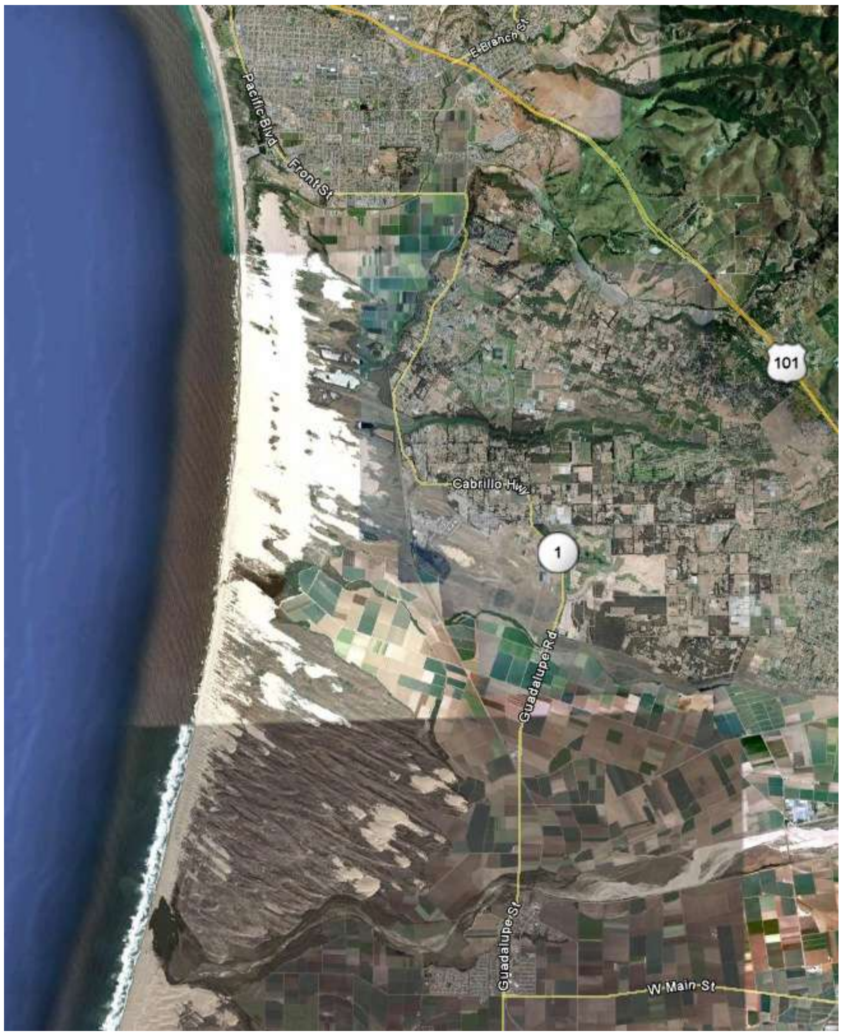
SOUTH COUNTY PHASE 2 PARTICULATE STUDY
San Luis Obispo County Air Pollution Control District
February 2010



Project Manager
Joel Craig, San Luis Obispo County APCD

Principal Authors
Joel Craig, San Luis Obispo County APCD
Dr. Thomas Cahill, University of California Davis
Duane Ono, Great Basin Unified APCD

ACKNOWLEDGEMENTS

This study and report is the result of efforts of numerous individuals and organizations. The San Luis Obispo County APCD would like to thank the following individuals for their involvement and support:

Principal Investigators
Dr. Thomas Cahill, University of California Davis
Dr. David Barnes, University of California Davis
Joel Craig, San Luis Obispo County APCD
Jay Courtney, San Luis Obispo County APCD
Duane Ono, Great Basin Unified APCD

Study Participants
Thomas Murphy, Santa Barbara County APCD
Larry Allen, San Luis Obispo County APCD
Phil Wagner, California Air Resources Board
Joe Petrini, Santa Barbara County APCD
Bill Cox, Great Basin Unified APCD
Nick Barbieri, Great Basin Unified APCD

Study Support
Ted Schade, Great Basin Unified APCD
Terry Dressler, Santa Barbara County APCD
Mike Worst, California Air Resources Board
Joel Cordes, Santa Barbara County APCD
Andy Zilke, California State Parks
Ronnie Glick, California State Parks
Denna Bellman, California State Parks
Will Harris, California Geologic Survey
Trinda Bedrossian, California Geologic Survey
Glen Greenwald, United States Fish and Wildlife Service
Bill Fisher, CDF/San Luis Obispo County Fire Department
Dr. Robert Moss, California Polytechnic State University, San Luis Obispo
Mario Castellanos, Guadalupe Dune Center
Tony Ulibarri, Oceano Elks Lodge

Peer Review
Dr. Michael Taylor, University of California, Davis
Dr. Meredith Kurpius, U.S. Environmental Protection Agency
Dr. Lynn Moody, California Polytechnic State University, San Luis Obispo
California Air Resources Board Technical Staff
Mel Zeldin, Environmental Consultant
Thomas Murphy, Santa Barbara County APCD

The District also acknowledges Google for providing all aerial photographs used in this report.

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EXECUTIVE SUMMARY

Historical ambient air monitoring on the Nipomo Mesa has documented atypical concentrations of airborne particulate matter compared to other areas of San Luis Obispo County and other coastal areas of California. These historical measurements show that the California health standard for PM10 (airborne particles with a mean aerodynamic diameter of 10 microns or less) is regularly exceeded in many locations on the Nipomo Mesa. Population-based studies in hundreds of cities in the U.S. and around the world have demonstrated that both short-term and long-term exposure to elevated particulate levels can cause significant increases in hospital admissions, emergency room visits, asthma attacks and premature deaths. Groundbreaking long-term studies of children's health conducted in California have also shown that particle pollution may significantly reduce lung function growth in children.

To better understand the extent and sources of these unusually high concentrations of particulate pollution on the Nipomo Mesa, the San Luis Obispo County Air Pollution Control District (SLO APCD) has conducted comprehensive air monitoring studies in that region. The Phase 1 South County Particulate Matter (PM) Study began in 2004 and utilized filter-based manual particulate samplers measuring both PM10 and PM2.5 (particles 2.5 microns in diameter or less) concentrations at 6 monitoring sites located throughout the Mesa. Samples were collected over a one year period and analyzed for mass and elemental composition; meteorological measurements of wind speed and direction were also performed at numerous locations in the study area.

Data from the Phase 1 study showed air quality on the Nipomo Mesa exceeds the state 24-hour PM10 health standard at one or more monitoring locations on over one quarter of the sample days. Elemental analysis of PM2.5 filter samples demonstrated that on these high particulate days, the largest fraction of particles are composed of the wind blown crustal material containing silicon, iron, aluminum, and calcium. Meteorological data showed that high wind events entraining crustal particulate from the dune fields at the Oceano Dunes State Recreational Vehicle Area (SRVA) upwind of the Nipomo Mesa area and transporting them inland as the likely cause; data from a directional PM10 sampler on the Mesa that only operated on high wind days strongly supported this conclusion. Further analysis of Phase 1 study data was unable to provide a conclusive determination on whether off-road vehicle (OHV) activity in the SVRA played a role, either direct or indirect, in the particulate pollution observed on the Nipomo Mesa.

The Phase 1 Study Report was presented to the SLO APCD Board of Directors in March of 2007. The Board directed staff to design and conduct a follow-up study with the primary goal of determining if OHV activity on the SVRA played a role in the high particulate levels measured on the Nipomo Mesa; a secondary goal of the study was to determine what, if any, particulate impacts on the Mesa are due to fugitive dust from the petroleum coke piles at the ConocoPhillips Refinery complex. To help design and conduct the Phase 2 study, the SLO APCD retained the services of the Delta Group, an affiliation of scientists, mostly from the University of California at Davis (UCD), dedicated to the detection and evaluation of aerosol transport. The Great Basin Unified Air Pollution Control District (GBUAPCD), a recognized leader nationwide in understanding and mitigating wind blown particulate pollution, also lent their considerable expertise to the design and implementation of the study. Scientists from the Santa Barbara County APCD, the California Air Resources Board (CARB) and the California State Parks Department also provided significant input in the design phase of the study.

The Phase 2 Study design involved three independent investigations using a broad array of technologies and measurement techniques to better understand the source(s) and activities responsible for the observed particulate pollution problem on the Nipomo Mesa. Determining the role of OHV activity on the SVRA was a key focus of the study, so it was important to conduct measurements and analyses both within and downwind of the dunes at the SVRA, as well within and downwind of “control site” dunes north and south of the SVRA where offroad vehicles are not allowed, to evaluate the differences between them. PM and meteorological measurements downwind of the refinery coke piles and agricultural fields on the Mesa were also a necessary design element to determine potential contributions from those areas. Further, since the Phase 1 study showed that high PM concentrations on the Mesa occur primarily on high wind days, it was critical to ensure that study measurements captured the high wind events that typically occur during the early spring and late fall months.

The field measurement phase of the study was conducted from January 2008 through March 2009. The portion of the study performed by the SLO APCD entailed the deployment and use of real–time particulate monitors and wind sensors at a variety of locations downwind of both the SVRA and the control sites, as well as downwind of the coke piles and agricultural fields. These measurements were designed to assess the relative levels of airborne particulate coming from those areas, particularly on high wind days.

The portion of the study directed by the GBUAPCD involved measuring the amount of sand movement at different wind speeds, both in the SVRA and a control site, to better understand the mechanism and potential source location responsible for wind blown emissions. The Delta Group was responsible for deploying and operating sophisticated research sampling instruments designed to measure the mass, size distribution and elemental composition of the particulate pollution. These samplers were located downwind from the SVRA and a number of control sites that currently do not allow OHV activity. The samplers were also used to look for tracer elements to assess if petroleum coke from the ConocoPhillips refinery facility was being entrained by winds and impacting ambient PM levels in the area. The Delta Group also collected and analyzed soil samples upwind from each monitoring station.

The 3-pronged field investigation effort for the Phase 2 study gathered well over two million data points, requiring nearly a year to review, validate and analyze the data and compile the results. The data analysis was performed by the three independent research groups involved in designing and implementing the study, followed by peer review of the draft study report by a diverse and respected group of scientists with expertise in this field. This wealth of data and critical review of the results by numerous independent experts, combined with the results from the Phase 1 study, provides a much more complete understanding of the particulate pollution problem in the area, leading to the following major findings:

- The airborne particulate matter predominantly impacting the region on high episode days does not originate from an offshore source.
- Neither the petroleum coke piles at the ConocoPhillips facility nor agricultural fields or activities in and around the area are a significant source of ambient PM on the Nipomo Mesa.
- The airborne particulate matter impacting the Nipomo Mesa on high episode days predominantly consists of fine sand material transported to the Mesa from upwind areas under high wind conditions.

- The primary source of high PM levels measured on the Nipomo Mesa is the open sand sheets in the dune areas of the coast.
- The open sand sheets subject to OHV activity on the SVRA emit significantly greater amounts of particulates than the undisturbed sand sheets at the study control sites under the same wind conditions.
- Vegetated dune areas do not emit wind blown particles; the control site dunes have significantly higher vegetation coverage than is present at the SVRA.

The major findings resulting from detailed analysis of the diverse and comprehensive data sets generated during the Phase 1 and Phase 2 South County PM Studies clearly lead to a definitive conclusion: OHV activity in the SVRA is a major contributing factor to the high PM concentrations observed on the Nipomo Mesa.

There are two potential mechanisms of OHV impact. The first is direct emissions from the vehicles themselves, which includes fuel combustion exhaust and/or dust raised by vehicles moving over the sand. Elemental analysis of study data shows combustion exhaust particles are not a significant component in the samples during high concentration periods. However, analysis of SVRA vehicle activity data does show a weak relationship between high PM10 concentrations and high vehicle activity. This indicates a very small direct emissions impact from OHV activity caused by wind entrainment of dust plumes raised by vehicles moving across the open sand. While significant, the study data shows this is not the major factor responsible for the high PM levels downwind from the SVRA.

The second potential mechanism of impact from OHV activities involves indirect emission impacts. Offroad vehicle activity on the dunes is known to cause de-vegetation, destabilization of dune structure and destruction of the natural crust on the dune surface. All of these act to increase the ability of winds to entrain sand particles from the dunes and carry them to the Mesa, representing an indirect emissions impact from the vehicles. The data strongly suggests this is the primary cause of the high PM levels measured on the Nipomo Mesa during episode days.

1 INTRODUCTION AND BACKGROUND

Historical ambient air monitoring on the Nipomo Mesa has shown atypical concentrations of airborne particulate matter compared to other areas of San Luis Obispo County and other coastal areas of California (8). A variety of air quality measurements have been made at several locations on the Nipomo Mesa over at least the last two decades. These historical measurements show that the California health standard for PM_{10} (airborne particles with a mean aerodynamic diameter of 10 microns or less) is regularly exceeded in many locations on the Mesa (6).

To better understand the extent and sources of these unusually high concentrations of particulate pollution, the San Luis Obispo County Air Pollution Control District (SLO APCD) has performed numerous air monitoring projects on the Mesa. The most comprehensive study in that area prior to the current effort was performed in 2004. In that study (Phase 1), filter-based manual particulate samplers measuring both PM_{10} and $PM_{2.5}$ (particles with a 2.5 micron diameter or less) were utilized to collect samples from 6 monitoring stations on the Nipomo Mesa over a one year period; the samples were then analyzed for mass and elemental composition.

The results of the Phase 1 study documented the extent and severity of the particulate pollution problem on the Nipomo Mesa. Data from this study showed exceedances of the state 24-hour PM_{10} health standard at one or more monitoring sites on the Mesa on more than one quarter of the sample days. Five of the six state and federal particulate health standards were exceeded over the study period. Elemental analysis of the particulate samples showed that on high concentration days, the majority of the particle mass consisted of earth crustal elements, along with 5 to 10 % sea salt, about 5% ammonium sulfate and less than 1% ammonium nitrate (6).

Review of the study data demonstrated a strong correlation between high PM concentrations and high winds. A directional PM_{10} sampler was installed at a monitoring site located at the CDF fire station on the Mesa; it was designed to measure particles only when the wind was blowing from the direction of the dunes upwind from the monitoring site, as compared to the other nearby samplers which measured particulates from all directions. Figure 1.1 presents this data, clearly demonstrating that the majority of the mass captured on high concentration days originated in the direction of the upwind dunes.

The non-dune related PM levels measured with the directional sampler (shown in red) at CDF are similar to levels found at other monitoring locations on the central coast, as shown in Figure 1.2. This chart presents the 24-hour average PM_{10} levels measured at the Morro Bay monitoring station during the Phase 1 study, and are typical for the Central Coast (8). Comparing the data from the CDF site to the Morro Bay site demonstrates how atypical the PM_{10} measurements on the Nipomo Mesa are for this region. The comprehensive Phase 1 monitoring study documented a PM concentration gradient that peaked near the coastal sites and declined at sites located further inland. Localized contributions appeared to be minimal, with the exception of one site located near a dirt road.

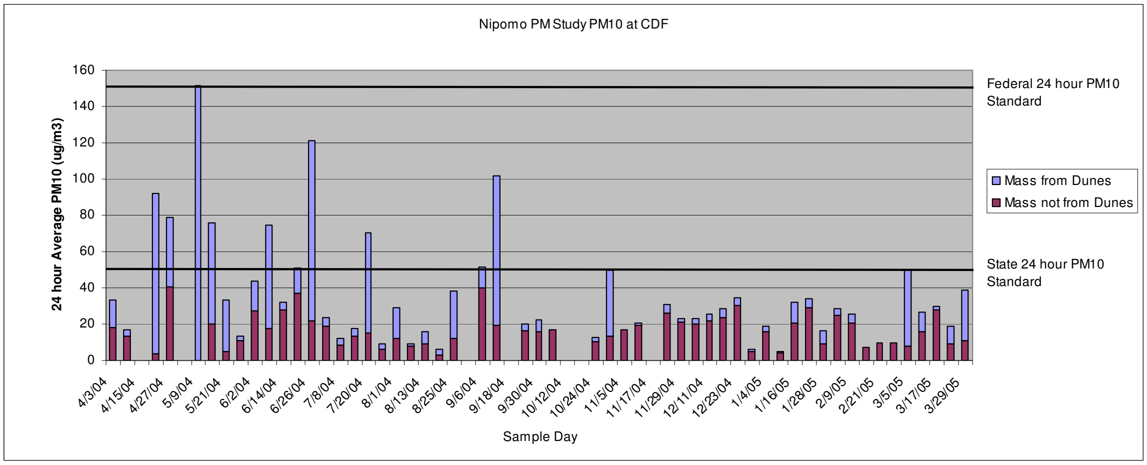

Figure 1.1 – Directional Sampler PM_{10} Measurements at CDF (Phase 1 Study)

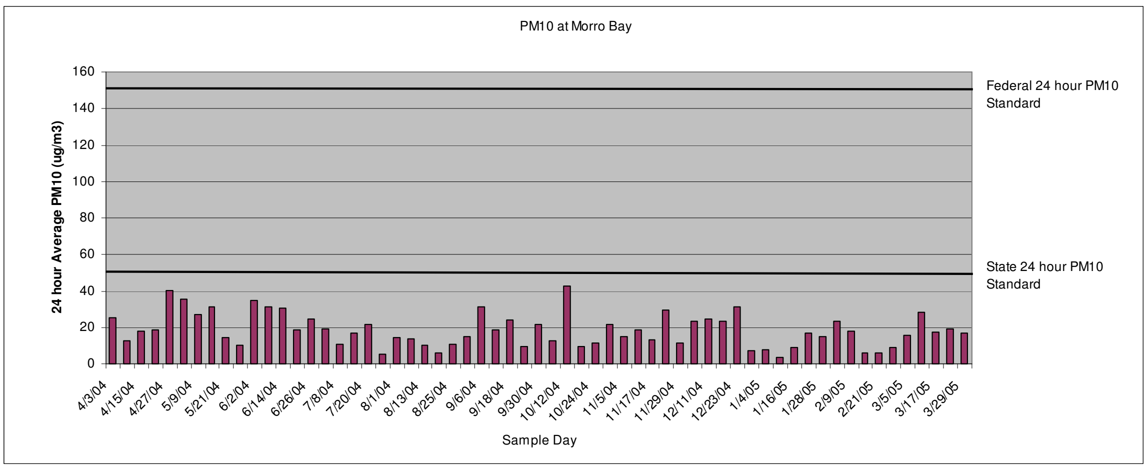

Figure 1.2 - PM_{10} Measurements at Morro Bay (Phase 1 Study)

Data from the Phase 1 study as well as historical data were used to investigate the relationship between off-road vehicle activity at the Oceano Dunes State Vehicle Recreation Area (SRVA) located in the dunes upwind from the Nipomo Mesa) and the observed particulate concentrations. That analysis did not yield definitive conclusions on the issue. After the Phase 1 study results were presented to the APCD Board of Directors, they directed staff to perform a second study to determine the specific cause of the high PM_{10} levels measured on the Nipomo Mesa, including whether or not the off-road activity at the SVRA plays any role in the problem.

To help design and conduct the Phase 2 study, the San Luis Obispo County APCD retained the services of the Delta Group, an affiliation of scientists, mostly from the University of California at Davis (UCD), dedicated to the detection and evaluation of aerosol transport. The Delta Group is led by UCD professors Dr. Thomas Cahill and Dr. David Barnes. Additionally, the APCD retained assistance from the Santa Barbara County APCD, the Great Basin Unified APCD (GBUAPCD), the California Air Resources Board (CARB) and California State Parks.

An additional area of investigation added to the Phase 2 study was whether or not high winds had the potential to entrain and transport petroleum coke particles from the large storage piles located at the ConocoPhillips refinery on the Nipomo Mesa. The Delta Group has developed and utilized advanced sampling technology that is particularly well suited to the detection of the type of particles found in coke piles.

1.1. Evaluation of Potential Sources of Aerosols

Two factors are vital in the evaluation of potential aerosol sources:

1. The friability and particle size profiles of the materials, which provides an estimate of the nature of the materials that might be suspended into the ambient atmosphere; and
2. The wind shear present on the materials, which is a combination of the strength of the wind and the ground level, the friction velocity, and momentum transfer, modulated by the parameter z_o that gives the effective wind profile as it approaches the ground. (Seinfeld and Pandis, 1997, pg 873)

Thus, a highly friable soil under a vegetative cover that effectively reduces the wind velocity to zero at and just above the ground may not be emitted into the atmosphere, while a less friable soil exposed to the full wind velocity may be resuspended in the air. The nature of the sources of the materials and the mode of resuspension can be further clarified by classification of source type and mechanisms. Since airborne dust comes from a variety of sources, it helps to break them into categories. Each category has its own characteristics that allow source identification.

Table 1.1 Characterization of Ambient Dust Sources

Source of Materials		**Categories of Airborne Dust**	
		Caused by Wind	**Caused by Man's Activities**
Natural – unmodified by humans		**1**: Natural background	**2**: Resuspended dust
Man made – tailing piles, dirt roads		**3:** Fugitive dust	**4**: Primary pollutant emissions

Categories 1 and 4 in Table 1.1 above are the easiest to identify, but the second and third are the most important.

The first, **natural background** represents unmodified soil surfaces eroded by natural winds. Since soils over time protect themselves with physical and biological crusts, vegetation, and the like, these dusts are usually low in concentration except in high wind events (Saharan dust storms, some Chinese storms, etc.). Exceptions may occur for dry lake playas and vegetative free beach zones.

The fourth, **primary pollutant emissions** are also easy to identify as both the particle size and composition are different from natural dusts. In many cases, the source itself is known or suspected such as a tall stack at an industrial facility, a cement plant, or in this case, motor vehicles and the ConocoPhillips refinery.

The second, **resuspended dust**, represents a natural material that has become airborne through human activity. Examples include vehicles traveling on unpaved roads, construction equipment clearing a site, and farming operations. While the resulting airborne particles may be chemically the same as natural background, human activities may modify particle size and its correlation to wind velocity. For example, a farm field stripped of vegetation that can then be picked up by natural winds falls into this category, since chemically the materials are still soil.

The third, **fugitive dust,** is represented by a human created material capable of being picked up and transported by natural winds. Wind-blown dust from industrial tailings piles are a prime example, as these materials are chemically different from natural soils. Roadway dusts are also polluted with metals from brakes, rubber from tire wear and other non-soil compounds. Thus, compositional analysis aids in their identification. In this study, the ConocoPhillips coke piles are a potential source of fugitive dust.

The South County Phase 2 PM Study was designed to examine all four source categories of ambient dust described above and their potential role in contributing to the high particulate levels observed on the Nipomo Mesa. The following chapters describe the study design, monitoring and analyses performed, results obtained and conclusions reached:

Chapter 2: Study Design
Chapter 3: Ambient PM_{10} and Meteorological Measurements and Data Analysis
Chapter 4: Sand Flux Measurements and Data Analysis
Chapter 5: Aerosol and Soil Particle Composition and Size Measurements and Data Analysis
Chapter 6: Major Findings, Summary and Conclusions
Chapter 7: References

2 STUDY DESIGN

The primary goals of the Phase 2 Particulate Study are as follows:

1. To definitively identify the source(s) of the observed high particulate levels on the Nipomo Mesa, including:
    a. Assessing if the off-road vehicle activity at the Oceano Dunes State Vehicle Recreational Area significantly impacts downwind particulate concentrations; and,
    b. Determining what, if any, off-site particulate impacts are due to fugitive dust from the petroleum coke piles at the ConocoPhillips Refinery on the Mesa;
    c. Assessing if agricultural or other activities in the area significantly impact downwind particulate concentrations.
2. To determine the contribution of direct and/or indirect emissions as causative factors in the PM levels observed.

Accomplishing these goals presents many technical challenges. Demonstrating that a particular activity is responsible for the ambient particulate levels measured in a given area requires a clear linkage between the particles being emitted by the activity and the concentrations being measured at the receptor locations. Demonstrating that a particular activity is not responsible for that impact requires demonstrating the particles are not emitted in the area of the activity, and/or the activity is not causing particulate emissions.

It is important to recognize that there are two distinctly different potential mechanisms by which the off highway vehicle (OHV) activity on the Oceano Dunes might contribute to the observed particulate pollution problem on the Nipomo Mesa. Direct emission impacts from the vehicles themselves, such as fuel combustion exhaust and dust raised by vehicles moving over the sand, are one potential mechanism. Indirect emission impacts can also result from offroad vehicles causing de-vegetation, destabilization of dune structure, destruction of the natural crust on the dune surface, and/or creation of finer sand particles by grinding action of the tires, all of which can increase the ability of winds to entrain sand particles from the dunes and carry them to the Mesa.

To achieve the two primary study goals described above, the study design incorporated a broad array of both of regulatory and research analysis techniques, including:

- Real-time PM monitors used in conjunction with wind measurements to identify source locations.
- Analysis of elemental and particle size distribution using drum samplers to determine the source type and area.
- Measurement of sand movement on the dunes to evaluate its correlation to downwind PM_{10} concentrations and help define the emission mechanism responsible for the elevated downwind PM_{10} concentrations. Sample sites included the SVRA and an un-ridden control dune area to calculate the wind speed at which sand movement occurs and the mass of sand movement at a given wind speed, both indicators of susceptibility to wind erosion.
- Comparison of PM_{10} concentrations downwind from the SVRA and control sites to gauge the PM contribution from areas with different activities.

Utilizing these diverse sampling techniques directed by independent research groups is a key strength of the Phase 2 study design, making it much more comprehensive and objective than a study performed by a single group using a single analysis method. Each research group is composed of professionals and scientists recognized as experts in their field and in the sampling techniques they employed. Table 2.1 below lists the three areas of investigation, the responsibilities of each group and their sampling methods.

Table 2.1 - Group Responsibilities in Phase 2 Study

Group	**SLO APCD**	**Delta Group**	**GBUAPCD/CARB**
Responsibility	*Ambient PM levels & meteorology measurements*	*Elemental composition & size distribution of particles*	*Sand movement (flux) in potential source areas*
Sampling Methods	US EPA-approved continuous tapered element oscillating microbalance (TEOM); non-EPA approved beta attenuation monitor; EPA-approved manual gravimetric particulate samplers; continuous wind speed, wind direction and temperature measurements	Customized drum samplers for elemental composition & continuous mass concentration by particle size; soil analysis for particle size distribution and elemental composition	”Sand catchers” to measure overall sand flux, and “Sensit” samplers to record sand movement at a specific point in time.

SLO APCD Sampling and Analysis

The SLO APCD portion of the study included operating PM_{10} monitors and wind direction and speed sensors at locations downwind from the SVRA, as well as locations to the north and south of the SVRA that are downwind from “control areas” where no OHV traffic is present. In the District operated network, most monitoring stations were equipped with new technology continuous PM_{10} monitors. Past particulate monitoring on the Nipomo Mesa has been performed with only manual samplers that produce a single 24-hour average every 6 days. The new technology PM_{10} monitors produce a continuous recording of PM_{10} concentration that is much easier to correlate to wind conditions and therefore the source of the particulates. The SLO APCD PM_{10} measurements record only the mass of airborne particles smaller than 10 microns, and do not typically analyze the composition of the particles being measured. An exception is the Pier Avenue station, where manual 24 hour PM_{10} measurements were made. In order to better understand the role of salt particles on samples taken so close to the ocean, the Pier Avenue filters were analyzed for chloride ions by the CARB inorganic laboratory in Sacramento.

Delta Group Sampling and Analysis

The Delta Group portion of the study included the use of their customized drum samplers (figures 2.1 and 2.2 below). The drum sampler was developed by the Delta Group and has been used worldwide; it provides much more detail on the size and composition of PM_{10} particles than is available with traditional monitoring methods. The drum sampler has the capability to measure the mass and elemental composition of various size categories of airborne particles, which provides a much wider range of information for determining the source of particles.

The Delta Group performed both long term (one year) drum sampler measurements and short term ambient PM_{10} measurements during the spring and fall of 2008 when high wind conditions were forecast. In addition to the ambient drum sampler measurements, the Delta Group collected over 150 soil samples along upwind transects from most monitoring locations. Selected soil samples were analyzed for particle size distribution as well as elemental composition.

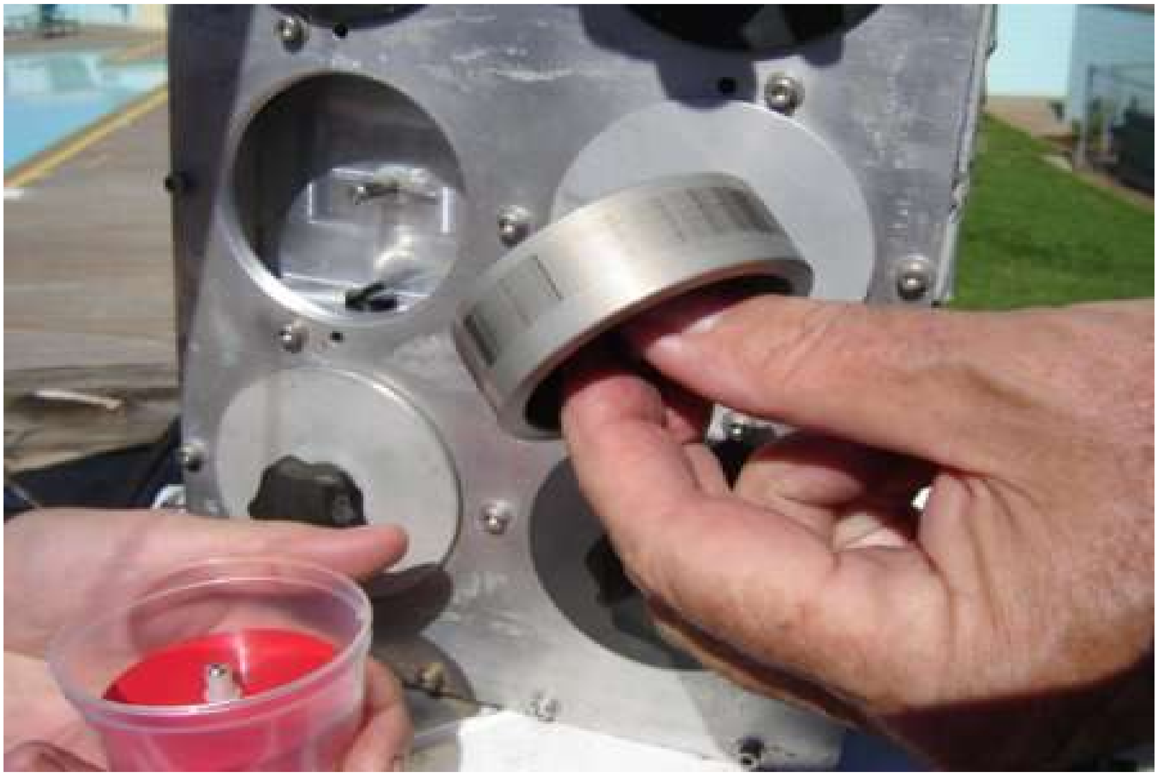

Figure 2.1- Drum Sampler with One Drum Removed

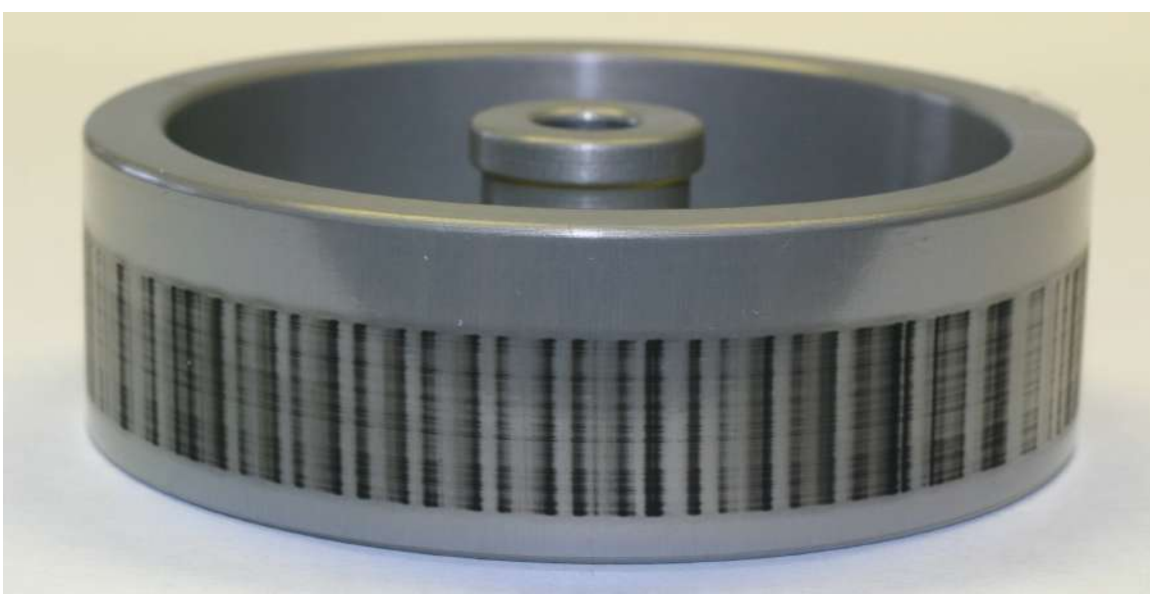

Figure 2.2 - Drum with Deposited Fine Particulates

Table 2.2 and Figure 2.3 below outline the specific location and type of measurement performed by both the SLO APCD and the Delta Group.

Table 2.2– Listing of Measurements Performed by SLO APCD and the Delta Group

Site Name	Main Purpose of Site	Delta Group Measurements	Delta Group Sampling Period	APCD Measurements	APCD Sampling Period
Ten Commandments	South Control Site	8 Drum Sampler (battery powered)	4/26/08-5/12/08	None	None
Dune Center	South Control Site	8 Drum Sampler	Sept 2008 – Nov 2008	Continuous PM_{10} (E-BAM)	March 2009
Oso	South Control Site	8 Drum Sampler (battery powered)	4/26/08-5/12/08	Continuous PM_{10} (solar powered E-BAM), Wind Speed, Wind Direction, Temp., Relative Humidity	March 2008-March 2009
Mesa2	Site Downwind From SVRA	8 Drum Sampler	January 2008-February 2009	Continuous PM_{10} (TEOM),FRM PM_{10} (one is six days) Wind Speed, Wind Direction, Temperature	March 2008-March 2009
Conoco Upwind	Site Downwind From SVRA	8 Drum Sampler (battery powered)	4/26/08-5/12/08	None	None
Hillview	Continued From Phase1, asses localized impact from dirt road.	None	None	FRM PM_{10} (one in six days)	March 2008-March 2009
CDF	Site Downwind From SVRA	8 Drum Sampler	4/26/08-6/20/08	Continuous PM_{10} (TEOM),Wind Speed, Wind Direction, Relative Humidity	March 2008-March 2009
Bluff	North Control Site, also downwind from agricultural operations.	8 Drum Sampler	4/26/08-5/12/08	None	None
Silver Spur	North Control Site	3 Drum Sampler	4/26/08-5/12/08	None	None
Pier Ave.	Asses PM10 exposure in an areas where monitoring has never been performed	3 Drum Sampler	4/26/08-5/12/08	FRM PM_{10} (one in six days) for mass and chloride ion	March 2008-March 2009
Grover Beach	North Control Site	8 Drum Sampler	4/26/08-5/12/08	Continuous PM_{10} (TEOM),Wind Speed, Wind Direction	March 2008-March 2009

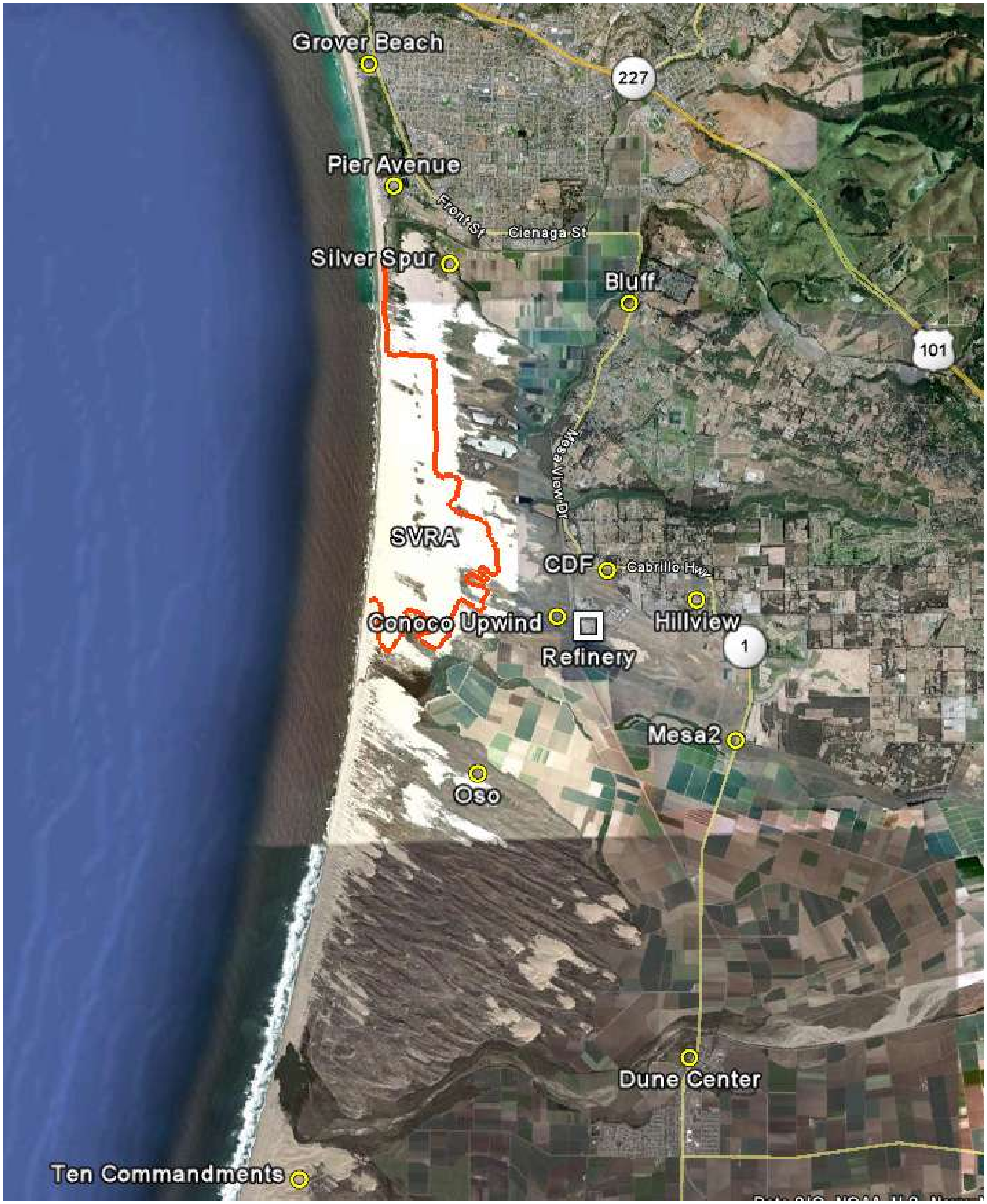

Figure 2.3 – Location of SLO APCD and Delta Group Monitoring Stations

Great Basin Unified APCD and CARB Sampling and Analysis

The GBUAPCD and CARB portion of the study collected measurements of sand movement in the SVRA and in a control area south of the SVRA where OHV traffic is currently not allowed. Measuring the movement of soil/sand by winds provides data on the mechanism by which crustal particles become entrained in the air. The entrainment process, depicted in Figure 2.4 below, involves saltation, creep, and suspension of particles in the air.

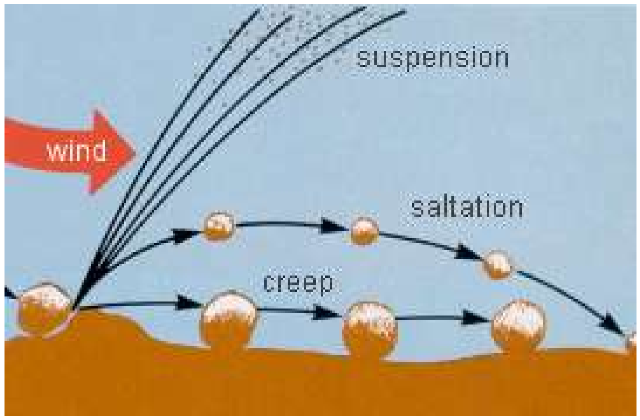

Figure 2.4 – Graphic of the Saltation Process

Various techniques to measure sand movement have been used by many researchers to better understand the "sand flux" process and resulting particulate emissions. The GBUAPCD has utilized and refined these techniques as part of their comprehensive monitoring and mitigation program on the Owens Lakebed. They provided all the necessary equipment, technical guidance, training, and data analysis for this portion of the study. The actual operation and maintenance of the measurement devices, informally known as "sand catchers", was managed by a local employee of the CARB, Phil Wagner, under the oversight of GBUAPCD. Mr. Wagner also directed the work of several interns hired by SLO APCD to assist him with sample collection from the measurement network.

The sand flux measurement network used two different types of sand catchers (figures 2.5, 2.6, and 2.7 below) designed to measure the total mass of sand movement each day; it also included Sensit samplers , which record how much sand is moving at any point in time by recording each time a grain of sand hits the Sensit. The sand flux measurements were performed from April 23, 2008 through May 24, 2008, the period of highest historical winds in the study area; the Delta Group also conducted their two week intensive monitoring during this period.

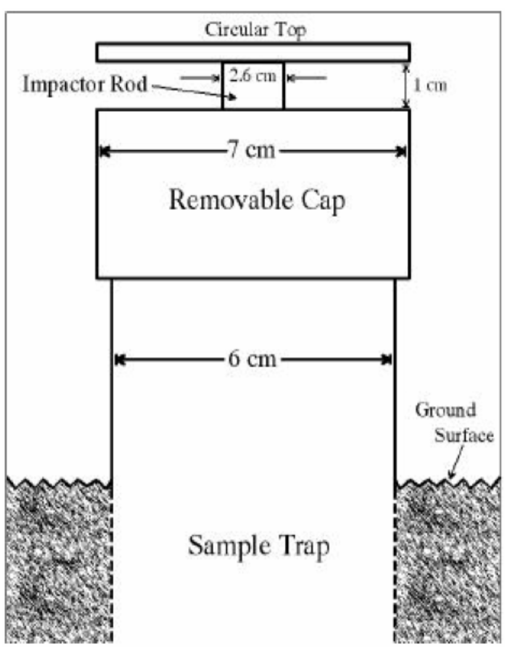

Figure 2.5 - Cox Sandcatcher

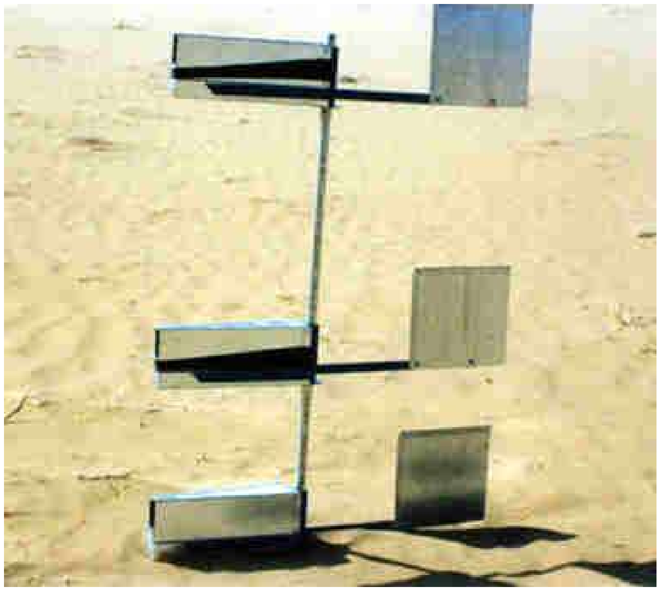

Figure 2.6 - BSNE Sandcatcher

Figure 2.7 - Site C2 with Sensit, Cox Sandcatcher, and Datalogger

Figure 2.8 below shows the sand flux measurement locations for the study. Site C1 and C2 were equipped with a sensit, cox sandcatcher, and a BSNE sandcatcher. Site C12 was equipped with a sensit and a cox sandcatcher. All other sand flux measurement sites were equipped with a single cox sandcatcher.

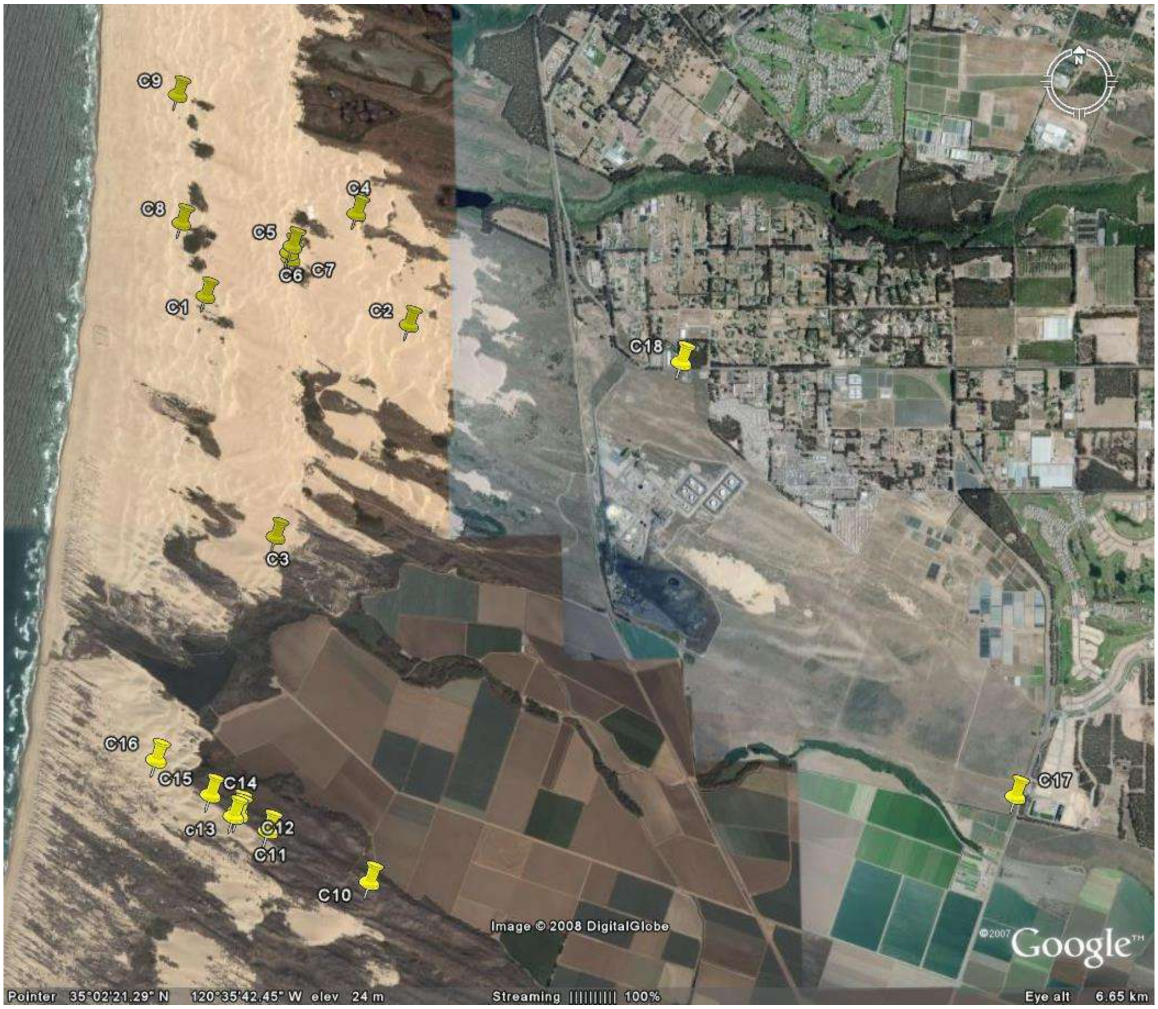

Figure 2.8 – Location of Sand Flux Measurement Locations

3 AMBIENT PM_{10} AND METEOROLOGICAL MEASUREMENTS AND DATA ANALYSIS

The San Luis Obispo County APCD installed, operated and maintained the instruments used to measure ambient PM_{10}, as well as the meteorological instruments used to record wind speed, wind direction and other weather parameters. This chapter describes the measurements performed and presents the data collected by the SLO APCD during the Phase 2 PM Study.

Monitoring Site Descriptions and Measurements Performed
Each monitoring station and the data gathered are described starting with the most northern station and ending with the most southerly station. Refer to Figure 2.3 for the location of each monitoring station.

Grover Beach Monitoring Station
The Grover Beach monitoring station was selected as a northern control site to measure PM_{10} particulate concentrations and meteorological conditions north of the SVRA where there is no upwind OHV traffic. It is located 0.3 miles from the ocean following prevailing ocean winds (300 deg). This station was operated by the SLO APCD for many years as a background site, measuring gaseous pollutant concentrations of the oceanic air mass as it comes onshore. Because of the close proximity to the ocean, particulates had never been previously measured at this station as it clearly would be heavily influenced by airborne sea salt. However, for this study, particulate measurements provide a record of conditions upwind of any OHV/SVRA influence, while acknowledging the heavy influence of sea salt.

Figure 3.1– Aerial View of Grover Beach Monitoring Station

Figure 3.2 - Grover Beach Monitoring Station (North View)

Study measurements at this site included wind speed, wind direction and sigma theta at 10 meters and continuous PM_{10} at 3.5 meters. The PM_{10} measurements were made using a Rupprect and Patashnick tapered element oscillating microbalance (TEOM). This instrument is certified by the US EPA as a Federal Equivalent Method (FEM), which allows the data to be compared to the PM_{10} health standards.

Figure 3.3 below is a wind rose depicting wind patterns for the Grover Beach Monitoring Station during the Study Period. The wind rose shows the predominant wind direction is from the west. It also shows wind speeds greater than 17 mph only occur under westerly winds.

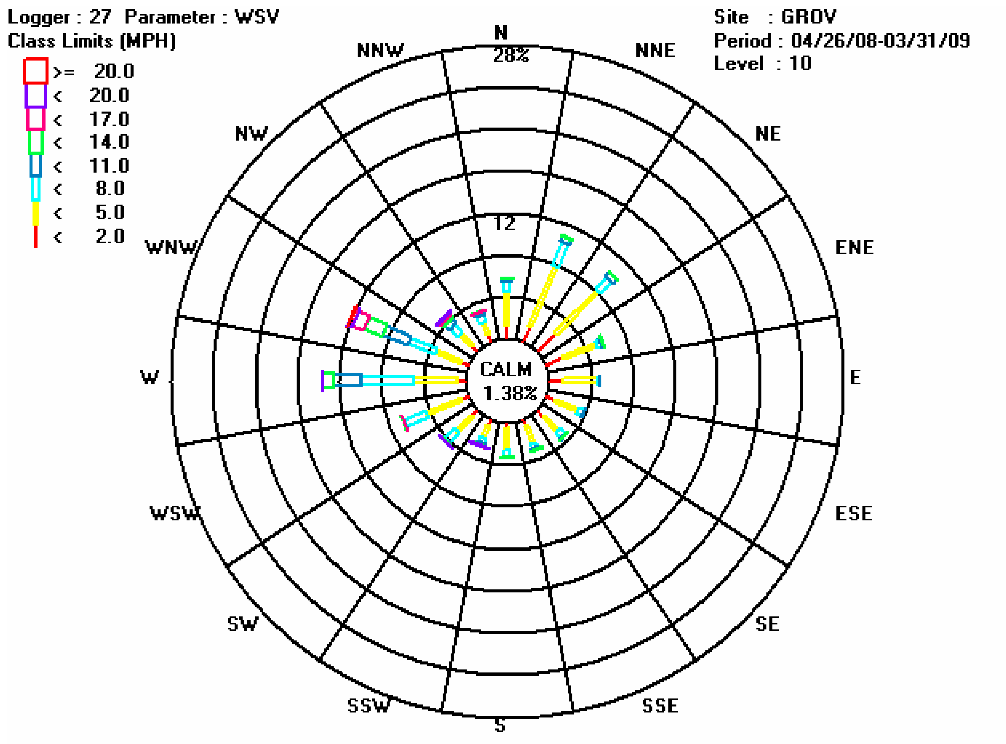

Figure 3.3 – Grover Beach Wind Rose Summarizing Wind Conditions

Figure 3.4 below presents the 24-hour average PM_{10} values for the study period. The Grover Beach dataset shows numerous violations of the state 24-hour PM_{10} standard of 50 ug/m3. However, examining the hourly data in Figures 3.5 and 3.6 below shows nearly all of these violations occurred under light or calm winds, with no consistent wind direction apparent when high concentrations are measured. Measurement of high PM_{10} values from a location so close to the ocean typically represents the impacts of sea salt carried in dissolved form by ocean fog. When the salt-laden fog enters the heated inlet of the PM sampler the moisture evaporates, leaving salt deposits on the filter element. State guidelines provide that if sea salt is a contributing factor to a measured exceedance of the state PM_{10} standard, it will not be considered a violation if it can be demonstrated that no exceedance would have occurred without the salt portion (3). Sea salt particulate or sea salt dissolved in fog has not been shown to have a negative health impact.

Figure 3.5 also shows that strong northwesterly winds off the ocean, with a wind direction around 300 degrees, do not result in high hourly PM_{10} values at Grover Beach. This demonstrates that the high PM_{10} levels associated with northwesterly wind events observed on the Nipomo mesa are not present in the air mass prior to reaching land. Additionally, these data indicate that the undisturbed beach and narrow strip of undisturbed dunes upwind of the monitoring station are not capable of emitting significant amounts of PM_{10} particles, even in high wind conditions.

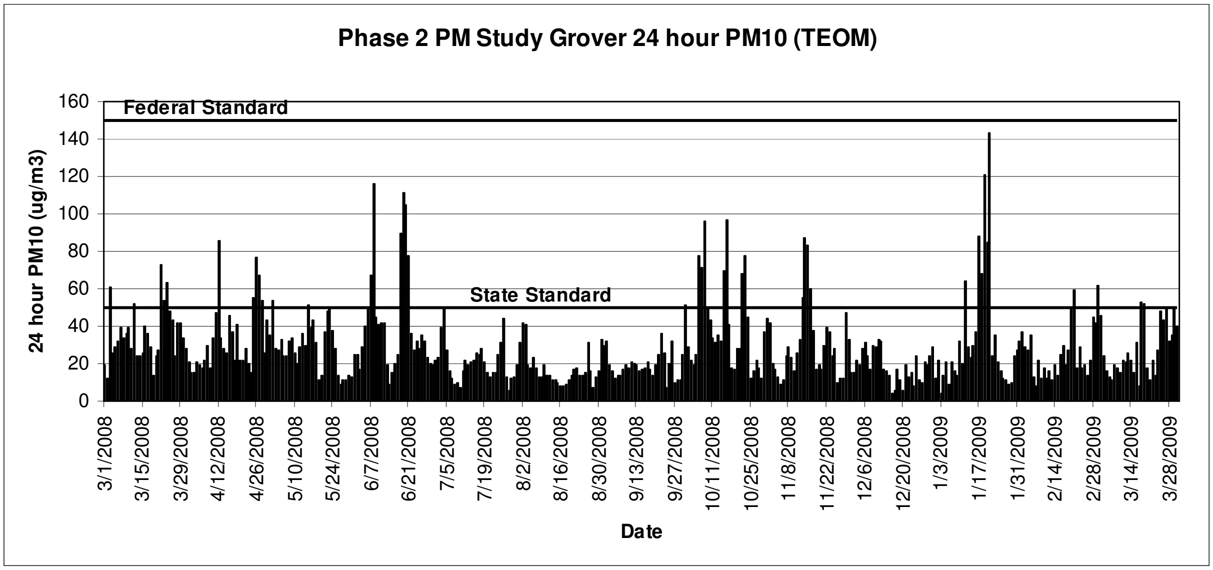

Figure 3.4 – Grover Beach 24-hour PM_{10} Averages

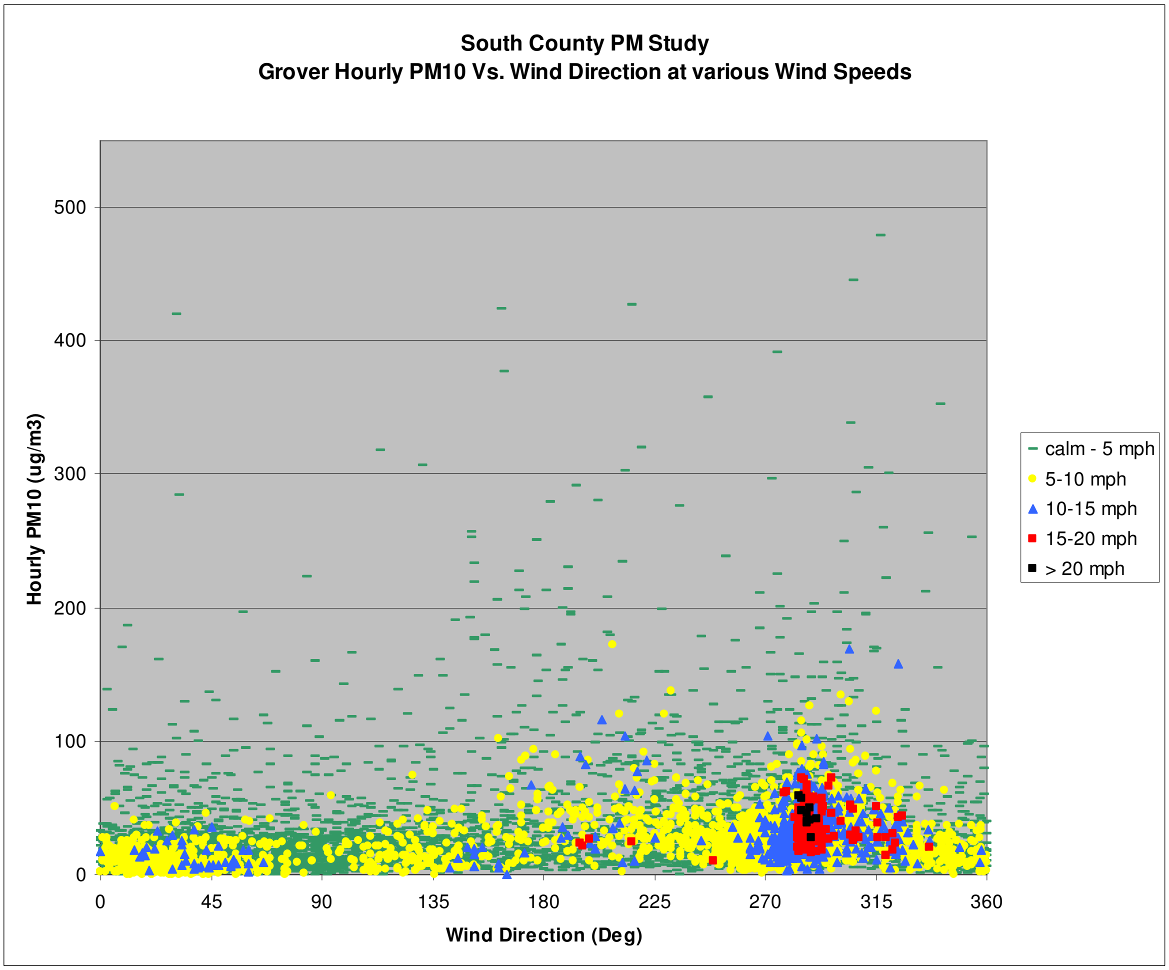

Figure 3.5 – Grover Beach Hourly PM_{10} Compared to Wind Direction at Various Wind Speeds

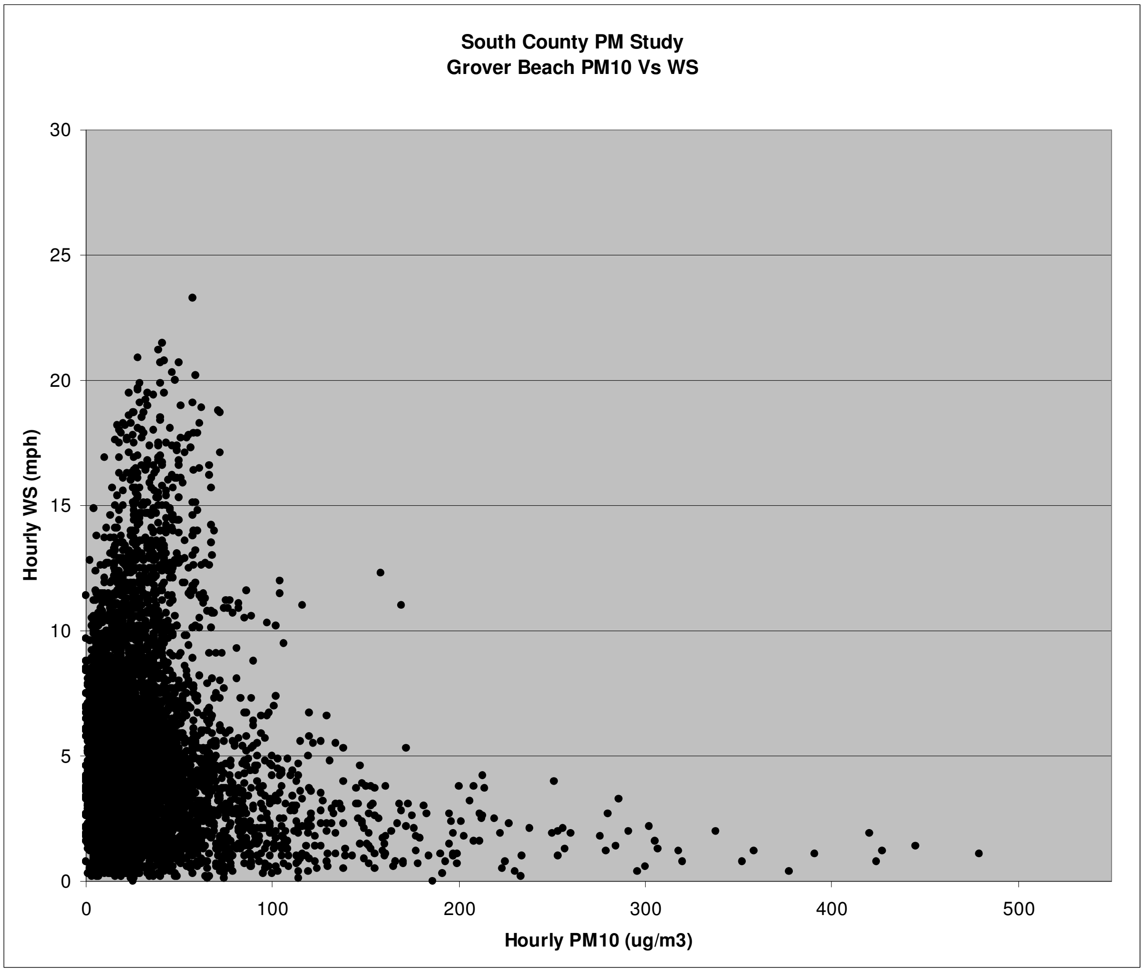

Figure 3.6 – Grover Beach Hourly PM_{10} as Compared to Wind Speed

Figure 3.7 below is a digital strip chart from the Grover Beach monitoring station. This chart shows a typical day with high PM_{10} concentrations, demonstrating that the high values occur when the winds are calm and meandering in different directions.

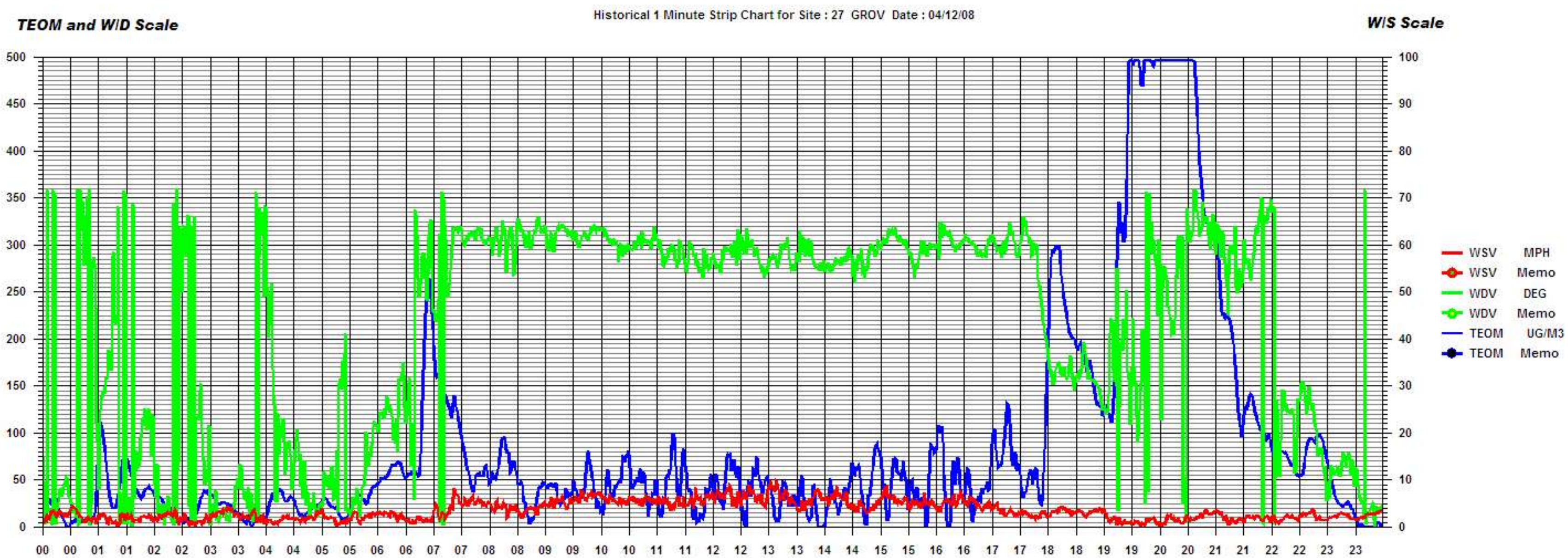

Figure 3.7 - Example Chart for a High PM_{10} Episode at Grover Beach

Pier Avenue Monitoring Station

The Pier Avenue monitoring station was sited to assess the level of PM_{10} exposure experienced by the residents of Oceano. Historical PM monitoring in the area has only been performed further south on the Nipomo Mesa, with no measurements prior to this study in the beach community of Oceano. However, it was deemed important in this study to perform PM measurements in a populated area close to the dunes for comparison to the data collected on the Mesa. The Pier Ave. monitoring station is located 0.3 miles from the ocean following prevailing ocean winds (300 deg). As with the Grover Beach monitoring station, sea salt was expected to influence the particulate measurements due to the close proximity to the ocean. The site location is downwind (under normal daytime winds) of Pier Avenue, which is the southern entrance to the SVRA. Traffic on Pier Avenue can be quite heavy, and the south side of the street (the SVRA exit lane) is typically covered with a layer of sand (red arrow, below). Observation of vehicles exiting the SVRA showed that much of the deposited sand is track-out from the vehicles coming off the beach; windblown sand may also be a contributing factor.

Figure 3.8 – Aerial View of Pier Avenue Monitoring Station

Data collected at this site were 24-hour average PM_{10} measurements using a hi-volume sampler at 3 meters, measured every 6 days per the national sampling schedule. This instrument is certified by US EPA as the Federal Reference Method for PM_{10}, which allows the data to be compared to the PM_{10} health standards. To allow for differentiation between sea salt particulate and other particles, the PM_{10} sample filters from this site were analyzed for Chloride ion by the CARB inorganic laboratory in Sacramento.

Figure 3.9 below presents the 24-hour PM_{10} measurements from the Pier Avenue monitoring station. Each 24-hour measurement is presented as a single bar, with the red portion representing the portion of mass composed of sea salt, and the black portion representing the mass due to all other non-sea salt sources. Clearly, sea salt is a contributing element in many of the samples taken, as was expected due to the close proximity of the site to the ocean.

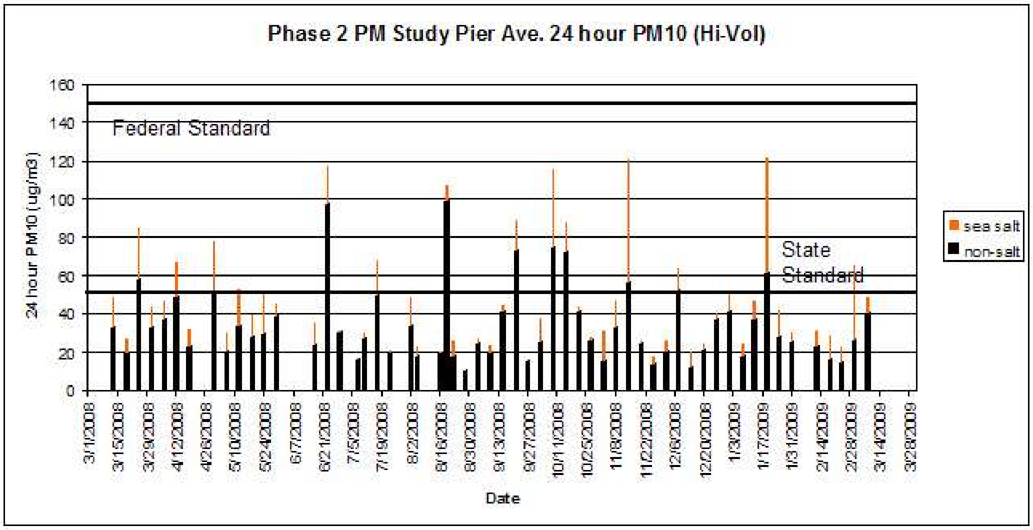

Figure 3.9 – Pier Avenue 24-hour Average PM_{10} Values

Figure 3.10 below provides a comparison of the PM_{10} measurements between the Grover Beach and Pier Ave locations. This graph demonstrates that in all but one sample day, the PM_{10} concentrations measured at Pier Ave. are similar to Grover Beach or higher. There are a number of sample days (3/25/08, 6/23/08,8/19/08,9/21/08,10/9/08) where elevated PM_{10} levels measured at Pier Ave are not heavily influenced by sea salt. The PM_{10} values at Grover Beach for these same days were not significantly elevated and each of these days was characterized by moderate to high wind events. This indicates wind blown particulate, rather than sea salt, was responsible for the high concentrations measured at Pier Ave on these days.

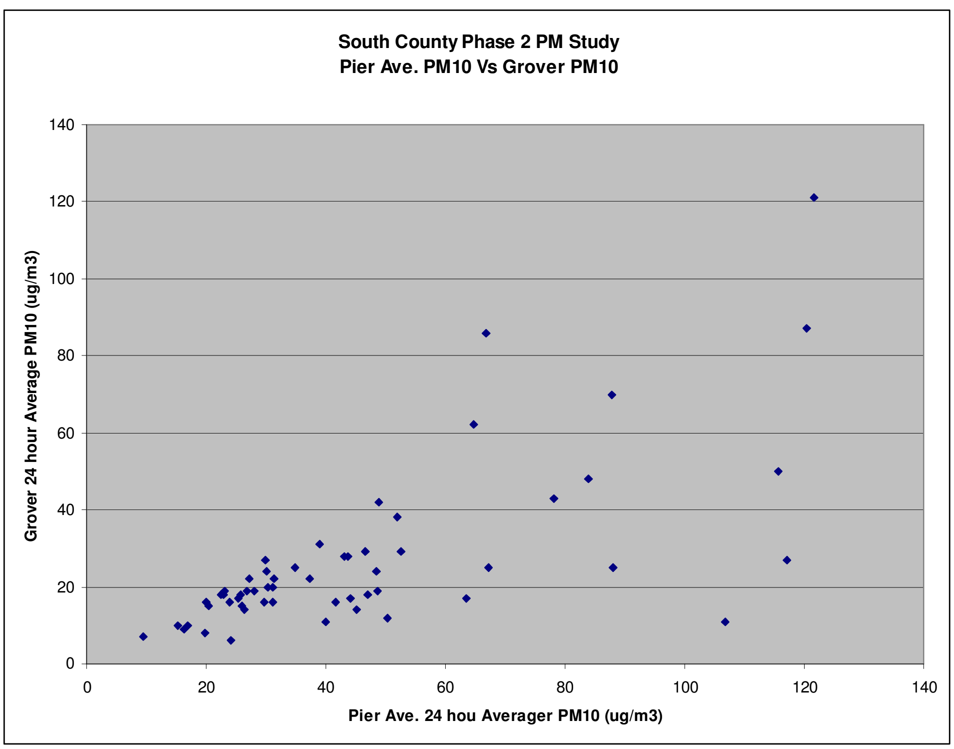

Figure 3.10 – Pier Ave. PM_{10} Plotted Against Grover PM_{10}

CDF Monitoring Station

The CDF monitoring station was selected to measure meteorological parameters and PM_{10} levels immediately downwind of the SVRA; this site has been used in previous investigations of high particulates on the Nipomo Mesa. It is located 1.5 miles downwind from the SVRA and 2.7 miles from the ocean following prevailing ocean winds (300 deg).

Figure 3.11 – Aerial View of CDF Monitoring Station

Figure 3.12 – CDF Monitoring Station (Northwest View)

Study measurements at this site include wind speed and wind direction, sigma theta at 7 meters, relative humidity at 4 meters, and continuous PM_{10} at 3.5 meters. The PM_{10} measurements were made using a Rupprect and Patashnick tapered element oscillating microbalance (TEOM). This instrument is certified by the US EPA as a Federal Equivalent Method (FEM), which allows the data to be compared to the PM_{10} health standards.

Figure 3.13 below is a wind rose depicting wind patterns at the CDF Monitoring Station during the Study Period. The wind rose shows the predominant wind directions from the westerly directions. The highest wind speeds are from the WNW and NW segments.

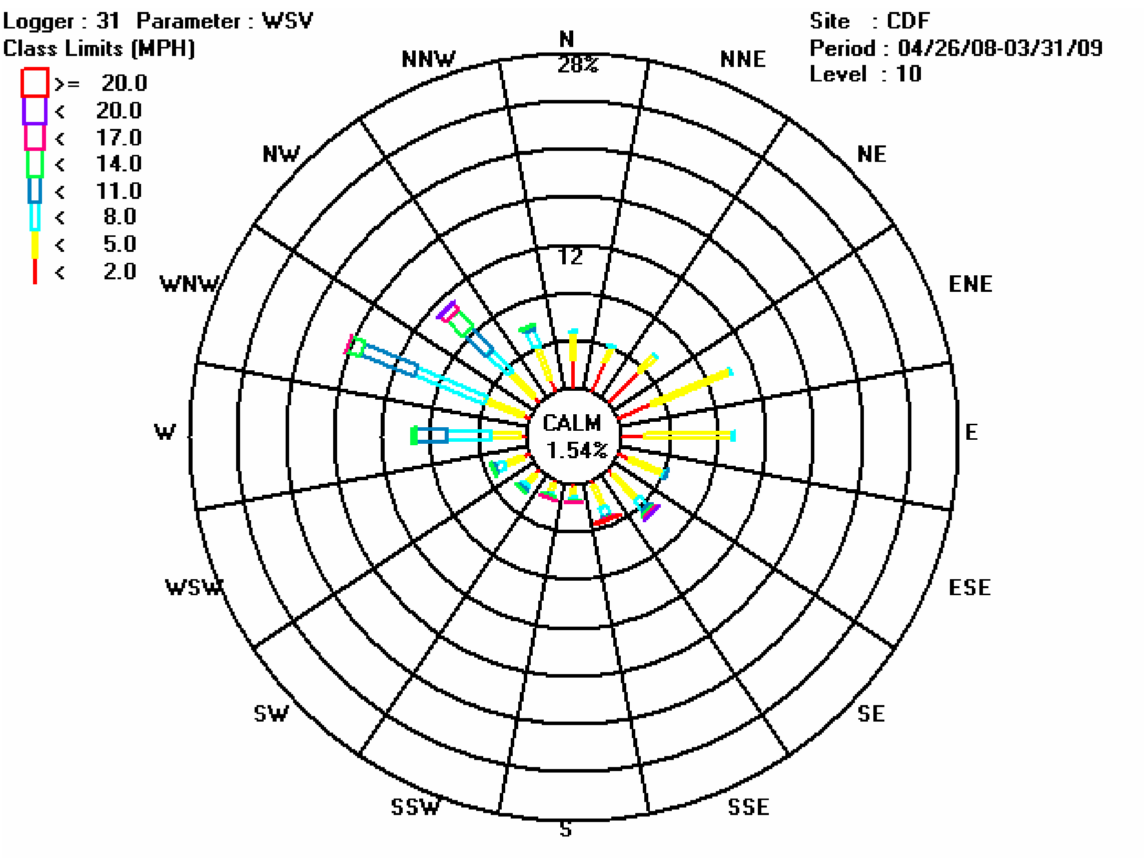

Figure 3.13 – CDF Wind Rose Summarizing Wind Conditions

Figure 3.14 below presents the 24-hour averaged PM_{10} concentrations from the CDF site; as shown, numerous days exceeded the state 24-hour PM_{10} health standard of 50 ug/m3. The highest concentration observed here was a 24-hour average of 149 ug/m3, measured on May 21, 2008; the federal 24-hour PM_{10} health standard is 150 ug/m3. Note that most high concentration days occurred during the spring and fall periods.

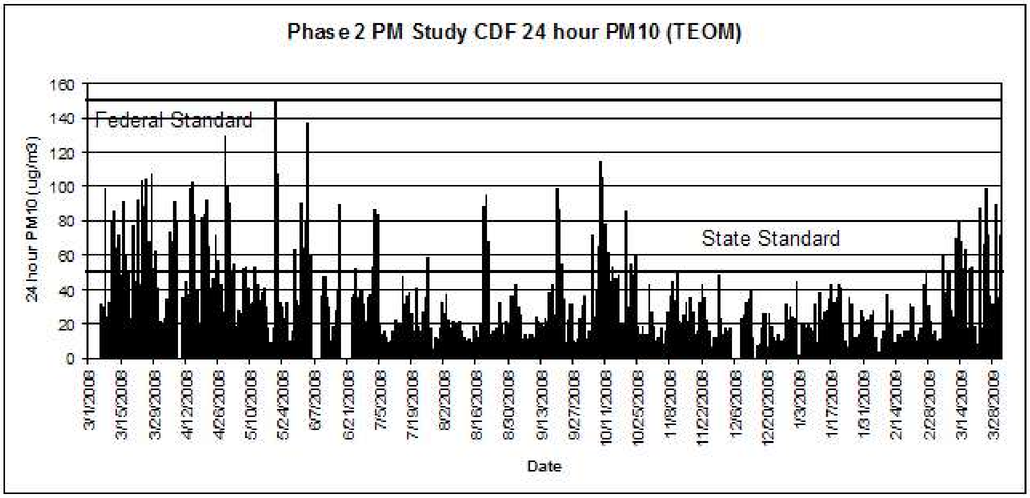

Figure 3.14 – CDF 24-hour Average PM_{10} Values

Figure 3.15 below presents hourly PM_{10} concentrations measured at CDF as compared to wind direction at various wind speeds. As shown, the majority of high concentration values occur at a wind direction of approximately 310 degrees, with the higher concentrations from this direction occurring at higher wind speeds. This dominant cluster of high values around 310 degrees clearly indicates a significant source of particulates upwind in this direction. The high wind speeds associated with these high concentrations provide a strong indication that the PM_{10} source is wind blown material.

There are a few moderately high PM_{10} data points that occur when the wind speed is below 5 mph, as shown in Figure 3.16 below. Because these values occur under calm conditions it is unlikely they are a result of wind blown particles. These values tend to occur in the morning when the winds are calm and the direction is shifting from drainage winds to onshore flow. This pattern indicates that these moderate concentration PM_{10} data points are most likely due to sea salt making its way from the coast under stable conditions that limit dispersion, such as fog. While the data does not prove that these moderate PM_{10} values are salt, it is clear that these moderate values are not caused by wind blown sand due to the wind speed being well below the threshold for sand movement identified in Chapter 4.

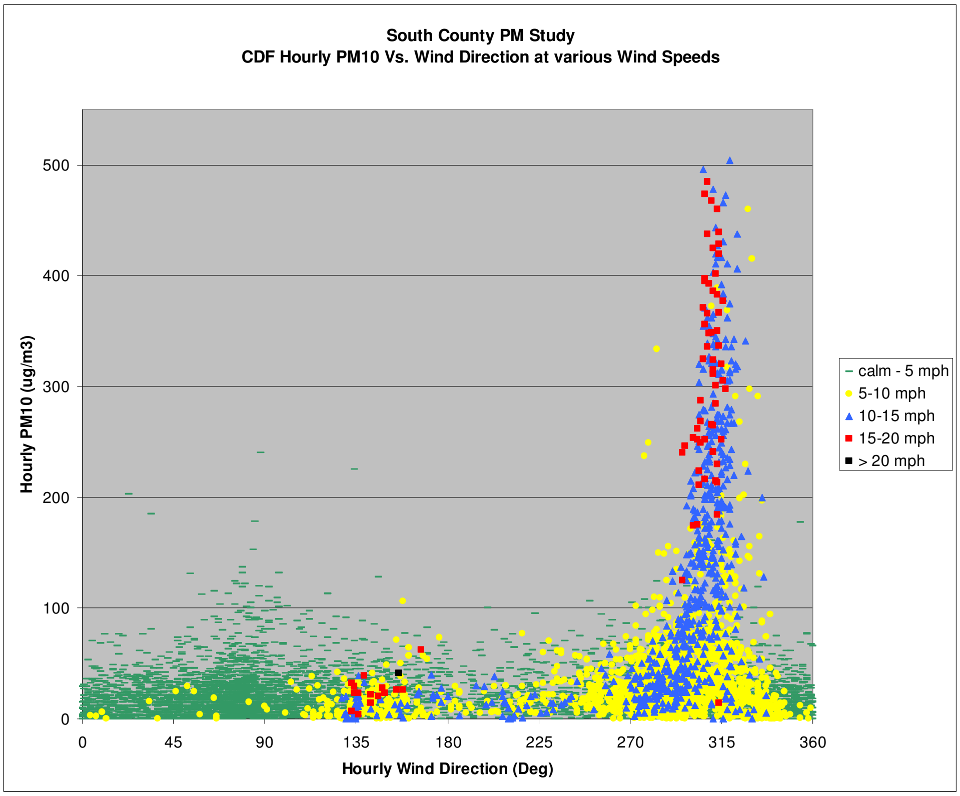

Figure 3.15– CDF Monitoring Station Hourly PM_{10} as compared to Wind Direction

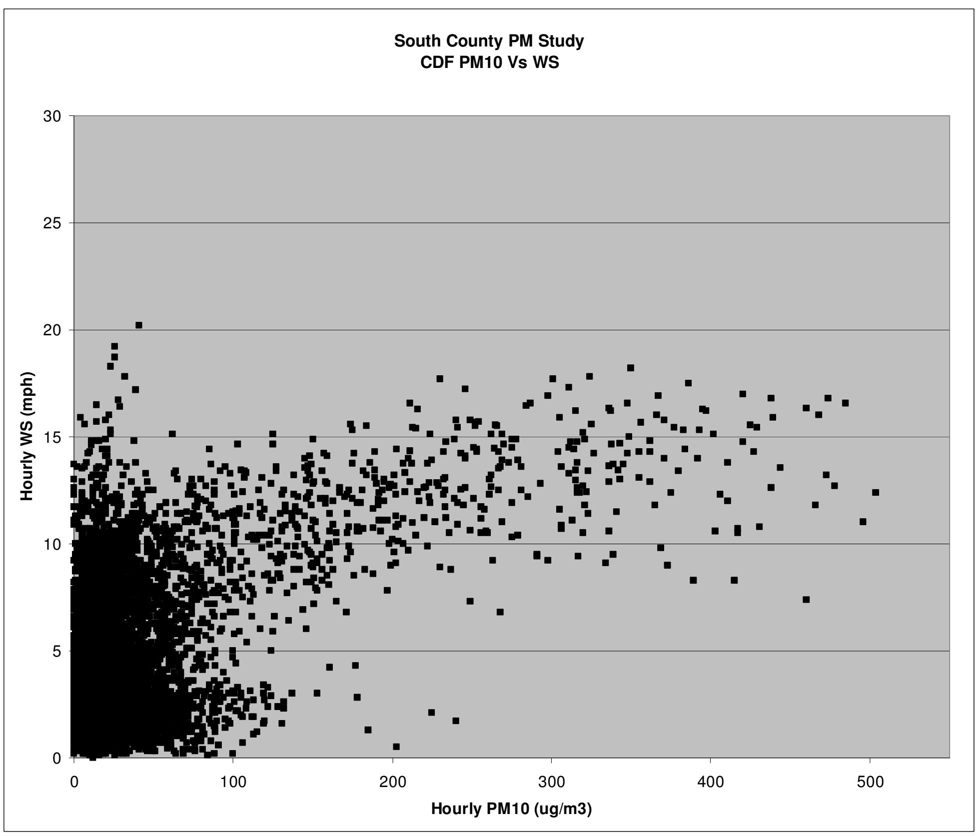

Figure 3.16 – CDF Hourly PM10 as compared to Wind Speed

Hillview Monitoring Station

The Hillview monitoring station is located 2.8 miles downwind from the SVRA and 3.8 miles from the ocean following prevailing ocean winds (300 deg). The sampler is located approximately 15 meters north of Hillview Road, a dirt road used to access this small neighborhood. The station was utilized for the Phase 1 PM Study and appeared to show influence from a nearby dirt road. During that study it was often observed that, under light wind conditions, a cloud of dust would move across the sampling location when a car drove past the site. However, the dust plume would disperse quickly, indicating a highly localized, short-term influence from the dirt road. Thus, the operation of this monitoring site was continued past the Phase1 sampling period and included in the Phase 2 study.

Study measurements at this site were 24-hour averaged PM_{10} at 2 meters, measured every 6 days per the national sampling schedule using a hi-volume sampler. This instrument is certified by US EPA as the Federal Reference Method for PM_{10}, which allows the data to be compared to the PM_{10} health standards.

Figure 3.17 - Aerial View of Hillview Monitoring Station

Figure 3.18 below presents the 24-hour average PM_{10} concentrations measured at Hillview. Figures 3.19 and 3.20 below present the relationship between the 24-hour PM_{10} measurements at Hillview compared to Mesa2 and CDF. Examining these figures shows that, at the lower concentrations typically found at lower wind speeds, Hillview is consistently higher than Mesa2 and CDF; however, at the higher concentrations typically associated with high wind speeds, the levels at the two sites are much closer. This relationship is consistent with localized impacts from a nearby source, such as a dirt road. On sample days without a wind event, the impact of the dirt road is significant due to less dispersion and very little influence from wind blown dust. However, on days with a significant wind event, the impact of the local dirt road is much less significant because of better dispersion and the overwhelming influence of wind blown dust, minimizing the impact of this local source.

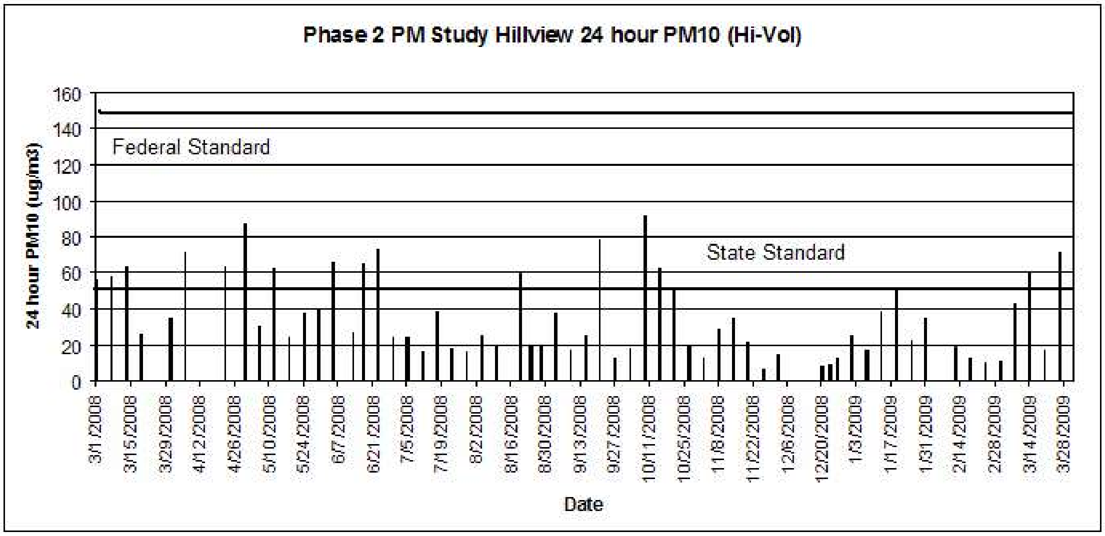

Figure 3.18- Hillview 24-hour Average PM_{10} Values

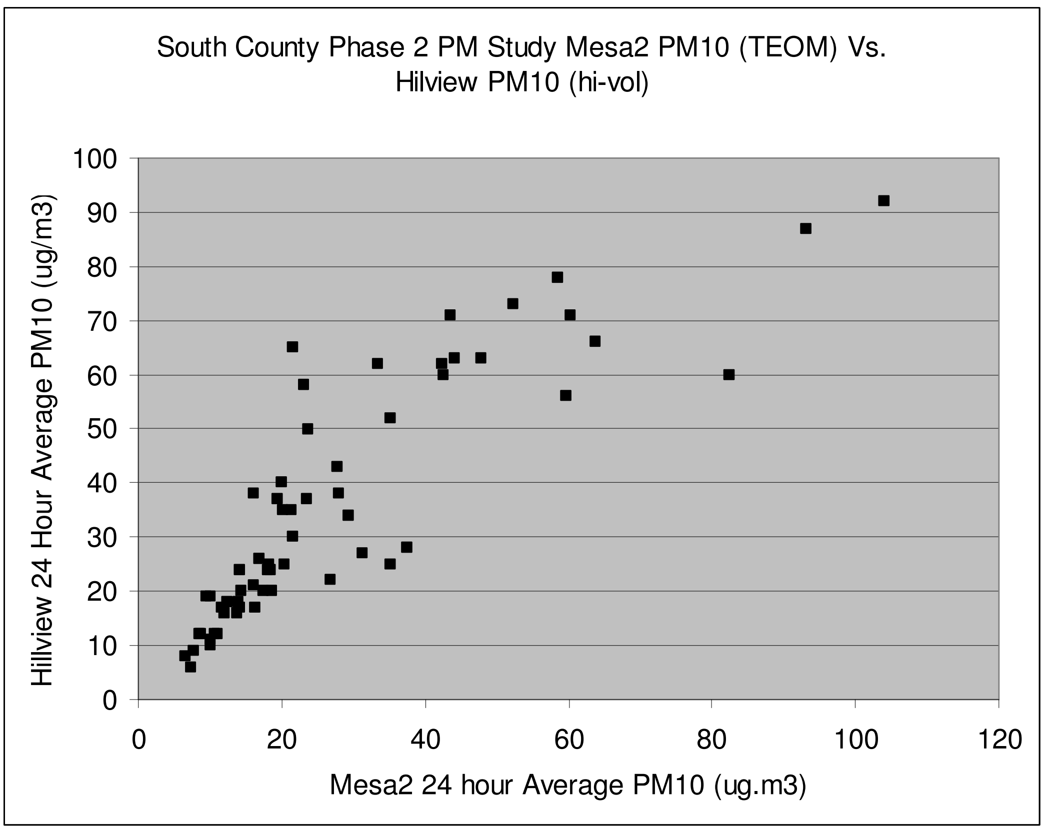

Figure 3.19 – Hillview 24-hour PM_{10} as Compared to Mesa2 24-hour PM_{10}

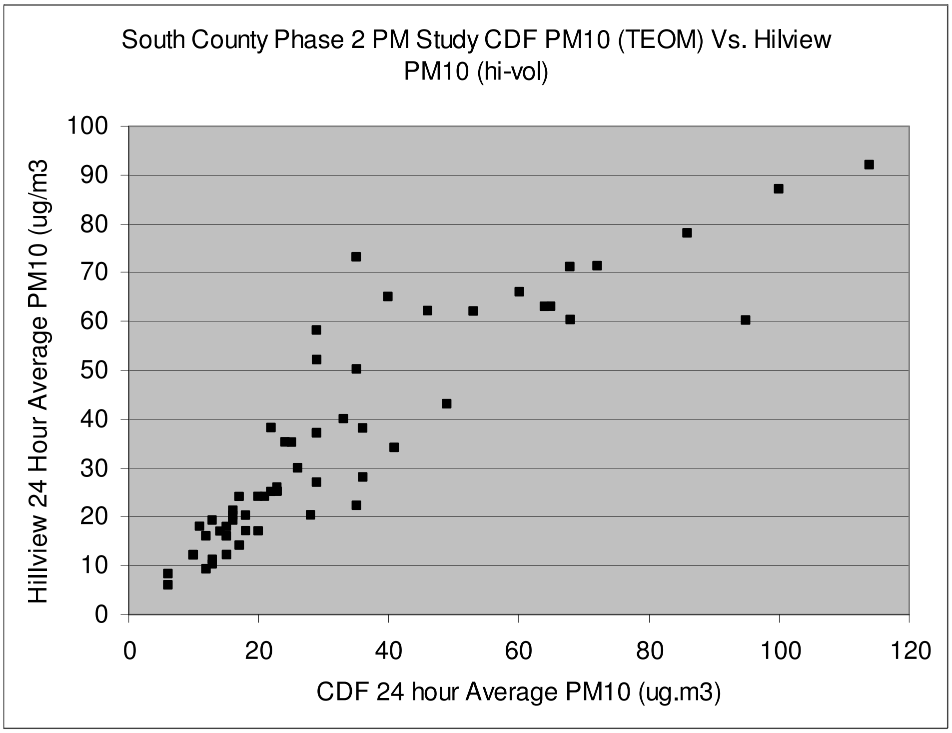

Figure 3.20 – Hillview 24 hour PM10 as Compared to CDF 24-hour PM_{10}

<u>Mesa2 Monitoring Station</u>

The Mesa2 monitoring station was selected to measure particles downwind from the SVRA. This site is located 3.1 miles downwind from the SVRA and 4.4 miles from the ocean following prevailing ocean winds (300 deg). The Mesa2 monitoring station is owned by ConocoPhillips and has been operational since the early 1990's. As a study partner, ConocoPhillips allowed the SLO APCD to utilize existing equipment at the station and install additional new equipment for this study.

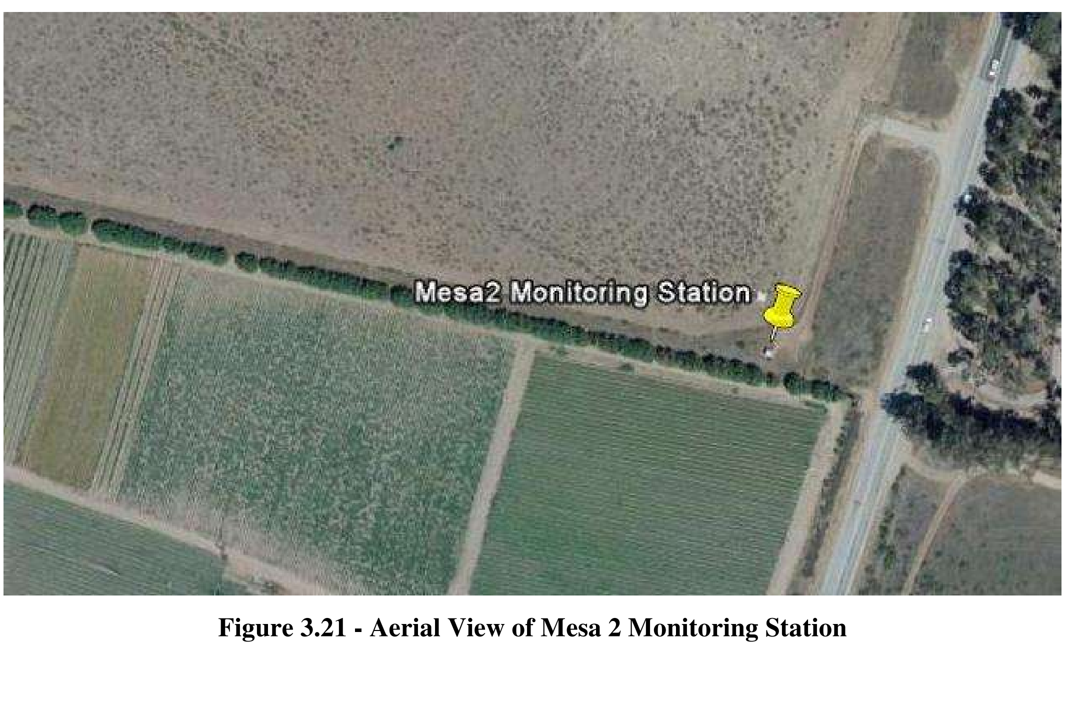

Figure 3.21 - Aerial View of Mesa 2 Monitoring Station

Figure 3.22 - Mesa 2 Monitoring Station

Study measurements at this site include wind speed, wind direction and sigma theta at 10 meters, temperature at 3.5 meters, continuous PM_{10} at 3.5 meters, and 24-hour average PM_{10} at 2 meters. The continuous PM_{10} measurements were made using a Rupprect and Patashnick tapered element oscillating microbalance (TEOM). This instrument is certified by the US EPA as a Federal Equivalent Method (FEM), which allows the data to be compared to the PM_{10} health standards. The 24-hour PM_{10} measurements were made using a hi-volume sampler. This instrument is certified by US EPA as the Federal Reference Method for PM_{10}, which allows the data to be compared to the PM_{10} health standards.

Figure 3.23 below presents the wind rose for Mesa2, summarizing wind conditions for the site. As is typical throughout the area, the most predominate direction is WNW and the highest wind speeds are from the northwesterly directions.

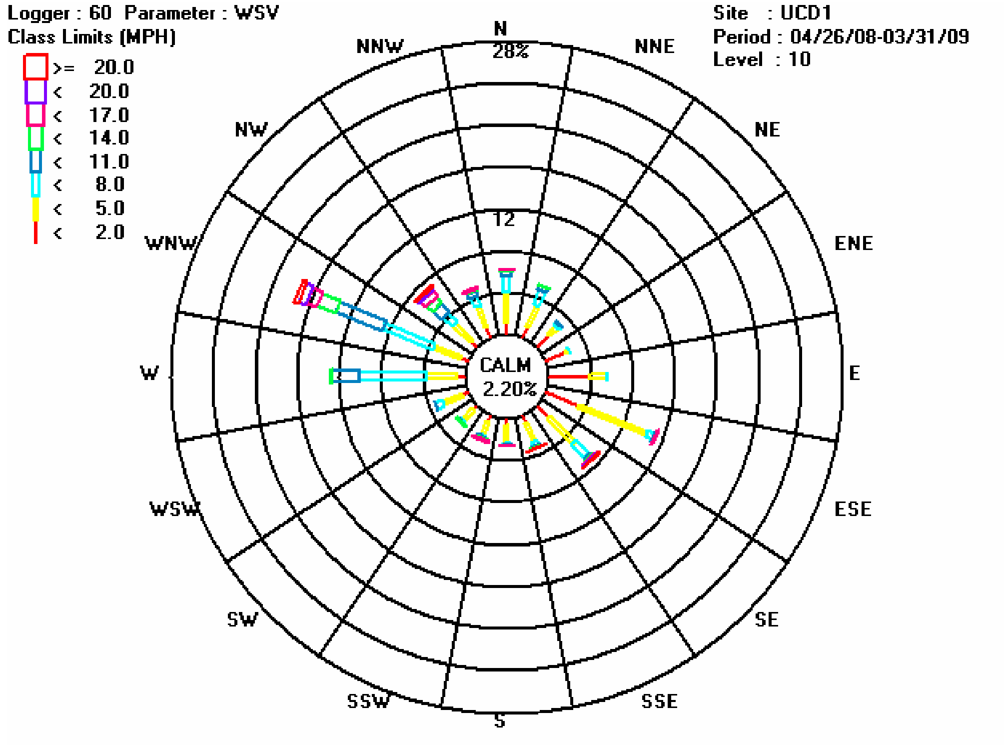

Figure 3.23 – Mesa2 Wind Rose Summarizing Wind Conditions

Figure 3.24 below presents the 24-hour average PM10 values for Mesa2, showing most exceedances of the state health standard occurring in the spring and fall. The highest level seen was 147 ug/m measured on 6/6/08, approaching the federal health standard of 150 ug/m3.

