Desert Research Institute

DOE/NV/0000939-20

Tonopah Test Range Air Monitoring: CY2013 Meteorological, Radiological, and Airborne Particulate Observations

prepared by

Steve A. Mizell, George Nikolich, Craig Shadel,
Greg McCurdy, Vicken Etyemezian, and Julianne J. Miller

submitted to

Nevada Field Office
National Nuclear Security Administration
U.S. Department of Energy
Las Vegas, Nevada

October 2014

Publication No. 45258

Nevada System of Higher Education

Available for sale to the public from:

U.S. Department of Commerce
National Technical Information Service
5301 Shawnee Rd.
Alexandria, VA 22312
Phone: 800.553.6847
Fax: 703.605.6900
Email: orders@ntis.gov
Online ordering: http://www.osti.gov/ordering.htm

Available electronically at http://www.osti.gov/bridge

Available for a processing fee to the U.S. Department of Energy and its contractors, in paper, from:

U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
Phone: 865.576.8401
Fax: 865.576.5728
Email: reports@adonis.osti.gov

DOE/NV/0000939-20

Tonopah Test Range Air Monitoring: CY2013 Meteorological, Radiological, and Airborne Particulate Observations

prepared by

Steve A. Mizell, George Nikolich, Craig Shadel,
Greg McCurdy, Vicken Etyemezian, and Julianne J. Miller

Division of Hydrologic Sciences
Desert Research Institute
Nevada System of Higher Education

Publication No. 45258

submitted to

Nevada Field Office
National Nuclear Security Administration
U.S. Department of Energy
Las Vegas, Nevada

October 2014

The work upon which this report is based was supported by the U.S. Department of Energy under Contract #DE-NA0000939. Approved for public release; further dissemination unlimited.

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

In 1963, the U.S. Department of Energy (DOE) (formerly the Atomic Energy Commission [AEC]), implemented Operation Roller Coaster on the Tonopah Test Range (TTR) and an adjacent area of the Nevada Test and Training Range (NTTR) (formerly the Nellis Air Force Range). This test resulted in radionuclide-contaminated soils at Clean Slate I, II, and III. This report documents observations made during on-going monitoring of radiological, meteorological, and dust conditions at stations installed adjacent to Clean Slate I and Clean Slate III and at the TTR Range Operations Control center. The primary objective of the monitoring effort is to determine if winds blowing across the Clean Slate sites are transporting particles of radionuclide-contaminated soils beyond both the physical and administrative boundaries of the sites. Results for the calendar year (CY) 2013 monitoring include: (1) the gross alpha and gross beta values from the monitoring stations are approximately equivalent to the highest values observed during the CY2012 reporting at the surrounding Community Environmental Monitoring Program (CEMP) stations (this was the latest documented data available at the time of this writing); (2) only naturally occurring radionuclides were identified in the gamma spectral analyses; (3) the ambient gamma radiation measurements indicate that the average annual gamma exposure is similar at all three monitoring stations and periodic intervals of increased gamma values appear to be associated with storm fronts passing through the area; and (4) the concentrations of both resuspended dust and saltated sand particles generally increase with increasing wind speed. However, differences in the observed dust concentrations are likely due to differences in the soil characteristics immediately adjacent to the monitoring stations. Neither the resuspended particulate radiological analyses nor the ambient gamma radiation measurements suggest wind transport of radionuclide-contaminated soils.

THIS PAGE INTENTIONALLY LEFT BLANK

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

AEC	Atomic Energy Commission
BSNE	Big Spring Number Eight
CAU	Corrective Action Unit
CEMP	Community Environmental Monitoring Program
CS I	Clean Slate I, also known as Clean Slate 1
CS II	Clean Slate II, also known as Clean Slate 2
CS III	Clean Slate III, also known as Clean Slate 3
CY	Calendar year
DOE	Department of Energy
DRI	Desert Research Institute
FY	Fiscal year
GOES	Geostationary Operational Environmental Satellite
GZ	Ground zero
NNSA/NFO	National Nuclear Security Administration, Nevada Field Office
NRC	Nuclear Regulatory Commission
NTTR	Nevada Test and Training Range
PIC	Pressurized ionization chamber
PM	Particulate matter
ROC	Range Operations Center
RSL	Radiological Services Laboratory
SNL	Sandia National Laboratories
TDR	Time domain reflectometry
TTR	Tonopah Test Range
VWC	Volumetric water content
WRCC	Western Regional Climate Center

INTRODUCTION

In May and June 1963 the U.S. Department of Energy (DOE) (formerly the Atomic Energy Commission [AEC]) implemented Operation Roller Coaster to evaluate the dispersal of radionuclides when nuclear devices were subjected to chemical explosions while in storage or transit (Dick *et al.*, 1963; Johnson and Edwards, 1996). The operation consisted of four tests, Double Tracks conducted in Stonewall Flat on the Nevada Test and Training Range (NTTR) and Clean Slate I, II, and III conducted in Cactus Flat on the Tonopah Test Range (TTR). Both test areas are southeast of Tonopah, Nevada, in Nye County (Figures 1 and 2).

Double Tracks was designed to assess plutonium release with minimum entrainment, but the Clean Slate tests were intended to evaluate weapons storage scenarios. The Clean Slate tests involved one weapon containing plutonium and several simulated weapons containing uranium (Dick *et al.*, 1963; Johnson and Edwards, 1996). For each test, data collection was distributed along arcs within a quarter-circle, wedge-shaped area that emanated from the test ground zero (GZ) and centered on a radius that extended from GZ to the south or southeast (Dick *et al.*, 1963; Johnson and Edwards, 1996), the expected downwind directions. Data collection during the tests focused on the plutonium and uranium due to their radiological toxicity (Dick *et al.*, 1963). Subsequent surveys to characterize radionuclide-contaminated soils focused on the detection of plutonium through the measurement of americium-241 (Proctor, 1995).

Immediate post-shot cleanup at each test involved disposing of contaminated debris in a pit at GZ, scraping the surface soil around GZ to a depth of several inches, and placing the soil in the disposal pit or mounding it over the contaminated debris. The mound of contaminated materials was covered with additional soil and compacted and watered (Johnson and Edwards, 1996). Based on soil survey data collected using a handheld meter, the GZ disposal area was then fenced to demarcate the area exhibiting plutonium concentrations greater than or equal to 1,000 $\mu g/m^2$. In 1973, following another soil survey, a second fence was constructed at the approximate limit of 40 pCi/g of plutonium in soil (Duncan *et al.*, 2000).

Aerial surveys of Operation Roller Coaster contamination areas were conducted in 1977 (EG&G, 1979) and 1993 (Proctor and Hendricks, 1995). These surveys used gamma detectors to identify americium-241, which, as a daughter product, is a readily measured indicator of plutonium-241 that is typically present in nuclear devices in small quantities. Based on the 1977 survey, the total area of diffuse plutonium for all Operation Roller Coaster sites was estimated to be 20×10^6 m^2 (4,942.11 acres). The 1993 survey estimated the maximum concentration at the Clean Slate I GZ to be between 200 and 400 pCi/g. At Clean Slate II and III, the maximum concentrations at GZ were reported to be in excess of 2,000 pCi/g. Contamination was reported outside the outer perimeter fence at all three Clean Slate sites. At Clean Slate III, plutonium concentration outside of the fence did not exceed 200 pCi/g. However, the concentrations reported outside the fences at Clean Slate I and II were greater than 200 pCi/g but less than 400 pCi/g (Proctor and Hendricks, 1995).

After soil remediation reduced the concentration of transuranics, which include plutonium and americium, to less than or equal to 200 pCi/g, Double Tracks was closed in 1996 (Duncan *et al.*, 2000). Soil contamination at Clean Slate I was remediated in 1997 so that the concentration of transuranics was less than or equal to 400 pCi/g (SNL, 2012). Clean Slate II and III have not been remediated.

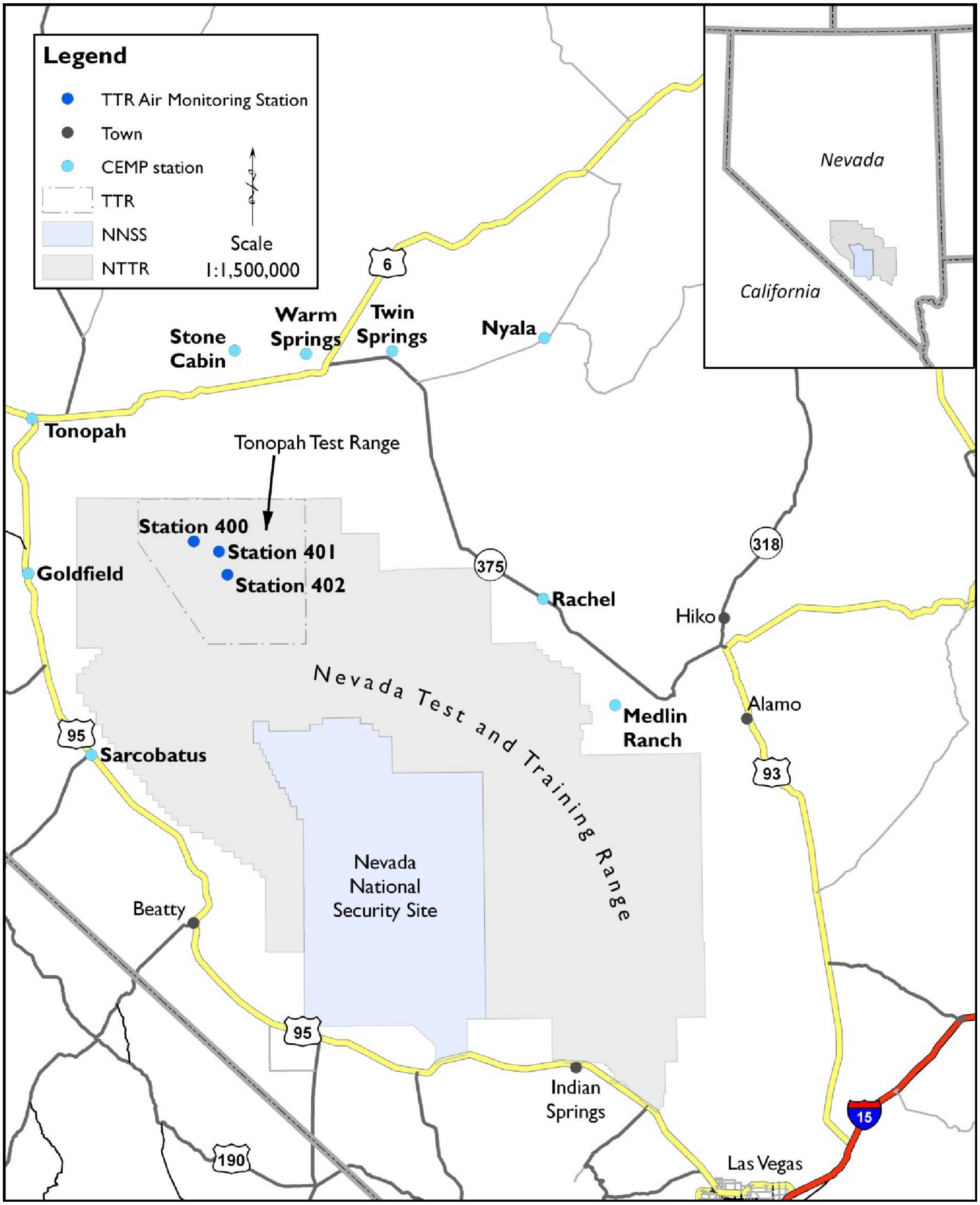

Figure 1. The Tonopah Test Range (TTR) is located at the north end of the Nevada Test and Training Range in southern Nevada. Station 400 is located on the south edge of the Sandia National Laboratory compound. Station 401 is on the north edge of Clean Slate III. Station 402 is on the north edge of Clean Slate I.

Figure 2. The TTR environmental monitoring stations are located on the south side of the Sandia National Laboratory compound (Station 400) and the north ends of the Clean Slate I (Station 402) and III (Station 401) contamination areas.

In 2008, at the request of the DOE National Nuclear Security Administration, Nevada Field Office (NNSA/NFO), the Desert Research Institute (DRI) constructed and deployed two portable environmental monitoring stations at the Tonopah Test Range (TTR) as part of the Environmental Restoration Project Soils Activities. A third station was deployed in 2011. The DRI has operated these stations continuously since installation. The primary objective of the monitoring stations is to evaluate whether there is wind transport of radiological contaminants, specifically plutonium, from the Soils Corrective Action Units (CAUs) associated with Operation Roller Coaster, and if so, under what conditions such transport occurs. Instrumentation currently in use is intended to quantify radiological constituents in the air to a height of six to eight feet above the local ground surface.

MONITORING STATIONS LOCATIONS AND CAPABILIITIES

As part of its work under the Soils Activity, DRI operates three portable monitoring stations at TTR. Stations 400 and 401 were installed in May and June 2008, respectively. Station 402 was installed in May 2011. The monitoring stations were installed to facilitate the assessment of wind transport of plutonium from the surficial soil contamination sites that resulted from the Clean Slate tests. Wind direction, access, and power availability were key considerations in selection of specific monitoring station locations. Wind data for the Tonopah Airport (Engelbrecht *et al.*, 2008) indicated that the predominant wind directions in the area were from the northwest and south-southeast. Wind direction data collected from the TTR monitoring stations substantiate the assessment of Engelbrecht *et al.* (2008).

Station 400 was located at the Sandia National Laboratories (SNL) Range Operations Center (ROC). Station coordinates are given in Table 1. The ROC, adjacent TTR airfield, and surrounding work area are downwind of the Clean Slate contamination sites when winds are out of the south-southeast. At a distance of eight to nine kilometers (five to six miles), these facilities are the closest, regularly manned work locations to the Clean Slate contamination sites. Therefore, Station 400 facilitates the characterization of radiological conditions in the TTR work areas that may result from wind transport of radionuclide-contaminated soils at the Clean Slate sites and provides data to compare radiological conditions at the ROC with conditions at the Clean Slate sites. Station 400 was originally located just north of the center of the SNL compound, approximately 145 m west-northwest of the ROC. In the summer of 2012, the station was moved about 200 m (675 yd) to the southeast at the request of SNL. In the new location, Station 400 is approximately 90 m (300 yd) south of the ROC near the southeast corner of the SNL compound (Figure 2). Sandia National Laboratories provides line power to operate the equipment at Station 400, which consists of a meteorological tower and air sampling equipment installed on a 2.1 m x 4.3 m (7 ft x 14 ft) trailer (Figure 3).

Stations 401 and 402 are located at the demarcation fence on the northwest perimeter of the Clean Slate III and Clean Slate I sites, respectively (Figure 2). These locations were chosen because they place the monitoring instrumentation in proximity to the contamination sites and on the downwind side of the sites during south-southeast winds, one of the two predominant wind directions through the area. Both Stations 401 and 402 are solar powered with battery backup power and the batteries are recharged continuously by solar panels. Table 1 gives the coordinates for these monitoring stations. At Stations 401 and 402, the air samplers, solar panels, and the batteries used to power them are on trailers. This arrangement requires that the meteorological towers be installed on free-standing tripods that are separate from the trailer (Figures 4 and 5).

Figure 3. Station 400 is a trailer mounted radiological and meteorological measurement system located near the Range Operations Center (ROC) in the Sandia National Laboratories (SNL) compound on the TTR.

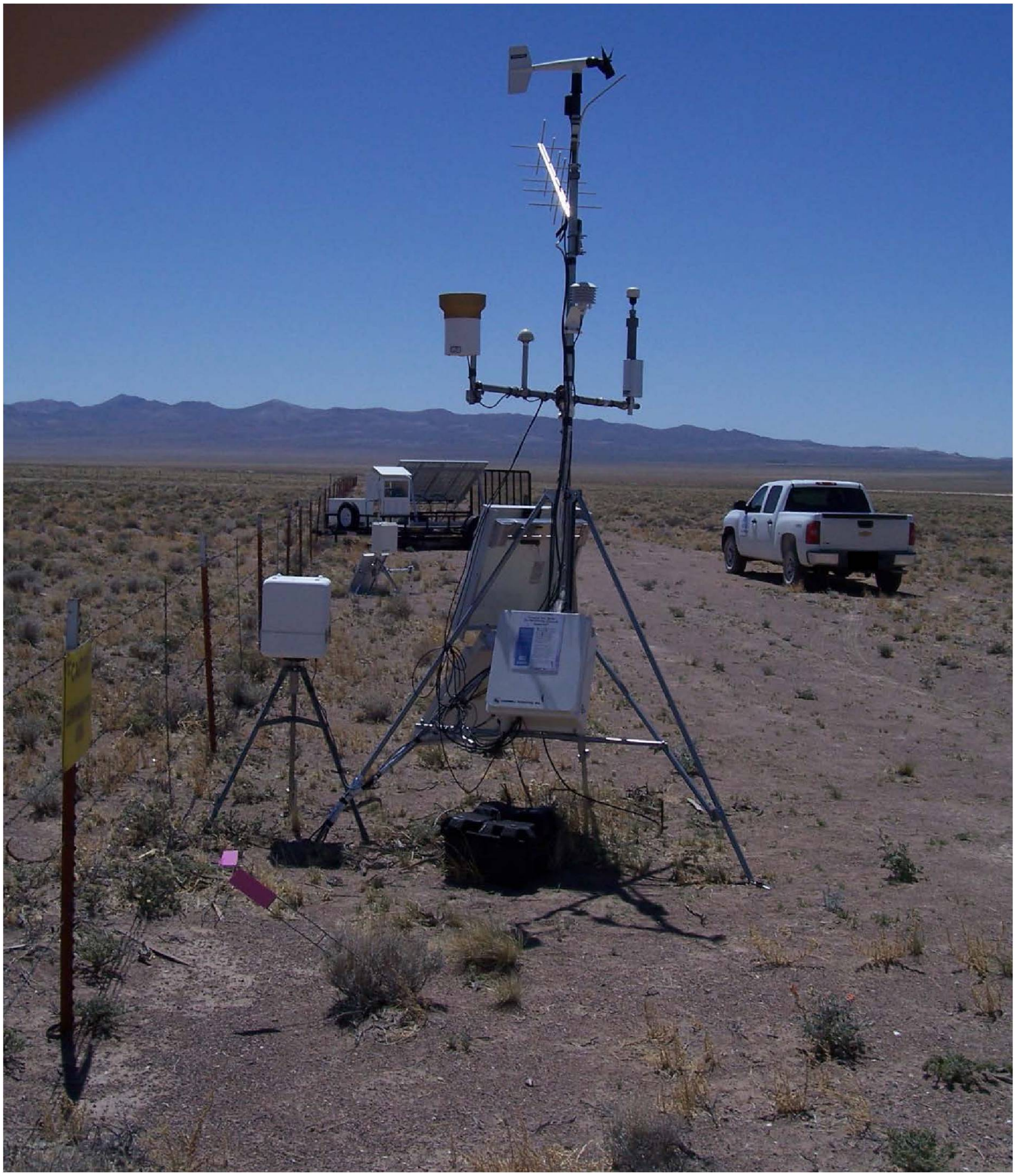

Figure 4. The solar powered air sampler, saltation sensor, and meteorological tower (background, center, and foreground, respectively) at Station 401 are located along the north fence that bounds the Clean Slate III contamination area.

Table 1. Location coordinates for the TTR air monitoring stations.

Station	Latitude	Longitude
Station 400 – original	37° 47' 15" N	116° 45' 26" W
– current	37° 47' 10" N	116° 45' 21" W
Station 401	37° 45' 39" N	116° 40' 58" W
Station 402	37° 42' 33" N	116° 39' 32" W

Figure 5. The solar powered air sampler, saltation sensor, and meteorological tower (center right, foreground left, and center left, respectively) at Station 402 are located along the north fence that bounds the Clean Slate I contamination area.

The fundamental design of these stations is similar to that used in the Community Environmental Monitoring Program (CEMP) (NSTec, 2013). The equipment deployed provides data on radiological, meteorological, and environmental conditions. Table 2 lists the parameters measured and the approximate date of the initial data collection at each of the three monitoring stations. Plutonium was the principal radionuclide released into the environment during the Clean Slate experiments. It attaches to small soil particles and is likely to be suspended in the air and transported from the site along with windblown dust. Americium-241, a daughter product of plutonium-241 that releases gamma energy during decay, is much easier to detect than the alpha particle released during plutonium decay. Therefore, two radiological data collection systems are deployed at each of the monitoring stations. Gamma energy is measured using a pressurized ionization chamber (PIC) and airborne particulates are collected for radiological analysis. Continuous flow, low-volume air samplers (flow rate is approximately 0.05663 m^3 [2 ft^3] per minute) are used to collect airborne particulates. Glass-fiber filters (pore size: 0.3 μm) are used at Station 400 and cellulose-fiber filters (pore size: 20 μm to 25 μm) are used at Stations 401 and 402. All filters are 10 cm (4 inch) in diameter. During Calendar Year (CY) 2013, the cellulose-fiber filters at Stations 401 and 402 were replaced with glass-fiber filters. The conversion to glass-fiber filters was made to ensure that the smaller-sized particulates to which plutonium might be attached are collected. Filters are retrieved every two weeks and are delivered to the Radiological Services Laboratory (RSL) at the University of Nevada, Las Vegas, for analyses.

The total mass of collected dust is submitted for gross alpha, gross beta, and gamma spectroscopy analyses in an effort to assess the magnitude of radionuclides associated with the suspended dust. Gamma spectroscopy is performed to determine if americium-241, the daughter product of plutoinum-241, is present. If americium-241 is detected, then alpha spectroscopy is performed to determine the quantity of plutonium-241 present. Because plutonium particles tend to attach to small soil particles, suspension or resuspension of dust from contaminated soil sites by wind and transport by rainfall runoff are the likely mechanisms for transporting radiological contaminants beyond the administrative boundaries of each site. The effort reported here is focused on possible transport by wind resuspension. Additionally, inhaling contaminated dust particles is the most likely mechanism for human exposure. Suspension and transport of contaminated dust is controlled by local meteorological and other environmental conditions, such as wind speed and soil moisture content. Many meteorological parameters influence these conditions. Electronic sensors measure meteorological and other environmental conditions every three seconds. These measurements are averaged or totaled, as appropriate, and stored in the on-site data logger every 10 minutes. The maximum and minimum value of each parameter is also saved on the data logger. These values are used to evaluate data quality. The data loggers are downloaded during site visits every two weeks. To assess instrument performance and provide rapid updates of observations, hourly averages of the 10-minute data are transmitted to the Western Regional Climate Center (WRCC) via the Geostationary Operational Environmental Satellite (GOES) system. At the WRCC, data are quality checked and archived for analysis.

Table 2. Radiological, meteorological, and environmental sensors deployed at the TTR air monitoring stations. The dates refer to the first occurrence of data collection for that parameter at the given station.

Instrument/Measurement	Station 400	Station 401	Station 402
Wind speed	5/27/2008	6/10/2008	5/18/2011
Wind direction	5/27/2008	12/22/2009	5/18/2011
Precipitation	5/27/2008	12/22/2009	5/18/2011
Temperature	5/27/2008	6/10/2008	5/18/2011
Relative humidity	5/27/2008	6/10/2008	5/18/2011
Solar radiation	5/27/2008	na	5/18/2011
Barometric pressure	5/27/2008	na	5/18/2011
Soil temperature	5/27/2008	12/22/2009	5/18/2011
Soil moisture content	5/27/2008	12/22/2009	5/18/2011
Airborne particle size profiler	5/27/2008	6/10/2008	5/18/2011
Airborne particle collector	5/27/2008	7/30/2008	8/23/2011
Saltation senor	na	8/X/2011	8/X/2011
Gamma radiation PIC	5/27/2008	12/22/2009	12/15/2011
MiniVol™[1]	5/27/2008	na	na
Data logger	5/27/2008	6/10/2008	5/18/2011
GOES transmitter	5/27/2008	12/22/2009	5/18/2011

[1] Samples have never been collected from the MiniVol™ collectors.
na = not available.

In addition to the automatic sensors, two MiniVols™ (Air Metrics, Eugene, Oregon) are deployed at Station 400. These samplers are intended to be run in the event of a nearby wildfire or during extreme dust storms because they are set up to facilitate analyses that distinguish organic and inorganic constituents. The MiniVols™ are manually activated, low-volume air samplers equipped with Teflon-filter media. No events caused the MiniVols™ to be activated in 2013, so no data were collected from these instruments.

RADIOLOGICAL ASSESSMENT OF AIRBORNE PARTICULATES

Airborne dust particles are collected continuously using Hi-Q™ dust collectors located at each of the TTR air monitoring stations. A glass-fiber filter (diameter: 10 cm [4 in]; pore size: 0.3 μm) was used at Station 400. Initially, cellulose-fiber filters (diameter: 10 cm [4 in]; pore size: 20 μm to 25 μm) were used at Stations 401 and 402. On April 3, 2013, cellulose filters were replaced with glass filters at these two stations in order to standardize the filter media at all three stations. Additionally, on May 29, 2013, a duplicate air sampler was installed at Station 400. This sampler was operated using a cellulose filter in order to evaluate any differences in the analytical results due to the pore size differences of these filter materials. (Data collection for this evaluation was completed in May 2014 but analysis of the data has not been completed and reporting on the results will be deferred until a later date.)

The Hi-Q™ equipment draws ambient air through the filters at a rate of approximately 56.6 lpm (2 cfm) and is designed to maintain the same flow rate as dust gathers on the filter. The total volume of air passed through the filter and the total hours of operation are recorded when filters are recovered from the monitoring stations and new filters are deployed every two weeks. Filters are weighed before and after deployment to determine the mass of particulates collected. Sample filters are accumulated and periodically submitted to the RSL at the University of Nevada, Las Vegas, for gross alpha, gross beta, and gamma spectroscopy assessment. The gross alpha and gross beta observations for CY2013 are summarized below in Tables 3 and 4, respectively.

Filters collected during CY2013 were deployed between December 26, 2012, and December 23, 2013. This generated 26 air particulate filter samples for Stations 400 and 402. Only 25 particulate samples were collected from Station 401 because the air pump failed during the two-week period of February 20 to March 6, 2013. The mean annual gross alpha activity (Table 3) ranged from 1.05 x 10^{-15} μCi/mL at Station 401 to 2.04 x 10^{-15} μCi/mL at Station 402. The mean annual gross beta activity (Table 4) ranged from 0.82 x 10^{-14} μCi/mL at Station 401 to 2.13 x 10^{-14} μCi/mL at Station 402. The higher mean annual gross alpha and gross beta concentrations observed at all stations for the glass filters are likely due to their smaller pore size relative to the cellulose filters.

Table 3. Gross alpha results for TTR sampling stations 2013.

Sampling Location	Number of samples	Concentration (x10^{-15} μCi/mL [3.7 x 10^{-5} Becquerel (Bq)/m^3])			
		Mean	Standard Deviation	Minimum	Maximum
Station 400(G)	26	2.03	1.01	0.66	5.69
Station 400(C)	15	1.33	0.64	0.18	2.63
Station 401(G)	19	1.60	0.67	0.55	3.08
Station 401(C)	6	1.05	0.30	0.70	1.63
Station 402(G)	19	2.04	0.80	0.35	3.65
Station 402(C)	7	1.70	0.61	0.89	2.96

NOTES: Bq = Becquerel; m^3 = cubic meter; μCi/ml = microcurie per milliliter; TTR = Tonopah Test Range;
(G) = glass filter; (C) = cellulose filter; glass-fiber filters retain particulates greater than 0.3 μm; cellulose-fiber filters retain particulates greater than 20 μm.

Table 4. Gross beta results for TTR sampling stations 2013.

Sampling Location	Number of samples	Concentration (x10^{-14} µCi/mL [3.7 x 10^{-4} Becquerel (Bq)/m^3])			
		Mean	Standard Deviation	Minimum	Maximum
Station 400(G)	26	2.03	0.44	1.26	3.25
Station 400(C)	15	1.12	0.22	0.73	1.54
Station 401(G)	19	1.64	0.44	0.46	2.30
Station 401(C)	6	0.82	0.25	0.55	1.24
Station 402(G)	19	2.13	0.67	0.68	3.34
Station 402(C)	7	1.05	0.29	0.69	1.53

NOTES: Bq = Becquerel; m^3 = cubic meter; µCi/ml = microcurie per milliliter; TTR = Tonopah Test Range; (G) = glass filter; (C) = cellulose filter; glass-fiber filters retain particulates greater than 0.3 µm; cellulose-fiber filters retain particulates greater than 20 µm.

Table 5 gives the CY2012 gross alpha and gross beta concentrations reported for CEMP stations surrounding the TTR. The CY2012 data from the CEMP is the latest documented data available at the time of this writing. Glass filters are used in the air samplers at the CEMP stations. Mean annual gross alpha concentrations at the TTR monitoring stations are higher than the values at most of the surrounding CEMP stations regardless of the filter media used (Figure 6). Values for the TTR glass filter samples are 0.87 to 1.11 times the highest CY2012 CEMP station (Sarcobatus) result. The mean annual gross beta concentrations for the glass filters at TTR Stations 400 and 402 are about the same as the highest CY2012 CEMP station (Sarcobatus) result (Figure 7). However, the mean annual gross beta for glass filter samples from Station 401 is about the same as the lowest mean annual gross beta value for the CEMP stations (Nyala Ranch). Values for the TTR cellulose filter samples are approximately half of the CEMP values.

Table 5. Mean annual gross alpha and gross beta concentrations for 2012 reported at CEMP stations that surround the TTR (from NSTec, 2013).

Sampling Location	Gross alpha (x10^{-15} µCi/mL)			Gross beta (x10^{-14} µCi/mL)		
	Mean	**Minimum**	**Maximum**	**Mean**	**Minimum**	**Maximum**
Goldfield	1.05	0.31	2.58	1.88	1.12	3.13
Nyala Ranch	1.03	0.49	1.88	1.53	1.01	2.75
Rachel	1.03	0.56	1.66	1.87	1.08	2.58
Sarcobatus Flats	1.83	0.51	4.61	2.11	1.29	3.90
Stone Cabin Ranch	0.91	0.47	1.99	1.74	1.21	2.75
Tonopah	1.08	0.41	2.14	1.82	1.20	3.42
Twin Springs	0.95	0.53	1.81	1.81	1.19	3.06

na = value not available.

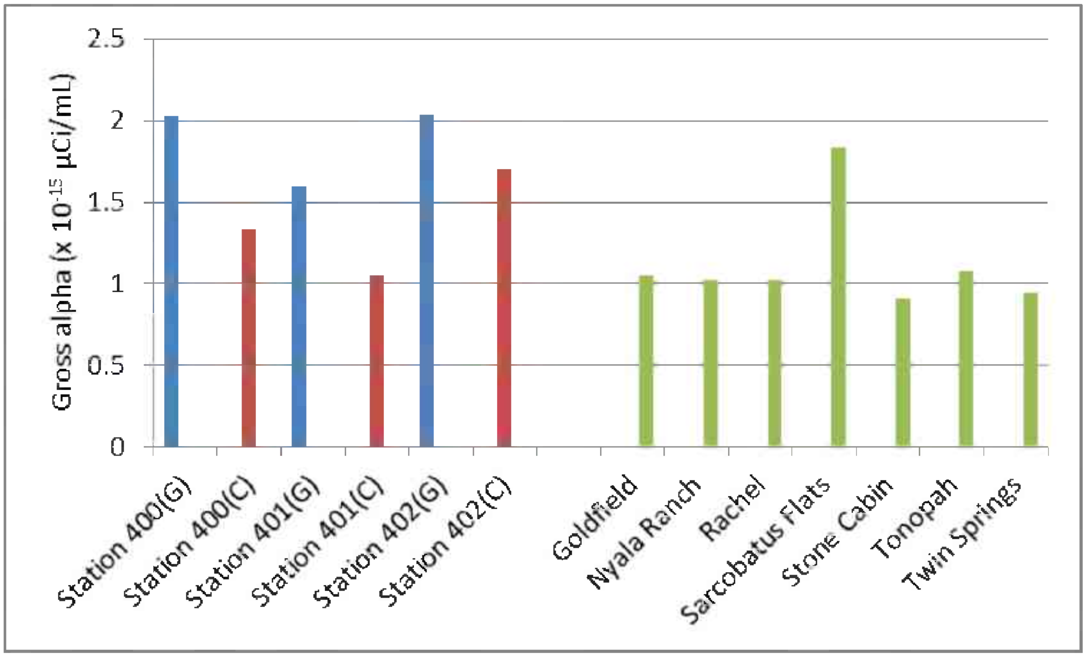

Figure 6. The mean annual gross alpha concentrations for TTR samples collected on glass filters (blue) are higher than the mean annual gross alpha concentrations for samples collected at the CEMP stations (green). The TTR samples collected on cellulose filters (red) have mean annual gross alpha concentrations in the upper range of the CEMP samples.

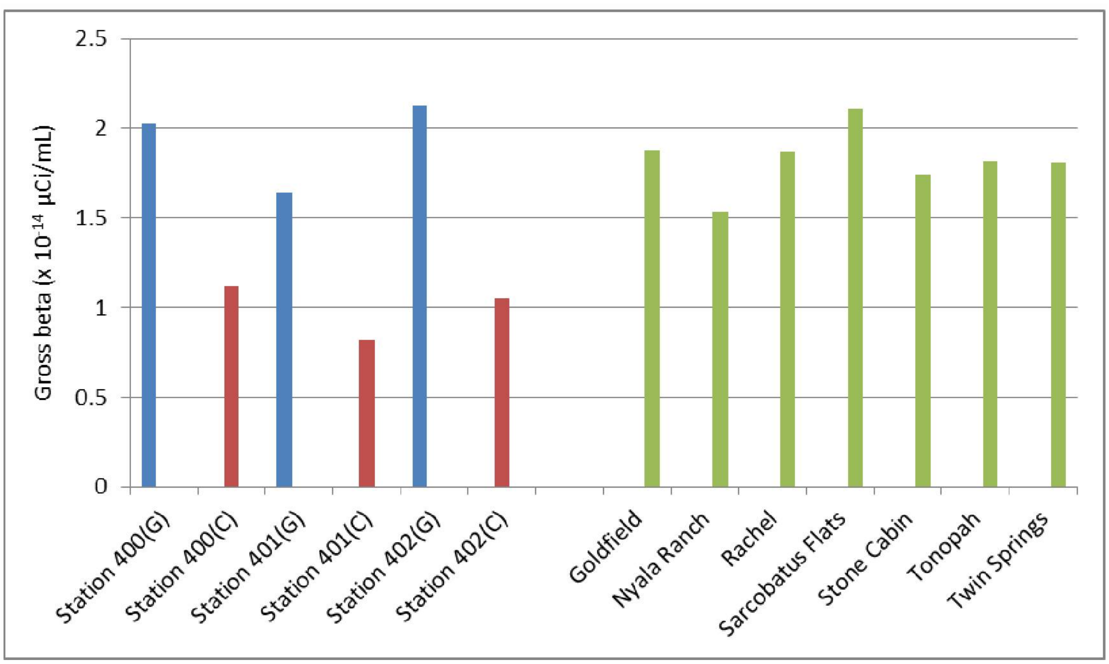

Figure 7. The mean annual gross beta concentrations for TTR samples collected on glass filters (blue) are in the same range as the mean annual gross beta concentrations for samples collected at the CEMP stations (green). The TTR samples collected on cellulose filters (red) have mean annual gross beta concentrations that are approximately half of the values for the CEMP sample.

