Modeling of Ambient Air Pollution in a Cluster of Brickfields

By

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CERTIFICATION OF THESIS WORK

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ABSTRACT

Verification of the applicability of an effective air quality model in Bangladesh condition, especially for brickfield pollution was the main concern of this thesis work. To achieve that objective, ambient pollutant concentrations were measured experimentally and compared with the results generated through modeling using Industrial Source Complex (ISC3) model. Then the model was applied to predict ambient air pollution loads under different circumstances. Air sampling was done at different locations in a cluster of brickfields of 41 brick kilns near Amin Bazar, Savar using Gastec tubes and High volume sampler. Gastec tubes were used for gaseous pollutants and High volume sampler was used for Total Suspended Particulates (TSP). Gaseous pollutants included Sulfur dioxide, Carbon monoxide, and Hydrocarbons. Effects of meteorological conditions, stack height, and stack exit velocity on the ambient pollutant concentration were analyzed for multiple pollution sources over a long period of time by using this model, after successful verification of its acceptability. Significant effect of the meteorological conditions on ambient air quality was observed. Effectiveness of increase in stack height to reduce air pollution was also analyzed. Increased stack height was found effective in reducing average ambient concentration up to a certain stack height. Beyond that stack height, change in ambient pollutant concentration with the increase of stack height was found to be insignificant. Stack exit velocity was found to have negligible influence on the ambient air quality at the surroundings of the sources but effect in the cluster area was prominent. In brief, Industrial Source Complex (ISC3) model was found very effective and appropriate both for gaseous pollutants and particulate matter for brickfield pollution in Bangladesh and its different utilizations were exercised successfully in this thesis work.

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CHAPTER 1
INTRODUCTION

1.1 BACKGROUND AND PRESENT STATE OF THE PROBLEM

Air pollution is one of the major manmade environmental problems that has recently gained importance among environmental issues in Bangladesh. Exposure to air pollution is the main environmental threat to human health in towns and cities. Numerous brick-making kilns operating in the dry season are one of the major sources of air pollution in cities. A significant factor is that brick kilns are usually clustered near big cites in different parts of Bangladesh. Therefore, the parts of the city in the immediate vicinity of the brick-field clusters have serious air pollution problems.

Air quality of Dhaka city is severely affected by the pollutants from hundreds of brickfields located at the entry points into the Dhaka city: Amin Bazar, Keraniganj, Fatulla, Pagla, Tongi, Ashulia. These kilns produce bricks using an old conventional process. Every year more than 20 lakh metric tonnes of low quality coal and 20 lakh metric tons of wood are burnt in these brick fields along with tires and rubber [BPPW, 2005]. Only few fields use natural gas where it is available. The pollution is caused by the poor quality of fuel, improper design of chimneys and combustion chamber. Pollutants such as oxides of carbon, sulfur dioxide, oxides of nitrogen, volatile organic compounds and particulates are produced from the brickfields. Moreover even under well-controlled processes worldwide, 0.2 microgram toxic equivalents of dioxins and furans are emitted as byproduct into the air during the production of each ton of brick, which is very harmful for lives [UNEP, 2005]. Brickfields also cause crop loss, corrosion of metallic objects and loss of soil fertility. The land in the burning area of a kiln becomes unusable for cultivation for several years.

Even though brickfields are one of the major sources of air pollution in Dhaka city, most of the research activities regarding air pollution in Dhaka deal with vehicle and industrial pollutions. Department of Environment (DOE), Bangladesh Council of Scientific and Industrial Research (BCSIR) and Bangladesh Atomic Energy Centre (BAEC), Dhaka are the main organizations working on air pollution, but none of the organizations were studying brickfields earlier. Recently this issue is being taken into consideration seriously. By the implementation of the national court order 2003, stack height of brick kilns have now been increased to 120ft. However, no study has verified whether this measure has reduced air pollution. If this measure has been effective, then it is important to know the extent. In India, some additional modifications are employed to combat pollution such as the installation of gravity settlers below the stack and controlled feeding of coal. From some survey results, it has been seen that the air pollution near Dhaka city increases to a large extent during the dry season [Khaliquzzaman et al., 1999 and BPPW, 2005]. As brickfields are operated during the dry season, it is clear that brickfields have large contribution to the air pollution.

Though Air quality modeling is a very effective tool to predict ambient pollution level and is used worldwide but it is a new concept in Bangladesh. Like brickfield pollutions, air pollution modeling has never been exercised in Bangladesh earlier. Air quality models, such as Gaussian plume model, urban air shed model, box model and other trajectory and meso-scale models had been studying worldwide for many years. Dispersion model is being used to determine the location of an unknown emission source [Islam, 1999]. Concentrations of different pollutants for different seasons are also being measured by using an urban scale Gaussian dispersion model (ADMS-Urban) [Owen et al., 2000]. Industrial Source Complex Short Term (ISCST-3) model can be utilized to facilitate the study of emission source contributions to ambient concentrations of different pollutants [Hao et al., 2001]. Even in our neighboring countries such as India and Nepal, air pollution modeling has been used for different purposes. ISCST-3 model is being used to examine the assimilative capacity and the dispersion of pollutants in the different seasons due to industrial sources [Krishna et al., 2004]. Apart from these, different other developed air quality models are being used for different purposes worldwide. So, introduction of an effective air pollution model to measure the pollution impacts from brick kiln in Bangladesh condition can be a breakthrough in improving the scenario. Our objective was to measure the pollutant from the brick kiln stacks at selected points on the ground level near the brickfields in Amin Bazar at different times during the dry season and to model air pollution caused by brickfields [Westbrook, 1999 and ESS, 2002].

1.2 OBJECTIVES WITH SPECIFIC AIMS AND POSSIBLE OUTCOME

The principal objective of this research work was to verify effectiveness of an air pollution model for brickfield pollution in Bangladesh condition and to utilize that model for further studies. The study included monitoring and then modeling of the air pollution load at ground level inside a brickfield cluster in Amin Bazar on different days during the dry season. Emission from a chosen brick kiln stack and the ground level concentration of different pollutants were measured and used for the modeling study. Different utilization of the verified model was also part of this work.

This study will help to portray a picture of the current air pollution caused by brickfields. The extent of reduction of pollution by increasing the stack height will also be established from that if the data for earlier condition are available. The air pollution model would give an idea of pollution near brickfields at any given time without having to do practical measurements. The model will help to test the effectiveness of further pollution control measure that the Department of Environment might propose. Thus the citing of new brickfields in an already congested area can be evaluated. Because of its applicability for different pollution sources, air quality model can be used as an effective tool for determining the effect of any pollution source prior to its establishment. From different utilizations of the air quality model, the trend of ambient pollutant concentration change for different conditions can also be predicted.

CHAPTER 2

LITERATURE REVIEW

2.1 COMPOSITION OF CLEAN AIR

The atmosphere is composed of different gases among which, Nitrogen and Oxygen and some noble gases are significant. However, there are a number of gases that occur in relatively small and sometimes highly variable amounts. Water vapor, Carbon dioxide and ozone fall in the latter category and these are also considered as common urban air pollutant. This composition of atmosphere is continuously changing due to vegetation, ocean and biological organisms. Gases are also changing by physical and chemical processes and sometimes are being produced by chemical processes within atmosphere itself. The average residence time of a gas molecule introduced into the atmosphere can range from hours to million years, depending on the species. The important atmospheric gases and their average compositions in atmosphere are presented in Table: 2.01 [Seinfeld, 1986]. The gases indicated with a range of concentrations are commonly classed as air pollutants.

Table 2.01: Average Composition of clean air

Gas	Average Concentration (ppm)
Ar	9340
Ne	18
Kr	1.1
Xe	0.09
N_2	780,840
O_2	209,460
CH_4	1.65
CO_2	332
CO	0.05 – 0.2
H_2	0.58
N_2O	0.33
SO_2	$10^{-5} - 10^{-4}$
NH_3	$10^{-4} - 10^{-3}$
$NO + NO_2$	$10^{-6} - 10^{-2}$
O_3	$10^{-2} - 10^{-1}$
HNO_3	$10^{-5} - 10^{-3}$
H_2O	Variable
He	5.2

2.2 AIR POLLUTANTS

A material present in the atmosphere, either from natural or man-made sources, may be considered to be a pollutant when its concentration reaches or exceed a certain level such that (a) some adverse effect on human health or welfare is observed; (b) some deleterious effect on animal or plant life is observed; or (c) damage to materials of economic values to society is observed. These are called air pollutants, when present in air. Certain level above that a compound will be treated as pollutant is decided by several environmental agencies. There is little difference among them and different countries follow different standards. Most of the countries have their own standards to follow. Different gases such as carbon monoxide, sulfur dioxide, oxides of nitrogen, organic volatile compounds and some solid particles are normally considered as air pollutant. These are produced both naturally and through anthropogenic processes. Due to industrial growth and technological evolution, air pollution is now a major concern all over the world.

2.3 CLASSIFICATION OF AIR POLLUTANTS

Pollutants in air can be classified in several ways. The most common classification is done according to the physical states of the pollutants, that is, gaseous, liquid and solid. However, the latter two types of pollutants are present in atmosphere as particle form. So in general, classification is done as gaseous and particulate form. Air pollutants may also be classified according to the manner in which they reached the atmosphere, namely

1. Primary Pollutant
2. Secondary pollutant

High concentration of sulfur compounds (SO_2 and sulfates), and particles, resulting from combustion of coal and high-sulfur containing fuel is of the first type. This type of pollutant is common in cities with cold climate where power generation and heating systems are major sources of emissions. The second type of pollutant appeared only with the widespread use of gasoline as motor fuel. This type of pollutant is also known as "smog" and it is, in fact, neither smoke nor fog but the reactants and products of complex series of reactions that take place when sunlight irradiates an atmosphere laden with organic gases and oxides of nitrogen. So sometimes it is also called photochemical smog. The main primary pollutants in photochemical smog are nitric oxide and hydrocarbons, which are rapidly converted to secondary pollutants, ozone, organic nitrates, oxidized hydrocarbons and photochemical aerosol.

There is another way of classification based on chemical composition of the pollutant. Though virtually all the components of periodic table are found in atmosphere but this classification is done considering some major groups of pollutants. These groupings are:

1. Sulfur-containing compounds
2. Nitrogen-containing compounds
3. Carbon-containing compounds
4. Halogen-containing compounds
5. Toxic substances
6. Radioactive compounds

Unlike first four groups, toxic substances such as, Arsenic, Asbestos, Benzene, Inorganic Lead, Carbon Tetrachloride etc. are not considered according to their main chemical elements rather considered as a different group. Because of its specialized nature, radioactive compounds are not normally dealt as a common pollutant but sometimes it can be one of the major concerns [Eisenbud, 1968].

2.3.1 Sulfur-containing compounds

The major sulfur containing compound in the atmosphere are carbonyl sulfide (COS), carbon disulfide (CS_2), dimethyl sulfide ($(CH_3)_2S$), hydrogen sulfide (H_2S), Sulfur dioxide (SO_2), and sulfate (SO_4^{-2}). The sources of atmospheric sulfur compounds are biological decay, combustion of fossil fuels and organic matters, and sea spray. Carbonyl sulfide is the most abundant gaseous sulfur species present in atmosphere and dimethyl sulfide is the most abundant volatile sulfur compound in sea water. Sulfur dioxide, hydrogen sulfide and sulfates are the main pollutants present in industrial and urban atmosphere [Seinfeld, 1986].

2.3.1.1 Sulfur Dioxide (SO_2)

Sulfur dioxide emissions result overwhelmingly from human activities – combustion of fuels and smelting of metals. Although natural sources of sulfur dioxide exist such as volcanoes and fumaroles, but the total amount of sulfur dioxide emission from natural sources is negligible compared to the total man-made emission. The major man-made source of sulfur dioxide is coal burning. Operations involving power production using coal and production of bricks from coal burning brickfields are the two major contributor of coal burning sulfur sources. SO_2 in atmosphere can be oxidized to sulfur trioxide in different conditions which finally results into sulfuric acid and comes down through acid rain. Analysis of power plant plumes tracked by helicopters indicated very rapid oxidation rates, 0.1-2% per minute [Bibbero, 1974]. The rate is dependent on the moisture content of the plume as well as the ambient relative humidity. The catalytic process is prevalent during high humidity condition when SO_2 is readily absorbed by water droplets. If the water droplets contain only water, essentially no reaction occurs. However, in presence of number of foreign substances such as metal salts (Fe^{3+}, Mn^{2+} etc.) or NH_3 rapidly promotes the reaction between SO_2 and oxygen dissolved in water leading to the formation of SO_4^{2-}.

2.3.1.2 Hydrogen Sulfide (H_2S)

Natural sources of hydrogen sulfide are oceans and land erosion due to decaying vegetation but there are several industrial processes that are responsible for hydrogen sulfide emission. Kraft pulping process for paper manufacturing and oil refining are two major sources of hydrogen sulfide emission. Specific H_2S emission data, however, are seldom obtained; it is frequently counted with SO_2. Since there is a serious odor problem with H_2S, it is monitored carefully and removed by scrubbing in the industries. It can be oxidized by atomic and molecular oxygen and ozone in the atmosphere. These reactions generally produce sulfur dioxide in the atmosphere. Reaction with ozone is normally slow in gas phase but that can occur much rapidly on surface of airborne particles [Hales et al., 1969].

$$H_2S + O_3 \rightarrow H_2O + SO_2$$

Hydrogen sulfide, oxygen and ozone are soluble in water, and thus the rate of oxidation of hydrogen sulfide in fog or cloud droplets could be very fast [Seinfeld, 1975].

2.3.1.3 Sulfates

Sulfuric acid and its salts do not exist in the atmosphere in gaseous state but rather as particulates in the form of aerosols. Sea spray is one of the major sources of these sulfates but only 10% of that penetrates land area and the remainder goes back to the ocean [Bibbero, 1974]. The other sources of sulfate aerosols are atmospheric oxidation of sulfur dioxide and hydrogen sulfide to form sulfuric acid or sulfate salts. These are produced through a set of chemical reactions in the atmosphere. Analysis shows that, sulfate aerosols are derived from oxidation of sulfur dioxide in the industrial areas and from hydrogen sulfide in the non industrial areas [Robinson, 1968].

2.3.2 Nitrogen-containing compounds

N_2O, NO, NO_2, NH_3, and salts of NO_3^-, NO_2^-, and NH_4^+ are the main nitrogen containing compounds available in the atmosphere. Though N_2O is formed in the atmosphere from natural sources but NO can be formed both from natural and anthropogenic sources [Seinfeld, 1986]. Burning of fuel at high temperature is the primary anthropogenic source of NO. A little amount of NO_2 can be formed during high temperature burning but normally it is produced after oxidation from NO in the atmosphere. Both NO and NO_2 are considered as air pollutants and sometimes considered together designating NO_x. Other oxides of nitrogen are also present in insignificant amount in atmosphere and are not generally considered as air pollutants.

2.3.2.1 Nitrous Oxide (N_2O)

The most abundant nitrogen compound in the atmosphere is N_2O, with a mean concentration of about 0.25 ppm [Bibbero, 1974]. This is relatively inert gas nd is apparently produced mainly by bacterial action on nitrogenous compounds in the soil [Robinson, 1968]. This view is supported by laboratory experiments in which bacterial action on ammonium and nitrate compounds produced N_2O and N_2. Another possible source of that is ocean. This doesn't take part in any reaction in troposphere but changes in to Nitric oxide by photodissociation in stratosphere [Seinfeld, 1975].

2.3.2.2 Nitric Oxide (NO) and Nitrogen dioxide (NO_2)

It is believed that Nitric oxide may be formed by reduction of nitrates by bacterial action under anaerobic conditions and that is then rapidly oxidized in air to NO_2. However, while considering man-made sources, it is difficult to distinguish between the sources of NO and NO_2 and so man-made sources of NO and NO_2 are considered together. The main sources of these two gases are combustion processes in which temperatures are high enough to oxidize the atmospheric nitrogen and the hot gas are rapidly quenched, minimizing decomposition of nitrogen oxides [Seinfeld, 1986]. This is the result of human activity in high population density, high technology urban areas.

2.3.2.3 Ammonia (NH_3)

Ammonia enters the atmosphere mainly from natural sources rather than human activity. The predominant natural source is the biosphere: bacterial breakdown of organic nitrogenous matter releasing nitrogen as ammonia. In soils, the release of this NH_3 depends partly on the pH of the soil, a higher pH favoring the release of gaseous NH_3. Man-made sources of ammonia are mainly combustion and some industrial processes. Like H_2S it has also an odor problem and is scrubbed from the effluent.

2.3.2.4 Nitrite (NO_2^-), Nitrate (NO_3^-) and Ammonium (NH_4^+) compounds

All of those are not present in atmosphere in ion forms but as ionic salts which are solids. The particle size is very low and probably less than 1μm. So their settling velocity is very low and can exist as aerosol in the atmosphere. The sources of these ions are chemical reactions of gaseous nitrogen compounds with substances already in the atmosphere such as oxygen, ozone, and water. The lower oxides of the nitrogen tend to be converted to nitric acid and nitrates as they persist in the atmosphere. Ammonia may be oxidized to oxides but normally most of the ammonia in the atmosphere is precipitated eventually as ammonium sulfate and ammonium nitrate [Seinfeld, 1975].

2.3.3 Carbon-containing compounds

There are two major classes of carbon-containing compounds are present in the atmosphere; gases of carbon and hydrocarbon. CO and CO_2 are the main gases of carbon found in the atmosphere. Though CO_2 is one of the natural components presents in air but CO is considered as a major air pollutant. Incomplete combustion is the prime source of CO in the atmosphere. Hydrocarbon can be present in different types in atmosphere such as alkanes, alkenes, alkynes, aldehydes, ketones. These can be formed from combustion of fossil fuel and vegetation. Different types of organic compounds can be emitted into the atmosphere by vegetation [Arnts, 1979].

2.3.3.1 Carbon Dioxide (CO_2)

Carbon dioxide is not considered as a major pollutant as it always present as a part of clean atmosphere up to a certain level. If the level is high enough then it should be handled as a pollutant. Production of CO_2 due to respiration of plants and animals, decay of organic material and release from the ocean are the natural source of that. However, this is very insignificant compared to total CO_2 production by natural and man-made sources. With the increased industrialization the CO_2 emission into the atmosphere is increased and overshadowed the contribution by natural sources. Carbon dioxide, along with ozone, water vapor and clouds exerts the so called greenhouse effect – that is solar radiation rich in UV reaches the surface, but the earth radiation, rich in IR, is absorbed. Thus the overall effect is to raise the mean temperature of the troposphere. Most interesting thing is that, this effect is reduced in presence of particulate matter, as solar radiation is prevented by particulate to reach to the surface.

2.3.3.2 Carbon Monoxide (CO)

Carbon monoxide is a product of almost all the combustion processes and is therefore as widespread a pollutant as the processes that generate it. It is colorless, odorless gas and therefore can not be detected by unaided human senses. The internal combustion engine is the largest single source of CO in the atmosphere [Seinfeld, 1986]. As a consequence, the highest concentrations are found in urban areas having the highest population as well as automobile density, thus exposing to greater number of people to hazard. Industrial combustion processes and other combustion processes such as power generation and brick production from fossil fuels are also major sources of man-made CO emission. Forest fire is known as the main natural source of CO emission. Apart from that, natural source of CO emission have not been investigated to any great extent. From some studies, volcanic gases, vegetation, some bacterial metabolism are also considered as contributors in CO emission to the atmosphere.

2.3.3.3 Hydrocarbons and Other Organic Compounds

Methane is produced in nature by bacterial decomposition reactions in swamps, marshes, and other waters. The principal component of "marsh gas" is methane. Natural gas also contains methane as the main constituent and methane from natural gas can goes in to the atmosphere through leakage from the reservoir tank. Methane is also emitted from automobile exhaust and different carbonaceous combustions. Apart from methane, there are different other hydrocarbons available in the atmosphere and their concentration in atmosphere varies place to place. In a number of studies, 56 hydrocarbon species were detected in Urban air [Air Quality Criteria for Hydrocarbons, 1970]. Ethane, Ethylene, Butane, Pentane, Hexane, acetaldehyde, Acetone, Methanol and ethanol, benzene, n-Butanol etc are the examples of hydrocarbons present in the atmosphere. These are also considered as pollutant once their levels exceed the maximum permissible value. Incineration of organic wastes is also a major source of organic compounds in the atmosphere. Moreover, when there is combustion then there must be carbonaceous emission either as an oxide of carbon or other carbonaceous compounds including hydrocarbons.

2.3.4 Halogen-containing compounds

Contribution of HCl to acidic precipitation, effect of chlorofluoro carbon on stratospheric ozone, atmospheric level of toxic pesticides and chemical intermediates in the tropospheric decomposition of chlorinated solvent have raised the attention about halogen-containing pollutant in the atmosphere recently. These are present in the atmosphere as compounds of carbon and halogen. Except CH_3Cl, CH_3Br and CH_3I, all other halogen-containing compounds are of anthropogenic origin. The major natural source of these three methyl compounds appears to be ocean [Seinfeld, 1986].

2.4 ATMOSPHERIC PARTICULATE MATTER

Substances in atmosphere, except water, present in liquid or solid form are known as particulate matters. Airborne particulate matter results not only from direct emissions of particles but also from emissions of certain gases that either condenses as particles directly or undergo chemical reaction to a species that condenses as a particle. Size of atmospheric particulate matters is normally expressed in micrometer (μm). Particles less than 2.5 μm are normally considered as "fine" particles and larger than that is considered as "coarse" particle. When considered as pollutant, the size is normally classified into less than 2.5μm and less than 10μm, known widely as $PM_{2.5}$ and PM_{10} respectively. Mass distribution of the major chemical species observed in atmosphere is done according to their size in different studies as shown in the Figure 2.01 [Seinfeld, 1986].

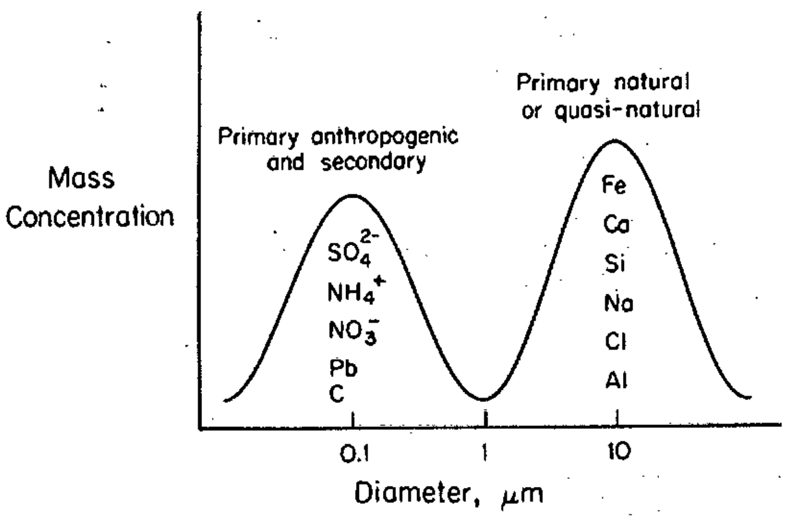


Figure 2.01: Typical segmentation of chemical species into fine and coarse particle fraction

2.4.1 Sources of atmospheric particulate matter

Sources of atmospheric particulate matter are of two types; natural and anthropogenic. Soil and Rock debris, forest fires, sea salt, volcanic debris, gaseous emission from natural processes etc. are the natural sources of particulate matter in atmosphere. On the other hand, fuel combustion, industrial processes, industrial process fugitive emissions and non industrial fugitive emissions, transportation etc are the major anthropogenic sources of particulate matters in the atmosphere. In combustion pollutant carbonaceous aerosol components account for up to ~ 50% of $PM_{2.5}$ in the lower atmosphere [Ulrich, 2003]. Industrial fugitive sources are the unidentified sources in the industrial processes unlike stacks. Non industrial fugitive sources are mainly roadway dust from paved and unpaved roads, wind erosion of croplands etc. transportation sources of emissions occur in two categories; vehicle exhaust and from vehicle related particles like tire, clutch, and brake wear. Engine related particulate emissions are composed primarily of lead halides, sulfates and carbonaceous matter. There are normally smaller than 1μm. Apart from that there are trace elements and trace element emissions arise from more than 60 different source types in a large urban area [EPA, 1977]. The primary chemical component of the fine particulate matters ($PM_{2.5}$) in urban and rural continental air are usually sulfate, nitrate, ammonium, organics and black or elemental carbon, each contributing about 10-30% of the overall mass loading [Ulrich, 2003].

2.4.2 Different Particulate matters

Particles can also be classified into four different types, namely: Dust particle, Fume particles, Smoke particles and Mist or fog particles [Seinfeld, 1975]. These are mainly classified from the basis of their source of generation. These are discussed in brief below:

2.4.2.1 Fume particles

Fume particles are formed in relatively high temperature. These are very fine and their size ranges between 0.1μm to 1μm. As these are very small, they have very low settling velocity and exhibits Brownian motion [Perry and Green, 1984]. Sublimation, condensation, combustion are the main processes through which fume particles can generate.

2.4.2.2 Dust particles

Dust particles are normally produced through pulverization or mechanical disintegration of solid matters following crushing, grinding and drilling. These are normally generated from the places where mechanical disintegration occurs like civil construction site, chemical and mechanical process industries. Fly ash, rock dust, ordinary flour, brick dust are common examples of dust particles. Dust particle size can very from 1μm to 200μm or larger and these are of irregular shape.

2.4.2.3 Smoke Particles

Smoke particles can be either solid or liquid in state. Its size ranges from 0.01μm to 1μm. If particles are solid then the shape is normally spherical and if particles are liquid then shape is normally irregular [Rahman, 2005]. Smoke particles are typically derived from burning of organic materials, biomass such as wood, coal, tobacco and plastics. Due to their fine size, smoke particles can remain suspended in the atmosphere and exhibits Brownian motion like fume particles.

2.4.2.4 Mist or Fog particles

Particle sizes of natural fog and mists usually lie between 2 and 200 μm. They are typically formed either by condensation of water or vapors on suitable nuclei giving suspension of small liquid droplets, or by atomization of liquids. When particles grow larger than 200 μm, they settle down as rain or drizzle.

2.5 DIFFERENT HAZARDOUS AIR POLLUTANT

Toxic air pollutants, also known as hazardous air pollutants, are those pollutants that are known or suspected to cause cancer or other serious health effects, such as reproductive effects or birth defects, or adverse environmental effects. Examples of toxic air pollutants include benzene, which is found in gasoline; perchlorethlyene, which is emitted from some dry cleaning facilities; and methylene chloride, which is used as a solvent and paint stripper by a number of industries [Rahman, 2005]. Examples of other listed air toxics include dioxin, asbestos, toluene, and metals such as cadmium, mercury, chromium, and lead compounds.

2.6 METALLIC AIR POLLUTANTS

There are different metals in air which are considered as air pollutant if exist in significant amount. Lead and mercury are the two major metallic air pollutant found in the environment. Cadmium and chromium are also found in some places. Concentration varies from place to place depending on the sources of air pollution. Nevertheless all of them are health hazardous above a certain level in different ways. Lead is a major pollutant in the urban areas of many countries because of its application in motor fuels.

2.6.1 Lead

Lead is a metal found naturally in the environment as well as in manufactured products. The major sources of lead emissions have historically been motor vehicles (such as cars and trucks) and industrial sources. Due to the phase out of leaded gasoline, metals processing is the major source of lead emissions to the air today. The highest levels of lead in air are generally found near lead smelters. Other stationary sources are waste incinerators, utilities, and lead-acid battery manufacturers. Lead is a highly toxic element. Exposure to lead can result in damage to the brain, kidneys, blood, central nervous system and reproductive system. Children are particularly sensitive to the chronic effects of lead, with slowed cognitive development, reduced growth and other effects. Exposure to lead may come through a number of other sources, including lead-based paint, petroleum, lead contaminated dust and lead contaminated residential soil.

2.6.2 Mercury

Mercury is a naturally occurring element that is found in air, water and soil. It exists in several forms: elemental or metallic mercury, inorganic mercury compounds, and organic mercury compounds. Mercury is found in many rocks including coal. When coal is burned, mercury is released into the environment. Burning hazardous wastes, producing chlorine, breaking mercury products, and spilling mercury, as well as the improper treatment and disposal of products or wastes containing mercury, can also release it into the environment. Mercury in the air eventually settles into water or onto land where it can be washed into water. Once deposited, certain microorganisms can change it into methylmercury, a highly toxic form that builds up in fish, shellfish and animals that eat fish. Fish and shellfish are the main sources of methylmercury exposure to humans. Mercury exposure at high levels can harm the brain, heart, kidneys, lungs, and immune system of people of all ages. Research shows that most people's fish consumption does not cause a health concern. However, it has been demonstrated that high levels of methylmercury in the bloodstream of unborn babies and young children may harm the developing nervous system, making the child less able to think and learn.

2.6.3 Cadmium

Cadmium is an important pollutant element. It is receiving wide attention as it is reaching from soil parent materials, environmental pollution, and cadmium containing fertilizers and sewage and sludge in various proportions. Cadmium is found widely used in plating of steel, Fe, Cu, brass and other alloys to protect from corrosion, in soldering electrical parts and in manufacture of batteries and semi conductors, in producing pigments and stabilized plastics and in manufacture of air craft. Cadmium may be ingested through air, water and food. 5% to 10% of the inhaled cadmium is ingested which may result in disturbance in gastro intestinal tract, vomiting etc [Wangner, 1993].

2.7 SOURCES OF AIR POLLUTION

Air pollution can be man-made or naturally occurring. Considering that, sources are classified in to two classes [Rahman, 2005]. They are:

- Biogenic or natural Sources
- Anthropogenic or man-made sources

Natural sources, also known as biogenic sources, are those generate pollutants naturally such as volcanoes, sea spray, lightning, forest fire, and transpiration from vegetation, windblown dust from desert, fields and agricultural land. Man-made or anthropogenic sources are the non-natural sources caused by human activities. These are classified considering the types human activities. Stationary and mobile sources are the two main classes. Point and area sources are the two different types of stationary sources. On-road and off-road sources are the two different types of mobile pollution sources.

However, from the types and activities of the sources they can also be classified into some general groups. From that consideration, the main sources of air pollution are:

- stationary and area sources
- mobile sources
- agricultural sources and
- natural sources.

2.7.1 Stationary and Area Sources

A stationary source of air pollution refers to an emission source that does not move (i.e., utilities, chemical and manufacturing industries). Often stationary sources are defined as large emitters who release relatively consistent qualities and quantities of pollutants. The term area source is used to describe the many smaller stationary sources located together whose individual emissions may be low but whose collective emissions can be significant. Typically area sources are those that emit less than 25 tons per year of any combination of hazardous air pollutants, or less than 10 tons per year of any single hazardous air pollutant.