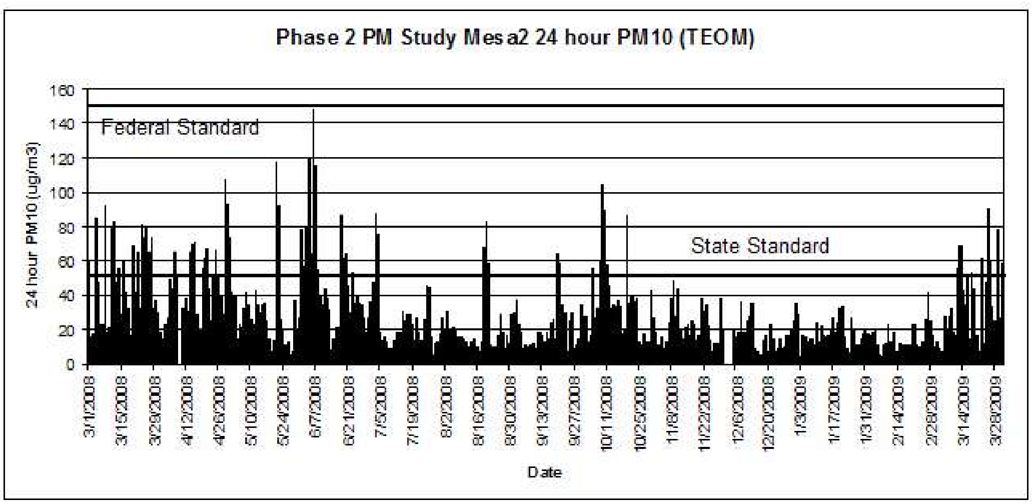

Figure 3.24 – Mesa2 24-hour Average PM_{10} Values

Figure 3.25 below presents the hourly PM10 concentration compared to wind direction at various wind speeds. Figure 3.26 presents hourly PM10 concentration compared to wind speed. As was observed at the CDF monitoring site, the vast majority of high concentration PM10 values occurred during high winds blowing from the northwesterly direction. Again, this clearly indicates a large source of wind blown material to the northwest of the monitoring location.

Figure 3.25 also shows a small number of high wind speed data points from the northwest, with low PM10 concentrations. Most obvious in these outliers are the three black (>20 mph) data points at 314-315 degrees and 15-20 ug/m3 PM10 concentration. Investigation of these three data points reveal they occurred on the same day (12/25/08) under post frontal conditions following rainfall when the ground was wet. Review of nearby weather stations and the relative humidity sensor at the CDF station show that the storm had passed and there was no rainfall during the hours when these data values occurred. Investigation of all other low PM10 concentrations measured during high winds from the northwest showed that all occurred during post frontal conditions associated with rainfall. This observation adds compelling evidence that the source of the high particulate concentrations is due to wind blown material.

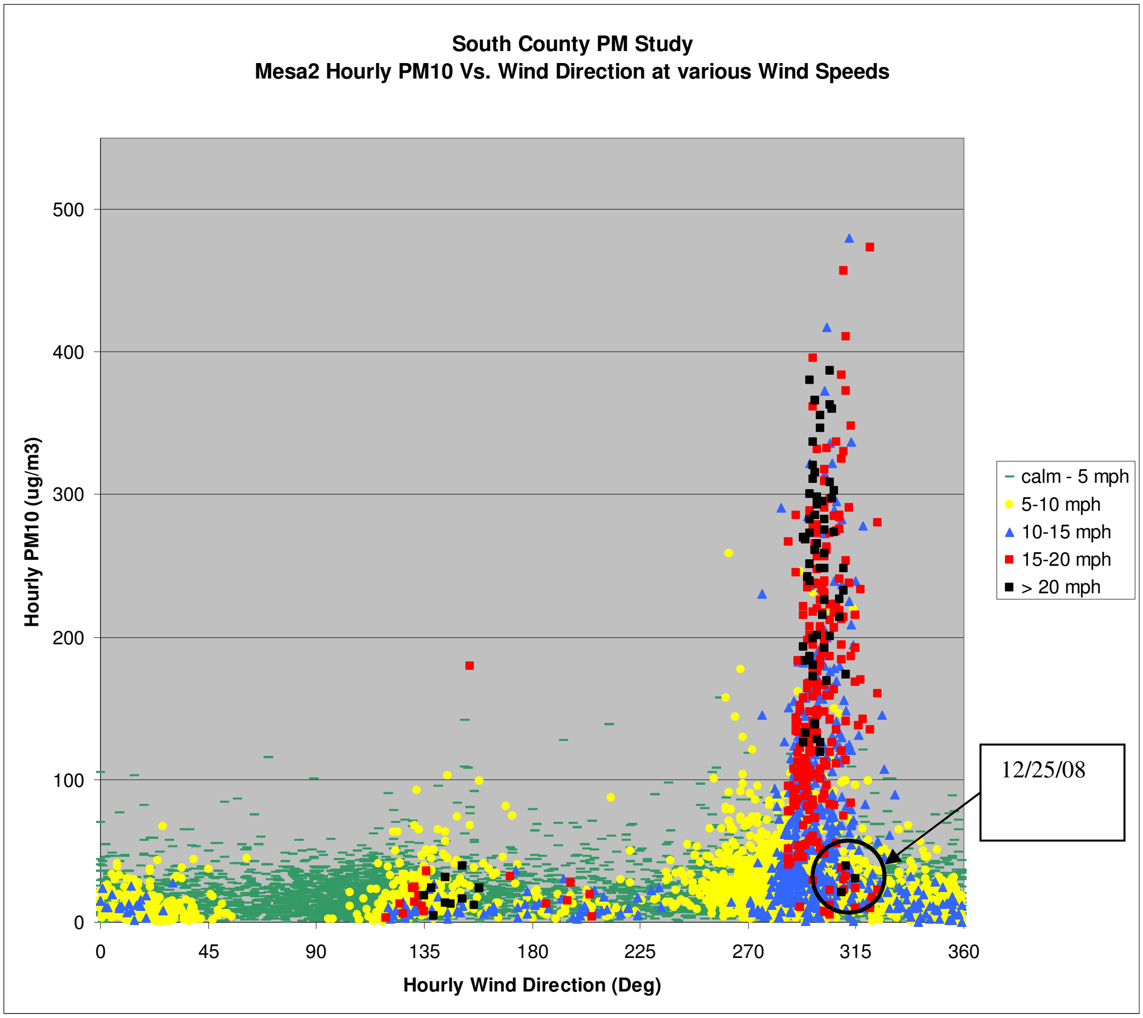

Figure 3.25 – Mesa 2 Hourly PM_{10} as Compared to Wind Direction at Various Wind Speeds

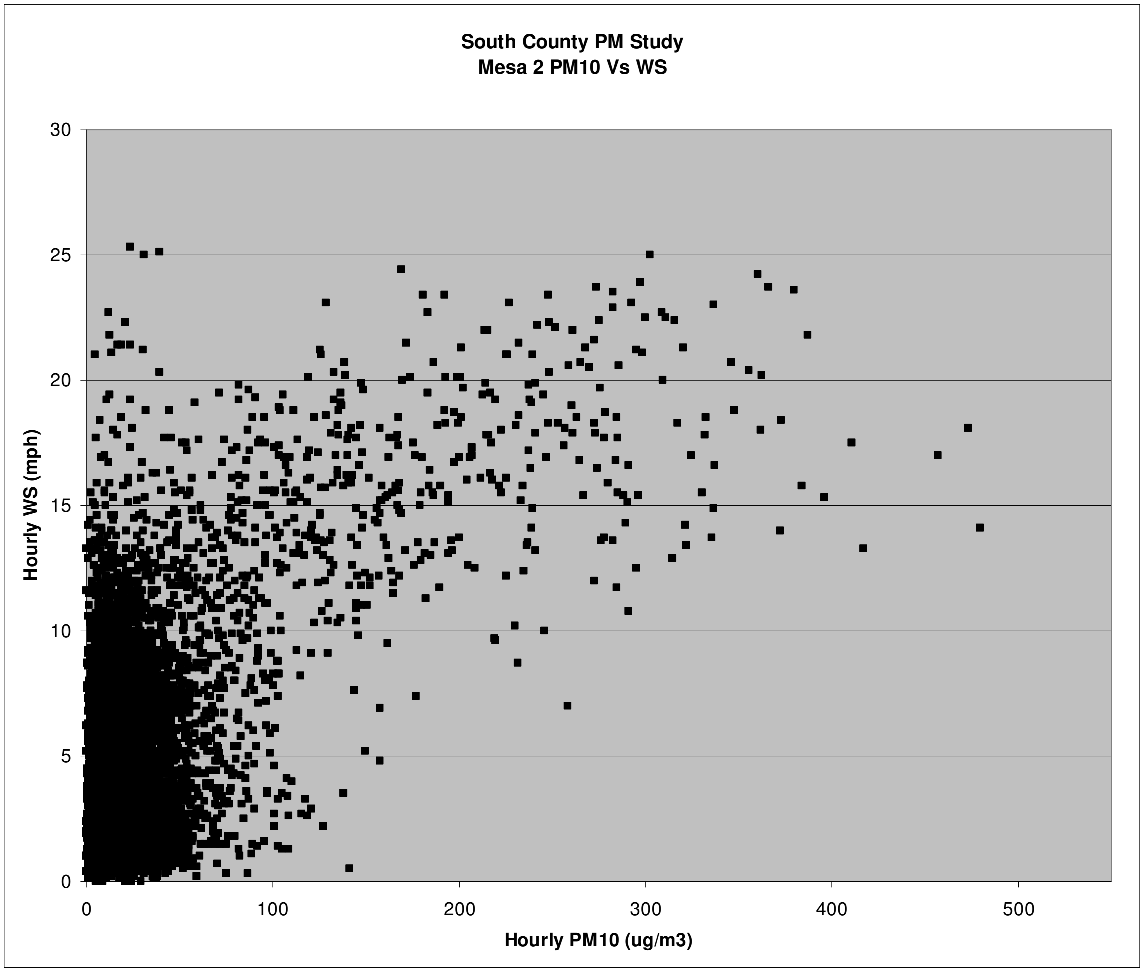

Figure 3.26 – Mesa2 Hourly PM_{10} as Compared to Wind Speed

<u>Oso Monitoring Station</u>

The Oso monitoring station was selected by State Parks Staff as a southern control site. This site is located downwind of a coastal dune complex where OHV traffic is currently not allowed. Interviews with State Parks personnel indicate that this area was likely used for OHV activity prior to the early 1980's when State Parks took control of the dune area (1). The Oso monitoring station is located 0.4 miles downwind from an open sand sheet and 1.6 miles from the ocean following prevailing ocean winds (300 deg). This location does not have any access to commercial power or other utilities, which required special monitoring methods to be utilized.

Figure 3.27 – Aerial View of Oso Monitoring Station Location

Figure 3.28 - Deployed EBAM

Figure 3.29 - Oso Monitoring Site

Study measurements at this site include wind speed, wind direction, temperature, and relative humidity at 2 meters, and continuous PM_{10} at 2.3 meters. The continuous PM_{10} measurements were made using a MetOne EBAM beta attenuation monitor. The EBAM is not an EPA approved monitoring method, but has compared favorably to EPA FRM measurements in other studies. The EBAM was selected for this monitoring site because it is the only continuous PM_{10} monitor available that can be operated on battery/solar power. In order to ensure comparability between the EBAM and other EPA approved methods, numerous comparisons between EBAM and TEOM measurements were performed at the Mesa2 monitoring station (Appendix A). The results of these comparisons showed excellent correlation during wind events (WS>10 mph); poorer correlation was observed when wind events were not occurring, but PM_{10} concentrations were generally low at those times.

One known limitation of the EBAM is its vulnerability to positive bias during very moist conditions due to the very low power of its inlet heater. This phenomenon was observed during calm/foggy conditions often present at this coastal location. For this study, the data of most interest occurs during wind events when fog is not present; this is likely why the comparisons to the TEOM were so well correlated when the wind was greater than 10 mph. A complete description of these comparisons and handling of the EBAM data is included in Appendix A. Because wind events only occur during a portion of a day, 24-hour averages of the data do not correlate as well with federal methods. Instead, data analysis from this monitoring site needs to be limited to those hourly averages when the wind speed is greater than 10 mph, which include all PM_{10} episode periods observed in this study.

Figure 3.30 below presents a wind rose for the Oso monitoring station. As elsewhere on the Mesa, the predominant wind direction and highest wind speeds are from the northwest. The percentage of higher wind speeds at Oso is much higher than at any of the other study sites that measured wind parameters. The wind sensors at the Oso site were located only slightly less than 2 meters above the ground due to site limitations. The power law can be used to adjust the Oso wind speed data to make it comparable to other sites where the wind sensors were mounted at the standard 10 meter height (2). (Note: the data presented in Figures 3.30, 3.31, 3.32 is the unadjusted wind speed data) Using the power law, the Oso wind speeds presented below would be multiplied by 1.259 to approximate what the speed would be at 10 meters about ground. Tests were performed to demonstrate that the power law does a good job of correcting the EBAM wind speed data to correlate with a sensor mounted at the standard 10 meter height. Appendix A presents these tests in detail. So clearly, the winds at the Oso monitoring station are much greater than any other study site.

It is also important to note that the wind direction at the Oso site appears much less variable than the other study site locations. This is likely due to the local terrain channeling the winds in the observed principal directions.

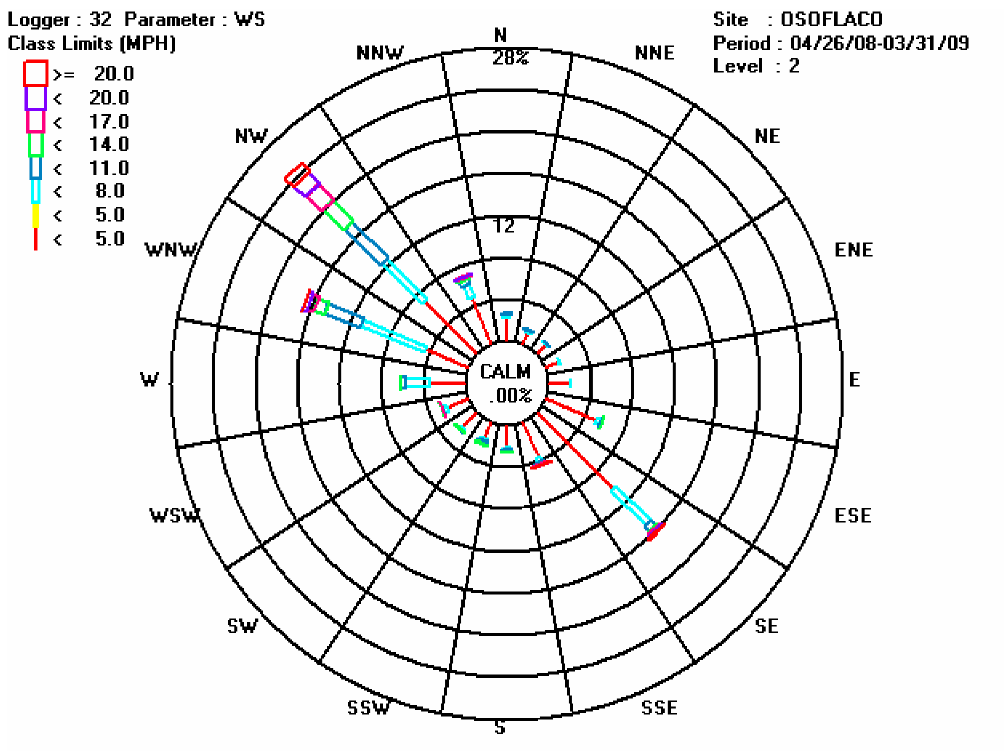

Figure 3.30 – Wind Rose for Oso Monitoring Station

Figure 3.31 below presents the hourly PM_{10} concentration verses wind direction at various wind speeds. Figure 3.32 presents the hourly PM_{10} concentration verses wind speed. As shown in these charts, the majority of high PM_{10} data values occur from a wind direction of approximately 300 degrees at wind speeds almost always over 20 miles per hour; in contrast, a significant portion of high concentration values at the non-control sites occurred at wind speeds between 10-20 mph. Further, the Oso 2-meter wind sensor measurements showing speeds greater than 20 mph would be equivalent to over 25 mph if measured at the standard 10 meter height used at the other sites. Thus, significantly higher wind speeds were required to cause high PM levels at the control site compared to the non-control sites. As was observed at the CDF and Mesa 2 sites, the preponderance of high PM measurements occurring at high wind speeds from the northwesterly direction indicates a source of wind blown material to the northwest of the Oso monitoring station.

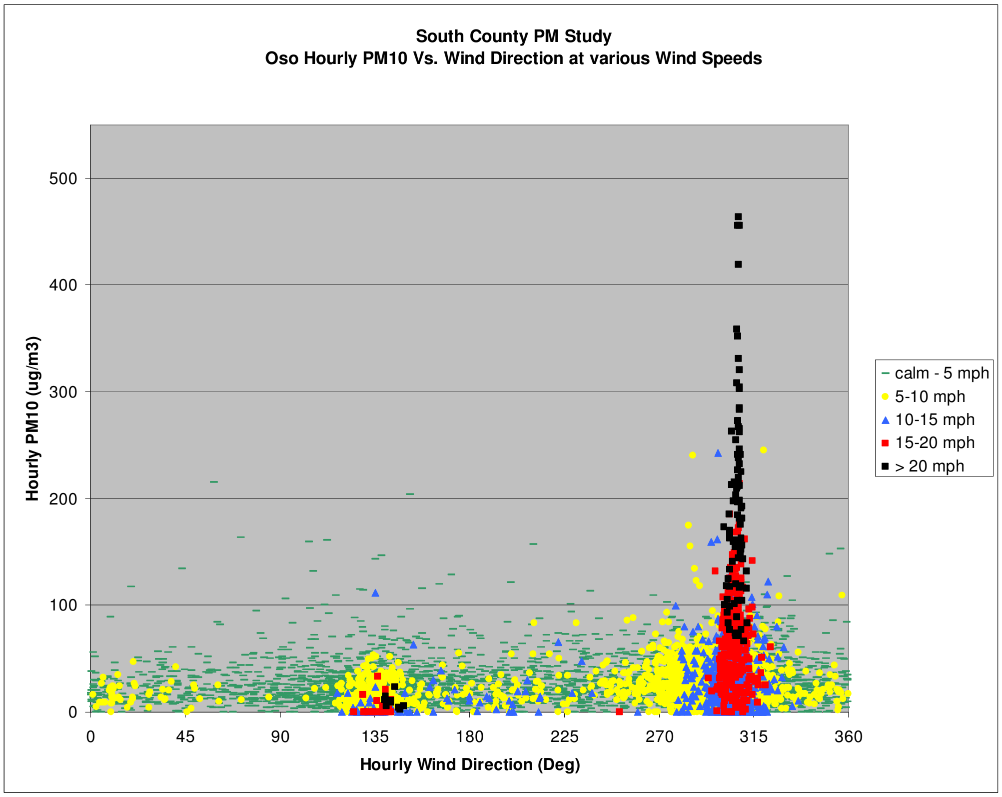

Figure 3.31 – Oso Hourly PM_{10} as Compared to Wind Direction at Various Wind Speeds

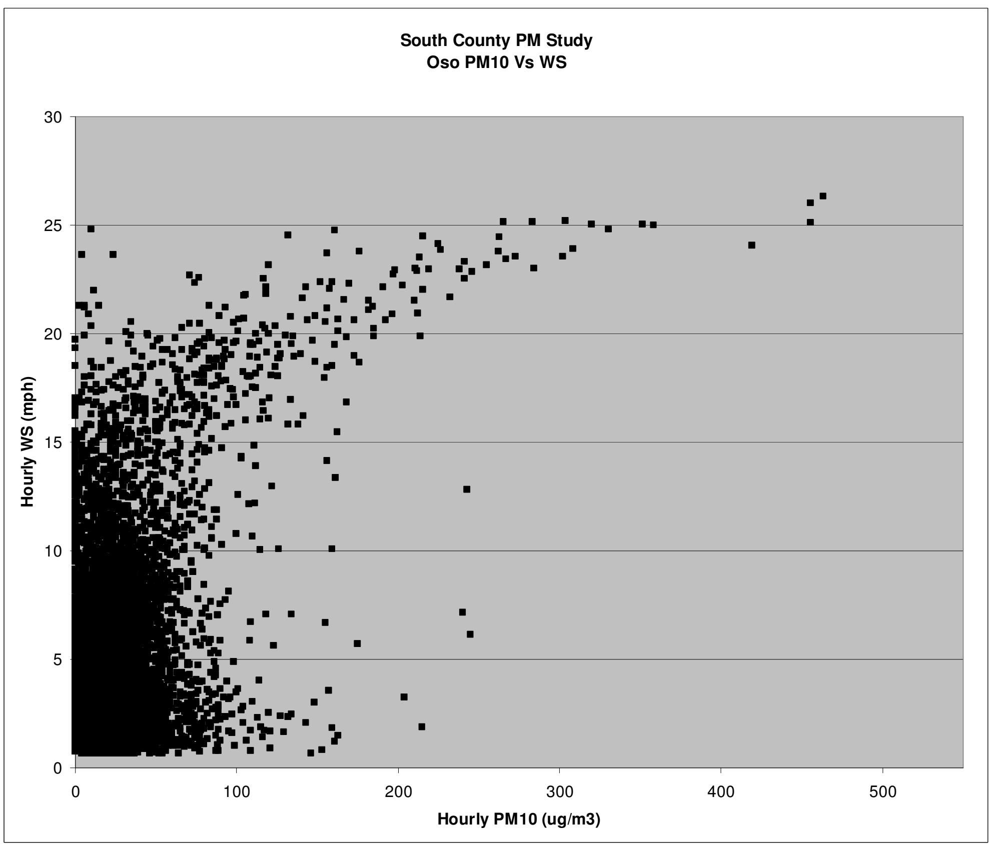

Figure 3.32 – Oso Monitoring Station Hourly PM_{10} as Compared to Wind Speed

Dune Center Monitoring Station

The Dune Center Monitoring Station was selected as an additional southern control site. This monitoring location was selected to measure particulates downwind from a dune complex where OHV activity is not present, and at a similar distance from the coast as Mesa2. The Dune Center location (Figures 3.33 and 3.34) is 1.6 miles downwind from open sand sheets and 4.4 miles from the ocean following prevailing ocean winds (300 deg).

Study Measurements at this location included only hourly PM_{10} at 2 meters. This site was selected late in the measurement phase of the study and utilized a second EBAM for its measurements. As with the other measurements made with an EBAM (Oso), data analysis should be limited to high wind event periods. (See Appendix A for a complete discussion of this issue.) Measurements at the Dune Center Monitoring Station were only performed from 3/13/09 through 3/31/09, with a data gap from 3/21/09 to 3/25/09 due to a tripped circuit breaker.

Figure 3.33 – Aerial View of the Dune Center Monitoring Station

Figure 3.34 – View of Dune Center Station (northwest)

Figure 3.35 below presents the hourly PM_{10} values for the Dune Center Station. A vague diurnal pattern responding to the daily wind events is present, but with hourly concentrations rarely exceeding 100 ug/m3.

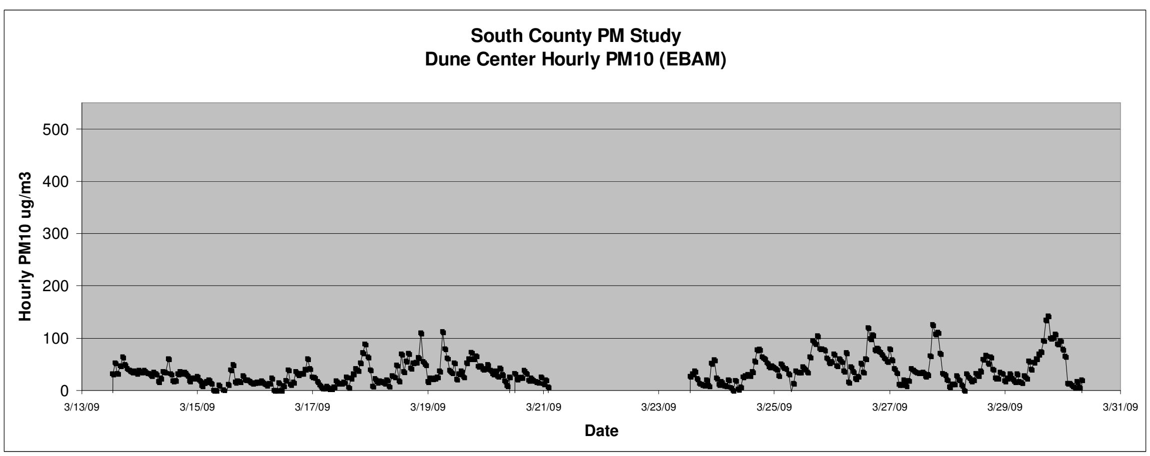

Figure 3.35 – Dune Center Hourly PM_{10} Values

3.1. SLO APCD Data Analysis

3.1.1. Analysis of Meteorological Data

Wind data was gathered as part of the Phase2 Study because previous studies have shown that high PM concentrations were associated with high winds. Wind sensors were located at study sites throughout the study area. Table 3.1 below summarizes the wind measurements performed at each meteorological site.

Table 3.1 - Wind Measurements at APCD Monitoring Sites

Monitoring Site	Parameters Measured	Sensor Height above Ground
Grover Beach	Wind Speed, Wind Direction, Sigma Theta (stability)	10 meters
CDF	Wind Speed, Wind Direction, Sigma Theta (stability)	7 meters
Mesa2	Wind Speed, Wind Direction, Sigma Theta (stability)	10 meters
Oso	Wind Speed, Wind Direction	2 meters

Historical data demonstrates that the winds associated with high PM episodes are the strong northwesterly winds that occur most often in the spring and fall of each year. These strong sea breezes from the northwest tend to occur in the mid-day to late afternoon as the inland areas heat and draw air inland from the coast.

In spring and summer, a semi-permanent high pressure cell frequently develops in the Eastern Pacific Ocean at the same time that a semi-permanent thermal low forms over the Lower Colorado River valley along the Southeastern California border. The resulting surface pressure gradient can produce periods of strong surface winds from the northwest along the Central Coast of California. These surface winds can be enhanced by periodic upper level weather features, such as a trough at 500 millibars.

These strong northwesterly winds move pristine air across the ocean with no significant terrain to channel or deflect the air flow. Upwind from the study area a portion of this air mass may encounter the Irish Hills prior to reaching the study area, depending on the exact wind direction. This encounter will likely reduce the wind speeds of this air mass. Once the air mass reaches the coast, the coastal terrain acts to change its direction and speed. Figure 3.36 below presents a generalized flow pattern under northwest flow, demonstrating how the coastal terrain can affect wind flow in the study area.

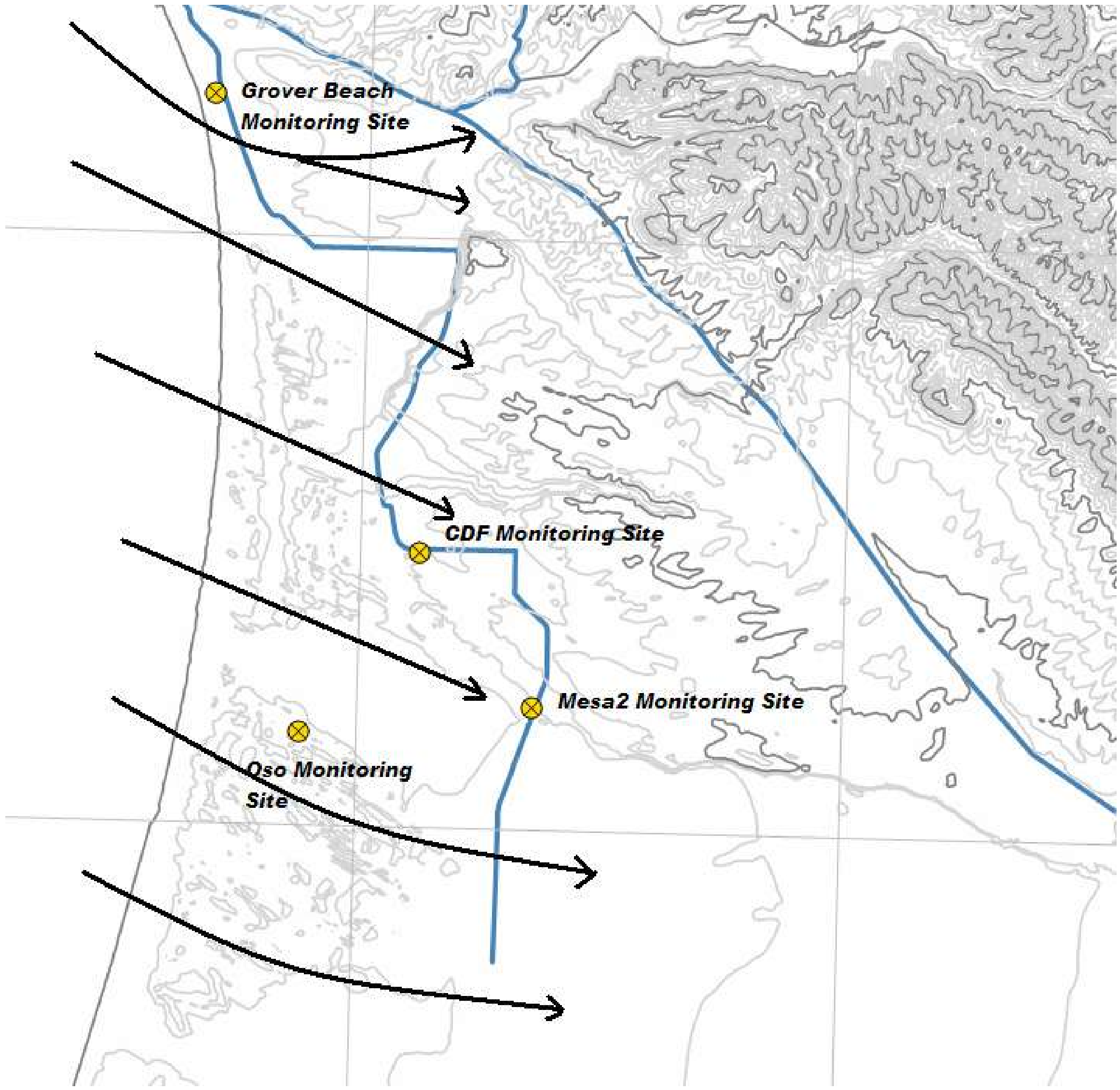

Figure 3.36 – Northwesterly Wind Pattern in Study Area

The Grover Beach and CDF sites have significant terrain downwind that will slow the winds and, in some cases, channel the direction. The Oso site and, to a lesser extent, the Mesa2 site do not have significant downwind terrain, so the winds there are relatively unimpeded and the pressure gradients draw the air mass directly inland.

Surface wind measurements are normally performed at the standard sensor height of 10 meters above ground level; however both the CDF and Oso study sites had wind sensors installed at non-standard heights. At the CDF site, State Parks representatives expressed concern that the wind sensors were to be mounted on an existing tower at 10 meters height while the PM_{10} inlet would be located about 35 feet away at a height of approximately 3.5 meters. While it is extremely unlikely that wind conditions or PM concentrations would vary over such a short distance, in order to address their concern, an additional tower was installed at the PM_{10} monitoring location and the wind sensor height was lowered to 7 meters. For the Oso monitoring station, its remote location prevented access for the equipment needed to install a 10 meter tower; the wind sensors were thus mounted per factory configuration on the EBAM support tripod at a height of about 2 meters.

The wind speed data from Oso and CDF can be adjusted by using the power law to approximate the speed that would have been measured if the sensors had been mounted at the standard 10 meter height (2). Tests were performed that clearly demonstrate the power law provides an accurate correction of the 2 meter sensor height used at Oso to the standard 10 meter height. This test is described in detail in Appendix A. Figure 3.37 below presents a comparison of daily maximum hourly wind speed (unadjusted) relative to the speeds at Grover Beach. Figure 3.38 below presents the same comparison with the Oso and CDF data adjusted using the power law.

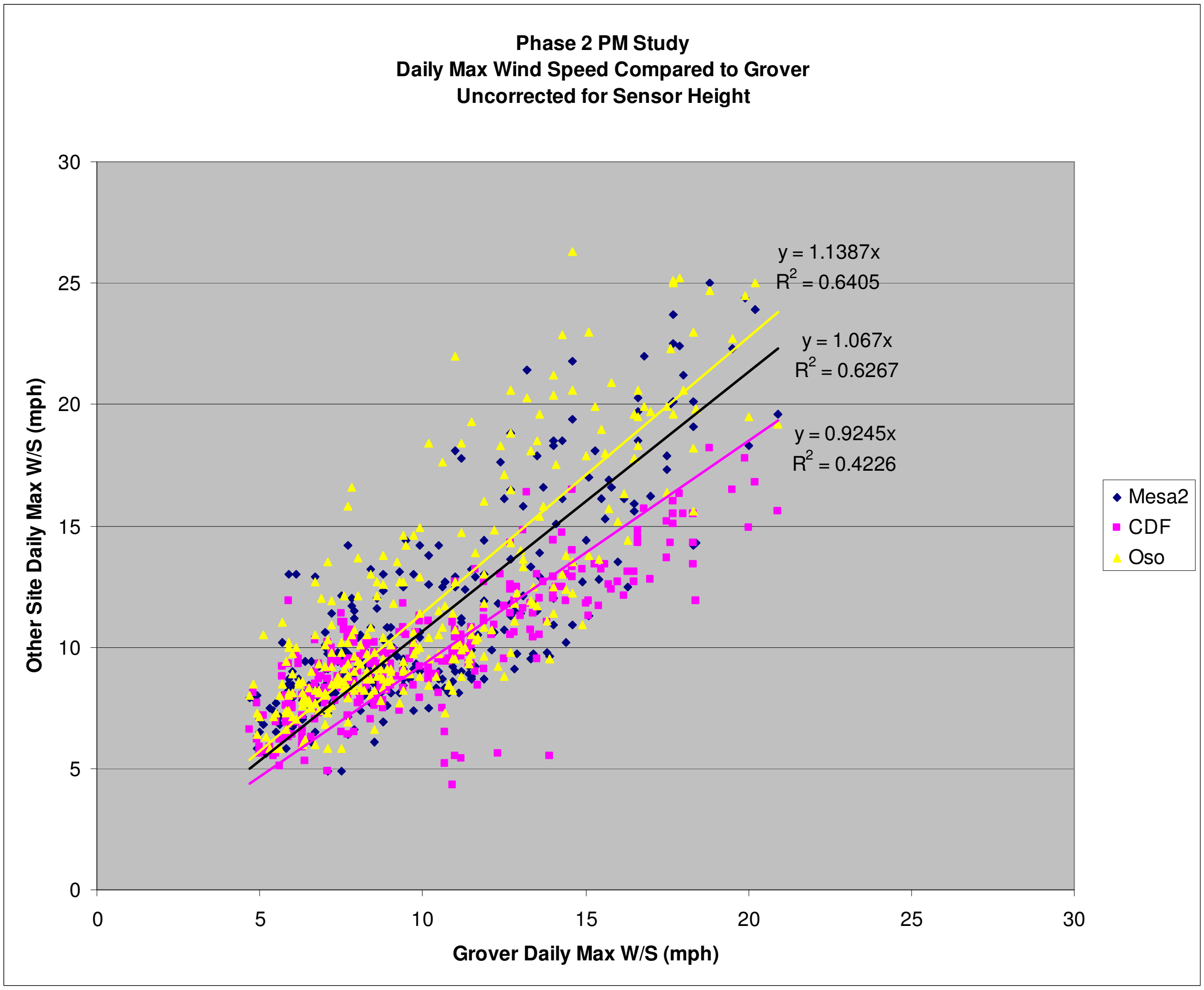

Figure 3.37 – Uncorrected Hourly Daily Maximum Wind Speed Compared to Grover Beach

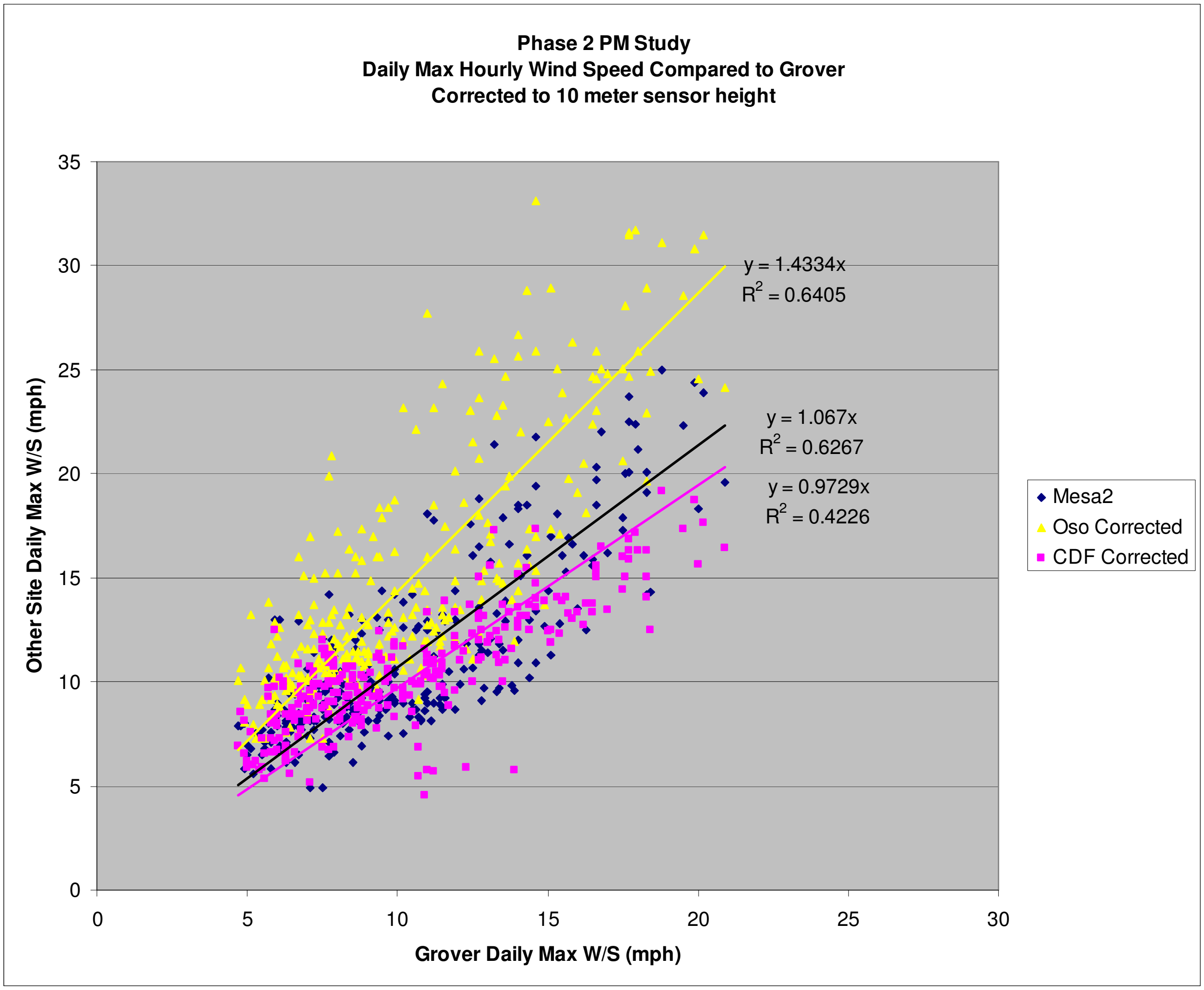

Figure 3.38 – Corrected Hourly Daily Maximum Wind Speed Compared to Grover Beach

The linear regression performed on the data corrected for sensor height shows that, on average, the maximum wind speeds at CDF are about 3% lower than Grover Beach; conversely, maximum winds at Mesa2 and Oso are about 7% and 43% greater, respectively, than Grover Beach. This data clearly demonstrates that the maximum wind speeds increase significantly at the mouth of the Santa Maria Valley as compared to other coastal locations to the north. It is unclear if this pattern is due to slowing of the air mass upwind by the Irish Hills, the effect of downwind terrain, and/or some other factor or a combination of factors. Nonetheless, this pattern is also seen in other historical data sets from monitoring performed throughout this area (6); thus, while the exact cause is not clear, this wind pattern is well documented.

3.1.2. Analysis of Wind Speed and Direction on Episode Days

Review of hourly PM_{10}, wind speed, and wind direction data from the Phase2 study reveals a consistent pattern on episode days (high PM_{10} days) that was not apparent in the Phase1 study, which only utilized the traditional 24-hour average PM_{10} measurements. Figures 3.39 through 3.42 below presents digital strip charts for 3/29/09, a typical episode day; figures 3.43 through 3.46 shows digital strip charts for 3/28/09, a typical non-episode day. Note that the Oso and Dune Center plots are using hourly averaged data, while the other sites plot minute data. The Oso and Dune Center data systems were not able to collect minute data.

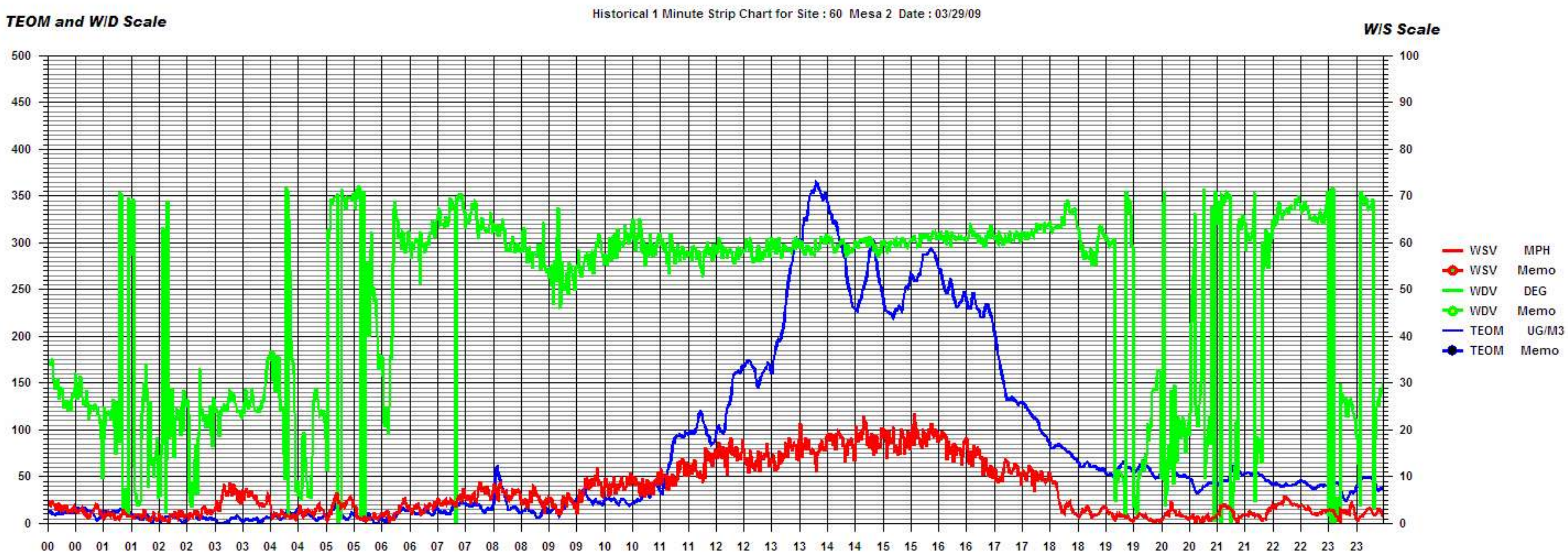

Figure 3.39– Digital Strip Chart for a Typical Episode (High PM10) Day at Mesa2

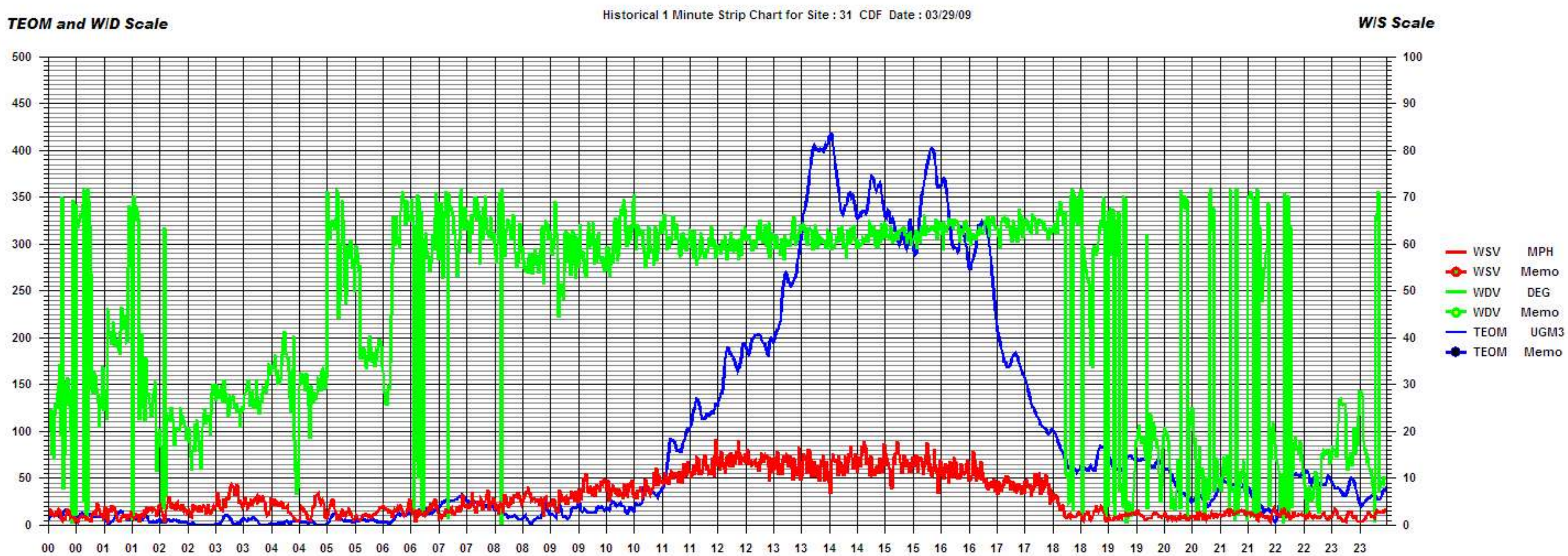

Figure 3.40 - Digital Strip Chart for a Typical Episode (High PM10) Day at CDF

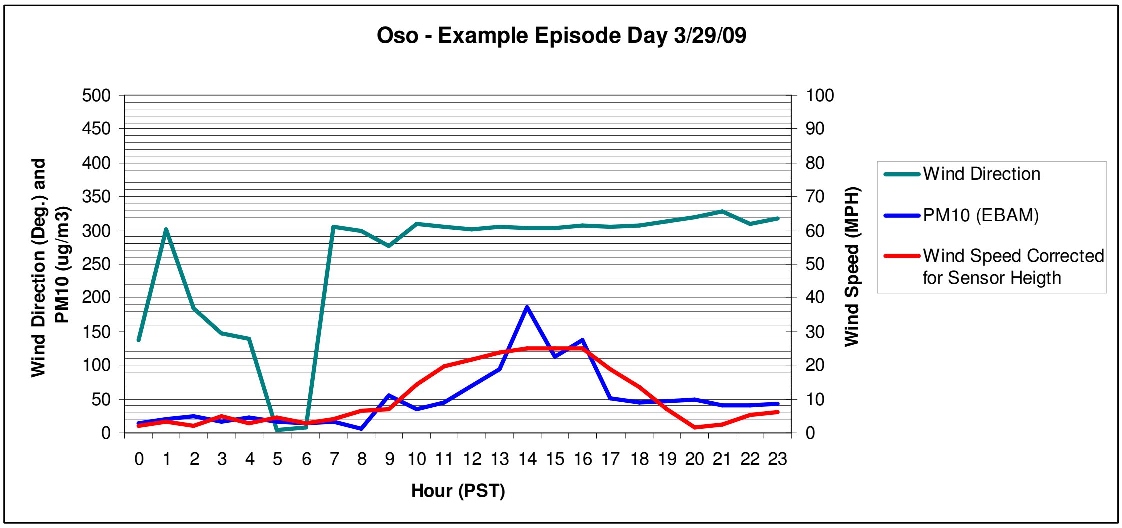

Figure 3.41 - Digital Strip Chart for a Typical Episode (High PM10) Day at Oso

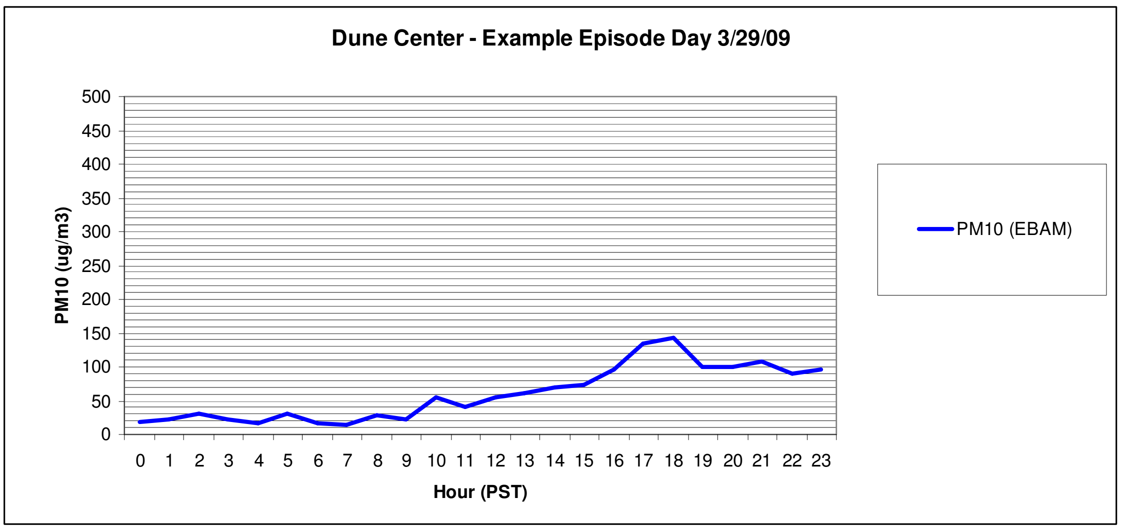

Figure 3.42 - Digital Strip Chart for a Typical Episode (High PM10) Day at the Dune Center

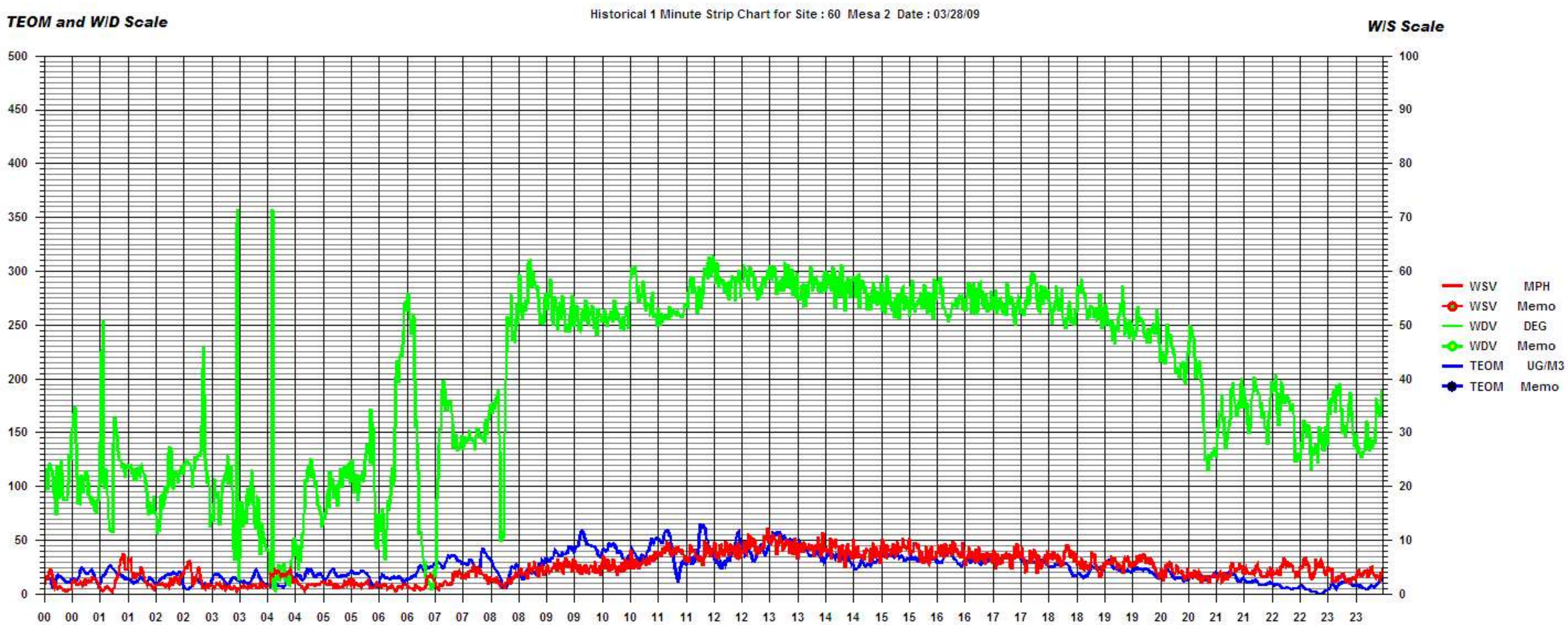

Figure 3.43 - Digital Strip Chart for a typical Non-Episode Day at Mesa2

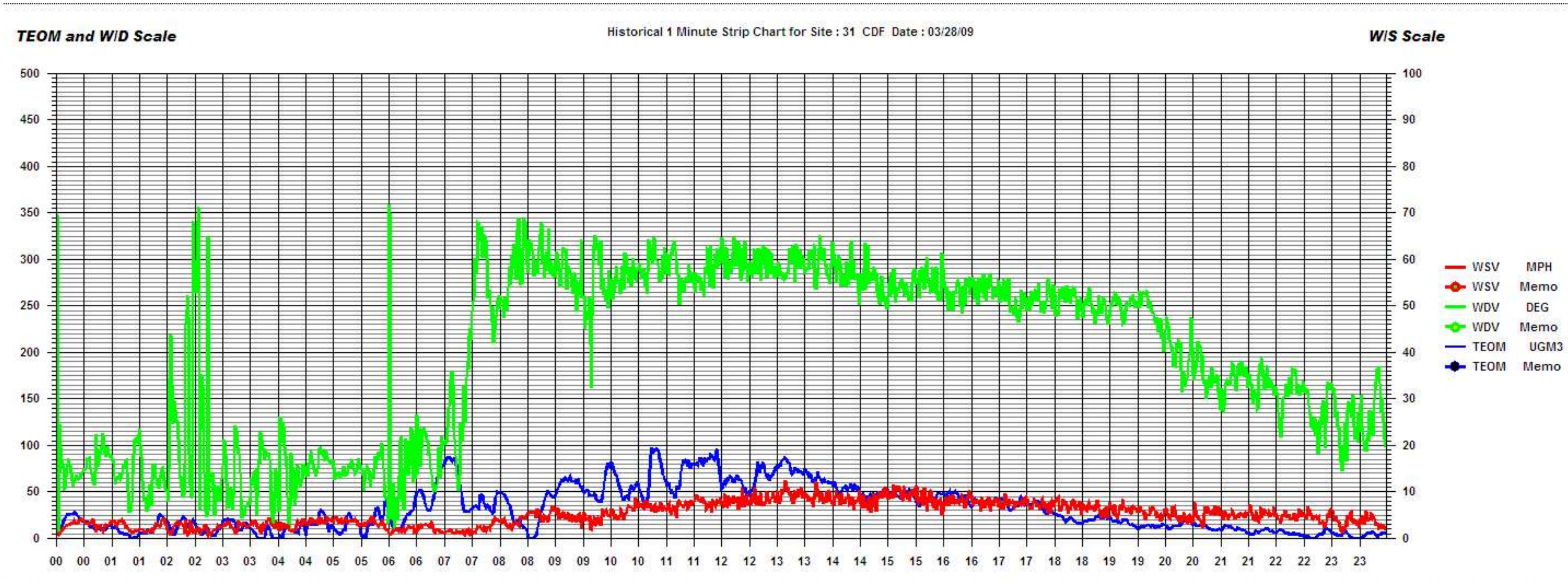

Figure 3.44 - Digital Strip Chart for a typical Non-Episode Day at CDF

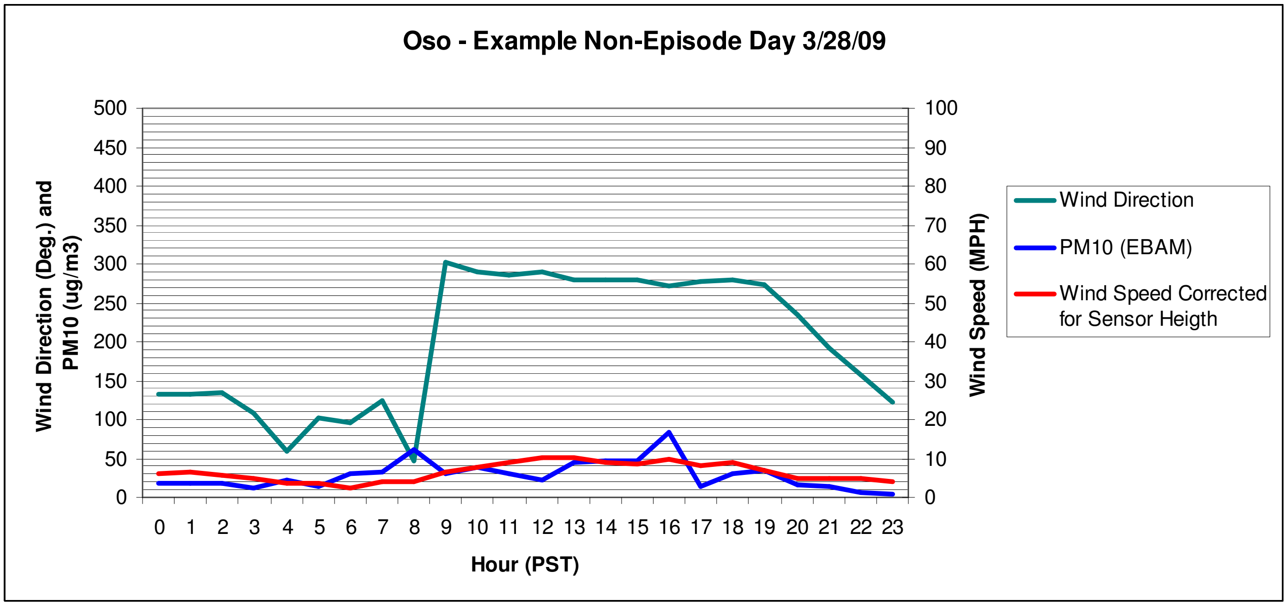

Figure 3.45 - Digital Strip Chart for a typical Non-Episode Day at Oso

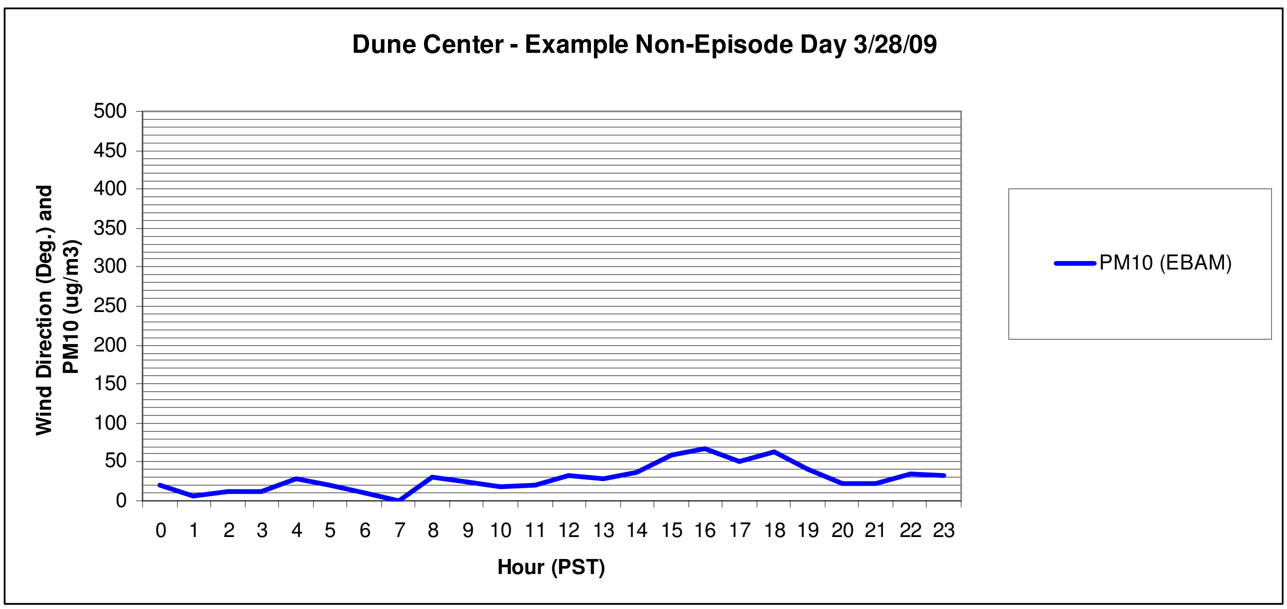

Figure 3.46 - Digital Strip Chart for a typical Non-Episode Day at the Dune Center

Maximum hourly PM_{10} values for all measurements made on these two example days are plotted on a map of the area in figures 3.47 and 3.48 below to show the spatial distribution of PM_{10} concentrations throughout the study area for these two types of days. The higher value for Grover on the non-episode day is due to sea salt artifacts; without the salt artifacts, the Grover concentrations would be similar to the other sites. These two example days are representative of the data for the majority of days sampled in the Phase2 study.

Weather conditions on both of these days begin similarly, with low wind speeds and variable wind directions, mostly from the east. Similarly, the wind direction on both days shifts to a consistent northwesterly direction in mid-morning and continues until late afternoon. The major difference between the two is that, in the late morning on the episode day the wind speed begins climbing, reaching a maximum hourly average of 13.8 mph at CDF, 18.1 mph at Mesa2, and 25.2 mph at Oso. The wind speed on the non-episode day reaches a maximum hourly average of 9.4 mph at CDF, 8.9 mph at Mesa2, and 10.4 mph at Oso.

Figures 3.15, 3.25 and 3.31 in the previous section present the hourly PM_{10} concentration versus wind direction and speed for CDF, Mesa2, and Oso. These graphs demonstrate that high PM_{10} concentrations usually occur only when the wind is blowing from the northwest at a speed greater than 10-15 miles per hour for CDF and Mesa2, and greater than 20 miles per hour for Oso. This relationship between wind speed, wind direction and PM_{10} concentration is clearly the primary determinant for whether a particular day will be an episode or non-episode day.

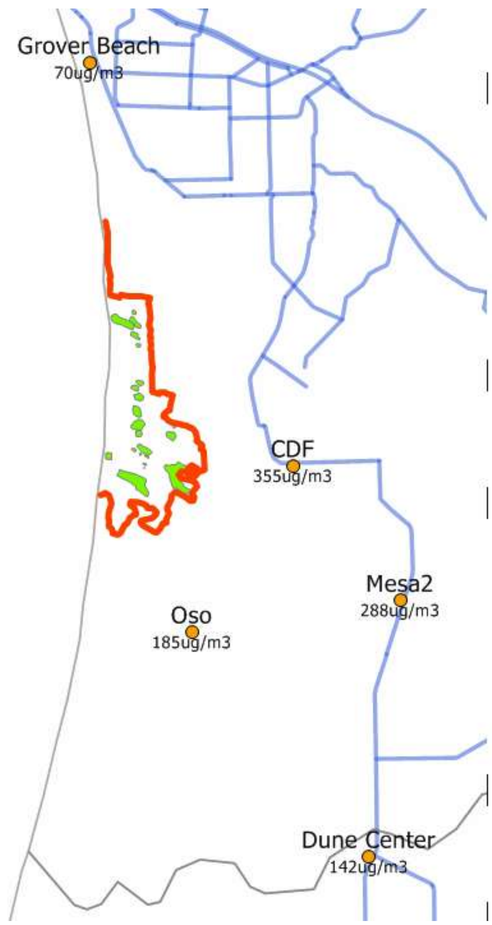

Figure 3.47 – Spatial Distribution of Maximum Hour PM_{10} Concentrations on a Typical Episode Day (3/29/09)

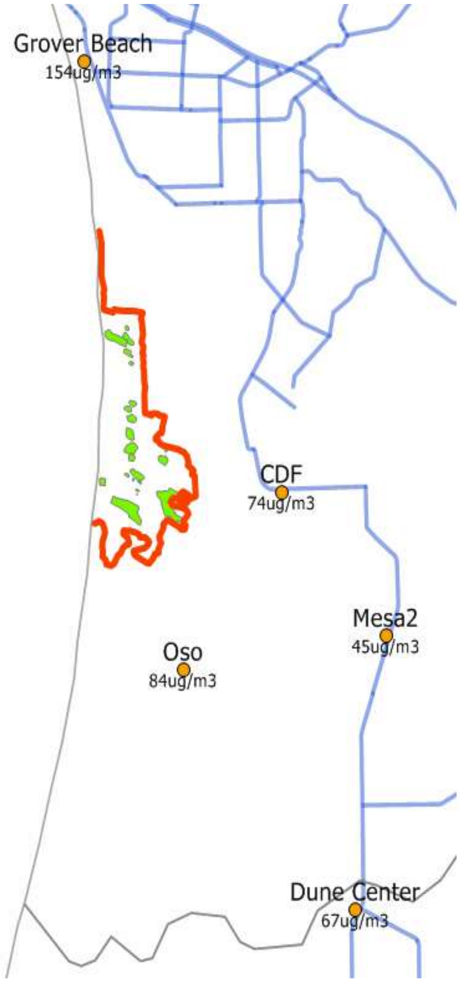

Figure 3.48 – Spatial Distribution of Maximum Hour PM_{10} Concentrations on a Typical Non-Episode Day (3/28/09)

Regarding the source of particulate on episode days, Figure 3.49 below plots the centerline direction (as determined from Figures 3.15, 3.25, and 3.31) of high PM_{10} concentrations for the CDF, Mesa2, and Oso sites. As shown in Section 3.1 above, the Grover Beach dataset clearly demonstrates that, on days with high winds blowing from the northwest, there are no significant sources of particulate upwind of the coast. Thus, the source of wind blown particulates measured at the CDF, Mesa2, and Oso sites is between the ocean and the monitoring station along the trajectories plotted below. All three trajectories pass through significant fetches of open sand sheets, as well as open rangeland with coastal scrub vegetation.

Figure 3.49 – Centerline Direction of High PM10 at CDF, Mesa2, and Oso

Review of the study dataset shows the PM_{10} measurements at the Mesa2 and CDF monitoring stations are closely correlated, as shown in Figure 3.50 below. This suggests both stations are measuring a similar source of particulates. Figure 3.50 also shows the CDF PM_{10} values consistently average about 18% higher than Mesa2. This consistent bias suggests the CDF site is closer to the source than the Mesa2 site. This bias pattern between CDF and Mesa2 was also observed in the Phase1 study and other investigations using different monitoring methods. In contrast, Figure 3.51 below shows no correlation between the Grover Beach and CDF PM_{10} measurements, indicating these two stations are not measuring the same source of particulates.

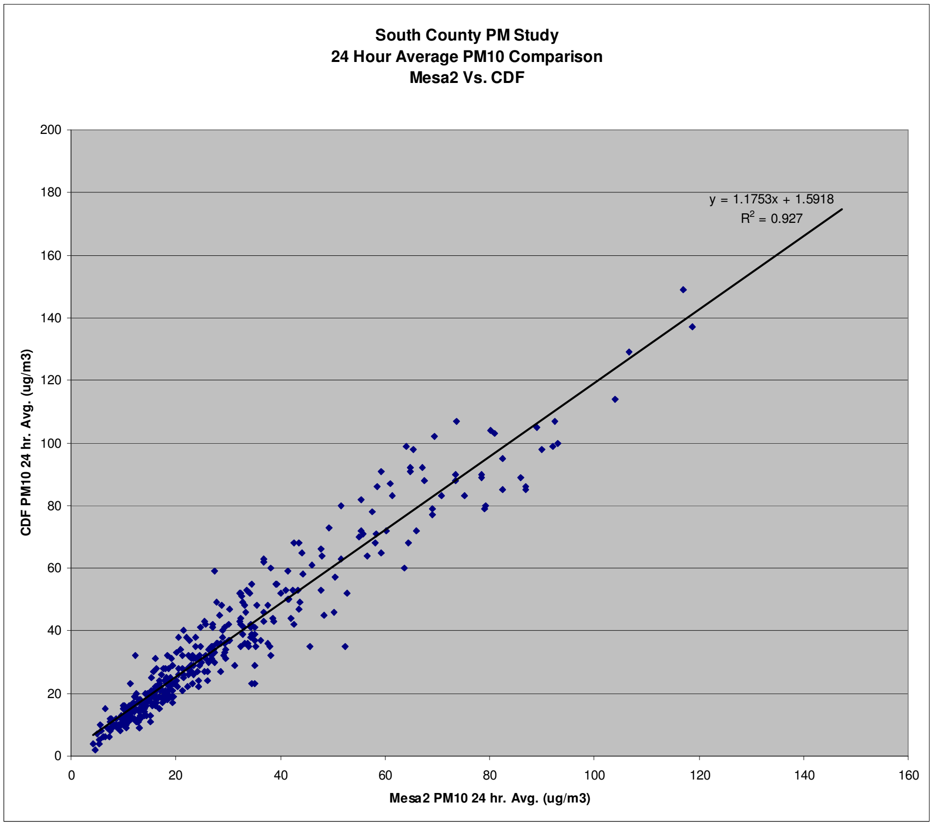

Figure 3.50 – Relationship between CDF and Mesa2 PM_{10} Measurements

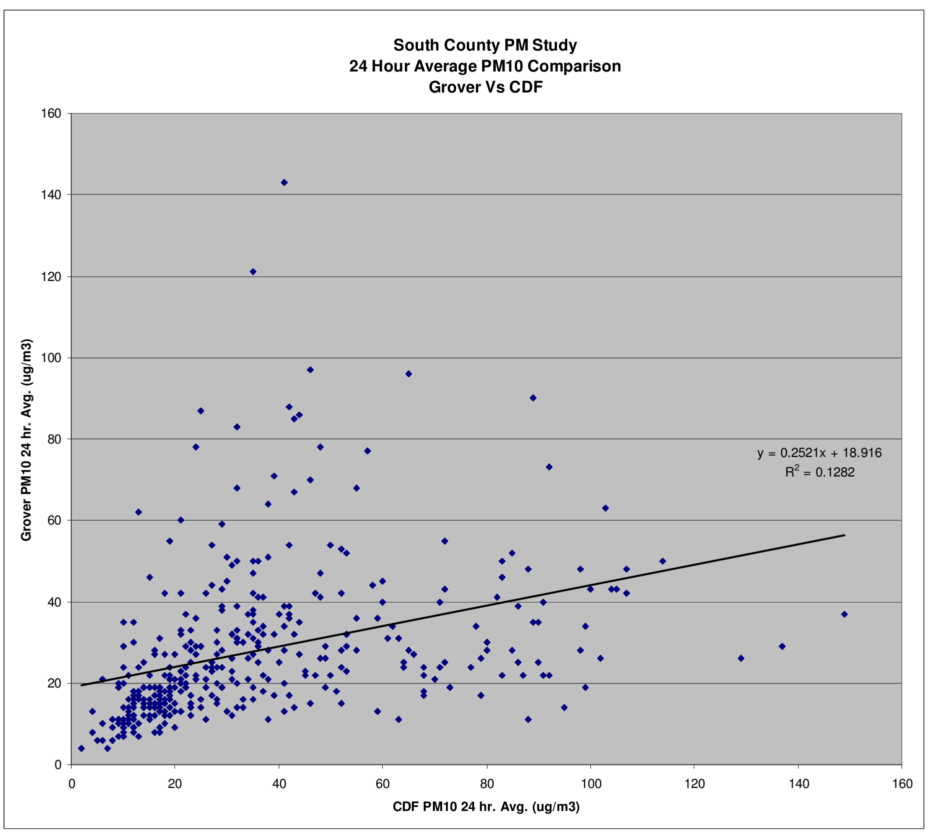

Figure 3.51 – Relationship between Grover Beach and CDF PM_{10} Measurements

The close relationship between the CDF and Mesa2 PM_{10} datasets, with the CDF site showing a consistent 18% positive bias, is evidence to suggest that the upwind source of particulate is the open sand sheets and not the open rangeland. The CDF site is 1.5 miles downwind from the SVRA; Mesa2 is 3.1 miles downwind from the SVRA. The physical laws governing atmospheric dispersion of primary pollutants dictate that concentrations decrease with distance from the source. Thus, if the source is the open sand sheets, one would expect the CDF site to record higher PM_{10} values than Mesa2, as was observed.

Supporting evidence is provided by the numerous measurements of high winds from directions other than the northwest that do not result in high PM_{10} values. The strongest winds from directions other than the northwest are mostly associated with rain events. However, there are numerous other non-rain event data points with high winds from a direction other than the northwest and low PM_{10} levels. Figure 3.52 below presents a digital strip chart showing an example of a day where high winds from the north did not result in high PM_{10} values; yet as soon as the winds shifted to the northwest, the PM_{10} concentration dramatically increased.

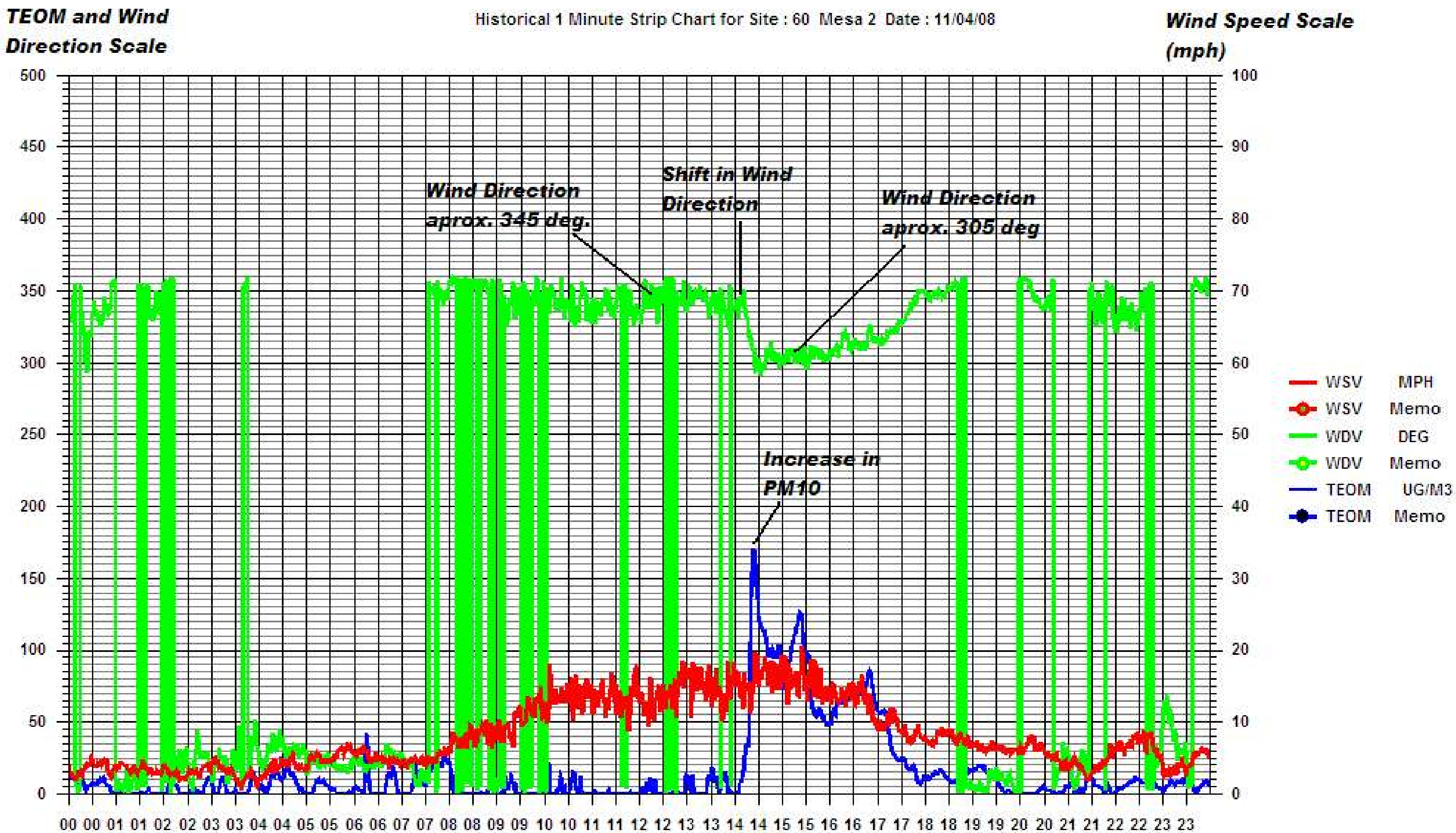

Figure 3.52– Digital Strip Chart from Mesa2 Demonstrating the Effect of Wind Direction on PM_{10} Concentration

This data further demonstrates that the source of the high particulate levels measured at the Mesa2, CDF and Oso sites is the open sand sheets to the northwest of each site. Periods with winds out of the north-north-west like the example above demonstrate that when the winds are blowing across the open rangeland, but not the open sand sheets, low PM_{10} is measured. This clearly shows that the rangeland is not a significant source of wind blown PM_{10}: the open sand sheets are the source.

The wind speed necessary to create significant downwind PM_{10} concentrations is different at different locations. Figure 3.53 below presents the relationship between hourly wind speed and PM_{10} concentration from the four monitoring sites with continuous measurements. This chart clearly demonstrates that wind speeds must be significantly higher at the Oso site to cause elevated PM_{10} levels similar to those measured at the Mesa2 and CDF sites . It is also important to note the complete absence of high PM_{10} values at the Grover Beach site under high wind conditions.

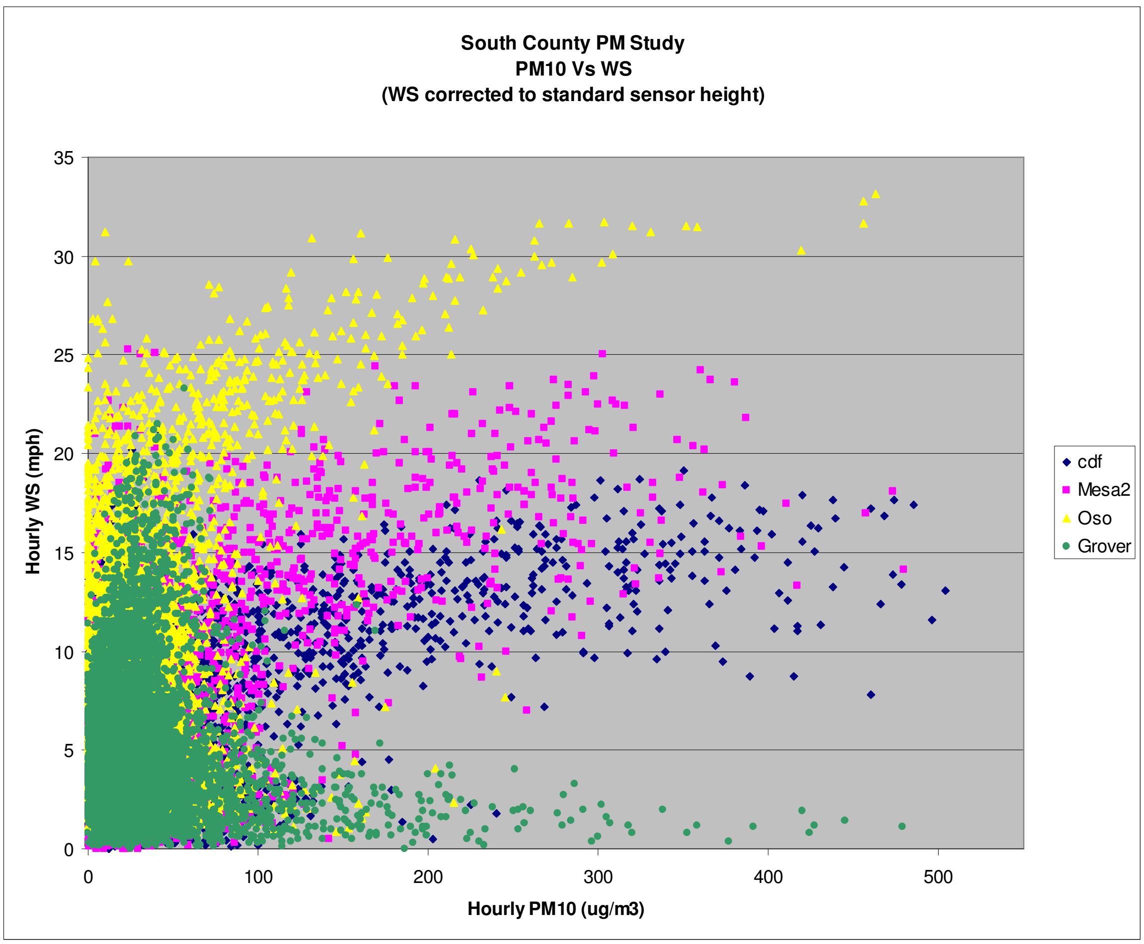

Figure 3.53 – Relationship between Wind Speed and PM10

3.1.3. Comparisons of Downwind PM_{10} Concentrations Between the SVRA and Control Areas

A major component of the Phase 2 study design was to compare PM_{10} measurements downwind from the SVRA to measurements taken downwind of the control site dunes with no OHV usage.

In performing this analysis it is most representative to focus the comparisons on the downwind concentrations observed during the actual hours of PM/wind episodes. To accomplish this, any day where the 24-hour average PM_{10} concentration at Mesa2 exceeded the state health standard of 50 ug/m3 was classified as an episode day. Data from the three sites for each episode day was then manually examined to exclude hours where the PM_{10} concentration was below 50 ug/m3, or when winds were calm or did not pass over the sand sheets. The remaining hours for each episode day represent only periods with strong, northwest winds and elevated PM_{10} levels. The PM_{10} episode-hourly values for each day were then averaged for each site (the same hours were averaged for all three sites). Finally, each site's daily episode-hourly values were totaled and averaged. Figure 3.54 presents this comparison.

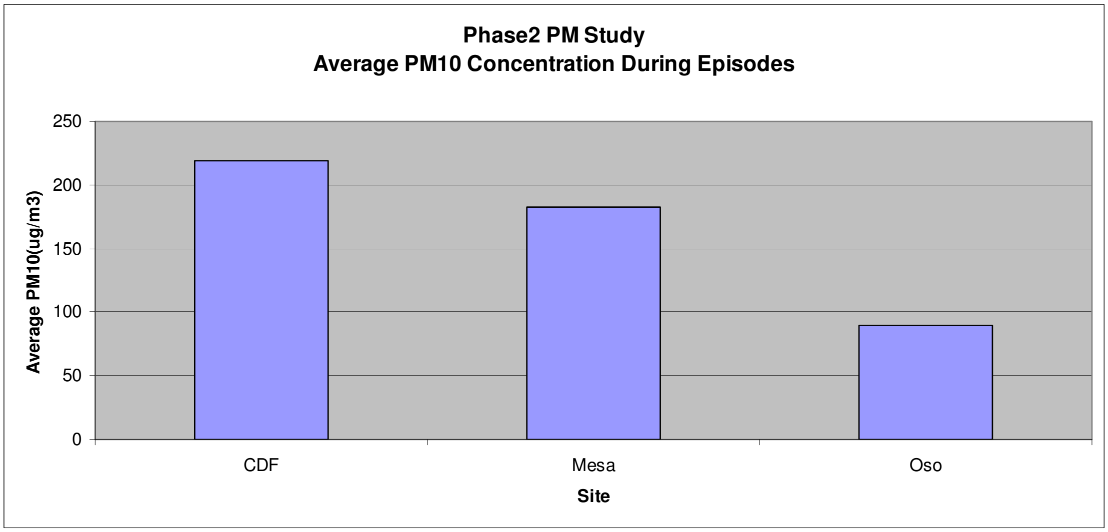

Figure 3.54 – Comparison of Average Downwind PM10 Concentration During Episodes

The chart above clearly demonstrates the Oso control site experiences significantly less downwind PM_{10} than either site downwind from the SVRA. It is important to note that the lower PM_{10} levels measured at the Oso site also occurred under much stronger winds than those recorded at CDF and Mesa2, as shown in Figure 3.55 below.

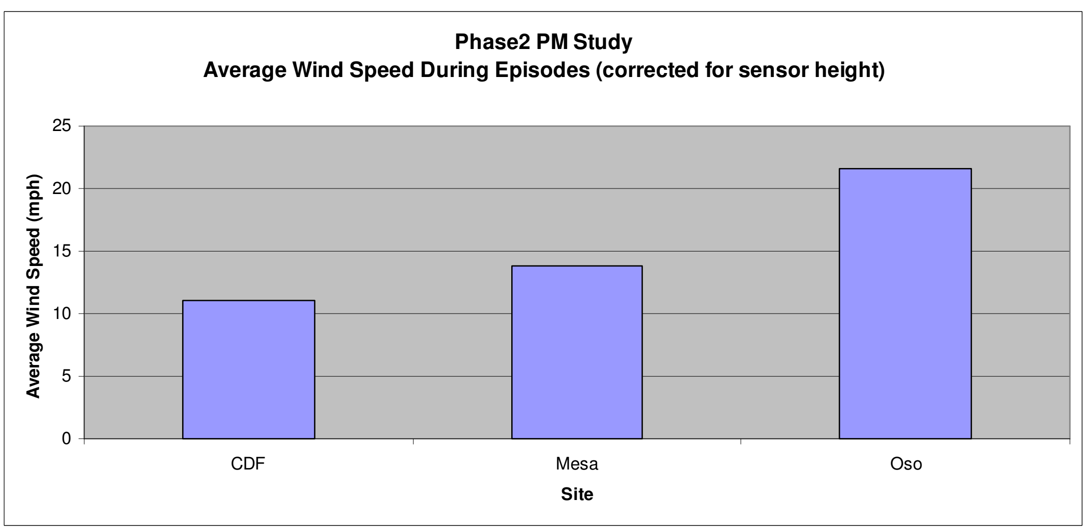

Figure 3.55 – Comparison of Average Wind Speed during Episode Periods

Further analysis of the Oso data shows that elevated PM_{10} concentrations were measured only when winds were considerably above 25 mph; the highest measured wind speed at CDF or Mesa2 for the entire study was 25.3 mph. Figure 3.56 below demonstrates this phenomenon. The two episodes noted on the charts where wind speed was around 25 mph showed very low PM_{10} concentrations at Oso and high levels at CDF. The chart does show an occasional, moderately high PM_{10} spike at Oso (mostly in June) without a corresponding spike at CDF. These only occurred at low wind speeds so are not due to wind blown material; they are likely either sea salt episodes or an artifact due to high moisture conditions.

Figure 3.57 below presents the average downwind PM_{10} concentration from Mesa2, CDF and Oso when the winds are from the northwest and between 10 mph and 25.3 mph (the highest wind speed measured at either Mesa2 or CDF). This presents an approximation of what the PM_{10} levels downwind from Oso would be if the winds were not significantly stronger than those that occur downwind from the SVRA.

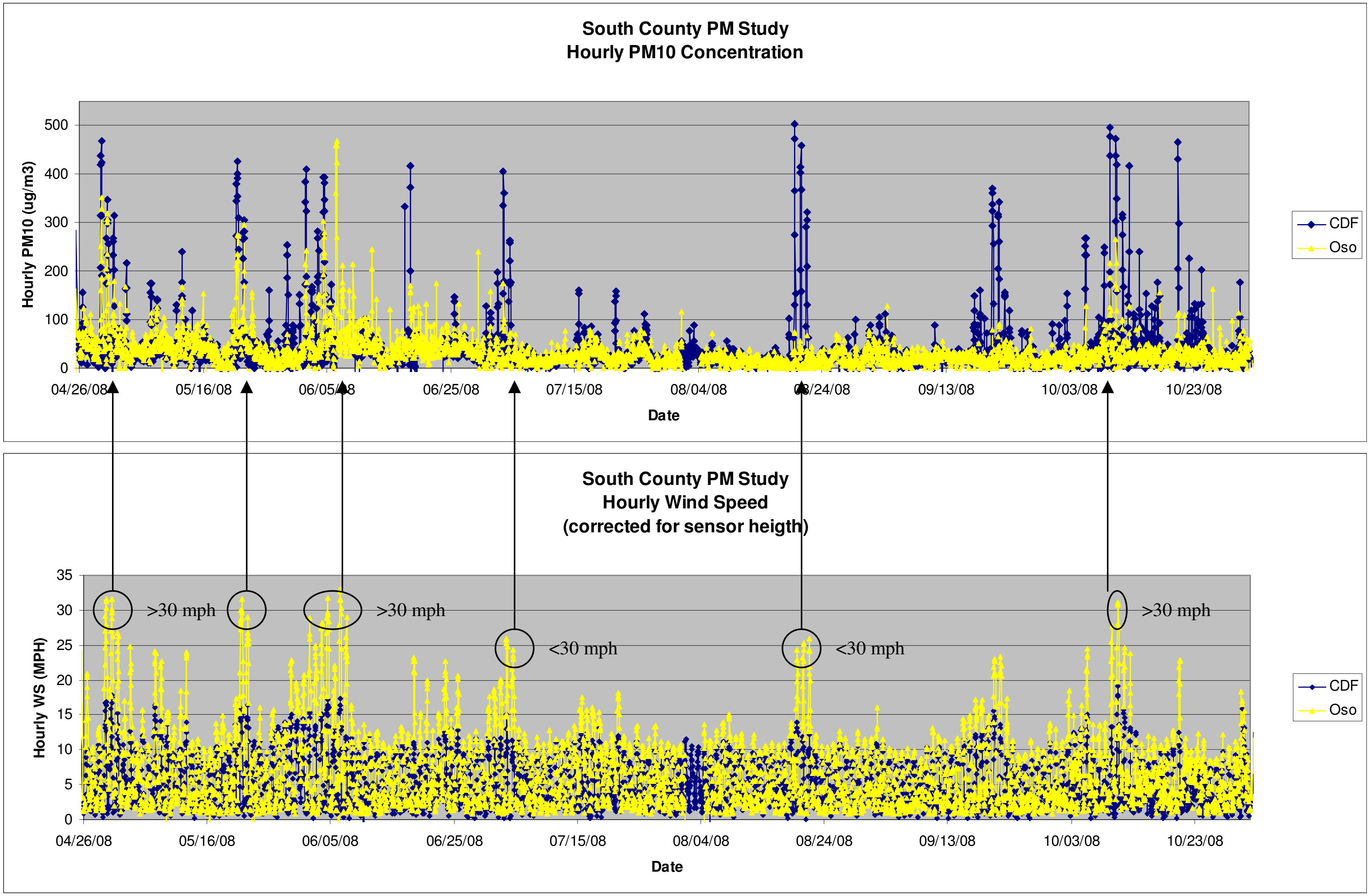

Figure 3.56 - Relationship between Wind Speed and PM Episodes at Oso and CDF

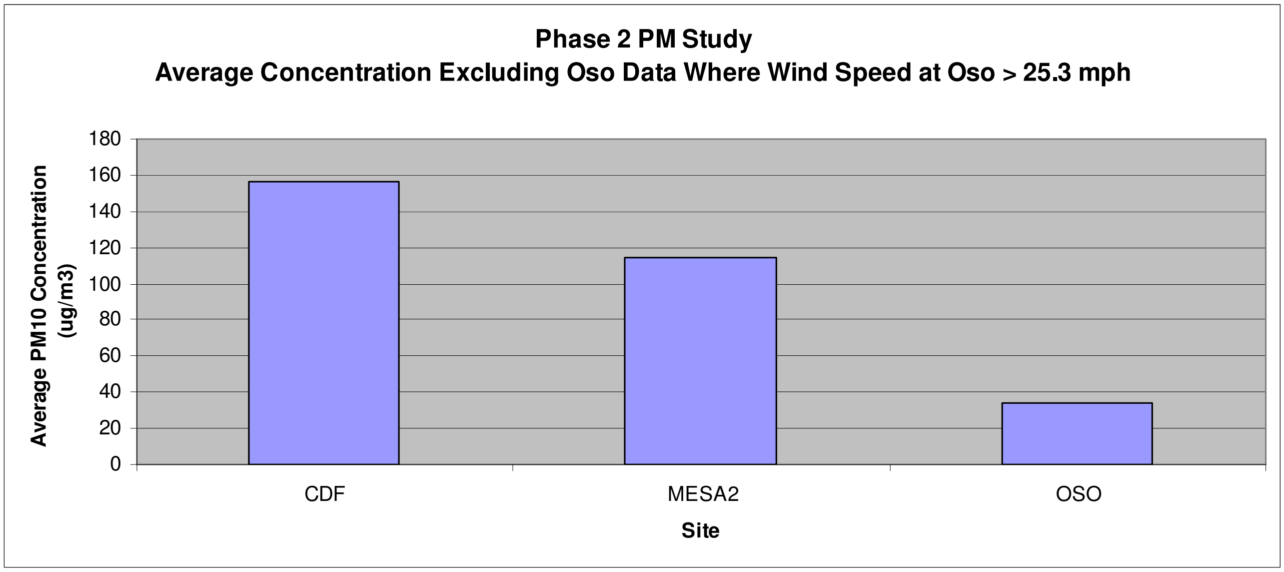

Figure 3.57 – Estimate of Episode Concentrations When Wind Speed is Less than 25 MPH

Late in the Phase2 study, SLOAPCD decided to perform PM_{10} measurements farther downwind from the Oso site at the Dune Center, which represents a control site a similar distance to the ocean as the Mesa2 site that is downwind from the SVRA. Data was only gathered at the Dune Center for about 3 weeks in March 2009. Figure 3.58 below presents the average PM_{10} concentration for episode periods when the Dune Center monitor was operational, while Figure 3.59 presents a time series plot of the hourly PM_{10} data for that period.

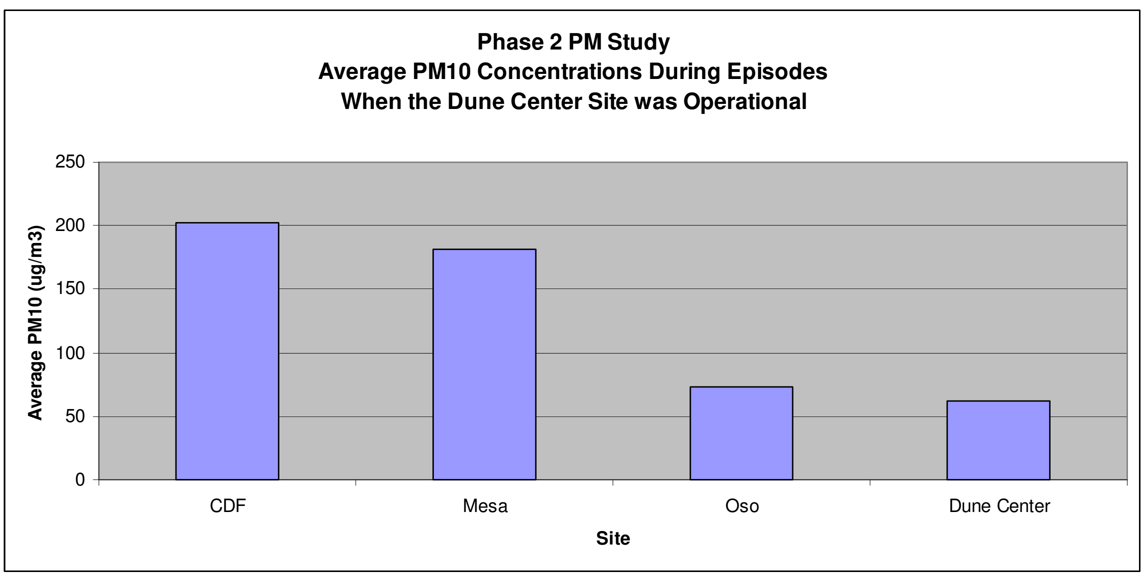

Figure 3.58 - Comparison of Average Downwind PM10 Concentration for Episode Periods when the Dune Center Monitor was Operational

As shown in both charts, the Dune Center PM_{10} values are less than measured at Oso and significantly less than the PM_{10} values seen at Mesa2. Figure 3.59 below also demonstrates the close correlation of the elevated readings from Mesa2 and the CDF monitoring sites compared to the control sites. Since the sand sheets downwind of each monitoring site appear to be the primary source of particulate on episode days, differences in those sand sheets must be responsible for the significant differences in PM_{10} levels measured at CDF and Mesa2 compared to the control sites. The primary difference between the sand sheets is the presence of OHV activity on the SVRA dunes upwind of CDF and Mesa2.

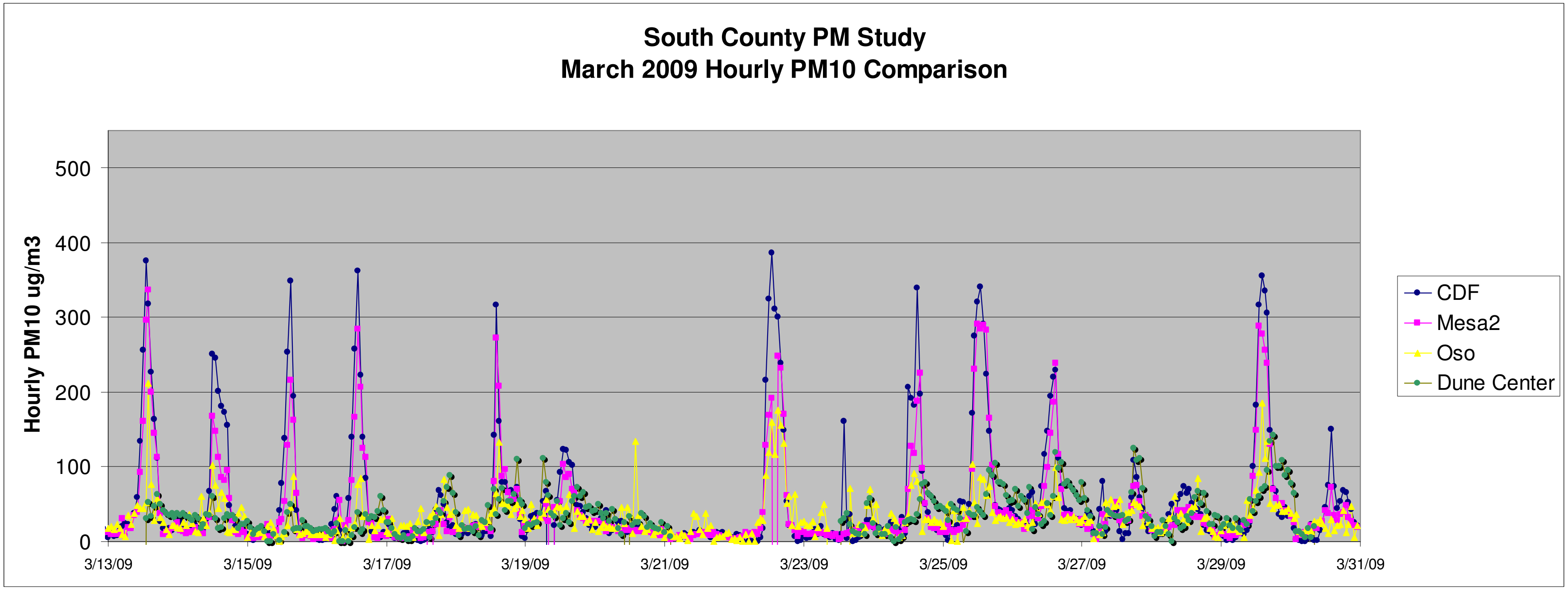

Figure 3.59 – Hourly PM10 From CDF, Mesa2, Oso, and the Dune Center

3.1.4. Contributing Factors Other Than Wind

Close examination of Figure 3.53 above shows that, for each site (other than Grover Beach), there is a threshold wind speed where elevated PM_{10} values begin to occur. In general, as wind speed increases PM_{10} also increases. However, Figure 3.53 shows that for any particular wind speed above the threshold where PM_{10} values become elevated, the range of hourly PM_{10} concentrations is quite variable. This indicates that, while wind speed and direction are the primary determinants of PM_{10} levels in this region, there are likely other variables that can influence just how high the PM_{10} concentrations will reach during a wind episode.