Gamma spectroscopy identified only naturally occurring radionuclides in the particulate samples collected from TTR air monitoring Stations 400, 401, and 402 during CY2013 (Table 6). The detected radionuclides occurred with varying frequency. Beryllium-7 and lead-210 were the most commonly detected. No anthropogenic, gamma-emitting radionuclides were detected. No indicators of plutonium-239 or plutonium-240 were detected.

Table 6. The number of CY2013 particulate samples in which naturally occurring radionuclides were identified by gamma spectroscopy varied by radionuclide and between stations.

Ion	Number of samples		
	Station 400	Station 401	Station 402
Beryllium-7 (Be-7)	26	18	26
Lead-210 (Pb-210)	21	9	16
Potassium-40 (K-40)	7	7	3
Protactinium-234m (Pa-234m)	1	0	0

GAMMA RADIATION OBSERVATIONS

Gamma radiation observations are measured using a PIC detector. The PIC detectors are generally deployed to detect gamma radiation events that substantially exceed ambient radiation levels as a result of human activities. In the absence of such activities, ambient gamma radiation rates are reported. These radiation values vary naturally among locations, reflecting differences in altitude (cosmic radiation) and radioactivity in the soil (terrestrial radiation). Additionally, slight variations in gamma radiation at a single location may be due to changes in weather (UNSCEAR, 2000).

During CY2013, the PIC instruments at all three TTR monitoring stations were submitted for recalibration by Technical Associates in Canoga Park, California, a factory authorized service provider. Technical Associates certified that the calibration was performed in conformation with the recommendations of the U.S. Nuclear Regulatory Commission (NRC, 1979) and that the calibrated instruments meet the NRC and manufacturer's tolerance of +/- 10 percent full-scale. The PICs were removed from the field May 16, 2013, and replaced temporarily by PIC instruments borrowed from the CEMP. After recalibration, the PICs were returned to the TTR stations, though not necessarily to the stations where they were located prior to recalibration. As a result of these instrument exchanges during the year, three different PICs were deployed at Station 400, three different PICs were deployed at Station 401, and two different PICs were deployed at Station 402. In early 2014, the PIC installed at Station 401 on October 2, 2013, was determined to have been incorrectly programmed. It was removed from service on April 1, 2014. The data collected from this PIC during CY2013 were not included in the effort to assess the relationship between the intervals of increased gamma values and other monitored meteorological and environmental parameters.

The PIC data collected at the TTR air monitoring stations measure gamma radiation exposure every three seconds. These measurements are averaged every 10 minutes before being recorded in the station database. The 10-minute average gamma values for CY2013 recorded at TTR monitoring Stations 400, 401, and 402 are presented in Figures 8, 9, and 10, respectively. Shown with the gamma record from each PIC are: the mean of all CY2013 gamma values at that station, the mean of the gamma values reported for each individual PIC deployed at that station, the PIC mean plus one standard deviation, the PIC mean plus two standard deviations, and the PIC mean plus 10 percent of the PIC mean. The statistical values are presented to illustrate the level of variability in the data. The "plus 10 percent" value is presented because it depicts the approximate upper limit of the tolerance range of the recalibrated PICs.

During the year, recorded gamma values exceeded the PIC mean plus 10 percent on multiple occasions for each PIC. In a preliminary effort to examine the reason for and ascertain the significance of these intervals of increased gamma values, the meteorological and environmental observations associated with them were reviewed. The interval of increased gamma values that produced the highest 10-minute average gamma value for each PIC at each station was selected. As a result of the combination of PICs deployed at the three stations, nine intervals of higher gamma values were selected for evaluation. These nine events occurred on six different dates. On three dates, only one station recorded an interval of higher gamma values. On two dates, two stations recorded intervals of higher gamma values, though not the same two stations each time. At no time did all three stations record intervals of higher gamma values on the same date.

Detailed descriptions of the behavior of monitored parameters associated with the intervals of increased gamma values are presented in Appendix A and are summarized in Table 7. Observed meteorological conditions associated with intervals of increased gamma values commonly included increasing wind speeds, wind direction changes, increased humidity, decreased air temperature, and precipitation. These conditions also indicate a passing storm front, which suggests an association between storm front passage and intervals of increased gamma values. Additionally, high dust counts observed prior to the intervals of increased gamma values are likely the result of the winds associated with these storm fronts.

Although it is probable that the high dust counts are the result of windy conditions, it is not possible to state that the dust is derived from the radionuclide-contaminated soil sites or that the intervals of increased gamma values are due to wind transport of radionuclide-contaminated soil material. Winds associated with the interval of higher gamma values recorded at Station 400 in January 2013 shifted from the south to the north immediately preceding and during the rising limb of the interval of higher gamma values. Winds associated with the April 2013, November 2013, and December 2013 intervals of higher gamma values were basically out of the northwest. Winds observed during the July 2013 intervals of higher gamma values were variable. Because the monitoring stations are on the north side of the Clean Slate I and III contamination areas, northerly winds traverse uncontaminated ground before they are recorded at the monitoring stations. Northerly and northwesterly winds would blow dust derived from the Clean Slate contamination areas away from the monitoring stations. The differences between the pre-event and peak gamma value for the intervals of higher gamma values ranged from 1.5 μR/hr to 5.8 μR/hr when the wind was from the west, northwest, and north. This range encompasses the increase in gamma values for intervals associated with variable winds and winds shifting from the south to the north. Additionally, the mean and standard deviation of the differences between the pre-event and peak gamma value for the intervals of higher gamma values was 3.73 µR/hr and 1.23 µR/hr, respectively. Only one value lies outside of the range of the mean plus/minus one standard deviation suggesting little difference between the gamma values observed at the three stations. Therefore, the observed intervals of increased gamma values do not appear to be associated with wind transport of radionuclide-contaminated soil material from the Clean Slate sites, other yet unidentified conditions must be contributing to the intervals of increased gamma values.

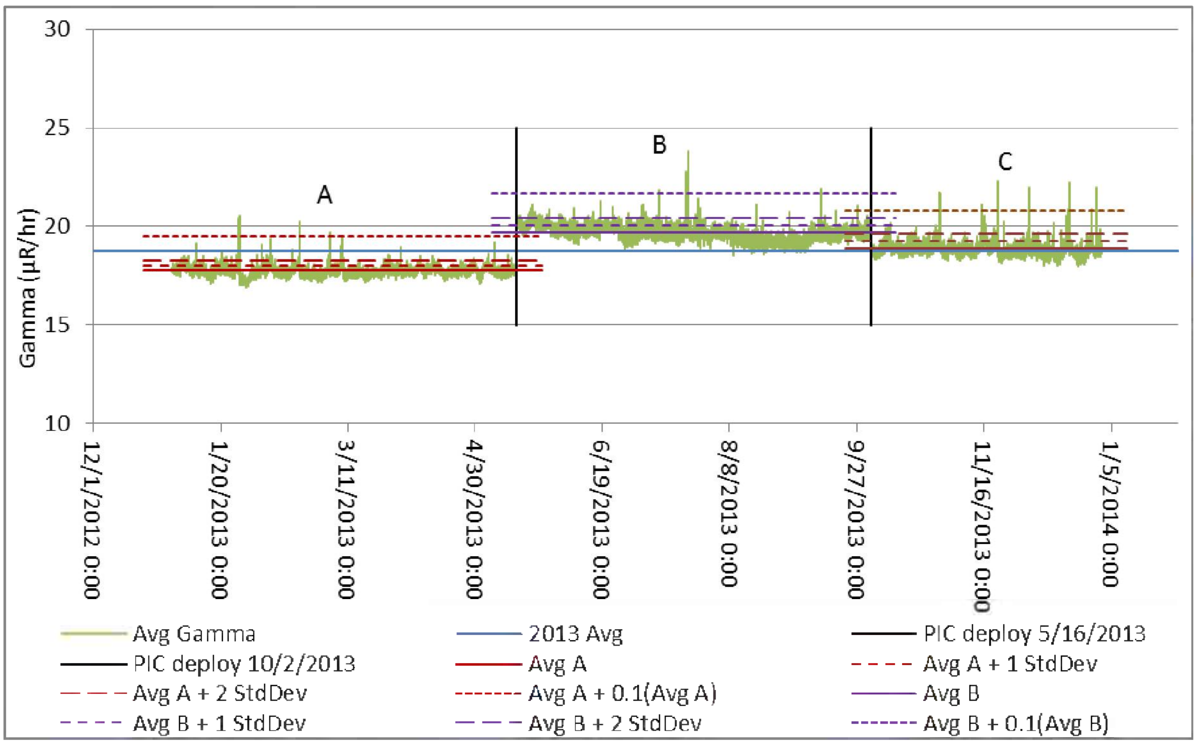

Figure 8. The CY2013 PIC gamma data for TTR Station 400. The PIC instruments were exchanged on May 16, 2013, and October 2, 2013, producing the three distinct segments in the annual gamma observations.

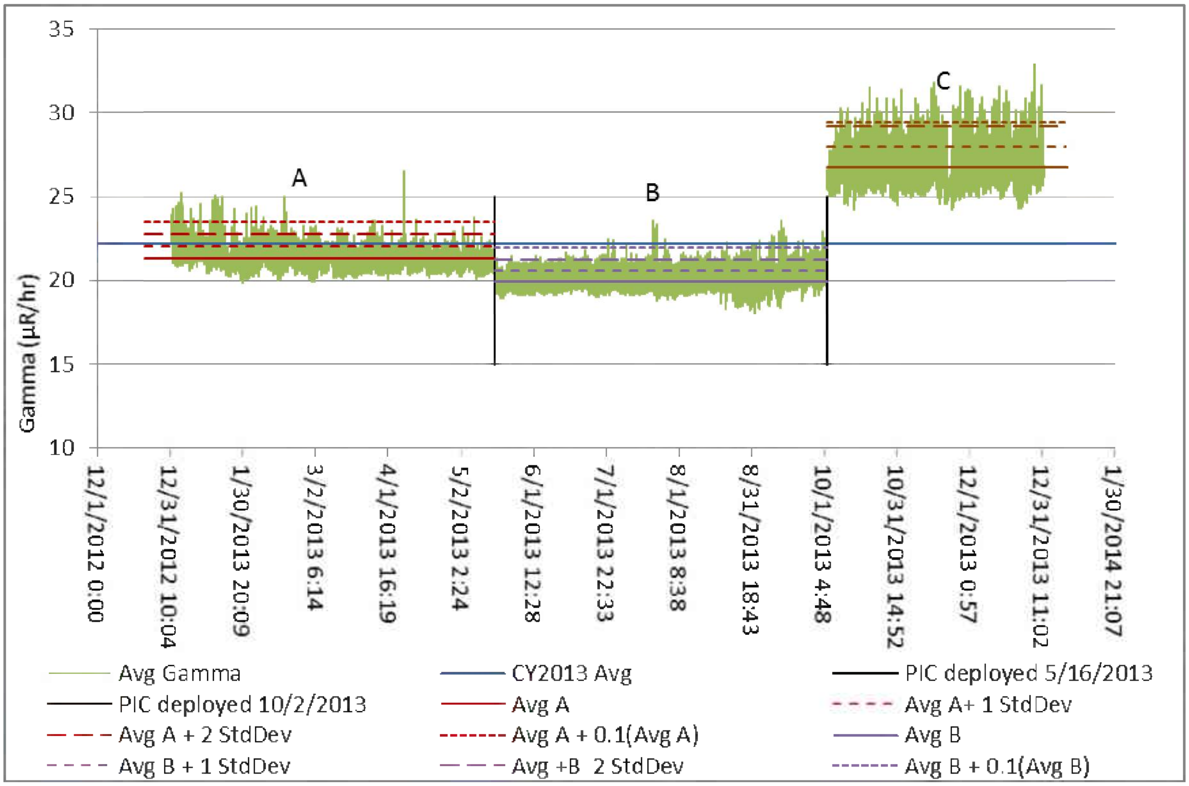

Figure 9. The CY2013 PIC gamma data for TTR Station 401. The PIC instruments were exchanged on May 16, 2013, and October 2, 2013, producing the three distinct segments in the annual gamma observations. Gamma values reported in the third (C) segment of CY2013 were later determined to be due to programming errors and the instrument was replaced in early 2014.

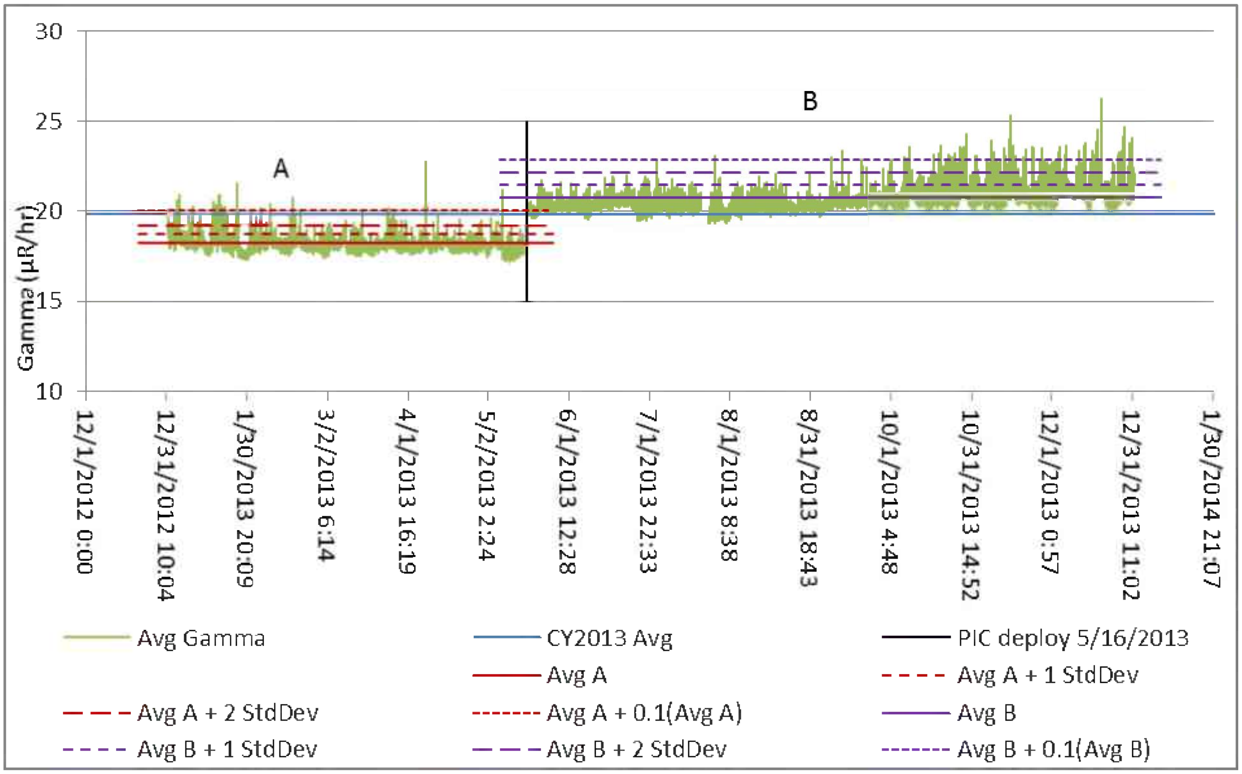

Figure 10. The CY2013 PIC gamma data for TTR Station 402. The PIC instruments were exchanged on May 16, 2013, producing the two distinct segments in the annual gamma observations.

Table 7. A generalized summary of meteorological conditions observed during the occurrence of increased gamma values at the TTR monitoring stations in CY2013.

Parameter	Common Conditions/Description
Wind Speed	Wind speed was generally increasing or peaking sharply immediately prior to an interval of increased gamma values, but the observed speeds were variable, ranging from a low of 8 mph to 10 mph to a high of 24 mph to 30 mph. Additionally, a distinct decline in wind speed appears to be typical immediately after onset of the increased gamma values.
Wind Direction	*Winds shifted from the south to the north during the interval of increased gamma values recorded in January 2013, were from the northwest during the April 2013 and November 2013 intervals of increased gamma, and were quite variable during the intervals of increased gamma values recorded in July. * At the two Clean Slate monitoring stations (Station 401 and Station 402), a northerly wind passes across the monitoring station before it passes over the contaminated areas.
Relative Humidity	Humidity was typically increasing or relatively high prior to the increased gamma and in the range of 80 % to 100 % during the increased gamma values.
Barometric Pressure	Various changes in barometric pressure associated with the increased gamma values were evident. Sometimes there were minor increases and at other times there were minor decreases in pressure.
Air Temperature	Decline in average air temperature common to all increasing gamma events reviewed. Temperature decline generally occurs coincident with or immediately prior to the increase in gamma values. One possible exception, Station 402 on 12/19/2013, when the temperature decline occurred approximately 10 hours prior to the main gamma value increase. However, the temperature drop was coincident with the first two minor gamma increase events that preceded the main gamma increase event.
Precipitation	*Precipitation events were generally coincident with the increased in gamma values. *At Station 400 on 1/27/2013, precipitation was measured after the increased gamma values. Air temperature during the increased gamma values was near 30 °F and precipitation may have fallen as snow or frozen on contact with the precipitation gage. Temperature increased immediately after the gamma increase and the temperature change may have been sufficient to melt the accumulated precipitation and allow it to pass through the gage. * No precipitation was recorded during two of the increased gamma values: Station 400 on 12/21/2013 and Station 401 on 4/8/2013.
Dust	Dust counts generally appear to be somewhat higher prior to the increased gamma values. The high dust counts occurred as little as 1 hour to as much as 17 hours prior to the gamma value increase. The counts for dust particles in the range of 0.3 μm varied over a wide range, from approximately 4,000 to 60,000.

WEATHER CONDITIONS AND OTHER ENVIRONMENTAL PARAMETERS

Air temperature trends recorded during the year at Stations 400, 401, and 402 between January 1, 2013, and December 31, 2013, are shown in Figures 11 and 12. The three traces shown on Figure 11 depict the maximum, average, and minimum daily temperature based on hourly average temperature for Stations 400, 401, and 402. The maximum temperature during summer was between 38 °C and 40 °C (100 °F to 104 °F) and the minimum temperature during winter was between -24 °C and -20 °C (-12 °F to -4 °F). On average, the maximum daily air temperature at Station 400 is approximately 10 °C (14 °F) above the daily average air temperature and the minimum daily air temperature is approximately 10 °C (14 °F) below the average, which suggests a diurnal temperature swing of approximately 20 °C (28 °F). The diurnal temperature swing at Stations 401 and 402 is approximately 16 °C (34 °F).

As expected, air temperature trends between all three stations are very similar (Figure 12) considering the close proximity and relatively small change in elevation between the three stations. The average air temperature at Station 400 is higher than Stations 401 and 402, possibly because Station 400 is located near several buildings and the presence of nearby paved roads that absorb more heat during the day or possibly due to a temperature inversion.

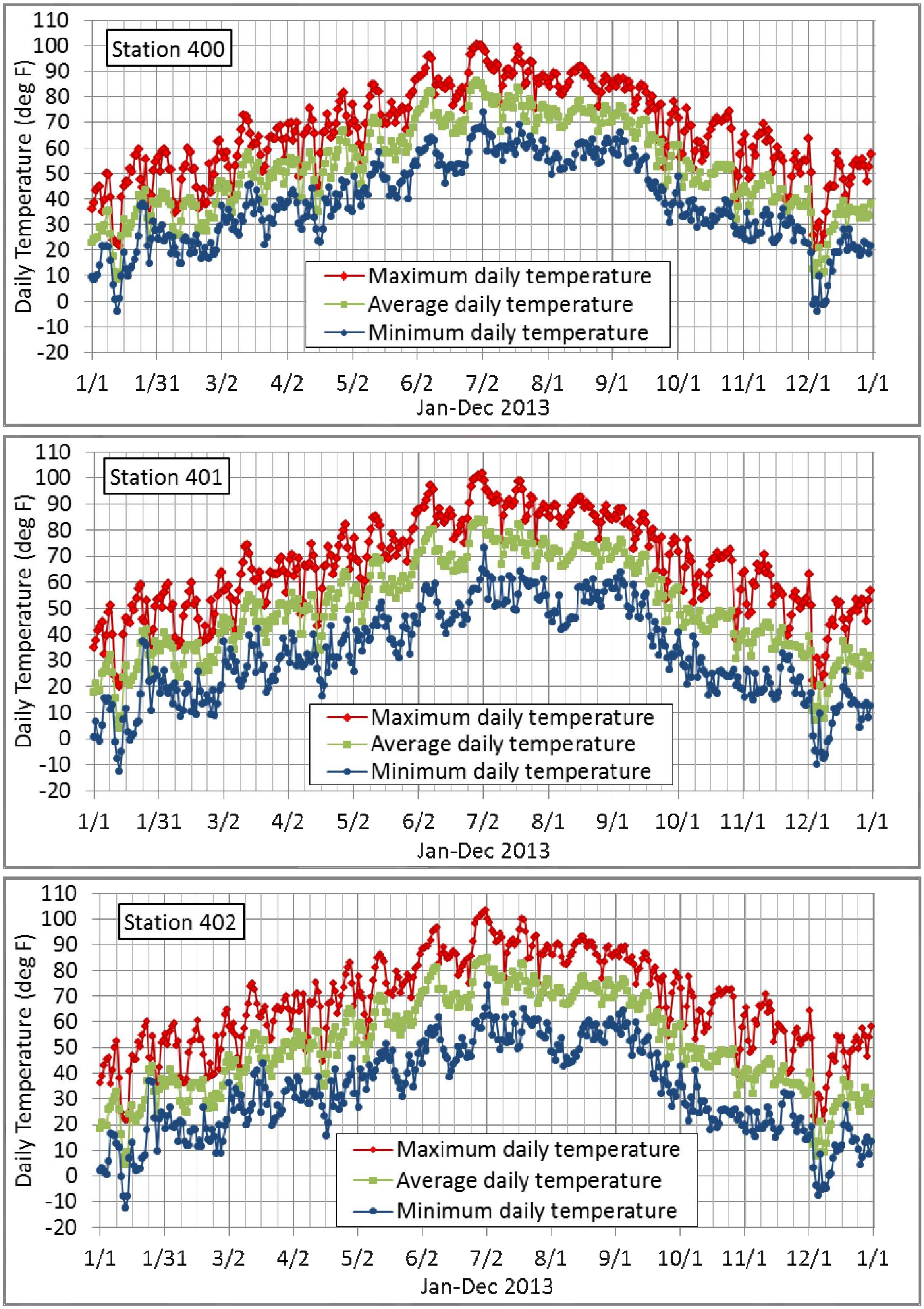

Figure 11. Ambient air temperature for Stations 400, 401, and 402 for CY2013.

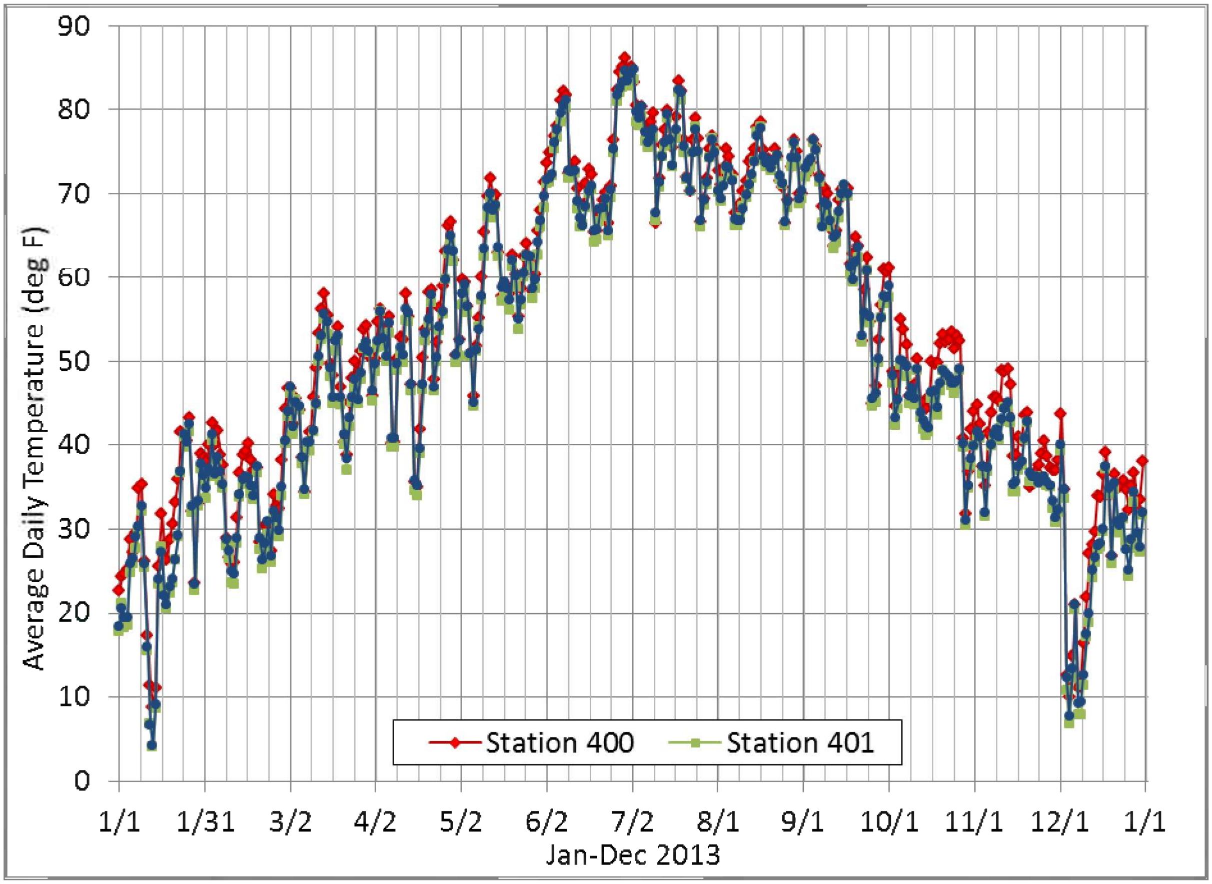

Figure 12. Average ambient air temperature for Stations 400, 401, and 402 CY2013.

The daily average soil temperatures for all three TTR stations are shown in Figure 13. Soil temperature is measured using temperature probes made of thermocouple wire that has been buried at a depth of 10 to 13 cm (4 to 5 in) in an effort to reflect the surficial soil's potential for drying. Generally there are minor differences in soil temperature readings between the stations. These minor differences may be explained in part by differences in local soil thermal conductivity, soil moisture, vegetation cover, probe burial depth, and exposure of the temperature probe. From late September to early November, soil temperature at Station 400 appears to be notably warmer than at Stations 401 and 402. Late summer rain events may be the cause of these differences. The gravel ground cover at Station 400 loses moisture more rapidly than the fine-grained soils at Stations 401 and 402. The absence of soil moisture at Station 400 would permit a stronger response of soil temperature to air temperature compared to the responses observed at Station 401 and 402 where soil moisture is more readily retained. Data from Station 401 (Figure 14) illustrate the close relationship between soil temperature and air temperature. Both the regression coefficient and the *x* coefficient, or slope of the regression line, express the strong dependency of the soil temperature on the air temperature. The intercept of the regression equation indicates that the soil temperature tends to be warmer by almost 4 °C (7 °F) than the air temperature.

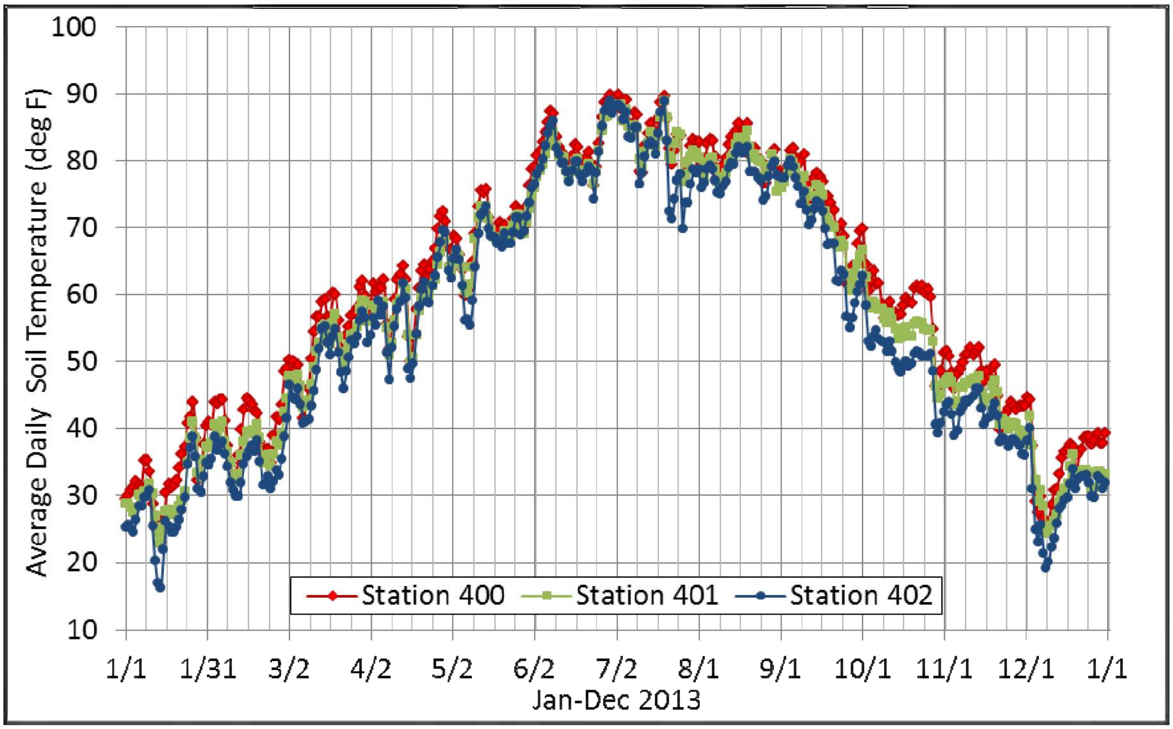

Figure 13. Average ambient soil temperature for Stations 400, 401, and 402 for CY2013.

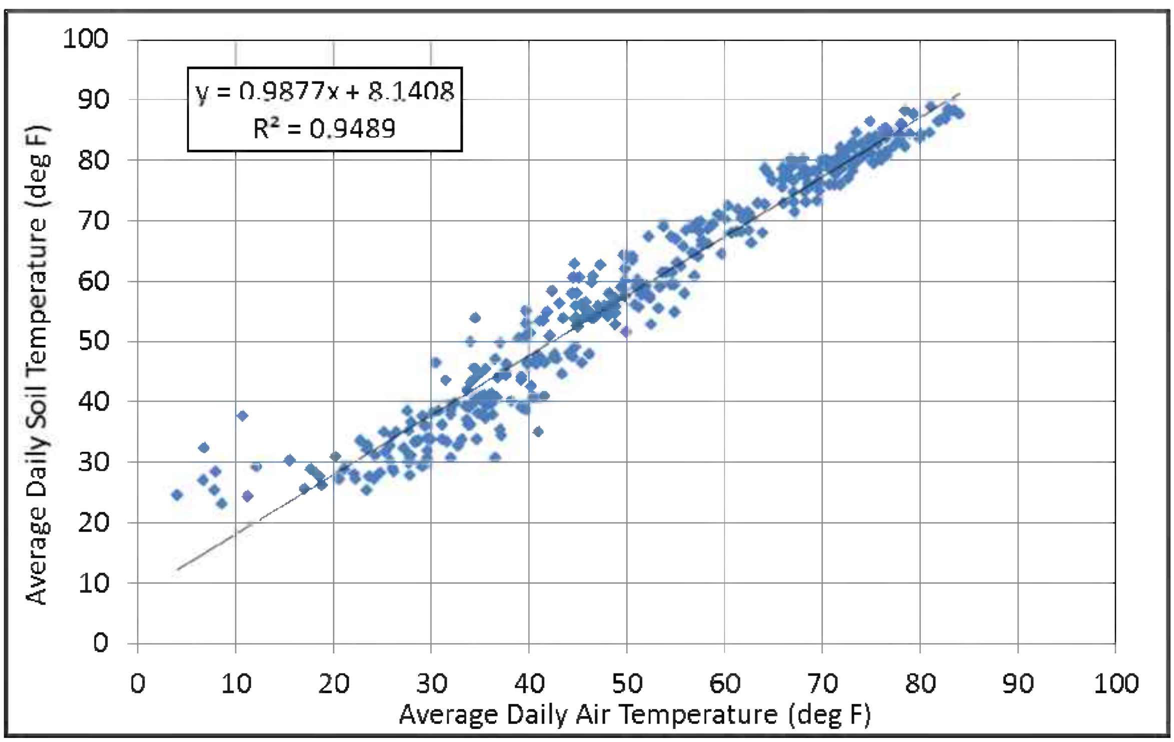

Figure 14. Comparison of average air and average soil temperatures by regression illustrates the close relationship between the two parameters at Station 401.

