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# DRAFT: Investigation of Effective Odor Control Strategies

# Year 1 Final Report

December 2016

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Report # (leave blank)

# ACKNOWLEDGEMENTS

The researchers would like to acknowledge the William W. “Bill Hinkley Center for Solid and Hazardous Waste Management for the funding for this project. The researchers would also like to thank the Technical Advisory Group members for their invaluable advice, feedback, and support of this work.

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# FINAL (ANNUAL) REPORT

12/01/2015 – 11/30/2016

**PROJECT TITLE: Investigation of Effective Odor Control Strategies**

**PRINCIPAL INVESTIGATOR(S):** Daniel E. Meeroff, Ph.D.

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**PROJECT WEBSITE:** http://labees.civil.fau.edu/leahcate.html

**COMPLETION DATE:** 12/30/2016

**TAG MEMBERS:** Mark Eyeington, Mark Maclean, Mark Bruner, Owrang Kashef, D.V. Reddy, Craig Ash, Ravi Kadambala, Ron Schultz, Jeff Roccapriore, André McBarnette, Dan Schauer, Damaris Lugo, Amanda Krupa, Richard Meyers, Amede Dimonnay, Art Torvela, Ted Batkin, Roshan Jachuk, Fred Bloetscher, Patrick Carol, Joseph Lakner, Kevin Leo, Hala Sfeir, Rebecca Rodriguez, Myles Clewner

**KEY WORDS:** Odor, meteorological conditions, landfills, biosensor, odor binding protein

**ABSTRACT:** Nuisance odor levels produced by solid waste management operations such as landfill facilities, wastewater treatment plants and confined animal feeding operations are subject to regulatory standards because of their impacts on the quality of life of the public living within range. Failure to meet such standards may result in costly fines, litigation, inability to acquire permits, mitigation, and re-siting operations. Since measurement of environmental nuisance odors is currently limited to subjective techniques, monitoring odor levels to meet such standards is often problematic. The objective of the proposed research is to investigate the conditions that impact odor complaints and to develop a standardized, non-subjective measurement of nuisance odors using human odorant binding protein 2a (OBP2A) or similar analog. Since OBP2A binds a wide range of odorants, it may be used singularly as an odorant detection method for municipal solid waste facilities whose odors are caused by a vast array of chemicals in varying proportions.

**METRICS:**

1. List graduate or postdoctoral researchers **funded** by **THIS** Hinkley Center project.

| Last name, first name | Rank | Department | Professor | Institution |
|---|---|---|---|---|
| Roblyer, Julia | MSCE Candidate | CEGE | Meeroff | FAU |
| Vidovic, Mateja | MSCE Candidate | CEGE | Meeroff | FAU |

2. List undergraduate researchers working on **THIS** Hinkley Center project.

| Last name, first name | Department | Professor | Institution |
|---|---|---|---|

| | | | |
|---|---|---|---|
| Martinez, Justin | CEGE | Meeroff | FAU |

3. List research publications resulting from **THIS** Hinkley Center project.

None yet

4. List research presentations resulting from **THIS** Hinkley Center project

2 TAG meetings

Roblyer, J. and Meeroff, D.E. (2017). Biosensor development for odor measurement. Florida Southeast Chapter of Air and Waste Management Association. January 17, 2017.

5. How have the research results from **THIS** Hinkley Center project been leveraged to secure additional research funding?

A proposal was submitted to EREF in August 2016: "Detection of nuisance odors using fluorescently labeled odor binding proteins", EREF, $175,000, August 2016.

A pre-proposal was also submitted to EREF in December 2016: "Detection of nuisance odors using odor binding protein biosensor," EREF, $169,569, December 2016.

6. What new collaborations were initiated based on **THIS** Hinkley Center project?

Dr. Jason Hallstrom (FAU I-SENSE Center), Dr. Binninger (FAU College of Science), Craig Ash and Jim Christiansen (Waste Management), Dick Pope (Hazen and Sawyer), Robert Bowker (Bowker and Asoociates), Philip Wolstenholme (Brown and Caldwell), Chris Hunniford (V&A Consulting Engineers), and Bruce Singleton (CDM Smith), Dr. Loic Briand, Research Director of the Center for Taste and Feeding Behaviour in Dijon, France, Artur Ribeiro, Professor of Biological Engineering at the University of Minho in Braga, Portugal, and Dr. Chelsea Smartt, Associate Professor of UF's Florida Medical Entomology Laboratory.

8. How have the results from **THIS** Hinkley Center funded project been used by FDEP or other stakeholders?

7. How have the results from THIS Hinkley Center funded project been used (not will be used) by FDEP or other stakeholders? (1 paragraph maximum).

To date, the results have not been used by stakeholders; however, a progress report presentation was made to Waste Management personnel to show the results of preliminary analysis of odor complaints relationship with meteorological data. We plan to continue to work with our partners to share our results and refine how odor complaints are dealt with by the industry.

# EXECUTIVE SUMMARY

12/01/2015 – 11/30/2016

**PROJECT TITLE: Investigation of Effective Odor Control Strategies**

**PRINCIPAL INVESTIGATOR(S):** Daniel E. Meeroff, Ph.D.

**AFFILIATION:** Florida Atlantic University

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**COMPLETION DATE:** 12/30/2016

In 2015, the Bill Hinkley Center for Solid and Hazardous Waste Management funded FAU Lab.EES to find ways to improve and standardize odor identification, evaluate additional methods to establish reasonable, objective standards for odor severity, and explore other options for mitigation and detection including a novel technology that will attempt to use human odorant binding protein to quantify odors. Areas of application include policy development, land use strategic planning, odor regulation, complaint assessment, odor impact assessment, odor master planning, odor control efficiency assessment, and process design.

Nuisance odor levels produced by solid waste management operations such as landfill facilities, wastewater treatment plants and confined animal feeding operations are subject to regulatory standards because of their impacts on the quality of life of the public living within range. Failure to meet such standards may result in costly fines, litigation, inability to acquire permits, mitigation, and re-siting operations. Since measurement of environmental nuisance odors is currently limited to subjective techniques, monitoring odor levels to meet such standards is often problematic.

The objective of the proposed research is to develop a standardized, non-subjective measurement of nuisance odors using human odorant binding protein 2a (OBP2A) or similar analog. Since OBP2A binds a wide range of odorants, it may be used singularly as an odorant detection method for municipal solid waste facilities whose odors are caused by a vast array of chemicals in varying proportions.

The OBP2A will be synthesized and isolated using standard laboratory methods. Following isolation, OBP2A will be labeled with fluorescent markers to indicate when odorant molecules have been bound to the protein. After fluorescent marking, OBP2A will be exposed to known odorants within a vacuum chamber. Fluorescence will be measured using a fluorometer and analyzed for fluorescence – concentration responses during odorant binding. If the relationship follows Beer's Law, then concentrations of odorants can be accurately determined using fluorometric measurements.

As a starting point, the fluorescently tagged OBP2A will be exposed to model compounds that generate specific responses in human olfactory cells such as formic acid and dimethyl disulfide, detected at concentrations as low as 0.1 ppm, to determine a positive response and concentration dependence.

# 1. INTRODUCTION

## 1.1 BACKGROUND

Odor emissions are one of the major environmental problems and one of the critical challenges facing solid waste management industry. They can last up to 100 years after the landfill site is closed. Odors around the landfills are a huge problem since these days landfills are located closer and closer to the urban settings. Population is growing fast and it is expanding rapidly. The landfills that were once operating normally, now are facing a lot of odor complaints due to the close neighborhoods. New housing developments, needed to accommodate the rapid population growth, are creeping closer and closer. As homes get closer to landfills, odor complaints are likely to become more frequent, causing landfill managers increased problems with public interactions. Big problem with detecting odors is the subjective perception of odors. What one individual can classify as a bad odor, for another person that doesn't necessary has to be the case. Fugitive nature of odors makes them difficult to intercept and treat. In a time when an odor complaint is occurred, and by just coming to the exact location couple of minutes later, odors could be already dispersed further and there wouldn't be anything to report by odor inspection team. Odors are greatly affected by atmospheric conditions and diluted in response to local winds. Solid waste facilities want to be a good neighbor and by identifying good odor mitigation strategies, odors can be prevented, minimized and managed.

The fugitive nature of odors is also not helping and makes them very difficult to intercept and treat since just in couple of minutes odors can be transmitted to other location and we could not be able to detect any nuisance odor. As already mentioned, strength of odors is affected by complex atmospheric conditions and diluted in response to local winds. Some of the meteorological conditions are increasing the strength of odors and others are allowing odors to be dispersed from landfill site. With all of that being said, relatively little can be done to modify the climate or microclimate.

Taking all issues that solid waste facilities are facing when nuisance odors are involved in consideration, management of facility must give attention to operating the facility in a manner that would reduce any potential impact to close by neighborhoods. One of the useful tools as well as

the less expensive one, is installing weather station or have a weather device at the site that could collect data on different meteorological conditions such as temperature, wind direction, wind speed, pressure, humidity, and other climatic data. By monitoring meteorological conditions, schedule for operations in solid waste could be changed. As an example, if the wind direction is known, trying to avoid working on part of the site that could potentially produce odors and wind could disperse it to close by residential area. Another example were monitoring meteorological data can be very useful tool, is to demonstrate regulators and legal personnel that on the day the community complained of odors, the wind was actually blowing in the opposite direction so there is no correlation between the site and odor complaints. Operating solid waste facilities in relation to meteorological conditions can greatly reduce impacts to surrounding areas. Public relations is also important. It can help the operator to identify the major source of nuisance odors so that improvements can be made in that specific area.

## 1.2 ODORS

In many parts of the world, landfilling has been the most common method for solid waste disposal. It has been known for its capability for safe disposing of solid waste without jeopardizing environmental and socio-economic aspects. Unlike other methods such as incineration and biological composting, landfilling can be considered as the cheapest method to run. Gases are formed in a landfill when buried wastes decompose (breakdown by bacteria) or volatize (change from a liquid or solid to a vapor). These bacterial and chemical processes create gases that are unlikely to pose any serious health hazards, but they may cause odors that some people find unpleasant. The most common type of landfill is the municipal solid waste facility, which accepts household and non -hazardous commercial and industrial waste. It typically contains 60% organic material, such as food and paper. Because organic material tends to produce a great deal of gas, municipal solid waste landfills have the potential to produce odors.

The amount of landfill gases depends on the type of waste present in the landfill, the age of the landfill, oxygen content, the amount of moisture, and temperature. Volatilization generates landfill gas when certain wastes change from a liquid or solid into a vapor. Chemical reactions occur when different waste materials are mixed together during disposal operations. Additionally, moisture plays a large role in the speed of decomposition. Generally, the more moisture, the more landfill gas is generated, both during the aerobic and anaerobic conditions. For example, gas production

will increase if the temperature or moisture content increases. Though production of these gases generally reaches a peak in five to seven years, a landfill can continue to produce gases for more than 50 years (Basics of Landfill Gas, 2016).

**Figure 1. Landfill site**

## 1.3 ODOR CAUSING COMPOUNDS

Sulfides and ammonia are the most common sources of odor in landfill gas. Sulfides produce a strong, rotten -egg smell that humans can detect even at very low concentrations. Ammonia produces a pungent odor that many people are familiar with because it is often used in household cleaning products. Both are normally present in the air, regardless of the presence of a landfill (Landfill Gas, 2016).

Figure 2 represents the way we smell odors. First we inhale the air. Ten percent of pass under the olfactory organ, the epithelium. Another twenty percent pass under the epithelium during sniffing. There is total of 10 to 25 million olfactory cells in the epithelium. The mucus layer on the epithelium traps chemical odorants that are water soluble and an electrical response is created that, depending on its strength, is sent along the brain in the form of pain stimulus (Epstein, 2011).

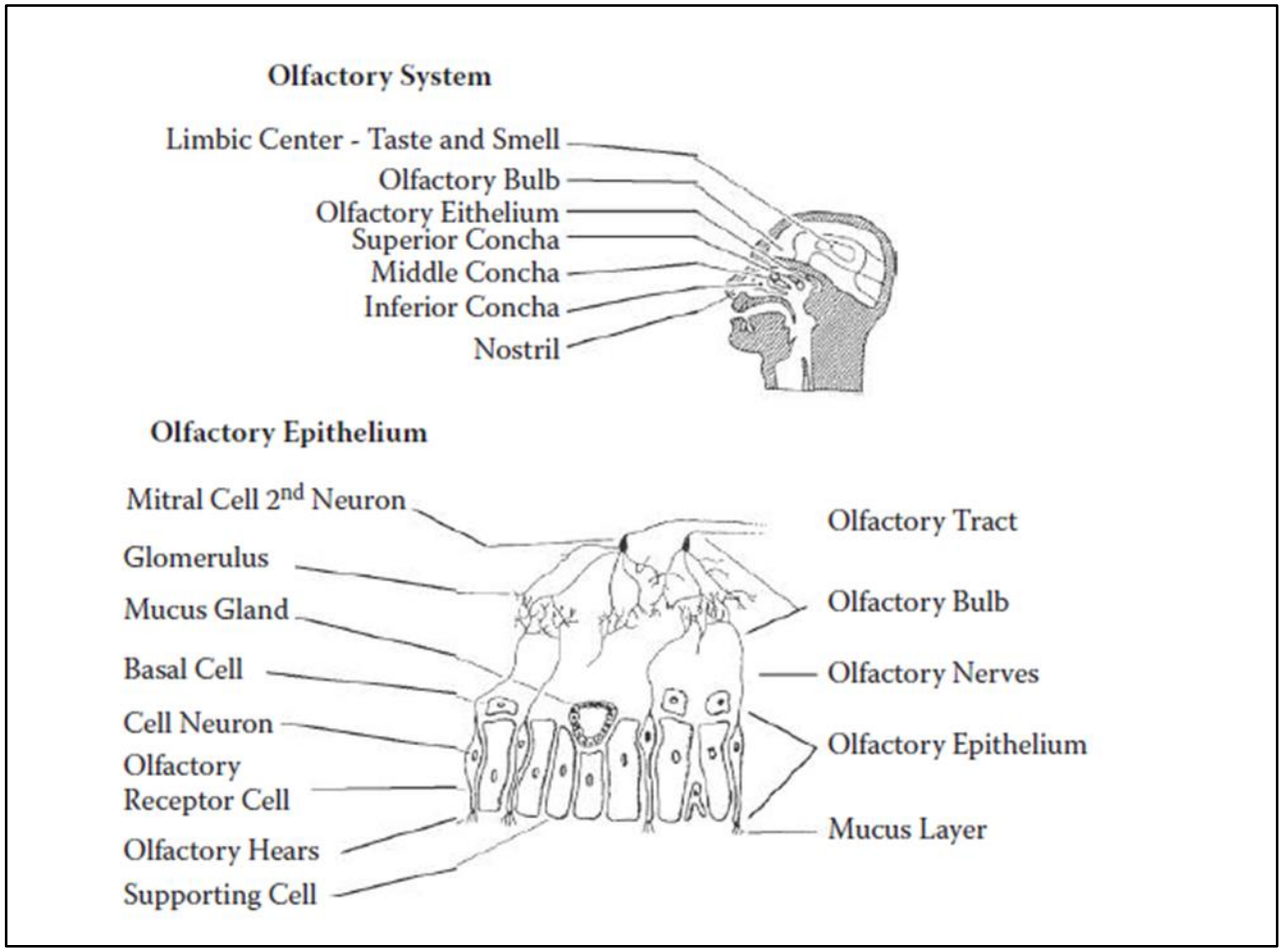


**Figure 2. Odorant receptors and the organization of the olfactory systems**

Common odor causing compounds in solid waste operations and their odor thresholds are presented in the figure below. We can see that threshold for hydrogen sulfide is very low which makes it very difficult, since people will complain on bad odors while the actual concentration is so low and it cannot poses any health threat to them. Also, common description characters for odors that can be found around the landfills are presented in the Figure 4. Trash was the most common odor descriptor with 88% but it cannot be placed to any of the given character categories since trash is a mixture of smells and cannot be described with only one type of smell (sweet, sour, etc.).

| Component | Odor Description | Odor Threshold (parts per billion) |
|---|---|---|
| Hydrogen Sulfide | Strong rotten egg smell | 0.5 to 1 |
| Ammonia | Pungent acidic or suffocating odor | 1,000 to 5,000 |
| Benzene | Paint-thinner-like odor | 840 |
| Dichloroethylene | Sweet, ether-like, slightly acrid odor | 85 |
| Dichloromethane | Sweet,chloroform-like odor | 205,000 to 307,000 |
| Ethylbenzene | Aromatic odor like benzene | 90 to 600 |
| Toluene | Aromatic odor like benzene | 10,000 to 15,000 |
| Trichloroethylene | Sweet, chloroform-like odor | 21,400 |
| Tetrachloroethylene | Sweet, ether-or chloroform-like odor | 50,000 |
| Vinyl Chloride | Faintly sweet odor | 10,000 to 20,000 |

**Figure 3. Common odor causing compounds in landfill gas**

| Odor Character Category | Percent | Common Descriptors |
|---|---|---|
| Non-descriptive | 88 | trash |
| Other | 0.1 | |
| Solvent/Hydrocarbon | 2.2 | chemical |
| Rancid | 2.5 | sour, dirty diaper, sweet-sour |
| Earthy/Musty/Grassy | 0.5 | musty, decaying vegetation |
| Sulfur/Cabbage/Garlic | 3 | rotten egg, natural gas, skunk |
| Sweet | 0.4 | sweet trash |
| Fishy/Ammonia | 0.3 | ammonia |
| Putrid/Dead Animal | 0.6 | dead animal |
| Burnt | 0.7 | burnt rubber, exhaust, burnt trash |
| Fecal/Sewery | 2.4 | feces, manure, sewage |
| Fragrant/Fruity | 2.4 | perfume |

**Figure 4. Odor Character Categories**

## 1.4 FACTORS INFLUENCING THE DISPERSION OF ODORS

The main factors affecting the dispersion of odors and their potential impact on sensitive receptors are climate, microclimate and topography. They are carried away from the source by wind and diluted by mixing with the ambient air. If odors move off-site before they are diluted, odor impacts are more likely to occur. Prevailing wind direction, wind speed, and atmospheric inversions can greatly affect odor impact to receptors. Odors can become trapped in the inversion layer. When the temperature increases, especially early in the morning, odors can move off-site and impact receptors. Microclimate is the climate affected by local conditions surrounding the landfill site. Topography is also an important factor affecting the odor dispersion since odor sources located at the elevation higher than the sensitive receptors are less apt to affect receptors because odors tend to mix and disperse in the air layers above the receptors. Under certain meteorological conditions, odors generated at higher elevations can be carried into lower elevations (Epstein, 2011).

Wind direction and speed can vary significantly over short distances. Meteorology can vary from location to location and greatly affect where and at what concentrations contaminants are present in ambient air. It has noted a strong correlation between certain types of atmospheric conditions and odor complaints at many landfills. Odor complaints tend to coincide with little or no wind, fog or high humidity, overcast skies, and during thermal inversions. These meteorological conditions

tend to occur early in the morning or evening. These types of weather conditions typically occur during the change in season from fall to winter and from winter to spring. Odor complaints are rarely received during clear, sunny, and windy days (Energy and Environmental Affairs, 2016)

Temperature and humidity affect odor because they increase molecular volatility. This is why trash smells stronger in the heat and cars smell musty after rain. A substance's solubility also affects its odor. Chemicals that dissolve in water or fat are usually intense odorants (Detection of Odorants, 2016). High temperatures in summer produce greater emissions from liquid area sources because of increased compound volatility; however, these emissions tend to disperse more readily because of frequent occurrence of unstable conditions. An opposite scenario occurs in winter, with lesser emissions due to lower temperatures, but also frequently less dispersion, due to stable atmospheric conditions.

Changes in temperature and moisture have a huge impact on both the strength of odors and also how quickly they dissipate. When the temperature drops, air and scent molecules become denser. When sunlight hits one pocket of air molecules, the air packet heats up making atmosphere conditions unstable (EPA, 2000). Humid air traps smells and causes them to linger longer than they usually would. With higher humidity, more odors are detected. Warm and humid air enhances our sense of smell, because the humidity carries odor molecules to our noses and our sense of smell becomes more enhanced. When there is a weak wind and stable conditions, odor complaints tend to occur more often while when there is a presence of strong wind, odor detection is significantly lower.

## 1.5 ODOR CONTROL TECHNIQUES

Most common techniques that are used for odor detection are Chemical Analyses, Dynamic Olfactometry and Electronic Noses. Each of them have their own advantages and disadvantages and summary of each is presented in the table below.

**Table 1. Odor monitoring techniques**

| Technique | Kind | Method | Advantages | Disadvantages | Reference |
|---|---|---|---|---|---|
| **Chemical analyses** | Analytical; Indirect method | Gas chromat.-Mass spectr. (GC-MS) | Detection of pollutants with low odor detection which may originate odor nuisance, useful to analyze odour composition in order to design intervention and treatment strategies, more objective, repeatable and accurate | Difficulty of relating the chemical composition of an odorous mixture to its olfactory properties, provide little information about the odorant real impact on human receptors | Capelli 2008, Lebrero 2011, Capelli 2013, Capelli 2014 |
| **Dynamic olfactometry** | Sensorial; Direct method | Use of human nose as a sensor | Determine the odor concentrations (Cod), giving indicative values of sensory impacts that are liable to affect off-site, the most common approach | Variability of human olfaction between different subjects, highly costly ($224-$336 per measurement), time consuming | Capelli 2008, Lebrero 2011, Capelli 2013 |
| **Electronic noses** | Senso-instrumental | Artificial noses which can distinguish between different odors, single odorants such as H2S and NH3 have been commonly used as surrogate markers | Make some assumptions about the landfill odor impact on the points where instruments are installed, effectively used as management tool in order to monitor site changes or operational failures | Depend critically on a set of operational choices (working conditions,measurment settings,data processing methods,etc.), provide only a partial characterization of odorous emssions because H2S and NH3 are not always responsible for the entire odor nuisance, problems with reliability and sensitivity-especially to temperature and humidity as well as with stability over time | Capelli 2008, Lebrero 2011, Capelli 2013, Capelli 2014 |

Some of the odor technologies and strategies used for mitigation odors around landfills such as Process Modification, Incineration, Adsorption, Biofiltration, and Odor Masking.

Process modification includes adjusting the solid waste operations in order to reduce the production of odorous compounds. Those can vary from simple changes in operations to extreme ones. Incineration is one of the most commonly used odor control technologies today. In a situations were great efficiencies are required and odorous compounds are flammable, this process

is very powerful. When the concentration of the odorous compounds is elevated and can potentially be recovered for reuse, adsorption is a successful technology.

For exhaust streams which contain VOCs, biofiltration can be effectively utilized. This process includes the use of a bed of biologically activated material through which the exhaust stream is fed. Odor masking includes the incorporation of a single or two or more compounds to an odorous pollutant to generate a cancellation of the nuisance odor impact. The process is affected by geography since the remotely from the source the complaint is, the odor masking will have smaller impact in reducing odors and won't be used as an effective technology. Summary of the all odor mitigation technologies is presented in the table below.

**Table 2. Odor mitigation technologies**

| Technology | Method | Impact | Reference |
|---|---|---|---|
| Process modification | Altering the manufacturing process to reduce the production of odorous compounds (eg. Changing the type and size of seals and gaskets,substituting alternative materials in the manufacturing process,etc.) | Very effective in reducing potential odour complaints by diminishing the emissions od odorous compounds at the source | Kehoe 1996 |
| Incineration | The oxidation of the hydrocarbons to carbon dioxide and water vapour | Most commonly used today, very effective when high efficiencies are required and the odourous compounds are combustible hydrocarbons, high investment and operation cost | Kehoe 1996, Lebrero 2011 |
| Adsorption | The adsorbent binds more and more of the adsorbed compounds | Effective technology when the concentration of the odourous compound is high and can possibly be recycled for reuse by the source,process efficiency decrease with time which requires the control technology to incorporate some means of regenerating the adsorbent without interruption of the ongoing process | Kehoe 1996 |
| Biofiltration | Use of a bed of biologically activated material through which the exhaust stream is fed, the microorganisms living within the bed metabolize the pollutants through aerobic degradation to produce carbon dioxide, water and microbial biomass | Successfully employed for exhaust streams which contain volatile organic compounds, most common biotechnology in WWTP, enviromentally friendly | Kehoe 1996, Lebrero 2011 |
| Odour masking | Addition of a single or two or more compounds to an odourous pollutant to produce a cancellation of the odourous impact | Process is limited by geography-the farther from the source the complaint is, the less likely odour masking will be an effective solution | Kehoe 1996 |

## 1.6 OBJECTIVES

One of the objectives of the proposed research is to categorize the meteorological conditions that have greatest influence on increasing number of odor complaints in solid waste operations and by using those meteorological conditions determine the existing patterns or trends, if any, that could lead to the development of effective management strategies.

Another objective is to develop a standardized, non-subjective measurement of nuisance odors using human odorant binding protein 2a (OBP2A) or similar analog. Since OBP2A binds a wide range of odorants, it may be used singularly as an odorant detection method for municipal solid waste facilities whose odors are caused by a vast array of chemicals in varying proportions

# 2. METHODOLOGY

## 2.1 CONDUCT LITERATURE REVIEW

Exhaustive literature review conducted was focused on identifying sources of odor in landfills, non-subjective odor monitoring techniques, and methods of odor control including best odor management practices. Databases have been created and are being constantly updated with: 1) lists of specific odor causing compounds in solid waste operations; 2) lists of parameters that can impact the efficiency of data collection; 3) lists of parameters which have the greatest influence on creating and spreading of nuisance odors; 4) lists of odor monitoring technologies that are used in solid waste operations; and 5) lists of case studies and best management practices for odor mitigation technologies. Some of the information gathered are presented in the databases below.

**Table 3. Database with odor causing compounds**

| Odorant | Descriptor | OTC (ppbv) | OTC(μg/m$^3$) |
|---|---|---|---|
| 1,2,4-trimethylbenzene | aromatic | 150 | 780 |
| 1,3,5-trimethylbenzene | aromatic | 230 | 1200 |
| acetic acid | vinegar, sour | 140 | |
| acetone | chemical,sweet | 14000 | 35000 |
| acrolien | acrid | 170 | 410 |
| **ammonia** | **pungent** | **5800** | **4100** |
| a-pinene | sweet,pine | 20 | 30 |
| benzene | sweet solvent | 3600 | 12000 |
| butanal | malty/burnt | 9 | 30 |
| butyric acid | rancid, sour, perspiration | 3.9 | 10 |
| butyl acetate | fruity | 200 | 900 |
| carbon disulfide | rotten | 100 | 300 |
| chlorobenzene | almond | 700 | 3500 |
| chloroform | sweet, ethereal | 12000 | 59000 |
| crotonaledehyde | pungent | 36.7 | 105 |
| decanal | not found | 0.9 | 6 |

**Table 4. Database with odor causing compounds**

| Odorant | Descriptor | OTC (ppbv) | OTC(µg/m3) |
|---|---|---|---|
| decane | gasoline | 700 | 4400 |
| dichloromethane | ethereal | 12000 | 59000 |
| dimethyl disulfide | sour,onion | 10 | 50 |
| dimethyl sulfide | decayig vegetation | 2 | 6 |
| ethylbenzene | aromatic | 3 | 10 |
| formic acid | | 28000 | 55000 |
| hexanal | fatty,green | 10 | 60 |
| **hydrogen sulfide** | **rotten egg** | **20** | **30** |
| indene | not found | 9 | 40 |
| isopropyl benzene | sharp, aromatic | 8 | 39.2 |
| limonene | lemon | 400 | 2500 |
| **methyl mercaptan** | **decayed cabbage** | **1** | **2** |
| naphthalene | math bakks, tar | 40 | 100 |
| nonanal | not found | 2 | 10 |
| nonane | not found | 1300 | 6800 |

**Table 5. Database with odor causing compounds**

| Odorant | Descriptor | OTC (ppbv) | OTC(µg/m3) |
|---|---|---|---|
| m-xylene | sweet | 300 | 1500 |
| ocatanal | not found | 1 | 7 |
| octane | gasoline | 5800 | 28000 |
| o-xylene | sweet | 900 | 3800 |
| pentanal | pungent | 6 | 20 |
| propanal | sharp | 30 | 70 |
| propanoic acid | vinegar, sour | 28 | 84 |
| p-xylene | sweet | 500 | 2200 |
| styrene | solvent, rubber | 100 | 600 |
| tetrachloroethene | sweet | 4900 | 130000 |
| trimethylamine | fishy | 2 | 6 |
| valeric acid | fecal, sour | 5 | 20 |
| vinyl acetate | sweet | 600 | 2200 |

**Table 6. Database with odor detection and monitoring techniques**

| Technique | Kind | Method | Advantages | Disadvantages | Reference |
|---|---|---|---|---|---|
| **Chemical analyses** | Analytical; Indirect method | Gas chromat.-Mass spectr. (GC-MS) | Detection of pollutants with low odor detection which may originate odor nuisance, useful to analyze odour composition in order to design intervention and treatment strategies, more objective, repeatable and accurate | Difficulty of relating the chemical composition of an odorous mixture to its olfactory properties, provide little information about the odorant real impact on human receptors | Capelli 2008, Lebrero 2011, Capelli 2013, Capelli 2014 |
| **Dynamic olfactometry** | Sensorial; Direct method | Use of human nose as a sensor | Determine the odor concentrations (Cod), giving indicative values of sensory impacts that are liable to affect off-site, the most common approach | Variability of human olfaction between different subjects, highly costly ($224-$336 per measurement), time consuming | Capelli 2008, Lebrero 2011, Capelli 2013 |
| **Electronic noses** | Senso-instrumental | Artificial noses which can distinguish between different odors, single odorants such as H2S and NH3 have been commonly used as surrogate markers | Make some assumptions about the landfill odor impact on the points where instruments are installed, effectively used as management tool in order to monitor site changes or operational failures | Depend critically on a set of operational choices (working conditions,measurment settings,data processing methods,etc.), provide only a partial characterization of odorous emssions because H2S and NH3 are not always responsible for the entire odor nuisance, problems with reliability and sensitivity-especially to temperature and humidity as well as with stability over time | Capelli 2008, Lebrero 2011, Capelli 2013, Capelli 2014 |

**Table 7. Database with odor mitigation technologies**

| Technology | Method | Impact | Reference |
|---|---|---|---|
| Process modification | Altering the manufacturing process to reduce the production of odorous compounds (eg. Changing the type and size of seals and gaskets,substituting alternative materials in the manufacturing process,etc.) | Very effective in reducing potential odour complaints by diminishing the emissions od odorous compounds at the source | Kehoe 1996 |
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**Table 8. Database with factors influencing the strength of odors**

| Factor | Kind | Conditions | Impact | Reference |
|---|---|---|---|---|
| **Wind speed and direction** | Meteorological | Weak wind,stable conditions | Highest odor detection | Capelli 2008 |
| **Wind speed and direction** | Meteorological | Clear presence of a predominant wind direction, strong wind | Odor detection significally lower | Capelli 2008 |
| **Time of the day** | | Nighttime | Most people are indoors, a decreased probability of affecting the surrounding community; inversion layer lower | EPA 2000; Air Quality Management District 2014 |
| | | Daytime | Eary in the morning or evening,increased probability of adversely affecting receptors; inversion layer is higher | |
| **Temperature** | Meteorological | High | Higher odor detection; When sunlight hits one packet of air molecules- the air packet heats up making atmosphere conditions unstable | EPA 2000 |
| **Anaerobic conditions** | | Low oxygen (<5%), PH value of leachate 6.5-8, tempearture 35-55°C | Wide range of compounds, most notoriously the reduced sulfur compounds (e.g. hydrogen sulfide, dimethyl sulfide, dimethyl disulfide, and methanethiol), volatile fatty acids, aromatic compounds and amines; ammonia. | http://compost.css.cornell.edu/odors/odor.html |

**Table 9. Database with factors influencing the strength of odors**

| | | | | |
|---|---|---|---|---|
| **Precipitation** | Meteorological | | Wet surface soil conditions may prevent landfill gas from migrating through the top of the landfill into the air above. Rain and moisture may also seep into the pore spaces in the landfill and "push out" gases in these spaces. | http://www.atsdr.cdc.gov/hac/landfill/html/ch2a.html |
| **Topography** | | Higher elevation; Winds sweep down a mountain or a ridge to a lower area | Odors generated at higher elevations can be carried into lower elevations; Important in determining where to monitor | Taylor & Francis Group 2011; *** |
| **Humidity** | Meteorological | High or fog | More odors detected; Warm and humid air enhances our sense of smell, because the humidity carries odor molecules to our noses; Traps smells and causes them to linger longer than they usually would | http://www.nbcnews.com/news/other/oooh-smell-odors-rise-temperature-f6C10663511 |
| **Weather Conditions** | Meteorological | Clear sky, sunny and windy day | Complains rarely received | Massachusetts Department of Environmental Protection 2007 |
| | | Overcast, no wind, high humidity or fog, thermal inversions | Complains tend to occur | |

**Table 10. Database with factors influencing the strength of odors**

| | | | | |
|---|---|---|---|---|
| **Thermal inversions** | Changes in the season | Fall to Winter, Winter to Spring | Period of the year that has tendency for those kind of meterorological conditions; hold odors closer to the ground where they are more likely to be detected | http://www.mass.gov/eea/docs/dep/recycle/laws/lfgasapp.pdf; NSWMA 2008 |
| **Type of waste** | Construction and demolition debris; Raw sewage sludge | Contain large quantities of wallboard (also called drywall or gypsum board) | Large amounts of hydrogen sulfide can be formed | https://www.health.ny.gov/environmental/outdoors/air/landfill_gas.htm |
| **Volume of potentially odorous material** | | Small amount/ large amount | A small amount of odorous waste can be quickly covered, or may not be noticable, while large amounts spread over a wider area requires more active management. | NSWMA 2008 |
| **Pressure** | Meteorological | Low: When the vapor pressure of the ambient air and the atmosphere is lower than the pressure of the gases inside the landfill | More landfill gas will seep out of the landfill into the air, because the vapors are trying to equilibrate the pressures, moving from areas of of high pressure to areas of low pressure | EPA 2000 |

## 2.2 DATA COLLECTION

The strategy of this study is to target partner landfills located in an urban setting. Therefore, several solid waste management facilities in those locations have been contacted in order to collect data about odor complaints. Data has been provided by the Solid Waste Authority of Palm Beach County as well as the real-time access to their weather station has been approved. Meteorological parameters such as, temperature, wind speed, wind direction, precipitation accumulation and pressure can be monitored via a wireless connection. Also, the meteorological data from previous years can be retrieved as well. Historical data sets have been collected from Waste Management Inc. of Florida as well as from Broward County, in order to collect more information on odor complaints to the county environmental protection unit. Installation of a wireless weather station (Figure 5) provided by FAU iSENSE has been arranged with Monarch Hill personnel. Weather station at Monarch Hill landfill provides information on wind direction, wind speed, temperature, humidity, pressure, precipitation intensity, etc.