2.7.2 Mobile Sources

A mobile source of air pollution refers to a source that is capable of moving under its own power. In general, mobile sources imply on-road transportation. In addition, there is also a non-road or off-road category that includes gas-powered lawn tools and mowers, farm and construction equipment, recreational vehicles, boats, planes, and trains.

2.7.3 Agricultural Sources

Agricultural operations, those that raise animals and grow crops, can generate emissions of gases, particulate matter, and chemical compounds. For example, animals confined to a barn or area (rather than field grazing), produce large amounts of manure. Manure emits various gases, particularly ammonia into the air. This ammonia can be emitted from the animal houses, manure storage areas, or from the land after the manure is applied. In crop production, the misapplication of fertilizers, herbicides, and pesticides can potentially result in aerial drift of these materials.

2.7.4 Natural Sources

Natural sources of air pollution are sources not caused by people or their activities. An erupting volcano emits particulate matter and gases; forest and prairie fires can emit large quantities of pollutants; plants and trees emit hydrocarbons; and dust storms can create large amounts of particulate matter. Wild animals in their natural habitat are also considered natural sources of pollution given that there is a certain amount of natural pollution, it is very important to control the "excess" pollution caused by man's activities.

2.8 SULFUR DIOXIDE IN URBAN ATMOSPHERE

Oxides of Sulfur, especially sulfur dioxide shows some different characteristics in the urban atmosphere than the rural atmosphere. Though it has been a subject of much study with respect to atmospheric chemistry, a general idea has been developed regarding the different behavior of sulfur dioxide in urban atmosphere. One of the problems that complicate the understanding of atmospheric sulfur dioxide processes is that reaction paths may be both homogeneous and heterogeneous. There are two processes of conversion of SO_2 to sulfate, namely

- Catalytic
- Photochemical

It is certainly an oversimplification to assume that SO_2 is oxidized by one or other of these two paths in any one circumstance. Nevertheless, under overcast, high humidity, and high particulate concentration in atmosphere it is likely that catalytic (heterogeneous) oxidation is the primary process for SO_2 conversion. In presence of sunlight, NO_x – hydrocarbon polluted atmosphere, it appears that the existence of a photochemical reaction path may be necessary to account for observed rates, particularly if the availability of particles containing catalysis and acid neutralizing compounds is insufficient to produce observed rates by the catalytic route. It is found that the average conversion of SO_2 to SO_4^{2-} at ground level in Dhaka was about 0.3% per hour, resulting in 7% conversion per day [Azad et al., 1998].

2.8.1 Catalytic Oxidation of SO_2

In clean air SO_2 is very slowly oxidized by homogeneous reactions. However, the rate of SO_2 oxidation in a power plant plume has been observed to be 10 to 100 times the clean air photo-oxidation rate [Gartrell et al., 1963]. Such a rapid rate of oxidation is similar to that expected of oxidation in solution in the presence of a catalyst. Sulfur dioxide dissolves readily in water droplets and can be rapidly oxidized to sulfuric acid by dissolved oxygen in the presence of metal salts, such as iron and manganese. The overall reaction can be expressed as

$$2SO_2 + 2H_2O + O_2 \xrightarrow{Catalyst} 2H_2SO_4$$

Catalysts for this reaction include several metal salts, such as sulfates and chlorides of manganese and iron, which usually exist in air as suspended particulate matter. At high

humidity these particles act as condensation nuclei or undergo hydration to become solution droplets. The oxidation process then proceeds by absorption of both SO_2 and O_2 by the liquid aerosol with subsequent chemical reaction in the liquid because of the decreased solubility of SO_2. However, if sufficient amount is present, the oxidation process is not impeded by the accumulation of H_2SO_4. Measurements of particulate compositions in urban air often show large concentrations of ammonium sulfate.
Oxidation mechanism of SO_2 is developed in terms of three different steps. The individual steps in the liquid-phase catalytic oxidation of SO_2 are:

- Gas phase diffusion of SO_2 to the drop
- Diffusion of SO_2 from the drop surface to the interior
- Catalytic reaction in the interior

At steady state conditions, the overall rate of SO_2 conversion is limited by the slowest of the above steps. If gas phase diffusion of SO_2 to the drop is the limiting step, then the rate of oxidation should depend on the gas velocity in the system. If liquid phase diffusion of SO_2 is the controlling step, then the conversion rate can be expected to be independent of the type of catalyst. Experimentally the chemical reaction was found to be the rate limiting step and that depends on the type of catalyst [Cheng et al., 1971].

Catalytic effectiveness is seen to follow the order $MnSO_4 > MnCl_2 > CuSO_4 > NaCl$ [Cheng et al., 1971]. Similar study was done by Matteson et al. (1969) with metal salt catalysts revealed catalytic effectiveness in the order $MnCl_2 > CuCl_2 > FeCl_2 > CoCl_2$. It was also found that the solubility of SO_2 decreased with the increase of the acidity of the solution. As H_2SO_4 dissociate completely in dilute solution, the H^+ concentration reduces the solubility of SO_2. Most data shows that the catalytic oxidation of SO_2 can be represented as a first order reaction based on the gas phase concentration of SO_2 with a rate constant dependent on the catalyst type and relative humidity [Cheng et al., 1971 and Matteson et al., 1969]. So in general, two conclusions can be drawn. First, catalytic oxidation of SO_2 is fostered in basic and neutral solutions and inhibited in acidic solution. Second, relative humidity plays an important role in the rate of oxidation.

2.8.2 Photochemical Oxidation of SO_2

In presence of air, SO_2 is slowly oxidized to SO_3 when exposed to solar radiation. If water is present, the SO_3 is rapidly converted to sulfuric acid. Since virtually no radiation of wavelength shorter than 2900 Å reaches the earth's surface, and since the dissociation of SO_2 into SO and O is possible only for wavelengths of absorbed light below 2180 Å, the primary photochemical processes following absorption by SO_2 in the lower atmosphere involve activated SO_2 molecules and not direct dissociation. Thus, the conversion of SO_2 to SO_3 in clean air is a result of several step reaction sequence involving excited SO_2 molecules, oxygen and oxides of sulfur other than SO_2 [Seinfeld, 1975]. In presence of reactive hydrocarbon and oxides of nitrogen the rate of conversion of SO_2 to SO_3 increases markedly. In addition, oxidation of SO_2 in systems of this type is frequently accompanied by considerable aerosol formation. The elucidation of the chemical reaction mechanism prevailing in irradiated systems of SO_2, hydrocarbons, NO_x, air and water is one of the most important current problems in air pollution chemistry.

Photochemical Oxidation of SO_2 in air: From the absorption spectrum of SO_2 shows two bands above 2900 Å and thus produce two different excited state of SO_2.

$$SO_2 + h\nu \Leftrightarrow {}^1SO_2 \qquad (2900 \text{ to } 3400 \text{ Å})$$
$$SO_2 + h\nu \Leftrightarrow {}^3SO_2 \qquad (3400 \text{ to } 4000 \text{ Å})$$

The more energetic ${}^1SO_2$ (singlet) decays either to ground-state SO_2 or to less energetic ${}^3SO_2$ (triplet) state by the following reactions:

$$\begin{aligned} {}^1SO_2 + M &\longrightarrow SO_2 + M \\ &\longrightarrow {}^3SO_2 + M \end{aligned}$$

It is found that, if not exclusive, chemical entity in the urban photochemistry of SO_2 is the triplet state ${}^3SO_2$ [Okuda et al., 1969]. Apparently the major role of the singlet species is the generation of the triplet molecule by the latter reaction. Then the excited SO_2 oxidizes into SO_3 in presence of oxygen. Gerhard and Johnstone (1955) studied the rate of photo-oxidation of SO_2 in air at concentration from 5 to 30 ppm SO_2. They found essentially a linear increase in H_2SO_4, corresponding to 0.1 to 0.2 percent conversion per hour of SO_2.

Photochemical Oxidation of SO_2 in mixtures of hydrocarbons, oxides of nitrogen and air: Once hydrocarbons and oxides of nitrogen are introduce into a mixture of SO_2 and air, the rate of SO_2 oxidation upon irradiation increases markedly over that observed in clean air. In contrast to that situation in an industrial fog containing metal ions, the existence of catalytic mechanism is unlikely in this case in spite of the fact that pronounced aerosol formation takes place in such systems. The reaction taking place in a system of SO_2, hydrocarbon, NO_x and air are probably the least well understood of all those in atmospheric chemistry. There potentially a number of paths for oxidation of SO_2 in such a system. The probable reaction paths are described elsewhere [Seinfeld, 1975]. SO_2 interacts strongly with many species present in photochemical smog. The most striking effect is the greatly enhanced tendency to form aerosol when SO_2 is present.

2.9 METEOROLOGICAL TERMS

The fate of atmospheric pollutants is affected by atmospheric flows or advection. This is controlled by the interaction between atmosphere and underlying earth surface. The atmospheric boundary layer is the layer of atmosphere that comes under the direct influence of the earth's surface. It contains the air we breathe and it is where we pour our pollutants. Dispersion of that pollutant and there movement always depend on some meteorological factors. Here some relevant meteorological terms are discussed in brief.

2.9.1 Soil temperature

The earth's surface reacts in a special way to the exchange of heat; it does not simply remain at a constant temperature. The cooling of the surface results in an upward flow of heat from the ground, down the temperature gradient. The largest temperature gradients occur within ±1 cm of the surface and may exceed 5°C per cm [Lyons, 1992]. Even over the ocean a temperature change of 0.5°C in the top millimeter of water may be realized because of evaporative cooling. Soil temperature plays an important role in many processes, which take place in the soil such as chemical reactions and biological interactions. Soil temperature varies in response to exchange processes that take place primarily through the soil surface. These effects are propagated into the soil profile by transport processes and are influenced by such things as the specific heat capacity, thermal conductivity and thermal diffusivity.

Soil temperature responds to changes in climate. Changes at great depth (10 m to 200 m) reflect decade-to-century scale climatic variability, because changes in surface conditions take years to propagate through the soil. Soil temperatures closer to the surface, measured by thermistors at about 1 meter depth, are reflective of changes on shorter time scales. The presence or absence of snow and the type and density of vegetation, as well as the composition of the soil itself, can affect the response of soil temperature to changing air temperature. Deep snow and dense vegetation, for example, insulate soil from changes in air temperature.

2.9.2 Solar radiation

Solar radiation is received by the earth's surface and transferred to the atmosphere in the form of sensible heat, latent heat and long-wave radiation. Solar radiation reaches the earth's surface either by being transmitted directly through the atmosphere (direct solar radiation), or by being scattered or reflected to the surface (diffuse sky radiation). About 50 percent of solar (or shortwave) radiation is reflected back into space, while the remaining shortwave radiation at the top of the atmosphere is absorbed by the earth's surface and re-radiated as thermal infrared (or longwave) radiation. The sun is the direct energy source but this transfer of heat from the solid earth and ocean is the second link of a chain process that drives the local and larger scale weather systems. On the local scale, the sea breeze is a direct consequence of the uplift resulting from preferred heating of the land and subsequent heating of the overlying air. On the larger scale, heat associated with water vapor, latent heat, is transferred to the air from the warm, moist ocean surface of the tropics [Lyons, 1992].

2.9.3 Temperature in the lower atmosphere

The layer of the atmosphere can be classified in a number of ways, such as by temperature, density, and chemical composition. From the standpoint of the dispersion of air pollutants, the most important classification is on the basis of temperature, on which the following layers can be identified [Seinfeld, 1986]:

Troposphere: The layer closest to the ground extending to an altitude of 15 km over the equator and 10 km over the poles. Temperature decreases with height at a rate of about 6.5°C per km. Vertical convection keeps the air relatively well mixed.

Stratosphere: It extends from the tropopause to about 50 km in altitude. Temperature is constant in the lower stratosphere and then increases with altitude owing to the absorption of short wave radiation by ozone. At the stratopause (the top of the stratosphere) the temperature reaches 270 K. There is little vertical mixing in the stratosphere.

Mesosphere: It extends from50 to 85 km, over which temperature decreases with altitude until it reaches 175 K, the coldest point in the atmosphere.

Thermosphere: It is the uppermost layer. Molecular densities are of the order of 10^{13} molecules cm^{-3}, as compared with 2.5×10^{19} at sea level.

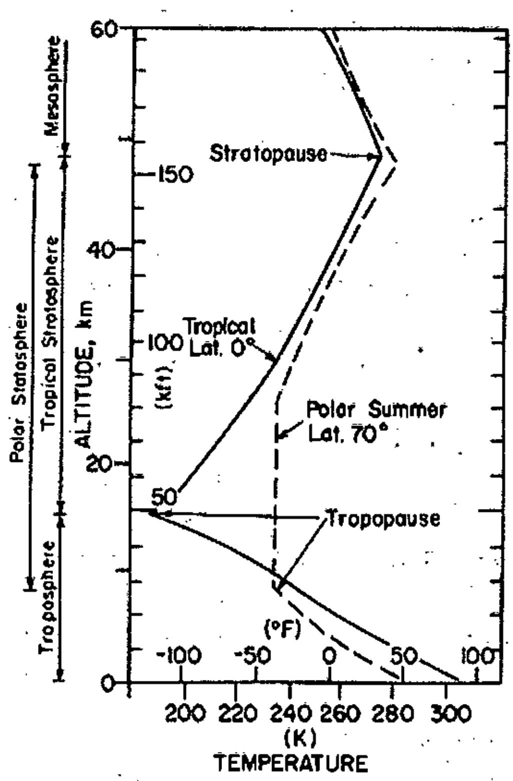


Figure 2.02: The variation of atmospheric Temperature with Altitude

2.9.4 Air Stability

The surface boundary layer of the atmosphere responds more quickly to temperature changes at the air-soil interface than does the soil. This is because the soil temperature changes primarily by conduction processes, i.e. the molecular motions of the molecules that determine the temperature are transmitted by simple direct coupling or molecular conduction [Lyons, 1992]. Adiabatic temperature change is an important factor in determining the stability of the air. We can think of air stability as the tendency for air to rise or fall through the atmosphere under its own "power". Stable air has a tendency to resist movement.

The stability of air in the atmosphere depends on the temperature of rising air relative to the temperature of the stationary surrounding air that it passes through, which varies from place to place and with changing atmospheric conditions. Air stability determines whether clouds form when air is uplifted, and the type of cloud. When a packet of air near the Earth's surface is heated it rises, being lighter than the surrounding air. Whether or not this air packet continues to rise will depend upon how the temperature in the surrounding air changes with altitude. The rising packet of air will lose heat because it expands as atmospheric pressure falls, and its temperature drops. If the temperature of the surrounding air does not fall as quickly with increasing altitude, the air packet will quickly become colder than the surrounding air, lose its buoyancy, and sink back to its original position. In this case the atmosphere is said to be stable. If the temperature of the surrounding air falls more quickly with increasing altitude, the packet of air will continue to rise. The atmosphere in this circumstance is said to be unstable.

As uplifted air cools, it condenses excess vapor out as cloud. The more unstable the atmosphere the more prolonged the uplift. Small cumulus clouds are evidence of a fairly stable atmosphere. Large cumulonimbus clouds are evidence of a highly unstable atmosphere, conducive to the formation of thunderstorms. Within depressions, atmospheric pressure is low and there is considerable atmospheric uplift and cooling at altitude, increasing atmospheric instability and this is usually associated with an abundance of cloud and precipitation. In high-pressure systems or anticyclones, air may be descending, compressing and gaining energy, such that temperature at altitude rises, thereby increasing atmospheric stability and this is often associated with cloudless skies.

2.9.5 Atmospheric Stability and Lapse Rate

The temperature-elevation relationship shown in the Figure 2.02 is the principal determinant of atmospheric stability. Four cases are possible with different elevation-temperature relationship as shown in Figure 2.03. On each of the elevation-temperature relationship, the adiabatic lapse rate, dT/dz = -5.4°F / 1000 ft, is shown as the dashed line whereas the actual lapse rate is shown as a solid line [Nevers, 2000].

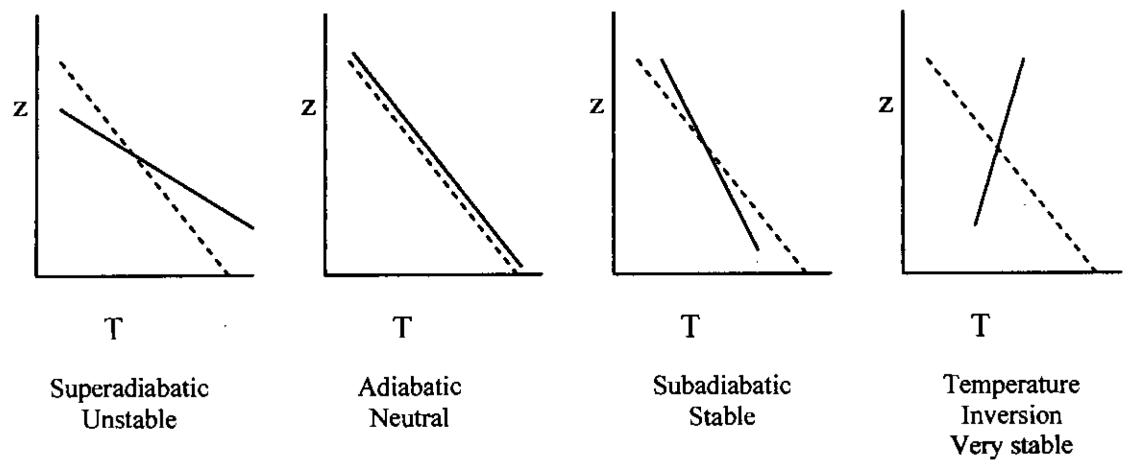


Figure 2.03: Relation between actual and adiabatic lapse rate and atmospheric stability

When the actual lapse rate is greater than the adiabatic lapse rate then it is superadiabatic situation. If an air parcel starts at some point where its temperature is same as that of the surrounding parcels and it moves upward along the adiabatic curve, it will be at a higher temperature than the surrounding parcels in its new location, so buoyancy will force it to continue to move upward. If, instead of moving upward, it is forced to move downward, then following the adiabatic path, its temperature will lower than that of surrounding parcels and negative buoyancy will cause it to move downward. This is the unstable situation.

When the actual lapse rate is the same as the adiabatic lapse rate, then that is the neutral stability condition. If a parcel is moved up or down and it follows adiabatic lapse rate, its temperature will be the same as that of the surrounding parcels in the location. Here buoyancy will move neither up nor down.

When the actual lapse rate is higher than the adiabatic lapse rate then it is called the subadiabatic condition. If an air parcel starts at some point where its temperature is same as that of the surrounding parcels and it moves upward along the adiabatic curve, it will be at a lower temperature than the surrounding parcels in its new location, so negative buoyancy will force it to move downward to the starting point. If, instead of moving upward, it is forced to move downward, then following the adiabatic path, its temperature will higher than that of surrounding parcels and buoyancy will cause it to move upward. This is the stable situation.

When the actual lapse rate has the opposite sign from the adiabatic lapse rate, then temperature increases with elevation. This is the temperature inversion condition. In this situation vertical movement is damped [Nevers, 2000].

2.9.6 Atmospheric Stability Classes

The states of the atmosphere, specifically weather were classified in 1950's by Pasquill and Gifford. Dispersion meteorologists frequently use the Pasquill-Gifford (PG) stability scheme to classify the amount of turbulence present in the atmosphere. The PG stability classes range from Unstable (Stability Classes A, B and C) through Neutral (Stability Class D) to Stable (Stability Classes E and F). Unstable conditions are primarily associated with daytime heating, which results in enhanced turbulence levels. Stable conditions are associated primarily with nighttime cooling, which results in suppressed turbulence levels. Neutral conditions are primarily associated with high wind speed conditions. The Pasquill-Gifford classification is listed in Table 2.02.

Table 2.02: Pasquill-Gifford stability Index

Pasquill-Gifford Stability Class	**Description**	**Surface wind speed and cloud cover Wind measured at 10m height in m/s**
A	Very unstable	Daytime; strong insulation and wind < 3 m/s or moderate insulation and wind < 2 m/s
B	Unstable	Daytime; strong insulation with wind between about 3 to 5 m/s or moderate insulation with wind between about 2 to 4 m/s or slight insulation and wind < 2 m/s
C	Slightly unstable	Daytime; strong insulation and wind > 5 m/s or moderate insulation with wind between about 4 to 5.5 m/s or slight insulation with wind between 2 to 5 m/s
D	Neutral	All overcast sky conditions, day or night; daytime and moderate insulation and wind > 5.5 m/s; daytime and slight insulation and wind > 5 m/s; nighttime and wind > 5 m/s; nighttime and more than 50% cloud cover or with thin overcast and wind > 3 m/s.
E	Slightly stable	Nighttime; thin overcast or > 50% cloud cover and wind < 3 m/s; < 50% cloud cover and wind between 3 to 5 m/s
F	Stable	Nighttime; < 50% cloud cover and wind < 3 m/s

2.9.7 Temperature inversion

Temperature inversion is the condition in which the temperature of the atmosphere increases with altitude in contrast to the normal decrease with altitude. When temperature inversion occurs, cold air underlies warmer air at higher altitudes. Usually, within the lower atmosphere (the troposphere) the air near the surface of the Earth is warmer than the air above it, largely because the atmosphere is heated from below as solar radiation warms the earth's surface, which in turn then warms the layer of the atmosphere directly above it. Under certain conditions, the normal vertical temperature gradient is inverted such that the air is colder near the surface of the Earth. This can occur when, for example, a warmer, less dense air mass moves over a cooler, denser air mass. This type of inversion occurs in the vicinity of warm fronts, and also in areas of oceanic upwelling. With sufficient humidity in the cooler layer, fog is typically present below the inversion cap. An inversion is also produced whenever radiation from the surface of the earth exceeds the amount of radiation received from the sun, which commonly occurs at night, or during the winter when the angle of the sun is very low in the sky. This effect is virtually confined to land regions as the ocean retains heat far longer. In the Polar Regions during winter inversions are nearly always present over land.

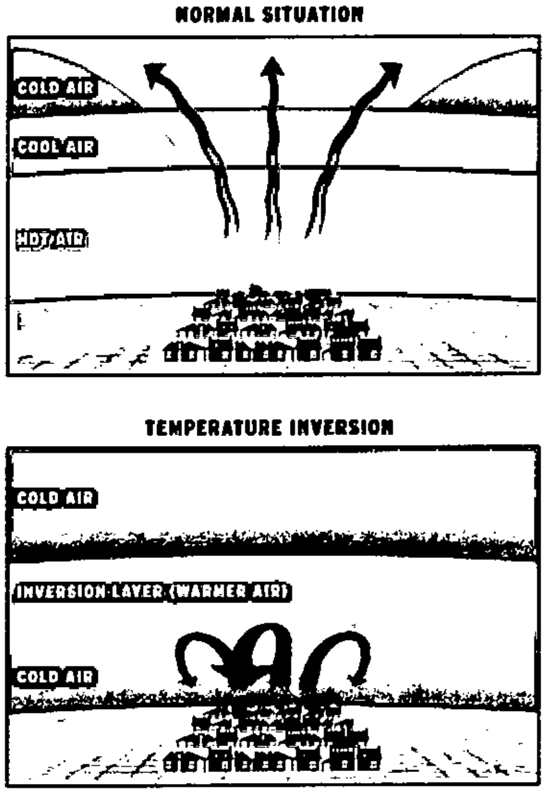


Figure 2.04: Pollutant movement during temperature inversion

Temperature inversion may occur during the passage of a cold front or result from the invasion of sea air by a cooler onshore breeze. A more long-lived temperature inversion accompanies the dynamics of the large high-pressure systems depicted on weather maps. Descending currents of air near the center of the high-pressure system produce a warming (by adiabatic compression), causing air at middle altitudes to become warmer than the surface air. Rising currents of cool air lose their buoyancy and are thereby inhibited from rising further when they reach the warmer, less dense air in the upper layers of a temperature inversion. During a temperature inversion, air pollution released into the atmosphere's lowest layer is trapped there and can be removed only by strong horizontal winds. Because high-pressure systems often combine temperature inversion conditions and low wind speeds, their long residency over an industrial area usually results in episodes of severe smog.

2.9.8 Wind Velocity

Wind is the roughly horizontal movement of air (as opposed to an air current) caused by uneven heating of the Earth's surface. It occurs at all scales, from local breezes generated by heating of land surfaces and lasting tens of minutes to global winds resulting from solar heating of the Earth. The two major influences on the atmospheric circulation are the differential heating between the equator and the poles, and the rotation of the planet (Coriolis effect). Given a difference in barometric pressure between two air masses, a wind will arise between the two which tends to flow from the area of high pressure to the area of low pressure until the two air masses are at the same pressure, although these flows will be modified by the Coriolis effect in the extratropics. The rate of the motion of the air on a unit of time is known as wind velocity. It can be measured in a number of ways. In observing, it is measured in knots, or nautical miles per hour. For air pollution consideration normal wind velocity is considered in meter per second or kilometer per hour.

Wind velocity increases with elevation, most of the time, in most of the troposphere. The reason is that ground friction slows the wind. Typically the wind will reach its frictionless velocity at about 500m above the ground [Nevers, 2000]. Inversion and stable atmospheres are normally associated with low ground level wind velocities.

2.9.9 Wind Direction

The direction from which the wind is blowing is known as wind direction. For example, an easterly wind is blowing from the east, not toward the east. It is reported with reference to true north, or 360 degrees on the compass, and expressed to the nearest 10 degrees, or to one of the 16 points of the compass (N, NE, WNW, etc.). General way of direction measurement and the scale is shown in the Figure 2.05.

Mountains, valleys, and shorelines all influence wind direction and magnitude as well as other meteorological parameters. On a clear night the ground is cooled by radiation to outer space, and a layer of air forms adjacent to it that is colder and hence denser than the air above it. If the ground is perfectly flat, the layer will be perfectly flat and the gravity would not tend to move it. However, if the ground is not flat, then the denser air would move to downhill. The steeper the hill, the faster it flows. During the day, opposite occurs. The heated ground level air moves upward due to buoyancy. Normally one side of the valley will be more strongly heated by sun than the other, so the air will begin to rise on that side causing a rotating flow with its axis along the axis of the valley. Mountains can also act as barriers to low level wind. Thus these factors may change the wind direction in different places [Nevers, 2000].

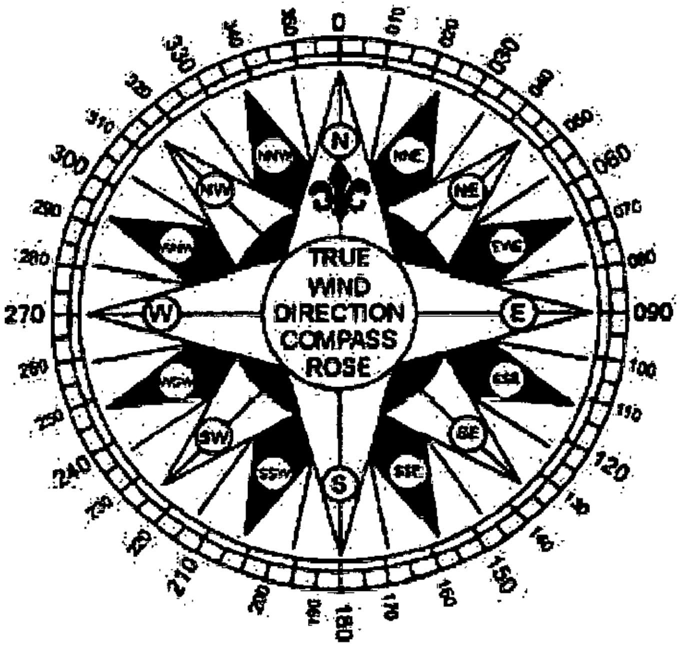


Figure 2.05: Wind direction scale

2.9.10 Wind Rose Diagram

Wind roses are the graphical representations of wind velocity and direction at certain area for certain time period. These summarize the frequency of winds of varying velocities and direction at one location.

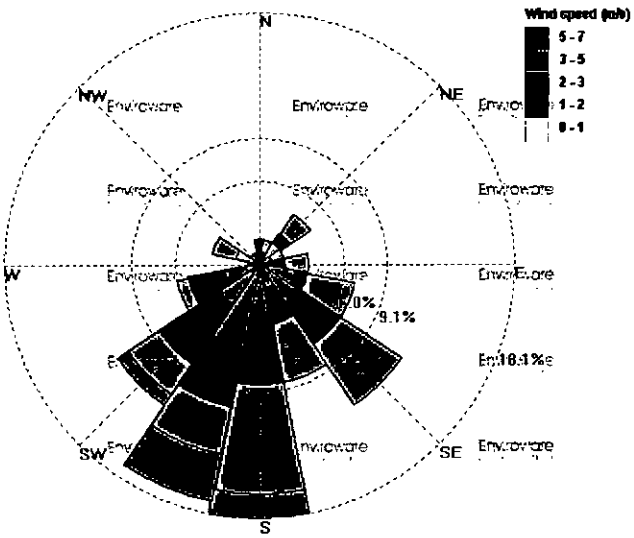


Figure 2.06: Typical wind rose diagram for February 2005 in Dhaka

In Figure 2.06 a wind rose diagram for February 2004 in Dhaka is shown. Here most of the time wind was blowing from North and northeast. The strongest wind was blown from northeast and maximum velocity was 7m/sec. Wind was blown from direct north for 18% of total time period. Thus from a single wind rose plot the whole wind profile and frequency can be interpreted easily.

2.9.11 Dry Deposition

Dry deposition may be broadly defined as the transport of particulate and gaseous contaminants from the atmosphere onto surfaces in the absence of precipitation. Therefore, dry deposition of gases and particles is an inter media transport process responsible for the removal of pollutants from the atmosphere. Dry deposition is affected by a multiplicity of factors that often interact in complex ways. The most important factors are the characteristics of the atmosphere, the nature of the surface, and properties of the depositing species. Transport of gases through the atmosphere depends on turbulent and molecular diffusion. In addition, solubility and chemical reactivity are also factors that affect the capture of gases by surfaces.

Dry deposition is affected by the following major factors:

- Meteorological variables (e.g., wind speed, temperature, terrain, atmospheric stability, and humidity).
- Surface variables (e.g., surface aerodynamic roughness and structure, pH, surface charge, hydrophobicity, porosity)
- Properties of the depositing material (e.g., chemical reactivity, solubility, diameter, surface charge, and shape).

The atmospheric turbulence plays an extreme important role in particular nearest the ground as it determines the rate at which a species is delivered down to the surface. The chemical composition and reactivity is for gases governing the reaction between gas and intercepting surface. Finally the nature and structure of the surface is involved by determining the rate of susceptibility from the atmosphere deposition of particles is strongly influenced by particle size. Transport of larger particles through the turbulent layer and to the surface can be enhanced by their inertia or by gravitational settling. Very small particles behave like gases and are transported through the turbulent layer by Brownian motion, whereas larger particles are either impacting or settling at the surface. Particles in the accumulation mode are long living in the atmosphere with removal no efficient removal mechanisms present.