Total cumulative precipitation for Stations 400, 401, and 402 in the period between January 1, 2013, and December 31, 2013, is shown in Figure 15. All three stations reported zero precipitation in January. The line representing Station 402 is drawn on top of the lines representing the other two stations. Total precipitation for the calendar year varied between 51.6 mm (2.03 in) for Station 400 and 94.5 mm (3.72 in) for Station 402. Precipitation during 2013 at Station 401 was about 56.9 mm (2.24 in). Most rainfall events were widespread enough to be recorded by all three stations. However, the amount of rain measured at each station varied considerably.

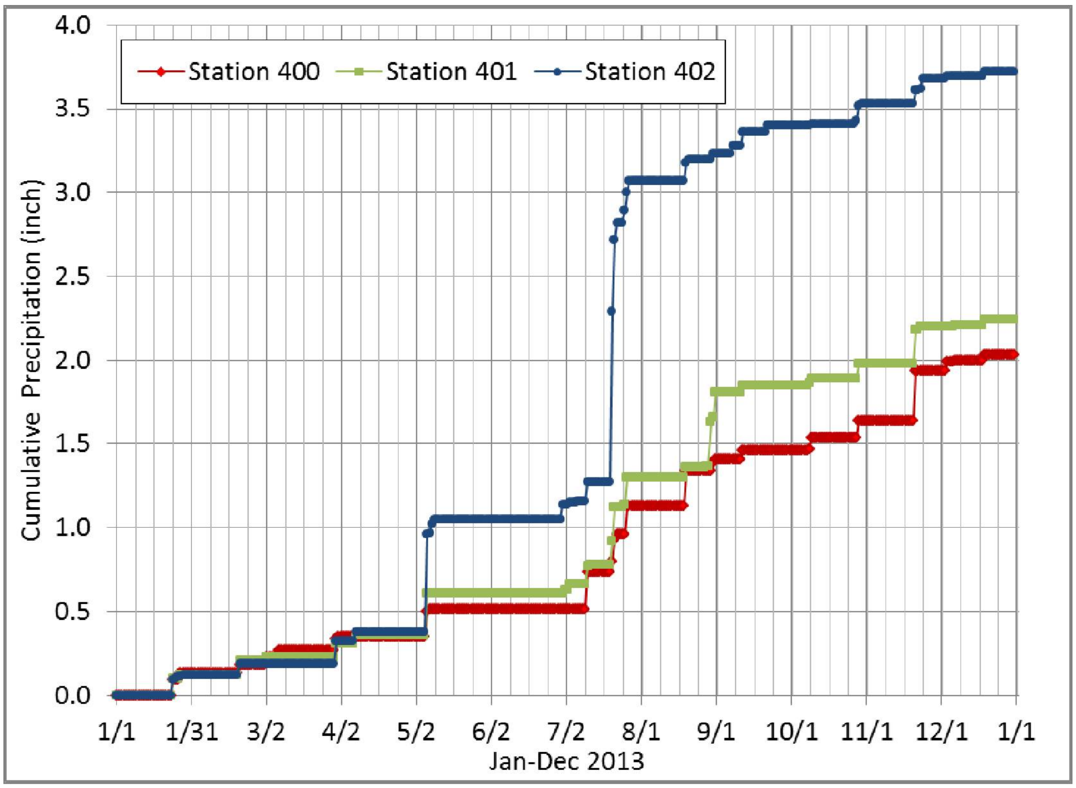

Figure 15. Cumulative precipitation for Stations 400, 401, and 402 for CY2013.

Total precipitation for the three stations during CY2013 averaged slightly more than 67.6 mm (2.6 in), which is approximately half of the historic average annual precipitation of 129.03 mm (5.08 in) measured at the Tonopah Airport from 1954 through 2013 (www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?nv8170, accessed May 17, 2013). Because non-heated rain gages are used at the three stations, the timing of snowfall may be delayed until the snow melts and the water content of snowfall may be underestimated if snow was blown out of the gage or sublimates before it melts.

Soil volumetric water content was monitored at all three stations in the top 5 cm (2 in) of soil using time domain reflectometry (TDR) probes. The TDR probes provide an estimate of soil water content based on direct measurement of soil conductivity. The TDR indicates the relative changes in soil water content associated with rain events and drying periods. The water content of this top layer of soil is most relevant to soil migration when soil is exposed to high winds. Sufficiently high soil moisture content is expected to diminish the soil material available for wind transport because moisture helps bind the soil particles together. Figure 16 shows the volumetric water content (VWC) of the topsoil layer at Stations 400, 401, and 402. Increases in soil VWC coincide with precipitation events and subsequent decreases in VWC correspond to drying. However, by itself soil VWC is not a reliable indicator of the potential for dust generation. For example, short intense rain events that would be expected to increase soil stability due to the addition of moisture may break up the soil crust and release fine soil particles for transport when exposed to wind.

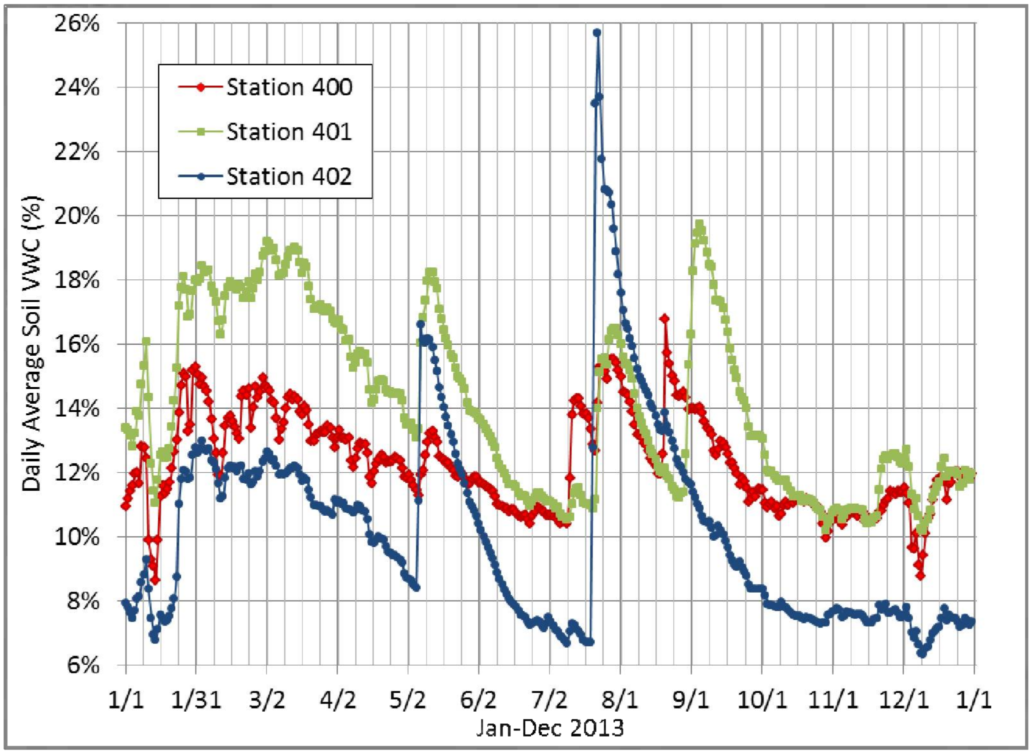

Figure 16. Soil volumetric water content for Stations 400, 401, and 402 for CY2013.

Wind is a major mechanism that drives soil migration at TTR. Therefore, it is important to monitor wind in conjunction with real-time particulate matter (PM) concentrations in order to determine the conditions under which dust transport by wind occurs. Annual wind rose diagrams (Figure 17) have been developed for all three stations for CY2013. In Figure 17, each station has two wind roses that cover the same time period: one on the left that shows all wind speeds and their contribution to the overall wind rose and one on the right that shows only winds above 24 km/hr (15 miles per hour [mph]). In general, winds above 24 km/hr (15 mph) result in elevated PM_{10} (particulate matter of aerodynamic radius of less than 10 micrometers) concentrations in the air. The PM_{10} is an indicator of small-sized particles that are suspended in air and can be easily inhaled. As seen in the multiple wind roses in Figure 17, the most prevalent winds are from the south or northwest, especially for wind speeds above 24 km/hr (15 mph).

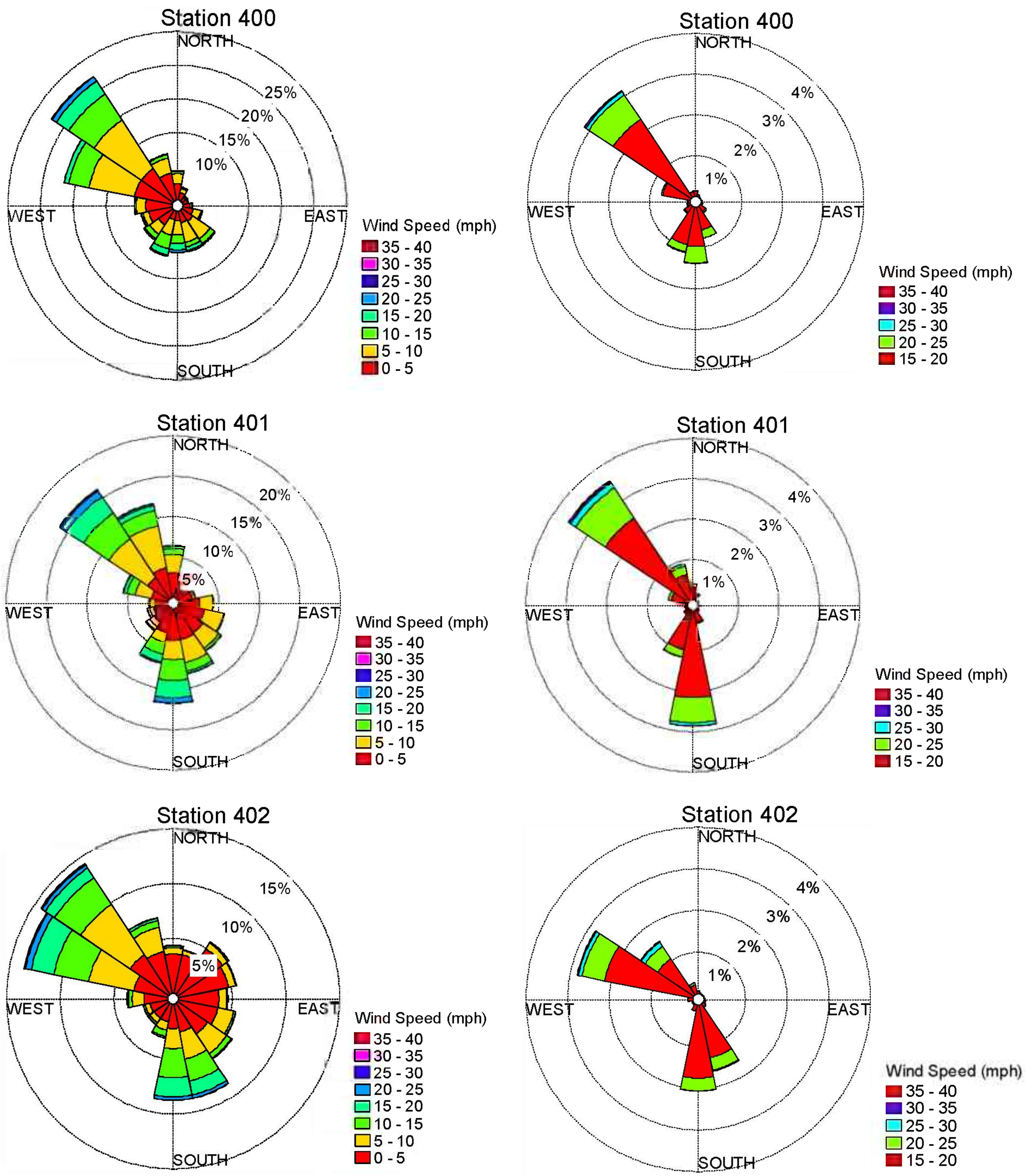

Figure 17. Annual wind roses for Stations 400, 401, and 402 for CY2013. Graphics on the left depict all winds, whereas graphics on the right depict winds greater than 24 km/hr (15 mph).

OBSERVATIONS OF SOIL TRANSPORT BY SALTATION

Saltation is the mechanism by which larger soil particles are transported across the ground surface. The saltation process and dust resuspension are the most likely mechanisms for transporting radionuclides from the contamination sites. Generally, saltation involves particles greater than about 50 µm. Particles are dislodged and carried small distances in the air before falling to the ground. Transport paths usually follow a parabolic trajectory; the particles essentially bounce across the ground. The amount of time the particles are in the air and the distances traveled are functions of wind speed and particle mass. Saltation is important because the impact of saltated particles dislodges smaller particles and ejects them into the air where they are transported by suspension.

The Sensit H11-LIN™ is deployed at TTR air monitoring Stations 401 and 402 to measure soil particles that bounce across the ground surface. The sensor impact area, which was set 10 cm (4 in) above the ground surface, wraps completely around the vertically oriented instrument and is capable of registering impacts from any direction. The impact area is made of piezoelectric material that converts particle impacts to electrical impulses that are recorded. Particle counts are summed over 10-minute intervals and stored on the station data logger. Presently, the saltation sensors are located in proximity to the metrological towers at each station in areas free of recent disturbances and vegetation that might interfere with their operation.

Because raindrop impact dislodges soil particles and ejects them into the air, counts on the saltation sensors increase during precipitation events. This type of sand particle movement is not synonymous with the saltation process and it does not result in the same type of particle trajectory nor transport distance associated with wind driven saltation. In addition to dislodging additional sand particles, raindrops can be carried by wind and impact the saltation sensor and register as false saltation counts. The saltation sensor is triggered by small mechanical impacts and cannot distinguish between the impact of raindrops or saltation-sized particles. Although precipitation events are typically accompanied by significant winds that cause saltation to occur, in order not to overestimate saltation due to raindrop interference, counting periods that are coincident with precipitation are removed from the data set so that analyses can be focused on the wind-driven saltation. Although rain plays an important role in the soil mechanics of desert soils, the saltation sensor is not suited to determine that role during the rain event itself because, as we already stated, raindrops are likely to cause false counts and eject sand particles due to raindrop impact.

Saltated particle counts are strongly dependent on wind speed. The relationship between wind speed and saltation particle counts was investigated by determining the average number of particle counts/10-minute interval for wind speeds categorized in 5-mph wind speed classes (Table 8) after removing those intervals influenced by rainfall. Figure 18 shows that the relationship between wind speed and saltation particle count is approximately exponential. As wind speed increases linearly, the particle count increases exponentially. Below the 15 mph wind class, both Stations 401 and 402 show similar saltation counts. Above 35 mph the saltation counts at Station 401 are notably greater than observed at Station 402. Higher saltation counts were observed at Station 402 than at Station 401 for wind speeds between 15 mph and 30 mph. However, for wind speeds in the 35 mph to 40 mph range the saltation counts at Station 402 dropped and were well below the counts observed at Station 401. This may indicated a temporary exhaustion of saltation-sized particles.

Table 8. Average saltation particle counts by wind speed class at TTR air monitoring Stations 401 and 402.

Wind Speed Class (mph)	Duration (hours)	Average Wind Speed (mph)	Average Particle Counts (count/10-min)
Station 401			
0 – 5	3,829.2	2.84	0.00
5 – 10	2,745.5	7.11	0.02
10 – 15	1,254.2	12.28	0.28
15 – 20	679.8	17.05	1.46
20 – 25	193.5	21.82	2.60
25 – 30	27.0	26.62	8.87
30 – 35	5.2	31.94	37.61
>35	2.3	37.01	328.26
Total	8,736.7	—	—
Station 402			
0 – 5	4,471.5	2.54	0.03
5 – 10	2,266.3	6.82	0.36
10 – 15	1,214.8	12.01	2.03
15 – 20	612.0	16.74	7.49
20 – 25	143.0	21.43	17.54
25 – 30	21.2	26.26	51.00
30 – 35	3.8	32.33	102.04
>35	1.2	35.98	74.29
Total	8,733.8	—	—

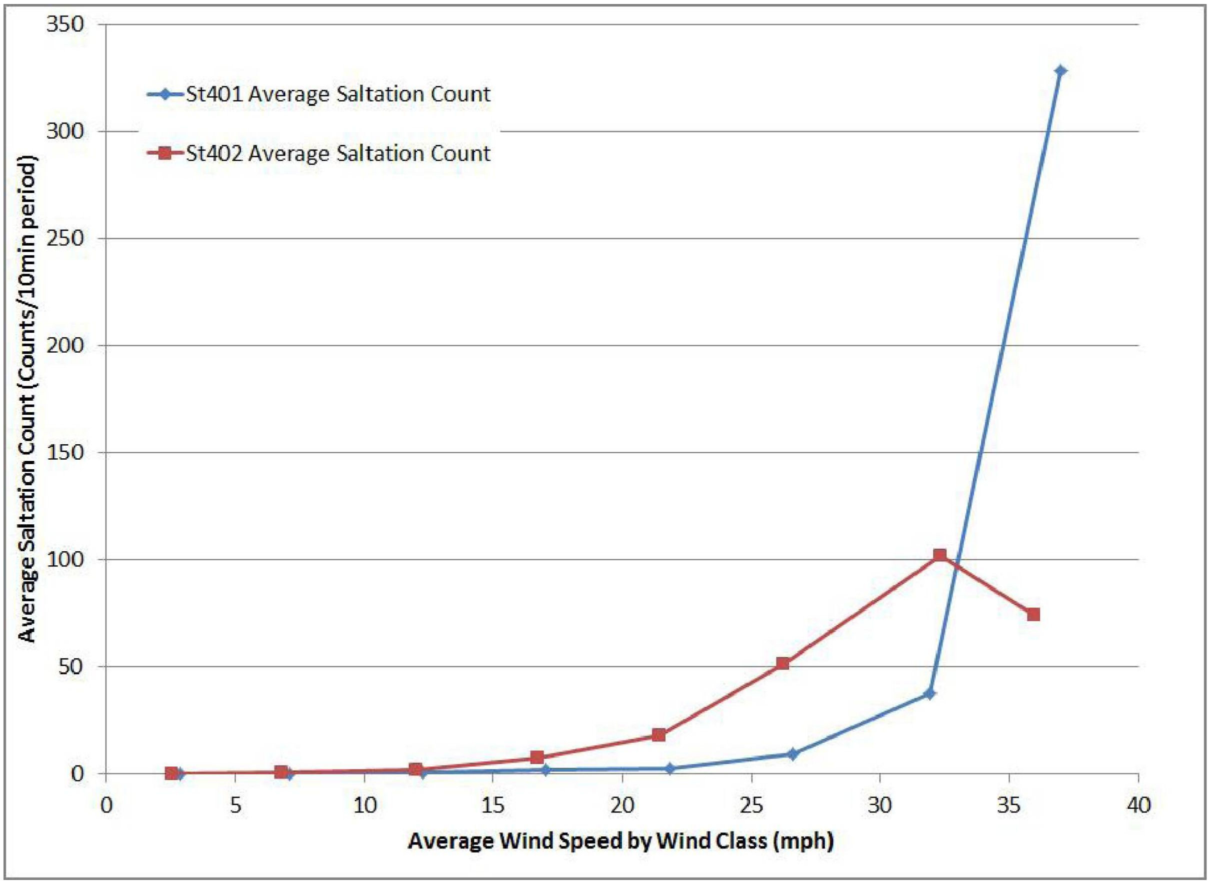

Figure 18. Average saltation counts generally increase exponentially as the wind speed increases at both TTR air monitoring Stations 401 and 402. The decline in saltation counts at Station 402 during winds in the 35 mph to 40 mph range may be due to the temporary exhaustion of saltatoin-sized particles.

Because saltated particles are likely to dislodge and eject smaller particles from the soil surface, the relationship between saltation particle counts and PM_{10} concentrations is important. A correlation analysis was performed to investigate this relationship. Strong correlation between high saltation values and high PM_{10} values would indicate that strong winds are driving the saltation activity, which in turn contributes to the fine dust emissions. Figure 19 shows the correlation between saltation counts and PM_{10} concentration at Stations 401 and 402. This correlation analysis was performed for data associated with wind speeds between 15 mph and 35 mph because the lower wind speeds do not generate meaningful saltation. Additionally, because they are statistically insignificant, data associated with wind speeds above 35 mph are also eliminated from the analysis. At both stations, the PM_{10} concentration increases significantly as the saltation counts increase. The PM_{10} concentration exhibits a strong relationship to the logarithm of the saltation counts with correlation coefficients above 99 percent.

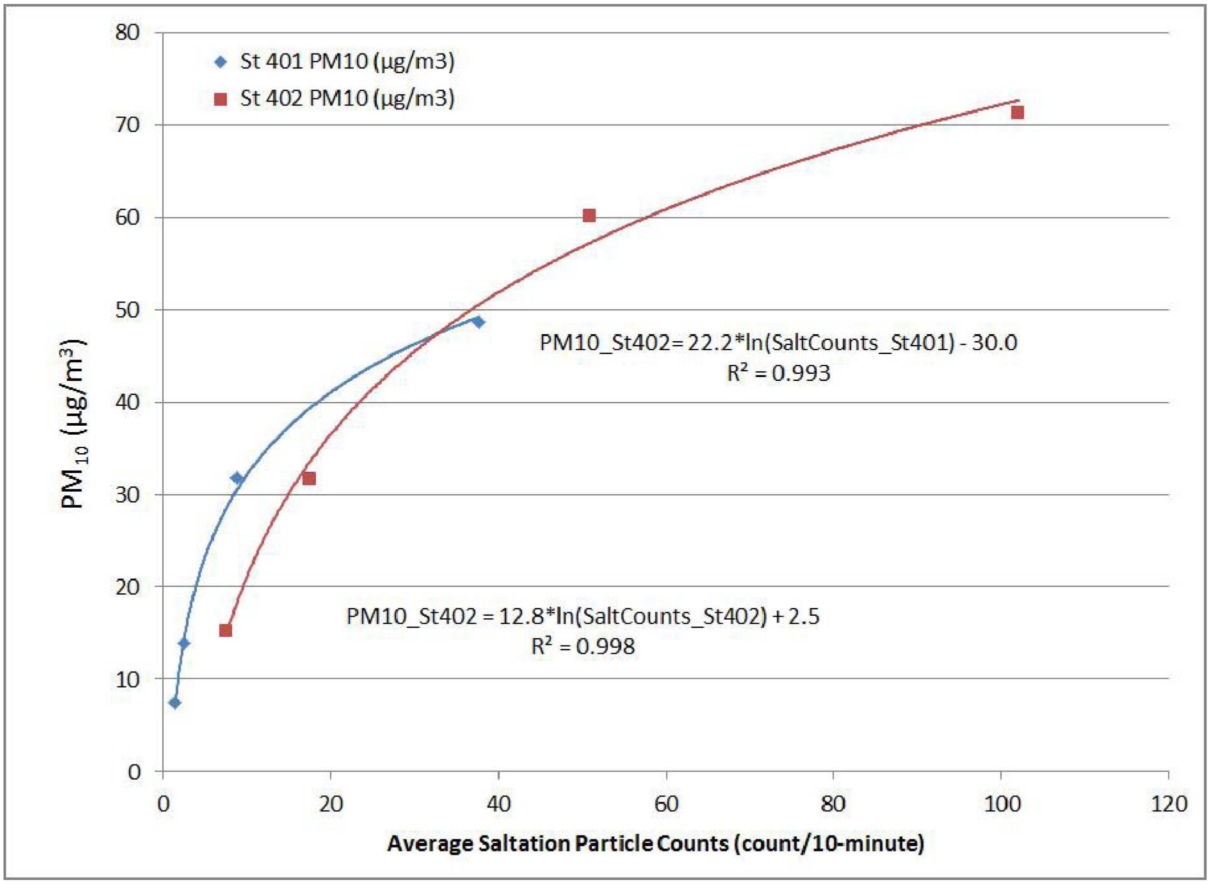

Figure 19. Regression of PM_{10} against saltation counts for wind speeds between 15 mph and 35 mph shows a strong logarithmic relationship.

OBSERVATIONS OF SOIL TRANSPORT BY SUSPENSION

Table 9 and Figure 20 summarize wind speed by the wind speed class for Stations 400, 401, and 402. Light winds (0 to 8 km/hr [0 to 5 mph]) are most common and occur between 38 percent of the time at Station 400 and 51 percent of the time at Station 402. Approximately 90 percent of the time, the wind speed at all three stations is less than 24 km/hr (15 mph). Winds in excess of 24 km/hr (15 mph) occur less than 10 percent of the time and wind speeds in excess of 32 km/hr (20 mph) occur less than two percent of the time.

Table 9 and Figure 21 summarize the PM_{10} concentrations corresponding to the wind speed classes. Average PM_{10} concentrations associated with wind speeds below 24 km/hr (15 mph) at all three stations is almost constant having a range of only 5.9 µg/m^3 to about 11.3 µg/m^3. The PM_{10} concentrations begin to rise almost exponentially for wind speeds in excess of 24 km/hr (15 mph). The rise in PM_{10} at Station 400 is somewhat erratic, increasing to more than 101 µg/m^3 for winds between 40 km/hr and 48 km/hr (25 mph and 30 mph) but decreasing for winds above 48 km/hr (30 mph). Local meteorological conditions and station characteristics are likely to contribute to the reduced PM_{10} concentration during high winds at Station 400. For example, Station 400, located on the south side of the ROC, is shielded from northwest winds by buildings and the open ground surrounding the station is covered with gravel for use as a storage yard.

At Stations 401 and 402, PM_{10} concentrations increased consistently with increasing wind speed. At Station 401, the PM_{10} concentration reached a maximum of about 68. At Station 402, the PM_{10} reached a maximum of about 133 $\mu g/m^3$. However, the highest wind and PM_{10} events are relatively rare and generally last for only short periods of time. Wind speed exceeds 48 km/hr (30 mph) only 0.04 percent (<3 hr) of the year at Station 400, 0.09 percent (approximately 8 hrs) of the year at Station 401, and 0.05 percent (<5 hr) of the year at Station 402.

Table 9. Summary of wind and PM_{10} data for Stations 400, 401, and 402 for calendar year 2013.

Wind Speed Class (mph)	Duration (hours)	Frequency (%)	Cumulative Frequency (%)	Average Wind Speed (mph)	PM_{10} ($\mu g/m^3$)
Station 400					
0 – 5	3,385.17	38.65	38.65	3.26	9.87
5 – 10	3,190.33	36.42	75.07	7.15	9.60
10 – 15	1,408.67	16.08	91.15	12.19	10.79
15 – 20	603.33	6.89	98.04	17.02	16.61
20 – 25	156.17	1.78	99.82	21.60	35.05
25 – 30	12.33	0.14	99.96	27.05	101.78
30 – 35	3.17	0.04	100.00	31.54	51.70
>35	0.33	0.00	100.00	35.73	64.70
Total	8,759.50	—	—	—	—
Station 401					
0 – 5	3,829.2	43.83	43.83	2.84	9.84
5 – 10	2,745.5	31.43	75.25	7.11	5.86
10 – 15	1,254.2	14.36	89.61	12.28	6.24
15 – 20	679.8	7.78	97.39	17.05	7.45
20 – 25	193.5	2.21	99.61	21.82	13.95
25 – 30	27.0	0.31	99.91	26.62	31.83
30 – 35	5.2	0.06	99.97	31.94	48.60
>35	2.3	0.03	100.00	37.01	67.98
Total	8,736.7	—	—	—	—
Station 402					
0 – 5	4,471.5	51.20	51.20	2.54	13.83
5 – 10	2,266.3	25.95	77.15	6.82	10.34
10 – 15	1,214.8	13.91	91.06	12.01	11.28
15 – 20	612.0	7.01	98.06	16.74	15.22
20 – 25	143.0	1.64	99.70	21.43	31.64
25 – 30	21.2	0.24	99.94	26.26	60.03
30 – 35	3.8	0.04	99.99	32.33	71.19
>35	1.2	0.01	100.00	35.98	132.96
Total	8,733.8	—	—	—	—

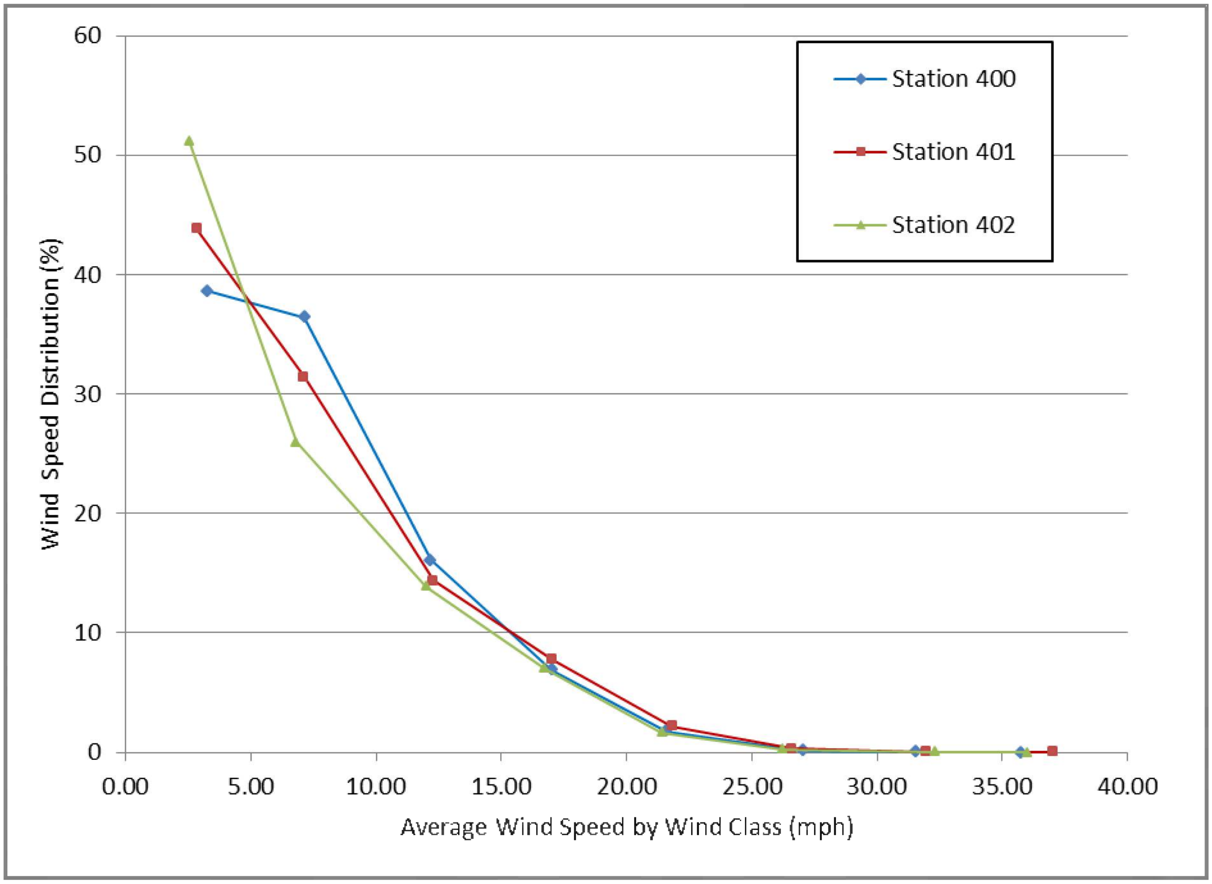

Figure 20. Wind speed frequency by wind class for Stations 400, 401, and 402 for CY2013. The portion of time wind speed falls within a given class is plotted against the average wind speed for that class.

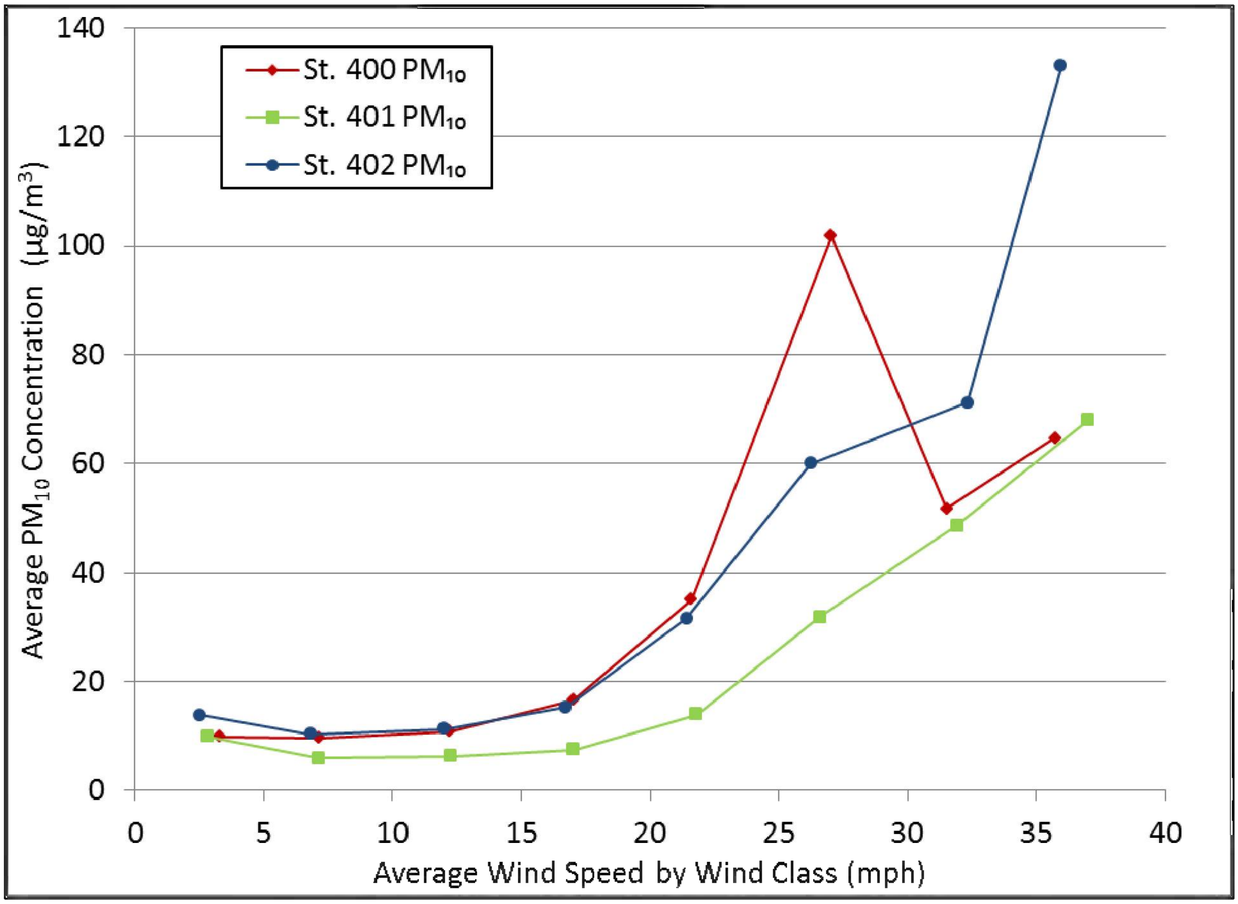

Figure 21. The PM_{10} trends as a function of wind speed for stations 400, 401, and 402 for CY2013.

