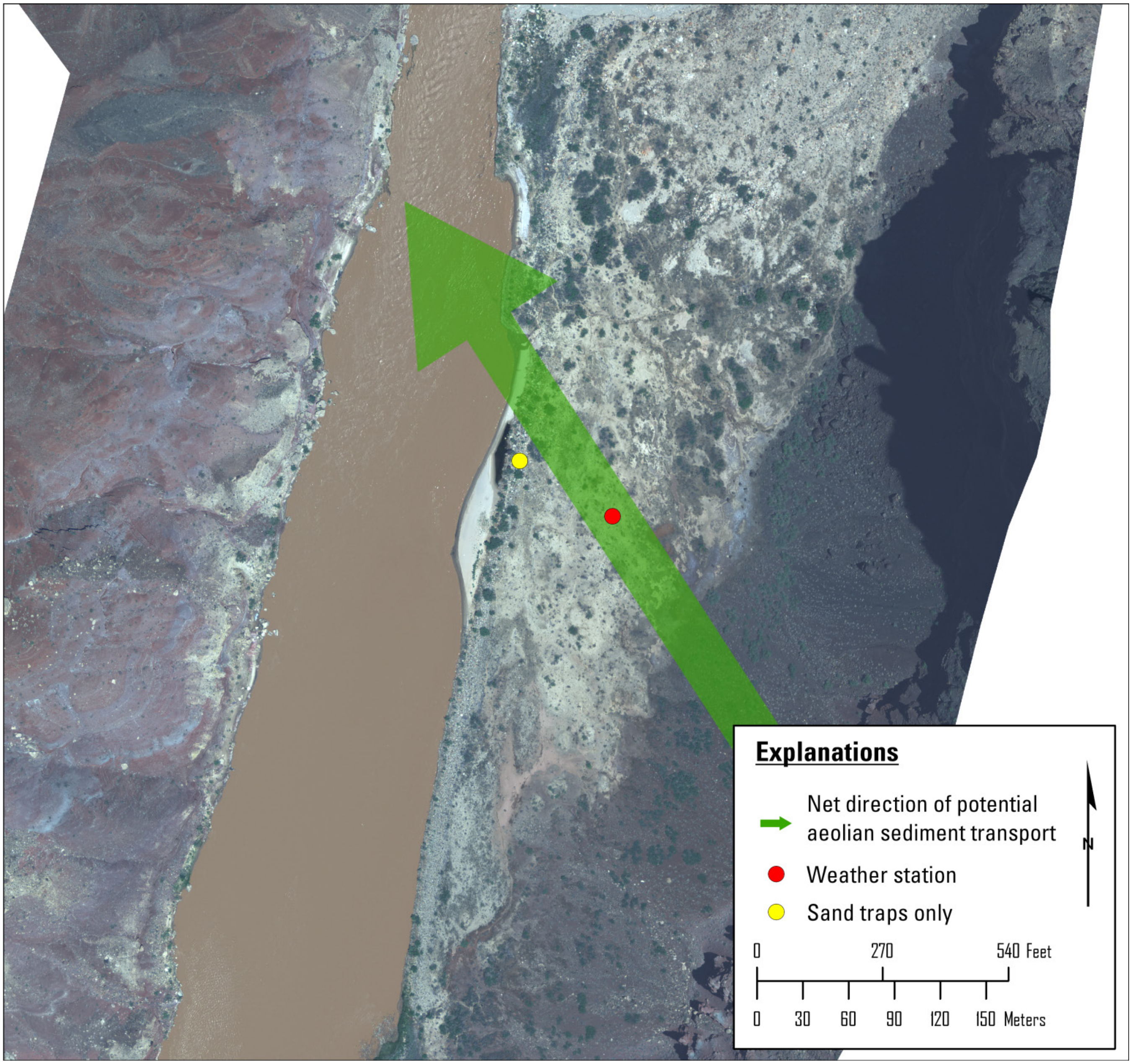

Figure 28. Aerial photograph of the area around site AZ C:13:0336 in Grand Canyon, Arizona. Red dot designates AZ C:13:0336 U, and yellow designates AZ C:13:0336. Arrow indicates the net direction of potential aeolian sediment transport measured at AZ C:13:0336 U in 2010. A vector sum of the *Qp* proxy variable (equation 1), calculated using all the wind data collected during dry conditions from station AZ C:13:0336 U in 2010, indicates net sediment transport from 148°.

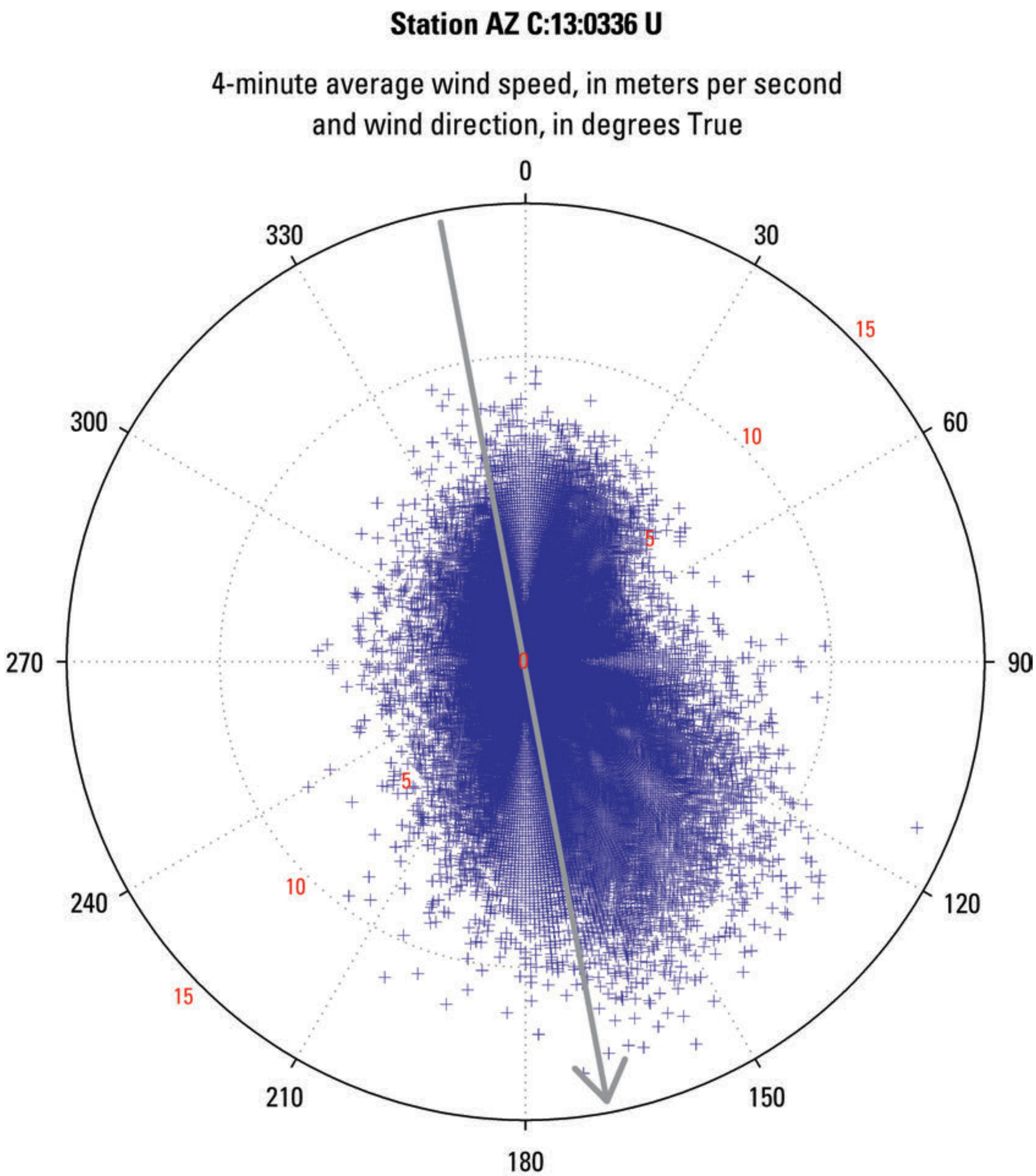

Figure 29. Plot showing magnitude and direction of wind velocity measured at the instrument station AZ C:13:0336 U with 4-minute resolution in Grand Canyon, Arizona, 2010. Magnitude is indicated by the concentric circles, and compass bearing indicates the wind direction. The gray arrow shows the orientation of the river corridor (169°); river flow is toward the south.

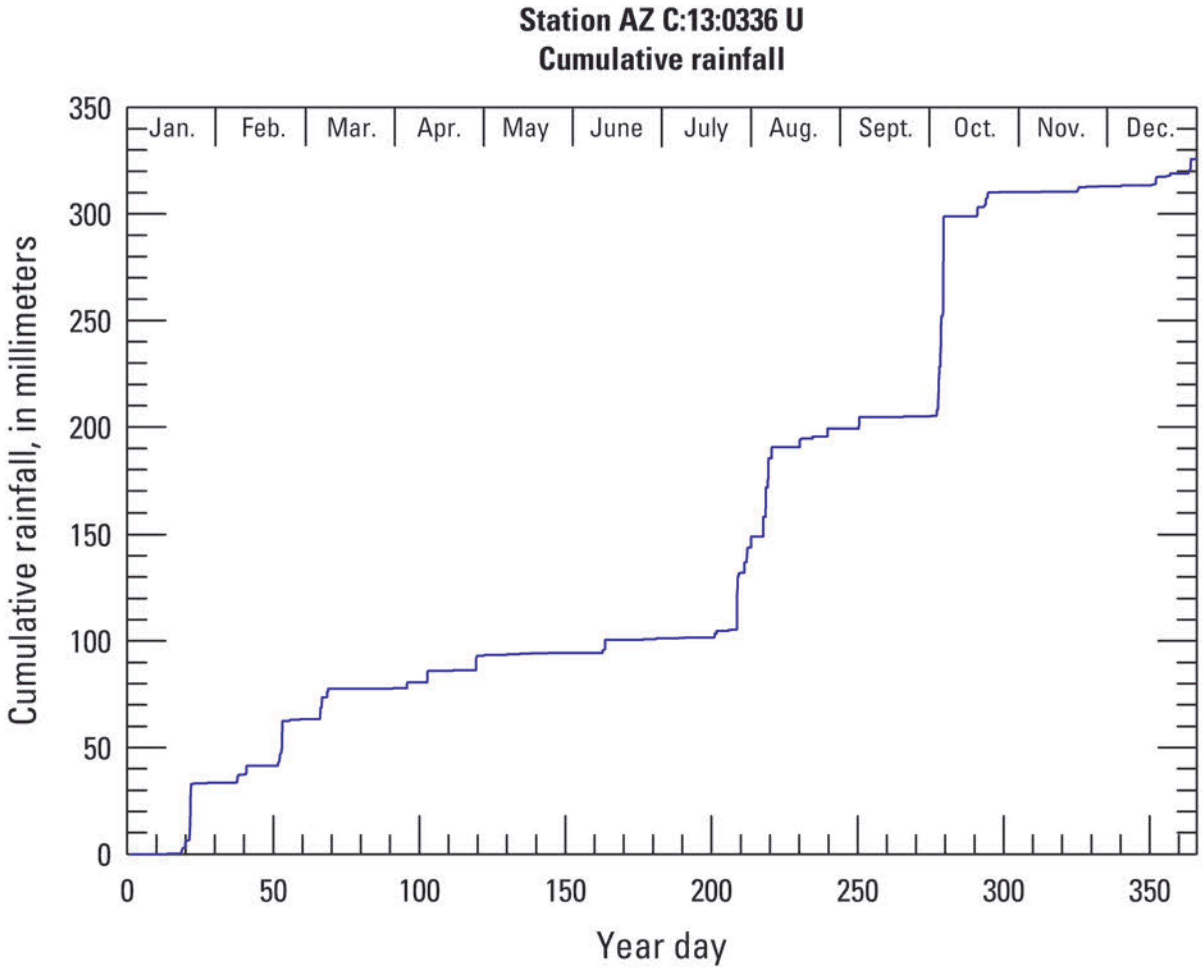

Figure 30. Plot showing cumulative rainfall recorded at station AZ C:13:0336 U compiled from data collected at 4-minute resolution in Grand Canyon, Arizona, 2010.

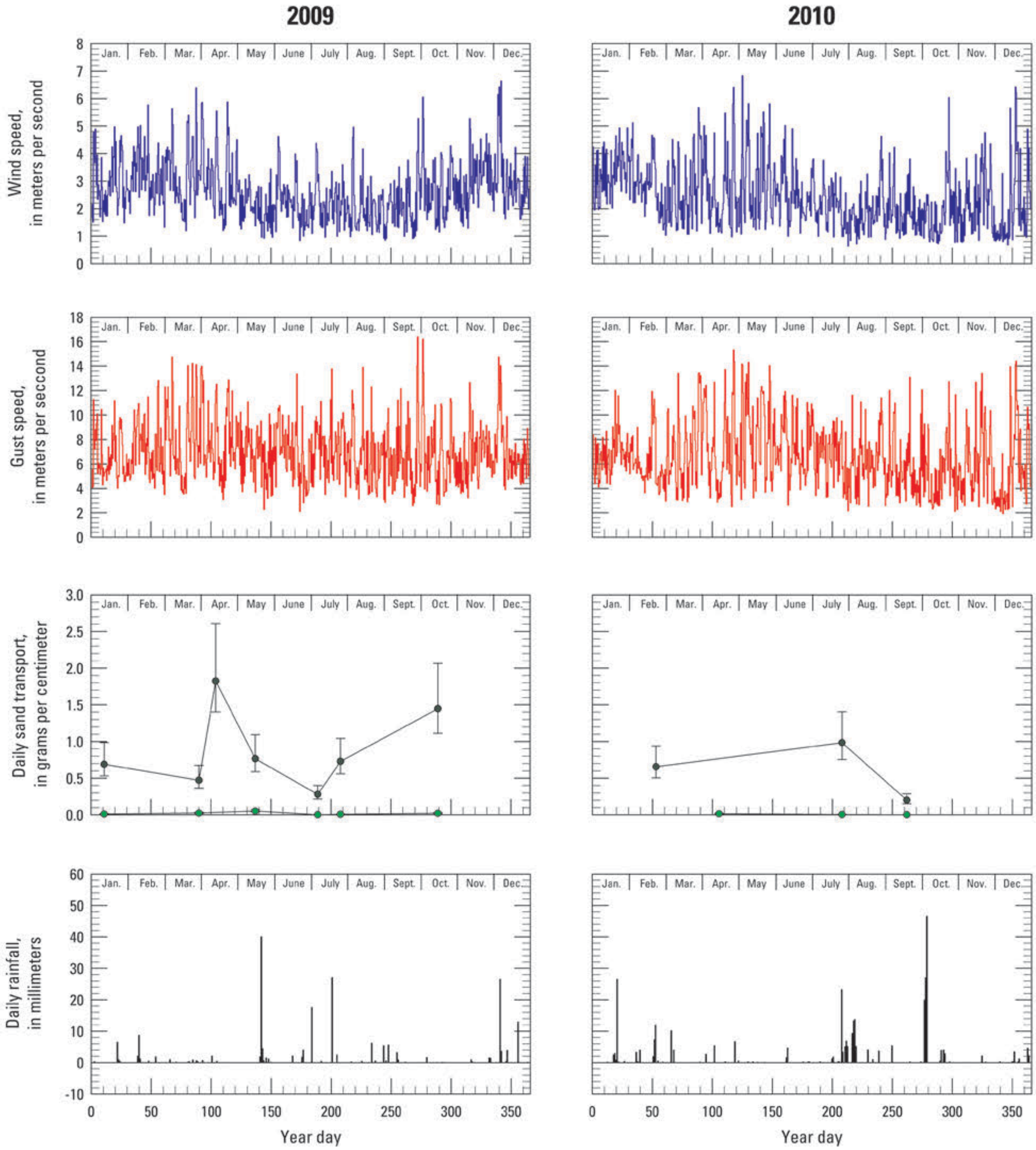

Figure 31. Plots showing wind, aeolian sand-transport, and rainfall data collected at the instrument station AZ C:13:0336 U in Grand Canyon, Arizona, 2009–10. Wind speed is presented as diurnal average values, using daytime (0600–1800 hours) and nighttime (1800–0600 hours) averages of data collected at 4-minute intervals. Gust speed is shown as maximum values that occurred during each diurnal interval. Daily sand transport is plotted in grams, normalized to a width of 1 centimeter. To obtain these values, total sand mass collected from four traps during each maintenance visit was divided by the number of days since the trap had last been emptied. The lower of the two sand-transport lines plotted indicates transport rates measured at the lower set of traps at this station (AZ C:13:0336 L). Rainfall is plotted as daily (24-hour) totals.

Site AZ C:13:0321

One set of BSNE sand traps measures sand-transport rates in an aeolian sand deposit near river level at AZ C:13:0321 with 30 percent vegetation cover (Draut, 2011). At this site, large (>10 m high), well-established aeolian dunes are present inland from a fluvial sandbar and above the post-dam high water level. Although wind conditions are not measured directly at this site, the orientation of dune slip faces indicates migration toward the northeast (inland), indicating that this site most likely is an MFS aeolian deposit downwind of an active, modern sandbar (Draut and others, 2010).

Daily sand flux measured near site AZ C:13:0321 was substantially higher during 2010 (2–6 g/cm) than during 2009 (1–3 g/cm) (fig. 33). The southwest-toward-northeast dune migration is consistent with net sediment-transport directions derived from wind measurements at the nearest weather stations (at site AZ C:13:0346), which are 700 m away from site AZ C:13:0321 (fig. 34).

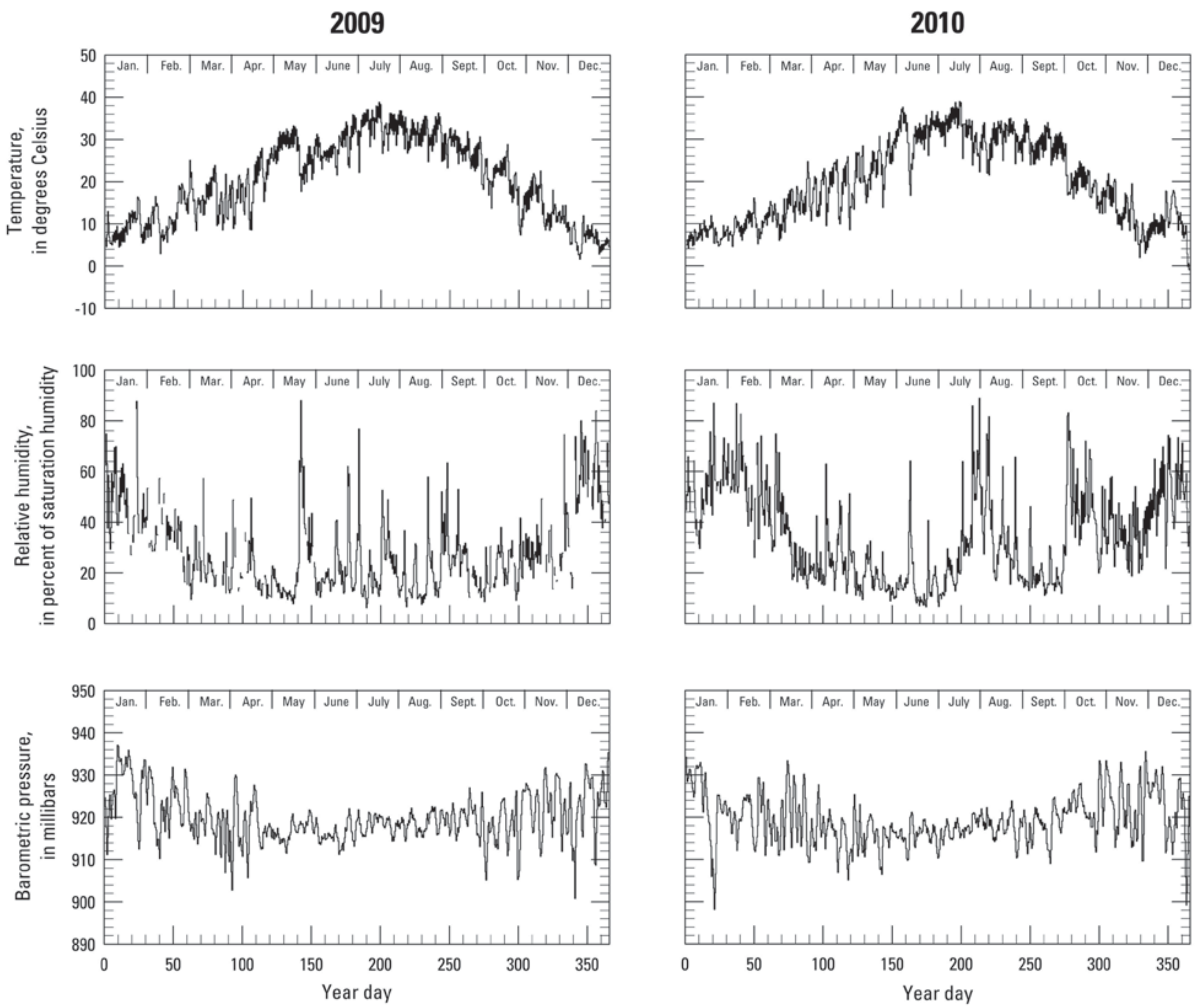

Figure 32. Plots showing temperature, relative humidity, and barometric pressure data collected at instrument station AZ C:13:0336 U in Grand Canyon, Arizona, 2009–10. All parameters are plotted as diurnal averages (defined using 0600–1800 and 1800–0600 hours).