2.9.12 Wet Deposition

The removal of atmospheric particles to the earth's surface by rain or snow is normally known as wet deposition. Wet deposition (precipitation scavenging) can increase the overall deposition rate of gaseous contaminant and thus lead to input of contaminants to the soil, water and vegetation media due to direct atmospheric deposition. Both rain and snow can remove contaminants from the atmosphere. Since wet deposition is an episodic process, the climatological conditions of the location in question must be considered when evaluating the relative importance of wet deposition as a process of removing contaminants from the atmosphere.

To remove a species from the atmosphere by wet deposition three steps are required

- The species must be near to water
- The species must be scavenged by a hydrometeor
- The species must be delivered together with the hydrometeor to Earth

All three steps are characterized by different reactions for a species, and one species might undergo during each step several different chemical reactions or transformations. To complicate the process even more almost all steps are reversible and can proceed in the backward direction as well. It is extremely difficult to describe and calculate the wet deposition process precisely since a great variety of parameter influences the process. Compared to dry deposition much more phases and phase transitions are involved and whole more reactions are possible. Additionally all process can happen inside a cloud, but also outside a cloud and one species might exist in various different phases with each phase having its characteristic parameters and reactions

2.9.13 Plume Rise

Plume rise is the distance above the top of the stack before leveling out. It is visible in the exhaust from the power plants, factories and smokestacks where it tends to rise then become horizontal. Plume rise buoyantly because they are hotter than the surrounding air and also because they exit the stack with a vertical velocity that carries them upward. They stop rising because, as they mix with the surrounding air, they lose velocity and cool by mixing. Finally they level off when they come to the same temperature as the atmosphere.

The most common formula to calculate plume rise is the Holland's formula for plume rise [Nevers, 2000]. It states,

$$\Delta h = \frac{V_s D}{u}\left(1.5 + 2.68\times10^{-3} PD\frac{(T_s - T_a)}{T_s}\right)$$

Where, Δh = plume rise in m

V_s = stack exit velocity in m/s

D = stack exit diameter in m

u = wind speed in m/s

P = pressure in millibars

T_s = stack exit temperature in K

T_a = atmospheric temperature in K

2.9.14 Monin-Obukhov Length

The Monin-Obukhov Length is the height over the ground, where mechanically produced (by vertical shear) turbulence is in balance with the dissipative effect of negative buoyancy, thus where Richardson number equals to 1. The Richardson number, named after Lewis Fry Richardson, is the dimensionless number that expresses the ratio of potential to kinetic energy. So mathematically Monin-Obukhov Length can be expressed by:

$$L = -\frac{\rho c_p T_{ref} (U^*)^3}{kgH}$$

Where: g = acceleration of gravity

C_p = Specific heat of air at constant temperature

ρ = density of air

k = 0.35; von Karman's constant (sometimes 0.4 is used)

U* = Friction velocity

T_{ref} = Ambient Temperature

The physical interpretation of the numerator is kinematic momentum flux in the vertical and the denominator is the vertical heat flux. Physically, L represents the height above which convectively driven turbulence dominates over mechanically driven turbulence. It generally varies from 1-200 m. L becomes smaller as the vertical heat flux becomes larger during the day. Hence L is indirectly a measure of the convective instability generated by the vertical heat flux through the surface layer. Thus, L is only meaningful in daytime convectively driven boundary layers, specifically within the surface layer.

2.9.15 Threshold Friction Velocity

Friction velocity is a very important term in some models of air-sea interaction. Since friction velocity is the square-root of the kinematic stress, these observations can easily be used to estimate the stress. Close to the surface, friction velocity is not a function of height. Furthermore, for modeling purposes, it is the near surface value that is of interest. Friction velocity can be calculated from the following equation:

$$U^* = U_z \left(\frac{k}{\ln \frac{Z}{Z_0}} \right)$$

Where:

	U^*	= Friction velocity (m/s)
	U_z	= Wind velocity at z meter height (m/s)
	Z	= Height where wind velocity is measured, 10m
	Z_0	= Surface Roughness (m)
	k	= 0.35; von Karman's constant (sometimes 0.4 is used)

For modeling purposes a threshold friction velocity is normally considered. The threshold friction velocity is an important parameter which is needed in the estimate of wind erosion from both "limited" and "unlimited" erosion potential sites. When the actual friction velocity at the site is greater than the threshold friction velocity wind erosion is to be expected. However, when the threshold friction velocity is equal to or greater than the actual friction velocity at the site then wind erosion will not occur.

In assessing the role of non-erodible elements on wind erosion it is useful to note that there are basically three mechanisms for particle erosion by wind. Particles in the size range of 0.5 mm - 1 mm are eroded by surface creep. These particles essentially roll along the ground. Thus, the presence of non-erodible elements and uneven terrain would significantly hinder this mode of wind erosion. Particles in the size range of 0.1 mm - 0.5 mm are eroded by a skipping action which is called saltation. Such particles rarely rise to a height greater than 1 meter above the ground surface. These particles extract wind energy and can disrupt the surface. Finally, particles smaller than 0.1 mm can be suspended by wind once they are airborne [Cowherd et al., 1988]. It is emphasized that wind erosion can take place only if the wind velocity exceeds the threshold wind velocity. Below the threshold wind velocity wind erosion cannot take place.

2.9.16 Surface Roughness

Surface roughness is one of the important parameters that can effect the pollutant movement in the atmosphere. It also related to threshold friction velocity. The more the surface roughness the more the friction velocity will be. It is normally expressed by Z_0 and it is the average surface roughness length in meters for the specified averaging period. It is also a vital parameter in air pollution modeling. Only one roughness length is supplied for each averaging period. Surface roughness lengths representative of several land-use types are given in Table 2.03 by season. Depending on the land-use type and climate, surface roughness may vary considerable by season, as shown for deciduous forests in Table 2.03.

Table 2.03: Surface roughness length in meters for land-use types and seasons [Shieh et al., 1979]

Land-Use Type	Spring	Summer	Autumn	Winter
Water Surface	0.0001	0.0001	0.0001	0.0001
Deciduous Forest	1.00	1.30	0.80	0.50
Coniferous Forest	1.30	1.30	1.30	1.30
Swamp	0.20	0.20	0.20	0.05
Cultivated Land	0.03	0.20	0.05	0.01
Grassland	0.05	0.10	0.01	0.001
Urban	1.00	1.00	1.00	1.00
Desert Shrubland	0.30	0.30	0.30	0.15

Where the definitions of Seasons are as follows:

Spring: Periods when vegetation is emerging or partially green. This is a transitional situation that applies for 1-2 months after the last killing frost in spring.

Summer: Periods when vegetation is lush and healthy, typical of mid-summer, but also of other seasons where frost is less common.

Autumn: Periods when freezing conditions are common, deciduous trees are leafless, crops are not yet planted or are already harvested (bare soil exposed) [EPA, 1995].

2.9.17 Mixing Height

The height to which relatively vigorous mixing of the atmosphere occurs is known as mixing height. In other words, it is the height to which atmospheric pollutants can be distributed by convective mixing in unstable conditions. Mixing Height or Mixing Depth is used by meteorologists to quantify the vertical height of mixing in the atmosphere. Forecasting of mixing height is done with the aid of the vertical temperature profile. A temperature increase with height is referred to as an inversion. The base of the temperature inversion may be at ground level or it may be elevated. In the case of an elevated mixing height, a two-layer atmosphere is created as shown in Figure 2.07. The lower layers tend to be well mixed and are characterized by unstable or neutral atmospheric conditions. The depth of this lower layer is referred to as the mixing height. The upper layer tends to be characterized by stable conditions. The vertical transfer of mass between these two layers is minimal.

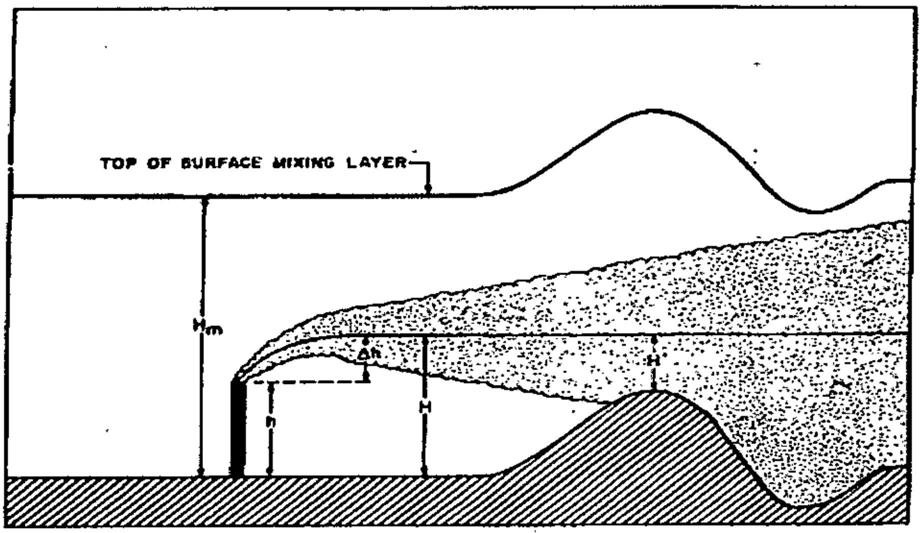


Figure 2.07: Mixing height (H_m) on a flat and elevated surface

For Stability Classes A to D, the mixing layer can be determined by mechanical interactions of the wind with surface features. The mixing layer depth is related to the wind speed by the following theoretical relationship [Benkley, 1979]:

$$Z_i = \frac{aU^*}{f}$$

where: Z_i = mechanical mixing layer height

a = constant = 0.185

U^* = friction velocity

f = Coriolis parameter = $2\Omega\sin\Phi$

Ω = 7.29×10^{-5} s^{-1}

Φ = latitude

$$U^* = \frac{0.35U_z}{\ln(Z/Z_0)}$$

where: U_Z = Wind speed at anemometer height Z

Z_0 = Surface roughness height

This equation is normally used to calculate the mixing height.

2.10 IMPACT OF AIR POLLUTION

Air pollution can be both natural and man-made, and occur both indoors and outside. Although natural emissions of air pollution may impact upon the environment from time to time, for example though a volcanic eruption, it is most often man-made air pollution which can lead to poor air quality on a more regular basis. The rates of increase of pollutant concentrations in the cities of developing countries are higher than those of developed countries [Kato et al., 1991].

Outdoors, common air pollutants which affect ambient air quality include sulphur dioxide, nitrogen oxides, carbon monoxide, particulate matter and volatile organic compounds (VOCs), emitted through the burning of fossil fuels for energy and transportation. Emission from poorly managed industries and power plants is one of the main sources of haze that envelopes the land during winter. The winter haze not only seriously compromises the health of millions, but can also drastically reduce crop yield. The presence of pollutants such as carbon monoxide, nitrogen oxides and hydrocarbons, leads to the formation of ozone close to the earth's surface. Unlike the stratospheric ozone, which protects the earth from harmful ultra violet rays, this ozone can enter the plants through their leaves and hamper photosynthesis, thereby reducing plant growth and crop yield [Jayan, 2006]. Ozone, a secondary pollutant, is formed in the atmosphere near ground level when primary pollutants are oxidized in the presence of sunlight. From studies over the Indo-Gangetic plains it was found that, ozone levels near the surface were between15-50 ppb in 1989-1990, but now range between 30-70 ppb. Besides, high levels of ozone now extended to almost the entire year (except January and February), whereas earlier high levels were restricted to about three months (March-May) [Jayan, 2006]. In addition, sulphur dioxide and nitrogen oxides may be converted into acids, and deposited as acid rain.

Apart from environmental damages, Air pollution has detrimental effects on human health, wildlife and vegetation. Asthma is an increasingly common respiratory disease which may be triggered by air pollution. Airborne particulate matter (PM) is associated with a number of health effects: increased mortality, increased emergency hospital admissions for cardio-pulmonary disease, increased frequency of chronic bronchitis, chronic obstructive pulmonary disease (COPD) and increased risk for lung cancer. Specifically for children a number of studies shows reduced lung function, asthma exacerbation, bronchitis and sinusitis due to PM exposure. Also increased infant mortality has been reported for areas with high levels of PM [EC, 2003]. From an analysis it has been predicted that due to urban agglomeration, population of Dhaka will be 22.766 million in 2015 [UNPD, 2001]. In an article published in *The Daily Star* (Bangladesh), it stated that air pollution is responsible for approximately 6000 deaths in Dhaka city each year and on average, each city dweller spends approximately US$12 per year on medical treatment for pollution related illness (Islam, 2003). The fraction of extremely small particles or ultra-fine fraction constitutes only a small fraction of the local mass. The ultra-fine particles penetrate deep into the lungs and may pass into the bloodstream [EC, 2003]. Ultra-fine particles may be involved in cardiovascular effects and have been found to be associated with mortality and asthma exacerbation in some studies, but more research is needed to quantify their health effects.

Indoors, poor ventilation can lead to a build-up of air pollutants, including carbon monoxide and nitrogen dioxide from faulty gas heaters and cookers, carbon monoxide and benzene from cigarette smoke, and volatile organic compounds (VOCs) from synthetic furnishings, vinyl flooring and paints. Like outdoor pollutants, indoor pollutants may also act as triggers for attacks of asthma. Since most of us spend up to 90% of the time indoors, indoor air quality could have a real bearing on our health.

2.11 AIR POLLUTION FROM BRICKFIELDS

Air pollution impact on environment is also same for Dhaka, Capital of Bangladesh. From the previous results it is found that Dhaka air quality is good for about 7 months of the air, April to October (monsoon period). Deterioration in this index starts from November and it continues up to march of each year [BAQ, 2004]. From different previous data it has been found that a large fraction (about 50%) of the $PM_{2.2-10}$ of mass at different sites Dhaka comes from soil dust and road dust rather than the pollution sources [BAQ, 2004]. From experimental data, in winter, motor vehicles and brick fields were found to be two major emission sources [Azad et al., 1998]. Besides vehicles and industries, Brickfields are now considered as a major source of pollution in Dhaka city. As brick is the main material for building construction in Dhaka, a lot of brick fields (which use coal as main fuel and operate only in winter due to meteorological condition) have grown up around Dhaka, especially in the northwest and southwest side of the city. These brick fields are one of the major contributors to the severe air pollution in winter in Dhaka. The adverse meteorological conditions in winter further aggravate the situation [Azad et al., 1998]. About 0.5 million ton of coal is imported from Meghalaya coal fields in India adjacent to the north-eastern border of Bangladesh. Import and use of this coal through convenient because of proximity (hence lower transport cost) contains about 4% sulfur. This imported coal is now mainly used in the brickfields [ADB, 2004]. Brickfields have some adverse effect on surrounding lands also. Studies have also shown that concentrations of essential nutrients like nitrogen, phosphorus and potassium are very low in the fields that have been used by the brick industry as the kilns use fertile topsoil. Areas that have been used by brick kilns also suffer from other problems such as drying of water wells, lower yields of crops, small landslides and poor visibility [Tuladhar et al., 2002].

In general, Air pollution due to brickfields is now major concerns in other developing countries also. A study of brick kiln pollutant by Clean Energy Nepal (CEN) found that the criteria air pollutants were three times higher during the brick kiln operating time than the off-season [Tuladhar et al., 2002]. From an emission inventory conducted under URBAIR program by The World Bank in rural areas and valleys in Nepal, it is found that Brick kilns contributed 31% of Total Suspended Particulates (TSP) and 28% of PM_{10} in that region [URBAIR, 1997]. Like other air pollutants, these pollutants also have health hazardous impact on local population. The particles are small enough to pass through nose and enter the respiratory system causing problems such as asthma and bronchitis. Survey over 100 children under age of five in these regions, 50.85% was found to have respiratory problems compared to 3.85% in the other regions [Tuladhar et al., 2002].

2.12 AIR QUALITY STANDARD

The national ambient Air Quality Standard of Bangladesh was adopted in 1997 which has currently been reviewed and amended by notification SRO 220-Law/2005 of July 19, 2005. Ambient air quality standard as per Environmental Conservation rule, 1997 and the amended version are shown in Table 2.04 and Table 2.05 respectively.

Table 2.04: Ambient Air Quality Standards for Bangladesh [ECR, 1997]

Category	Area	Concentration in $\mu g/m^3$			
		SPM	SO_2	NO_x	CO
A	Industrial and mixed	500	120	100	5000
B	Commercial and mixed	400	100	100	5000
C	Residential and rural	200	80	80	2000
D	Sensitive	100	30	30	1000

Table 2.05: Amended Ambient Air Quality Standards for Bangladesh [ECR, 2005]

Air Pollutant	Standard	Average Time
Carbon monoxide (CO)	$10\ mg/m^3$ (9 ppm) [a]	8-hour
	$40\ mg/m^3$ (35 ppm) [a]	1-hour
Lead (Pb)	$0.5\ \mu g/m^3$	Annual
Oxides of Nitrogen (NO_x)	$100\ \mu g/m^3$ (0.053 ppm)	Anuual
Suspended Particulate Matter (SPM)	$200\ \mu g/m^3$	8-hour
PM_{10}	$50\ \mu g/m^3$ [b]	Annual
	$150\ \mu g/m^3$ [c]	24-hour
$PM_{2.5}$	$15\ \mu g/m^3$	Annual
	$65\ \mu g/m^3$	24-hour
Ozone (O_3)	$235\ \mu g/m^3$ (0.12 ppm) [d]	1-hour
	$157\ \mu g/m^3$ (0.08 ppm)	8-hour
Sulfur dioxide (SO_2)	$80\ \mu g/m^3$ (0.03 ppm)	Annual
	$365\ \mu g/m^3$ (0.14 ppm) [a]	24-hour

[a] Not to be exceeded more than once per year

[b] Annual average value will be less than or equal to $50\ \mu g/m^3$

[c] Average value of 24 hours will be less than or equal to $150\ \mu g/m^3$ for one day each year

[d] Maximum average value for every one hour each year will be equal or less than 0.12 ppm

The Clean Air Act, which was last amended in 1990, requires EPA to set **National Ambient Air Quality Standards** for pollutants considered harmful to public health and the environment. The Clean Air Act established two types of national air quality standards. *Primary standards* set limits to protect public health, including the health of "sensitive" populations such as asthmatics, children, and the elderly. *Secondary* *standards* set limits to protect public welfare, including protection against decreased visibility, damage to animals, crops, vegetation, and buildings. The EPA Office of Air Quality Planning and Standards (OAQPS) has set National Ambient Air Quality Standards for six principal pollutants, which are called "criteria" pollutants. They are listed below in Table 2.06. Units of measure for the standards are parts per million (ppm) by volume, milligrams per cubic meter of air (mg/m^3), and micrograms per cubic meter of air ($\mu g/m^3$).

Table 2.06: National Ambient Air Quality Standards set by EPA

Pollutant	Primary Stds.	Averaging Times	Secondary Stds.
Carbon Monoxide	9 ppm (10 mg/m^3)	8-hour[1]	None
	35 ppm (40 mg/m^3)	1-hour[1]	None
Lead	1.5 $\mu g/m^3$	Quarterly Average	Same as Primary
Nitrogen Dioxide	0.053 ppm (100 $\mu g/m^3$)	Annual (Arithmetic Mean)	Same as Primary
Particulate Matter (PM_{10})	Revoked[2]	Annual[2] (Arith. Mean)	
	150 $\mu g/m^3$	24-hour[3]	
Particulate Matter ($PM_{2.5}$)	15 $\mu g/m^3$	Annual[4] (Arith. Mean)	
	65 $\mu g/m^3$	24-hour[5]	
Ozone	0.08 ppm	8-hour[6]	Same as Primary
	0.12 ppm	1-hour (Applies only in limited areas)	Same as Primary
Sulfur Oxides	0.03 ppm	Annual (Arith. Mean)	-------
	0.14 ppm	24-hour[1]	-------
	-------	3-hour[1]	0.5 ppm (1300 $\mu g/m^3$)

(1) Not to be exceeded more than once per year.

(2) Due to a lack of evidence linking health problems to long-term exposure to coarse particle pollution, the agency revoked the annual PM_{10} standard in 2006 (effective December 17, 2006).

(3) Not to be exceeded more than once per year on average over 3 years.

(4) To attain this standard, the 3-year average of the weighted annual mean $PM_{2.5}$ concentrations from single or multiple community-oriented monitors must not exceed 15.0 $\mu g/m^3$.

(5) To attain this standard, the 3-year average of the 98th percentile of 24-hour concentrations at each population-oriented monitor within an area must not exceed 35 $\mu g/m^3$ (effective December 17, 2006).

(6) To attain this standard, the 3-year average of the fourth-highest daily maximum 8-hour average ozone concentrations measured at each monitor within an area over each year must not exceed 0.08 ppm.

2.13 AIR QUALITY MODELS

Air quality models use mathematical and numerical techniques to simulate the physical and chemical processes that affect air pollutants as they disperse and react in the atmosphere. Based on inputs of meteorological data and source information like emission rates and stack height, these models are designed to characterize primary pollutants that are emitted directly into the atmosphere and, in some cases, secondary pollutants that are formed as a result of complex chemical reactions within the atmosphere. These models are important to our air quality management system because they are widely used by agencies tasked with controlling air pollution to both identify source contributions to air quality problems and assist in the design of effective strategies to reduce harmful air pollutants. For example, air quality models can be used during the permitting process to verify that a new source will not exceed ambient air quality standards or, if necessary, determine appropriate additional control requirements. In addition, air quality models can also be used to predict future pollutant concentrations from multiple sources after the implementation of a new regulatory program, in order to estimate the effectiveness of the program in reducing harmful exposures to humans and the environment. Air quality models can be classified with respect to their physical principles or their applicability. Considering physical principles, Box model, Dispersion model, Multiple-cell model and Receptor model are the major classification [Nevers, 2000]. In general, the most commonly used air quality models include the following:

2.13.1 Dispersion Modeling

These models are typically used in the permitting process to estimate the concentration of pollutants at specified ground-level receptors surrounding an emissions source. Dispersion modeling uses mathematical formulations to characterize the atmospheric processes that disperse a pollutant emitted by a source. Based on emissions and meteorological inputs, a dispersion model can be used to predict concentrations at selected downwind receptor locations. These air quality models are used to determine compliance with National Ambient Air Quality Standards (NAAQS), and other regulatory requirements such as New Source Review (NSR) and Prevention of Significant Deterioration (PSD) regulations. The most commonly used model for regulatory purposes is the so-called Gaussian steady-state model. It provides a steady-state solution to the transport and diffusion equations (transport plus diffusion = dispersion). Steady-state implies that the basic assumption is a constant emission and constant meteorological conditions. Here for the modeling this type of model is considered. Basic idea of the Gaussian dispersion model is discussed in detail in Chapter 3.

Within the last ten to fifteen years, two Gaussian dispersion models, SCREEN3 and the Industrial Source Complex (ISC3) model have become the most common modeling tools. SCREEN3 is a conservative screening model. EPA recommends using a screening model as an over predictive first modeling cut. Users can provide site-specific source information with model-provided meteorological parameters to predict maximum one-hour average concentrations in a single direction from a single source. Air concentrations for other averaging periods (e.g., eight hours, twenty-four hours) can be estimated using meteorological persistence factors. ISC3 is a "refined" model that can be used if SCREEN3 results indicate air quality impacts greater than regulatory thresholds. Multiple source and receptor networks with site-specific hourly input meteorological data are possible in ISC3. ISC3 generally provides greater modeling flexibility and lower air concentration estimates than SCREEN3. In turn, the more extensive data input requirements of ISC3 mean more effort is required to complete a dispersion modeling study [EPA, 2007].

2.13.1.1 The Gaussian steady-state dispersion model

The most commonly used model for regulatory purposes is the so-called Gaussian steady-state model. It provides a steady-state solution to the transport and diffusion equations (transport plus diffusion = dispersion). Steady-state implies that the basic assumption is a constant emission and constant meteorological conditions.

The basic Gaussian diffusion equation assumes [ESS, 2002]:

- that atmospheric stability and all other meteorological parameters are uniform and constant throughout the layer into which the pollutants is discharged, and in particular that wind speed and direction are uniform and constant in the domain;
- that turbulent diffusion is a random activity and therefore the dilution of the pollutant can be described in both horizontal and vertical directions by the Gaussian or normal distribution;
- that the pollutant is released at a height above the ground that is given by the physical stack height and the rise of the plume due to its momentum and buoyancy (together forming the effective stack height);

- that the degree of dilution is inversely proportional to the wind speed;
- that pollutant material reaching the ground level is reflected back into the atmosphere;
- that the pollutant is conservative, i.e., not undergoing any chemical reactions, transformation or decay.

The spatial dynamics of pollution dispersion is described by the following type of equation in a Gaussian model:

$$C(x,y,z)=\frac{Q}{2\pi u\sigma_y\sigma_z}\exp\left(-\frac{y^2}{2\sigma_y^2}\right)\left[\exp\left(-\frac{(z-H_{eff})^2}{2\sigma_z^2}\right)+\exp\left(-\frac{(z+H_{eff})^2}{2\sigma_z^2}\right)\right]$$

where C(x, y, z) : pollutant concentration at point (x, y, z);

u : wind speed (in the *x* "downwind" direction, m/s)

σ : standard deviation of the concentration in the y and z direction, in meters;

Q : emission strength (g/s)

H_{eff} : effective stack height

From the above equation one can deduce, in steady state, the concentration in any point (x, y, z) in the model domain, from a constant emission rate. The effective stack height (physical stack height plus plume rise) can be computed using standard equations [ESS, 2002].

2.13.2 Photochemical Modeling

These models are typically used in regulatory or policy assessments to simulate the impacts from all sources by estimating pollutant concentrations and deposition of both inert and chemically reactive pollutants over large spatial scales. Photochemical air quality models have become widely recognized and routinely utilized tools for regulatory analysis and attainment demonstrations by assessing the effectiveness of control strategies. These photochemical models are large-scale air quality models that simulate the changes of pollutant concentrations in the atmosphere using a set of mathematical equations characterizing the chemical and physical processes in the atmosphere. These models are applied at multiple spatial scales from local, regional, national, and global.

There are two types of photochemical air quality models commonly used in air quality assessments: the Lagrangian trajectory model that employs a moving frame of reference, and the Eulerian grid model that uses a fixed coordinate system with respect to the ground. Earlier generation modeling efforts often adopted the Lagrangian approach to simulate the pollutants formation because of its computational simplicity. The disadvantage of Lagrangian approach, however, is that the physical processes it can describe are somewhat incomplete. Most of the current operational photochemical air quality models have adopted the three-dimensional Eulerian grid modeling mainly because of its ability to better and more fully characterize physical processes in the atmosphere and predict the species concentrations throughout the entire model domain. Several photochemical air quality models are listed as follows [EPA, 2007]:

Community Multi-scale Air Quality (CMAQ) - EPA's CMAQ modeling system is supported by the Community Modeling and Analysis System (CMAS) Center. The CMAQ model includes state-of-the-science capabilities for conducting urban to regional scale simulations of multiple air quality issues, including tropospheric ozone, fine particles, toxics, acid deposition, and visibility degradation.

Comprehensive Air quality Model with extensions (CAMx) - The CAMx model simulates air quality over many geographic scales. The model treats a wide variety of inert and chemically active pollutants, including ozone, particulate matter, inorganic and organic PM2.5/PM10, and mercury and other toxics. CAMx also has plume-in-grid and source apportionment capabilities.

Regional Modeling System for Aerosols and Deposition (REMSAD) - REMSAD was designed to calculate the concentrations of both inert and chemically reactive pollutants by simulating the physical and chemical processes in the atmosphere that affect pollutant concentrations over regional scales. It includes those processes relevant to regional haze, particulate matter and other airborne pollutants, including soluble acidic components and mercury.

Urban Airshed Model Variable Grid (UAM-V ®) - The UAM-V Photochemical Modeling System was a pioneering effort in photochemical air quality modeling in the early 1970s and has been used widely for air quality studies focusing on ozone. It is a three-dimensional photochemical grid model designed to calculate the concentrations of both inert and chemically reactive pollutants by simulating the physical and chemical processes in the atmosphere that affect pollutant concentrations. This model is typically applied to model air quality "episodes" - periods during which adverse meteorological conditions result in elevated ozone pollutant concentrations.

2.13.3 Receptor Modeling

These models are observational techniques which use the chemical and physical characteristics of gases and particles measured at source and receptor to both identify the presence of and to quantify source contributions to receptor concentrations. Receptor models are mathematical or statistical procedures for identifying and quantifying the sources of air pollutants at a receptor location. Unlike photochemical and dispersion air quality models, receptor models do not use pollutant emissions, meteorological data and chemical transformation mechanisms to estimate the contribution of sources to receptor concentrations. Instead, receptor models use the chemical and physical characteristics of gases and particles measured at source and receptor to both identify the presence of and to quantify source contributions to receptor concentrations. These models are therefore a natural complement to other air quality models and are used as part of State Implementation Plans (SIPs) for identifying sources contributing to air quality problems. The EPA has developed the Chemical Mass Balance (CMB) and UNMIX models as well as the Positive Matrix Factorization (PMF) method for use in air quality management. CMB fully apportions receptor concentrations to chemically distinct source-types depending upon the source profile database, while UNMIX and PMF internally generate source profiles from the ambient data.

Chemical Mass Balance (CMB) - The EPA-CMB Version 8.2 uses source profiles and speciated ambient data to quantify source contributions. Contributions are quantified from chemically distinct source-types rather than from individual emitters. Sources with similar chemical and physical properties cannot be distinguished from each other by CMB.

UNMIX - The EPA UNMIX model "unmixes" the concentrations of chemical species measured in the ambient air to identify the contributing sources. Chemical profiles of the sources are not required, but instead are generated internally from the ambient data by UNMIX, using a mathematical formulation based on a form of factor analysis. For a given selection of species, UNMIX estimates the number of sources, the source compositions, and source contributions to each sample.

Positive Matrix Factorization (PMF) - The PMF technique is a form of factor analysis where the underlying co-variability of many variables (e.g., sample to sample variation in PM species) is described by a smaller set of factors (e.g., PM sources) to which the original variables are related. The structure of PMF permits maximum use of available data and better treatment of missing and below-detection-limit values [EPA, 2007].