To investigate other potential variables that may affect PM_{10} concentrations during a wind episode, hourly PM_{10} data collected at Mesa2 and CDF under northwest winds and a narrow range of hourly wind speeds were selected for the evaluation. Two wind speed ranges were tested where episodes occur with enough frequency to have sufficient data points to evaluate: 16.0-16.9 mph and 20.0 – 20.9 mph. The 16-16.9 mph range is at the lower end of northwest wind speeds where episodes occur, while the 20-20.9 mph wind speed range was selected to represent the higher range of episode wind speeds. In performing these comparisons it quickly became clear that some of the hours within each range spanned either the beginning or end of an episode, where only part of the hour was affected by the episode. These partial hours were excluded, so that only hours where both the wind speed and PM_{10} was at or near the maximum for that day's event were included for analysis. In addition, any data on a day with rainfall or the day following rainfall was excluded.

In this evaluation, factors such as temperature, and humidity were tested for a correlation to PM_{10} concentration at both wind speed ranges. Close examination of these datasets shows a weak but clear connection between temperature and PM_{10} at Mesa2 and CDF. Figures 3.60 and 3.61 below present this relationship for Mesa2 for both wind speed ranges tested. Figure 3.62 below presents this relationship for CDF for the 16.0-16.9 mph range; not enough data points were available at the higher range at CDF to perform this analysis. Because temperature was not measured at CDF, Mesa2 temperature was used for the CDF analysis.

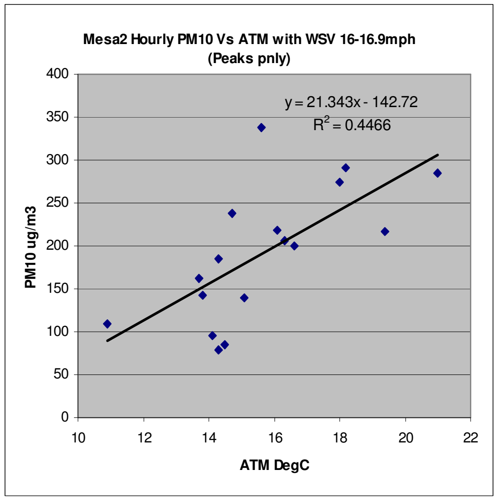

Figure 3.60 – Relationship between PM_{10} Episodes and Temperature

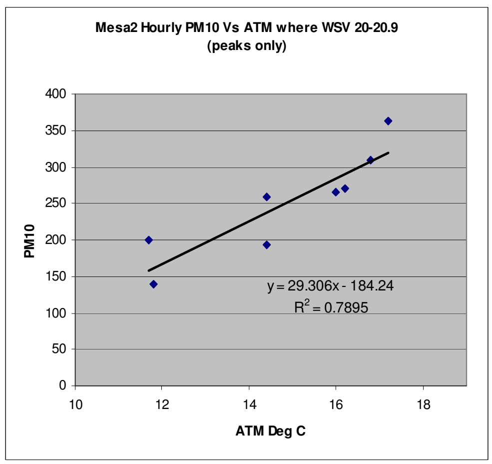

Figure 3.61 – Relationship between PM_{10} Episodes and Temperature

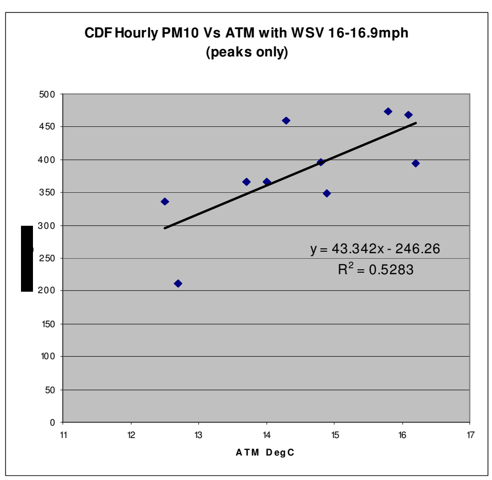

Figure 3.62 – Relationship between PM_{10} Episodes and Temperature

Care must be taken in evaluating any indirect variable such as temperature in terms of its relationship to particulate levels during episodes. An indirect variable, such as temperature could be related to another factor which correlates to both variables. However, the connection between temperature and PM_{10} concentration for similar wind speeds makes sense for a wind blown crustal source. Most days on the dunes begin with moisture on the sand surface from the moisture-laden marine air. On cold days moisture on the surface likely remains higher in the afternoon when the wind events occur than on hotter days with more evaporation potential. So, while wind speed and direction play the most important role in determining PM_{10} concentration, the temperature characteristics of the air mass may contribute as well.

Rainfall also has a major effect on PM_{10} concentrations observed during the study, as would be expected. Figure 3.63 below plots the 24-hour average PM_{10} values and 24-hour rainfall totals from Santa Maria NWS station. On all days with more than trace rainfall, PM_{10} values were very low.

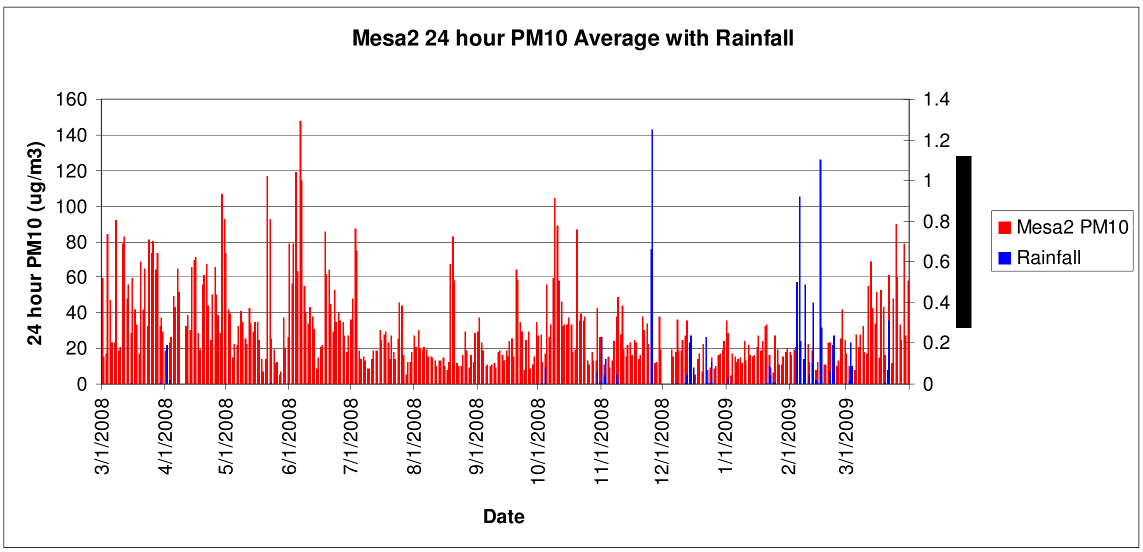

Figure 3.63 – Mesa2 24-hour PM_{10} and 24-hour Rainfall at Santa Maria NWS

SVRA Attendance Analysis

Comparison of control site to non-control site data in Section 3.2.3 showed significantly higher PM_{10} concentrations downwind from the SVRA, with this difference likely due to OHV activity. As discussed in Section 1, it is possible for the OHV activity in the SVRA to cause direct PM emission impacts from fuel combustion exhaust and/or dust plumes caused by vehicles driving on the dunes. Indirect impacts may also occur from vehicle activity causing de-vegetation, changes to the structure of the dunes and other impacts that make it easier for fine sand particles to become airborne during a wind event.

In order to assess if there are any direct PM impacts from the OHV activity in the SVRA an analysis was performed comparing activity in the SVRA to observed PM_{10} concentrations. The level of actual OHV activity is not measured or recorded, but the number of vehicles entering the SVRA is recorded by State Parks personnel. Figure 3.56 plots the relationship between daily PM_{10} levels at Mesa2 and daily number of vehicles entering the SVRA; the data shows no statistical correlation between the two. This is not surprising given the predominant role of wind speed and direction in determining PM_{10} concentrations.

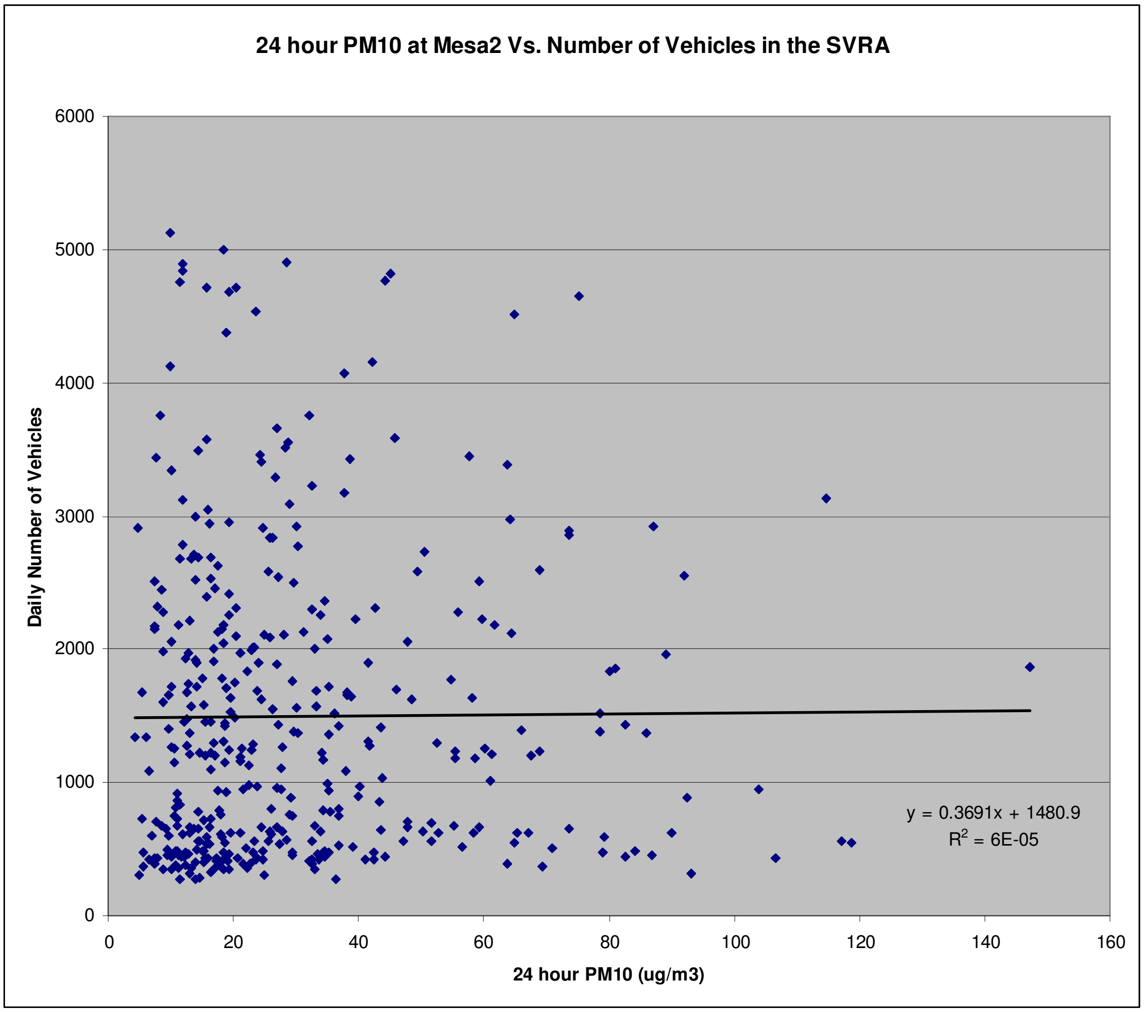

Figure 3.64– PM_{10} Concentration as Compared to Number of Vehicles in the SVRA

Averaging of the data may allow the strong correlation with winds to get averaged out and possibly show a relationship between the number of vehicles entering the SVRA and PM_{10} concentration downwind. Averaging weekend verses weekday values is a common technique used in air quality analysis to determine if different activity levels are a factor in pollutant levels. Since there are actual records of activity level, rather than use weekend/weekday averaging, a better approach is to average the highest activity days and the lowest activity days and see if there is a significant difference in average PM_{10} concentration downwind from the SVRA. Table 3.2 below summarizes the highest and lowest 50 days of SVRA activity based on number of vehicles entering the SVRA.

One must be cautious in using averaging to cancel out other variables. If the sample size is too small, the natural randomness of the dominant variable(s) (i.e., wind speed) can bias the averages. This could make it appear that vehicle activity is affecting the PM_{10} concentrations when, in actuality, the sample size is too small to allow the dominant variable to be fully averaged out, causing a bias in the averages. In this analysis however, the Oso site provides a control that can be used to assess if factors other than vehicle activity are causing a bias to the averages.

Table 3.2 below shows the PM_{10} average concentration downwind from the SVRA on high OHV activity days is higher than the average PM_{10} concentration on low activity days. However, at the Oso control site, the reverse is true, with PM_{10} concentrations being lower on high activity days. Because activity levels in the SVRA have no affect in the Oso control area, the Oso averages in Table 3.2 reflect a control that represents the likely affect of variables other than SVRA activity on the PM_{10} averages.

In order to assess if these average differences are indeed statistically significant, the Student T test was performed on these data. The results of the Student T test are presented as the confidence interval (1-P) in Table 3.2. It is generally accepted that a confidence interval greater than 95% indicates statistical significance (5). Mesa2 averages meet this threshold, indicating that the difference between the average concentration for the highest and lowest activity days is real and not an artifact of the randomness of the data. However, the 95% confidence is not met for the CDF or Oso data, indicating no statistical difference between the highest and lowest activity averages for those sites.

Showing no statistical difference between high and low activity days for Oso is expected because the activity in the SVRA should have no impact on PM_{10} levels at the Oso site. However, finding no statistical difference between the lowest and highest activity days at CDF, yet finding a statistical difference at Mesa2 appears a bit contradictory. Close inspection of the dataset shows that there is a handful of missing data points at CDF in these averages, which could have affected the statistical analysis. The CDF site is closer to the SVRA and, as a result, has larger swings in concentration, increasing the variability of that dataset, which may also explain the lack of a statistical difference.

The mixed message from this analysis shows that the direct emissions impacts of vehicle activity on the SVRA, even if statistically measurable, are small compared to the indirect impacts caused by OHV activity increasing the ability of winds to entrain sand particles from the dunes and carry them to the Mesa.

Table 3.2– Average PM10 Concentration for the Highest and Lowest SVRA Activity

	Highest 50 days for vehicles	Lowest 50 days for vehicles	Highest days - Lowest days	Statistical Confidence of Data (1-P)
Average SVRA Vehicles	3738	380	3357	
Average Mesa2 PM_{10}	32.1	24.2	7.9	96.4%
Average CDF PM_{10}	37.1	31.7	5.4	87.8%
Average Oso PM_{10}	27.7	28.8	-1.1	69.4%

4 SAND FLUX MEASUREMENTS AND DATA ANALYSIS

The Great Basin Unified Air Pollution Control District (GBUAPCD) was an integral part of the study design team and provided the equipment, training, oversight, and data analysis for the sand flux portion of the Phase 2 Study. Because wind erosion is the source mechanism for creating wind blown crustal PM_{10} emissions, understanding and quantifying wind erosion in the potential source areas is essential in understanding the source emission mechanism.

The GBUAPCD is one of the most experienced and respected organizations in the country regarding analysis and mitigation of wind blown, crustal PM. With studies beginning in the 1980's, the GBUAPCD has developed innovative techniques for measuring sand movement and calculating wind erosion and PM_{10} emission rates for the dry Owens Lakebed and nearby Keeler Dunes, the largest source of PM_{10} emissions in the nation. This chapter describes the measurements performed and presents the data collected for this part of the study.

Monitoring Site Descriptions and Measurements Performed

The study design called for sand flux measurements in the SVRA, as well as a control area south of the SVRA where no OHV activity is allowed, and an agricultural site northwest of the CDF, Mesa2 and Oso stations. This allowed for comparison of wind erosion rates between the SVRA, the control area and the vegetated rangeland to the northwest (upwind) of the CDF, Mesa2, and Oso sites. Table 4.1 below describes the three types of sand flux sensors deployed for this portion of the study:

Table 4.1 – Description of Sand Flux Sensors

Sensit	BSNE Sandcatcher	Cox Sandcatcher
A solid state sensor that measures the count and kinetic energy of sand/soil particles that impact the sensing element. (See Figure 2.7)	A device that traps sand/soil particles at a number of different heights above the soil surface. (See Figure 2.6)	A device that traps sand/soil particles at a single height above the soil surface. (See Figure 2.5)

Figure 4.1 and Table 4.2 below depict the location and description of measurements made at each sand flux sampling location. Site locations C1, C2 and C13 were all equipped with a Model H11 Sensit. Each Sensit was suspended so the sensing element was 15 cm above the surface of the sand. Each Sensit was also connected to a Cambell Scientific CR-100 data logger to provide a continuous record of the sensit readings. A solar panel with battery back-up was used to power the sensit and data logger. Sites C1 and C2 were also equipped with a BSNE (Box Springs Number Eight) sand catcher to provide a vertical profile of sand movement. The BSNE sandcatchers were configured to collect sand at 10 cm, 15 cm, 25 cm, 63 cm, and 100 cm above the sand surface. All sites also included a Cox Sandcatcher (CSC) set at a sensor height of 15 cm above the sand/soil surface.

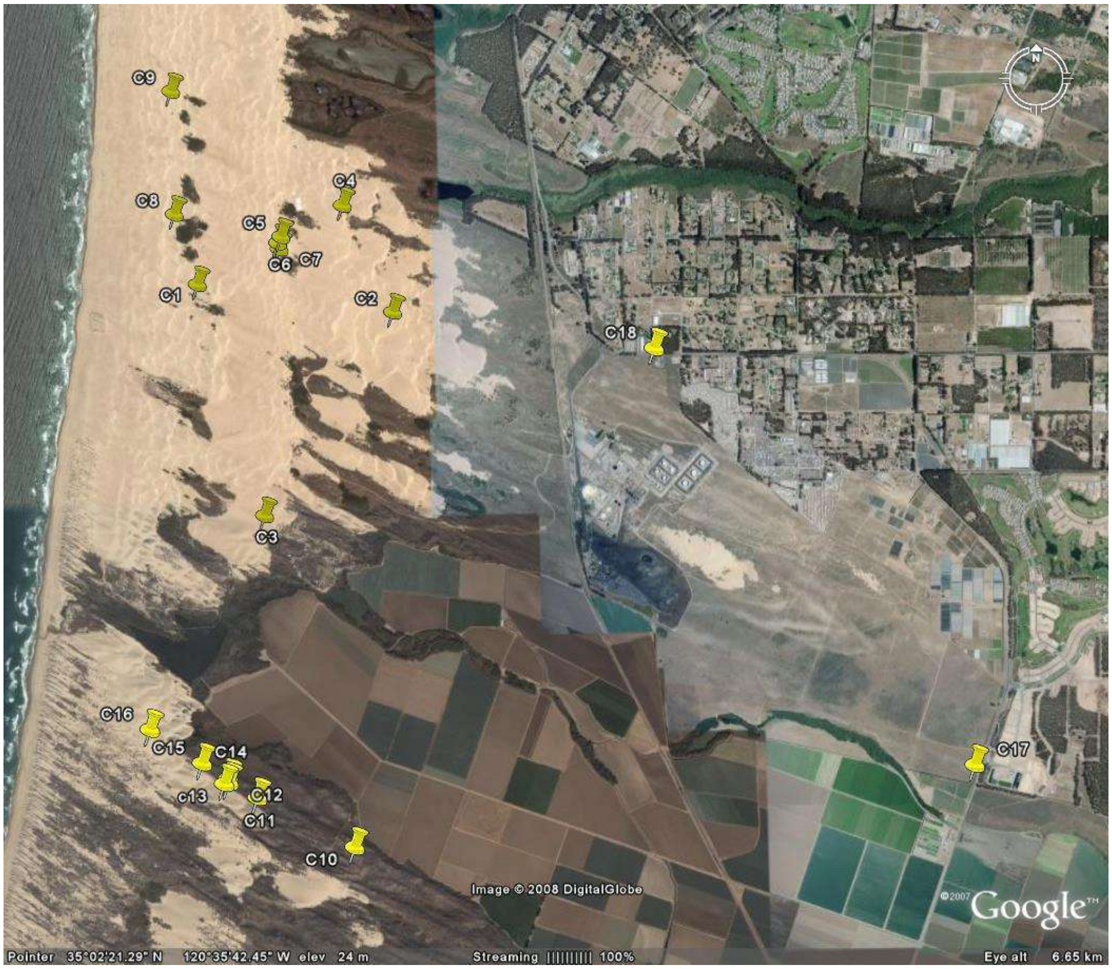

Figure 4.1– Location of Sand Flux Measurement Locations

Table 4.2 – Sand Flux Measurement Sites and Equipment

Site ID	General Location	Equipment
C1	SVRA	Sensit,BSNE, CSC
C2	SVRA	Sensit,BSNE, CSC
C3	SVRA	CSC
C4	SVRA	CSC
C5	SVRA	CSC
C6	SVRA	CSC
C7	SVRA	CSC
C8	SVRA	CSC
C9	SVRA	CSC
C10	Upwind of Oso Flaco	CSC
C11	Oso Flaco	CSC
C12	Oso Flaco	CSC
C13	Oso Flaco	Sensit, CSC
C14	Oso Flaco	CSC
C15	Oso Flaco	CSC
C16	Oso Flaco	CSC
C17	Upwind of Mesa2	CSC
C18	Upwind of CDF	CSC

The sensits and CSCs started collecting valid data on 4/22/08 and continued through 5/23/08. The BSNE sandcatchers started collecting valid data on 5/6/09 and continued through 5/23/09. After installation of the field equipment, all sand flux measurement locations were visited and serviced every 24 hours. The daily service of the sandcatchers (Cox and BSNE) included the following:

- Measure and record the "as found" sandcatcher height above surface
- Empty sandcatcher contents to labeled baggie
- If necessary, reset the sandcatcher height to the standard height (CSC set to 15 cm)

The sensits were checked daily and the as found sensor height was recorded and reset to 15 cm if needed. Data from the sensit dataloggers was downloaded approximately once per week to storage modules. The BSNE sandcatchers were also serviced daily and the as found sensor height was recorded and reset as needed.

Sand samples from the sandcatchers were transported to the SLO APCD laboratory and weighed to the nearest tenth of a gram by CARB staff. All sand weights and sensit data records were transferred to GBUAPCD staff for analysis. The results of GBUAPCD's data analysis, including a complete description of algorithms used for this analysis, are presented in full in Appendix B.

The major findings of the sand flux study are as follows:

- **During the sand flux study period, high sand flux was associated with high downwind PM_{10} values.** Figure 4.2 below is an example of this relationship.

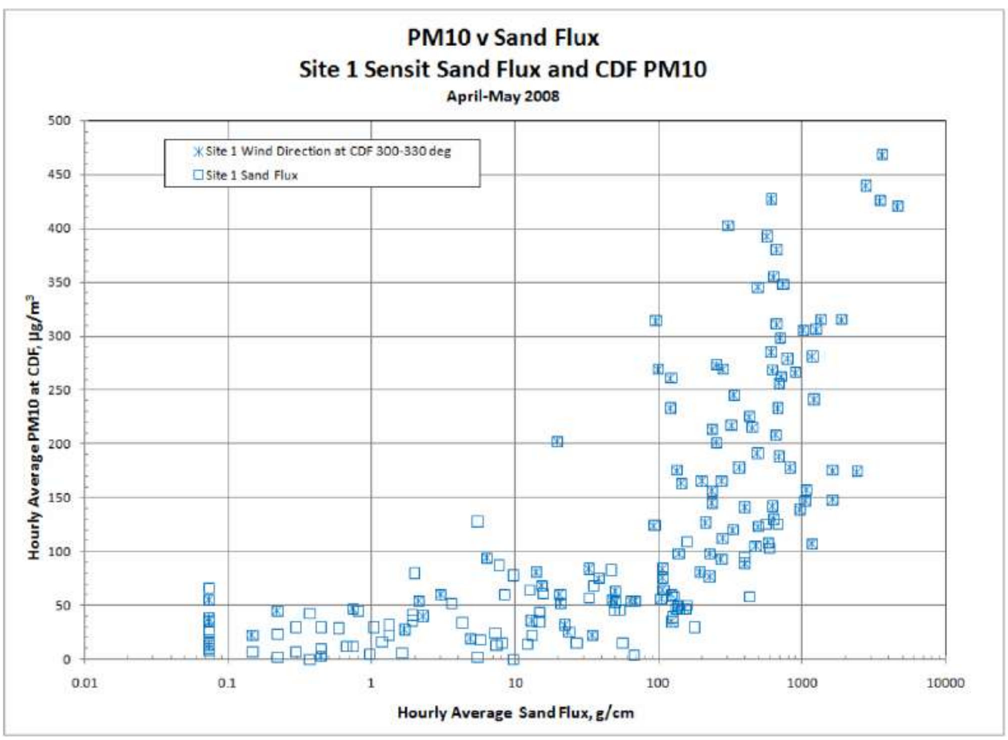

Figure 4.2 – PM10 at CDF Compared to Sand Flux at C1

- **The threshold wind speed where significant sand movement begins was significantly higher at the undisturbed Oso sand sheet as compared to all portions of the SVRA.**

Table 4.3 below presents the threshold wind speed comparison between the two SVRA areas and the natural Oso area.

Table 4.3 - Comparison of Threshold Wind Speed for Different Areas Tested

Location (Site ID)	Threshold Wind Speed at 10 Meters
SVRA – Beach Dunes (C1, C8, C9)	7.7 mph
SVRA – Interior Dunes (C2,C3,C4, C5, C6, C7)	10.6 mph
Natural Area – Oso (C11, C12,C13, C14, C15, C16)	13.3 mph

- **Using the sand flux data and the Gillette model, both areas in the SVRA were more erodible by wind than the Oso control area.** Not only does the wind need to blow harder to start significant sand movement in the natural area, but the Gillette model shows the Oso natural area to be much less erodible than the SVRA at the same wind speed. Figure 4.3 below presents this relationship.

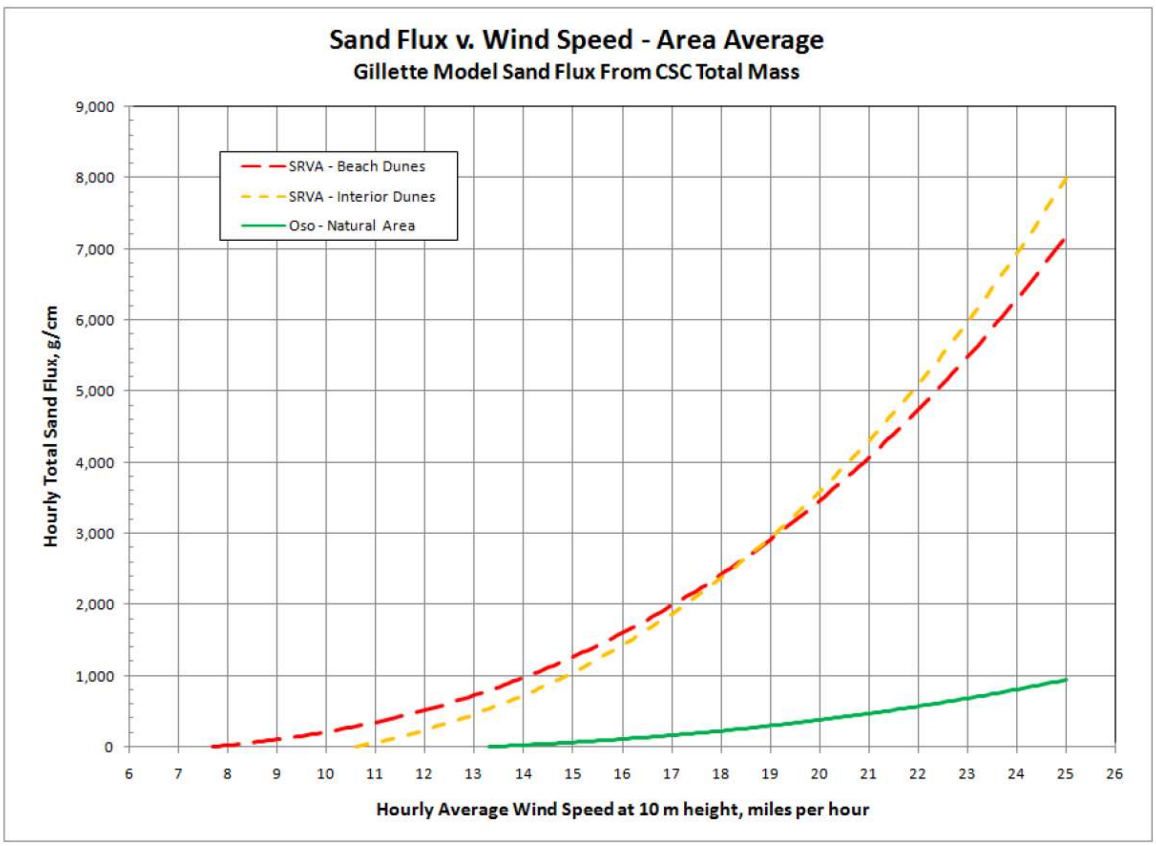

Figure 4.3 – Sand Flux for SVRA and Oso

- **The CSCs located in vegetated areas upwind from the Oso, Mesa2, and CDF sites (C10,C17, C18) did not collect any sand or soil for the entire sampling period.** This indicates these vegetated areas are not a source of wind blown dust.

These findings further confirm the open sand sheets to the northwest of the Oso, CDF, and Mesa2 monitoring stations as the source of high levels of wind blown crustal particulate measured during the study period. They also add important information to help determine the role of OHV activity in the wind blown PM events observed on the Nipomo Mesa, particularly the findings that open sand areas within the SVRA are more erodible by wind than similar areas in the Oso natural area, and the threshold wind speed for sand movement is greater in the natural area than in the SVRA.

5 AEROSOL AND SOIL PARTICLE COMPOSITION AND SIZE MEASUREMENTS AND DATA ANALYSIS

The UC Davis DELTA Group developed, installed and operated the instruments used to measure particle mass, size and composition; these measurements were conducted during short-term, high wind events and well as over longer periods through the summer, fall, and winter of 2008. Personnel from the University of Texas, El Paso, collected and analyzed soil samples from the various study sites. This chapter describes the measurements performed and presents the data collected for this portion of the study.

5.1. Monitoring Site Locations and Measurements Performed

Probably the most important diagnostic tool for this portion of the Phase 2 study was the ability to deploy DRUM aerosol samplers, on a north to south transect allowing source identification of aerosol episodes and comparisons between measurements downwind from the SVRA and downwind from dune areas without OHV activity. Continuous, highly time-resolved aerosol sampling allowed episodes to be tracked with an approximate 3-hour time resolution that facilitates close correlation with on site meteorology.

Table 5.1 below identifies the samplers used and associated sampling periods; Figure 5.1 shows the sampling site locations.

Table 5.1 Delta Group Aerosol Sampling

Site Name	Delta Group Measurements	Delta Group Sampling Period
Ten Commandments	8 DRUM	Intensive
Guadalupe Dunes	8 DRUM	Sept 08 – Nov 08
Oso Flaco	8 DRUM	Intensive
Mesa2	8 DRUM (also side by side all DRUMs 1 week)	Jan 08-Feb09
CDF	8 DRUM	Intensive + 6 weeks
Conoco Upwind	8 DRUM	Intensive
Bluff	8 DRUM and 3 DRUM	Intensive
Silver Spur	3 DRUM	Intensive
Pier Ave.	3 DRUM	Intensive
Grover Beach	3 DRUM	Intensive

Figure 5.1 - Aerosol Sampling Sites with Prevailing Wind Direction in Aerosol Episodes

5.2. *Analysis of Sands*

5.2.1. Collection of Sand Samples

The DELTA Group and University of Texas, El Paso (UTEP) collected over 150 sand samples over every transect from each ambient air sampler to the ocean, with photographs taken at every soil sampling site. The samples were placed into coded Ziplock™ bags and transported to UC Davis for analysis.

5.2.2. Sieving and Triages of Sand Samples

The samples were sieved in standard dry geological sieves, and then divided into bags; roughly 60 of these sample bags were sent to UTEP for Malvern particle sizing. From the results of the sieving a selection of the samples with relatively high mass in the < 50 µm bin were re-suspended using an air jet at UC Davis, and collected onto the stages of an 8 DRUM impactor, the same instruments used to collect aerosols in the ambient component of the study.

5.2.3. Observations from Sand Collection Field Effort

An important observation from the sand collection field effort was the presence or absence of ephemeral soil crusts, a key factor known to influence airborne particulate levels measured in other high wind, sandy areas such as Owens and Mono Lakes. Direct observations of the sand at Oso Flaco showed the presence of such a crust about 1/2 to 1 cm thick; it was capable of supporting itself over a few cm but was easily broken under any pressure, such as boots. The soil crust was observed throughout the open sand sheets upwind from the Oso site, but was not present in the SVRA.

Figure 5.2 - Sand crust at the eastern edge of the sand sheet upwind of Oso Flaco control site. The thickness of the layer was roughly 1 cm

Such crusts greatly suppress particle emission by gluing small particles into larger ones and suppressing the saltation processes that can occur when the crust breaks up. This is seen at Owens (dry) Lake, where almost no dust is emitted into the air, even in strong winds, until the robust salt crust formed every year by winter rains breaks up. (Reid at al, 1994)

5.2.4. Analysis of Sand/Soil Samples

Various methods were used to analyze the 150 samples of sand collected in sampler to beach transects upwind of all aerosol sampling sites. As shown in Figures 5.3 and 5.4 below, both sieving and the more complex Malvern soil analysis by UTEP showed very little mass in most samples for particles below about 50 µm, as expected.

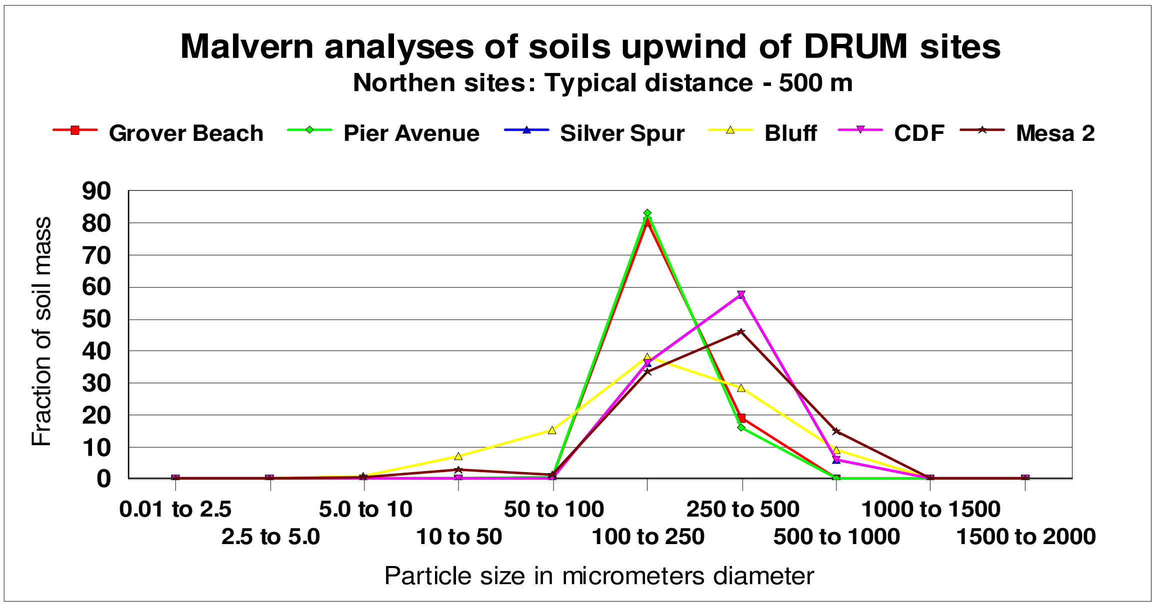

Figure 5.3- Malvern analyses of soils upwind of the northern sites

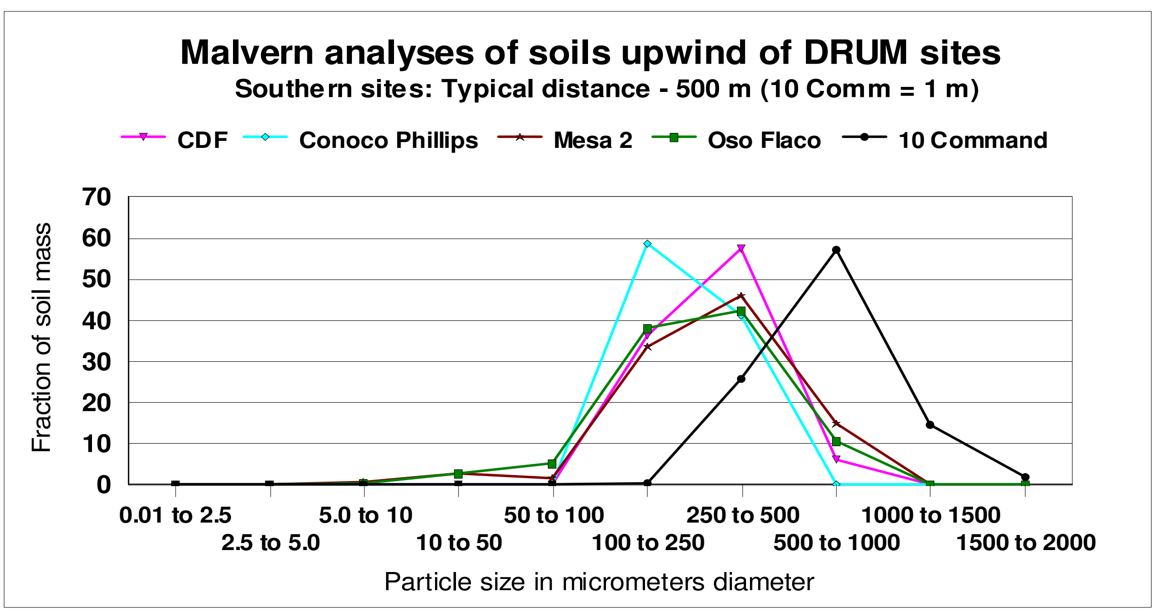

Figure 5.4 - Malvern analyses of soils from sites upwind of the southern DRM sampling sites

While the Malvern analysis shows very little particle mass below 10 microns, analysis of re-suspended samples, shown in Figure 5.5 below, demonstrates there is indeed a fraction of the sand with particle diameters less than 10 micron. The Malvern and re-suspended sample analysis show a similar particle size distribution between the various transects analyzed. Elemental analysis of the re-suspended samples showed a very similar composition between soil samples.

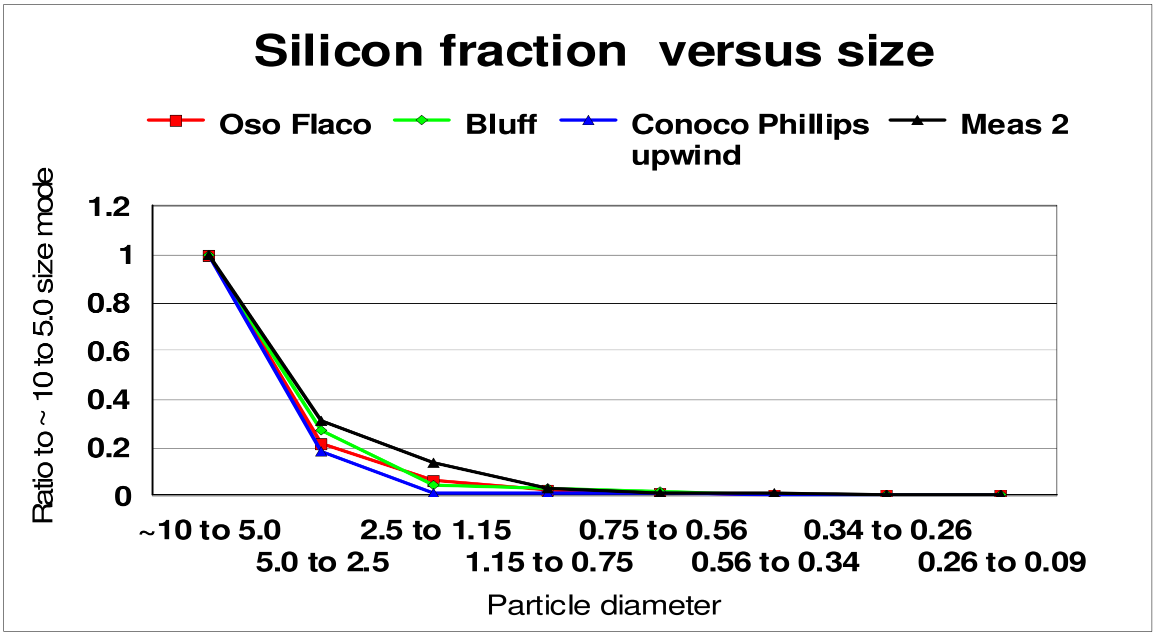

Figure 5.5 - Re-suspension of sieved samples resulting in size profiles of sand transect data relative to the 10 to 5.0 µm mode

A special effort to analyze the soil samples in the transect between the Bluff and Silver Spur site was made to better understand the potential for particulate emissions from this intensely cultivated agricultural land. The rich alluvial plane north of the SVRA, although under intense cultivation, will clearly have soils derived from upstream sources and thus, very different from the sandy soils common to the coastal area. Since such soils typically include silt and clay components with sizes well below 10 µm in diameter, and thus potentially able to impact windblown dusts, special efforts were made to analyze the soils both in a dry, "as-is" condition, as well as dispersed in water to break weakly adhering bonds.

Figures 5.6, 5.7 and 5.8 below show the Malvern analysis of the soils 600 meters upwind of the Silver Spur site, both at the edges of the sand dune field and in the rough middle of the farm fields; the figures show data from both the dry and wet analysis methods. As shown in Figure 5.6, there are few particles in sizes below 50 µm diameter, a common finding for almost all other samples from the non-disturbed dune sites.

In contrast, Figure 5.7 below shows farmland soils dried to essentially zero water content contain a small fraction of soil particles below 10 µm, with some extending to almost the $PM_{2.5}$ cut. These soils were taken at a road edge near the fields in the rough center of the farmed area.

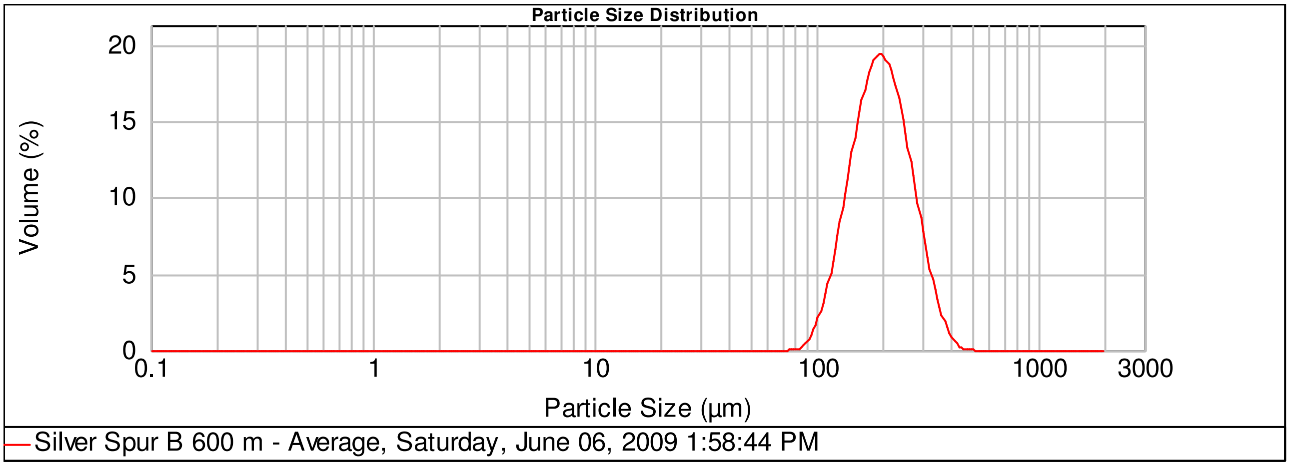

Figure 5.6 - Malvern analysis of soils 600 m upwind of the "Silver Spur" site

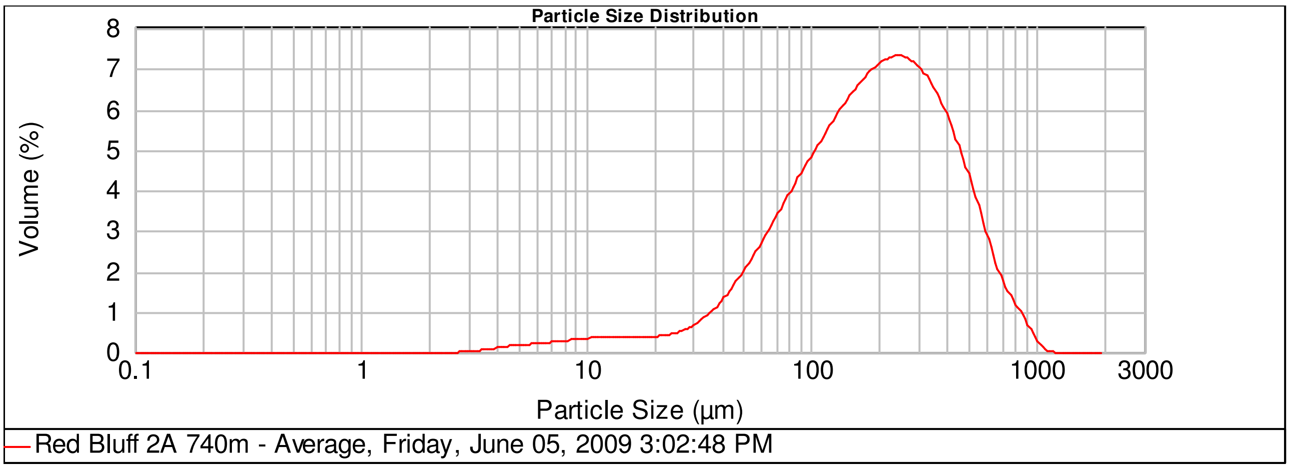

Figure 5.7 - Analysis of dried farmland soils 740 m upwind of the Bluff site

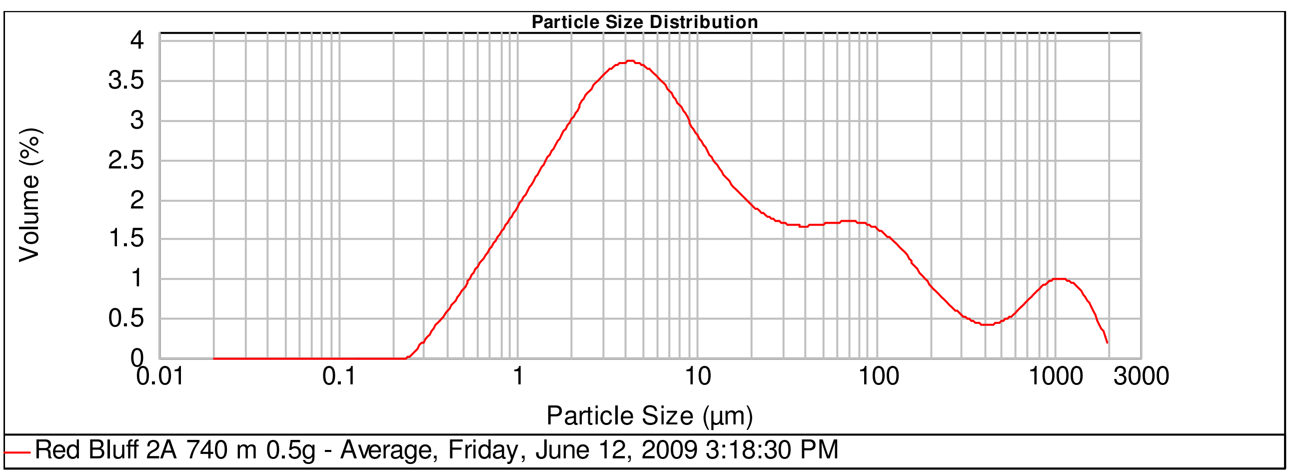

Figure 5.8 - Analysis of farmland soils 740 m upwind of the Bluff site dispersed into a water solution and then sized

The analysis of the same soil in a water solution, presented in Figure 5.8 above, shows that most particles disassociate into smaller particle sizes, with a mode around 4 µm. The condition of the actual soils was like neither of these extremes. Since the land is under intense cultivation, the actual soils are routinely irrigated and much of the area between Bluff and Silver Spur has crop cover, typically lettuce and broccoli. This can also be seen by the tendency of the soil as collected to form clumps or clods. As a result, any free particles in the fine alluvial soils do not normally occur in a re-suspendable form, and thus would be less likely to cause aerosols. This helps explain the almost total lack of aerosol episodes at the Bluff site, which is directly downwind of the farmed area. The combination of crop cover and routinely wetted soils and the crop cover provides very little potential for dust unless special conditions are met such as disking of a thoroughly dry field or vehicular traffic on dry, dirt farm roads.

5.3. Analysis of Ambient Air Aerosols

The Delta Group DRUM sampler used for ambient aerosol sampling is a powerful research tool that can measure particulate mass and elemental composition by particle size fraction. The DRUM sampler is capable of continuous measurements with a time resolution as short as 1.5 hours for the smallest particle fractions, and up to 6 hours for the coarsest particle fraction.

5.3.1. DRUM Sampler Side by Side Quality Control Check

Prior to deployment of the numerous DRUM samplers used in the spring intensive monitoring period, all DRUM samplers were co-located at the Mesa2 monitoring site for side by side quality assurance comparisons. Both 8-Stage DRUM samplers (measuring eight different particle size fractions) and 3-Stage DRUM samplers (measuring 3 different particle size fractions) were run and compared. The Stage 1 drums (10.0 – 5.0 um particles) showed poor time resolution during peak episode due to the width of the DRUM slots, so they are not included in the comparisons. Figure 5.9 below presents a comparison of all the Stage 2 drum data (5.0 to 2.5 µm particles).

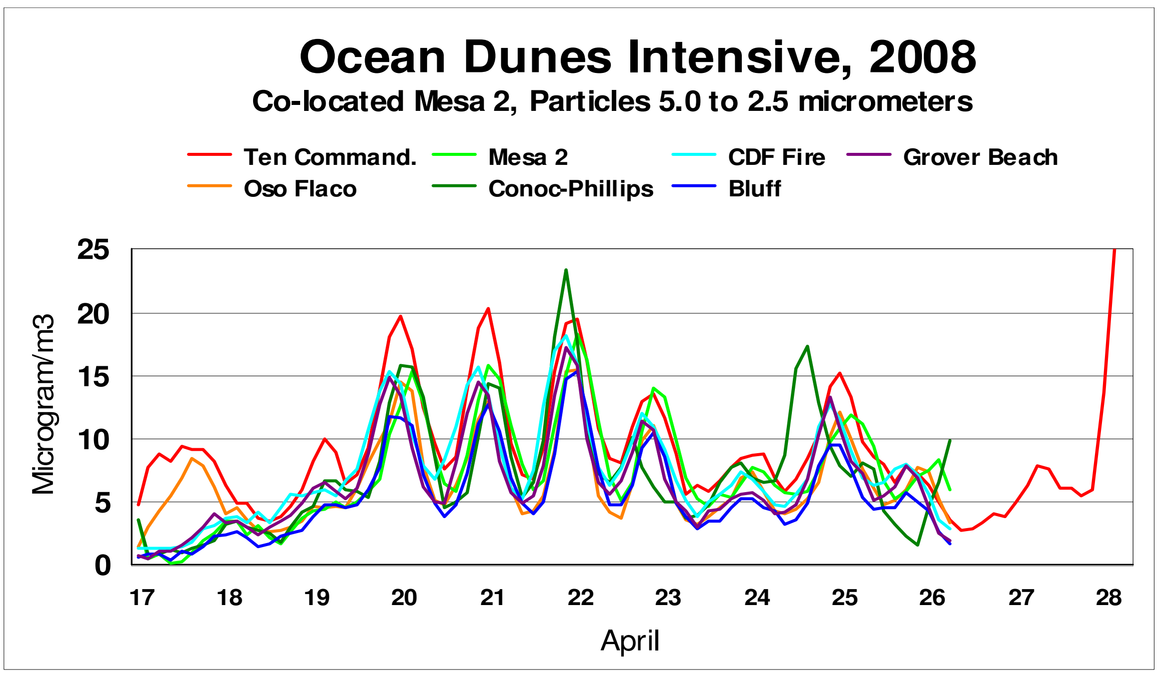

Figure 5.9 – Side by Side Comparison of DRUM samplers at Mesa2

These side by side tests showed accuracy within the standard EPA ± 15% quality assurance (QA) criterion for all samplers except the "Ten Commandments" site DRUM. That sampler did not meet the required QA criteria, so its data was not included in the study analysis.

Quantitative comparisons between the 3 DRUM and 8 DRUM samplers were also performed. For the Bluff site, both samplers ran concurrently and recorded 6 values with a mean aerosol mass of 5.8 ± 0.7 µg/m3. For Mesa 2, comparing the 3 DRUM and 8 DRUM sampler measurements for the April 26 episode showed a mean mass value of 30.5 ± 0.5 µg/m3. Overall, the 3 DRUM and 8 DRUM sampler measurements for the 3 peak episodes were quite similar, with a standard deviation of 3.7 µg/m3 across all sites.

While the comparisons between DRUM samplers were quite good (except the Ten Commandments sampler), comparison of that data to the APCD-operated TEOM sampler data during the side by side tests at Mesa2 was not as favorable. One factor that makes DRUM/TEOM comparisons difficult is that the DRUM sampler has a time resolution of about 1.5 hours for the finest stages, and up to 6 hours for the coarse stage, while the TEOM records hourly averages. In addition, the TEOM sampler is designated as a federally equivalent measurement method for use in determining compliance with ambient air quality standards; its data compared favorably to the federal reference method, hi-volume sampler data at Mesa 2. In contrast, the DRUM samplers are a research tool and were not designed to be a federally equivalent measurement method.

The comparisons at Mesa2 between the DRUM and TEOM showed generally good agreement for 24-hour averages on days with no wind/PM episode. On episode days, however, the TEOM data always showed higher 24-hour average concentrations than the DRUM samplers. Close examination of the data showed the coarsest fraction of the DRUM data appearing suppressed during wind/PM episodes, indicating the possibility of loss of mass on the coarsest drum stages. It is possible that the DRUM samplers were overwhelmed during the episode periods by the extreme wind and particle concentrations that are unique to this field study.

All particulate monitoring methods, including the federally approved methods, have various weaknesses. It is very common for a sampling method to work well in one application, but poorly in another application; thus, the poor comparability between the TEOM and DRUM samplers is not surprising. What is most important is that data comparability between each DRUM sampler is very good, which allows for accurate comparisons of DRUM sampler data from the different sampling locations. DRUM data should not be compared to TEOM data or health standards.

5.3.2. Analysis of Mesa 2 Winter 2008 DRUM Data

Continuous monitoring of aerosols at Mesa 2 in 8 particle size modes using a UC Davis DELTA Group 8 DRUM sampler was initiated on January 14, 2008, and continued to February, 2009. These data were designed to meet several of the Phase 2 study goals:

1. Supplement the co-located PM_{10} mass data with information on particle size so as to better identify sources and evaluate potential health impacts; and,
2. Provide samples suitable for compositional analyses in order to
    a. Connect coarse aerosols to potential dust sources; and,
    b. Evaluate the role of sea salt in Mesa 2 PM_{10} mass measurements

Figure 5.10 below shows a series of time plots from January 14 through February 25, 2008. The plots are segregated by particle diameter, with the two coarsest modes (10 to 5.0 and 5.0 to 2.5

microns) equivalent to the EPA-defined PM10 coarse particle fraction. Everything below 2.5 microns falls into the category of the EPA-defined $PM_{2.5}$ fine particle fraction. As previously discussed, the coarse particle mass appears to be significantly less than the fine fraction on episode days, an anomaly that suggests the coarse stages of the drum samplers may have been overwhelmed by the volume of suspended particles on those days.

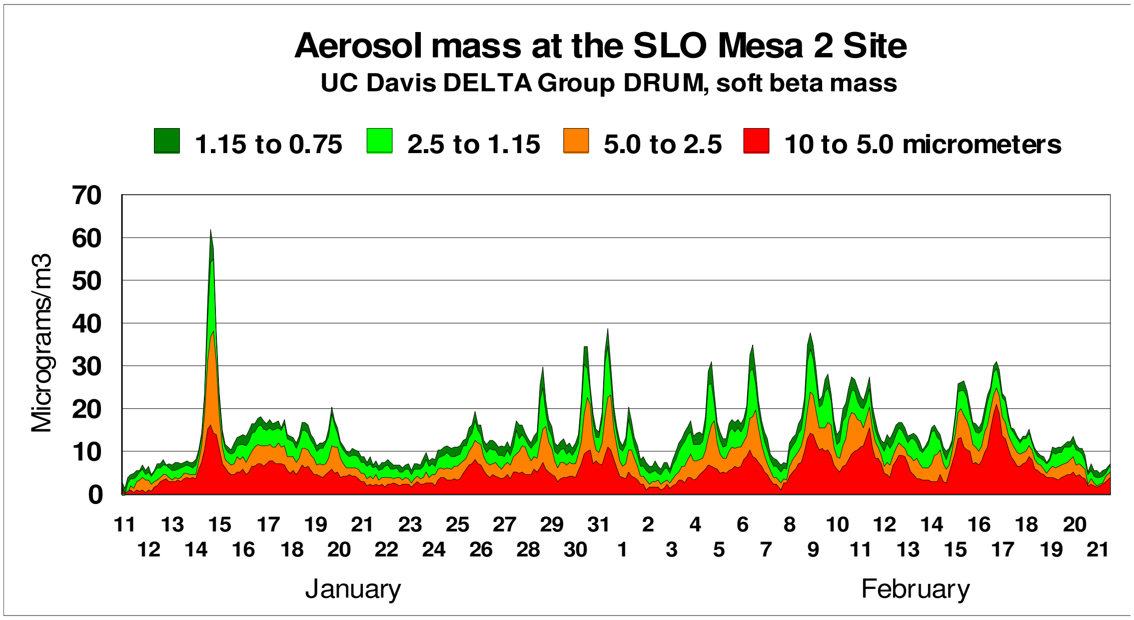

Figure 5.10 - Super-micron masses in the January – February DRUM sampling

In addition to size fractionation, X-Ray Fluorescence (XRF) analysis was also performed on drum particle samples from each sampling site to determine the composition and potential source of the collected particulate; each sample was analyzed for a broad range of potential constituents. Silicon in particular is a distinctive component of sand, and thus an important indicator compound for this study. Similarly, chlorine is a distinctive component of sea salt and generally indicates proximity to the ocean.

Figure 5.11 below presents the silicon concentration for the two coarsest fractions for the same time period.

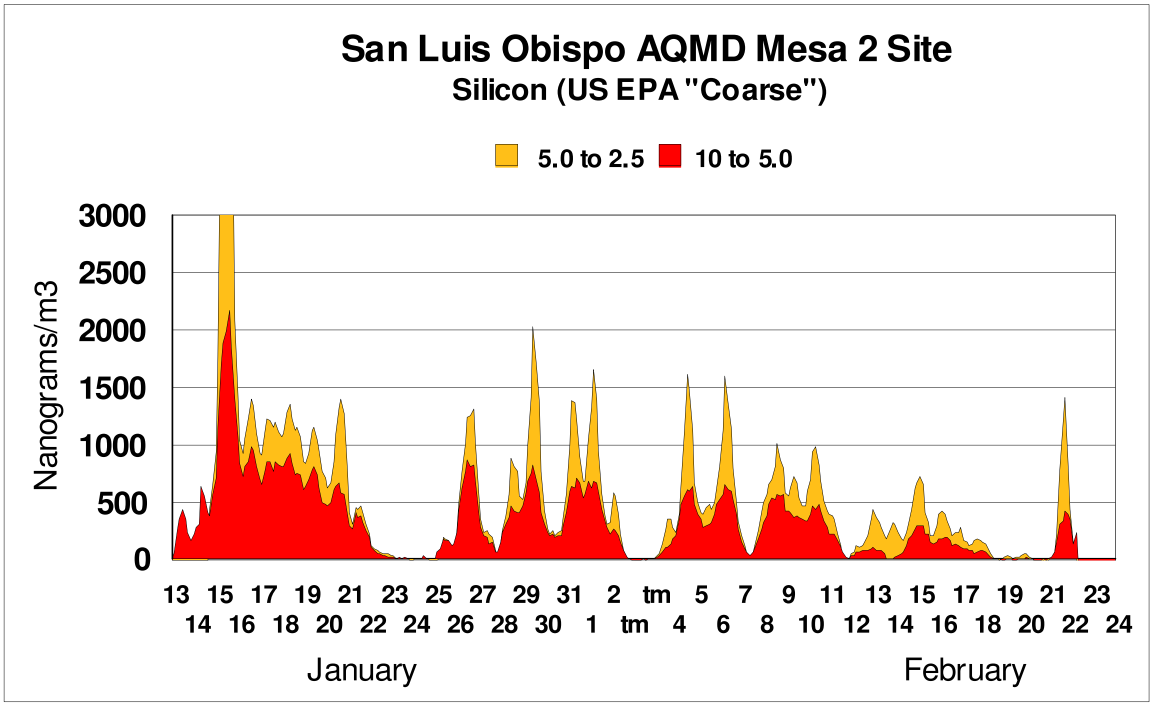

Figure 5.11 - Silicon, the major component of soil, in the coarse modes during the winter, 2008 deployment

Figure 5.12, below presents the chloride concentration for the two coarsest fractions for the winter period.

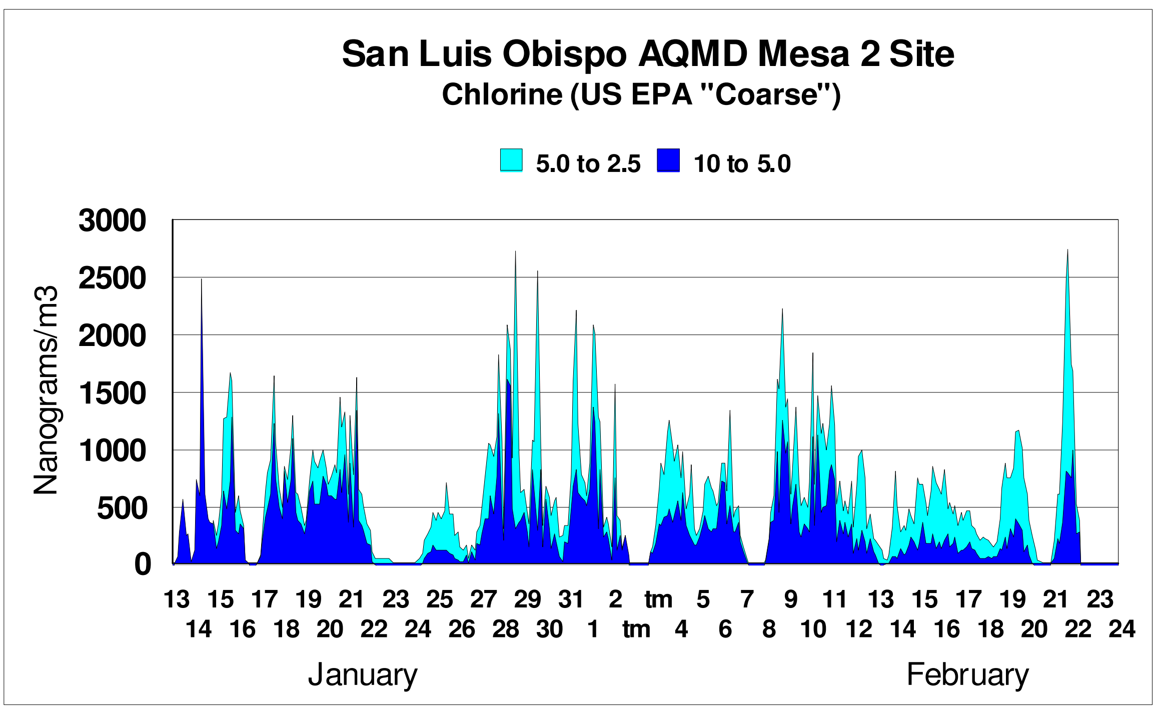

Figure 5.12 - Chlorine from sea salt during the winter, 2008 deployment

The measurement period of January through February, 2008 had several rain events. The wetting of soils strongly suppresses dust formation, thus increasing the sea salt to soil dust ratio above that found in dry conditions (circa 10%). This effect would not occur during most of the year when rainfall is absent. During the January – February deployment, the average sand/soil component was roughly ¾ of all PM_{10} mass, with the remainder almost entirely sea salt. However, during peak episodes, such as January 15, sea salt comprised only 10% of the mass. The higher salt values later in the month may be tied to repeated rain events that would suppress re-suspension of soil.

Particle size by element is presented in Figures 5.13 and 5.14 below.

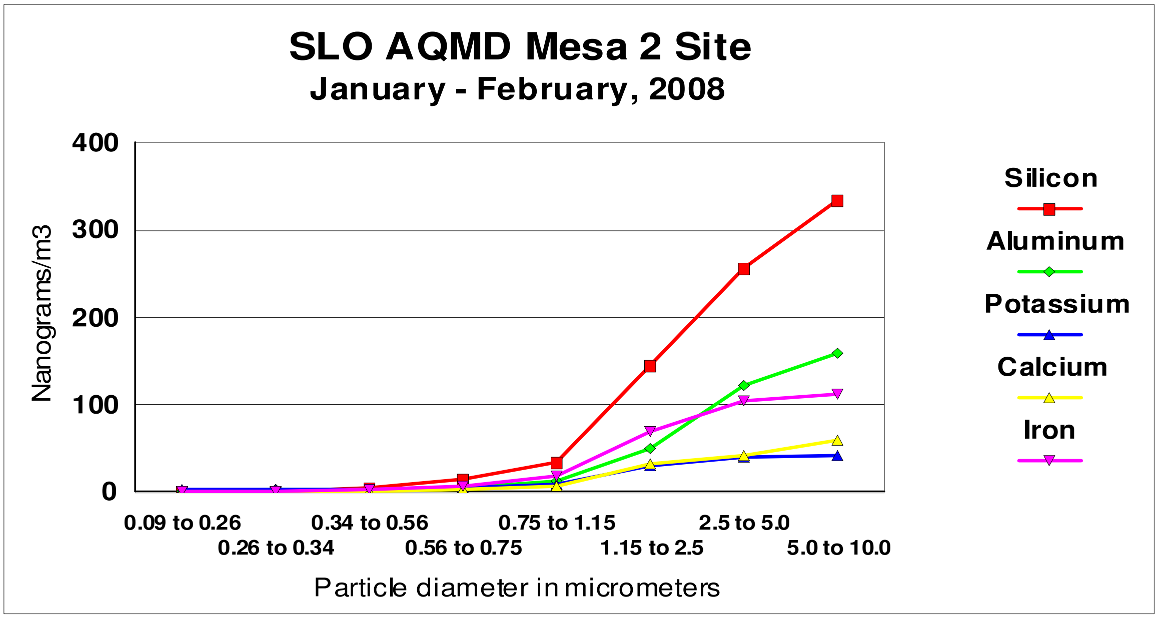

Figure 5.13 - Size distribution of the major soil components

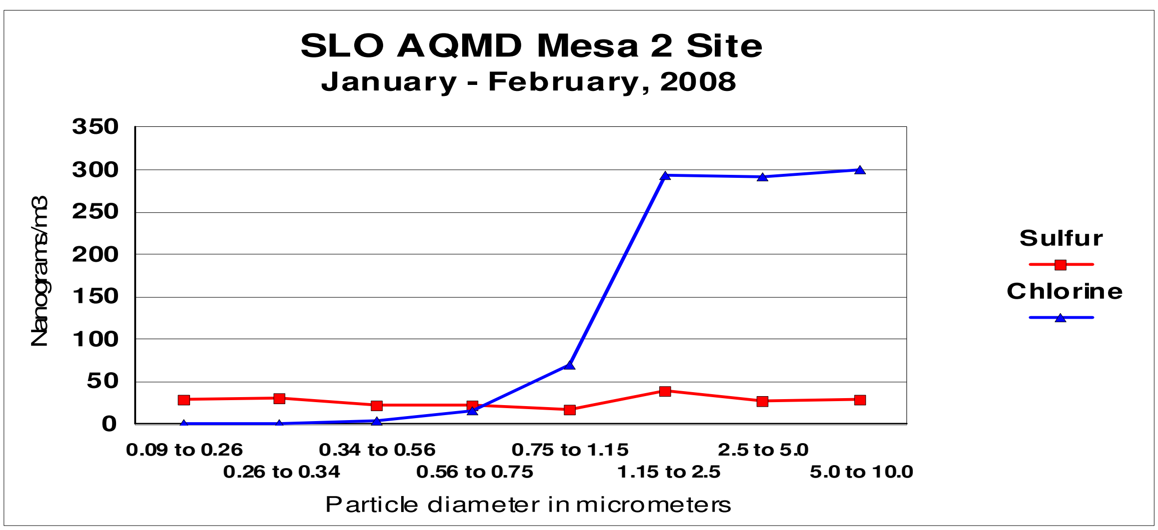

Figure 5.14 - Size distribution of chlorine from sea salt, along with sulfur data. The coarse sulfur is from sea spray, the fine sulfur is likely anthropogenic

Figure 5.15 below presents the ratio of soil elements showing a steady progression to a very pure alumino-silicate sand in the coarsest modes.

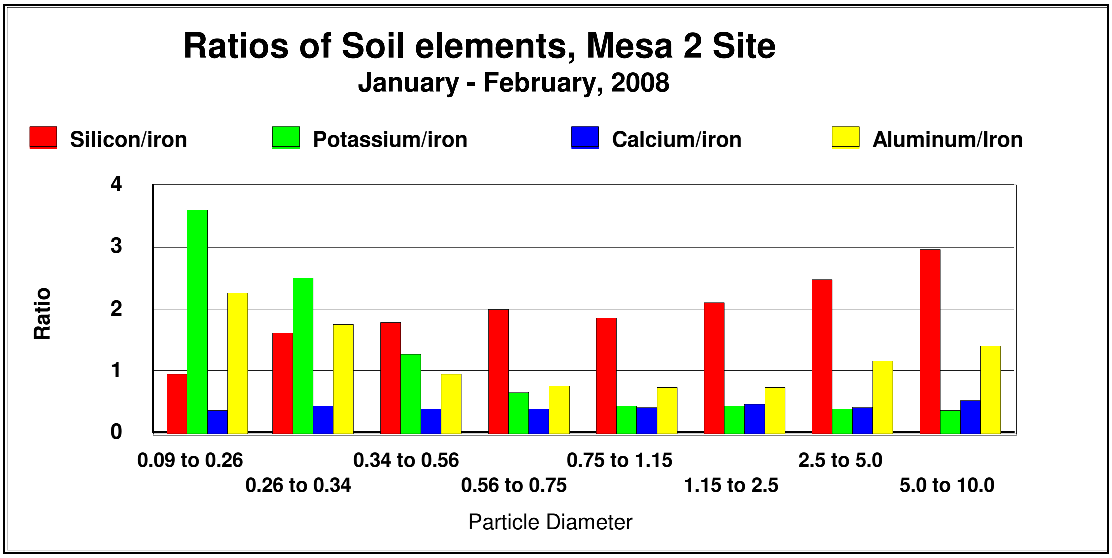

Figure 5.15 - Ratios of soil elements in the January – February period.

In Summary, DRUM data from the Mesa2 winter 2008 period showed that in the dry period, particulate composition was about 90 % sand/soil and 10% sea salt. In the rainy periods, the soil/sand ratio dropped to about 75% soil/25% salt. Overall, the coarse fraction dominated the mass of samples, with a composition consistent with sand.

5.3.3. Analysis of Spring Intensive DRUM Data

The heart of the Phase 2 study design was to conduct and compare particulate measurements downwind from the SVRA to measurements downwind from a variety of control sites. The intensive monitoring portion of the study was designed to provide numerous DRUM sampler measurements across the study area to capture potential source impacts during a period of likely wind/particulate events. Three of our optimally located sampling sites (ConocoPhillips, Oso Flaco, and 10 Commandments) were without line power, requiring transport of heavy batteries to each site every few days. In addition to this logistical difficulty, the Oso site experienced a number of periods of failure due to battery/inverter problems.

Intensive sampling was performed in April and May, 2008, with an array of both 3 DRUM and 8 DRUM aerosol sampling sites from Grover Beach to Santa Barbara County (see Table 5-1 and Figure 5-1). Note that samples from the 10 Commandments site are absent from these data because the 8 DRUM sampler used at this location failed the ± 15% equivalency in the side-by-side tests at Mesa 2. In addition, the Oso sampler failed due to battery/inverter problems after the 4/29 episode, and the Mesa2 sampler failed following the 4/30 episode due to electrical problems. As a result, the Oso data is only represented in the 4/29 episode, and the Mesa2 data presented represents an average of the 4/29 and 4/30 episodes. Data from the APCD TEOM monitors show that 4/29 was the highest concentration episode, followed by 4/30, 5/1 showing the lowest PM levels.

Figures 5.16. 5.17, and 5.18 below present these results. As shown in the first two charts, particulate levels in both the coarse and fine fractions were significantly higher at the sites downwind from the SVRA (CDF, Mesa 2 and ConocoPhillips) than the measurements taken downwind from the control sites where no vehicle activity is allowed. The third chart shows the high correlation between the PM concentrations measured at each site and the amount of open, disturbed sand upwind.

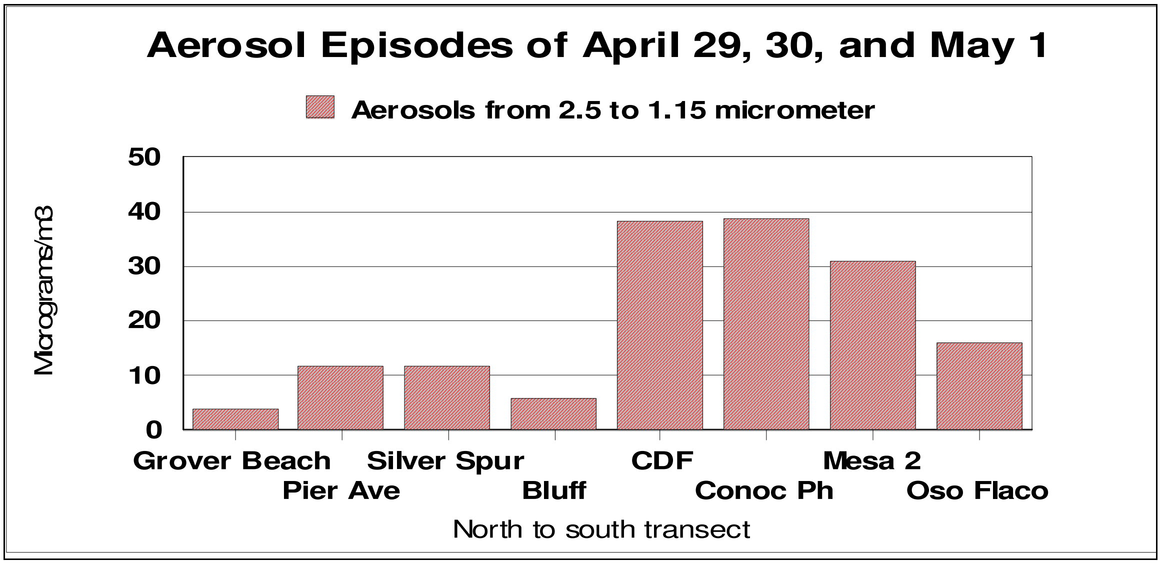

Figure 5.16 - Correlation between dust peaks and upwind disturbed sand

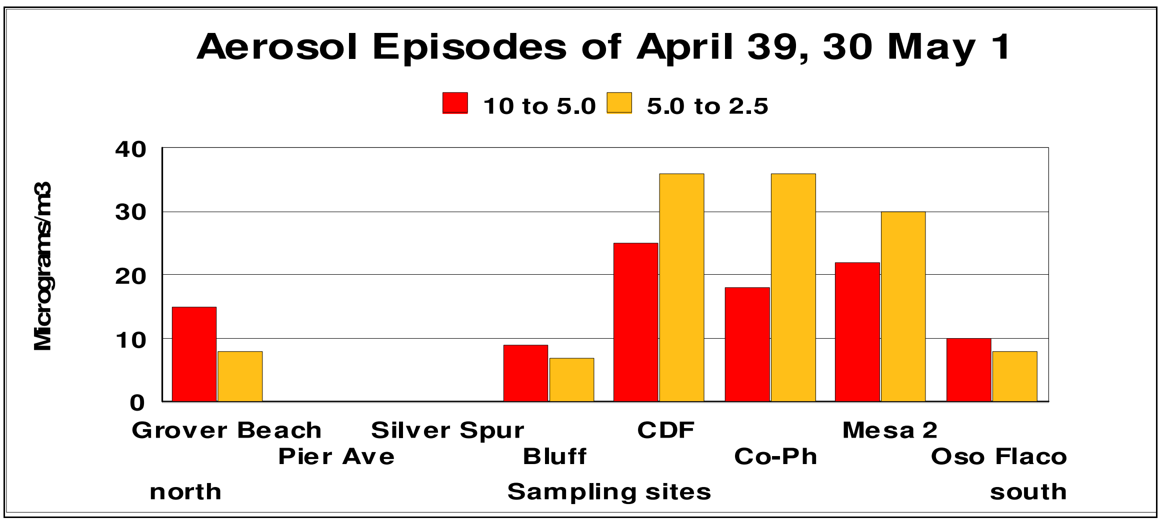

Figure 5.17 - Correlation between dust peaks and upwind disturbed sand

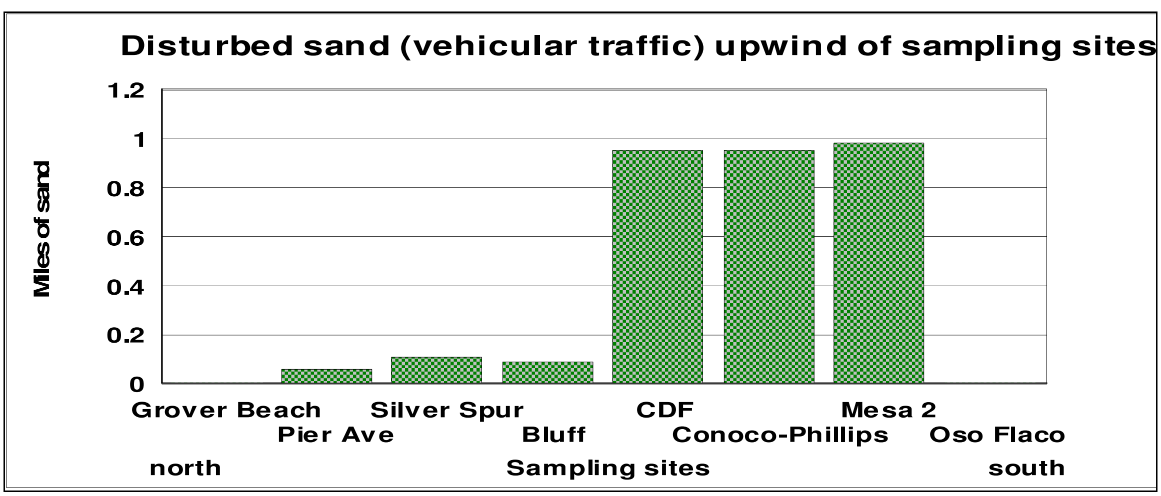

Figure 5.18 - Correlation between dust peaks and upwind disturbed sand

The set of time series plots below present the spring intensive data. Each chart depicts the side by side comparison tests at Mesa2 (shaded) up to April 26, followed by data from the individual sites where each sampler was deployed. Note that, for some of the spring intensive S-XRF data, an analytical error was made in performing the S-XRF scans at the Berkeley laboratory. The huge changes in particle density from episode to non-episode sample periods caused the detector to be overwhelmed at times by the number of x-rays, resulting in periods of data defaulting to zero (over range). This occurred most often in the 10-5 micron particle analysis, and less frequently in the 5-2.5 micron analysis; data presented with this problem is noted.

As shown in Figures 5.19 and 5.20 below, elemental analysis of the Grover Beach samples for the spring intensive confirmed that, as expected, this site is subject to high concentrations of sea salt (likely dissolved in fog) and very little sand/soil particulate.

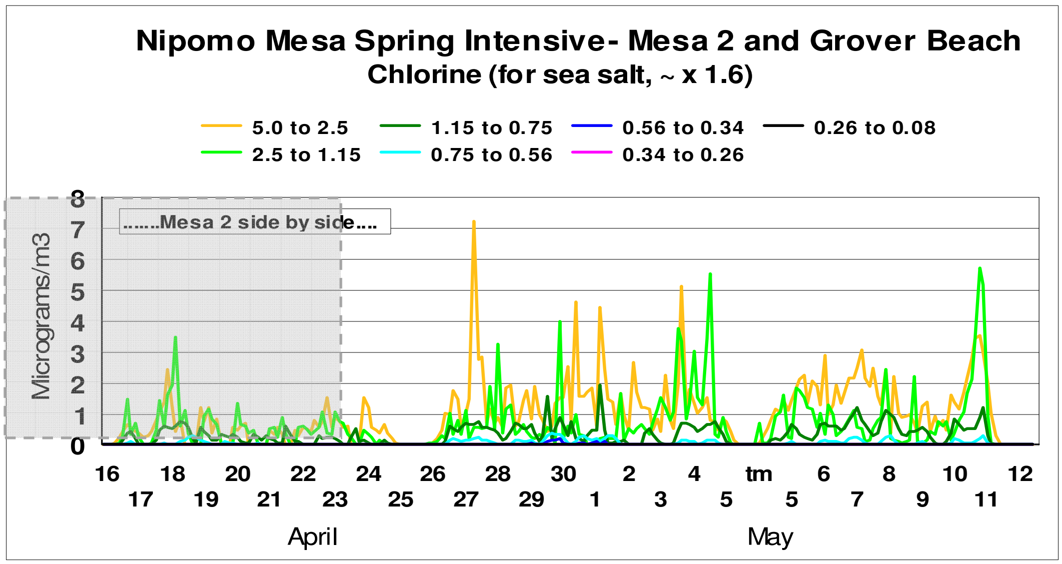

Figure 5.19 - Chlorine a sea salt tracer at Grover beach. Mass between 10 and 5.0 were eliminated due to overflows in the S-XRF detector at Mesa 2

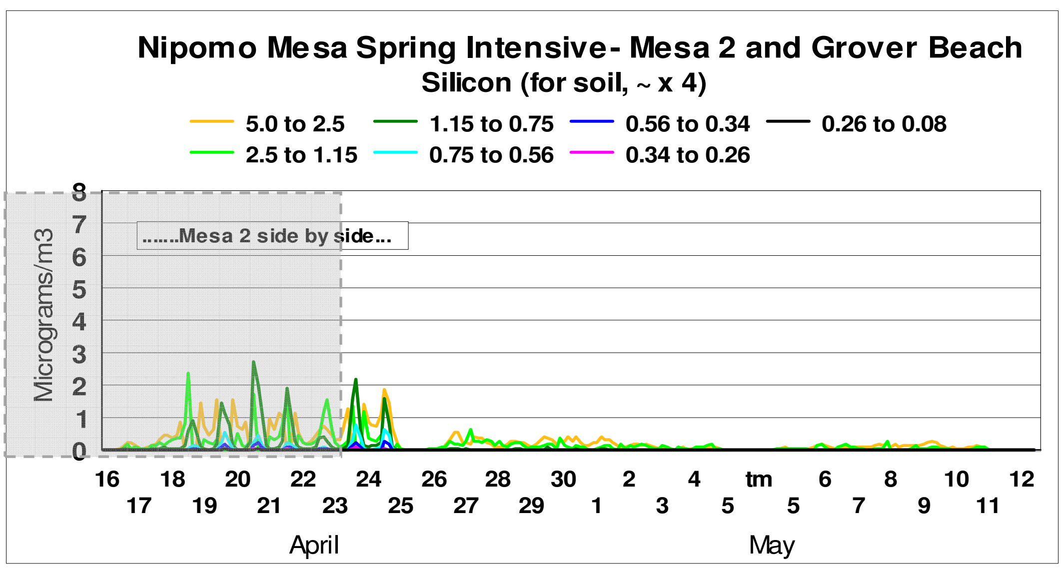

Figure 5.20 - Silicon a soil tracer at Grover Beach on the same scale as the chlorine

Elemental analysis of the Bluff intensive DRUM data with the Mesa2 side by side is presented in the Figures 5.21 to 5.22 below.

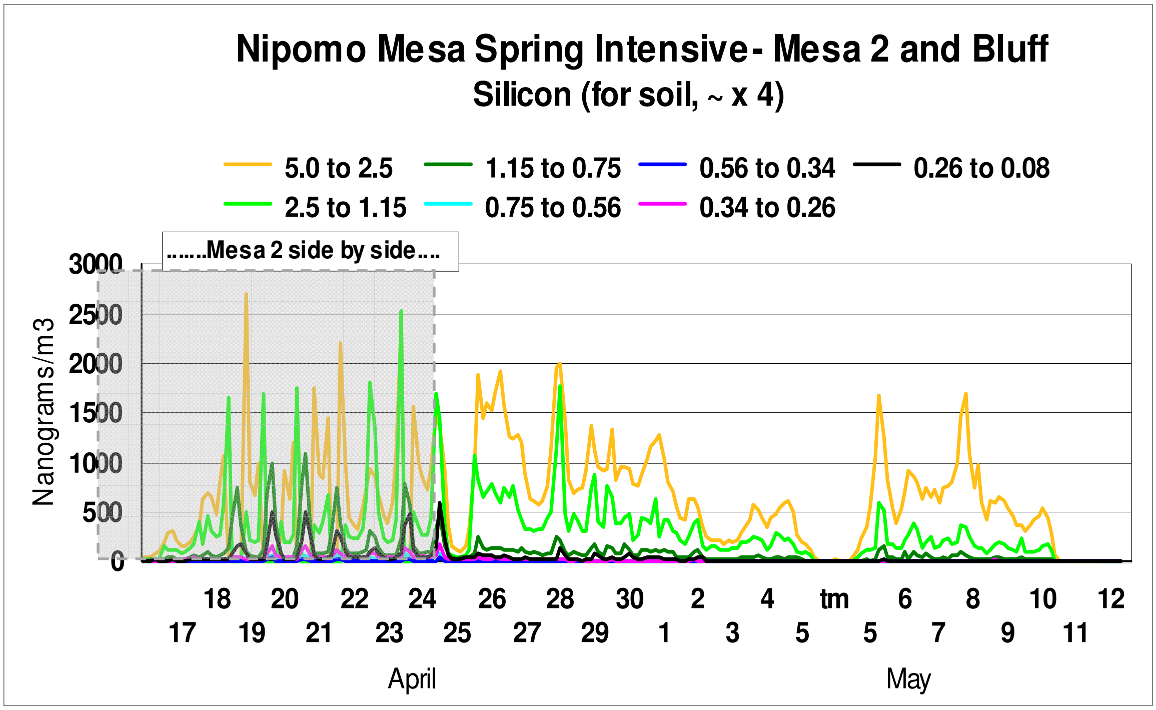

Figure 5.21 - Silicon at the Mesa 2 and Bluff sites

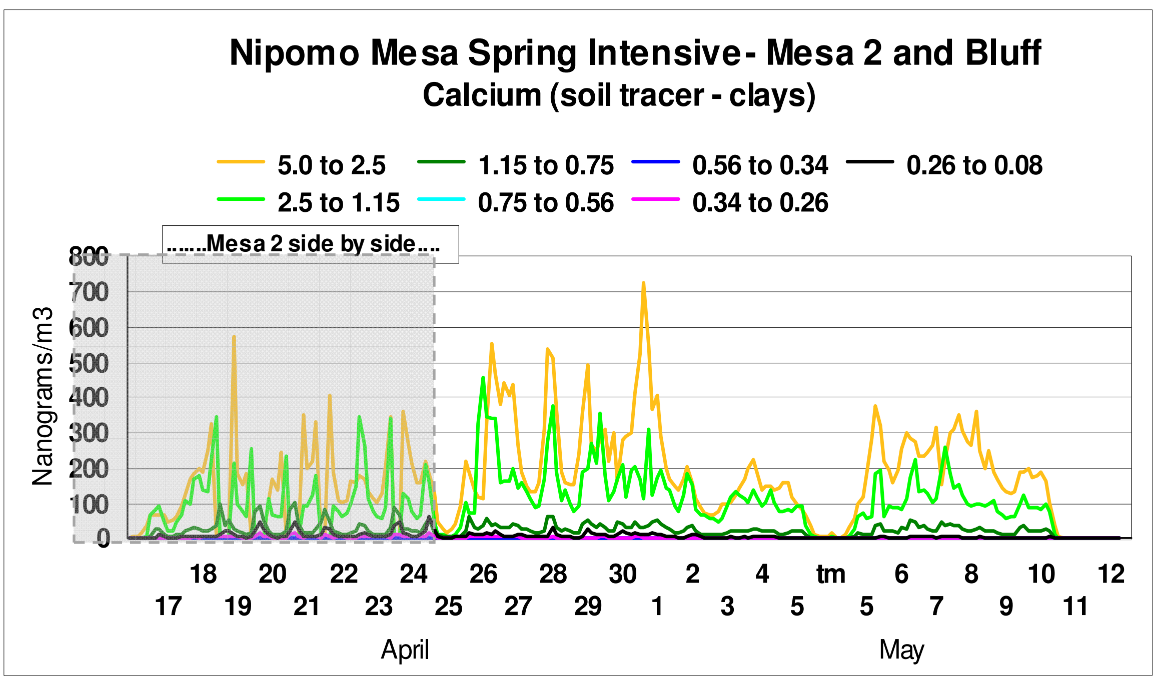

Figure 5.22 – Calcium at the Mesa2 and Bluff Sites

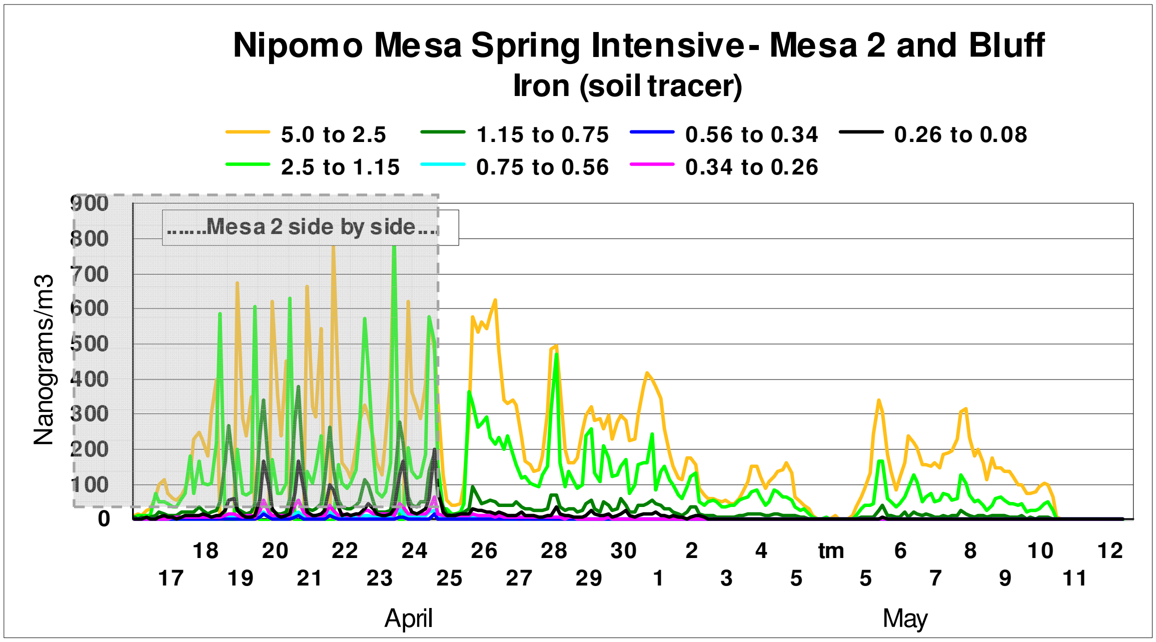

Figure 5.23 – Iron at the Mesa2 and Bluff Sites

The charts above reveal several differences between the Bluff site and the data collected at the Mesa 2 site, including a higher sea salt impact at Bluff and an almost total absence of the relatively fine particles that characterize the Mesa 2 and CDF samples. The Bluff site does show an enhancement of calcium in the aerosol, possibly indicating some local clays, but this is a small component of the total mass. The total mass overall at the Bluff site was significantly less for the intensive period than the sites downwind from the SVRA.

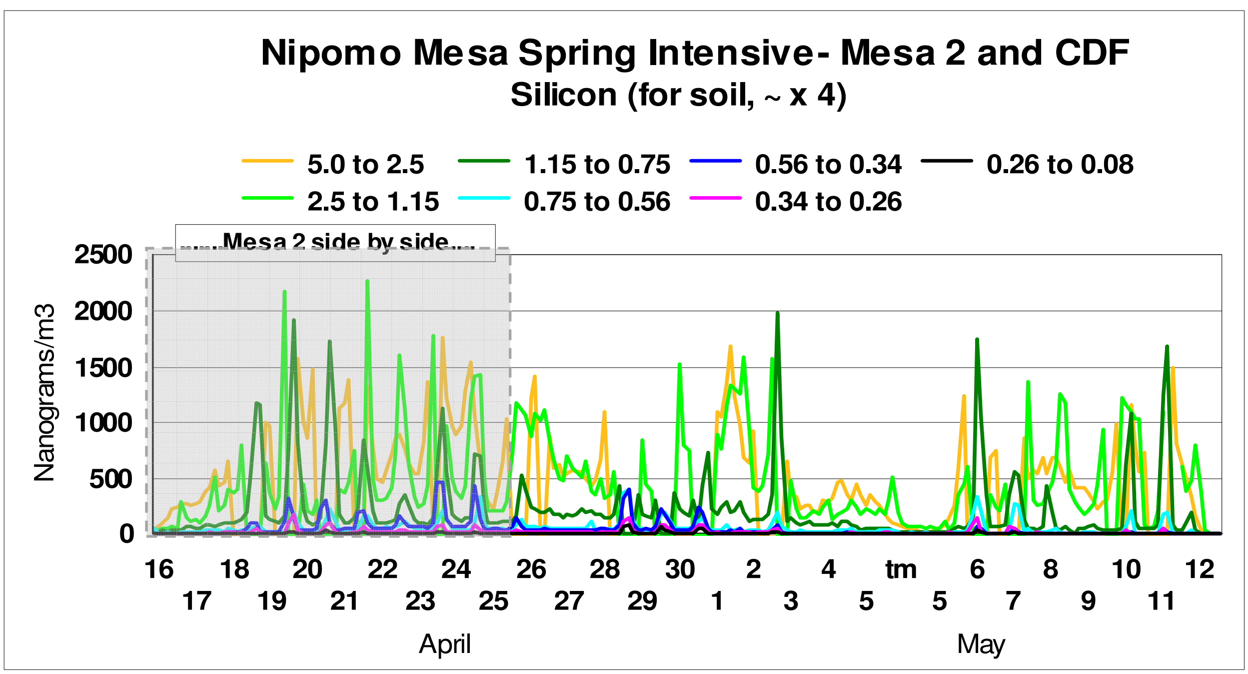

Figure 5.24 – Silicon at the Mesa2 and CDF Sites

Figure 5.24 above presents the silicon mass measured at CDF and the Mesa2 side by side comparisons. The CDF silicon data shows a similar pattern as that from Mesa2. Both sites show significant particle mass below one micron that is absent at all sites not downwind from the SVRA. (Note that no 5-2.5 and 2.5-1.15 micron peaks are present on the highest episode days in Figure 5.24 due to the S-XRF overflow problem.)

5.3.4. Analysis of Fall Mesa 2/Dune Center Comparisons

After evaluating the early mass data, it was deemed important to add a long term sampling site at the Guadalupe Dune Center in Guadalupe (see Figure 5-1). This was done because it was typically downwind of the relatively undisturbed dunes of the Santa Maria oil field, and its easy access allowed longer term sampling than could be performed at the very valuable but labor intensive Oso Flaco site. The Dune Center site is also about the same distance inland as Mesa2, which allows for good comparison between the two sites.

Sampling began in early September and continued through late November, after which dust episodes tend to be less intense and rainfall is to be expected. Most wind/particle episodes occurred in September and October, with low concentrations measured at both sites from late October through November. Figure 5.19 below presents a comparison between the 5.0 to 0.75 micron mass at both sites for the period with most episodes. As shown, aerosol levels measured at Mesa 2 were substantially higher than those at the Dune Center site on all episode days. (Note that the 10 to 5.0 micron particle fraction is not presented here due to its large time averaging, which averages out the peaks and is hard to align with meteorology; the three particle stages summed to calculate the 5.0-0.75 micron fraction are typically 2/3 of the total mass seen in the DRUM.)