**Figure 5. Installation of weather station at Monarch Hill**

## 2.3 PATTERN IDENTIFICATION AND TREND ANALYSIS

Based on the odor complaints data received from the Solid Waste Authority of Palm Beach County and databases from Waste Management Inc. of Florida, as well as using appropriate qualifiers for meteorological measurements and landfill operations, the datasets can be analyzed to determine the existence of patterns or trends that could lead to the development of effective management strategies.

Odor complaint data received from the Solid Waste Authority of Palm Beach County was used for preliminary analysis and to see if any patterns exist connected to meteorological conditions. Trend analysis was done in Excel, and the data from the weather station provided by SWA was used to get the information about the meteorological conditions in that specific time period (2005-2016). The initial dataset consisted of 423 points. An analysis was conducted to determine what year, month and day of the week as well as the time of the day in which the most odor complaints were logged. Also, the meteorological conditions on the most problematic days were compared to

determine any patterns. The next step was to see how many days in time period (2005-2016) had more than one odor compliant in the same day. Going through the literature review, three or more verified odor complaints in the same day triggers corrective action, so for further analysis, only days with the largest number of complaints in the same day were taken into consideration.

After receiving the data from Monarch Hill personnel and from Broward County on odor complaints, dates with three or more complaints in the same day were retrieved. The same was done for data provided from SWA of Palm Beach County. For the period from 2005- 2016, Monarch Hill landfill had 17 days in total with 3 or more odor complaints in the same day. Data provided from SWA of Palm Beach County for the period of 2005-2015 had a total of 25 days with 3 or more odor complaints in the same day. Meteorological data for both sites was collected from weather stations nearest to the location of sites for the day the odor complaint occurred as well as for the day before. Meteorological conditions taken into consideration are temperature, humidity, sea level pressure, wind direction, and wind speed. Data for each of the meteorological parameters was plotted for the day the complaints occurred and were compared to the corresponding values of the day before. Also, values are plotted for the exact time of received odor complaints and compared to the same time period on the previous day.

## 2.3 BACTERIAL EXPRESSION OF HUMAN ODORANT BINDING PROTEIN IIA (OBPIIA)

### 2.3.1 Trial 1

The bacterial expression plasmid absorbed in filter paper was obtained from Artur Ribeiro, Professor of Biological Engineering at the University of Minho in Braga, Portugal.[1] The plasmid DNA contained the coding sequence for OBPIIa. The plasmid had been cloned prior to shipment into the pET-28 expression vector with a Kanamycin drug selection marker and a Hexa-His affinity tag. The Hexa-His affinity tag indicates that a polyhistidine tag is used for affinity purification of a polyhistidine-tagged recombinant protein expressed in *E. coli*. Once expressed, OBPIIa will be separated from other proteins using a histidine affinity-resin that contains cobalt ions.

[1] Silva, C. M.-P. (2013). *Odorant Binding Proteins: a biotechnological tool for odour control.* Berlin: Appl Microbiol Biotechnol

The following should be the nucleotide sequence that encodes just the amino acid sequence of OBPAII[2]: Nucleotide Sequence (513 nt):

ATGAAGACCCTGTTCCTGGGTGTCACGCTCGGCCTGGCCGCTGCCCTGTCCTTCACC
CTGGAGGAGGAGGATATCACAGGGACCTGGTACGTGAAGGCCATGGTGGTCGATAA
GGACTTTCCGGAGGACAGGAGGCCCAGGAAGGTGTCCCCAGTGAAGGTGACAGCCC
TGGGCGGTGGGAACTTGGAAGCCACGTTCACCTTCATGAGGGAGGATCGGTGCATC
CAGAAGAAAATCCTGATGCGGAAGACGGAGGAGCCTGGCAAATTCAGCGCCTATGG
GGGCAGGAAGCTCATATACCTGCAGGAGCTGCCCGGGACGGACGACTACGTCTTTT
ACTGCAAAGACCAGCGCCGTGGGGGCCTGCGCTACATGGGAAAGCTTGTGGGTAGG
AATCCTAATACCAACCTGGAGGCCCTGGAAGAATTTAAGAAATTGGTGCAGCACAA
GGGACTCTCGGAGGAGGACATTTTCATGCCCCTGCAGACGGGAAGCTGCGTTCTCGA
ACACTAG

Translation(170aa):

MKTLFLGVTLGLAAALSFTLEEEDITGTWYVKAMVVDKDFPEDRRPRKVSPVKVTALG

GGNLEATFTFMREDRCIQKKILMRKTEEPGKFSAYGGRKLIYLQELPGTDDYVFYCKDQ

RRGGLRYMGKLVGRNPNTNLEALEEFKKLVQHKGLSEEDIFMPLQTGSCVLEH

Figure 6 and Figure 7 indicate restriction of endonuclease sites used to clone the gene of interest into this vector.

[2] https://www.ncbi.nlm.nih.gov/CCDS/CcdsBrowse.cgi?REQUEST=CCDS&DATA=CCDS6992

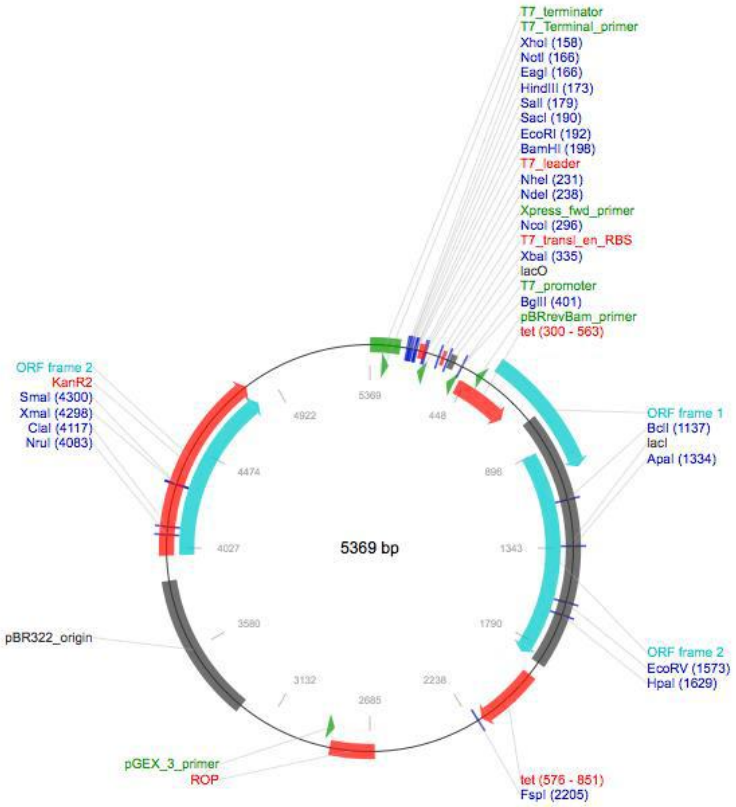



**Figure 6. Generated plasmid map for pET28a vector.**[3]

[3] Plasmid where the gene is cloned: https://www.addgene.org/vector-database/2565/

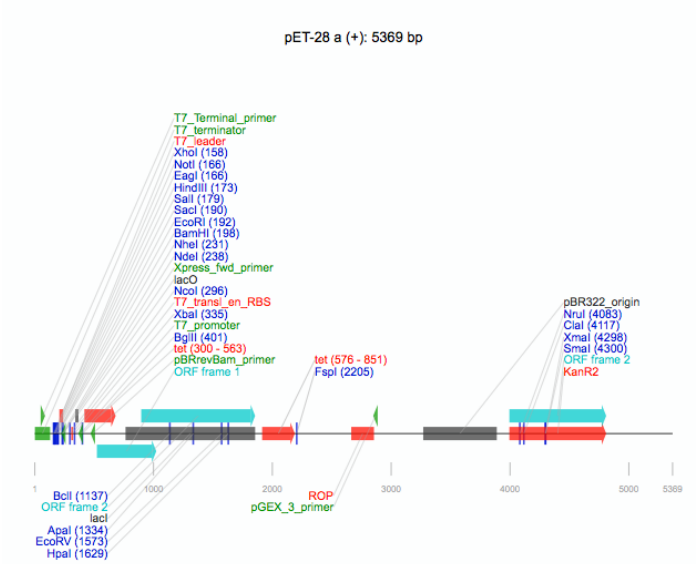



**Figure 7. Linear map of analyze sequence: pET-28 a (+)[3]**

The plasmid was eluted from the filter paper using tris-EDTA buffer in a heat sealable bag to maintain minimum volume of buffer. The buffer was allowed to saturate for 1 day in refrigeration at 4°C. The next step to isolate the plasmid was ethanol precipitation. Prior to ethanol precipitation, the eluted plasmid-tris-EDTA buffer solution was stored in deep freeze at -80°C.

A culture of *E. coli* expression strain XL1 Blue II was grown in overnight culture to serve as an expression vector for the DNA plasmid. The DNA was concentrated by ethanol precipitation, centrifugation, and removal of ethanol. Nanopure water was added to the concentrated DNA so that there would be no ions to interfere with electroporation. The DNA was added to the concentrated *E. coli* culture and electroporated. Transformants were inoculated onto Kanamycin Luria Broth Agar plates and incubated at 37°C.

The method used to transform competent *E. coli* cells is is to transform the cells resulting in transformation efficiency that goes up to the 107-108 CFU (colony forming units) per microgram of DNA. A single colony, isolated and grown in a LB-agar plate, is used to inoculate 10 mL of LB medium and is grown at 37ºC with shaking (250 rpm), until the media reaches an optical density ($\lambda$ = 600 nm) of 0.3 – 0.4. At this point, the metabolism and cell growth is stopped by incubation on ice for 5 minutes. The cell suspension is centrifuged at 3000 rpm (1100G) for 10 minutes at 4ºC. The supernatant is discarded and the pellet is resuspended in 1 mL of cold x1TSS solution. About 1-10 ng of plasmid in final volume of 1-10 µL are added to the mix. The cellular suspension

plus the plasmidic DNA are kept on ice for one hour and after that a heat shock is given to the cells by exposition of the mix at 42ºC for 2 minutes. The heat shock is stopped by immersion on ice for 2 minutes. After this, 1mL of warm LB is added and the suspension is incubated one hour at 37ºC with shaking (250 rpm) in order to activate and express the gene that confers resistance to the selective marker (antibiotic). Last, 50-200 µL of the transformation mix is plated on LB-agar plus the kanamycin plates that are incubated for 16-20 hours at 37ºC.

### 2.3.2 Trial 2

A transformed BL21 *E. coli* strain provided again by Artur Ribeiro already containing the plasmid to make OBP was incubated overnight on LB Agar + Kanamycin plates at 37°C. Instead of using a plasmid that needed to be transformed into *E. coli*, transformants were already prepared and sent as agar stabs, which is a very stable format in which to transport clones. Following incubation, colonies were inoculated into fresh media and an overnight culture grown. The overnight culture was prepared with 50% glycerol to be frozen at -80ºC for use indefinitely.

Clones from the frozen stock will be centrifuged and run on acrylamide gels with and without IPTG to observe whether the protein remains soluble in the supernatant or ends up in the cell pellet. Once it is confirmed that the protein remains soluble and is of the expected base-pair length, protein expression and purification will be done using the cobalt-based IMAC medium from GE Healthcare (Figure 8). His SpinTrap TALON® is a single-use column for histidine-tagged proteins and comes prepacked with 100 µl TALON® Superflow™ cobalt-IMAC (immobilized metal affinity chromatography) medium. The benefit of cobalt based media rather than nickel-charged is that it offers better selectivity and purity. One run takes approximately 10 minutes with a microcentrifuge.

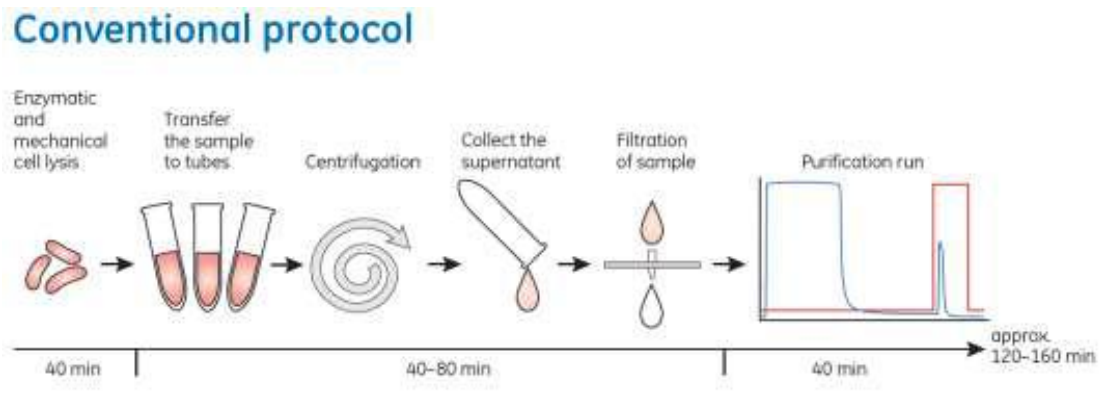



**Figure 8. Conventional protocol for protein purification from GE Healthcare.**

A gas reactor prototype was built and air was bubbled through water at the bottom of the reaction chamber (Figure 4). The reactor was built using two one-way check valves, flexible air line tubing and a 250mL HDPE sample bottle. It is planned to bubble hydrogen sulfide, mercaptans, and/or dimethyl sulfide gas through odorant binding protein (OBPIIa) suspended in liquid phase. Within the vessel, the protein will be exposed to a steady stream of pressurized gas from a tank with flow rate carefully controlled with a regulator. After the gas exposure period, an aliquot of liquid sample will be transferred by pipette to a cuvette for analysis by fluorometry to quantify binding and establish a relationship between concentration and fluorescence.

1-aminoanthracene (1-AMA) is an intrinsic fluorophore that will be used to observe binding of OBP to the pure odorous gasses, hydrogen sulfide, mercaptans and dimethyl sulfide. By monitoring fluorescence excitation spectra, Kmiecik and Albani (2010)[4] studied the binding effect of 1-AMA on odorant binding protein structure. Results show that the conformation of OBP is modified by binding 1-AMA at low probe concentrations. Fluorescence excitation spectra incurs a red shift. The aqueous protein-AMA complex will exist in the bottom of the gas reactor chamber. A Y-connector will connect the gaseous cylinder and a flowmeter with the one-way valve at the bottom of the chamber. Gas will escape the top of the chamber through a second one-way valve. Fluorescence spectra will reveal the relationship between fluorescence and odorous gas concentration. Air successfully bubbled through the water at the bottom of the chamber and out

[4] J Fluoresc. 2010 Sep;20(5):973-83. doi: 10.1007/s10895-010-0643-z. Epub 2010 Mar 30.

the valve at the top of the chamber (Figure 9).

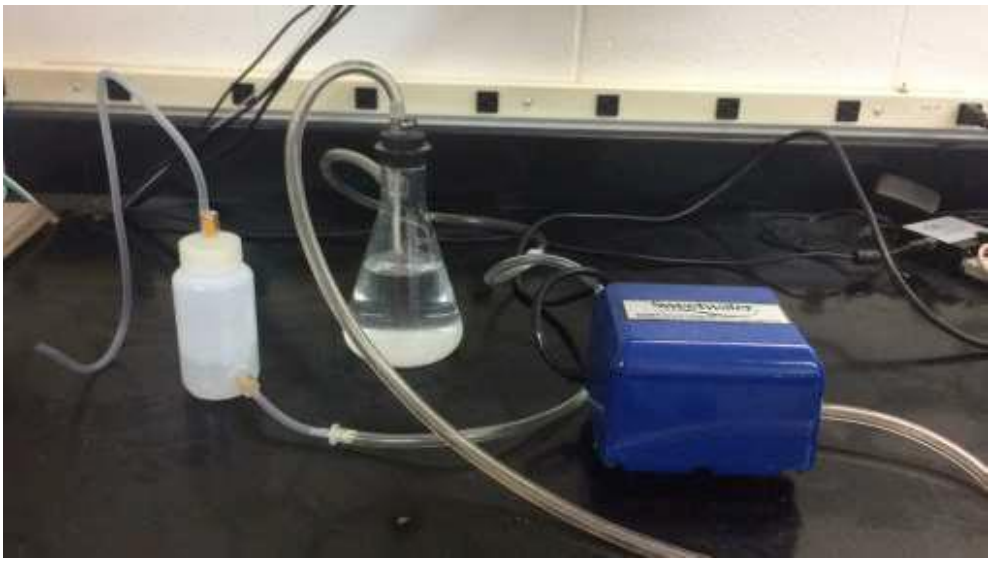
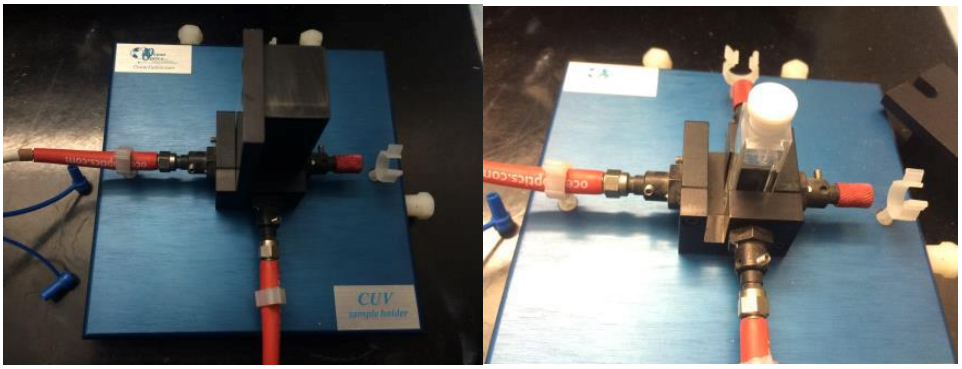


**Figure 9. Gas reactor prototype being tested using an air compressor and beaker of water for humidifying the air connected to the valve at the bottom of the chamber.**

The Ocean Optics Spectrometer (Figure 10) was configured for future fluoroscopy of fluorescently marked OBP2A as it binds odorants. Updated software called SpectraSuite was acquired and advanced operator training was conducted with the vendor.



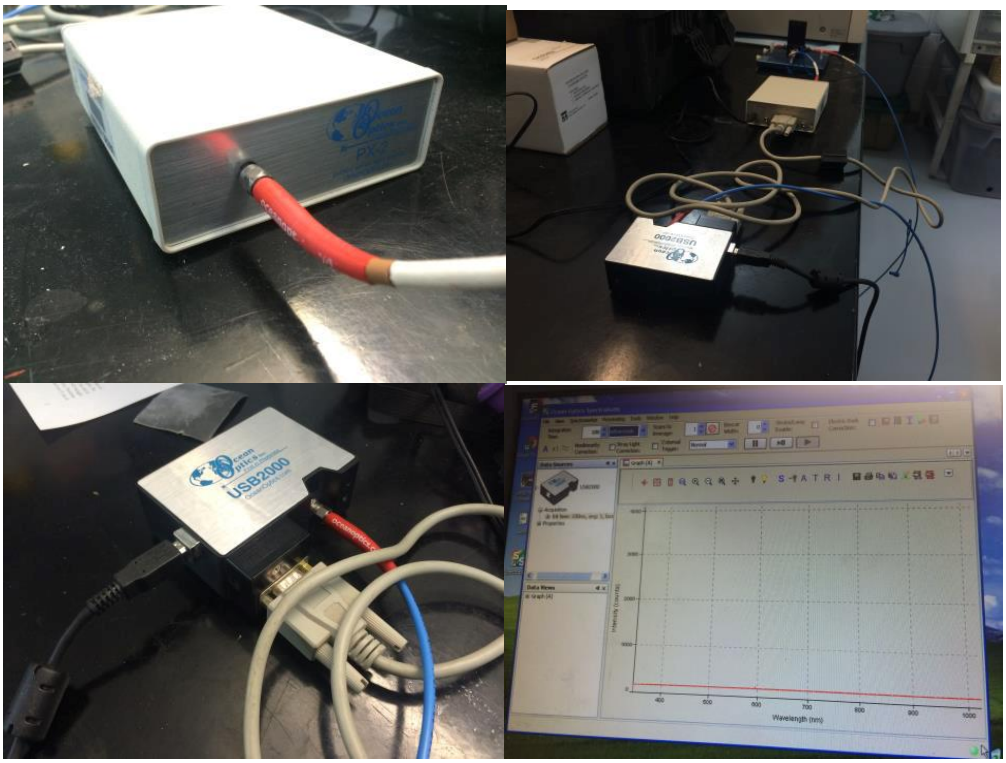



**Figure 10. Photos of OceanOptics Spectrometer and accompanying SpectraSuite software interface[5]**

[5] http://www.spectroscopytv.com/the-basics-of-spectrasuite/
http://oceanoptics.com/wp-content/uploads/px-2.pdf

# 3. RESULTS AND DISCUSSION

This chapter explains in detail the results obtained from the analysis procedures that were described in the methodology section.

## 3.1 PRELIMINARY ANALYSIS

Odor complaint data received from the Solid Waste Authority of Palm Beach County was used for preliminary analysis and to see if any patterns exist connected to meteorological conditions.

Preliminary results showed that the year 2014 had the largest number of odor complaints (n=98). Average number of odor complaints per month in 2014 was 9, with the most number being logged in the month of September with 51 complaints; followed by December with 44 complaints and February with 43. When comparing the most problematic days, analysis showed that working days had more odor complaints than the weekends, potentially because most people were not home during the weekends. Most odor complaints were received in the afternoon hours, which can be related to people coming home from work in the afternoon and spending more time at home than in the morning hours.