2.14 EARLIER MODELING WORKS

Many previous studies have been reported in the field of air quality models, such as Gaussian plume model, urban air shed model, box model and other trajectory and meso-scale models. Islam (1999) used a dispersion model to determine the location of an unknown emission source; Owen et al. (2000) calculated the concentrations of NO_x for a summer and winter period in London by using an urban scale Gaussian dispersion model (ADMS-Urban); Hao et al. (2001) applied the Industrial Source Complex Short Term (ISCST-3) model to facilitate the study of emission source contributions to ambient concentrations of CO and NO_x in Beijing; Kuhlwein et al. (2002) developed a Gaussian multi-source model to calculate pollutant concentrations in the Augsburg area of southern Germany; Krishna et al. (2004) applied the ISCST-3 model to examine the assimilative capacity and the dispersion of pollutants in the summer and winter seasons due to industrial sources in the Visakhapatnam bowl area of India. Manju *et al.* (2002) investigated the assimilative capacity of SO_2, NO_x and TSP in Manali of India for the four seasons by applying the industrial source complex short term (ISCST-3) model. In terms of urban airshed models, Winner and Cass (1999) evaluated the relationship between pollutant emissions and the long-term frequency distribution of O_3 concentrations in Southern California using a photochemical airshed model; Chang and Cardelino (2000) applied an Eulerian 3-D photochemical-transport grid model for generating next-day peak ozone concentration forecasts in Atlanta of USA; Baertsch-Ritter *et al.* (2003) applied the 3-D photochemical Urban Airshed Model with variable grid (UAM-V) to investigate the temporal and spatial dynamics of the photo-oxidant production in the highly polluted Milan area of Italy; Oanh and Zhang (2004) applied the integrated variable-grid urban airshed model/systems applications international meso-scale model (UAM-V/SAIMM), to investigate photochemical pollution in the Bangkok Metropolitan Region of Thailand.

In terms of box models, Jin and Demerjian (1993) developed a photochemical box model (PBM) based on the principle of mass conservation to calculate pollutant concentration due to horizontal advection, vertical entrainment, source emissions and chemical reactions, while the model had a horizontal domain of the city size and a vertical dimension defined by the mixed-layer height; Middleton (1998) forecasted the concentrations of NO_2 in urban areas by developing a box model called Boxurb which can use synoptic observations of the meteorology and numerical forecasts of wind and cloud; Jorquera (2002a, b) applied a box model to estimate the contributions of different economic activities to the air pollutant concentrations of CO, NO_x, SO_2, $PM_{2.5}$

and PM_{10} in Santiago of Chile, while the model explicitly included the seasonal behavior of meteorological variables and considered various processes such as emission, advection, dry and wet deposition, and chemical transformation within the atmospheric mixing height; Aumont *et al.* (2003) applied a two-layer box model to examine the contribution of nitrous acid (HONO) photolysis to the primary production of OH radicals and the impact of HONO sources to the O_3 and NO_x budgets, while three sources of HONO were considered including direct emissions, heterogeneous production on the ground surface and heterogeneous production on the aerosol surface; Lin *et al.* (2004) proposed a Lagrangian box model to locate the influential pollution sources and estimate their contributions to pollutant concentrations observed at a receptor site in southern Taiwan by taking into account the effects of source emissions, atmospheric dilution, and chemical transformation and deposition; Meszaros *et al.* (2004) examined the European carbon monoxide (CO) budget with the help of a box-model which allows the assessment of atmospheric CO concentration change caused by the CO emission and chemical production in Europe; Shon *et al.* (2005) employed a photochemical box model (PCBM) to estimate reactive gaseous mercury (RGM) concentrations in the urban atmospheric boundary layer (ABL) of Seoul in Korea, while the model used a mass balance approach to calculate the pollutant concentrations by considering various processes such as the emission flux into the ABL, chemical reactions and dry deposition, and mass transfer between gas and aqueous phases. Qin and Oduyemi (2003) combined a receptor model and an atmospheric dispersion model to identify aerosol sources and estimate source contributions to air pollution in Dundee of UK. Other related air quality models may include trajectory model (Sturman and Zawar- Reza, 2002), and meso-scale model (Chandrasekar *et al.*, 2003).

Generally, the Gaussian plume models neglected the chemical interactions and physical removal mechanisms in the atmosphere, and their application was often limited to point sources. For air quality prediction in an urban area, the use of Gaussian models may result in relatively low prediction accuracy due to complexities of source and environmental conditions (Cheng, 2000). The airshed and meso-scale models were developed based on detailed analyses of complicated interrelationships among a number of factors that affect ambient air quality. However, their applicability is often affected by limitations in data availability/quality and the costly processes of meteorological survey as well as the high computational requirements for model calibration (Lashmar and Cope, 1995). The box models were considered to be easier to implement, with relatively low requirements for meteorological data and computational efforts (Middleton, 1998). Such models have difficulties in effectively simulating the effects of point source emissions especially when the emission stacks are high, but they can more effectively simulate urban air quality due to area emission sources.

CHAPTER 3

EXPERIMENTAL AND MODELING WORK

3.1 DESCRIPTION OF THE EXPERIMENTAL WORKS

This thesis work was mainly based on ambient air quality modeling near the brickfields in Bangladesh. As air quality modeling is a new concept in Bangladesh, it was intended to introduce an effective air pollution model to measure the pollution impacts from brick kiln. This work was divided into two major parts. Verification of the applicability of this model in Bangladesh especially for brickfield pollution was the main concern. Then different applications of that model were exercised to predict ambient air pollution loads under different circumstances. Industrial Source Complex or ISC3 model was considered for the modeling purpose for this work. It was an EPA recommended air quality modeling software. Ground level concentrations of several pollutants were measured experimentally using different suitable equipments. These were also calculated using the ISC3 model. From the comparison of the experimental data and model generated data, performance of the air quality modeling software was ensured. In this thesis work, both gaseous pollutants and Total Suspended Particulates (TSP) from brick kilns were considered.

The second part of the work was to utilize the established model to perform some impact analysis. This impact analysis can be used for regulatory purposes in determining the environmental impacts from any proposed project having source of pollution. Ground level concentrations at different points were measured using this model and from those modeled data, the worst region at the surroundings of brickfields was determined. This was done for different meteorological conditions. From the brick kiln point of view, height of the brick kiln stack is a vital variable which determines the ground level concentration caused by pollutants from that stack. So an analysis was done to determine the impact of the brick kiln stack height on the ground level concentration of pollutants. Starting from 5 meter height, ground level concentrations were determined for up to 38 meter stack height with 5 meter interval. As minimum 120 feet stack height is now promulgated by government rule, impact after that modification is also found my modeling with that stack height. The impact of the stack exit gas velocity was also analyzed with help of that model.

3.2 SITE SELECTION

For this thesis work a specific site near Dhaka was selected for observation. A cluster of brick fields having 41 brick kilns near Aminbazar bridge, was the site for observation. There are too many brickfields situated along the northern side of Dhaka and those have major impact on Dhaka city air quality compared to other brick kilns. As the wind direction in dry season is from north to south, observation site was selected in the northern side of Dhaka. All 41 stacks of this cluster had an average 125ft stack height and similar operating condition. Sampling site is shown on a map and in a satellite image in Figures 3.01 and 3.02 respectively.

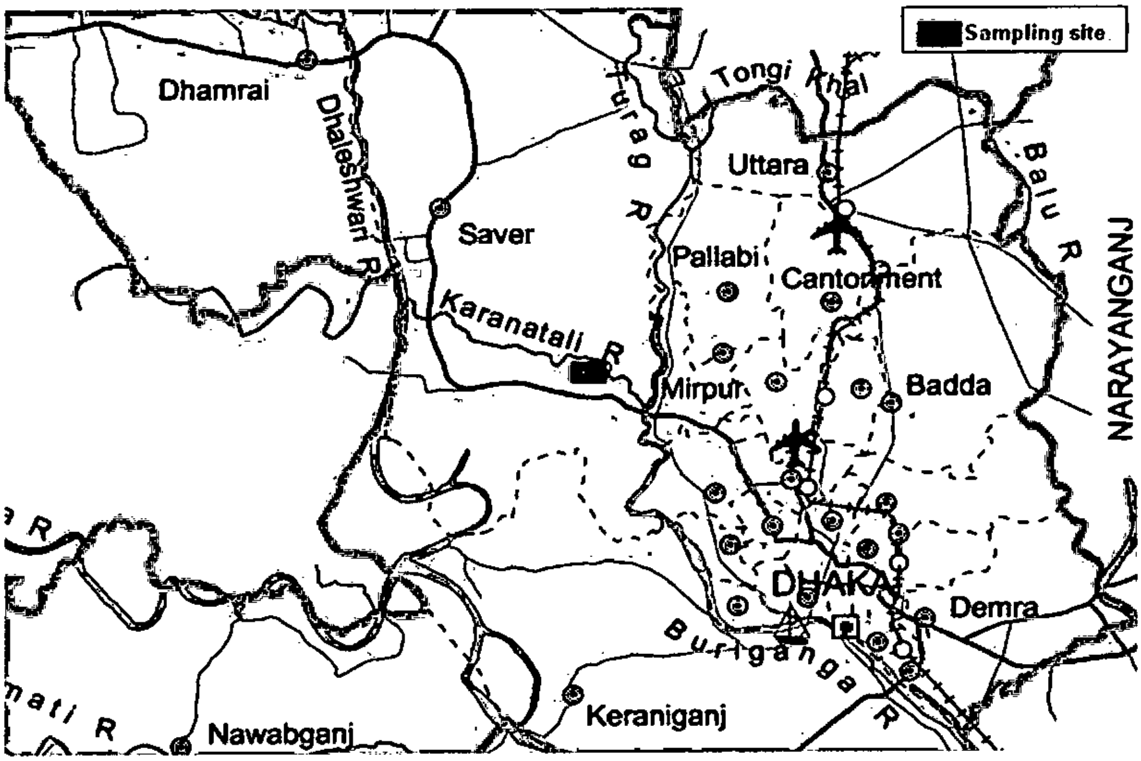


Figure 3.01: Location of the sampling site on the northern Dhaka map

Total cluster area was considered of equal elevation and ground level concentrations of pollutant were measured in two different points within the observation area. Sampling point 1 was near the edge of the cluster and sampling point 2 was at the centre of the cluster. Multiple sets of data were collected at those points on different days. These data include ambient concentration of Total Suspended Particulates (TSP), Sulfur dioxide (SO_2), Carbon monoxide (CO) and Hydrocarbons. Sampling points and the brick kilns in the observation site are shown later in Figure 3.10.

Figure 3.02: Satellite image of the cluster of brick kilns of the sampling site

3.3 TSP SAMPLING

Total Suspended Particulates (TSP) was measured at the sampling sites by using a high volume sampler. It was a most commonly used high volume sampler available at the Environmental Laboratory of Chemical Engineering Department, BUET. Total Suspended Particulates (TSP) of the ambient air at the sampling site was measured in microgram/m^3 from the air flow rate and cumulative particle accumulation data.

3.3.1 TSP sampling experimental setup

A high volume sampler machine was used to collect Total Suspended Particulates (TSP) in the atmosphere. That was a portable High volume sampler (Model No.: APM 415, Envirotech, India). A schematic diagram of the sampler system is shown in Figure 3.03. Since it was for total particulate matter it includes both PM_{10} and $PM_{2.5}$ of the ambient air. As shown in the pictures of the Figure 3.04, the sampler has it suction section at the top where a filter paper is placed in a filter holder. A pre-weighed and preconditioned EPM 200 (8"×10") glass microfibre filter paper is placed on the netted flat surface which gives support to the paper. The filter paper is fastened by a face plate and tightened by the wing nuts. The filter paper is attached by four nuts with the filter paper holder. It has a gable roof on the filter holder that protects the filter paper and the main housing from

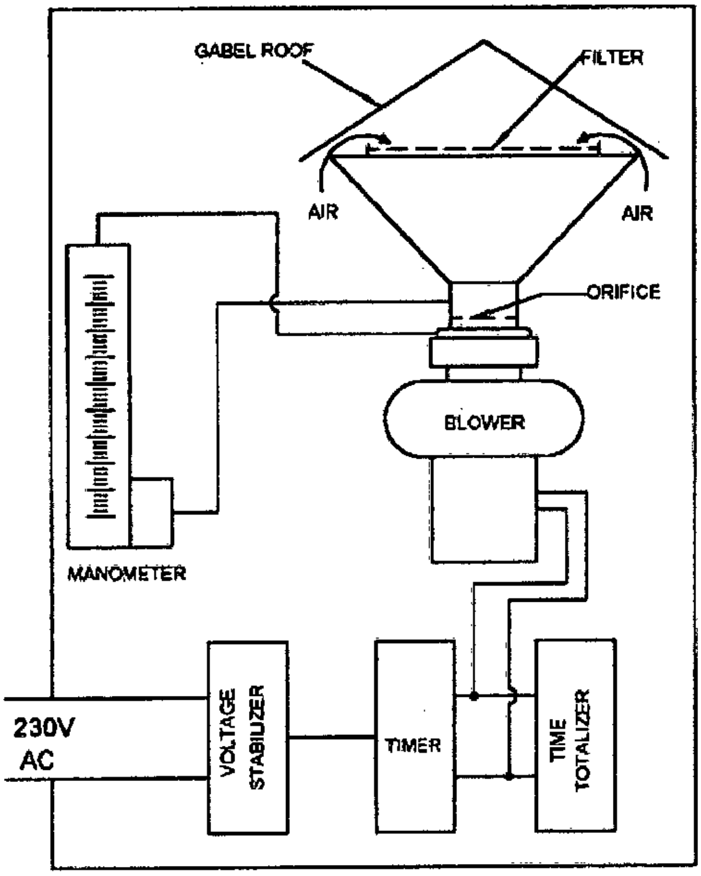
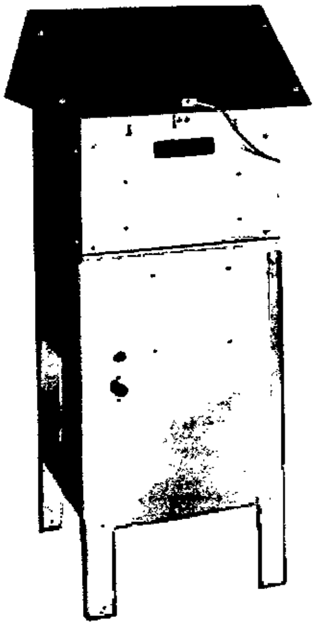


Figure 3.03: Schematic diagram of the Envirotech APM-415 High Volume Sampler



(a)

(b)

Figure 3.04: (a) High Volume Sampler used for sampling; (b) Inside of a High volume sampler

precipitation and other weather. The ambient air is sucked by a blower inside the sampler. It is attached with a timer which shows the running time of the sampler. An orifice plate placed between filter holder and the blower is used to measure pressure drop to calculate the air flow rate. There is a differential water manometer connected across that orifice plate for flow rate measurement. It is scaled from zero flow to 8 m^3/min flow rate. In general it was operated in the 1.0–1.3 m^3/min flow range. The sampler rating is 220 Volt and 2 Amps single phase and it was powered by a portable AC source. As there is no power source in the brickfield, for uninterrupted power supply a gasoline generator was used. When the blower starts, it sucks the ambient air through the filter paper and releases it again. However, in the meantime all the particulate matters are captured in the filter paper.

3.3.2 Working principle of high Volume sampler

All types of high volume samplers for Total Suspended Particulates (TSP) generally work under similar principle. A blower is used to suck the ambient air through the filter paper. When the machine operates blower mounted below the orifice plate sucks the ambient air. The air enters the assembly at the top of the sampler where the filter paper is placed. As there is no leak or any other inlet in the machine, so all the air sucked by the pump must pass through the filter. Air then goes to the bottom and moves toward the outlet. During the process all the suspended particulate materials are trapped in the filter paper. There is a manometer which gives the direct reading of air flow rate. It is a differential water manometer which accurately measures the pressure drop across the orifice plate built into the filter adaptor casting. The orifice has the simple principle. It measures the drop in air pressure across it because of sudden contraction in flow path. The pressure difference shifts the water level of the manometer accordingly. The scale was calibrated for air flow rate against the pressure drop. So when high volume sampler works it gives the flow rate in m^3/min from the pressure drop of air.

3.3.3 Preparation and procedure of TSP sampling

There are certain stages to be followed before the particulate matter sampling. The most important is the conditioning of the filter paper. Conditioning was done before and after the measurement to ensure similar filter paper condition when it was weighed. Filter paper was placed in desiccators for 48 hours before taking the weight of the fresh filter paper. The sampling was started as soon as possible after taking the filter paper from the desiccators. As desiccators, silica gel balls were used in the desiccators' container. Once the sampling was done, the filter paper with the dust trapped in that was placed in the desiccators' container again for 48 hours for conditioning. Weight of the dust and the filter paper was taken once the conditioning was done. Before starting the sampling, manometer fluid (water) level was kept at a fixed height and that was the datum of the air flow rate calculation.

The High volume sampler was placed in the desired location and was connected with power supply. On each day it was operated for an average 6-8 hours. A picture of the high volume sampler during its operation is shown in the Figure 3.05. During the sampling time air flow rate was constantly observed to measure total air flow through the filter paper. Total air flow rate was calculated from the average air flow rate and total sampling time. From the difference in weight between the fresh and dusted filter paper, weight of total dust particle was calculated.

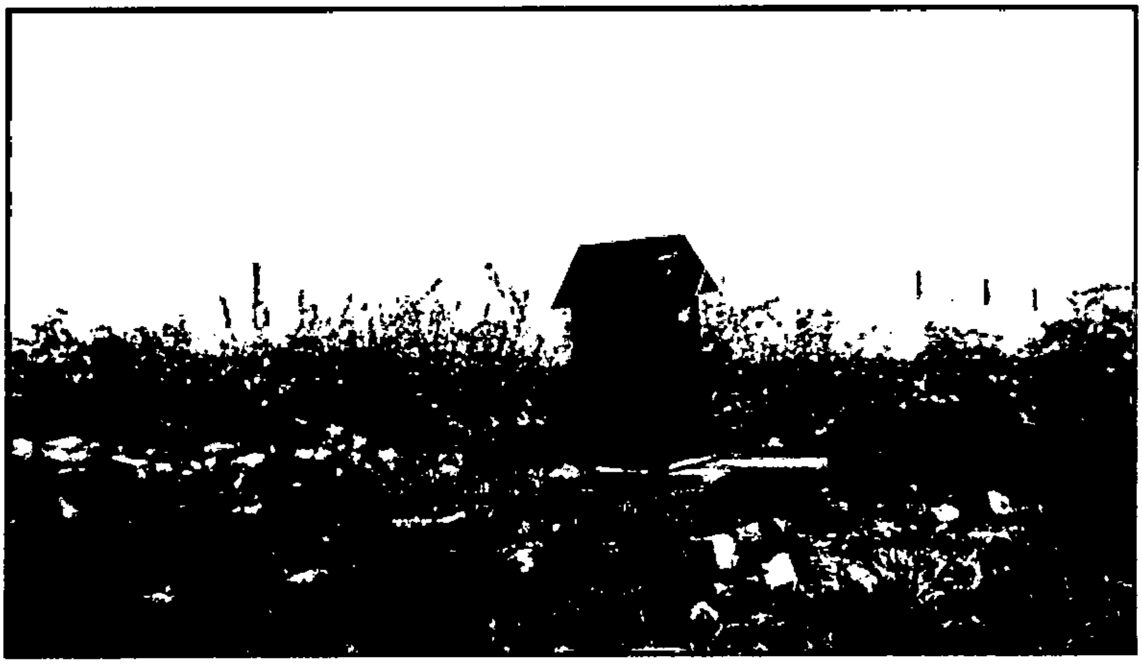


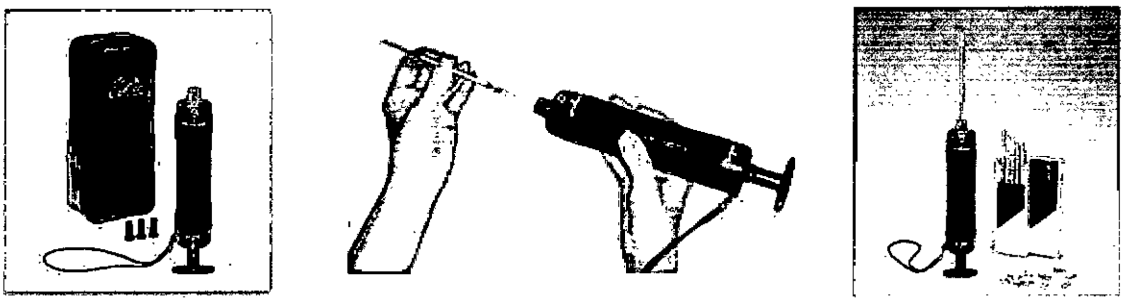
Figure 3.05: The high volume sampler during its operation in the brickfield

3.4 GASEOUS POLLUTANT MEASUREMENT

Gaseous pollutants were measured at different location on different days using Standard Gastec tube system. Ambient concentrations of Carbon monoxide, Sulfur dioxide and lower hydrocarbon were measured using standard detector tubes of the Gastec tube system.

3.4.1 Gastec Tube system

The Gastec Standard Detector tube system mainly consists of the Model GV 100S Gas sampling pump and Gastec standard detector tubes as shown in the Figure 3.06. This system is capable of analyzing a wide variety of gases and vapors accurately, quickly and easily. Gastec standard detector tubes are thin glass tubes with calibration scales printed by which one can directly read concentrations of the substances (gases and vapors) to be measured. Each tube contains detecting regents that are especially sensitive to the target substance and quickly produces a distinct layer of color change. The tubes are hermetically sealed. Gastec tubes are broken at both ends before using. One end is attached to the gas sampling pump and other end is kept open for suction. Some detector tubes are used as twin tubes by being connected with their pretreatment tubes that make samples more sensitive to the detecting reagents in the detector tube.



(a) (b) (c)

Figure 3.06: (a) Gastec pump (b) Adding Gastec detector tube (c) Gastec pump with detector tube in it

For the measurement purposes the appropriate detector tube was selected. Both ends of that tube were broken using a built-in tube tip breaker. If necessary a twin tube similarly broken was connected with the main tube by a rubber connector. The detector tube was then connected with the pump when pump handle is fully pushed in. Setting up the direction and the alignment of pump and tubes, the handle of the pump was pulled out until it was locked. Then the setup was kept steady for specified time to allow the ambient air to be sucked and reacted with the chemical inside the tube. From the reading in the tube scale the pollutant concentration of that ambient air was easily determined directly. For detecting lower class hydrocarbon model 103 standard Gastec tube was used and for sulfur dioxide measurement model 5LC standard Gastec tube was used. During Hydrocarbon measurement SO_3 filter tube was used to traps SO_3 to prevent it from entering sampling pump. Model 1L was used for carbon monoxide detection purposes. Reactions involved in these tubes are shown below:

CO $CO + K_2Pd(SO_3)_2 \rightarrow Pd + CO_2 + SO_2 + K_2SO_3$

HC Lower class hydrocarbon (C_2 to C_7) + $Cr^{6+} + H_2S_2O_7 \rightarrow Cr^{3+}$

SO_2 $SO_2 + I_2 + 2H_2O \rightarrow H_2SO_4 + 2HI$

3.5 AIR QUALITY MODELING

Air quality modeling is the mathematical simulation of how air pollutants spread in the ambient atmosphere. It is performed with computer programs that solve the mathematical equations and algorithms which simulate the pollutant dispersion. Models can be either of dispersion type or receptor type. However, Dispersion type model is the most commonly used for different pollution modeling. The dispersion models are used to estimate or to predict the downwind concentration of air pollutants emitted from sources such as industrial plants and vehicular traffic. Such models are important to governmental agencies tasked with protecting and managing the ambient air quality. The models are typically employed to determine whether existing or proposed new industrial facilities are or will be in compliance with the local or international ambient air quality Standards. The models also serve to assist in the design of effective control strategies to reduce emissions of harmful air pollutants. Gaussian plume type dispersion concept is the most widely used for modeling.

Many of the modern, advanced dispersion modeling programs include a pre-processor module for the input of meteorological and other data, and many also include a post-processor module for graphing the output data and/or plotting the area impacted by the air pollutants on maps. The atmospheric dispersion models are also known as atmospheric diffusion models, air dispersion models, air quality models, and air pollution dispersion models.

3.5.1 Gaussian Plume Dispersion Model

The Gaussian model is perhaps the oldest and perhaps the most commonly used model type. It assumes that the air pollutant dispersion has a Gaussian distribution, meaning that the pollutant distribution has a normal probability distribution. Gaussian models are most often used for predicting the dispersion of continuous, buoyant air pollution plumes originating from ground-level or elevated sources. Gaussian models may also be used for predicting the dispersion of non-continuous air pollution plumes (called *puff models*).

Gaussian plume idea is nothing but a material balance model. In it, one considers a point source such as a factory smokestack (which is not really a point but a small area that can be satisfactorily approximated as a point) and attempts to compute the downwind concentration resulting from this point source. The schematic representation and nomenclature are shown in Figure 3.07, where the origin of the coordinate system is placed at the base of the smokestack, with the *x* axis aligned in the downwind direction. The contaminated gas stream, normally called a plume is shown rising from the smokestack and then leveling off to travel in the *x* direction and spreading in the *y* and *z* directions as it travels.

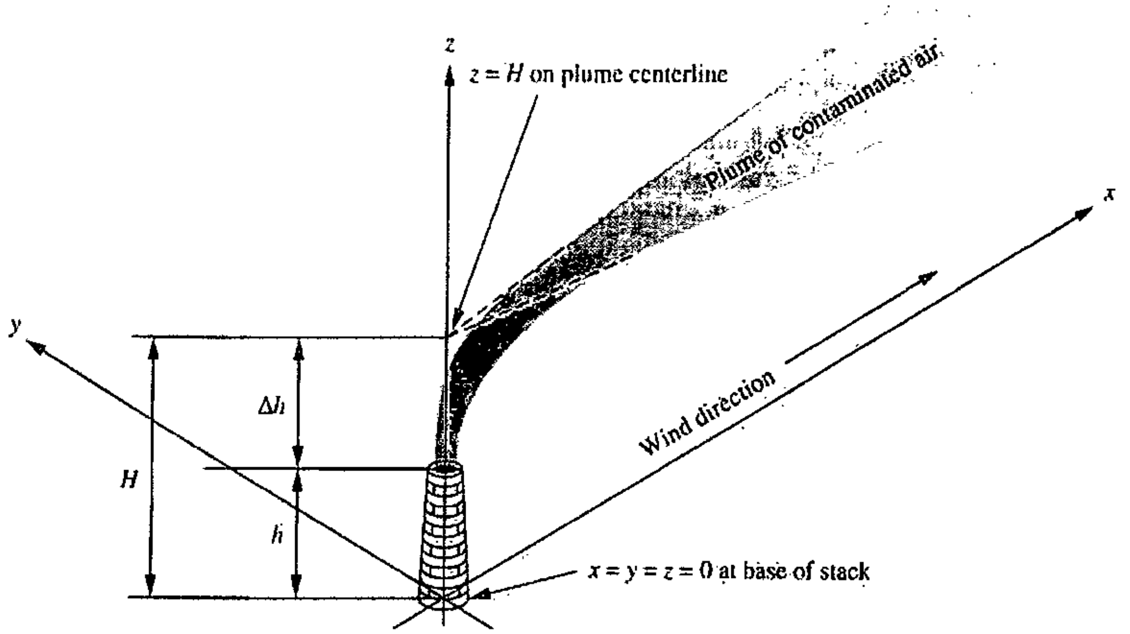


Figure 3.07: Coordinate system and nomenclature for the Gaussian plume idea

Such plumes normally rise a considerable distance above the smokestack because they are emitted at temperatures higher than atmospheric and with a vertical velocity. For Gaussian plume calculations the plume is assumed to be emitted from a point with coordinates 0, 0, H, where H is called the effective stack height, which is the sum of the physical stack height (h in Figure 3.07) and the plume rise (Δh in Figure 3.07). Physical stack height for any existing plant can be determined with ordinary measuring instruments. For the moment lets assume that we are dealing with a point source located at 0, 0, H that steadily emits a non-buoyant pollutant at emission rate Q (normally in g/s). Let us assume the wind blows in the *x* direction with velocity u and that this velocity u is independent of time, location, or elevation. Concentration profile of the Gaussian plume concept is shown in Figure 3.08 where σ represents the dispersion parameter or the standard deviation of the concentration. The problem is to compute the concentration due to this source at any point (x, y, z) for $x > 0$.

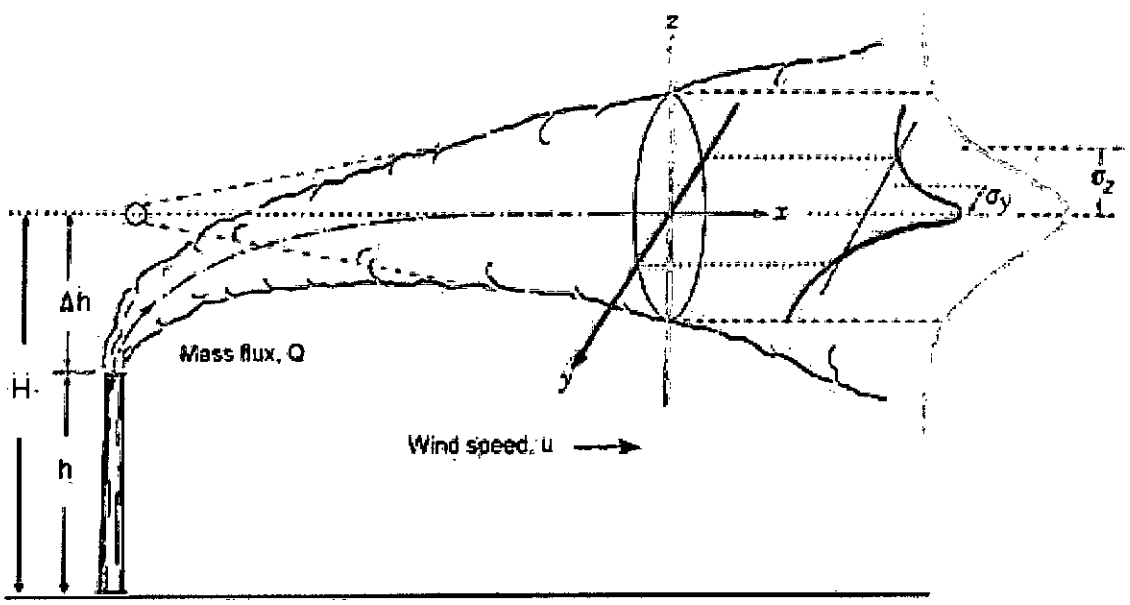


Figure 3.08: Concentration profile of the Gaussian plume concept

If molecular diffusion alone were causing the plume to mix with the surrounding air, the plume would spread slowly and appear (if the pollutant is visible) as a thin streak moving straight down the sky. The actual cause of the spread of plumes is the large-scale turbulent mixing that exists in the atmosphere, which may be visualized by comparing a snapshot of a plume with a time exposure of the same plume (Figure 3.09). At any instant the plume will appear to have a twisting, snake-like shape as it moves down the sky. The twisting behavior is caused by the turbulent motion of the atmosphere that is superimposed on the plume's large scale linear motion caused by the horizontal wind. This turbulent motion is random in nature, so that a snapshot taken a few minutes after the first would show the twists and turns in different places, but the overall form would be similar. However, time averages out these short-term variations of the plume, and thus a time exposure appears quite uniform and symmetrical. For this reason, if we placed a pollutant concentration meter at some fixed point in the plume, we would see the concentration oscillate in an irregular fashion about some average value. The Gaussian plume approach tries to calculate only that average value without making any statement about instantaneous values. The results obtained by Gaussian plume calculations should be considered only as averages over periods of at least 10 minutes, and preferably one-half to one hour.