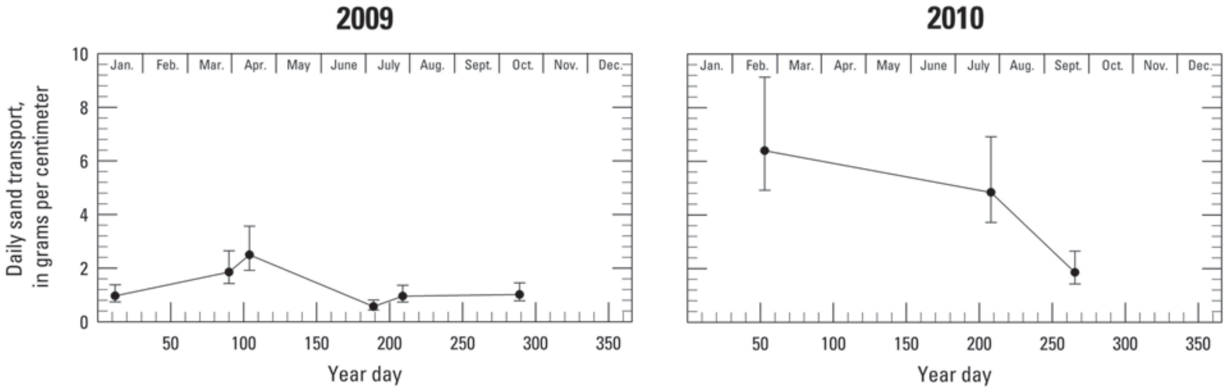

Figure 33. Plots showing aeolian sand-transport data collected near AZ C:13:0321 in Grand Canyon, Arizona, 2010. Daily sand transport is plotted in grams, normalized to a width of 1 centimeters. To obtain these values, total sand mass collected from four traps during each maintenance visit was divided by the number of days since the trap had last been emptied.

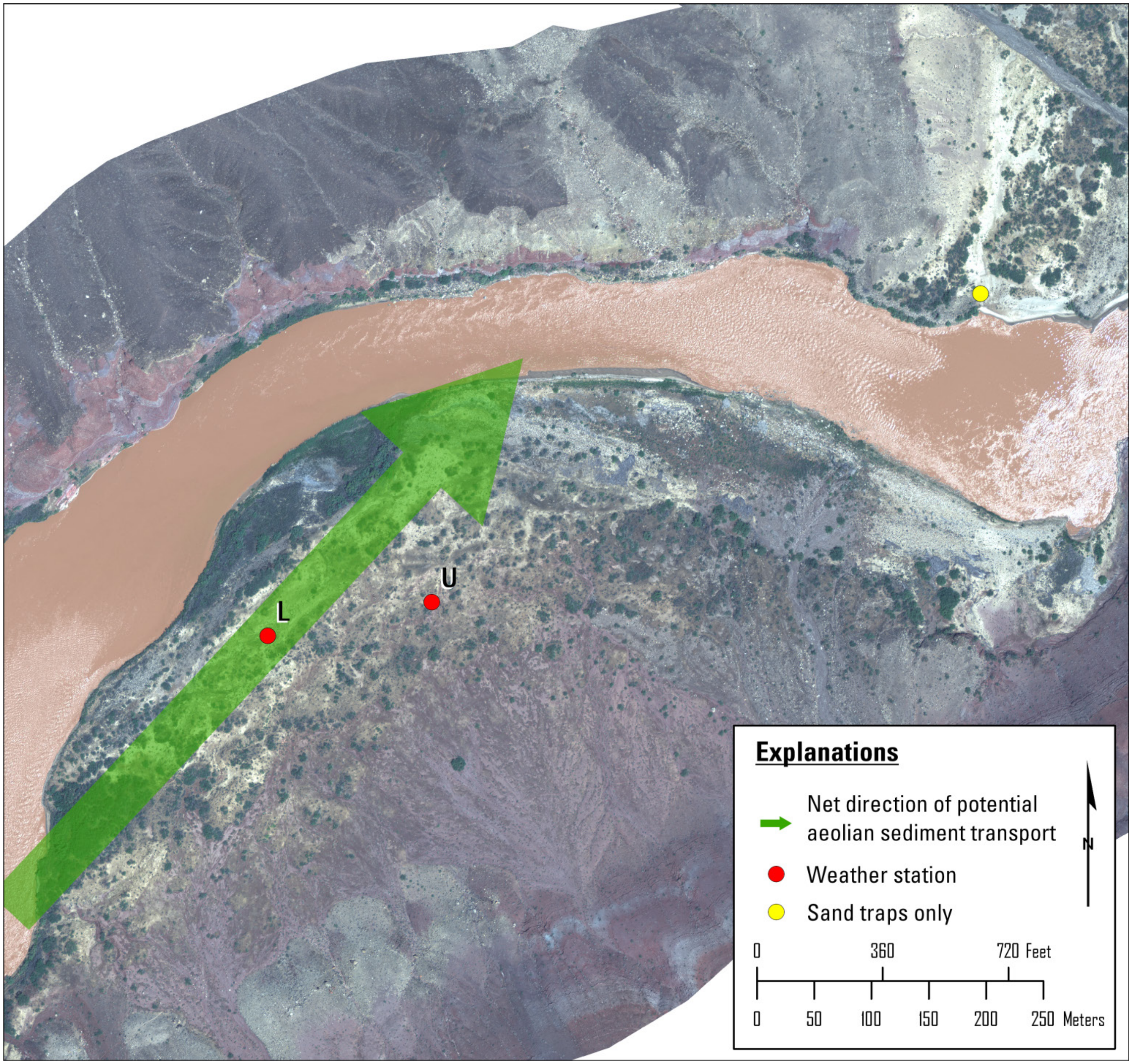

Figure 34. Aerial photograph of the area around site AZ C:13:0346 in Grand Canyon, Arizona. Arrow indicates the net direction of potential aeolian sediment transport measured at AZ C:13:0346 L in 2010. A vector sum of the *Qp* proxy variable (equation 1), calculated using all the wind data collected during dry conditions from station AZ C:13:0346 L in 2010, indicates net sediment transport from 217°. Yellow dot in upper right corner designates sand traps at AZ C:13:321.

Site AZ C:13:0346

Two instrument stations operated in 2010 near river mile 70, AZ C:13:0346 L and AZ C:13:0346 U. This reach of the Colorado River corridor in eastern Grand Canyon is several kilometers wide, is characterized by broad meander bends in the river, and is a continuation of the geomorphic setting referred to as the Furnace Flats reach by Schmidt and Graf (1990). The dune field at this site generally is bordered by riparian vegetation and not by sandbars (fig. 34). Draut (2011, 2012) interpreted the aeolian dune field in this area as relict fluvial sourced, receiving negligible new sediment influx from modern sand bars. Station AZ C:13:0346 L is in the dune field that has well-developed dune forms and locally active sediment transport.

The Nexsens™ data logger at station AZ C:13:0346 L reached its maximum storage capacity on September 16, 2010, and randomly overwrote stored data to continue storing new data. The data download in September 2010 was terminated before the downloading of all data could be completed because of trip logistics. Although the data logger was programmed to stop collecting data once it reached its storage capacity, the data logger malfunctioned and overwrote previously collected data, resulting in some data loss from this station.

Wind speed and direction measured at station AZ C:13:0346 L in 2010 are plotted in figure 35. Cumulative rainfall data are shown in figure 36; approximate total rainfall measured at that station in 2010, excluding 14 days of data between September 16 and December 31, was 233.0 mm (table 2). All weather parameters and sand transport measured at station AZ C:13:0346 L in 2010 are summarized in figures 37 and 38, with 2009 data shown for comparison.

A vector sum of available wind data from weather station AZ C:13:0346 L in 2010 (excluding the dates of malfunction) yields a net *Qp* magnitude of 652,360 m^3/s^3 from a direction of 217º; using wind data collected from the same time interval only when the sand is estimated to have been dry, a vector sum yields a net *Qp* magnitude of 362,210 m^3/s^3 from a direction of 223º (table 3). These net potential sand-transport directions reflect a strong directional component from the west-southwest (fig. 34). Daily sand-transport rates in 2010 at station AZ C:13:0346 L were highest in spring (April–May), and were lower in magnitude compared to those in spring (March–April) 2009 (fig. 37).

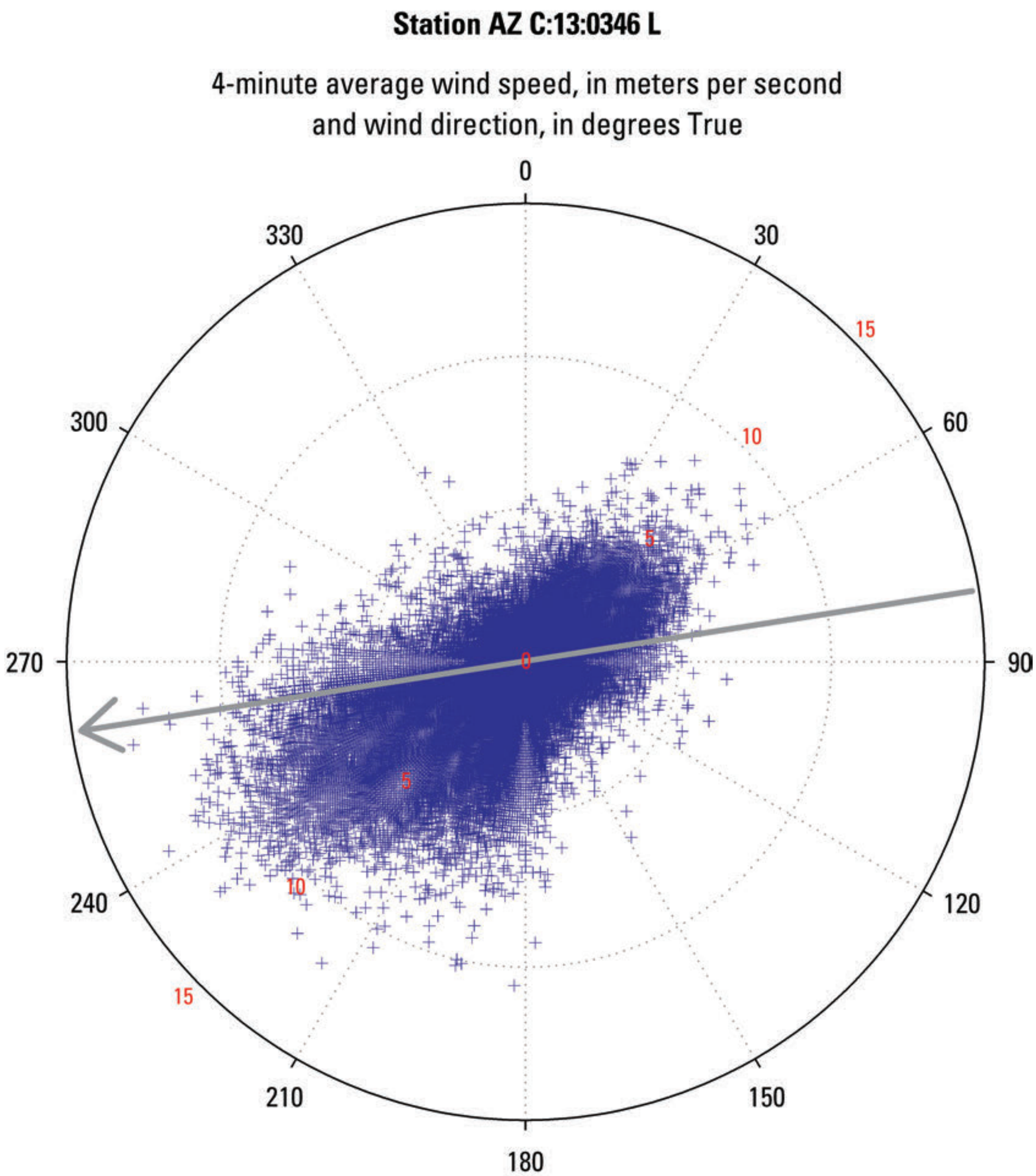

Figure 35. Plot showing magnitude and direction of wind velocity measured at the instrument station AZ C:13:0346 L with 4-minute resolution in Grand Canyon, Arizona, 2010. Magnitude is indicated by the concentric circles, and compass bearing indicates the wind. The gray arrow shows the orientation of the river corridor (261°); river flow is toward the west.

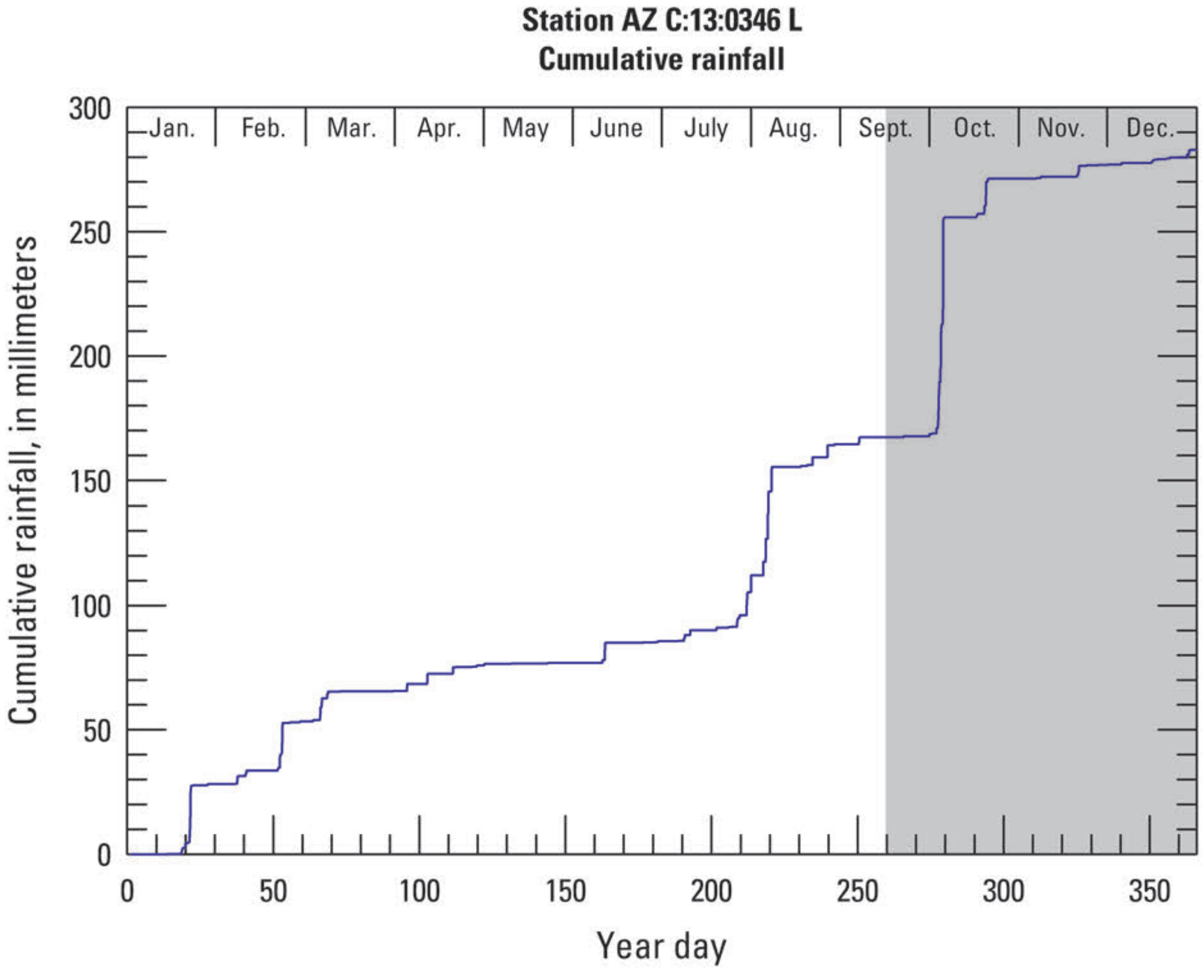

Figure 36. Plot showing cumulative rainfall recorded at station AZ C:13:0346 L compiled from data collected at 4-minute resolution in Grand Canyon, Arizona, 2010. Gray shading indicates that isolated occurrences of station malfunction occurred on 14 days between September 16 and December 31, 2010, during which period no data were collected. The cumulative rainfall data, therefore, represents minimum values for this station after September 16, 2010.

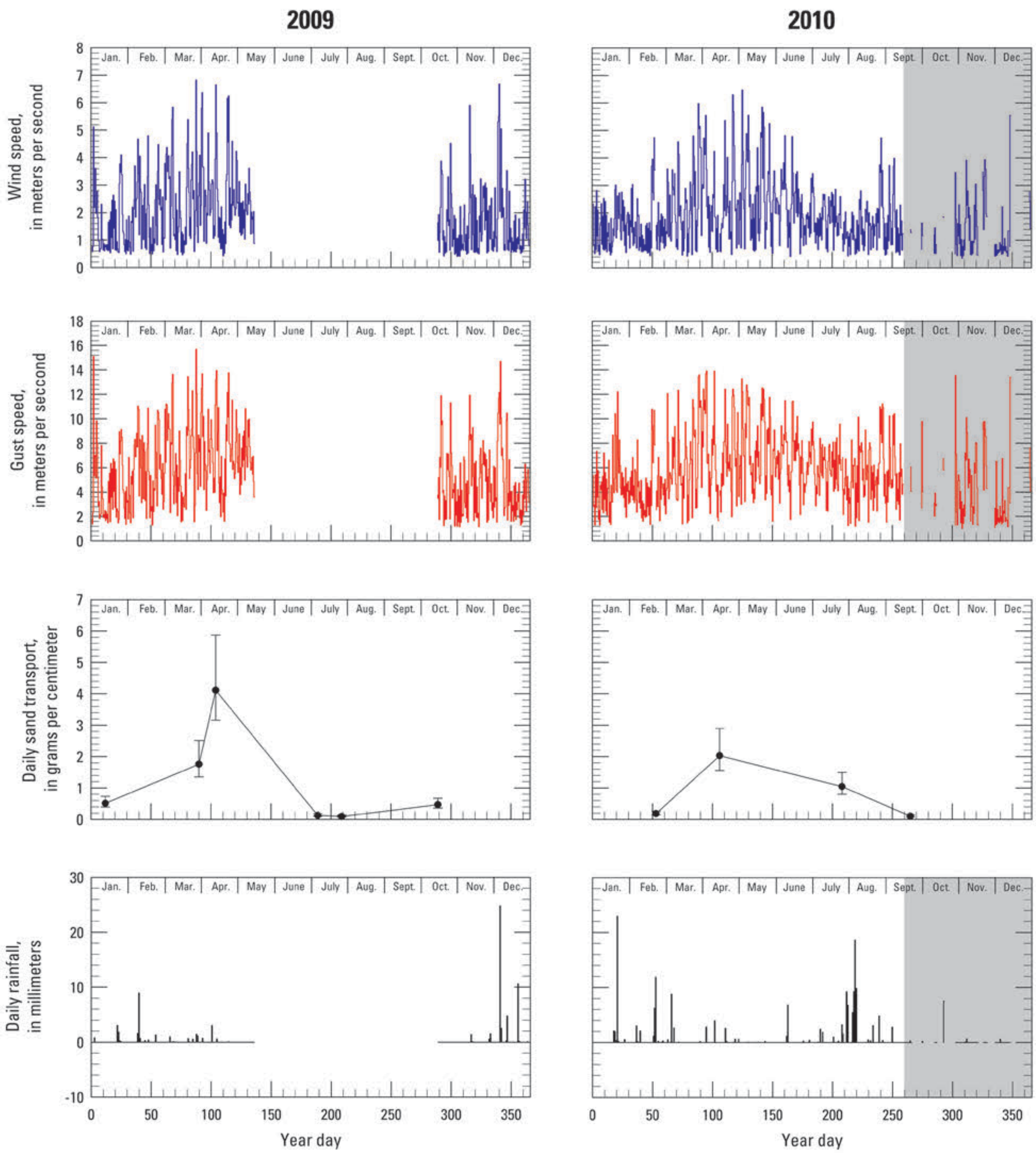

Figure 37. Plots showing wind, aeolian sand-transport, and rainfall data collected at the instrument station AZ C:13:0346 L, in Grand Canyon, Arizona, 2009–10. Wind speed is presented as diurnal average values, using daytime (0600–1800 hours) and nighttime (1800–0600 hours) averages of data collected at 4-minute intervals. Gust speed is shown as maximum values that occurred during each diurnal interval. Daily sand transport is plotted in grams, normalized to a width of 1 centimeter. To obtain these values, total sand mass collected from four traps during each maintenance visit was divided by the number of days since the trap had last been emptied. Rainfall is plotted as daily (24-hour) totals. Gray shading indicates that isolated occurrences of station malfunction occurred on 14 days between September 16 and December 31, 2010, during which period no data were collected.