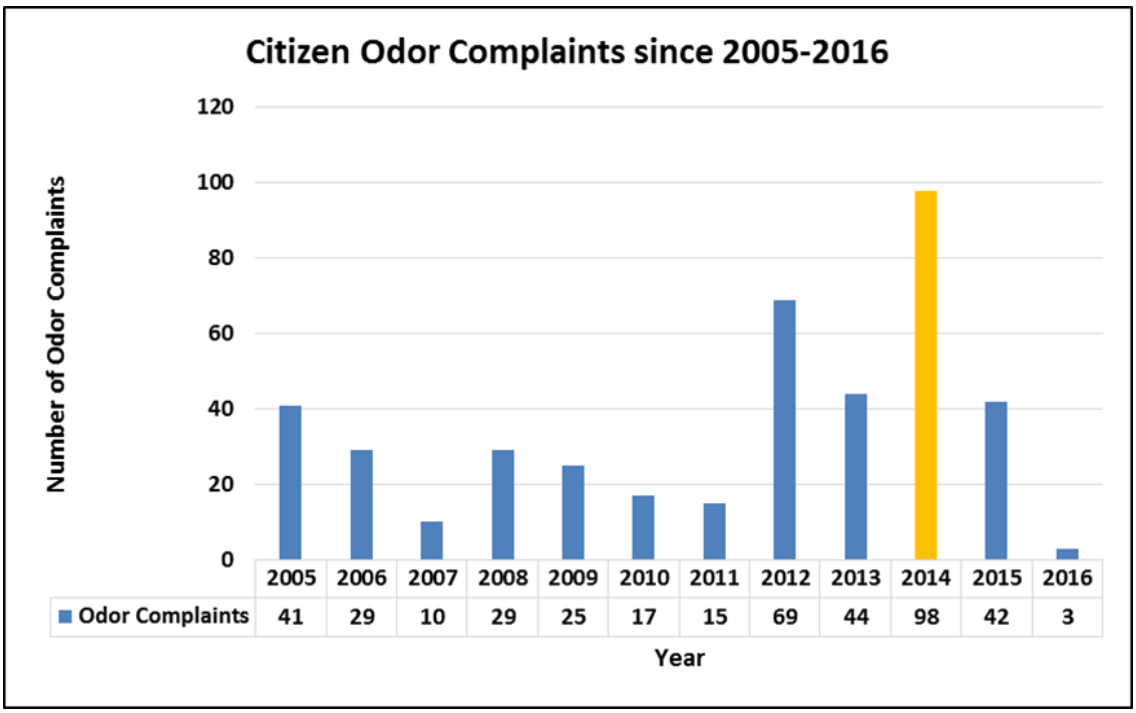



**Figure 11. Year with the greatest number of odor complaints**

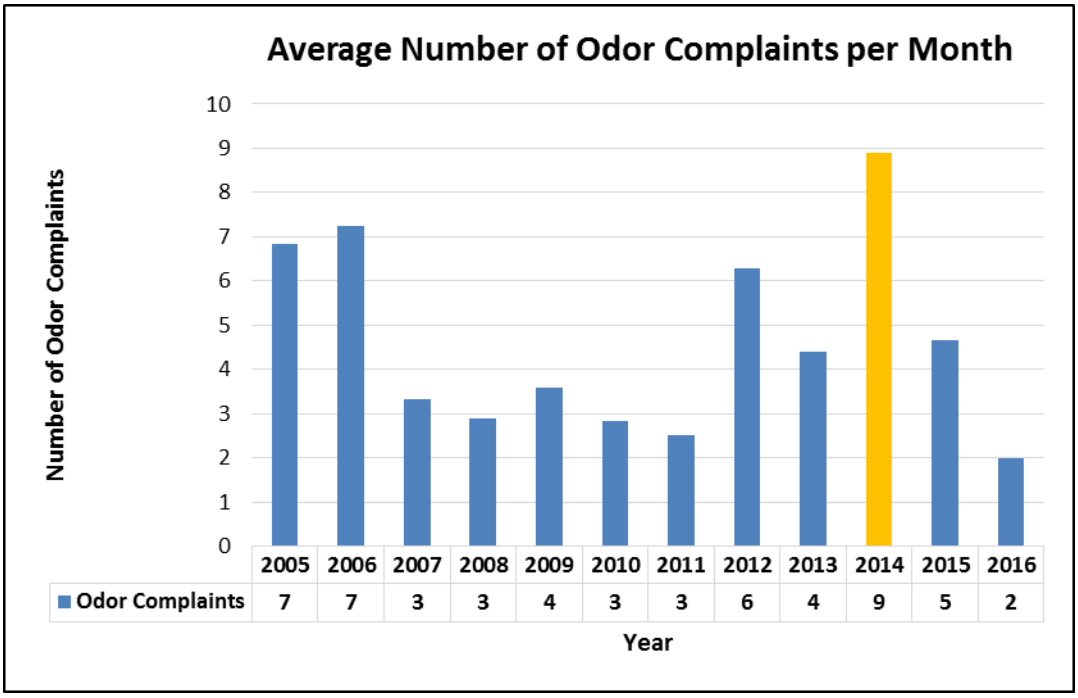



**Figure 12. Average number of odor complaints per month in a year**

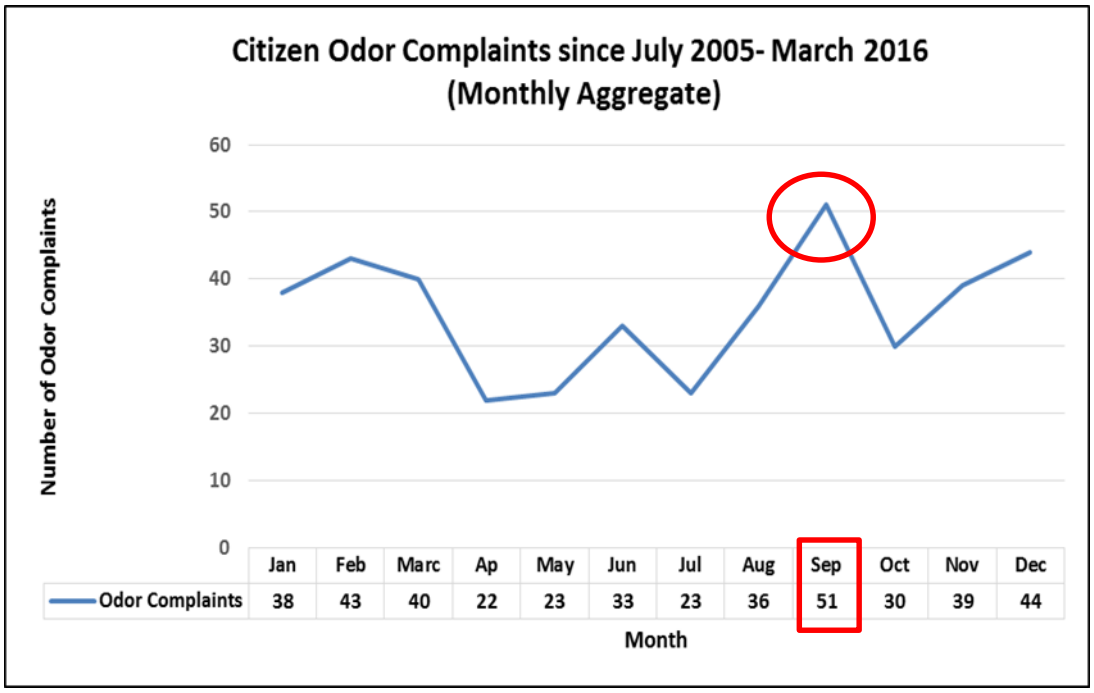



**Figure 13. Month with the greatest number of odor complaints**

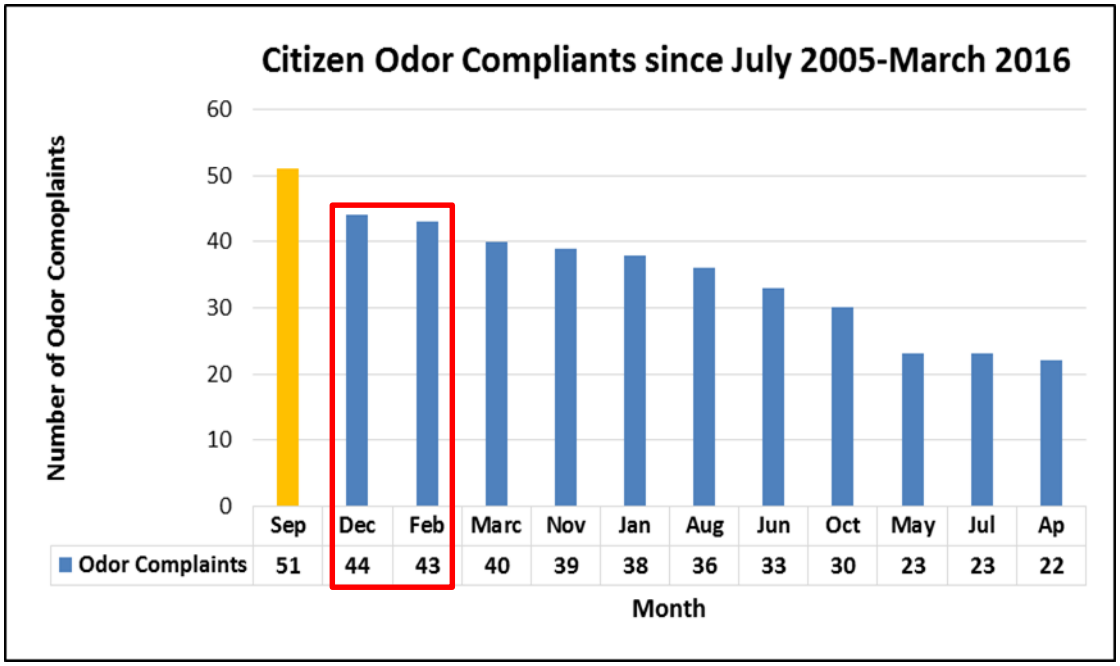



**Figure 14. Months with the greatest number of odor complaints**

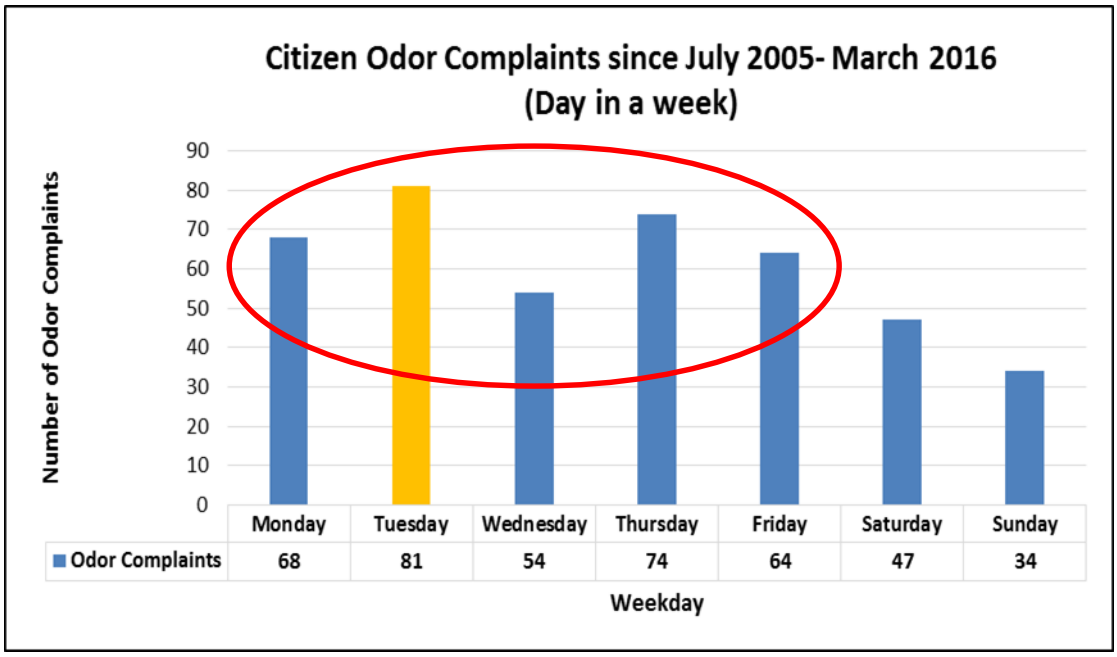



**Figure 15. Odor complaints based on the day in a week**

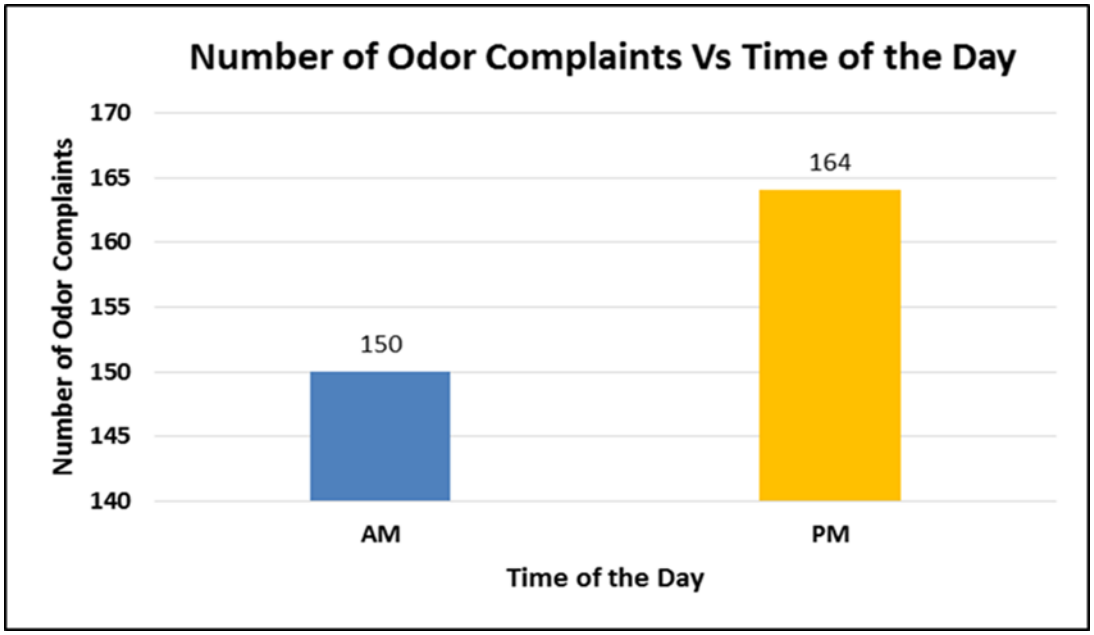



**Figure 16. Odor complaints based on the time of the day**

Next step was to see how many days in time period (2005-2016) had more than one odor compliant in the same day. Since the year 2016 had only three data points, it was excluded from the further analysis. Results showed that the most odor complaints in the same day were in 2005, 2006, 2009 and from 2012-2015. Year 2005 had 6 odor complaints in the same day on 9$^{th}$ of December and 3 odor complaints on the 5$^{th}$ and 6$^{th}$ of December. Year 2006 on the 2$^{nd}$ of February had 4 odor complaints in the same day while 13$^{th}$ of February had 3 of them. Year 2009 had up to 4 odor complaints in almost consecutive days, on the 26$^{th}$ and 28$^{th}$ of May. Year 2012 had 4 odor complaints on the 7$^{th}$ of June. Most interesting situation was in the year 2014. Even though there was a lot of odor complaints in the same day throughout the whole year, there were couple of days with continuous large number of odor complaints in the same day. Dates 16$^{th}$, 18$^{th}$ and 19$^{th}$ of September had total of 10 complaints all together. Also, large number of 5 complaints in the same day were noticed on the 25$^{th}$ of November. Year 2015 also had a lot of odor complaints in the same day throughout the whole year, but the largest number was 6 on the 26$^{th}$ of March.

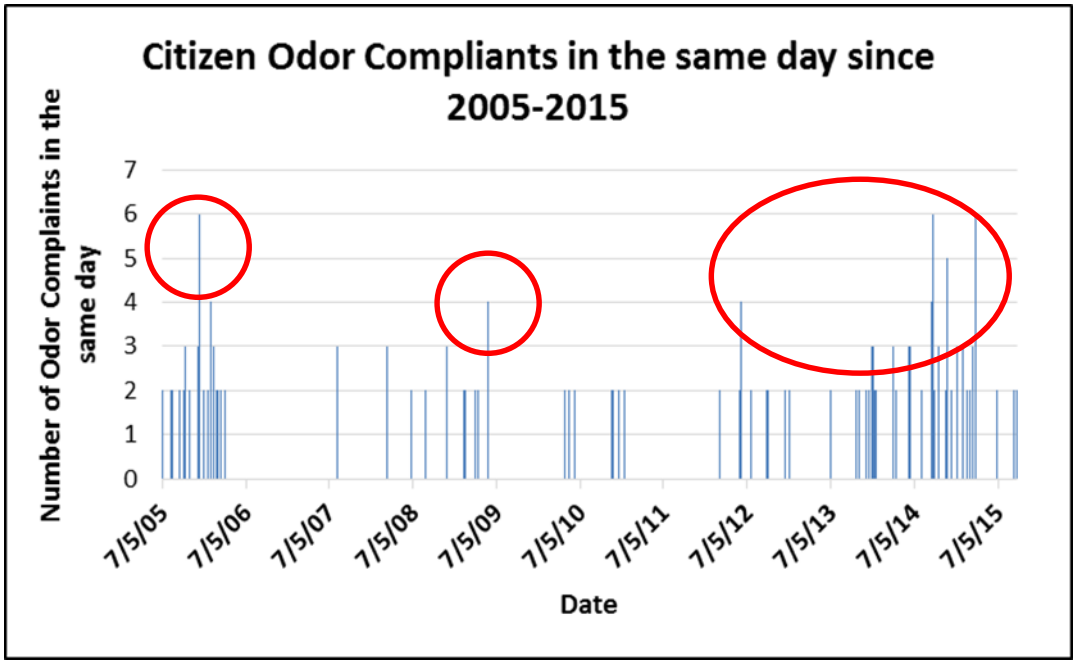



**Figure 17. Years with the greatest number of odor complaints in the same day**

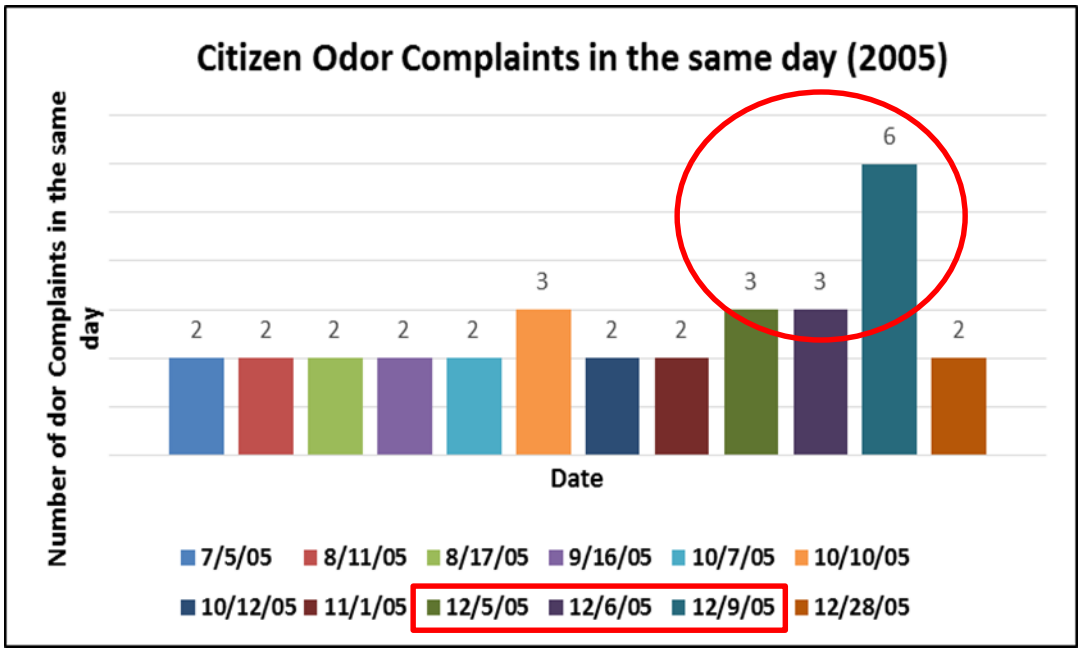



**Figure 18. Odor complaints in the same day for 2005**

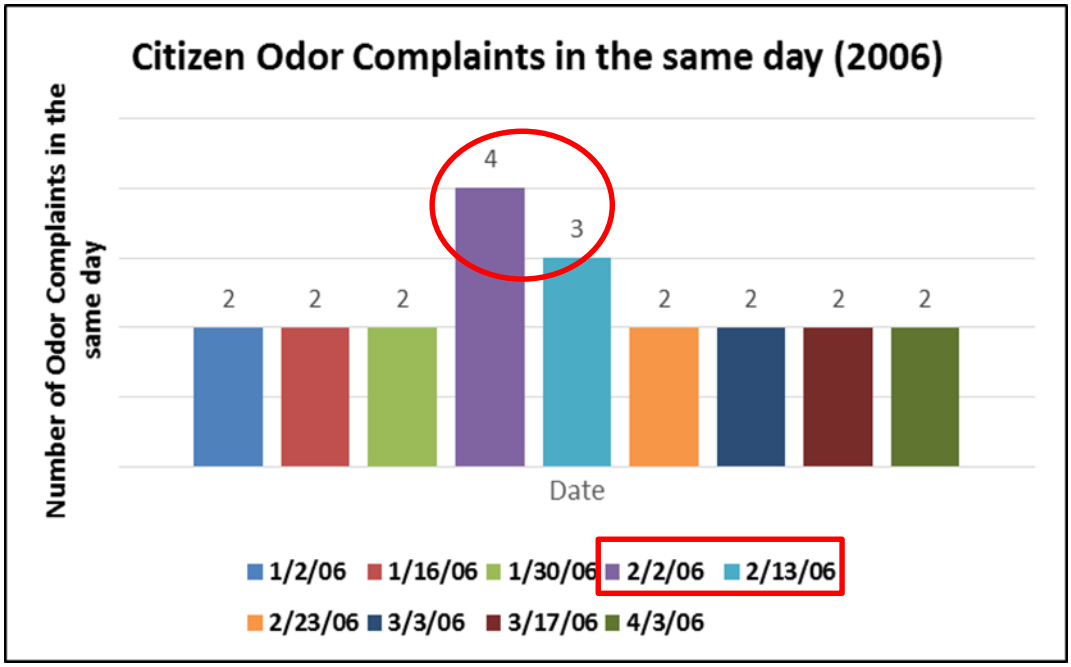



**Figure 19. Odor complaints in the same day for 2006**

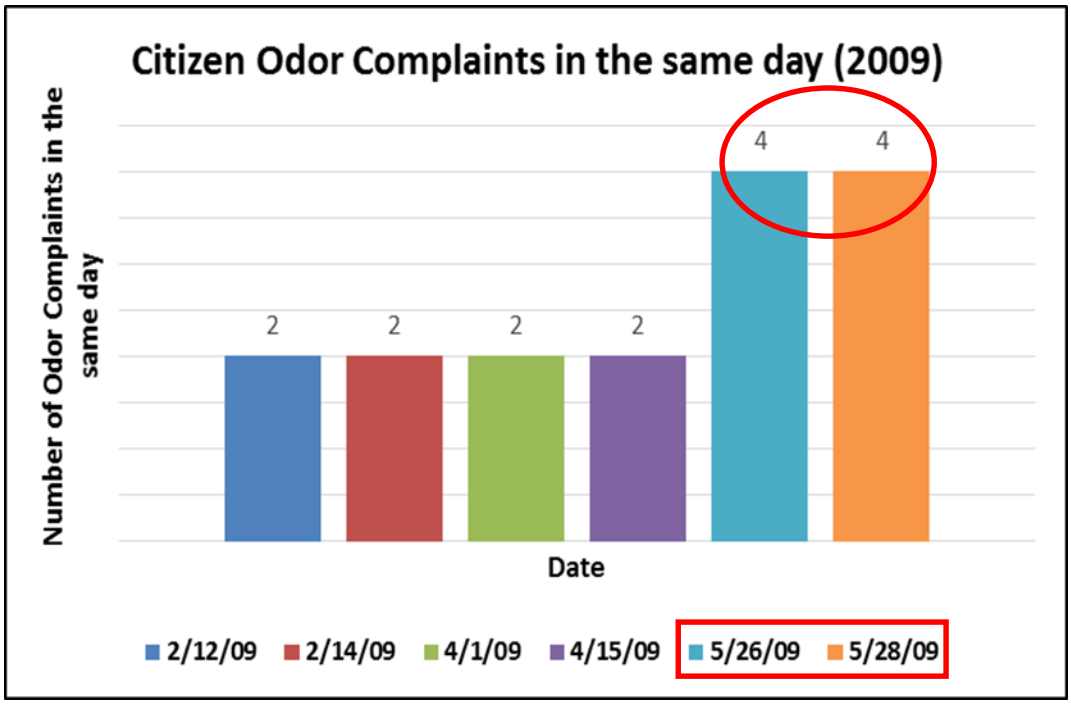



**Figure 20. Odor complaints in the same day for 2009**

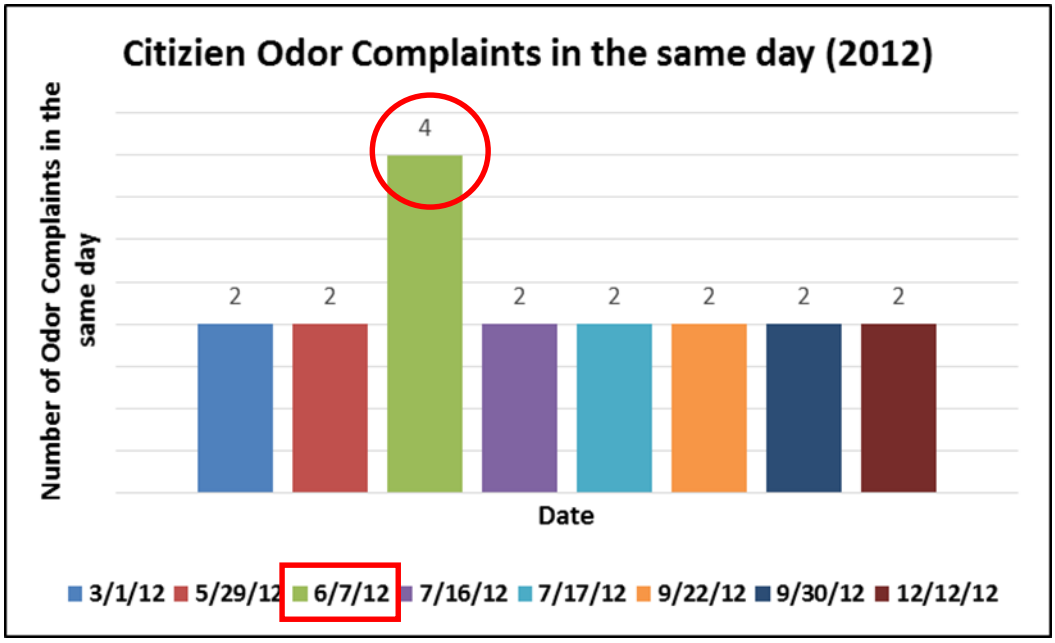



**Figure 21. Odor complaints in the same day for 2012**

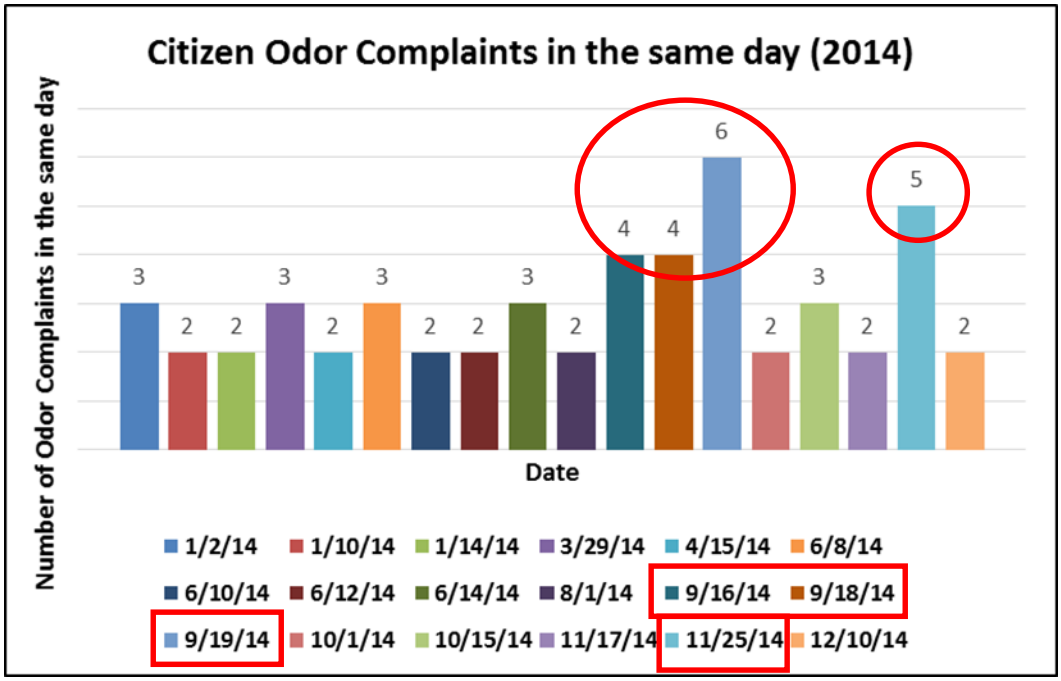



**Figure 22. Odor complaints in the same day for 2014**

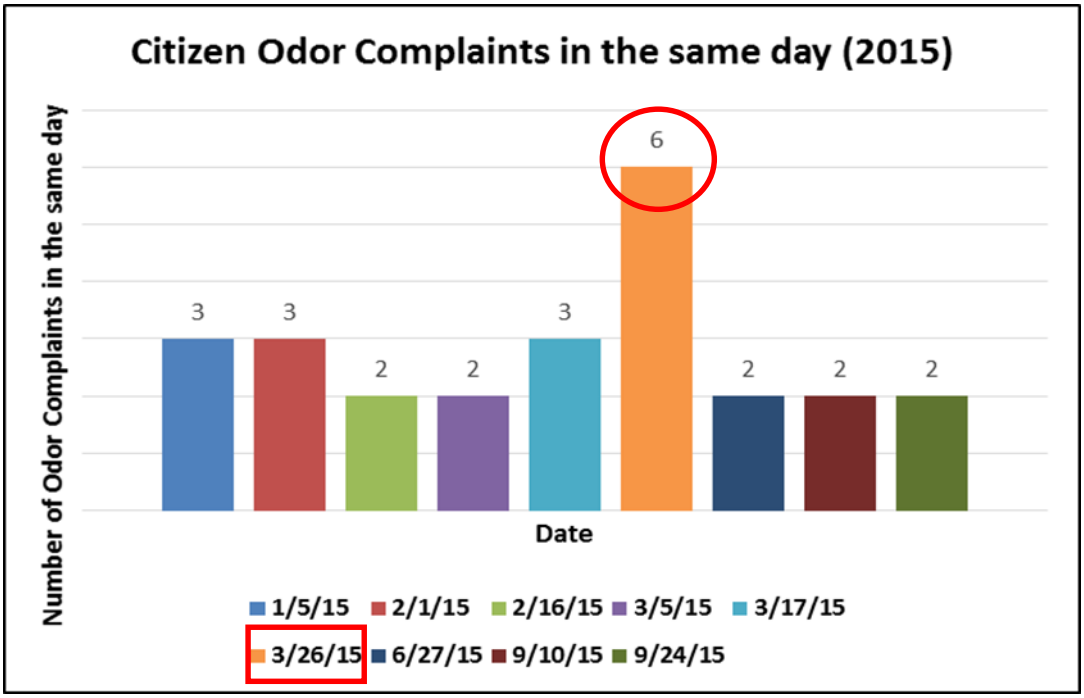



**Figure 23. Odor complaints in the same day for 2015**

Going through the literature review, three and more odor complaints in the same day verified triggers corrective action so for further analysis only days with the largest number of complaints (6) in the same day were took into consideration. Since in 2014 couple of continuous days in a row had a large number of complaints in the same day and it might be related, two days with 4 complaints and one day with 6 complaints were used for analysis. Dates taken for analysis were: 12/09/05 (6 complaints); 9/16/14 (4 complaints); 9/18/14 (4 complaints); 9/19/14 (6 complaints) and 3/26/15 (6 complaints). When mapping the locations of the odor complaints received for each date, it was concluded that the largest number of complaints is coming from the same neighborhood for all cases. Next step was to examine the meteorological conditions in the time of the call as well as for the day in general and information were gathered from the weather station. Year 2005 was excluded from the analysis since the weather station doesn't provide information on meteorological conditions before 2008. Meteorological conditions showed that there is possibility for correlation between the number of odor complaints and weather conditions since for all cases they were very similar. In all examined cases wind speed was weak, wind direction was south, temperature was high, pressure would drop and there were no precipitation, also the weather conditions were stable. Only in the case of 19$^{th}$ of September 2014, according to weather

station data, average wind direction was ENE, but the exact time of odor complaint reported showed that the wind direction was also south.