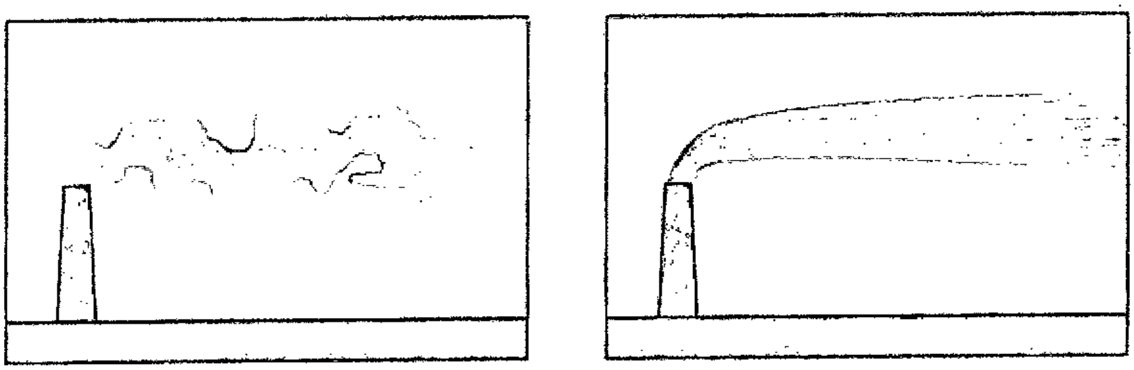


Figure 3.09: Comparison of snapshot and time exposure of a visible plume

Most commonly used air pollution dispersion models include Industrial Source Complex (ISC) Model, AERMOD, and CALPUFF. There are some other models apart from those such as ADAM, ADMS-3, AFTOX, ASPEN, DEGADIS, HGSYSTEM, HOTMAC/RAPTAD, HYROAD, OBODM, OZIPR, Panache, PLUVUEII, SCIPUFF, SDM, SLAB, BLP, CALINE3, CAL3QHC/CAL3QHCR, CTDMPLUS, and OCD [EPA, 2007]. ISC was selected for this thesis work.

3.5.2 Reasons for selecting ISC3

The Industrial Source Complex (ISC) Short Term model provides options to model emissions from a wide range of sources that might be present at a typical industrial source complex. The basis of the model is the straight-line, steady-state Gaussian plume equation, which is used with some modifications to model simple point source emissions from stacks, that experience the effects of aerodynamic downwash due to nearby buildings, isolated vents, multiple vents, storage piles, conveyor belts, and the like. Industrial Source complex model is one of the most famous Air quality models used by different organization. It has been considered as the Preferred/Recommended Model of the US Environmental Protection Agency for many years. Because of wide range of facilities and capacity it is considered as the working model for this work.

- The ISC models include a wide range of options for modeling air quality impacts of pollution sources, making them popular choices among the modeling community for a variety of applications.
- Industrial Source complex model (ISC3) operates in both long-term and short-term modes. It can be used to measure the pollution for as low as 1 hour up to as high as several years.

- The Industrial Source Complex model (ISC3) provides options to model emissions from a wide range of sources that might be present at a typical industrial source complex.
- ISC3 handle meteorological data on hourly basis. Each hour's meteorological data are needed to be input. Therefore, it gives the result considering very accurate meteorological condition by considering very precise meteorological data.
- It can handle different types of pollution sources such as Point, Area, Line, and Volume sources
- During modeling particulate materials, it considers settling and dry deposition of particles. So result can be measured either in terms of concentration or in terms of deposition rate.
- ISC3 considers downwash which makes the result more accurate in presence of buildings or any tall obstacles.
- It can handle multiple sources with arbitrary separation of point sources. Sources can be considered at any location within the modeling region rather than following any specific source allocation method.
- However, in case of this thesis work one of the major reasons for selecting this model was the availability of knowledge resource. ISC3 was easy to get and because of its wide applications, different documents were available that made it understand comfortably.

3.5.3 ISC3 Model Setup

There are two basic types of inputs that are needed to run the ISC models. They are (1) the input runstream file, and (2) the meteorological data file.

3.5.3.1 Input runstream data

The run stream setup file contains the selected modeling options, as well as source location and parameter data, receptor locations; meteorological data file specifications, and output options. Input run stream files have five different parts and each requires different information. They are:

- Dispersion Options
- Source Options

- Receptor Options
- Meteorology Options
- Output Options

Dispersion Options: Since the ISC3 models are especially designed to support the EPA's regulatory modeling programs, the regulatory modeling options are the default mode of operation for the models. These options include the use of stack-tip downwash, buoyancy-induced dispersion, final plume rise (except for sources with building downwash), a routine for processing averages when calm winds occur, default values for wind profile exponents and for the vertical potential temperature gradients, and the use of upper bound estimates for super-squat buildings having an influence on the lateral dispersion of the plume. The use of the regulatory default options can easily be ensured by selecting a single keyword on the modeling option input card.

To maintain the flexibility of the model, the non-regulatory default options have been retained, and by using descriptive keywords to specify these options it is evident at a glance from the input or output file which options have been employed for a particular application. Either rural or urban dispersion parameters may be selected, depending on the characteristics of the source location. It also has the option of calculating concentration values or deposition values for a particular run.

Source Options: The model is capable of handling multiple sources, including point, volume, area and open pit source types. Line sources may also be modeled as a string of volume sources or as elongated area sources. Several source groups may be specified in a single run, with the source contributions combined for each group. This is particularly useful for applications where combined impacts may be needed for a subset of the modeled background sources that consume increment. The models contain algorithms for modeling the effects of aerodynamic downwash due to nearby buildings on point source emissions, and algorithms for modeling the effects of settling and removal (through dry deposition) of large particulates.

The model also contains an algorithm for modeling the effects of precipitation scavenging for gases or particulates. Source emission rates can be treated as constant throughout the modeling period, or may be varied by month, season, hour-of-day, or other optional periods of variation. These variable emission rate factors may be specified for a single source or for a group of sources.

Receptor Options: The ISC3 models have considerable flexibility in the specification of receptor locations. This is capable of specifying multiple receptor networks in a single run, and also mixing Cartesian grid receptor networks and polar grid receptor networks in the same run. This is useful for applications where there may be need of a coarse grid over the whole modeling domain, but a denser grid in the area of maximum expected impacts. There is also flexibility in specifying the location of the origin for polar receptors, other than the default origin at (0,0) in x,y, coordinates.

Elevated receptor heights can be input in order to model the effects of terrain above (or below) stack base, and receptor elevations above ground level may also be specified to model flagpole receptors. The gridded observation site for this thesis work is shown in Figure 3.10.

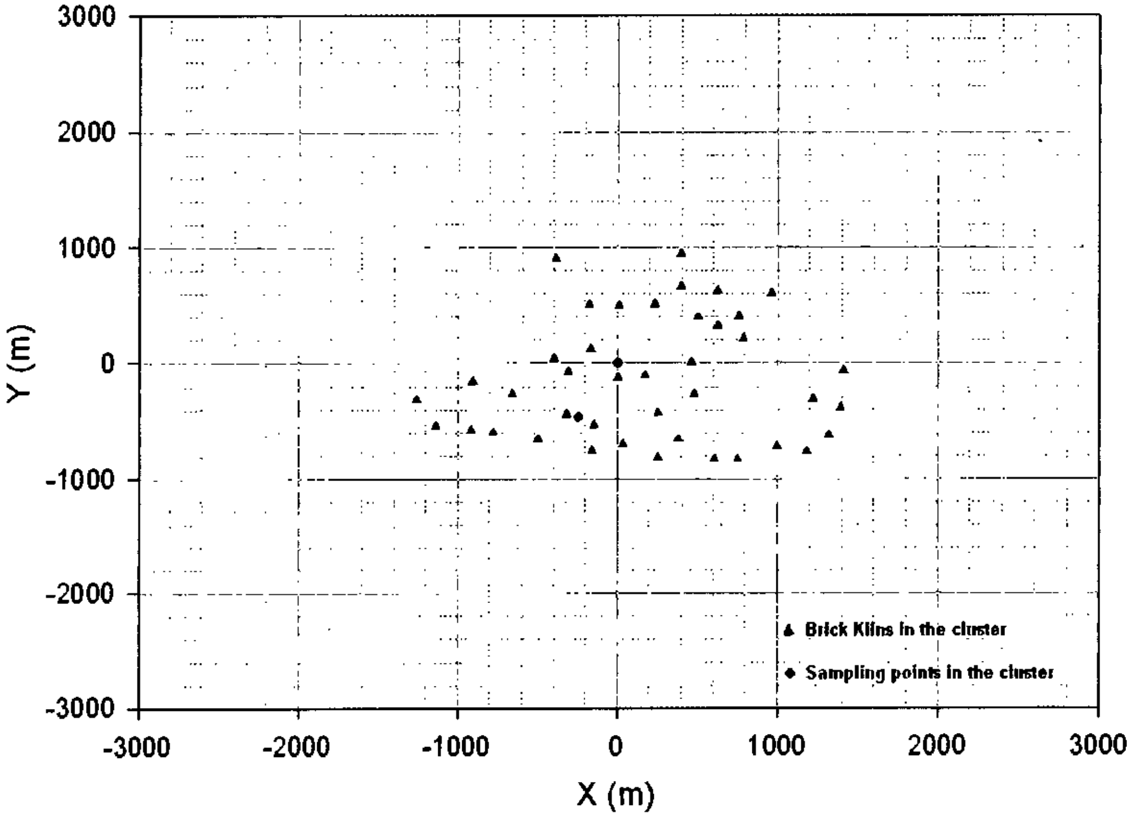


Figure 3.10: Brick kilns on the gridded observation site

Meteorological Options: In meteorological data section the year and meteorological file name is mentioned and all the meteorological data are specified in that file.

Output Options: The basic types of printed output available with the model are:

1. Summaries of high values (highest, second highest, etc.) by receptor for each averaging period and source group combination;

2. Summaries of overall maximum values (e.g., the maximum 50) for each averaging period and source group combination; and
3. Tables of concurrent values summarized by receptor for each averaging period and source group combination for each day of data processed. These "raw" concentration values may also be output to unformatted (binary) files.

For the Long Term model, output tables of values for each receptor, and/or tables of overall maximum values can also be selected. The tables by receptor and maximum value tables can be output for the source group values or for the individual source values, or both. In addition, when maximum values for individual sources are output, it has the option of specifying whether the values are to be the maximum values for each source independently, or the contribution of each source to the maximum group values, or both.

In addition to the tabular printed outputs, the ISC models provide options for several types of file output products. One of these options for ISCST is to output an unformatted ("binary") file of all concentration and/or deposition values as they are calculated. These files are often used for special post-processing of the data. In addition to the unformatted concentration files, ISCST provides options for three additional types of file outputs. One option is to generate an ASCII formatted file with the same results that are included in the unformatted post-processing file.

Another option is to generate a file of (X,Y) coordinates and design values (e.g., the second highest values at each receptor for a particular averaging period and source group combination) that can be easily imported into many graphics plotting packages to generate contour plots of the concentration and/or deposition values. Separate files can be specified for each of the averaging period and source group combinations.

Another output file option of the ISCST model is to generate a file of all occurrences when a concentration or deposition value equals or exceeds a user-specified threshold. Again, separate files are generated for only those combinations of averaging period and source group that are of interest. These files include the date on which the threshold exceedance occurred, the receptor location, and the concentration value.

3.5.3.2 Meteorological Data required

Meteorological data file contains all the required meteorological data on hourly basis. The major meteorological data that are necessary for the ISC3 model are ambient temperature, wind velocity and direction, mixing height. The Short Term model includes a dry deposition algorithm and a wet deposition algorithm. For these purposes some other data are also required such as Monin-Obukhov length, surface friction velocity, surface roughness and stability class. All those hourly data is preceded with the date and time. The wet deposition algorithm in the Short Term model also needs particle precipitation rate data in the meteorological data file. For this thesis work all the meteorological data of our specified location were collected from World Meteorological Organization (WMO) data [NOAA]. These are very much reliable and most of the models including climate models run on these data.

It also has considerable flexibility to utilize formatted ASCII files that contain sequential hourly records of meteorological variables. For these hourly ASCII files, this model may use a default ASCII format, may specify the ASCII read format, or may select free-formatted reads for inputting the meteorological data. A utility program called BINTOASC is provided with the ISC3 models to convert unformatted meteorological data files of several types to the default ASCII format used by ISCST and ISCEV. This greatly improves the portability of applications to different computer systems. The model process all available meteorological data in the specified input file by default, but some selected days or ranges of days can easily be specified to process.

3.5.3.3 Air Quality Modeling with ISC3

With the help of the ISC3 modeling software and the run stream and meteorological files an air quality modeling can easily be done. A sample run stream file for ISC3 is shown below:

```
CO STARTING
   TITLEONE  Brickfield Cluster in Amin Bazar
   MODELOPT  DFAULT  RURAL  CONC
   AVERTIME  24  MONTH
   POLLUTID  SO2
   TERRHGTS  FLAT
   RUNORNOT  RUN
   EVENTFIL  EVENTEXP.INP
   ERRORFIL  ERRORS.OUT
CO FINISHED

SO STARTING
   LOCATION  STACK01 POINT  -1260.0  -320.0
   LOCATION  STACK02 POINT  -1140.0  -550.0
   LOCATION  STACK03 POINT   -920.0  -580.0
   LOCATION  STACK04 POINT   -910.0  -160.0
   LOCATION  STACK05 POINT   -780.0  -600.0
   LOCATION  STACK06 POINT   -660.0  -270.0
   LOCATION  STACK07 POINT   -500.0  -660.0
   LOCATION  STACK08 POINT   -400.0    40.0
   LOCATION  STACK09 POINT   -390.0   900.0
   LOCATION  STACK10 POINT   -320.0  -440.0
```

```
LOCATION   STACK11 POINT   -310.0    -80.0
LOCATION   STACK12 POINT   -180.0    505.0
LOCATION   STACK13 POINT   -170.0    120.0
LOCATION   STACK14 POINT   -160.0   -760.0
LOCATION   STACK15 POINT   -150.0   -540.0
LOCATION   STACK16 POINT      0.0   -130.0
LOCATION   STACK17 POINT     10.0    490.0
LOCATION   STACK18 POINT     30.0   -705.0
LOCATION   STACK19 POINT    170.0   -110.0
LOCATION   STACK20 POINT    230.0    505.0
LOCATION   STACK21 POINT    250.0   -430.0
LOCATION   STACK22 POINT    250.0   -820.0
LOCATION   STACK23 POINT    380.0   -660.0
LOCATION   STACK24 POINT    395.0    660.0
LOCATION   STACK25 POINT    395.0    940.0
LOCATION   STACK26 POINT    460.0      5.0
LOCATION   STACK27 POINT    475.0   -265.0
LOCATION   STACK28 POINT    500.0    395.0
LOCATION   STACK29 POINT    605.0   -835.0
LOCATION   STACK30 POINT    620.0    620.0
LOCATION   STACK31 POINT    625.0    320.0
LOCATION   STACK32 POINT    750.0   -835.0
LOCATION   STACK33 POINT    755.0    400.0
LOCATION   STACK34 POINT    785.0    210.0
LOCATION   STACK35 POINT    960.0    595.0
LOCATION   STACK36 POINT    995.0   -725.0
LOCATION   STACK37 POINT   1180.0   -765.0
LOCATION   STACK38 POINT   1220.0   -310.0
LOCATION   STACK39 POINT   1320.0   -625.0
LOCATION   STACK40 POINT   1390.0   -385.0
LOCATION   STACK41 POINT   1410.0    -70.0

** Point Source          QS      HS     TS        VS    DS
** Parameters:          ----    ----   ----      ----   ---

   SRCPARAM   STACK01  78.575   38.0   335.43    7.40   1.0
   SRCPARAM   STACK02  78.575   38.0   335.43    7.40   1.0
   SRCPARAM   STACK03  78.575   38.0   335.43    7.40   1.0
   SRCPARAM   STACK04  78.575   38.0   335.43    7.40   1.0
   SRCPARAM   STACK05  78.575   38.0   335.43    7.40   1.0
   SRCPARAM   STACK06  78.575   38.0   335.43    7.40   1.0
   SRCPARAM   STACK07  78.575   38.0   335.43    7.40   1.0
   SRCPARAM   STACK08  78.575   38.0   335.43    7.40   1.0
   SRCPARAM   STACK09  78.575   38.0   335.43    7.40   1.0
   SRCPARAM   STACK10  78.575   38.0   335.43    7.40   1.0
   SRCPARAM   STACK11  78.575   38.0   335.43    7.40   1.0
   SRCPARAM   STACK12  78.575   38.0   335.43    7.40   1.0
   SRCPARAM   STACK13  78.575   38.0   335.43    7.40   1.0
   SRCPARAM   STACK14  78.575   38.0   335.43    7.40   1.0
   SRCPARAM   STACK15  78.575   38.0   335.43    7.40   1.0
   SRCPARAM   STACK16  78.575   38.0   335.43    7.40   1.0
   SRCPARAM   STACK17  78.575   38.0   335.43    7.40   1.0
   SRCPARAM   STACK18  78.575   38.0   335.43    7.40   1.0
   SRCPARAM   STACK19  78.575   38.0   335.43    7.40   1.0
   SRCPARAM   STACK20  78.575   38.0   335.43    7.40   1.0
   SRCPARAM   STACK21  78.575   38.0   335.43    7.40   1.0
   SRCPARAM   STACK22  78.575   38.0   335.43    7.40   1.0
   SRCPARAM   STACK23  78.575   38.0   335.43    7.40   1.0
   SRCPARAM   STACK24  78.575   38.0   335.43    7.40   1.0
   SRCPARAM   STACK25  78.575   38.0   335.43    7.40   1.0
   SRCPARAM   STACK26  78.575   38.0   335.43    7.40   1.0
   SRCPARAM   STACK27  78.575   38.0   335.43    7.40   1.0
   SRCPARAM   STACK28  78.575   38.0   335.43    7.40   1.0
   SRCPARAM   STACK29  78.575   38.0   335.43    7.40   1.0
   SRCPARAM   STACK30  78.575   38.0   335.43    7.40   1.0
   SRCPARAM   STACK31  78.575   38.0   335.43    7.40   1.0
   SRCPARAM   STACK32  78.575   38.0   335.43    7.40   1.0
   SRCPARAM   STACK33  78.575   38.0   335.43    7.40   1.0
   SRCPARAM   STACK34  78.575   38.0   335.43    7.40   1.0
```

```
   SRCPARAM  STACK35  78.575  38.0  335.43  7.40  1.0
   SRCPARAM  STACK36  78.575  38.0  335.43  7.40  1.0
   SRCPARAM  STACK37  78.575  38.0  335.43  7.40  1.0
   SRCPARAM  STACK38  78.575  38.0  335.43  7.40  1.0
   SRCPARAM  STACK39  78.575  38.0  335.43  7.40  1.0
   SRCPARAM  STACK40  78.575  38.0  335.43  7.40  1.0
   SRCPARAM  STACK41  78.575  38.0  335.43  7.40  1.0
   SRCGROUP  ALL
SO FINISHED

RE STARTING
   GRIDCART CG1 STA
            CG1 XYINC -5000. 21 500. -5000. 21 500.
   GRIDCART CG1 END
RE FINISHED

ME STARTING
   INPUTFIL  dec04.met
   ANEMHGHT  10.
   SURFDATA  99999  2004
   UAIRDATA  99999  2004
ME FINISHED

OU STARTING
   RECTABLE  ALLAVE  FIRST
   MAXTABLE  ALLAVE  50
   PLOTFILE  24  ALL  FIRST 24hr500m.xyz
   PLOTFILE  MONTH  ALL  FIRST m500m.xyz
   MAXIFILE  24  ALL  100. 24hr500m.max
   MAXIFILE  MONTH  ALL  80. m500m.max
OU FINISHED
```

Meteorological file for ISC3 model can be of different sizes considering the observation period. All the data for the file are in hourly basis. Here is a part of the sample meteorological file for the above run stream file:

```
99999   04  99999      04
 412 1 1 204.6940    2.5593 289.4 5 1235.9 1235.9    0.0824        -0.6  0.0000   0    0.00
 412 1 2 204.6940    2.5593 289.4 5 1235.9 1235.9    0.0824        -0.6  0.0000   0    0.00
 412 1 3 204.6940    2.5593 289.4 5 1235.9 1235.9    0.0824        -0.6  0.0000   0    0.00
 412 1 4 204.6940    2.5593 289.4 5 1235.9 1235.9    0.0824        -0.6  0.0000   0    0.00
 412 1 5 204.6940    2.5593 289.4 5 1235.9 1235.9    0.0824        -0.6  0.0000   0    0.00
 412 1 6 204.6940    2.5593 289.4 5 1235.9 1235.9    0.0824        -0.6  0.0000   0    0.00
 412 1 7 212.2222    1.4686 298.2 3 1467.1 1467.1    0.0473        -0.1  0.0000   0    0.00
 412 1 8 212.2222    1.4686 298.2 3 1467.1 1467.1    0.0473        -0.1  0.0000   0    0.00
 412 1 9 212.2222    1.4686 298.2 3 1467.1 1467.1    0.0473        -0.1  0.0000   0    0.00
 412 110 212.2222    1.4686 298.2 3 1467.1 1467.1    0.0473        -0.1  0.0000   0    0.00
 412 111 212.2222    1.4686 298.2 3 1467.1 1467.1    0.0473        -0.1  0.0000   0    0.00
 412 112 212.2222    1.4686 298.2 3 1467.1 1467.1    0.0473        -0.1  0.0000   0    0.00
 412 113 188.2591    2.0597 297.2 2   902.5  902.5   0.0663         0.9  0.0000   0    0.00
 412 114 188.2591    2.0597 297.2 2   902.5  902.5   0.0663         0.9  0.0000   0    0.00
 412 115 188.2591    2.0597 297.2 2   902.5  902.5   0.0663         0.9  0.0000   0    0.00
 412 116 188.2591    2.0597 297.2 2   902.5  902.5   0.0663         0.9  0.0000   0    0.00
 412 117 188.2591    2.0597 297.2 2   902.5  902.5   0.0663         0.9  0.0000   0    0.00
 412 118 188.2591    2.0597 297.2 2   902.5  902.5   0.0663         0.9  0.0000   0    0.00
 412 119 172.1862    3.4647 290.7 6 1000.0 1000.0    0.1115         4.7  0.0000   0    0.00
 412 120 172.1862    3.4647 290.7 6 1000.0 1000.0    0.1115         4.7  0.0000   0    0.00
 412 121 172.1862    3.4647 290.7 6 1000.0 1000.0    0.1115         4.7  0.0000   0    0.00
 412 122 172.1862    3.4647 290.7 6 1000.0 1000.0    0.1115         4.7  0.0000   0    0.00
 412 123 172.1862    3.4647 290.7 6 1000.0 1000.0    0.1115         4.7  0.0000   0    0.00
 412 124 172.1862    3.4647 290.7 6 1000.0 1000.0    0.1115         4.7  0.0000   0    0.00
 412 2 1 187.7346    2.6514 288.8 5 1254.2 1254.2    0.0853        -0.6  0.0000   0    0.00
 412 2 2 187.7346    2.6514 288.8 5 1254.2 1254.2    0.0853        -0.6  0.0000   0    0.00
 412 2 3 187.7346    2.6514 288.8 5 1254.2 1254.2    0.0853        -0.6  0.0000   0    0.00
 412 2 4 187.7346    2.6514 288.8 5 1254.2 1254.2    0.0853        -0.6  0.0000   0    0.00
 412 2 5 187.7346    2.6514 288.8 5 1254.2 1254.2    0.0853        -0.6  0.0000   0    0.00
```

412	2 6	187.7346	2.6514	288.8	5	1254.2	1254.2	0.0853	-0.6	0.0000	0	0.00
412	2 7	245.5807	0.6793	297.4	3	1458.7	1458.7	0.0219	0.0	0.0000	0	0.00
412	2 8	245.5807	0.6793	297.4	3	1458.7	1458.7	0.0219	0.0	0.0000	0	0.00
412	2 9	245.5807	0.6793	297.4	3	1458.7	1458.7	0.0219	0.0	0.0000	0	0.00
412	210	245.5807	0.6793	297.4	3	1458.7	1458.7	0.0219	0.0	0.0000	0	0.00
412	211	245.5807	0.6793	297.4	3	1458.7	1458.7	0.0219	0.0	0.0000	0	0.00
412	212	245.5807	0.6793	297.4	3	1458.7	1458.7	0.0219	0.0	0.0000	0	0.00
412	213	157.1529	1.5155	295.6	2	1002.9	1002.9	0.0488	0.4	0.0000	0	0.00
412	214	157.1529	1.5155	295.6	2	1002.9	1002.9	0.0488	0.4	0.0000	0	0.00
412	215	157.1529	1.5155	295.6	2	1002.9	1002.9	0.0488	0.4	0.0000	0	0.00
412	216	157.1529	1.5155	295.6	2	1002.9	1002.9	0.0488	0.4	0.0000	0	0.00
412	217	157.1529	1.5155	295.6	2	1002.9	1002.9	0.0488	0.4	0.0000	0	0.00
412	218	157.1529	1.5155	295.6	2	1002.9	1002.9	0.0488	0.4	0.0000	0	0.00
412	219	175.2754	3.8778	289.2	6	1009.8	1009.8	0.1248	6.2	0.0000	0	0.00
412	220	175.2754	3.8778	289.2	6	1009.8	1009.8	0.1248	6.2	0.0000	0	0.00
412	221	175.2754	3.8778	289.2	6	1009.8	1009.8	0.1248	6.2	0.0000	0	0.00
412	222	175.2754	3.8778	289.2	6	1009.8	1009.8	0.1248	6.2	0.0000	0	0.00
412	223	175.2754	3.8778	289.2	6	1009.8	1009.8	0.1248	6.2	0.0000	0	0.00
412	224	175.2754	3.8778	289.2	6	1009.8	1009.8	0.1248	6.2	0.0000	0	0.00
412	3 1	190.8540	2.7083	288.6	5	1240.0	1240.0	0.0872	-0.8	0.0000	0	0.00
412	3 2	190.8540	2.7083	288.6	5	1240.0	1240.0	0.0872	-0.8	0.0000	0	0.00
412	3 3	190.8540	2.7083	288.6	5	1240.0	1240.0	0.0872	-0.8	0.0000	0	0.00
412	3 4	190.8540	2.7083	288.6	5	1240.0	1240.0	0.0872	-0.8	0.0000	0	0.00
412	3 5	190.8540	2.7083	288.6	5	1240.0	1240.0	0.0872	-0.8	0.0000	0	0.00
412	3 6	190.8540	2.7083	288.6	5	1240.0	1240.0	0.0872	-0.8	0.0000	0	0.00
412	3 7	156.7267	2.4841	296.9	3	1427.5	1427.5	0.0799	-0.5	0.0000	0	0.00
412	3 8	156.7267	2.4841	296.9	3	1427.5	1427.5	0.0799	-0.5	0.0000	0	0.00
412	3 9	156.7267	2.4841	296.9	3	1427.5	1427.5	0.0799	-0.5	0.0000	0	0.00
412	310	156.7267	2.4841	296.9	3	1427.5	1427.5	0.0799	-0.5	0.0000	0	0.00
412	311	156.7267	2.4841	296.9	3	1427.5	1427.5	0.0799	-0.5	0.0000	0	0.00
412	312	156.7267	2.4841	296.9	3	1427.5	1427.5	0.0799	-0.5	0.0000	0	0.00
412	313	171.7338	1.6159	296.2	2	1001.4	1001.4	0.0520	0.4	0.0000	0	0.00
412	314	171.7338	1.6159	296.2	2	1001.4	1001.4	0.0520	0.4	0.0000	0	0.00
412	315	171.7338	1.6159	296.2	2	1001.4	1001.4	0.0520	0.4	0.0000	0	0.00
412	316	171.7338	1.6159	296.2	2	1001.4	1001.4	0.0520	0.4	0.0000	0	0.00
412	317	171.7338	1.6159	296.2	2	1001.4	1001.4	0.0520	0.4	0.0000	0	0.00
412	318	171.7338	1.6159	296.2	2	1001.4	1001.4	0.0520	0.4	0.0000	0	0.00
412	319	167.4908	4.0093	290.6	6	951.1	951.1	0.1290	4.4	0.0000	0	0.00
412	320	167.4908	4.0093	290.6	6	951.1	951.1	0.1290	4.4	0.0000	0	0.00
412	321	167.4908	4.0093	290.6	6	951.1	951.1	0.1290	4.4	0.0000	0	0.00
412	322	167.4908	4.0093	290.6	6	951.1	951.1	0.1290	4.4	0.0000	0	0.00
412	323	167.4908	4.0093	290.6	6	951.1	951.1	0.1290	4.4	0.0000	0	0.00
412	324	167.4908	4.0093	290.6	6	951.1	951.1	0.1290	4.4	0.0000	0	0.00
412	4 1	185.2084	3.1016	289.0	5	1199.5	1199.5	0.0998	-1.2	0.0000	0	0.00
412	4 2	185.2084	3.1016	289.0	5	1199.5	1199.5	0.0998	-1.2	0.0000	0	0.00
412	4 3	185.2084	3.1016	289.0	5	1199.5	1199.5	0.0998	-1.2	0.0000	0	0.00
412	4 4	185.2084	3.1016	289.0	5	1199.5	1199.5	0.0998	-1.2	0.0000	0	0.00
412	4 5	185.2084	3.1016	289.0	5	1199.5	1199.5	0.0998	-1.2	0.0000	0	0.00
412	4 6	185.2084	3.1016	289.0	5	1199.5	1199.5	0.0998	-1.2	0.0000	0	0.00
412	4 7	196.3707	1.1555	297.0	3	1458.8	1458.8	0.0372	-0.1	0.0000	0	0.00
412	4 8	196.3707	1.1555	297.0	3	1458.8	1458.8	0.0372	-0.1	0.0000	0	0.00
412	4 9	196.3707	1.1555	297.0	3	1458.8	1458.8	0.0372	-0.1	0.0000	0	0.00
412	410	196.3707	1.1555	297.0	3	1458.8	1458.8	0.0372	-0.1	0.0000	0	0.00
412	411	196.3707	1.1555	297.0	3	1458.8	1458.8	0.0372	-0.1	0.0000	0	0.00
412	412	196.3707	1.1555	297.0	3	1458.8	1458.8	0.0372	-0.1	0.0000	0	0.00
412	413	155.3127	1.7332	294.9	2	999.8	999.8	0.0558	0.5	0.0000	0	0.00
412	414	155.3127	1.7332	294.9	2	999.8	999.8	0.0558	0.5	0.0000	0	0.00
412	415	155.3127	1.7332	294.9	2	999.8	999.8	0.0558	0.5	0.0000	0	0.00
412	416	155.3127	1.7332	294.9	2	999.8	999.8	0.0558	0.5	0.0000	0	0.00
412	417	155.3127	1.7332	294.9	2	999.8	999.8	0.0558	0.5	0.0000	0	0.00
412	418	155.3127	1.7332	294.9	2	999.8	999.8	0.0558	0.5	0.0000	0	0.00
412	419	185.6624	3.9786	289.7	6	959.0	959.0	0.1280	5.6	0.0000	0	0.00
412	420	185.6624	3.9786	289.7	6	959.0	959.0	0.1280	5.6	0.0000	0	0.00
412	421	185.6624	3.9786	289.7	6	959.0	959.0	0.1280	5.6	0.0000	0	0.00
412	422	185.6624	3.9786	289.7	6	959.0	959.0	0.1280	5.6	0.0000	0	0.00
412	423	185.6624	3.9786	289.7	6	959.0	959.0	0.1280	5.6	0.0000	0	0.00
412	424	185.6624	3.9786	289.7	6	959.0	959.0	0.1280	5.6	0.0000	0	0.00
412	5 1	179.3803	2.9146	287.8	5	1247.0	1247.0	0.0938	-0.9	0.0000	0	0.00
412	5 2	179.3803	2.9146	287.8	5	1247.0	1247.0	0.0938	-0.9	0.0000	0	0.00
412	5 3	179.3803	2.9146	287.8	5	1247.0	1247.0	0.0938	-0.9	0.0000	0	0.00
412	5 4	179.3803	2.9146	287.8	5	1247.0	1247.0	0.0938	-0.9	0.0000	0	0.00
412	5 5	179.3803	2.9146	287.8	5	1247.0	1247.0	0.0938	-0.9	0.0000	0	0.00
412	5 6	179.3803	2.9146	287.8	5	1247.0	1247.0	0.0938	-0.9	0.0000	0	0.00
412	5 7	268.9965	1.4684	296.8	3	1540.0	1540.0	0.0473	-0.1	0.0000	0	0.00
412	5 8	268.9965	1.4684	296.8	3	1540.0	1540.0	0.0473	-0.1	0.0000	0	0.00
412	5 9	268.9965	1.4684	296.8	3	1540.0	1540.0	0.0473	-0.1	0.0000	0	0.00
412	510	268.9965	1.4684	296.8	3	1540.0	1540.0	0.0473	-0.1	0.0000	0	0.00
412	511	268.9965	1.4684	296.8	3	1540.0	1540.0	0.0473	-0.1	0.0000	0	0.00
412	512	268.9965	1.4684	296.8	3	1540.0	1540.0	0.0473	-0.1	0.0000	0	0.00
412	513	107.9090	1.3518	295.0	2	1071.9	1071.9	0.0435	0.7	0.0000	0	0.00
412	514	107.9090	1.3518	295.0	2	1071.9	1071.9	0.0435	0.7	0.0000	0	0.00
412	515	107.9090	1.3518	295.0	2	1071.9	1071.9	0.0435	0.7	0.0000	0	0.00
412	516	107.9090	1.3518	295.0	2	1071.9	1071.9	0.0435	0.7	0.0000	0	0.00
412	517	107.9090	1.3518	295.0	2	1071.9	1071.9	0.0435	0.7	0.0000	0	0.00
412	518	107.9090	1.3518	295.0	2	1071.9	1071.9	0.0435	0.7	0.0000	0	0.00
412	519	185.8810	3.1106	290.6	6	1007.5	1007.5	0.1001	2.5	0.0000	0	0.00