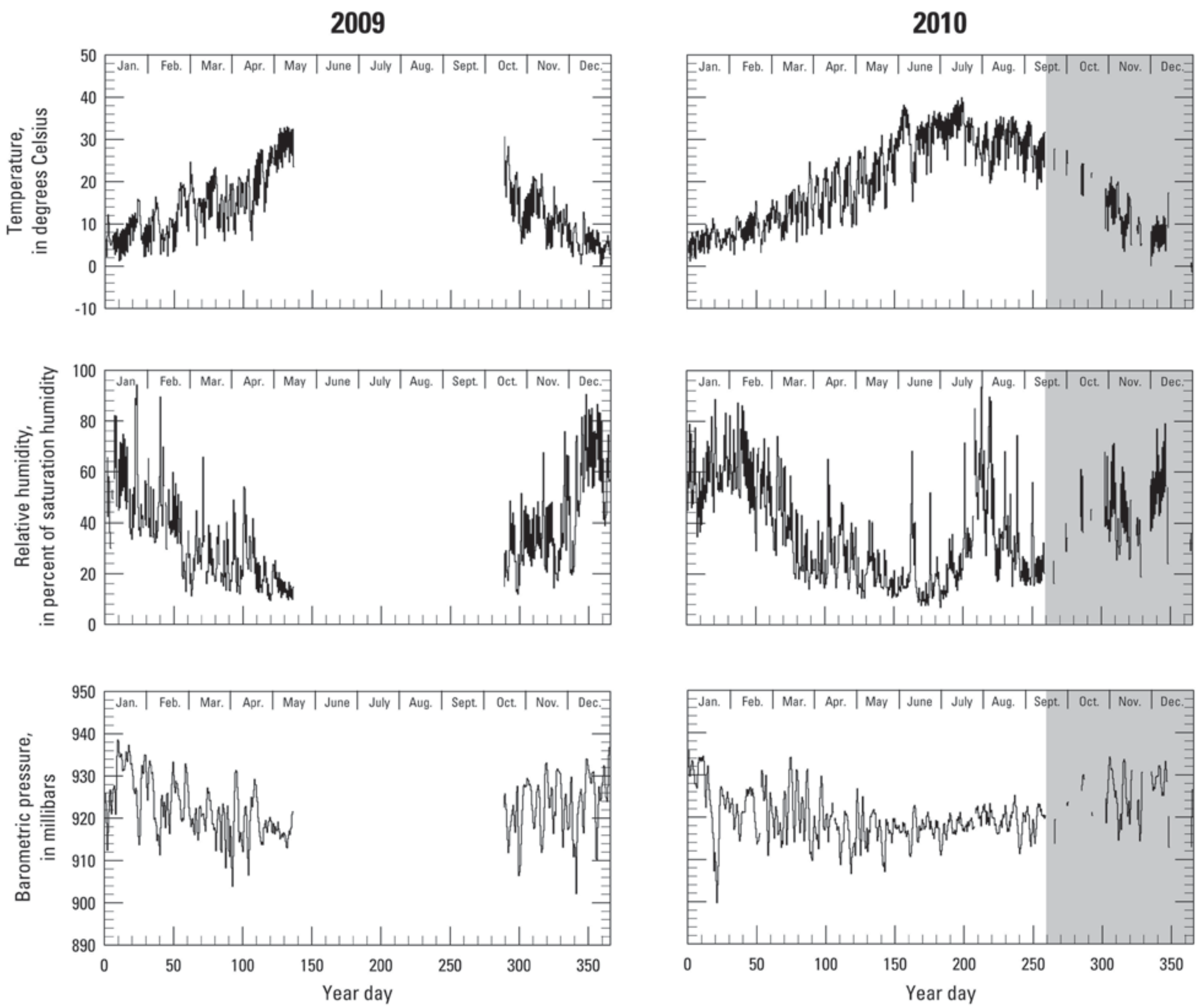

Figure 38. Plots showing temperature, relative humidity, and barometric pressure data collected at instrument station AZ C:13:0346 L in Grand Canyon, Arizona, 2009–10. All parameters are plotted as diurnal averages (defined using 0600–1800 and 1800–0600 hours). Gray shading indicates that isolated occurrences of station malfunction occurred on 14 days between September 16 and December 31, 2010, during which period no data were collected.

Station AZ C:13:0346 U is upstream of station AZ C:13:0346 L and slightly farther inland from the river (fig. 39). The land surface near station AZ C:13:0346 U includes relatively inactive dunes on a broad, flat landscape with abundant silty material, some derived from relict fluvial deposits and some composed of distal slopewash from local bedrock. Biological soil crust is more abundant around station AZ C:13:0346 U than around station AZ C:13:0346 L (Draut, 2011). Wind speed and direction measured at station AZ C:13:0346 U in 2010 are plotted in figure 40. Cumulative rainfall data are shown in figure 41; total rainfall measured in 2010 was 308.1 mm (table 2). All weather parameters and sand transport measured at station AZ C:13:0346 U in 2010 are summarized in figures 42 and 43, with 2009 data shown for comparison.

A vector sum of all available wind data from station AZ C:13:0346 U in 2010 yields a net *Qp* magnitude of 500,130 m^3/s^3 from a direction of 225º; using wind data collected only when the sand is estimated to have been dry, a vector sum yields a net *Qp* magnitude of 330,000 m^3/s^3 from a direction of 228º (table 3). These net potential sand-transport directions reflect a consistent directional component from the southwest (fig. 39).

The highest wind speeds in 2010 were observed slightly later (April–May) than in 2009 (March–April) (fig. 42). Sand-transport rates at station AZ C:13:0346 U generally decreased between 2007 and 2010, likely attributable to increasing vegetation cover over that time period. The greater amount of precipitation recorded in 2010 compared to 2009 may have been another contributing factor.

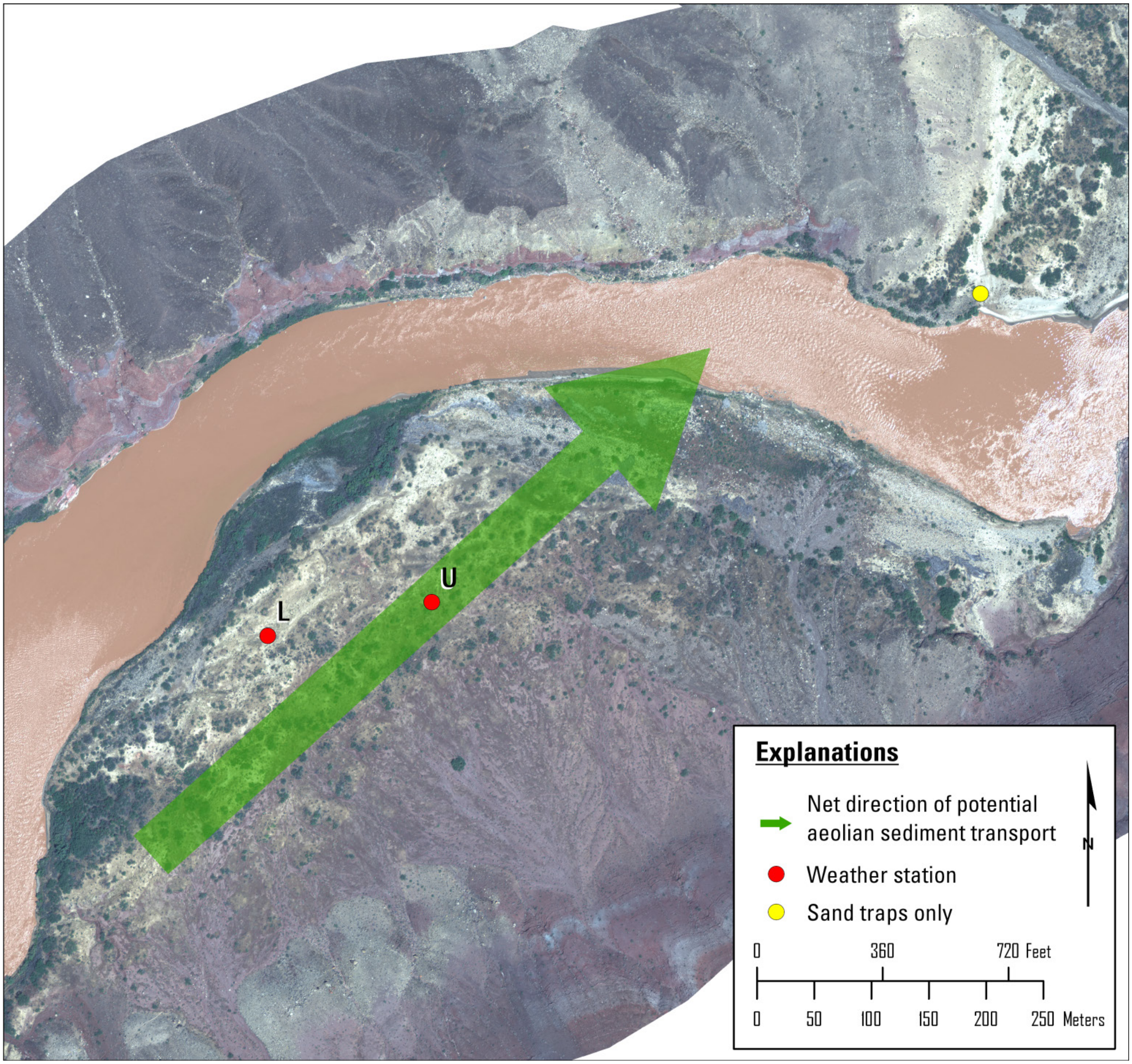

Figure 39. Aerial photograph of the area around site AZ C:13:0346 in Grand Canyon, Arizona. Arrow indicates the net direction of potential aeolian sediment transport measured at AZ C:13:0346 U in 2010. A vector sum of the *Qp* proxy variable (equation 1), calculated using all the wind data collected during dry conditions from AZ C:13:0346 U in 2010, indicates net sediment transport from 225°.

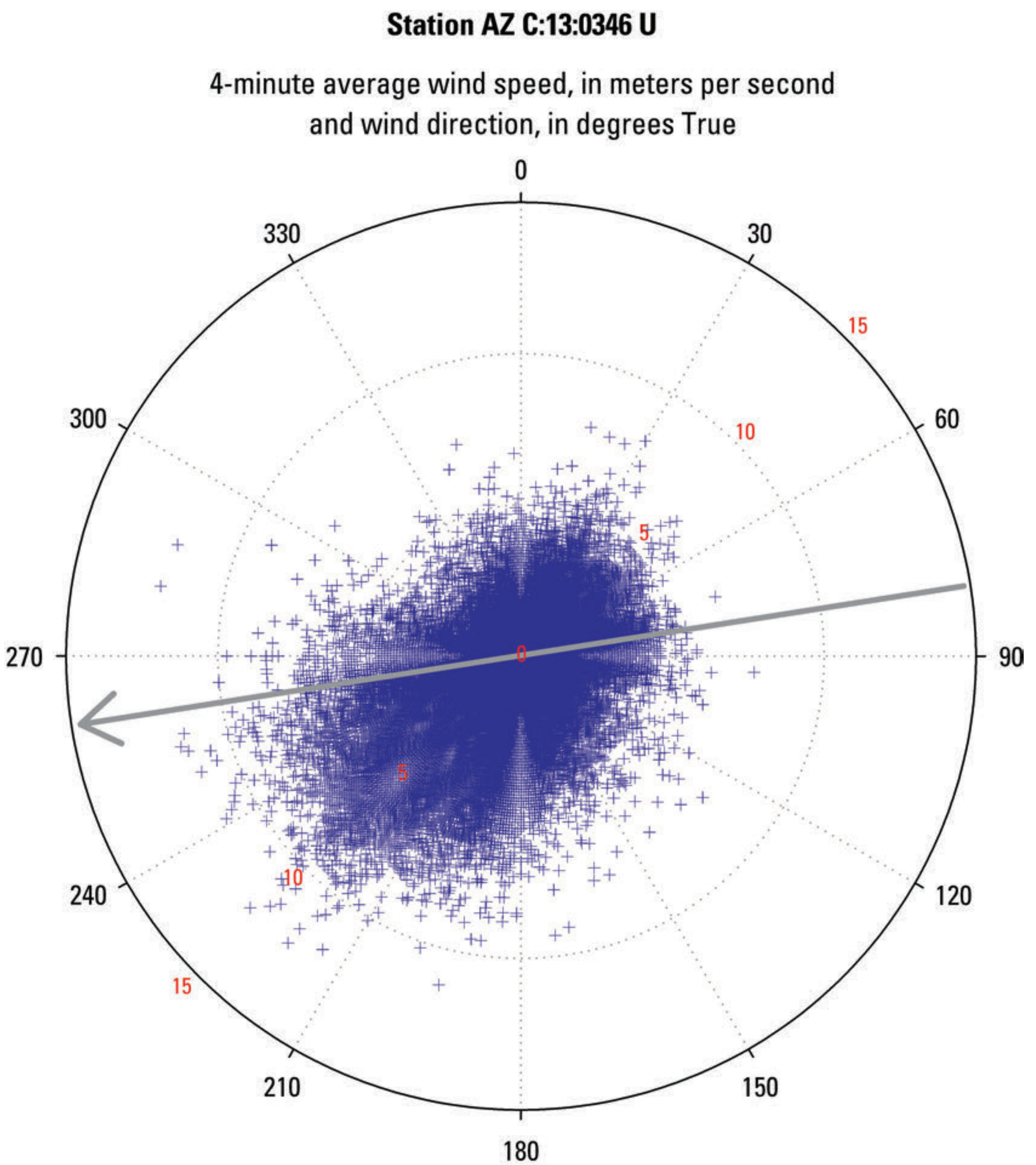

Figure 40. Plot showing magnitude and direction of wind velocity measured at the instrument station AZ C:13:0346 U with 4-minute resolution in Grand Canyon, Arizona, 2010. Magnitude is indicated by the concentric circles, and compass bearing indicates the wind direction. The gray arrow shows the orientation of the river corridor (261°); river flow is toward the west.

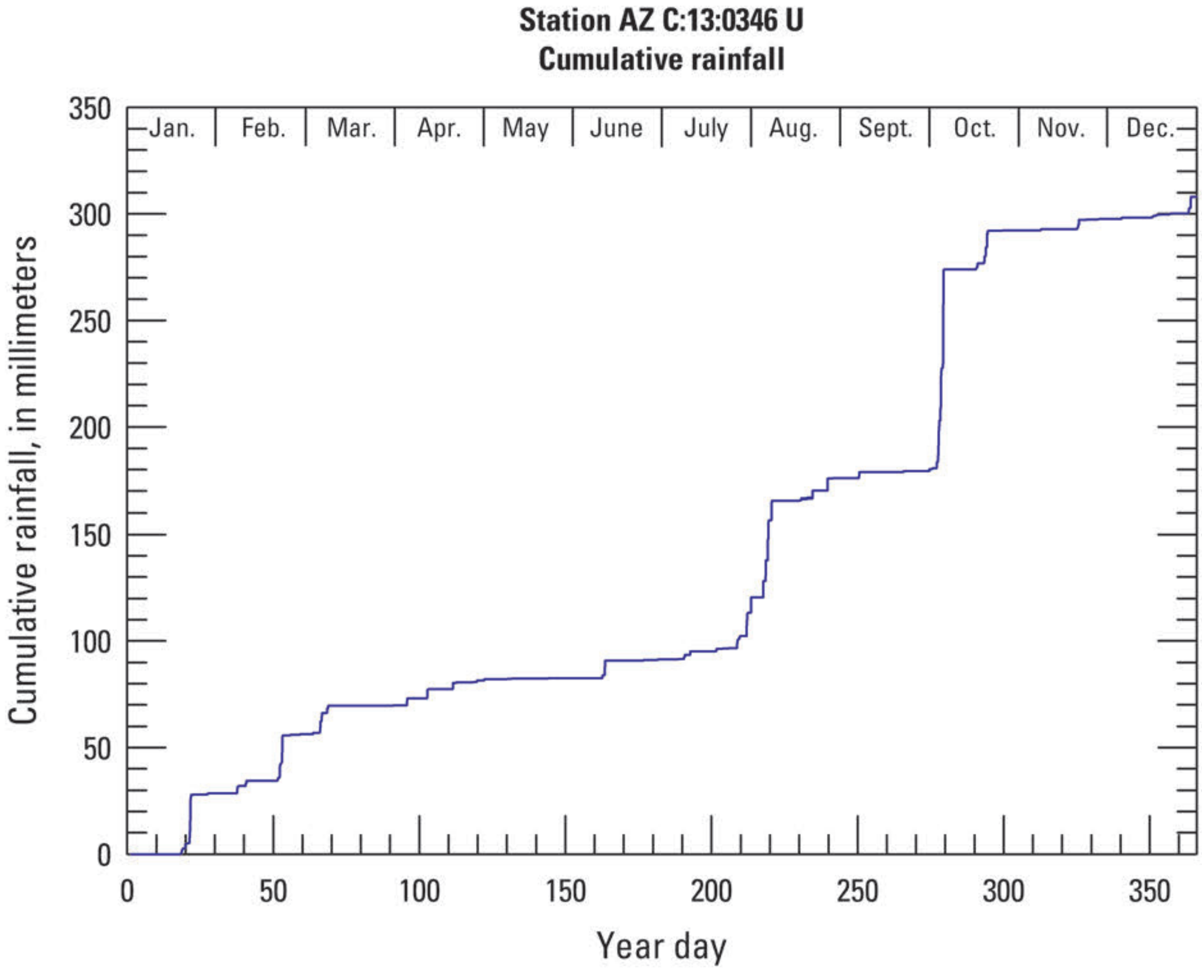

Figure 41. Plot showing cumulative rainfall recorded at station AZ C:13:0346 U compiled from data collected at 4-minute resolution in Grand Canyon, Arizona, 2010.

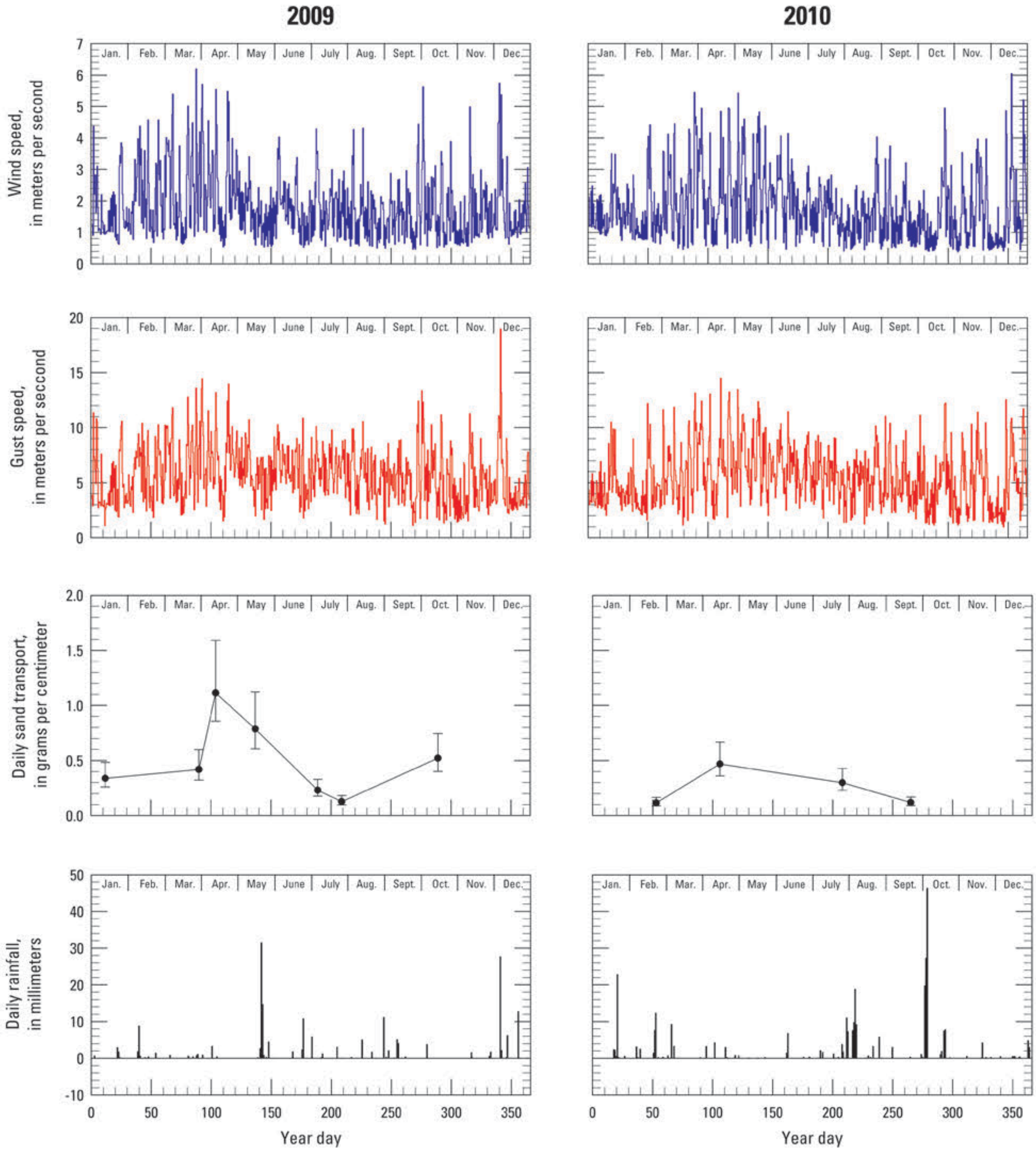

Figure 42. Plots showing wind, aeolian sand-transport, and rainfall data collected at the instrument station AZ C:13:0346 U in Grand Canyon, Arizona, 2009–10. Wind speed is presented as diurnal average values, using daytime (0600–1800 hours) and nighttime (1800–0600 hours) averages of data collected at 4-minute intervals. Gust speed is shown as maximum values that occurred during each diurnal interval. Daily sand transport is plotted in grams, normalized to a width of 1 centimeter. To obtain these values, total sand mass collected from four traps during each maintenance visit was divided by the number of days since the trap had last been emptied. Rainfall is plotted as daily (24-hour) totals.