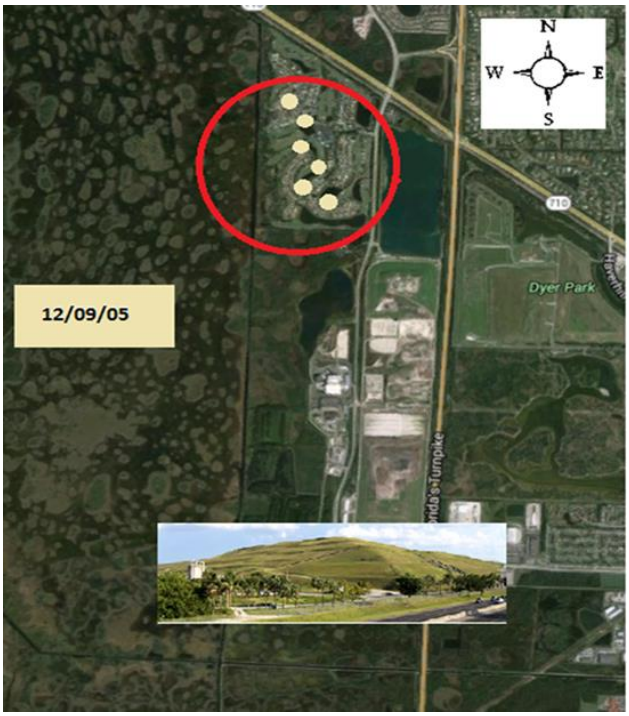



**Figure 24. Location of odor complaints on the 9th of December 2005**

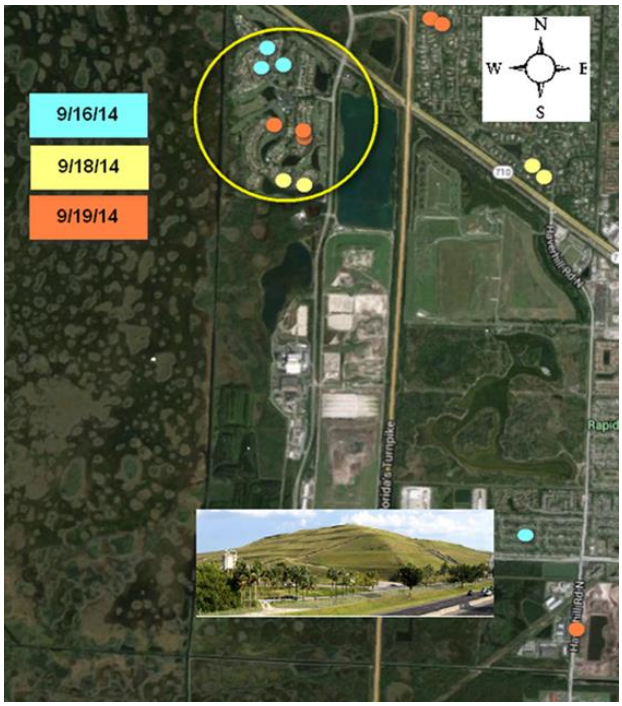



**Figure 25. Location of odor complaints on the 16th, 18th and 19th of September 2014**

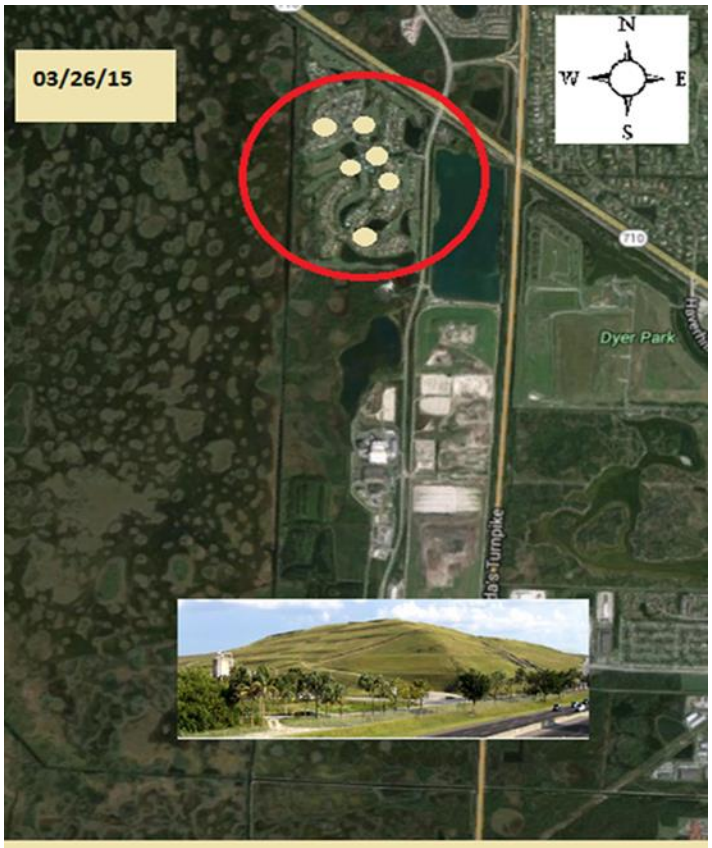



**Figure 26. Location of odor complaints on the 26th of March 2015**

## September 16, 2014

| | High | Low | Average |
|---|---|---|---|
| Temperature | 88.1 °F | 74.4 °F | 81.1 °F |
| Dew Point | 75.9 °F | 72.8 °F | 74.4 °F |
| Humidity | 96% | 63% | 81% |
| Precipitation | 0 in | -- | -- |

| | High | Low | Average |
|---|---|---|---|
| Wind Speed | 8 mph | -- | 1 mph |
| Wind Gust | 10 mph | -- | -- |
| Wind Direction | -- | -- | SE |
| Pressure | 30.03 in | 29.89 in | -- |

## September 18, 2014

| | High | Low | Average |
|---|---|---|---|
| Temperature | 92.4 °F | 73.1 °F | 79.6 °F |
| Dew Point | 76.7 °F | 71 °F | 73.7 °F |
| Humidity | 95% | 58% | 83% |
| Precipitation | 0 in | -- | -- |

| | High | Low | Average |
|---|---|---|---|
| Wind Speed | 13 mph | -- | 3 mph |
| Wind Gust | 13 mph | -- | -- |
| Wind Direction | -- | -- | South |
| Pressure | 29.9 in | 29.83 in | -- |

## September 19, 2014

| | High | Low | Average |
|---|---|---|---|
| Temperature | 88.7 °F | 71.2 °F | 77.2 °F |
| Dew Point | 77.6 °F | 69.7 °F | 74.4 °F |
| Humidity | 98% | 67% | 92% |
| Precipitation | 0.54 in | -- | -- |

| | High | Low | Average |
|---|---|---|---|
| Wind Speed | 14 mph | -- | 2 mph |
| Wind Gust | 14 mph | -- | -- |
| Wind Direction | -- | -- | ENE |
| Pressure | 29.92 in | 29.84 in | -- |

## March 26, 2015

| | High | Low | Average |
|---|---|---|---|
| Temperature | 84 °F | 71.5 °F | 76.6 °F |
| Dew Point | 74.7 °F | 67.1 °F | 70.8 °F |
| Humidity | 94% | 68% | 83% |
| Precipitation | 0.07 in | -- | -- |

| | High | Low | Average |
|---|---|---|---|
| Wind Speed | 22 mph | -- | 5 mph |
| Wind Gust | 22 mph | -- | -- |
| Wind Direction | -- | -- | South |
| Pressure | 30.04 in | 29.84 in | -- |

**Figure 27. Meteorological conditions on the dates**

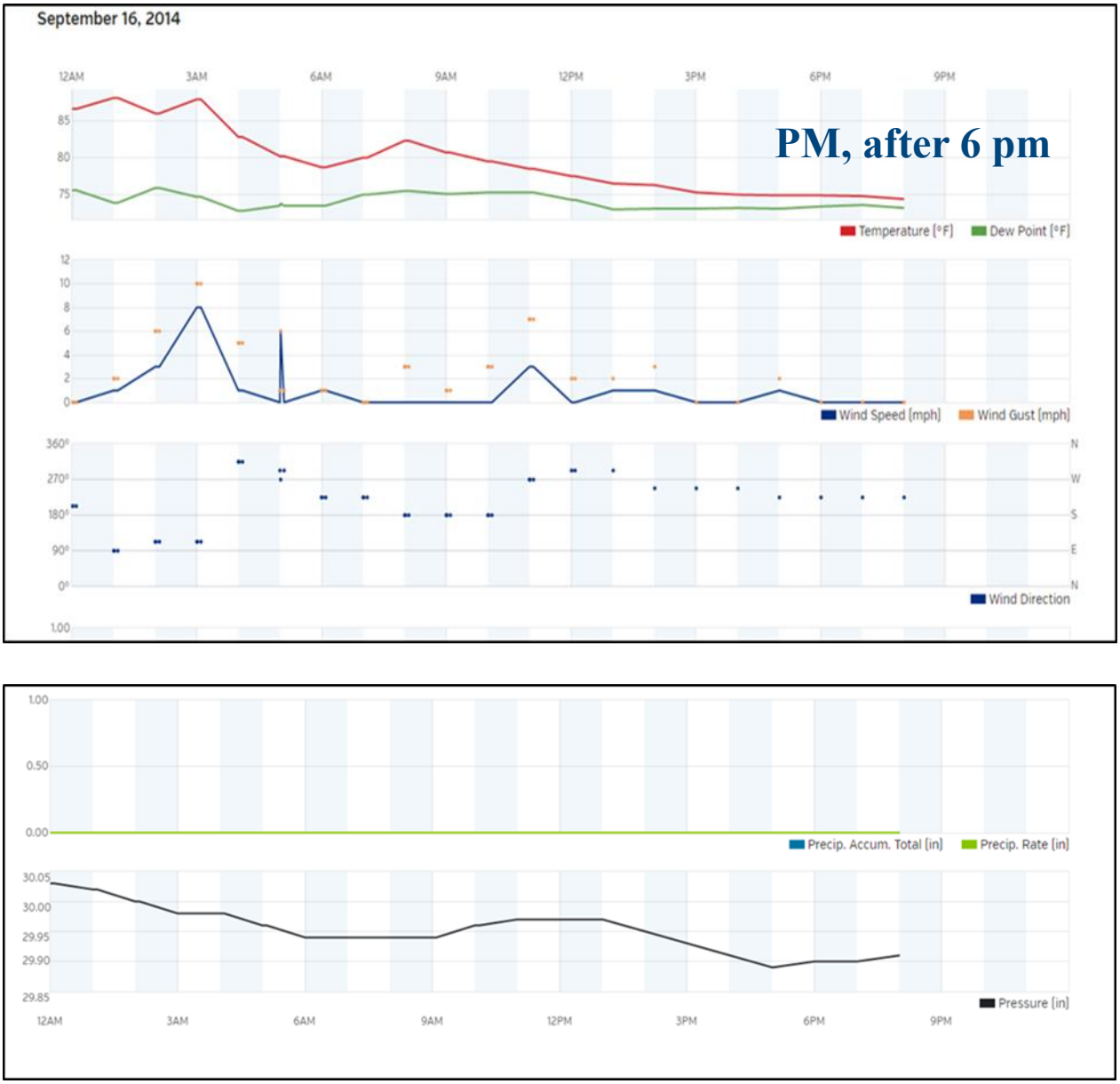



**Figure 28. Graphical representation of meteorological conditions on the 09/16/14 (Odor complaints occurred in the afternoon- after 6pm)**

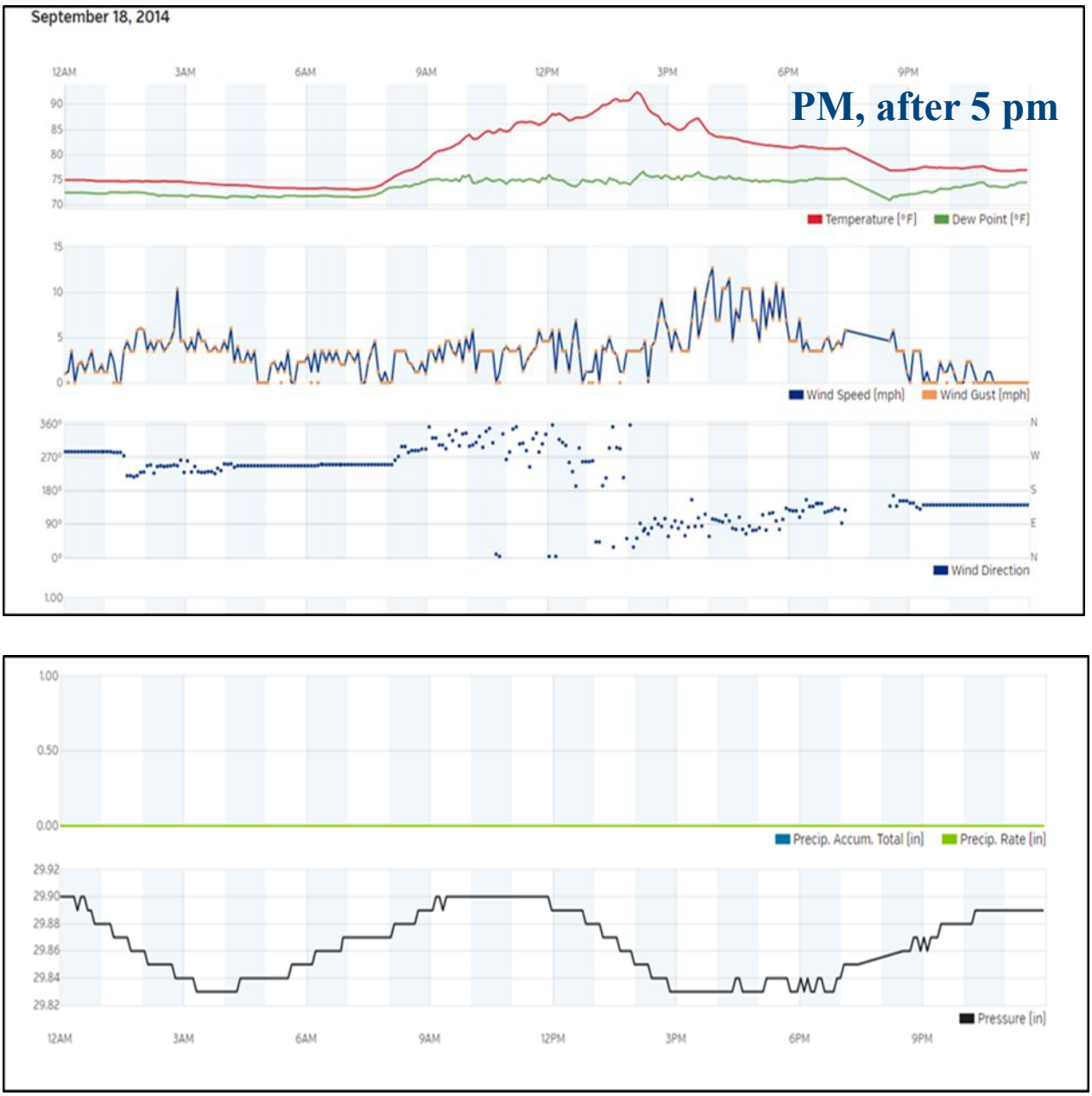



**Figure 29. Graphical representation of meteorological conditions on the 09/18/14 (Odor complaints occurred in the afternoon- after 5 pm)**

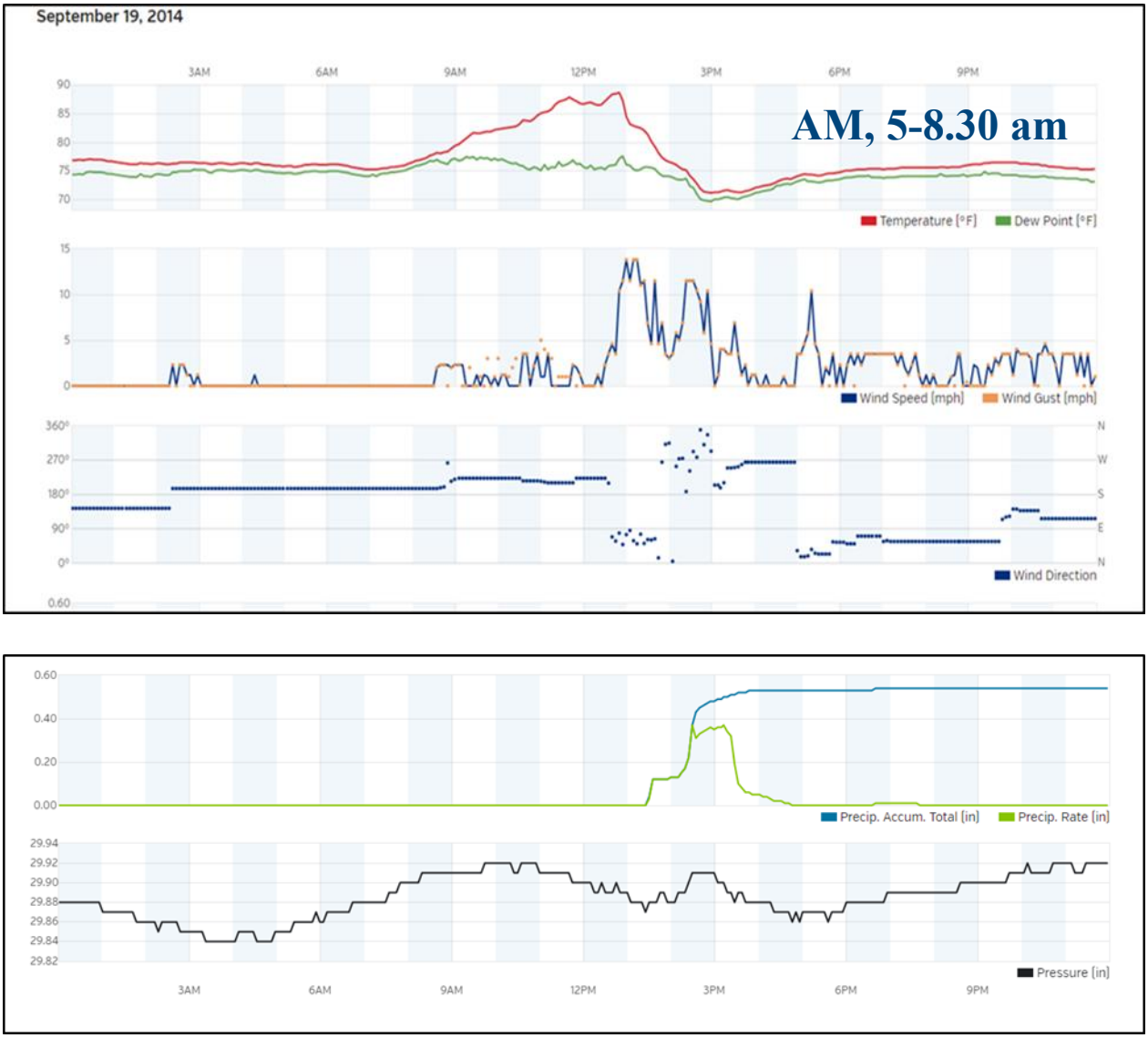



**Figure 30. Graphical representation of meteorological conditions on the 09/19/14 (Odor complaints occurred in the morning- 5-8.30 am)**

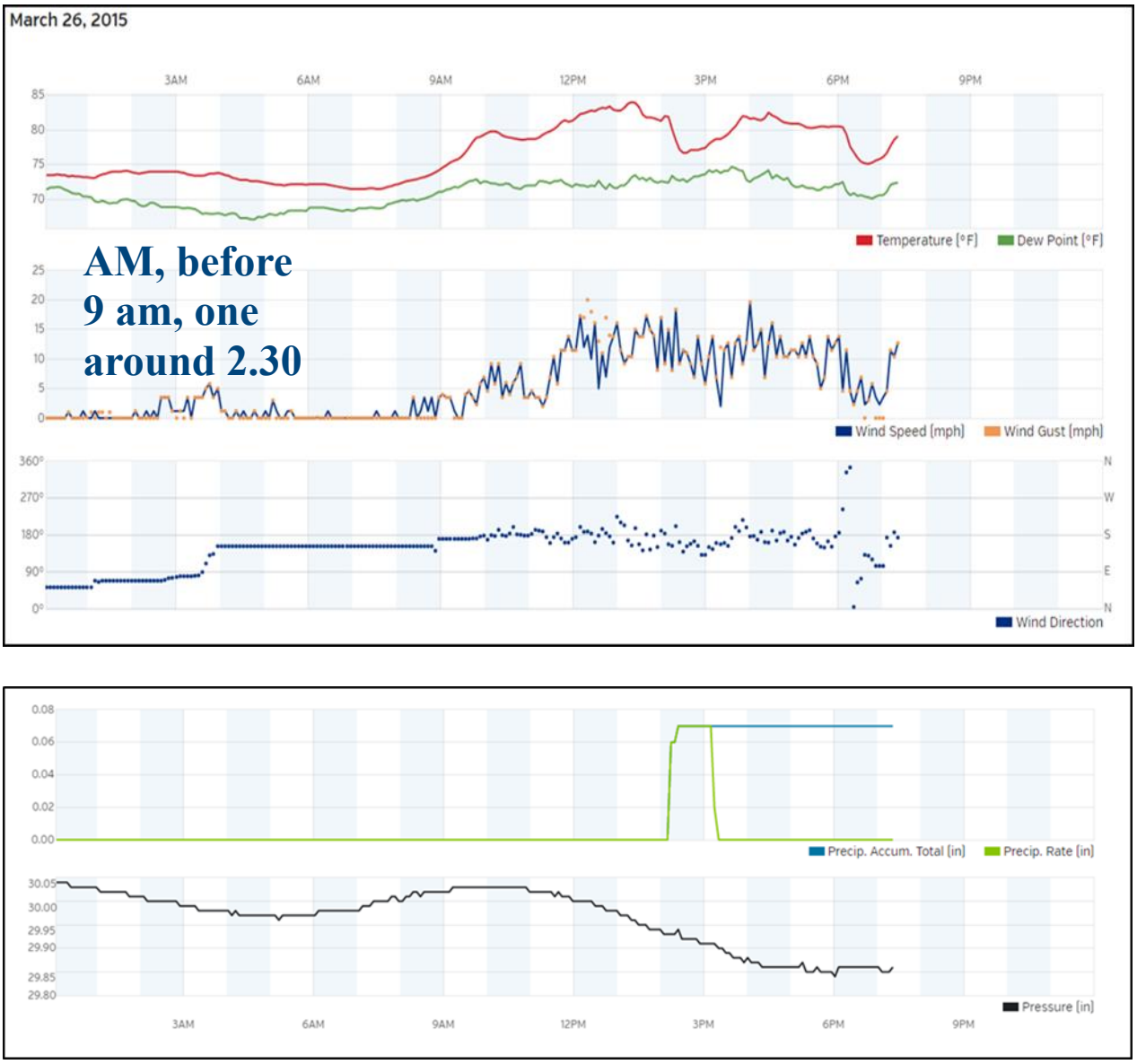



**Figure 31. Graphical representation of meteorological conditions on the 03/26/15 (Most of the odor complaints occurred in the morning- before 9 am; one occurred around 2.30 pm)**

## 3.2 METEOROLOGICAL DATA ANALYSIS

After receiving the data from Monarch Hill and from Broward County personnel on odor complaints, dates with three or more complaints in the same day were retrieved. The same was done for data provided from SWA of Palm Beach County. Meteorological data for both sites was collected from weather stations nearest to the location of sites for the day the odor complaint occurred as well as for the day before. Meteorological conditions taken into consideration are temperature, humidity, sea level pressure, wind direction, and wind speed.

Correlations between parameters showed that wind direction and wind speed are the parameters with lowest correlations when compared to the values from the day before, which is expected, while temperature, humidity, and pressure had constantly higher correlation values. Results for some of the dates for each site are presented in the figures that follow.