412	520	185.8810	3.1106	290.6	6	1007.5	1007.5	0.1001	2.5	0.0000	0	0.00
412	521	185.8810	3.1106	290.6	6	1007.5	1007.5	0.1001	2.5	0.0000	0	0.00
412	522	185.8810	3.1106	290.6	6	1007.5	1007.5	0.1001	2.5	0.0000	0	0.00
412	523	185.8810	3.1106	290.6	6	1007.5	1007.5	0.1001	2.5	0.0000	0	0.00
412	524	185.8810	3.1106	290.6	6	1007.5	1007.5	0.1001	2.5	0.0000	0	0.00
412	6 1	199.1434	3.0858	287.8	5	1273.5	1273.5	0.0993	-1.0	0.0000	0	0.00
412	6 2	199.1434	3.0858	287.8	5	1273.5	1273.5	0.0993	-1.0	0.0000	0	0.00
412	6 3	199.1434	3.0858	287.8	5	1273.5	1273.5	0.0993	-1.0	0.0000	0	0.00
412	6 4	199.1434	3.0858	287.8	5	1273.5	1273.5	0.0993	-1.0	0.0000	0	0.00
412	6 5	199.1434	3.0858	287.8	5	1273.5	1273.5	0.0993	-1.0	0.0000	0	0.00
412	6 6	199.1434	3.0858	287.8	5	1273.5	1273.5	0.0993	-1.0	0.0000	0	0.00
412	6 7	252.4460	0.6785	296.0	3	1496.5	1496.5	0.0218	0.0	0.0000	0	0.00
412	6 8	252.4460	0.6785	296.0	3	1496.5	1496.5	0.0218	0.0	0.0000	0	0.00
412	6 9	252.4460	0.6785	296.0	3	1496.5	1496.5	0.0218	0.0	0.0000	0	0.00
412	610	252.4460	0.6785	296.0	3	1496.5	1496.5	0.0218	0.0	0.0000	0	0.00
412	611	252.4460	0.6785	296.0	3	1496.5	1496.5	0.0218	0.0	0.0000	0	0.00
412	612	252.4460	0.6785	296.0	3	1496.5	1496.5	0.0218	0.0	0.0000	0	0.00
412	613	227.7011	1.0072	295.4	2	894.2	894.2	0.0324	0.1	0.0000	0	0.00
412	614	227.7011	1.0072	295.4	2	894.2	894.2	0.0324	0.1	0.0000	0	0.00
412	615	227.7011	1.0072	295.4	2	894.2	894.2	0.0324	0.1	0.0000	0	0.00
412	616	227.7011	1.0072	295.4	2	894.2	894.2	0.0324	0.1	0.0000	0	0.00
412	617	227.7011	1.0072	295.4	2	894.2	894.2	0.0324	0.1	0.0000	0	0.00
412	618	227.7011	1.0072	295.4	2	894.2	894.2	0.0324	0.1	0.0000	0	0.00
412	619	197.0333	5.5075	288.4	4	1005.0	1005.0	0.1772	15.4	0.0000	0	0.00
412	620	197.0333	5.5075	288.4	4	1005.0	1005.0	0.1772	15.4	0.0000	0	0.00
412	621	197.0333	5.5075	288.4	4	1005.0	1005.0	0.1772	15.4	0.0000	0	0.00
412	622	197.0333	5.5075	288.4	4	1005.0	1005.0	0.1772	15.4	0.0000	0	0.00
412	623	197.0333	5.5075	288.4	4	1005.0	1005.0	0.1772	15.4	0.0000	0	0.00
412	624	197.0333	5.5075	288.4	4	1005.0	1005.0	0.1772	15.4	0.0000	0	0.00
412	7 1	201.5411	3.0293	288.0	5	1254.0	1254.0	0.0975	-1.1	0.0000	0	0.00
412	7 2	201.5411	3.0293	288.0	5	1254.0	1254.0	0.0975	-1.1	0.0000	0	0.00
412	7 3	201.5411	3.0293	288.0	5	1254.0	1254.0	0.0975	-1.1	0.0000	0	0.00
412	7 4	201.5411	3.0293	288.0	5	1254.0	1254.0	0.0975	-1.1	0.0000	0	0.00
412	7 5	201.5411	3.0293	288.0	5	1254.0	1254.0	0.0975	-1.1	0.0000	0	0.00
412	7 6	201.5411	3.0293	288.0	5	1254.0	1254.0	0.0975	-1.1	0.0000	0	0.00
412	7 7	201.8550	4.1457	296.0	3	1503.5	1503.5	0.1334	-2.4	0.0000	0	0.00
412	7 8	201.8550	4.1457	296.0	3	1503.5	1503.5	0.1334	-2.4	0.0000	0	0.00
412	7 9	201.8550	4.1457	296.0	3	1503.5	1503.5	0.1334	-2.4	0.0000	0	0.00
412	710	201.8550	4.1457	296.0	3	1503.5	1503.5	0.1334	-2.4	0.0000	0	0.00
412	711	201.8550	4.1457	296.0	3	1503.5	1503.5	0.1334	-2.4	0.0000	0	0.00
412	712	201.8550	4.1457	296.0	3	1503.5	1503.5	0.1334	-2.4	0.0000	0	0.00
412	713	114.7411	0.3370	295.0	2	895.7	895.7	0.0108	0.0	0.0000	0	0.00
412	714	114.7411	0.3370	295.0	2	895.7	895.7	0.0108	0.0	0.0000	0	0.00
412	715	114.7411	0.3370	295.0	2	895.7	895.7	0.0108	0.0	0.0000	0	0.00
412	716	114.7411	0.3370	295.0	2	895.7	895.7	0.0108	0.0	0.0000	0	0.00
412	717	114.7411	0.3370	295.0	2	895.7	895.7	0.0108	0.0	0.0000	0	0.00
412	718	114.7411	0.3370	295.0	2	895.7	895.7	0.0108	0.0	0.0000	0	0.00
412	719	178.3769	4.5009	290.7	6	843.4	843.4	0.1448	8.2	0.0000	0	0.00
412	720	178.3769	4.5009	290.7	6	843.4	843.4	0.1448	8.2	0.0000	0	0.00
412	721	178.3769	4.5009	290.7	6	843.4	843.4	0.1448	8.2	0.0000	0	0.00
412	722	178.3769	4.5009	290.7	6	843.4	843.4	0.1448	8.2	0.0000	0	0.00
412	723	178.3769	4.5009	290.7	6	843.4	843.4	0.1448	8.2	0.0000	0	0.00
412	724	178.3769	4.5009	290.7	6	843.4	843.4	0.1448	8.2	0.0000	0	0.00

Before generating the input stream, the total observation area is to be divided into grids and expressed in terms of Cartesian coordinate system. Thus all the source location can be defined with their coordinate values. The receptor locations were also expressed by the coordinate system. As the whole area was divided in to rectangular grids, the receptors must be at the corner of the rectangle not anywhere on that. So the model generated values were the ambient concentrations at those previously specified grid points. Once a set of required files were run successfully, different output files were generated. These output files included the maximum concentrated areas, total model output and the coordinate based concentration data. These sorted data help to generate graphical representation of the model output. To analyzing the effect of different parameters like stack exit velocity, stack height and meteorology, this model was run in a similar way changing the required parameters only. All the experimental and modeled results are discussed in the next chapter.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 INTRODUCTION

Air sampling was done in the cluster of brickfields at different locations as shown in Figure 4.01 to verify the applicability of the Industrial Source Complex model (ISC3) in Bangladesh especially for brickfield emissions. For this work a cluster of 41 brick kilns were considered near Amin Bazar, Savar. That cluster is situated to the north of Dhaka and very near to locality. In that cluster, all the stacks were identical with a stack height of 130 ft on an average. Dimension of the stacks were considered to be same with the diameter being 1 meter at exit point. Ambient pollutant concentrations at different locations were measured experimentally using Gastec tubes and High volume sampler. Similar data were also generated through model to verify the acceptability of this model.

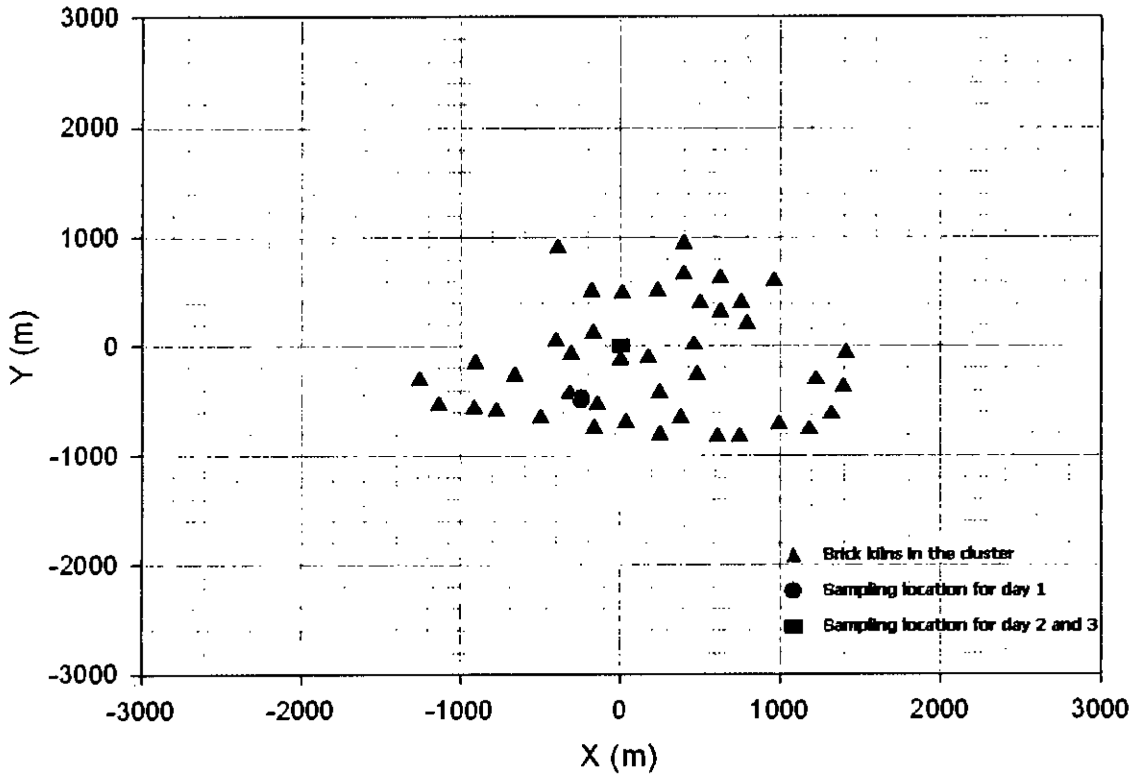


Figure 4.01: Two sampling locations on the gridded observation site

After verification of the applicability of the model, it was used for different air pollution assessments and predictions. Effects of different factors on the ambient pollution concentration were also assessed using this model. Following are the main assessment done using this model.

- Effect of meteorological conditions
- Effect of stack height
- Effect of stack exit velocity

First of all, it was applied to measure the effects of air pollution from the brickfield emissions on the surroundings. This was done for different meteorological conditions for the dry months in Bangladesh. Significant effect of the meteorological conditions was observed. ISC3 model was also applied to predict the ambient air pollution level for different proposed modifications. Effectiveness of increase in stack height to reduce air pollution was analyzed. Ambient air pollution level was predicted for different assumed stack exit velocity to asses the impact of stack exit velocity on ambient pollution load. Results of these observations are shown and elaborated for understanding and logical reasons for discrepancies are also stated in different parts of this section.

4.2 COMPARISON OF MODELING AND EXPERIMENTAL DATA

Ambient air quality modeling software has several utilities in controlling air pollution and implementation of rules and regulations. However, before starting with the utilization of the modeling software, its accuracy should be checked. To establish the acceptability of the Industrial Source Complex (ISC3) model for Bangladesh, especially for brick kiln pollution modeling, limited experimental data were collected on different days at some specified locations in a brickfield cluster in Aminbazar, Savar as shown in Figure 4.01. Two different locations were selected for sampling on different days. Sampling on day 1 was done near the edge of the cluster and that on Day 2 and 3 were done at the centre of the brickfield cluster.

The sampling data include the ambient concentration of Sulfur dioxide, Carbon monoxide, Hydrocarbon and Total Suspended Particulates (TSP). Similar data were also generated using the ISC3 model. Comparison of those data is presented in Table 4.01. The minimum averaging period allowed by ISC3 model is 1 hr but Gastec tubes give the instantaneous values of the ambient concentration. So 1-hr averaged concentrations were compared with the experimental values for gaseous pollutants for better comparison. 6-hr averaged concentrations are also shown for illustrative purposes. In case of Total Suspended Particulates (TSP) both the experimental and modeled values were measured for a 6-hr averaging time. Different observations from this comparison table were made and those are elaborated in the subsequent sections.

Table 4.01: Comparison of the experimental and modeling results

Observation day and sampling point	Pollutants	Averaging time	Modeled value	Reading by sampling
Day 1 24/02/2006 Sampling point 1	SO_2	1 hr avg.	0.044 ppm	0.05 ppm
		6 hr avg.	0.013 ppm	
	H-C	1 hr avg.	Negligible	0.011 %
		6 hr avg.	Negligible	
	CO	1 hr avg.	0.016 ppm	2.5 ppm
		6 hr avg.	0.012 ppm	
	TSP	6 hr avg.	508.5 $\mu g/m^3$	780.72 $\mu g/m^3$
Day 2 08/03/2006 Sampling point 2	SO_2	1 hr avg.	0.1205 ppm	0.06 ppm
		6 hr avg.	0.035 ppm	
	H-C	1 hr avg.	Negligible	0.02 %
		6 hr avg.	Negligible	
	CO	1 hr avg.	0.032 ppm	2.6 ppm
		6 hr avg.	0.016 ppm	
	TSP	6 hr avg.	1338 $\mu g/m^3$	1389.8 $\mu g/m^3$
Day 3 20/03/2006 Sampling point 2	SO_2	1 hr avg.	0.09 ppm	0.06 ppm
		6 hr avg.	0.03 ppm	
	H-C	1 hr avg.	Negligible	0.014 %
		6 hr avg.	Negligible	
	CO	1 hr avg.	0.02 ppm	2.8 ppm
		6 hr avg.	0.014 ppm	
	TSP	6 hr avg.	652 $\mu g/m^3$	728.5 $\mu g/m^3$

4.2.1 Sulfur dioxide

During the dry season experimental data for SO_2, CO, Hydrocarbon and Total Particulate Matter were collected on different days. From the 1-hr averaged experimental values of SO_2 it was found that, the concentrations of ambient SO_2 were more or less same for different days. Using the ISC3 model, concentrations of SO_2 were found to vary within a certain range. Naturally, the lower time average values of those concentrations were found more than values generated with a higher time average.

In general the experimental values varied from 0.05 to 0.06 ppm whereas the modeling values varied from 0.044 to 0.12 ppm. This is shown through a comparative bar chart in Figure 4.02 with the Bangladesh standard value for SO_2. Ambient concentration of SO_2 was found satisfactory according to that standard. Gastec tubes give the instantaneous concentration values and that can vary within a certain range depending on when the measurement was made. Moreover, as we know that the Gastec tube readings have some errors and don't give precise result, this modeling values can be considered acceptable for the large scale modeling. This negligible discrepancy in result will not affect much when this model would be used for long range modeling such as for one month or several months or year.

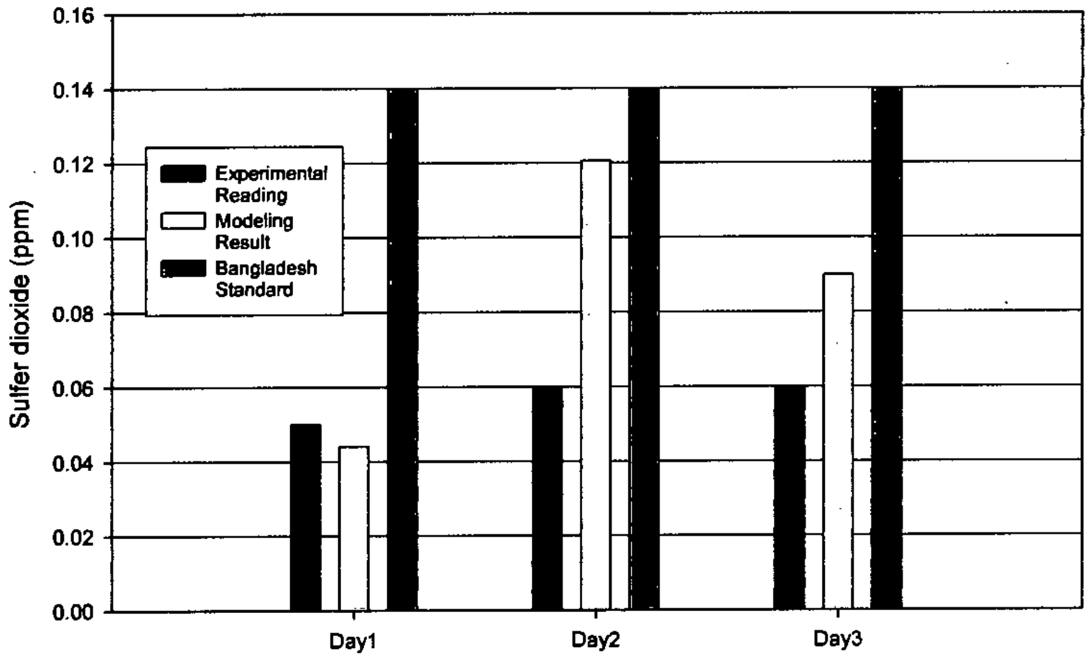


Figure 4.02: Comparison of different SO_2 data

4.2.2 Hydrocarbons

The most confusing and difficult part of the measurement was when Hydrocarbons and Carbon monoxide were considered. Both the experimental and modeling results of hydrocarbon were too small to be compared properly. The experimental values were determined using a Gastec tube of wide range. So it was difficult to identify the accurate values of the concentrations with that wide scaled Gastec tube. From modeling, the exact values of concentration were generated but those were also too small to be considered. Comparing with the other pollutant concentrations in ambient air, concentrations of hydrocarbons were considered to be negligible. So in the subsequent modeling works hydrocarbons concentration have not been considered for the case studies, instead TSP and Sulfur dioxide were used.

4.2.3 Carbon monoxide

When the concentrations of CO were considered, a significant difference between the experimental and modeling results was seen. Modeling results varied from 0.012 – 0.32 ppm whereas experimental values varied from 2.5 to 2.8 ppm. This large discrepancy can probably be explained by considering the interferences of the transport vehicles moving around the sampling sites. As all the samplings were done within the brickfield areas and there were continuous movement of trucks around the sampling points carrying raw materials and bricks, the ambient concentrations were affected. Those vehicles exhausted substantial amount of pollutants into the atmosphere and CO is one of the major pollutant in that. Thus the concentration of ambient CO in the whole brickfield cluster area was generally higher compared to the normal ambient concentration of other places of the surroundings. Moreover pure ambient air itself contains CO up to 0.2 ppm. Here the modeling result was based on the brickfield stack emissions only but the experimental values were the combined effect of stacks and vehicles, thus making the CO concentration higher. Therefore, due to the lack of facility to do source apportionment of the ambient pollutant, it was not possible to determine the exact effect of the brick field sources. Considering the major interferences of the secondary pollution sources and the accuracy of results for other pollutants, it can be expected that modeling results of CO could be compared with the practical results if the secondary sources of pollution were absent.

4.2.4 Total Suspended Particulates (TSP)

Good agreement was found between experimental and modeling results of ambient concentrations of Total Suspended Particulates (TSP). On the first day, the 6-hr average experimental value was 781 $\mu g/m^3$ whereas that from the modeling was 581 $\mu g/m^3$. These values were found to be different for the second and third day. On the second day the experimental value was 1390 $\mu g/m^3$ whereas the modeling result was 1338 $\mu g/m^3$ and on the third day the experimental value was 729 $\mu g/m^3$ whereas the modeling result was 652 $\mu g/m^3$. Like day 1, all these data were calculated considering a 6-hr averaging period. These results are shown in a comparative bar chart in Figure 4.03 along with the Bangladesh standard value for TSP. Ambient concentration of TSP was found quite higher according to that standard. Experimental data of the first day were collected at the edge of the brickfield cluster besides the road. Last two data were collected in the centre of the cluster where vehicle interference was less. So the last two values were quite near to the modeled values and the first experimental value was found little higher than the modeled value due to the dust contribution from the road.

However, in general it was quite satisfactory and this provides good evidence to strengthen the acceptability of the modeling software. It should be noted that though the last two data were collected at the same point but they had huge differences. This is because of the different meteorological conditions on these days. On the second day most of the time wind blew in such direction that pollutant from the most of the stacks transported towards the sampling point. So on that day the concentration value was found very high compared to the sampling data of the other day.

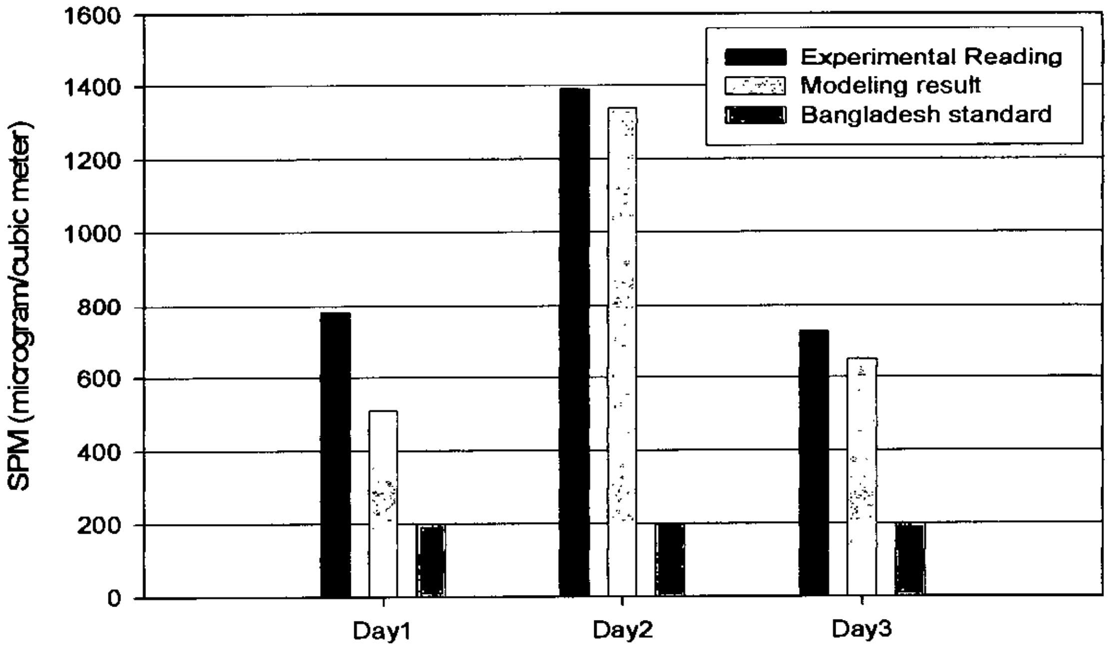


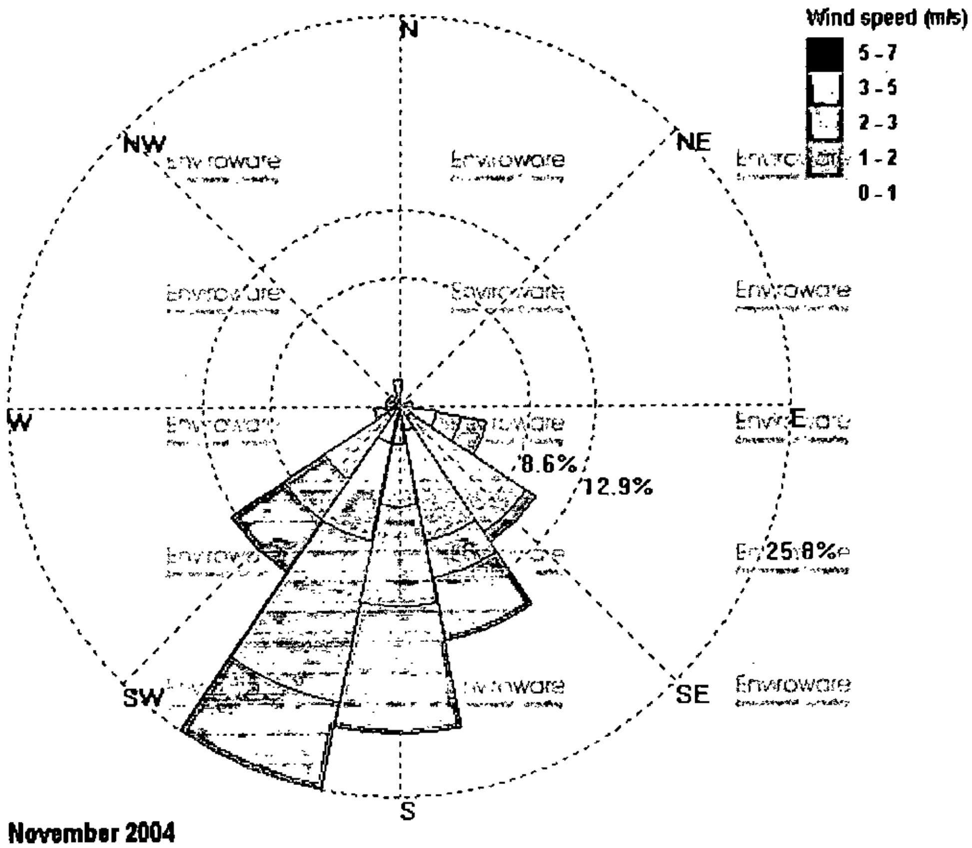
Figure 4.03: Comparison of different TSP data

Apart from all these experimental errors, there might be some modeling errors. The meteorology data for the modeling were taken from the World Meteorological Organization which gives 6 hour interval values (i.e. only 4 data for a day). For simplicity of calculation, every one hour value was considered to be same for next five hours. However, in practice that is far from reality. Another possible reason for this discrepancy can be in the source emission data. Source data was taken from the earlier project report of the Chemical Engineering Department, BUET and considered to be same for all the brick kilns. It was also assumed that these sources emitted at the fixed rate constantly for total operating hours. However, practically this value is not same for all the kilns and no kiln deliver at a constant rate for the total operating period. As all of the kilns are operated by coal firing, the emission depends on coal charging time. When the fresh coal is charged there is an incomplete combustion due to lack of sufficient air to burn that coal. So during the coal charging time the emission rate is high and the flue gas looks black because it is full of carbon soot. After some time the combustion occurs with sufficient air and flue gas doesn't look black any more. So there is always a remarkable variation of flow rate and pollutant concentration during incomplete and complete combustion cycles. Since these are occurring in regular cycles of 20-30 minutes, the flow can be assumed to be fixed for the longer observation period. To make this more accurate, the source data was measured for three consecutive cycles and the average value was taken for modeling.