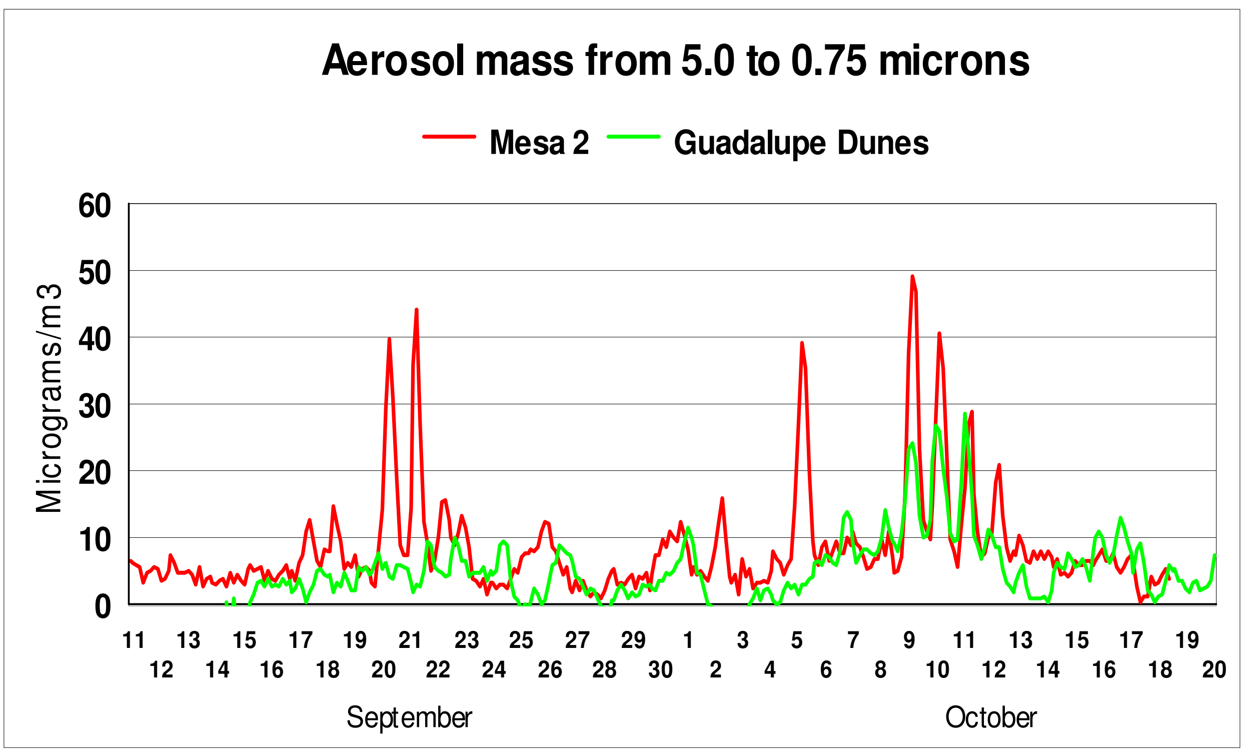

Figure 5.25 - Mesa 2 to Guadalupe Dunes comparison Fall, 2008

Figure 5.26 below present a comparison of chlorine for the two sites. Clearly the Dune Center site is much more impacted by sea salt, likely due to the higher wind speeds recorded at the mouth of the Santa Maria River and/or the slightly lower elevation of the Dune Center site.

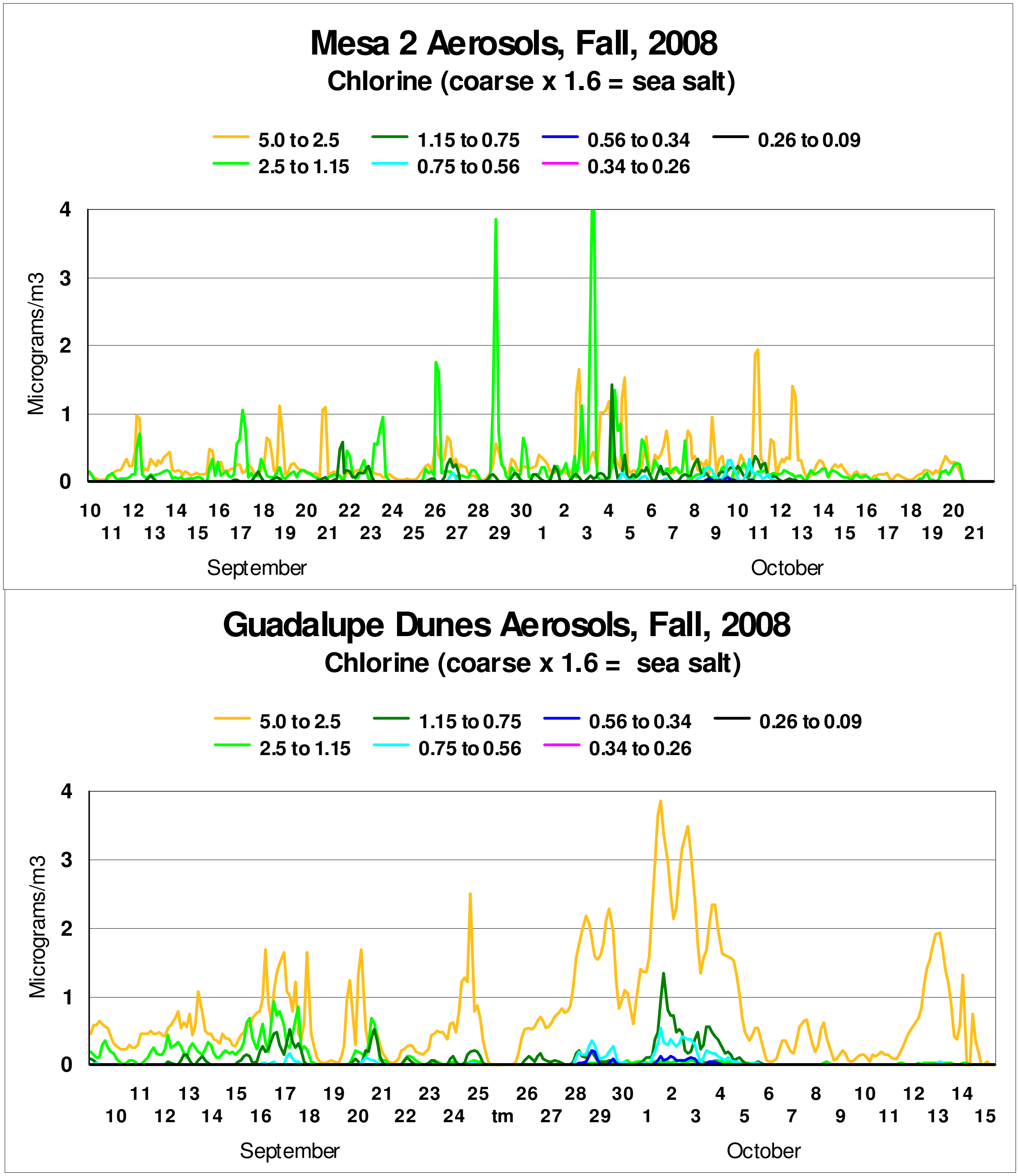

Figure 5.26 - Mesa 2 to Guadalupe Dunes comparison, for chlorine, a tracer of sea salt

Figure 5.27 below compares the amount of silicon mass, a soil tracer, found at Mesa2 to that measured at the Guadalupe Dune Center.

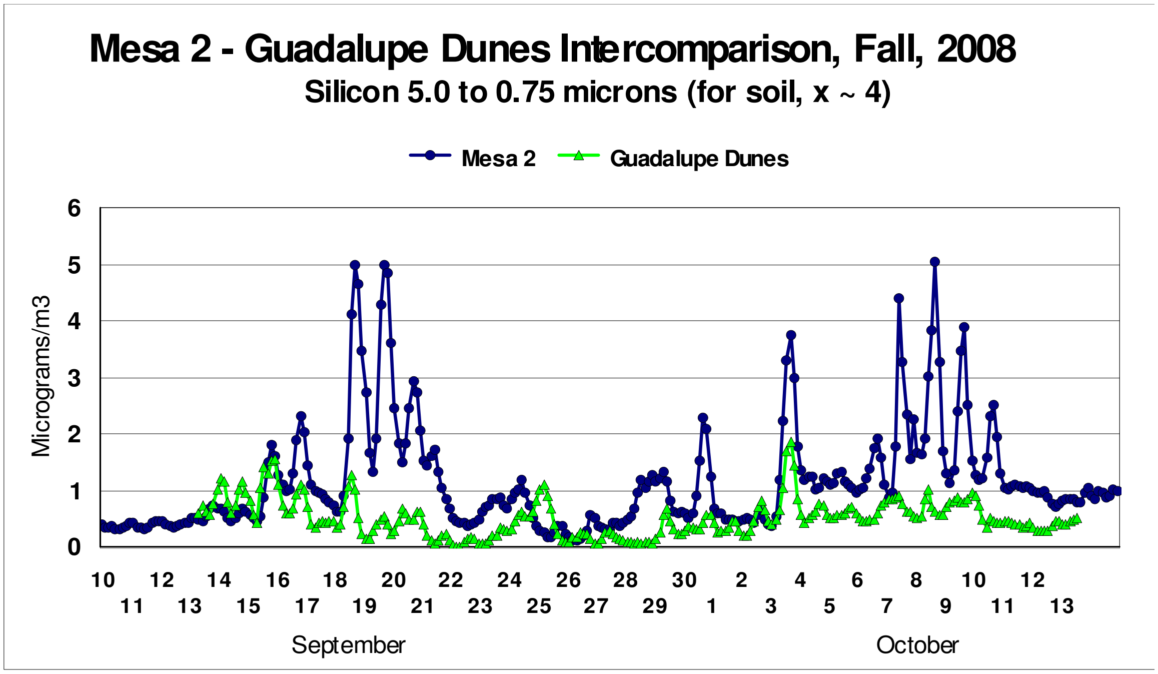

Figure 5.27 - Mesa2 to Guadalupe Dune Center Comparison for Silicon 5-.75 microns

In summary, the Guadalupe Dunes – Mesa 2 summer-fall comparison strongly supports the results of the Spring Intensive, showing that sites with undisturbed sands upwind have far less dust than those sites downwind of disturbed soils.

5.4. Analysis of Soils and Ambient Aerosols Near the ConocoPhillips Petroleum Coke Piles

Many of the tools used by the Delta group for the Phase 2 study also provide information on the potential impact of the ConocoPhillips (COP) petroleum coke storage piles on PM_{10} levels measured at Mesa 2. The reasons for conducting this part of the investigation include the following:

- The petroleum coke storage site is one of only two uncovered coke storage sites in California
- The COP coke piles are located along the wind trajectory to Mesa 2
- SO_2 emissions from the refinery are recorded at Mesa 2 when their SO_2 suppression systems are inoperable.
- Visual observations and photographs of dust created during transfer of coke to the pile

5.4.1. Soil Analysis in the Vicinity of Petroleum Coke Piles

Heavy oils in California and elsewhere contain sulfur, vanadium and nickel. The latter two in the coarse aerosol modes are robust tracers of coke materials; in the fine modes, they are good indicators of heavy oil combustion. As shown in Figure 5.28 below, analysis of soil samples taken along the entire transect from Mesa 2 to ConocoPhillips shows some enrichment of vanadium over the typical earth crustal average, with the amount growing by a factor of 70% as one approaches the edge of the petroleum coke pile. There is even some modest enrichment of vanadium in the soil at sites generally upwind of the ConocoPhillips facility. No consistent vanadium enrichment is seen in soil samples from either the Oso Flaco or Bluff transects.

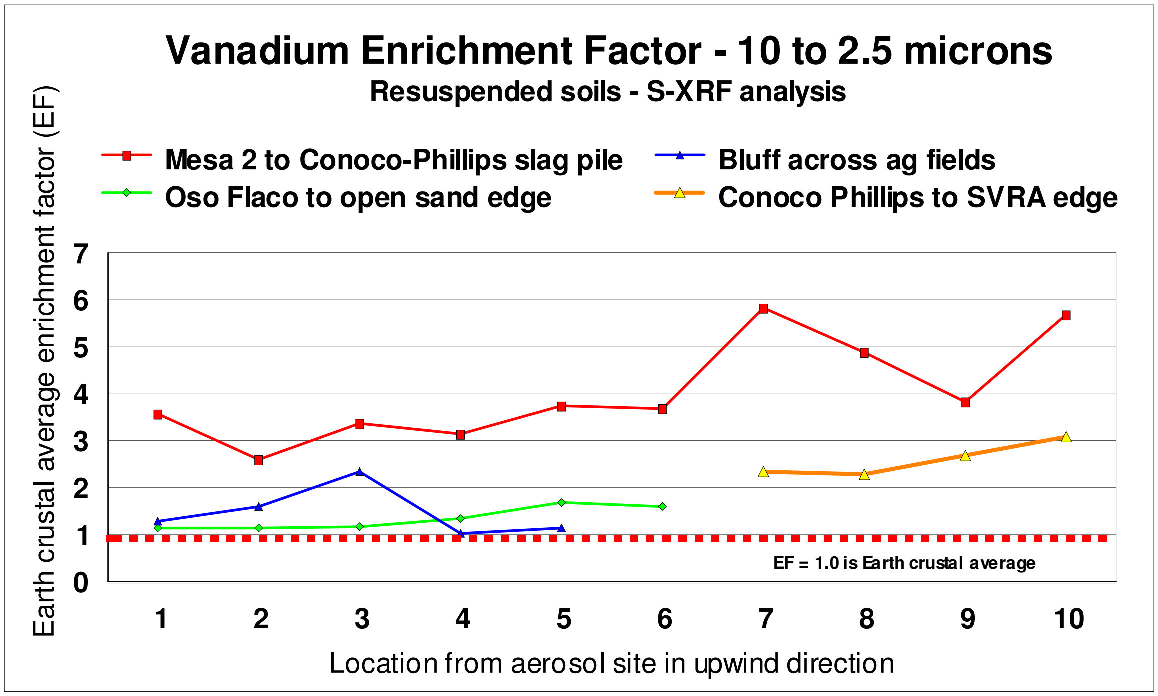

Figure 5.28 – Vanadium Enrichment Factor in Soil Samples

Finding above background levels of vanadium in soils within the vicinity of the petroleum coke piles is not surprising considering the many decades of petroleum coke storage and processing in this area. While this data demonstrates past historical deposition of petroleum derived particles, it does not demonstrate where the particles originated (entrained by the wind or from combustion processes in the refinery), nor the relative contribution of these particles to the elevated ambient PM concentrations measured on the Mesa.

5.4.2. Analysis of Ambient DRUM Data

The DRUM aerosol data at the Mesa 2 site does show minor traces of vanadium, nickel, and sulfur, but the levels are negligible relative to the overall PM_{10} mass. Figure 5.23 below plots concentrations of very fine (0.34 to 0.26 µm diameter) vanadium, nickel, and sulfur found in the Mesa 2 samples (note the units are in nanograms rather than micrograms). The strong association of vanadium and nickel, and the support of fine sulfur particles, is a signature of operations using heavy crude oil. The levels of these materials, however, are less than 0.001 $\mu g/m^3$, versus overall PM_{10} mass levels that range from the 10s to 100s of $\mu g/m^3$.

Analysis of Mesa2 and the Dune Center DRUM data from the Fall of 2008 show that vanadium concentrations measured at Mesa2 are 2.5 times higher overall than those measured at the Dune Center site. However, most of the vanadium measured at Mesa2 in the fall period was in the fine particle fraction, as seen in Figure 5.29 below. This indicates the source of this trace amount of vanadium is not the coke piles; rather, it likely originates from a combustion process using heavy oil as fuel.

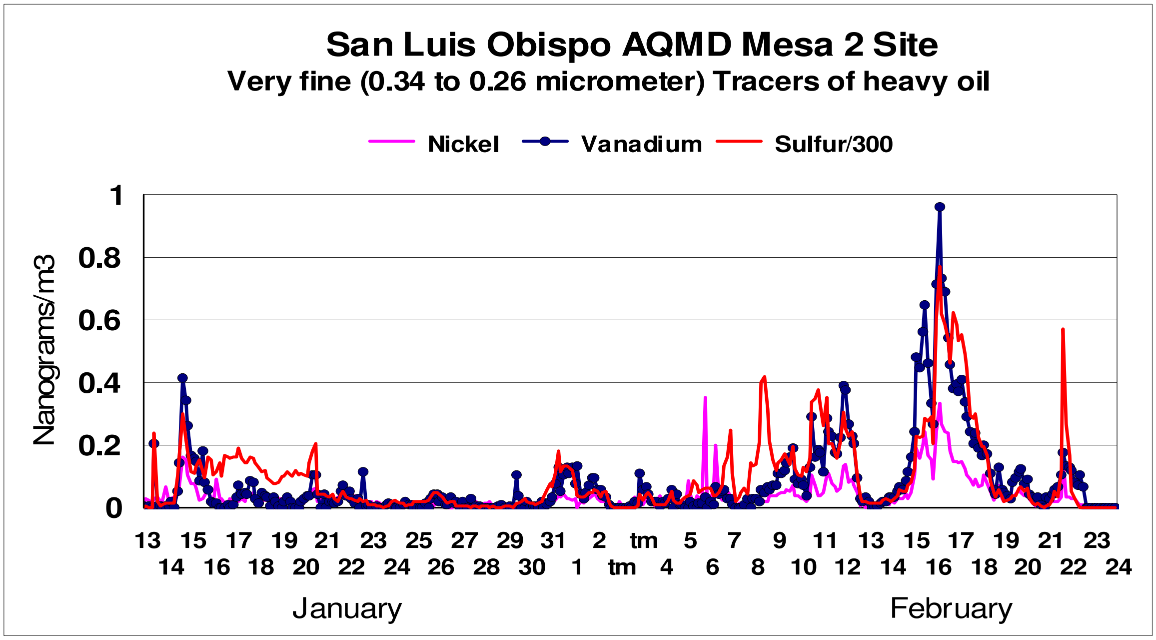

Figure 5.29 – Very Fine Tracers of Heavy Crude Oil

In summary, the measurements and analyses presented above support a definitive conclusion that the ConocoPhillips petroleum coke storage piles were not a significant source of PM_{10} aerosols during the study period, despite the occurrence of strong winds and several episodes of high PM concentrations.

6 MAJOR FINDINGS, SUMMARY AND CONCLUSIONS

The South County Phase 2 PM Study was designed to achieve two primary goals:

3. To definitively identify the source(s) of the observed high particulate levels on the Nipomo Mesa, including:
    a. Assessing if the off-road vehicle activity at the Oceano Dunes State Vehicle Recreational Area significantly impacts downwind particulate concentrations; and,
    b. Determining what, if any, off-site particulate impacts are due to fugitive dust from the petroleum coke piles at the ConocoPhillips Refinery on the Mesa.
    c. Assessing if agricultural or other activities in the area significantly impact downwind particulate concentrations.
4. To determine the contribution of direct and/or indirect emissions as causative factors in the PM levels observed.

To achieve these goals, the Phase 2 Study incorporated a broad array of both regulatory and research sampling and analysis methods designed to characterize the composition, size distribution, concentration and origin of particulate matter impacting the Mesa. The field measurement portion of the Study was carried out over a 15 month period from January 2008 through March 2009 to ensure the study captured the full range of meteorological conditions and potential source activities that might influence the particulate levels on the Mesa. Nearly two million data points were gathered in this effort, and nearly a year was spent analyzing the data and compiling the results. The data analysis was performed by the three independent research groups involved in designing and implementing the study, followed by peer review of the draft study report by a broad spectrum of scientists and experts in this field.

6.1. MAJOR FINDINGS

The following discussion presents the major findings and conclusions reached in this study, including brief summaries of supporting data from both the Phase 1 and Phase 2 studies.

1) **The airborne particulate matter predominantly impacting the region on high episode days does not originate from an offshore source.**
    - There are numerous particulate monitors located along the coast of California, including at Morro Bay and Grover Beach. None of the measurements at these sites show high PM concentrations during high onshore wind speed conditions, such as those seen on the Nipomo Mesa.
    - Grover Beach PM_{10} data shows a negative correlation to high winds. The only elevated PM_{10} readings at this site are associated with calm wind periods, likely the result of localized sea salt episodes typical of coastal locations. Further, these calm periods do not correlate to the periods of high PM seen on the Mesa. (See Section 3.1, Figure 3.6)
    - Elemental analysis of drum samples from Grover Beach showed high levels of chloride, a tracer for sea salt, and low levels of silica, a tracer for sand and soil. (See Section 5.3.3, Figure 5.13)

2) **A localized source of wind blown particulate is present in the Oceano area near Pier Avenue and may be impacting nearby residential neighborhoods.**

- Phase 2 study data shows high PM_{10} concentrations at the Pier Avenue monitoring site on wind event days that cannot be attributed to sea salt. (See Section 3.1, Figure 3.9)
- Data does not show high PM_{10} concentrations on wind event days at the Grover Beach site, just 1.3 miles to the north of Pier Ave. (See Section 3.1, Figure 3.6)
- Drum sampler PM measurements from the Bluff site, 2.7 miles downwind from the Pier Avenue did not see high PM readings during wind event periods, indicating that the Pier Avenue measurements represent a localized source that disperses to insignificant levels farther downwind. (See Section 5.3.2 and Figure 5.12)
- Visual observations suggest track-out and re-entrainment of sand from vehicles exiting the SVRA at Pier Ave. may be a significant source of particulate here.

3) **The petroleum coke piles at the ConocoPhillips facility are not a significant source of ambient PM on the Nipomo Mesa.**
    - Elemental analysis did not detect significant amounts of the tracer elements for petroleum coke at the Mesa2 monitoring site. (See Section 5.4)

4) **Upwind agricultural activities are not a significant source of ambient PM on the Nipomo Mesa on high episode days.**
    - Drum sampler data showed low PM concentrations at the Bluff Site, directly downwind from agricultural fields. These agricultural fields were actively worked during the measurement period. (See Section 5.3.2 and Figure 5.12)

5) **The airborne particulate matter impacting the Nipomo Mesa on high episode days predominantly consists of crustal material transported to the Mesa from upwind areas under high wind conditions.**
    - Earth crustal elements such as silicon, iron, aluminum and potassium were the predominant compounds found in elemental analysis of filter samples for episode days from the Phase 1 Study. When PM concentrations increased, the earth crustal elements also increased. Sea salt was also present in the samples, consistent with samples taken a few miles from the coast.
    - Elemental analysis from drum sampler data in the Phase 2 Study showed a preponderance of earth crustal elements during episode periods, similar to the Phase 1 analysis; sea salt was also present in the samples.
    - Both the Phase 1 and Phase 2 data showed a strong relationship between high PM concentrations and high wind speed, suggesting wind is the primary emission mechanism for the high particulate concentrations. (See Section 3.1, Figures 3.16, 3.26, 3.32)
    - Study data shows high wind speeds do not result in high PM levels on the Mesa when the soil has been recently moistened by rain, even under the strong northwest wind conditions typically associated with high PM_{10} readings there. This indicates the wetting of the sand/soil disrupts the emission mechanism. (See Section 3.1, Figure 3.25)
    - Analysis of episode days for this study period showed that for a particular wind speed, higher PM_{10} concentrations were measured on days with higher temperatures. This suggests that heating of the soil surface, which reduces

moisture content, is a factor that increases PM_{10} concentrations during a high wind episode. (See Section 3.2.4, Figures 3.60-3.62)

- The sand flux measurements performed with the sensit samplers showed a strong correlation between sand movement on the dunes due to wind and high PM_{10} readings downwind from the dunes. (See Section 4.0, Figure 4.2)

6) **The predominant source of high PM concentrations measured on the Nipomo Mesa are the open sand sheets in the dune area of the coast.**
   - All of the data results cited under #4 above.
   - Directional sampler data from the Phase 1 Study showed that, on sample days with high levels of PM_{10}, the majority of particulate mass occurred when the wind was blowing from the direction of the dunes. (See Section 1.0, Figure 1.1)
   - A strong relationship between high PM concentrations and high winds blowing across the open sand sheets was seen in the Phase 2 Study PM_{10} data. (See Section 3.1, Figures 3.15, 3.25, 3.31)
   - Phase 2 study data showed a lack of high PM_{10} concentrations with high wind speeds from directions that do not pass across open sand sheets. (See Section 3.1, Figures 3.15, 3.25, 3.31, 3.52)
   - Zero mass was collected in sandcatchers located in vegetated areas adjacent to open sand sheets. The three cox sandcatchers located upwind from the CDF, Mesa2, and Oso monitoring stations did not collect any mass for the entire month of the sand flux study. This clearly demonstrates that these vegetated areas are not emission sources. (See Appendix B)

7) **Open sand sheets disturbed by OHV activity emit significantly greater amounts of particulates than undisturbed sand sheets under the same wind conditions.**
   - Average PM_{10} concentrations from the Oso and Dune Center control area monitoring sites were substantially lower than the CDF and Mesa2 monitoring sites during episode periods. This occurred despite the significantly higher wind speeds measured at the control sites on episode days. (See Section 3.2.3, Figures 3.54, 3.55, 3.56, 3.57, 3.58 and 3.59)
   - Drum sampler measurements showed average PM concentrations were substantially lower downwind from both north and south control areas than downwind from the SVRA. (See Section 5.3.2 and Figure 5.12)
   - Sensit sampler measurements showed significantly higher wind speeds were required for sand movement to occur in the control sand sheet west of the Oso site than in the SVRA, indicating more structural stability in the undisturbed sand sheet. (See Section 4.0, Table 4.2)
   - Sand Flux measurements show significantly higher wind erosion rates in the SVRA compared to the control sand sheet west of the Oso site for the same wind speeds. (See Section 4.0, Figure 4.3)
   - It was observed that the open sand sheet west of the Oso site had a thin crust on the sand surface that was easily fractured when walking on the sand. This crust was not observed in the SVRA. (See Section 5.2.3 and Figure 5.2)
   - On average, high OHV activity days on the SVRA result in higher downwind PM_{10} concentrations than low OHV activity days. (See Section 3.2.5, Table 3.2)

8) **Vegetated dune areas do not emit wind blown particles.**

- Phase 2 study data showed a lack of high PM_{10} concentrations with high wind speeds from directions that do not cross open sand sheets but do pass over vegetated areas of the dunes. (See Section 3.1, Figures 3.15, 3.25, 3.31, 3.52)
- Zero mass was collected in sandcatchers located in vegetated dune areas adjacent to open sand sheets. The three cox sandcatchers located upwind from the CDF, Mesa2, and Oso monitoring stations did not collect any mass for the entire month of the sand flux study. This clearly demonstrates that these vegetated dune areas are not emission sources. (See Appendix B and Section 4)

6.2. SUMMARY AND CONCLUSIONS

The major findings resulting from detailed analysis of the diverse and comprehensive data sets generated during the Phase 1 and Phase 2 South County PM Studies clearly point to OHV activity in the SVRA as the primary contributing factor to the high PM concentrations observed on the Nipomo Mesa.

There are two potential mechanisms of OHV impact. The first is direct emissions from the vehicles themselves, which includes fuel combustion exhaust and/or dust raised by vehicles moving over the sand. Elemental analysis of study data shows combustion exhaust particles are not a significant component in the samples for episode periods. Analysis of SVRA vehicle activity data does show a weak relationship between high PM_{10} concentrations and high vehicle activity. This indicates a small but measurable direct emissions impact from OHV activity caused by wind entrainment of dust plumes raised by vehicles moving across the open sand. The magnitude of this impact appears to be a small increase in average PM_{10} concentrations on high OHV activity days compared to low OHV activity days. While important, the study data shows this is not the primary factor responsible for the high PM levels measured downwind from the SVRA.

The second potential mechanism of impact from OHV activities involves indirect emission impacts. Offroad vehicle activity on the dunes is known to cause de-vegetation, destabilization of dune structure and destruction of the natural crust on the dune surface (8). All of these act to increase the ability of winds to entrain sand particles from the dunes and carry them to the Mesa, which is an indirect emissions impact from the vehicles. The data strongly suggests these indirect emissions are the primary cause of the high PM levels measured on the Nipomo Mesa during episode days.

The Phase 2 study data demonstrates that any open sand sheet represents a significant potential emission source of wind blown dust. Even though substantially lower PM concentrations were measured downwind from the undisturbed open sand sheets in the control areas compared to the SVRA, the data clearly shows that even the undisturbed sand sheets are a notable source of PM under high wind conditions. However, study measurements indicate the substantially lower PM emissions from the undisturbed control area dunes result from two important features not found in the SVRA: the presence of an ephemeral crust on the sand surface and a higher density of vegetation.

The crust present on the surface of undisturbed dunes lends considerable stability to the sand, requiring substantially higher wind speeds to move the surface sand particles compared to the SVRA, as demonstrated by the sand catcher data from the control dune sites. Thus, far less sand becomes airborne for a given wind speed at the control site dunes compared to the SVRA. Similarly, the complete lack of sand collected by the sandcatcher located in a vegetated area of the control site dunes provides a clear demonstration of the ability of vegetation to control wind erosion. The much higher density of vegetation and the presence of an undisturbed crust on the open sand areas of the control site dunes appear to be vital factors that combine to significantly reduce the amount of sand available for wind entrainment there compared to the SVRA.

OHV activity prevents formation of a stabilizing crust in the SVRA through continual disturbance of the sand surface; as noted earlier, the crust present on the control site dunes was easily broken by walking on the sand. Similarly, OHV activity prevents vegetation from growing in the riding area areas of the SVRA, as stated in the State Parks report, *"Review of ODSVRA Vegetation Islands"*. That study clearly documents that revegetation efforts in unfenced areas have failed, and that fencing to prohibit OHV access is necessary to help generate new vegetation and preserve existing vegetation.

Denuding of vegetation and the resulting increase in the aerial extent of open sand sheets from OHV activity on the SVRA is obviously a significant factor in the level of wind blown sand emissions from that area. Staff discussions with experts (4, 9) on dune morphology and vegetation showed a consensus of opinion that OHV activity has increased the size of open sand sheets in the SVRA. However, they also agree it is not possible to accurately estimate how much smaller the open sand sheets in the SVRA might be today if OHV activity in that area had never occurred.

Regarding the open sand sheets used as control areas (Ten Commandments, Oso and Silver Spur sites), the experts concluded they are likely larger today than they otherwise would be due to past OHV activity prior to the early 1980's, when the State Parks took control of these areas and prohibited OHV activity in non-designated areas. It is also important to note that some of the dune vegetation in this region is composed of non-native species such as veldt grass. The invasion by non-native species would have occurred regardless of whether OHV activity was present. Thus, even though the vegetation of the area is not "pristine", it is the current condition of the local environment.

The great success of the re-vegetation efforts undertaken by State Parks provides important insights into the effect of OHV activity in expanding the open sand sheets in the SVRA. Figures 6.1 and 6.2 below present nearly the same aerial view of the southern border of the SVRA, both prior to and after State Parks re-vegetation efforts in this area. Note Oso Flaco Lake in both images as a common point of reference.

Figure 6.1 – 1979 View of Southern Section of SVRA

Figure 6.2 – 2005 View of Southern Section of SVRA

Close inspection of Figure 6.2 shows the fence line limiting OHV activity is also the border between vegetated and non-vegetated areas of the dunes. Much of the vegetated area was replanted by State Parks in their re-vegetation effort; however, some regrowth occurred in these areas prior to any planting efforts, simply by eliminating OHV activity (4). This strongly indicates that much more vegetation and less open sand would be present in the SVRA area in the absence of OHV activity.

In summary, it appears the most significant impact of OHV activity in contributing to high downwind PM levels on the Nipomo Mesa results from denuding of vegetation and prevention of natural crust formation on the sand surface.

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South County Phase 2 PM Study

Appendix A

SLO APCD Quality Control/Quality Assurance

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A.1. Validation Criteria and Data Completeness

24 Hour PM_{10} at Pier Avenue, Hillview, and Mesa2 was measured with the Federal Reference Method (FRM), Hi-Volume Samplers followed by gravimetric analysis and ion chromatography (only Pier Avenue) of all valid filters. Procedures for calibration, sampling, and weighing followed the District Standard Operating Procedure.

Co-located samplers were operated at the Mesa 2 monitoring station to access precision of these measurements. As can be seen in Figure A-1, the collocated measurements demonstrate good measurement precision.

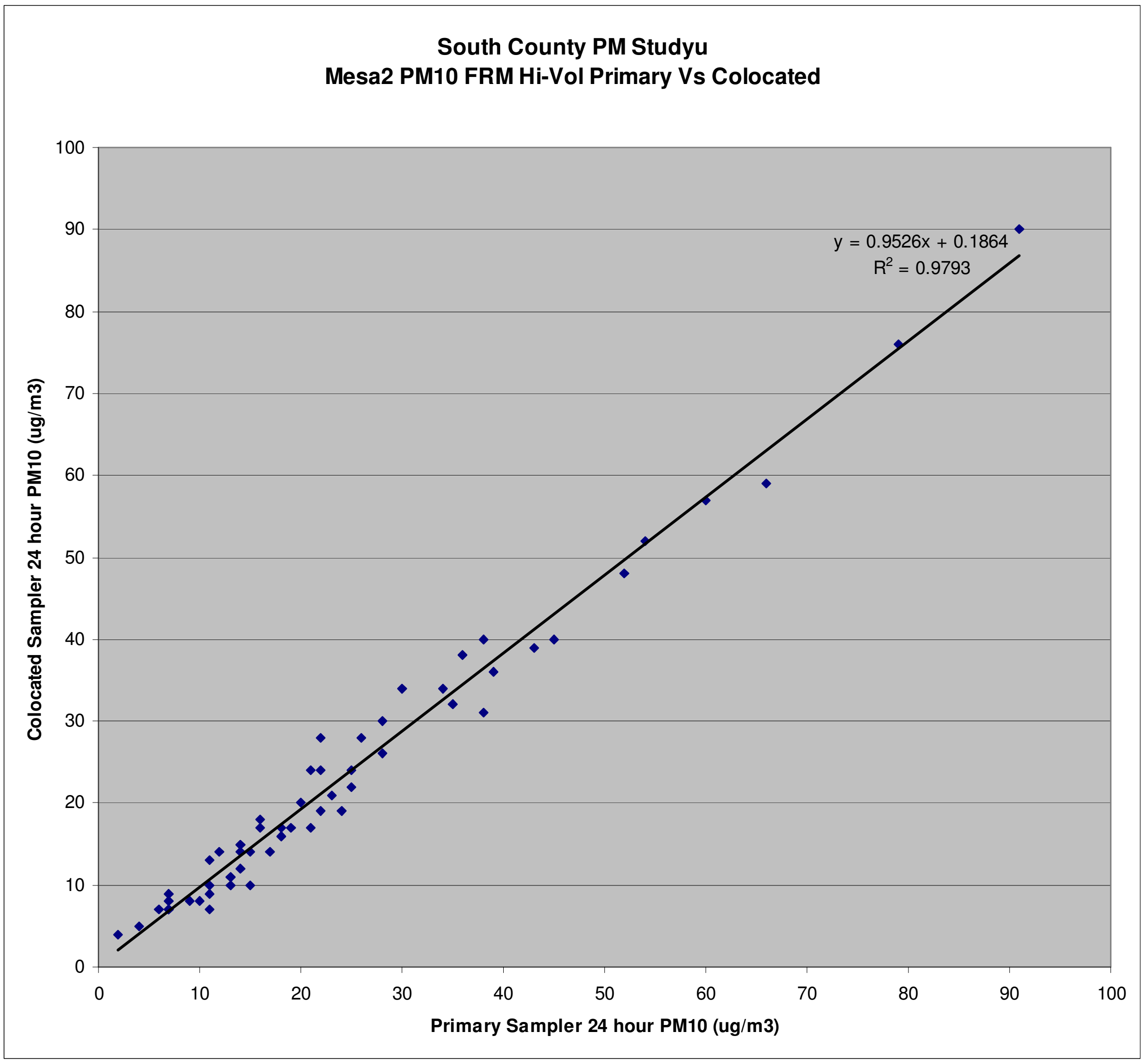

Figure A 1 – Hi-Volume PM10 Co-located Measurements

Filters were weighed by the CARB inorganic laboratory in Sacramento for sample run dates from January 1, 2008 through December 31, 2008. Study filters for run dates from January 1, 2009 to the present were weighed by the SLO APCD in their filter processing laboratory. The SLO APCD filter laboratory was audited by CARB on September 28, 2009.

The validation criteria used for the study is the same criteria used for other District PM_{10} sampling. Table A-1 summarizes the data validation criteria.

Table A 1 – Hi-Volume Sampler PM10 Data Validation Criteria

PARAMETER	MEASURED BY	VALIDATION CRITERIA
Sampler Flowrate	calibrated flow recording device on sampler	36-44 cfm
Sample Duration	elapse time meter on sampler	24 hrs +/- 1 hr
Filter Inspection	Visual inspection	no tears, pinholes, obvious foreign material

Continuous PM_{10} at Grover Beach, CDF, and Mesa2 was measured with a Federal Equivalent Method (FEM), Tapered Element Oscillating Microbalance (TEOM) manufactured by Rupprecht and Patashnick (Model 1400a). TEOM operating procedures for study measurements follow the District Standard Operating Procedures. The validation criteria used for the study is summarized in Table A-2 below.

Table A 2 – TEOM Data Validation Criteria

PARAMETER	MEASURED BY	VALIDATION CRITERIA
Main Flow	Bi-weekly Flow Checks with Certified Flowmeter	+/- 10% Standard Conditions
Total Flow	Bi-weekly Flow Checks with Certified Flowmeter	+/- 10% Actual Conditions
LeakCheck	Sampler Flowmeter	<1.0 l/m
Fault Status	Operator Observation	No Fault Conditions
Filter Loading	Instrument Display	<90% loading

Continuous PM_{10} at Oso and Dune Center was measured with a Met One EBAM Beta Attenuation Monitor. EBAM operating procedures follow the procedures described in the Met One EBAM operations manual. The validation criteria used for the study is summarized in Table A-3 below.

Table A 3 – EBAM Validation Criteria

PARAMETER	MEASURED BY	VALIDATION CRITERIA
Sampler Flow	Bi-weekly Flow Checks with Certified Flowmeter	+/- 10% Actual Conditions
LeakCheck	Sampler Flowmeter	<1.0 l/m
Error Status	Operator Observation	No Error Message

Installation of new equipment for study measurements began in late January 2008. After the three TEOM (Grover Beach, CDF, and Mesa2) installations were completed and the units were brought on line, the first flow check revealed that all three units had major leaks in the plumbing between the inlet and the measurement and control units. The leaks were corrected for all samplers and the flow checks were successfully performed. All data prior to correcting the TEOM leaks was invalidated and the frequency of performing a leak check for the remainder of the study was increased to bi-weekly. Once the leaks were corrected, no new leaks were found for the entire study.

Ambient temperature measurements taken with the EBAM at the Oso site were determined to be in biased 2 to 3 degree centigrade low mid way through the study period, even though the calibrations performed on the unit continued to show correct calibration. After working with the manufacture, it was determined that there was a ground loop passing through the EBAM serial data port ground that caused the temperature bias. The ground loop problem is not present when the EBAM pump was off, which occurs when calibrating the temperature sensor. An optical isolator was placed on the EBAM serial data port to prevent the ground loop, and solved the temperature bias problem. Because the temperature measurements at Oso are not needed for data analysis, the entire temperature dataset at Oso was invalidated.

The overall data completeness for the study measurements was very good. The specific data completeness for each hourly parameter is listed in Table A-4 below. While there is some study data prior to April 1, 2008 for calculating data completeness, an April 1, 2008 start date is used.

Table A 4 – Data Completeness for Hourly Data

Site / Parameter	Possible Number of Hours	Invalid Hours	% Data Recovery
GROVER WSV	8760	946	89.2%
GROVER WDV	8760	946	89.2%
GROVER SIGT	8760	946	89.2%
GROVER PM10	8760	41	99.5%
CDF WSV	8760	13	99.9%
CDF WDV	8760	13	99.9%
CDF PM10	8760	335	96.2%
CDF SIGT	8760	14	99.8%
CDF RH	8180	17	99.8%
MESA2 WSV	8760	35	99.6%
MESA2 WDV	8760	35	99.6%
MESA2 ATM	8760	35	99.6%
MESA2 SIGT	8760	35	99.6%
MESA2 PM10	8760	152	98.3%
OSO RH	8760	859	90.2%
OSO WSV	8760	859	90.2%
OSO WDV	8760	925	89.4%
OSO PM10	8760	1565	82.1%
Dune Ctr PM10	403	59	85.4%

The 24 hour sampler data completeness is presented in Table A-5 below. The Mesa2 Main sampler had additional samples taken beyond the 1 in 6 national schedule in order to provide additional comparisons to other PM methods, this is why it has a higher than 100% data recovery rate.

Table A 5 – Data Completeness for 24 Hour Samples

Site/Sampler	Possible Samples	Samples Collected	% Data Recovery
Mesa2 Main	61	64	104.9%
Mesa2 Co-located	61	51	83.6%
Hillview	61	56	91.8%
Pier Avenue	61	57	93.4%

A.2. Method Comparisons

All PM_{10} monitoring methods have one or more weakness, and it is not uncommon for one method to react differently to different types of particulates. While the Hi-Vol FRM method has known weaknesses, it is the standard that all other methods are measured against. To demonstrate that the three PM_{10} monitoring methods used in the study are reasonably comparable, a number of comparisons of these methods were performed.

A.2.1. Hi-Volume FRM/TEOM FEM Comparisons

Co-located Hi-volume PM_{10} samplers were operated alongside a TEOM at Mesa2 for the entire study period. Figure A-2 below presents the comparison of these two methods.

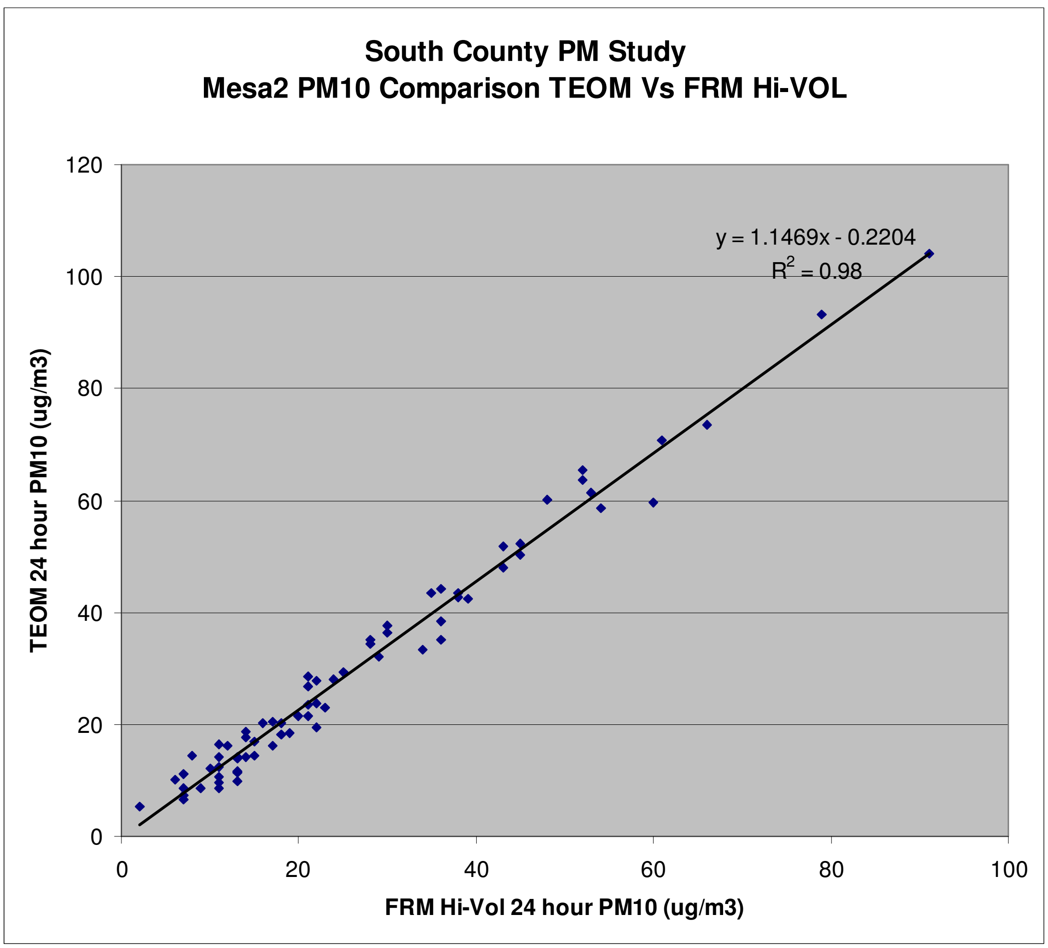

Figure A 2 – Hi-Volume/TEOM Method Comparison

Figure A-2 demonstrates the good correlation between the two methods, with a slight positive bias for the TEOM. Other comparisons between these two methods performed by other organizations also show this slight positive bias, so it is likely due to inherent differences in the methods.

A.3. EBAM/TEOM Comparisons

The initial comparisons performed between the EBAM, TEOM, and Hi-Volume sampler at Mesa 2 showed significant differences between the EBAM and the other two methods. After consultation with the manufacture of the EBAM, the unit was returned to the factory for re-calibration and further testing. Testing by the manufacture did not find any significant reason for the discrepancy in measurement between the other methods. The manufacture provided an additional EBAM to allow further testing. Comparisons between the two EBAM's and the other methods demonstrated that the two EBAM's compared very similarly to each other, showing the same differences compared to the other methods, indicating that there is just a different response by the EBAM method under the conditions present in this study. The EBAM's are calibrated by the manufacture using very fine particulate from incense, and the nature of the particulate for this study is that it is much coarser than the fine particulate used to calibrate the EMAB. This may be why these comparisons showed significant difference in the measurement methods.

Because the EBAM is the only known method that can provide continuous PM_{10} measurements using only solar power, which is the only option for the remote Oso site location, a method for correcting the EBAM data to match the other methods needed to be developed. Luckily, comparisons between the EBAM and TEOM showed that when the wind speed was greater than 10 mph, the relationship between the TEOM and EBAM was very consistent. It was only under lower wind speeds that the relationship between the EBAM and TEOM changed and became much more variable. The EBAM is known to have problems in very moist conditions (due to the very low power inlet heater used), which often occur in the study area when winds are calm. So it is likely that this moisture effect is the cause of the poor correlation between the TEOM and EBAM when the wind speed is less than 10 mph. Because there are virtually no high PM_{10} values in the study area under low wind conditions (other than Grover Beach), using the EBAM to only measure under the higher wind speeds when tests showed an excellent correlation to the TEOM seem like the best way to use the EBAM measurements and ensure comparability to the other measurement methods used in the study.

A process of cycling the two EBAMS between the Oso site and the Mesa2 site was developed that would allow frequent comparisons between the EBAM and the TEOM methods. Thought the study, one EBAM would be located at the Oso site and the other at Mesa2 and every couple of weeks the two EBAMs were swapped. The EBAM that was previously being used at Oso would be located at Mesa2 to allow comparison to the TEOM. This process would ensure that the relationship between the TEOM and EBAMs did not change with time, and the all data (when the wind speed was greater than 10 mph) collected at the Oso site would be directly comparable to the TEOM measurement method.

This procedure of cycling the two EBAMs between Oso and Mesa2 worked very well. It turned out that there was no difference in the comparison between both EBAMS and the TEOM, allowing a single correction factor to be applied to all EBAM data when the winds were greater than 10 mph.

Figure A-3 presents all comparisons performed between both EBAMs and the TEOM at Mesa2 at all wind speeds with no adjustment to the data. This graph demonstrates the poor correlation between the two methods. Figure A-4 and A-5 present the relationship between each EBAM and the TEOM at Mesa2 when the wind speed is greater than 10 mph. These graphs demonstrate the good correlation between both the EBAMs and the TEOM when the wind speed is greater than 10 mph and that both EBAMs respond almost exactly the same. Figure A-6 presents all EBAM comparisons from both units when the wind speed is greater than 10 mph and the single correction factor applied. This graph demonstrates that the method of correcting the data when the wind speed is greater than 10 mph makes the EBAM data comparable to the TEOM data.

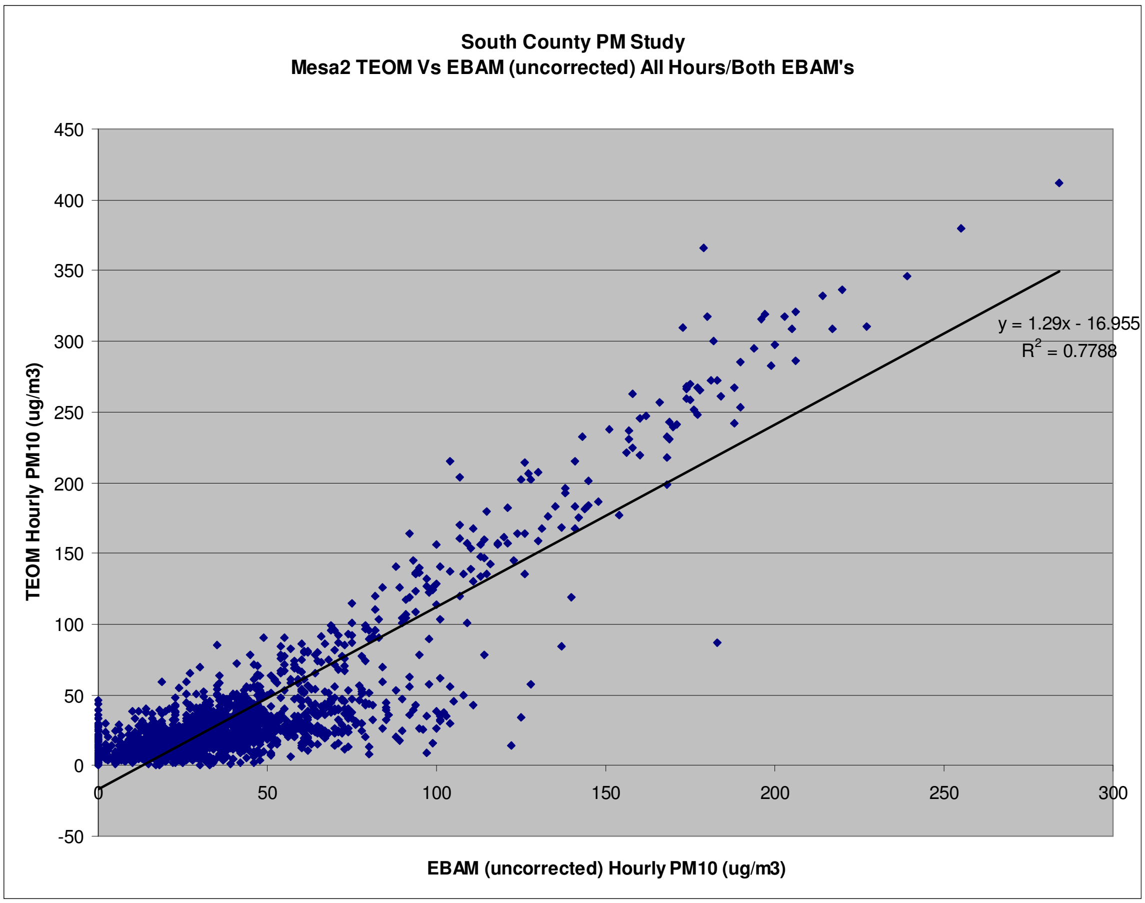

Figure A 3 – All Comparisons between TEOM and Both EBAMS, no adjustment

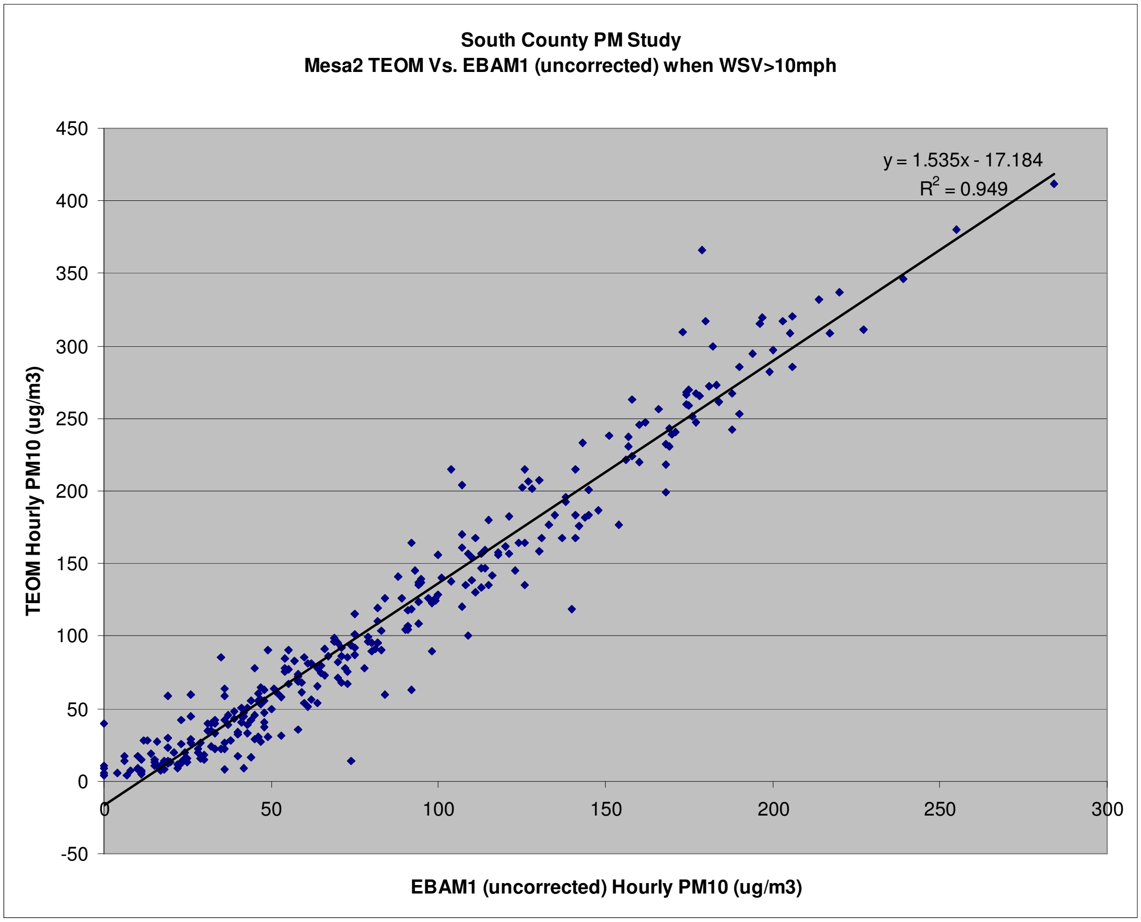

Figure A 4 – Comparisons between EBAM1/TEOM at Mesa2 (Wind Speed >10 mph)

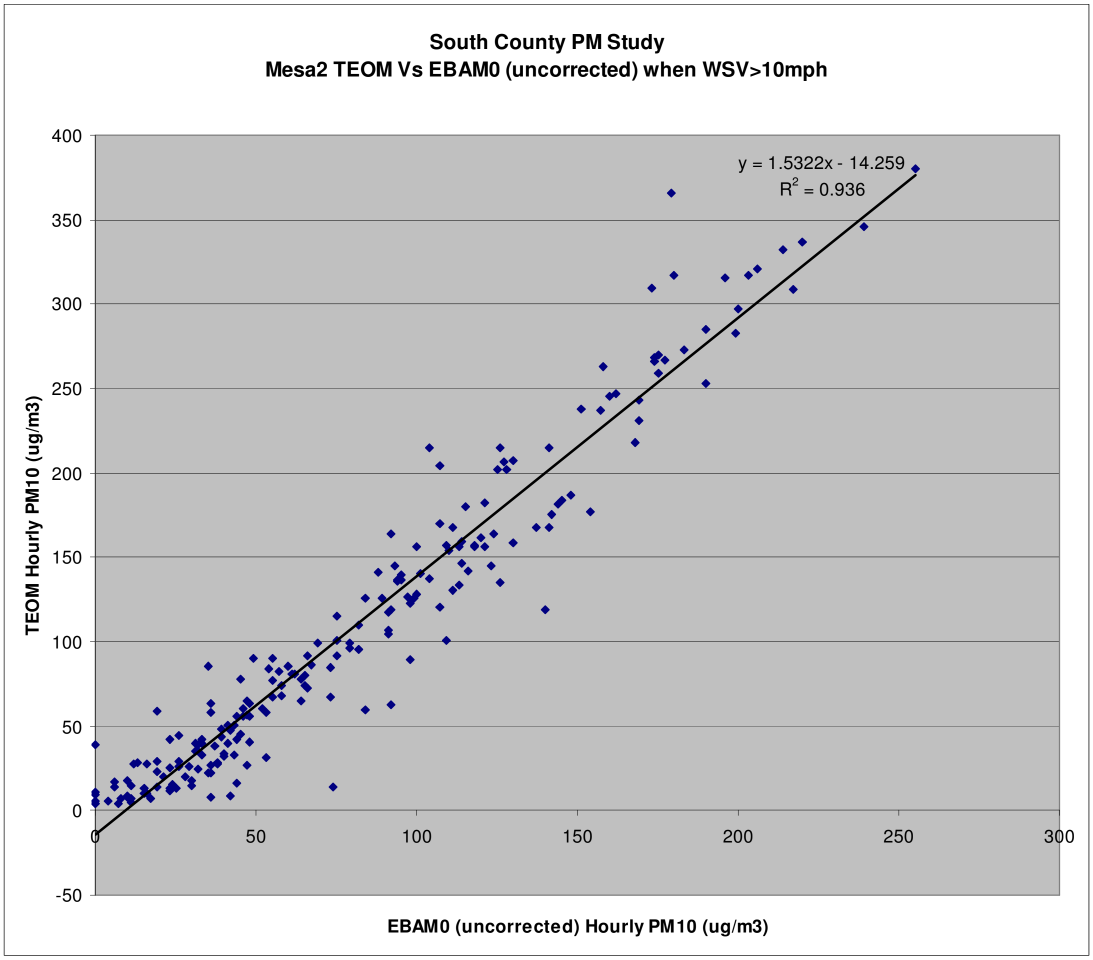

Figure A 5 – Comparisons between EBAM0/TEOM at Mesa2 (Wind Speed >10 mph)

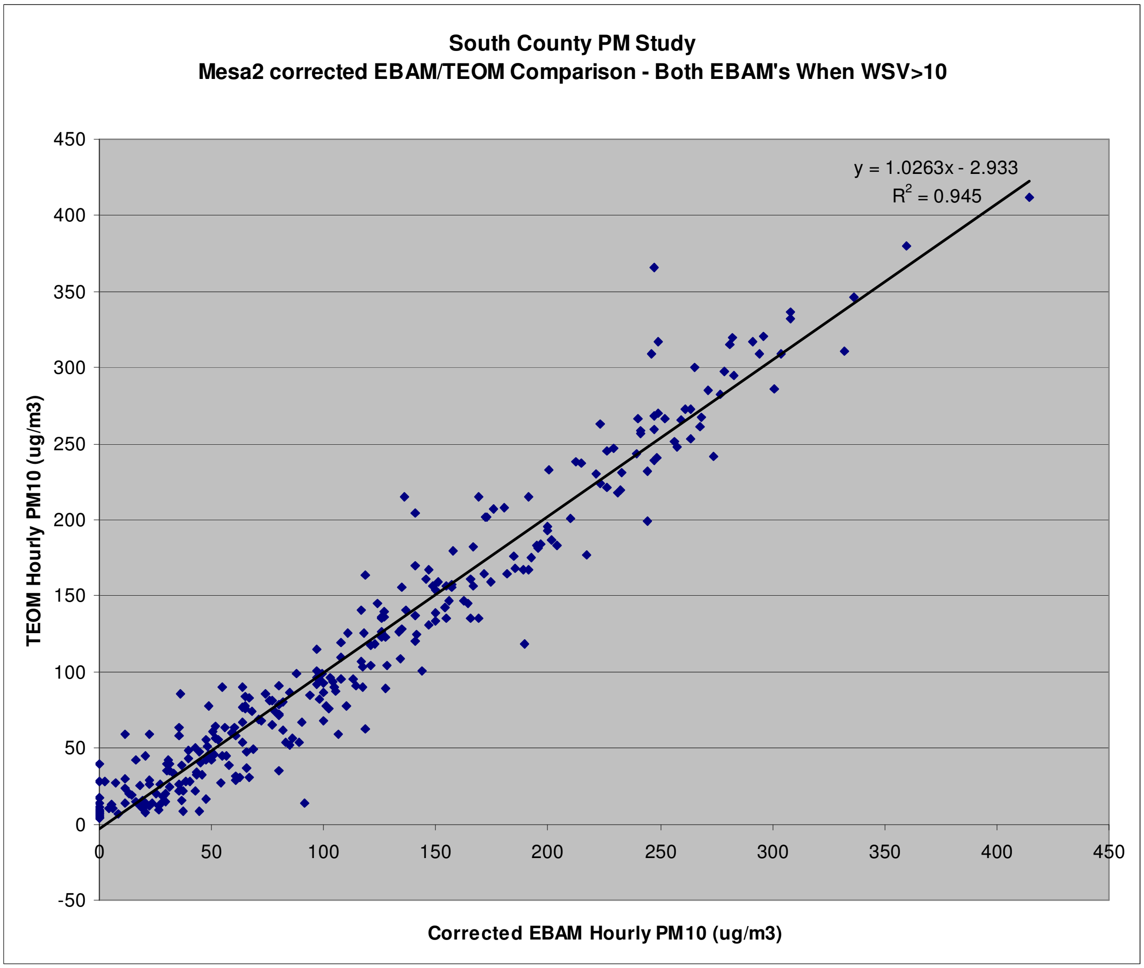

Figure A 6 – Comparison of Both EBAMS to TEOM when Wind Speed >10mph

A.4. Testing Power Law Correction to Wind Speed Sensor Height

Due to access limitations for construction equipment at the Oso monitoring site, the wind sensors at that site were located on the EBAM tripod at a height of about 2 meters above the ground surface. In order to compare wind speeds measured at the Oso site with other study sites where the sensor height is at the standard 10 meter height, the power law was used to adjust the wind speed data. While the power law is widely used for this purpose, it is always helpful to have actual data demonstrate that the power law adjustment works correctly and that this adjustment is appropriate.

For a few weeks, the EBAM tripod that was eventually located at Oso was located at the Mesa2 monitoring site for testing. This period of data presents a perfect opportunity to test the power law adjustment to the wind speed data. Figure A-7 below presents the raw data from both sensors for this comparison period. Figure A-8 below presents the comparison with the EBAM 2 meter sensor data adjusted by the power law. The results of this comparison demonstrate that the power law corrected 2 meter wind speed is within the US EPA accuracy guidelines of +/- 5% of the 10 meter sensor.

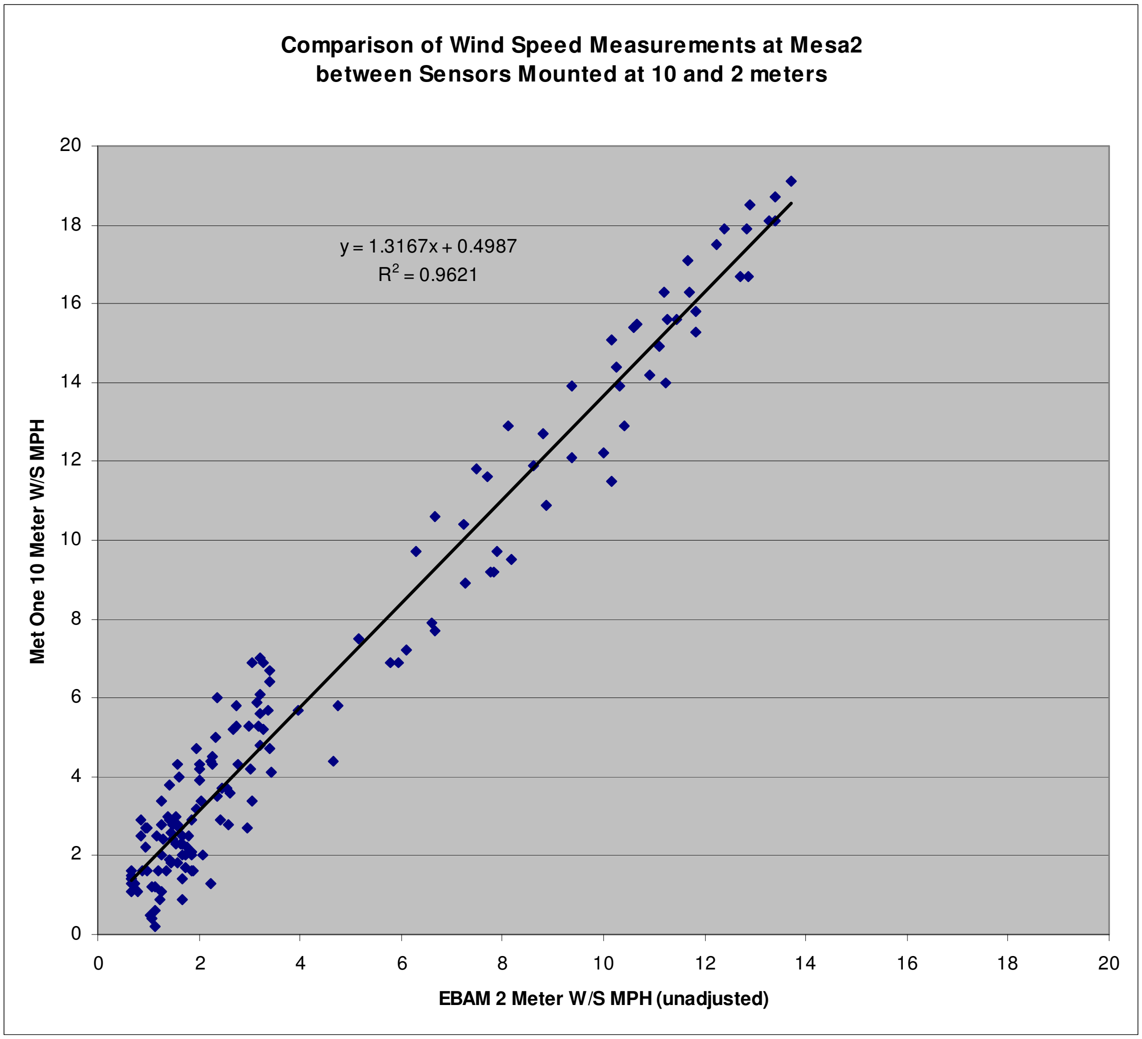

Figure A 7- Comparison Between 10m and 2m Wind Speed Measurements

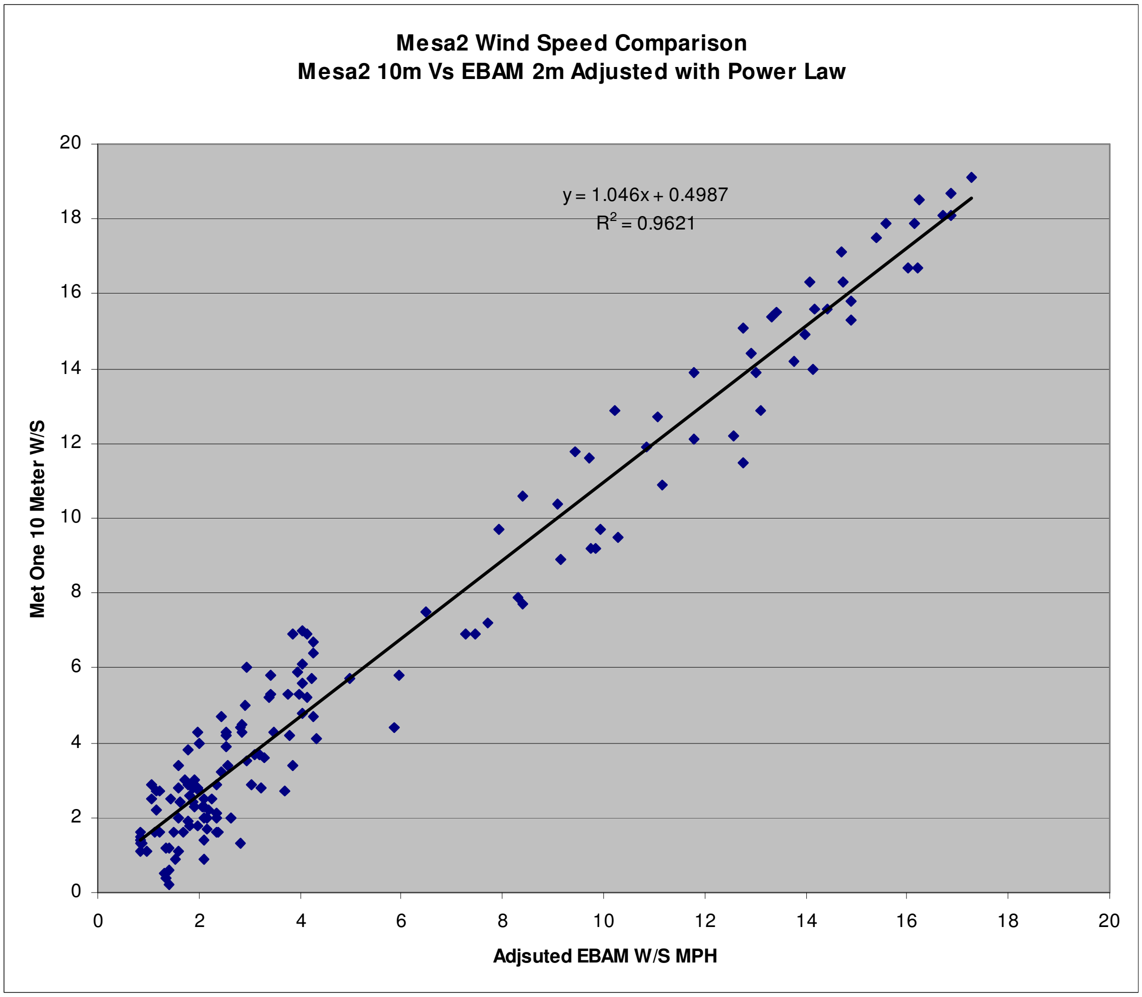

Figure A 8 – Comparison Between 10m and 2m Wind Speed Measurements with Power Law Applied to 2m Measurements

South County Phase 2 Particulate Study

Appendix B

Great Basin Unified Air Pollution Control District Sand Flux Analysis

Theodore D. Schade
Air Pollution Control Officer

GREAT BASIN UNIFIED AIR POLLUTION CONTROL DISTRICT

157 Short Street, Bishop, California 93514-3537
Tel: 760-872-8211

November 19, 2008

MEMORANDUM

Subject: Nipomo Mesa Sand Flux Analysis

From: Duane Ono

To: Joel Craig

This report evaluates the relationship between windblown dust from sand dunes in the Nipomo Mesa Project area and PM10 concentrations at downwind monitor sites. Air quality monitoring data from the Nipomo Mesa Study area clearly show that high hourly PM10 levels at the CDF, Mesa and Oso sites are associated with periods when high winds transport dust from the dune areas toward these monitors. Figure 1 shows a map of the PM10 monitor network. Comparisons of hourly PM10 concentrations to hourly wind speed and direction show that during the period of the study (April-May 2008) PM10 levels increased with higher wind speeds. Figures 2 through 4 show the relationship of wind speed and direction to PM10 levels at the CDF, Mesa and Oso monitor sites. High wind speed is a good indicator for the likelihood of windblown dust and high PM10 emissions, but a more direct measurement of wind erosion activity can provide quantitative information on wind erosion intensity and the timing of dust emissions. For this study, sand flux measurements were taken to directly measure wind erosion activity. These measurements were used to explore the relationship between windblown dust from the dunes and high PM10 readings at downwind sites.

Sand Flux Measurement Devices - Wind erosion activity was monitored using three types of measurement devices to measure sand flux. One type was a Sensit, which is an electronic device that counts moving sand grains that impact its sensor, and another was a passive sand collection device called the Cox Sand Catcher (CSC). The Sensit was used to measure hourly sand flux rates at 3 sites, and CSCs were used to calibrate the Sensits and to provide information on sand flux at 18 sites located throughout the study area. The CSC and Sensit network was used to compare wind erosion rates within the state recreational vehicle area (SRVA) and an adjacent natural area that was protected from surface disturbances by off-road activity. Site locations are shown in Figure 5. A third sand flux measurement device, the Big Springs Number Eight (BSNE), was operated at two sites by UC Davis. BSNE data was used to determine the relationship between sand flux measured at 15 cm above the surface to the total sand flux passing through a vertical column from the surface to the upper height of saltating particles. This information was used to convert the CSC and Sensit measurements (g/cm^2 at 15 cm height) to total sand flux units (g/cm), units which are commonly used by researchers in the wind erosion field.

High Sand Flux and PM10 - The hourly sand flux information collected from the Sensits showed that during the study period (April-May 2008), high sand flux rates were associated with high PM10 readings at downwind monitor sites. As observed with the high wind speed directions, the same wind directions accounted for the high sand flux and high PM10 readings. As seen in figures 6 though 10, high hourly sand flux rates from the direction of the dunes were strongly associated with high PM10 concentrations.

Relationship of Sand Flux at 15 cm to Total Sand Flux - CSC and Sensit sand flux rates were converted from measurements at 15 cm above the surface (g/cm^2) to total sand flux units (g/cm). Figure 11 shows the average sand catch at each BSNE collector height for the 2-month sampling period. Two BSNE sites were sampled and an exponential fit of the data following Shao and Raupach (1992) was used to define the vertical distribution of horizontal sand flux. By comparing the integrated sand flux between 14.5 and 15.5 cm to the total sand flux (0 to 100 cm), a multiplier of 42.4 was calculated to convert the sand flux (g/cm^2) at 15 cm to total sand flux (g/cm). This compares favorably with the conversion factor of 41.7 determined at Owens Lake, CA using the same BSNE collector technique (Gillette, *et al.*, 2004).

Threshold Wind Speed - Sensit data from sites in the SRVA and Oso areas were used to determine threshold wind speeds for each area. Following procedures described by Ono (2006) to determine threshold for the Gillette wind erosion model, threshold wind speed is the median value of the minimum wind speeds for all events that generated significant sand flux (total sand flux > 40 g/cm/hr, or >1 $g/cm^2/hr$ at 15 cm height). Threshold wind speeds for the three study areas are shown in Table 1. They are shown as threshold wind speeds in miles per hour (at 10-m height) and corresponding threshold friction velocities, u_{*t} (z_o = 0.1 cm).

Table 1. Threshold wind speeds in 3 study areas.

Area	Threshold Wind Speed at 10-m	Threshold Friction Velocity, u_{*t}
SRVA - beach dunes	7.7 mph	14.8 cm/s
SRVA - interior dunes	10.6 mph	20.4 cm/s
Natural Area – Oso	13.3 mph	25.6 cm/s

Wind speeds in wind erosion literature are often shown as friction velocity, u_*, which is related to the wind speed measured at a given height, z and the surface roughness, z_o as shown in equation 1.

$$u(z) = \frac{u_*}{0.4} \ln\left(\frac{z}{z_o}\right) \qquad \text{Equation 1}$$

Based on the hourly average threshold wind speed, the SRVA - beach dunes were found to have the lowest threshold wind speed and to be the most unstable area for wind erosion. The Oso area had the more stable, but still erodible surface based on threshold wind speed. For comparison, the threshold wind speed in the Keeler dunes at Owens Lake is around 15 mph (u_{*t} = 26 cm/s, z_o = 0.01 cm), which is close to the measurement for the Oso area. The two SRVA areas were generally more erodible than the natural (non-RVA) surfaces found at Owens Lake and the Oso area. (Ono, 2006)

Sand Flux and Wind Speed - CSC sand mass was used to calibrate Sensit particle readings to determine hourly sand flux rates at each Sensit site (Gillette, *et al*., 2004). Figures 12 through 14 show that hourly sand flux rates at the 3 Sensit sites generally increase with hourly average wind speeds at the CDF, Mesa and Oso met sites (all wind speeds are in mph at 10-m). The Gillette wind erosion model shown in equation 2 was used to estimate the relationship between hourly sand flux, Q (g/cm) and wind speed, u_* (cm/s).

$$Q = \frac{A\rho}{g}\, u_*(u_*^2 - u_{*t}^2)\, \Delta t \qquad \text{Equation 2}$$

The value for A (dimensionless) is derived empirically from the total CSC sand catch for the 2-month sampling period and by integrating the wind speed term over the entire sampling period. At sea level $\rho/g = 1.22 \times 10^{-6}$ g s^2 cm^{-4} where ρ is air density and g is gravitational acceleration. Δt = 3600 s for each hour. (Ono, 2006)

A comparison of the Gillette model to the hourly Sensit-derived sand catch is shown for each of the Sensit sites in Figures 12 through 14. Note that the Gillette model is not a best fit curve of the hourly sand flux data points, but is derived from wind speed and total sand catch using equation 2. The scatter seen in hourly sand flux rates with respect to wind speed is typical of the high variability in windblown dust. As seen in these figures, the Gillette model provides a reasonable approximation of sand flux as a function of wind speed.

Comparison of Erosion in SRVA and Natural Area - The difference in erosion potential for each area can be seen by applying the Gillette model to each site and area. For this comparison, threshold wind speeds from the 3 Sensit sites were applied to the CSC sites in the SRVA – beach dunes (sites 1, 8 & 9), SRVA - interior dunes (sites 2-7), the natural dunes – Oso (sites 11-16), and agricultural areas (sites 17 & 18). The total CSC catch was used to derive a value for A for each site. Wind speed data were taken from the CDF site for CSCs in the SRVA, and from the Oso met site (adjusted 2-m wind speed to 10-m using equation 1, z_o = 0.1 cm) for the natural dunes. An average value for A was calculated for each site and area. Figure 15 shows that the most erodible area for a given wind speed is the SRVA. Within the SRVA, the beach dunes and interior dunes show similar erosion potentials. The natural dunes in the Oso area have a lower erosion potentials at any given wind speed than the SRVA. Figures 16 through 18 show the Gillette model curves for each of the CSC sites within the three study areas.

Table 2 shows a summary of the Gillette model input values for each of the CSC sites and the average values for each area. For comparison, monthly A values at Owens Lake ranged from 1 to 10 for sandy areas, with u_{*t} values from 26 cm/s to 37 cm/s. This is similar to the values for the natural dunes in this study. The SRVA had higher values for A and lower threshold wind speeds than sites at Owens Lake, which indicates that the SRVA areas are more susceptible to wind erosion than are the sandy areas at Owens Lake. (Ono, 2006) CSC sites 17 and 18 were located in agricultural areas near the CDF and Mesa sites. As shown in table 2 these sites had a zero value for A because no wind erosion was measured at these sites. In other words, the agricultural sites were not a source of windblown dust.

Table 2. Input values for Gillette model.		
Area/ CSC Site	A	Threshold Friction Velocity u_{*t} (cm/s)
SRVA – beach dunes (avg.)	16.26	14.8
• CSC Site 1	15.95	14.8
• CSC Site 8	5.10	14.8
• CSC Site 9	28.56	14.8
SRVA – interior dunes (avg.)	19.99	20.4
• CSC Site 2	20.82	20.4
• CSC Site 3	40.07	20.4
• CSC Site 4	4.12	20.4
• CSC Site 5	29.96	20.4
• CSC Site 6	13.69	20.4
• CSC Site 7	13.31	20.4
Natural Dunes – Oso (avg.)	2.71	25.6
• CSC Site 11	0.99	25.6
• CSC Site 12	5.50	25.6
• CSC Site 13	2.76	25.6
• CSC Site 14	3.33	25.6
• CSC Site 15	1.95	25.6
• CSC Site 16	2.00	25.6
Agricultural Area (avg.)	0.00	> 45.9
• CSC Site 17	0.00	> 45.9
• CSC Site 18	0.00	> 32.5

Higher Wind Speeds at Oso than at CDF – During the study period, the natural dune sites generally had more sand collected in the CSCs than the sites in the SRVA. However, the cause of the higher sand flux amounts in the natural dune area is likely due to the higher wind speeds at Oso as compared to the SRVA. Figure 19 shows that wind speeds at Oso were about 70% higher than wind speeds measured at CDF. In addition, wind speeds measured at Mesa, which is between Oso and CDF were 40% higher than CDF. This wind speed difference would explain why sand catches from an undisturbed dune area were higher than in the SRVA where the surface was disturbed by off-road vehicles.

Conclusion - The monitored PM10 impacts at the CDF, Mesa and Oso PM10 sites, along with the wind direction, sand flux and wind speed information show that windblown dust from the SRVA and the natural dunes caused high PM10 levels at downwind monitor sites. However, considering the difference in wind speeds at the natural dune sites and the SVRA, the Gillette model shows that the SRVA was more erodible at any given wind speed than the natural dune area. Dust events in the SRVA were also found to be triggered by lower wind speeds than the natural dune area. Significant wind erosion was initiated in the off-road vehicle area at hourly average wind speeds from 7.7 to 10.6 mph. Higher wind speeds, greater than 13.3 mph, were required to trigger significant wind erosion in the natural dune area.

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Gillette, Dale, Duane Ono, Ken Richmond, *A combined modeling and measurement technique for estimating wind-blown dust emissions at Owens (dry) Lake, CA*, Journal of Geophysical Research, Volume 109, 2004.

Ono, Duane, *Application of the Gillette model for windblown dust at Owens Lake, CA*, Atmospheric Environment, Volume 40, 3011-3021, 2006.

Shao, Y., and M.R. Raupach, *The overshoot and equilibrium of saltation,* Journal of Geophysical Research, Volume 97, 20,559-20564, 1992.

Figure 1. Nipomo Mesa Project ambient monitoring network.

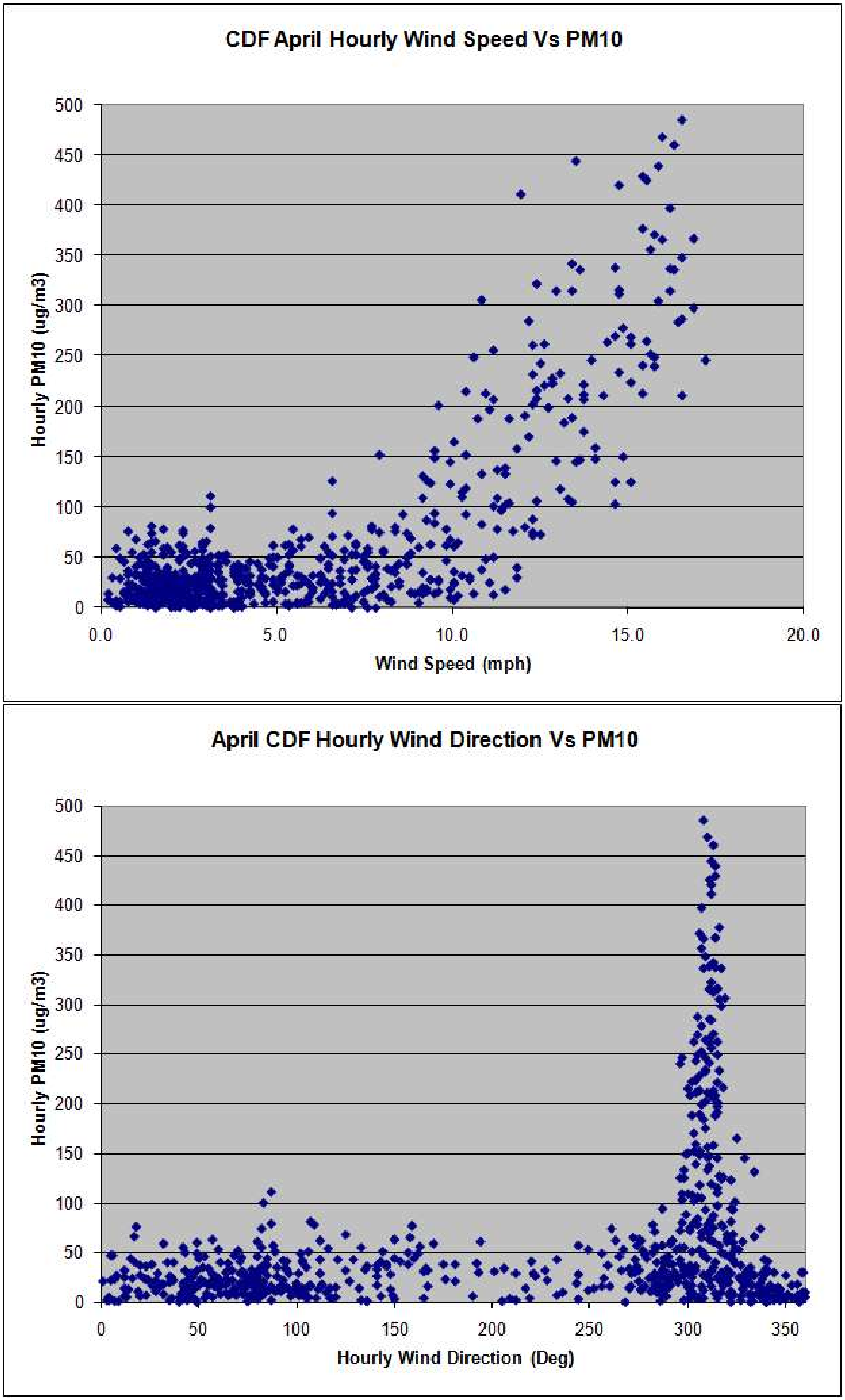


Figure 2. PM10 compared to wind speed and direction at CDF monitor site (April 2008).

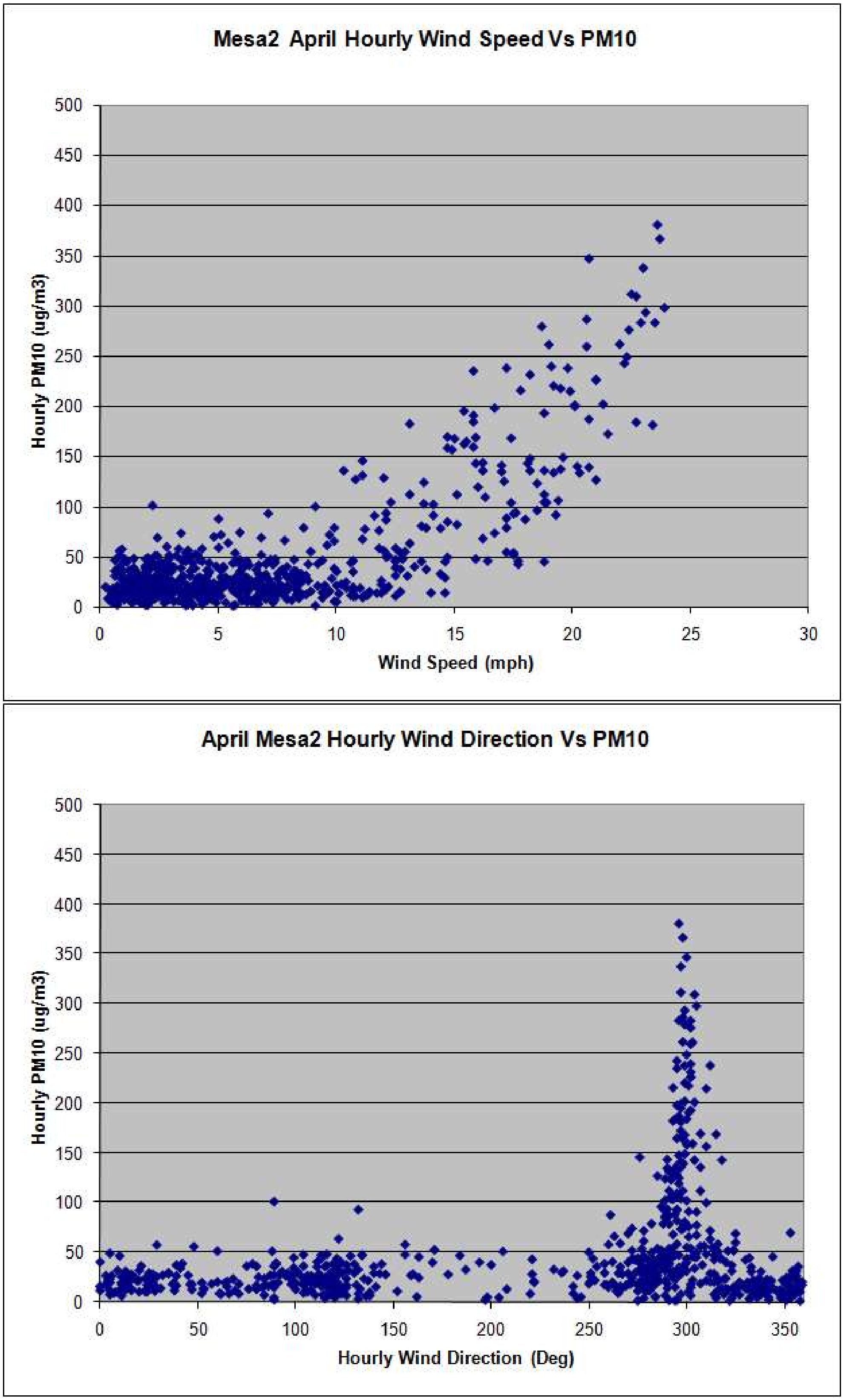
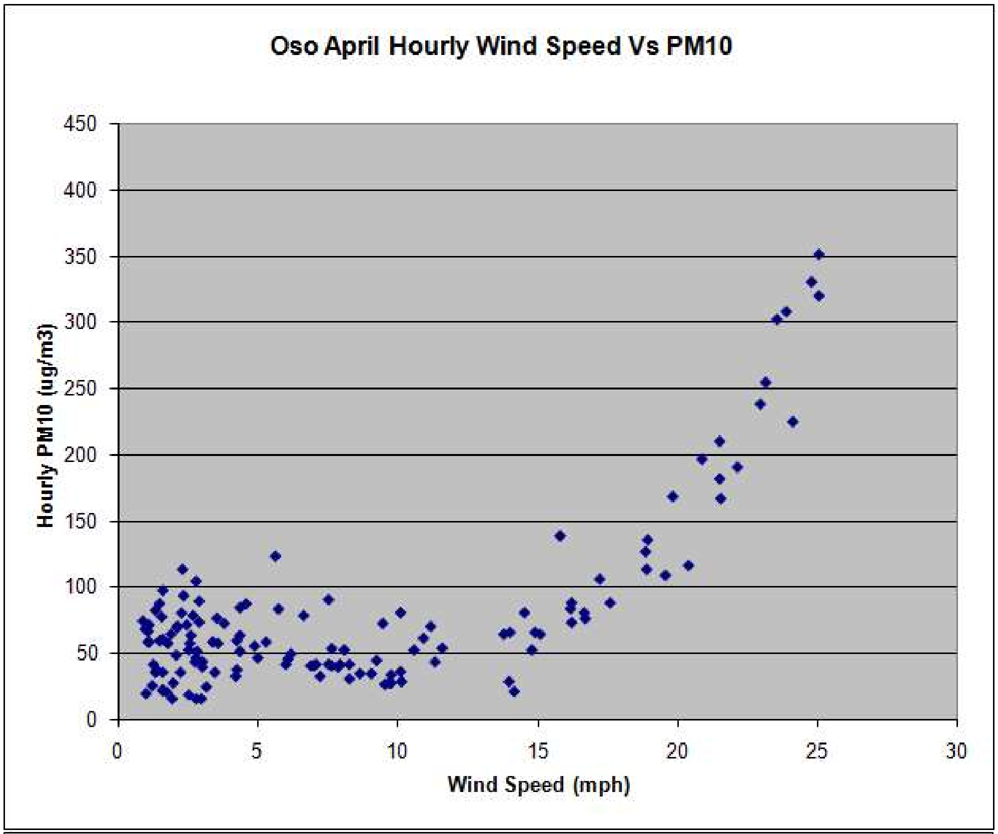


Figure 3. PM10 compared to wind speed and direction at Mesa monitor site (April 2008).



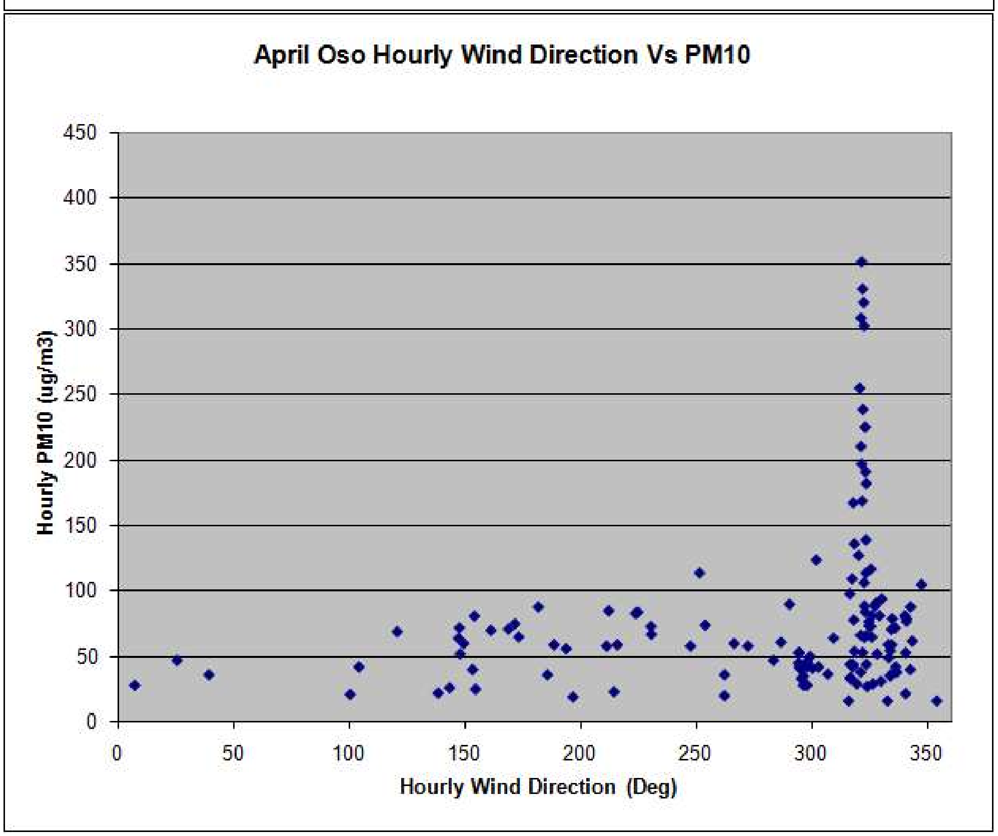


Figure 4. PM10 compared to wind speed and direction at Oso monitor site (April 2008).

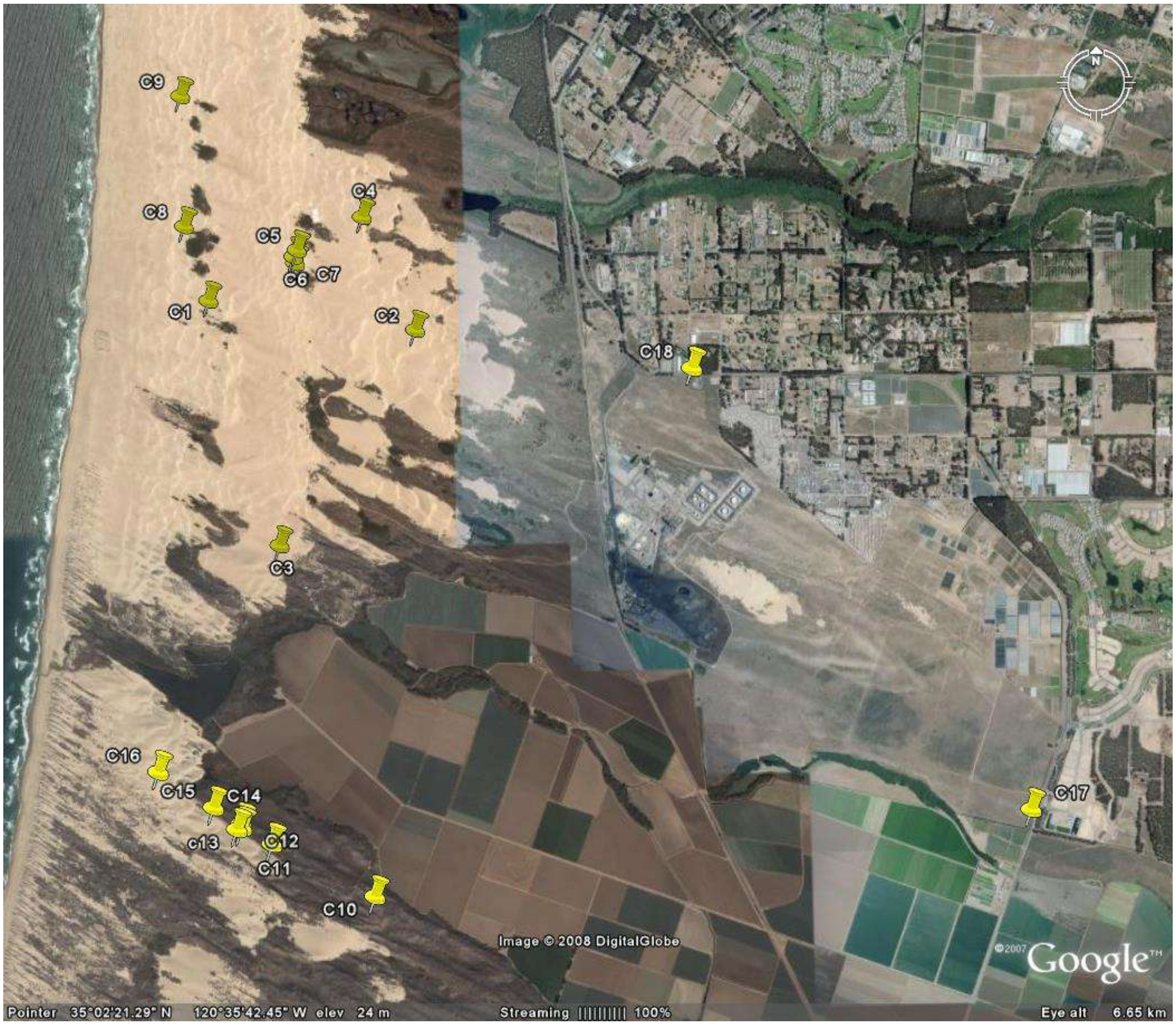


Figure 5. Nipomo Mesa Project sand flux monitoring site network.

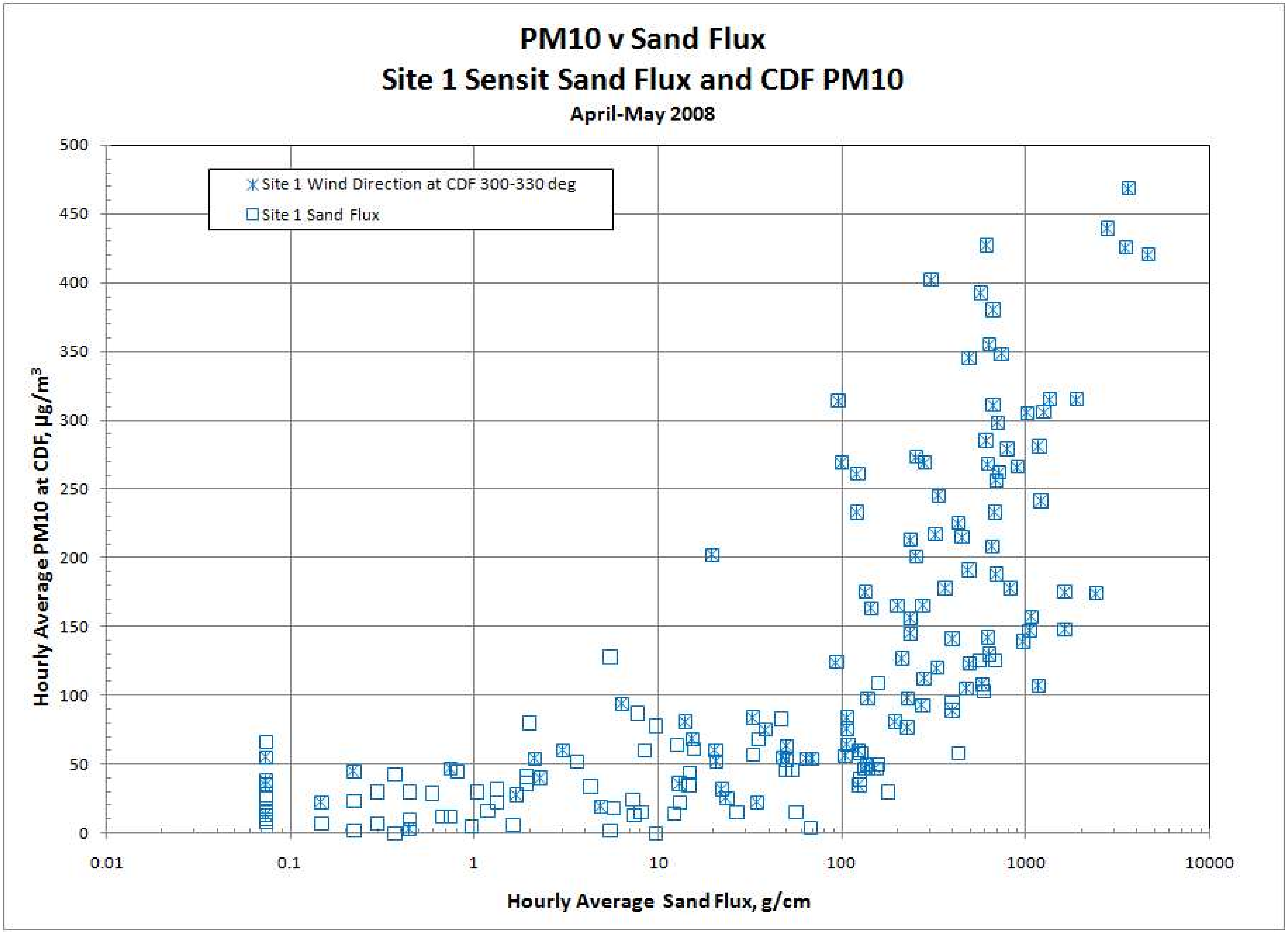


Figure 6. PM10 at CDF compared to sand flux from Sensit site #1.