Although the PM_{10} concentration increases approximately exponentially at high wind speeds, the wind speeds necessary to generate the higher PM_{10} concentrations occur less than about five percent of the time. Additionally, it should be noted that the higher wind speeds only persist for a short period of time during each occurrence. Therefore, wind transport of large masses of resuspended dust is an infrequent occurrence. This observation does not preclude transport of radionuclide-contaminated soil particles but only suggests that events during which large amounts of soil are moved by wind are infrequent.

CONCLUSIONS

1. Neither the results of radiological analysis of airborne particulates nor the record of 10-minute average gamma energy detections identified any definitive occasions when radionuclide-contaminated soils were migrating past the monitoring stations. There appears to be no evidence of wind-driven transport of radionuclide-contaminated soil material from the Clean Slate I and III sites under the ambient meteorological conditions experienced in CY2013.

2. The highest mean gross alpha and mean gross beta activities were observed at Station 402, adjacent to Clean Slate I. Values reported for Station 400, at the SNL ROC, were only slightly lower than the Station 402 values. Gamma spectroscopy analyses for all three sites identified only naturally occurring radionuclides.

3. The mean gross alpha values for the TTR stations were equivalent to or about 27 percent higher than the highest value observed at the surrounding CEMP stations. The mean gross beta value for Station 402 was approximately equivalent to the value reported for the CEMP station at Sarcobatus, the highest reported at the surrounding CEMP stations. The mean gross beta values for Station 400 were slightly below this level and the value for TTR Station 401 was near the low end of the values reported for the surrounding CEMP stations. These comparisons were made to the CY2012 CEMP data, which was the latest documented data available at the time of this writing. The gamma spectroscopy results for both the TTR and surrounding CEMP monitoring stations identified only naturally occurring radionuclides. The similarity between TTR and CEMP radiological observations suggests that there is no transport from the Clean Slate sites, that radiation at the TTR monitoring stations is due to natural (terrestrial and cosmic) sources, and that the levels of radiation observed are approximately equivalent to levels observed at the surrounding CEMP stations.

4. A preliminary assessment suggests that the glass-fiber filters returned higher mean gross alpha and mean gross beta results than the cellulose-fiber filters. This is believed to be due to the smaller pore size of the glass-fiber filters. This preliminary assessment is based on samples collected at different times during the year. During CY2013 and CY2014, samples were collected simultaneously to permit a direct comparison of the two sampling media. These data will be evaluated in fiscal year (FY) 2014 or a later date.

5. Intervals of increased gamma values were associated with meteorological conditions that indicate passage of storm fronts and typically include precipitation events. The high dust counts observed prior to the intervals of increased gamma values are likely due to the increased wind speed associated with the storm front passage. Winds associated with the intervals of increased gamma values were variable, changing direction, or from the northwest. The difference between the high gamma values and the preceding observations were similar despite the differences in wind direction. Winds from the northwest would transport uncontaminated soils rather than soils from the contamination areas as they reached the monitoring stations. Therefore, it appears the observed intervals of higher gamma values are not due to resuspension and transport of soil particles from the contamination areas.

6. Saltation counts increase with wind speed in a generally exponential manner. Below the 24 km/hr (15 mph) wind class, both Stations 401 and 402 show similar saltation counts. Between the 24 km/hr and 48 km/hr (15 mph and 30 mph) wind classes, the saltation counts at Station 402 are higher than those observed at Station 401. But for winds in the 56 km/hr (35 mph) wind class, the saltation counts at Station 401 are substantially higher than those observed at Station 402. The reduction in saltation counts at Station 402 for the highest wind speed class may be due to a temporary exhaustion of saltation-sized particles at the monitoring location.

7. Both saltation counts and PM_{10} increase approximately exponentially with wind speed. However, the highest wind speed events and associated saltation counts and PM_{10} concentrations are rare and generally last for only short periods of time. The potential for transport of radionuclide-contaminated soil materials during moderate winds may be more important than transport during high winds because the high winds are infrequent.

8. The PM_{10} concentration increases with increasing saltation counts. The correlation between saltation counts and PM_{10} concentration at Stations 401 and 402 exhibits a strong correlation, correlation coefficients above 99 percent.

RECOMMENDATIONS

1. Collection of duplicate air samples at Station 400 should continue until a full year of samples is obtained. These data can then be used to compare radiological analyses for samples collected using the glass and cellulose filter media. Hopefully, the analysis will define a relationship that can be used to adjust the historical cellulose-fiber filter samples and produce a long-term consistent data set for evaluating the radiological characteristics of airborne dust.

2. Recognizing a need to collect soil material transported by saltation for radiological evaluation, Big Spring Number Eight (BSNE) samplers were installed during CY2014. The BSNEs are isokinetic wind aspirated samples that collect a large portion of airborne dust and sand that enters the opening regardless of wind speed. Three replicate samplers were installed at Stations 401 and 402, and Clean Slate III and I, respectively. Each sampler is constructed with two collectors facing in opposite directions and is mounted approximately 15 cm above the ground surface. The samplers should be oriented so that one collector faces the predominant southeast wind direction from a position downwind of the Clean Slate contamination sites. This physical setup and orientation will allow the collection of samples to determine the net movement of soil material from the Clean Slate sites. The initial samples from these collectors will be retrieved in late CY2014 or in CY2015. The DRI, in conjunction with other DOE contractors, will develop a procedure for collection, handling, and radiological analyses of the samples. Information collected will help us determine if contaminated material reaches the monitoring fence line and the amount of net soil migration across the site boundary over time. These samples will aid in assessing the transport of radionuclide-contaminated soil particles that do not get resuspended.

3. It would be advisable to perform a size analysis of a representative sample of the soil material on the surface at each of the monitoring stations. This would facilitate characterization of the amount of PM_{10} and saltation material available at each site. This information would in turn aid in the interpretation of the saltation and dust transport observations.

4. Because of the difficulty establishing background conditions for the airborne particulate samples and the PIC gamma data, it would be desirable to establish an additional monitoring/sample collection station in a nearby location that is not downwind of the Clean Slate contamination sites. Such a site would provide control samples presumably from a clean area against which measurements at the contamination areas could be compared.

5. One of the difficulties in evaluating the transport of contaminated soil particles from the Clean Slate sites is determining the near-source and far-source dust. Smaller soil particulates remain airborne over greater distances than larger particles. The ratio of PM_{10} to $PM_{2.5}$ in desert environments is generally between 7 and 10. However, in a dust plume that has traveled a few miles, the ratio is likely to be lower (in the range of 5 to 6). Likely the PM_{10} and $PM_{2.5}$ concentrations can be extracted from the dust particle size distribution data reported by the MetOne™ sensor. It is recommended that the analysis comparing PM_{10} to $PM_{2.5}$ be performed as an indication of the proximity of dust sources detected at the TTR monitoring stations.

REFERENCES

Dick, J.L., J.D. Shreve, and J.S. Iveson, 1963. Operation Roller Coaster, Interim Summary Report (II). POIR-2500 (Volume 1) Defense Atomic Support Agency predecessor to Defense Threat Reduction Agency, Washington, D.C.

Duncan, D., W. Forston, and R. Sanchez, 2000. 1999 Annual Site Environmental Report Tonopah Test Range, Nevada. SAND2000-2229, Sandia National Laboratories, Albuquerque, NM.

EG&G, 1979. An Aerial Radiological Survey of Clean Slates 1, 2, and 3, and Double Track, Test Range. EGG-1183-1737, Energy Measurement Group, EG&G, Las Vegas, NV.

Engelbrecht, J.P., I.G. Kavouras, D. Campbell, S.A. Campbell, S. Kohl, D. Shafer, 2008. Yucca Mountain Environmental Monitoring System Initiative, Air Quality Scoping Study for Tonopah Airport, Nye County, Nevada, Letter Report DOE/NV/26383-LTR2008-04.

Johnson, W.G. and S.R. Edwards, 1996. A historical evaluation of Operation Roller Coaster, Stonewall and Cactus Flats, Nellis Air Force Range and Tonopah Test Range, Nye County, Nevada. NTS Project #9649MA, Historic Evaluation Short Report #SR090996-1, prepared by Desert Research Institute for U.S. Department of Energy, Nevada Operations Office, Las Vegas, Nevada.

NRC, 1979. Regulatory Guide 8.12 Health physics surveys for byproduct material at NRC-licensed processing and manufacturing plants, subsection 1.12 Calibration of radiation safety instruments. U.S. Nuclear Regulatory Commission, Office of Standards Development, Washington, D.C.

NSTec, 2013. Nevada National Security Site Environmental Report 2012. DOE/NV/25946-1856, prepared by National Security Technologies, LLC for the US Department of Energy, National Nuclear Security Administration, Nevada Site Office.

Proctor, A.E. and T.J. Hendricks, 1995. An aerial radiological survey of the Tonopah Test Range including Clean Slate 1, 2, 3, Roller Coaster, Decontamination area Cactus Springs Ranch Target areas Central Nevada. EGG 11265-1145, The Remote Sensing Laboratory, EG&G Energy Measurements prepared for the US Department of Energy.

SNL, 2012. Calendar Year 2011 Annual Site Environmental Report for Tonopah Test Range, Nevada and Kauai Test Facility, Hawaii. SAND2012-7341P, Sandia National laboratories, Albuquerque, NM.

UNSCEAR, 2000. Sources and effects of ionizing radiation, Annex B: Exposures from natural radiation sources. United Nations Scientific Committee on the Effects of atomic Radiation. Available May 6, 2013 at: http://www.unscear.org/unscear/publications/2000_1.html.

APPENDIX A: DESCRIPTIONS OF OBSERVED INTERVALS OF INCREASED GAMMA VALUES

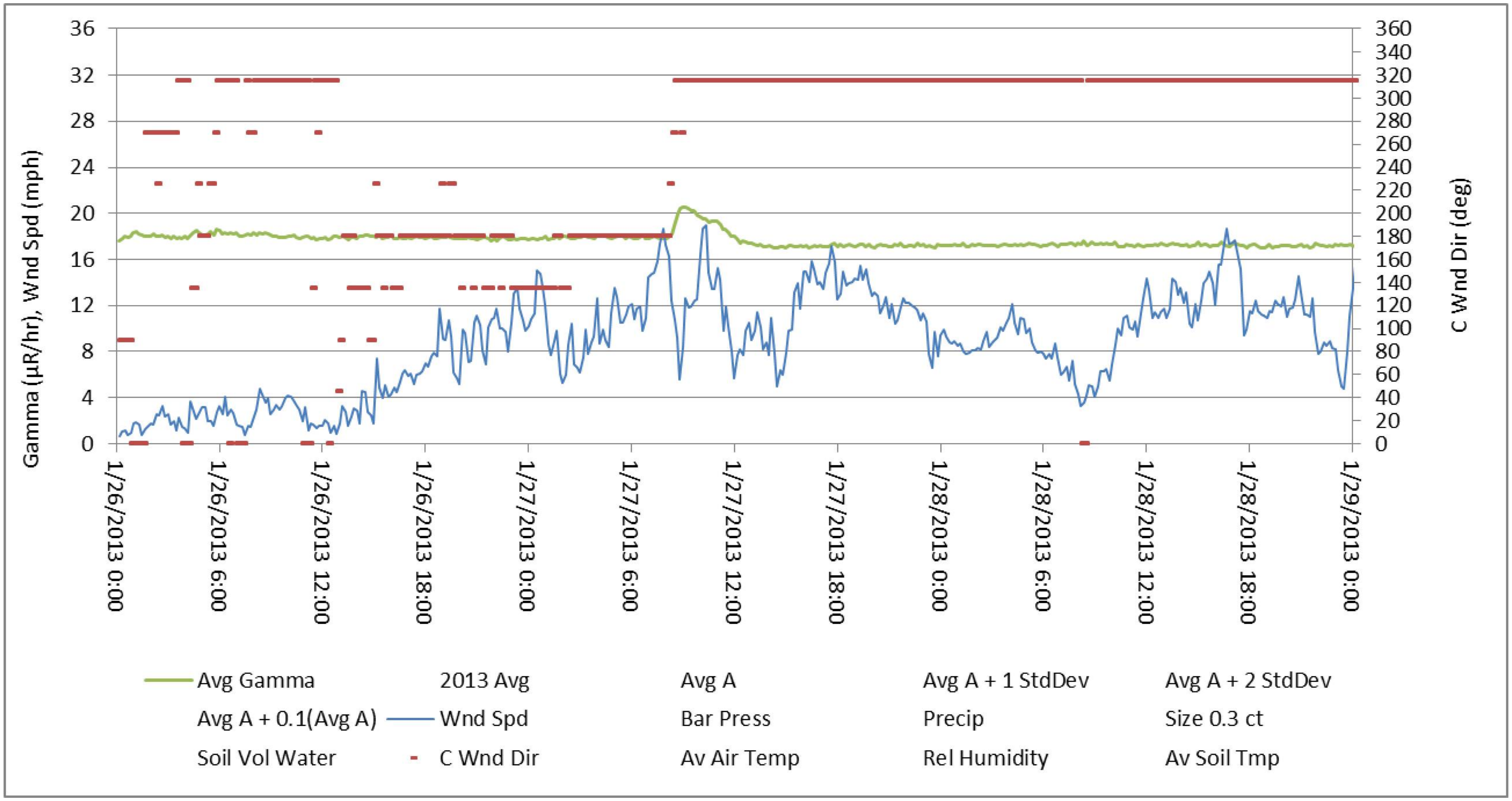

Figure A-1. Gamma, meteorological, and soil parameters observed during the period of increased gamma values recorded at TTR monitoring station 400 on January 27, 2013, showing the wind speed and direction.

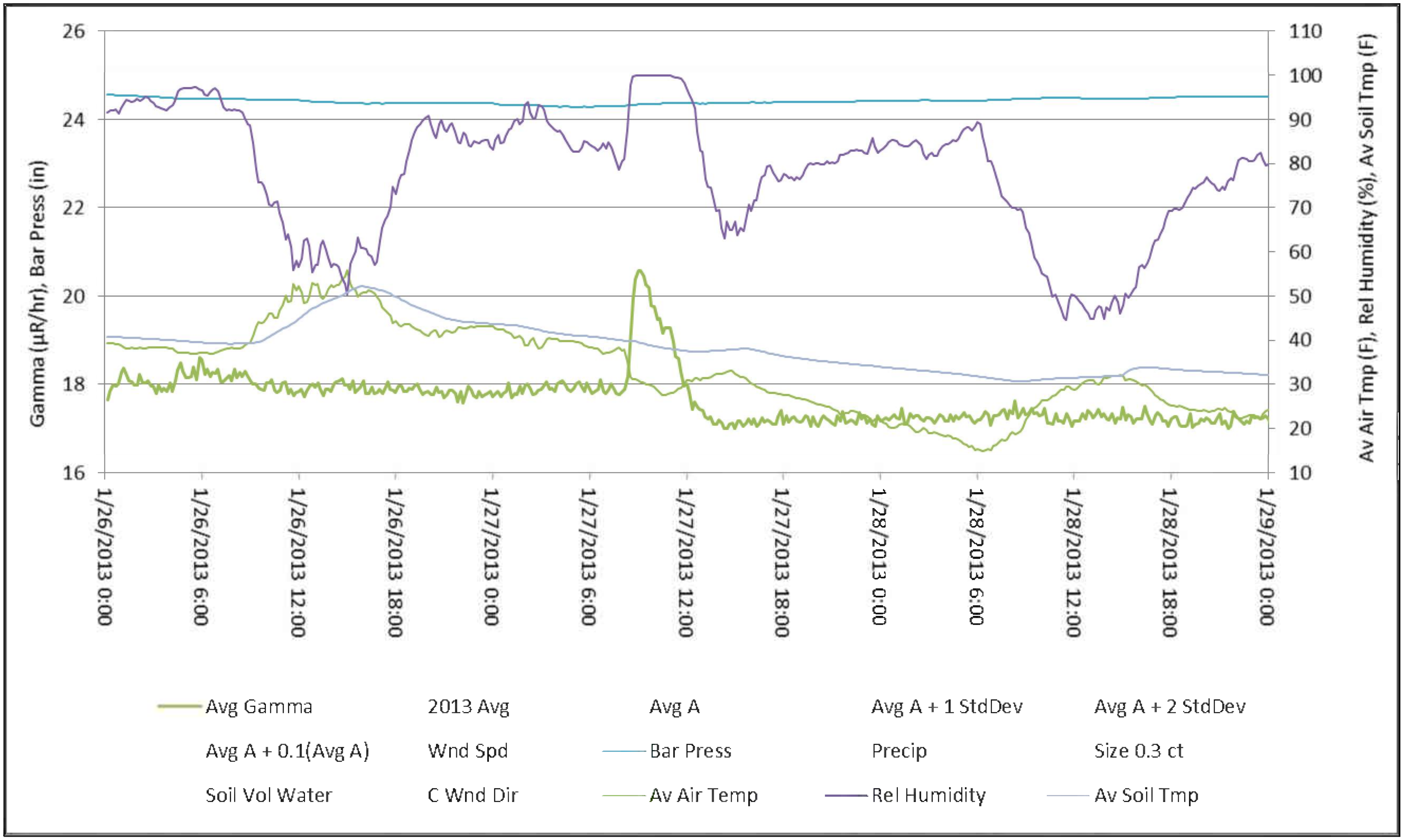

Figure A-2. Gamma, meteorological, and soil parameters observed during the period of increased gamma values recorded at TTR monitoring station 400 on January 27, 2013, showing the barometric pressure, air and soil temperature, and relative humidity.

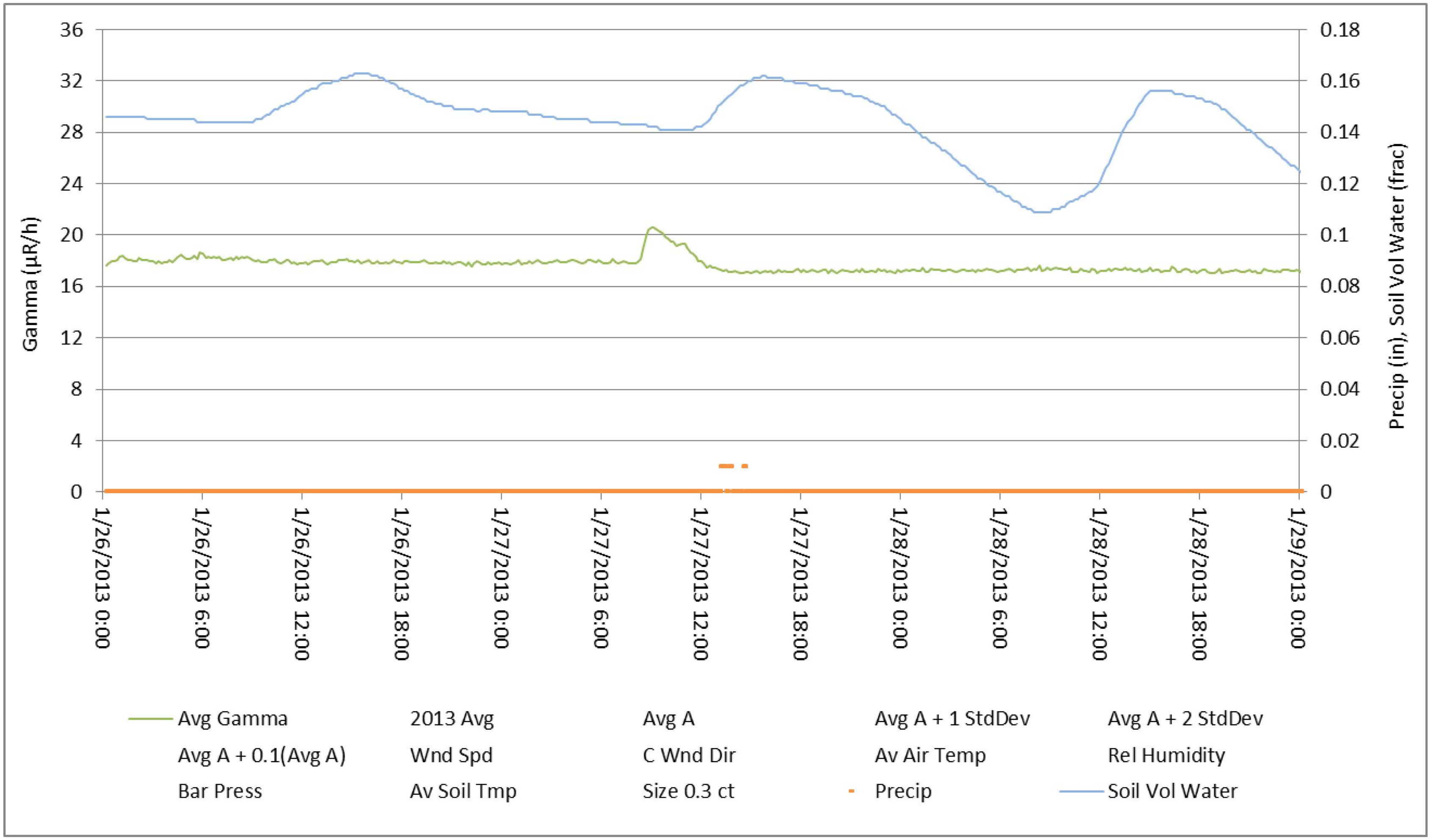

Figure A-3. Gamma, meteorological, and soil parameters observed during the period of increased gamma values recorded at TTR monitoring station 400 on January 27,2013, showing the precipitation and soil water content.

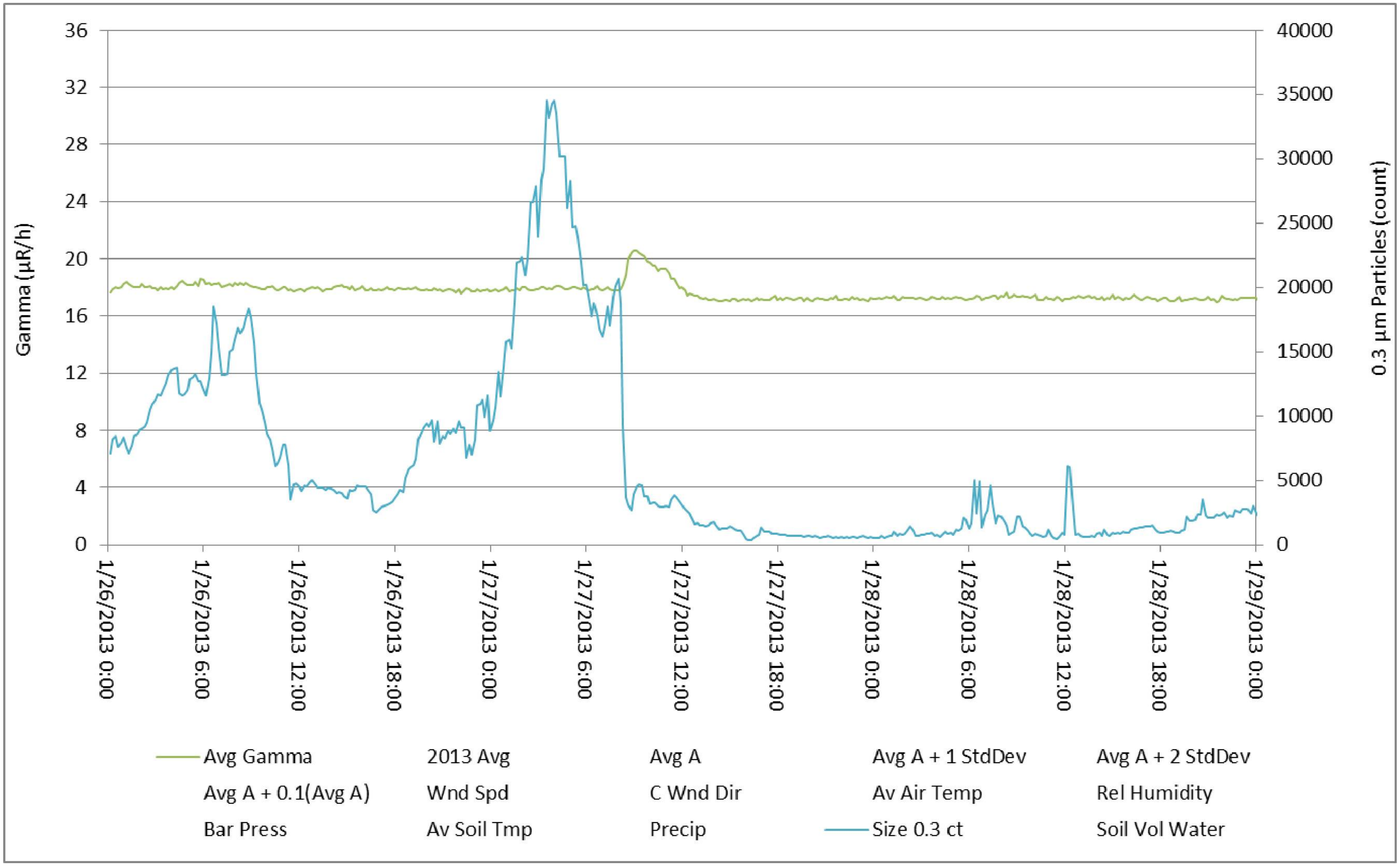

Figure A-4. Gamma, meteorological, and soil parameters observed during the period of increased gamma values recorded at TTR monitoring station 400 on January 27,2013, showing the suspended dust counts.

Table A-1. Monitoring parameters observed during the increase in gamma values at Station 400, January 27, 2013.

Parameter	Description
Avg Gamma	Pre-event minimum: 17.89 at 0730 (+ 10% = 19.68) Event maximum: 20.39 at 0850 (-10% = 18.35) Post-event minimum: 17.09 at 1350 <u>By virtue of the resolution (+/- 10%) of values reported by the PIC instruments, the reported pre-event minimum and event maximum values could represent the same level.</u> The overlap between the highest value represented by the reported pre-event minimum and the lowest value represented by the reported event maximum is 53% of the difference between the reported pre-event minimum and event maximum values.
Wnd Spd	Wind speed was generally increasing from about 2 mph at 1200 on 1/26/2013 to 18.68 mph at 0750 on 1/27/2013 as the high gamma event began. Wind speed dropped to about 5.63 mph at the time of the maximum reported gamma value and then fluctuated through the period of decline of the interval of increased gamma values.
C Wnd Dir	Cardinal wind direction was generally from the southeast and south during the 12 to 16 hours preceding the reported gamma value increase. During the rising limb of the gamma value the cardinal wind direction shifted from the south to the northwest during the hour over which the gamma value reached the maximum value. The winds continued to be from the northwest during the falling limb of the gamma event and throughout the remainder of 1/27/2013 and all of 1/28/2013.
Av Air Temp	Average air temperature declined from the afternoon high of about 54 °F on 1/26/2013 to 38° immediately preceding the gamma rise. The rise in reported gamma values was accompanied with a six degree drop in air temperature. Air temperature continued to fall to a minimum of 29 °F at about 1010 hours. It recovered to an afternoon high of 32 °F after the reported gamma values had fallen to below the pre-event minimum.
Rel Humidity	Relative humidity fluctuated between 80% and 90% during the 14 hours preceding the reported gamma increase. Almost coincidentally with the gamma increase, the humidity increased to almost 100 %. As the declining gamma value reached almost the halfway, the relative humidity began to decline sharply from approximately 100 % to about 65 %.
Bar Press	Barometric pressure was in a slight decline from 24.56 to 24.29 during the 32 hours prior to the increased gamma values. At about the time the gamma values began to increase, the barometric pressure began to increase and the increase continued throughout the following 40 hours.
Av Soil Tmp	Average soil temperature exhibited a subdued pattern that paralleled the average air temperature. It showed the highest values in the late afternoon, but was generally declining throughout the time surrounding the gamma increase.
Size 0.3 ct	The count of small dust particulates in the air began to increase about 15 hours before and reached a maximum about 4 hours before the increase in reported gamma values. The dust count dropped dramatically at about the same time the gamma values began to increase.
Precip	Approximately 0.3 in of precipitation fell after the gamma values had declined to levels below the pre-event minimum. The observed precipitation was measured during the afternoon high temperature on 1/27/2013 and may reflect the snowfall melt that had occurred at an unspecified earlier time.
Soil Vol Water	The soil water volume fraction exhibits a generally diurnal pattern similar to the air and soil temperature. However, there was a relatively steep increase in soil water volume that coincided with the measured precipitation.
Summary	* The overlap of the resolution range of the pre-event minimum and event-maximum gamma values suggests that the minimum and maximum values may not be distinguishable. * It appears that the increased wind speeds from the south and southeast increased the dust in the air prior to the reported increase in the gamma values. The sharp drop in air temperature that occurred as the gamma values increased likely was accompanied by snow that cleared the dust from the air but was not reported as precipitation by the tipping-bucket gage until the temperatures again rose above freezing during the afternoon after the gamma event had receded.

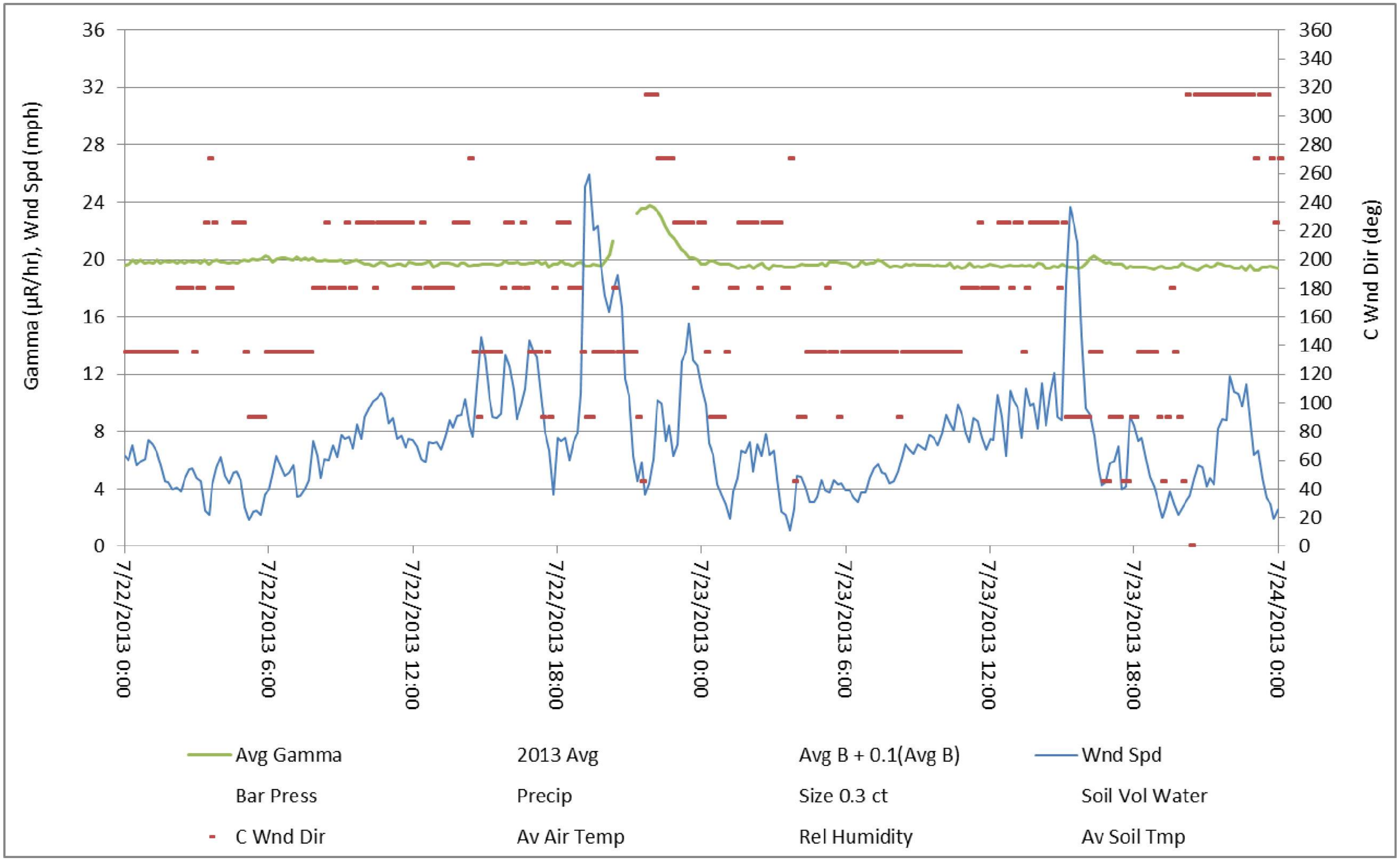

Figure A-5. Gamma, meteorological, and soil parameters observed during the period of increased gamma values recorded at TTR monitoring station 400 on July 22, 2013, showing the wind speed and direction.