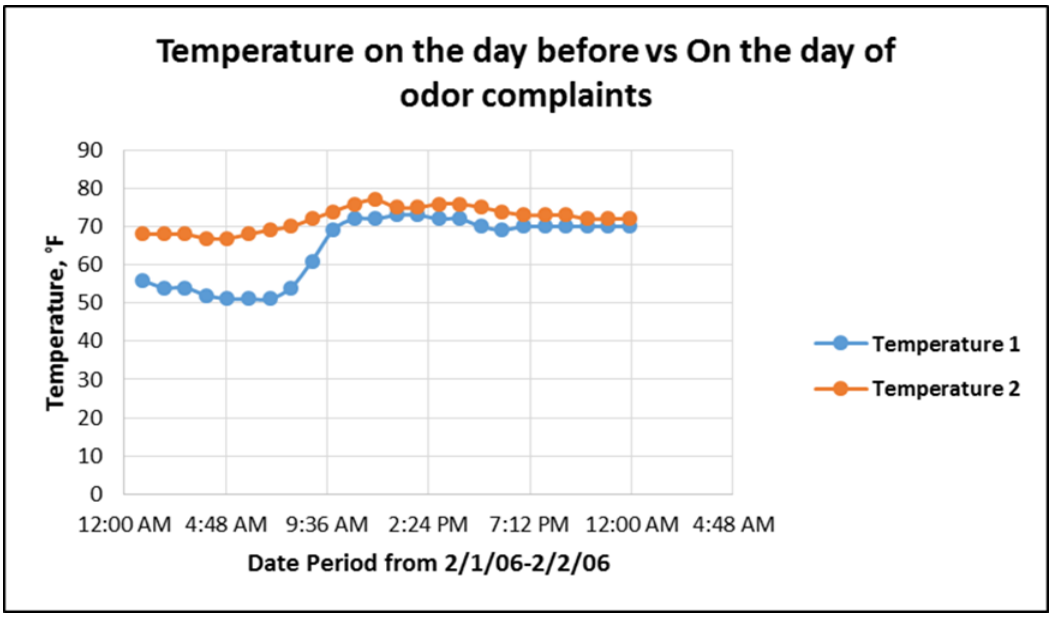



**Figure 32. SWA of Palm Beach County, 2/2/06**

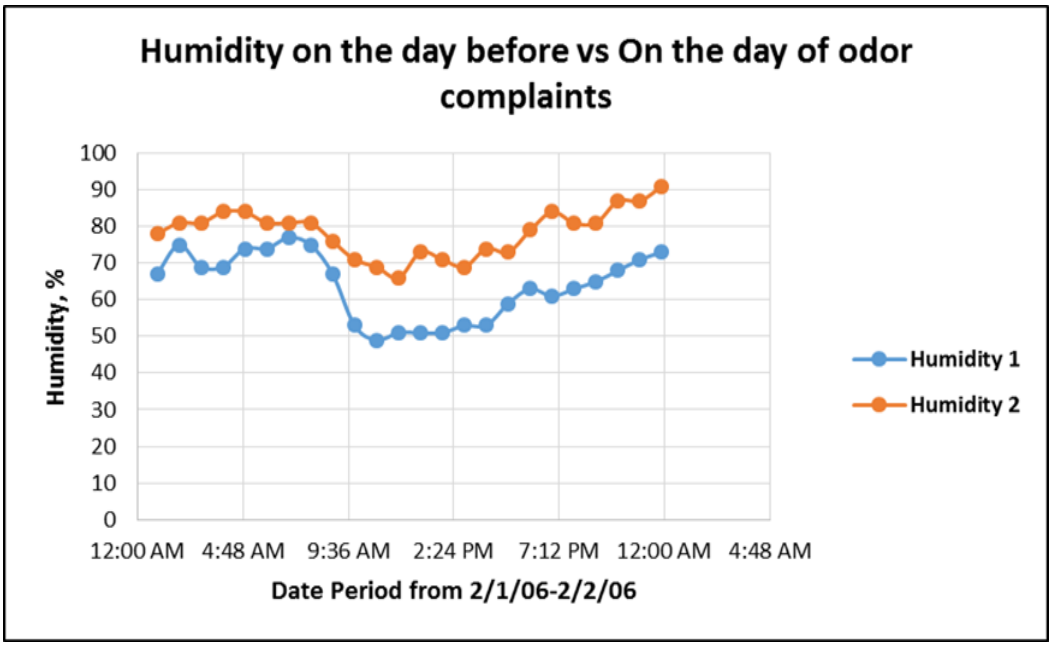



**Figure 33. SWA of Palm Beach County, 2/2/06**

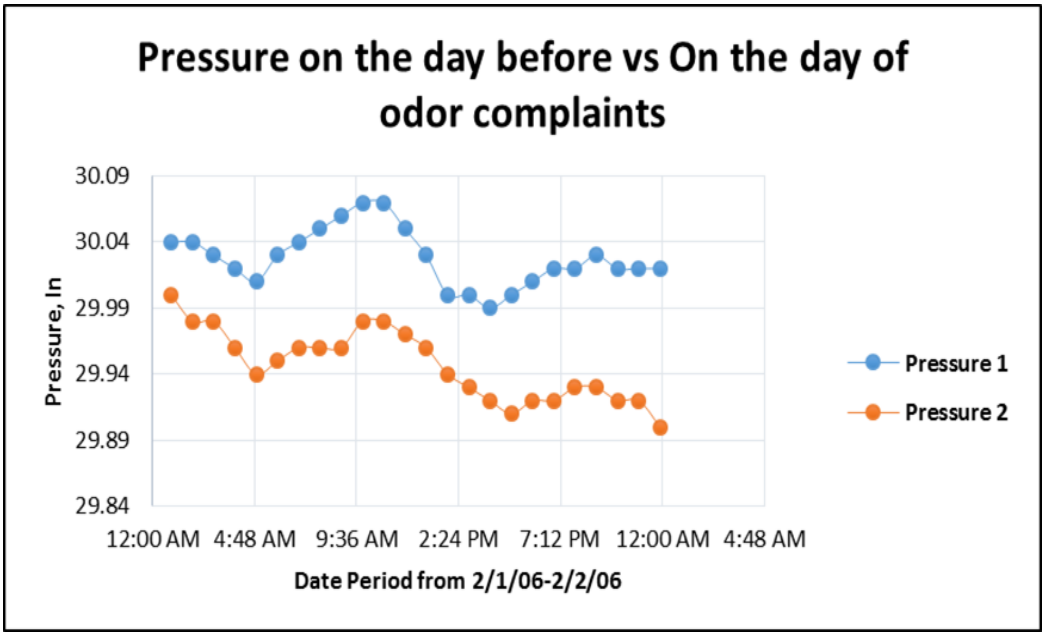



**Figure 34. SWA of Palm Beach County, 2/2/06**

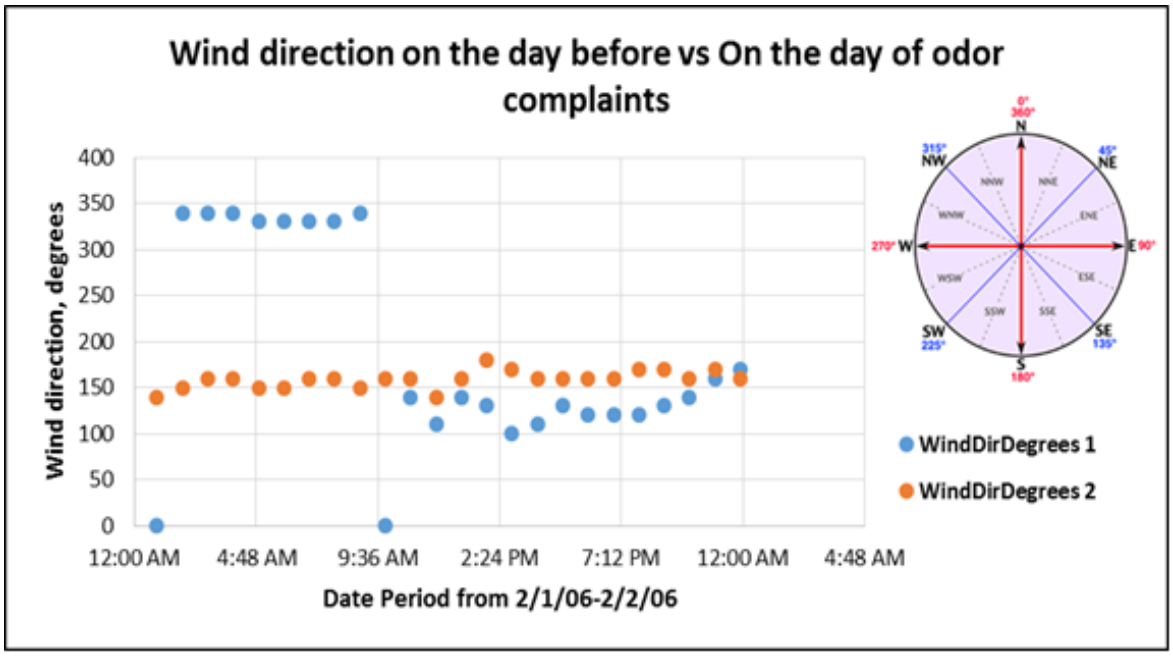



**Figure 35. SWA of Palm Beach County, 2/2/06**

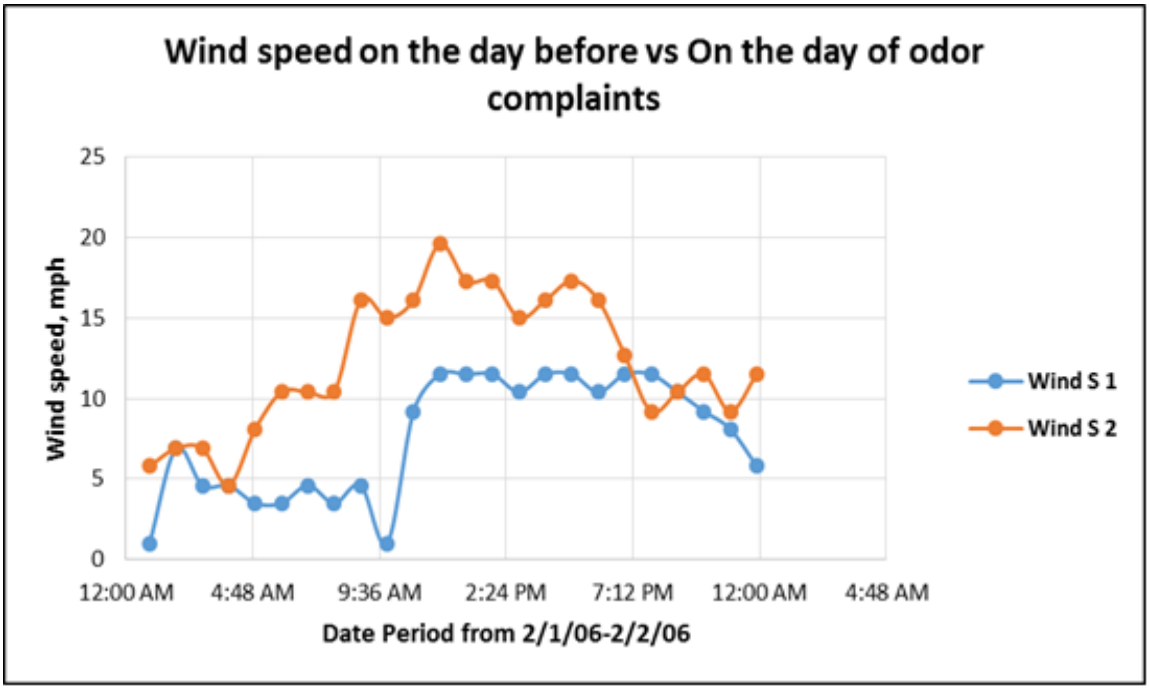



**Figure 36. SWA of Palm Beach County, 2/2/06**

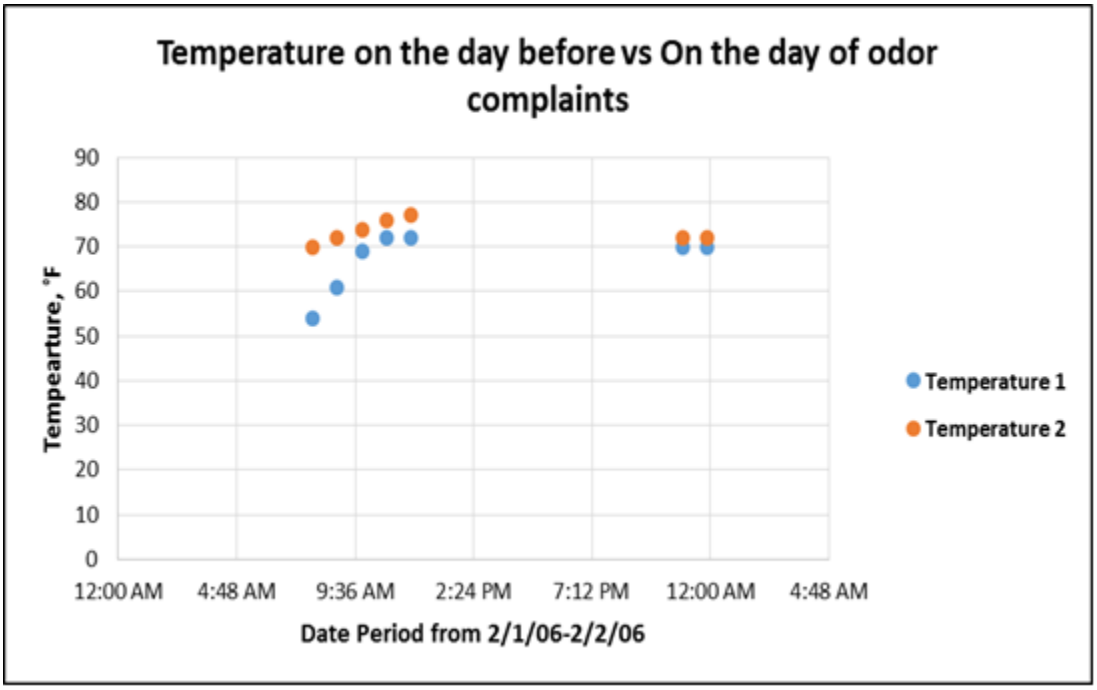



**Figure 37. SWA of Palm Beach County, 2/2/06**

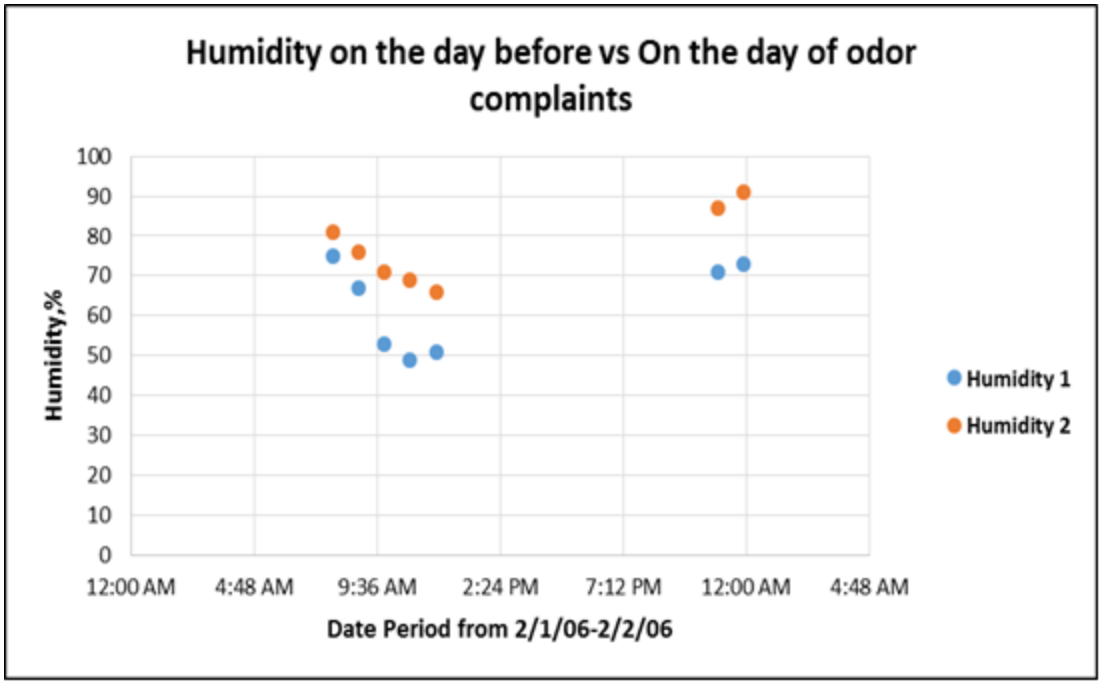



**Figure 38. SWA of Palm Beach County, 2/2/06**

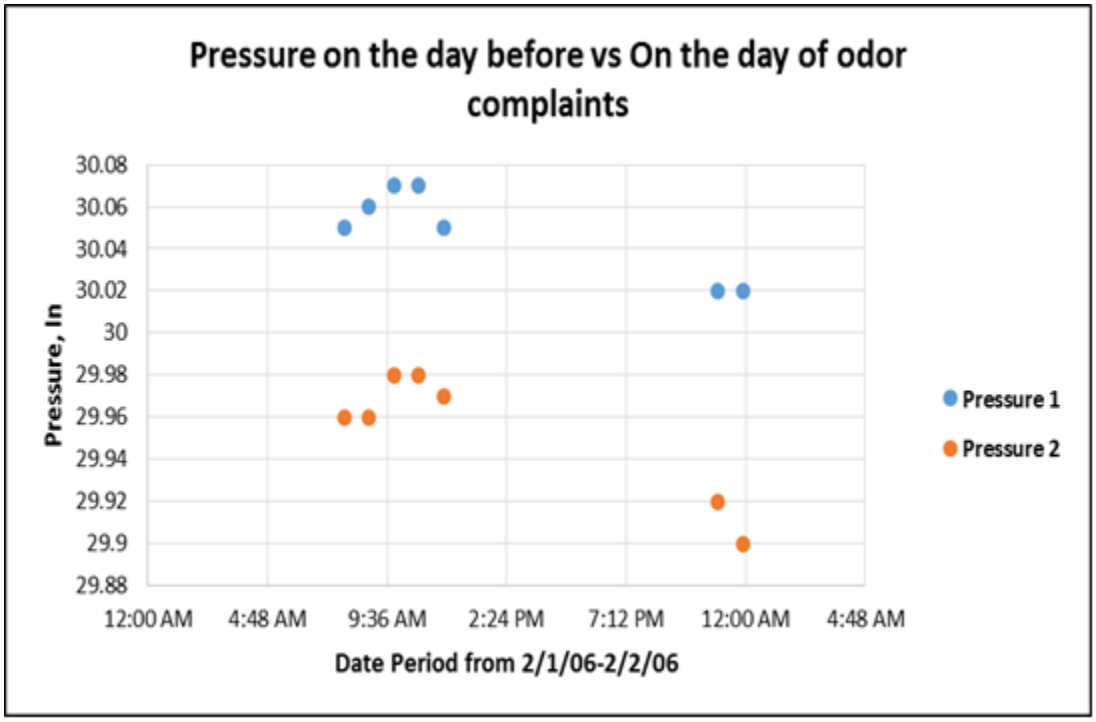



**Figure 39. SWA of Palm Beach County, 2/2/06**

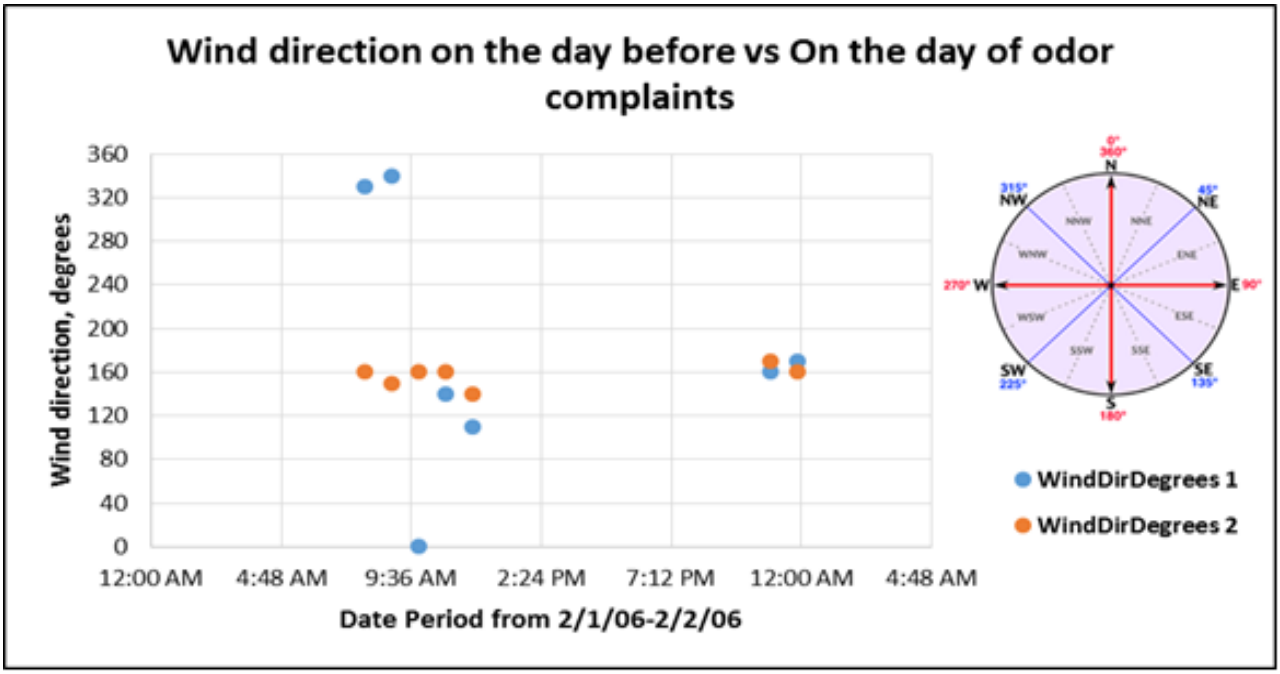



**Figure 40. SWA of Palm Beach County, 2/2/06**

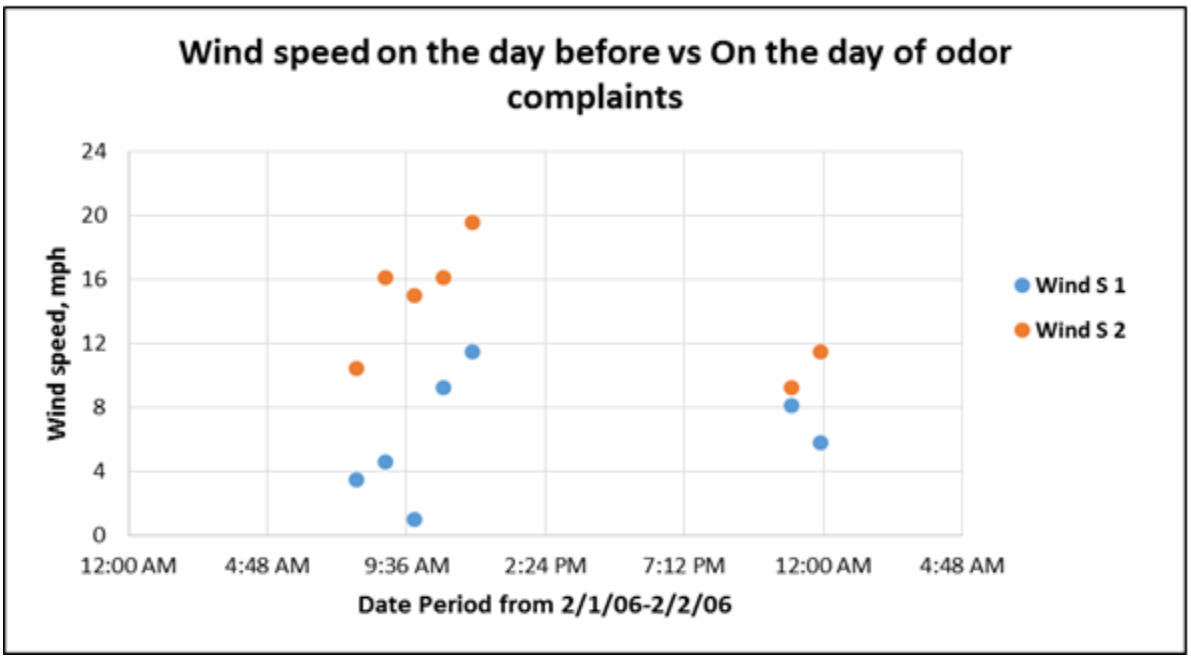



**Figure 41. SWA of Palm Beach County, 2/2/06**

**Table 11. Correlations between each meteorological parameter**

| | T | H | P | W s | W d |
|---|---|---|---|---|---|
| Correlation 1 | 0.749037471 | 0.89097 | 0.9494 | 0.3604 | -0.0622 |
| Correlation 2 | 0.922759472 | 0.81613 | 0.71673 | 0.56778 | -0.1714 |