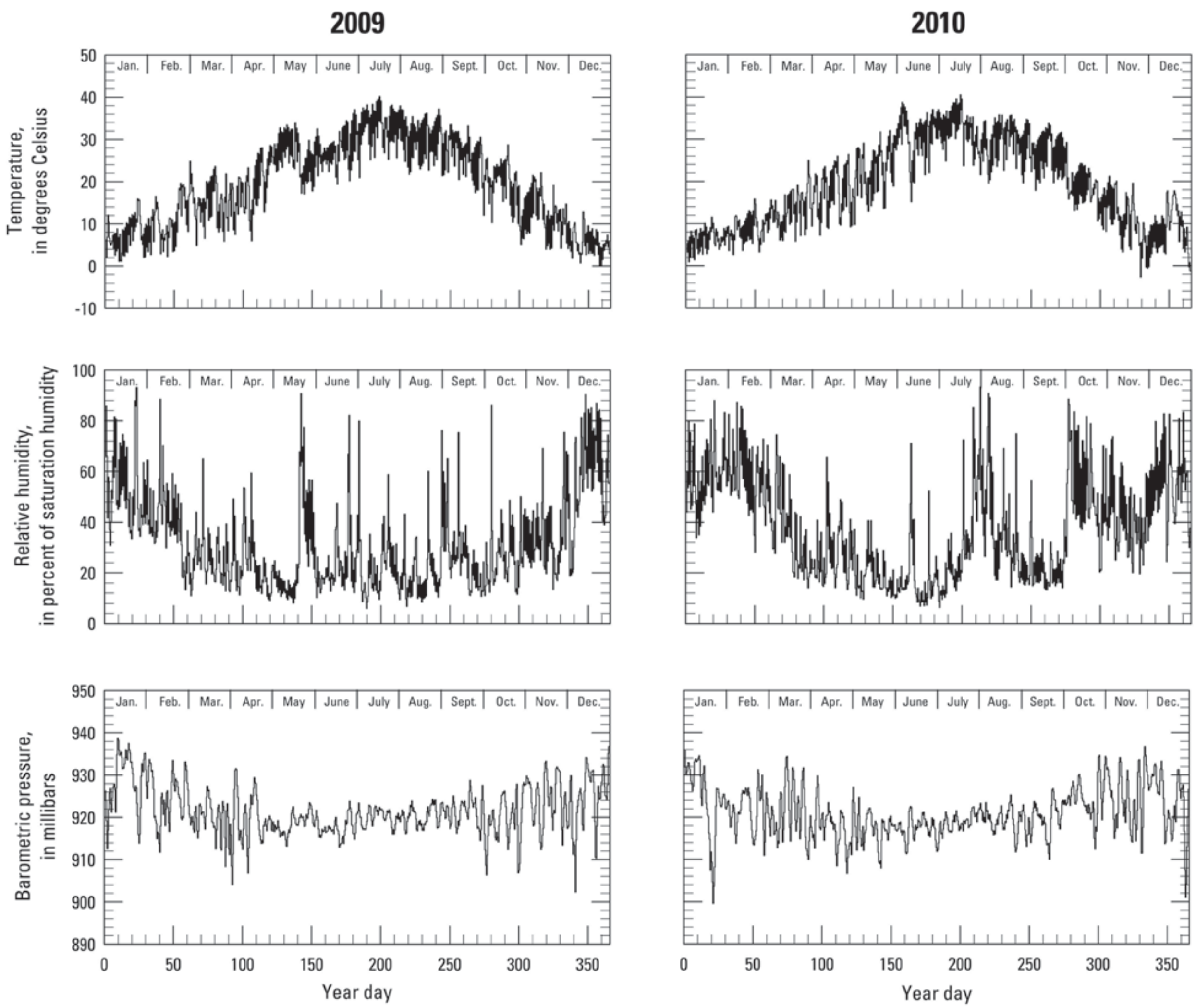

Figure 43. Plots showing temperature, relative humidity, and barometric pressure data collected at instrument station AZ C:13:0346 U in Grand Canyon, Arizona, 2009–10. All parameters are plotted as diurnal averages (defined using 0600–1800 and 1800–0600 hours).

Site AZ B:11:0281

One instrument station operated near site AZ B:11:0281 throughout 2010 with no interruptions. This station is on the upstream side of a small debris fan that formed at the mouth of an ephemeral tributary drainage (fig. 44). The land surface at this site is composed of moderately active aeolian dunes with moderate vegetation cover and biological soil crust. Inland from the river on its south side, fine-grained sedimentary deposits occur near site AZ B:11:0281 that are thought to have been deposited as the river flow ponded behind a large landslide deposit (Huntoon, 2003), temporarily damming the river 3 km downstream about 20 thousand years ago (R.H. Webb, USGS scientist, written comm., 2008).

Wind speed and direction measured at site AZ B:11:0281 in 2010 are plotted in figure 45. Cumulative rainfall data are shown in figure 46; total rainfall measured in 2010 was 421.8 mm (table 2). All weather parameters and sand transport measured at site AZ B:11:0281 in 2010 are summarized in figures 47 and 48, with 2009 data shown for comparison.

A vector sum of all wind data from site AZ B:11:0281 in 2010 yields a net *Qp* magnitude of 257,450 m^3/s^3 from a direction of 104º; using wind data collected only when the sand is estimated to have been dry, a vector sum yields a net *Qp* magnitude of 208,770 m^3/s^3 from a direction of 105º (table 3). These net potential sand-transport directions reflect a consistent directional component from the east-southeast (fig. 44). Spring sand transport around site AZ B:11:0281 showed only a marginal increase during the spring windy season from 2008 to 2009, and again from 2009 to 2010, but showed a substantial increase in the summer. Daily sand-transport rates were greater than 0.1 g/cm between April and July of 2010, whereas they remained less than 0.1 g/cm for most of 2009. The relatively low sand-transport rates at this site may be attributed to vegetation upwind (east) of the sand traps that limited sand entrainment.

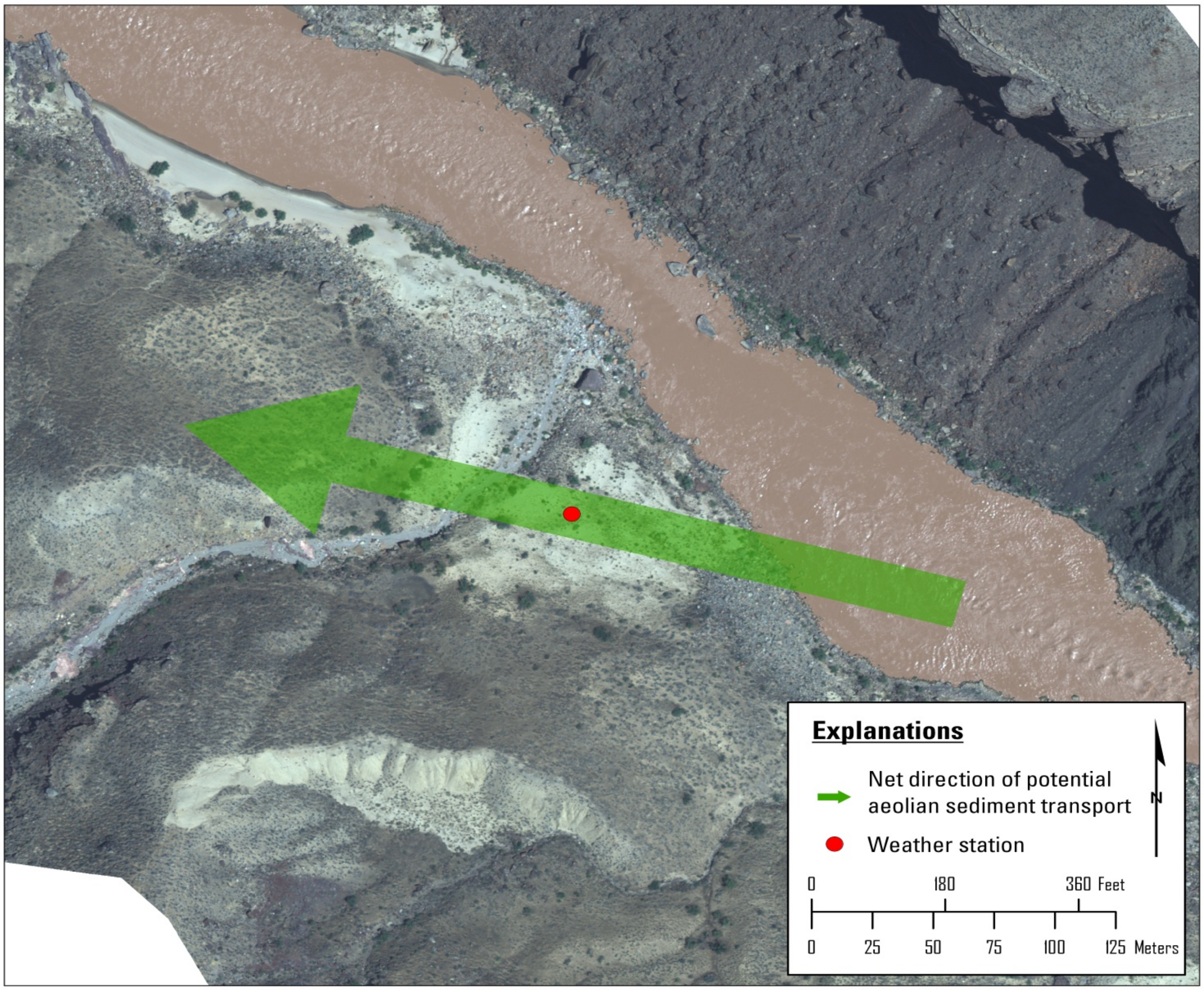

Figure 44. Aerial photograph of the area around site AZ B:11:0281 in Grand Canyon, Arizona. Arrow indicates the net direction of potential aeolian sediment transport measured at AZ B:11:0281 in 2010. A vector sum of the Qp proxy variable (equation 1), calculated using all the wind data collected during dry conditions from AZ B:11:0281 in 2010, indicates net sediment transport from 104°.

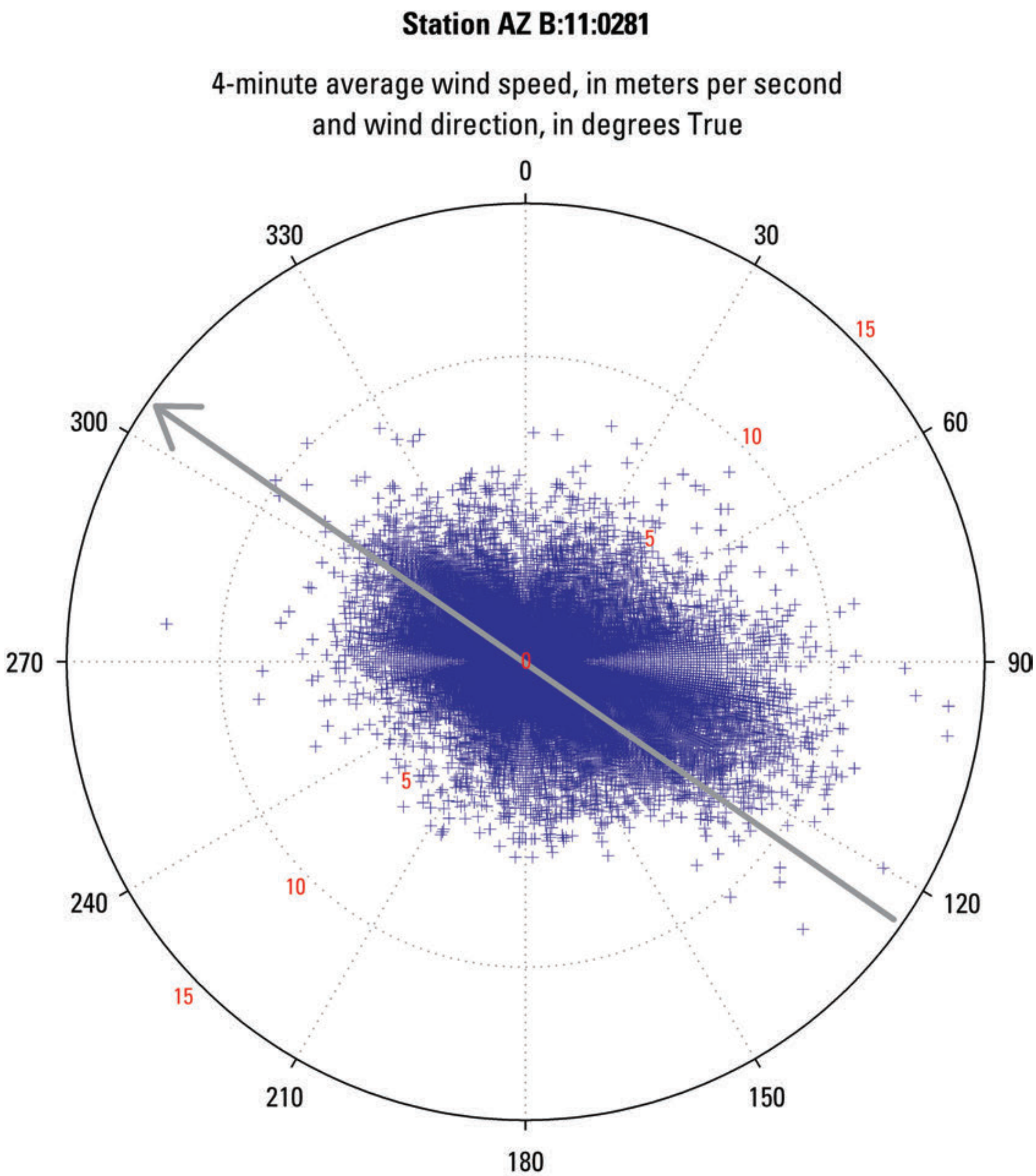

Figure 45. Plot showing magnitude and direction of wind velocity measured at the instrument station AZ B:11:0281 with 4-minute resolution in Grand Canyon, Arizona, 2010. Magnitude is indicated by the concentric circles, and compass bearing indicates the wind direction. The gray arrow shows the orientation of the river corridor (305°); river flow is toward the northwest.

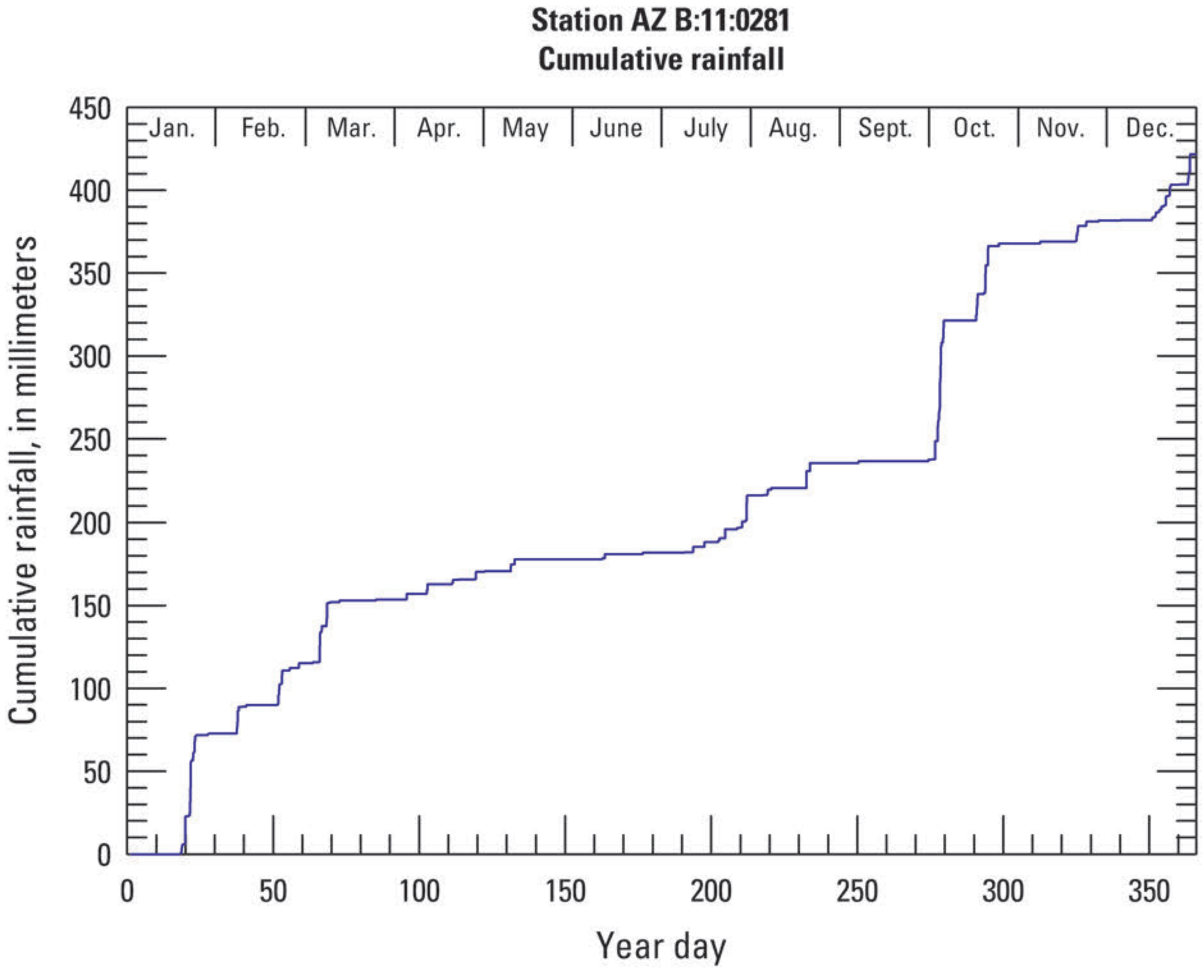

Figure 46. Plot showing cumulative rainfall recorded at site AZ B:11:0281 compiled from data collected at 4-minute resolution in Grand Canyon, Arizona, 2010.