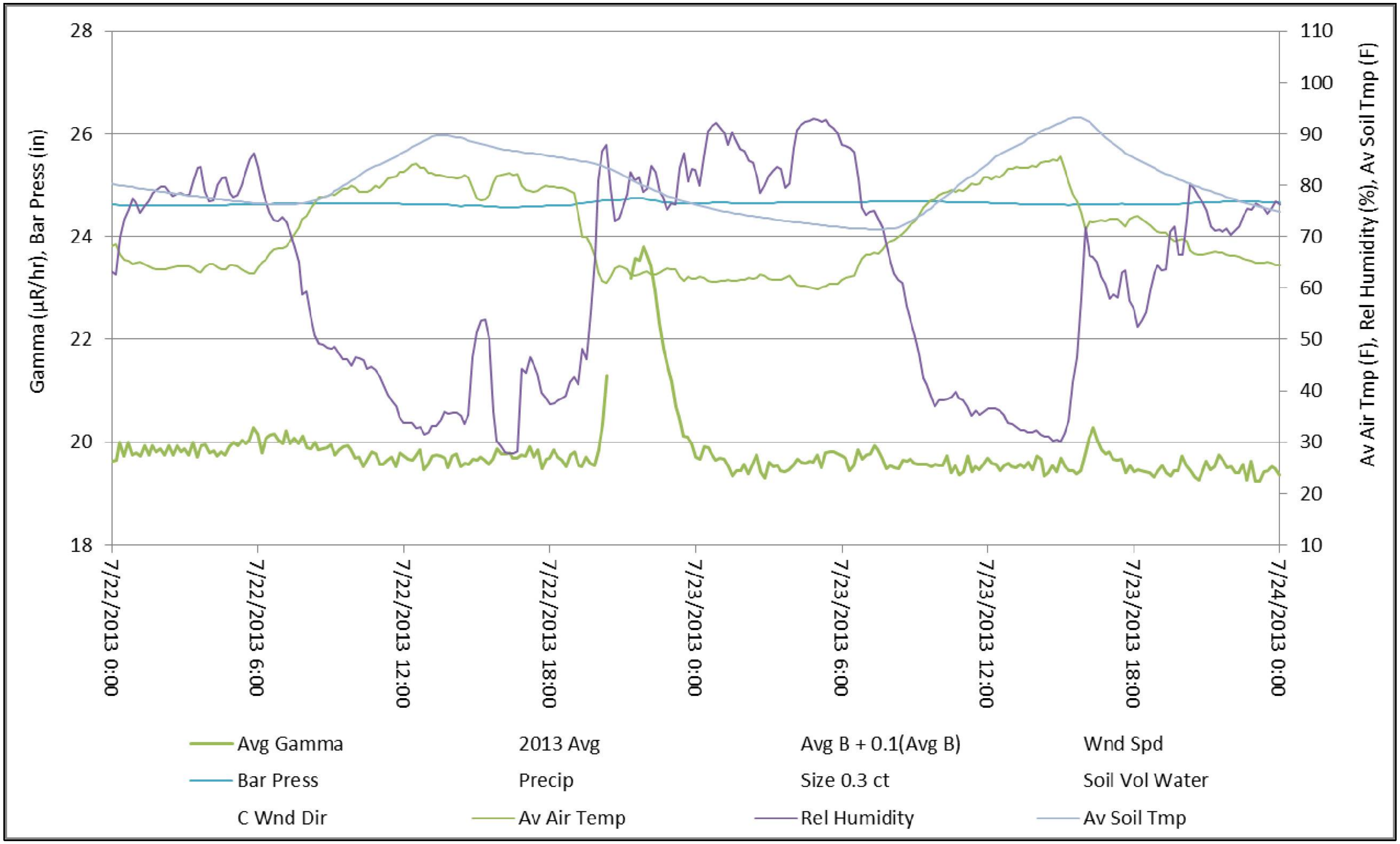

Figure A-6. Gamma, meteorological, and soil parameters observed during the period of increased gamma values recorded at TTR monitoring station 400 on July 22, 2013, showing the barometric pressure, air and soil temperature, and relative humidity.

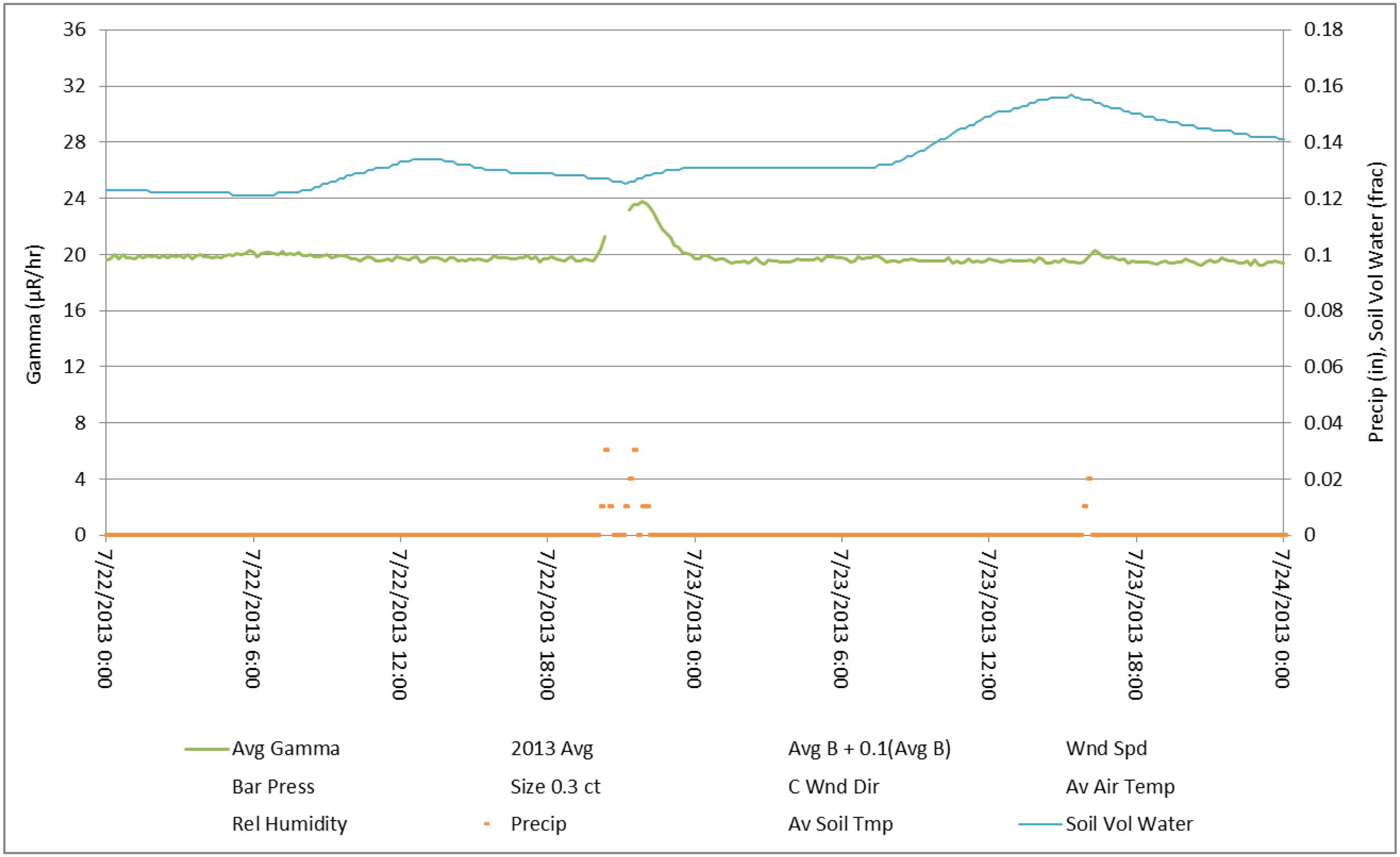

Figure A-7. Gamma, meteorological, and soil parameters observed during the period of increased gamma values recorded at TTR monitoring station 400 on July 22, 2013, showing the precipitation and soil water content.

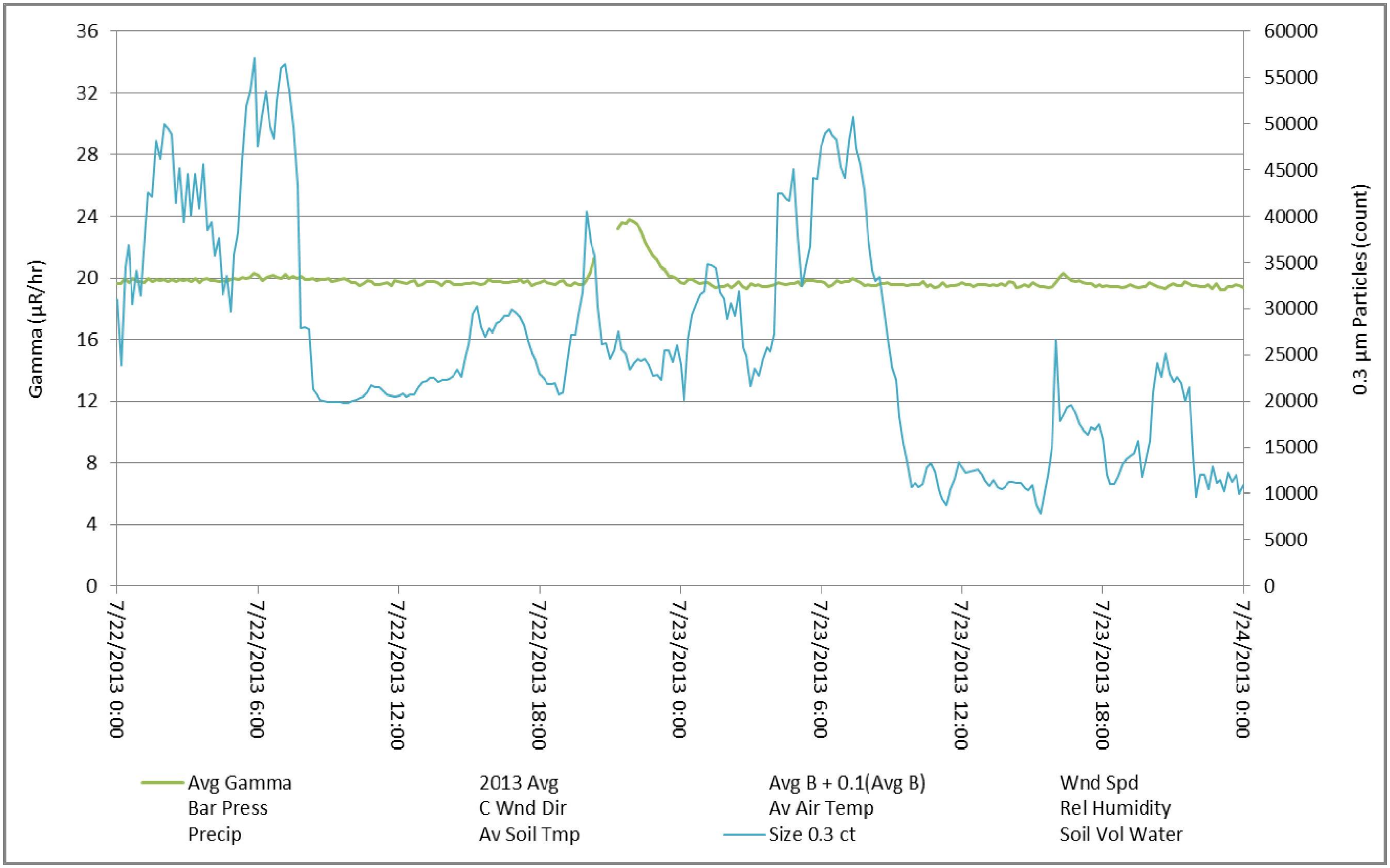

Figure A-8. Gamma, meteorological, and soil parameters observed during the period of increased gamma values recorded at TTR monitoring station 400 on July 22, 2013, showing the suspended dust counts.

Table A-2. Description of observed monitoring parameters during the increase in the gamma values reported for Station 400 on July 22, 2013.

Parameter	Description
Avg Gamma	Pre-event minimum: 19.61 at 1950 (+ 10% = 21.57) Event maximum: 23.81 at 2150 (-10% = 21.43) Post-event minimum: 19.43 at 0240 By virtue of the resolution (+/- 10%) of values reported by the PIC instruments, the reported pre-event minimum and event maximum values could represent the same level. The overlap between the highest value represented by the reported pre-event minimum and the lowest value represented by the reported event maximum is 3% of the difference between the reported pre-event minimum and event maximum values.
Wnd Spd	Wind speed began to increase slowly at about 0500 on 7/22/2013. At 1700, wind speed dropped from about 15 mph to 4 mph. Between 1830 and 1920 it increased from about 6 mph to 26 mph. The peak wind speed occurred prior to the beginning of the increasing gamma values. Wind speed declined to a minimum, approximately 4 mph, at about the same time the peak gamma values were reported. The wind speed again increased during the falling limb of the gamma peak.
C Wnd Dir	Wind direction prior to and following the interval of increased gamma values was quite variable. Immediately preceding the increase in gamma, winds were from southeast to southwest. They were more southerly and southeasterly during the rising limb of the increased gamma values, westerly to northwesterly during the peak gamma values, and southwesterly during the falling limb of the interval of increased gamma values. They then varied between easterly and southwesterly following the gamma increase.
Av Air Temp	Minimums in daily air temperature generally occurred around dawn (0500) and maximum daily temperatures occurred in the early to mid-afternoon (between 1200 and 1500). Air temperature declined from about 80 °F to 63 °F during the evening of 7/22/2013. Throughout the night, the temperature continued to decline to about 60° at 0430. There was little change in air temperature during the time period of the increased gamma value.
Rel Humidity	Relative humidity increased from a low value of 28 % at 1620 to 87 % at 2010. Humidity remained in the range of 73 % to 86 % during the increased gamma values and throughout the early morning hours of 7/23/2013.
Bar Press	A slight increase in barometric pressure from approximately 24 to 25 was coincident with the increased gamma values.
Av Soil Tmp	Average soil temperature is a subdued reflection of the air temperature, even though it tends to retain more heat than the air temperature. Soil temperature was declining throughout the period of the increased gamma values.
Size 0.3 ct	From 0900 on 7/22/2013 until 0700 on 7/23/2013 dust in the air was generally increasing though the detailed pattern was quite irregular with dust counts ranging from 20,000 to 50,000. A peak in dust counts was coincident with the beginning of the increased gamma values but was short lived. Throughout most of the increased gamma values, the dust counts were below 25,000.
Precip	Approximately 0.13 in of precipitation was reported during the 2 hour period of the rising limb and peak of the increased gamma values.
Soil Vol Water	Diurnal fluctuations in the average soil water fraction were interrupted by precipitation. The soil water fraction increased from 0.126 to 0.13 following the precipitation.
Summary	*There is a small (3%) overlap of the resolution ranges for the pre-event minimum and event maximum gamma values. It seems unlikely that the pre-event minimum and the event maximum represent the same levels of gamma. *Dust counts in the air increased in association with the stronger winds that preceded the increased gamma values. Precipitation that followed these winds appears to have washed much of the dust from the air. It appears that the dust washed from the atmosphere by the precipitation may be the cause of the increased gamma. However, the dust suspended in the air did not affect the gamma values until it was washed out by the precipitation.

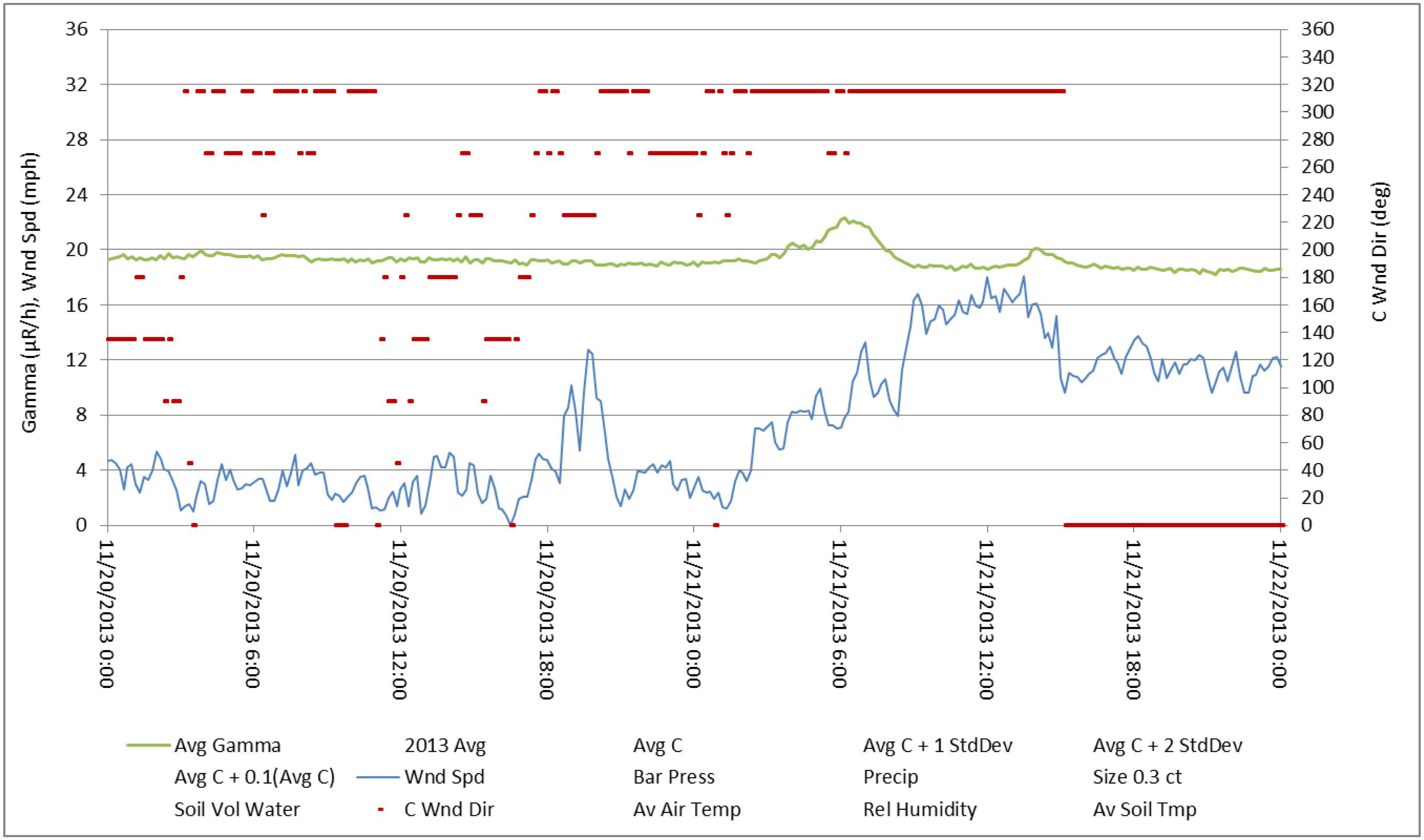

Figure A-9. Gamma, meteorological, and soil parameters observed during the period of increased gamma values recorded at TTR monitoring station 400 on November 21, 2013, showing the wind speed and direction.

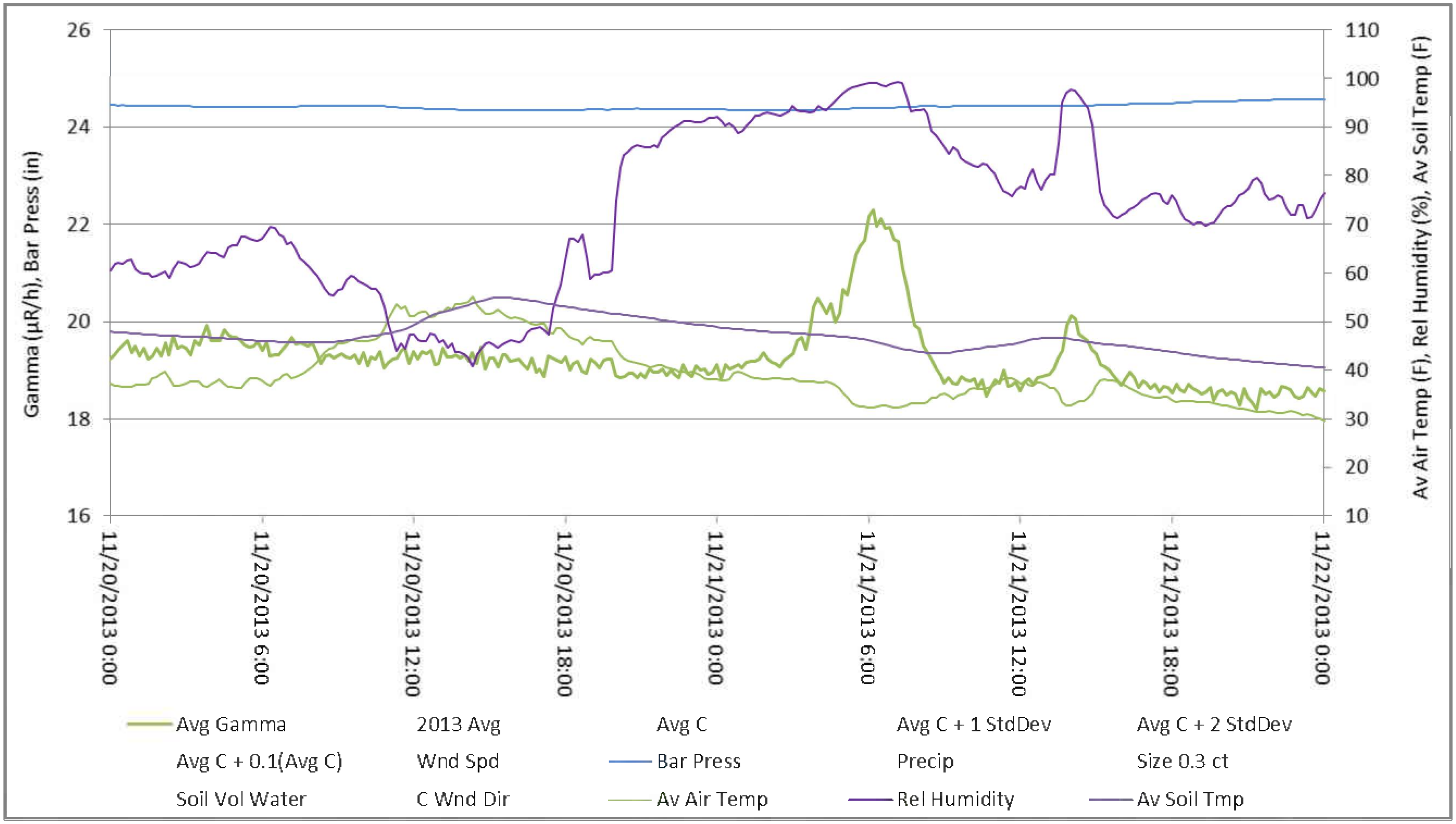

Figure A-10. Gamma, meteorological, and soil parameters observed during the period of increased gamma values recorded at TTR monitoring station 400 on November 21, 2013, showing the barometric pressure, air and soil temperature, and relative humidity.

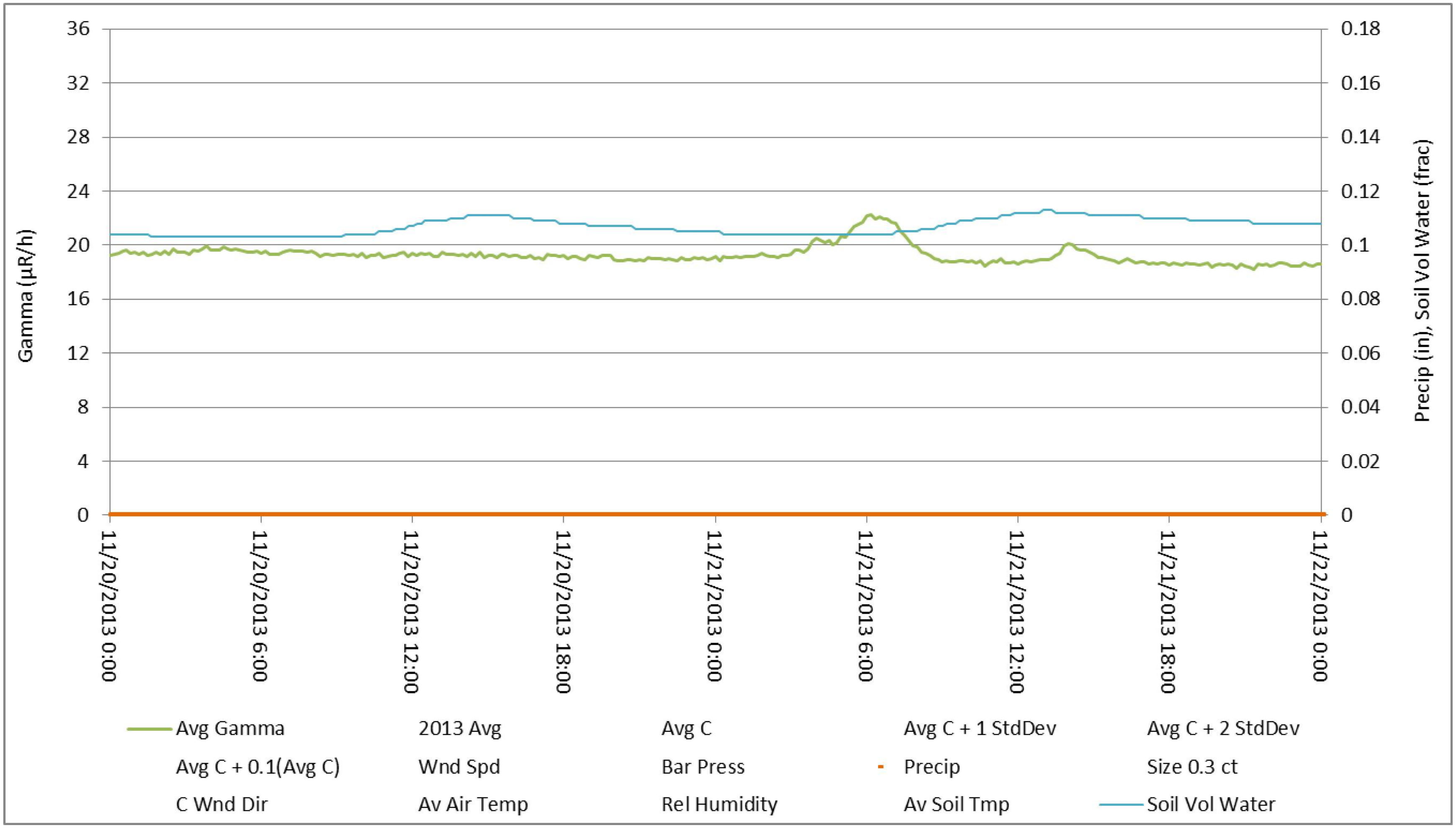

Figure A-11. Gamma, meteorological, and soil parameters observed during the period of increased gamma values recorded at TTR monitoring station 400 on November 21, 2013, showing the precipitation and soil water content.

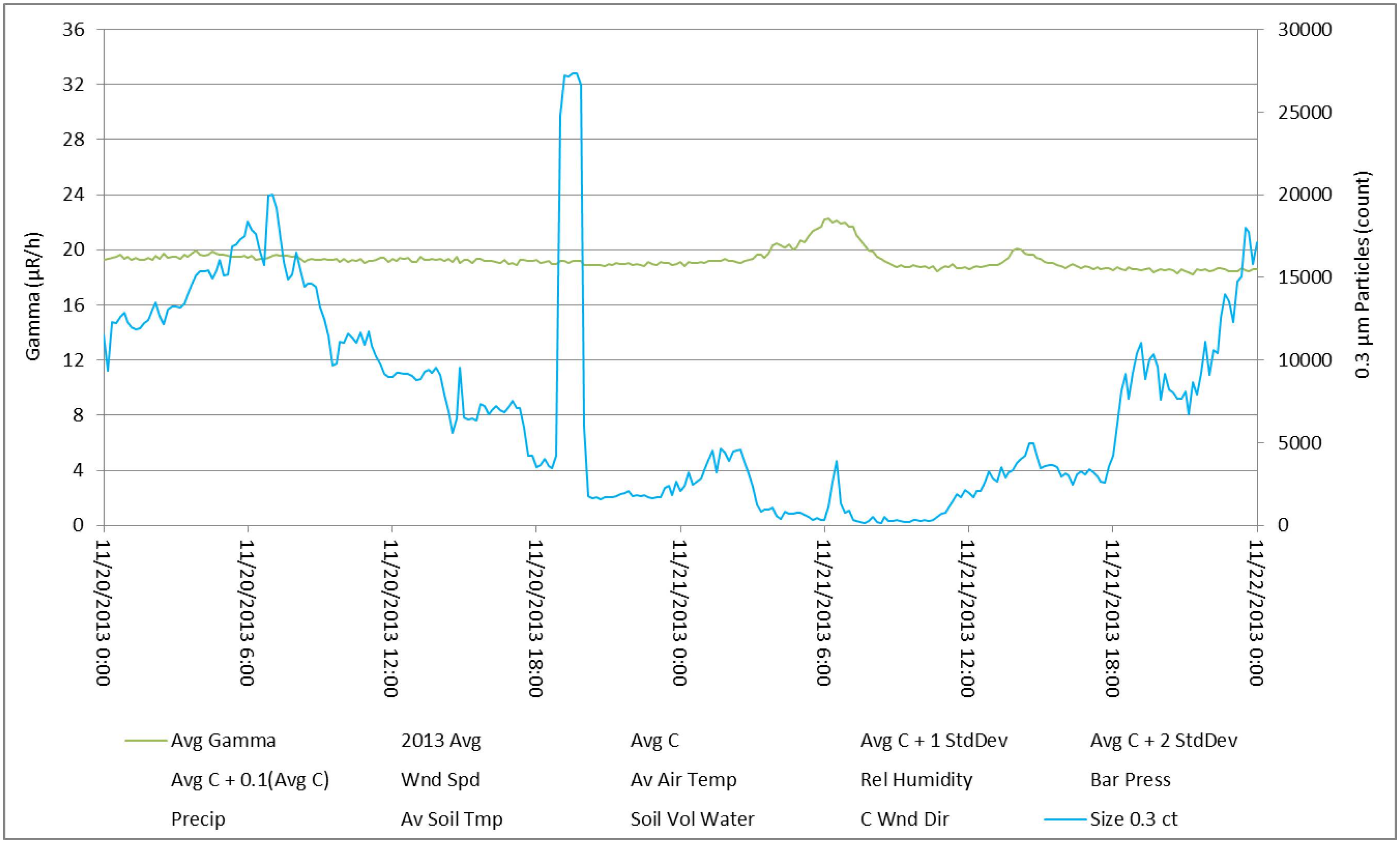

Figure A-12. Gamma, meteorological, and soil parameters observed during the period of increased gamma values recorded at TTR monitoring station 400 on November 21, 2013, showing the suspended dust counts.

Table A-3. Description of observed monitoring parameters during the increase in the gamma values reported for Station 400 on November 21, 2013.

Parameter	Description
Avg Gamma	Pre-event minimum: 18.89 at 2000 11/20/2013 (+ 10% = 20.78) Event maximum: 22.17 at 0600 11/21/2013 (-10% = 19.95) Post-event minimum: 18.48 at 1040 11/21/2013 <u>By virtue of the resolution (+/- 10%) of values reported by the PIC instruments, the reported pre-event minimum and event maximum values could represent the same level.</u> The overlap between the highest value represented by the reported pre-event minimum and the lowest value represented by the reported event maximum is 25% of the difference between the reported pre-event minimum and event maximum values. *A secondary blip in the gamma observations peaked at 1350 on 11/21/2013. Pre-event minimum: 18.59 at 1200 11/21/2013 (+ 10% = 20.45) Event maximum: 20.13 at 1350 11/21/2013 (-10% = 18.12) Post-event minimum: 18.70 at 1600 11/21/2013 <u>By virtue of the resolution (+/- 10%) of values reported by the PIC instruments, the reported pre-event minimum and event maximum values are indistinguishable.</u> The overlap between the highest value represented by the reported pre-event minimum and the lowest value represented by the reported event maximum is 100% of the difference between the reported pre-event minimum and event maximum values.
Wnd Spd	Although there was some variability, the wind speed was generally increasing from about 1.3 mph at 0110 11/21/2013 until 1200 11/21/2013 when it reached a maximum of about 18 mph. A temporary peak wind speed of 12.6 mph occurred about 50 minutes after the peak gamma value was recorded. During the 6 hours following the gamma pulse, the wind speed remained near 16 mph but there was no clear bump in the gamma readings during this period. An earlier peak in wind speed reached 12.7 mph at 1940 on 11/20/2013 but did not produce an increase in the observed gamma values.
C Wnd Dir	Winds began to shift at about 1840 on 11/20/2013 and remained out of the west and northwest throughout the period of increased gamma values.
Av Air Temp	Average air temperature was exhibiting a declining trend throughout the increase in gamma values. The rate of decline increased sharply at about the mid-point of the rising limb of the increased gamma values. A second sharp dip in the average air temperature was coincident with the secondary peak in observed gamma values.
Rel Humidity	Relative humidity increased sharply between 1400 and 2030 on 11/20/2013. It continued to increase, though more slowly, until 0700 on 11/21/2013. The relative humidity peaked at near 99% during the time of the peak in gamma observations. A secondary humidity peak, which reached about 97 %, was coincident with the secondary peak in gamma observations.
Bar Press	Barometric pressure exhibited a slow increasing trend throughout the evening of 11/20/2013 and throughout the day of 11/21/2013.
Av Soil Tmp	Average soil temperature declined continuously through the first peak in the gamma. It rose slightly in the hours before the secondary peak, and then continued to decline.
Size 0.3 ct	0.3 µm dust particle counts spiked at 27,500 at about 1930 on 11/20/2013. Two smaller increases in dust counts occurred as the rising limb of the gamma readings began to rise and again just before the falling limb began to show sharp decline.
Precip	No precipitation was recorded on 11/20/2013 and 11/21/2013.
Soil Vol Water	Fractional soil water content peaked in the early afternoon in an apparent diurnal cycle. Following the afternoon peaks on 11/20/20143 and 11/21/2013, the soil water content was a little higher than on the previous overnight period.
Summary	* The overlap of the resolution range of the pre-event minimum and event-maximum gamma values suggests that the minimum and maximum values may not be distinguishable. Relatively minor winds preceding and during the increased gamma observations appear to have caused short lived spikes in the observed dust counts. Although the humidity rose to almost 100%, no precipitation that would wash the dust out of the air was recorded.