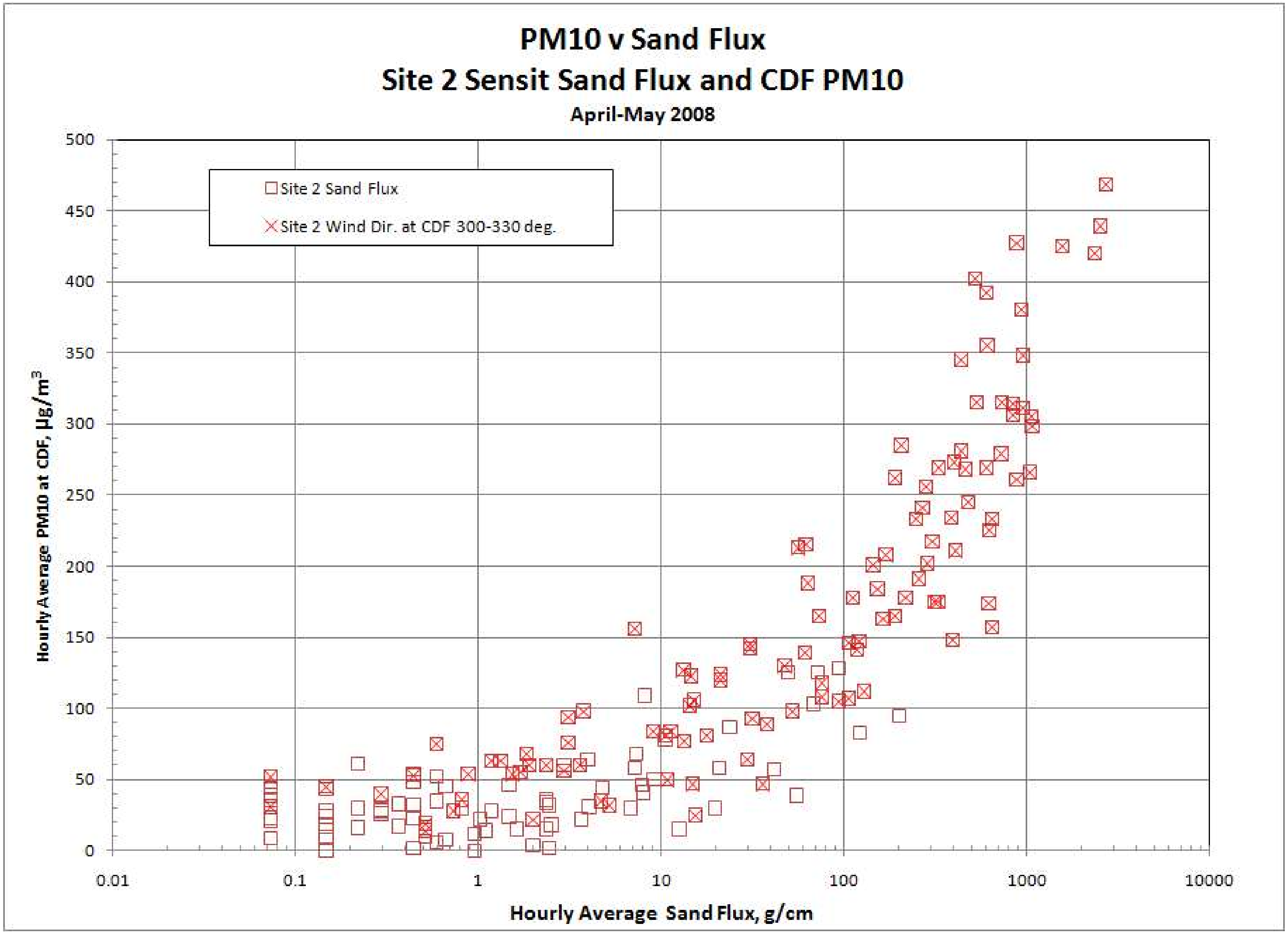


Figure 7. PM10 at CDF compared to sand flux from Sensit site #2.

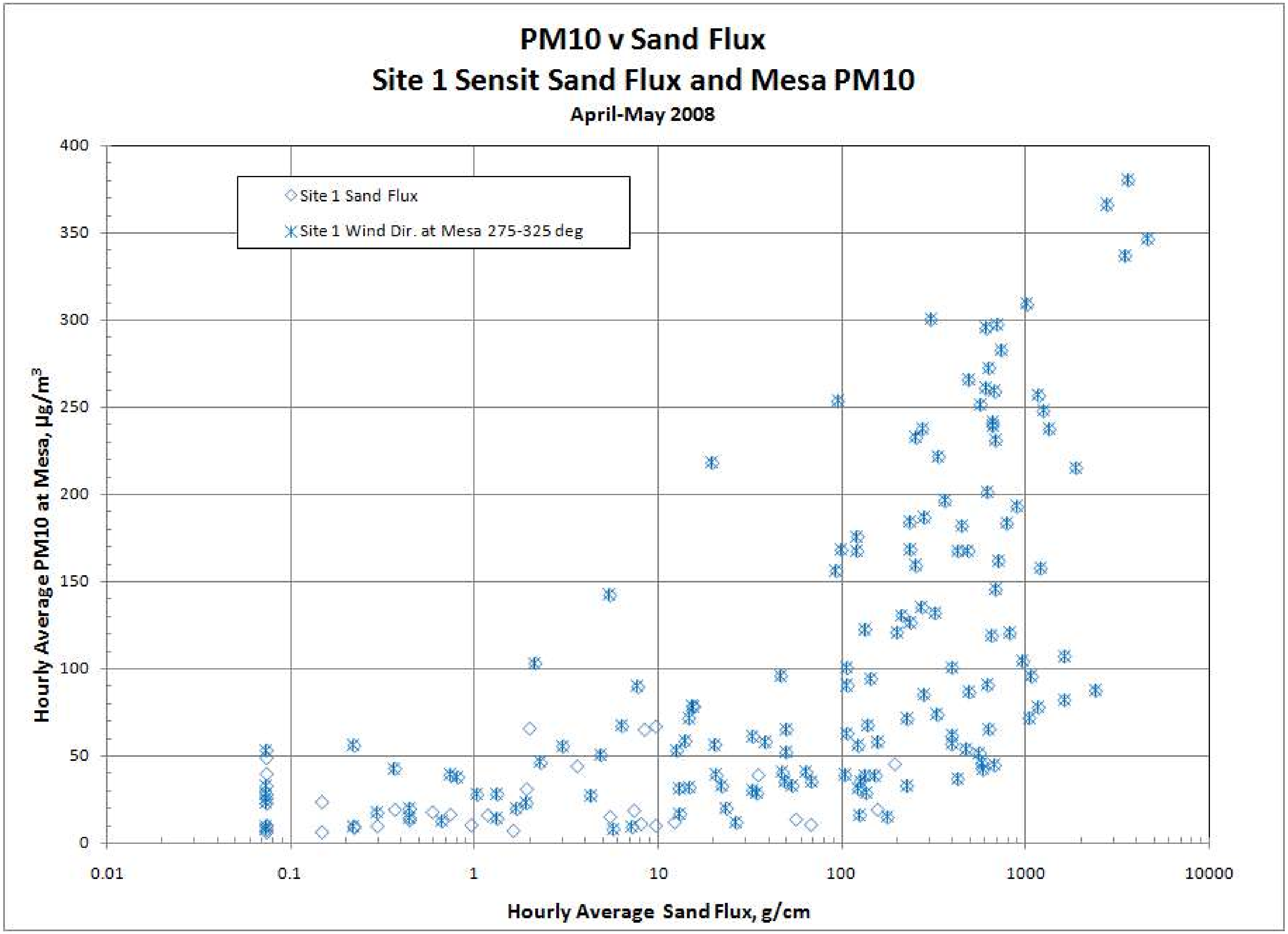


Figure 8. PM10 at Mesa compared to sand flux from Sensit site #1.

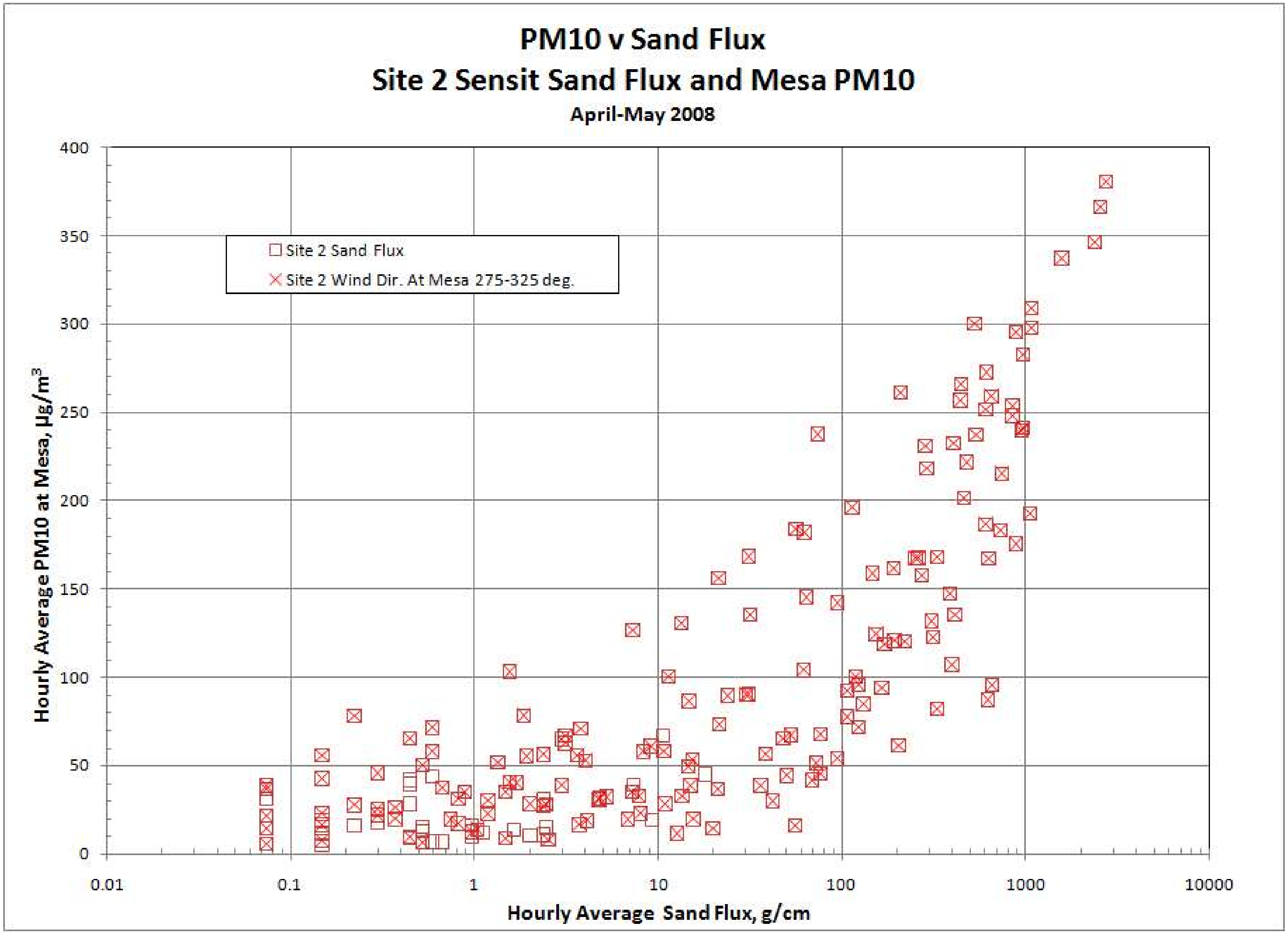


Figure 9. PM10 at Mesa compared to sand flux from Sensit site #2.

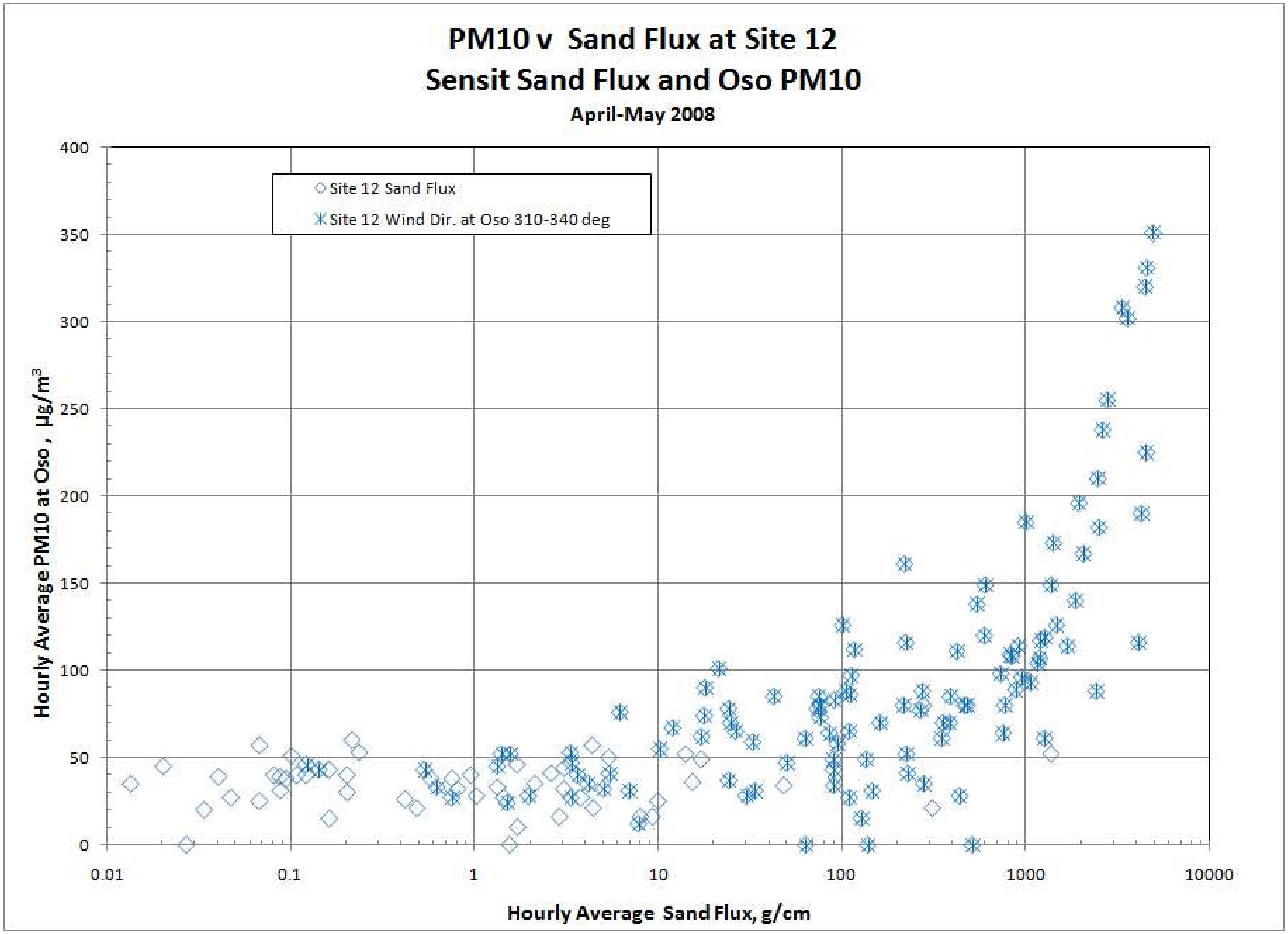


Figure 10. PM10 at Oso compared to sand flux from Sensit site #12.

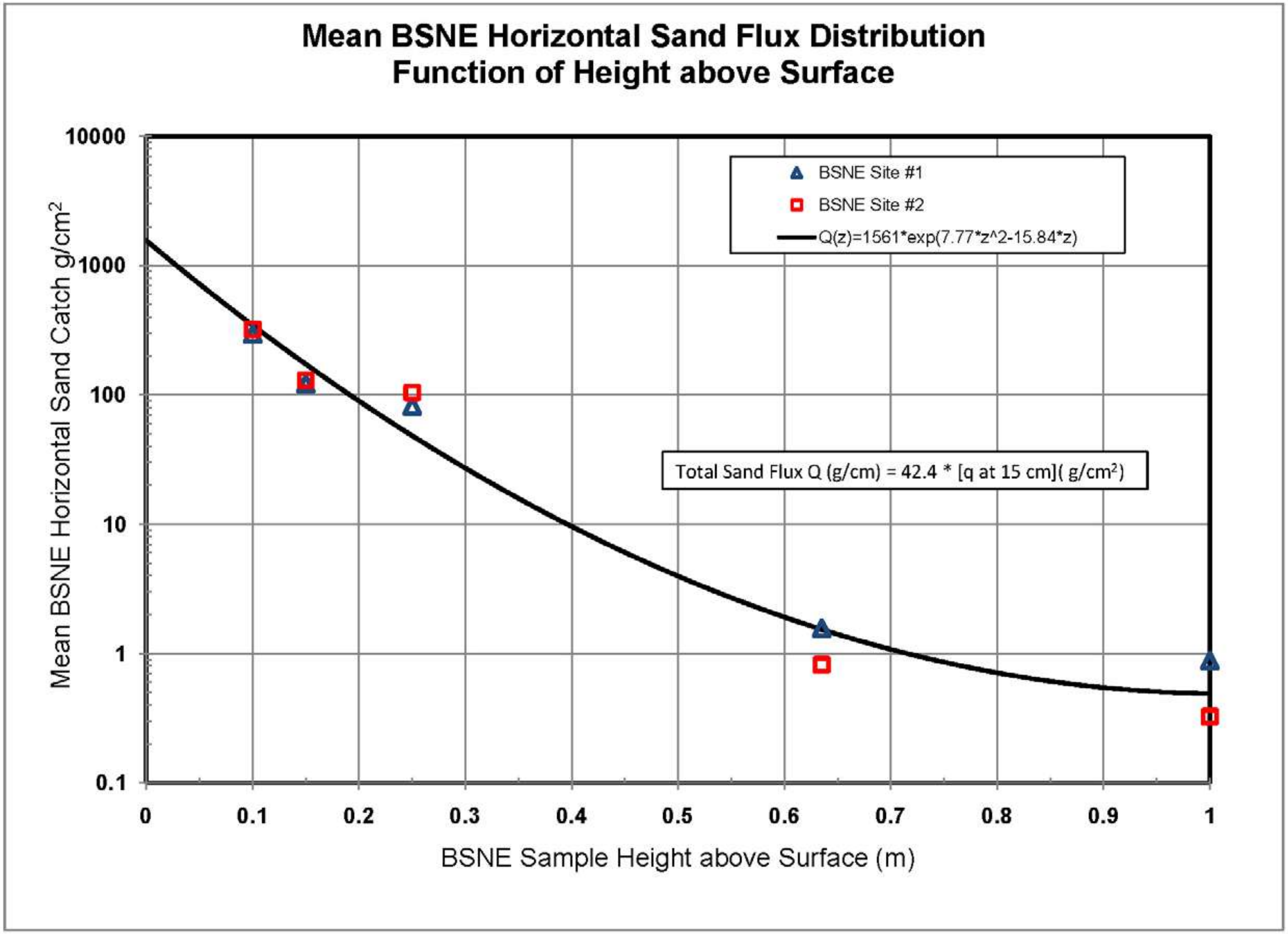


Figure 11. Vertical distribution of horizontal sand flux measured by BSNEs (April-May 2008).

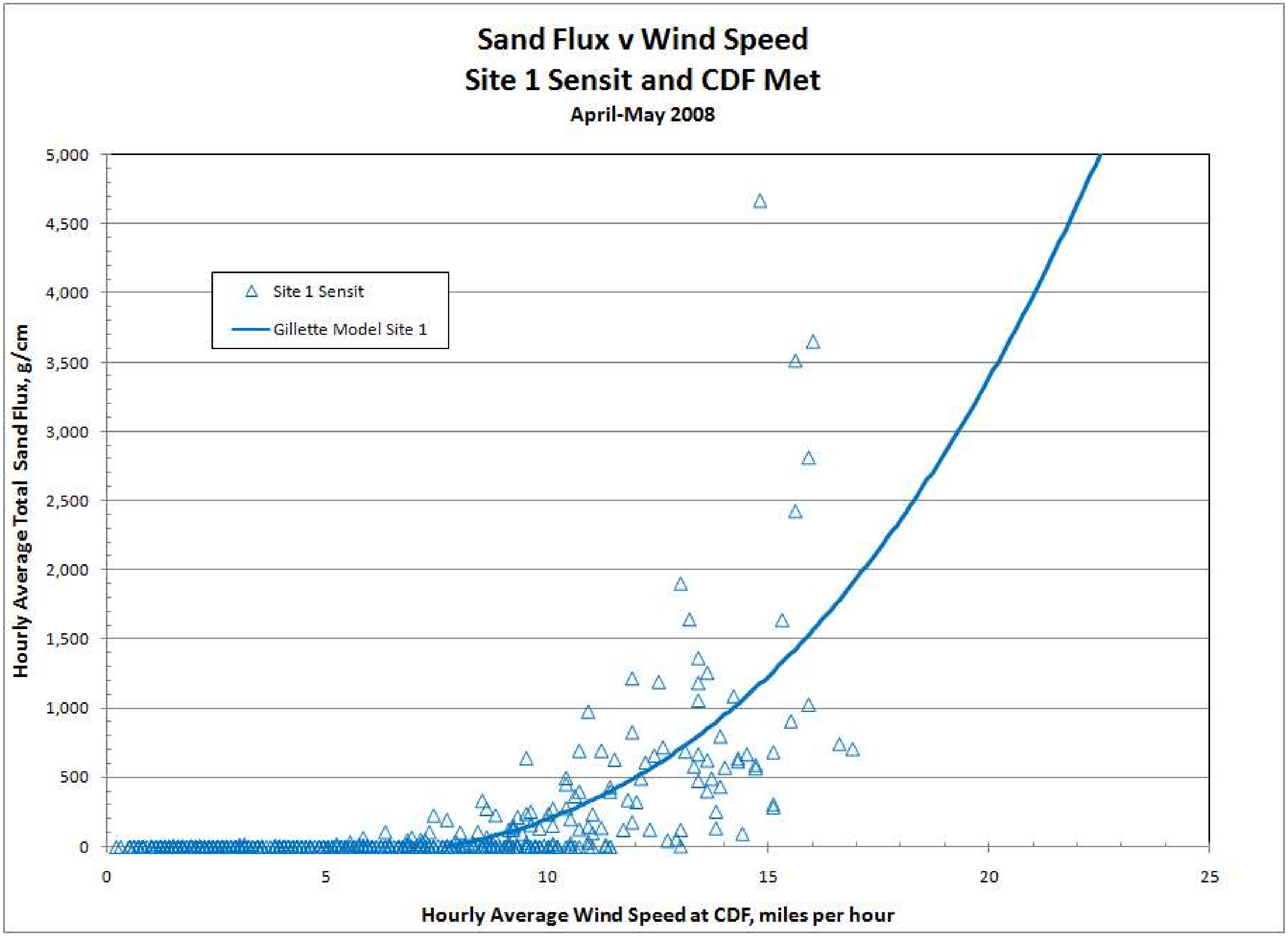


Figure 12. Sand flux at Sensit site #1 compared to wind speed at CDF.

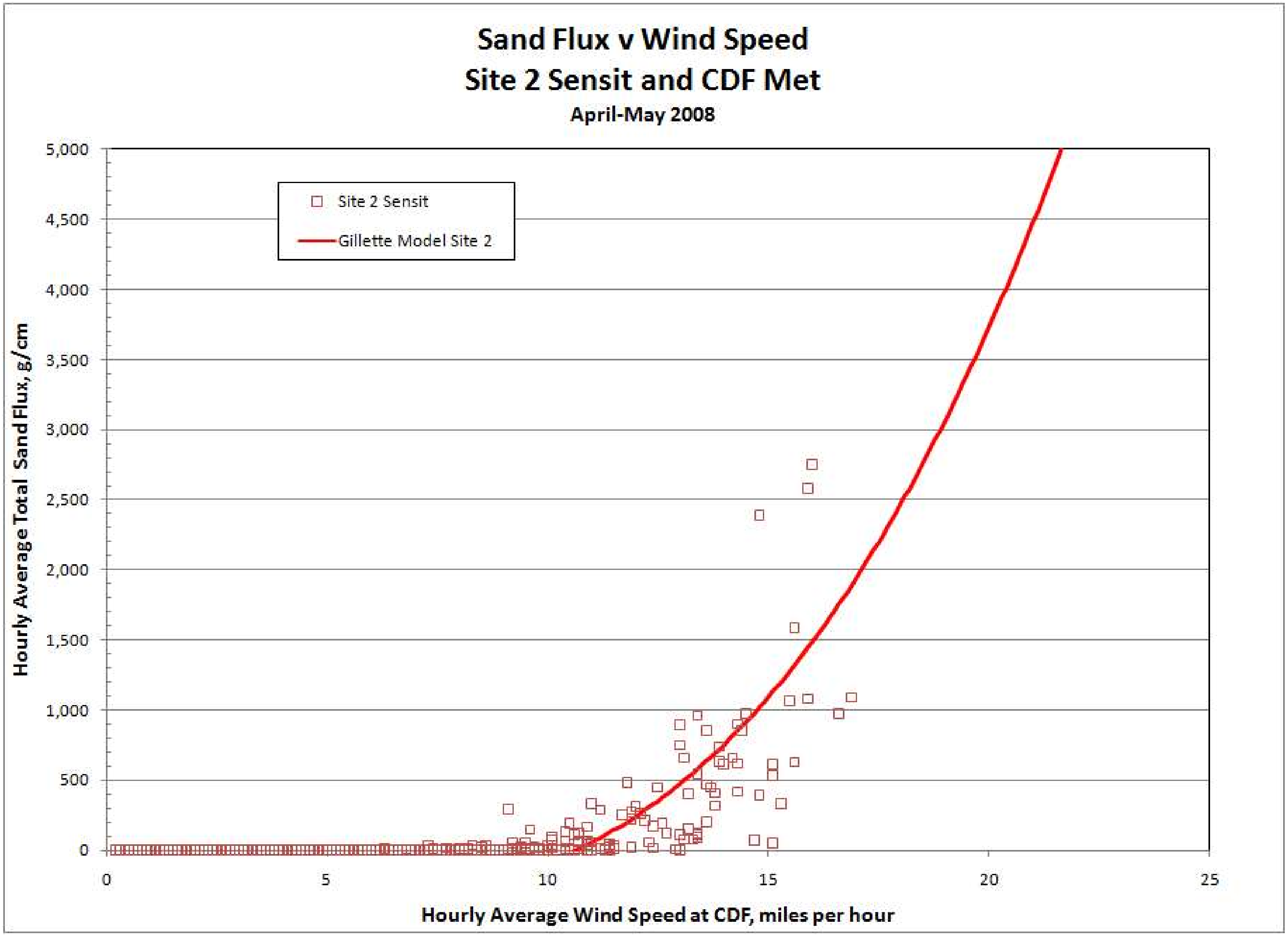


Figure 13. Sand flux at Sensit site #2 compared to wind speed at CDF.

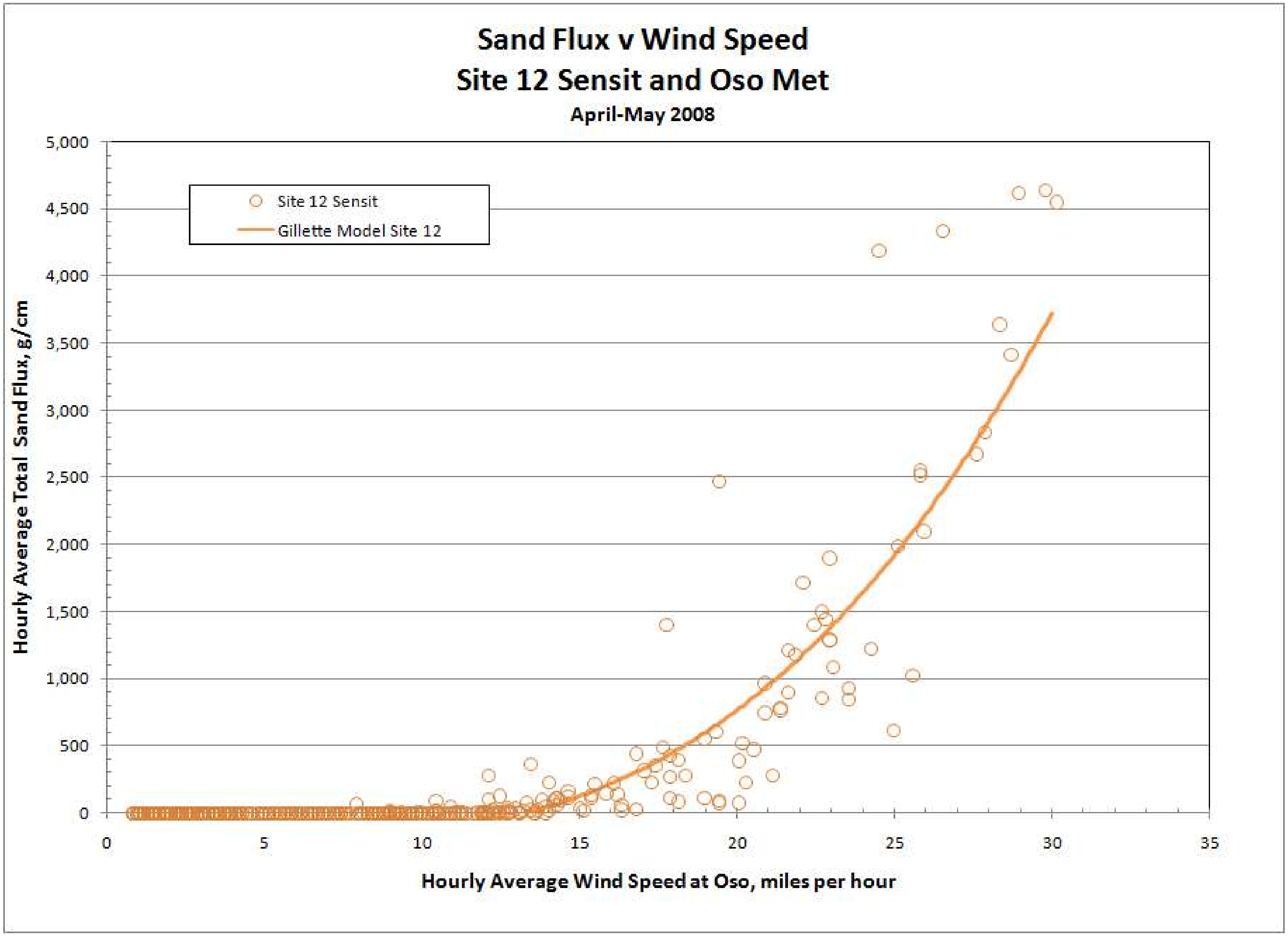


Figure 14. Sand flux at Sensit site #12 compared to wind speed at Oso.

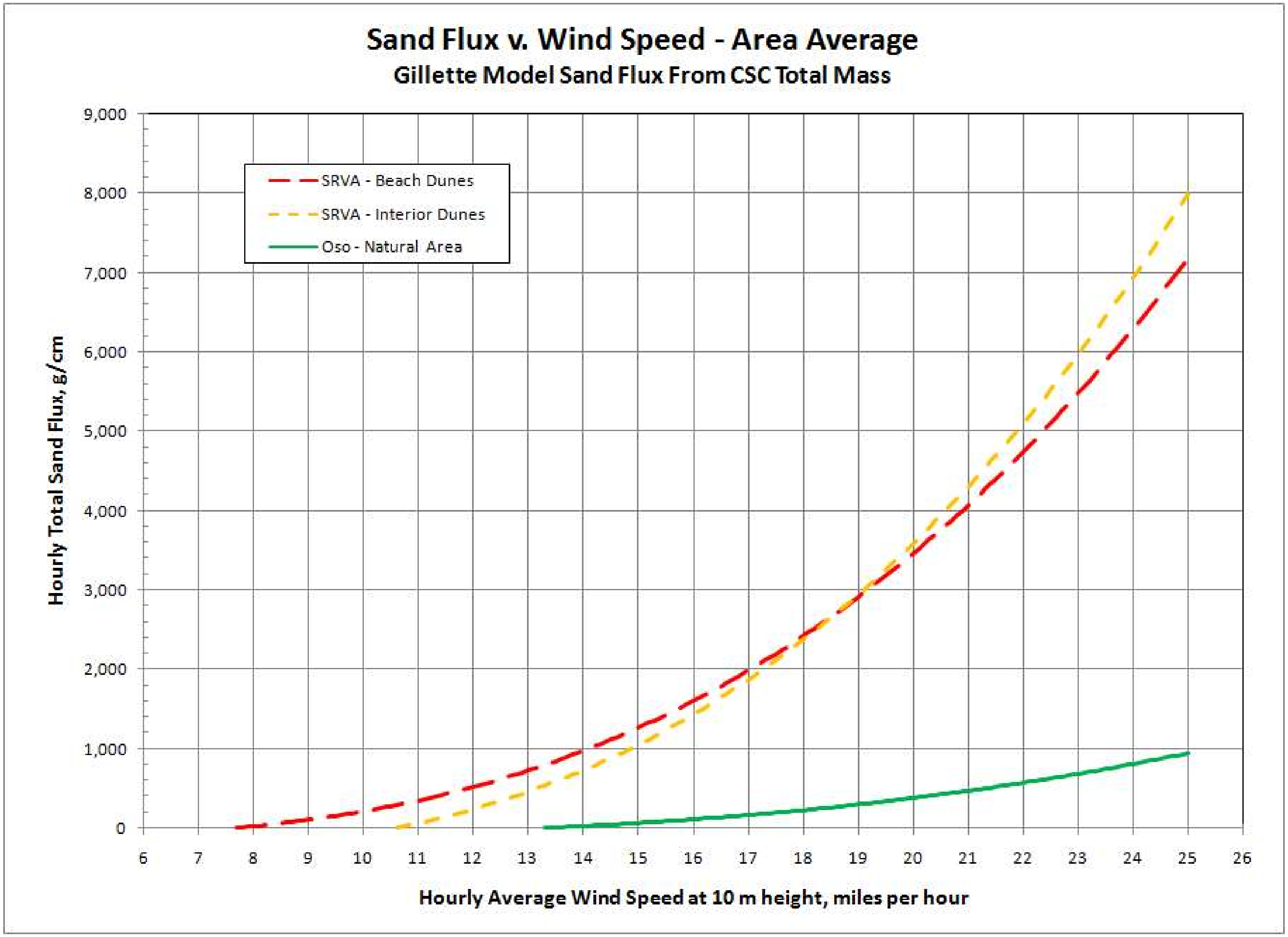


Figure 15. Gillette model sand flux for the SRVA beach and interior dunes, and the natural area.

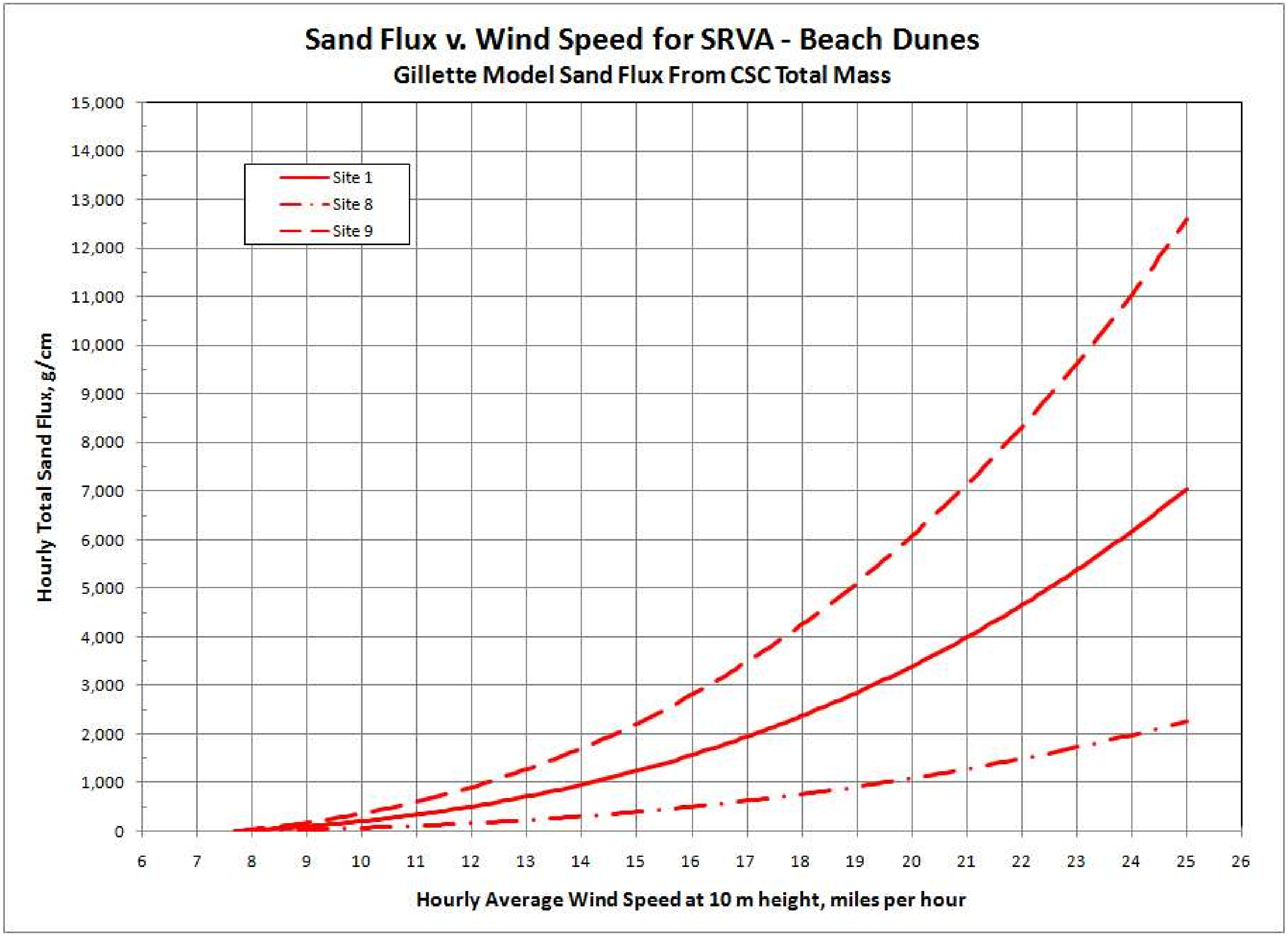


Figure 16. Gillette model sand flux for the SRVA beach dune sites.

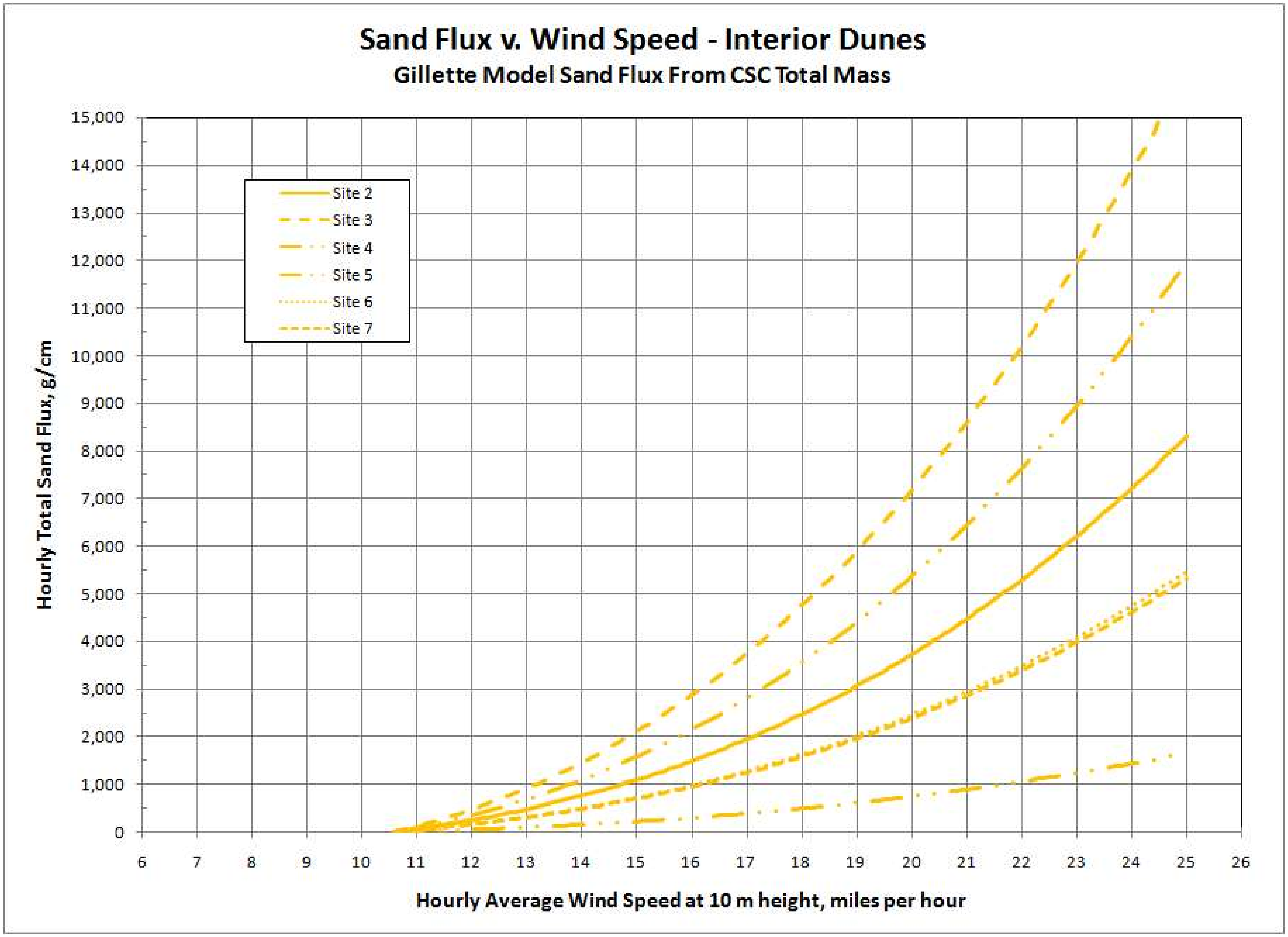


Figure 17. Gillette model sand flux for the SRVA interior dune sites.

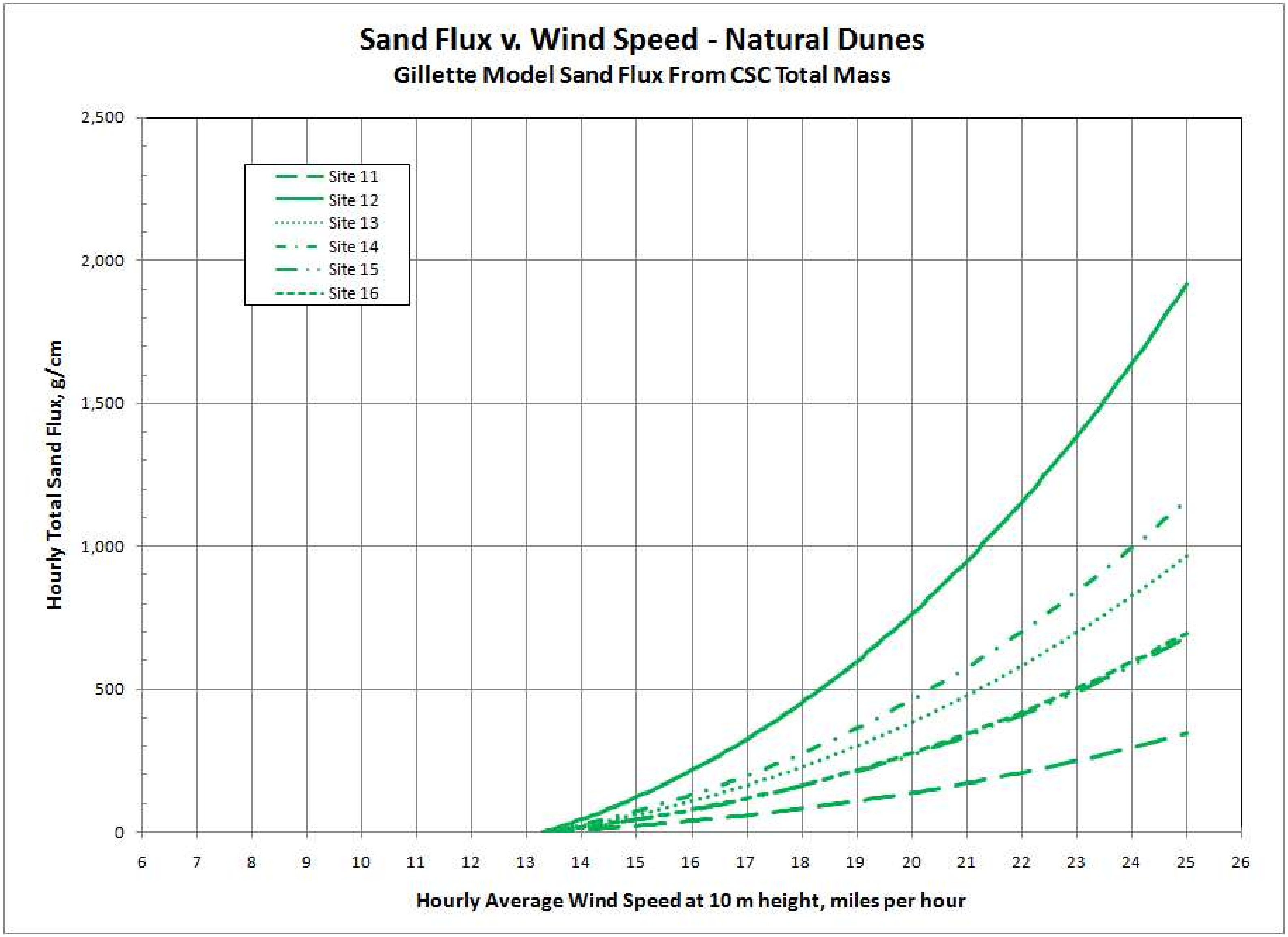


Figure 18. Gillette model sand flux for the natural dune sites.

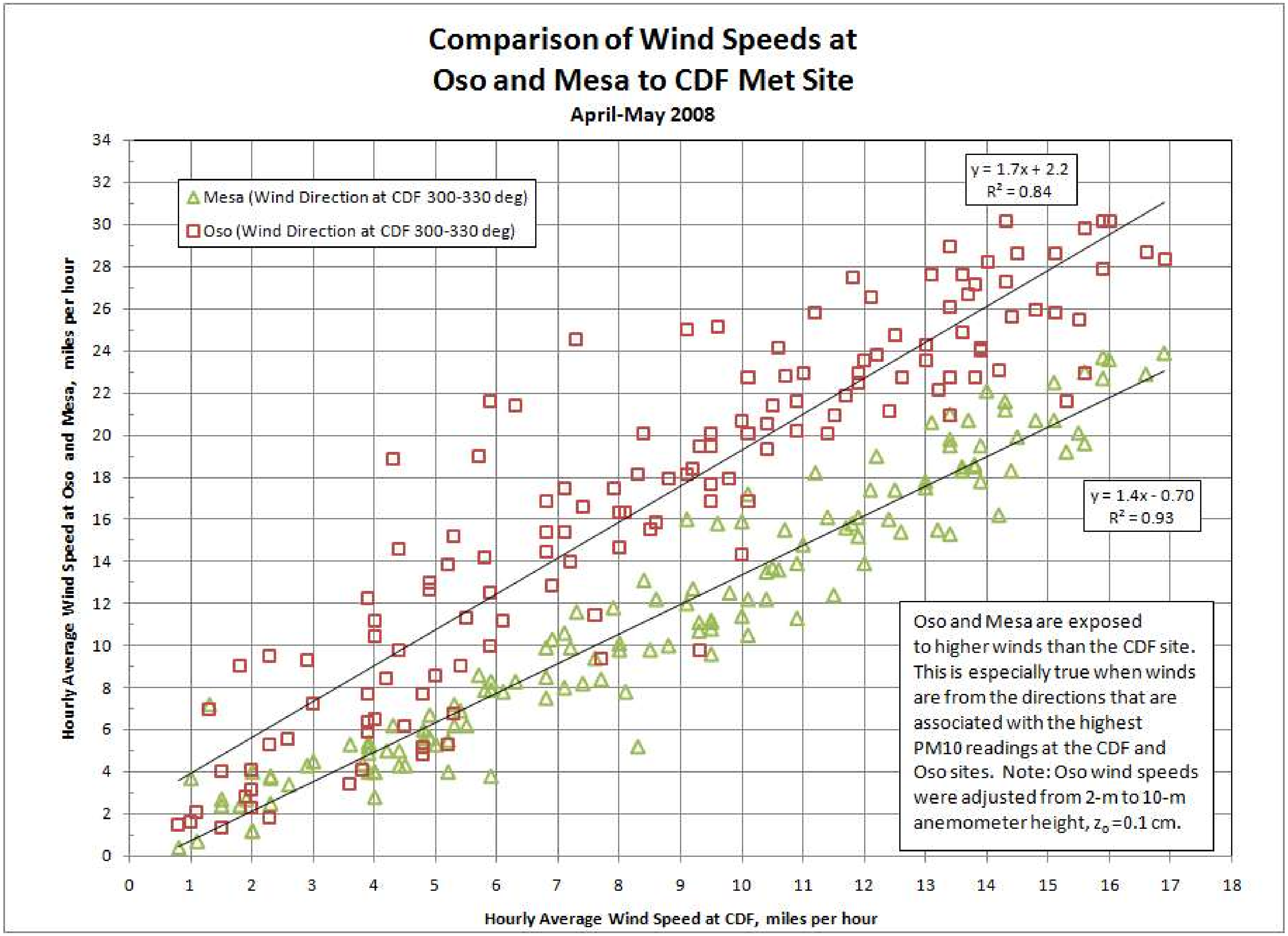


Figure 19. Hourly wind speeds at Mesa and Oso were 40% and 70% higher, respectively, than at CDF when the wind direction at CDF was between 300 and 330 degrees. This corresponded to the wind direction when PM10, sand flux and wind speeds were highest.

South County Phase 2 Particulate Study

Appendix C

Delta Group Final Report

Aerosol Measurements for the

NIPOMO MESA/SOUTH COUNTY PARTICULATE STUDY – PHASE 2

Final Report to the
San Luis Obispo Air Pollution Control District
(SLO APCD)
Larry Allen, APCO

December 30, 2009

Prof. Thomas A. Cahill, P.I., and Geoff Schladow, Co P.I.,
Dr. David E. Barnes, Project Manager,
Prof. Kevin D. Perry and Steve S. Cliff, S-XRF Analysis,
Bernie Lee, Jonathan Lawton, Nikki Nguyen, Ceci Chen, with student interns
Audrey Chow and Nate Ellebracht, Soil Resuspension,
DELTA Group, University of California, Davis,
and
Prof. Thomas E. Gill, Robert Velarde, and Kevin Floyd,
Department of Geology, University of Texas, El Paso

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Executive Summary

The UC Davis DELTA Group developed, installed and operated instruments used to measure particle mass, size and composition for the San Luis Obispo County APCD *Phase 2 South County PM Study*. This study was designed to determine the cause of high PM_{10} levels measured in the Nipomo Mesa area of the county, including potential impacts from offroad vehicle (OHV) activity at the Oceano Dunes State Vehicle Recreation Area (SVRA); the role of wind entrainment of fine particles from the large petroleum coke storage piles at the nearby ConocoPhillips refinery facility was also investigated. Sampling was conducted during short-term, high wind events and over longer periods through the summer, fall and winter of 2008. Personnel from the University of Texas, El Paso, collected and analyzed soil samples from the various study sites.

Monitoring Site Locations and Measurements Performed

Probably the most important diagnostic tool for this portion of the Phase 2 study was the ability to deploy DRUM aerosol samplers on north to south transects, allowing source identification of aerosol episodes and comparisons between measurements downwind from the SVRA and downwind from dune areas without OHV activity. Continuous, highly time-resolved aerosol sampling allowed episodes to be tracked with an approximate 3-hour time resolution that facilitates close correlation with on site meteorology. Table EX-1 below identifies the samplers used and associated sampling periods; Figure EX.1 shows the sampling site locations.

Table EX 1 - Delta Group Aerosol Sampling

Site Name	Delta Group Measurements	Delta Group Sampling Period
Ten Commandments	8 DRUM	Intensive
Guadalupe Dunes	8 DRUM	Sept 08 – Nov 08
Oso Flaco	8 DRUM	Intensive
Mesa2	8 DRUM (also side by side all DRUMs 1 week)	Jan 08-Feb09
CDF	8 DRUM	Intensive + 6 weeks
Conoco Upwind	8 DRUM	Intensive
Bluff	8 DRUM and 3 DRUM	Intensive
Silver Spur	3 DRUM	Intensive
Pier Ave.	3 DRUM	Intensive
Grover Beach	3 DRUM	Intensive

Figure EX 1 - Aerosol sampling sites with prevailing wind direction in aerosol episodes

Analysis of Soils

The DELTA Group and University of Texas, El Paso (UTEP) collected over 150 sand samples over every transect from each ambient air sampler to the ocean, with photographs taken at every soil sampling site. The samples were placed into coded Ziplock™ bags and transported to UC Davis for analysis, using the following methods:

- Sieving – 150 samples - UC Davis, 425, 212, 106, 75, 56 µm
- Malvern Particle Size Analyses – 60 samples - UTEP
- Re-suspension analysis – 33 samples - UC Davis of the 56 µm sieved mode, mass and Elemental composition by S-XRF

The samples were sieved in standard dry geological sieves, then divided into bags; roughly 60 sample bags were sent to UTEP for Malvern particle sizing. From the results of the sieving a selection of the samples with relatively high mass in the < 50 µm bin were resuspended, using an air jet at UC Davis, and collected onto the stages of an 8 DRUM impactor, the same instruments used to collect aerosols in the ambient component of the study.

An important observation from the sand collection field effort was the presence or absence of ephemeral soil crusts, a key factor known to influence airborne particulate levels measured in other high wind, sandy areas such as Owens and Mono Lakes. Direct observations of the sand at Oso Flaco showed the presence of such a crust about 1/2 to 1 cm thick; it was capable of supporting itself over a few cm, but was easily broken under any pressure, such as boots. This crust was observed throughout the open sand sheets upwind from the Oso site, but was not present in the SVRA.

Figure EX 2- Sand crust at the eastern edge of the sand sheet upwind of Oso Flaco control site. The thickness of the layer was roughly 1 cm

Such crusts greatly suppress particle emission by gluing small particles into larger ones and suppressing the saltation processes that can occur when the crust breaks up. This is seen at Owens (dry) Lake, where almost no dust is emitted into the air, even in strong winds, until the robust salt crust formed every year by winter rains breaks up. (Reid at al, 1994)

Figures EX.3 and EX.4 below, demonstrate that both sieving and the more complex Malvern soil analysis by UTEP showed very little mass for particles below about 50 µm for most soil samples, as expected.

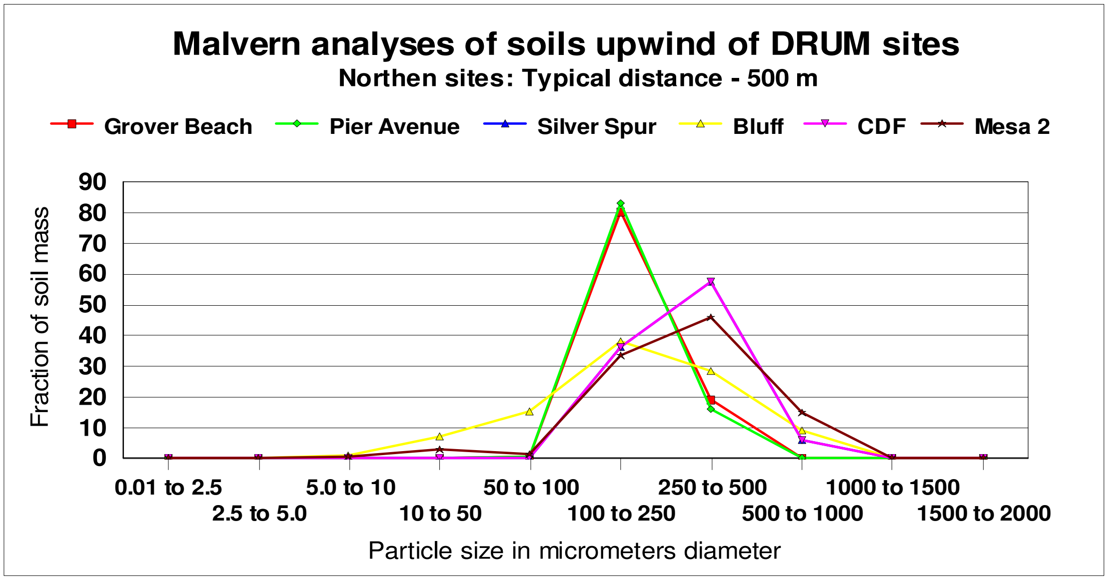


Figure EX 3 - Malvern analyses of soils upwind of the northern sites

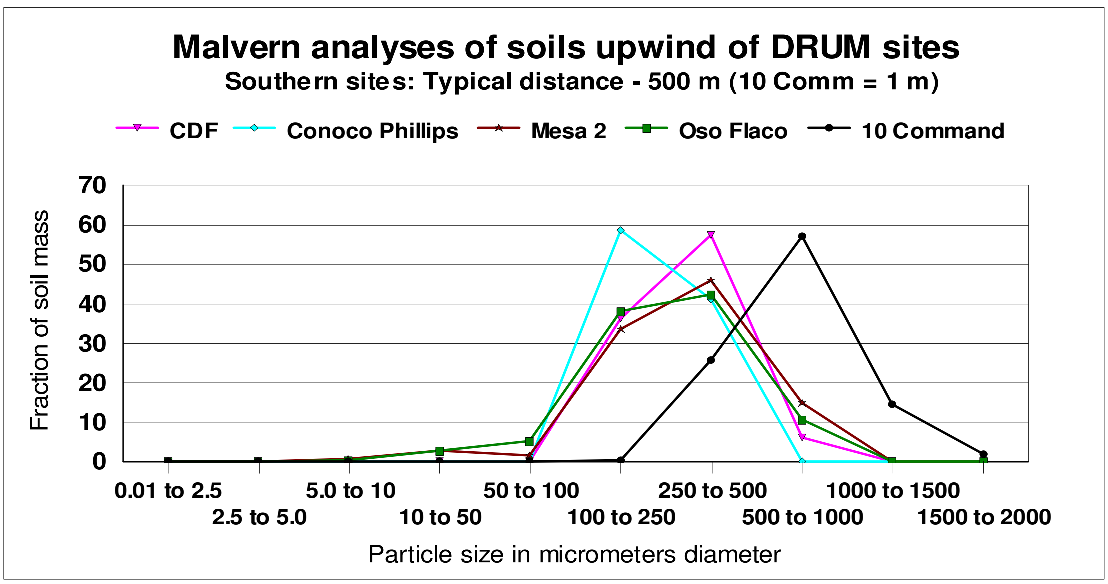


Figure EX 4 - Malvern analyses of soils from sites upwind of the southern DRM sampling sites

While the Malvern analysis shows very little particle mass below 10 microns, analysis of the resuspended samples, shown in Figure EX.5 below, demonstrates there is indeed a fraction of the sand with particle diameters less than 10 micron. The Malvern and re-suspended sample analysis show a similar particle size distribution between the various transects analyzed.

Elemental analysis of the re-suspended samples showed a very similar composition between soil samples.

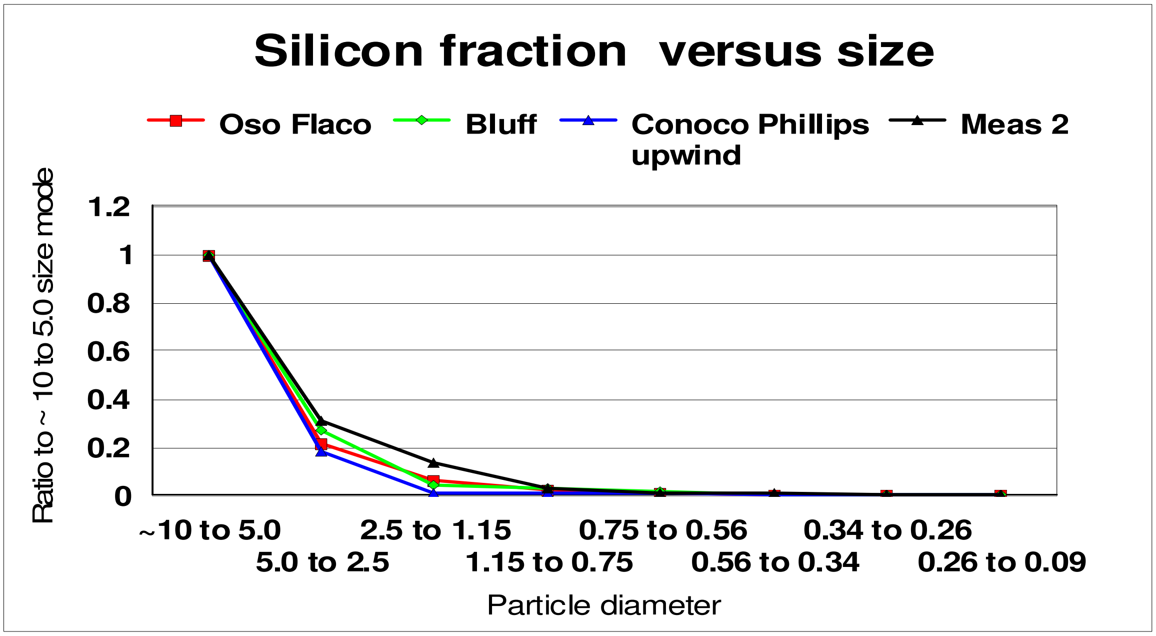


Figure EX 5 - Re-suspension of sieved samples resulting in size profiles of sand transect data relative to the 10 to 5.0 µm mode.

A special effort to analyze the soil samples in the transect between the Bluff and Silver Spur site was made to better understand the potential for particulate emissions from this intensely cultivated agricultural land. Soil samples from the agricultural fields upwind of the Bluff site were analyzed both dry and in solution by the Malvern particle size analyzer. The results for the dry analysis showed only a small portion of the sample with particle diameters below 10 µm. However, the same soil sample dispersed in water showed the majority of particle diameters below 10 µm, peaking at about 4 micron.

The condition of the actual soils was like neither of these extremes, since the land is under intense cultivation, the actual soils are routinely irrigated and much of the area between Bluff and Silver Spur has crop cover, typically lettuce and broccoli. This can also be seen by the tendency of the soil as collected to form clumps or clods. As a result, any free particles in the fine alluvial soils do not normally occur in a re-suspendable form and, thus, would be less likely to cause aerosols. This helps explain the almost total lack of aerosol episodes at the Bluff site, which is directly downwind of the farmed area. The combination of crop cover and routinely wetted soils provides very little potential for dust unless special conditions are met, such as disking of a thoroughly dry field, or vehicular traffic on dry, dirt farm roads.

Analysis of Ambient Air Aerosols

The Delta Group DRUM sampler used for ambient aerosol sampling is a powerful research tool that can measure particulate mass and elemental composition by particle size fraction. The DRUM sampler is capable of continuous measurements with a time resolution as short as 1.5 hours for the smallest particle fractions, and up to 6 hours for the coarsest particle fraction.

DRUM Sampler Side by Side Quality Control Check
Prior to deployment of the numerous DRUM samplers used in the spring intensive monitoring period, all DRUM samplers were located at the Mesa2 monitoring site for side by side comparisons to ensure the data from each DRUM sampler is comparable to each other. Both 8 DRUM samplers (measuring eight different particle size fractions) and 3 DRUM samplers (measuring 3 different particle size fractions) were used. These side by side tests showed accuracy within the standard EPA ± 15% quality assurance criterion for all samplers except the "Ten Commandments" site DRUM. That sampler did not meet the required criterion, so its data was not included in the study analysis.

Quantitative comparisons between the 3 DRUM and 8 DRUM samplers were also performed. For the Bluff site, both samplers ran concurrently and recorded 6 values with a mean aerosol mass of 5.8 ± 0.7 $\mu g/m^3$. For Mesa 2, comparing the 3 DRUM and 8 DRUM sampler measurements for the April 26 episode showed a mean mass value of 30.5 ± 0.5 $\mu g/m^3$. Overall, the 3 DRUM and 8 DRUM sampler measurements for the 3 peak episodes were quite similar, with a standard deviation of 3.7 $\mu g/m^3$ across all sites.

While the comparisons between DRUM samplers were quite good (except the Ten Commandments sampler), comparison of that data to the APCD-operated TEOM sampler data during the side by side tests at Mesa2 was not as favorable. One factor that makes the DRUM/TEOM comparisons difficult is that the DRUM sampler has a time resolution of about 1.5 hours for the finest stages, and up to 6 hours for the coarse stage, while the TEOM records hourly averages. In addition, the TEOM sampler is designated as federally equivalent measurement method for use in determining compliance with ambient air quality standards; its data compared favorably to the federal reference method, hi-volume sampler data at Mesa 2. In contrast, the DRUM samplers are a research tool and were not designed to be a federally equivalent measurement method.

The comparisons at Mesa2 between the DRUM and TEOM showed generally good agreement for 24-hour averages on days with no wind/PM episode. On episode days, however, the TEOM data always showed higher 24-hour average concentrations than the DRUM samplers. Close examination of the data showed that the coarsest fraction of the DRUM data appeared suppressed during wind/PM episodes, indicating the possibility of loss of mass on the coarsest stage drums. It is possible that the DRUM samplers were overwhelmed during the episode periods by the extreme wind and particle concentrations that are unique to this field study.

All particulate monitoring methods, including the federally approved methods, have various weaknesses. It is very common for a sampling method to work well in one application but poorly in another application; thus, the poor comparability between the TEOM and DRUM samplers is not surprising. What is most important is that data comparability between each DRUM sampler is very good, which allows for accurate comparisons of DRUM sampler data from the different sampling locations. DRUM data should not be compared to TEOM data or health standards.

Analysis of Mesa2 Winter 2008 DRUM Data
Figure EX.6 below shows a series of time plots from January 14 through February 25, 2008. The plots are segregated by particle diameter, with the two coarsest modes (10 - 5.0 and 5.0 - 2.5 microns) equivalent to the EPA-defined PM_{10} coarse particle fraction. Everything below

2.5microns falls into the category of EPA-defined $PM_{2.5}$. As previously discussed, the coarse particle mass appears to be significantly less than the fine fraction on episode days, an anomaly that suggests the coarse stages of the drum samplers may have been overwhelmed by the volume of suspended particles on those days.

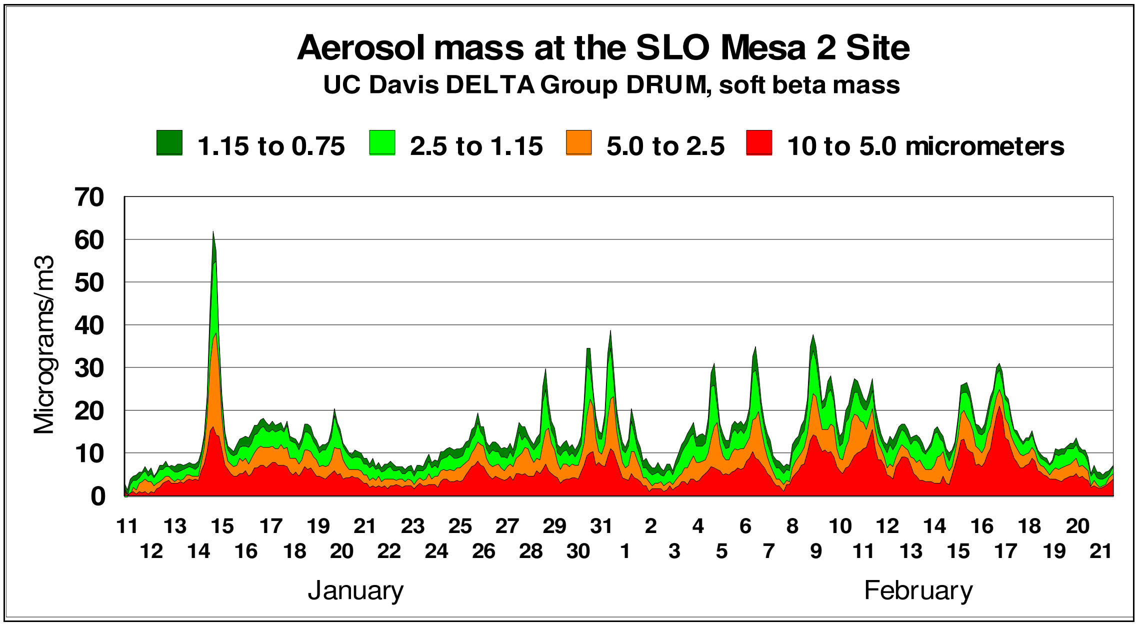


Figure EX 6- Super-micron masses in the January – February DRUM sampling

In addition to size fractionation, X-Ray Fluorescence (XRF) analysis was also performed on drum particle samples from each sampling site to determine the composition and potential source of the collected particulate. Silicon in particular is a distinctive component of sand and thus, an important indicator compound for this study. Similarly, chlorine is a distinctive component of sea salt and generally indicates proximity to the ocean.

Figure EX.7 below presents the silicon concentration for the two coarsest fractions for the same time period.

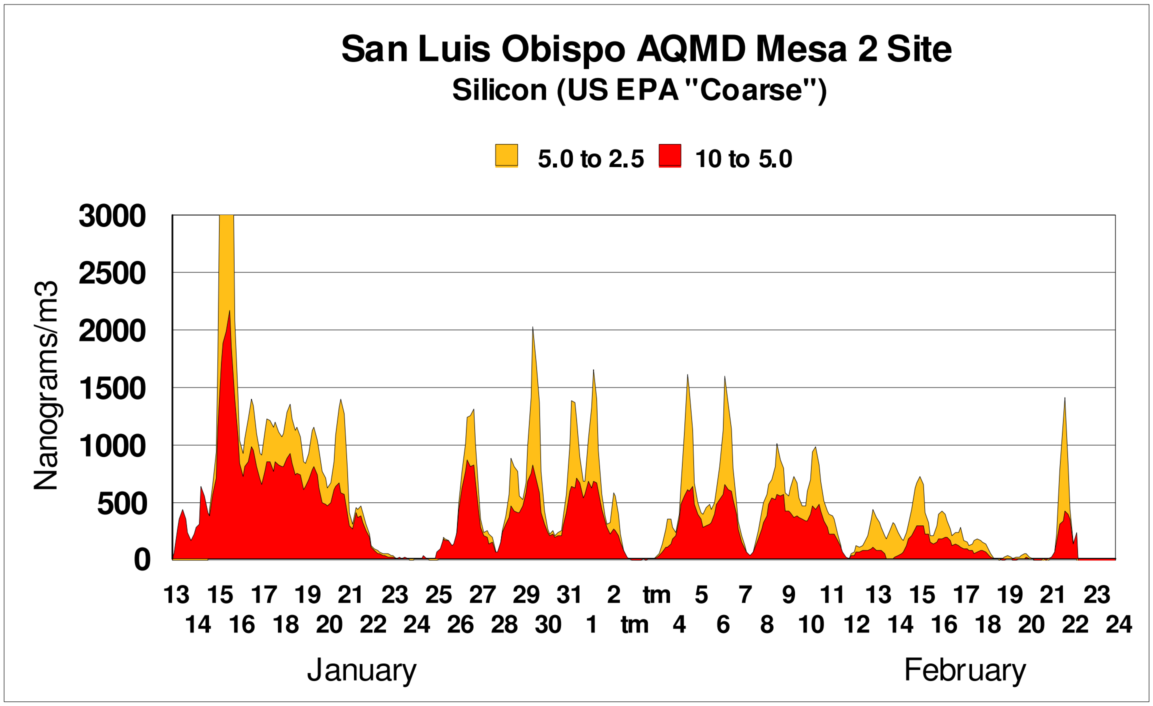


Figure EX 7 - Silicon, the major component of soil, in the coarse modes during the winter, 2008 deployment

Figure EX.8, below presents the chloride concentration for the two coarsest fractions for the winter period.

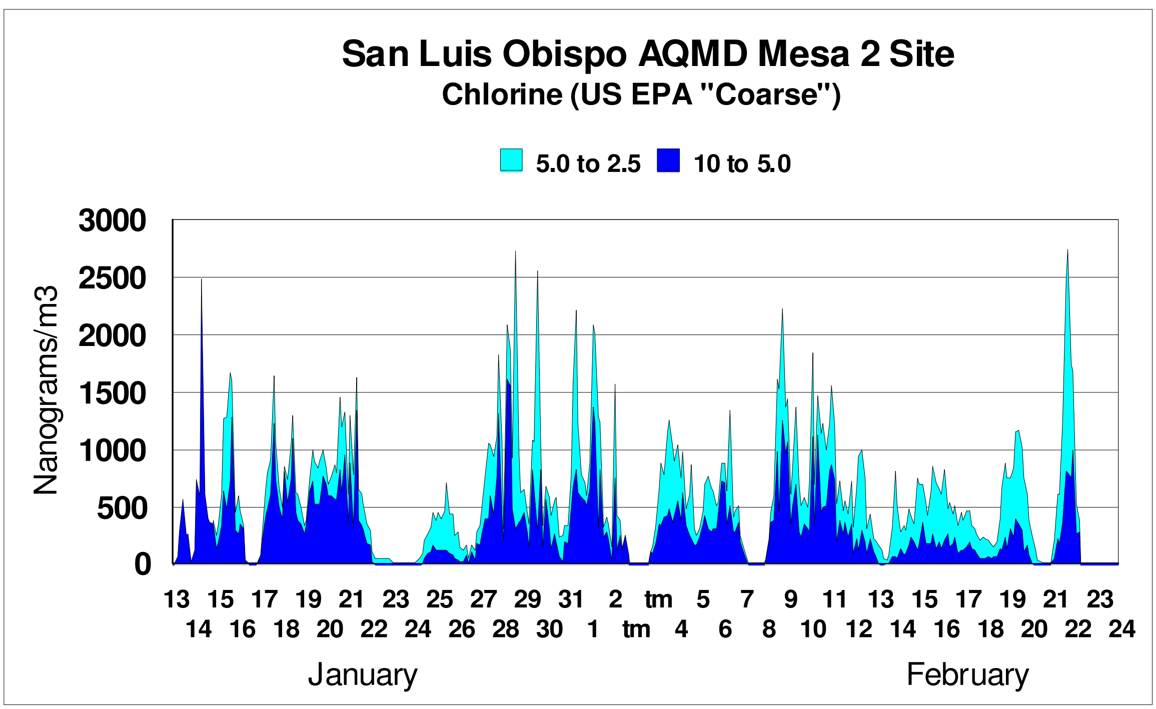


Figure EX 8 - Chlorine from sea salt during the winter, 2008 deployment

The measurement period of January through February, 2008 had several rain events. The wetting of soils strongly suppresses dust formation, thus increasing the sea salt to soil dust ratio above that found in dry conditions (circa 10%). This effect would not occur during most of the year when rainfall is absent. During the January – February deployment, the average sand/soil component was roughly ¾ of all PM_{10} mass, with the remainder almost entirely sea salt. However, during peak episodes, such as January 15, sea salt comprised only 10% of the mass. The higher salt values later in the month may be tied to repeated rain events that would suppress re-suspension of soil.

Figure EX.9 below presents data from Mesa 2 for sub-micron diameter silicon mass, a tracer for sand/soil particles. As shown, significant soil mass with particle size below one micron was found on high episode days. This was a surprising finding, as soil-derived particles below one micron are highly unusual. Such fine particles are almost entirely absent in normal soil-derived aerosols, typically constituting about 1 part in 5,000. This points to an unusual upwind source and raises additional concerns for human health, as sub-micron particles are highly respirable and penetrate more deeply into the lungs.

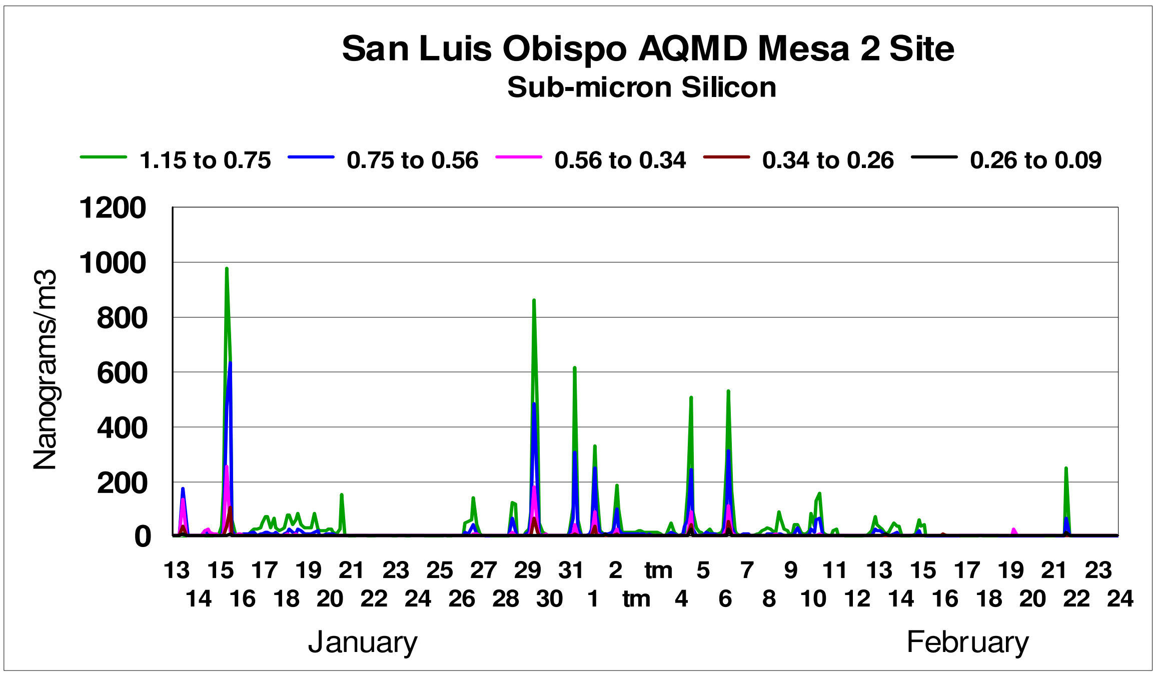


Figure EX 9 - Silicon in the submicron or highly respirable fraction, $PM_{1.0}$

In Summary, DRUM data from the Mesa2 winter 2008 period showed that in the dry period, particulate composition was about 90 % sand/soil and 10% sea salt. In the rainy periods, the soil/sand ratio dropped to about 75% soil/25% salt. Overall, the coarse fraction dominated the mass of samples, with a surprising finding of a small but significant mass of soil particles with sub-micron diameters. The coarse particles composition is consistent with sand.

Analysis of Spring Intensive DRUM data

The heart of the Phase 2 study design was to conduct and compare particulate measurements downwind from the SVRA to measurements downwind from a variety of control sites. The intensive monitoring portion of the study was designed to provide numerous DRUM sampler measurements across the study area to capture potential source impacts during a period of likely wind/particulate events.

Intensive sampling was performed in April and May, 2008, with an array of both 3 DRUM and 8 DRUM aerosol sampling sites from Grover Beach to Santa Barbara County (see Table EX.1 and

Figure EX.1). Note that samples from the 10 Commandments site are absent from these data because the 8 DRUM sampler used at this location failed the ± 15% equivalency in the side-by-side tests at Mesa 2. In addition, the Oso sampler failed due to battery/inverter problems after the 4/29 episode, and the Mesa2 sampler failed following the 4/30 episode due to electrical problems. As a result, the Oso data only is only represented in the 4/29 episode, and the Mesa2 data presented represents an average of the 4/29 and 4/30 episodes. Data from the APCD TEOM monitors show that 4/29 was the highest concentration episode, followed by 4/30, with 5/1 showing the lowest PM levels.

Figures EX.10, EX.11, and EX.12 below present these results. As shown in the first two charts, particulate levels in both the coarse and fine fractions were significantly higher at the sites downwind from the SVRA (CDF, Mesa 2 & ConocoPhilips) than the measurements taken downwind from the control sites where no vehicle activity is allowed. The third chart shows the high correlation between the PM concentrations measured at each site and the amount of open, disturbed sand upwind.

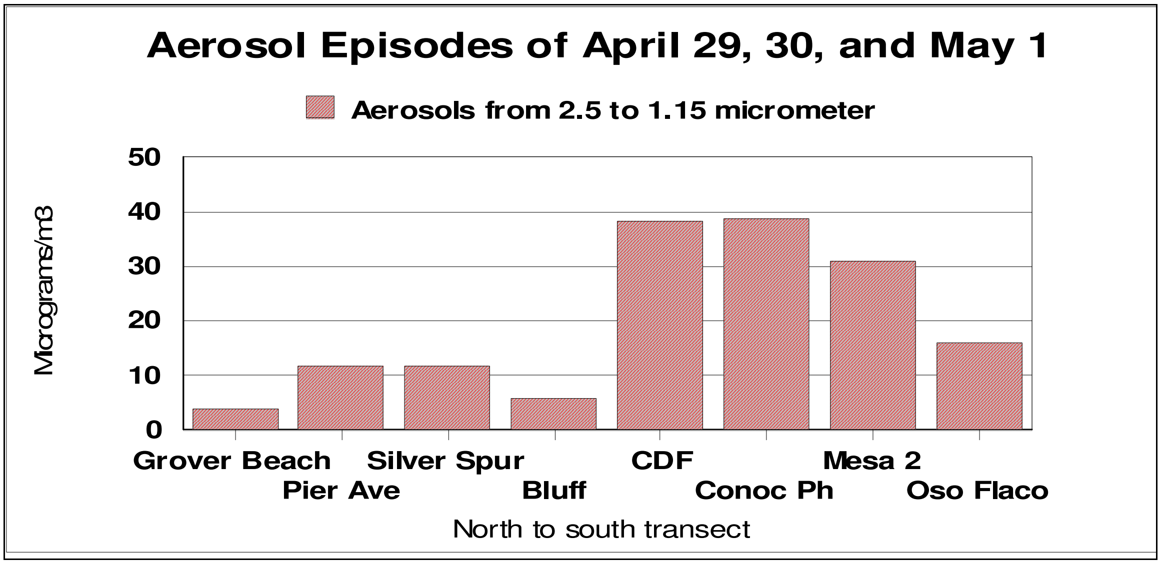


Figure EX 10 - Correlation between dust peaks and upwind disturbed sand

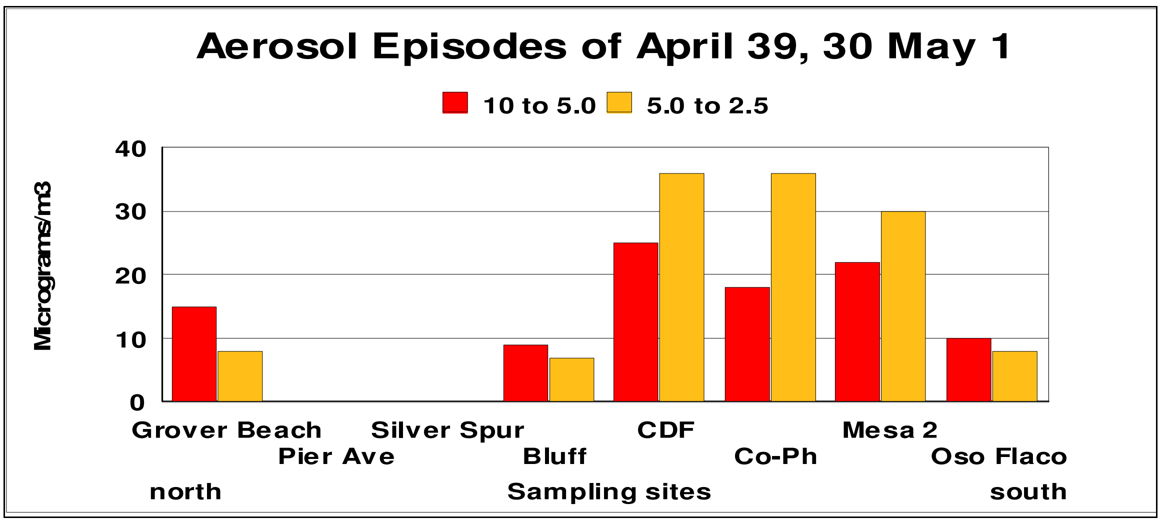


Figure EX 11- Correlation between dust peaks and upwind disturbed sand

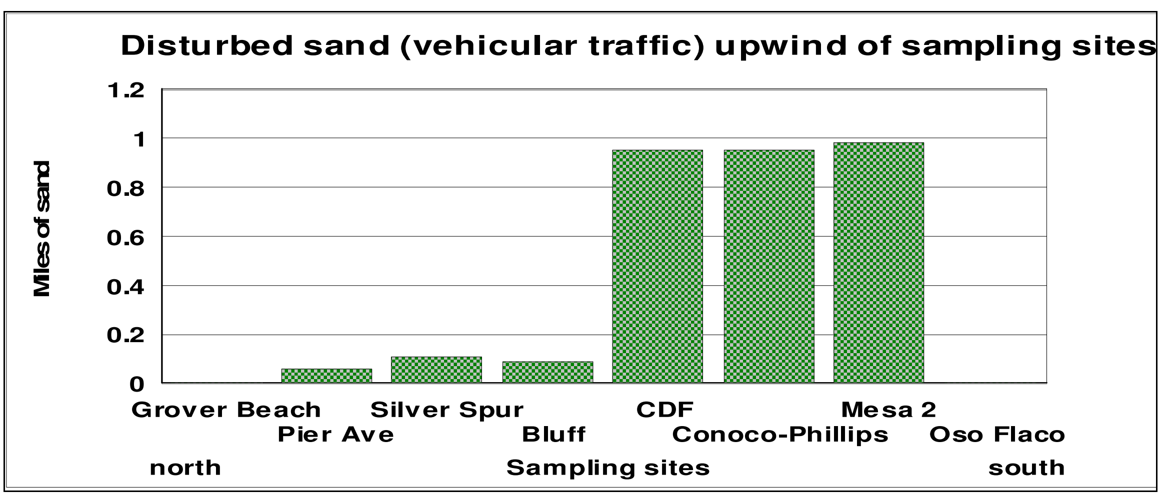


Figure EX 12- Correlation between dust peaks and upwind disturbed sand

Elemental analysis of the Grover Beach DRUM sampling for the spring intensive confirmed that, as expected, this site is subject to high concentrations of sea salt (likely dissolved in fog) and very little sand/soil particulate.

Elemental analysis of the Bluff intensive DRUM data reveals several differences between this site and the data collected at the Mesa 2 and CDF sites, including a higher sea salt impact at Bluff and an almost total absence of the relatively fine soils that characterize the Mesa 2 and CDF samples. The Bluff site does show an enhancement of calcium in the aerosol, possibly indicating some local clays, but this is a small component of the total mass. The total mass overall at the Bluff site was significantly less for the intensive period than the sites downwind from the SVRA.

The CDF silicon data from the spring intensive shows a similar pattern as the Mesa2 silicon data. Both sites show significant soil mass below one micron.

Analysis of Fall Mesa2/Dune Center Comparisons

After evaluating the early mass data, it was deemed important to add a long term sampling site at the Guadalupe Dune Center in Guadalupe. This was done because it was typically downwind of the relatively undisturbed dunes of the Santa Maria oil field, and its easy access allowed longer term sampling than could be performed at the very valuable, but labor intensive, Oso Flaco site. The Dune Center site is also about the same distance inland as Mesa2, which allows for good comparison between the two sites. (Figure EX.1)

Sampling began in early September and continued through late November, after which dust episodes tend to be less intense and rainfall is to be expected. Most wind/particle episodes occurred in September and October, with low concentrations measured at both sites from late October through November. Figure EX.13 below presents a comparison between the 5.0 to 0.75 micron mass at both sites for the period with most episodes. As shown in this chart, PM levels measured at Mesa 2 were substantially higher than those seen at the Dune Center site on all episode days.

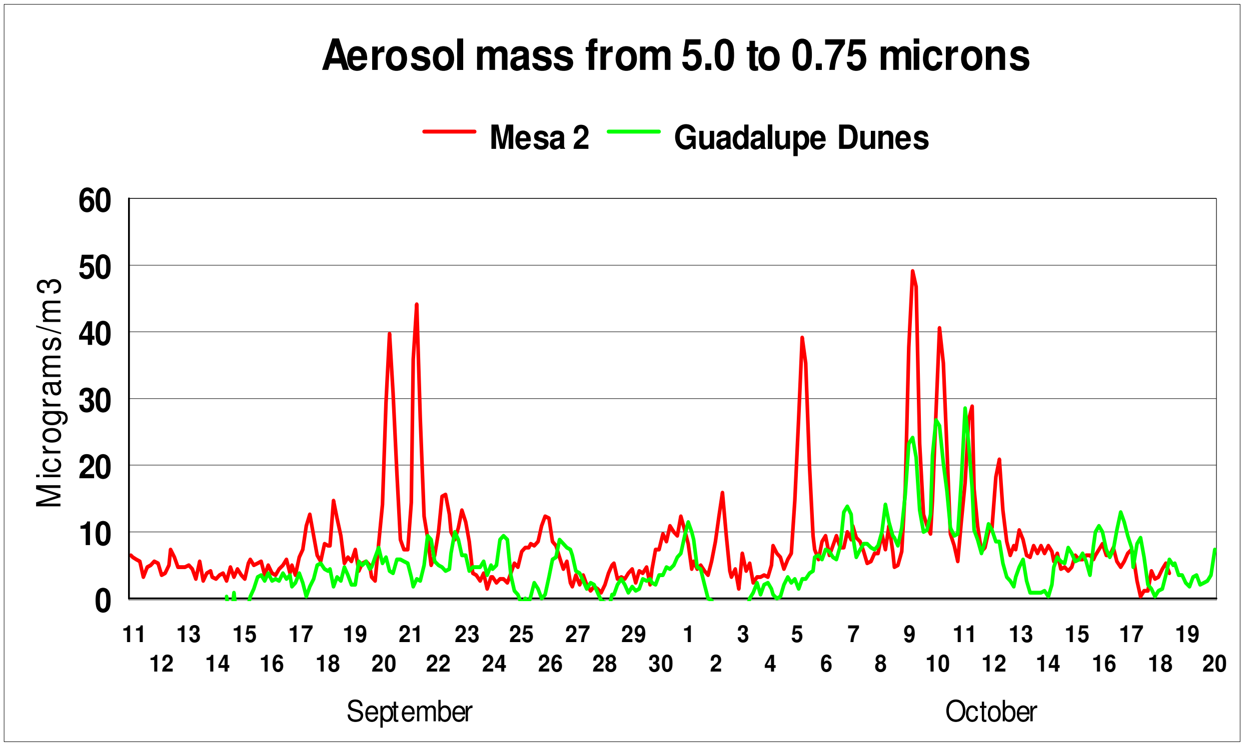


Figure EX 13 - Mesa 2 to Guadalupe Dunes comparison fall, 2008

Figure EX.14 below compares the amount of silicon mass, a soil tracer, found at Mesa2 to that measured at the Guadalupe Dune Center.

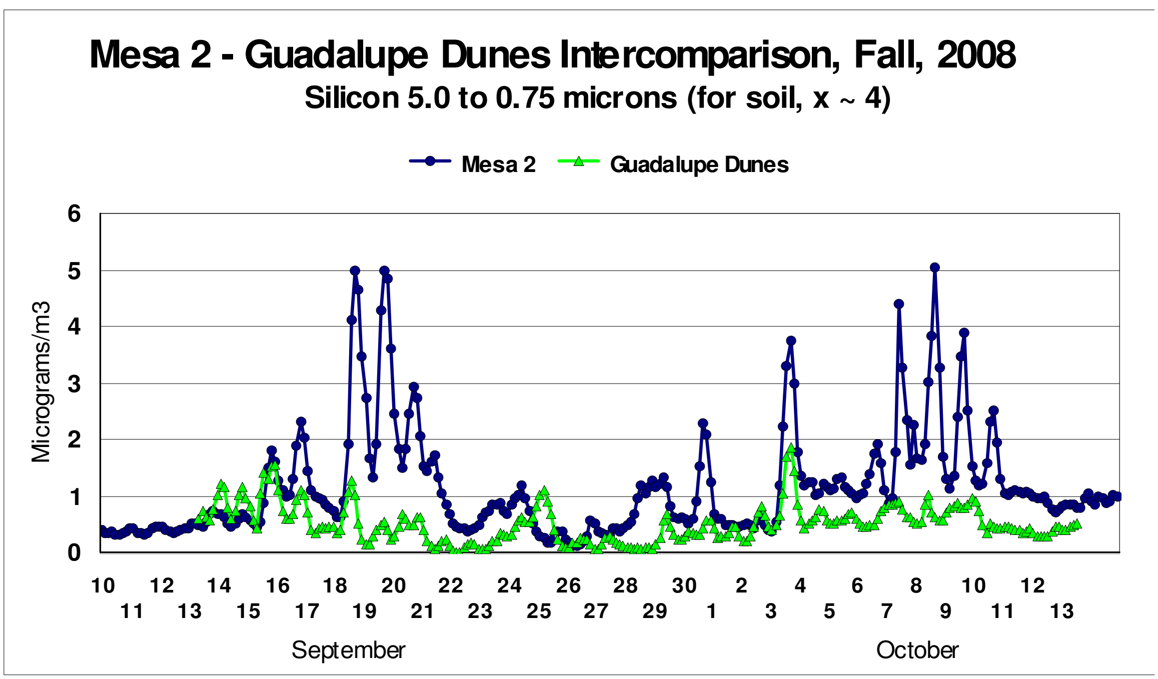


Figure EX 14 - Mesa2 to Guadalupe Dune Center Comparison for Silicon, 5-.75 microns

Analysis of chloride for both Mesa 2 and the Guadalupe Dune Center site showed significantly higher chloride concentrations at the Dune Center. This indicates the presence of higher sea salt levels at the Dune Center, which is likely due to the higher winds measured at the mouth of the Santa Maria Valley, and/or the slightly lower elevation of the Dune Center site compared to Mesa 2.

In summary, the Guadalupe Dunes – Mesa 2 summer-fall comparison strongly supports the results of the Spring Intensive, showing that sites with undisturbed sands upwind have far less dust than those sites downwind of disturbed soils.

Analysis of Soils and Ambient Aerosols Near the ConocoPhillips Petroleum Coke Piles

Many of the tools used by the Delta group for the Phase 2 study also give information on the potential impact of the ConocoPhillips coke pile on PM_{10} dust at Mesa 2. Heavy oils in California and elsewhere contain sulfur, vanadium and nickel. The latter two in the coarse aerosol modes are robust tracers of coke materials; in the fine modes, they are good indicators of heavy oil combustion.

As shown in Figure EX.15 below, analysis of soil samples taken along the entire transect from Mesa 2 to ConocoPhillips shows some enrichment of vanadium over the typical earth crustal average, with the amount growing by a factor of 70% as one approaches the edge of the petroleum coke pile. There is even some modest enrichment of vanadium in the soil at sites generally upwind of the ConocoPhillips facility. No consistent vanadium enrichment is seen in soil samples from either the Oso Flaco or Bluff transects.

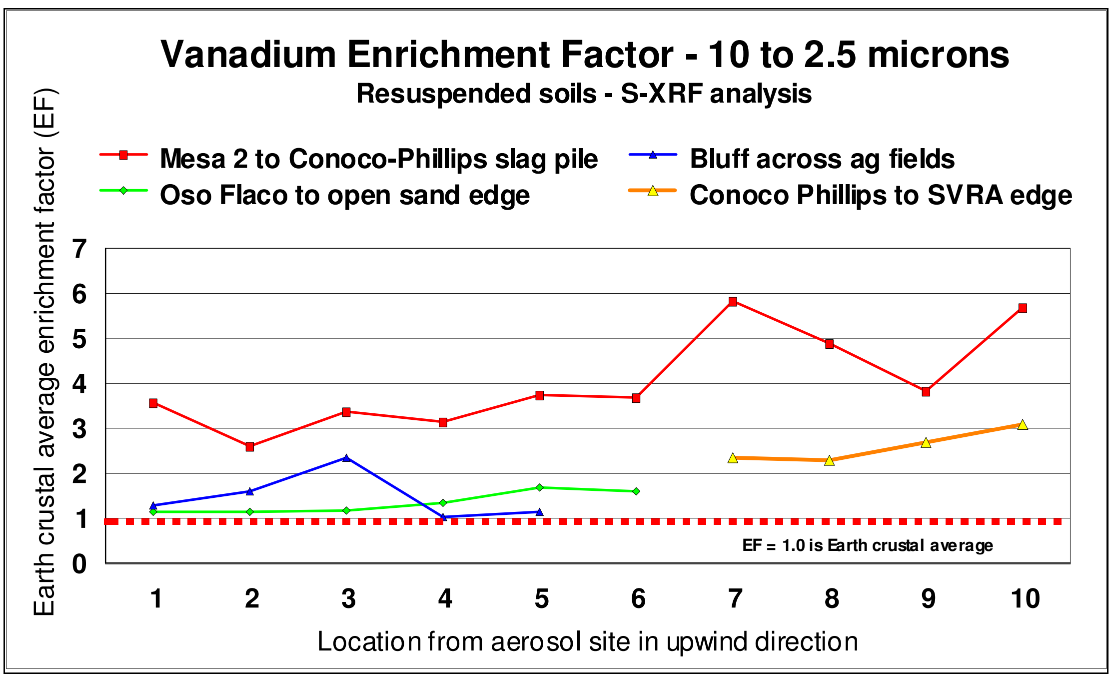


Figure EX 15 – Vanadium Enrichment Factor in Soil Samples

Finding above background levels of vanadium in soils within the vicinity of the petroleum coke piles is not surprising considering the many decades of petroleum coke storage and processing in this area. While this data demonstrates past historical deposition of petroleum derived particles, it does not demonstrate where the particles originated (entrained by the wind or from combustion processes in the refinery), nor the relative contribution of these particles to the elevated ambient PM concentrations measured on the Mesa.