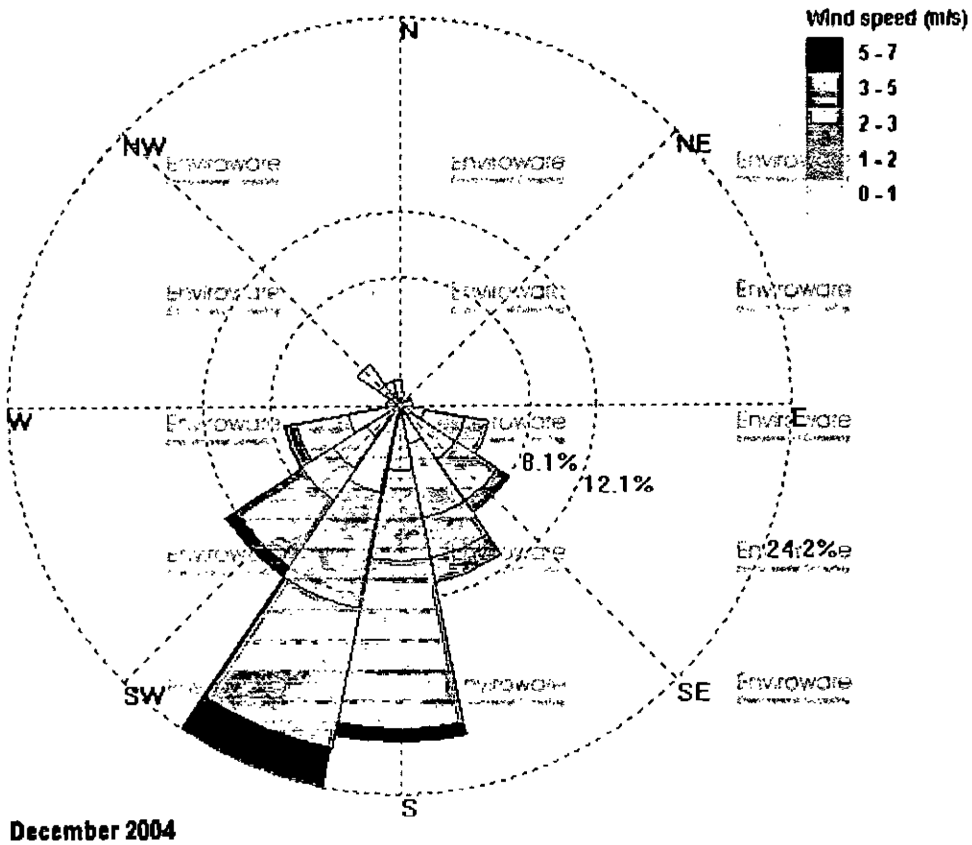
As discussed earlier, meteorological data and measurement methods along with some general simplified assumptions could be the sources of errors in the process of the verification of the accuracy of ISC3 model. Considering these probable errors and some measuring flaws, the Industrial Source Complex (ISC3) model can be considered as an acceptable one for Bangladesh, especially for brick kiln pollution modeling. So this model can be adopted for this thesis work.

4.3 EFFECT OF METEOROLOGICAL CONDITIONS

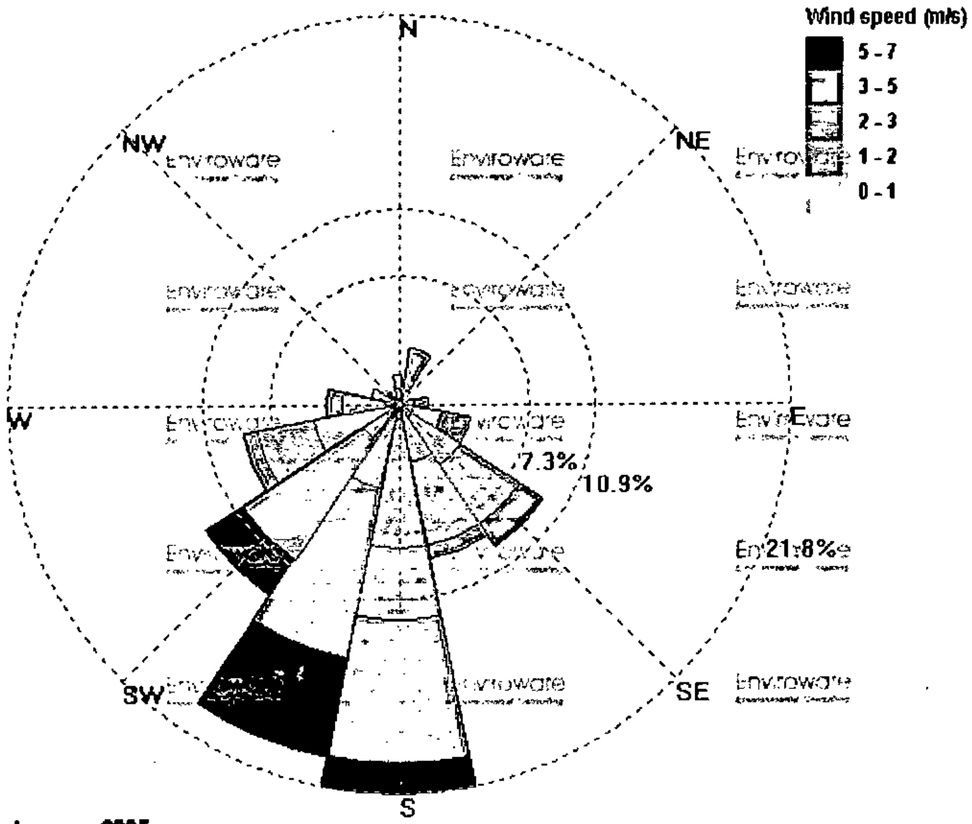
Meteorological condition is one of the most important factors that can effect the ambient concentrations. Dispersion of pollutants depends largely on the meteorological condition of the surroundings. A part of this thesis work was intended to consider the effects of the meteorological conditions. To verify the effect of the meteorological conditions on the ambient concentration, different runs were made with the ISC3 model for the same receptor point. As all the brickfields in Bangladesh operate only in the dry season, meteorological data of November 2004 to March 2005 were considered for this modeling purpose. These data were collected from the reliable sources of World Meteorological Organization. Most common and major components of those meteorological data were wind direction and velocity. For a specific time period, these two data items with prevailing time are shown in Figure 4.04 through the windrose diagrams. Windrose diagram explains the direction and prevailing time of certain wind flow as percentage over the total observation period of that diagram. In the Figure 4.04 for November 2004, it is shown that wind blew slightly towards the south west direction for the maximum time and that was 25.8% of the total observation period (i.e. 30 days) of that windrose diagram. Similarly wind blew towards the south east direction for 13% of the total time in November 2004. Maximum wind velocity in November 2004 was 5 m/s but in the other months it was found to be above 5m/s as shown by dark black color in other diagrams. So velocity distribution for a certain period can be retrieved from these windrose diagrams.



November 2004



December 2004



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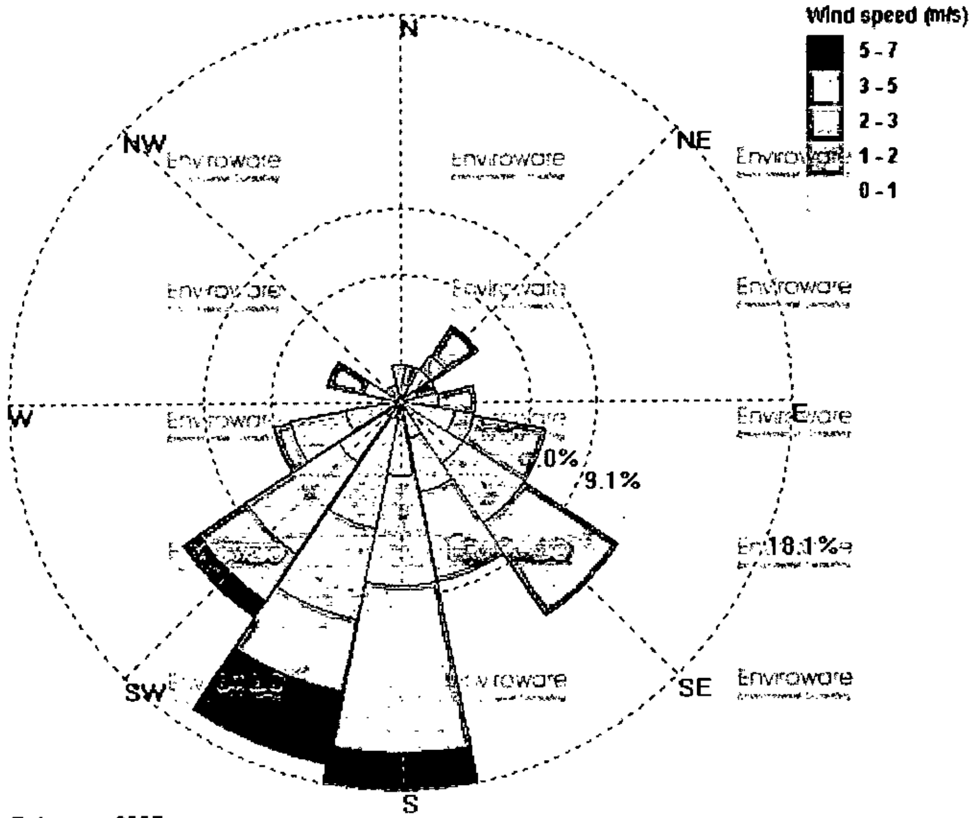

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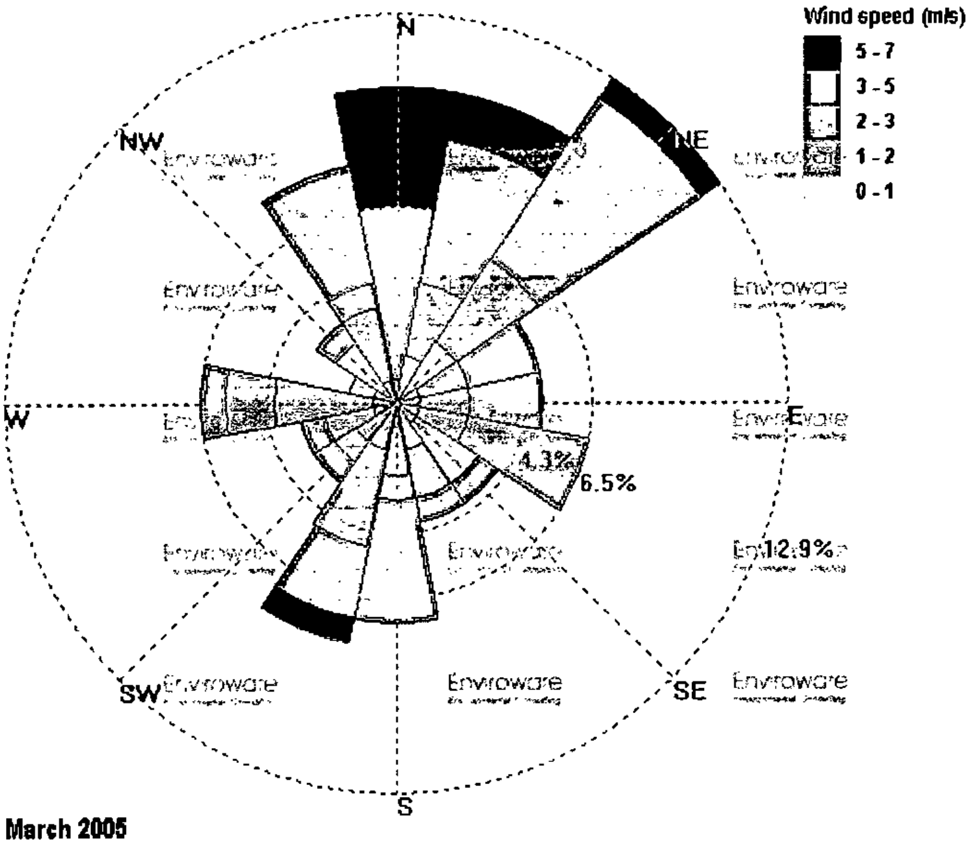

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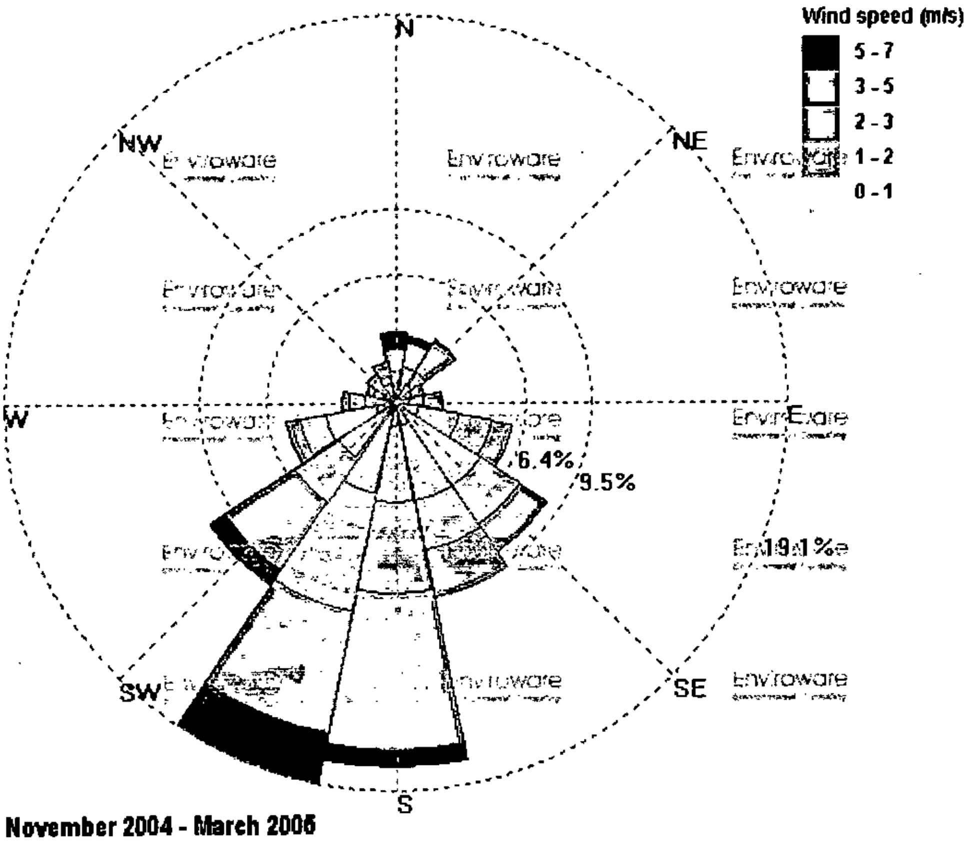

November 2004 - March 2005

Figure 4.04: Windrose diagram of different months considered for modeling

Velocity distribution can also be represented by the bar charts as shown in Figure 4.05. Here different velocity ranges are specified and the prevailing time for each range is plotted against the velocity ranges. The maximum range was 5.0-7.0 m/s but that was not common for the dry season. For December 2004, wind velocity was 1.0-2.0 m/s for the 29% of the total observation period (i.e. 31 days). Whereas the maximum velocity 5.0-7.0 m/s ranges prevailed only for 4% of the total observation period. These bar charts can give idea of the velocity range that prevailed for maximum time and the contribution of each velocity range in a certain observation period. So these bar charts can also be a medium of velocity distribution representation for certain period. The overall velocity distribution for the whole dry season (November 2004 – March 2005) is also shown in the Figure 4.05.

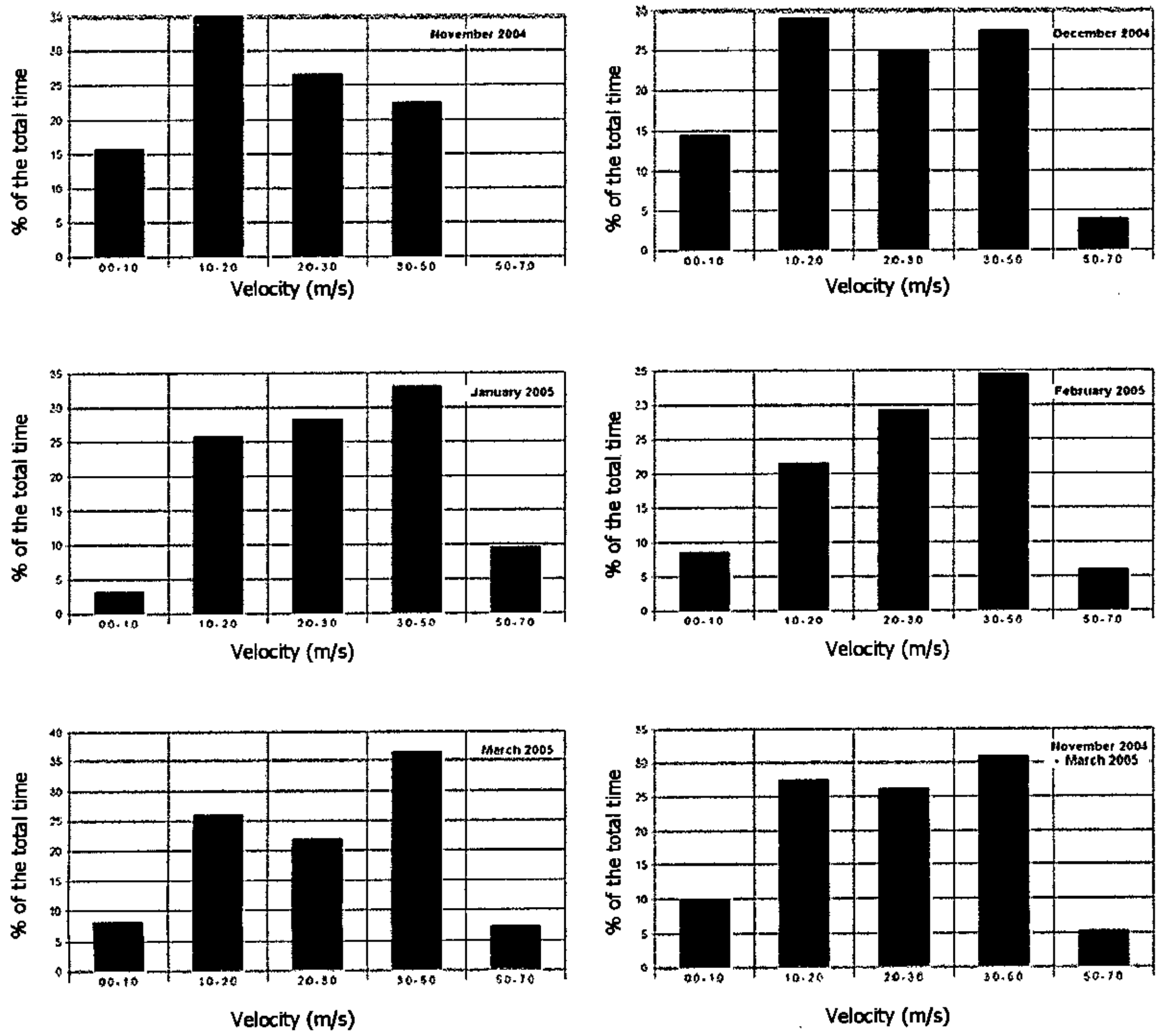

Figure 4.05: Velocity distribution for different months

As discussed earlier, because of the different wind direction and velocity for different months, pollutants traveled to different directions. Flow direction of the pollutants prevailing for maximum time of any month is shown in Figure 4.06. This figure is drawn according to the windrose diagram of the specified months as shown earlier. From this figure it is clearly observed that pollutants dispersed in the south direction for most of the time in January and February, whereas in November and December, this direction was slightly southwest. This trend was totally different for March. Pollutants moved to the northeast direction for maximum time of March. These are the three major flow directions observed during our observation period. Therefore, from this figure it is seen that, central Dhaka was not affected significantly by the pollution from the brickfields of Aminbazar.

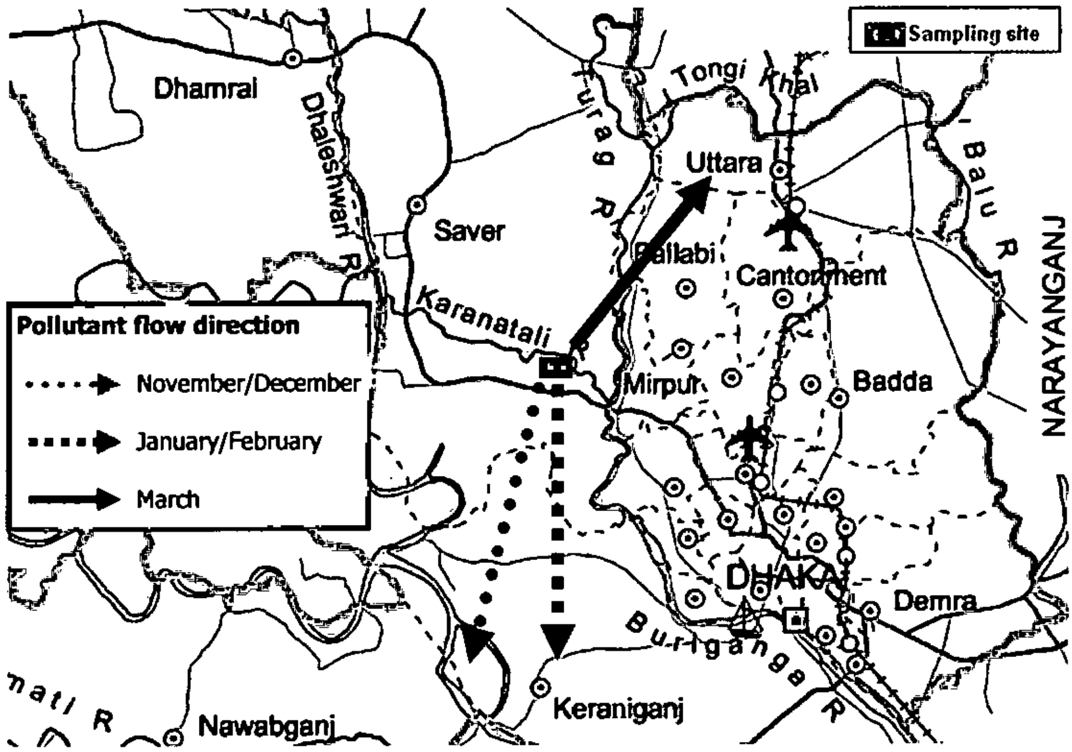

Figure 4.06: Direction of the pollutant flow prevailed for maximum time

Monthly average concentrations of different pollutants from November'04 to March'05 at a certain point are shown in the Figures 4.07 to 4.09. Here all the stack source data for each pollutant were assumed same and all the concentrations were determined at the centre of the cluster. These data are listed in Table A-01. It is clearly evident that the monthly average concentrations are not same for all the months. This is because of the different meteorological conditions in different times. Since in the dry season, wind velocity and change in direction of wind are very small, the monthly average concentrations did not vary much from each other. The last bar of each figure represents the average concentration of five months at the centre of the brick kiln cluster. For Carbon monoxide, the monthly average concentrations varied within the range 0.015 – 0.018 ppm over the five month observation period. Similarly for Total Suspended Particulates, monthly average concentrations were in the 688 – 853 microgram/m^3 range. It is interesting that the concentration trend is similar for CO and particulate matters but it is little different for SO_2. This is because, SO_2 is not only dependent on the dispersion but also the reaction mechanism involved in the atmosphere. Due to this reaction with other atmospheric components, the concentration of SO_2 doesn't follow the same trend like CO and Total Suspended Particulates (TSP). This mechanism is discussed in Chapter 2.

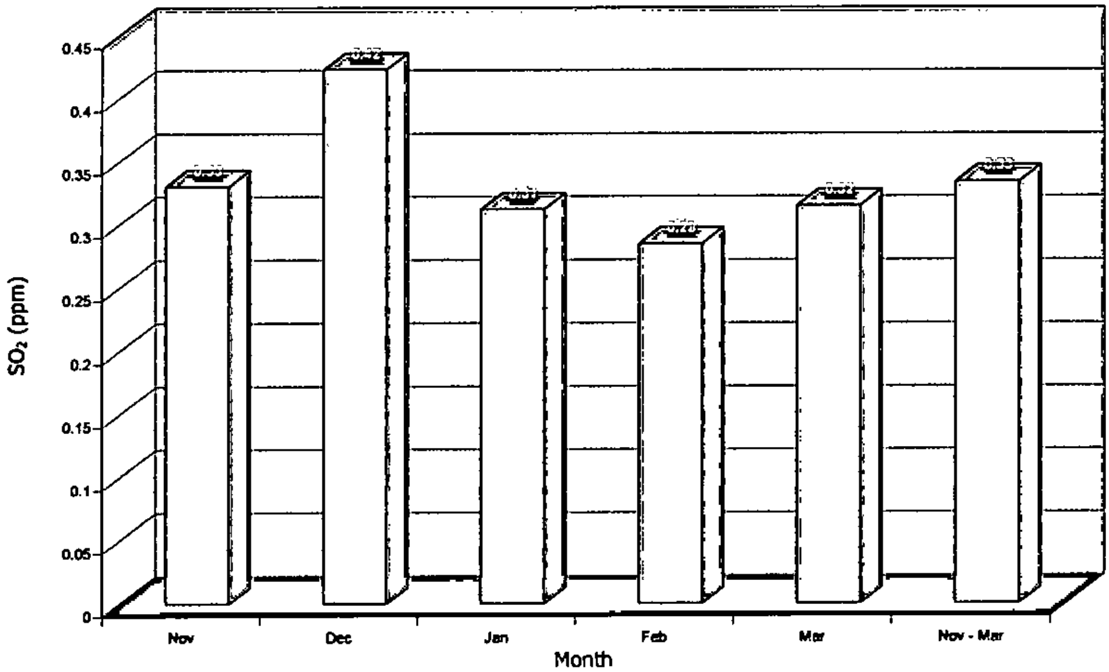

Figure 4.07: Monthly average concentration of SO_2 at the centre of the cluster

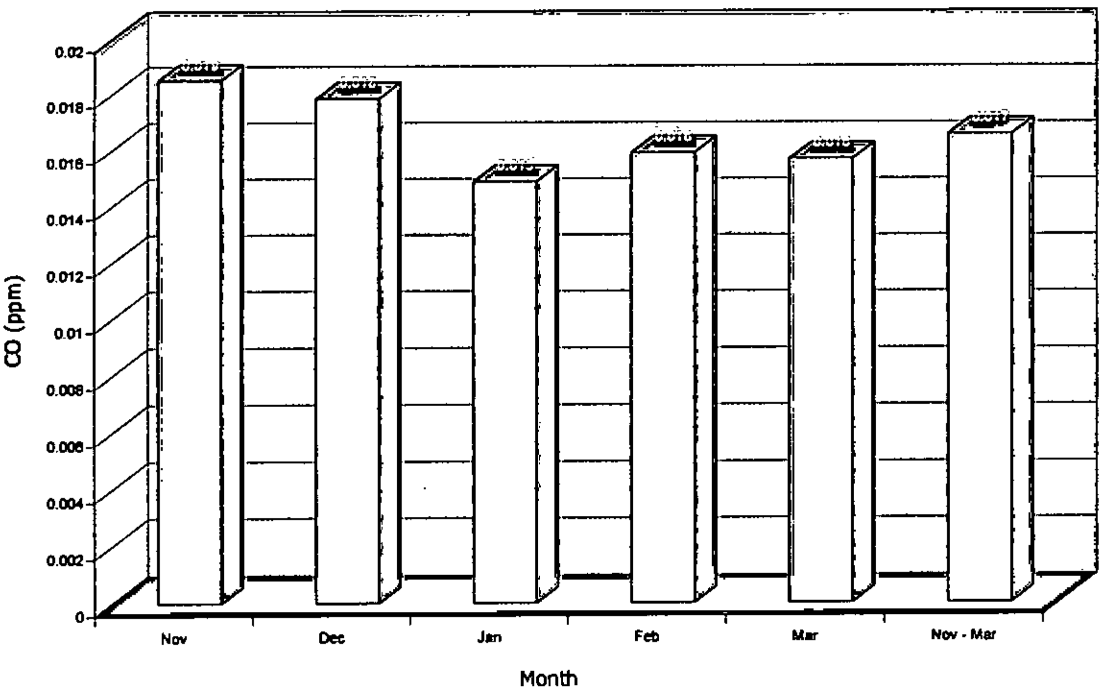

Figure 4.08: Monthly average concentration of CO at the centre of the cluster

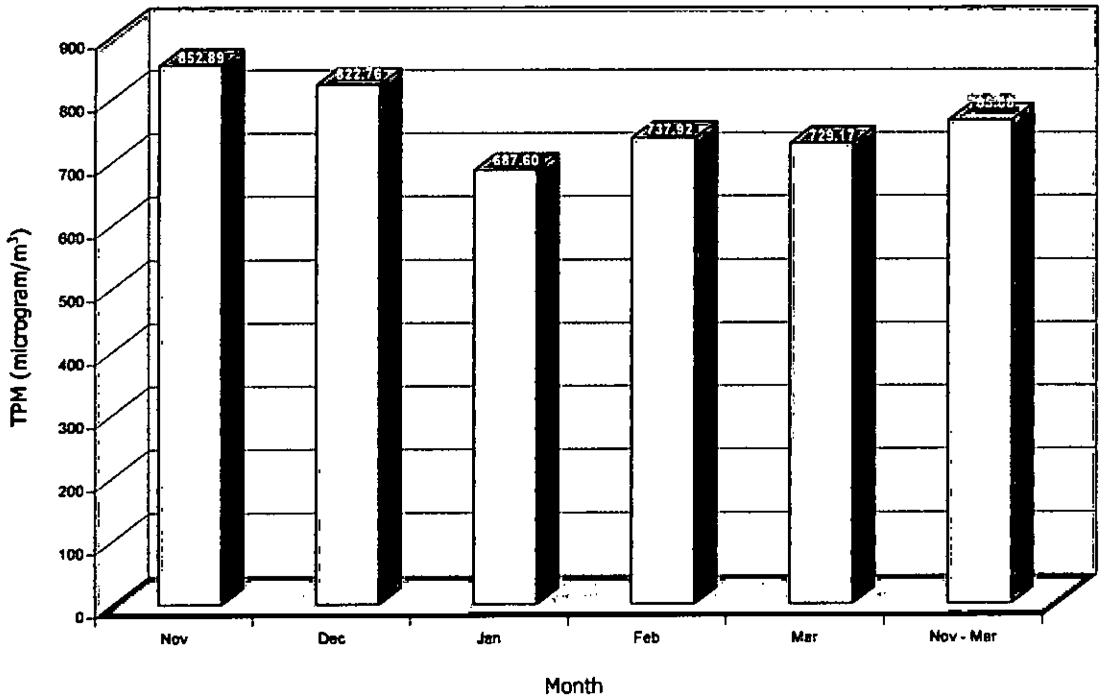

Figure 4.09: Monthly average concentration of Total Suspended Particulates (TSP) at the centre of the cluster

The monthly average concentrations of different pollutants at the worst point are shown in the Figures 4.10 to 4.12. All the stack source data for each pollutant were also same in these figures and all the concentrations are measured at the worst point of the surroundings.