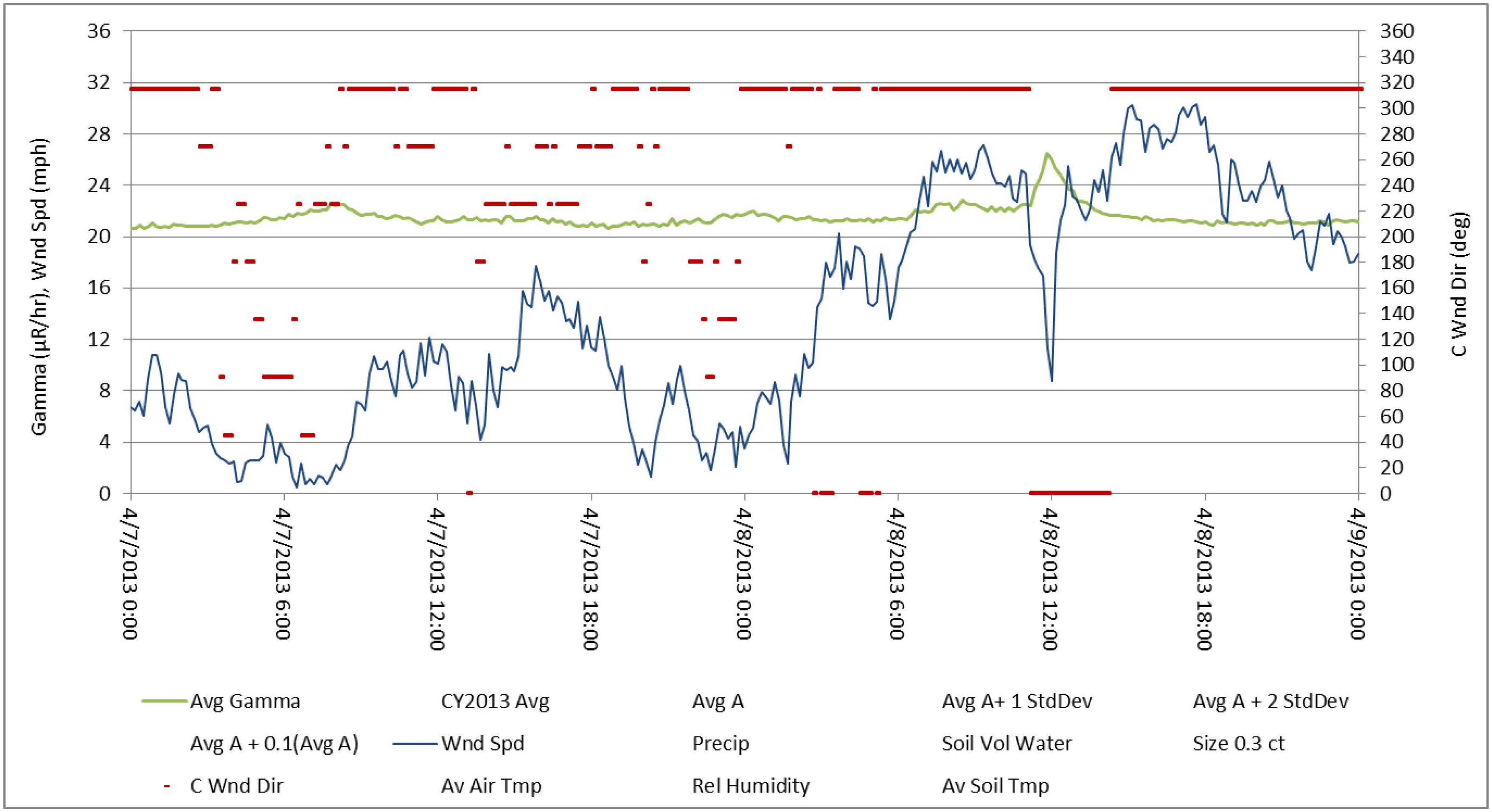

Figure A-13. Gamma, meteorological, and soil parameters observed during the period of increased gamma values recorded at TTR monitoring station 401 on April 8, 2013, showing the wind speed and direction.

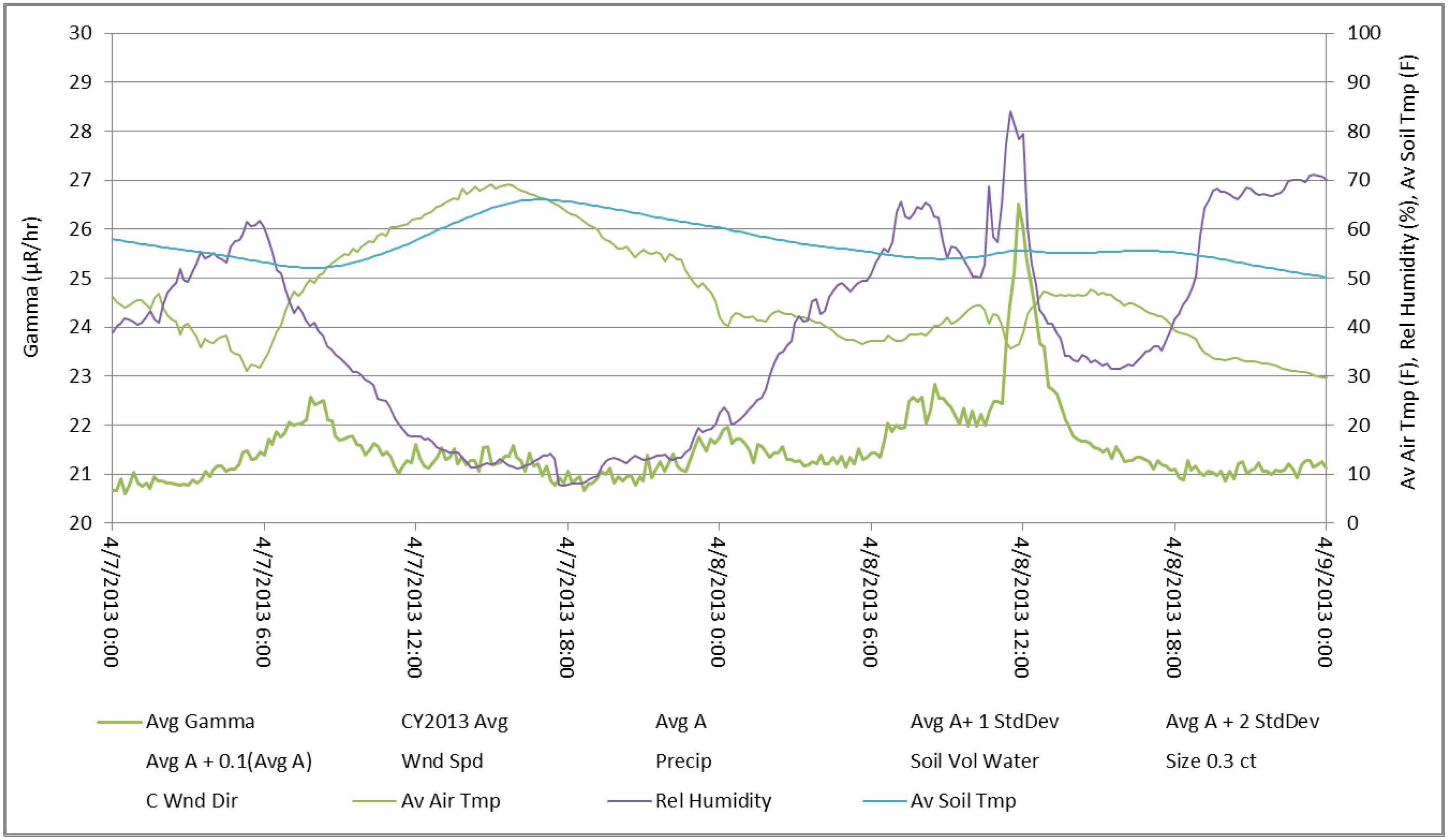

Figure A-14. Gamma, meteorological, and soil parameters observed during the period of increased gamma values recorded at TTR monitoring station 401 on April 8, 2013, showing the air and soil temperature and relative humidity.

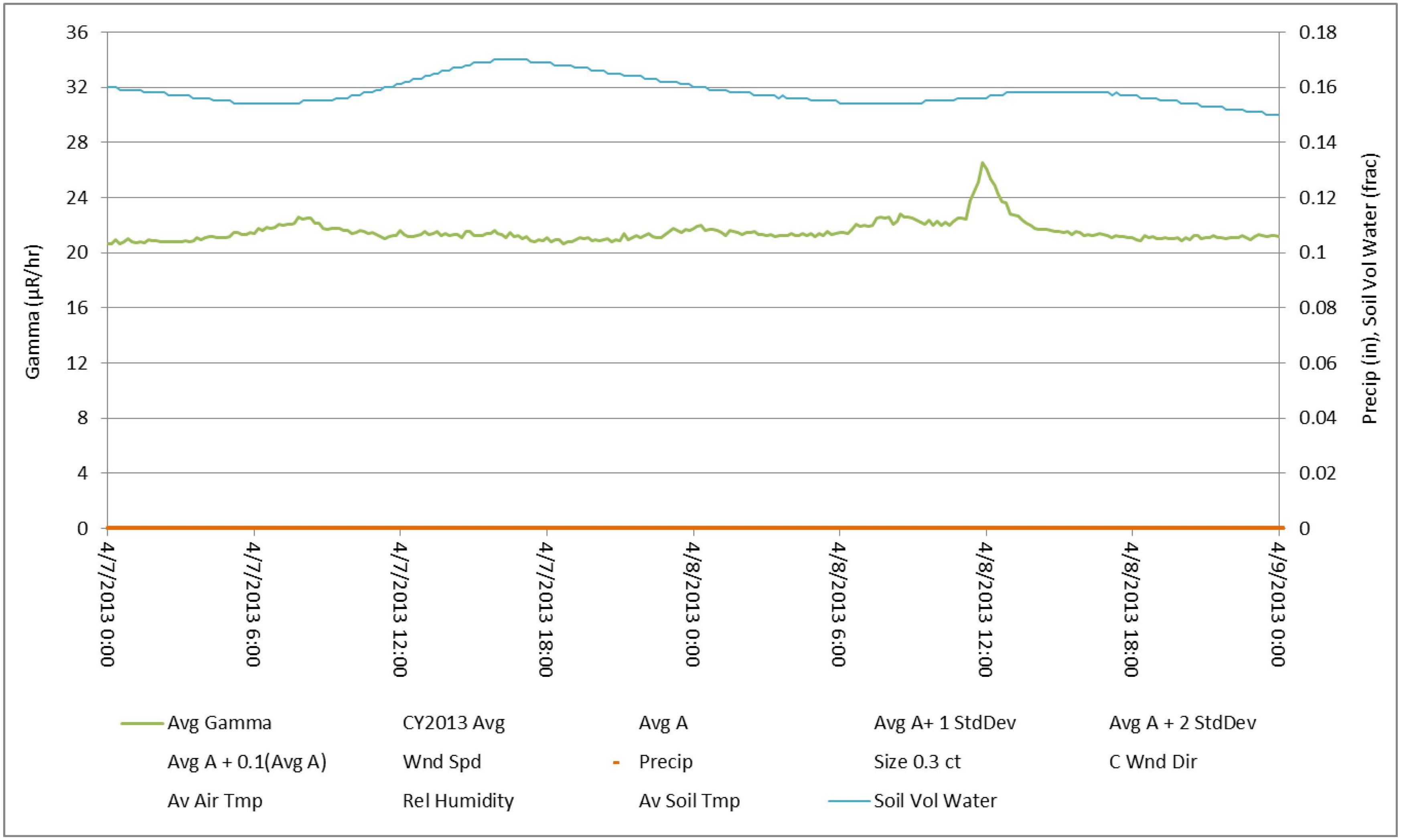

Figure A-15. Gamma, meteorological, and soil parameters observed during the period of increased gamma values recorded at TTR monitoring station 401 on April 8, 2013, showing the precipitation and soil water content.

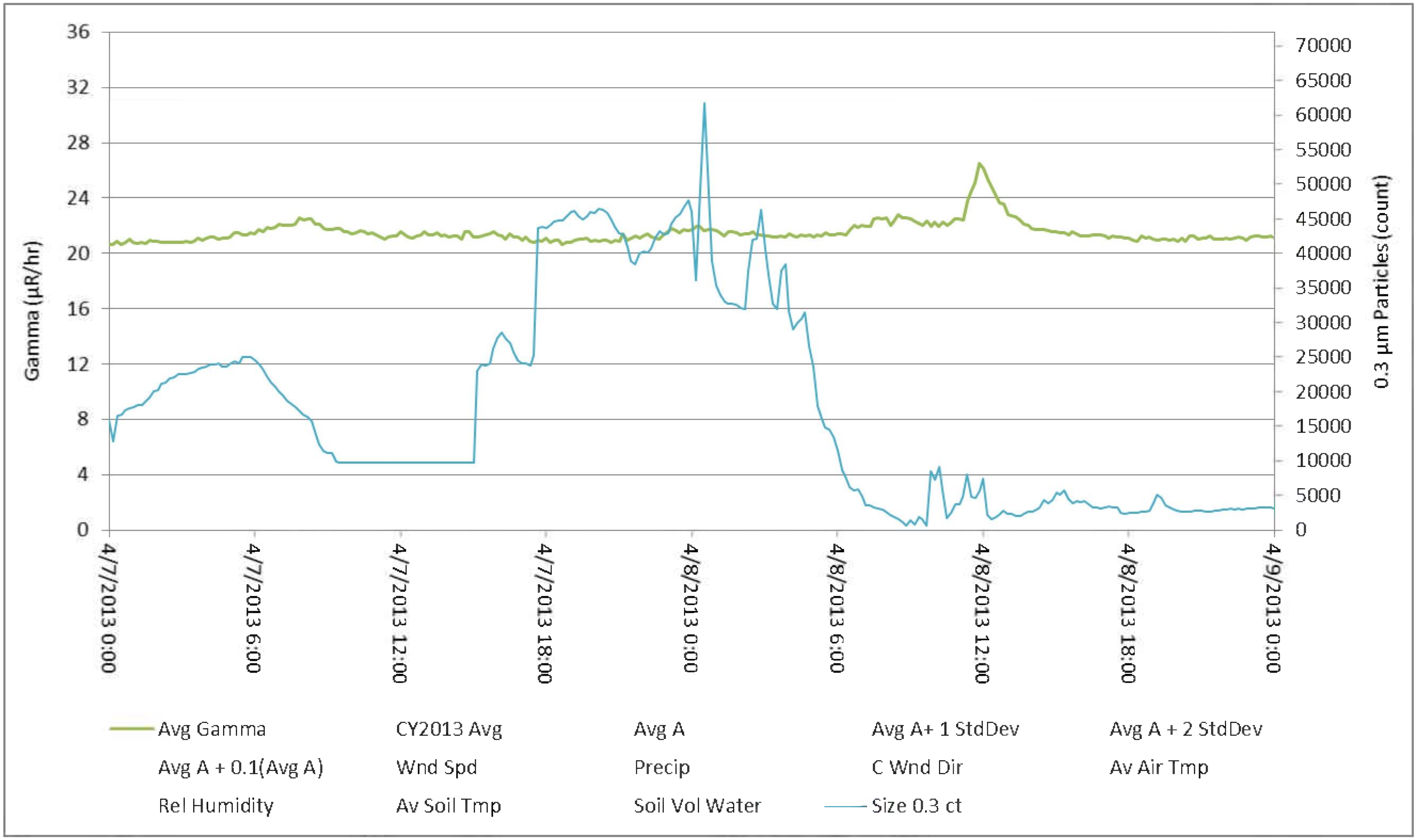

Figure A-16. Gamma, meteorological, and soil parameters observed during the period of increased gamma values recorded at TTR monitoring station 401 on April 8, 2013, showing the suspended dust counts.

Table A-4. Description of observed monitoring parameters during the increase in the gamma values reported for Station 401 on April 8, 2013.

Parameter	Description
Avg Gamma	Pre-event minimum: 20.67 at 1840 4/7/2013 (+ 10% = 22.74) Event maximum: 26.50 at 1150 4/8/2013 (-10% = 23.85) Post-event minimum: 20.94 at 1810 4/8/2013 *By virtue of the resolution (+/- 10%) of values reported by the PIC instruments, the reported pre-event minimum and event maximum values do not represent the same level. There is no overlap between the highest value represented by the reported pre-event minimum and the lowest value represented by the reported event maximum.
Wnd Spd	For the 7 hours prior to the increased gamma values the winds were in the range of 24 mph to 26 mph. In the 2 hours following the increased gamma values, wind speed increased from about 22 mph to near 30 mph, and then it fluctuated between 27 mph and 30 mph for about 4 hours. However, during the increased gamma values the wind speed dropped off to about 9 mph. The minimum wind speed during this period was approximately coincident with the maximum gamma value.
C Wnd Dir	Wind direction was from the northwest before and after the increased gamma values. However, during the period of increased gamma values the winds were from the north.
Av Air Temp	Average air temperature was rising from the early morning minimum (37 $^{\circ}$F at 0510) but began to decline from 43 $^{\circ}$F at 0950 to 37 $^{\circ}$F at 1120 immediately prior to the maximum of the increased gamma values. From this point the temperature increased to about 48 $^{\circ}$F at 1230 and returned to the typical diurnal pattern.
Rel Humidity	The relative humidity increased continuously from a low of about 10 % the previous afternoon to a high of 84 % at 1130, 20 minutes before the maximum gamma increase was reported. The humidity dropped sharply at 1140 and remained in the 30 % to 40 % range throughout the afternoon, climbing again to almost 70 % in the early evening of 4/8/2013.
Bar Press	No barometric pressure data is available from TTR monitoring station 401.
Av Soil Tmp	Average soil temperature exhibits a diurnal pattern that appears to reflect the average air temperature. The soil temperature does not exhibit the same diurnal variation as the air temperature and it appears to lag behind the air temperature.
Size 0.3 ct	The dust counts began to increase in the mid to late afternoon on 4/7/2013 and continued to be elevated until about dawn on 4/8/2013. During this period the dust counts generally ranged between 35,000 and 45,000 with one narrow peak rising to 60,000 counts. By 0830 on 4/8/2013 the dust counts were below 10,000 and remained low through the period of increased gamma values.
Precip	No precipitation was reported during the increased gamma values.
Soil Vol Water	The soil water content appears to have a general diurnal pattern. Conditions that might have critical influence on the soil water content have not been determined. Soil water content was increasing throughout the period of increased gamma values.
Summary	*There is no overlap of the resolution range of the pre-event minimum and event maximum of the increased gamma values. *Significant dust levels were evident overnight prior to the increased gamma values, but, the higher wind speeds immediately before and after the increased gamma values are not associated with increased dust counts. Additionally, even though there were sharp increases in relative humidity coincident with the increased gamma value, there was no precipitation to wash the dust from the air.

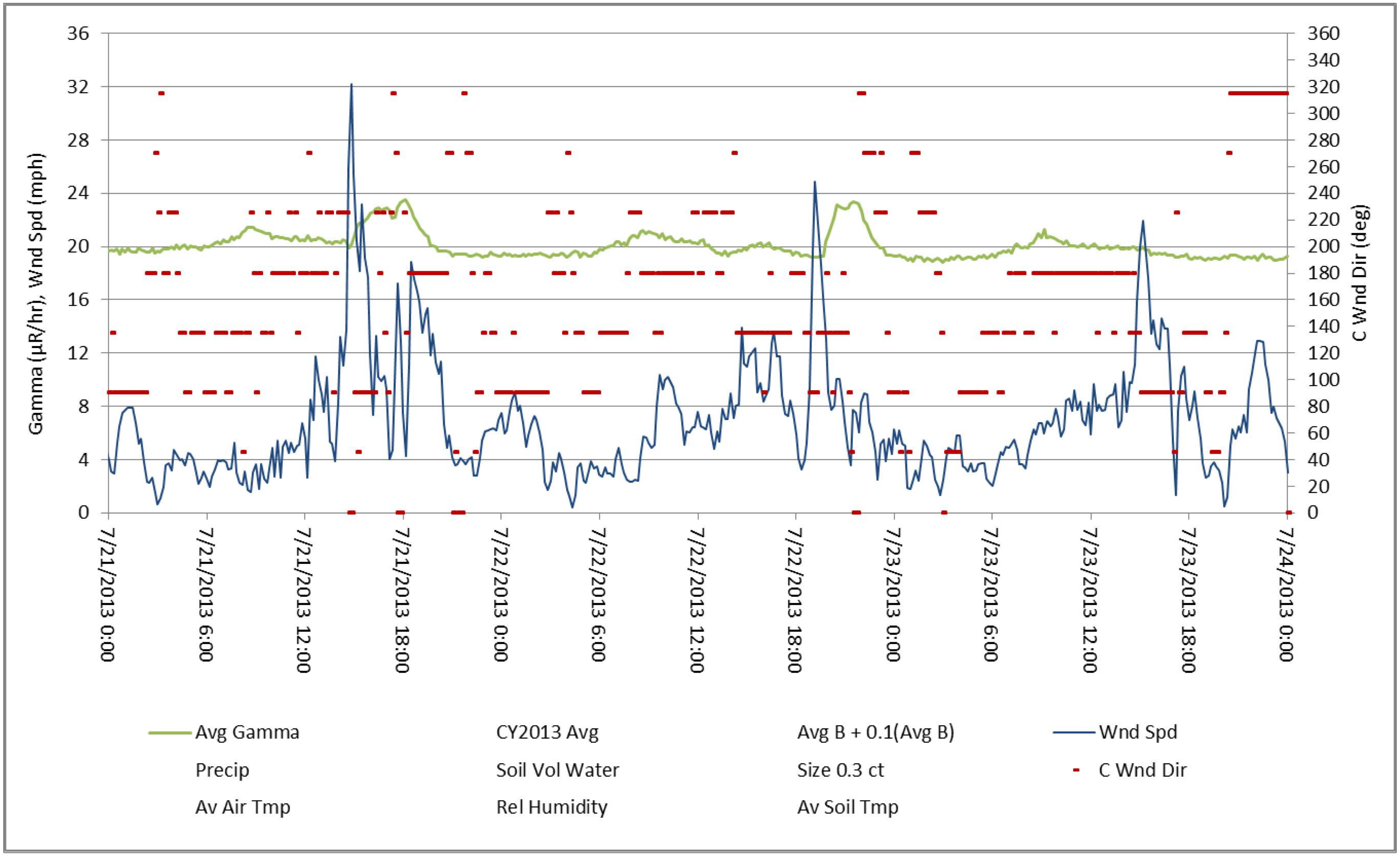

Figure A-17. Gamma, meteorological, and soil parameters observed during the period of increased gamma values recorded at TTR monitoring station 401 on July 22, 2013, showing the wind speed and direction.

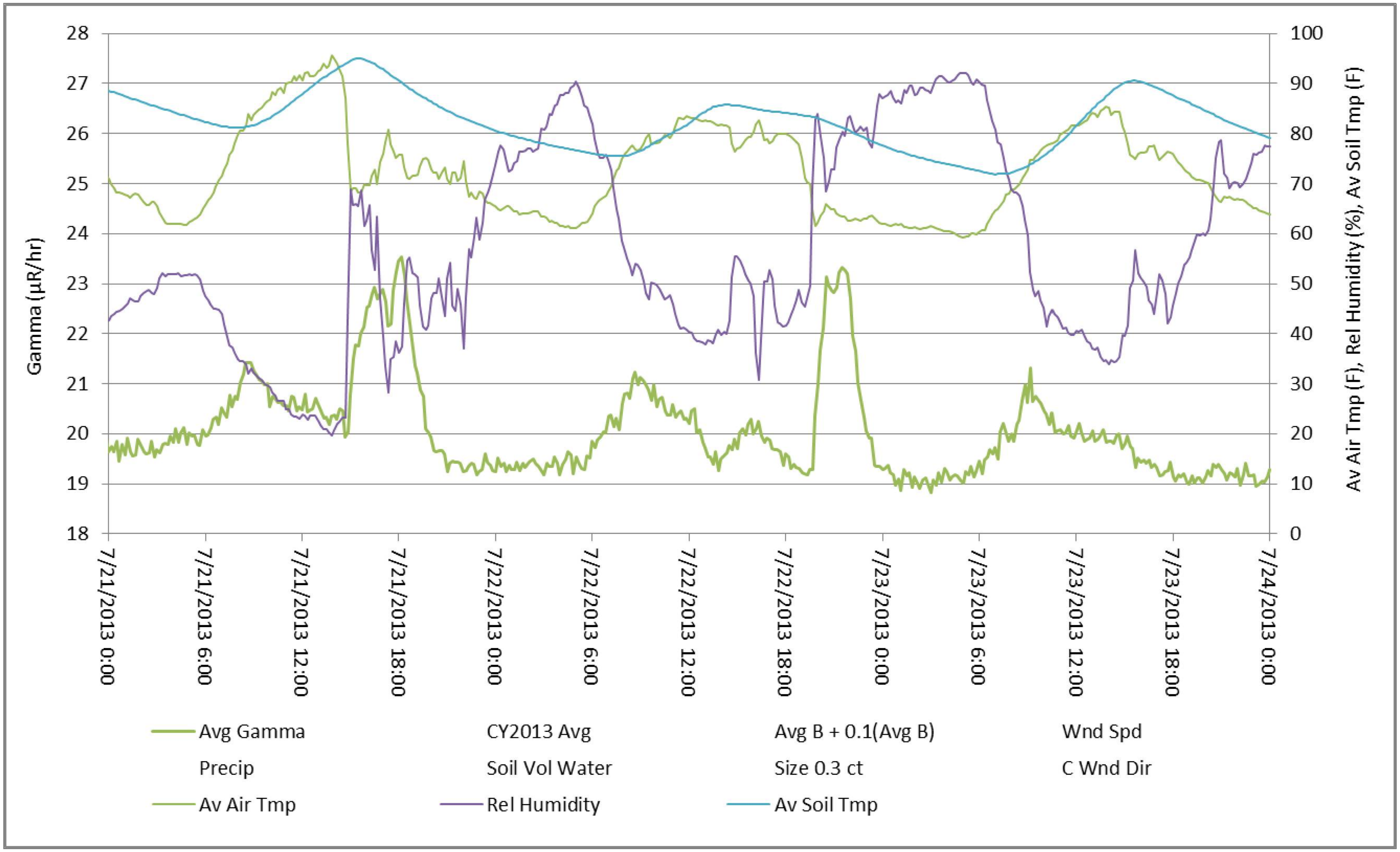

Figure A-18. Gamma, meteorological, and soil parameters observed during the period of increased gamma values recorded at TTR monitoring station 401 on July 22, 2013, showing the air and soil temperature and relative humidity.

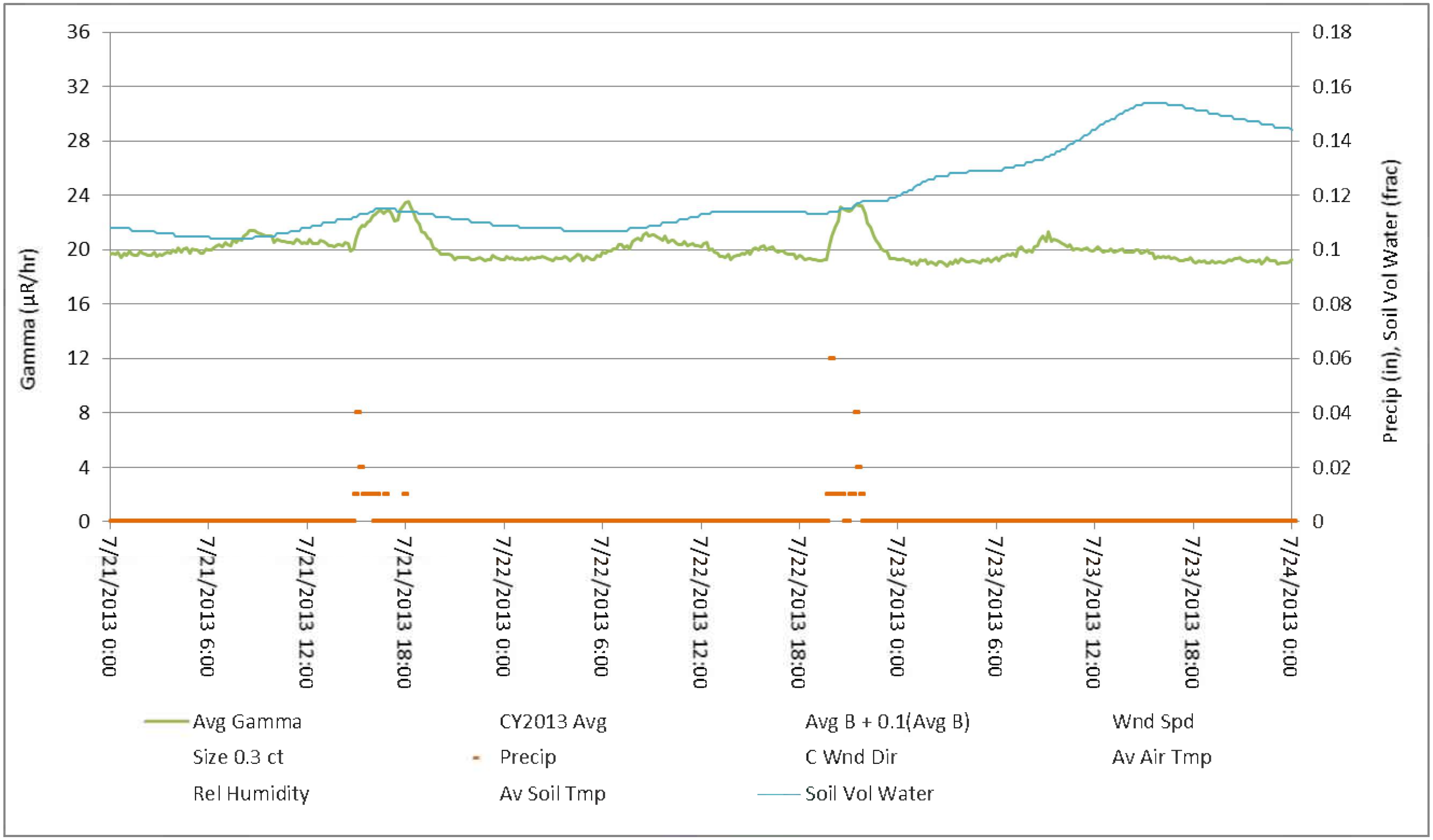

Figure A-19. Gamma, meteorological, and soil parameters observed during the period of increased gamma values recorded at TTR monitoring station 401 on July 22, 2013, showing the precipitation and soil water content.

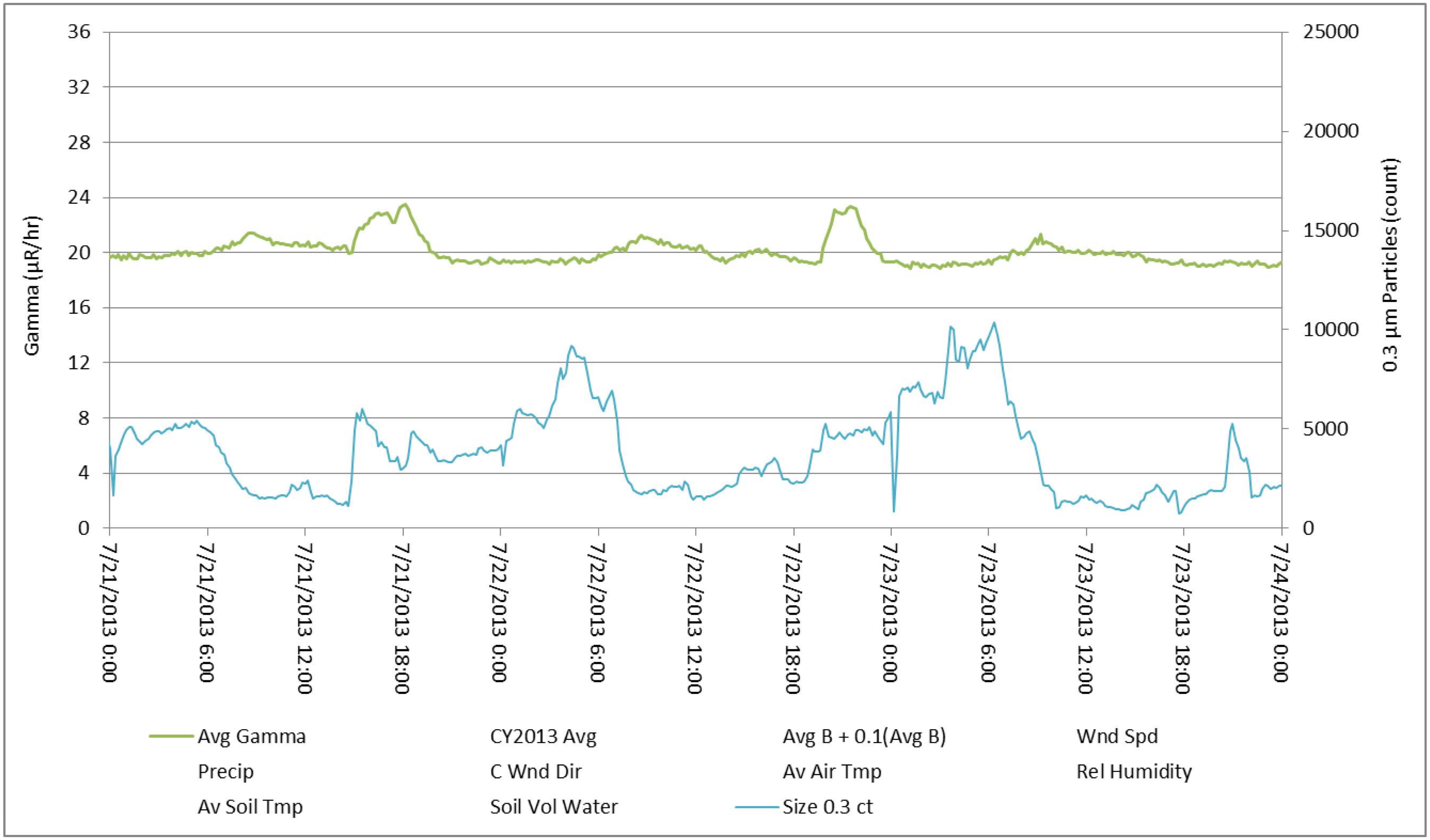

Figure A-20. Gamma, meteorological, and soil parameters observed during the period of increased gamma values recorded at TTR monitoring station 401 on July 22, 2013, showing the suspended dust counts.