The DRUM aerosol data at the Mesa 2 site does show minor traces of vanadium, nickel, and sulfur, but the levels are negligible relative to the overall PM_{10} mass. Figure EX.16 below plots concentrations of very fine (0.34 to 0.26 µm diameter) vanadium, nickel, and sulfur found in the Mesa 2 samples (note the units are in nanograms rather than micrograms). The strong association of vanadium and nickel, and the support of fine sulfur particles, is a signature of operations using heavy crude oil. The levels of these materials, however, are less than 0.001 µg/m^3, versus overall PM_{10} mass levels that range from the 10s to 100s of µg/m^3.

Analysis of Mesa2 and Dune Center DRUM data from the Fall of 2008 show that vanadium concentrations measured at Mesa2 are 2.5 times higher overall than those measured at the Dune Center site. However, most of the vanadium measured at Mesa2 in the fall period was in the fine particle fraction, similar to what is seen in Figure EX.16. This indicates the source of this trace amount of vanadium is not the coke piles; rather, it likely originates from a combustion process using heavy oil as fuel.

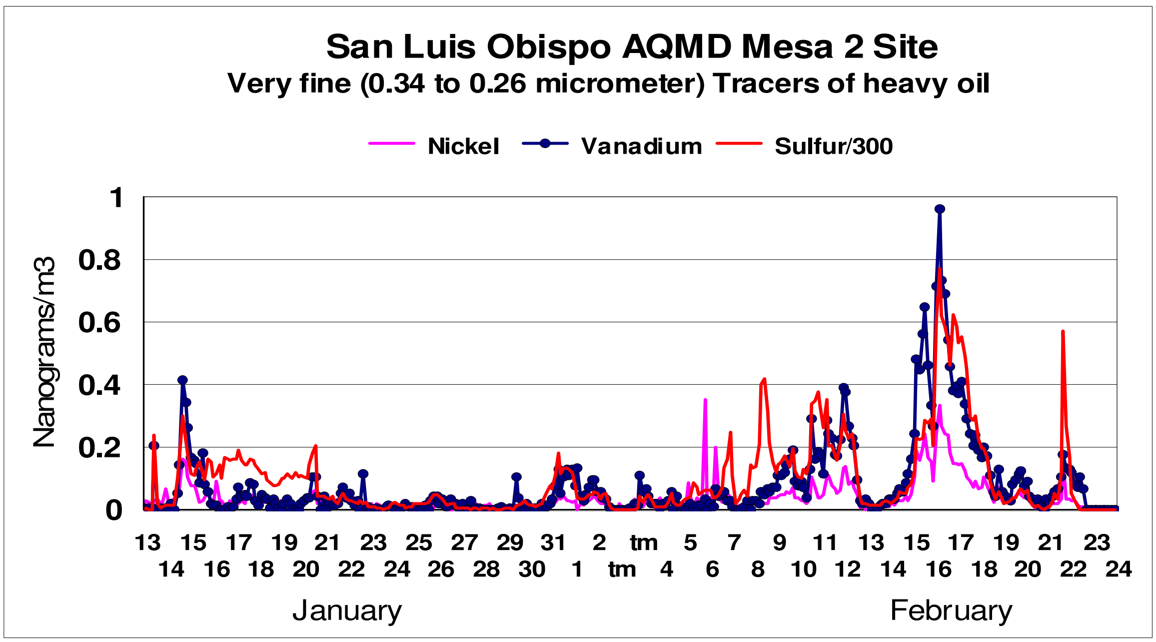


Figure EX 16 – Very Fine Tracers of Heavy Crude Oil

Part 1: Evaluation of potential sources of aerosols.

Two factors are vital in the evaluation of potential aerosol sources:

1. The friability and particle size profiles of the materials, which provides an estimate of the nature of the materials that might be suspended into the ambient atmosphere; and
2. The wind shear present on the materials: a combination of the strength of the wind and the ground level, the friction velocity and momentum transfer, modulated by the parameter z_o that gives the effective wind profile as it approaches the ground. (Seinfeld and Pandis, 1997, pg 873)

Thus a highly friable soil under a vegetative cover that effectively reduces the wind velocity to zero at and just above the ground will not be emitted into the atmosphere, while a less friable soil exposed to the full wind velocity will be resuspended.

The nature of the sources of the materials and the mode of resuspension can be further clarified by classification of source type and mechanisms. Since airborne dust comes from a variety of sources, it helps to break them into categories. Each category has its own characteristics that allow source identification.

Table C 1 - Characterization of ambient dust sources

Materials		**Mechanisms: Wind**	**Mechanisms: Man's activities**
Natural – unmodified by humans		[1] Natural background	[2] Resuspended dust
Man made – tailing piles, dirt roads		[3] Fugitive dust	[4] Primary pollutant emissions

Categories 1 and 4 are the easiest to identify, but the second and third are the most important.

The first, **natural background** represents unmodified soil surfaces eroded by natural winds. Since soils over time protect themselves with physical and biological crusts, vegetation, and the like, these dusts are usually low in concentration except in high wind events (Saharan dust storms, some Chinese storms). Exceptions may occur for dry lake playas and vegetative free beach zones.

The fourth, **primary pollutant emissions** are also easy to identify as both the particle size and composition are different from natural dusts. In many cases, the source itself is known – a tall stack, a cement plant, and in this case, vehicles and the ConocoPhillips refinery.

The second, **resuspended dust**, represents a natural material that has been raised into the air by human activity. Cars on dirt roads, construction activities, and farming operations all are major sources of this material. Chemically, it may represent the same material as natural background, but in the course of human operations, there may be a modification in particle size as well as lack of correlation to wind velocity. In addition, a farm field stripped of vegetation that can then be picked up by natural winds falls into this category, since chemically the materials are still soil, as in the 1930's dust bowl.

The third, **fugitive dust,** would be represented by a human created material capable of being picked up and transported by natural winds. Industrial tailing piles are a prime example, and these materials are chemically different from the soils. Cattle feed lots fall into both categories – cattle can raise dust, resuspended, and the area is also subject to fugitive dust rich on organics, etc., absent in natural soils. Roadway dusts are also polluted with metals from brakes and other parts of cars. Thus, compositional analysis aids in their identification. In our case, the ConocoPhillips petroleum coke piles are potential sources of fugitive dust.

Probably the most important diagnostic tool for the Phase 2 study was the ability to deploy aerosol samplers on a north to south transect allowing source identification of aerosol episodes. Continuous highly time resolved aerosol sampling allows us to follow episodes on a 3 hr time resolution that allows close correlation with on site meteorology.

Each of the aerosol samplers were placed at the sites shown on the reference map in Figure 5.1, below. The upwind soils and terrain along the trajectory of episode winds (WNW) are described below for each site using the following soil and terrain descriptors and abbreviations:

a.	Sand – disturbed (vehicles)	S D
b.	Sand – non disturbed	S ND
c.	Vegetation	Veg
d.	Farm lands	Farm

The nomenclature used in the site descriptions below identifies the distance in miles from the wetted soil's edge (where ocean meets sand) to each of the soil/ terrain features listed above. For example, the abbreviated soil/terrain descriptors used for the Grover Beach site below mean that the transect between the ocean and the site contained the following features:

- An area of non-disturbed sand along the transect, located 0.14 miles from the ocean edge (S - ND 0.14)
- No vehicle-disturbed sand along the transect (S – D 0.00)
- A vegetated area along the transect, located 0.13 miles from the ocean edge (Veg 0.13)
- No farm land along the transect (Farm 0.00)

The following describes each site location and the soil and terrain features along the transect between the ocean and the site:

1. Grover Beach DELTA 8 DRUM
   S - ND 0.14 S – D 0.00 Veg 0.13 Farm 0.00
   The sampler was close to the ocean behind modest dunes in an area with no vehicular traffic on the sand. As such, it should respond primarily to oceanic aerosols with a sea salt signature.

2. Pier Avenue DELTA 3 DRUM

S - ND 0.09 S – D 0.00 road ? Building 0.13 Veg 0.00 Farm 0.00

The sampler was a few blocks from the shore at a point that vehicles traveled down a typical sand impact street. Beach travel was constrained to travel near the wetted area in transit to the main SVRA zones further south.

3. Silver Spur DELTA 3 DRUM

S - D 0.11 Veg 0.17 S – ND 0.35 Veg 0.18 Farm 0.00

The Silver Spur sampler was placed behind the beach dunes in an area, like Pier Avenue, merely used for vehicles to transit to the main SVRA. It was also in line with a transect to the bluff sampler and upwind of the farm fields.

4. Bluff site DELTA 8 DRUM and DELTA 3 DRUM

S – D 0.09 Veg 0.27 S – ND 0.31 Veg 1.00 Farm 0.52 Veg 0.12

The Bluff site was chosen with strong State Park personnel support in order to evaluate the effect of dust from the extensive (and intensive) farming operations between the Silver Spur and Bluff sites.

5. CDF site DELTA 8 DRUM

S - D 0.95 S – ND 0.70 Veg 0.87 Farm 0.00

The CDF site was also used in the Phase 1 study, and lies downwind of the northern reaches of the active SVRA area.

6. ConocoPhillips DELTA 8 DRUM

S – D 0.95 S – ND 0.64 Veg 0.51 Farm 0.00

The ConocoPhillips site was directly downwind of the most heavily used portion of the SVRA and directly upwind of the ConocoPhillips refinery. It was almost the same distance from the SVRA as the CDF site.

7. Mesa 2 DELTA 8 DRUM

S - D 0.98 Veg 1.22 C.- P. (petroleum coke) 0.65 Veg 1.48 Farm 0.00

This is the key long term monitoring site for the region and the site of the side-by-side quality assurance tests for all units before dispersal to the sites. It was in line to gather aerosols from upwind SVRA areas, the ConocoPhillips refinery operations, and the petroleum coke piles. It benefits from comparisons with the ConocoPhillips site

8. Oso Flaco DELTA 8 DRUM

S – ND 0.07 S – ND 1.00 Veg 0.41 Farm 0.00

This is a key "control site" to compare to CDF, selected in close consultation with State Parks personnel, as the site lies downwind of an extensive sand sheet that has not had vehicular traffic since the 1980's.

Figure C 1 - Aerosol sampling sites with prevailing wind direction in aerosol episodes

9. Guadalupe Dunes (Dune Center) DELTA 8 DRUM

S – ND 0.70 Veg 2.7 Farm 0.30

This is another key "control site" to compare to Mesa 2 used in the summer-fall extension, selected as it lies downwind of an area of undisturbed vegetation in the Santa Maria oil field.

10. 10 Commandments DELTA 8 DRUM

S – ND 0.58 Veg 0.00 Farm 0.00

This site was different in several ways from all other sites, and thus is not part of the north south transect. It is the only DRUM site directly located on an active sand sheet with no barrier vegetation. It is far south of other sites and was chosen because it lies directly downwind of an area previously heavily disturbed by vehicles (and the set of "The 10 Commandments" movie). It is at a higher elevation than other sites and, lying on the northern shoulder of the coastal mountain, should be subject to higher wind velocities. The site had no local meteorological measurements. Presently it is protected because it is a site for plover nesting, however, and because of the plover constraints, no upwind sand profiles were taken.

While only estimates can be made of the wind profiles at the vegetated sites, we can use values developed in the extensive studies of Owens (dry) lake by Dale Gillette and co-workers for sites without vegetation. In the latter cases, the z_o parameters was often less than 1 cm, while in the typical coastal scrub with a height 1.5 m, one estimates a z_o of at least 15 cm. Thus, bare sand will have an order of magnitude greater likelihood of resuspension than equally friable soils under vegetation.

Figure C 2 - Upwind of the Oso Flaco site at the transition between dune sands and vegetation.

A second factor involves ephemeral soil crusts, a key factor at Owens and Mono Lake. Direct observations of the sand at Oso Flaco showed that such a crust existed, about ½ to 1 cm thick, capable of supporting itself over a few cm but friable under any pressure such as boots. Such crusts greatly suppress particle emission by gluing small particles into larger ones and suppressing saltation processes that can occur when the crust breaks up. There is almost no dust emitted into the air on Owens (dry) Lake, even in strong winds, until the robust salt crust formed every winter in rains breaks up. (Reid at al, 1994)

Figure C 3 - Sand crust at the eastern edge of the sand sheet upwind of Oso Flaco.

Figure C 4 - Sand moving in a thin layer over a surface crust at Oso Flaco

Below we will develop considerable information on the nature of the potential soil sources, but the actual dust emissions must include all the factors mentioned above.

Analysis of Sands

Summary of Sand Flux Measurements

Sand Flux measurements were made in both the SVRA and the Oso Flaco control area sites. In addition, basic sand flux measurements were performed just upwind from the long term ambient monitoring stations. Table 2 below presents the equipment used and measurements performed. Figure 10 presents the location of each sampling location.

A variety of instruments were utilized to accomplish the sand flux measurements, as listed below:

- Sensit™ Real time sand flux monitor. These sensors, used with Campbell Scientific data loggers, provide a time series record of particle movement at 15 cm above the sand/soil surface as well as the kinetic energy of the particle movement.
- Cox Sand Catchers. These sensors collect the mass of particles moving at 15 cm above the sand/soil surface.
- BSNE Sand Catchers. These sensors collect the mass of particles moving at 10,15,25,63.5, and 100 cm above the sand/soil surface. Data from the BSNE sand catchers provide a vertical profile of the sand flux.

Table C 2 – Equipment and Measurements for sand studies

Instrument Type	No. of Instruments	Site Location Designator *(see figure 2)*
Sensit™	3	C1,C2,C12
BSNE Sand Catcher	2	C1,C2
Cox Sand Catcher	18	C1-C18
Surface sand collections	150	See Figure 5

Great Basin Unified APCD staff was responsible for the operation of the sand flux measurements. Great Basin Unified APCD has provided most of the equipment and trained the California Air resources Board staff on set-up and operation of the equipment. The Delta Group provided the BSNE sand towers and assisted with their installation and operation.

Collection of sand samples

The DELTA Group and UTEP collected over 150 sand samples over every transect from sampler to the ocean (except Ten Commandments), with photographs taken at every sampling site. (Appendix F). The samples were placed into coded Ziplock™ bags and transported to UC Davis. The samples were sieved in standard dry geological sieves, and then divided into bags, of which roughly 60 were sent to U. Texas El Paso for Malvern particle sizing.

Sieving and triages of sand samples

From the results of the sieving, a selection of the samples with relatively high mass in the < 50 µm bin were resuspended in an air jet at UC Davis and collected onto the stages of an 8 DRUM impactor, the same instrument used to collect aerosols in the ambient sampling phase of the study. These were subject to analyses for mass and elemental composition in the S-XRF run in Berkley in October.

In summary:

- Sand samples collected: 150, UTEP
- Samples sieved: 150 (425, 212, 106, 75, 56 µm), UC Davis,
- Malvern Analyses: 60, UTEP
- Re-suspension analysis of the 56 µm sieved mode: 30 to 50, UC Davis
    - Mass
    - Elemental composition

The last set of re-suspended samples was analyzed by the Lawrence Berkley National Laboratories for elemental composition in October, 2009, but the results were not returned until late December 2009.

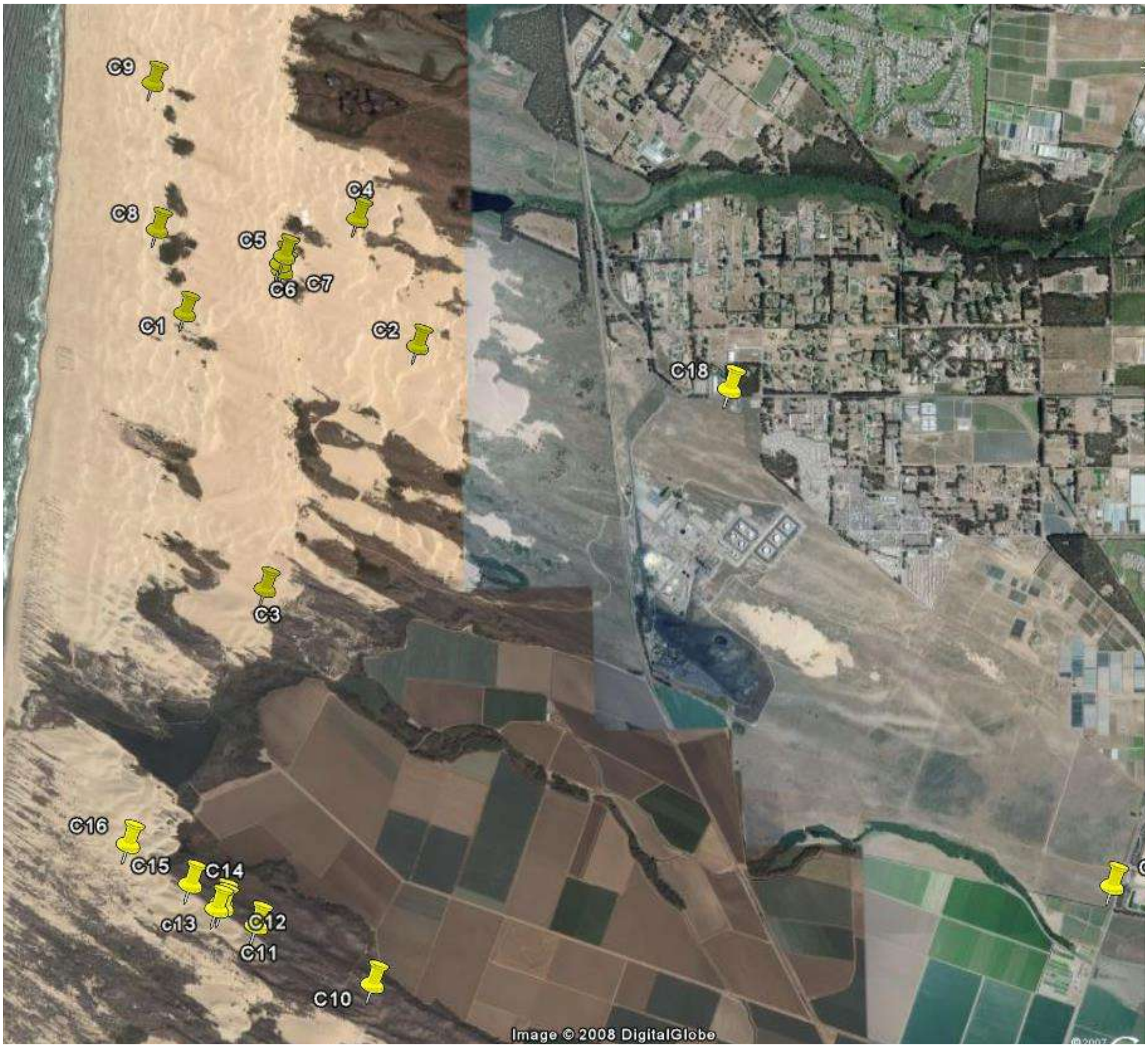


Figure C 5 – Sand Flux Measurements

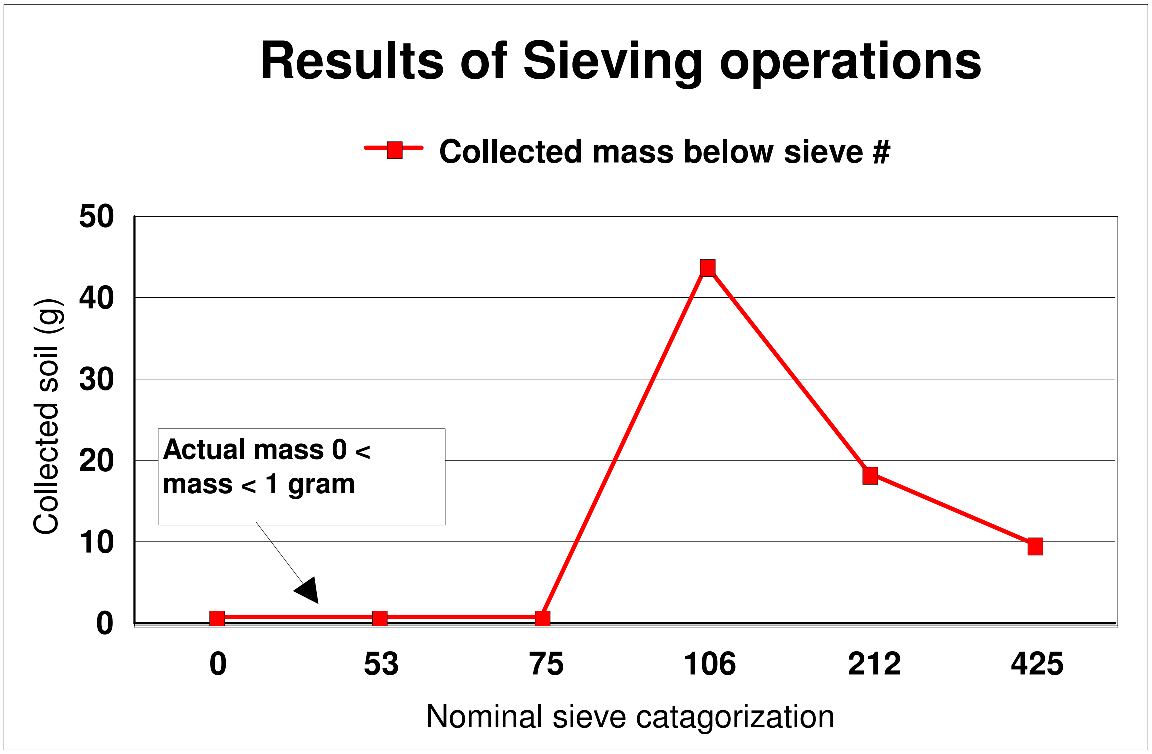


Figure C 6 - Results of sand sieving – one of circa 150 samples

Sand size profiles by Malvern

The Malvern particle analyzer at the Geology Department, University of Texas, El Paso, has the capability to analyze an extremely wide range of particles sizes simultaneously using either a dry or wet (dispersed into water) protocol.

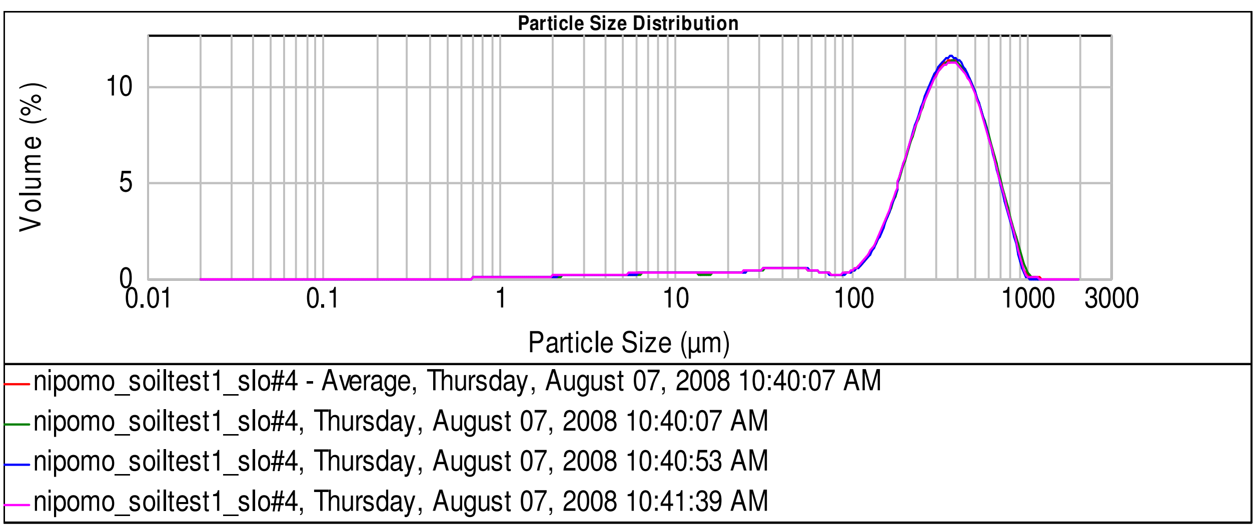


Figure C 7 - Example of a Malvern analysis

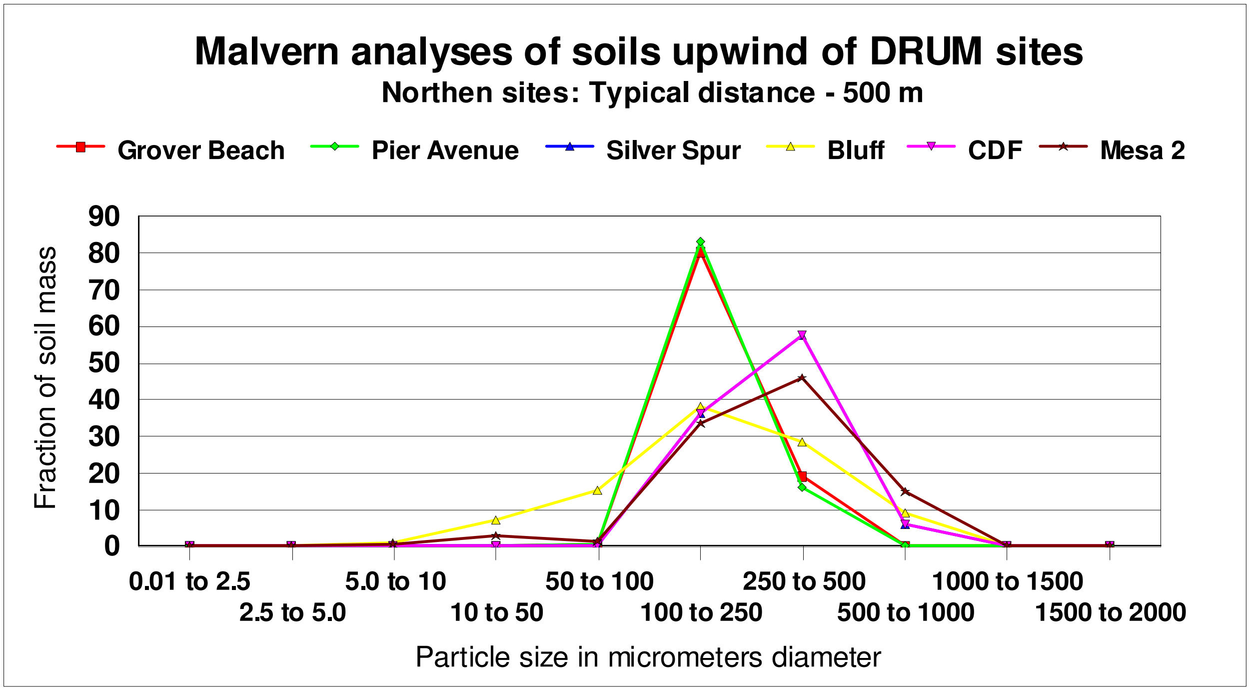


Figure C 8 - Malvern analyses of soils from sites upwind of the northern DRUM sampling sites

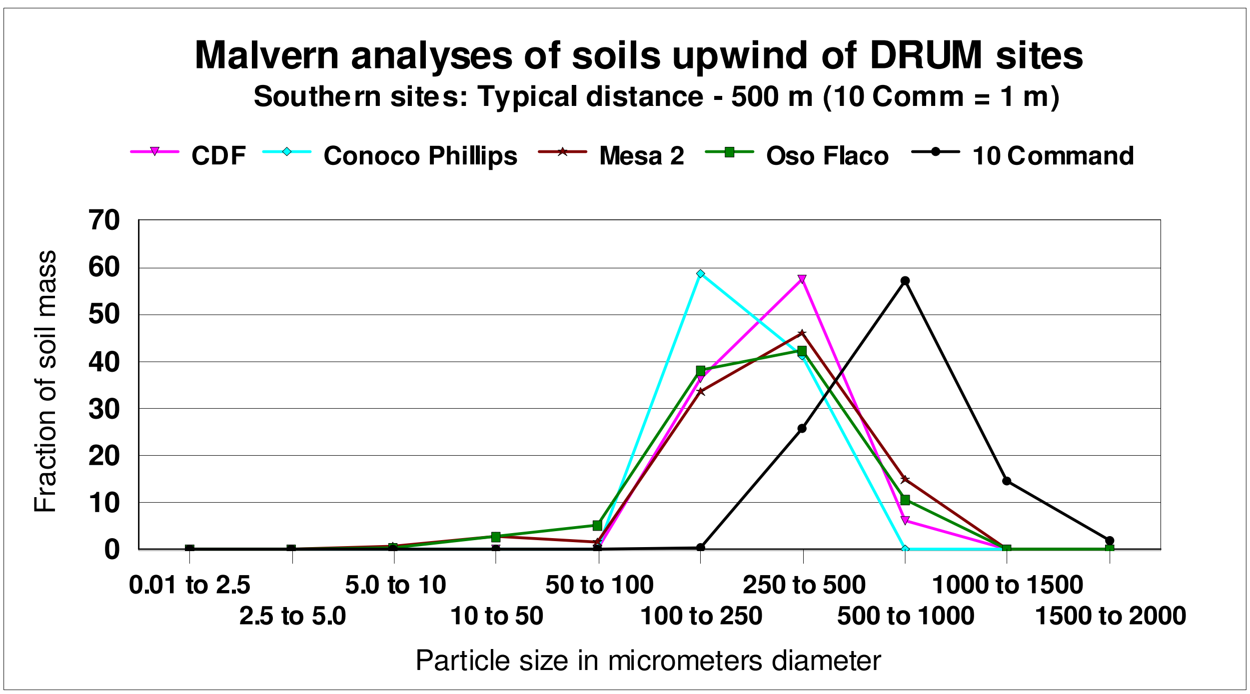


Figure C 9 - Malvern analyses of soils from sites upwind of the southern DRM sampling sites

What is notable in these analyses is the very small amount of mass in the < 10 µm size mode. Yet, abundant aerosols are seen in such size modes. The sand samples on the transect upwind from Mesa 2, however, did show some PM_{10} mass.

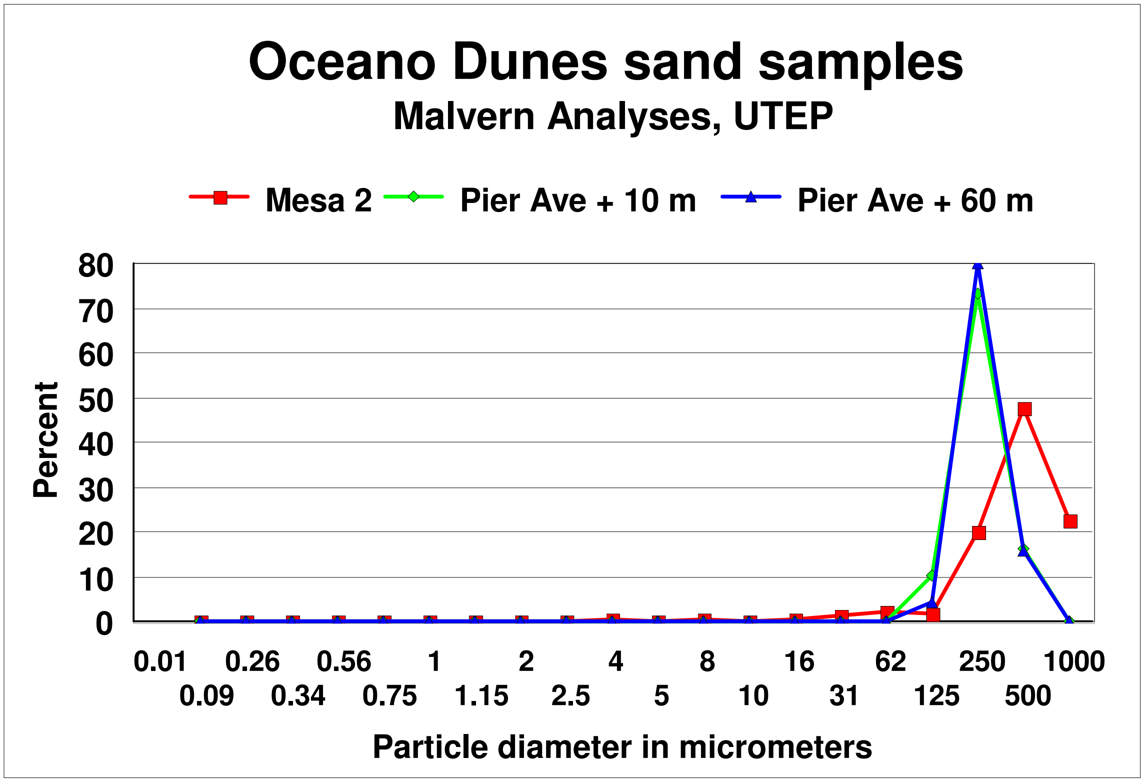


Figure C 10 - PM Mass in Soils

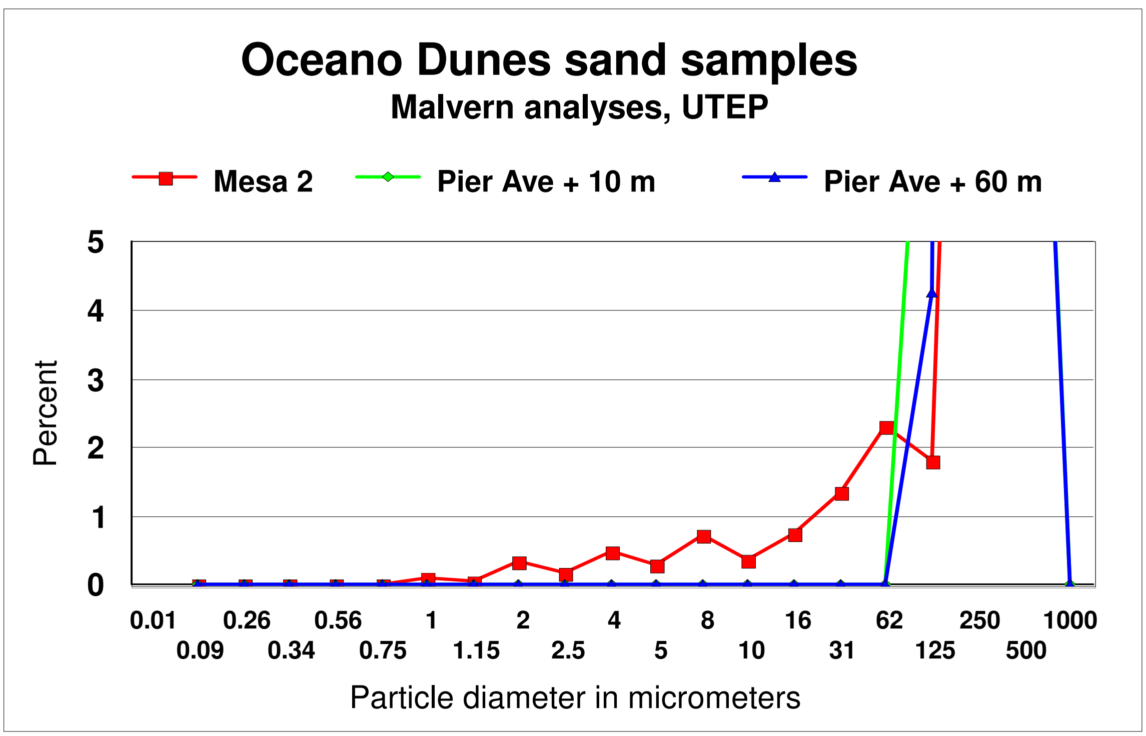


Figure C 11- PM Mass in Soils

Figures 10 and 11 above: Pier Avenue and Mesa 2, showing some PM_{10} mass in soils near the sampling site, with a sub-10 µm component at Mesa 2. However, these samples were taken between tall bushes and had greatly reduced wind sheer.

The transect samples from Mesa 2, CDF, and ConocoPhillips stopped at the edge of the vegetation. In addition to these transect samples, sand samples were collected using the same protocol within the Oceano Dunes SVRA. These results were obtained by running approximately 10-15 g of sample dry through the Malvern Mastersizer. Two sub-samples were taken from each bagged sample, and three replicate readings were made from each sub-sample, with those results averaged. The graphs presented below show the averaged results from the two sub-samples from each bag of sediment.

Below we show the data moving NW from the BSNE site distances of 200m, 600m, 1,000 m, 1,400 m, and 1,800 m.

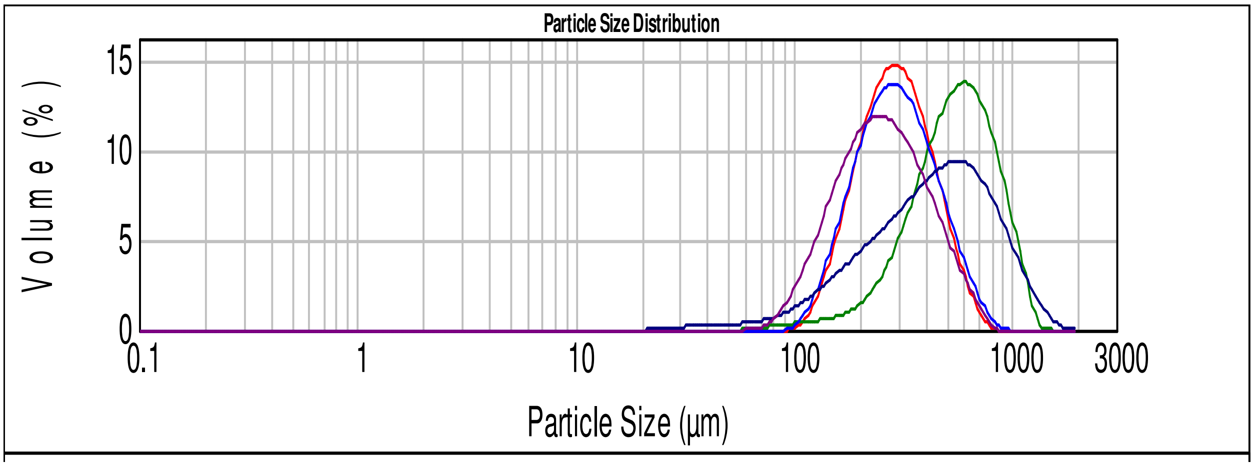


Figure C 12-Malvern analysis of sands within the Oceano Dunes SVRA

Figure 12 - Malvern analysis of sands within the Oceano Dunes SVRA at distances of 200m,(red) 600m (green), 1,000 m (blue), 1,400 m (grey) and , and 1,800 (purple).NW (towards the ocean) from the BSNE site (Site C2 on Figure 1) at the Sand Highway. The samples taken within the SVRA at 1,400m and 1,800 m show somewhat finer sand than other sites within or downwind of the SVRA. (The same order of colors is used on all plots)

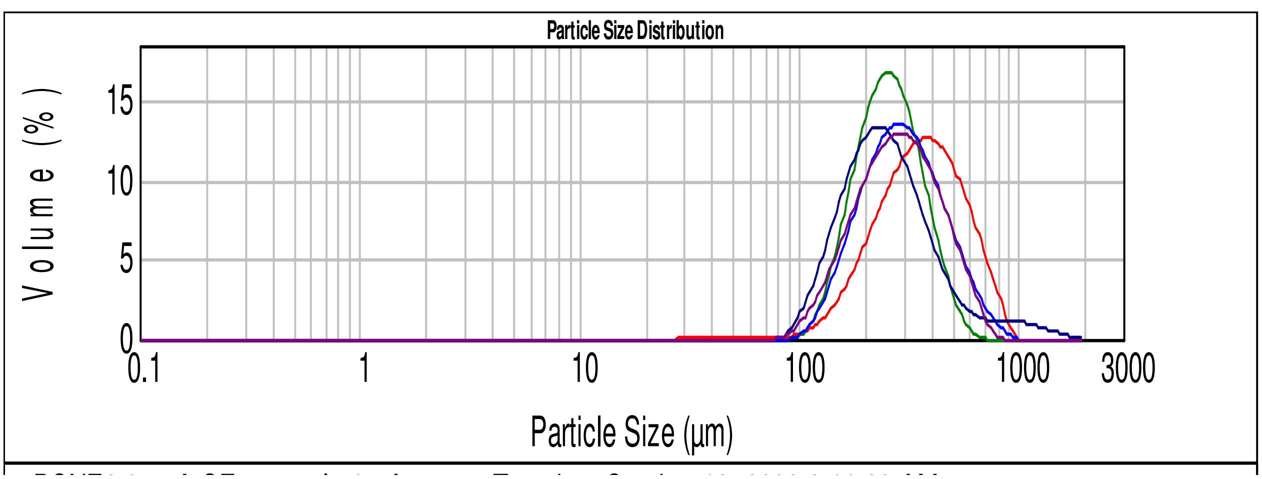


Figure C 13 - Malvern analysis of sands within the Oceano Dunes SVRA at distances of 0 (red), 150 (green) , 200 (blue) , 400 (grey), and 564 m (purple) SE (towards Mesa 2) from the BSNE site at the Sand Highway.

We note that the sands NW of the Sand Highway had a larger component of fine soil particles than those SE of the Sand Highway, moving inland into undisturbed sand.

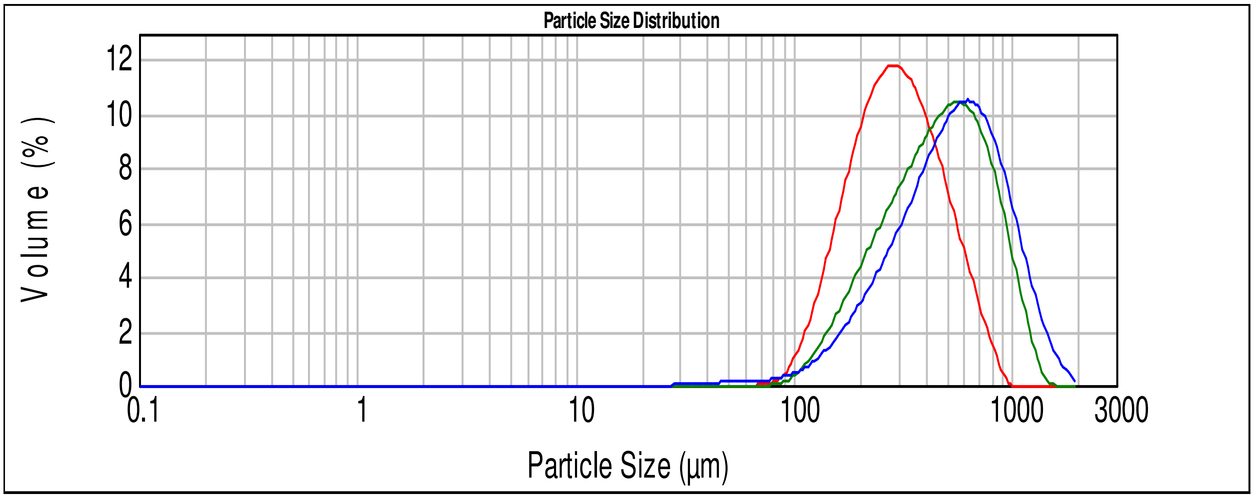


Figure C 14 - Malvern analysis of sands between Mesa 2 and the Oceano Dunes SVRA at distances of 200m (red), 400 m (green), and 600m (blue).

Resuspension and elemental composition

S-XRF analysis was performed on the Apiezon-L grease coated DRUM stages identical to those used in the aerosol sampling. Two such sample sets were made, each consisting of 8 DRUM stages from inlet to 0.09 µm diameter. The upper cut point was achieved by having the DRUM mounted upside down and making the upward air flow velocity roughly equal to the settling velocity of a 10 µm particle. The two sets of data are presented:

- Re-suspension 1 (17 samples, Oso Flaco, Bluff, ConocoPhillips upwind, and road side samples)
- Re-suspension 2 (16 samples, from Mesa 2 to the petroleum coke pile and Mesa SE in the SVRA).

Table C 3 - Samples selected for soil re-suspension and S-XRF analysis

#	Re-suspension Set #1		#	Re-suspension set #2
1	087D 30m Oso Flaco 2C		1	014D 0m Mesa 1B
2	089 D 100m Oso Flaco 3B		2	17D 200m Mesa B
3	095D 300m Oso flaco 5B		3	019D 400m Mesa
4	101D 575m Oso Flaco 7B		4	022D 800m Mesa B
5	103D 800m Oso Flaco 8A sand		5	025D 1.20km Mesa
6	105D 1200m Oso Flaco 10A sand		6	028D 1.60km Mesa A
7	153D Oso Flaco Road off Hwy 1		7	033D 2.0 km Mesa
8	152D parking lot		8	034D 2.26km Mesa A
9	154D Bluff 245m 1A		9	035D 2.26km Mesa B
10	155D 250m Bluff 2A		10	036D 2.36km Mesa
11	157D 740m Bluff 2A agriculture		11	115D 200m Mesa SE S1
12	159D 2.83km Bluff 4A agriculture		12	116D 400m Mesa SE S1
13	158D 1.65km Bluff		13	117D 600m Mesa SE S1
14	078D 0m Conoco upwind A		14	118D 767m Mesa SE S1
15	079D 200m Conoco upwind A			- note: very little sample to work with for 118D
16	080D 400m Conoco upwind		15	119D 800m Mesa SE S1
17	081D 585m Conoco upwind			- note: little sample to work with for 119D

Figure 15 below shows examples of the data for silicon, the major soil elements, for the Resuspension 1 sample set.

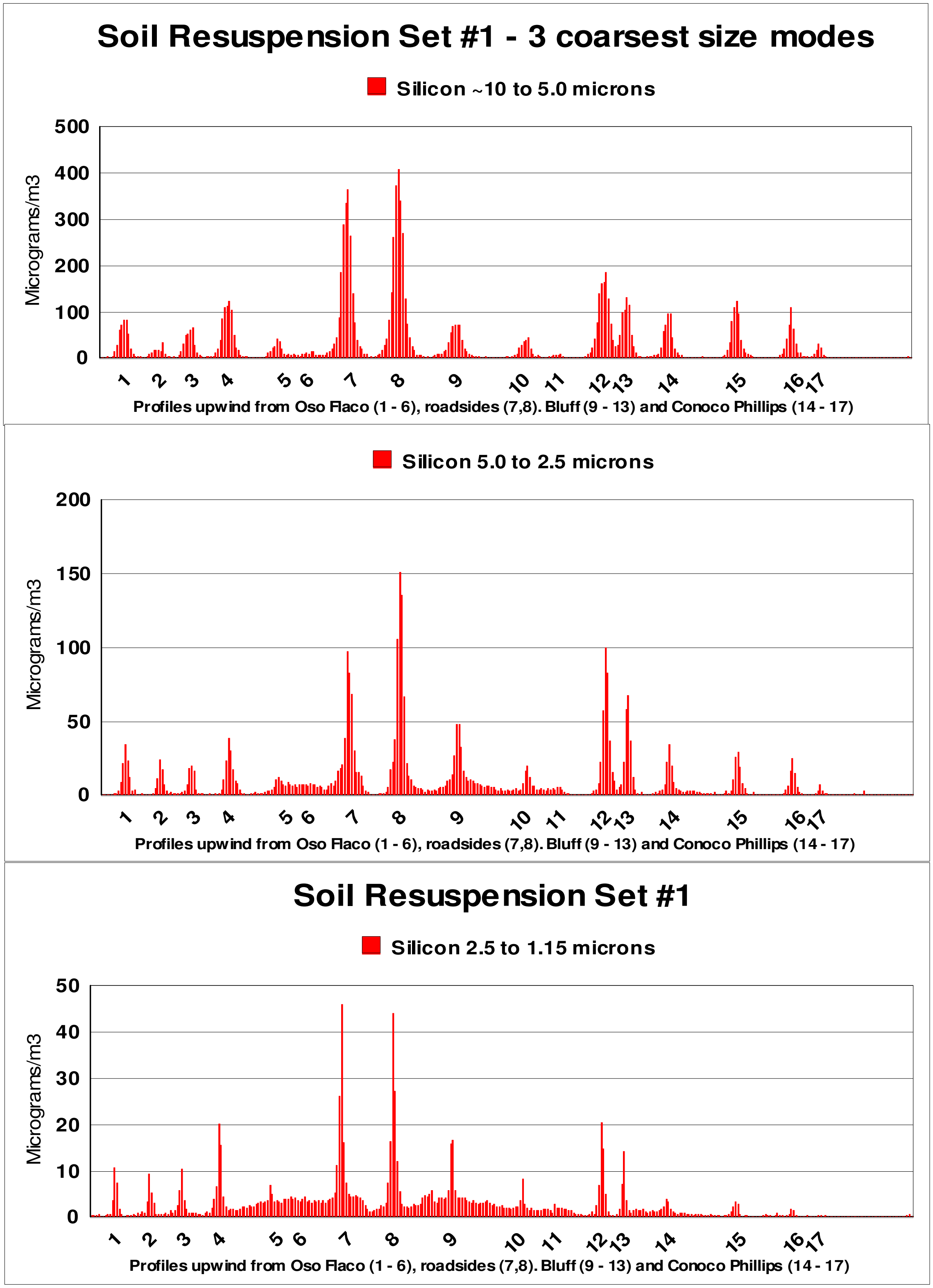


Figure C 15 - Example of soil resuspension data for the three coarsest size mode particles that dominate PM10 mass. Peaks are integrated and background on either side is subtracted.

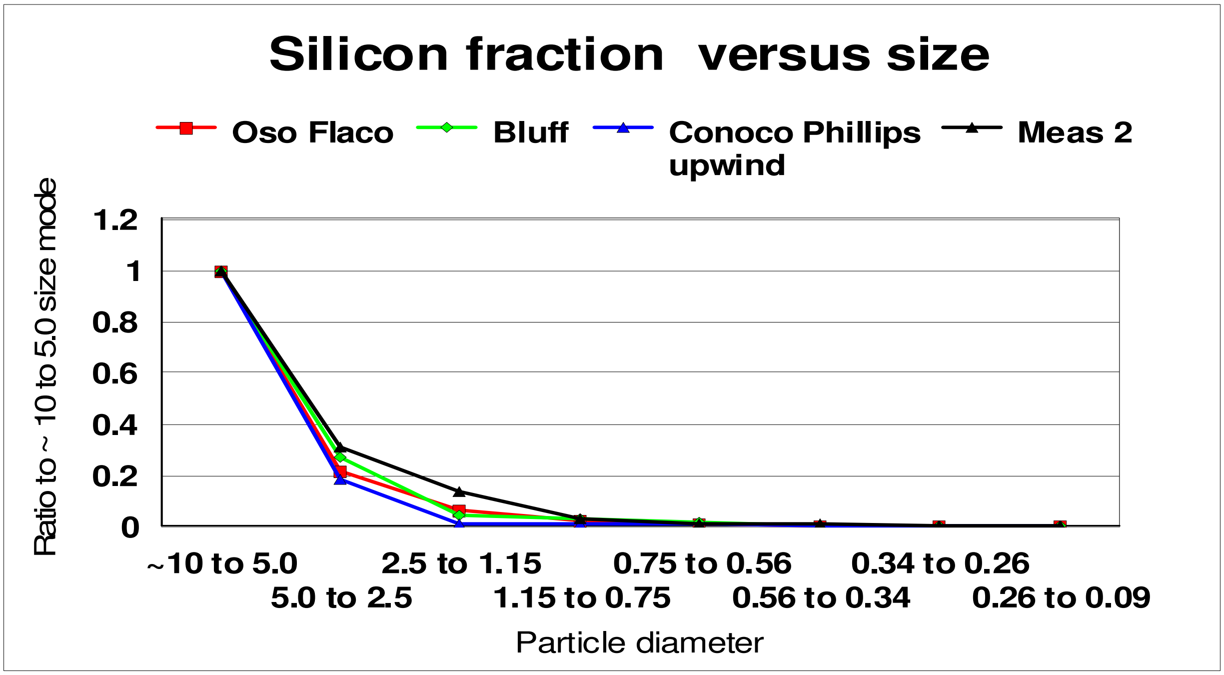


Figure C 16 - Size profiles of sand transect data relative to the 10 to 5.0 µm mode

The size profiles show that, as expected from the mass data, the coarsest size particles dominate the soil resuspended mass at all sites. Note that no major differences are seen even though the soils involved appeared quite variable. The re-suspension technique is especially suitable for seeing the smallest particles that can be separated by the low velocity air flow through the sample, mimicking natural wind re-suspension processes.

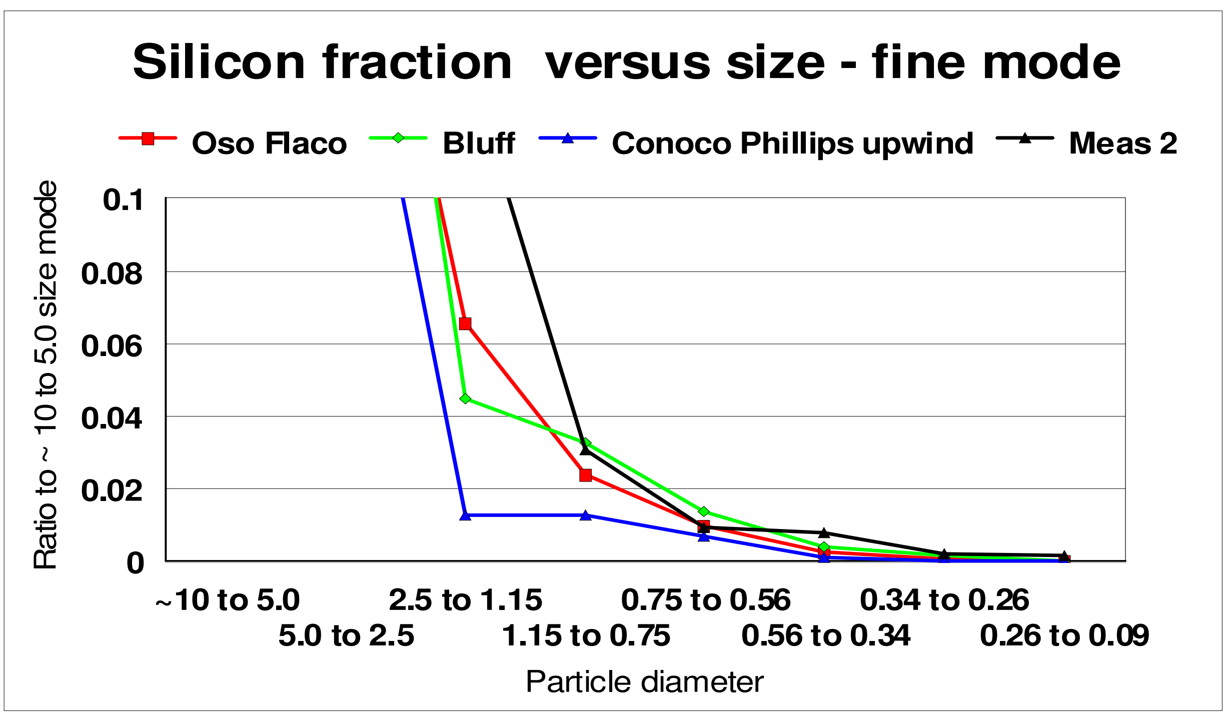


Figure C 17- The same data as Figure 16 with a finer scale to show finer soil particle

Data on elemental ratios are also available along the transects. Figures 18 and 19 below show the data from the Mesa 2 sampling site upwind to near the downwind edge of the ConocoPhillips petroleum coke pile.

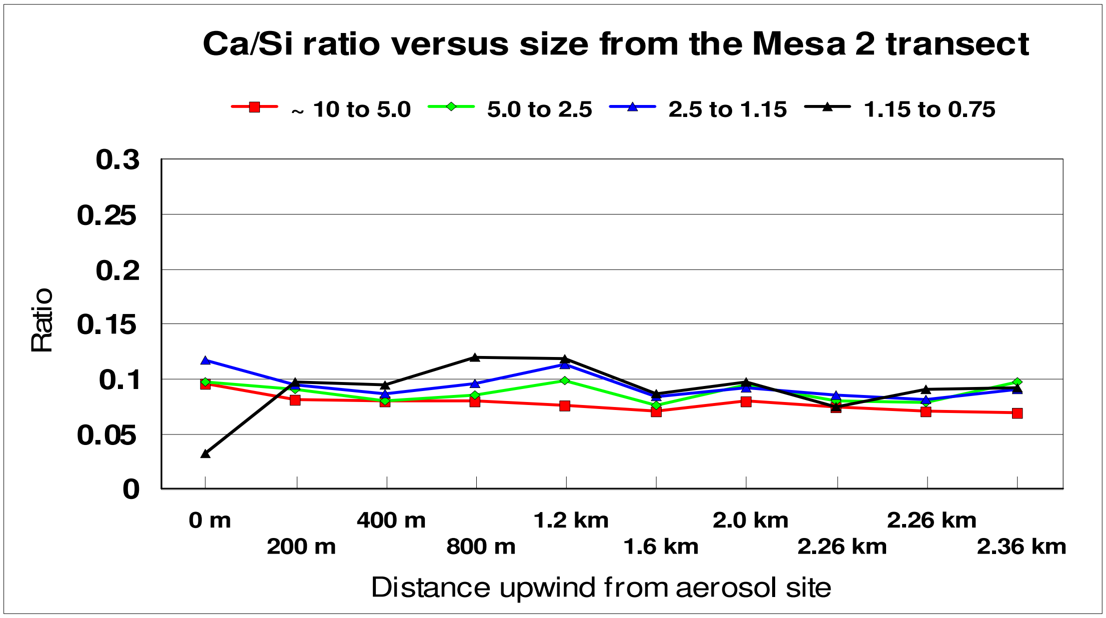


Figure C 18 - Ca/Si ratios along the mesa 2 transect

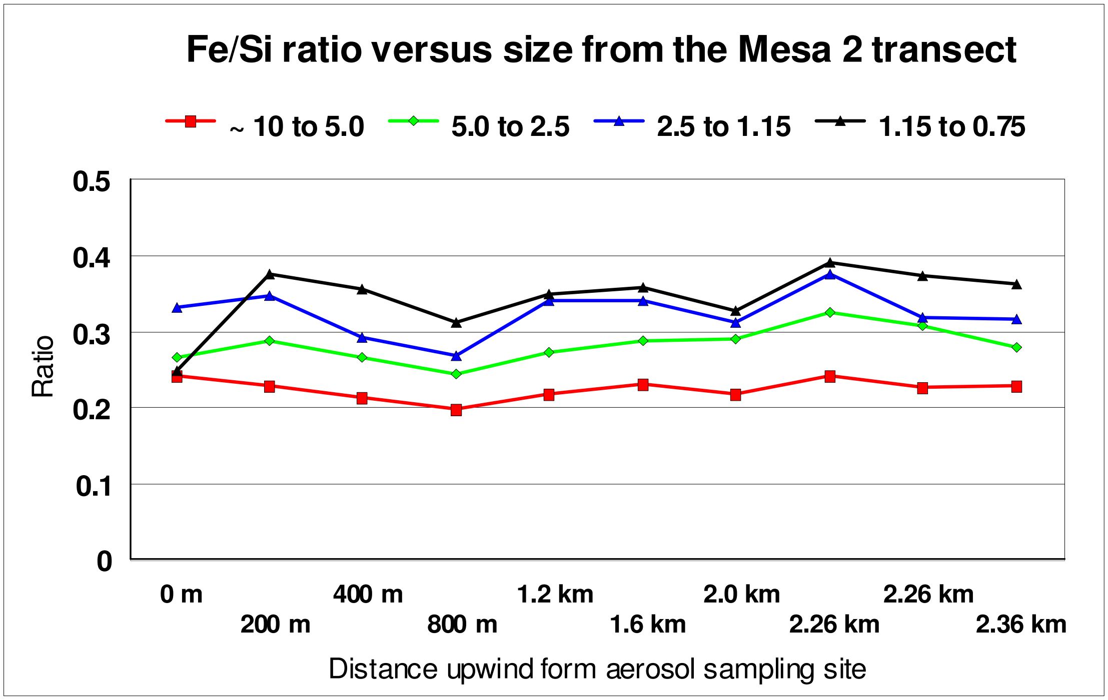


Figure C 19 - Fe/Si ratios along the Mesa 2 transect

In summary, the re-suspended soil samples showed a very similar pattern of size distribution as well as the Ca/Si and Fe/Si ratios. It is also important to note that particles with a diameter of less than 10 micron were present in these soil samples.

Analysis of farmlands transect - Silver Spur to Bluff

The soils in the rich alluvial plain north of the SVRA, although under intense cultivation, clearly originate from upstream sources and are thus very different from the sandy soils common in the coastal area. Since such soils commonly include silt and clay components with sizes well below 10 µm in diameter, and thus potentially able to impact windblown dusts, special efforts were made to analyze the soils both in a dry "as-is" condition, as well as dispersed in water to break weakly adhering bonds.

The three figures below show the Malvern analysis of the soils 600 m upwind of the Silver Spur site, at the edges of the sand dune field and in the rough middle of the farm fields. The latter analyses were done both dry and wet.

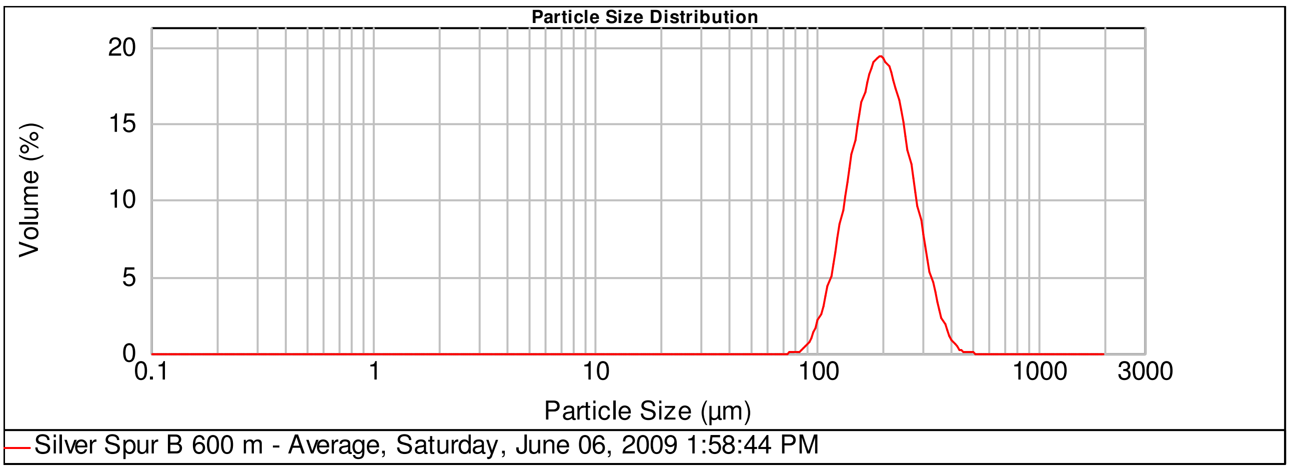


Figure C 20 - Malvern analysis of soils 600 m upwind of the "Silver Spur" site

In common with almost all other samples from non-disturbed dune sites, there are essentially no particles detected by the Malvern analysis in sizes below 50 µm diameter; thus, such soils should have little impact on PM_{10} aerosols. In contrast, farmland soils dried to essentially zero water content, when sized by the Malvern, show a small fraction below 10 µm and some extending to almost the $PM_{2.5}$ cut. These soils were taken at a road edge near the fields in the rough center of the farmed area,

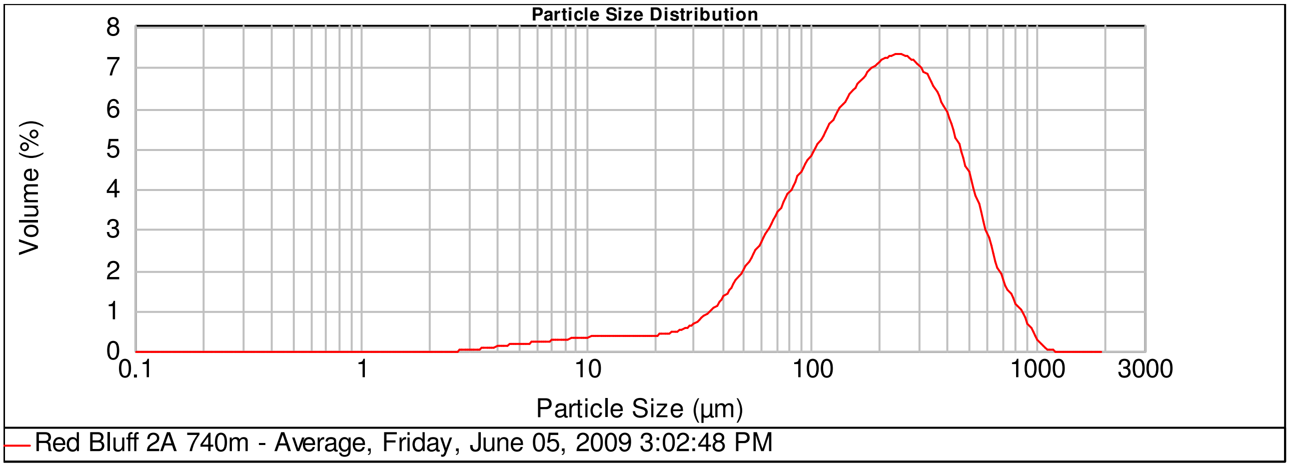


Figure C 21 - Analysis of dried farmland soils 740 m upwind of the Bluff site

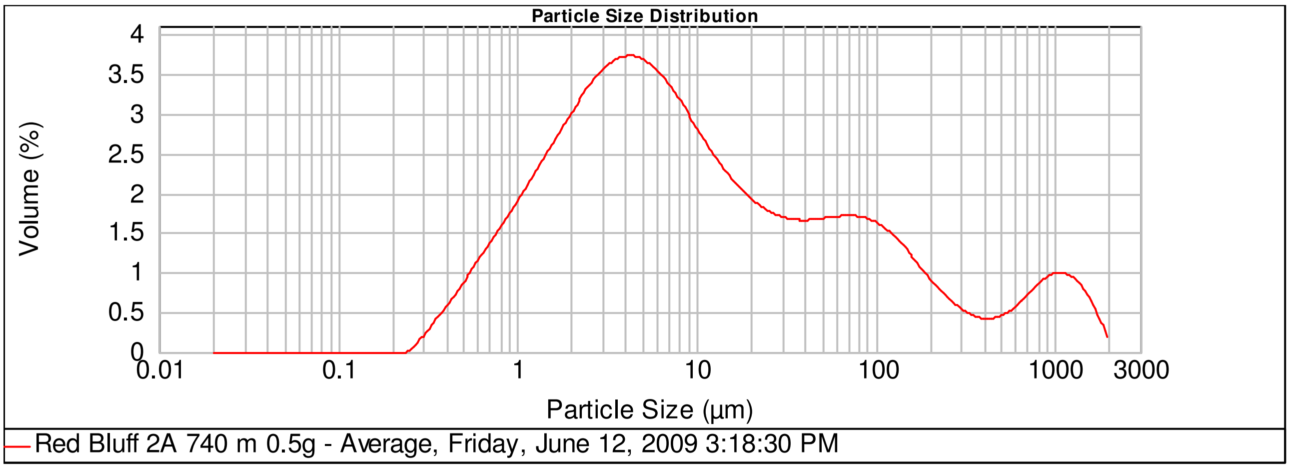


Figure C 22 - Analysis of farmland soils 740 m upwind of the Bluff site dispersed into a water solution and then sized

The analysis of the same soil dispersed into water shows that most particles disassociate into particles with a mode around 4 µm. The condition of the actual soils was like neither of these extremes; since the land is under intense cultivation, the actual soils are routinely irrigated and much of the area between Bluff and Silver Spur has crop cover, typically lettuce and broccoli.

This can also be seen by the tendency of the soil as collected to form clumps or clods. Thus, any free particles in the fine alluvial soils do not occur in a resuspendable form and thus would be unlikely to cause aerosols. This helps explain the almost total lack of aerosol episodes at the Bluff site, directly downwind of the farmed area.

Figure C 23 - Drip irrigated lettuce field

The combination of the routinely wetted soils and the crop cover give a region with very little potential for dust unless special conditions are met, such as disking a dry field or vehicular traffic on dirt farm roads that are dried out.

As shown below, there were very low mass values at Bluff (5.8 ± 0.7 $\mu g/m^3$) in the particle size range 2.5 to 1.15 µm, the most respirable dust. These were seen over the three largest dust events of April 27, 28, and 29, seen by both the 3 DRUM and 8 DRUM samplers during the entire 3 week period,. Higher values were measured upwind at Silver Spur, (11.7 ± 0.9 $\mu g/m^3$), so it is clear such conditions did not occur with any frequency during this study. In fact, the vegetation and farmland are acting as a particle sink, not source, during high wind conditions.

Figure C 24 - Preparing a field by dry disking

Elemental Composition of Soils and Aerosols

S-XRF analysis was performed on the Apiezon-L grease coated DRUM stages identical to those used in the aerosol sampling. Two such sample sets were made, each consisting of 8 DRUM stages from inlet to 0.09 µm diameter. The upper cut point was achieved by having the DRUM mounted upside down and making the upward air flow velocity roughly equal to the settling velocity of a 10 µm particle. The two sets of data are presented: Re-suspension 1 (17 samples from Oso Flaco, Bluff, ConocoPhillips upwind and road side), and Re-suspension 2 (16 samples from Mesa 2 to the petroleum coke piles and Mesa SE in the SVRA).

Figures 25 and 26 below show examples of the data for silicon, the major soil element, for the Re-suspension 1 sample set which includes the Bluff transect samples.

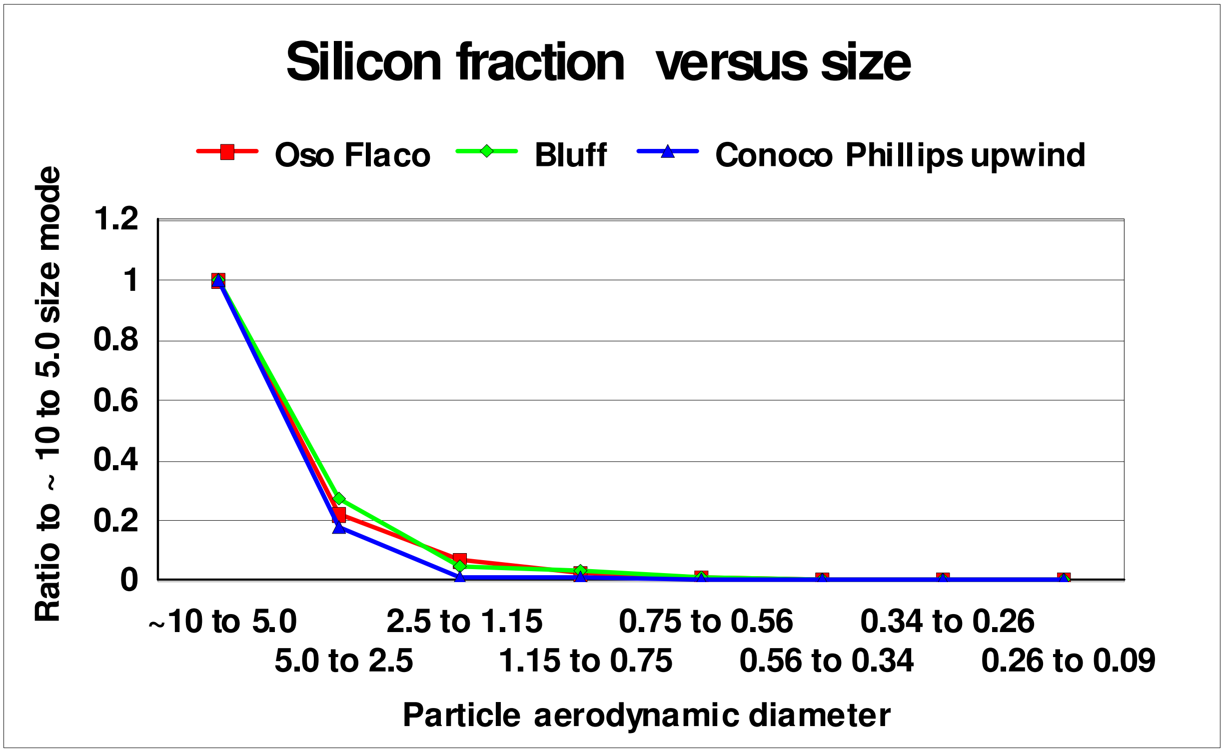


Figure C 25 - Size profile of the average of the entire Bluff transect silicon data set

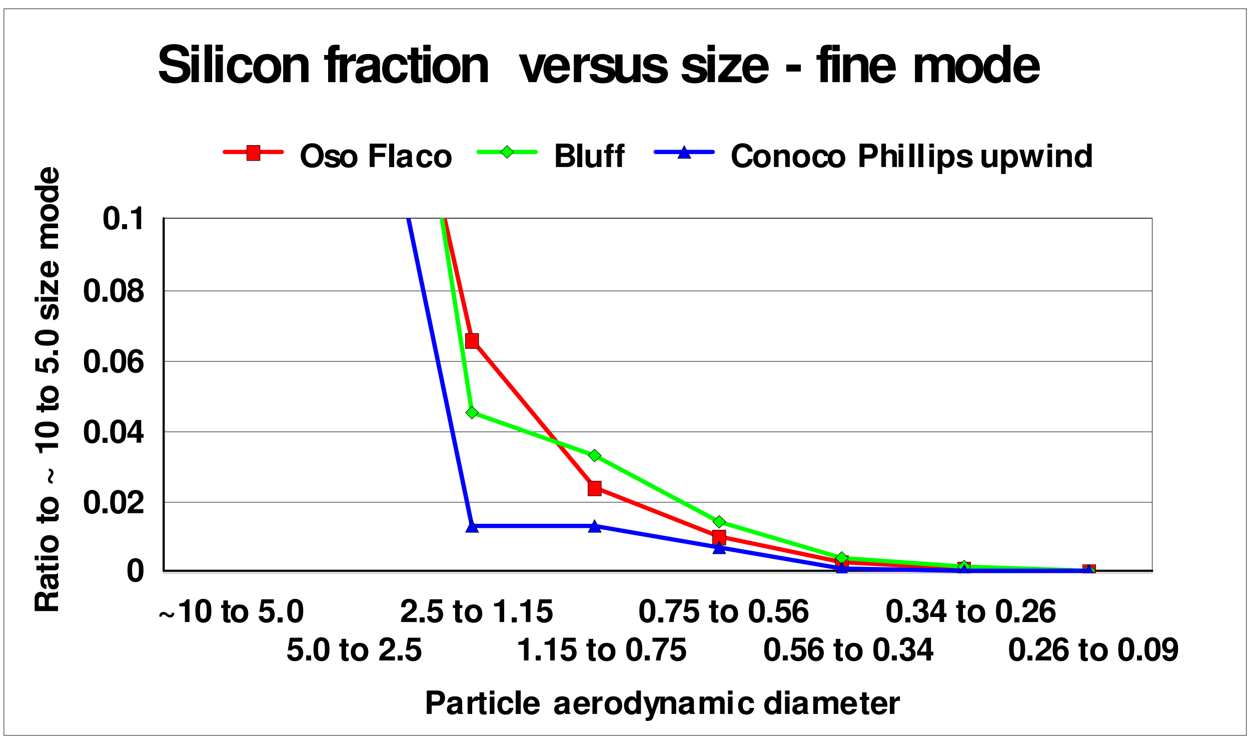


Figure C 26 - Fine mode in the average of all Bluff transect silicon values versus other sites

In these profiles, note that there is only a very modest enhancement of silicon in the sizes that should represent clay particles. This can be further examined by the Ca/Si ratio, which should favor clay minerals over sand. However, note that as shown above, very little soil mass was present below 0.56 µm and thus the ratios become highly uncertain below this value.

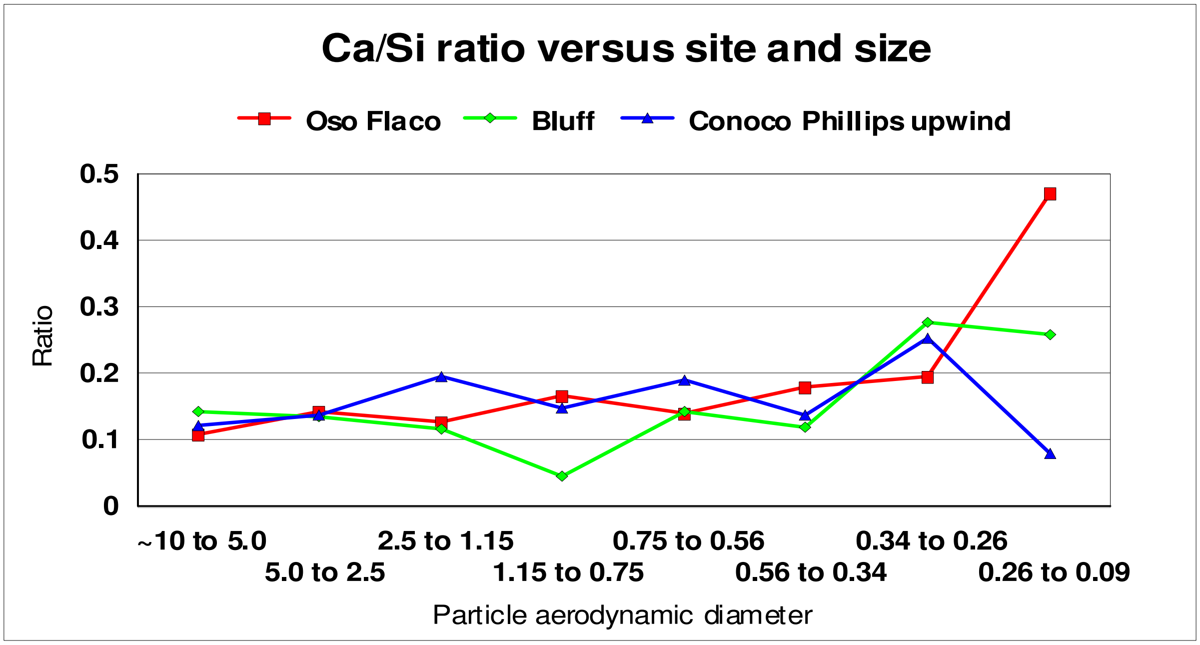


Figure C 27- Ca/Si ratio for the average of all Bluff samples in comparison with other sites

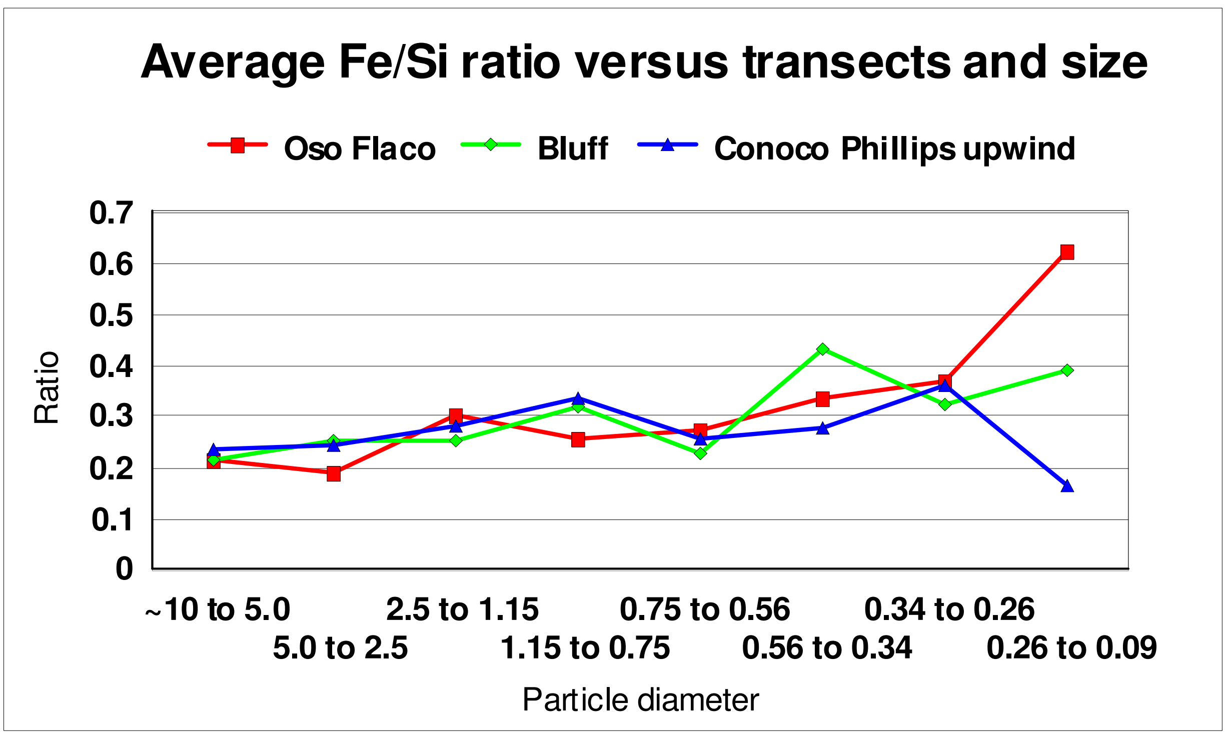


Figure C 28 - Fe/Si ratio for the average of all Bluff samples in comparison with other sites

Note there is no particular enhancement of calcium in the Bluff transects; they are similar to Earth crustal averages (Handbook of Chemistry and Physics). Further information can be obtained by examining the elemental ratios as a function of distance.

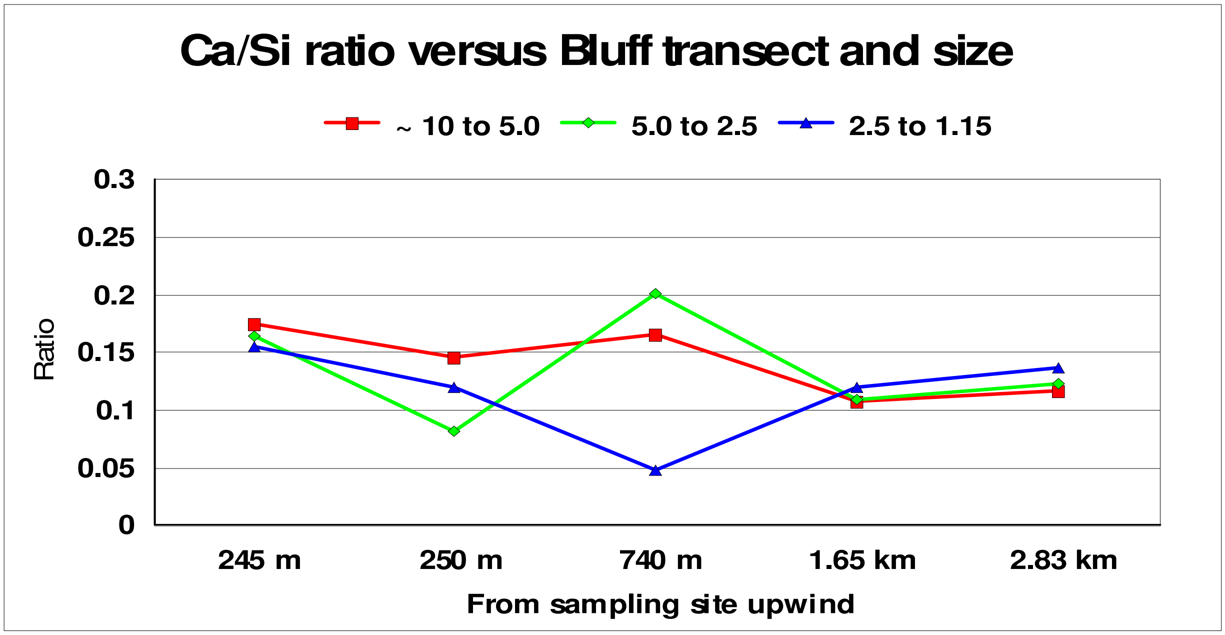


Figure C 29 - Ca/Si ratios as a function of distance along the transect in the upwind direction

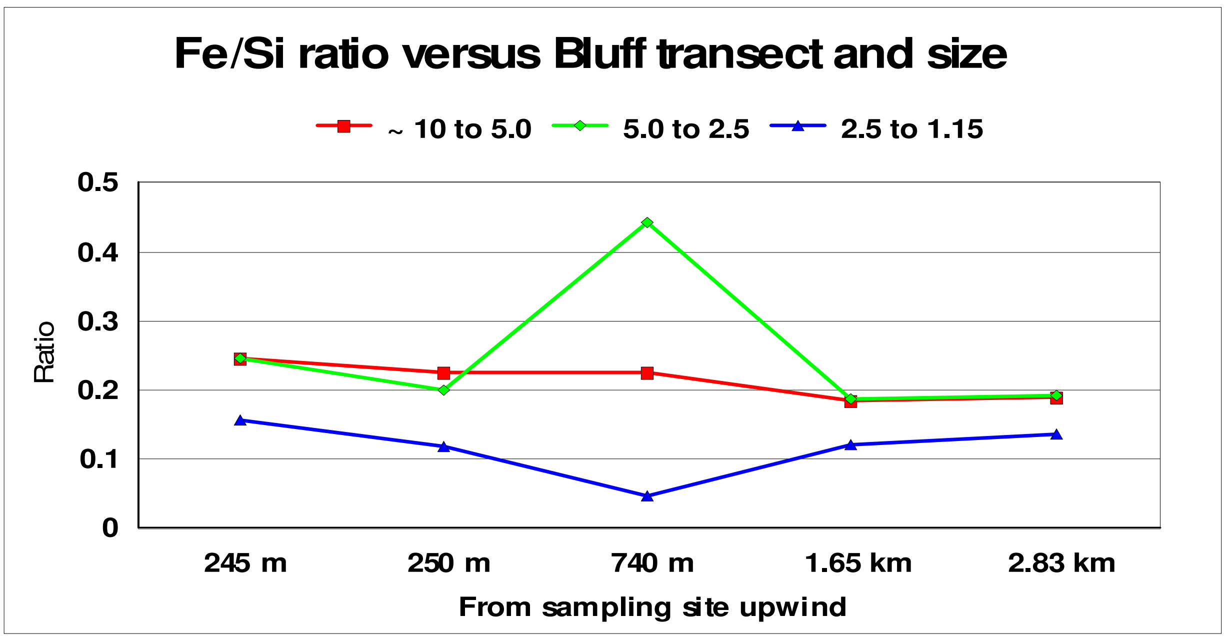


Figure C 30 - Fe/Si ratios as a function of distance along the transect in the upwind direction The samples at 740 m and 2.83 km were taken from intensively cultivated fields

In addition to the soil re-suspension data, improvements in S-XRF efficiency allowed additional elemental analysis of the Spring intensive DRUM samples from the Bluff site; the elemental analysis allows for the separation of mass by element. Samplers used in the Spring intensive were all located at Mesa2 for a 10 day period for QC purposes prior to deployment to each specific site. The set of time series plots below depict the side by side comparison data at Mesa 2 (shaded) up to April 26, followed by the data from the individual sites where each sampler was deployed.

Figure 31 below shows the elemental analysis results for Mesa 2 and the Bluff site for chlorine, a sea salt tracer, which was somewhat higher at the Bluff site.

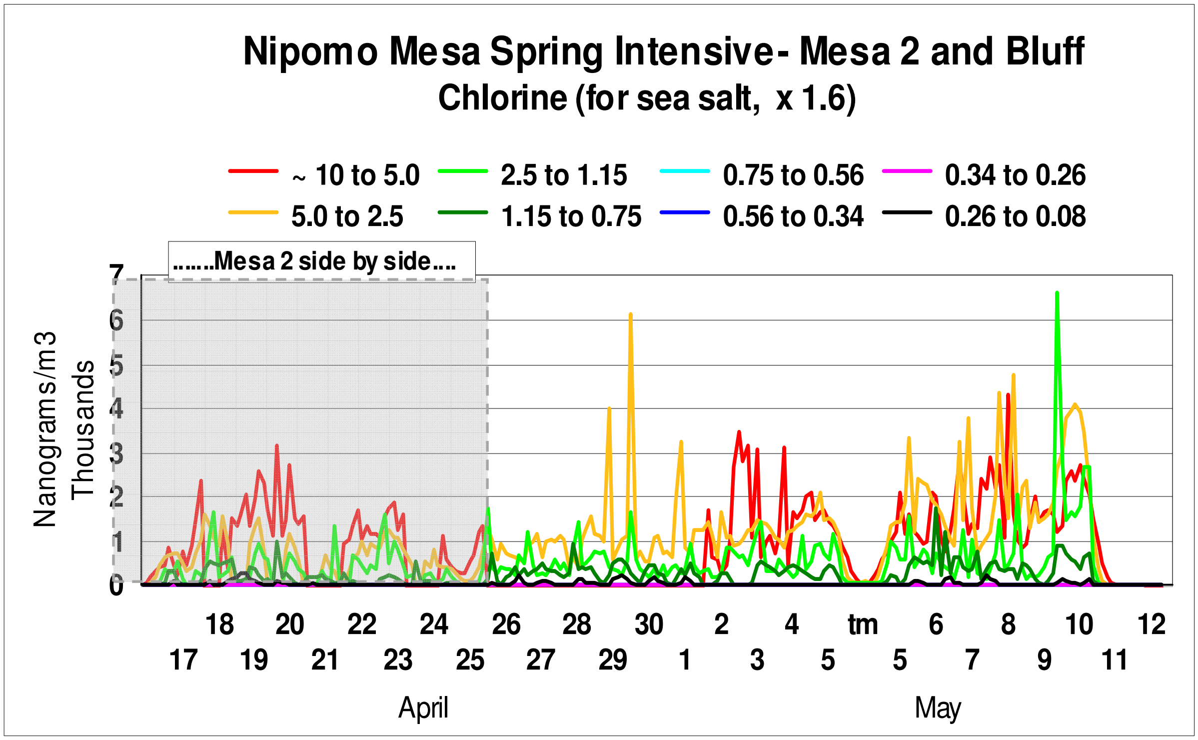


Figure C 31 - Chlorine at the Mesa 2 and Bluff sites

In the chart above, note that the coarsest particle masses often fall to 0 at the Mesa 2 site and occasionally at the Bluff site. This resulted from an analytical error in which the S-XRF detector was overwhelmed by the number of x-rays and exceeded the protocol for dead time correction; these data have been removed from the record. This was far more prevalent at Mesa 2 and Bluff than the other sites, which skews comparisons. For that reason we use the 5.0 to 2.5 µm size modes as a more reliable metric.

We must also note that meteorology impacts these comparisons, as these data must be viewed in association with wind velocity. However, the high sea salt levels qualitatively indicate strong oceanic winds. Figure 32 below shows the comparisons for the soils, while noting that the sea salt concentrations often exceed the soil concentrations at the Bluff site.

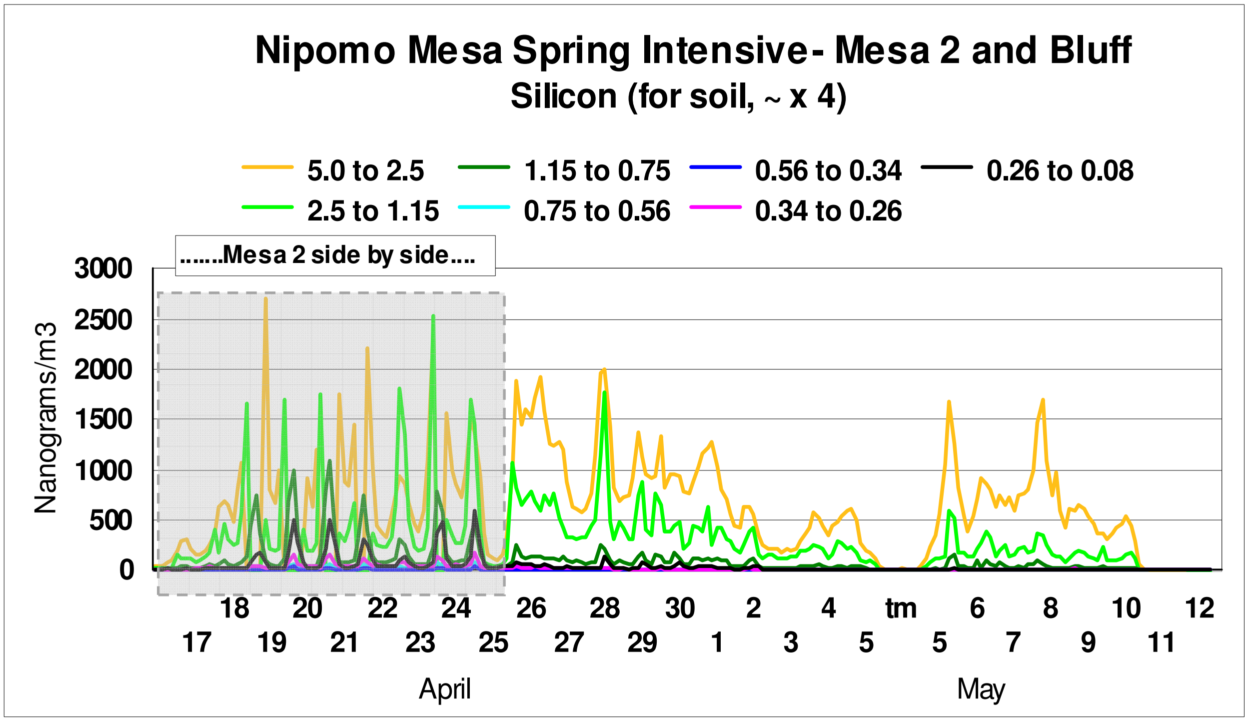


Figure C 32 - Silicon at the Mesa 2 and Bluff sites. The coarsest mode (10 to 5.0) at Mesa 2 overloaded the S-XRF detector and thus these data are unavailable.

The most comparable site to the Bluff site is the CDF site as they are a similar distance from the coast. Note the very different responses to the dust episodes at CDF versus Bluff in fine particles.

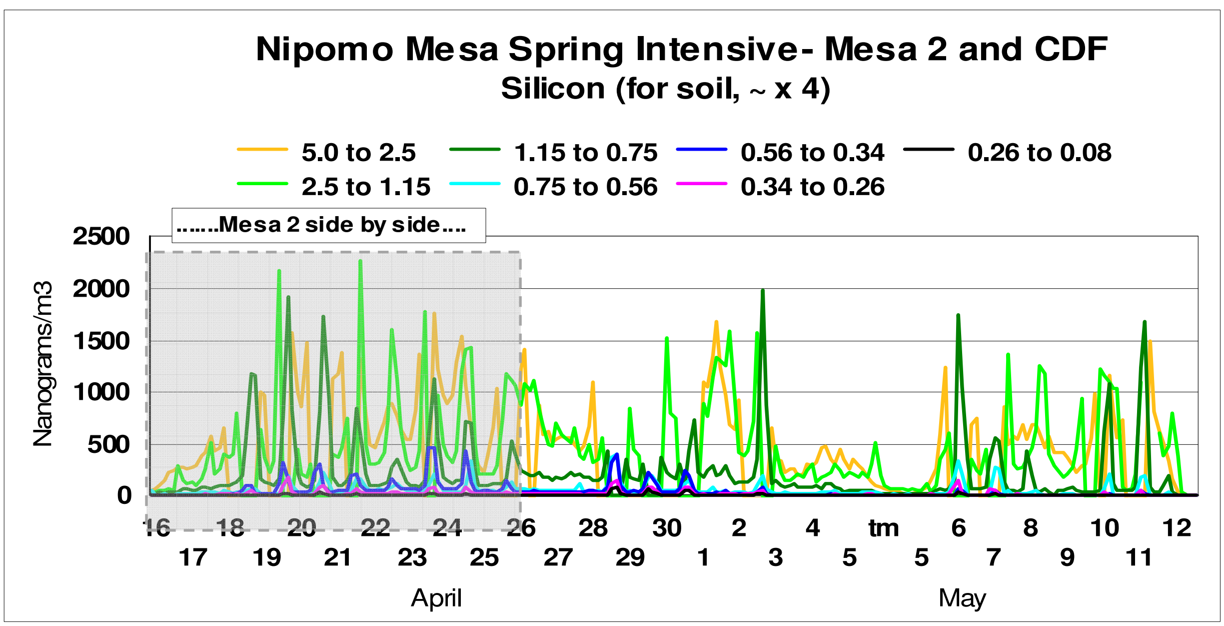


Figure C 33 - Silicon at the Mesa 2 and CDF sites (Note that all the 10 to 5.0 and the highest peaks in the 5.0 – 2.5 fraction at CDF are missing due to the S-XRF overflow problem)

The most comparable site to the Bluff site is the CDF site. Note the much higher fine particle fraction seen at CDF during the dust episodes versus Bluff.

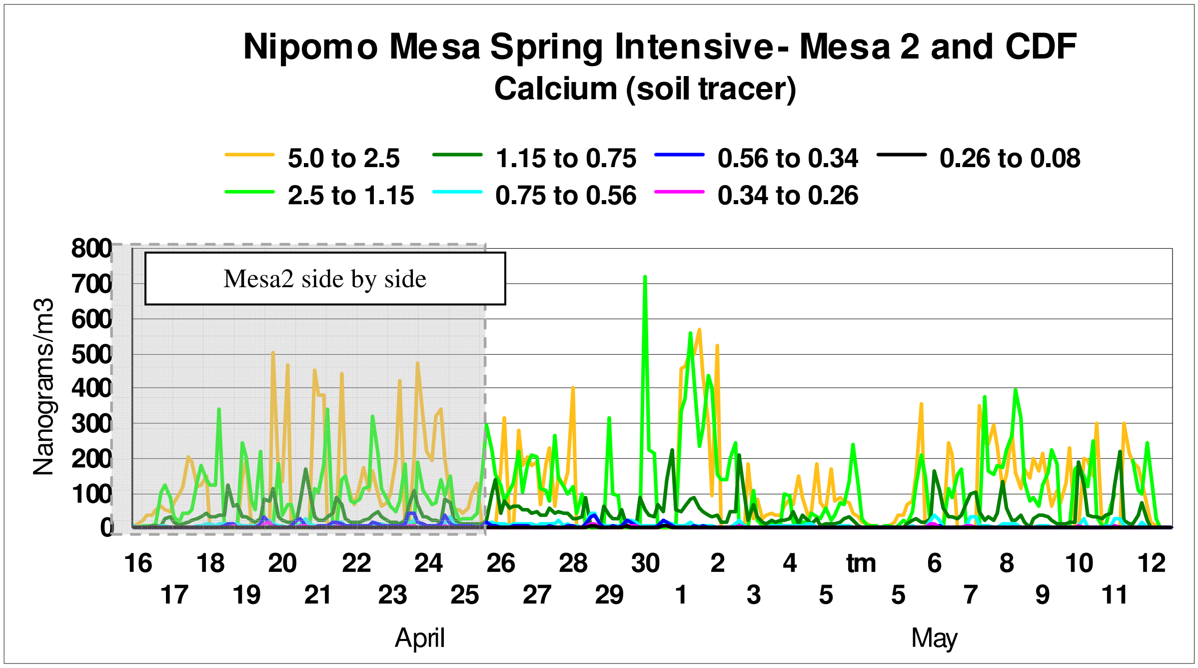


Figure C 34 - Calcium from the Mesa 2 and CDF sites

The CDF site, downwind of disturbed dunes, again shows the response to dust episodic events in finer soils absent at Bluff.