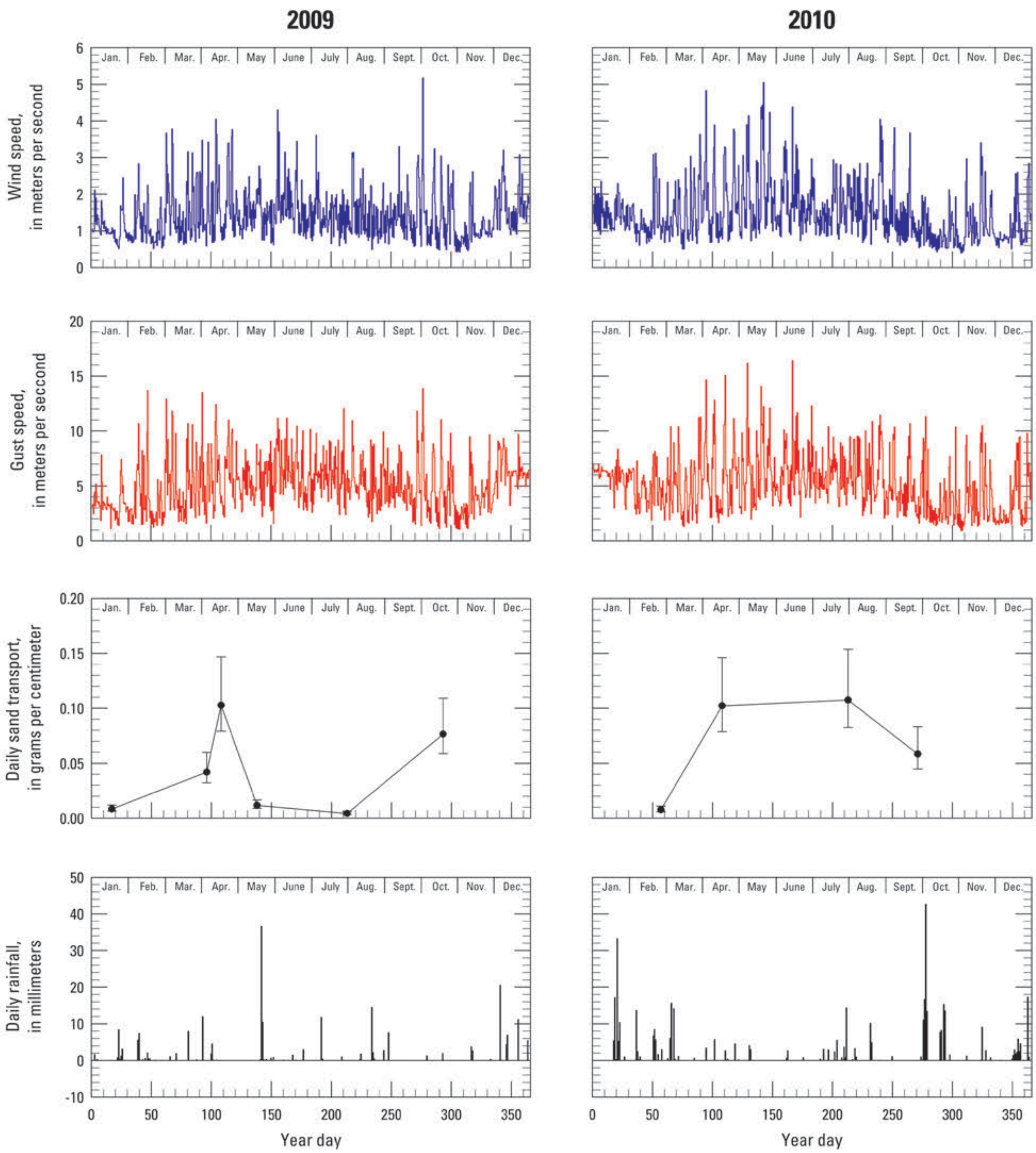

Figure 47. Plots showing wind, aeolian sand-transport, and rainfall data collected at the instrument station AZ B:11:0281, in Grand Canyon, Arizona, 2009–10. Wind speed is presented as diurnal average values, using daytime (0600–1800 hours) and nighttime (1800–0600 hours) averages of data collected at 4-minute intervals. Gust speed is shown as maximum values that occurred during each diurnal interval. Daily sand transport is plotted in grams, normalized to a width of 1 centimeter. To obtain these values, total sand mass collected from four traps during each maintenance visit was divided by the number of days since the trap had last been emptied. Rainfall is plotted as daily (24-hour) totals.

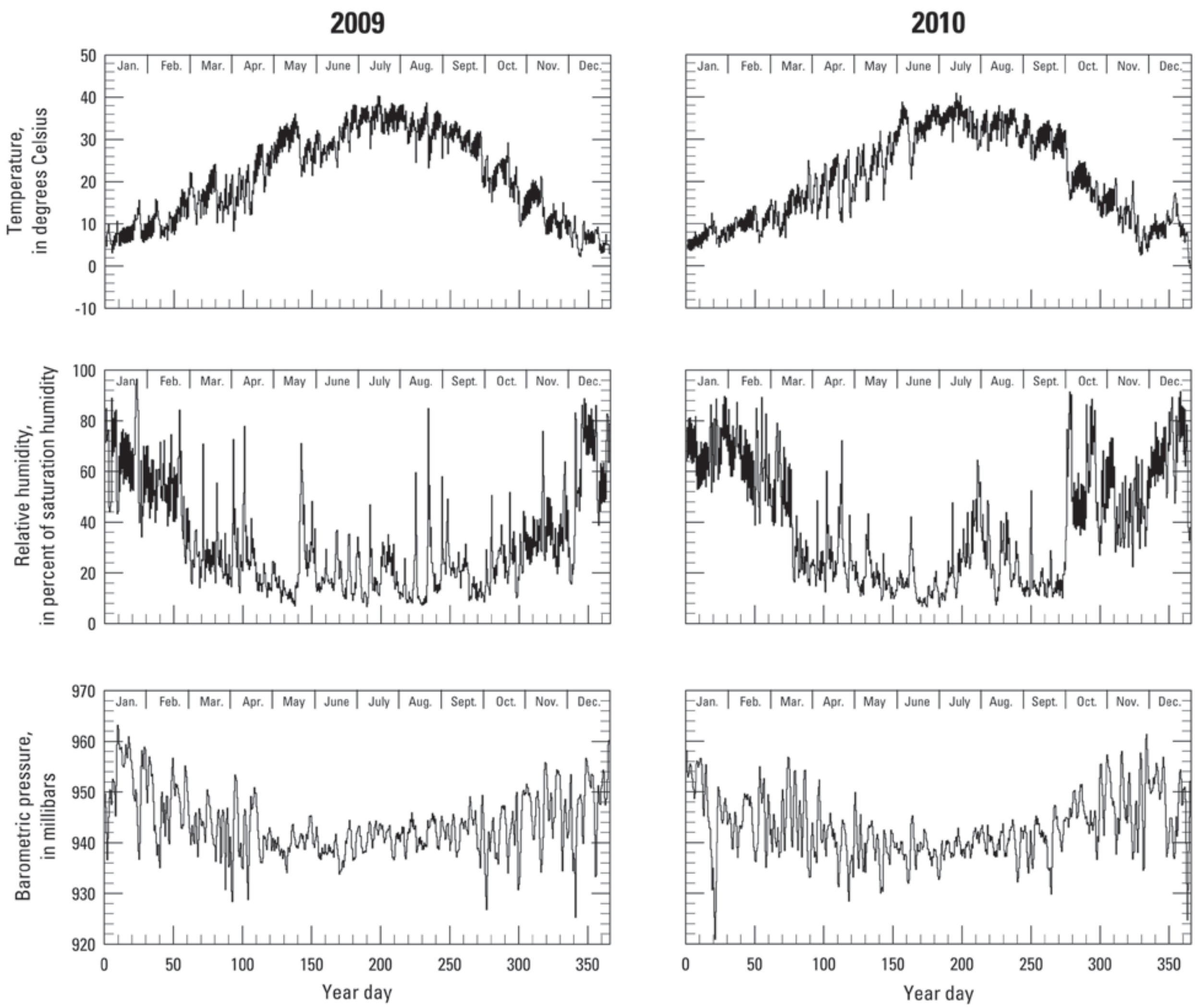

Figure 48. Plots showing temperature, relative humidity, and barometric pressure data collected at instrument station AZ B:11:0281 in Grand Canyon, Arizona, 2009–10. All parameters are plotted as diurnal averages (defined using 0600–1800 and 1800–0600 hours).

Site AZ A:15:0033

One instrument station operated near archeological site AZ A:15:0033 in 2010. No data were collected by the instrument station between September 2 and 29, 2010, because of a loss of power as a result of rodent damage to the power cable. The power cable was replaced and the station operated without interruption for the remainder of the year. The study site includes an aeolian dune field near river level that is covered by relatively dense vegetation (63 percent area cover according to Draut, 2011) (fig. 49). The vegetation has overgrown the dune field and a large river-level sandbar just downstream of the dune field since the 1960s, and now covers much of the previously open sand (Draut and Rubin, 2008).

Wind speed and direction measured at site AZ A:15:0033 in 2010 are plotted in figure 50. Cumulative rainfall data are shown in figure 51; total rainfall measured while the station was operating in 2010 was 357.4 mm, excluding the data gap in September, mentioned above (table 2). All weather parameters and sand transport measured at site A:15:0033 in 2010 are summarized in figures 52 and 53, with 2009 data shown for comparison.

Wind conditions measured at station AZ A:15:0033 in past years (2004 through 2009) have been complex; although upstream and downstream winds nearly balanced each other, vector components from the north-northeast can result in net potential sand flux toward the river at times (Draut and Rubin, 2006, 2008). A vector sum of all wind data from site AZ A:15:0033 in 2010 yields a net *Qp* magnitude of 16,664 m^3/s^3 from a direction of 185º; using wind data only from when the sand is estimated to have been dry, a vector sum yields a net *Qp* magnitude of 11,782 m^3/s^3 from a direction of 194º (table 3). These magnitudes of net potential sand-transport are comparable to those of 2009 at the same location. Although the net transport was from a more southwesterly direction in 2010 compared to 2009 (221º for all wind data and 225º for dry conditions), as in past years, the net potential sand-transport directions reflect a balance between upstream and downstream winds, with only a slightly dominant net transport vector from the southwest (figs. 49 and 50).

As in past years, daily sand-transport rates at site AZ A:15:0033 were the lowest measured at any study site in 2010—always less than 0.02 g/cm, even during spring winds when gust speeds exceeded 10 m/s (fig. 52). This is attributed to the density of vegetation cover near the instrument station, which effectively inhibits entrainment of sand by decreasing wind velocity near the bed (Bressolier and Thomas, 1977; Buckley, 1987). Sand transport at this site was no higher in the spring than at other times of year in 2007, 2008, 2009, or 2010 (fig. 52; Draut and others, 2009a).

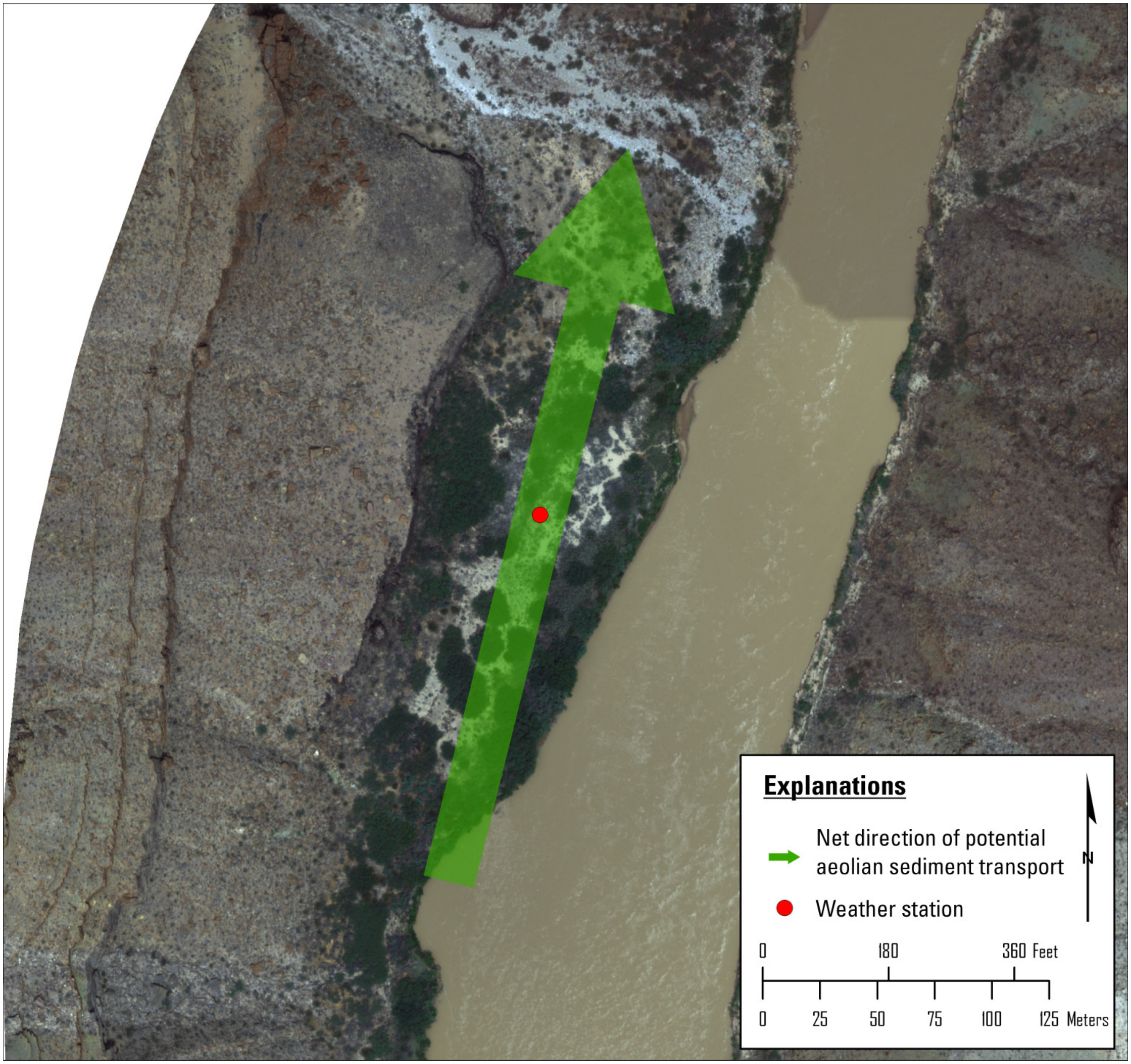

Figure 49. Aerial photograph of the area around site AZ A:15:0033 in Grand Canyon, Arizona. Arrow indicates the net direction of potential aeolian sediment transport measured at AZ A:15:0033 in 2010. A vector sum of the Qp proxy variable (equation 1), calculated using all the wind data collected during dry conditions from AZ A:15:0033 in 2010, indicates net sediment transport from 185°.

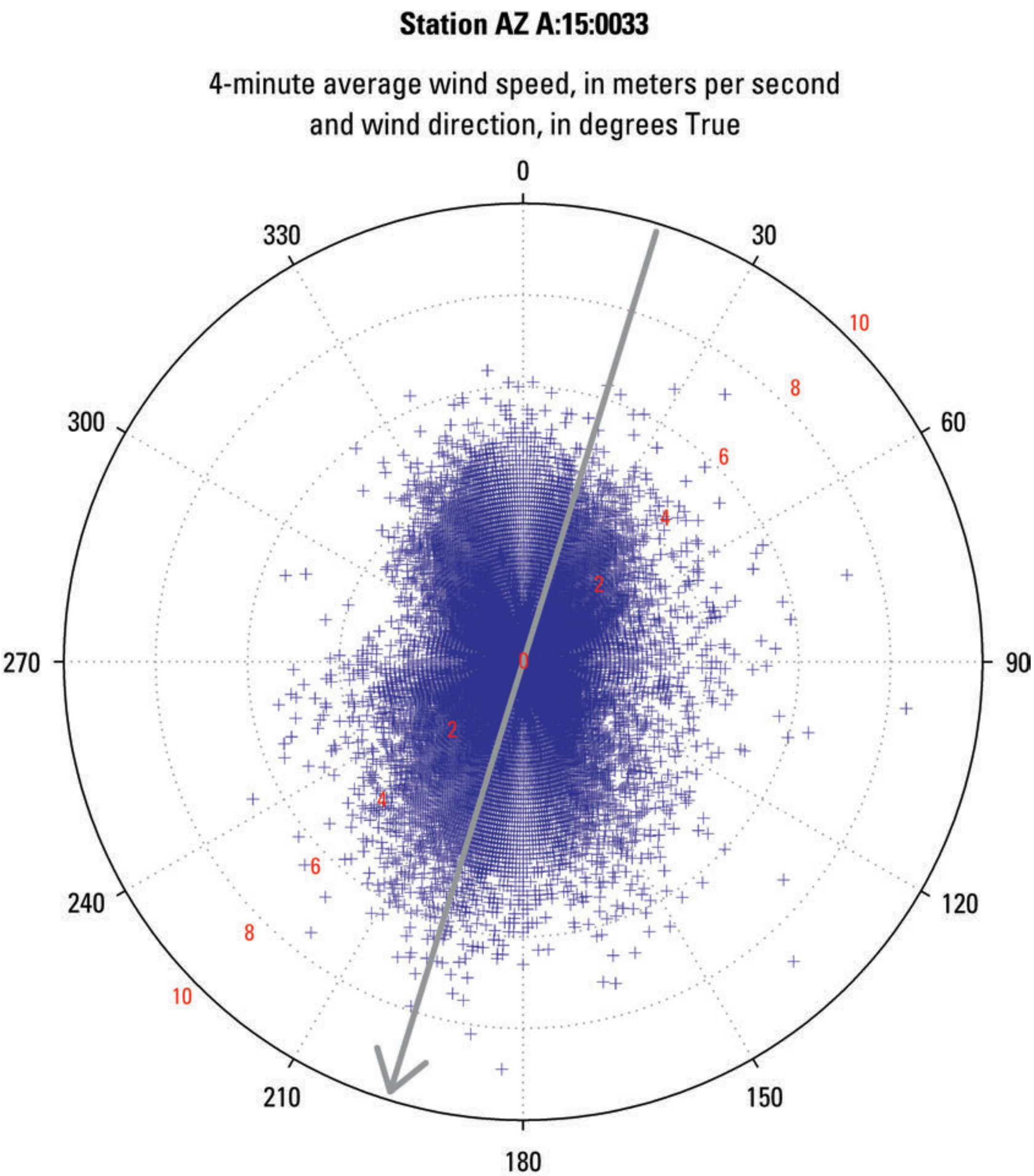

Figure 50. Plot showing magnitude and direction of wind velocity measured at the instrument station AZ A:15:0033 with 4-minute resolution in Grand Canyon, Arizona, 2010. Magnitude is indicated by the concentric circles, and compass bearing indicates the wind direction. The gray arrow shows the orientation of the river corridor (197°); river flow is toward the northwest.

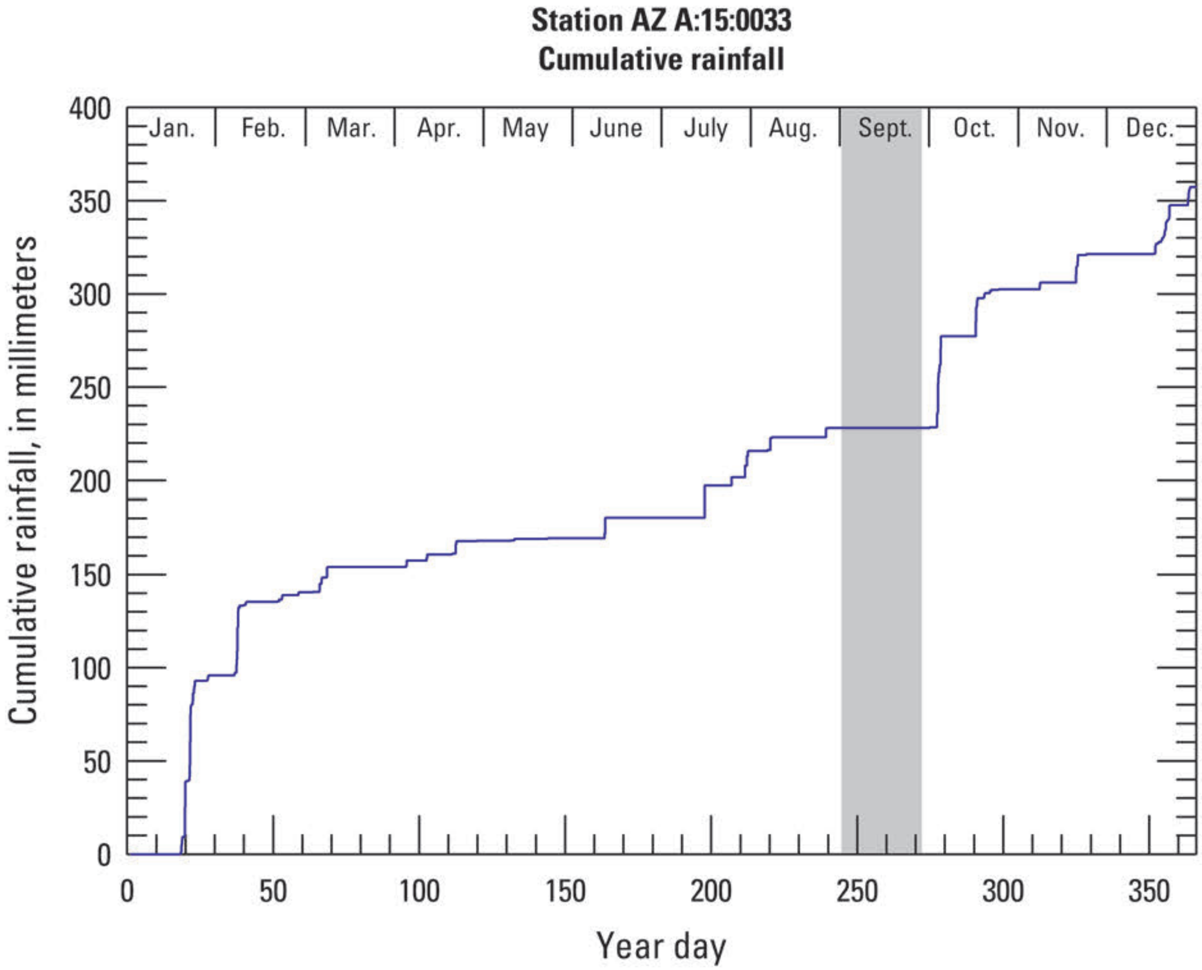

Figure 51. Plot showing cumulative rainfall recorded at site AZ A:15:0033 compiled from data collected at 4-minute resolution in Grand Canyon, Arizona, 2010. Gray shading indicates that station malfunction occurred between September 2 and 29, 2010, during which period no data were collected.