Table A-5. Description of observed monitoring parameters during the increase in the gamma values reported for Station 401 on July 21, 2013 and July 22, 2013.

Parameter	Description
Avg Gamma	Pre-event minimum: 19.93 at 1440 7/21/2013 (+ 10% = 21.92) Event maximum: 23.54 at 1810 7/21/2013 (-10% = 21.19) Post-event minimum: 19.24 at 2100 7/21/2013 *By virtue of the resolution (+/- 10%) of values reported by the PIC instruments, the reported pre-event minimum and event maximum values could represent the same level. The overlap between the highest value represented by the reported pre-event minimum and the lowest value represented by the reported event maximum is 20 % of the difference between the pre-event minimum and event maximum. Pre-event minimum: 19.38 at 1830 7/22/2013 (+ 10% = 21.32) Event maximum: 23.21 at 2120 7/22/2013 (-10% = 20.89) Post-event minimum: 18.91 at 0220 7/23/2013 *By virtue of the resolution (+/- 10%) of values reported by the PIC instruments, the reported pre-event minimum and event maximum values do not represent the same level. The overlap between the highest value represented by the reported pre-event minimum and the lowest value represented by the reported event maximum is 11 % of the difference between the pre-event minimum and event maximum.
Wnd Spd	Although wind speed was generally increasing from about 4 mph between 0400 and 0800 on 7/21/2013, a sharp increase in wind speed began about 1400 and increased from 20 mph to over 30 mph between 1430 and 1450. The winds remained in excess of 20 mph until about1600. This wind speed spike corresponded with the rising limb of the increased gamma values. A secondary wind speed spike was approximately coincident with the peak gamma values at 1810 on 7/21/2013. Wind speed also spiked (about 20 mph at 1900) immediately before the increased gamma values reported on 7/22/2013. In this case the winds reached about 25 mph and remained above 20 mph for only about 30 minutes.
C Wnd Dir	During both increased gamma events (7/21/2013 and 7/22/2013) the wind direction was highly variable but appears to have been generally from the east to south.
Av Air Temp	*Average air temperature dropped sharply from about 94 ^{o}F at 1350 to about 68 ^{o}F at 1510 on 7/21/2013. The temperature remained in the 70 ^{o}F to 80 ^{o}F range during the period of increased gamma values. *On 7/22/2013 air temperature dropped from about 80 ^{o}F at 1800 to 61 ^{o}F at 1950. The timing was coincident with the rising limb of the increased gamma values.
Rel Humidity	Relative humidity fell sharply coincident with the increased gamma values on 7/21/2013 but increased sharply on 7/22/2013 coincident with the increase in gamma values.
Bar Press	No barometric pressure data are available from TTR monitoring station 401.
Av Soil Tmp	Throughout this two day period, the average soil temperature exhibited a diurnal pattern that did not reflect the sharp changes in the air temperature.
Size 0.3 ct	At no time during the two increased gamma value events did the dust counts exceed 10000.
Precip	0.14 in of precipitation was reported during the 7/21/2013 increased gamma values. An additional 0.2 in was reported during the 7/22/2013 increased gamma values.
Soil Vol Water	Soil moisture content was in the range of 0.1to 0.12 during the two increased gamma value events and only increased to about 0.155 following the rainfall of the second gamma event.
Summary	*The overlap of the resolution range of the pre-event minimum and event maximum gamma values suggests that it is possible for the reported minimum and maximum values to represent the same environmental conditions. *Winds during the increased gamma values may have suspended dust in the air, but the dust counts were fairly low. However, the precipitation would have washed any dust from the air, possibly causing the increased gamma values.

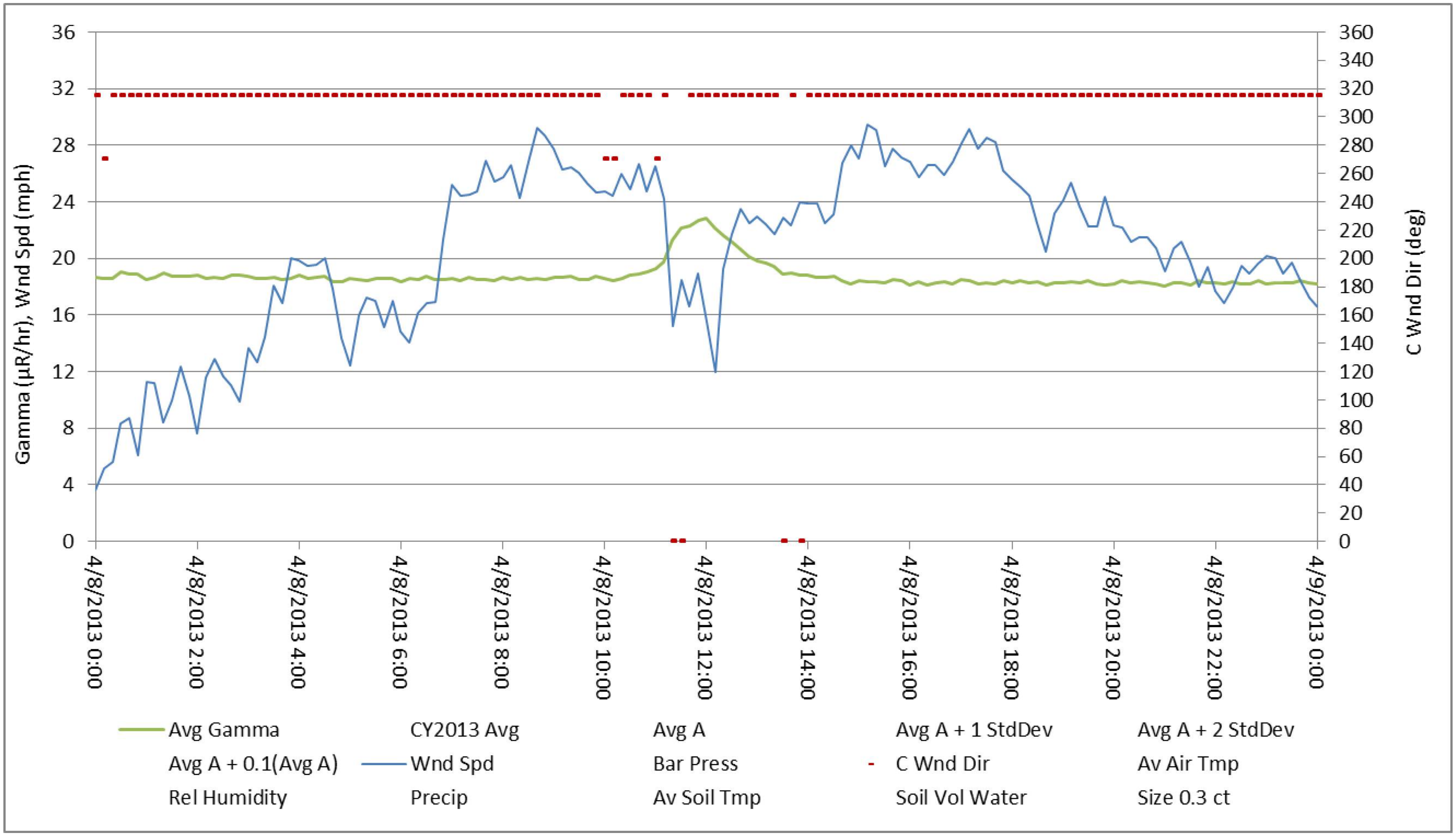

Figure A-21. Gamma, meteorological, and soil parameters observed during the period of increased gamma values recorded at TTR monitoring station 402 on April 8, 2013, showing the wind speed and direction.

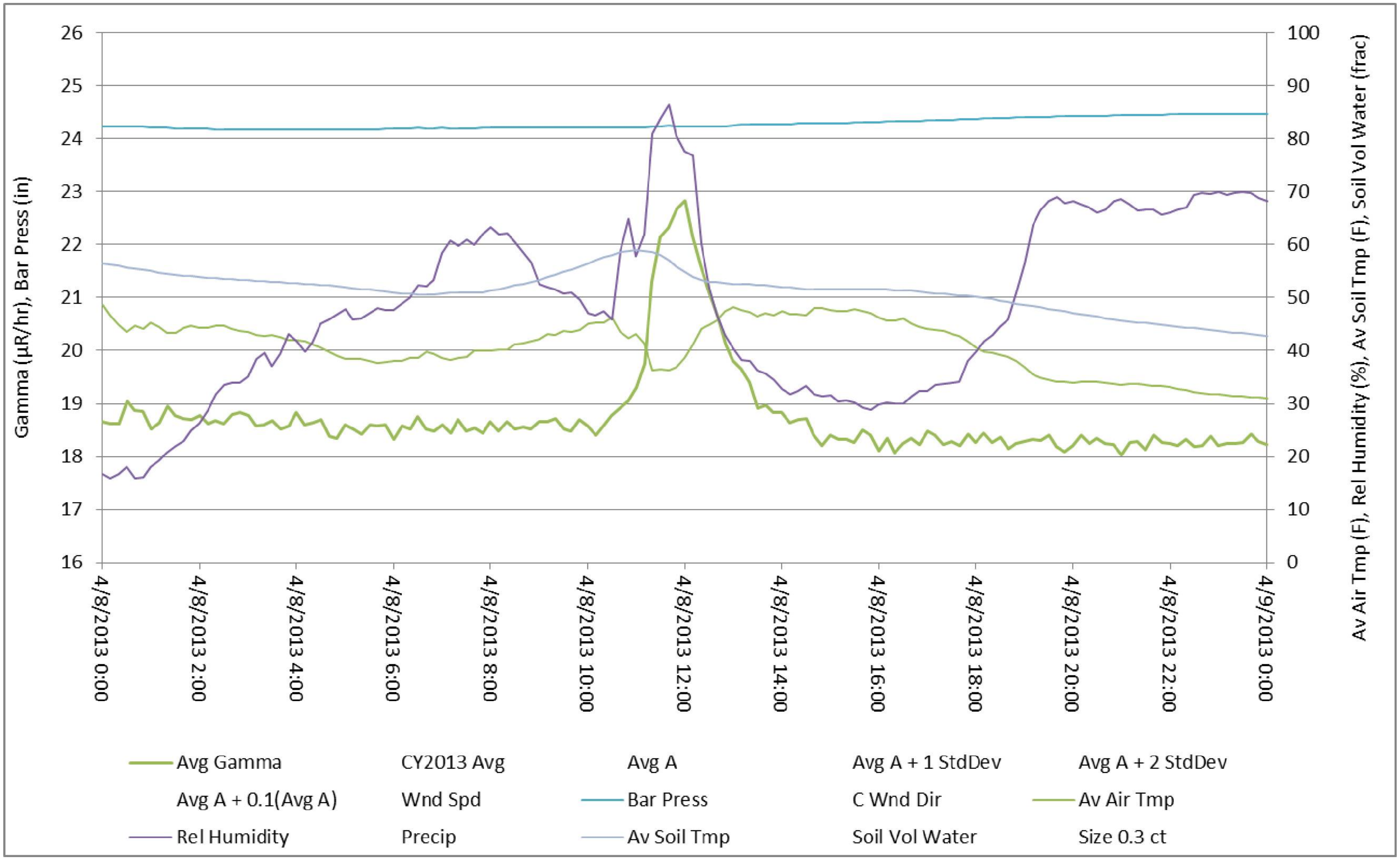

Figure A-22. Gamma, meteorological, and soil parameters observed during the period of increased gamma values recorded at TTR monitoring station 402 on April 8, 2013, showing the barometric pressure, air and soil temperature, and relative humidity.

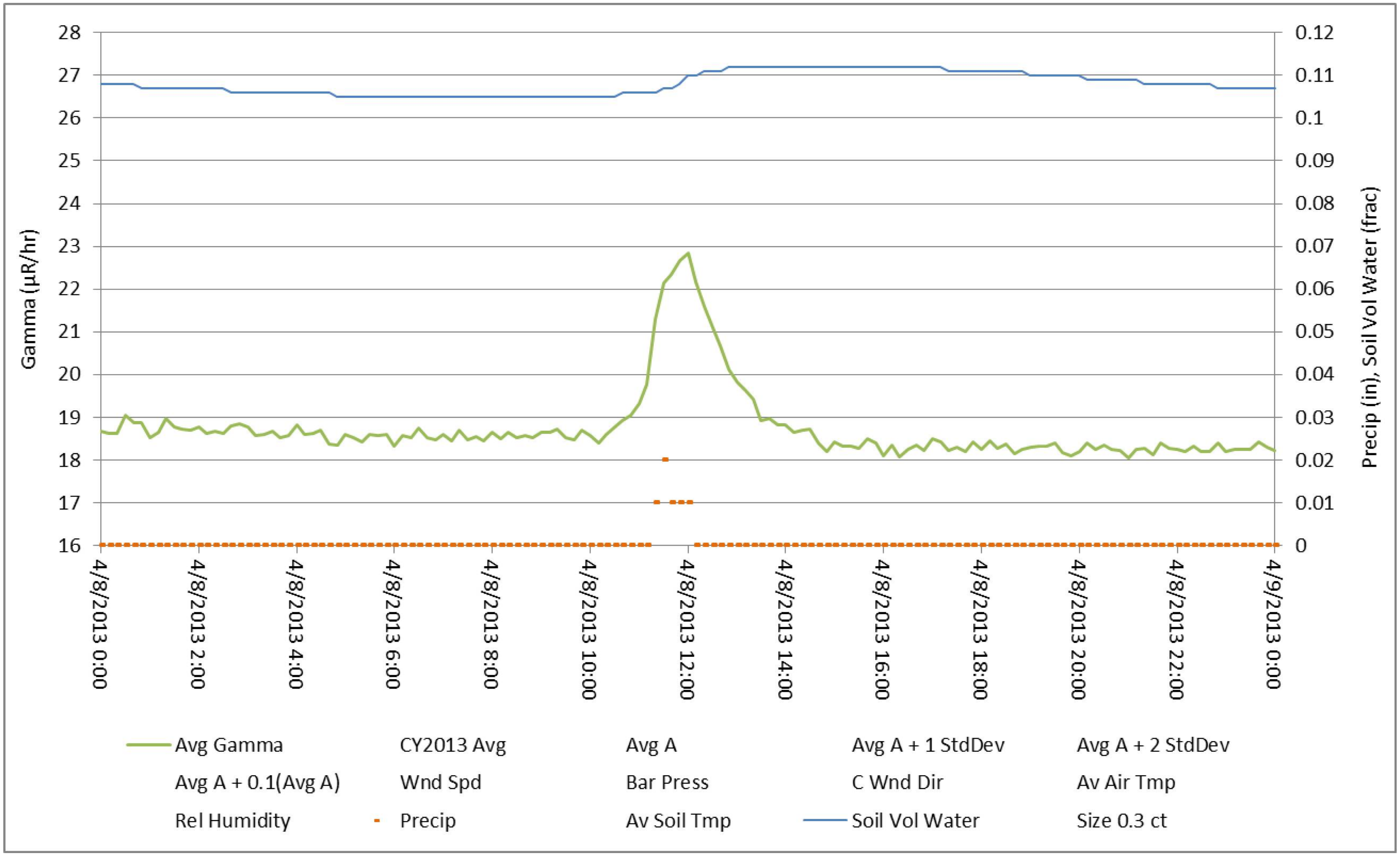

Figure A-23. Gamma, meteorological, and soil parameters observed during the period of increased gamma values recorded at TTR monitoring station 402 on April 8, 2013, showing the precipitation and soil water content.

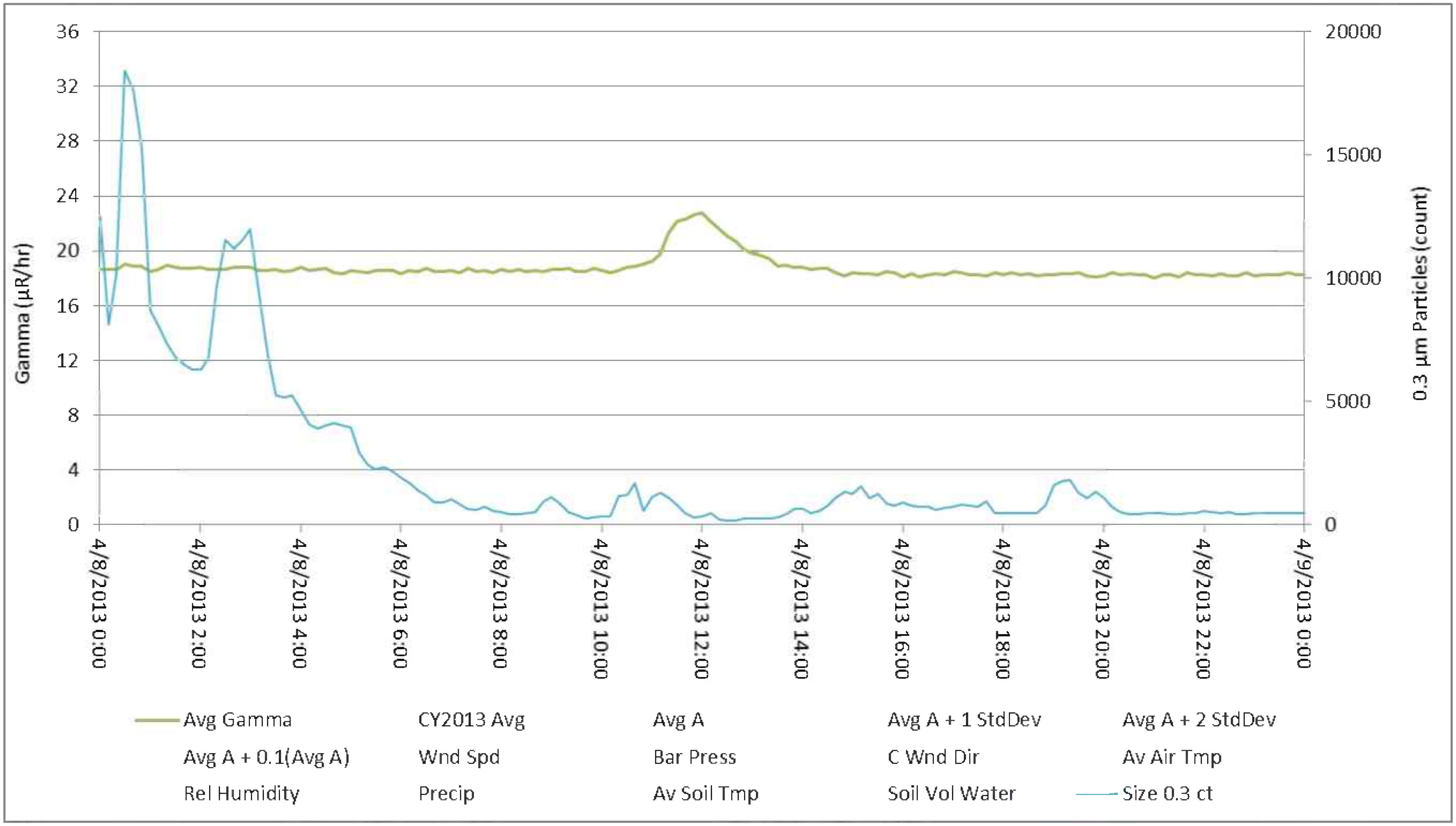

Figure A-24. Gamma, meteorological, and soil parameters observed during the period of increased gamma values recorded at TTR monitoring station 402 on April 8, 2013, showing the suspended dust counts.

Table A-6. Description of observed monitoring parameters during the increase in the gamma values reported for Station 402 on 4/8/2013.

Parameter	Description
Avg Gamma	Pre-event minimum: 18.58 at 1000 4/8/2013 (+ 10% = 20.44) Event maximum: 22.67 at 1150 4/8/2013 (-10% = 20.40) Post-event minimum: 18.08 at 1620 4/8/2013 *By virtue of the resolution (+/- 10%) of values reported by the PIC instruments, the reported pre-event minimum and event maximum values could represent the same level. The overlap between the highest value represented by the reported pre-event minimum and the lowest value represented by the reported event maximum is 1 % of the difference between the pre-event minimum and event maximum.
Wnd Spd	Wind speed prior to (3 hours) and during the first part (1.5 hours) of the rising limb of the increased gamma values was in the range of 24 mph to 29 mph. The wind speed diminished to between 12 mph and 19 mph through the period of maximum gamma values, and then after 1220, it increased again to the range of 26 mph to 29 mph.
C Wnd Dir	Winds were out of the north and northwest through the period of increased gamma values.
Av Air Temp	The diurnal pattern of average air temperature was interrupted at about 1030 when the temperature dropped from about 45 ^{o}F to about 36 ^{o}F. At about 1140 the temperature began to rise again, reaching about 47 ^{o}F at about the time when the gamma values were approximately halfway between the peak and the post-event minimum.
Rel Humidity	Relative humidity rose from 45% to 85% just ahead of the rising of the gamma values. The decrease in humidity was approximately coincident with the decline in gamma values.
Bar Press	Barometric pressure was increasing in what appears to be a diurnal pattern and there was no noticeable change in the pressure during the increased gamma values.
Av Soil Tmp	Average soil temperature generally mirrors the air temperature, even though the soil temperature did not display the decline observed in the air temperature during the increased gamma values.
Size 0.3 ct	High dust counts were reported between midnight and 0400 and peaked at about 18,400 at 0030. However, the dust count had declined to less than 2,000 by 0600 and remained at that level throughout the day.
Precip	Approximately 0.06 in of precipitation was reported during the first half of the increased gamma values.
Soil Vol Water	The soil water content was on a decline coming up to the increased gamma values but showed an increase in response to the precipitation. After this increase the soil water content continued to show a slow decline.
Summary	*The minimal overlap between the resolution range of the pre-event minimum and event maximum gamma values suggests that the low and high values are distinctly different. *Winds consistently from the north and northwest would be blowing across the monitoring station before crossing the Clean Slate contamination area, suggesting that the Clean Slate soils were not responsible for the increased gamma values. *Additionally, the high dust counts just after midnight are associated with relative low wind speeds and the higher wind speeds later in the day failed to generate significant dust counts.

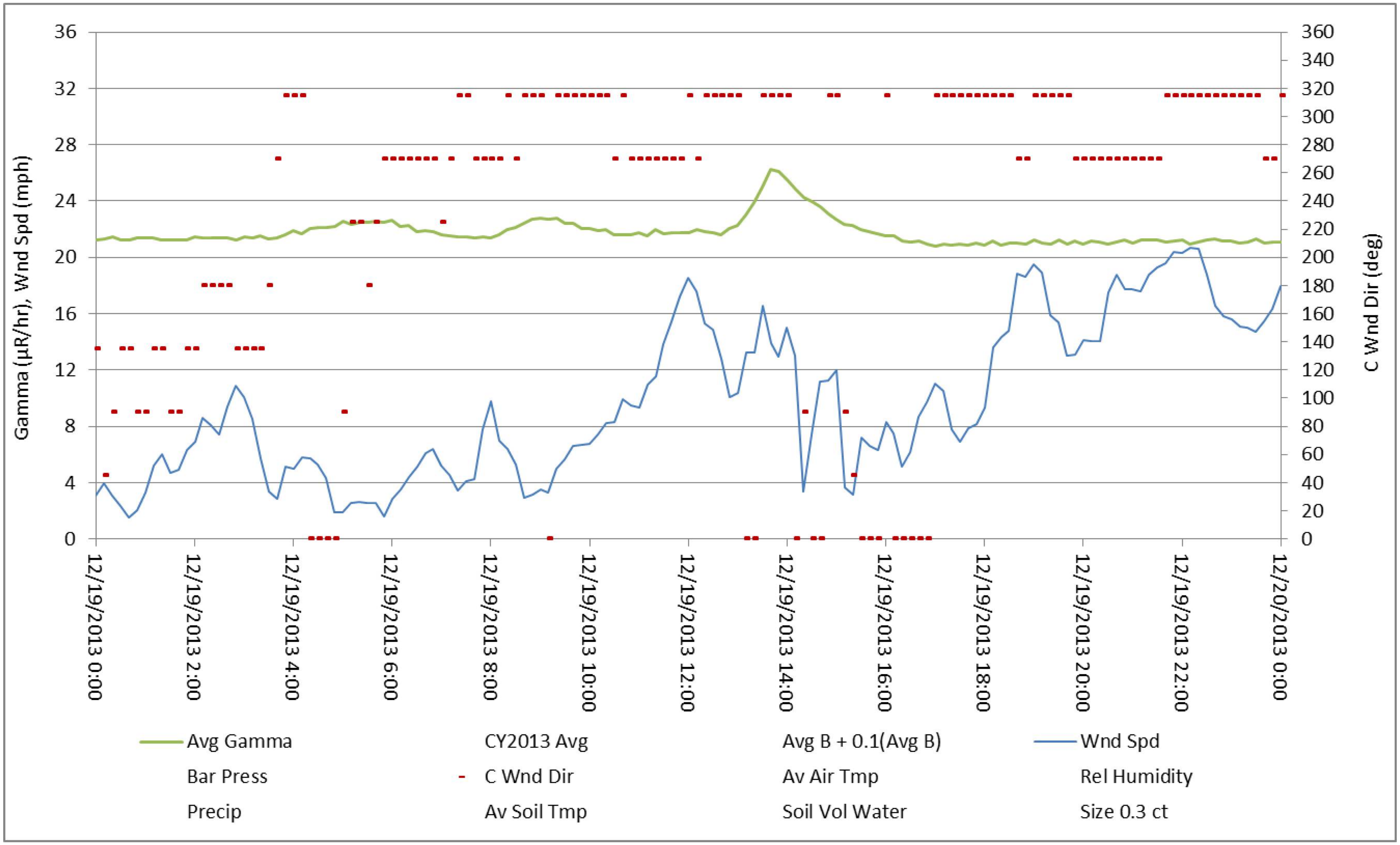

Figure A-25. Gamma, meteorological, and soil parameters observed during the period of increased gamma values recorded at TTR monitoring station 402 on December 19, 2013, showing the wind speed and direction.

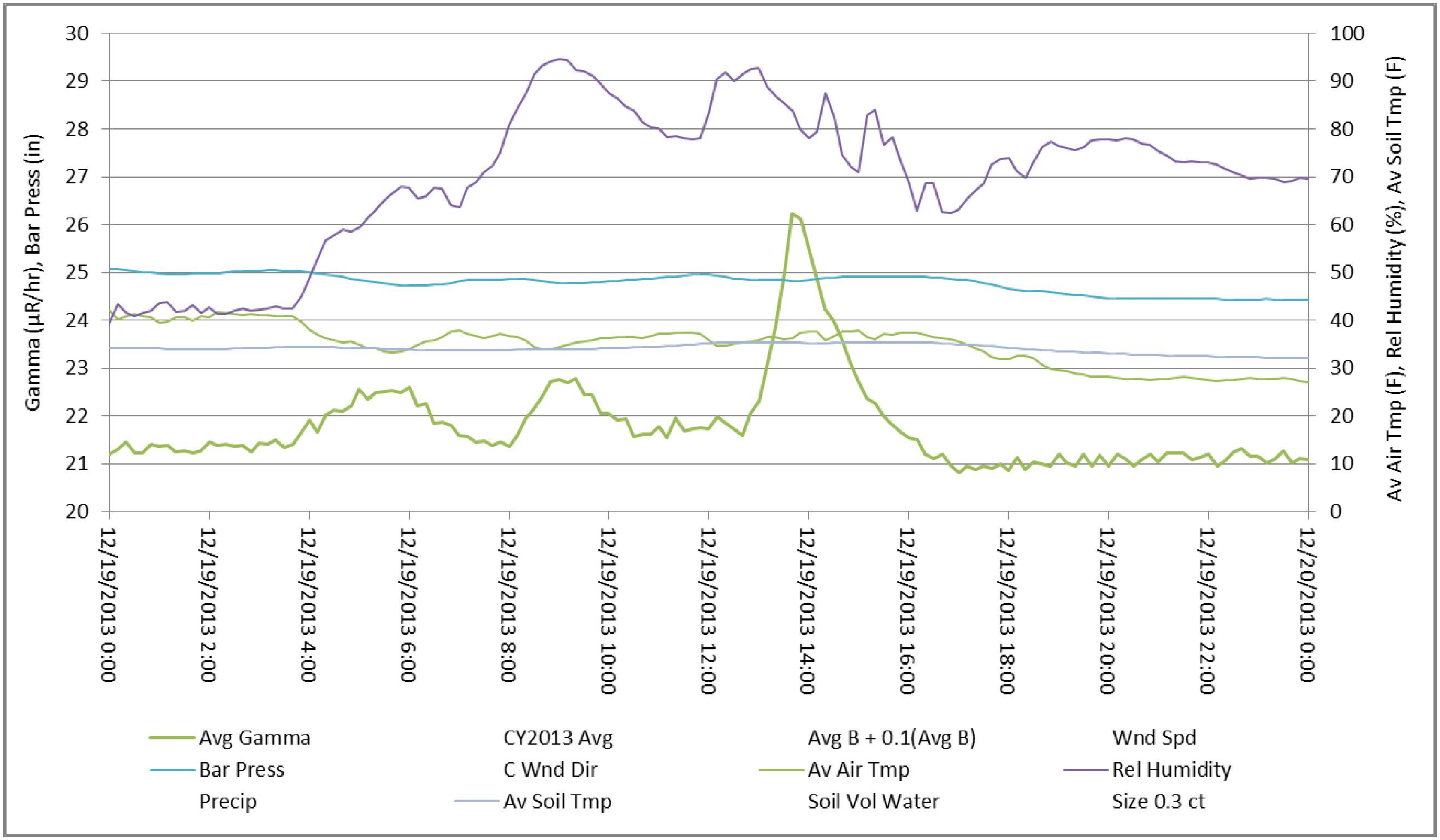

Figure A-26. Gamma, meteorological, and soil parameters observed during the period of increased gamma values recorded at TTR monitoring station 402 on December 19, 2013, showing the barometric pressure, air and soil temperature, and relative humidity.

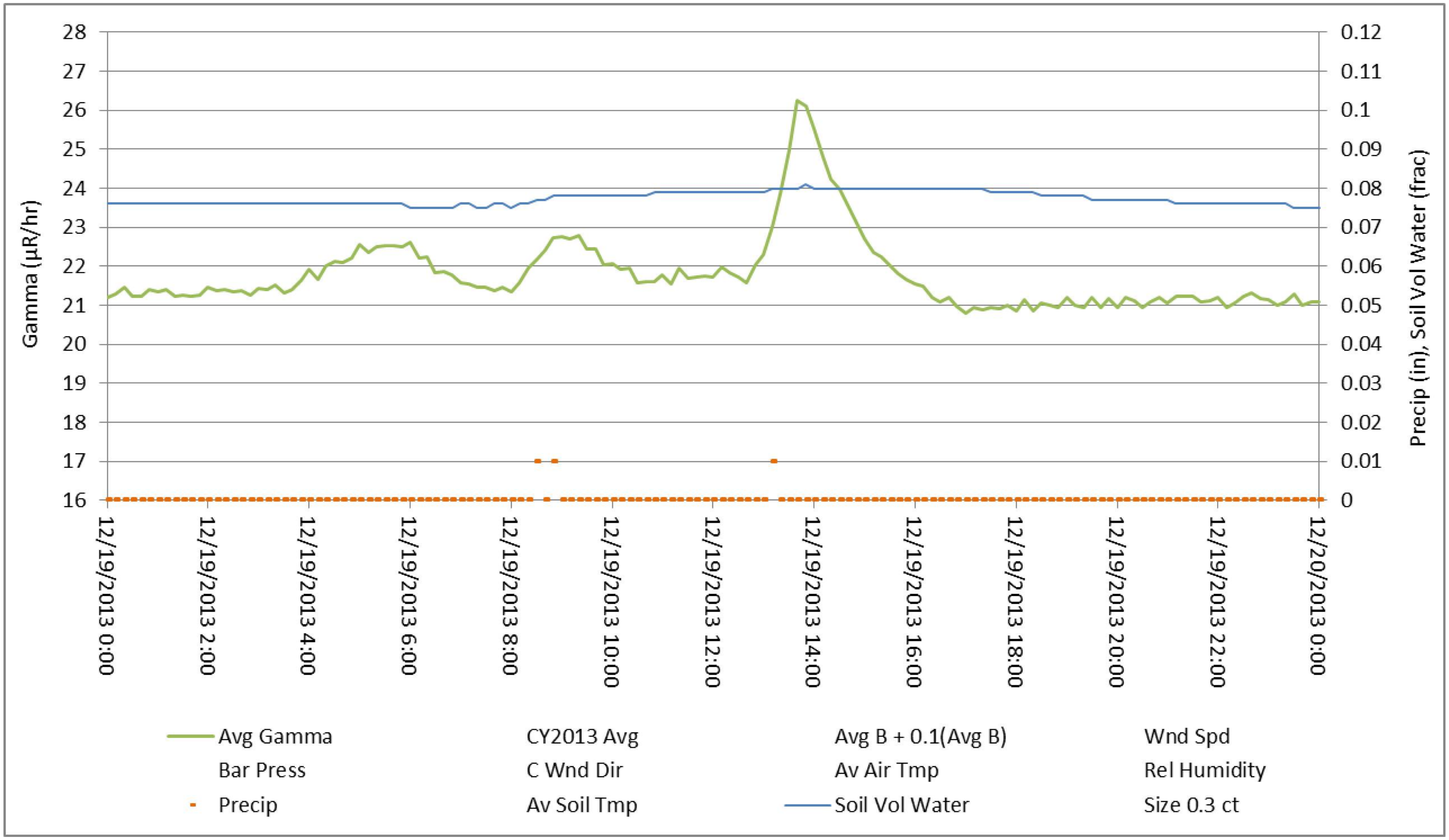

Figure A-27. Gamma, meteorological, and soil parameters observed during the period of increased gamma values recorded at TTR monitoring station 402 on December 19, 2013, showing the precipitation and soil water content.