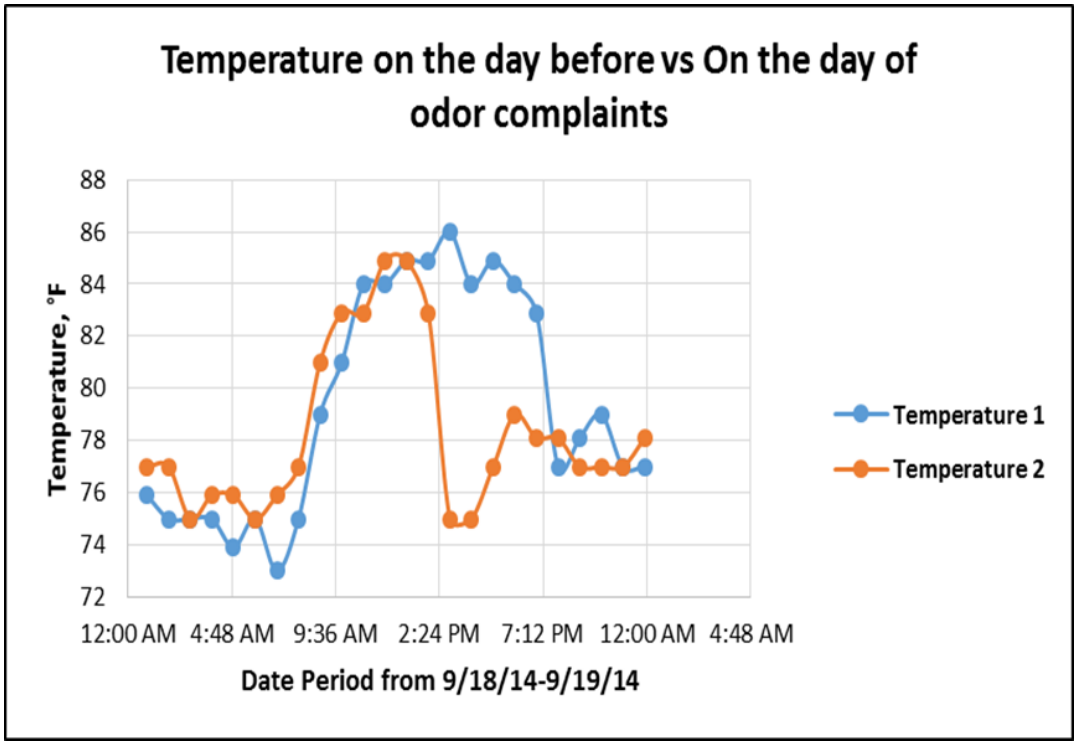



**Figure 42. SWA of Pam Beach County, 9/19/14**

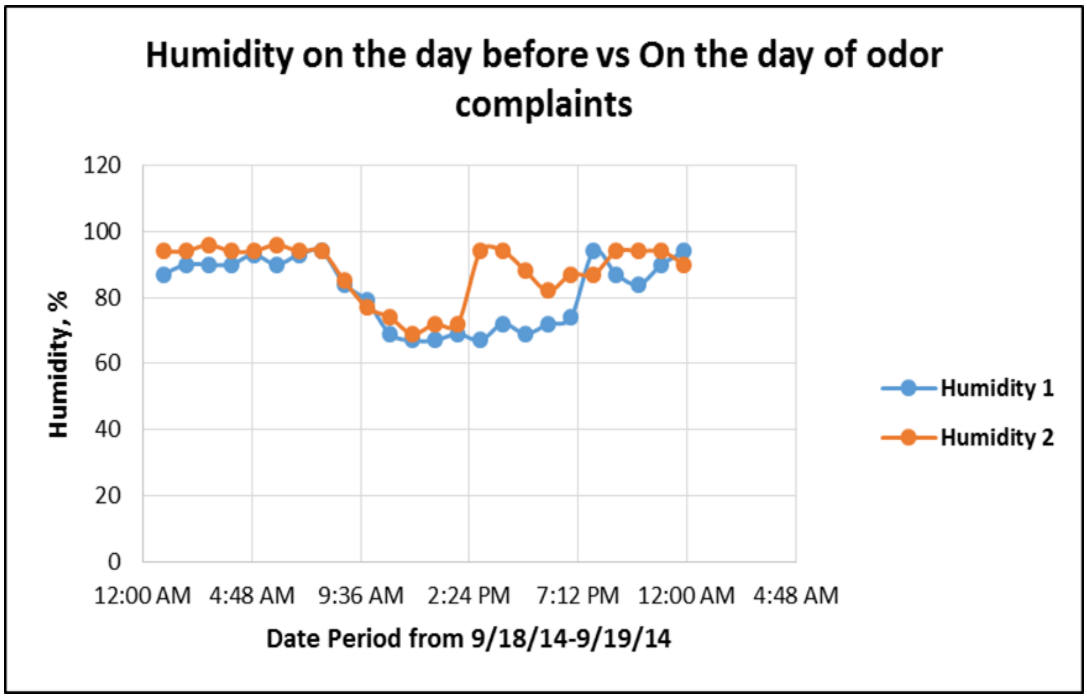



**Figure 43. SWA of Pam Beach County, 9/19/14**

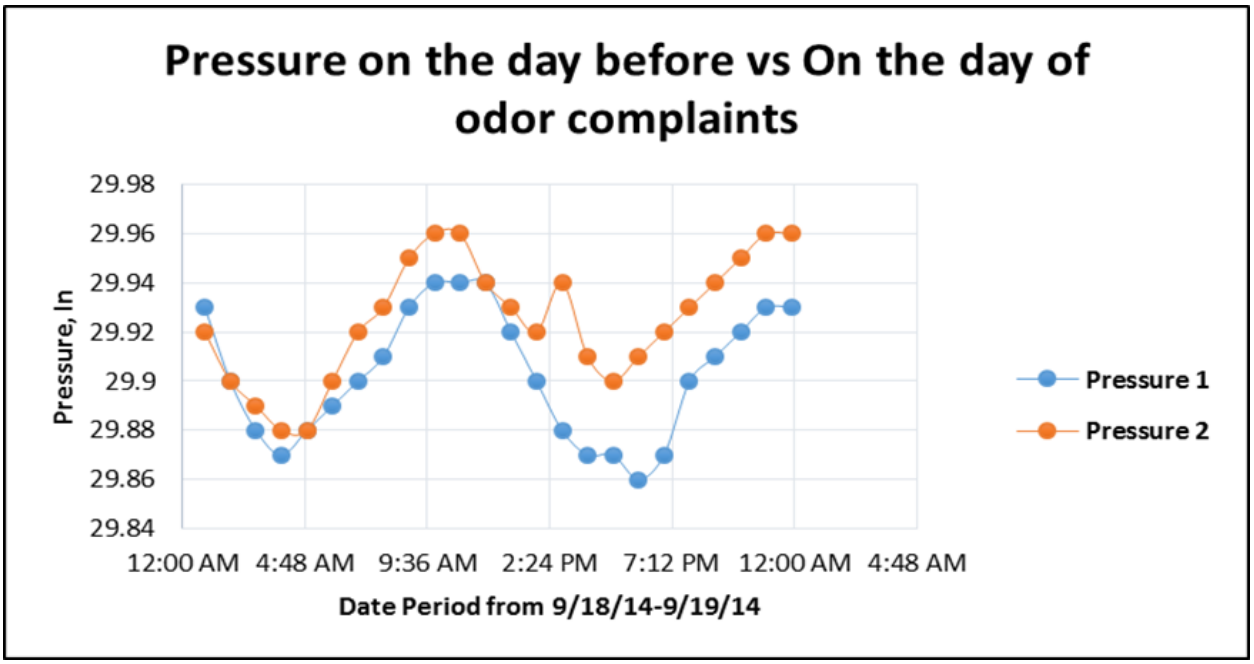



**Figure 44. SWA of Pam Beach County, 9/19/14**

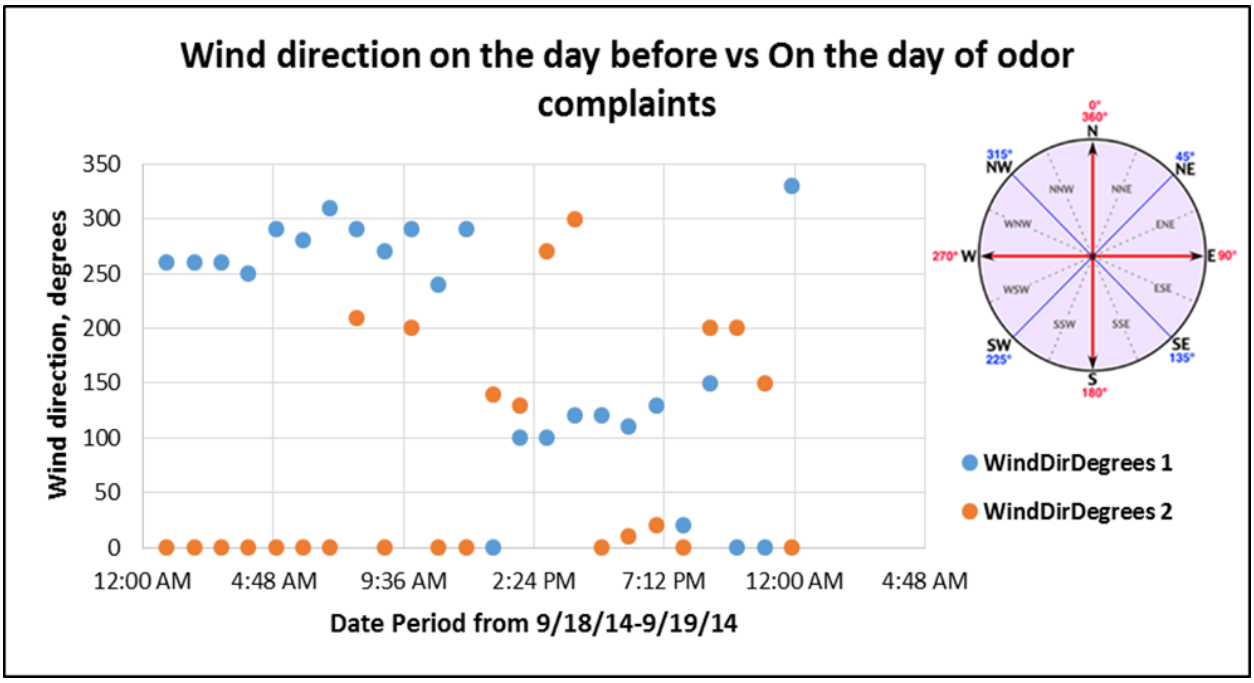



**Figure 45. SWA of Pam Beach County, 9/19/14**

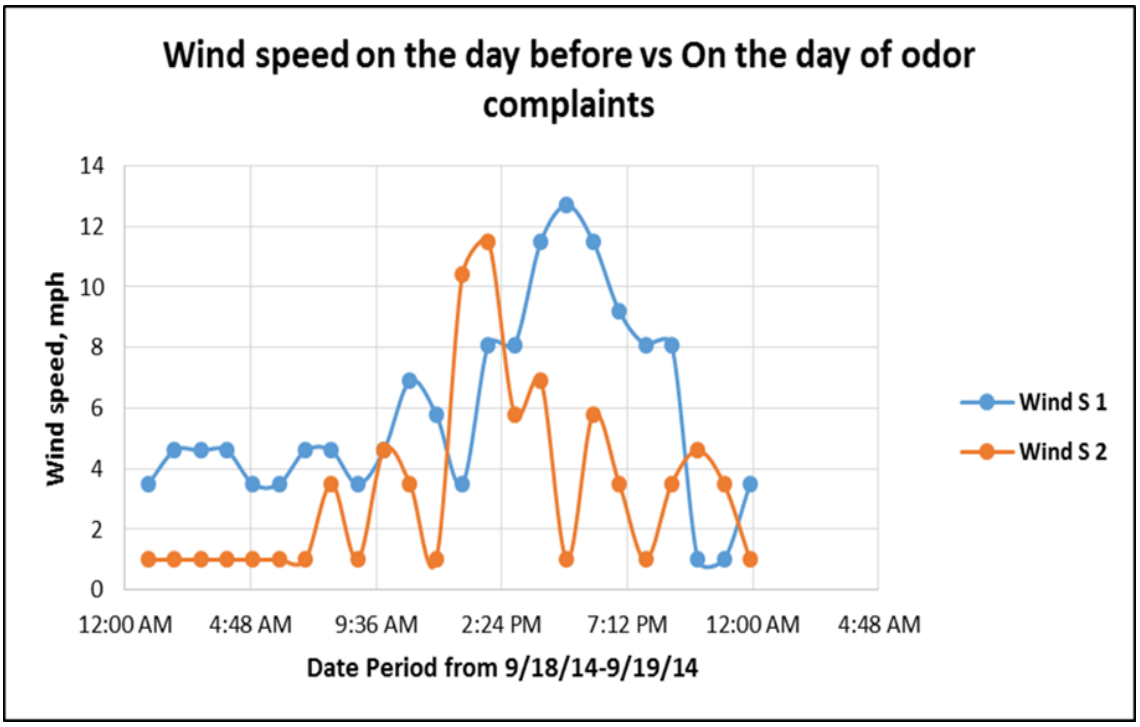



**Figure 46. SWA of Pam Beach County, 9/19/14**

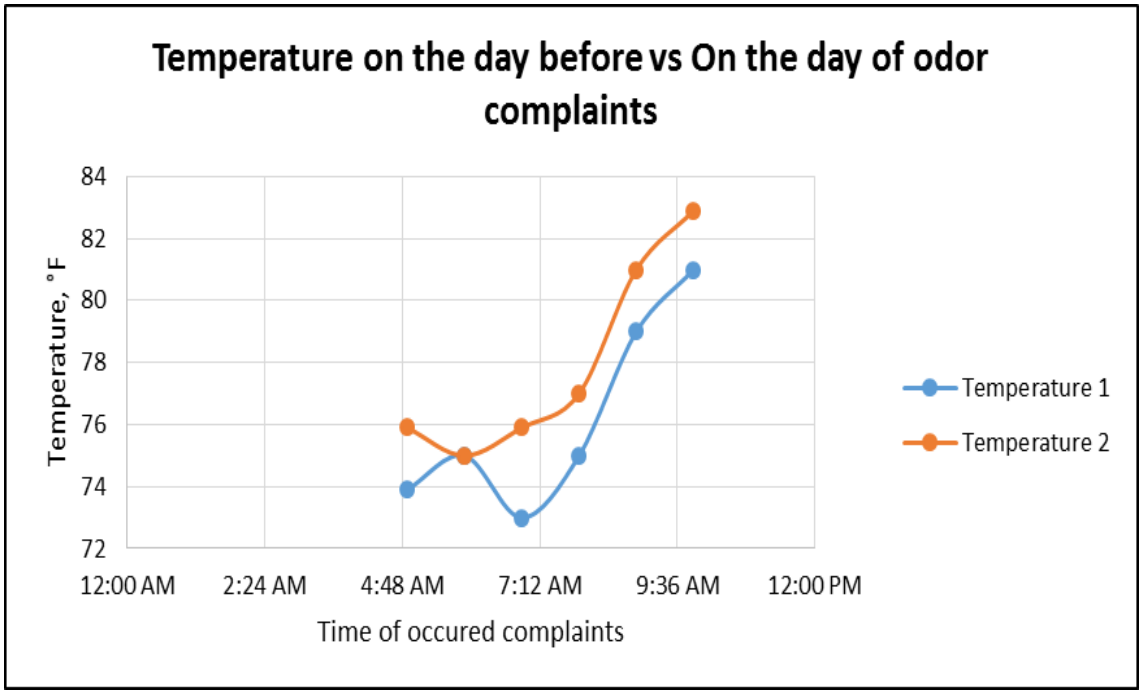


**Figure 47. SWA of Pam Beach County, 9/19/14**

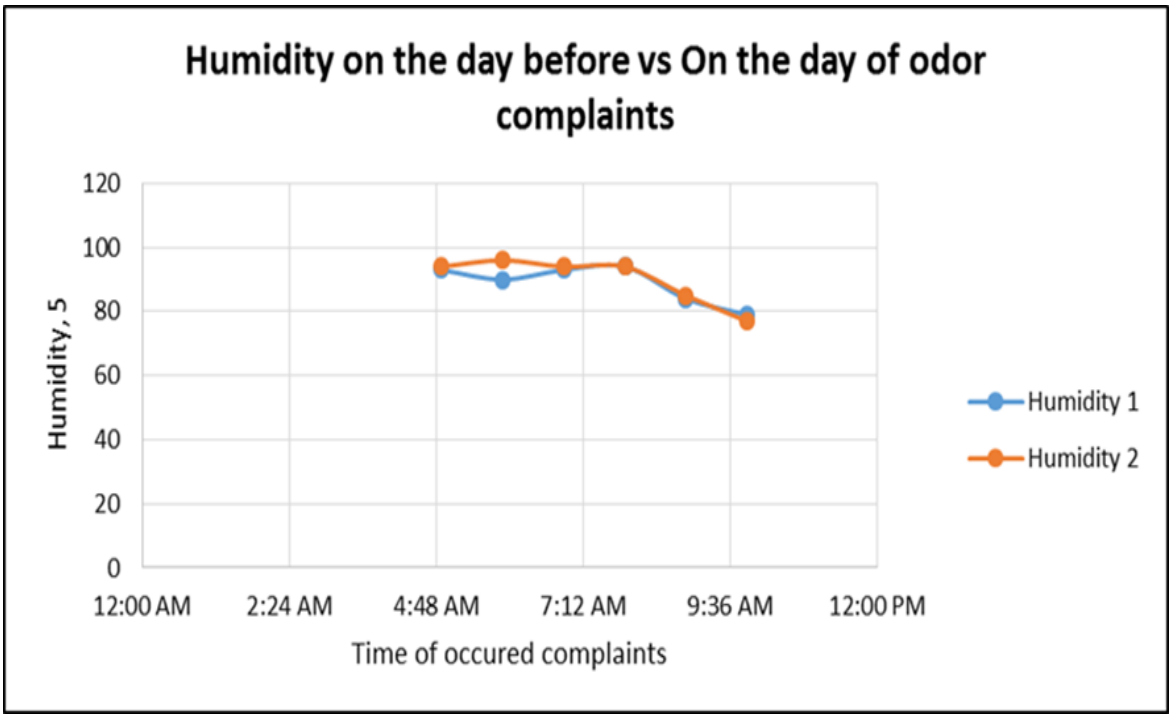



**Figure 48. SWA of Pam Beach County, 9/19/14**

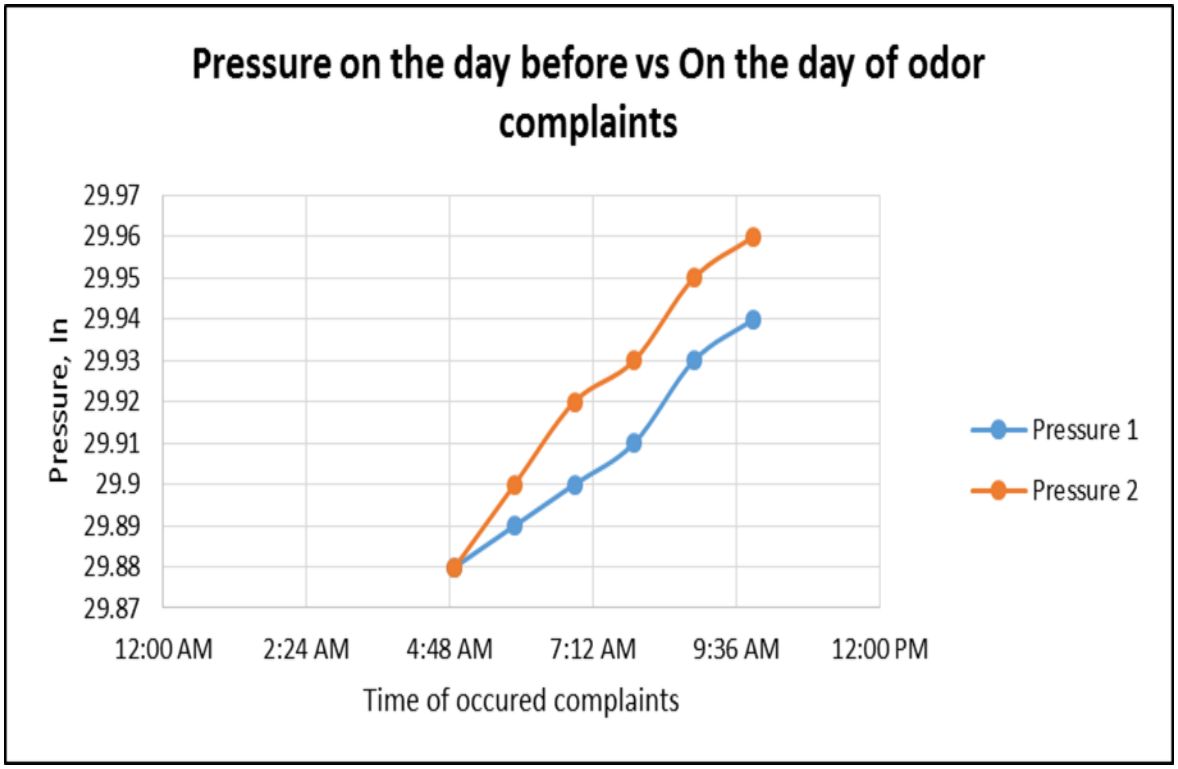


**Figure 49. SWA of Pam Beach County, 9/19/14**

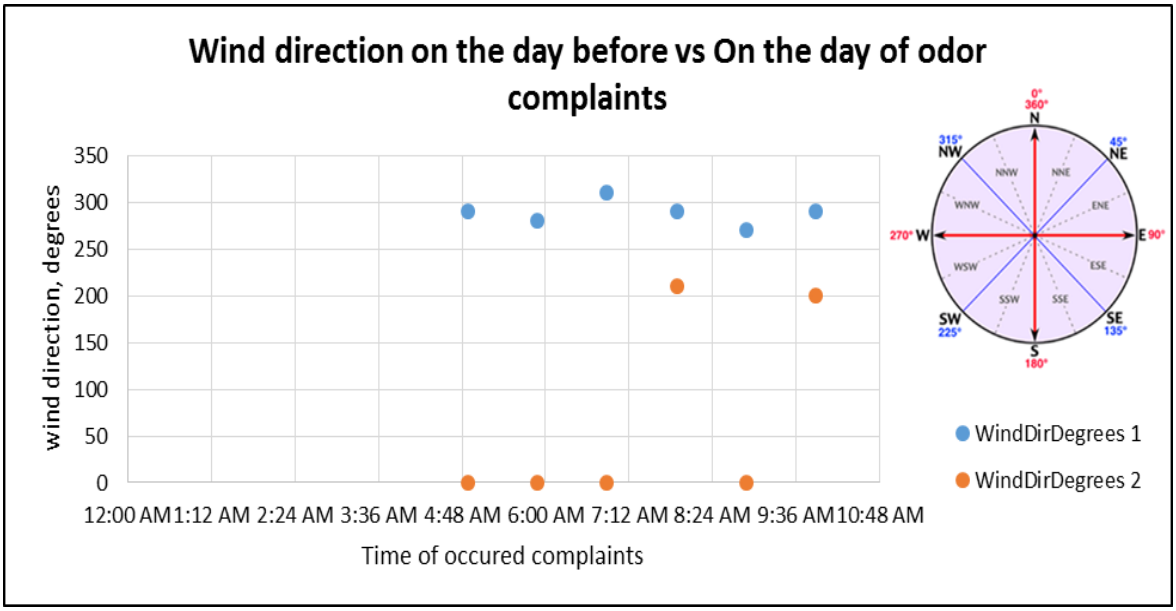



**Figure 50. SWA of Pam Beach County, 9/19/14**

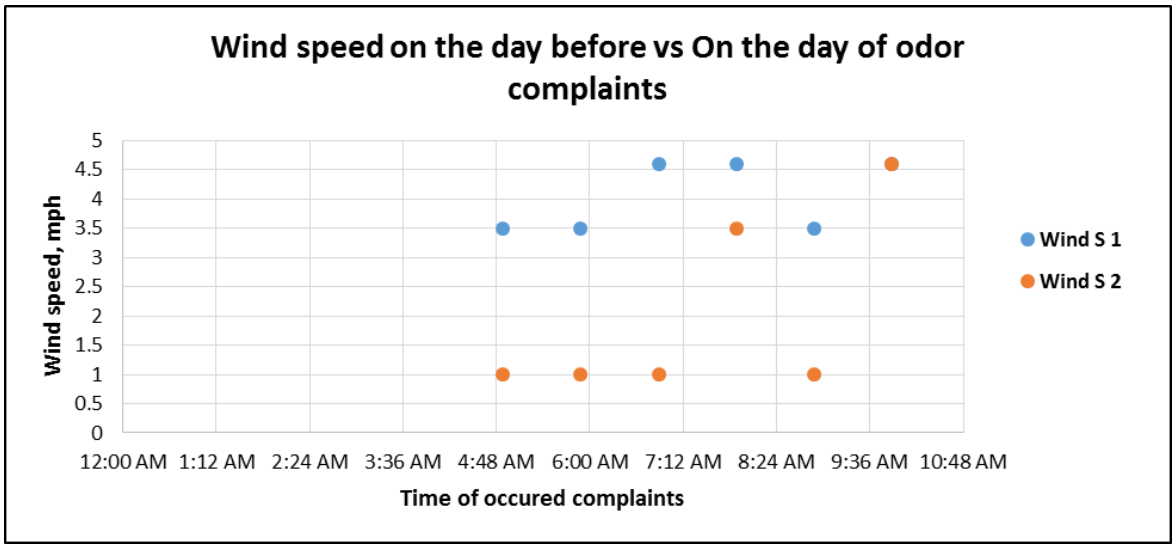



**Figure 51. SWA of Pam Beach County, 9/19/14**

**Table 12. Correlations between parameters**

| | T | H | p | W s | W d |
|---|---|---|---|---|---|
| Correlation 1 | 0.955 | 0.94478 | 0.9844 | 0.69047 | 0.09709 |
| Correlation 2 | 0.53161 | 0.675 | 0.77619 | 0.23389 | -0.424 |