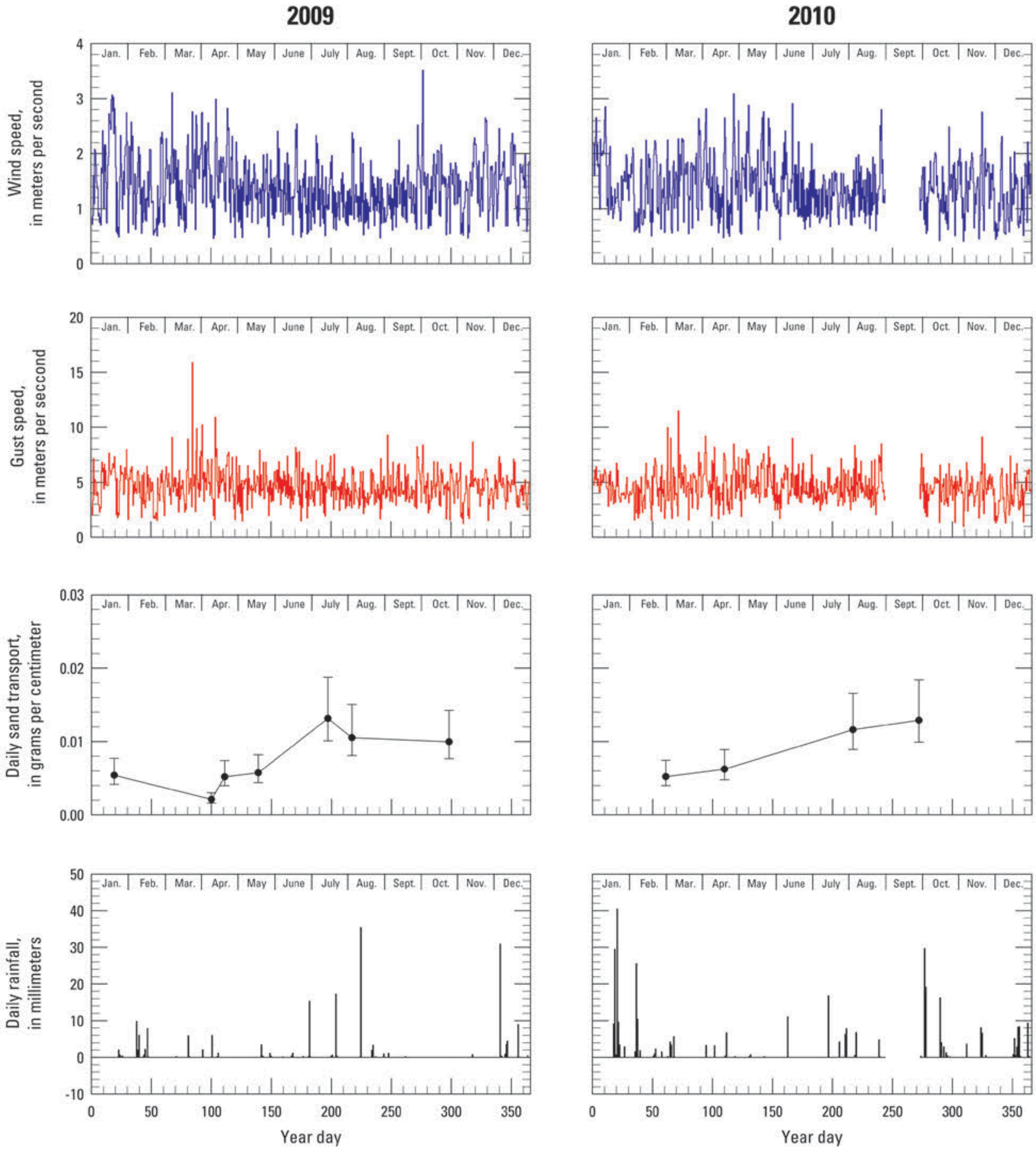

Figure 52. Plots showing wind, aeolian sand-transport, and rainfall data collected at the instrument station AZ A:15:0033 in Grand Canyon, Arizona, 2009–10. Wind speed is presented as diurnal average values, using daytime (0600–1800 hours) and nighttime (1800–0600 hours) averages of data collected at 4-minute intervals. Gust speed is shown as maximum values that occurred during each diurnal interval. Daily sand transport is plotted in grams, normalized to a width of 1 centimeter. To obtain these values, total sand mass collected from four traps during each maintenance visit was divided by the number of days since the trap had last been emptied. Rainfall is plotted as daily (24-hour) totals.

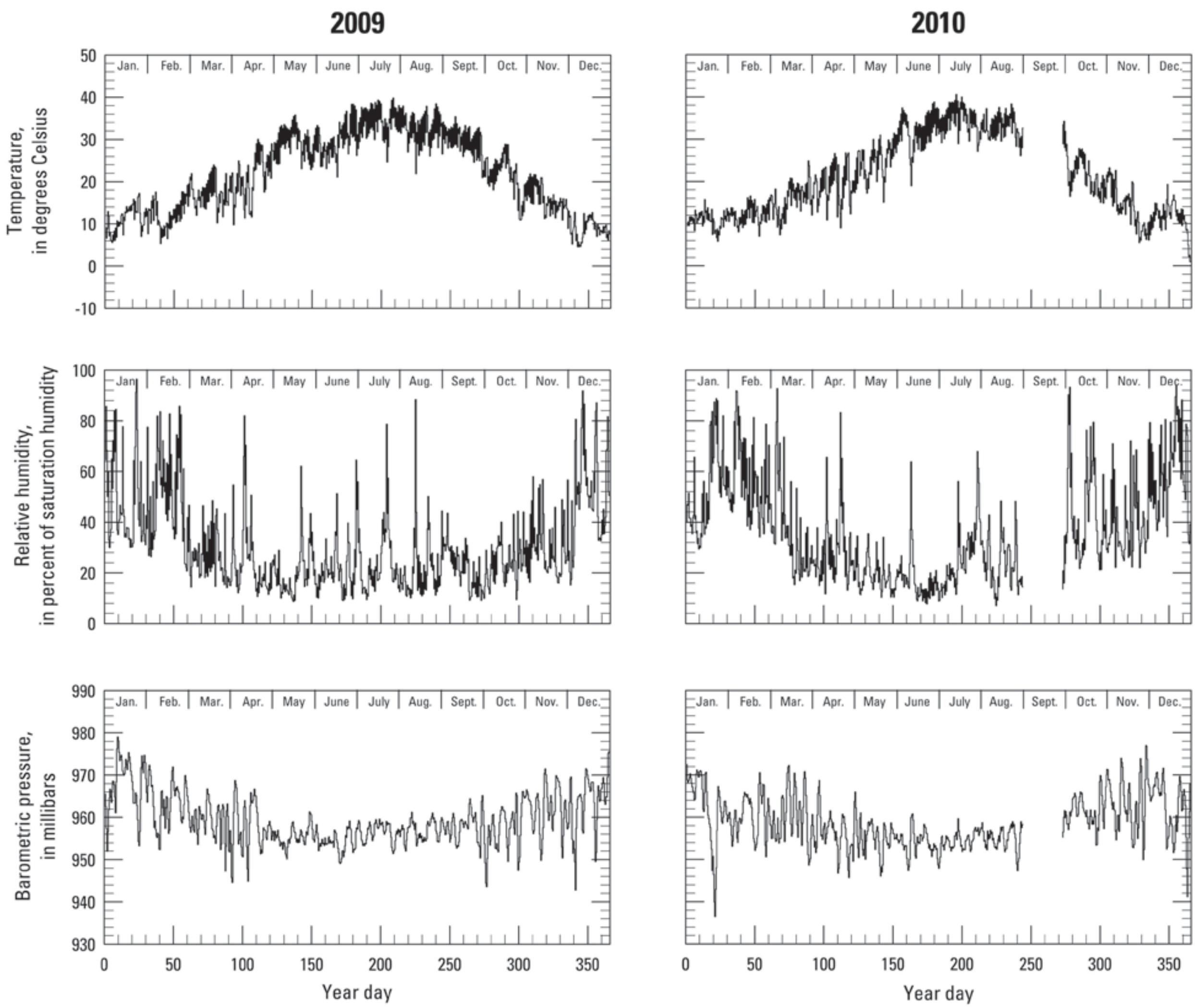

Figure 53. Plots showing temperature, relative humidity, and barometric pressure data collected at instrument station AZ A:15:0033 in Grand Canyon, Arizona, 2009–10. All parameters are plotted as diurnal averages (defined using 0600–1800 and 1800–0600 hours).

Site AZ G:03:0072

During 2010, one complete instrument station operated at site AZ G:03:0072 (station AZ G:03:0072 U) along with one additional set of sand traps (station AZ G:03:0072 L); equipment locations are shown in figure 54. For unknown reasons, no barometric pressure data were collected by the instrument station at site AZ G:03:0072 between March 2 and June 30, 2010. The weather transmitter was replaced on June 30, and there was no further loss of data. 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 49 percent vegetation cover and 6 percent biological soil crust cover near the weather station (Draut, 2011). The sand traps at station AZ G:03:0072 L are lower in elevation and closer to the river than station AZ G:03:0072 U, in an area with nearly 100 percent biological soil crust cover; thick vegetation is present between the lower site and the river (fig. 54). All equipment near site AZ G:03:0072 operated throughout 2010 with no interruptions.

Wind speed and direction measured at station AZ G:03:0072 U in 2010 are plotted in figure 55. Cumulative rainfall data are shown in figure 56; total rainfall measured in 2010 was 294.2 mm (table 2). All weather parameters and sand transport measured at station G:03:0072 U in 2010, and sand transport measured at station AZ G:03:0072 L, are summarized in figures 57 and 58, with 2009 data shown for comparison.

A vector sum of all available wind data from station AZ G:03:0072 U in 2010 yields a net *Qp* magnitude of 127,970 m^3/s^3 from a direction of 198º; using wind data collected only when the sand is estimated to have been dry, a vector sum yields a net *Qp* magnitude of 103,370 m^3/s^3 from a direction of 200º (table 3). This net flux direction toward upstream reflects a balance between upstream and downstream winds, with a slightly stronger upstream-directed velocity component (figs. 54 and 55). Daily sand-transport rates measured at stations AZ G:03:0072 L and AZ G:03:0072 U were similar (commonly on the order of 0.1 g/cm), and, similar to previous years, showed no substantial increase during the spring (fig. 57), which may be attributed to the presence of vegetation-limiting wind velocities and, therefore, sand-entrainment potential in the area around both sets of sand traps.

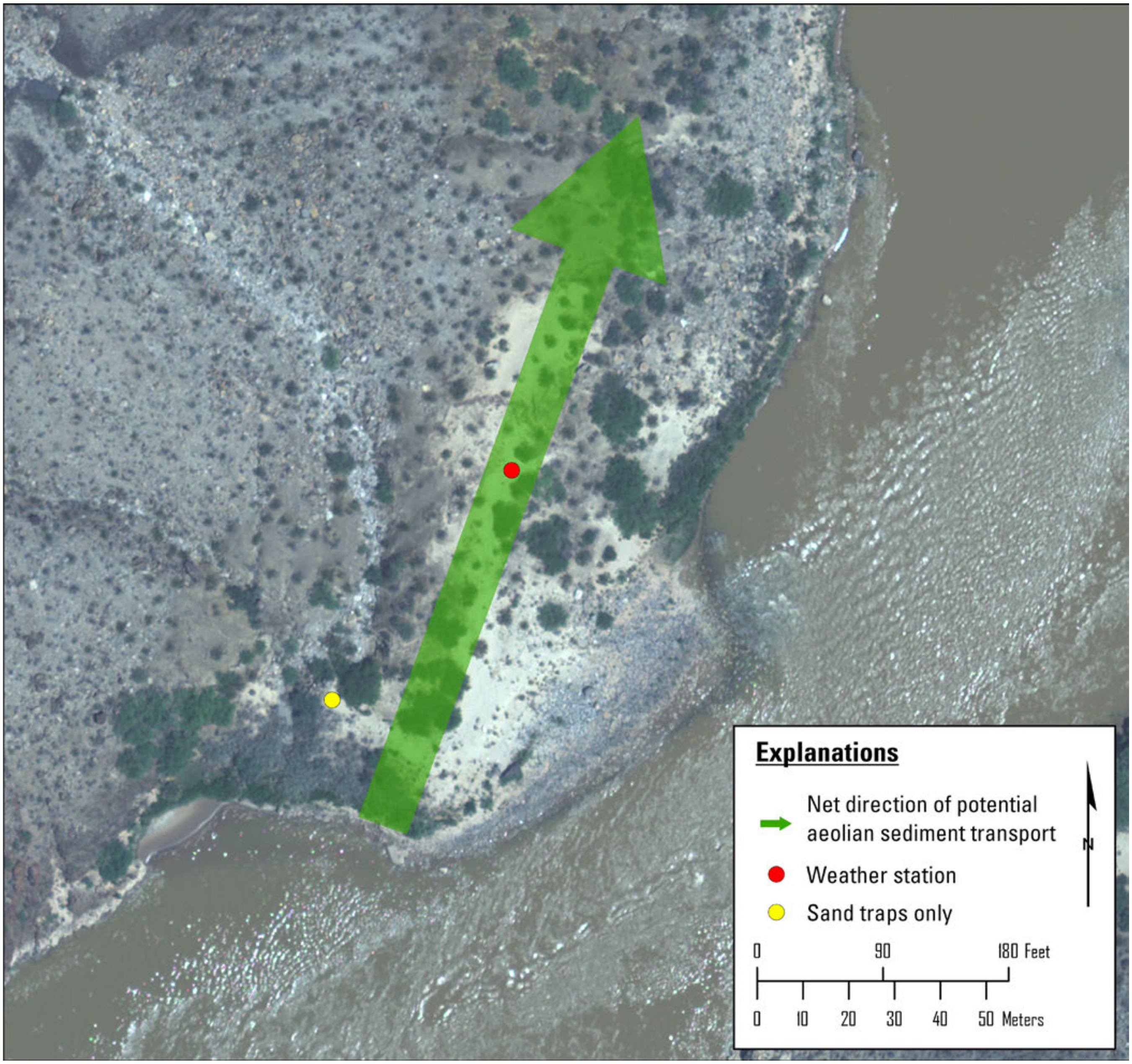

Figure 54. Aerial photograph of the area around site AZ G:03:0072 in Grand Canyon, Arizona. Arrow indicates the net direction of potential aeolian sediment transport measured at AZ G:03:0072 in 2010. A vector sum of the Qp proxy variable (equation 1), calculated using all the wind data collected during dry conditions from AZ G:03:0072 in 2010, indicates net sediment transport from 198°.

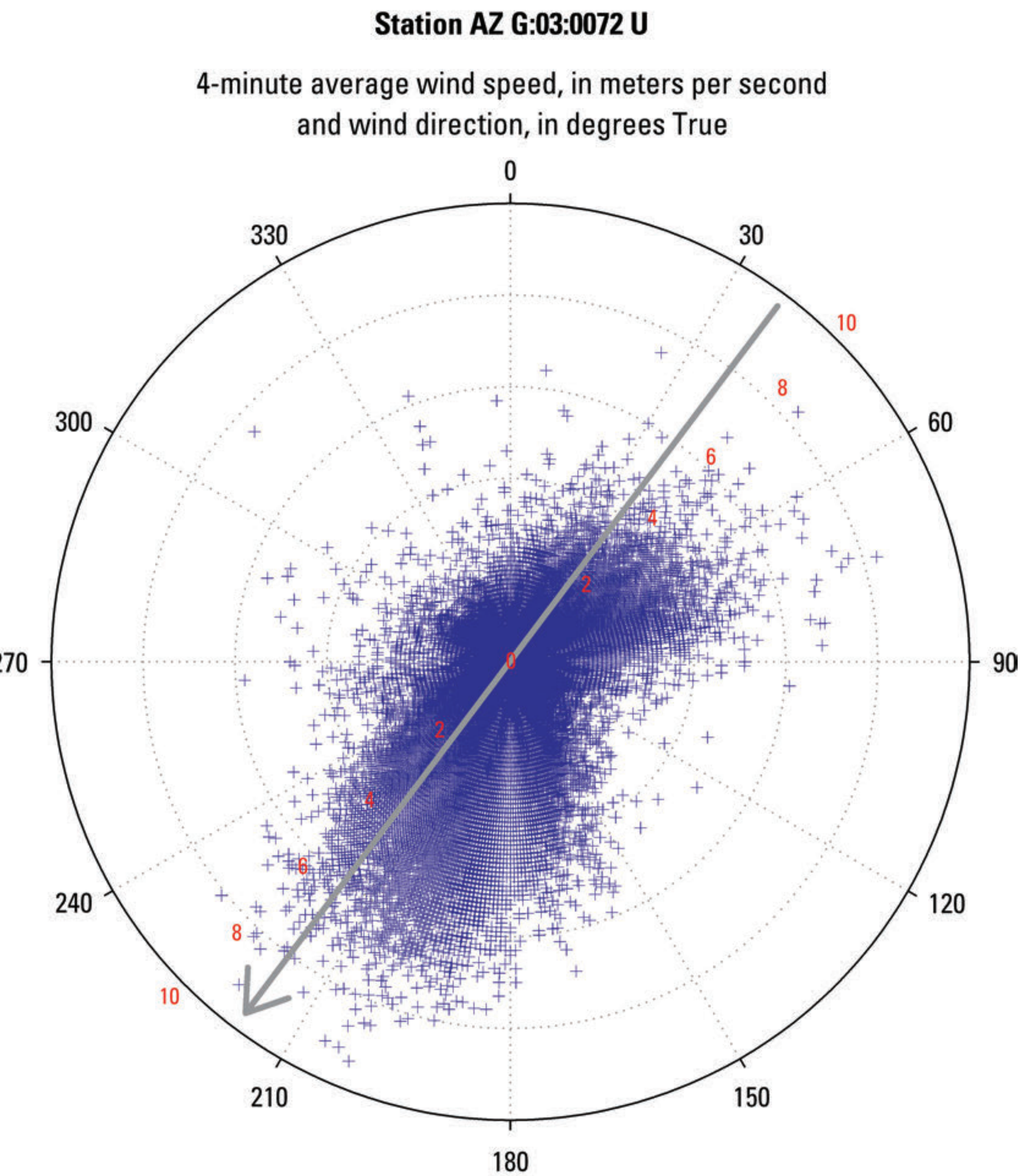

Figure 55. Plot showing magnitude and direction of wind velocity measured at the instrument station AZ G:03:0072 with 4-minute resolution in Grand Canyon, Arizona, 2010. Magnitude is indicated by the concentric circles, and compass bearing indicates the wind direction. The gray arrow shows the orientation of the river corridor (217°); river flow is toward the southwest.