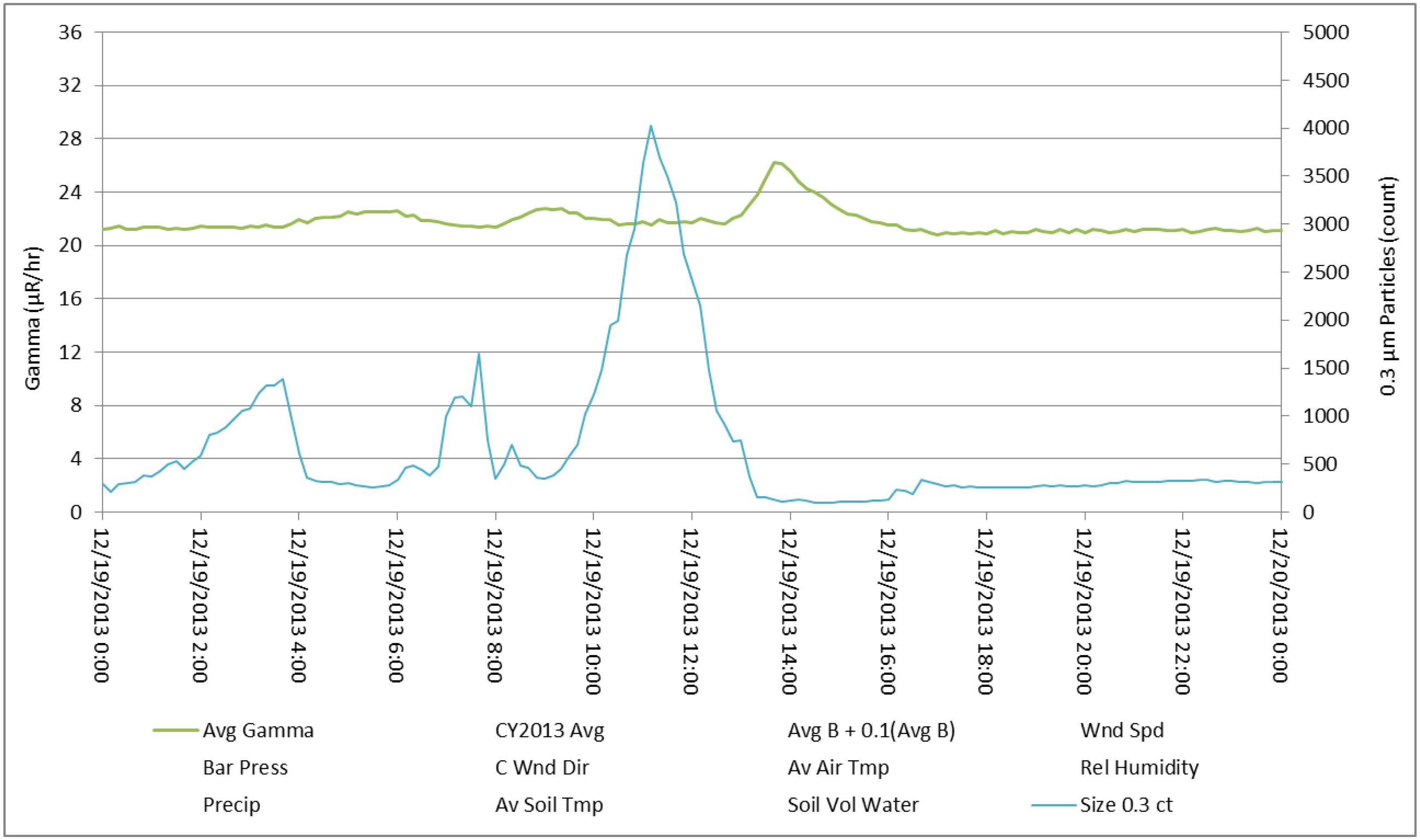

Figure A-28. Gamma, meteorological, and soil parameters observed during the period of increased gamma values recorded at TTR monitoring station 402 on December 19, 2013, showing the suspended dust counts.

Table A-7. Description of observed monitoring parameters during the increase in the gamma values reported for Station 402 on December 19, 2013.

Parameter	Description
Avg Gamma	Pre-event minimum: 21.58 at 1240 12/19/2013 (+ 10% = 23.74) Event maximum: 26.24 at 1340 12/19/2013 (-10% = 23.62) Post-event minimum: 20.80 at 170012/19/2013 *By virtue of the resolution (+/- 10%) of values reported by the PIC instruments, the reported pre-event minimum and event maximum values could represent the same level. The overlap between the highest value represented by the reported pre-event minimum and the lowest value represented by the reported event maximum is 2.6 % of the difference between the pre-event minimum and event maximum. *Additional blips in the gamma values occurred at around 0500 and 0900. These increases reached maximum levels of about 22.5 µR/hr and 22.7 µR/hr, respectively.
Wnd Spd	Wind speed was generally increasing from 0600 until 1200 when it peaked at about 18 mph. After peaking the wind speed declined to between 10 mph and 16 mph during the bulk of the increased gamma values. As increased gamma values declined, the wind speed also dropped off.
C Wnd Dir	During the increased gamma values the wind direction was generally from the north and northwest with a few periods of wind from the northeast.
Av Air Temp	The average air temperature dipped noticeably at about 0330 and remained between 34 $^{\circ}$F and 3734 $^{\circ}$F through the daytime before dropping to below 3034 $^{\circ}$F after 1900.
Rel Humidity	The relative humidity increased noticeably as the pressure and air temperature were dropping. The humidity reached several intermediate and maximum high values that correspond to increased gamma values during the day.
Bar Press	Barometric pressure changes during the day were small but appear to be coincident with the same direction as the average air temperature; that is, lower temperature and lower pressures were coincident.
Av Soil Tmp	Though modulated, the average soil temperature reflected the general pattern of the air temperature.
Size 0.3 ct	Dust counts fluctuated between about 100 and 1400; peaks occurred at about 0330 (1,323), 0740 (1,645), and 1110 (4,000). Each of these dust peaks is approximately coincident with wind speed peaks and precedes observed increases in gamma values.
Precip	Minor amounts of precipitation were reported at about 0900 and 1310. These times were coincident with the increased gamma values at 0900 and 1340.
Soil Vol Water	Soil water volume increased in response to the measured precipitation. However, the long-term soil water volume was not changed as water content declined in accordance with a typical diurnal pattern.
Summary	*The small percentage of overlap between the resolution range of the pre-event minimum and event maximum gamma values suggests that the reported gamma values are not likely to represent the same levels of gamma radiation. *Wind direction during the increased gamma values reported on 12/19/2013 was from the north and northwest and would have reached the monitoring station prior to crossing the Clean Slate I contamination area. Therefore, the observed gamma values are not likely to have been derived from the contaminated ground at Clean Slate I. *Wind speeds appear to have been sufficient to raise dust into suspension, but the increased gamma values do not correspond well with the higher dust counts. Light precipitation observed at 0900 and 1310 may have washed dust from suspension and onto the PIC instruments, and thus contributed to the increased gamma values. However, no precipitation was reported during the increased gamma values recorded between 0400 and 0600.

APPENDIX B: DAILY AVERAGE METEOROLOGICAL AND ENVIRONMENTAL DATA OBSERVED AT TTR AIR MONITORING STATIONS 400, 401, AND 402 DURING CY2013

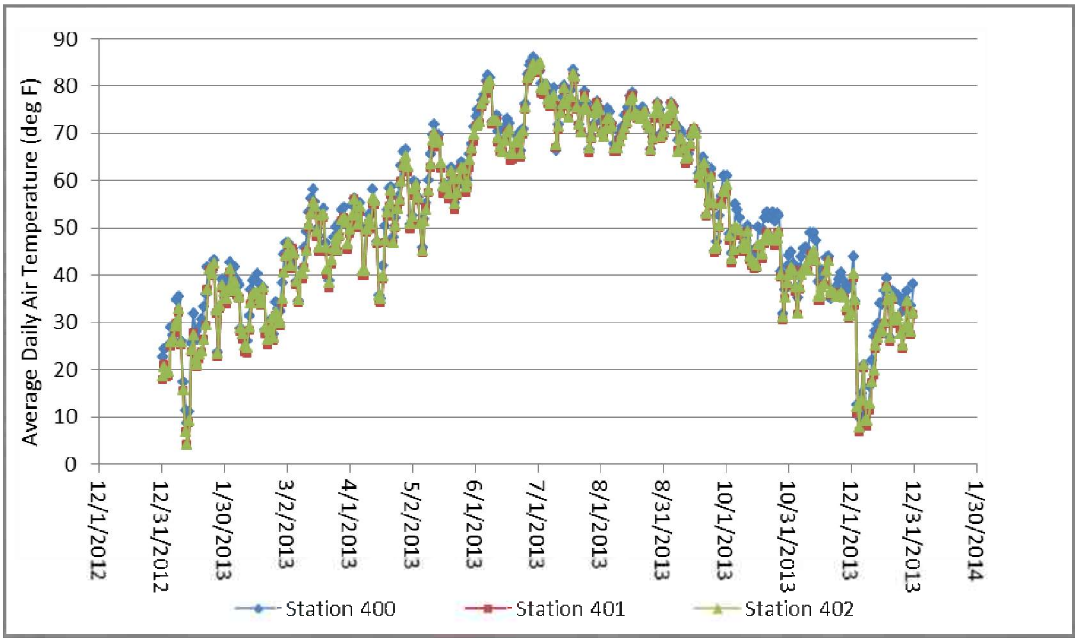

Figure B-1. Average daily air temperature (°F) for TTR air monitoring Stations 400, 401, and 402 during CY2013.

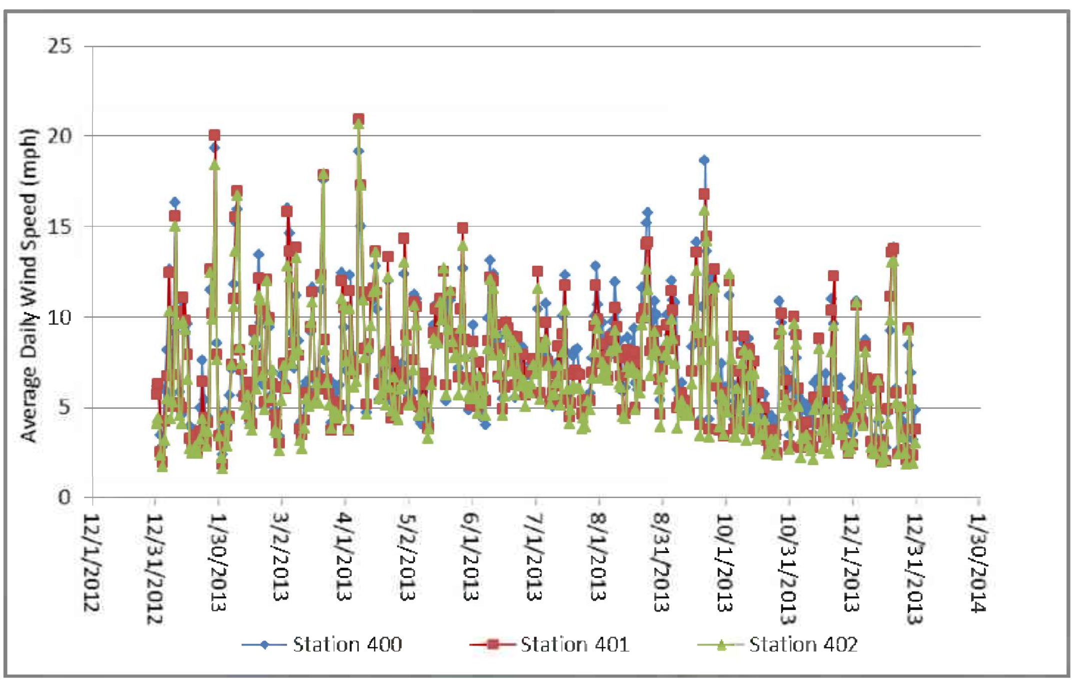

Figure B-2. Average daily wind speed (mph) at TTR air monitoring Stations 400, 401, and 402 during CY2013.

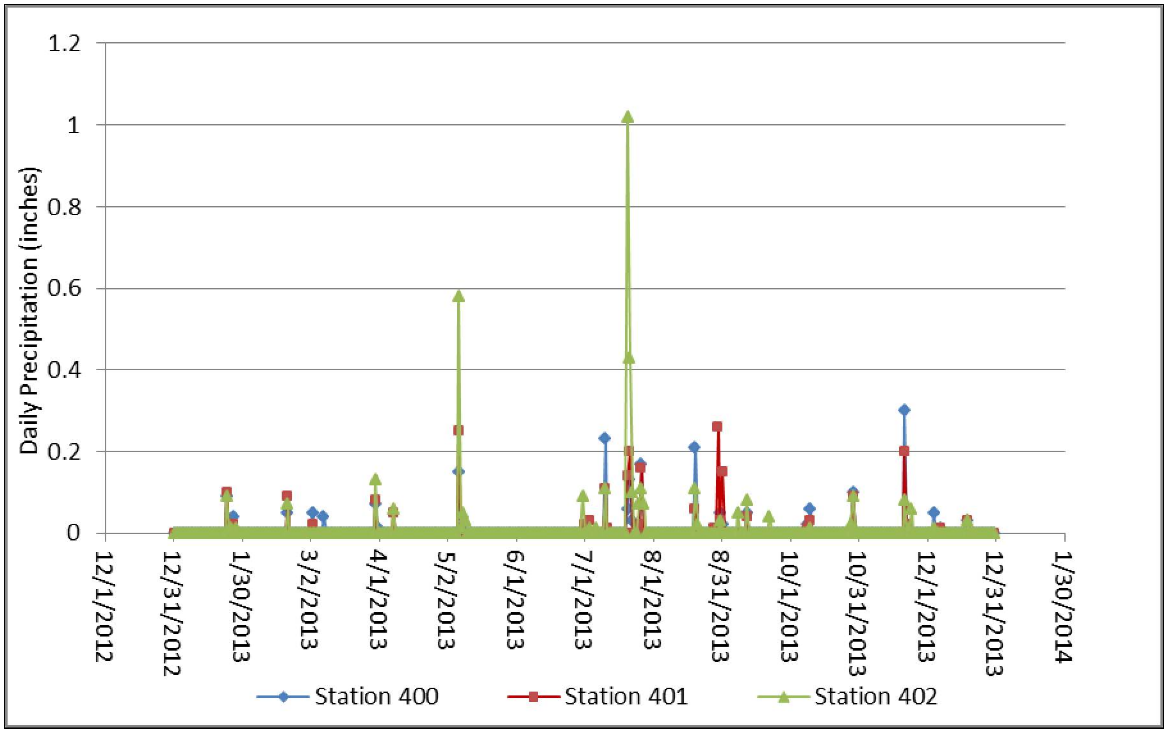

Figure B-3. Total daily precipitation amounts for TTR air monitoring Stations 400, 401, and 402 during CY2013.

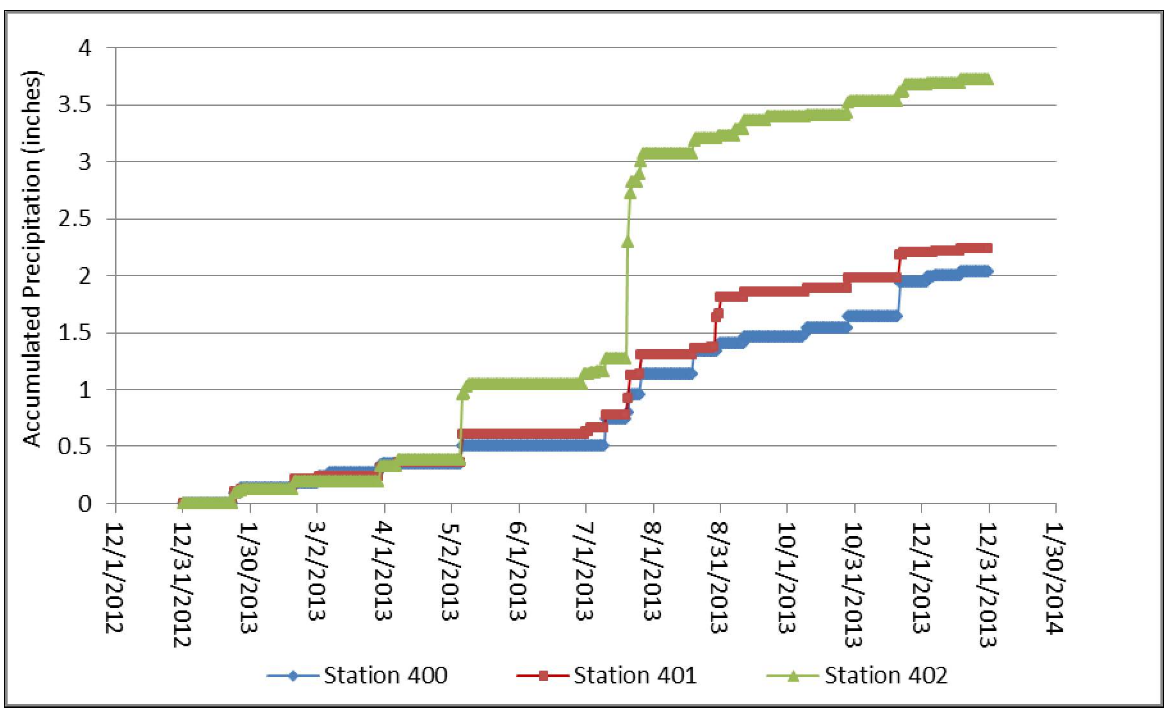

Figure B-4. Cumulative annual precipitation for TTR air monitoring Stations 400, 401, and 402 during CY2013.

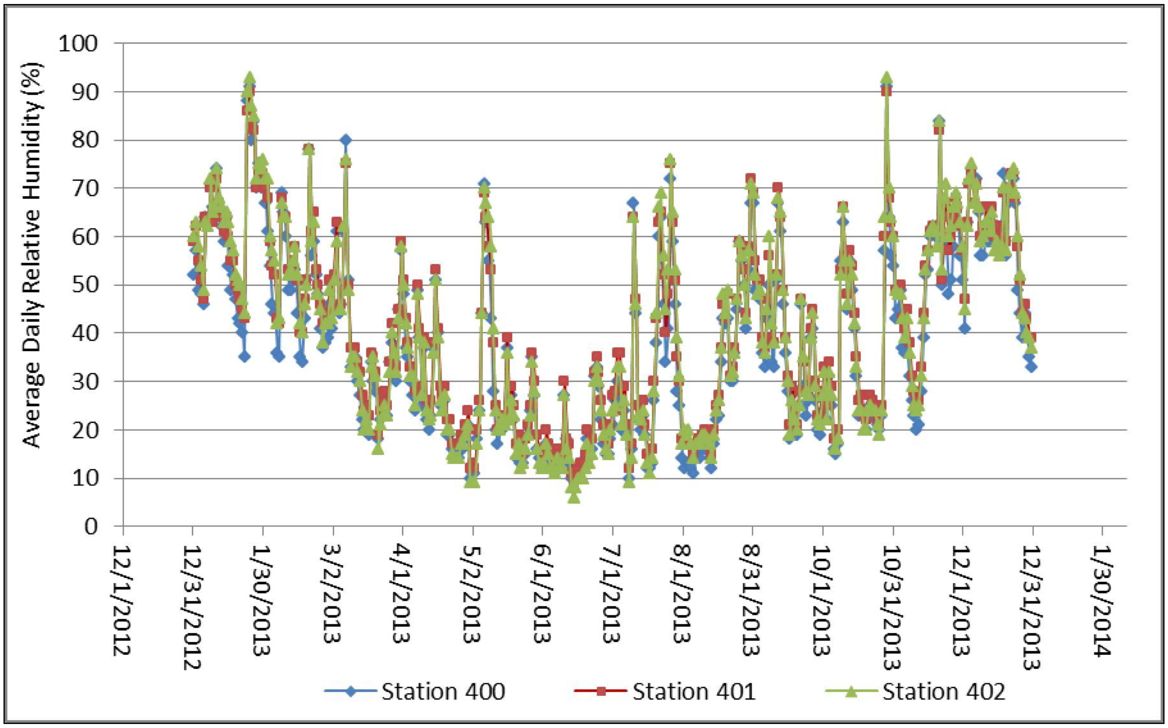

Figure B-5. Average daily relative humidity for TTR air monitoring Stations 400, 401, and 402 during CY2013.

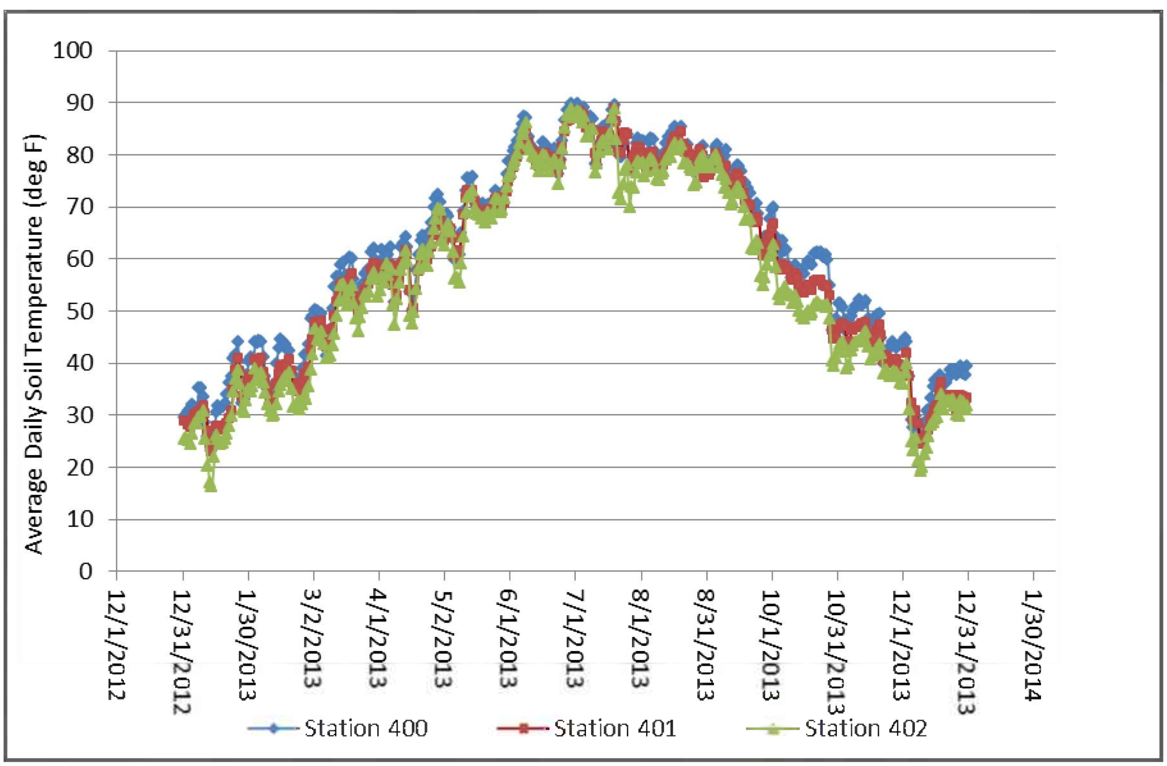

Figure B-6. Average daily soil temperature at TTR air monitoring Stations 400, 401, and 402 during CY2013.

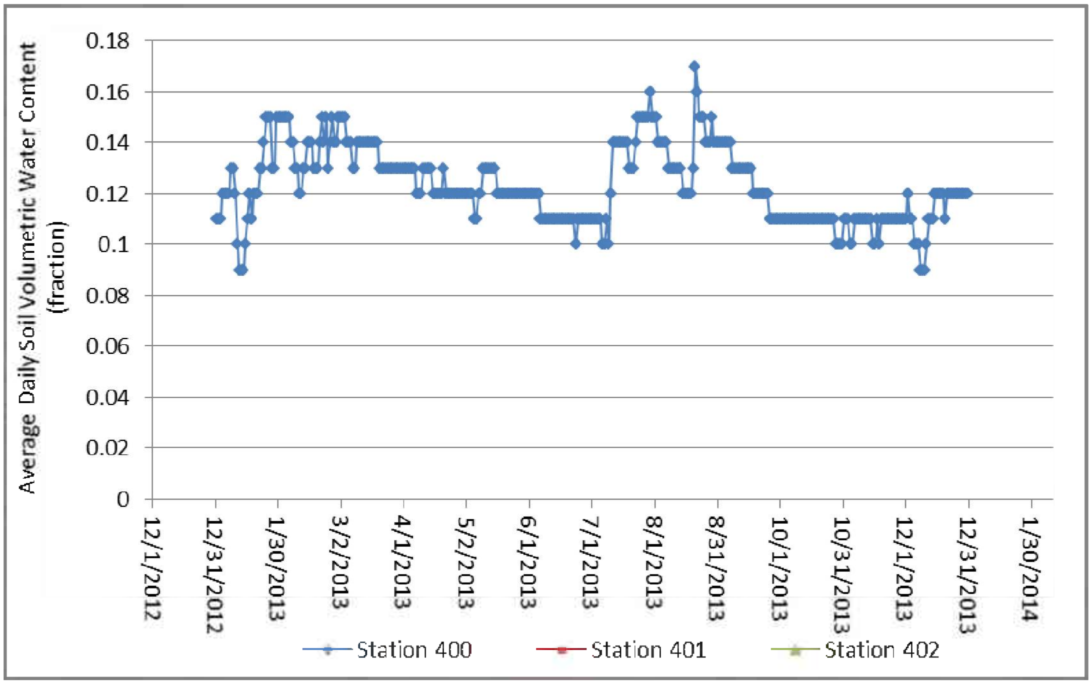

Figure B-7. Average daily volumetric soil water content at TTR air monitoring Stations 400, 401, 402 during CY2013.

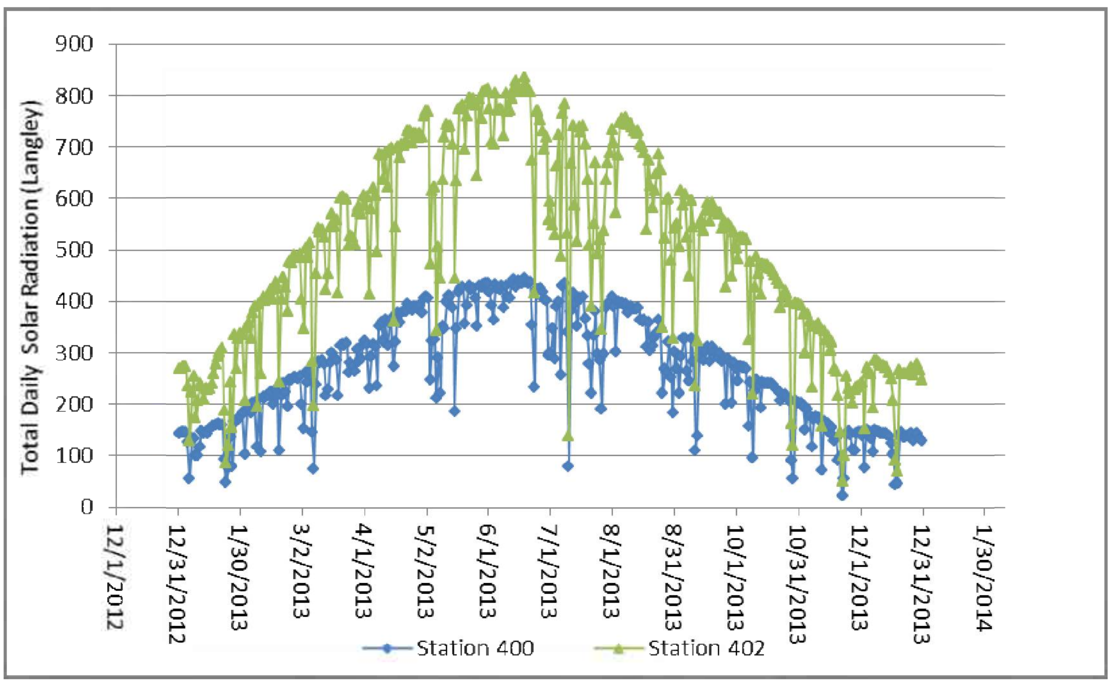

Figure B-8. Total daily solar radiation (Langley) for TTR air monitoring Stations 400 and 402 during CY2013. Solar radiation data from one of these stations is believed to be incorrectly calculated due to use of improper scaling parameters in the data collection program. This issue is being investigated but had not been resolved when this report was submitted. The problem will be resolved before subsequent reports of this monitoring effort are completed.

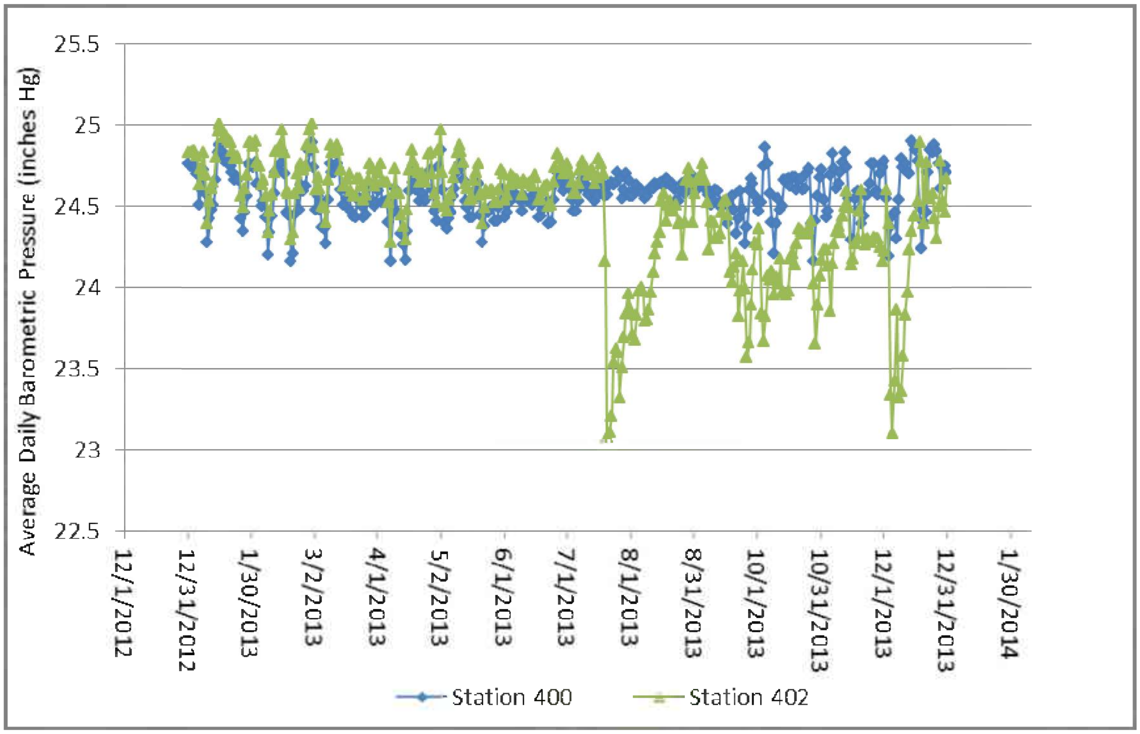

Figure B-9. Average daily barometric pressure at TTR air monitoring Stations 400 and 402 during CY2013.

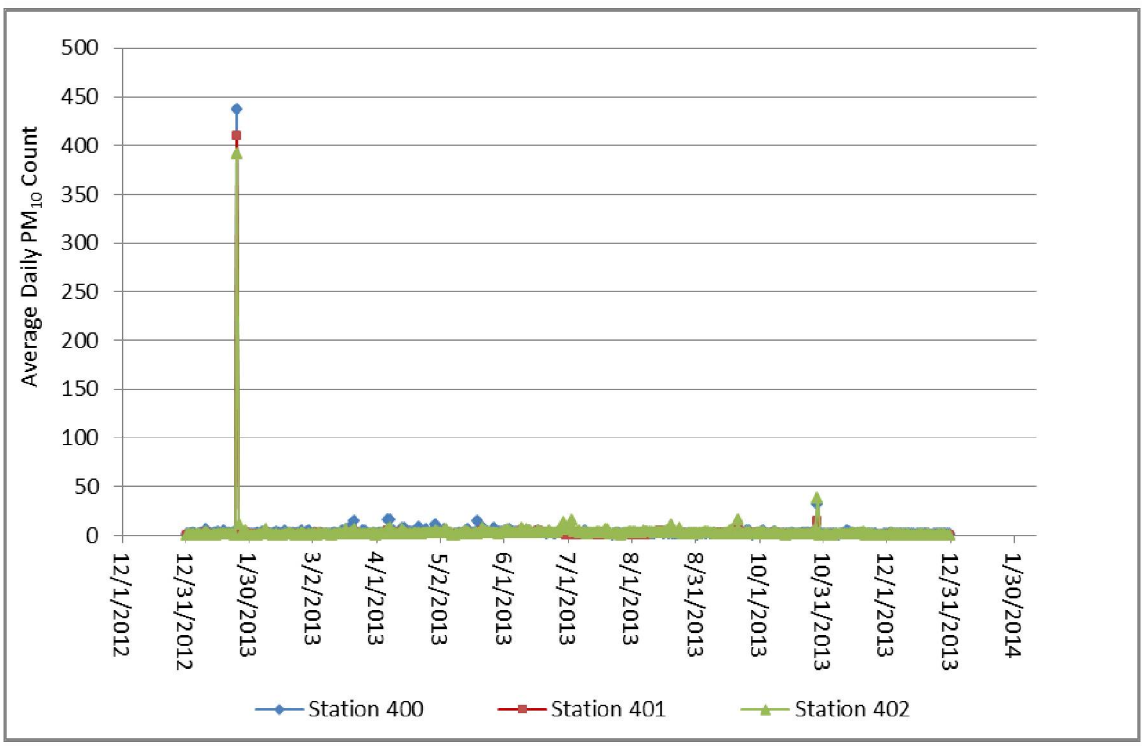

Figure B-10. Average daily PM_{10} count at the TTR air monitoring Stations 400, 401, and 402 duirng CY2013.