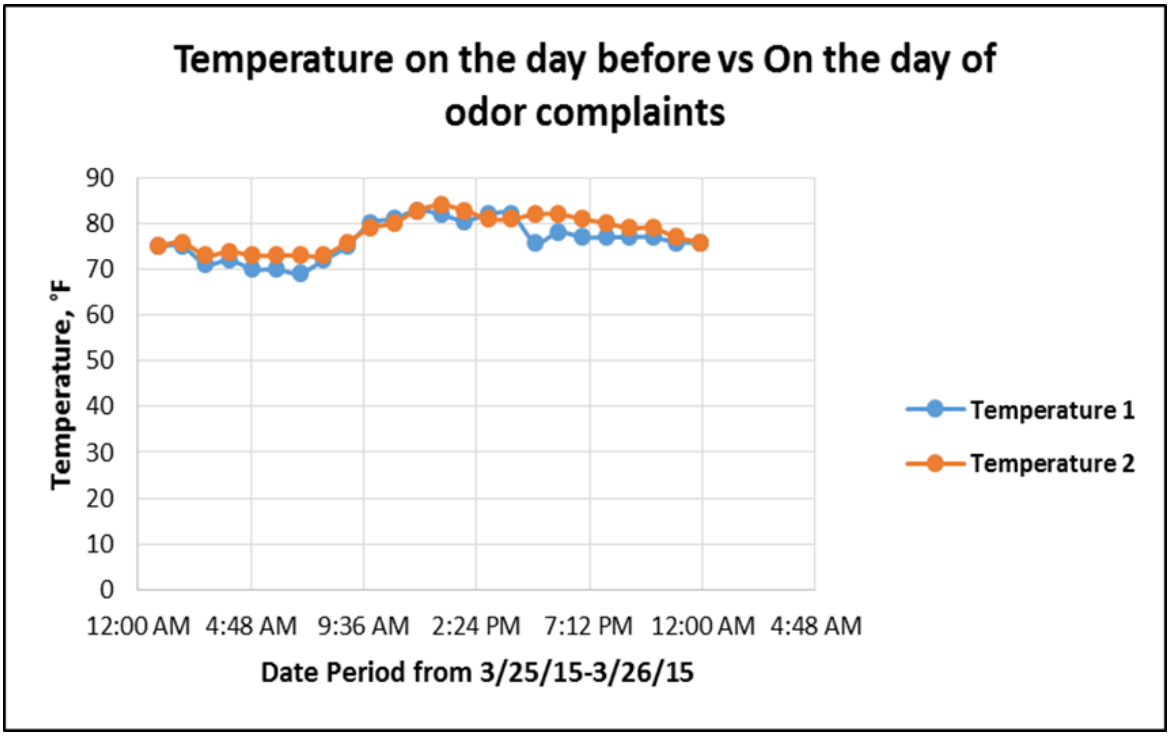



**Figure 52. SWA of Palm Beach County, 3/26/15**

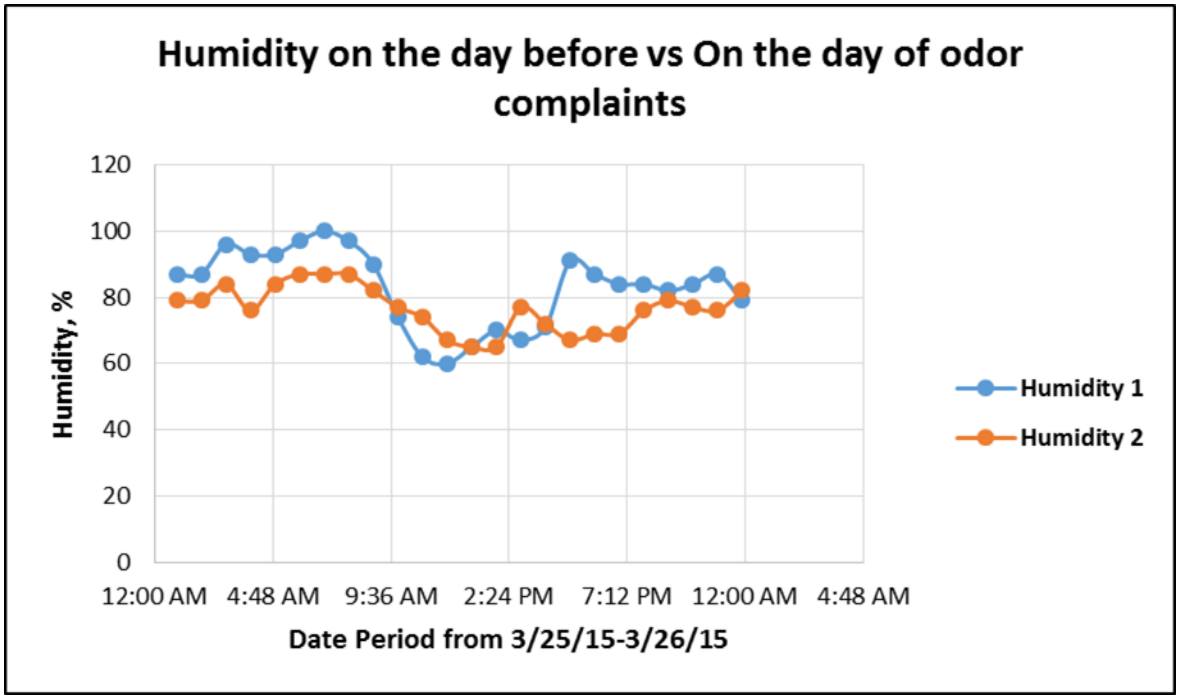



**Figure 53. SWA of Palm Beach County, 3/26/15**

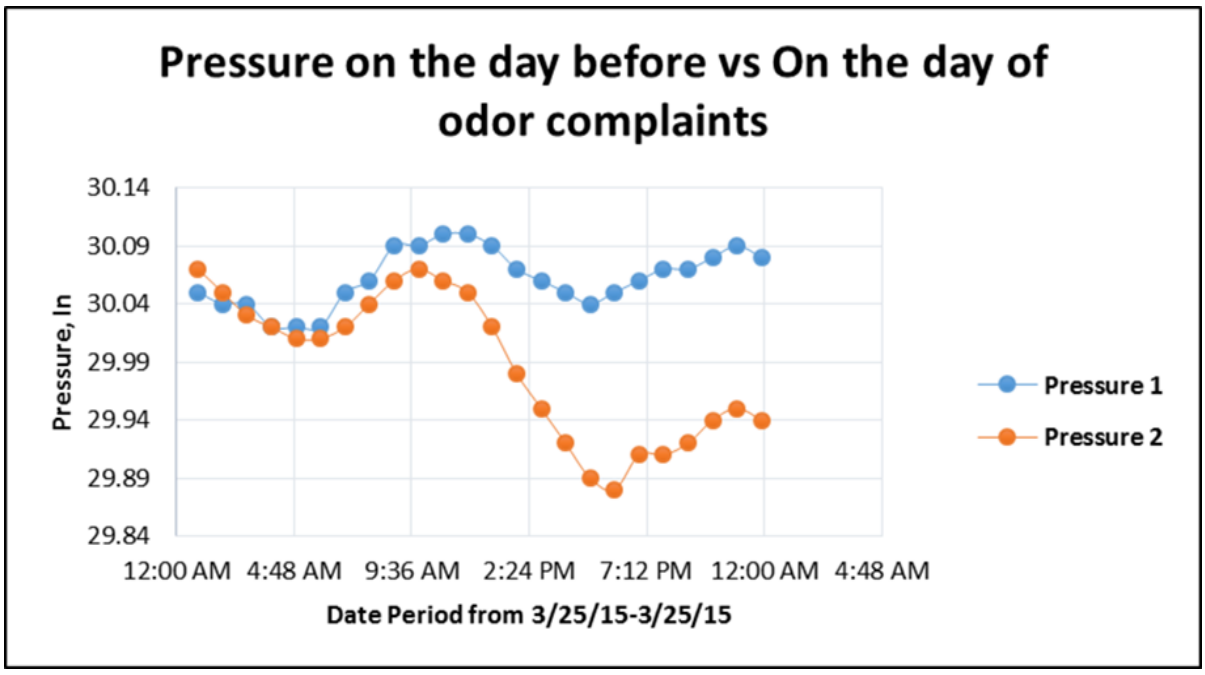



**Figure 54. SWA of Palm Beach County, 3/26/15**

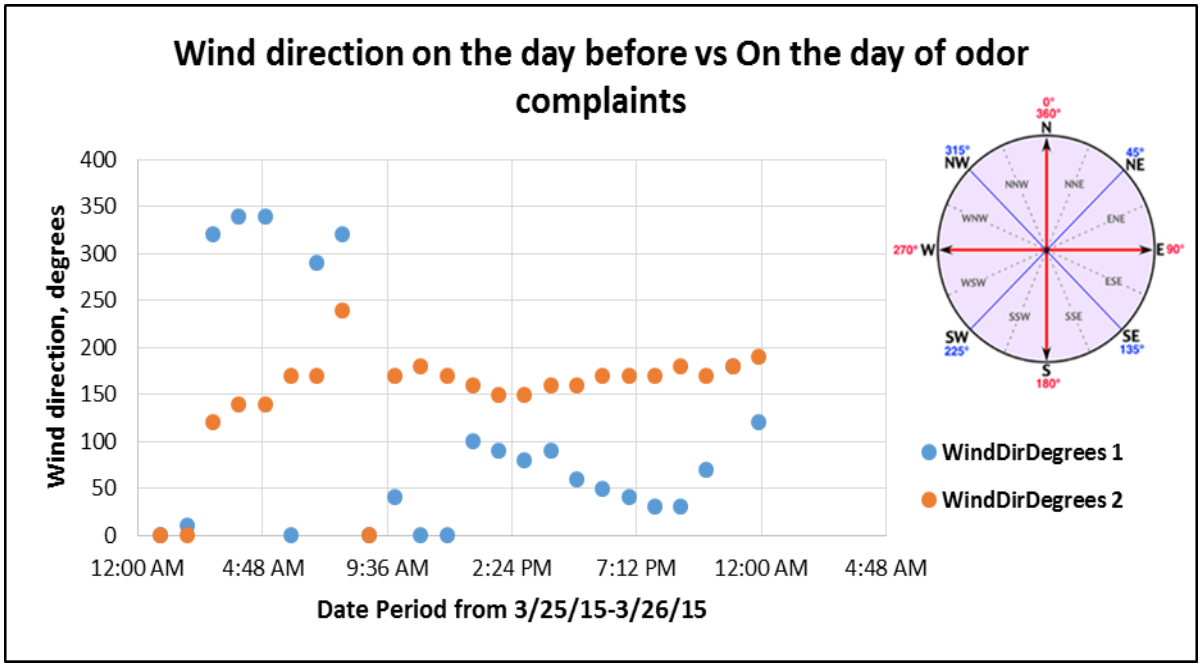



**Figure 55. SWA of Palm Beach County, 3/26/15**

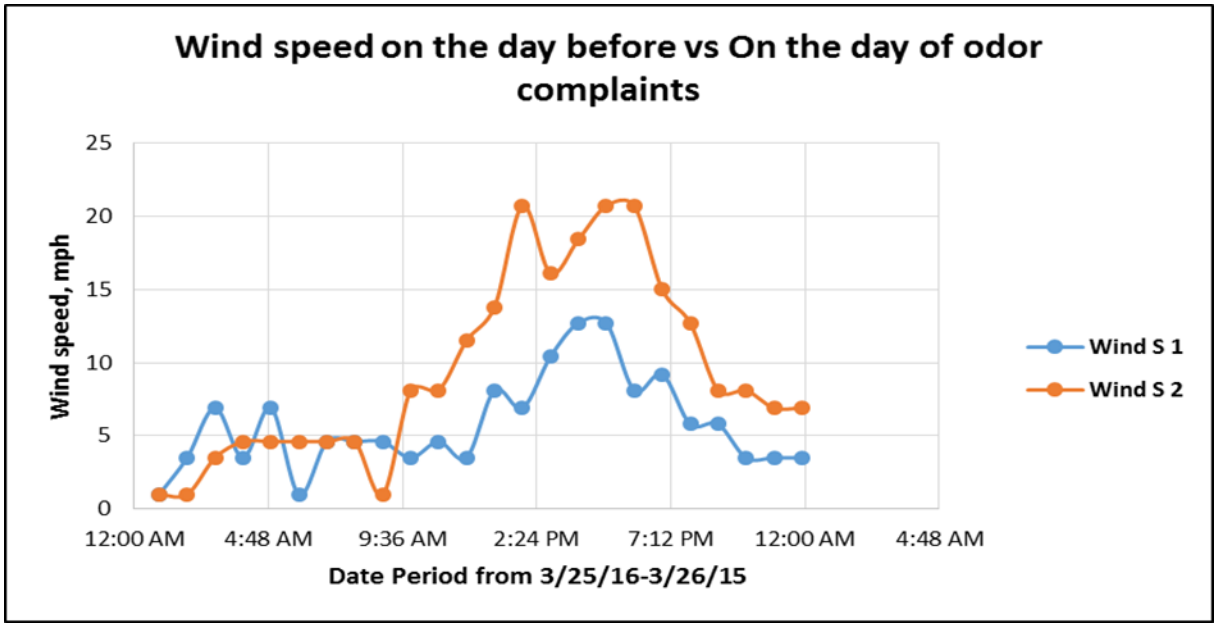



**Figure 56. SWA of Palm Beach County, 3/26/15**

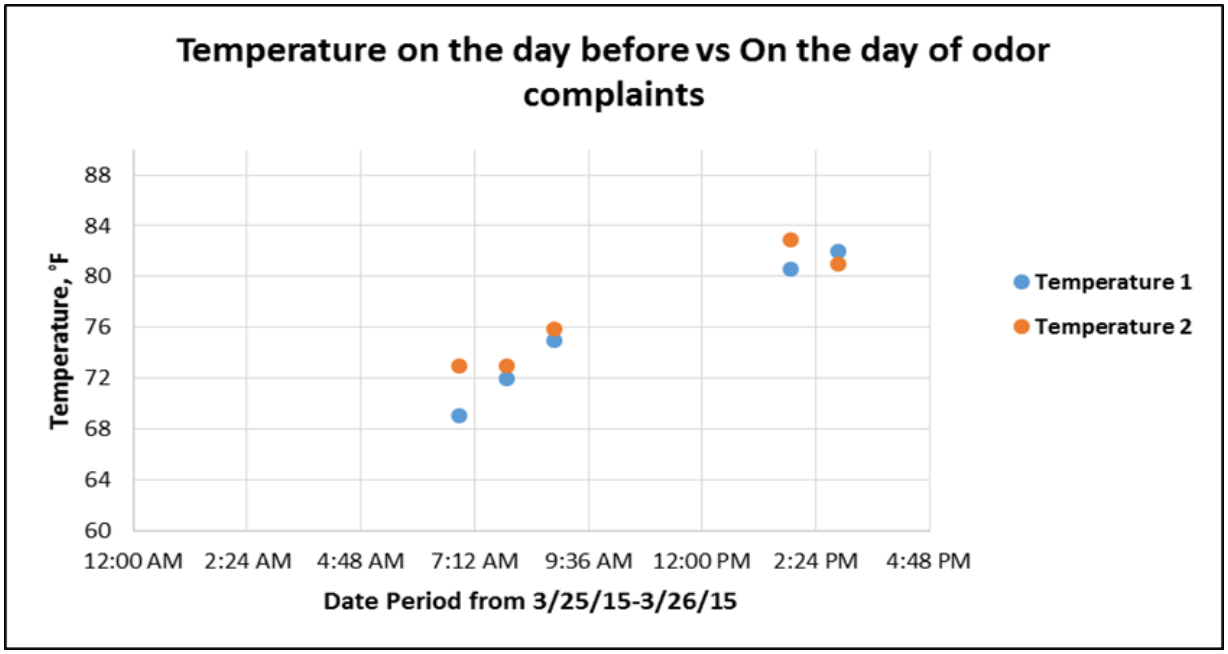



**Figure 57. SWA of Palm Beach County, 3/26/15**

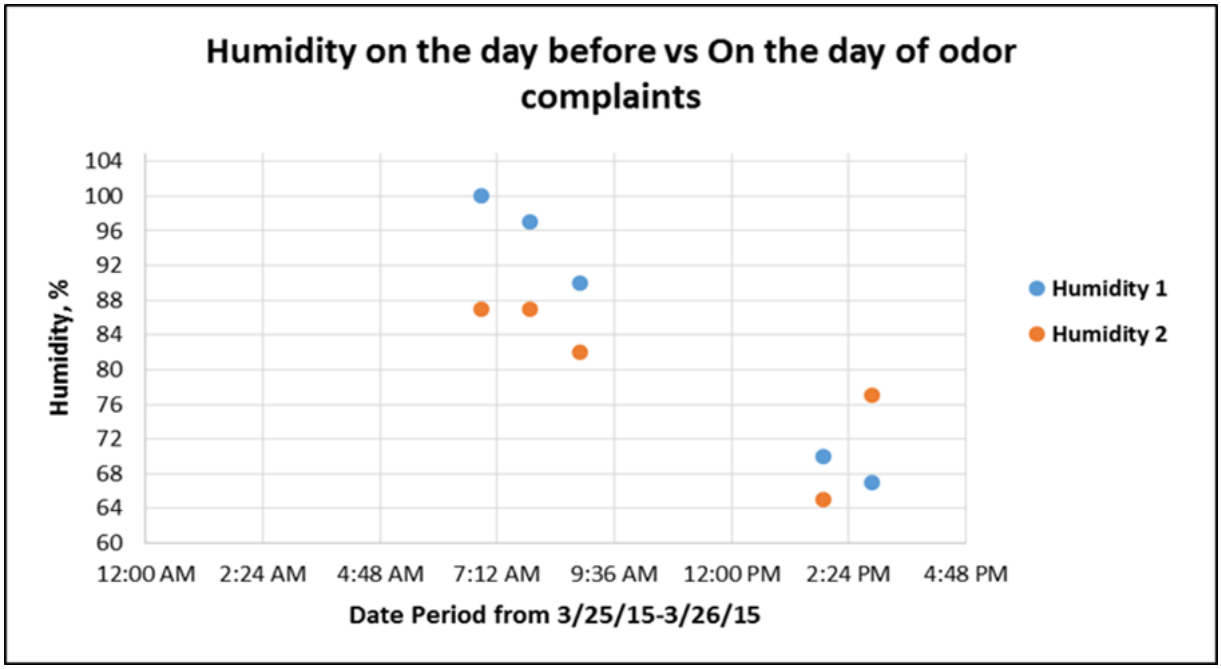



**Figure 58. SWA of Palm Beach County, 3/26/15**

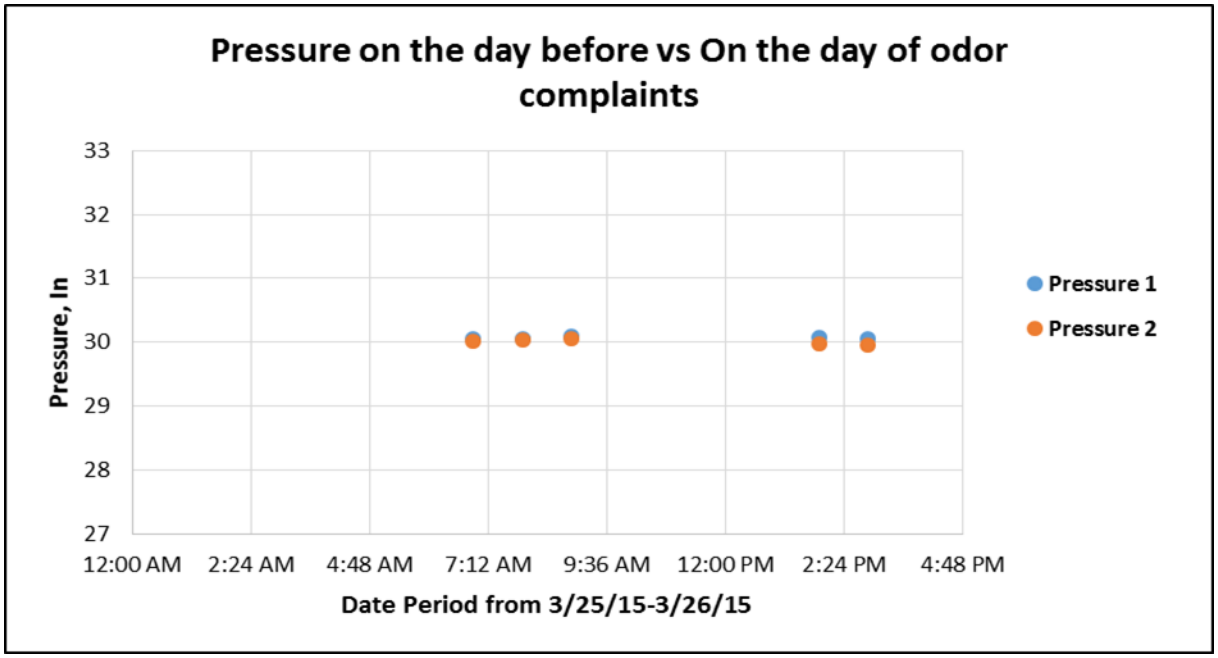



**Figure 59. SWA of Palm Beach County, 3/26/15**

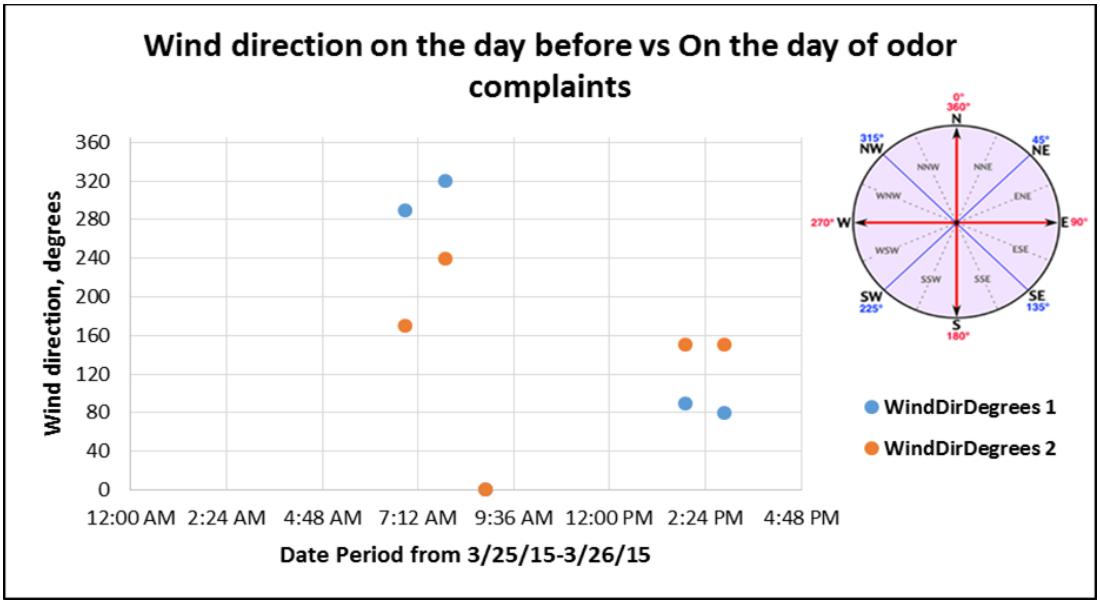



**Figure 60. SWA of Palm Beach County, 3/26/15**

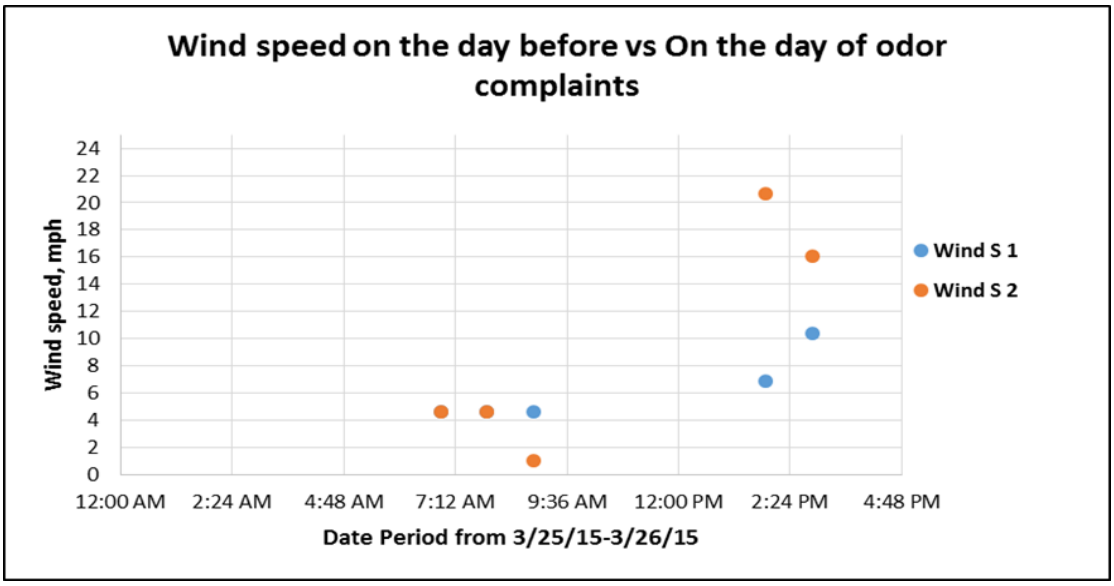



**Figure 61. SWA of Palm Beach County, 3/26/15**

**Table 13. Correlations between parameters**

| | T | H | P | Ws | Wd |
|---|---|---|---|---|---|
| Correlation 1 | 0.95162 | 0.84958 | 0.40547 | 0.75062 | 0.82788 |
| Correlation 2 | 0.89462 | 0.65304 | 0.10686 | 0.75806 | 0.26634 |

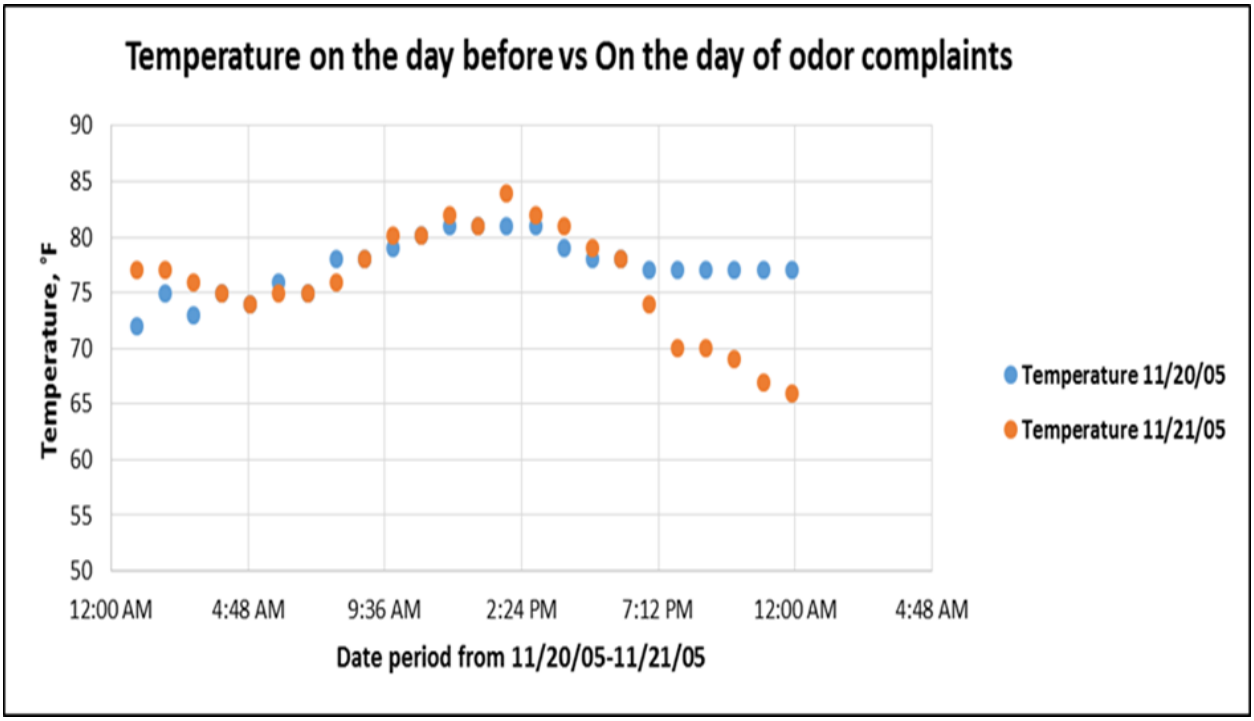



**Figure 62. Monarch Hill, 11/21/05**

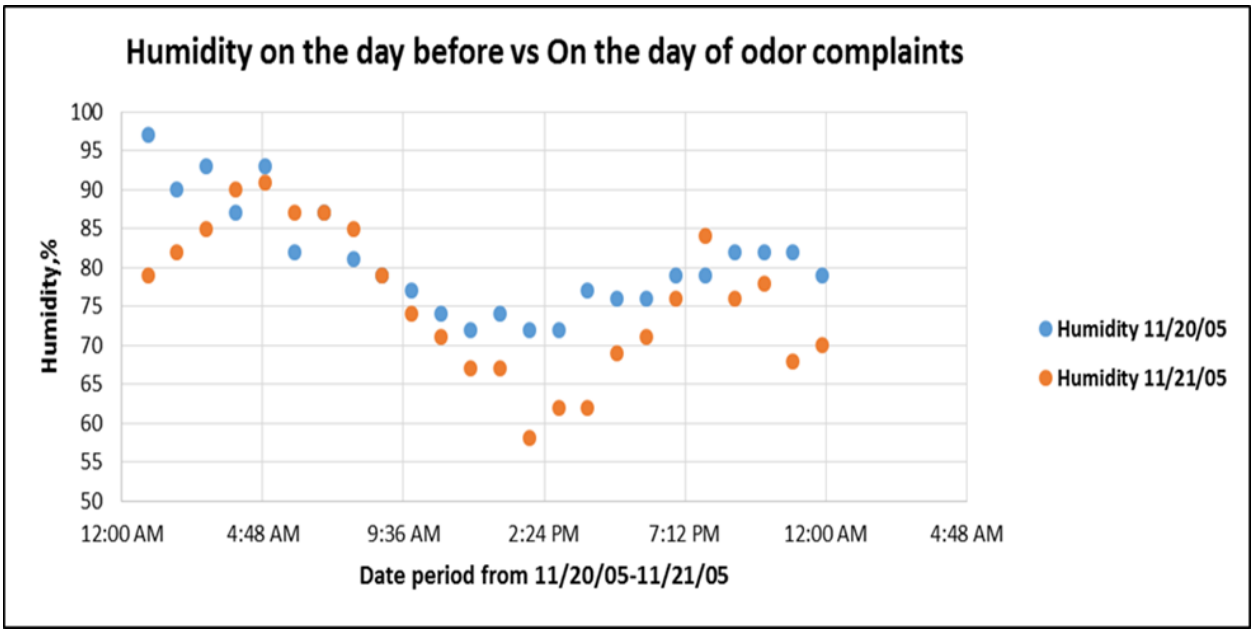



**Figure 63. Monarch Hill, 11/21/05**

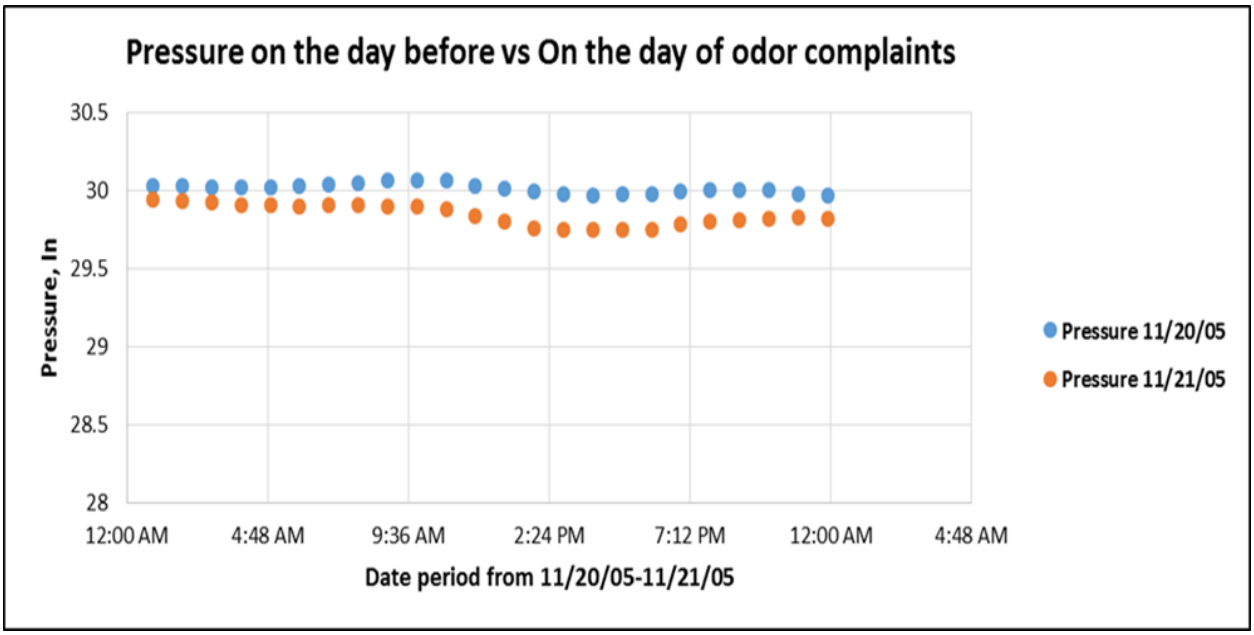



**Figure 64. Monarch Hill, 11/21/05**

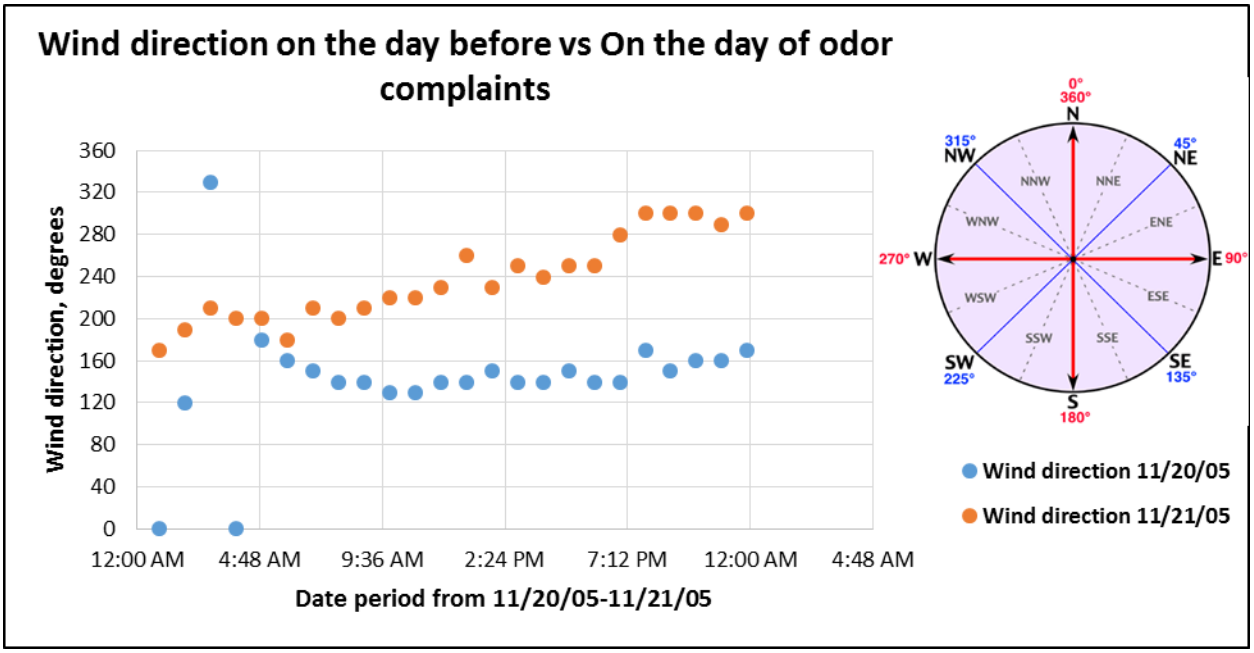



**Figure 65. Monarch Hill, 11/21/05**

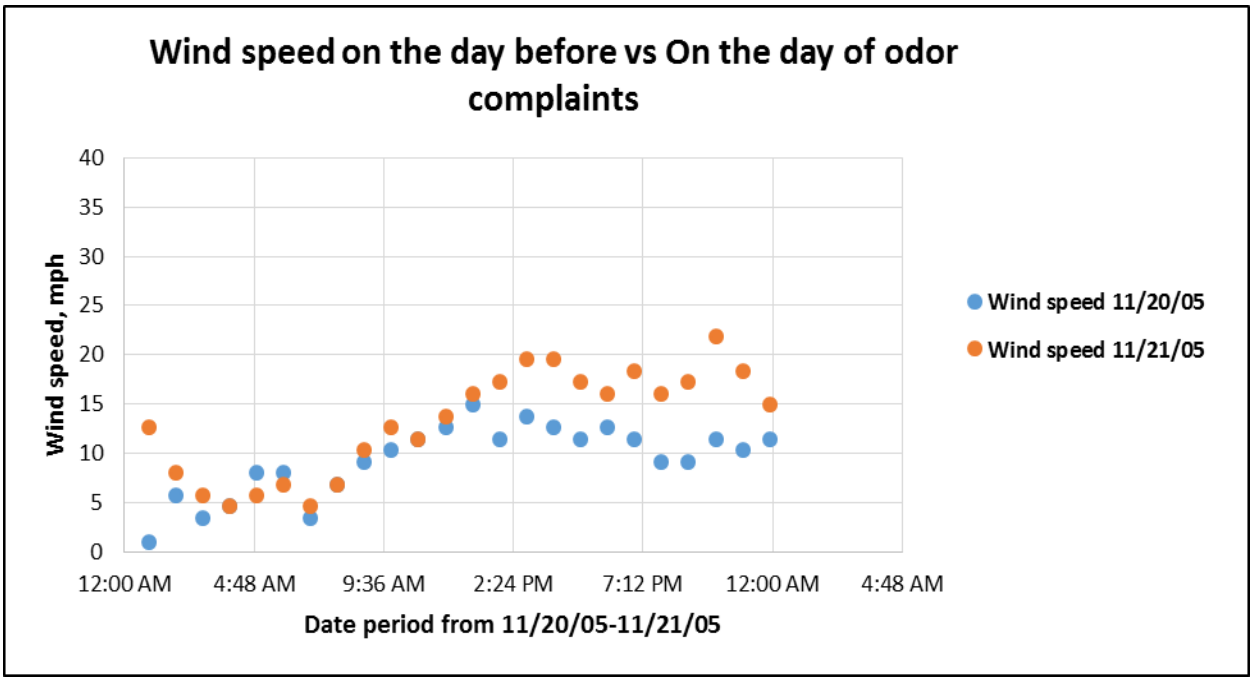



**Figure 66. Monarch Hill, 11/21/05**

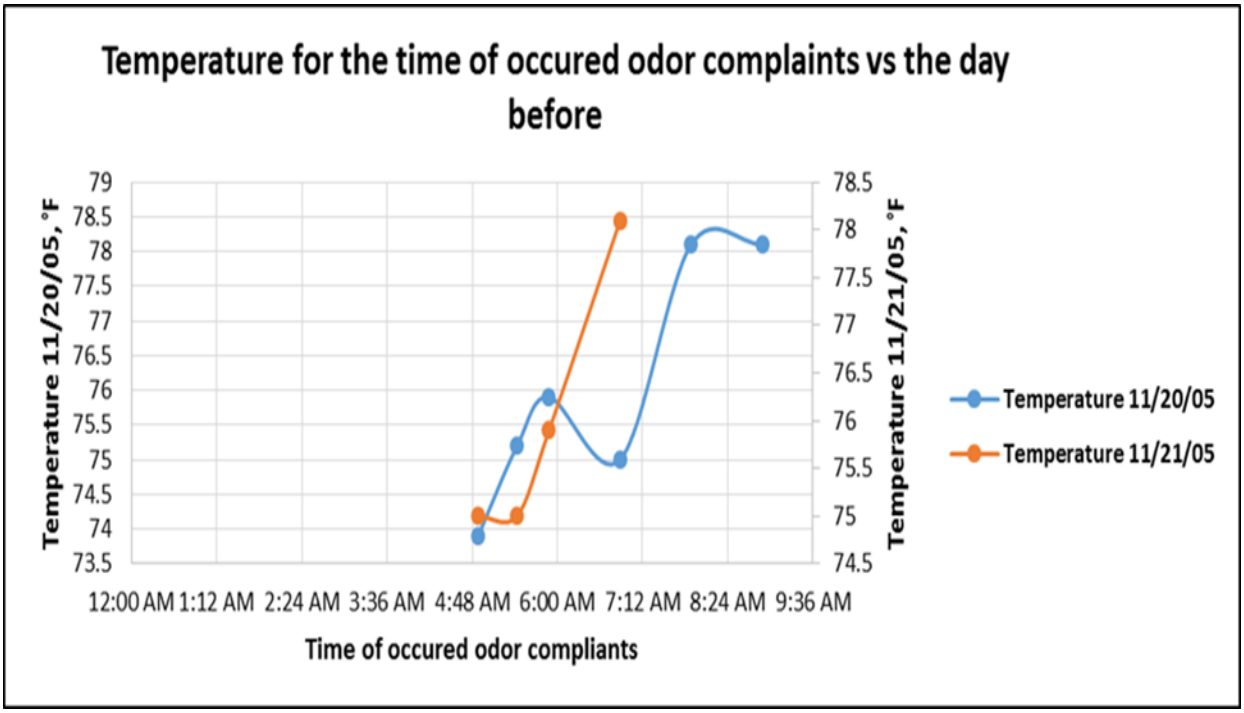



**Figure 67. Monarch Hill, 11/21/05**

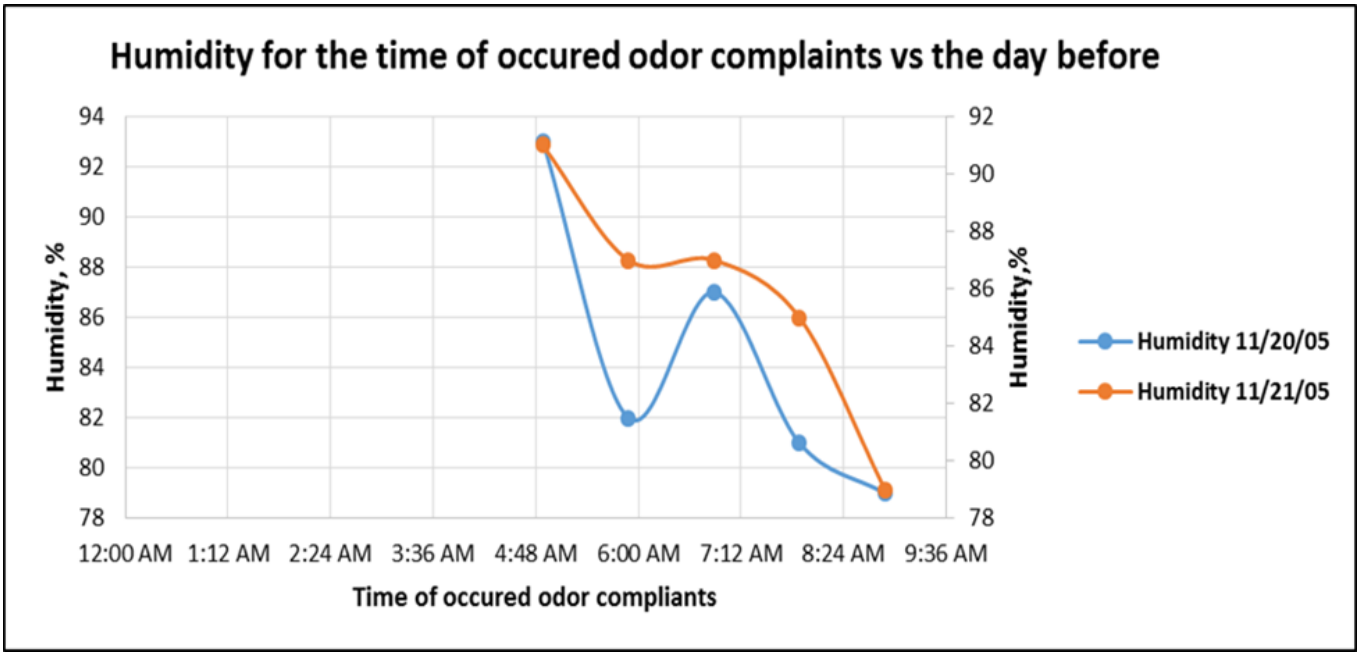



**Figure 68. Monarch Hill, 11/21/05**

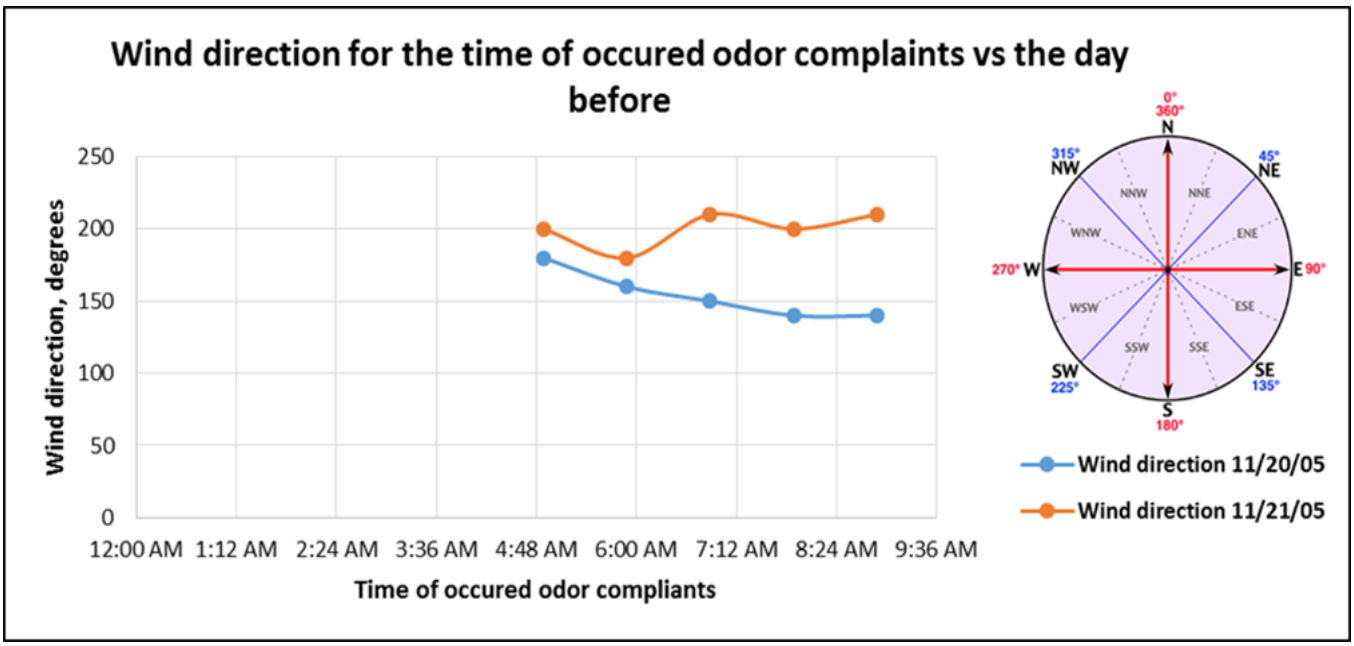



**Figure 69. Monarch Hill, 11/21/05**

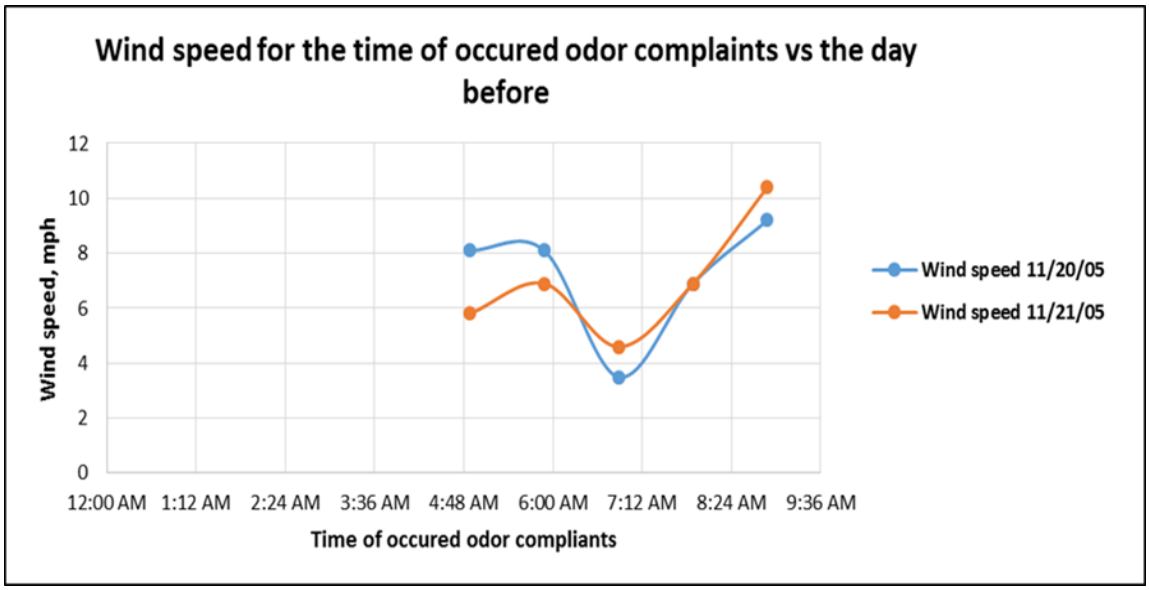



**Figure 70. Monarch Hill, 11/21/05**

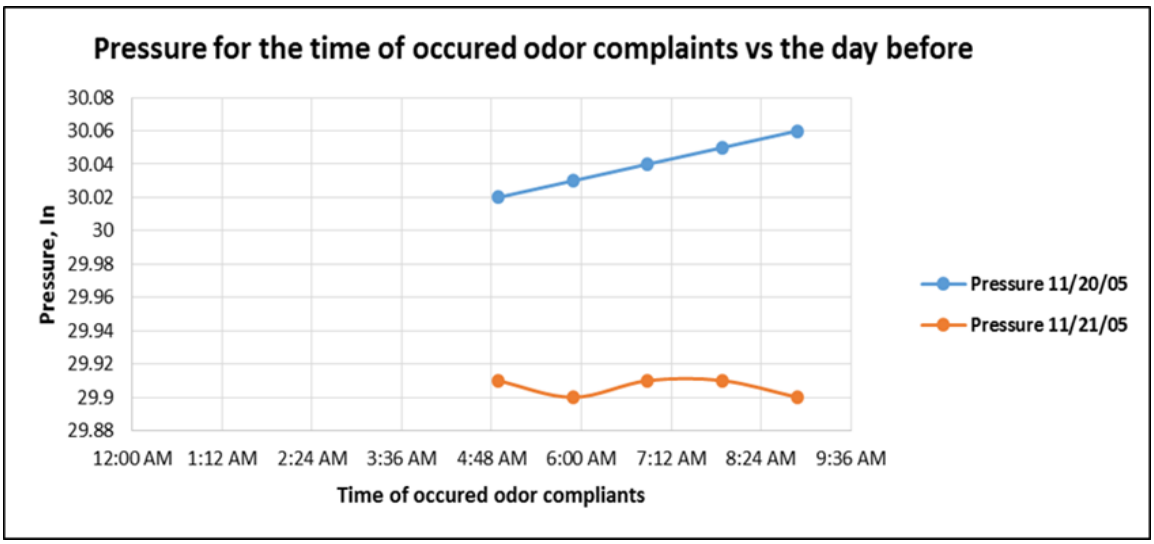



**Figure 71. Monarch Hill, 11/21/05**

**Table 14. Correlations between parameters**

| | *T1* | *T2* |
|---|---|---|
| T1 | 1 | |
| T2 | **0.500763** | 1 |

| | *H1* | *H2* |
|---|---|---|
| H1 | 1 | |
| H2 | **0.740545** | 1 |

| | *P1* | *P2* |
|---|---|---|
| P1 | 1 | |
| P2 | **0.805885** | 1 |

| | *Wind s 1* | *Wind s 2* |
|---|---|---|
| Wind s 1 | 1 | |
| Wind s 2 | **0.717638** | 1 |

| | *Wind d 1* | *Wind d 2* |
|---|---|---|
| Wind d 1 | 1 | |
| Wind d 2 | **0.262026** | 1 |