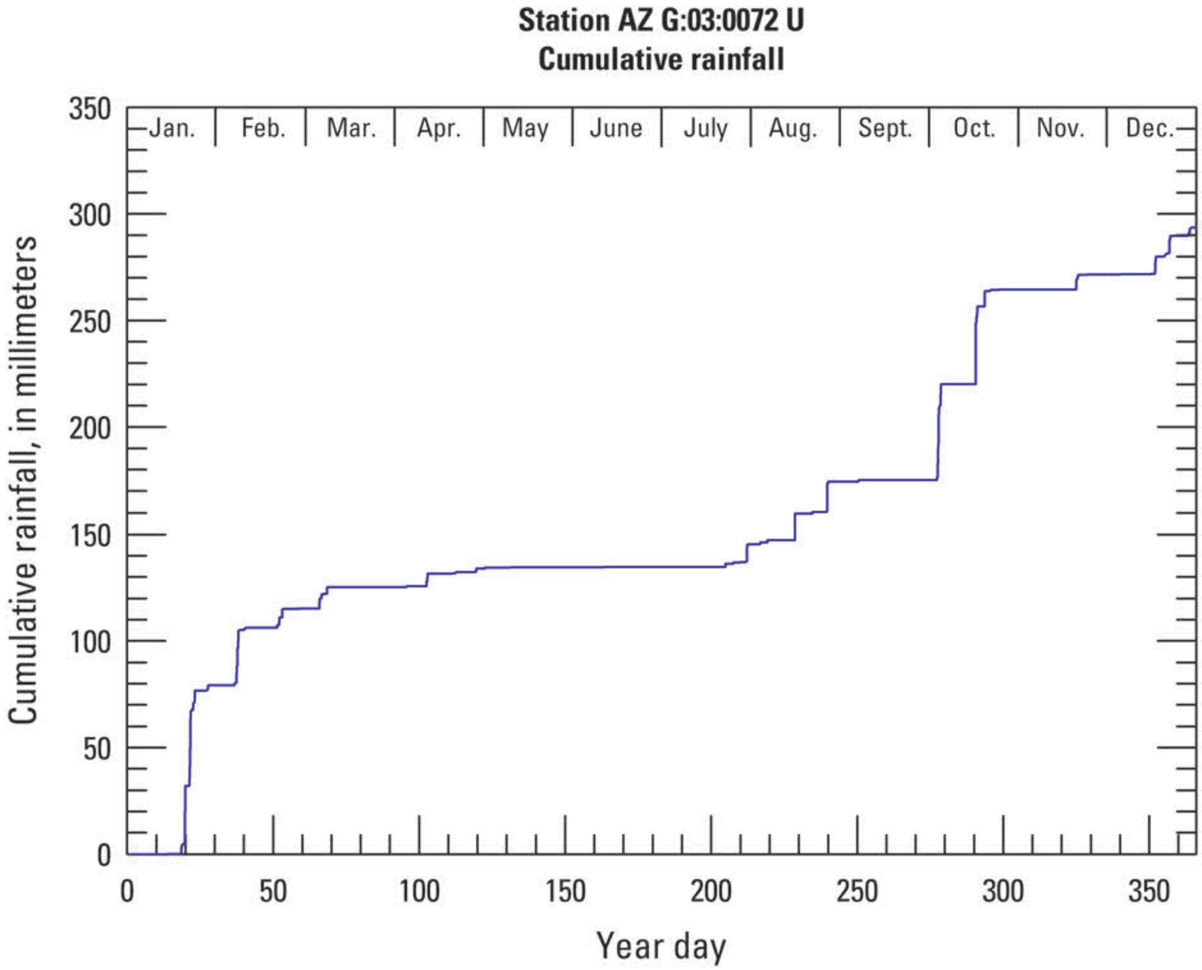

Figure 56. Plot showing cumulative rainfall recorded at site AZ G:03:0072 compiled from data collected at 4-minute resolution in Grand Canyon, Arizona, 2010.

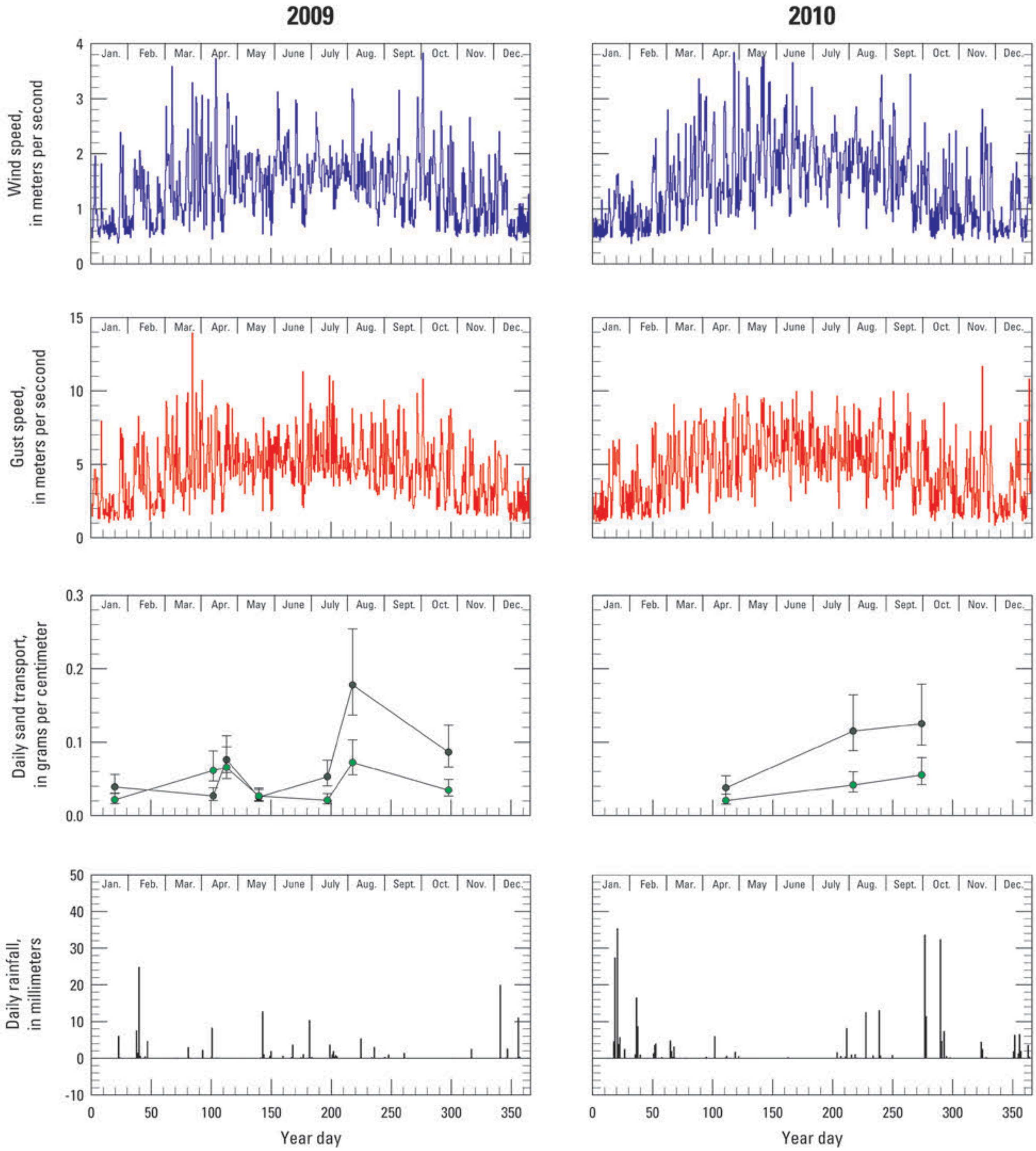

Figure 57. Plots showing wind, aeolian sand-transport, and rainfall data collected at the instrument station AZ G:03:0072 in Grand Canyon, Arizona, 2009–10. Wind speed is presented as diurnal average values, using daytime (0600–1800 hours) and nighttime (1800–0600 hours) averages of data collected at 4-minute intervals. Gust speed is shown as maximum values that occurred during each diurnal interval. Daily sand transport is plotted in grams, normalized to a width of 1 centimeter. To obtain these values, total sand mass collected from four traps during each maintenance visit was divided by the number of days since the trap had last been emptied. The lower of the two sand-transport lines plotted indicates transport rates measured at the lower set of traps at this station (AZ G:03:0072 L). Rainfall is plotted as daily (24-hour) totals.

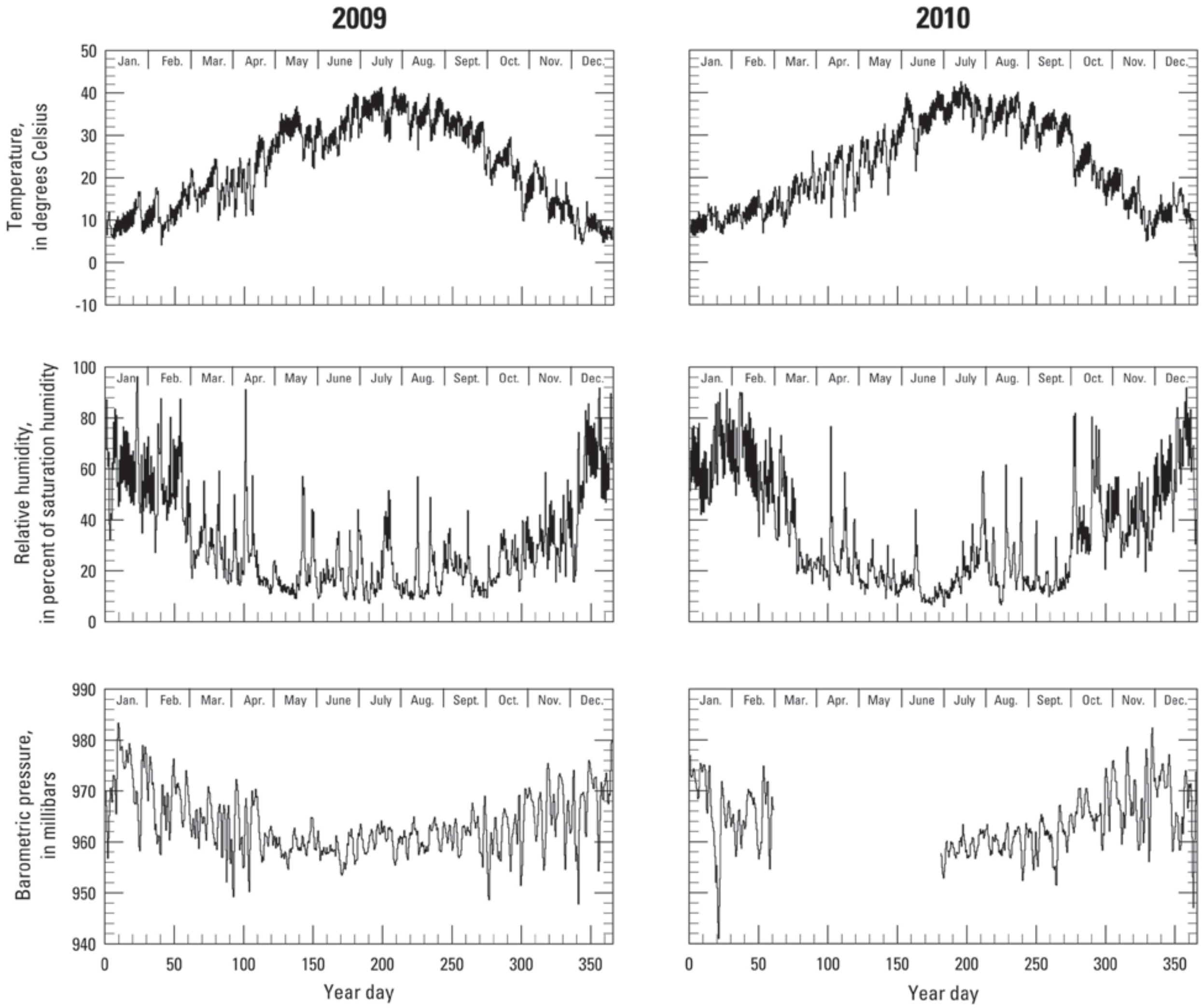

Figure 58. Plots showing temperature, relative humidity, and barometric pressure data collected at instrument station AZ G:03:0072 in Grand Canyon, Arizona, 2009–10. All parameters are plotted as diurnal averages (defined using 0600–1800 and 1800–0600 hours).

Discussion

Collection of weather data at various locations in the Colorado River corridor of Grand Canyon, Arizona, was facilitated in 2009 and 2010 by improved equipment performance compared with 2007 and 2008; however, software updates recommended by Nexsens Technology, Inc. more than tripled the data download times. This increased download time prevented a complete download at station AZ C:13:0346 L in September 2010, resulting in some data being overwritten and, therefore, lost.

At two of the three sites where two stations were deployed (AZ C:13:0005 and AZ C:13:0365), the data showed substantial differences in rainfall between the upper and lower stations (table 2). It is unclear whether the discrepancy between rainfall totals at the upper and lower stations from those two sites is attributable to instrument performance or to actual differences in rainfall over short distances. We consider it more likely a result of instrument performance, given that the rainfall totals were consistently higher at one particular station in each case (AZ C:13:0005 L and AZ C:13:0365 L). At site

AZ C:13:0346, the two stations recorded comparable rainfall for the events when both stations (AZ C:13:0346 L and AZ C:13:0346 U) were operating.

As in past years, seasonal differences in aeolian sand flux were apparent at most study sites, although the resolution of sand-transport variations depends on the intervals of manual sample collection. Data collected in 2010 also clearly show event- and seasonal-scale variations in rainfall, wind, temperature, humidity, and barometric pressure, some of which were more similar to patterns recorded in 2008 than patterns recorded in 2009. The most notable difference between 2009 and 2010 is the substantially greater overall precipitation recorded in 2010, particularly in the spring and fall. Precipitation amounts recorded in 2010 were approximately double the amounts recorded in 2009.

A later spring windy season also was notable in 2010 (April–May 2010 in contrast to March–April 2009), as were later onset of the reduced diurnal barometric-pressure fluctuations commonly associated with summer monsoon conditions (which began in late May 2010 in contrast to having begun in late April in 2009). Weather patterns in early to mid-2010 were affected by El Niño conditions during spring, whereas the patterns in late 2010 were affected by a delayed transition to an El Niño-Southern Oscillation (ENSO) neutral phase (National Climatic Data Center, 2012). These changes in the cycle presumably were responsible for the greater rainfall in Grand Canyon in 2010 compared to 2009. The increased rainfall in Grand Canyon in 2010 compared to 2009 is consistent with measurements elsewhere in Arizona (for example, Draut and others, 2012), with 2009 having been an exceptionally dry year—Arizona’s fourth driest year in the 117 years in which records have been kept, with below-normal rainfall statewide (National Climatic Data Center, 2012). In contrast, 2010 was Arizona’s 85th driest year on record, with above-normal rainfall statewide (National Climatic Data Center, 2012); although northeastern Arizona received below-average rainfall in 2010, the summer monsoon of 2010 nevertheless brought substantial rainfall to the Grand Canyon region, as the data in this report show (also see Draut and others, 2012).

The quantitative methods and data discussed here form a basis for monitoring ecosystem processes that affect archeological site stability. Combined with ongoing work by other researchers to evaluate landscape evolution at nearby archeological sites (for example, Collins and others, 2012), these data can be used to document the relation between physical processes, including weather and aeolian sand transport, and the stability of archeological sites. Such a comparison is the subject of a new study supported by the Glen Canyon Dam Adaptive Management Program and initiated in 2013 (Fairley and others, 2012), which builds on earlier work by Fairley and others (1994), Neal and others (2000), Thompson and Potochnik (2000), Collins and others (2012), and Draut (2012), linking weather data, geomorphic processes and landscape change on a large scale with measurements of smaller-scale effects at individual archeological sites.

Conclusions

This report presents meteorological and aeolian sand-transport data collected at weather stations in the Colorado River corridor through Grand Canyon National Park in 2010. Compared to 2009, measurements from 2010 included a slightly later spring windy season, greater spring precipitation and annual rainfall totals, and a later onset and length of the reduced diurnal barometric-pressure fluctuations commonly associated with summer monsoon conditions. The increase in spring precipitation was consistent with the 2010 spring El Niño conditions compared to the 2009 spring La Niña conditions, whereas the subsequent transition to an El Niño-Southern Oscillation neutral phase apparently delayed the reduction in diurnal barometric fluctuations. These data provide the basis for understanding landscape change that can affect archaeological sites and their surrounding environment.

Acknowledgments

This study is supported by funding from the Bureau of Reclamation through the U.S. Geological Survey (Grand Canyon Monitoring and Research Center). Weather station maintenance also was facilitated through cooperation with the non-profit organization, Grand Canyon Youth of Flagstaff, Arizona.

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Table 2. Total rainfall, in millimeters, recorded daily by each weather station.

["N/A" indicates rain data were not collected]

Date (2010)	AZ C:05:0031 U	AZ C:05:0031 L	AZ C:13:0365 U	AZ C:13:0365 L	AZ C:13:0006	AZ C:13:0336 U	AZ C:13:0346 U	AZ C:13:0346 L	AZ B:11:0281	AZ A:15:0033	AZ G:03:0072 U	Year day
1/1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1
1/2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2
1/3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3
1/4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4
1/5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5
1/6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6
1/7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7
1/8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8
1/9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9
1/10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10
1/11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11
1/12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12
1/13	0.00	0.00	0.00	0.00	0.03	0.15	0.00	0.03	0.00	0.00	0.08	13
1/14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	14
1/15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	15
1/16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16
1/17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	17
1/18	0.46	0.43	3.63	4.57	5.59	2.44	2.34	2.11	5.41	9.17	4.52	18
1/19	4.57	4.62	2.87	2.90	3.76	2.95	2.18	2.01	17.17	29.51	27.41	19
1/20	2.95	2.97	1.12	1.27	1.35	0.84	0.48	0.36	0.20	0.69	0.00	20
1/21	14.81	18.08	33.40	35.79	25.93	26.52	22.81	22.99	33.25	40.46	35.31	21
1/22	3.00	3.48	7.77	9.12	4.14	0.23	0.20	0.23	5.31	9.68	3.78	22
1/23	0.18	0.20	0.03	0.00	0.03	0.03	0.00	0.00	10.39	3.43	5.66	23
1/24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	24
1/25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	25
1/26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	26
1/27	2.18	2.44	1.52	1.47	1.02	0.43	0.53	0.53	0.97	2.87	2.39	27
1/28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	28
1/29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	29
1/30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	30
1/31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	31
2/1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	32
2/2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	33
2/3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	34

Date (2010)	AZ C:05:0031 U	AZ C:05:0031 L	AZ C:13:0365 U	AZ C:13:0365 L	AZ C:13:0006	AZ C:13:0336 U	AZ C:13:0346 U	AZ C:13:0346 L	AZ B:11:0281	AZ A:15:0033	AZ G:03:0072	Year day
2/4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	35
2/5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	1.50	0.99	36
2/6	4.60	4.70	4.32	4.39	4.24	3.30	3.18	3.05	13.61	25.55	16.48	37
2/7	0.41	0.38	0.46	0.51	0.86	0.38	0.23	0.15	2.39	10.44	8.61	38
2/8	0.25	0.38	0.18	0.23	0.25	0.13	0.00	0.03	0.15	0.13	0.00	39
2/9	4.06	4.50	7.04	7.62	5.08	3.99	2.46	2.08	1.02	1.83	0.91	40
2/10	0.41	0.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	41
2/11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	42
2/12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	43
2/13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	44
2/14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	45
2/15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	46
2/16	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	47
2/17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	48
2/18	0.00	0.00	0.03	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	49
2/19	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	50
2/20	10.41	11.43	1.47	1.63	0.84	1.96	1.40	1.14	6.68	0.36	1.27	51
2/21	26.21	27.86	14.02	13.67	11.53	7.26	7.57	6.22	8.43	0.99	3.58	52
2/22	8.03	8.69	9.73	10.39	12.78	11.91	12.29	11.89	5.64	2.29	3.94	53
2/23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	54
2/24	0.23	0.28	0.30	0.33	0.58	0.53	0.23	0.23	1.60	0.00	0.00	55
2/25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	56
2/26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	57
2/27	0.13	0.15	2.16	1.88	0.66	0.08	0.05	0.08	2.97	1.50	0.25	58
2/28	0.10	0.18	0.10	0.08	0.13	0.18	0.30	0.28	0.00	0.00	0.00	59
3/1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	60
3/2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	61
3/3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	62
3/4	0.03	0.03	0.46	0.36	0.20	0.08	0.69	0.51	0.51	0.25	0.00	63
3/5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	64
3/6	0.53	0.71	0.08	0.05	0.05	0.05	0.05	0.03	6.05	4.24	4.75	65
3/7	9.70	10.44	12.04	12.19	10.62	10.16	9.25	8.79	15.65	3.43	1.85	66
3/8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.28	67
3/9	1.63	2.06	1.07	1.50	3.07	3.99	3.30	2.67	14.12	5.69	3.15	68
3/10	0.00	0.03	0.00	0.00	0.00	0.08	0.00	0.00	0.38	0.05	0.05	69
3/11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	70