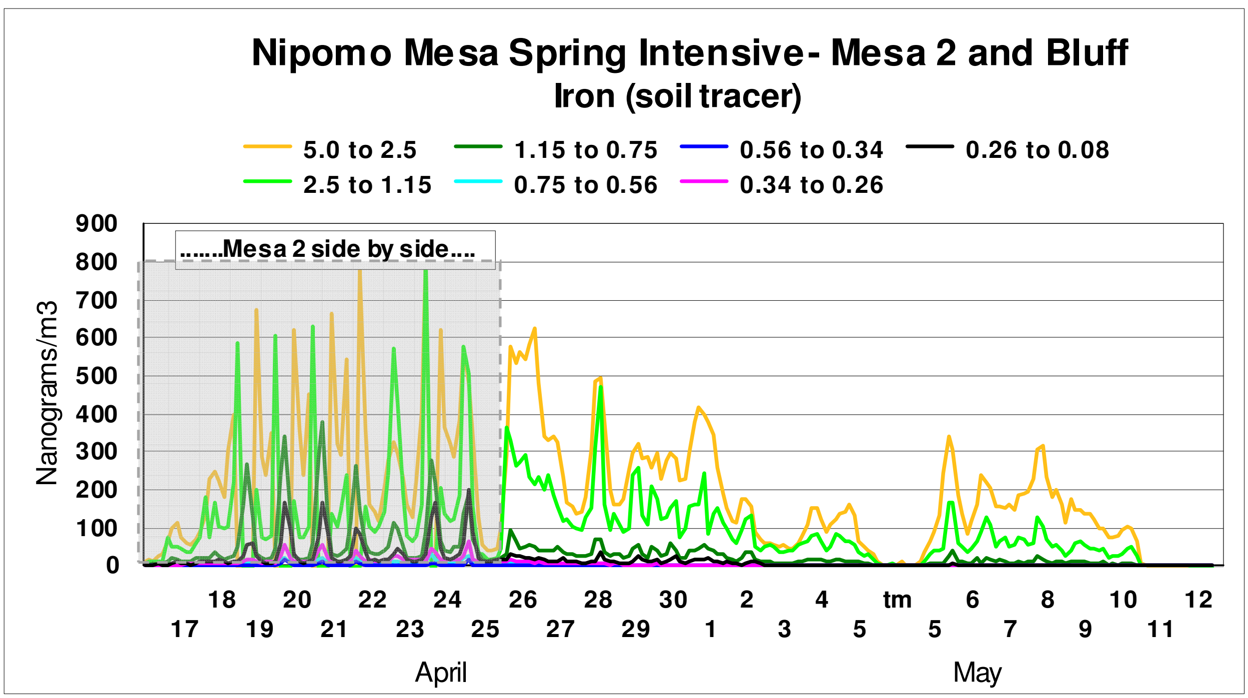


Figure C 35 - Iron at the Mesa 2 and Bluff sites

In summary, the soils and aerosols affecting the Bluff site are significantly different than the Mesa 2 site in several ways, including a higher sea salt impact at Bluff and an almost total absence of the relatively fine soils so characteristic of the Mesa 2 and CDF sites. The Bluff site does show an enhancement of calcium in the aerosol, possibly indicating some local clays, but this is a small component of the total mass. It is also important to note that overall mass particle concentrations measured at the Bluff site were substantially lower than those seen at the CDF or Mesa2 site.

Analysis of samples from SVRA fences

Fine particles were seen clinging to portions of the sand fences during the inspection of SVRA sites in spring, 2008. Particles were collected both down at the beach area (Sample 1, Spot A) and up at the "Sand Highway" (Sample 2, Spot B). Portions were placed on a Mylar substrate and stabilized by a solution of Apiezon L grease in toluene, the same solution used to protect against particle bounce off on drums. Samples were analyzed by S-XRF for elements from aluminum though molybdenum, plus lead.

The results showed the surprising presence of lead at the beach site, which was absent up at the "Sand Highway". Lead is a robust tracer of leaded gasoline, which has not been present in California gasoline for decades. It is possible this is a relic of vehicle use of the beach prior to banning leaded gasoline in the state;, or it may reflect local illegal use of leaded gasoline.

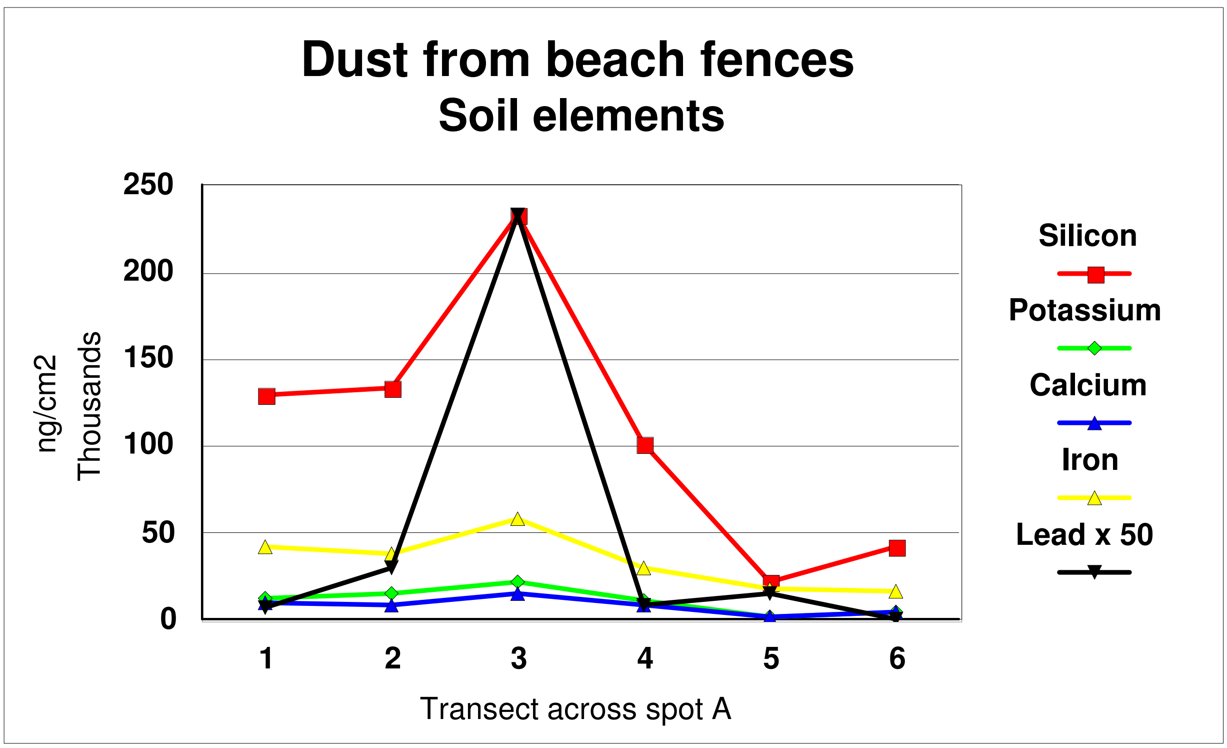


Figure C 36 - Analysis of materials adhering to beach fences

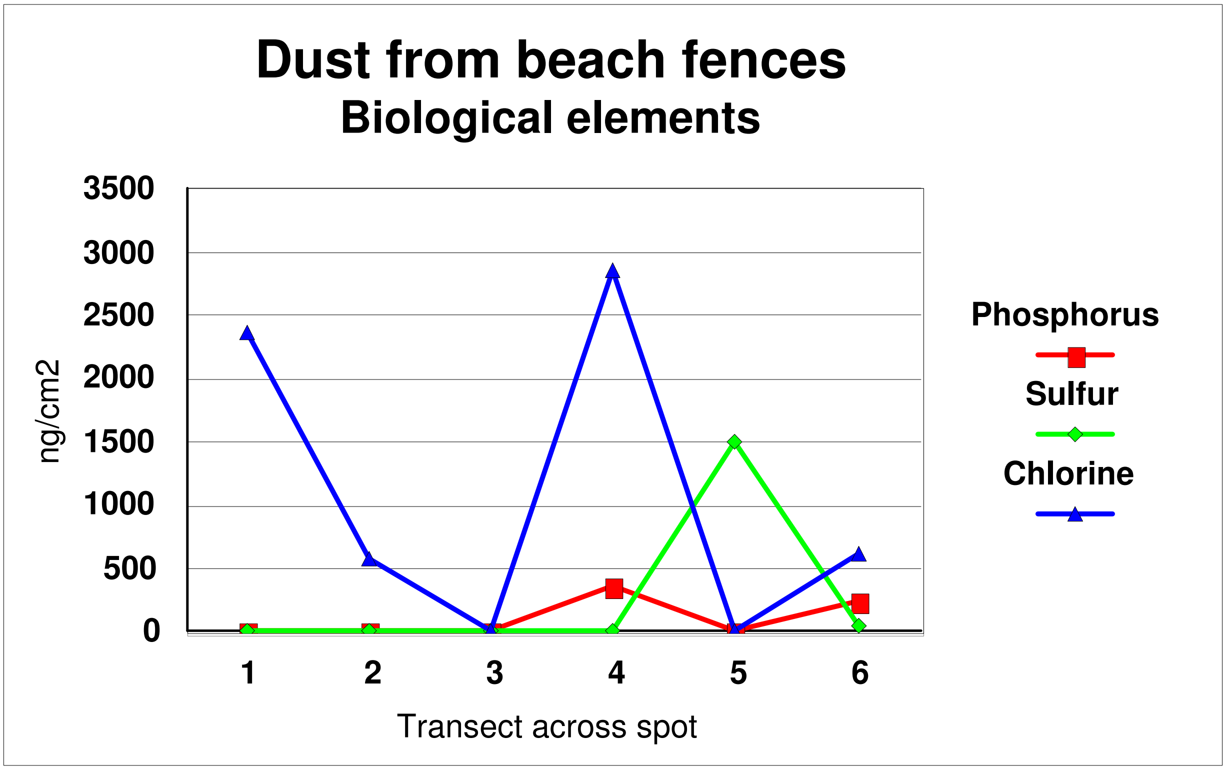


Figure C 37 - Analysis of typical biological elements in dust adhering to beach fences

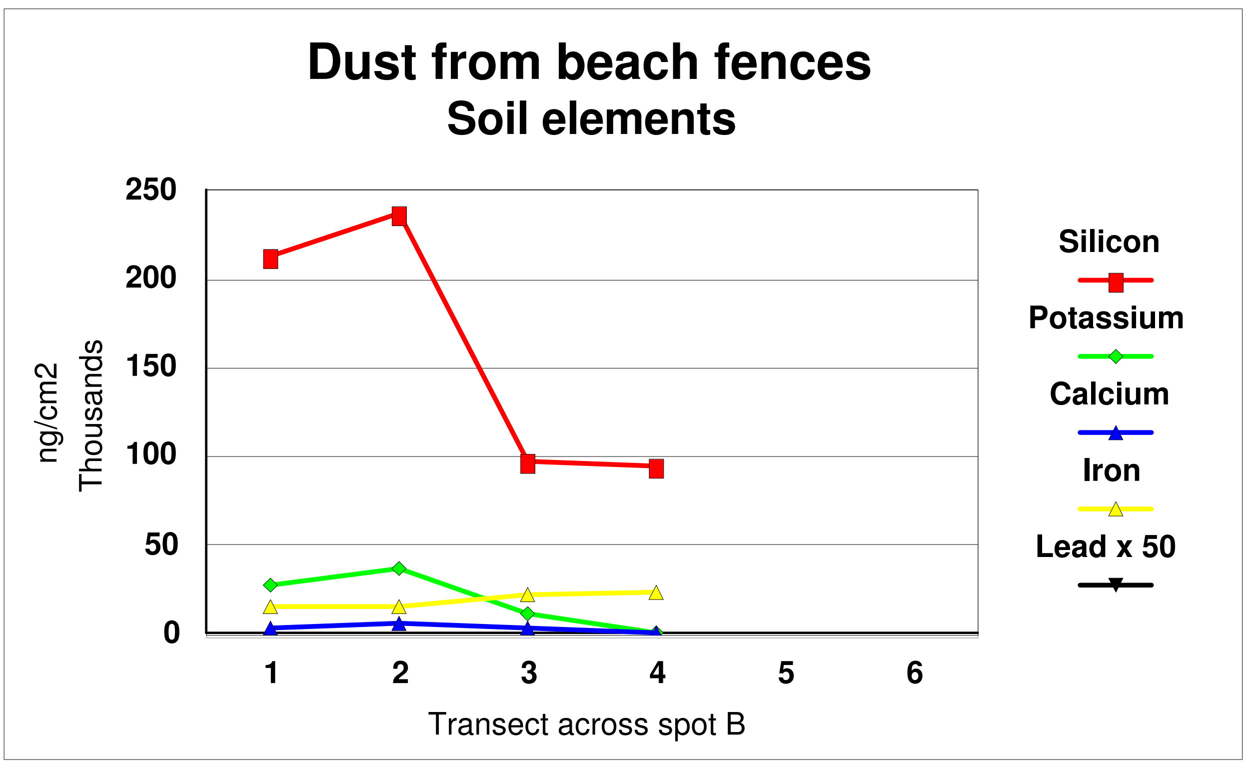


Figure C 38 - Analysis of materials adhering to beach fences – inland sites

In summary, the deposit appears to be very fine soil-derived material with only a small admixture of oceanic components. Thus, the fence deposit at the beach had a composition close to silt and clay, with about ~ ½ % sea salt. Lead was also seen. At the Sand Highway, the deposit was fine sand, with very little chlorine or lead.

Part 2: Aerosol Sampling – Winter 2008 Mass and Elemental Data

Instrumentation and Quality Assurance

The instrumentation used by the UC Davis DELTA Group was developed by the Delta Group and included both 8 DRUM and 3 DRUM samplers. The details of the sampler design, operation, and quality assurance are given in full in the *DRUM Quality Assurance Protocols*, ver 1/09 (DQAP 1/09) available in hard copy and at http://delta.ucdavis.edu. This is an integral component of this Report and will be included on the data CD. Table 4 below shows the type of sampler and sampling period for each sampling location.

Table C 4 - Aerosol measurements in the Nipomo Mesa – Phase 2

Site Name	Delta Group Measurements	Delta Group Sampling Period
Ten Commandments	8 DRUM	Intensive
Guadalupe Dunes	8 DRUM	Continuation Sept - Dec
Oso Flaco	8 DRUM	Intensive
Mesa2	8 DRUM (also side by side all DRUMs 1 week)	Jan 2008-Feb 2009
CDF	8 DRUM	Intensive + 6 weeks
Conoco Upwind	8 DRUM	Intensive
Bluff	8 DRUM and 3 DRUM	Intensive
Silver Spur	3 DRUM	Intensive
Pier Ave.	3 DRUM	Intensive
Grover Beach	3 DRUM	Intensive

DELTA 8 DRUM 1999 - Present

In 1999, the DELTA Group began a process to convert an existing jetted 8 drum impactor to the slotted configuration of the very successful IMPROVEd 3 DRUM. Professor Otto Raabe ran his aerodynamical model for 6 mm slots, generating cut points that better met the needs of Mie Theory than the jetted DRUM, with the increased flow to 10.8 L/min and the better precision of the IMPROVEd DRUM (Raabe, private communication).

Parameters of the DELTA DRUM Slotted Drum Impactor

The width of the mass at full width, half maximum, W mass, represents the measured footprint of a non-rotating DRUM, accurate to about ± 15%. This results in a resolution in time using a 42 day rotation period (4 mm/day) given in T (hr). The after filter was not used in this work. Note the much poorer time resolution in the 10 to 5.0 µm size mode.

Table C 5 - Parameters of the UC Davis DELTA Group 8 DRUM

Stage No.	W (s) cm	L Cm	S cm	P out kPa	Re	u out m/s	ECD ae, µm	W (d) µm	ΔTime hr
1	0.360	0.6	1.44	101.3	2231	7.7	5.0	750	4.5
2	0.163	0.6	0.65	101.1	2810	17.1	2.5	500	3.0
3	0.073	0.6	0.29	100.2	3195	38.3	1.15	300	1.8
4	0.049	0.6	0.20	98.3	3331	58.3	0.75	265	1.6
5	0.038	0.6	0.15	94.9	3416	77.4	0.56	240	1.4
6	0.026	0.6	0.11	86.8	3575	122.2	0.34	245	1.8
7	0.024	0.6	0.10	75.1	3692	156.0	0.26	180	0.9
8	0.021	0.6	0.10	39.7	4595	315.9	0.09	175	0.9
Filter									

This impactor (along with an IMPROVEd DRUM) was deployed in the BRAVO study in Big Bend NP, July - October 1999, and operated with essentially no loss of samples. The time resolution was obtained by the size of the analytical beams used, and could be as low as 1 hour when analyzed at the synchrotron x-ray fluorescence microprobe of the Advanced Light Source, Lawrence Berkley National Laboratories.

One advantage of the DRUM samplers is they require far less field labor than the typical EPA-certified high volume filter samplers; in many cases, no field labor is needed once the DRUM is plugged in. In standard operation, the DRUM (3 or 8) will collect 504 samples in 42 days at 2-hour resolution, each sample with 3 to 8 size modes. Note that just buying the Teflon filter media for 504 samples is $2,500 for filter samplers.

In 2000, in response to ARB-sponsored studies at the Fresno Supersite, the DELTA DRUM sampler was modified to directly match the 16.7 liter/min flow of standard PM10 heads on low volume filter samplers. This was done by simply extending the length of the slot without changing any other parameters, an option only available to a slotted DRUM. The wider slot has the added advantage of allowing dual aluminum-Mylar substrates. While not recommended for coarse stages in dry conditions due to particle bounce on the aluminum, it works well for most conditions while delivering an aluminum strip ideal for laser desorption ionization time-of-flight mass spectrometry, and thus speciated organic matter.

DELTA 3-DRUM 2000 – Present

In 1992, a new impactor was designed for visibility studies in the IMPROVE program (Malm et al., 1984). In it, three size classifications were achieved designed to match the needs of Mie Theory for visibility: 2.5 > Dp > 1.15 µm; 1.15 > Dp > 0.34 µm; and 0.34 > Dp > 0.1 µm, plus an integrating afterfilter. The coarsest particles, while optically efficient, are too few in number to have much effect on visibility by the 1/r3 dependence on number and mass. The middle group is the heart of light scattering, with very high optical efficiency/particle, expressed as Qscat = $\sigma scat/\pi r^2$, the ratio of scattering to the particle area, which can reach values like 5 or 6. In addition, this mode is the peak of the Accumulation Mode (Whitby et al., 1975) and has high mass and many particles. The finest stage normally possesses many particles, but since the 0.34 µm cut point is set where Qscat = 1.0 and dropping rapidly, the particles are highly inefficient in scattering light. This sampler, because it lays down a 6 mm wide strip instead of a line, is much easier to analyze and has far better precision than the jetted drum configurations (Cahill et al., 1995). Finally, the increased flow of 10 L/min gives 10 times more mass to analyze than the 1.0 L/min jetted DRUM.

For the NSF-funded ACE-Asia program, 2000- 2004, 10 new 3 DRUM samplers were purchased from Integrity Manufacturing (RTP, NC) with revised parameters. The flow was raised to 23 l/min by lengthening the slots while keeping all other parameters fixed. The flow was designed to match the IMPROVE cyclone, which was then added as a pre-cut to the sampler. These are the 3 DRUMs used in the Oceano Dunes study.

a. Aerosol analysis and quality assurance

1. Synchrotron-Induced X-ray Fluorescence (S-XRF)

This is basically a form of x-ray fluorescence with polarized x-ray beams. Note that we had on occasion used S-XRF on filters and impactors for the Kuwait oil fire studies (Cahill et al., 1992) and other special uses, but the difficulty and access was such as to discourage regular use. The S-XRF microprobe at the Advanced Light Source, Lawrence Berkeley NL provided us support and encouragement to make this procedure widely applicable for aerosol studies. The DELTA Group spent 4 years developing a white beam, 4 keV to 18 keV, with a beam spot size matched to the DRUM impactor impaction “footprint. Typically, we obtain about 0.1 ng/m^3 sensitivity in a 30 sec analysis run at a sampling time bite of 3 hrs. for elements sodium through lead.

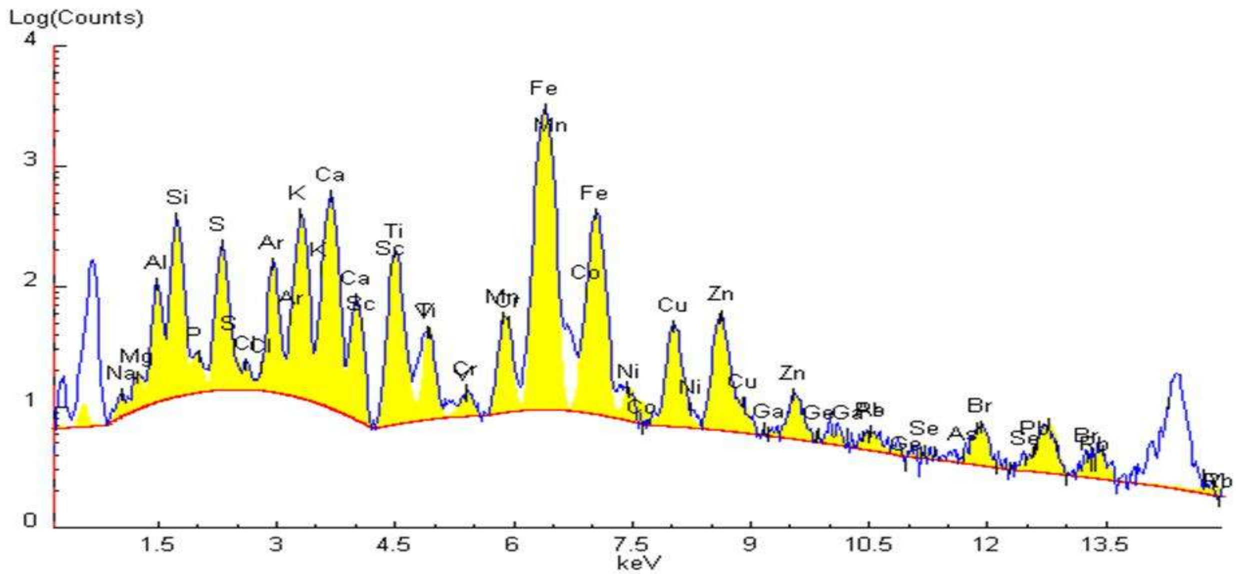


Figure C 39 - S-XRF spectrum of an aerosol sample

Table 6 below summarizes all DELTA Group S-XRF inter-comparisons in the past 5 years. Note there were problems with the ARB RAAS analyses since the two internal ARB X-RF to ARB RAAS comparisons agreed only at the level 1.29 ± 0.63 for all co-measured elements. (DQAP v. 8.02, pg 32) We also give averages below without the ARB RAAS data. A comparison was also done with IMPROVE in the Yosemite study (2002), but this comparison is not included since IMPROVE has since identified serious problems (White et al, AAAR 2004)

Table C 6 - Quality assurance of S-XRF data – blind intercomparisons

Study and date	Methods	**Average ratio, Al to Fe**	Std. dev.	**Average ratio, Cu to Pb**	Std. dev.
BRAVO, 1999	PIXE vs S-XRF	**0.99**	0.04		
BRAVO, 1999	CNL XRF vs S-XRF			**1.24**	0.14
FACES, 2001	ARB XRF vs S-XRF	**0.93**	0.21	**1.02**	0.08
FACES, 2001	ARB (alt) vs S-XRF	**(0.98)**	0.27	**(0.74)**	0.23
ARB LTAD 2005	DRI XRF vs S-XRF	**1.037**	0.085	**0.907**	0.009
All prior studies	**Average** (wo ARB alt)	**0.984**	**0.15**	**0.977**	**0.115**

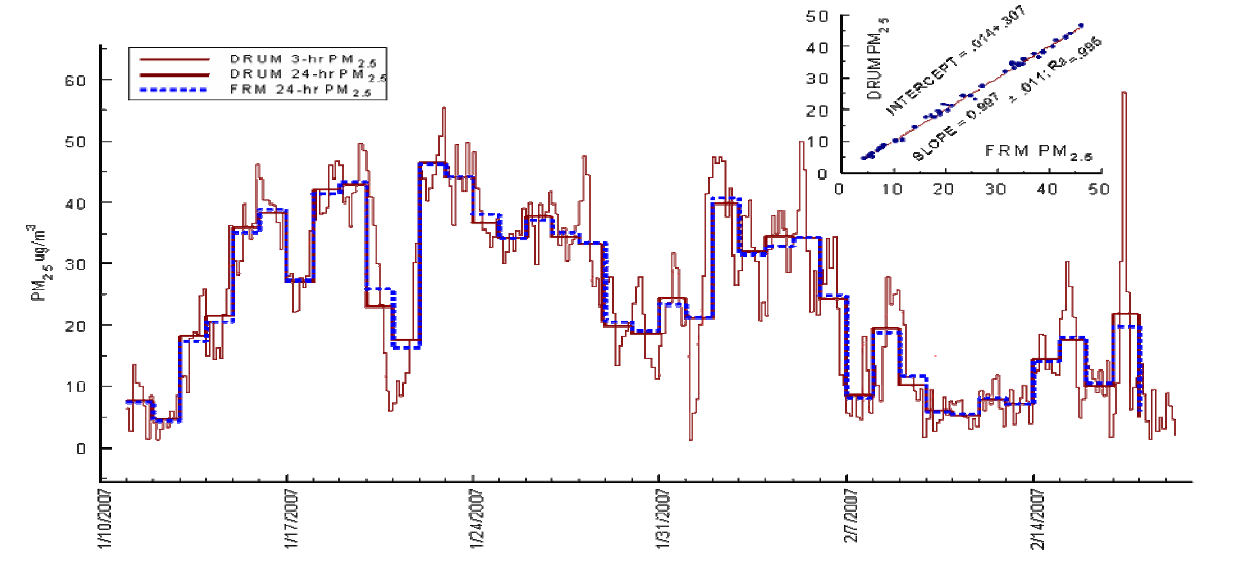


Figure C 40 - ARB staff analysis of side by side UC Davis DRUM and FRM mass, Sacramento

2. Aerosol mass by soft beta ray transmission

The ability of the DELTA Group to measure mass was validated in a side-by-side comparison to the US Standard Federal Reference method (FRM) for $PM_{2.5}$, at the ARB test site at 13^{th} and Street, Sacramento. The results, as evaluated by ARB staff, are shown above in Figure 40. The key to better agreement is close control of the initial timing.

Aerosol Sampling and Analysis in the Nipomo Mesa Study

Winter January – February, 2008

Continuous monitoring of aerosols at Mesa 2 in 8 particle size modes by a UC Davis DELTA Group 8 DRUM sampler was initiated on January 14, 2008, and continued to February, 2009. These data were designed to meet several of the Phase 2 study goals:

1. Supplement the co-located PM_{10} mass data with information on particle size so as to better identify sources and evaluate health impacts by lung capture; and,
2. Provide samples suitable for compositional analyses in order to
   a. Connect coarse aerosols to potential dust sources,
   b. Evaluate the role of sea salt to Mesa 2 PM_{10} masses, and
   c. Evaluate the impact of the ConocoPhillips petroleum coke piles to Mesa 2 aerosols.

The period January through February, 2008, also had several rain events (figure 41). The wetting of soils strongly suppresses dust formation, and thus raises the sea salt to soil dust ratio from that of dry conditions (circa 10%). This effect would not happen during most of the year when rainfall is absent.

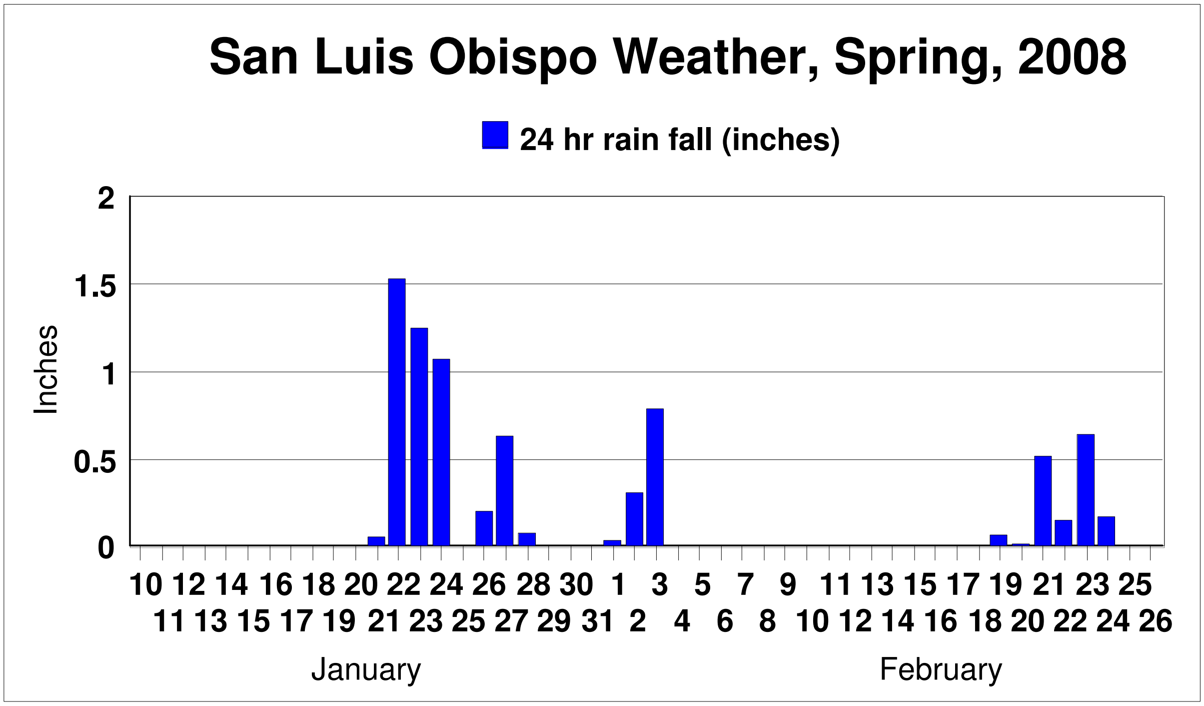


Figure C 41 - Rainfall in the January-February period

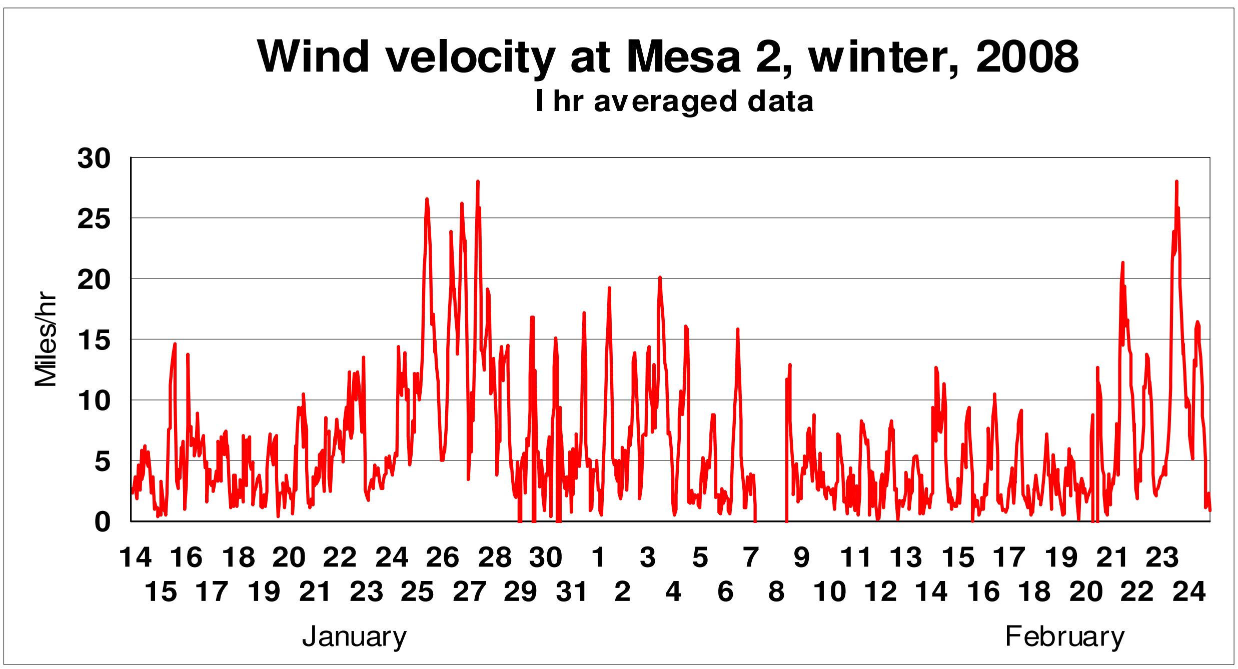


Figure C 42 - Wind velocity at Mesa 2 during the winter study

Below we show a series of time plots from January 14 through February 25, 2008. The plots are segregated by aerodynamic diameter, with the two coarsest modes (10 to 5.0um, and 5.0 to 2.5um) equivalent to EPA-regulated coarse particulate, PM_{10}. Everything below 2.5 is equivalent to EPA-regulated fine particulate, $PM_{2.5}$.

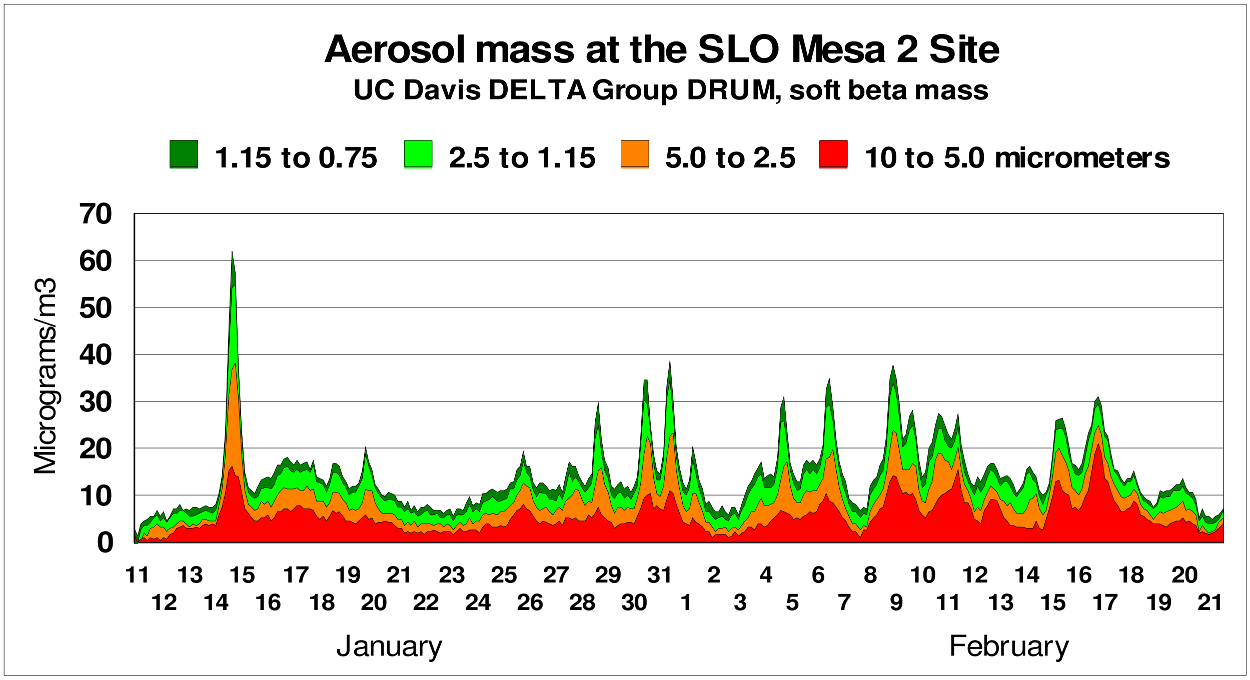


Figure C 43 - Super-micron masses in the January – February DRUM sampling

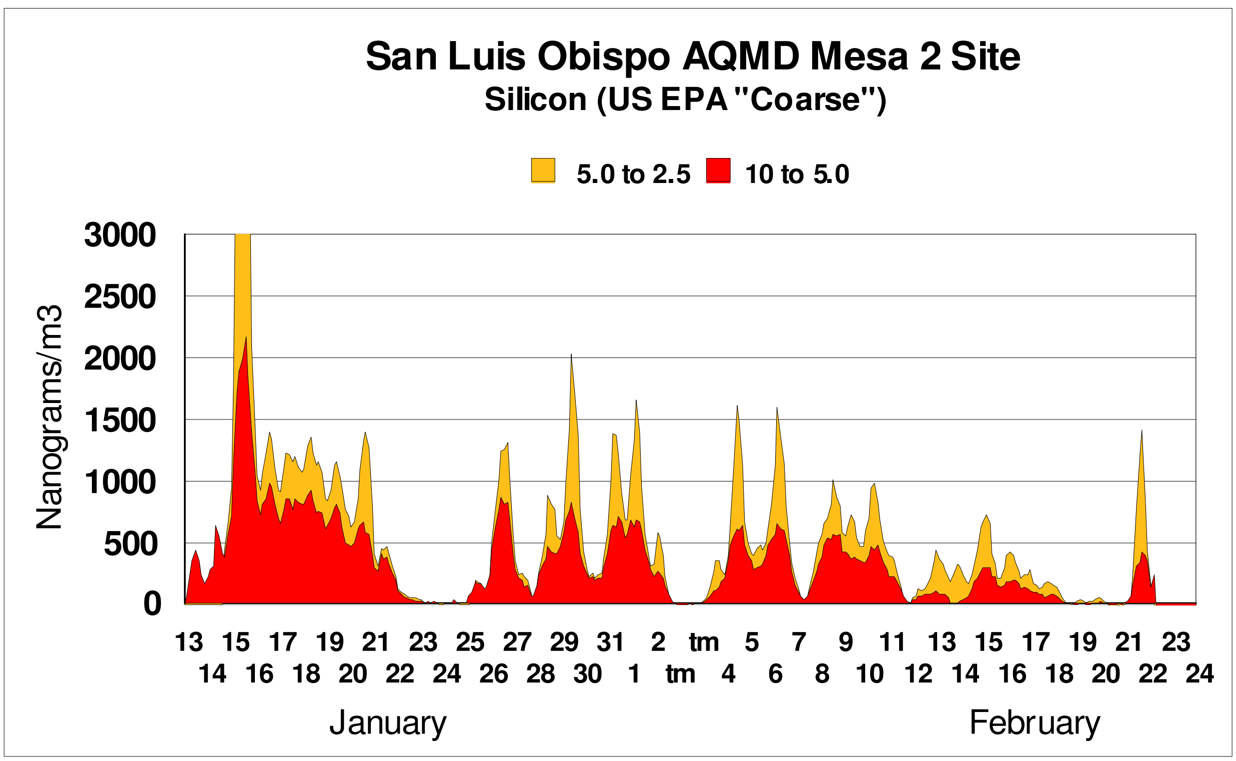


Figure C 44 - Silicon, the major component of soil, in the coarse modes during winter, 2008

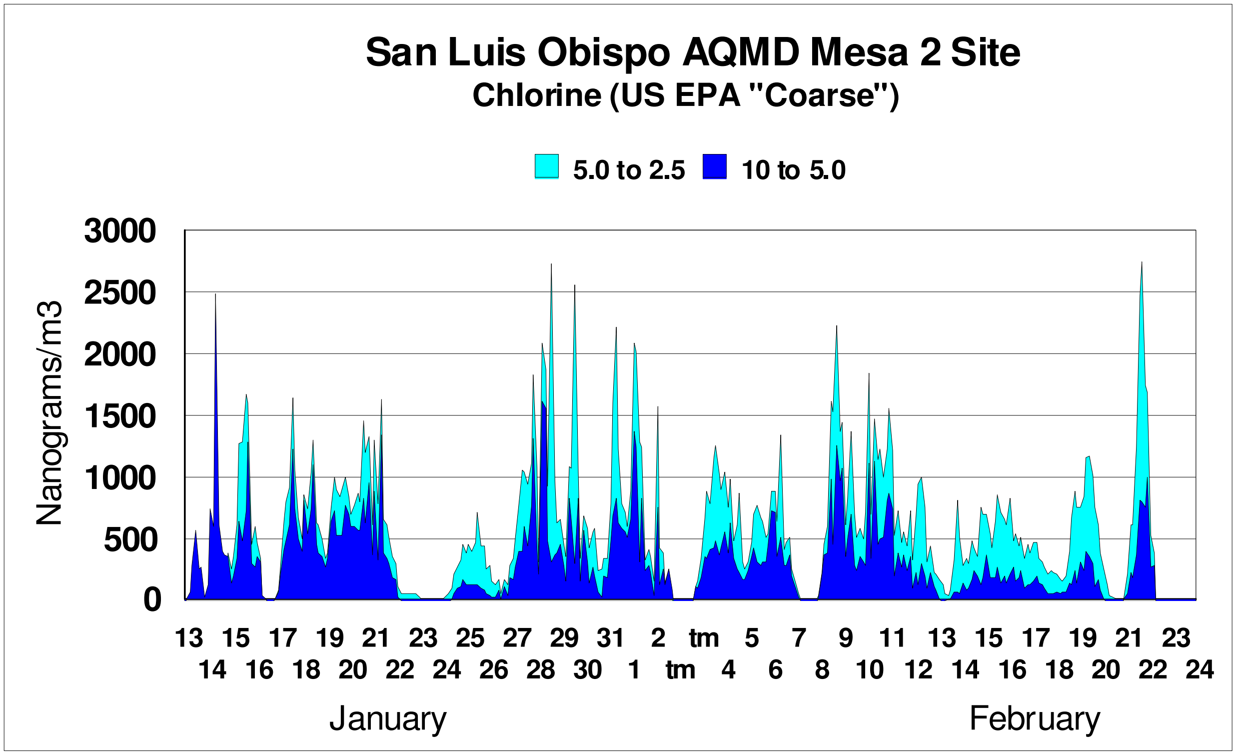


Figure C 45 - Chlorine from sea salt during the winter, 2008 deployment

In this period, we obtained elemental profiles via S-XRF analyses (see Appendix CD-A). The very low values seen around January 21, 22, and 23 are a response to heavy rainfall,, which also occurred around February 20 through 24. The low values around February 4 are a blank section inserted for quality assurance purposes.

Figure 46 below presents the relationship between the soil and salt mass for the January 15, 2008 episode.

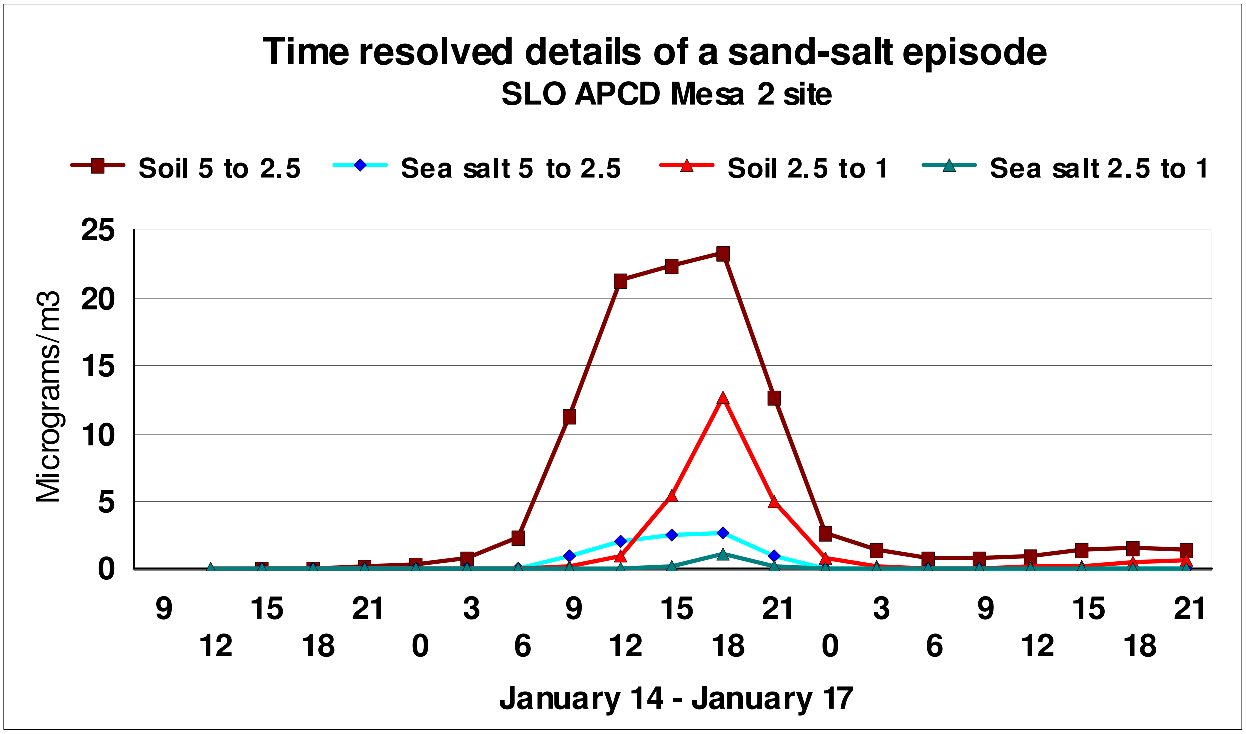


Figure C 46 - Details of a dust episode

The peak of wind velocity and peak TEOM readings occurred in the late afternoon circa 4 PM, but the averaging effect of the finite DRUM slot widths blurs the time record for the coarsest stages. Note how much sharper the soils are in the 2.5 to 1 µm size mode than the 5 to 2.5 µm size mode. The 10 to 5.0 µm size mode averages 4.5 hours (Table 5).

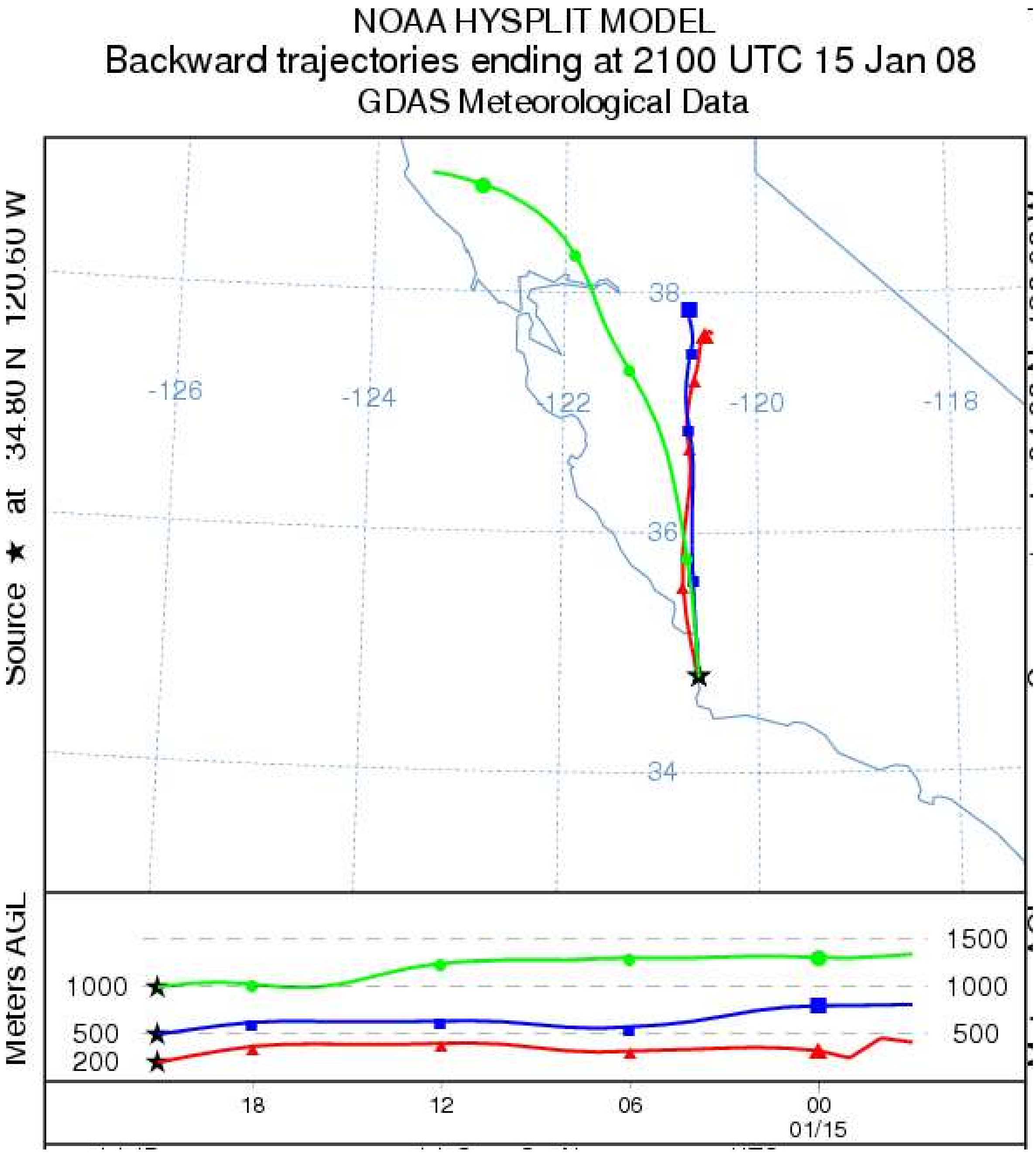


Figure C 47 - Hysplit trajectory analysis of the regional air motion during the January 15 dust event

During the January – February deployment, soil comprised roughly ¾ of all PM_{10} mass on average, with the remainder almost entirely sea salt. However, in the major episodes, such as January 15, the salt was only 10% of the soil. The higher salt values later in the month may be tied to repeated rain events that would suppress re-suspension of soil. Additional information regarding particle size is provided by the DRUM sampler data.

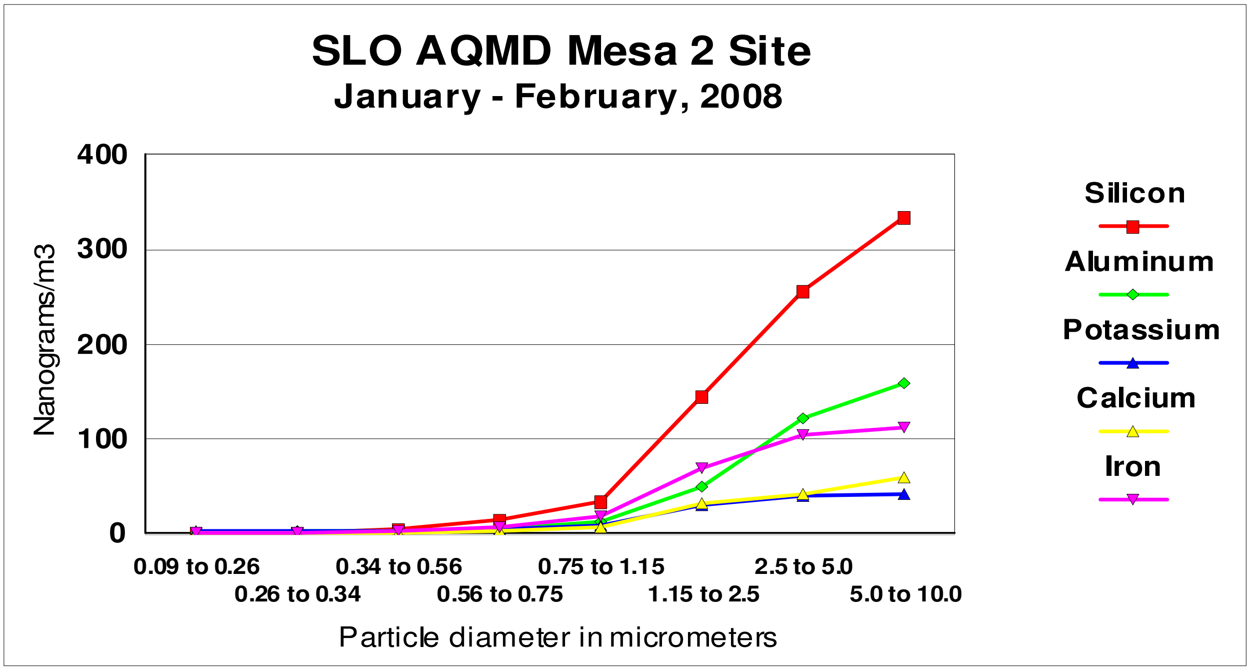


Figure C 48 - Size distribution of the major soil components

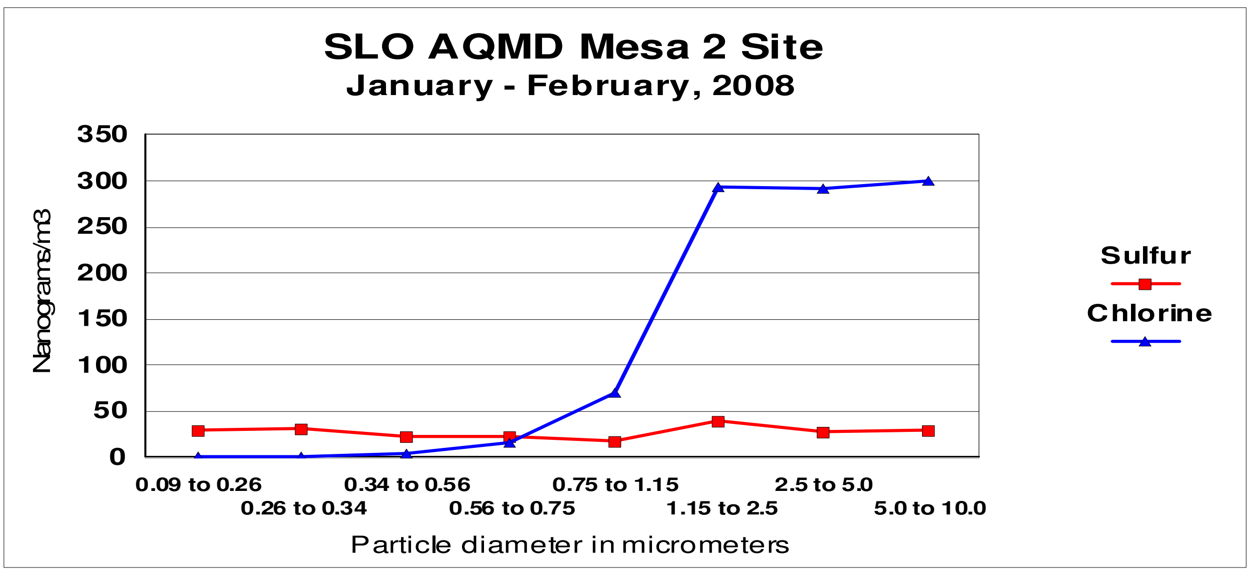


Figure C 49 - Size distribution of chlorine from sea salt, along with sulfur data. The coarse sulfur is from sea spray, the fine sulfur is likely anthropogenic.

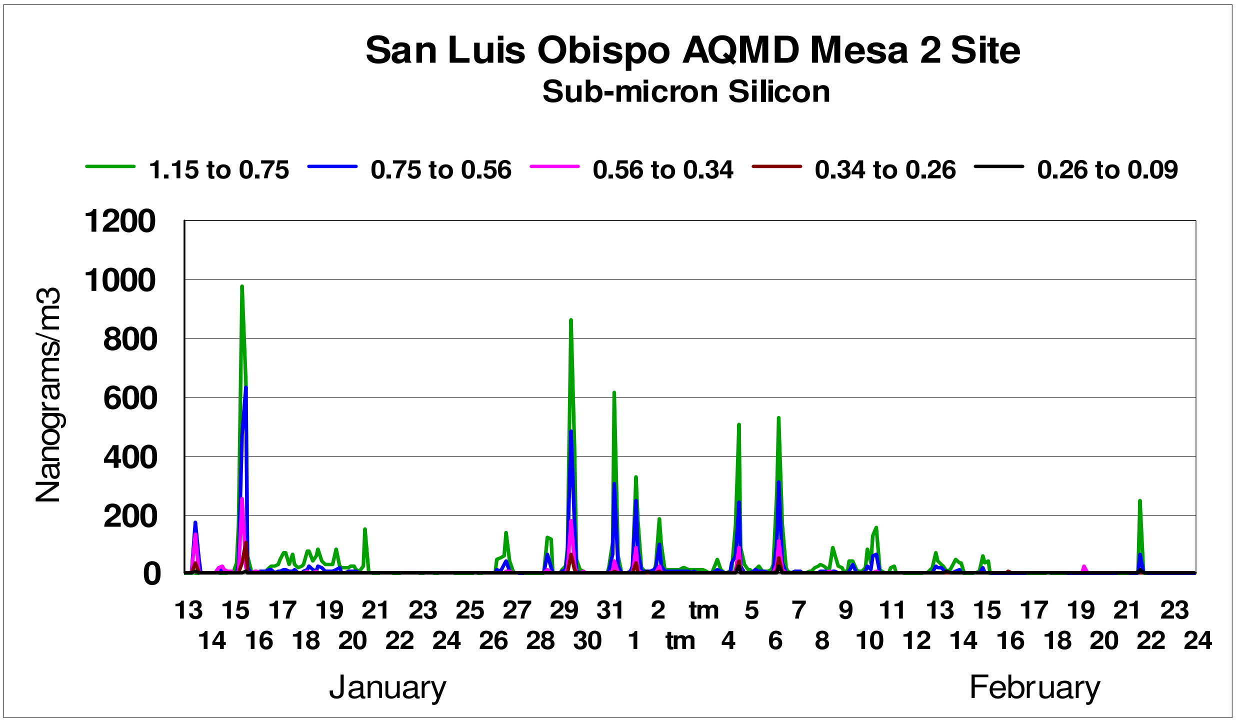


Figure C 50 - Silicon in the submicron or highly respirable fraction, PM1.0, which penetrates more deeply into the lung

The presence of soil-derived, sub-micron particles, shown in Figure 50 above, is unusual; in normal soil-derived aerosols such particles are almost entirely absent below 1.0 µm.

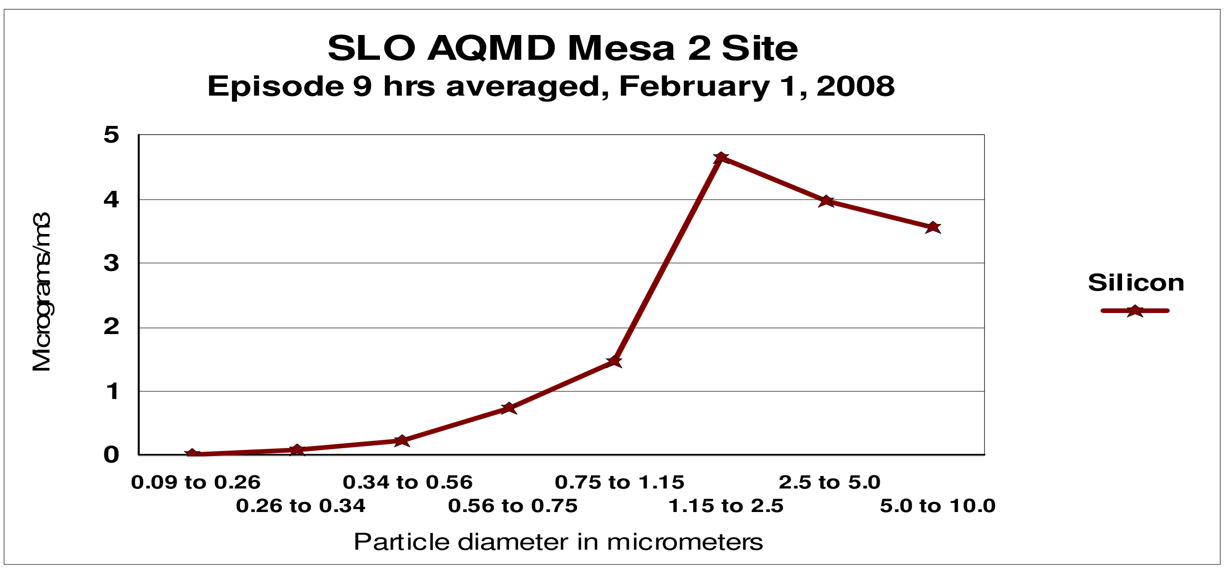


Figure C 51 - Silicon size distribution averaged over 9 hrs in the February 1 episode

Figure 51 above presents an example of the silicon particle size distribution for a small episode during a rainy period. This size distribution would be expected for a source 2 miles away but would not occur from local dust at or dust immediately upwind of the site.

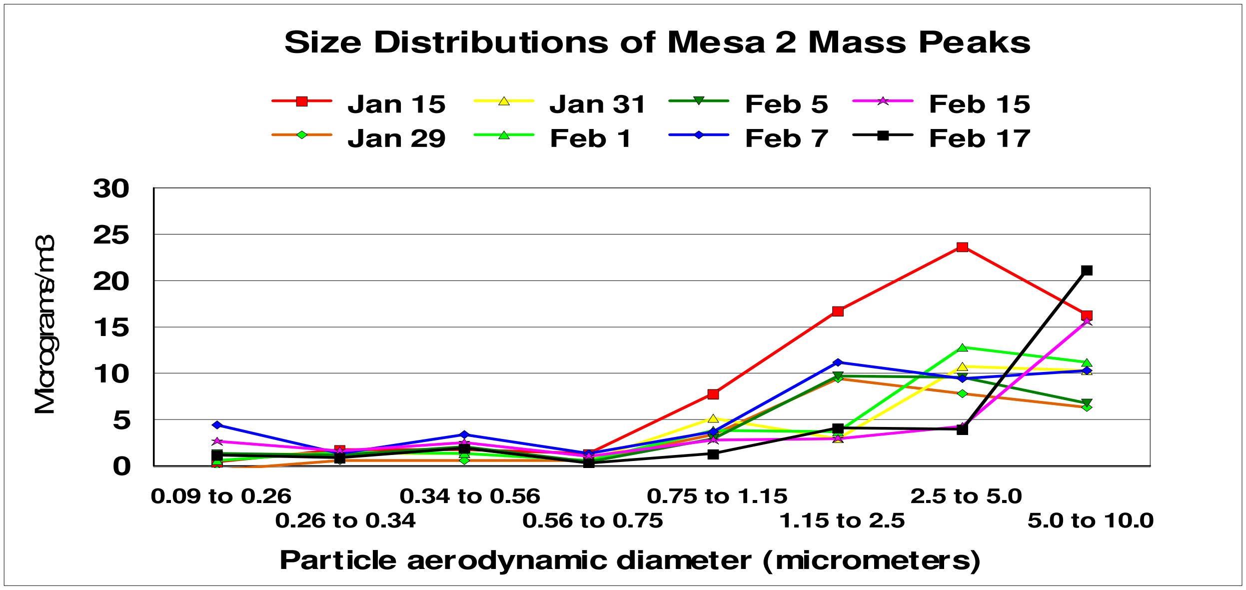


Figure C 52 - Size distribution of mass peaks for episodes

Figure 52 above examines all episodes in the January 14 through February 24 period; the variability in particle sizes shown in this chart is due to changes in meteorology and conditions of the soils. All of the 8 dust episodes shown were accompanied by northwest winds and elevated chlorine levels, indicating a source near the ocean.

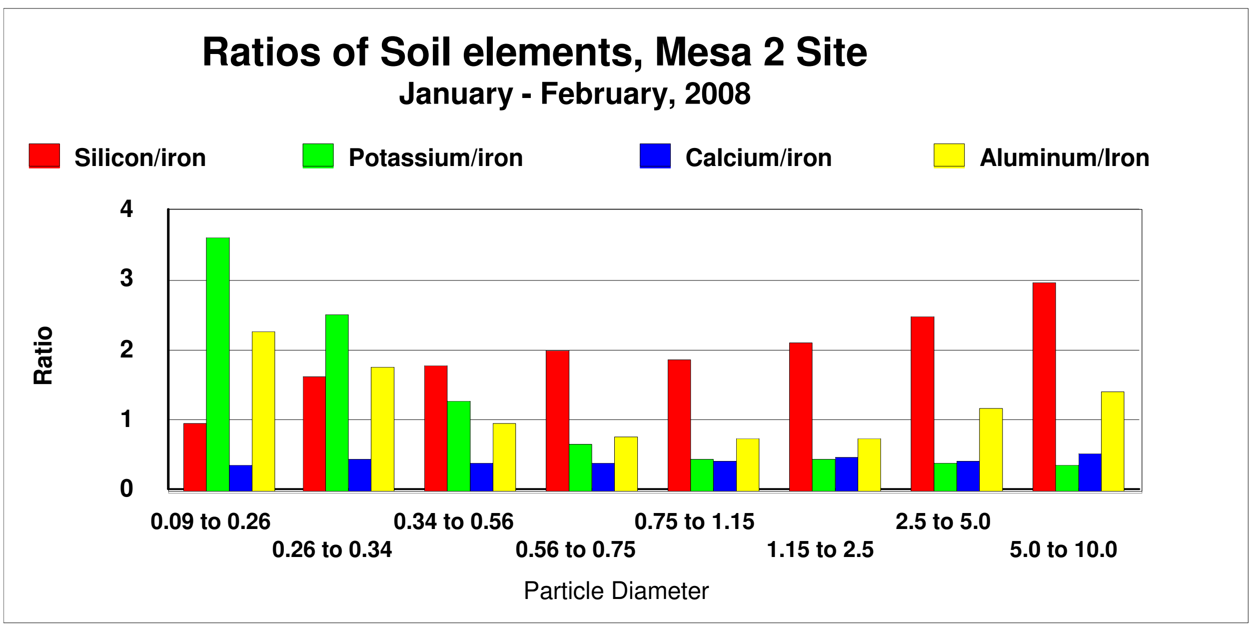


Figure C 53 - Ratios of soil elements in the January – February period

Finally, the ratio of soil elements depicted in Figure 53 above shows a steady progression to a very pure alumino- silicate sand in the coarsest modes.

Analysis of Aerosols and Soils Near the ConocoPhillips Petroleum Coke Pile

These data also give information on the potential impact of the ConocoPhillips coke pile on PM_{10} dust at Mesa 2. The reason to suspect an impact include:

- The petroleum coke pile is one of only two uncovered coke piles in California
- Location of the petroleum coke pile is along the wind trajectory to Mesa 2
- SO_2 levels increase at Mesa 2 when the refinery SO_2 suppression systems are inoperable.
- Photographs and personal observations of dust occurring during transfer of coke to the pile

Heavy oils in California and elsewhere contain sulfur, vanadium and nickel. The latter two in the coarse aerosol modes are robust tracers of coke materials; when present in the fine particle fraction they are good indicators of combustion of heavy oils.

No black particles were seen in the optical scans of the January-February DRUM samples in the coarse size modes. In addition, while vanadium was routinely seen, the three coarsest modes (10.0 to 1.15 µm) are almost exactly on the Earth crustal ratio, and thus are entirely natural in origin; this is supported by the fact that there is no associated coarse nickel. Finally, the soil samples immediately downwind of the petroleum coke piles only showed visible black particles within the first 100 m or so, indicating little transport of large particles from the piles; most of the coke in the piles consists of large particles with relatively few re-suspendable particles.

ConocoPhillips is currently implementing an active mitigation program to reduce the size of the coke piles and suppress dust formation, including watering of the piles. Nevertheless, visual dust was seen during a transfer of material to the petroleum coke pile during the intensive study. An effective and relatively low cost of suppressing these particles would be a series of 2m high sand fences placed across the pile at right angles to the prevailing winds, perhaps every 30m or so. This would reduce wind sheer and reduce or even eliminate any use of water as a dust suppressant and thus provide less stress to ground water beneath the piles. The technique was successfully used at Owens (dry) Lake, and is referenced below in the Mitigation section.

There is evidence that minor levels of aerosols from heavy oil combustion are seen at the Mesa 2 site, but in levels negligible in terms of violations of PM_{10} mass. Figure 55, below plots concentrations of very fine (0.34 to 0.26 µm) vanadium, nickel, and sulfur, signature pollutants for operations using heavy crude oil. Measured levels of these aerosols, however, were less than 0.001 $\mu g/m^3$, compared to PM_{10} mass levels measured in tens of micrograms/m^3 and exceeding 100 $\mu g/m^3$ during PM episode conditions.

Figure C 54 - The ConocoPhillips refinery and coke pile - The ConocoPhillips refinery and coke pile

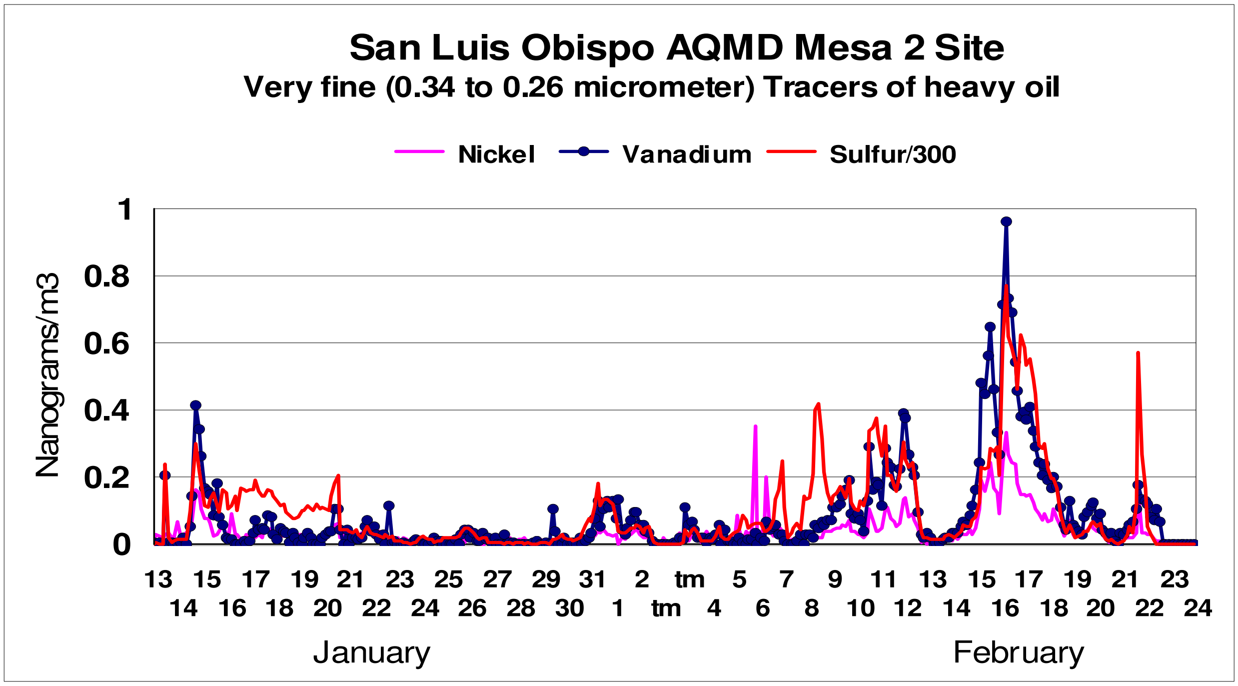


Figure C 55 - Fine aerosol components typical of heavy crude oil combustion

From the resuspended soil data, we see that the entire transect from Mesa 2 to ConocoPhillips has some enrichment of vanadium, with the amount growing by a factor of 70% as one approaches the edge of the petroleum coke pile. There is even some modest enrichment of vanadium at sites generally upwind of the ConocoPhillips facility. No consistent vanadium enrichment is seen in either the Oso Flaco or Bluff transects.

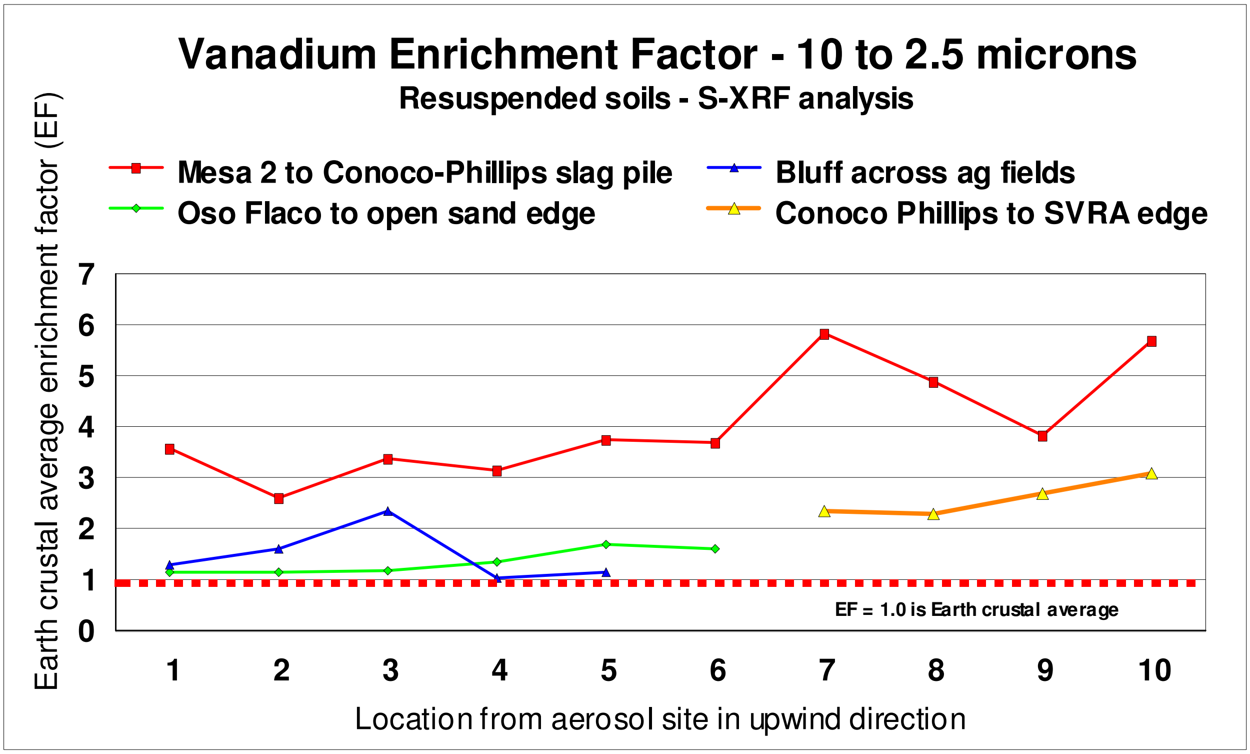


Figure C 56 - Vanadium enrichment factor versus Earth crustal averages

This result is reinforced by the comparison of aerosol measurements between Guadalupe Dunes and Mesa 2, during Fall of 2008. In this 2 month period, Mesa 2 had about 2.5 times more vanadium in the aerosols than Guadalupe Dunes, but largely in the very fine particle fraction as shown in Figure 36. This indicates a combustion source rather than the coke pile. Additionally, the measured amount is very low. This all supports a conclusion that the ConocoPhillips petroleum coke pile was not a significant source of PM_{10} aerosols during this period, despite strong winds and several episodes of enhanced dust.

Part 3: Aerosol Sampling - The Spring Intensive

Background

The heart of the Phase 2 study design is comparing particulate measurements downwind from the SVRA to particulate measurements downwind from a variety of control sites. The intensive monitoring period was designed to provide numerous measurements across the study area to test potential source impacts using DRUM samplers during a period of likely wind/particulate events. Three sites identified as optimum sampling locations (ConocoPhillips, Oso Flaco, and 10 Commandments) were without line power, requiring transport of heavy batteries to each site every few days. In addition to this logistical difficulty, the Oso site experienced a number of periods of sampler failure due to battery/inverter problems.

The picture below shows the heavily instrumented, battery-powered Oso Flaco site with ancillary solar power. All equipment and 100s of pounds of batteries had to be transported manually over ¼ mile of stabilized sand dunes to the site, and thus labor requirements were high. However, it is a key control site for the study as it is most comparable to the CDF site.

Figure C 57 - Picture of the Oso Flaco site

Quality Assurance Side by Side Tests

The full quality assurance protocols for DRUM samplers is included in detail in DRUM Quality Assurance Protocols ver 1/09 (appended in full on the data CD). Before the 10 DRUM samplers (6 8 DRUMs, 4 3 DRUMs) were dispersed to the sampling sites, all were operated simultaneously at the Mesa 2 site to establish equivalency.

Below is shown one such comparison for the Stage 2 particles (5.0 to 2.5 µm). The coarsest particles in Stage 1 had a poorer time resolution because of the width of the DRUM slots and thus could not cleanly time resolve the dust episodes.

As shown in Figure 59 below, side by side tests were accurate within the standard EPA ± 15% quality assurance criterion, with an average of 7.1 $\mu g/m^3$ for all but one of the samplers, with a standard deviation 0.70 $\mu g/m^3$, or ± 10%. Only the "Ten Commandments" DRUM did not meet the EPA ± 15% criterion. For this reason and others, it is not included in the north-south transects.

In addition, we are able to make the 3 DRUM - 8 DRUM comparisons quantitative. For example for Bluff site, both samplers ran and delivered 6 values with a mean aerosol mass of 5.8 ± 0.7 $\mu g/m^3$. For Mesa 2, the value for April 26 was 30.5 ± 0.5 $\mu g/m^3$. For all sites, the 3 peak episodes were very similar with a standard deviation of 3.7 $\mu g/m^3$.

While the comparisons between DRUM samplers were quite good (except the Ten Commandments sampler), the comparison to TEOM data at Mesa2 for the side by side tests did not show good comparability. The DRUM samplers are a research tool and were never designed to be an EPA-equivalent sampling method like the TEOM. One aspect that makes the DRUM/TEOM comparisons difficult is that the DRUM sampler has a time resolution of about 1.5 hours for the finest stages, and up to 6 hours for the coarse stage, while the TEOM data is in hourly averages.

The comparisons at Mesa2 between the DRUM and TEOM showed generally good agreement for 24 hour averages for days where there was not a wind/PM episode, but poor agreement on episode days. On episode days, the TEOM data always showed higher 24 hour concentrations than the DRUM samplers. Close examination of the data showed that the coarsest fraction of the DRUM data appeared suppressed during wind/PM episodes, indicating the possibility of loss of mass on the coarse stages. It is possible the DRUM samplers were overwhelmed during the episode periods by the extreme winds and particle concentrations.

Every particulate monitoring method, including the federally approved methods has various weaknesses. It is very common for a particular method to work well in one application, but poorly in another application. While the TEOM/DRUM comparisons showed poor comparability, the comparisons between DRUM samplers were very good, which ensures that relative comparisons between DRUM sampler data is valid. Conversely, DRUM data related to mass PM concentrations should not and were not intended to be compared to TEOM data or health standards.

8 DRUM Profiles

The charts and graphs presented below in Figures 58 – 65 show DRUM data collected during the spring intensive wind/PM episode periods, as well as related meteorology and PM data collected by the APCD during those same periods.

DRUM samples – Mesa 2 Intensive

Figure C 58 - 8 DRUM strips for the coarsest 5 fractions (from top to bottom) for the March-April intensive period. The white lines are dust episodes

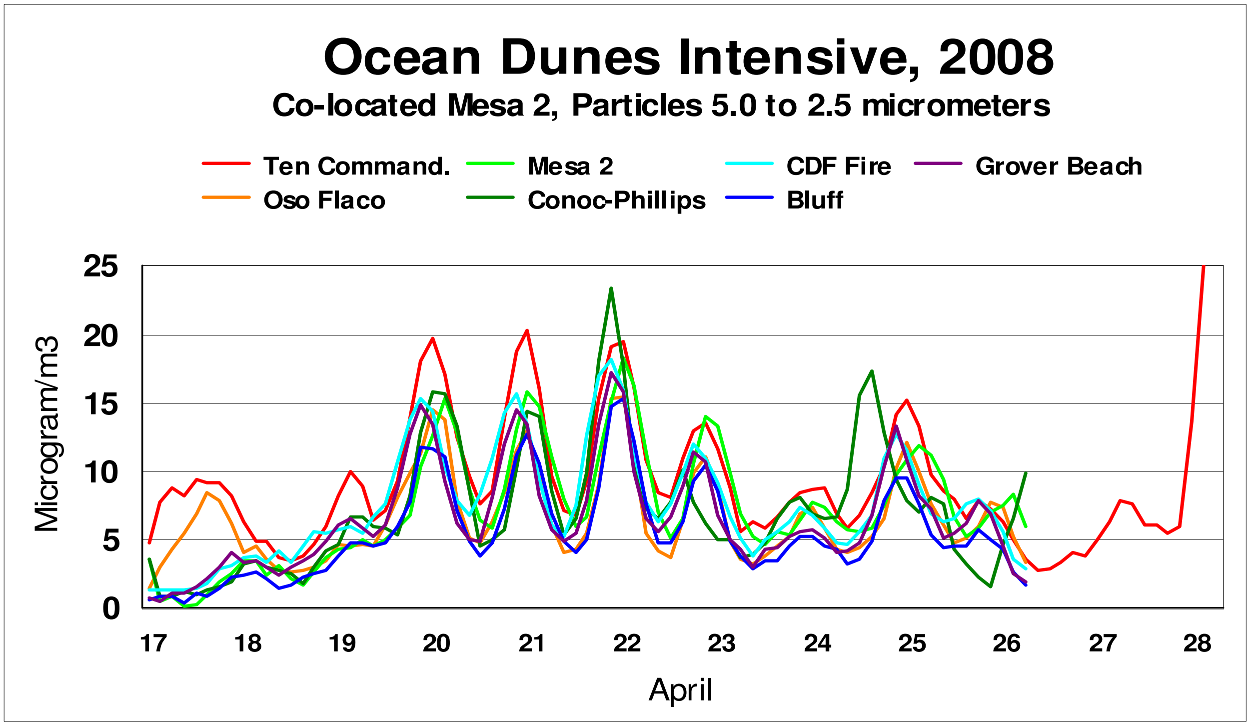


Figure C 59 - Side by side quality assurance tests at Mesa 2

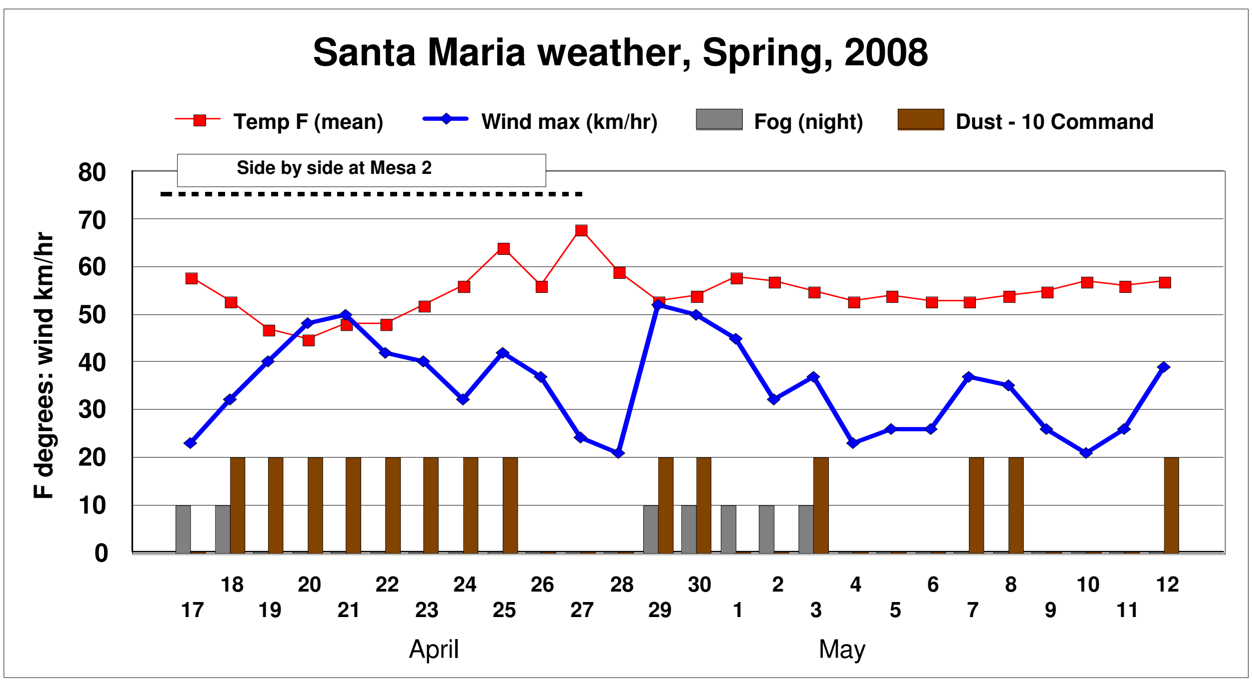


Figure C 60 - Weather at Santa Maria

Spring intensive: 8 DRUM sampling and analysis

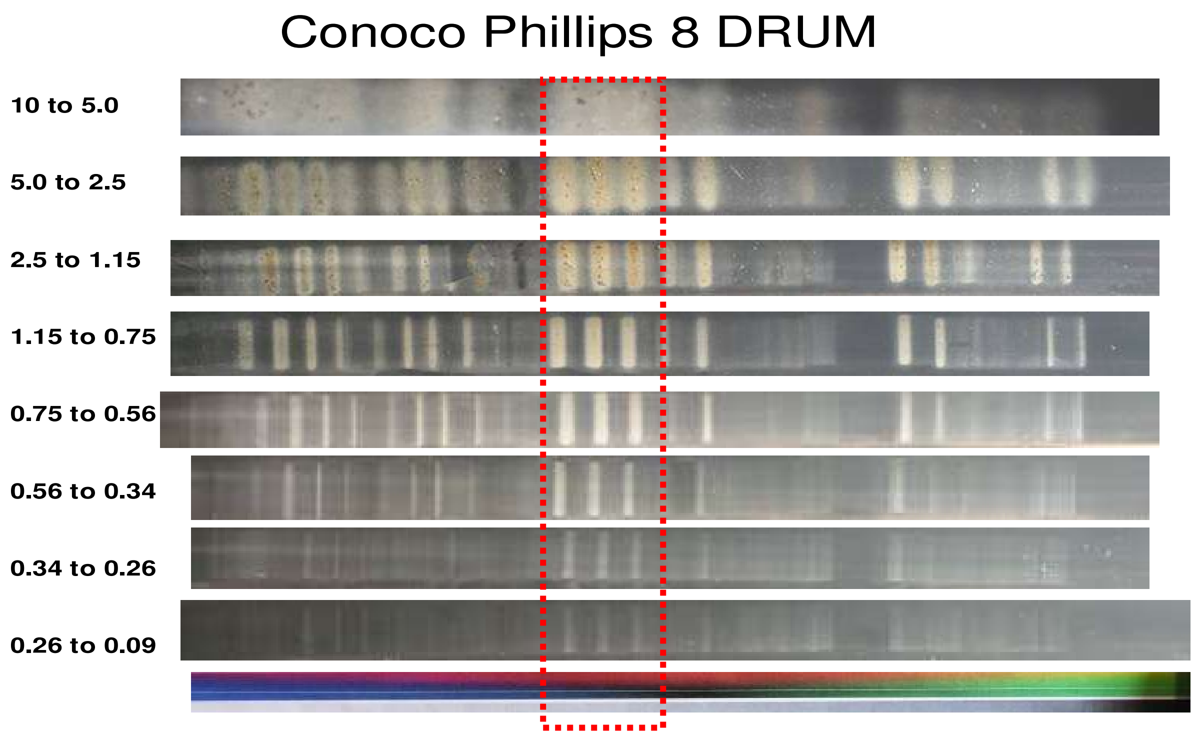


Figure C 61 - DRUM strips from the ConocoPhillips site, showing the April 27 – 30 episodes. The color and black to white fiducial strips are shown at the bottom. The clean area to the right of the episodes is the quality assurance and time check blank entered by the program.

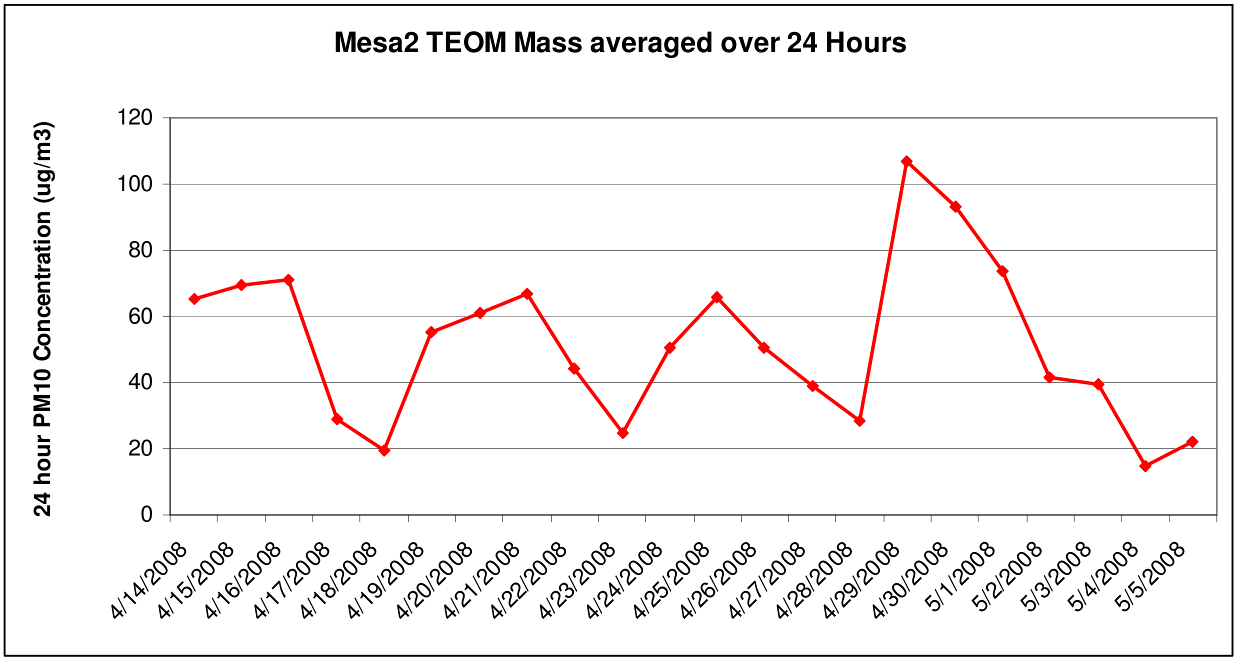


Figure C 62 - 24 hr PM10 from SLOAPCD Mesa 2 TEOM during the intensives

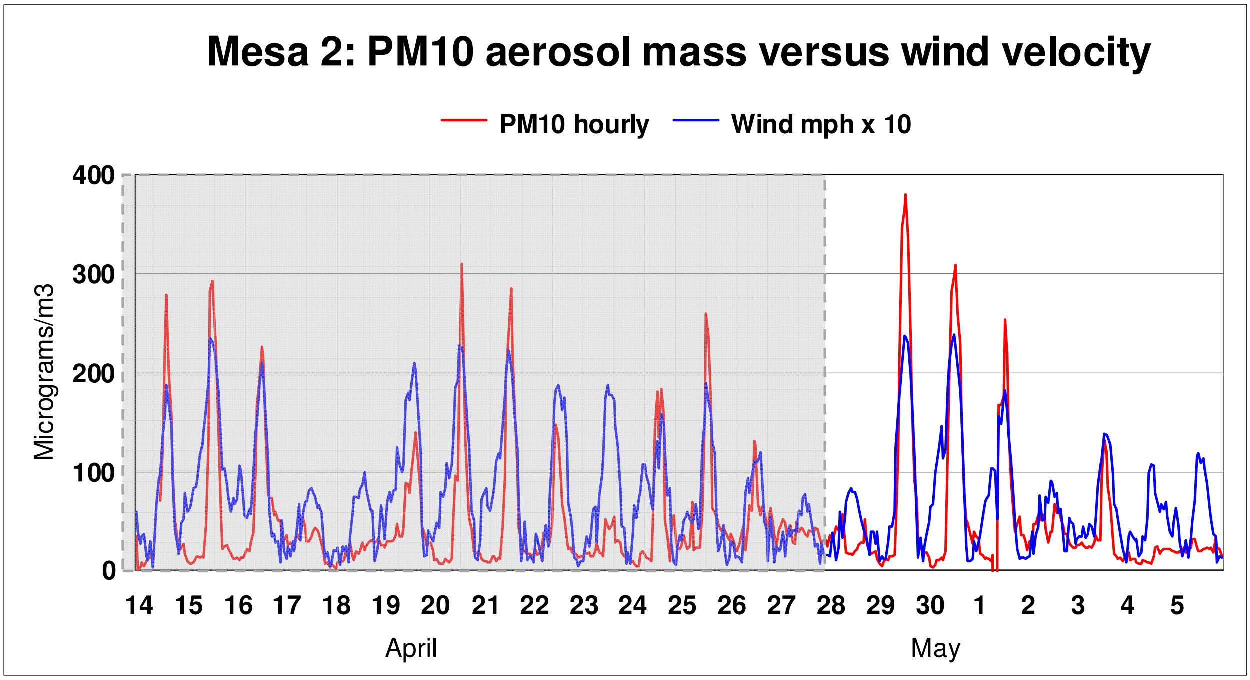


Figure C 63 - 1 hr winds and PM10 from SLOAPCD Mesa 2 TEOM during the intensives

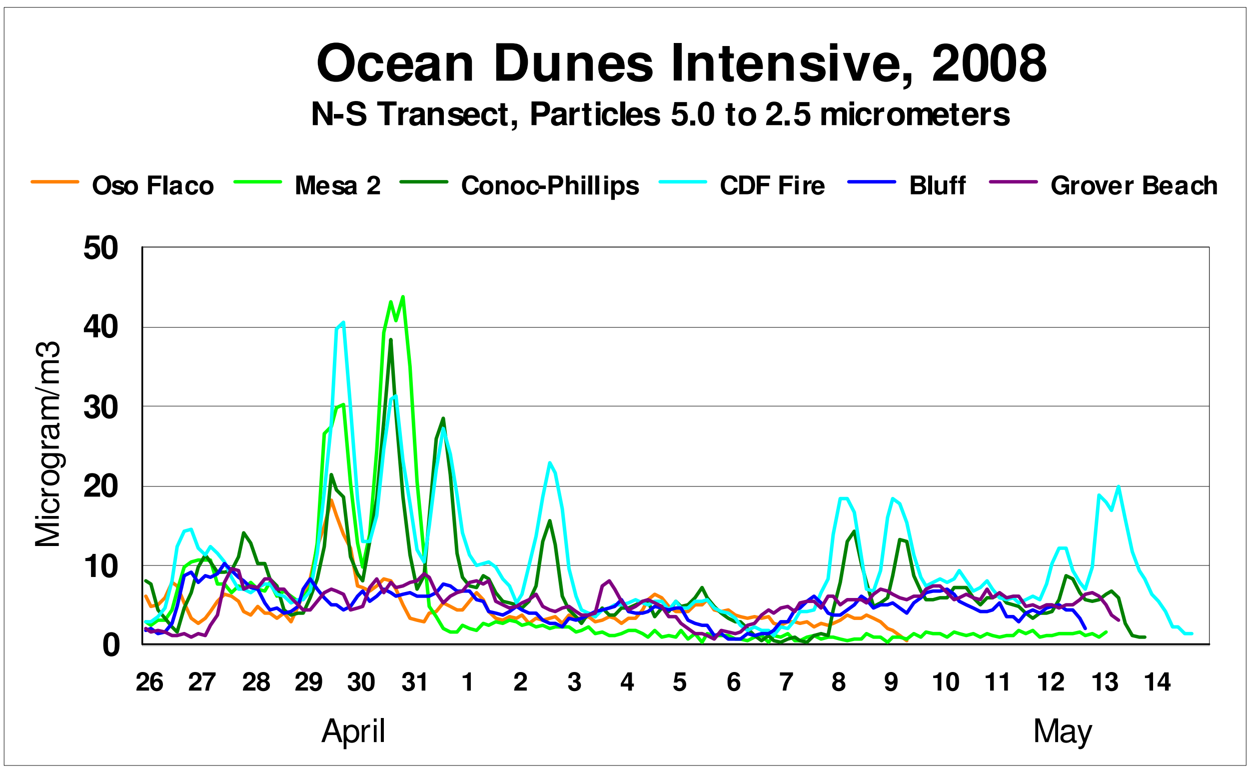


Figure C 64 - 8 DRUM transect to 5.0 to 2.5 micrometer particles. The second ½ of the double Mesa 2 peak on April 30 is an artifact. Note: Oso sampler failed 4/30 and Mesa 2 failed 4/31 data after that point is invalid.

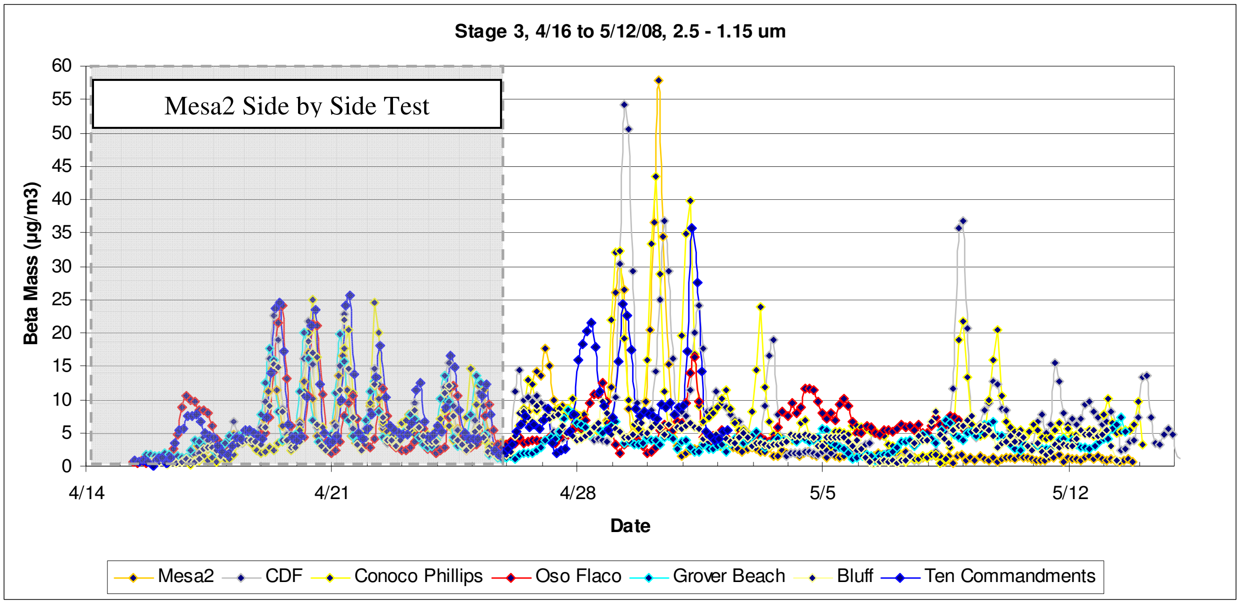


Figure C 65 - 8 DRUM transect, particles from 2.5 to 1.15 micrometers

3 DRUM Profiles

The UC Davis DELTA Group 3 DRUM sampler was first developed by the National park Service in 1993 as the IMPROVED DRUM ideally designed for smoke impact studies. In 2000, 12 more were made for the NSF ACE-Asia study, and deployed throughout the orient, Alaska, and Oregon.

The cut points partially match the standard 8 DRUM sampler: inlet to 1.15 µm, 1.15 µm to 0.34 µm, and 0.34 to 0.15 µm aerodynamic diameter. All other components are identical with the 3 DRUM giving the same 24 mm/day rotation rates as the 8 DRUM. Side by side testing was done to confirm this at Mesa 2 during the quality assurance analysis described above, and at the Bluff and Mesa 2 sites during the general intensive.