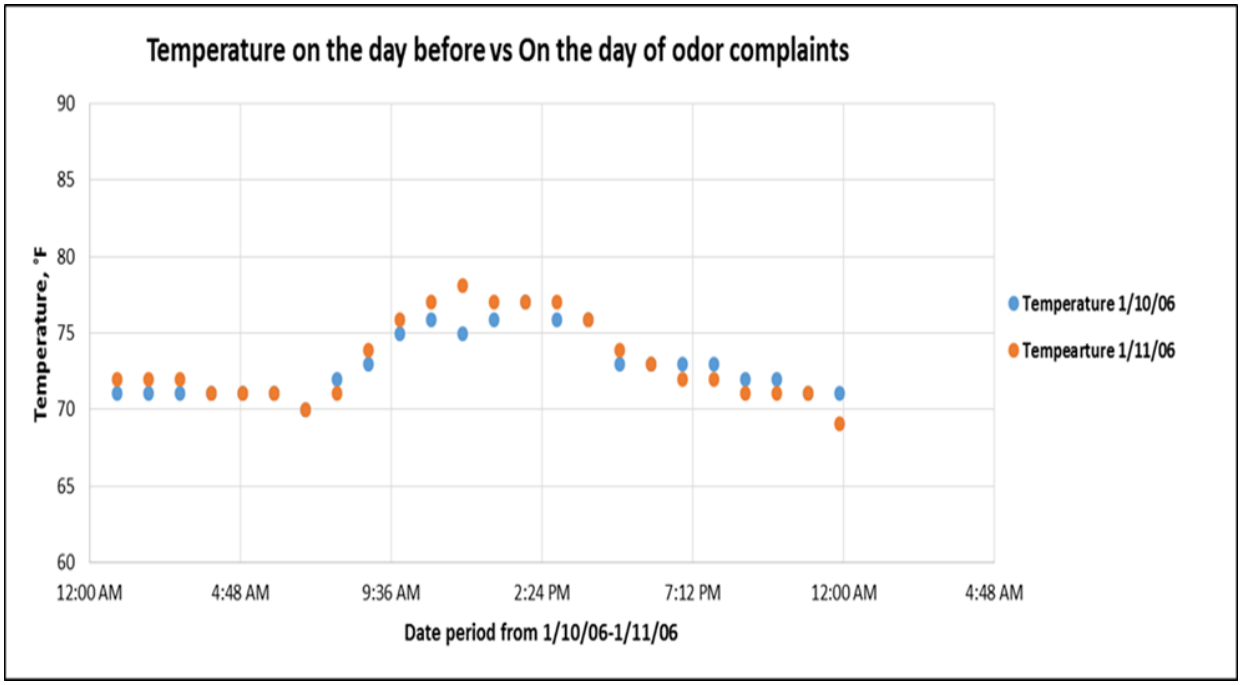



**Figure 72. Monarch Hill, 1/11/06**

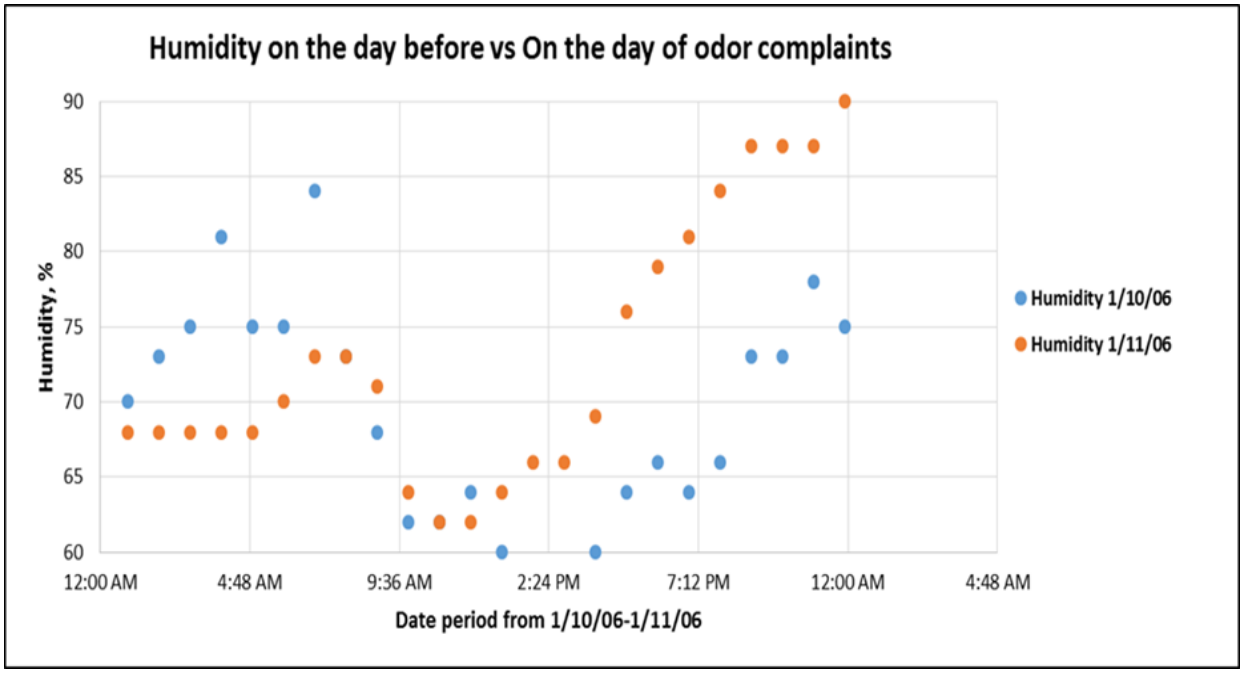



**Figure 73. Monarch Hill, 1/11/06**

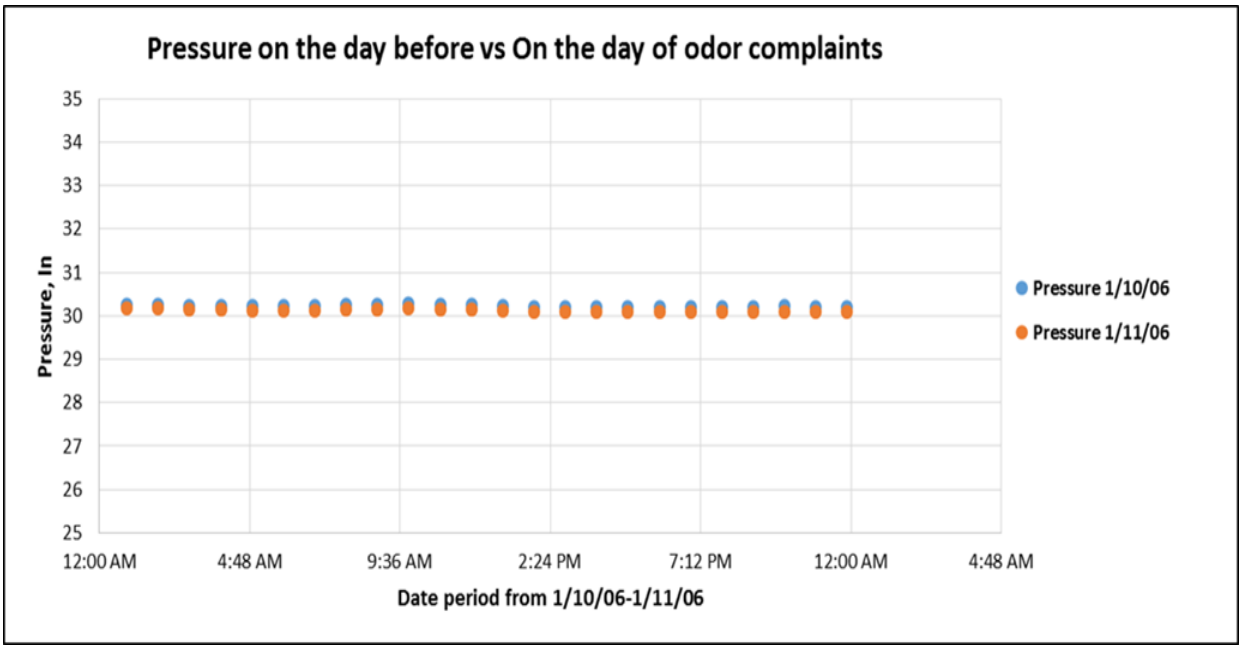



**Figure 74. Monarch Hill, 1/11/06**

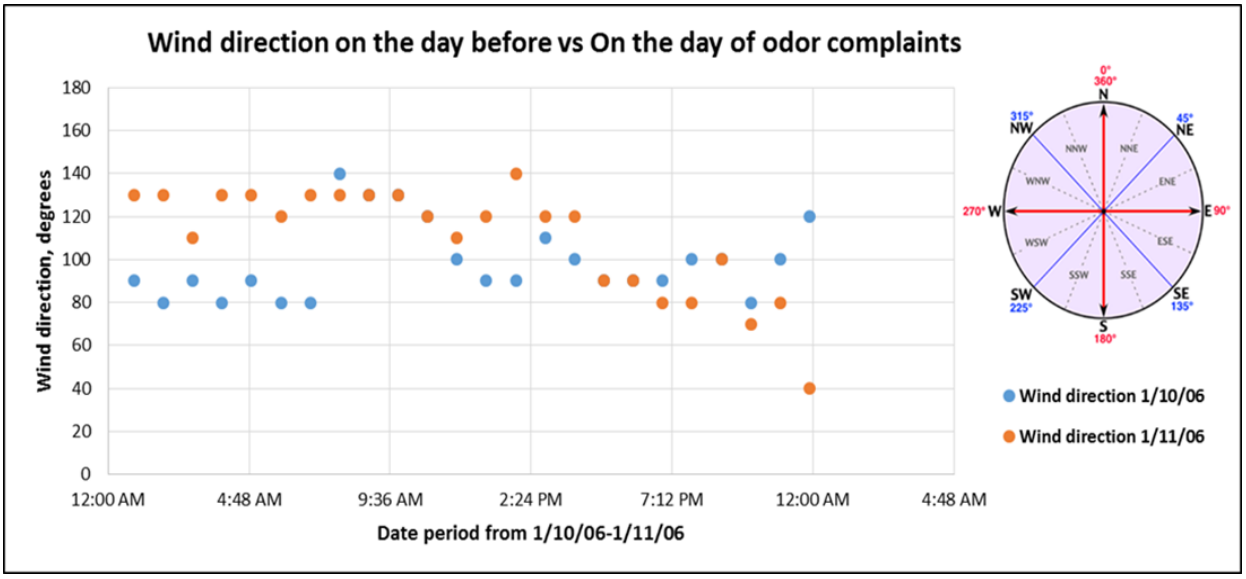



**Figure 75. Monarch Hill, 1/11/06**

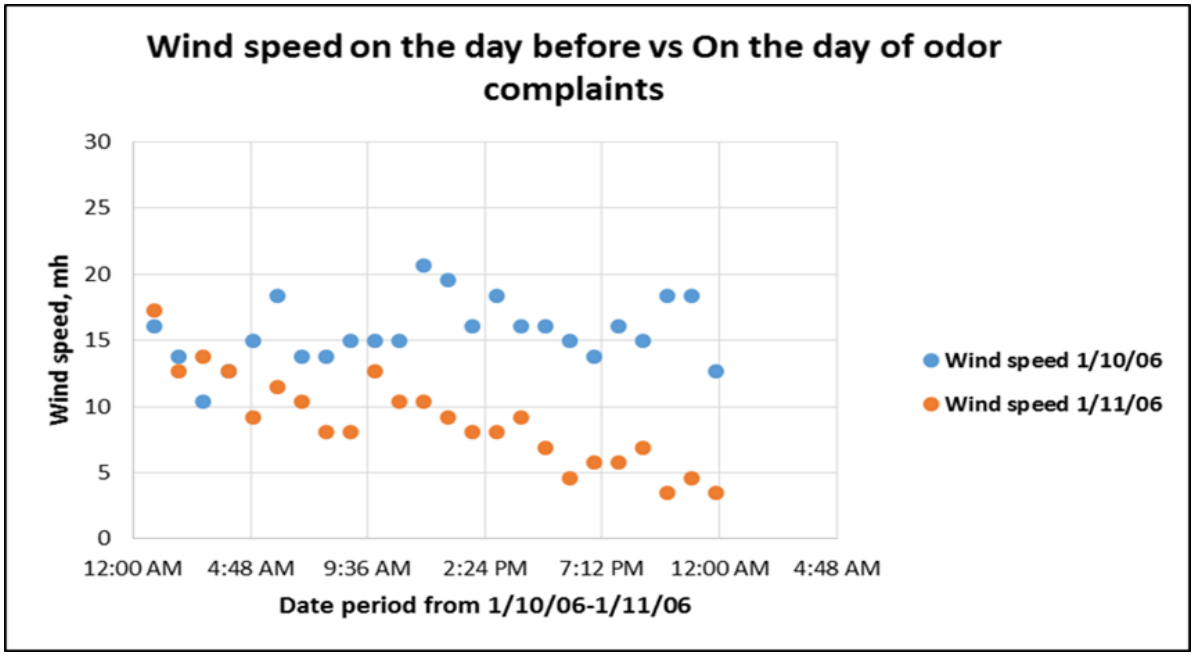



**Figure 76. Monarch Hill, 1/11/06**

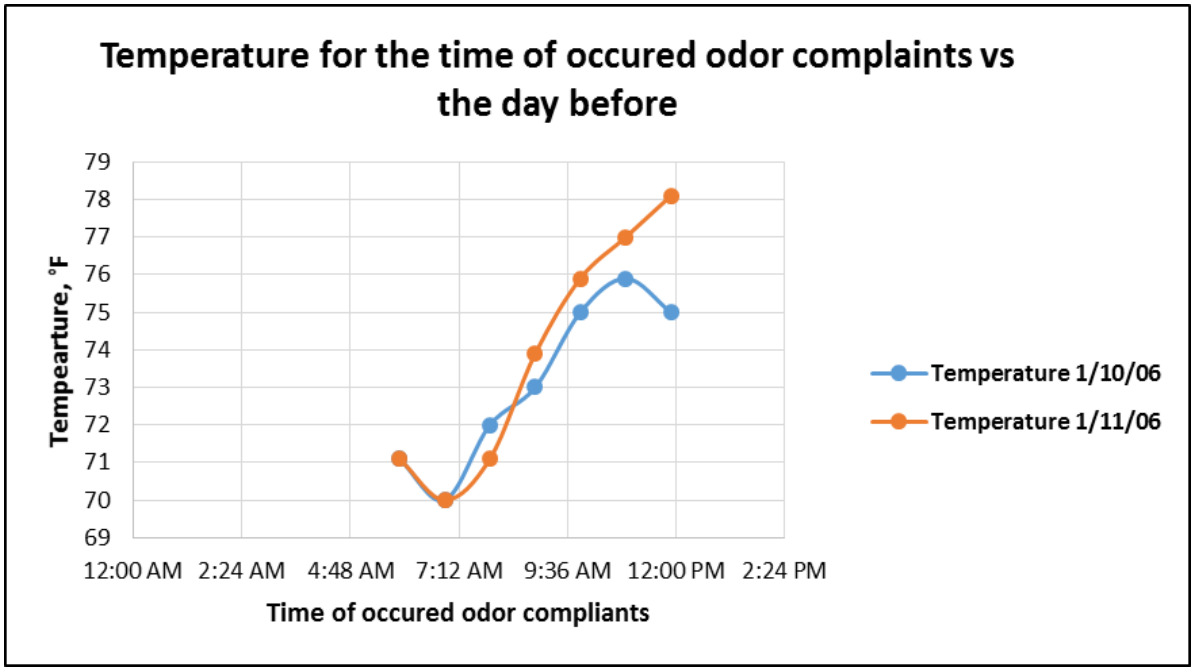



**Figure 77. Monarch Hill, 1/11/06**

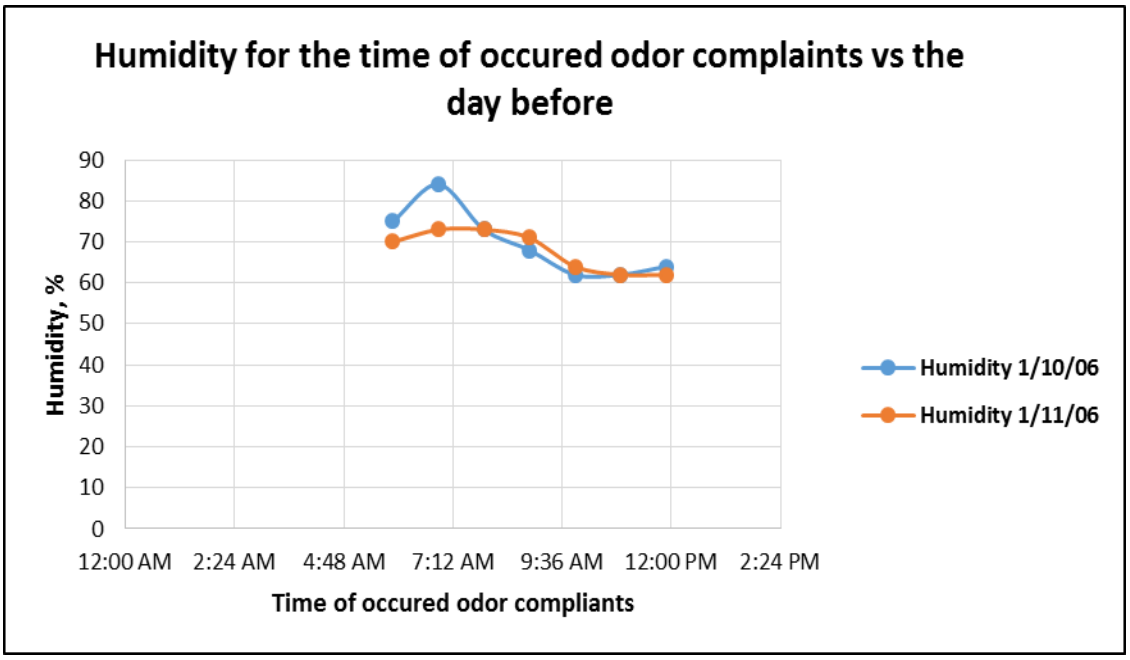



**Figure 78. Monarch Hill, 1/11/06**

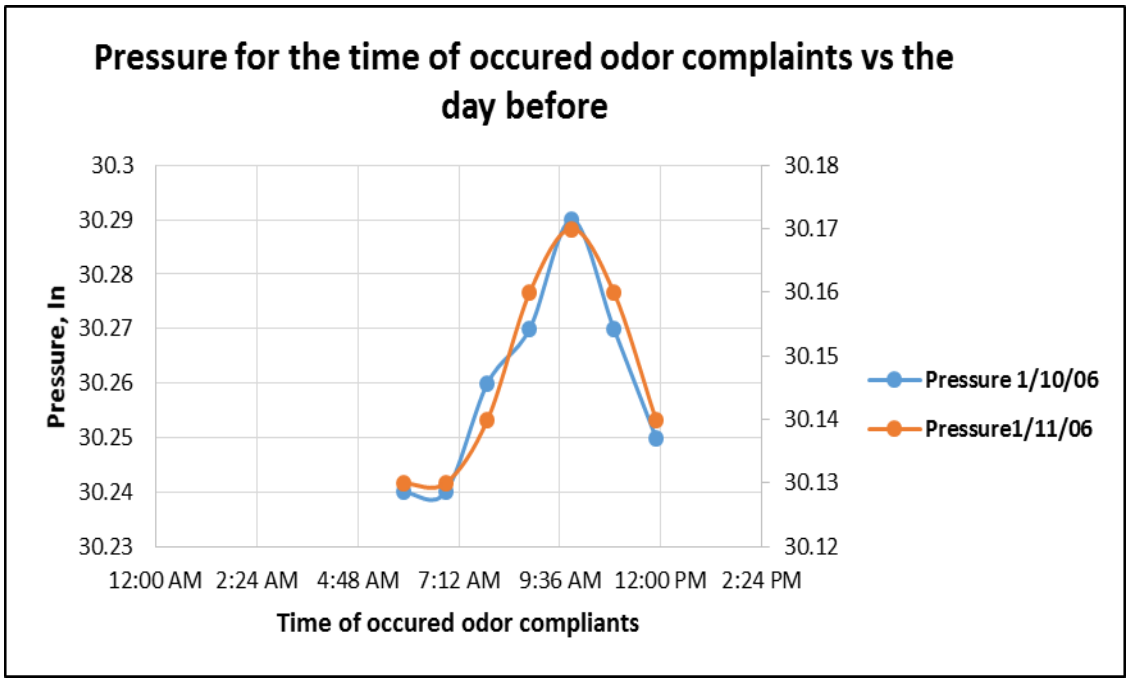



**Figure 79. Monarch Hill, 1/11/06**

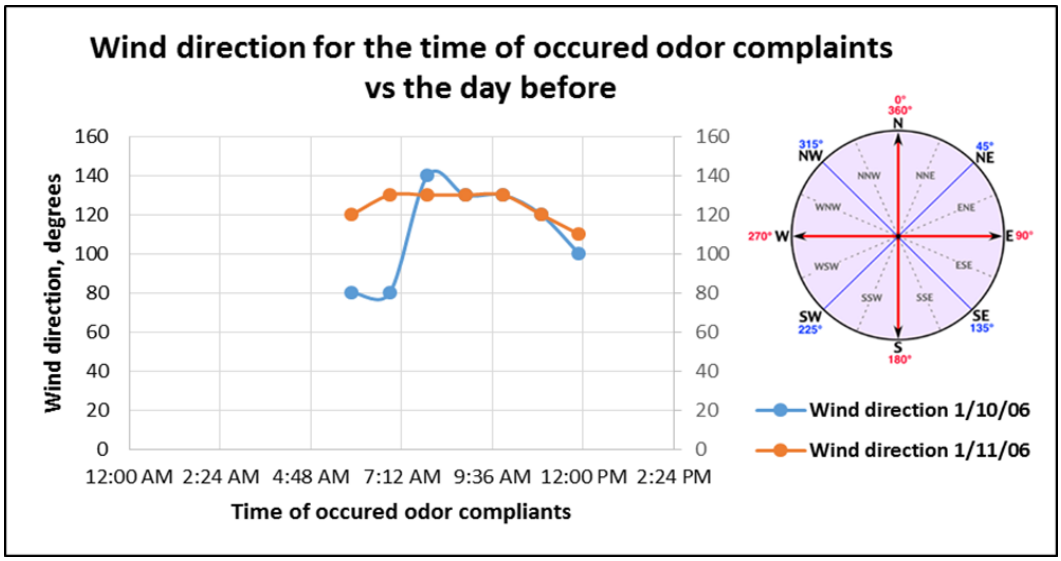



**Figure 80. Monarch Hill, 1/11/06**

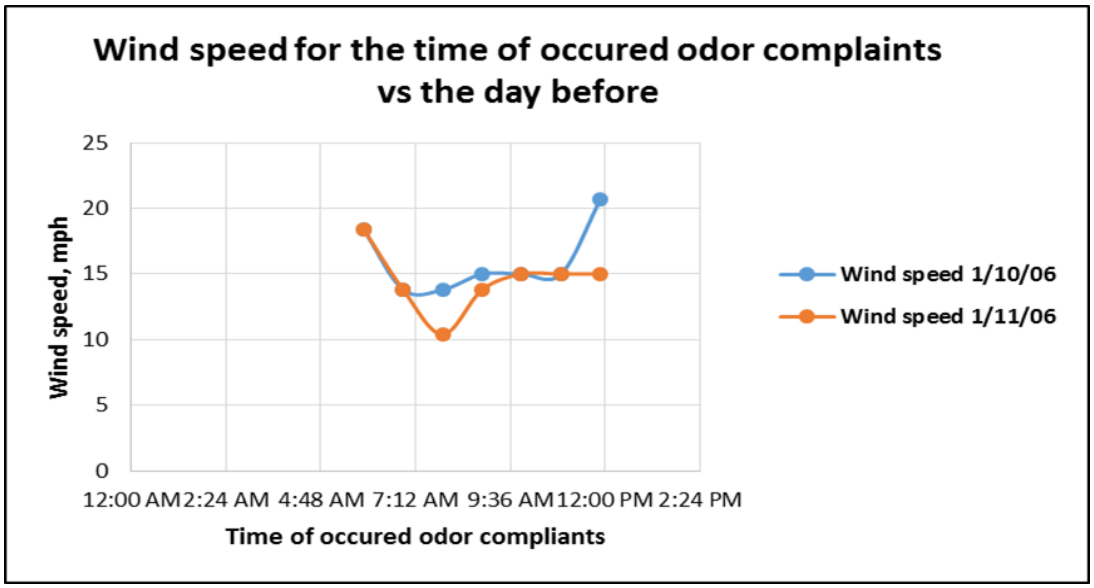



**Figure 81. Monarch Hill, 1/11/06**

| | *T1* | *T2* | | *Hum 1* | *Hum 2* | | *P1* | *P2* |
|---|---|---|---|---|---|---|---|---|
| T1 | 1 | | H1 | 1 | | P1 | 1 | |
| T2 | 0.930906 | 1 | H2 | 0.836057 | 1 | P2 | 0.939247 | 1 |

| | *Wd 1* | *Wd2* | | *Wd 1* | *Wd2* |
|---|---|---|---|---|---|
| Wd 1 | 1 | | Wd 1 | 1 | |
| Wd2 | 0.018405 | 1 | Wd2 | 0.018405 | 1 |

## 3.3 BACTERIAL EXPRESSION RESULTS

No transformants grew on Kanamycin LB Agar plates for trial 1 of bacterial expression of OBPIIA. Since there were no transformants, the protein could not be synthesized. Healthy transformants grew for bacterial expression of OBPIIA Trial 2 and are ready for the next phase of the experiment: protein purification (Figure 82).

**Figure 82. Healthy *E. coli* cultures following incubation.**

For bacterial expression of OBPIIA) Trial 1, it is possible that there was too little DNA on the filter paper to begin with, although that seems unlikely since electroporation is sensitive to as little as 15 μL of DNA. It may be more likely that the DNA was degraded by the time it was received by mail from Portugal. Another possibility is that the electroporation step did not work to create transformants. Alternatively, the *E.coli* culture may have been too unhealthy to survive the transformation process. No transformants grew on the first attempt. Future strategies to ensure successful transformation include: ensure adequate amount of starting plasmid, ensure preservation of plasmid, test electroporator to ensure adequate functioning, and ensure *E. coli* is healthy enough to survive the process. Since bacterial expression of OBPIIA Trial 2 was effective, the next step is to isolate the protein using the His SpinTrap TALON® is a single-use column for histidine-tagged proteins. Following protein isolation, the protein will be tagged with 1-AMA.

# 4. CONCLUSION

## 4.1 SUMMARY

With all the issues that solid waste facilities are facing when nuisance odors are involved in consideration, management of facility must give attention to operating the facility in a manner that would reduce any potential impact to close by neighborhoods. By monitoring meteorological conditions, assumptions can be made in order to predict possible situations when odor complaints could occur. With atmospheric conditions being so complex, it is difficult to exactly forecast what will happen in the future.

Preliminary analysis showed possibility for pattern identification since there is a trend that occurred in all the cases when odor complaints were made. In all scenarios, odor complaints were received while wind speed was weak, wind direction was from the south, temperature was high, pressure was dropping, and there was no precipitation; also the weather conditions were stable. Only in the case of September 19, 2014 weather station data, average wind direction was ENE, but at the exact time of the odor complaint report, the wind direction was logged as from the south. Correlations between meteorological parameters, both for SWA of Palm Beach County and Monarch Hill landfill, showed that wind direction and wind speed are the parameters with lowest correlations when compared to the values from the day before, which is expected, while temperature, humidity, and pressure had constantly higher correlation values.

Synthesizing the OBPIIa in the lab rather than purchasing it from a supplier was more time consuming but ultimately was the more sustainable and cost effective choice. Small amounts of the protein are commercially available, but once the stock is used for experimentation, more would need to be purchased. The scope of the protein experiments is currently limited to measuring the concentrations of three pure odorous gasses, but the eventual purpose of the research in general is to measure a mixture of odorous gasses at a landfill site. Resource barriers to continued research would be significantly reduced since we can now produce the protein integral to the biosensor easily and inexpensively in our lab in whatever quantity needed. It is important that a coherent protocol for producing the protein is readily available in the laboratory, and necessary materials are stored, such as the *E. coli* expression strain, which can be stored indefinitely in deep freeze.

The next phase of the experimental procedure involves marking the protein with 1-AMA and beginning testing and data collection using the reaction chamber and spectrometer.

## 4.2 RECOMMENDATIONS

Further analysis on meteorological conditions should be done to gain more insights to the possible patterns. Include more meteorological parameters that could have great influence on increasing number of odor complaints, while excluding those that don't. Work on analysis of overnight pressure drop and precipitation accumulation as indicators of odor complaints. Measure concentrations of $H_2S$ to see if there is any trend or correlation between the concentrations and number of odor complaints.

When collecting the data on odor complaints, try to have more consistent databases with information of weather conditions at the exact time of the occurred odor complaints, as well as information on the odor character that has been noticed so that analysis can be also done based on most common odor descriptors and see what pollutants could be responsible for those nuisance odors. In that way, by knowing the odor causing compound, it provides information on which solid waste operations could be involved and management measurements can be applied to lower nuisance odors that are produced by those exact operations. Also, more data information on solid waste operations that were active at the time of occurred odor complaint would be very significant since odor complaints can be marked as verified or not, and it would provide more insight to what was happening that particular day or was someone just calling and making complaints that didn't have any correlation to the specific landfill site.

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