Date (2010)	AZ C:05:0031 U	AZ C:05:0031 L	AZ C:13:0365 U	AZ C:13:0365 L	AZ C:13:0006	AZ C:13:0336 U	AZ C:13:0346 U	AZ C:13:0346 L	AZ B:11:0281	AZ A:15:0033	AZ G:03:0072 U	Year day
3/12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	71
3/13	0.03	0.00	0.10	0.05	0.03	0.00	0.05	0.08	1.09	0.00	0.00	72
3/14	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	73
3/15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	74
3/16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	75
3/17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	76
3/18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	77
3/19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	78
3/20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	79
3/21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	80
3/22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	81
3/23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	82
3/24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	83
3/25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	84
3/26	0.03	0.03	0.03	0.03	0.00	0.00	0.00	0.00	0.61	0.00	0.00	85
3/27	0.00	0.00	0.23	0.15	0.13	0.03	0.00	0.00	0.00	0.00	0.00	86
3/28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	87
3/29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	88
3/30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	89
3/31	0.00	0.00	0.05	0.03	0.03	0.18	0.18	0.18	0.00	0.00	0.00	90
4/1	0.00	0.00	0.00	0.00	0.00	0.03	0.03	0.00	0.00	0.00	0.00	91
4/2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	92
4/3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	93
4/4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	94
4/5	2.01	2.13	1.96	2.08	0.94	2.67	3.25	2.84	3.43	3.33	0.30	95
4/6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	96
4/7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	97
4/8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	98
4/9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	99
4/10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100
4/11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	101
4/12	1.50	2.95	3.15	4.85	6.05	5.41	4.29	3.96	5.72	3.23	5.94	102
4/13	0.03	0.05	0.53	0.61	0.20	0.00	0.03	0.03	0.00	0.00	0.00	103
4/14	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	104
4/15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	105
4/16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	106

Date (2010)	AZ C:05:0031 U	AZ C:05:0031 L	AZ C:13:0365 U	AZ C:13:0365 L	AZ C:13:0006	AZ C:13:0336 U	AZ C:13:0346 U	AZ C:13:0346 L	AZ B:11:0281	AZ A:15:0033	AZ G:03:0072 U	Year day
4/17	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	107
4/18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	108
4/19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	109
4/20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	110
4/21	0.00	0.00	0.00	0.03	0.05	0.30	3.00	2.59	2.64	0.43	0.13	111
4/22	0.00	0.00	0.00	0.00	0.00	0.03	0.23	0.18	0.05	6.73	0.58	112
4/23	0.00	0.00	0.08	0.08	0.10	0.00	0.05	0.00	0.36	0.00	0.00	113
4/24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	114
4/25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	115
4/26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	116
4/27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	117
4/28	0.00	0.00	0.10	0.00	0.03	0.00	0.03	0.05	0.00	0.00	0.00	118
4/29	0.13	0.10	3.33	4.19	1.42	6.71	0.79	0.61	4.57	0.20	1.65	119
4/30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	120
5/1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	121
5/2	0.13	0.18	0.46	0.53	0.51	0.56	0.71	0.61	0.23	0.00	0.53	122
5/3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	123
5/4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	124
5/5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	125
5/6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	126
5/7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	127
5/8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	128
5/9	0.00	0.00	0.05	0.00	0.03	0.03	0.00	0.00	0.03	0.00	0.03	129
5/10	0.03	0.00	0.10	0.18	0.61	0.25	0.08	0.05	0.00	0.00	0.00	130
5/11	0.36	0.46	0.20	0.25	0.53	0.03	0.05	0.03	4.11	0.25	0.03	131
5/12	0.05	0.10	0.08	0.08	0.03	0.00	0.00	0.00	3.00	0.76	0.00	132
5/13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	133
5/14	0.03	0.00	0.05	0.08	0.05	0.28	0.00	0.03	0.03	0.00	0.00	134
5/15	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	135
5/16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	136
5/17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	137
5/18	0.00	0.00	0.03	0.00	0.03	0.13	0.10	0.08	0.00	0.00	0.00	138
5/19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	139
5/20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	140
5/21	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	141
5/22	0.00	0.00	0.08	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	142

Date (2010)	AZ C:05:0031 U	AZ C:05:0031 L	AZ C:13:0365 U	AZ C:13:0365 L	AZ C:13:0006	AZ C:13:0336 U	AZ C:13:0346 U	AZ C:13:0346 L	AZ B:11:0281	AZ A:15:0033	AZ G:03:0072 U	Year day
5/23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.00	143
5/24	0.00	0.00	0.03	0.05	0.00	0.10	0.20	0.20	0.03	0.13	0.00	144
5/25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	145
5/26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	146
5/27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	147
5/28	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	148
5/29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	149
5/30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	150
5/31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	151
6/1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	152
6/2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	153
6/3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	154
6/4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	155
6/5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	156
6/6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	157
6/7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	158
6/8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	159
6/9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	160
6/10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	161
6/11	2.08	3.99	6.17	8.00	2.11	1.55	1.40	1.14	0.61	0.00	0.00	162
6/12	2.31	3.33	8.15	9.45	6.02	4.65	6.76	6.83	2.62	11.10	0.20	163
6/13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	164
6/14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	165
6/15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	166
6/16	0.00	0.00	0.03	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	167
6/17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	168
6/18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	169
6/19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	170
6/20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	171
6/21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	172
6/22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	173
6/23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	174
6/24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	175
6/25	0.20	0.20	3.56	3.58	4.80	0.23	0.25	0.28	0.76	0.00	0.00	176
6/26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	177

Date (2010)	AZ C:05:0031 U	AZ C:05:0031 L	AZ C:13:0365 U	AZ C:13:0365 L	AZ C:13:0006	AZ C:13:0336 U	AZ C:13:0346 U	AZ C:13:0346 L	AZ B:11:0281	AZ A:15:0033	AZ G:03:0072 U	Year day
6/27	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	178
6/28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	179
6/29	0.03	0.03	0.00	0.00	0.13	0.20	0.05	0.03	0.00	0.00	0.00	180
6/30	0.03	0.03	0.10	0.10	0.20	0.28	0.33	0.41	0.00	0.00	0.00	181
7/1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	182
7/2	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	183
7/3	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	184
7/4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	185
7/5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	186
7/6	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	187
7/7	0.00	0.00	0.00	0.00	0.00	0.05	0.08	0.08	0.00	0.00	0.00	188
7/8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	189
7/9	0.00	0.03	0.81	1.30	0.94	0.30	2.06	2.41	0.36	0.00	0.00	190
7/10	0.51	0.76	0.84	0.76	0.79	0.00	0.00	0.00	0.03	0.00	0.00	191
7/11	1.07	1.91	1.55	1.75	0.97	0.03	1.60	1.85	0.00	0.00	0.00	192
7/12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.07	0.00	0.00	193
7/13	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	194
7/14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	195
7/15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	196
7/16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.90	16.81	0.00	197
7/17	0.03	0.03	2.64	3.07	1.55	0.00	0.00	0.00	0.00	0.00	0.00	198
7/18	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	199
7/19	22.99	29.08	0.00	0.00	0.00	1.24	0.00	0.03	0.00	0.00	0.00	200
7/20	0.41	0.53	1.09	1.70	2.03	1.80	1.17	0.99	0.00	0.00	0.00	201
7/21	0.10	0.08	0.13	0.18	0.05	0.08	0.05	0.03	2.34	0.00	0.00	202
7/22	1.37	1.19	11.35	16.48	6.20	0.00	0.03	0.03	0.00	0.00	0.00	203
7/23	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.03	5.51	0.00	1.55	204
7/24	0.00	0.00	0.00	0.00	0.00	0.36	0.30	0.25	0.00	0.00	0.00	205
7/25	0.00	0.00	0.00	0.00	1.96	0.30	0.00	0.05	0.00	4.29	0.00	206
7/26	3.58	5.11	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.53	207
7/27	0.53	1.22	28.68	35.71	26.44	23.22	3.78	3.25	0.76	0.00	0.00	208
7/28	0.03	0.03	1.70	2.08	4.42	3.30	1.70	1.50	0.08	0.03	0.03	209
7/29	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	3.71	0.00	0.00	210
7/30	0.03	0.00	0.00	0.00	0.00	5.03	0.05	0.00	0.79	6.30	0.41	211
7/31	8.53	11.43	10.01	13.44	6.35	6.88	11.00	9.22	14.33	7.82	8.13	212
8/1	11.07	16.00	1.78	2.74	7.01	5.11	7.26	6.81	0.00	0.00	0.00	213

Date (2010)	AZ C:05:0031 U	AZ C:05:0031 L	AZ C:13:0365 U	AZ C:13:0365 L	AZ C:13:0006	AZ C:13:0336 U	AZ C:13:0346 U	AZ C:13:0346 L	AZ B:11:0281	AZ A:15:0033	AZ G:03:0072 U	Year day
8/2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	214
8/3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	215
8/4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.89	216
8/5	6.20	8.33	0.00	0.00	4.04	9.30	7.57	5.44	0.25	0.00	0.00	217
8/6	0.30	0.41	13.21	13.74	7.24	13.31	9.75	9.22	0.00	0.00	0.00	218
8/7	6.25	9.78	14.63	18.80	13.64	13.74	18.80	18.64	3.30	0.58	1.02	219
8/8	0.00	0.00	0.00	0.05	0.33	5.16	9.19	9.83	0.94	6.78	0.08	220
8/9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	221
8/10	0.00	0.03	0.30	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	222
8/11	0.00	0.00	0.05	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	223
8/12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	224
8/13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	225
8/14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	226
8/15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	227
8/16	7.59	10.21	0.00	0.00	0.00	0.00	0.05	0.03	0.03	0.03	12.47	228
8/17	0.05	0.08	0.23	0.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	229
8/18	0.33	0.41	2.87	3.33	2.44	4.01	0.66	0.48	0.03	0.00	0.00	230
8/19	7.80	10.92	0.03	0.05	0.00	0.00	0.00	0.03	0.00	0.00	0.00	231
8/20	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.30	10.16	0.00	0.00	232
8/21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.93	0.05	0.00	233
8/22	0.00	0.00	0.08	0.13	0.41	1.02	3.28	3.10	0.00	0.00	0.71	234
8/23	0.00	0.00	0.03	0.05	0.28	0.00	0.00	0.00	0.00	0.00	0.00	235
8/24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	236
8/25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	237
8/26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	238
8/27	0.36	0.69	2.64	2.74	2.29	3.73	5.77	4.83	0.08	4.80	13.03	239
8/28	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.13	0.71	240
8/29	0.00	0.00	0.05	0.05	0.00	0.03	0.08	0.03	0.00	0.00	0.00	241
8/30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.38	0.00	0.00	0.00	242
8/31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	243
9/1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	244
9/2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	N/A	0.00	245
9/3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	N/A	0.00	246
9/4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	N/A	0.00	247
9/5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	N/A	0.00	248
9/6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	N/A	0.00	249

Date (2010)	AZ C:05:0031 U	AZ C:05:0031 L	AZ C:13:0365 U	AZ C:13:0365 L	AZ C:13:0006	AZ C:13:0336 U	AZ C:13:0346 U	AZ C:13:0346 L	AZ B:11:0281	AZ A:15:0033	AZ G:03:0072 U	Year day
9/7	1.09	1.52	1.32	1.68	1.47	5.41	3.00	2.82	1.09	N/A	0.79	250
9/8	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	N/A	0.00	251
9/9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	N/A	0.00	252
9/10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	N/A	0.00	253
9/11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	N/A	0.00	254
9/12	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	N/A	0.00	255
9/13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	N/A	0.00	256
9/14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	N/A	0.00	257
9/15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	N/A	0.00	258
9/16	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	N/A	0.00	259
9/17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	N/A	0.00	260
9/18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	N/A	0.00	261
9/19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	N/A	0.00	262
9/20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	N/A	0.00	263
9/21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	N/A	0.00	264
9/22	0.08	0.18	3.02	3.45	2.54	0.25	0.30	0.30	0.00	N/A	0.00	265
9/23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	N/A	0.00	266
9/24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	N/A	0.00	267
9/25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	N/A	0.00	268
9/26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	N/A	0.00	269
9/27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	N/A	0.00	270
9/28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	N/A	0.00	271
9/29	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.0	0.00	272
9/30	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.00	273
10/1	0.00	0.00	0.03	0.00	0.00	0.23	1.04	1.04	0.99	0.33	0.00	274
10/2	0.00	0.00	0.00	0.00	0.00	0.05	0.28	0.20	0.05	0.00	0.00	275
10/3	6.20	9.63	1.14	1.24	0.00	0.05	0.08	0.03	11.05	0.00	0.00	276
10/4	20.73	33.35	17.04	22.15	30.48	19.91	19.71	16.05	16.69	29.69	33.58	277
10/5	30.99	48.06	38.28	45.69	43.18	27.05	27.36	23.09	42.62	19.13	11.35	278
10/6	18.29	28.83	36.04	43.92	43.18	46.58	46.33	5.61	13.41	0.03	0.00	279
10/7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	280
10/8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	281
10/9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	282
10/10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	283
10/11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	284
10/12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	285

Date (2010)	AZ C:05:0031 U	AZ C:05:0031 L	AZ C:13:0365 U	AZ C:13:0365 L	AZ C:13:0006	AZ C:13:0336 U	AZ C:13:0346 U	AZ C:13:0346 L	AZ B:11:0281	AZ A:15:0033	AZ G:03:0072 U	Year day
10/13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	286
10/14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	287
10/15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	288
10/16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	289
10/17	0.58	0.74	0.03	0.03	0.00	0.51	0.99	0.89	7.75	16.28	32.36	290
10/18	2.01	3.10	4.55	5.54	2.54	3.89	1.83	0.30	8.20	4.09	4.62	291
10/19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	292
10/20	1.27	1.40	4.44	5.11	5.08	3.99	7.44	7.54	15.37	2.82	7.29	293
10/21	4.57	7.01	0.36	0.41	2.54	2.79	7.77	1.27	13.56	0.00	0.00	294
10/22	0.08	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.27	0.48	295
10/23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.46	0.00	296
10/24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	297
10/25	0.69	0.94	0.15	0.15	0.00	0.30	0.15	0.05	1.52	0.20	0.18	298
10/26	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	299
10/27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	300
10/28	0.03	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	301
10/29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	302
10/30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	303
10/31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	304
11/1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	305
11/2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	306
11/3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	307
11/4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	308
11/5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	309
11/6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	310
11/7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.00	0.03	0.00	311
11/8	0.58	0.94	0.69	0.81	0.00	0.05	0.56	0.66	1.19	3.63	0.00	312
11/9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	313
11/10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	314
11/11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	315
11/12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	316
11/13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	317
11/14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	318
11/15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	319
11/16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	320
11/17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	321

Date (2010)	AZ C:05:0031 U	AZ C:05:0031 L	AZ C:13:0365 U	AZ C:13:0365 L	AZ C:13:0006	AZ C:13:0336 U	AZ C:13:0346 U	AZ C:13:0346 L	AZ B:11:0281	AZ A:15:0033	AZ G:03:0072 U	Year day
11/18	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	322
11/19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	323
11/20	0.05	0.08	0.66	0.99	0.00	0.08	0.10	0.05	0.13	8.10	4.42	324
11/21	1.27	1.47	3.07	4.34	0.00	2.13	4.22	4.22	9.17	6.65	2.44	325
11/22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	326
11/23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	327
11/24	0.00	0.00	0.23	0.20	0.00	0.20	0.23	0.03	2.67	0.53	0.25	328
11/25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	329
11/26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	330
11/27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	331
11/28	0.10	0.18	0.00	0.00	0.00	0.25	0.25	0.20	0.74	0.05	0.03	332
11/29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	333
11/30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	334
12/1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	335
12/2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	336
12/3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	337
12/4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	338
12/5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	339
12/6	0.05	0.08	0.13	0.10	0.00	0.33	0.51	0.61	0.08	0.05	0.08	340
12/7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	341
12/8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	342
12/9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	343
12/10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	344
12/11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	345
12/12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	346
12/13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	347
12/14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	348
12/15	0.03	0.03	0.00	0.00	2.54	0.00	0.05	0.08	0.00	0.00	0.00	349
12/16	0.00	0.03	1.22	1.73	0.00	0.38	0.48	0.71	0.53	0.00	0.13	350
12/17	0.00	0.00	0.63	0.76	0.00	0.30	0.43	0.43	1.37	0.79	1.80	351
12/18	0.00	0.00	1.73	2.31	7.62	3.43	0.51	0.05	2.87	5.16	6.30	352
12/19	0.03	0.00	0.15	0.25	0.00	0.03	0.08	0.03	1.70	0.53	0.03	353
12/20	0.00	0.00	3.43	4.37	0.00	0.00	0.00	0.00	2.21	2.79	0.08	354
12/21	0.00	0.00	0.66	1.12	0.00	0.20	0.10	0.08	5.87	8.26	1.24	355
12/22	0.46	0.51	1.50	1.60	2.54	1.24	0.38	0.10	2.39	8.36	6.53	356
12/23	0.33	0.46	0.03	0.08	0.00	0.00	0.05	0.00	4.60	0.25	1.91	357

Date (2010)	AZ C:05:0031 U	AZ C:05:0031 L	AZ C:13:0365 U	AZ C:13:0365 L	AZ C:13:0006	AZ C:13:0336 U	AZ C:13:0346 U	AZ C:13:0346 L	AZ B:11:0281	AZ A:15:0033	AZ G:03:0072 U	Year day
12/24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	358
12/25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	359
12/26	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	360
12/27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	361
12/28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	362
12/29	3.02	3.30	6.07	7.90	7.62	4.57	4.83	1.65	17.32	9.45	3.58	363
12/30	0.25	0.99	0.81	2.08	2.54	2.21	3.00	0.00	0.91	0.33	0.36	364
12/31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	365
Total	**275.9**	**369.2**	**354.8**	**421.3**	**360.1**	**325.8**	**308.1**	**233.0**	**421.8**	**357.4**	**294.2**	**Total**

Table 3. Vector sums of the sediment-transport proxy variable, *Qp* (equation 1), by month for each weather station, 2010.

[Vector sums are reported as the magnitude of *Qp*, in cubic meters per cubic second, followed by the direction from which the net transport would occur, in degrees true. *A*, Vector sums were calculated using all available wind data, irrespective of rain events. *B*, Vector sums were calculated using only wind data from periods when sand was assumed to be dry enough to be transported. "N/A" indicates data were not collected.]

A

Station name	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Net vector sum
AZ C:05:0031 U	680, 146	442, 210	9603, 231	41611, 245	43098, 246	14788, 250	5266, 236	10539, 253	3969, 243	2059, 261	8672, 248	10238, 246	149490, 245
AZ C:05:0031 L	106, 81	251, 217	2588, 223	15679, 251	12425, 242	3621, 249	329, 216	2695, 265	476, 220	142, 200	2537, 237	3547, 258	43465, 246
AZ C:13:0365 U	24239, 350	5903, 145	140570, 151	315440, 154	379410, 154	157920, 155	84859, 156	119260, 155	86783, 155	50073, 157	80613, 156	103660, 156	1500600, 154
AZ C:13:0365 L	1772, 325	1510, 327	3762, 197	23165, 170	22975, 166	5833, 171	733, 80	5339, 171	3466, 173	1350, 203	2953, 178	7504, 167	72645, 171
AZ C:13:0006	731, 166	434, 8	4992, 77	29688, 137	21001, 129	13226, 135	5965, 135	8766, 143	3691, 125	4274, 142	5961, 124	5168, 121	100400, 131
AZ C:13:0336 U	64633, 53	40206, 72	91313, 147	172260, 155	246740, 156	78005, 161	38632, 164	38729, 161	32358, 154	45096, 153	57464, 147	111500, 149	907640, 148
AZ C:13:0346 U	9620, 204	21308, 221	80082, 220	95474, 224	114860, 232	36003, 229	14348, 215	15086, 223	17561, 226	2826, 225	31180, 222	64237, 230	500130, 225
AZ C:13:0346 L	3265, 228	22045, 238	98078, 232	146460, 237	201030, 238	60045, 237	19017, 235	27572, 237	28636, 237	N/A	N/A	N/A	652360, 217
AZ B:11:0281	14347, 127	1475, 181	2427, 48	47717, 99	74332, 102	38586, 106	16000, 109	38138, 108	14881, 103	3872, 112	9111, 94	3301, 95	257450, 104
AZ A:15:0033	4559, 351	1179, 349	1393, 154	5835, 189	6044, 180	4170, 188	1266, 185	4152, 191	N/A	835, 315	727, 270	806, 268	16664, 185
AZ G:03:0072 U	373, 171	684, 111	10276, 189	18890, 198	25958, 197	18598, 200	15268, 205	17527, 203	12278, 202	3962, 191	4034, 192	1374, 170	127970, 198

B

Station name	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Net vector sum
AZ C:05:0031 U	74, 117	123, 252	9640, 233	30861, 246	38407, 247	13585, 252	3283, 242	3295, 255	1637, 237	1698, 278	4015, 244	1902, 247	107740, 246
AZ C:05:0031 L	47, 104	16, 285	2827, 225	15521, 253	12977, 245	3477, 251	403, 227	396, 315	126, 146	133, 234	1708, 234	3685, 266	40270, 249
AZ C:13:0365 U	4449, 352	1288, 128	77615, 147	227110, 155	124690, 154	142440, 155	39449, 157	17312, 156	31315, 154	24547, 156	48077, 155	2240, 160	730990, 154
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