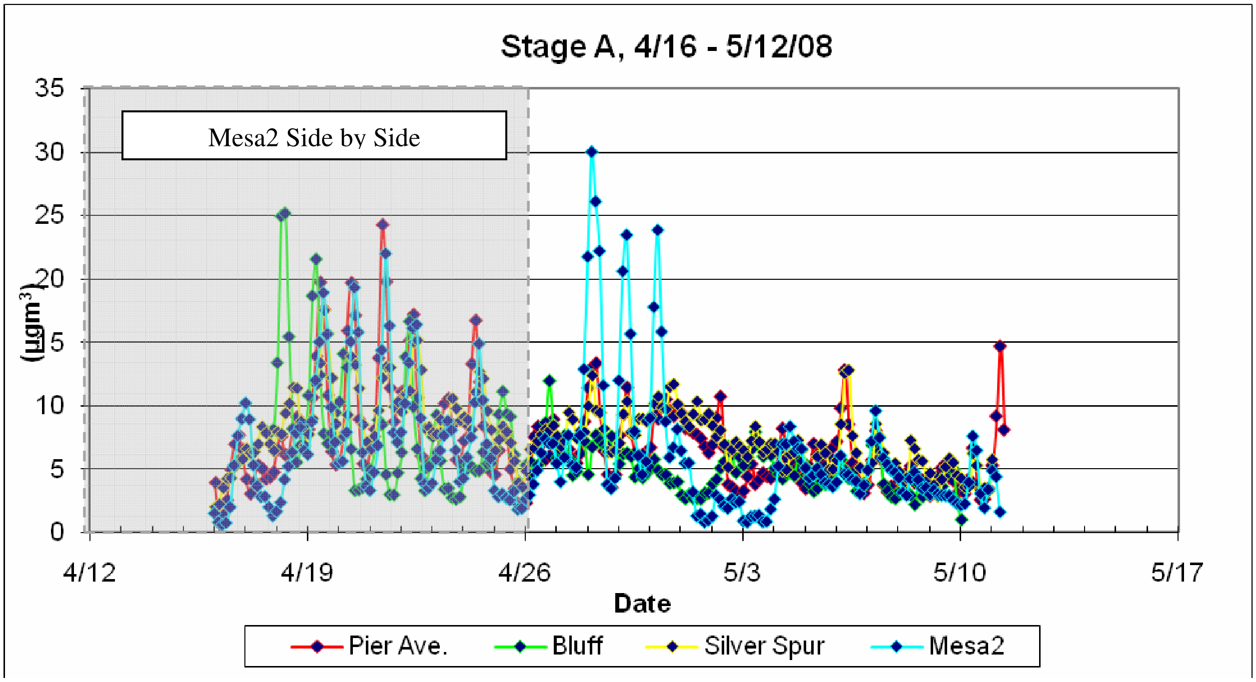


Figure C 66 - 3 DRUM transect, particles from 2.5 to 1.15 micrometers

The good agreement between sample data from Stage 3 of the 8 DRUM (2.5 to 1.15) and Stage A of the 3 DRUM (inlet circa 2.5 to 1.15) seen in the side by side tests at Mesa 2 allows a single transect across the entire array, as shown below, mixing 3 DRUM and 8 DRUM data. In addition, we are able to make the 3 DRUM - 8 DRUM comparisons quantitative. For example for Bluff site, both samplers ran and delivered 6 values a mean aerosol mass of 5.8 ± 0.7 µg/m^3. For Mesa 2, the value for April 29 was 30.5 ± 0.5 µg/m^3. For all sites, the 3 peak episodes were surprisingly similar with a standard deviation of 3.7 µg/m^3.

Note that with the other 8 DRUM stages, the peak 3 hr values exceed 100 µg/m^3 at Mesa2, CDF, and Conoco Upwind.

Analysis and Modeling of Upwind Impacts

The equivalency of both the 3 DRUM and 8 DRUM samplers is established by the side by side tests and the co-located samplers at Bluff. Specifically, the size mode from 2.5 to 1.15 µm was identical for both 3 DRUM (at Pier Avenue, Silver Spur, and co-located at Bluff) and 8 DRUM samplers, so the data from the two DRUM types can be used to generate a complete north to south transect averaging over the three episodes.

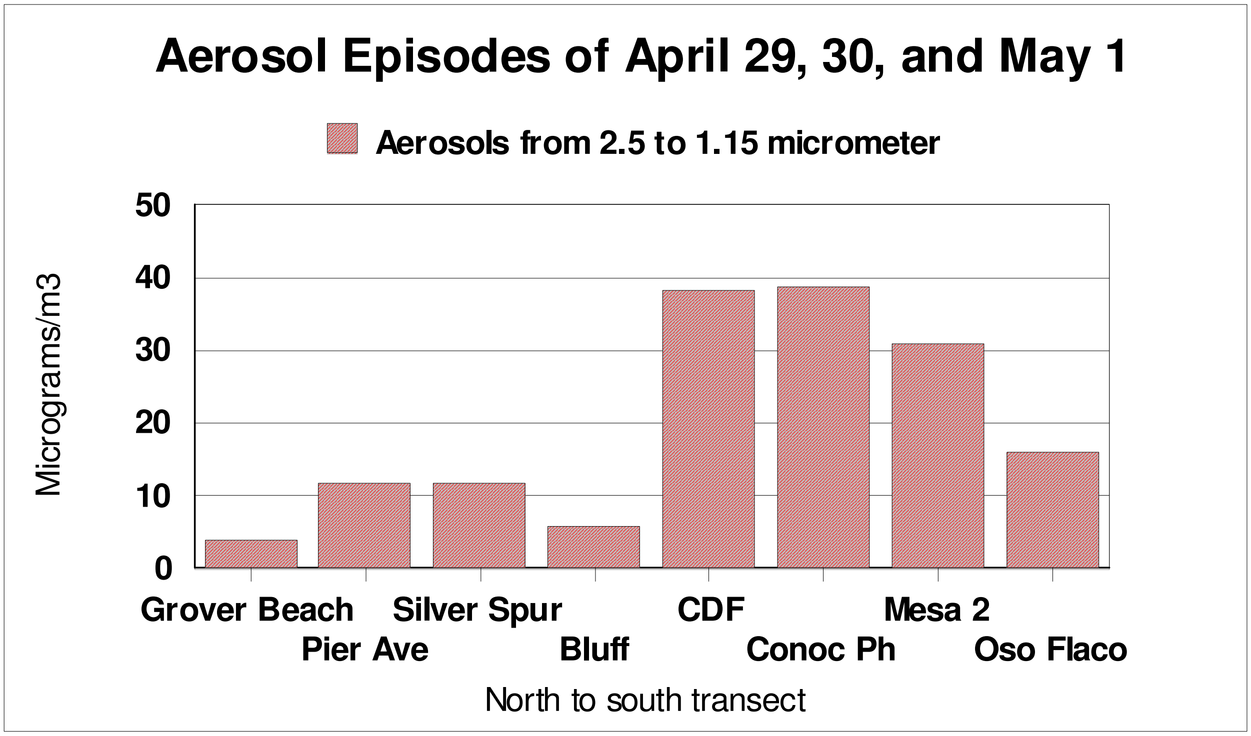


Figure C 67 - Transect across the sampling array for particles between 2.5 and 1.15 micrometers, averaged over all 3 daytime episode peaks April 29 through May 1. (Note that, due to sampler failures, the Oso data represents only 4/29, and Mesa 2 represents only 4/29 and 4/30. Data from TEOM monitors show 4/29 was the highest PM episode, followed by 4/30; 5/1 was the lowest.)

We can provide an additional plot without the Pier Avenue and Silver Spur sites for m8 DRUM samplers only, and now add the larger size mode, 10 to 5.0 and 5.0 to 2.5 µm.

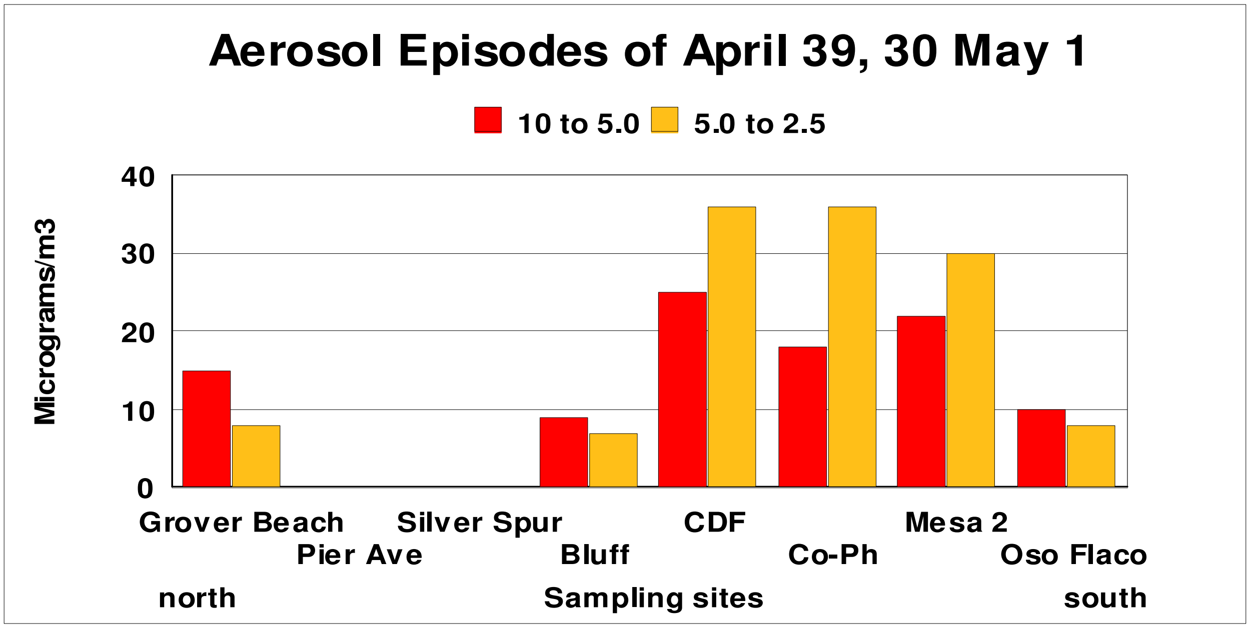


Figure C 68 - Transect across the array for particles between 10 and 5.0, and 5.0 to 2.5 micrometers, averaged over all 3 daytime episode peaks April 29 through May 1.

As shown in Table 1, each site is characterized by the upwind conditions into 4 categories – sand (vehicular traffic), sand (undisturbed), vegetation and farm lands. The amount of each type was then calculated for each site.

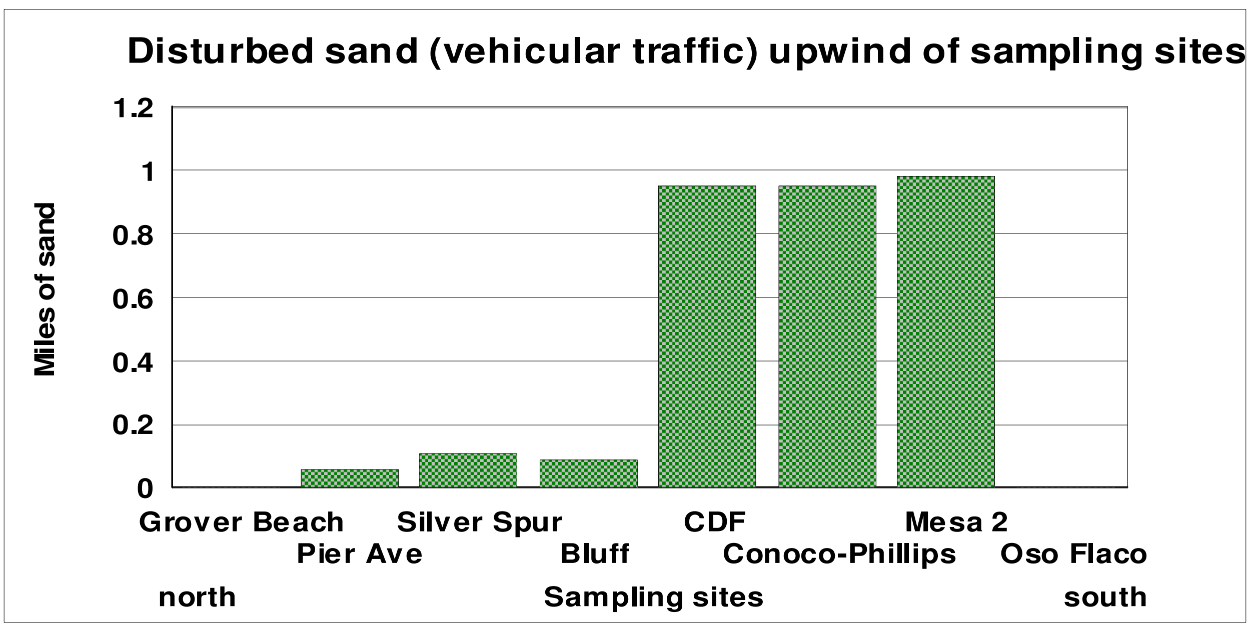


Figure C 69 - Fetch of vehicular disturbed sand upwind of sampling sites

Thus, the presence of high dust levels on the April 29, 30 and May 1 episodes was well correlated with the amount of vehicularly disturbed sand upwind of the site.

Part 4: Summer – Fall Continuation

DRUM monitoring was continued beyond the Spring Intensive. After evaluating the early mass data, it was decided to add a long term sampling site at the Guadalupe Dune Center in Guadalupe. This was done because the site was downwind of the relatively undisturbed dunes of the Santa Maria oil field and provided a longer term record than could be obtained at the very valuable but labor intensive Oso Flaco site. The site also is about the same distance from the ocean as the Mesa 2 site, as opposed to the Oso Flaco site which was quite close to the ocean.

Figure C 70 - Photograph of the oceanic edge of the Santa Maria oil field, looking north from the "10 Commandments" site. The type of vegetation seen on the distant dunes extends north to Oso Flaco and is thus upwind of Guadalupe Dunes.

Sampling was begun in early September and continued until late November, after which dust episodes tend to be less intense and rainfall is to be expected. To make the comparison, we only used the DRUM stages that gave 5.0 to 0.75 µm particle diameter because the first stage, 10 to 5.0, has such a large time averaging; it averages out the peaks and is hard to align with meteorology. The three stages summed however, are typically 2/3 of all the mass seen in the DRUM. Note that even these stages still average over several hours and therefore do not record the very short term, intense episodes seen by District TEOM samplers.

Figures 71 and 73 below compare the daily 5.0-0.75 um particle mass measured at Mesa 2 and Guadalupe Dunes during the fall sampling period.

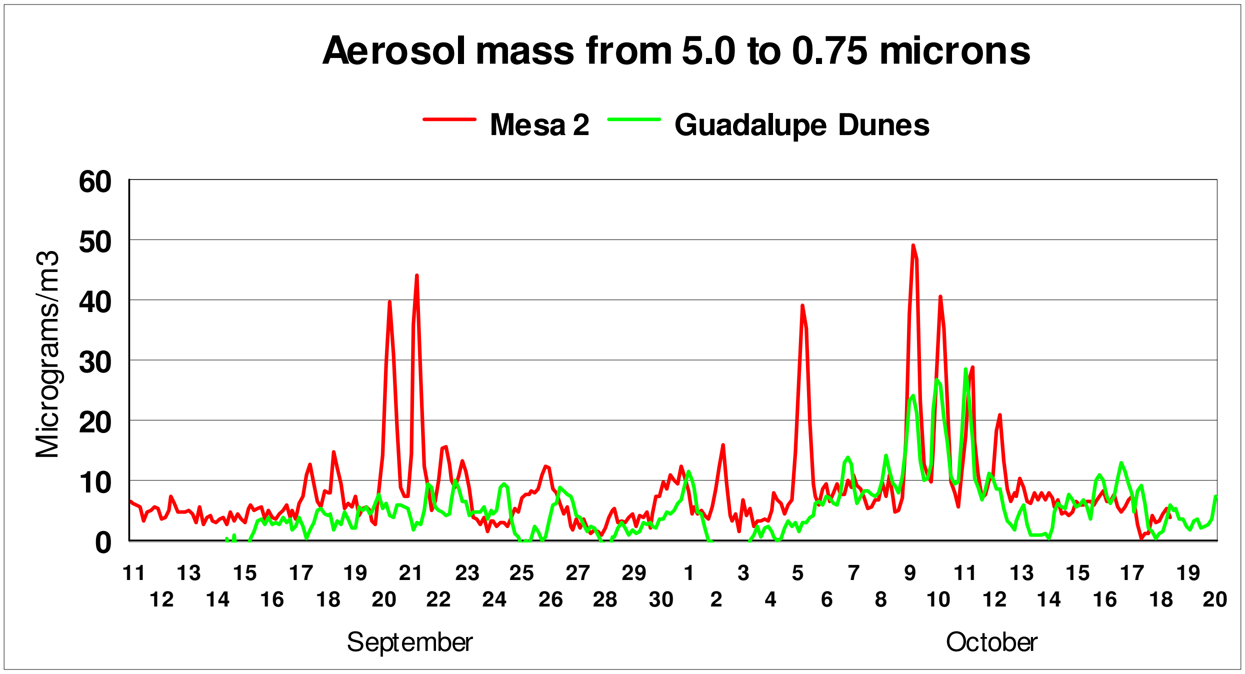


Figure C 71 - Mesa 2 to Guadalupe Dunes comparison, summer and fall, 2008

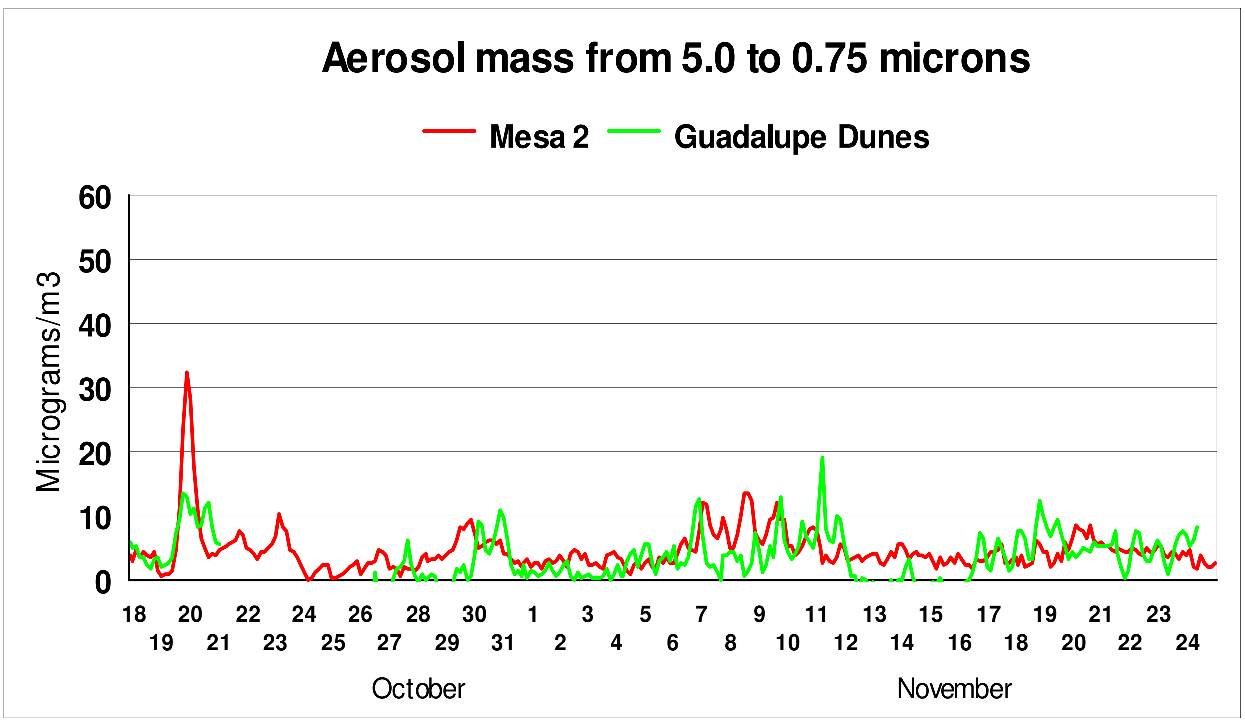


Figure C 72 - Mesa 2 to Guadalupe Dunes comparison, fall, 2008

Figure73 below compares the sea salt tracer, chlorine for the Dune Center and Mesa2 sites.

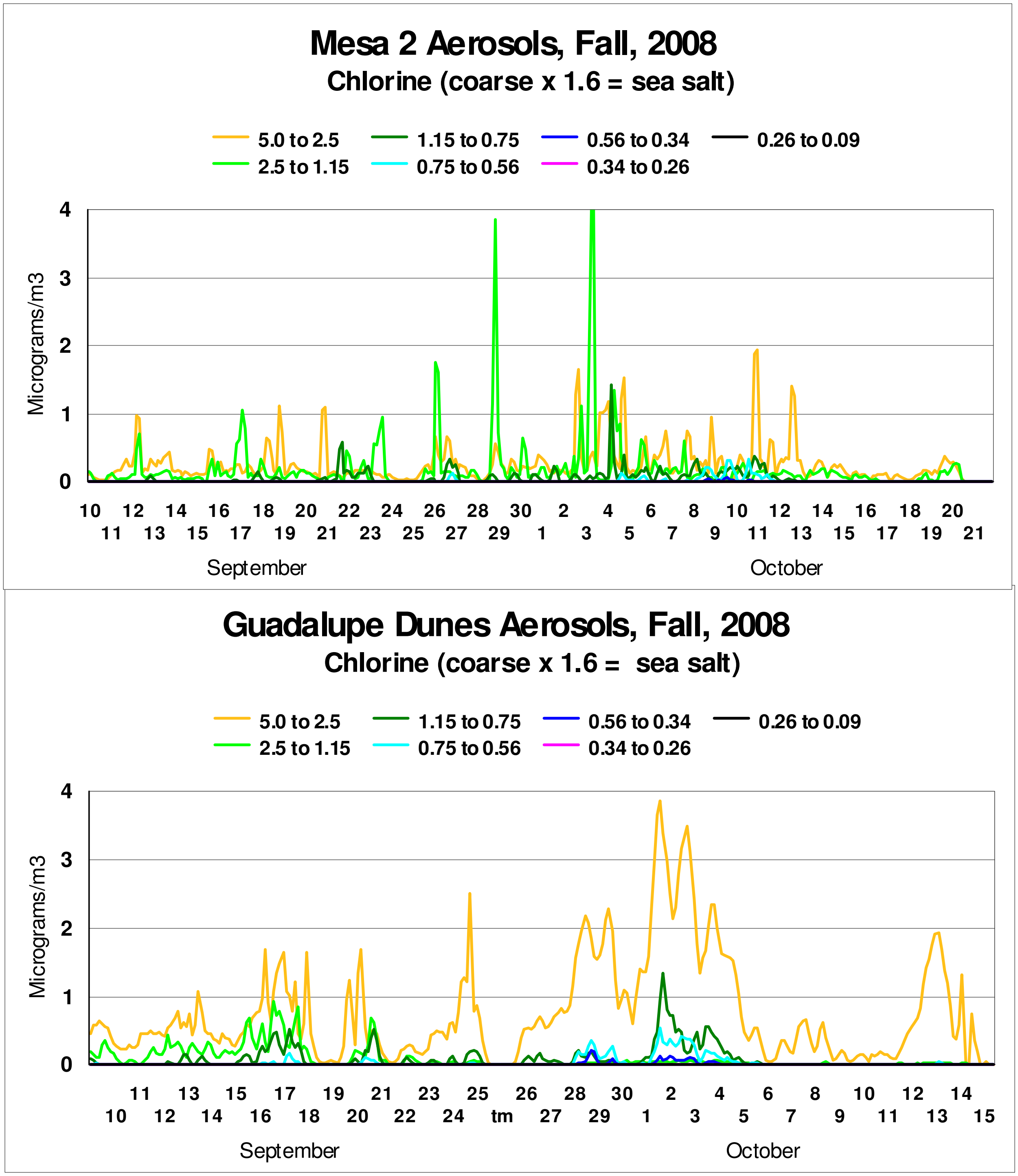
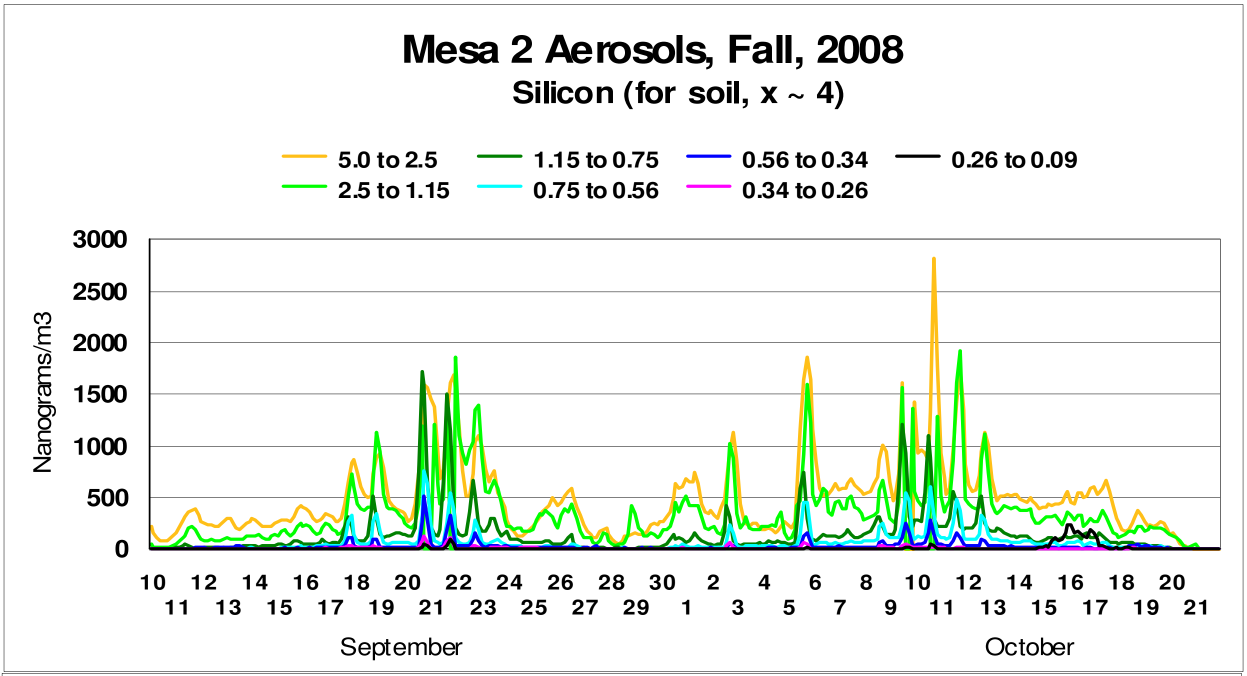


Figure C 73 - Mesa 2 to Guadalupe Dunes comparison, summer and fall, 2008, for chlorine, a tracer of sea salt

More sea salt is seen at Guadalupe Dunes than Mesa 2, possibly a reflection of the lower elevation of the Guadalupe Dunes sampling site as compared to Mesa 2 and/or the higher windspeeds measured at the mouth of the Santa Maria Valley.



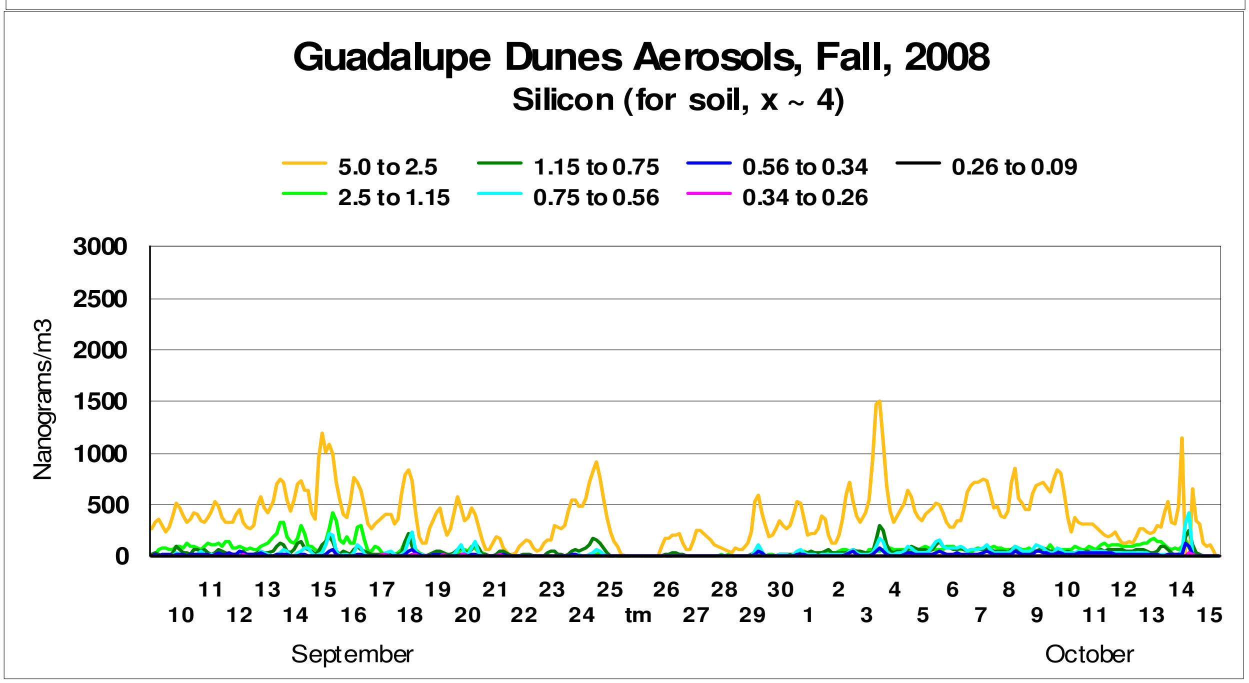


Figure C 74 - Aerosols below 5.0 µm size mode plotted on the same scale at both sites to emphasize the lower soil values at Guadalupe Dunes.

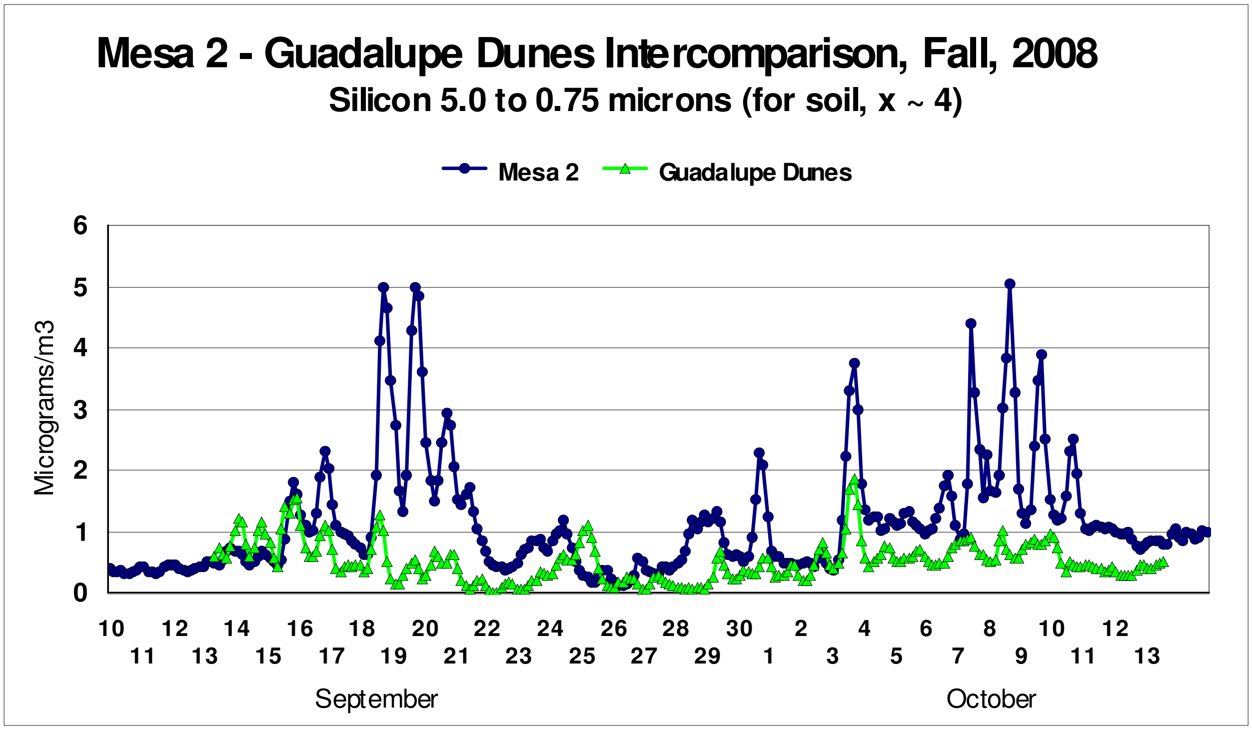


Figure C 75 – Mesa2 to Guadalupe Dune Center Comparison for Silicon 5-.75 microns

In summary, the figures above, dust episodes in the summer-fall period are far less intense (average 18.5 %) at Guadalupe Dunes than Mesa 2, with only rare exceptions. By mid-November, episodes are much weaker and the results at the two sites similar. Note that in the April intensive, the ratio of Oso Flaco to CDF/C-F/Mesa 2 was 25%. In summary, the Guadalupe Dunes – Mesa 2 summer-fall comparison strongly supports the results of the Spring Intensive, showing that sites with undisturbed sands upwind have far less dust than those sites downwind of disturbed soils.

Part 5: Analysis of Mass Components at Grover Beach

Grover Beach is an APCD monitoring site with an extensive record of gaseous pollutant and meteorological measurements. It lies close to the ocean and directly downwind of an area of grass, then vegetated dunes, and finally a beach area with no vehicles. Figure 76 below shows the land areas upwind of this site.

Figure C 76 - Dune and beach area upwind of the Grover Beach sampling site

The three figures below present S-XRF analyzed DRUM data for the Grover Beach monitoring station for the spring intensive period. The shaded portion of each graph shows the side by side quality assurance comparisons performed at Mesa 2; the unshaded portion shows the data from the Grover Beach site.

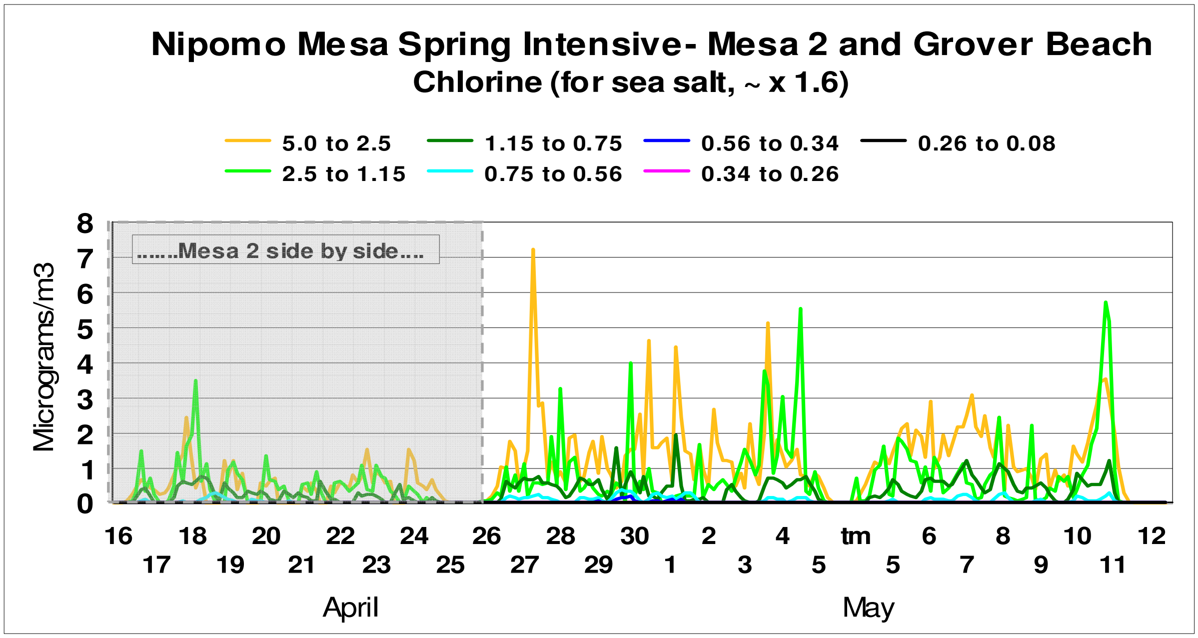


Figure C 77 - Chlorine a sea salt tracer at Grover Beach. Mass between 10 and 5.0 were eliminated due to overflows in the S-XRF detector at Mesa 2.

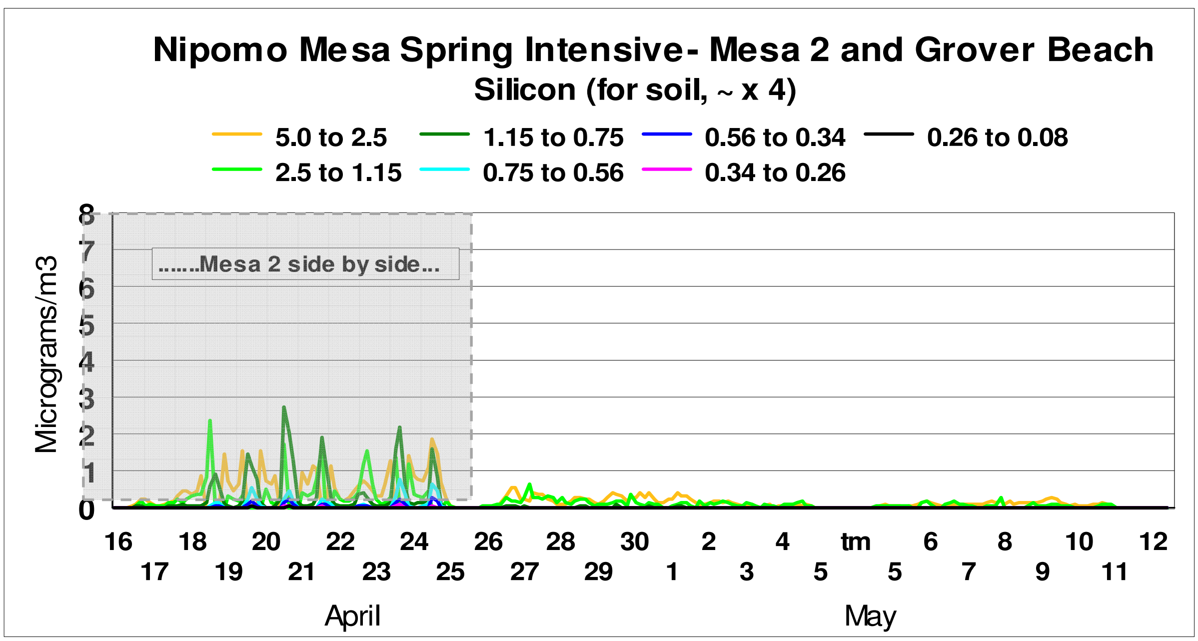


Figure C 78 - Silicon a soil tracer at Grover Beach on the same scale as the chlorine

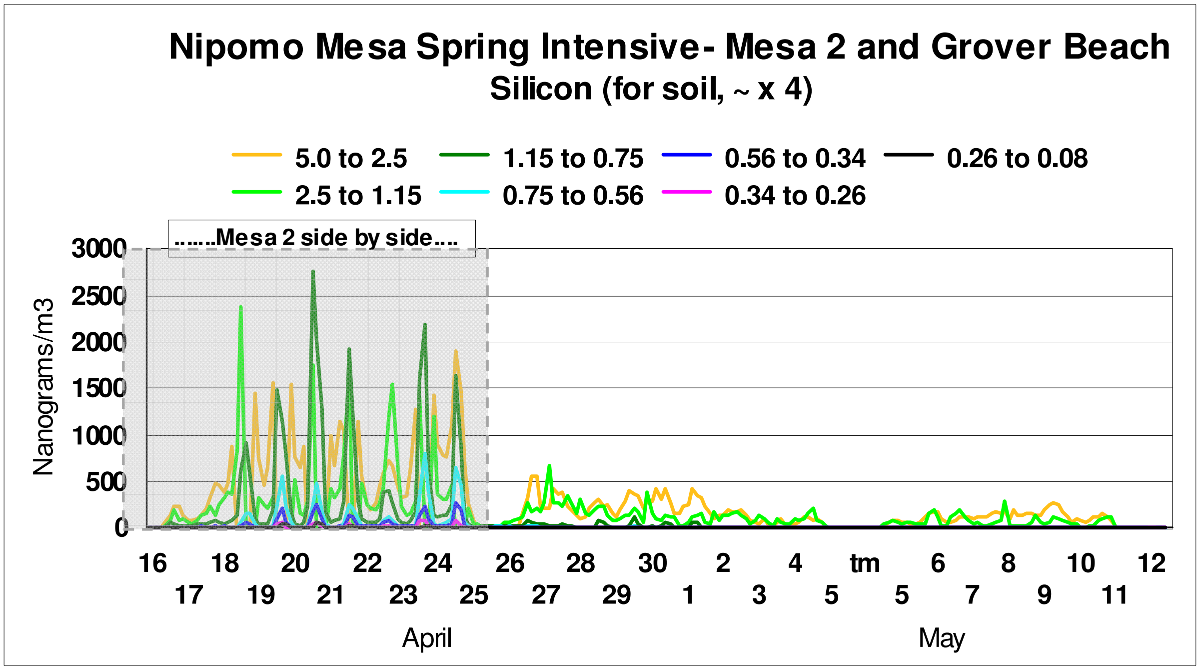


Figure C 79 - Silicon a soil tracer at Grover Beach. Note the scale change to the one typically used at other sites in the Spring intensive.

As shown in Figures 77, 78 and 79 above, there are very high levels of seas salt and an almost total absence of earth crustal material in the samples taken at Grover Beach. This strongly supports the hypothesis that an undisturbed vegetated dunes and a beach area without vehicles does not generate soil mass.

Part 6: Mitigation Options

Finally, from these results and those of other parts of the study, mitigation protocols can be developed. The key facts are over the disturbed areas, greater dust is entrained into the air at a given wind velocity than over undisturbed sands. The data from Oceano Dunes, and other areas such as Owens (dry) Lake, show that sand motion across the surface is a key factor in liberating or, in some cases, creating PM10 dust from sand and soil. The other point is that these events are relatively infrequent, occurring especially in late winter and spring; and that while very intense, last at most a few hours. There are three major options:

1. Lower the wind velocity at the surface,
2. Trap and restrain blowing sand and thus reduce saltation, and
3. Make the surface less resuspendable at a given wind velocity

Lower the wind velocity

Vegetation

Lowering the wind velocity is the natural situation when sand becomes re-vegetated. Bushes grow up and reduce the wind sheer, mediated by the z_o displacement parameter. From the comparison with the vegetated sites, and especially the Oso Flaco transect, it is clear that this is an effective and ecologically sound approach that both reduces dust and returns the landscape to a more natural condition**.**

California Parks already is making efforts in this regard. Existing areas of vegetation, much reduced from natural levels, are being protected by sand fences. This is especially effective in the area just inland from the heavily traveled beach zone and, if extended north and south, could provide a barrier to sand motion originating in the disturbed beach zone.

Mechanical (Sand Fences)

Sand fences are a highly effective way to reduce surface wind velocity as well as trapping sand. The method has been highly developed and tested at Owens (dry) Lake, and numerous other studies attest to their effectiveness, including 2 reports of the State Lands Commission, an Air Resources Board study and considerable work by the Great basin Unified APCD, supported by 11 refereed papers,. (Appendix C) The situation is made easier by the data from the BSNE sand towers showing that almost all sand motion is in the lowest 10 cm, so that a short (1 m – 3.3 foot) high fence would trap the sand. This might be the preferred way directly west of the Sand Highway.

Trap and retain blowing sand

Vegetation and Mechanical (see above)

Both techniques above effectively trap sand

Figure C 80 - State Lands Commission/UC Davis sand fence array at Owens Lake

Sand dunes have started to build up behind fences. Surface in foreground is playa salt crust, which does not generate dust without saltating sand.

Figure C 81 - Detail of partially built sand dune

When completed, the entire fence is buried except for about 6" of webbing. Note that the material was computer matched to the color of the lake bed, making the fences far less evident to the eye.

Make the surface less resuspendable at a given wind velocity

Maintenance of sand crust.
By barring traffic over the sand, crust will naturally develop and stabilize the surface. Conversely, one possibility that could be evaluated is spreading sea water on the sand; the wetting plus the salt will encourage and strengthen crust development. This must be supported by restrictions on travel over the sand.

Acknowledgements

The DELTA Group gratefully acknowledges the intellectual and financial support of the staff and leadership of the San Luis Obispo Air Pollution Control District, and especially Joel Craig and Larry Allen, APCO. The financial support of EPA Region IX, and the encouragement of its staff, especially Meredith Kurpius, is warmly appreciated. Numerous discussions with CA State Parks personal and CA Geology were important in the design of the experiment.
We would like to especially acknowledge the exceptional efforts of Prof. Kevin Perry, U. Utah, in last minute reductions of almost 1.4 million S-XRF data just before Christmas, 2009.

References

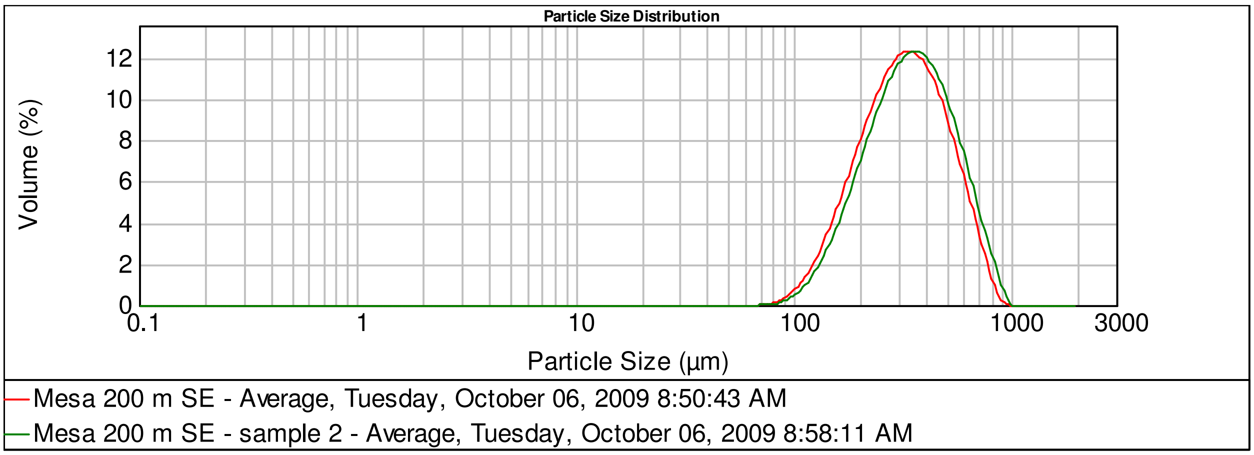
(see Appendices B and D)

Appendices

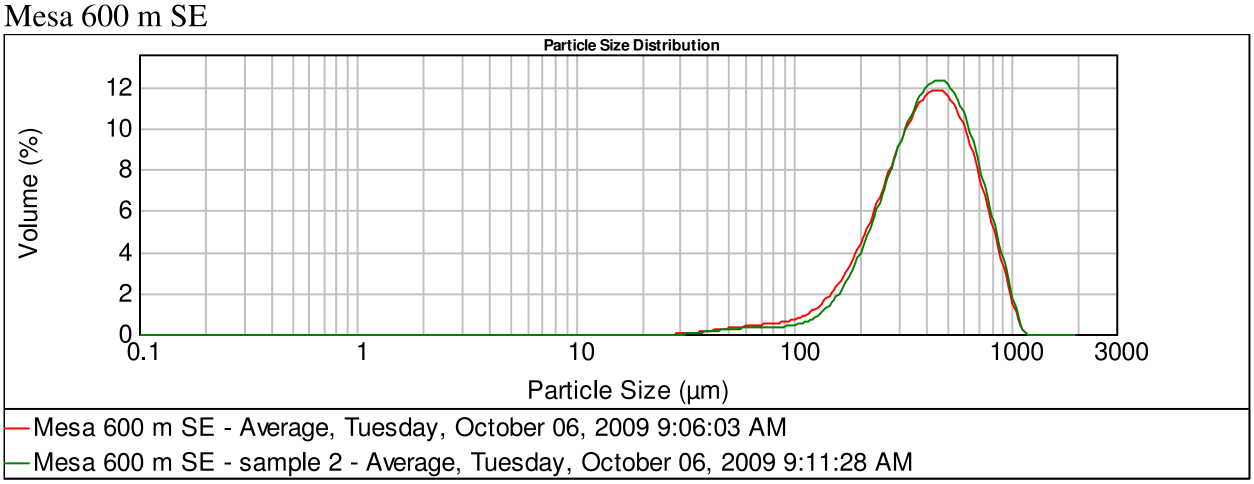
Appendix A Malvern Results for UC Davis samples

These results are from running approximately 10-15 g of sample dry through the Malvern Mastersizer. Two sub-samples were taken from each bagged sample, and three replicate readings were made from each sub-sample, with those results averaged. The graphs presented below show the averaged results from the two sub-samples from each bag of sediment.

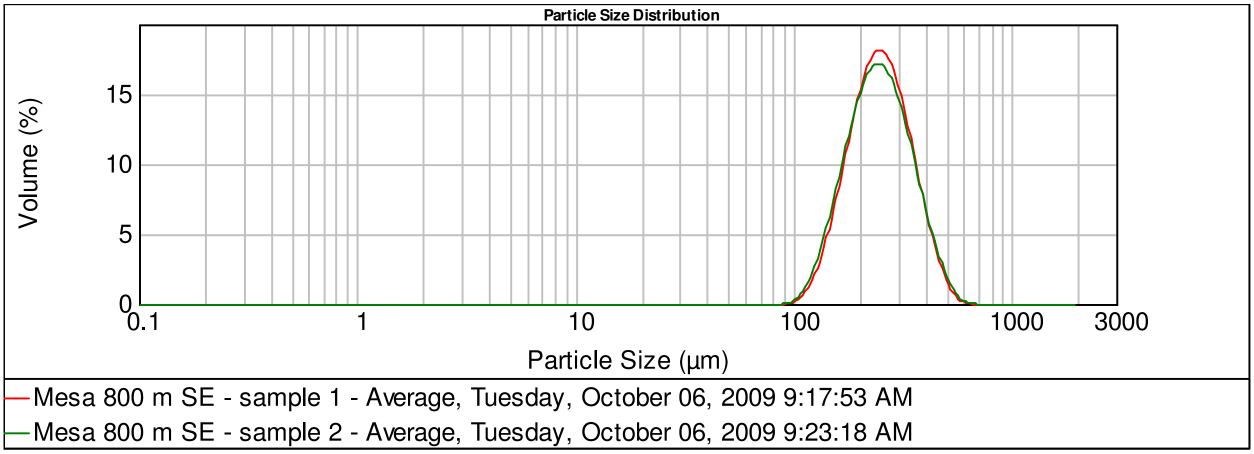
Mesa 200 m SE



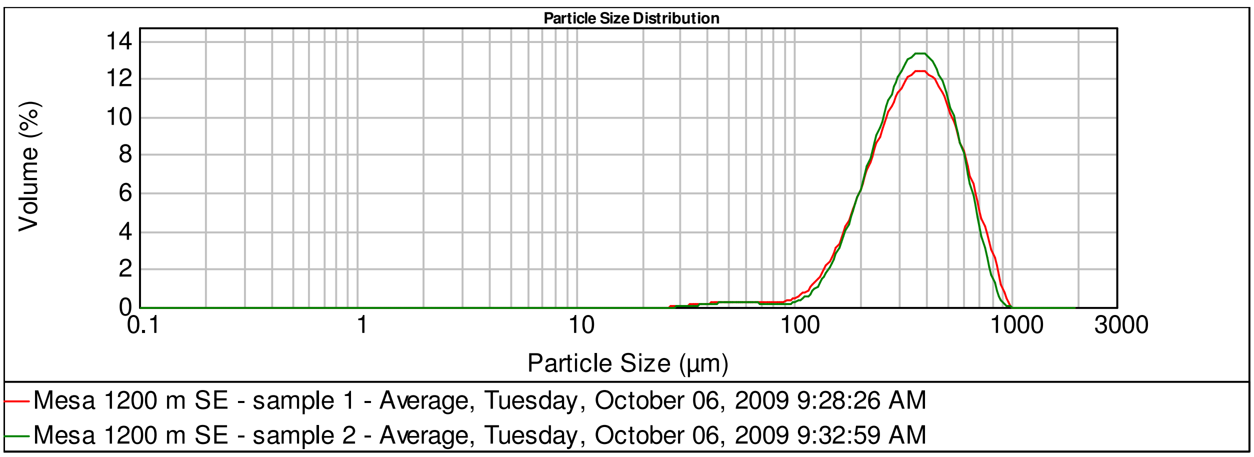
Mesa 600 m SE



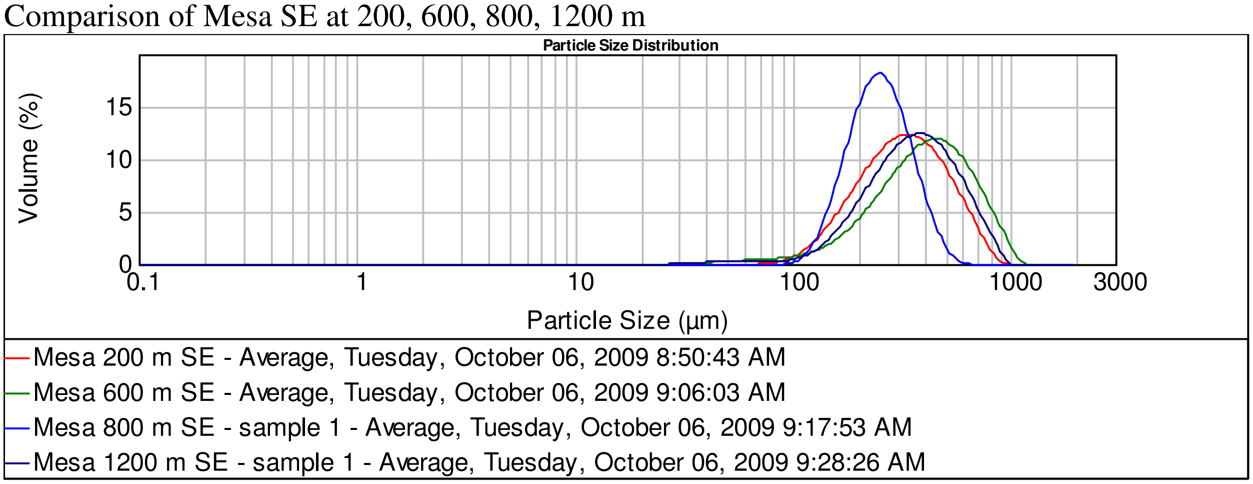
Mesa 800 m SE



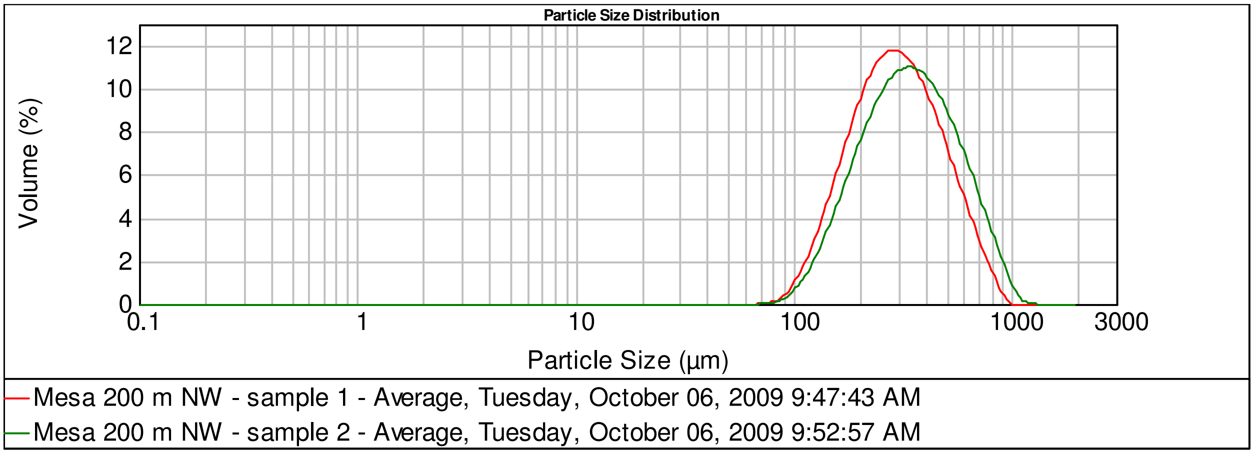
Mesa 1200 m SE



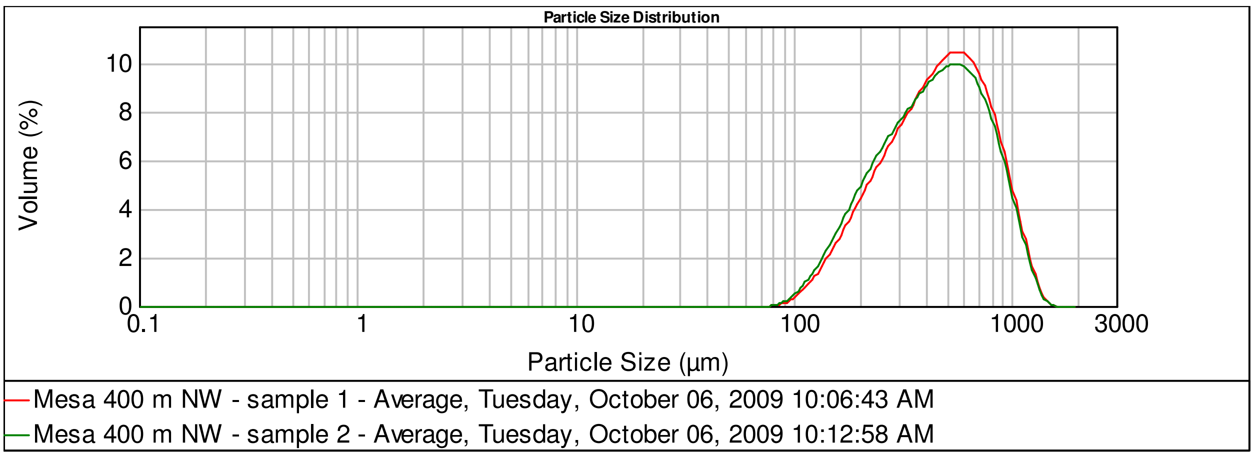
Comparison of Mesa SE at 200, 600, 800, 1200 m



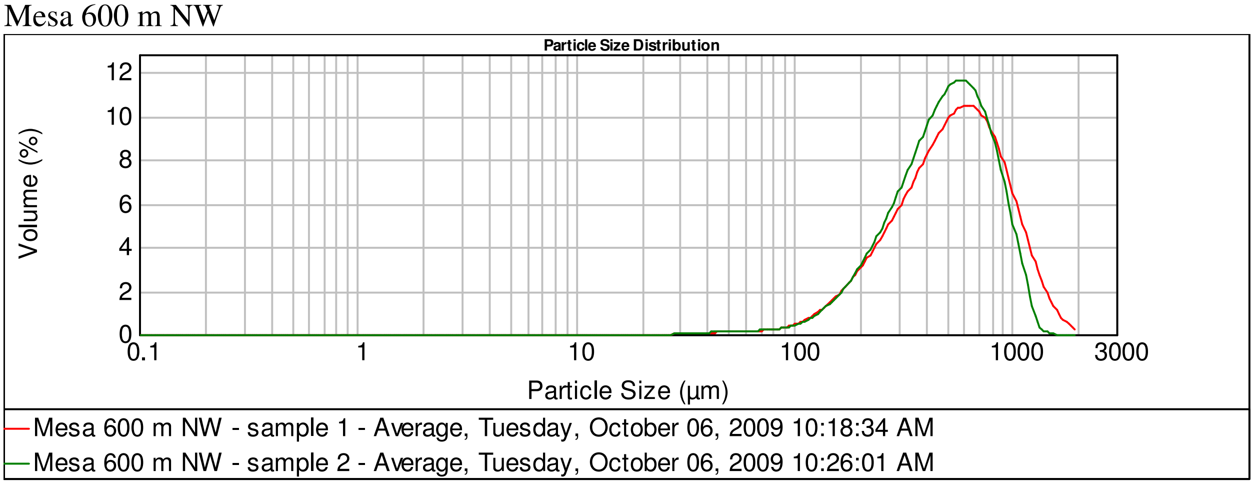
Mesa 200 m NW



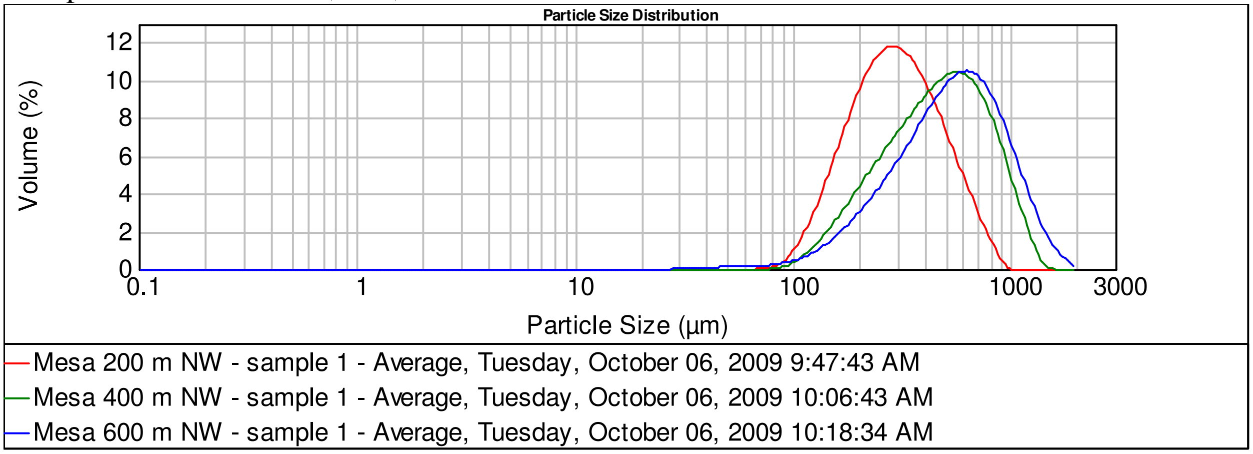
Mesa 400 m NW



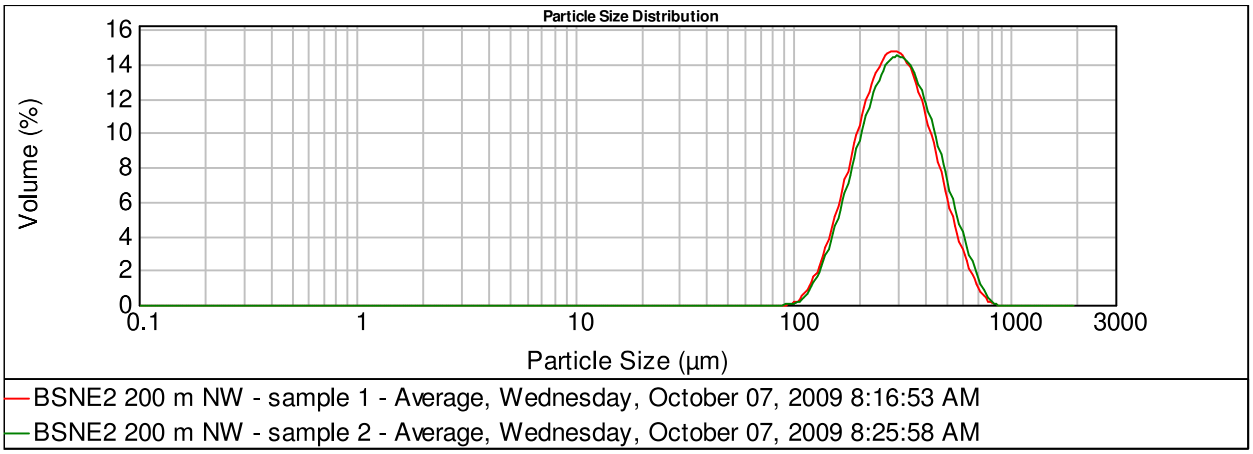
Mesa 600 m NW



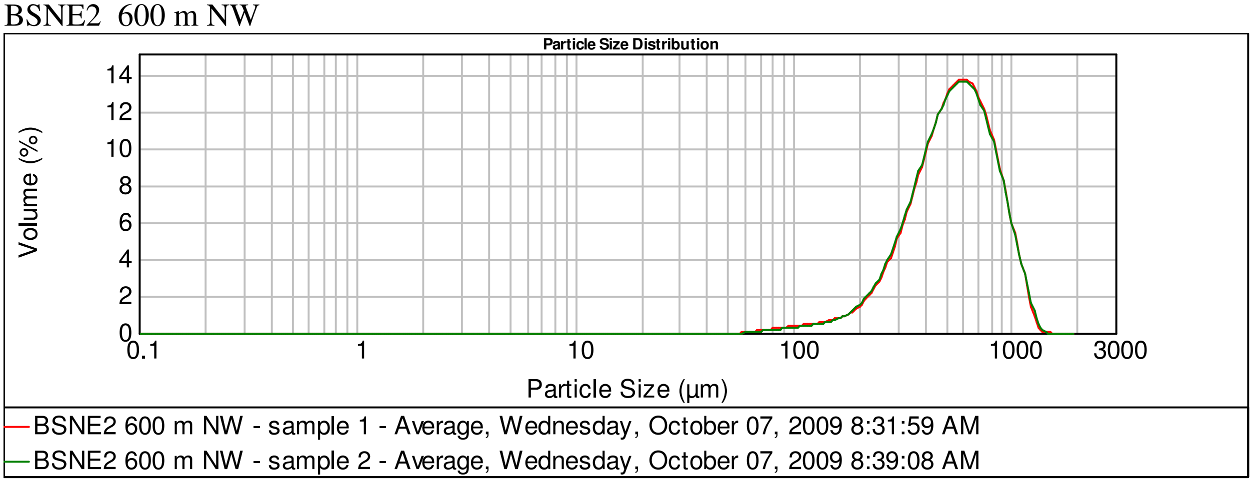
Comparison of Mesa 200, 400, and 600 m NW



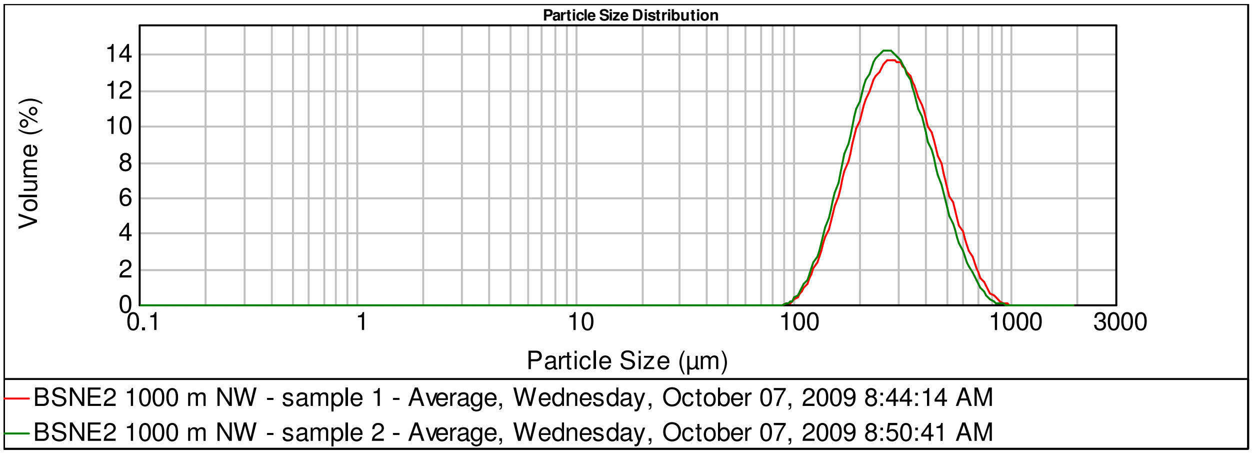
BSNE 2 200 m NW



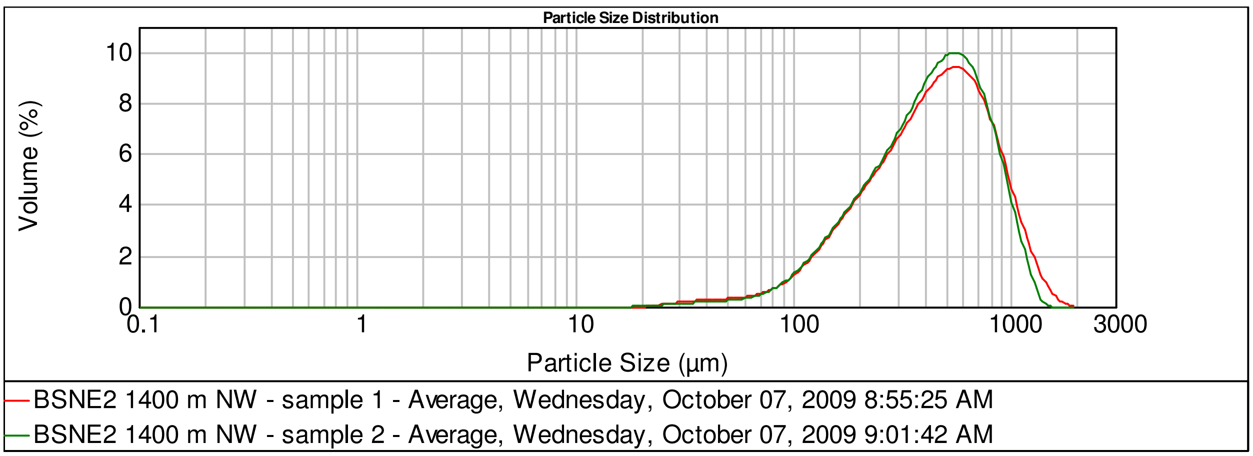
BSNE2 600 m NW



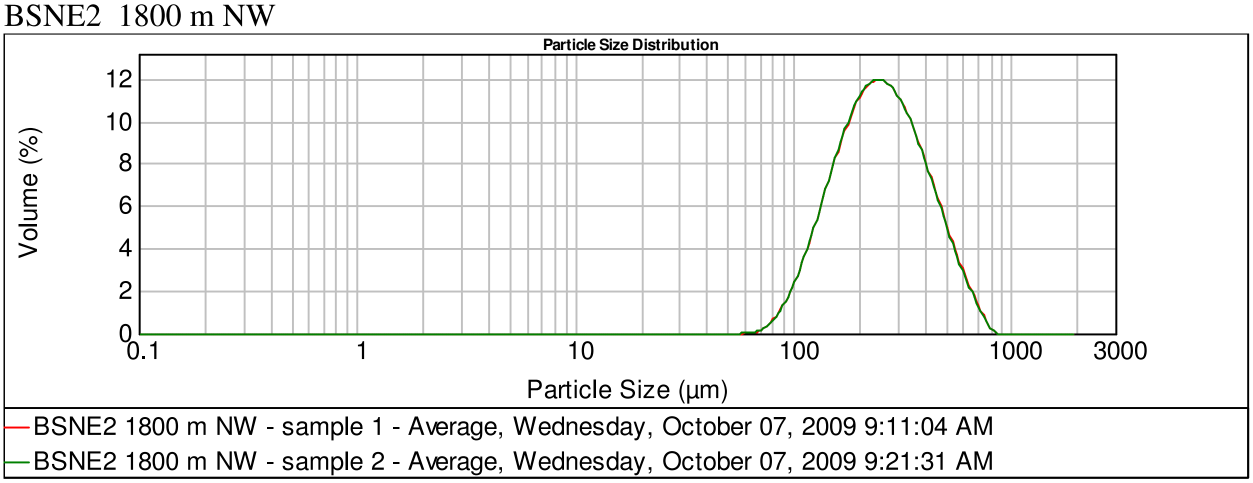
BSNE2 1000 m NW



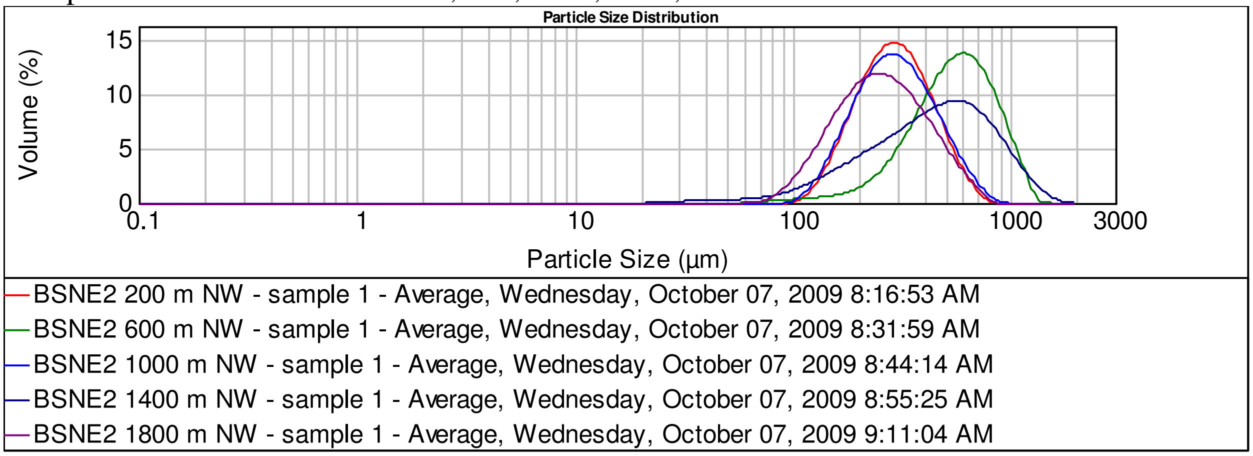
BSNE2 1400 m NW



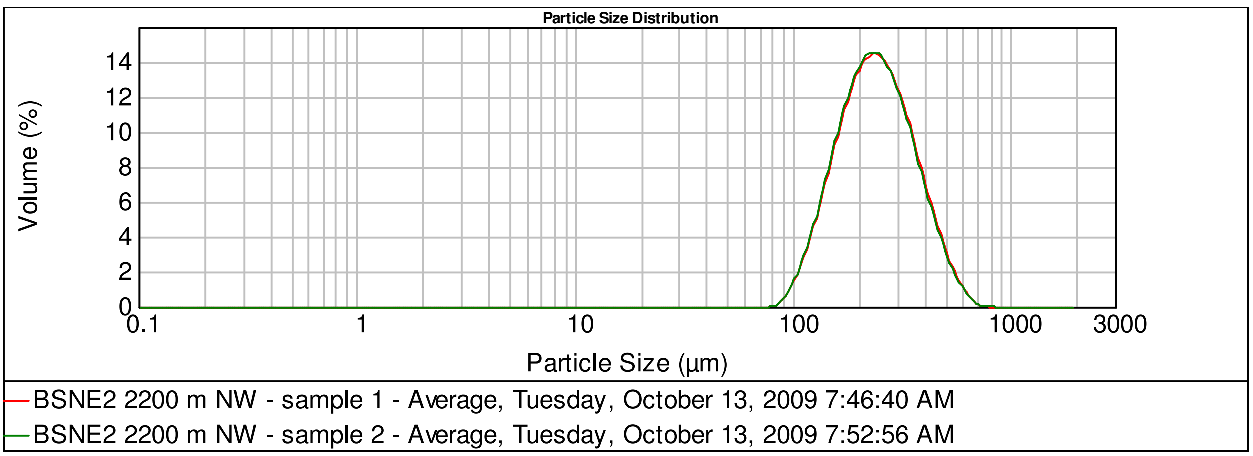
BSNE2 1800 m NW



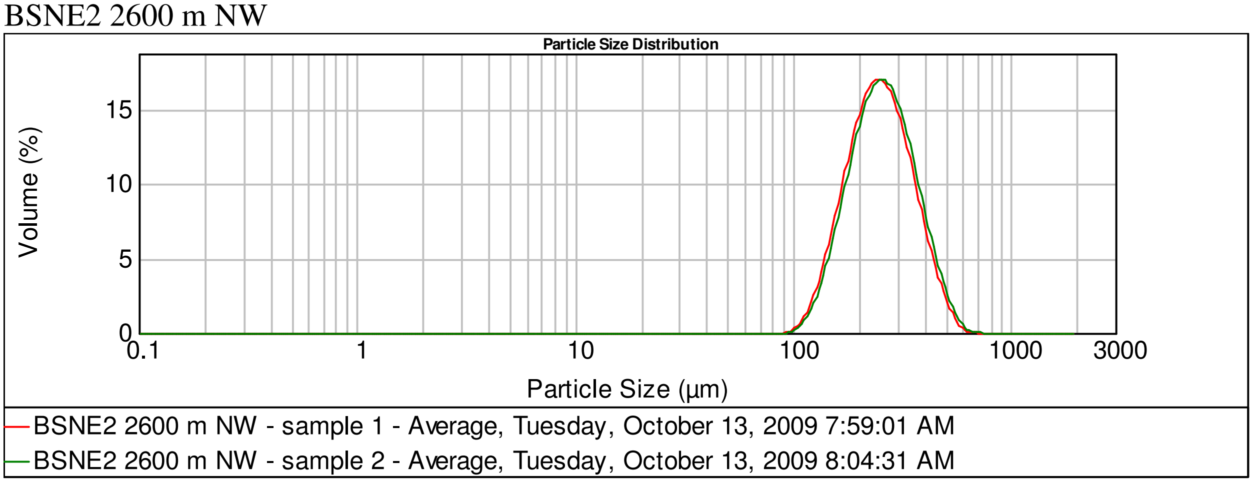
Comparison of BSNE2 NW at 200, 600, 1000, 1400, and 1800 m



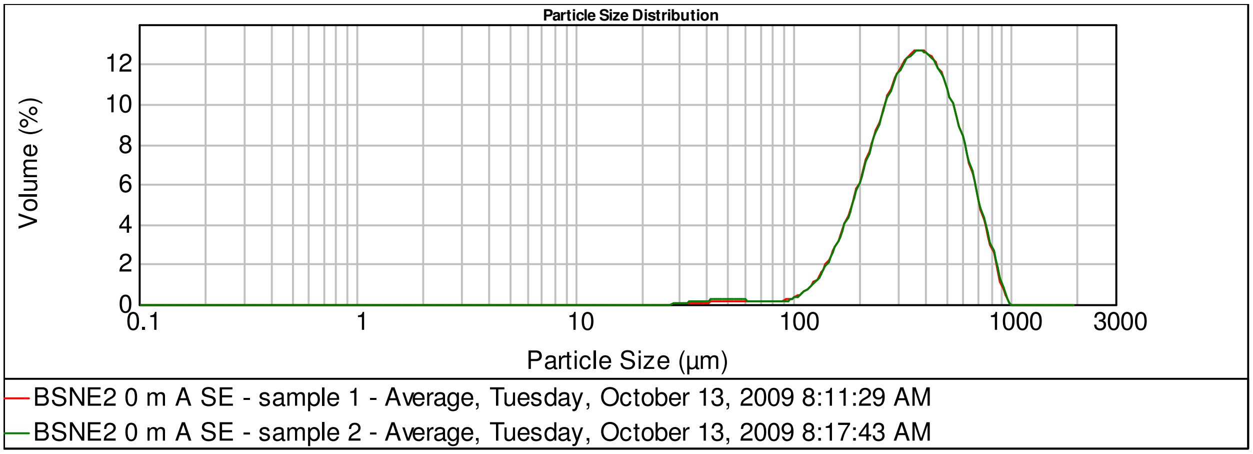
BSNE2 2200 m NW



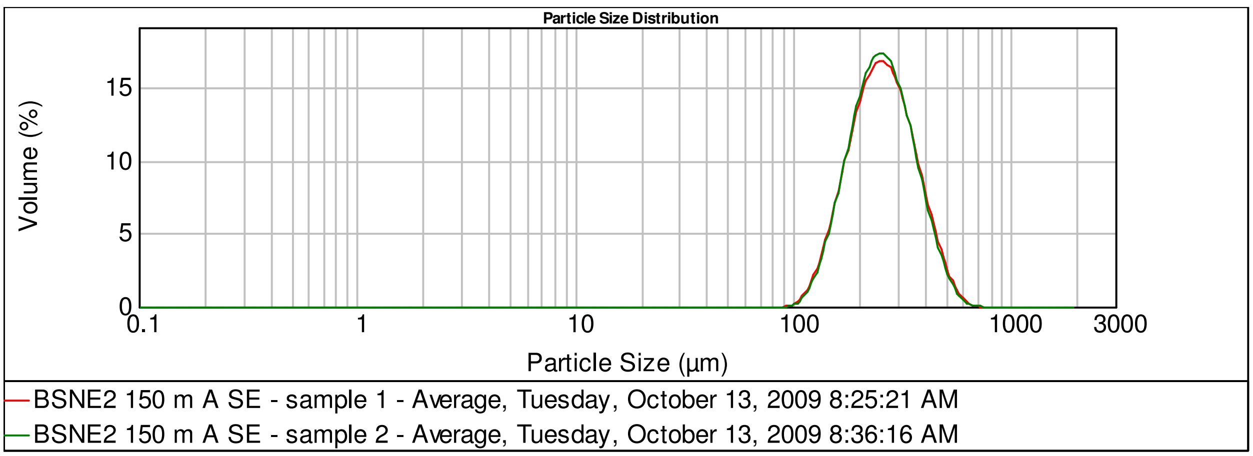
BSNE2 2600 m NW



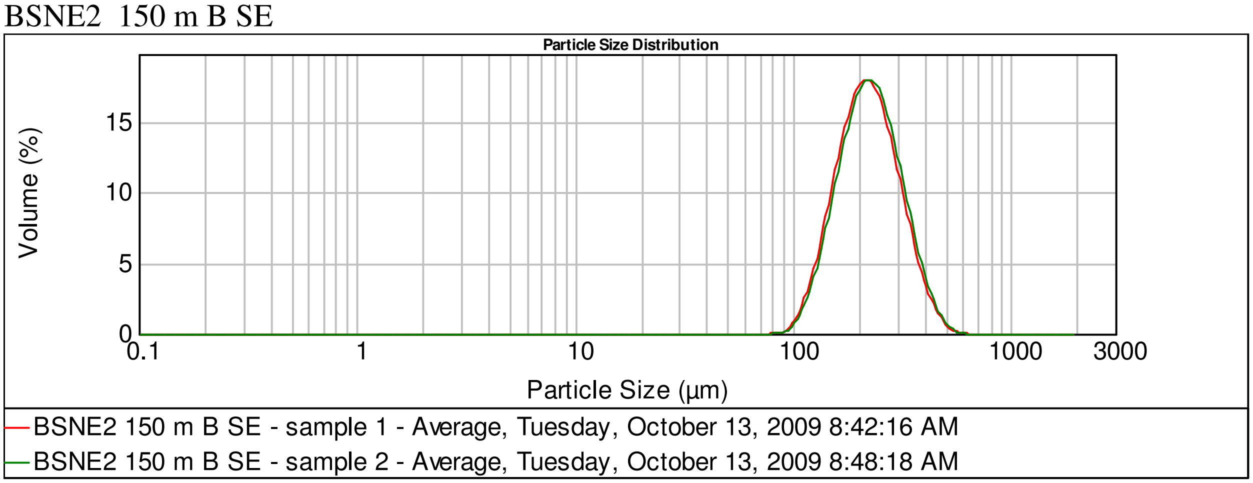
BSNE2 0 m A SE



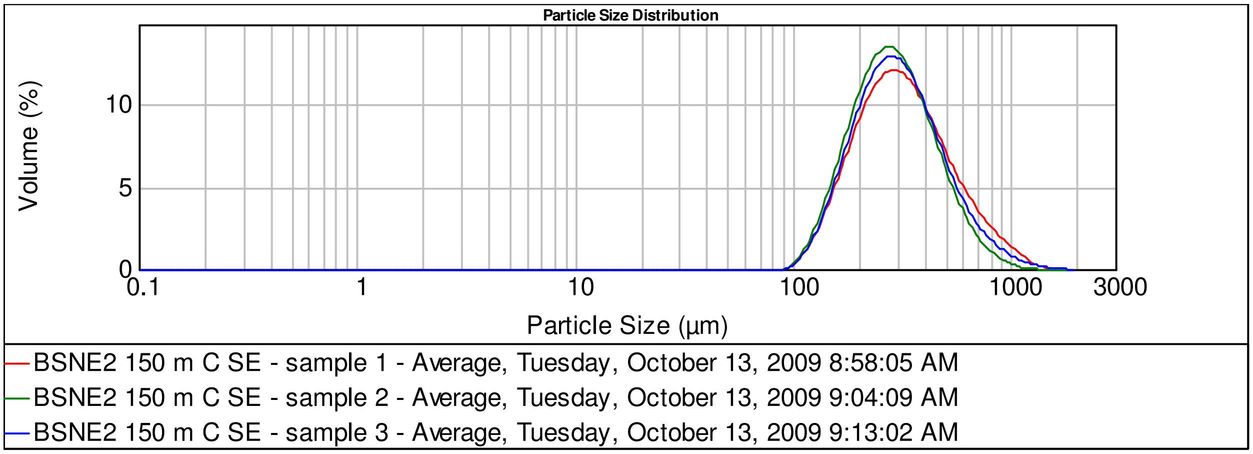
BSNE2 150 m A SE



BSNE2 150 m B SE

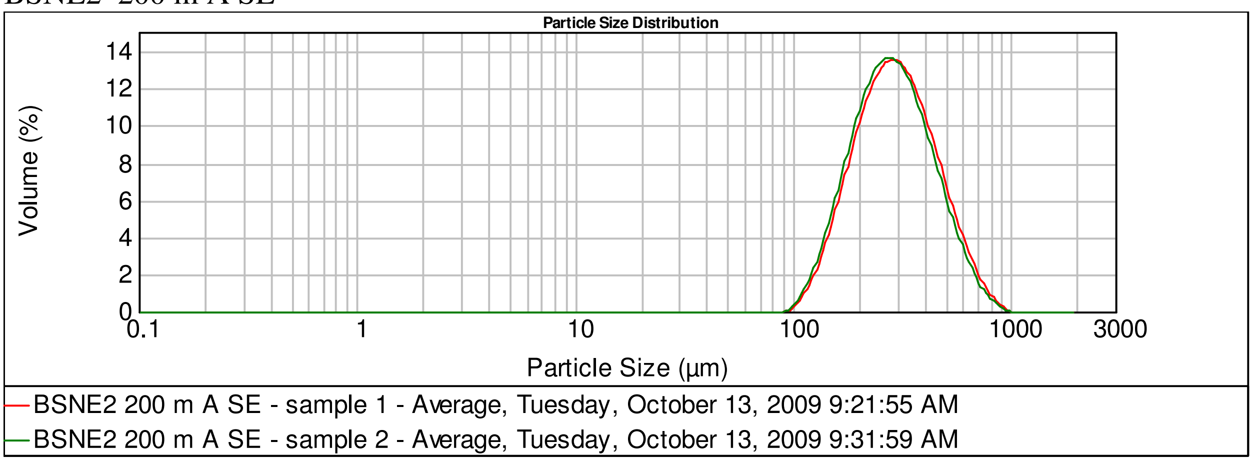


BSNE2 150 m C SE

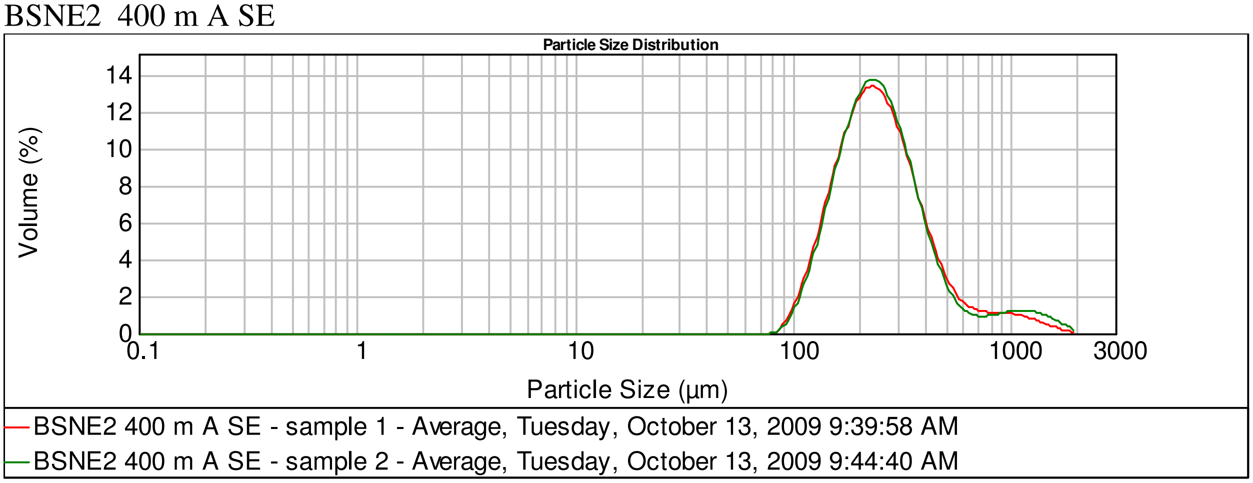


Note that three subsamples from this site were run because of more heterogeneity in the sample (small percentage of larger sand grains). The particle size distribution on these three subsamples were still very consistent with each other.

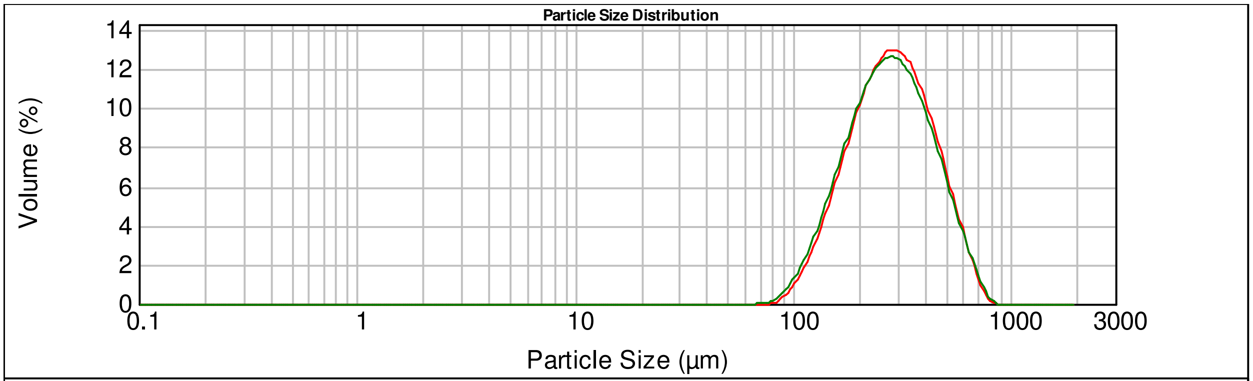
BSNE2 200 m A SE



BSNE2 400 m A SE

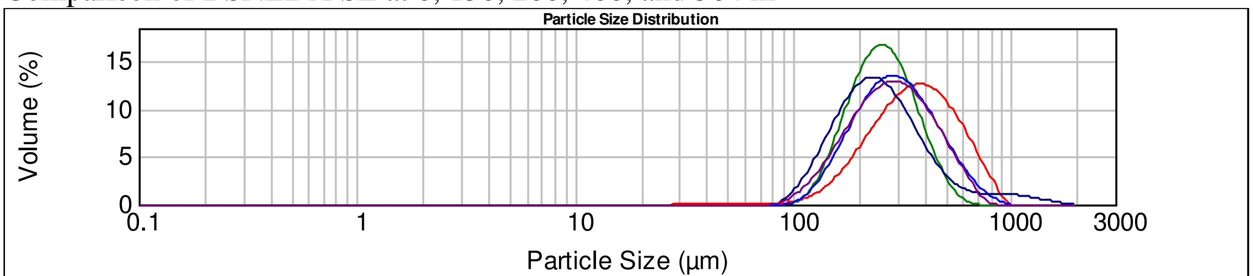


BSNE2 564 m A SE



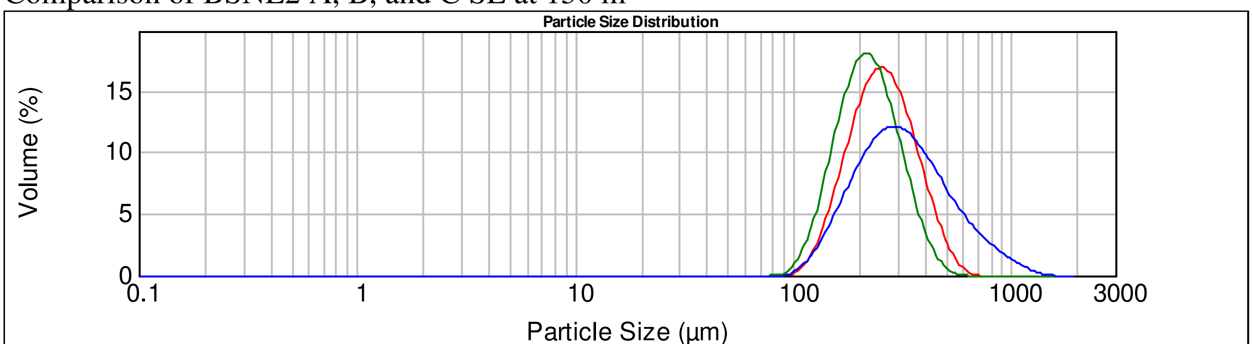
BSNE2 564 m A SE - sample 1 - Average, Tuesday, October 13, 2009 9:51:34 AM
BSNE2 564 m A SE - sample 2 - Average, Tuesday, October 13, 2009 9:58:35 AM

Comparison of BSNE2 A SE at 0, 150, 200, 400, and 564 m



BSNE2 0 m A SE - sample 1 - Average, Tuesday, October 13, 2009 8:11:29 AM
BSNE2 150 m A SE - sample 1 - Average, Tuesday, October 13, 2009 8:25:21 AM
BSNE2 200 m A SE - sample 1 - Average, Tuesday, October 13, 2009 9:21:55 AM
BSNE2 400 m A SE - sample 1 - Average, Tuesday, October 13, 2009 9:39:58 AM
BSNE2 564 m A SE - sample 1 - Average, Tuesday, October 13, 2009 9:51:34 AM

Comparison of BSNE2 A, B, and C SE at 150 m



BSNE2 150 m A SE - sample 1 - Average, Tuesday, October 13, 2009 8:25:21 AM
BSNE2 150 m B SE - sample 1 - Average, Tuesday, October 13, 2009 8:42:16 AM
BSNE2 150 m C SE - sample 1 - Average, Tuesday, October 13, 2009 8:58:05 AM

Appendix B: Vanadium Data

Re-suspension of Nipomo Mesa soils										
Vanadium										
Re-suspension set #1										
	Size		**Coarse**							
	~10 to 5.0	5.0 to 2.5	**average**	**std dev**	2.5 to 1.15	1.15 to 0.75	0.75 to 0.56	0.56 to 0.34	0.34 to 0.26	0.26 to 0.09
014D 0m Mesa 1B	3.8	3.4	**3.6**	**0.2**	3.2	na	na	na	na	na
17D 200m Mesa B	2.7	2.5	**2.6**	**0.1**	3.2	0.8	na	na	na	na
019D 400m Mesa	3.4	3.4	**3.4**	**0.0**	4.3	2.2	na	na	na	na
022D 800m Mesa B	3.8	2.5	**3.2**	**0.7**	3.7	4.9	na	na	na	na
025D 1.20km Mesa	4.0	3.5	**3.8**	**0.3**	2.5	4.0	na	na	na	na
028D 1.60km Mesa A	3.6	3.8	**3.7**	**0.1**	3.7	3.7	na	na	na	na
033D 2.0 km Mesa	5.2	6.5	**5.9**	**0.7**	5.6	4.4	na	na	na	na
034D 2.26km Mesa A	4.6	5.2	**4.9**	**0.3**	5.4	3.1	*10.6*	*5.5*	*9.5*	*4.8*
035D 2.26km Mesa B	4.1	3.6	**3.9**	**0.3**	4.6	4.2	*na*	*2.5*	*7.6*	*7.6*
036D 2.36km Mesa	5.1	6.3	**5.7**	**0.6**	6.6	7.3	*7.6*	*10.8*	*18.6*	*71.9*
115D 200m Mesa SE S1	5.5	na	**5.5**	**0.0**	na	na	na	na	na	na
116D 400m Mesa SE S1	3.3	3.4	**3.4**	**0.1**	3.0	na	na	na	na	na
117D 600m Mesa SE S1	2.8	5.2	**4.0**	**1.2**	na	na	na	na	na	na
118D 767m Mesa SE S1	10.1	na	**10.1**	**0.0**	na	na	na	na	na	na

- note: very little sample to work with for 118 D										
119D 800m Mesa SE S1	2.9	na	**2.9**	**na**	na	na	na	na	na	na
- note: very little sample to work with for 119 D										
120D 975m Mesa SE S1 - on road east of fence	4.1	na	**4.1**	**na**	na	na	na	na	na	na
Re-suspension set #2										
087D 30m Oso Flaco 2C	1.2	1.1	**1.2**	**0.1**	1.3	na	na	na	na	na
089 D 100m Oso Flaco 3B	0.9	1.4	**1.2**	**0.3**	0.9	na	na	na	na	na
095D 300m Oso flaco 5B	1.4	1.0	**1.2**	**0.2**	0.7	na	na	na	na	na
101D 575m Oso Flaco 7B	1.4	1.3	**1.4**	**0.0**	1.5	na	na	na	na	na
103D 800m Oso Flaco 8A sand	1.4	2.0	**1.7**	**0.3**	0.4	na	na	na	na	na
105D 1200m Oso Flaco 10A sand	1.6	na	**1.6**	**na**	na	na	na	na	na	na
153D Oso Flaco road off hwy 1	0.38	1.2	**0.8**	**0.4**	1.6	na	na	na	na	na
152D parking lot	0.19	0.4	**0.3**	**0.1**	1.4	na	na	na	na	na
154D Bluff 1A 245m	1.1	1.5	**1.3**	**0.2**	1.7	na	na	na	na	na
155D 250m Bluff 2A	1.7	1.5	**1.6**	**0.1**	1.1	na	na	na	na	na
157D 740m Bluff 2A agriculture	4.1	0.6	**2.4**	**1.8**	6.0	na	na	na	na	na

159D 2.83km Bluff 4A agriculture	1.2	0.9	**1.1**	**0.2**	0.7	na	na	na	na	na
158D 1.65km Bluff	1.2	1.1	**1.2**	**0.1**	1.0	na	na	na	na	na
078D 0 m Conoco upwind A	2.5	2.2	**2.4**	**0.1**	5.9	na	na	na	na	na
079D 200 m Conoco upwind A	2.5	2.1	**2.3**	**0.2**	4.2	na	na	na	na	na
080D 400 m Conoco upwind	3.1	2.3	**2.7**	**0.4**	4.6	na	na	na	na	na
081D 585 m Conoco upwind	2.1	4.1	**3.1**	**1.0**	na	na	na	na	na	na

Appendix C: Mitigation References

Mitigation of Windblown Dusts and Reclamation of Public Trust Values, Owens Lake, California: ***Partial Mitigation of PMIO Episodes Through Control of Salting Particles and Reduction of Wind Shear.***
Final Report to the California State Lands Commission on Contract No. C9175.
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October 12, 1995.
Prepared By: *Thomas A. Cahill, Thomas E. Gill, Scott A. Copeland, Michael S. Taylor, Kyle S. Noderer, Bruce R. White, Hyon M. Cho, Michael A. Patterson, Mee Ling Yau, Gregory A. Torres, Dabrina D. Dutcher, and Tezz Niemeyer.*

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Appendices on CDs

Appendix CD - A DRUM Quality Assurance Protocols, DELTA* Group

DRUM samplers Original Version 8/02. (DQAP 8/02), Current version January, 2008 (DQAP 1/08) .

Appendix CD – B List of UC Davis DELYA Group DRUM publications

Appendix CD – C Data files

Mass data
S-XRF elemental data
Sand data