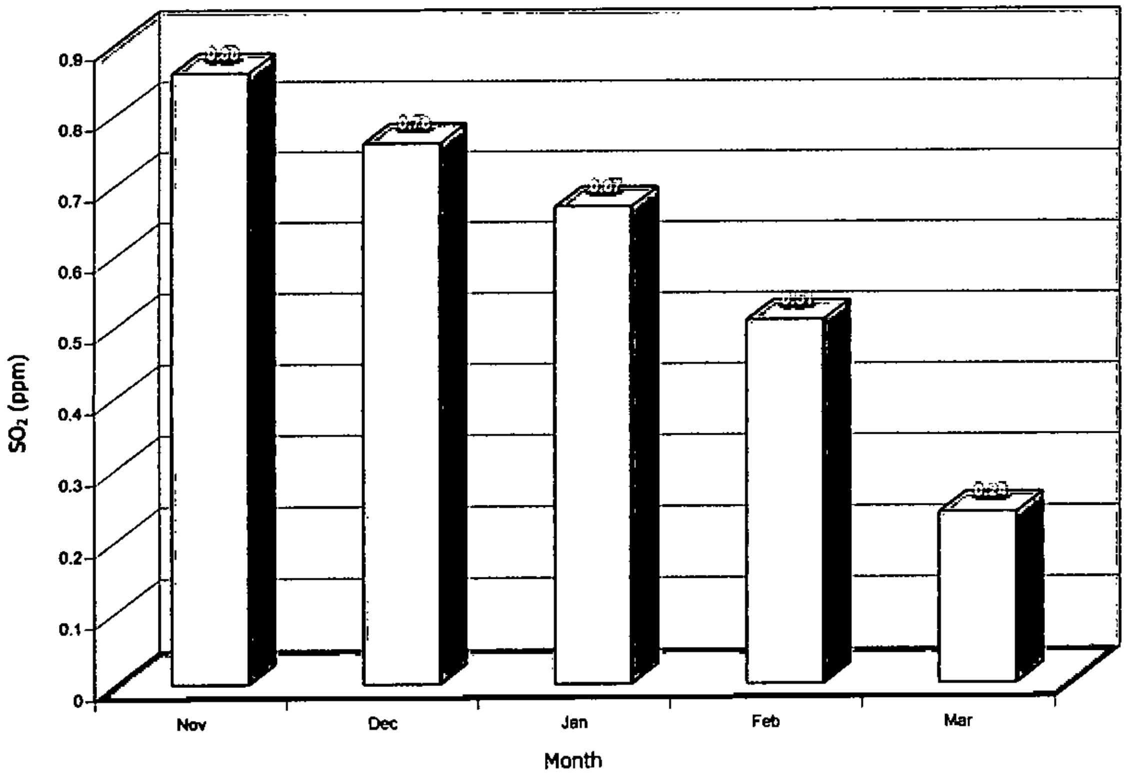

Figure 4.10: Monthly average concentration of SO_2 at the worst point of surroundings

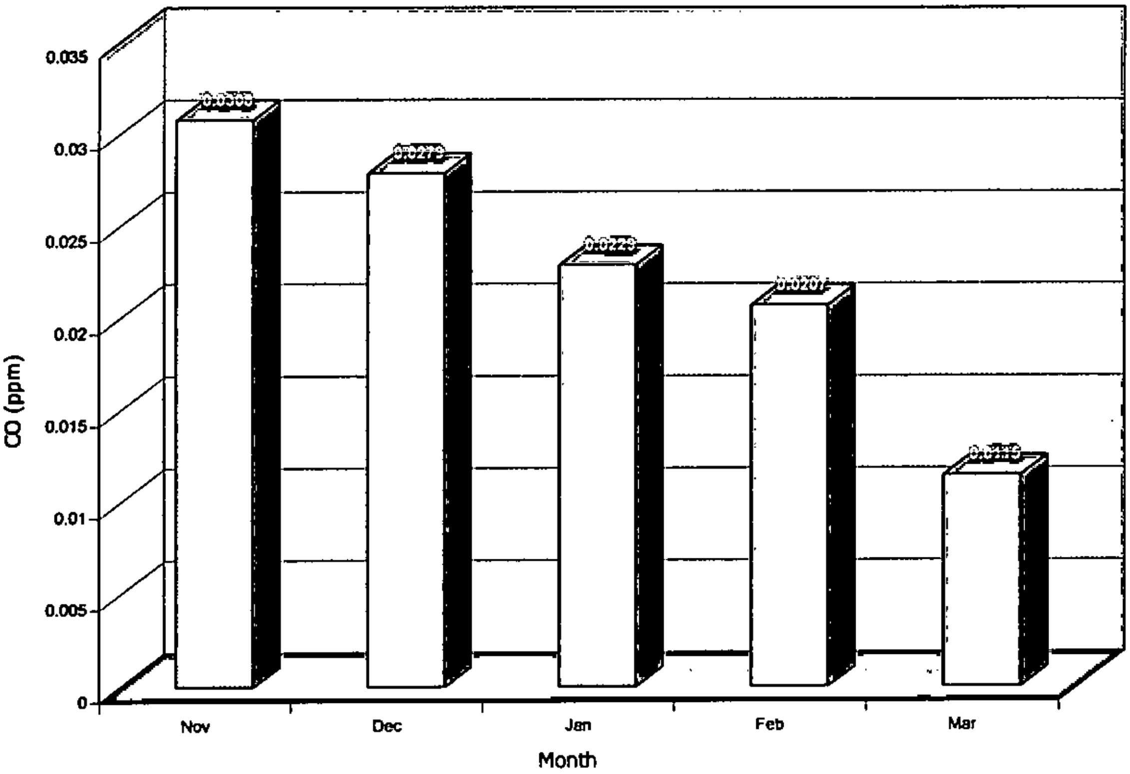

Figure 4.11: Monthly average concentration of CO at the worst point of surroundings

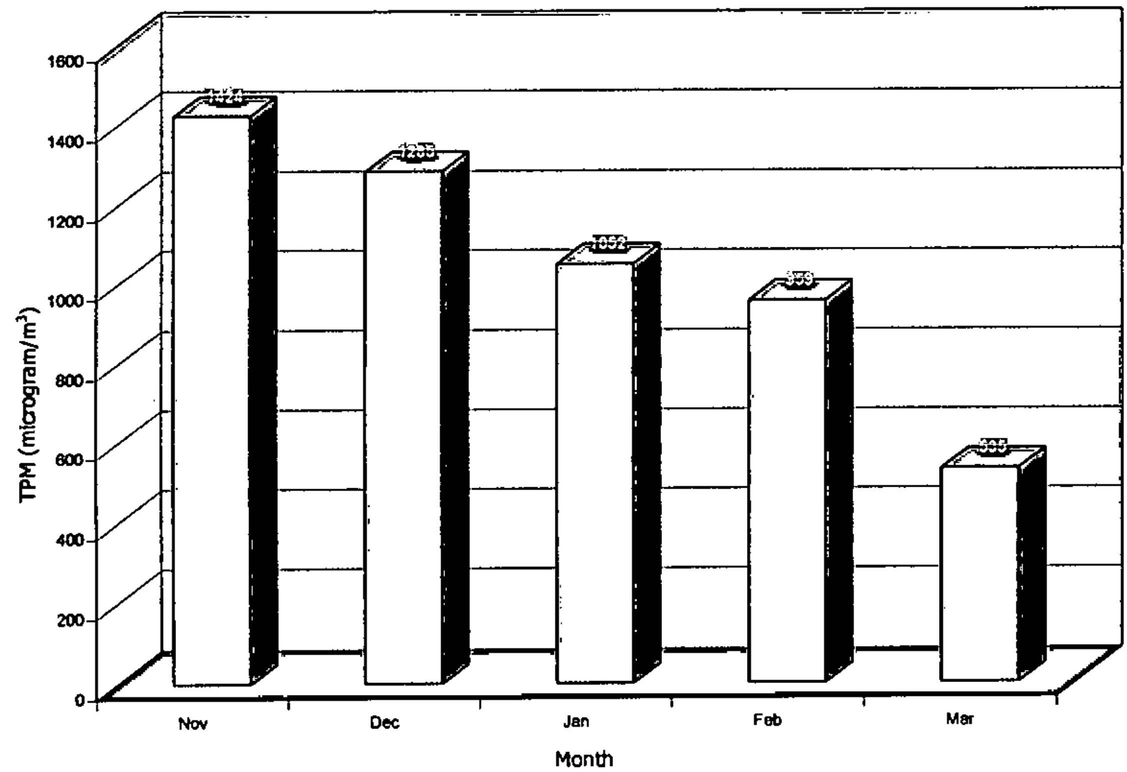

Figure 4.12: Monthly average concentration of Total Suspended Particulates (TSP) at the worst point of surroundings

As during the dry season most of the time wind blows from north to south, the worst point was found to the south of the brickfield cluster. To be exact, the worst point was the 1 kilometer south from the centre of the previously specified grid system for this modeling. This point was found to have highest ambient pollutants concentration for maximum time for all the pollutant considered. These representations of data don't have any specific relation with this particular point but it is used to show the effect of meteorological condition at a distant place from the sources. From figure it is seen that the 6-hr averaged ambient concentration of SO_2 at that specified location decreased from 0.86 ppm to 0.24 ppm over the 5 month observation period. This trend is found for CO and TSP also. 6-hr averaged ambient concentration of CO at that point decreased from 0.0308 ppm to 0.0115 ppm and that of TSP decreased from 1424 microgram/m^3 to 535 microgram/m^3 over the same observation period.

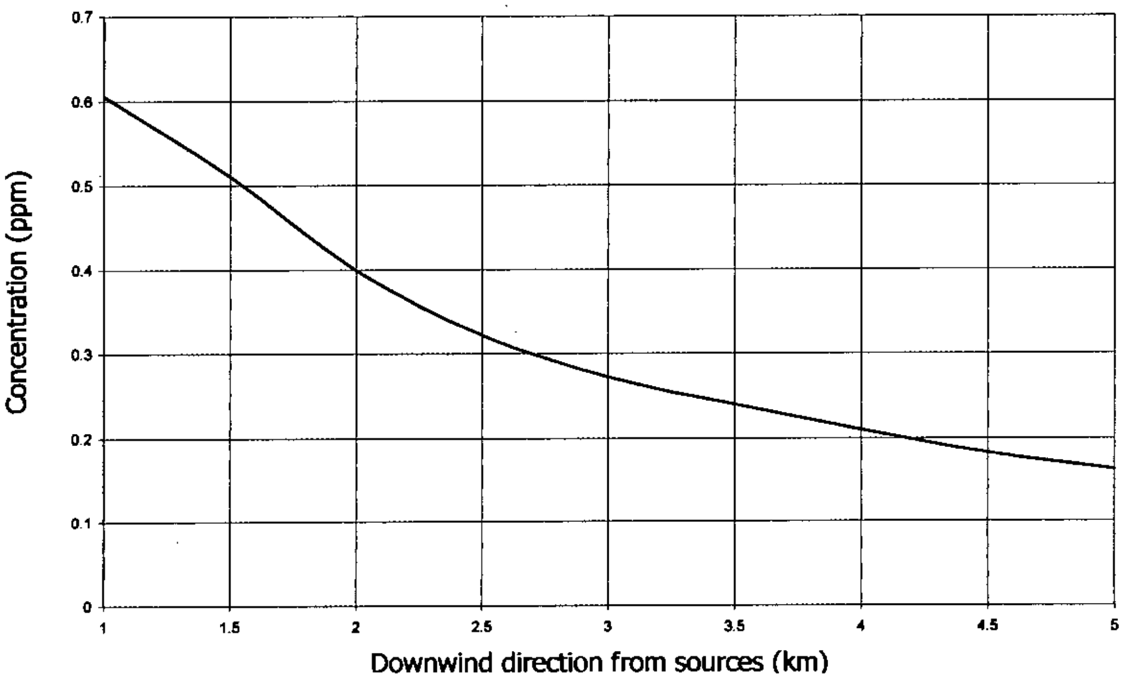

Figure 4.13: 5-month averaged concentration of SO_2 at the downwind direction

As stated before, because of the different meteorological conditions in different times, the results were not same. In most of the time of November and December, wind blew to the direct south and slightly south-west direction. Most of the stacks were found in the north and slightly north-east direction of the worst point as shown in Figure 4.01. So the concentration was found very high there and that became the worst point. However, after November and December the direction of wind didn't remain steady and fluctuated very much. That made the pollutants disperse into the atmosphere rather than moving towards a certain direction. Finally, in March the wind direction varied the most and the pollutants dispersed in all directions. So that this made the concentration of the pollutants lower with time at the worst point found earlier. During November to March, all the wind velocities and directions are shown through wind rose diagrams in Figure 4.04 and those data are compiled in Tables B-01 to B-05.

The downwind (north to south) concentration values of SO_2 for a five month averaging period are shown in Figure 4.13. As the brick kilns within the cluster were present up to 1 kilometer south from the sources, the concentration values were considered after that distance. It is seen from the curve that, the concentration level decreases exponentially as one moves far from the source. At the edge of the cluster the concentration level was 0.62 ppm, but it dropped to 0.165 ppm at a point 5 km far from the sources in the downwind direction. This is the typical phenomena of pollutant dispersion in the downwind direction. According to this trend the pollutant level would be negligible at a downwind point very far from the sources. This scenario was little different within the cluster region. Concentration was normally decreasing along the downwind direction unless there were other sources emitting near the measuring point. Because of the interference from multiple sources, the pollution level was found more compared to locations nearer the sources. Then again the concentration decreased along the downwind direction. To avoid this fluctuating characteristic, this curve was drawn for the downwind distance outside the cluster.

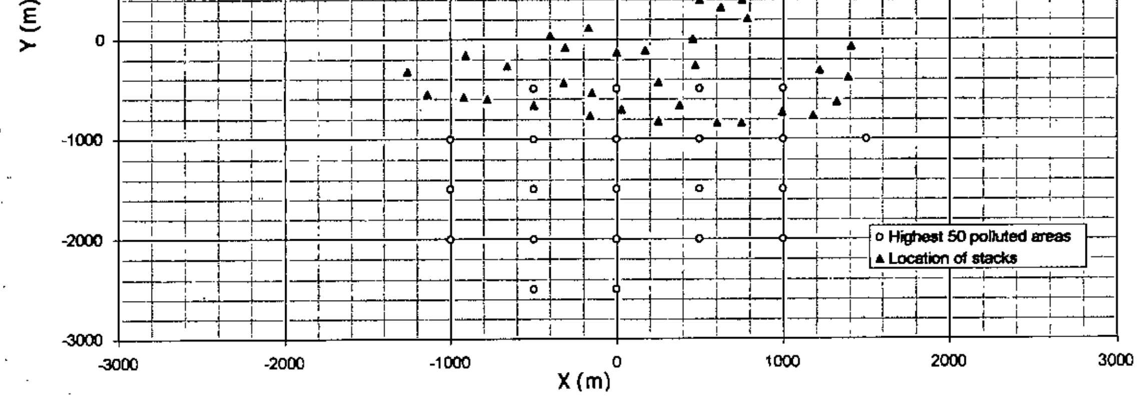

Figure 4.14: Highest 50 Monthly average concentrations of SO_2 at surroundings

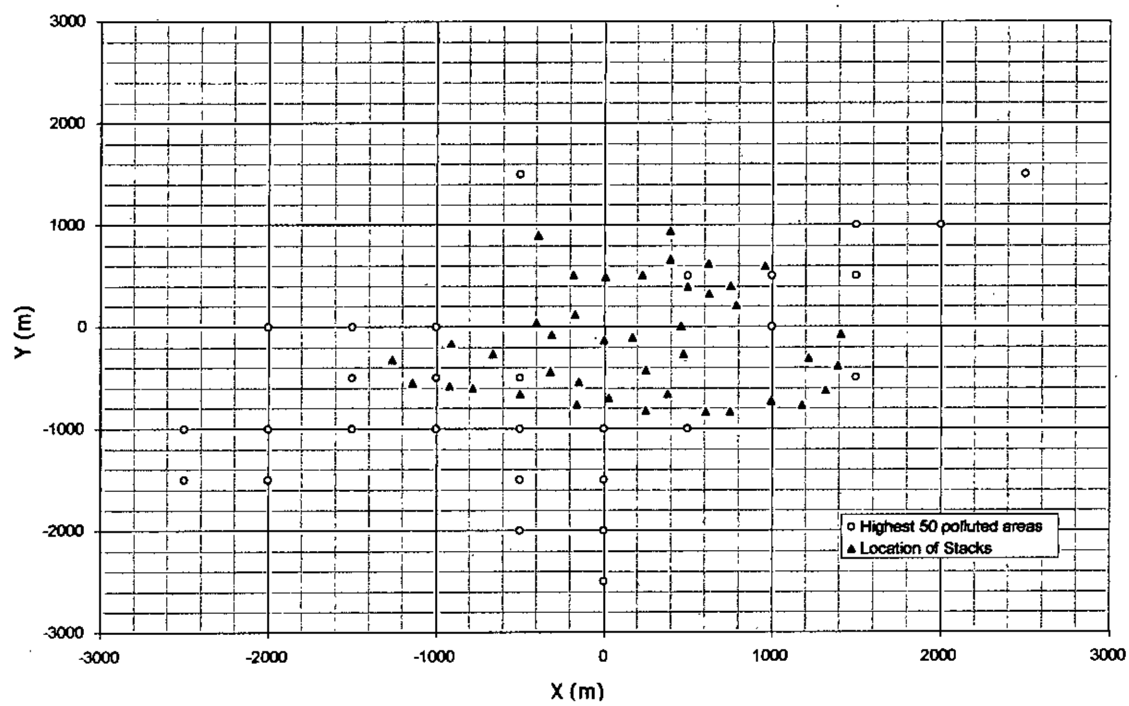

Figure 4.15: Highest 50 Monthly average concentrations of Total Suspended Particulates (TSP) at surroundings

Effect of meteorological conditions can clearly be understood through the figures showing highest pollutant concentration points and the source locations. Highest 50 monthly average ambient pollutant concentration points and the location of the 41 stacks are listed in Table A-5 and are shown in Figures 4.14 and 4.15. Those diagrams are drawn for SO_2 and TSP for the whole modeling period of 5 months. Values for SO_2 varied from 0.46ppm to 0.86ppm and that for particulate materials varied from 1884μg/m^3 to 2437μg/m^3. Within this period, the highest monthly average concentration value of each month was determined for each pollutant. From those 5 monthly averaged values (one for each month) for each pollutant, the highest one was selected and plotted against that pollutant. That represents the worst case possible with this meteorological condition. Thus Figure 4.14 is drawn for SO_2 and Figure 4.15 is drawn for TSP. Those monthly average values don't represent any specific month; one can be of November 2004 and other can be of March 2005 but all of them are within the modeling period November 2004 to March 2005. From the figures it is evident that the maximum concentration areas are along the direction of the wind from the stacks. As the values were the monthly averages within the whole 5 month period so few values are found at dispersed regions rather than along the wind direction. This is because except November and December 2004, wind blew towards different directions and thus carried maximum pollutants at different points rather than towards a fixed direction. So during that 5 months there were many highest monthly average concentration points in the surroundings rather than at the fixed region. As only one monthly average values for the 5 month period is chosen for a specific point, so this point could be anywhere based on its numerical value. Thus some values were found little dispersed.

However, it should be noted that, all the 50 highest ambient concentration points doesn't represent equal concentration values. From the modeling output as shown in Figures 4.10 to 4.12, it is found that at any case the worst point was the same based on the wind direction prevailing for maximum time. The slightly lower values were within the highest 50 values but those were not consistent for the whole modeling period. These are rather the unanticipated monthly averaged highest value because of fluctuating wind direction. As mentioned earlier for a fixed point there were 5 monthly averaged values and only the highest one was considered, so these values could be of any month considering their numerical values. These values could be low again if the wind direction changes. These results are only just impressions of worst possible case of pollution for this meteorological condition and are subject to change at any moment with the change in wind direction. When the total modeling period is to be considered and 5 month averaged concentration is to be determined then the worst point mentioned earlier would be the area of maximum ambient pollutant concentration for the overall 5 month period.

4.4 EFFECT OF STACK HEIGHT

One of the most important factors that effect the ambient pollutant concentration is the height of the brick kiln stack. It is a general conception that a higher stack height contributes to lower ambient concentration. From that idea, Government of Bangladesh has already imposed an environmental rule of minimum 120 feet stack height. This part of modeling was done to verify this idea and to identify the impacts of different stack heights. As there are some new technologies available now with a very low stack height, this observation was done for different stack heights starting from 5 meter up to 50 meter. As the average stack height near Dhaka is now around 38 meter so it was also taken into the consideration. Change in ambient concentration at the centre of the brickfield cluster with the stack height is shown in the Figures 4.16 to 4.18. These ambient concentrations are the 5 month (November'04 –March '05) averaged values at the specified location (i.e. centre of the cluster). Data for these curves are listed in

Table A-03. Similar data is also shown in Table A-02 for one month average. Using these data similar curves can be drawn.

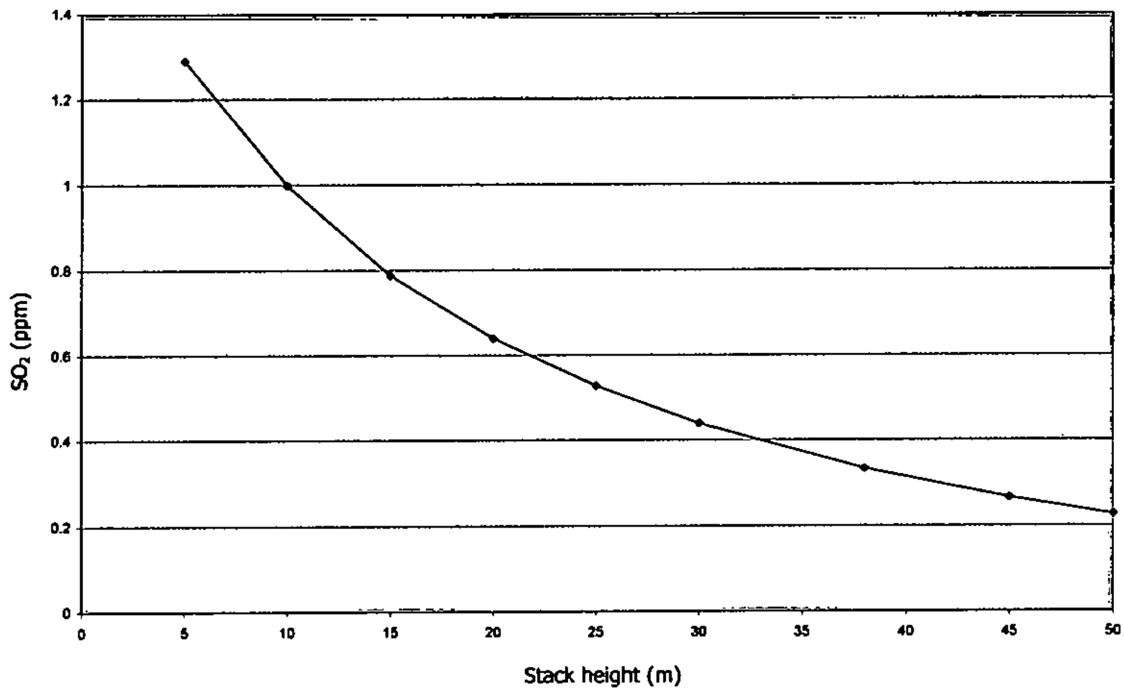

Figure 4.16: Change in SO_2 concentration at the centre of the cluster with stack height

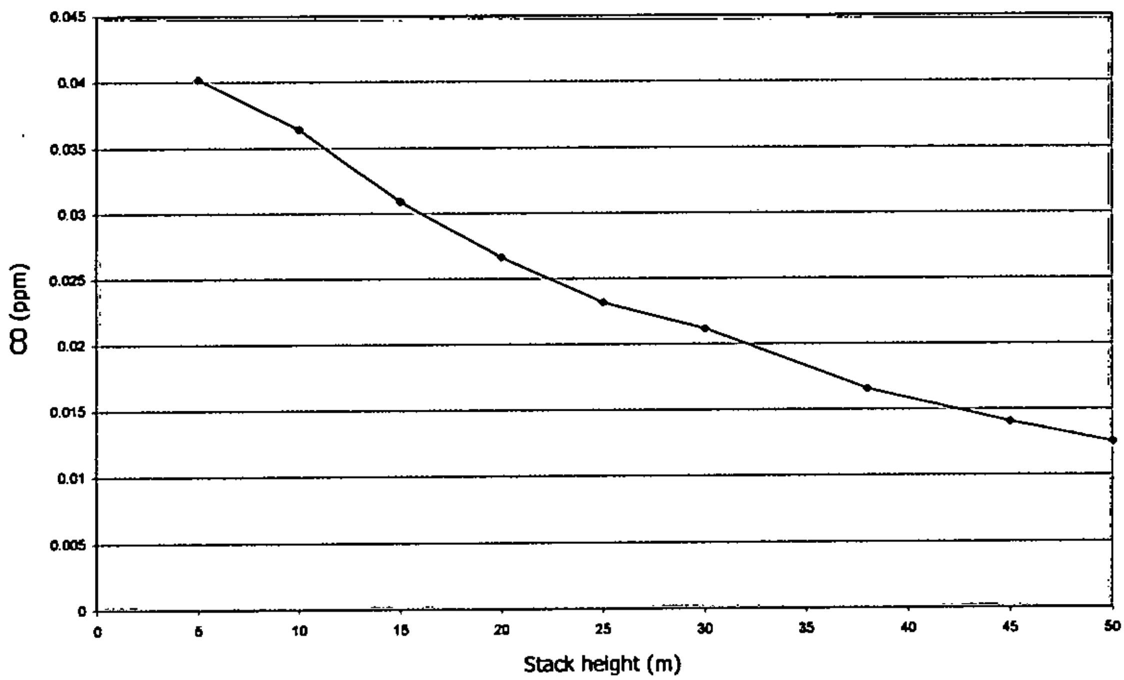

Figure 4.17: Change in CO concentration at the centre of the cluster with stack height

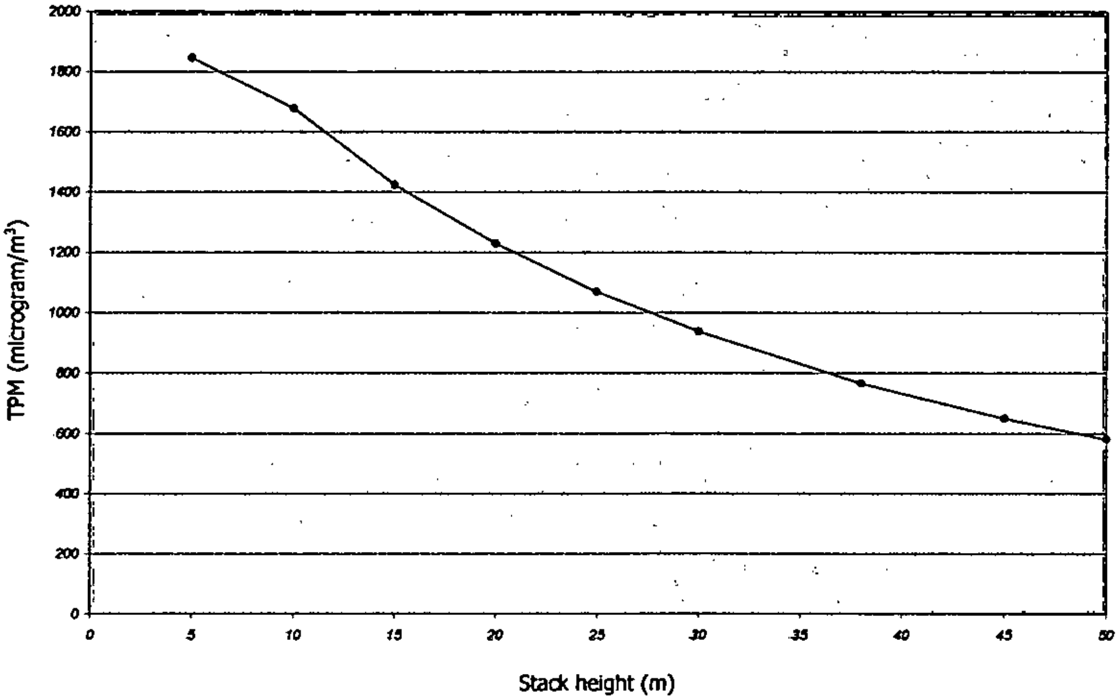

Figure 4.18: Change in Total Suspended Particulates (TSP) concentration at the centre of the cluster with stack height

From the figures, it is quite evident that when the stack height increases the ambient concentration of pollutant at the centre of the cluster decreases. In case of SO_2 the ambient concentration was 1.3 ppm for stack height 5 meter and that dropped to 0.22 ppm when the stack height was 50 meter. As the stack height increased the pollutants got more dispersion area compared to the shorter stack emissions. So the pollutants dispersed in to a large area and the average ambient pollutant concentration became lower. When the stack height was less, the pollutants dispersed into a smaller area making the ambient concentration higher. Thus it affected the ambient concentration of the surroundings whereas higher stacks affected the ambient concentration of the more distant places from the sources, though in this case pollutant load was lower at the distant places. Among these three curves for three different pollutants, the trend was a little different for the SO_2. This was because SO_2 didn't behave similarly in the atmosphere like the other pollutants such as TSP and CO. As discussed in Chapter 2, reaction mechanism of SO_2 in presence of other materials in the atmosphere was the reason for this slightly different behavior.

Though in both cases total pollutant contribution into the atmosphere is same, but making stack height higher could be a temporary solution to make the average ambient pollutant concentration lower. In both cases amount of total pollutant is equal but for higher stack height pollutants was distributed in to a large area and thus became less concentrated in the surroundings. It is also to be noted that the slope of the curve decreases with the increase in the stack height. In other words the change in ambient air concentration with the stack height decreases with the increase in stack height. It suggests that there will be a negligible change in concentration with increase in stack height beyond a certain height. In the Figures 4.16 to 4.18, it is seen that the concentration changes little as the height increases beyond a certain value. These curves are drawn up to 50m stack height but the curves appear to be horizontal after certain stack height and show strong evidence of the negligible effect beyond a certain stack height. Therefore, increase in stack height alone until the ambient concentration reaches a certain level cannot be the ultimate solution to combat the air pollution problem.

4.5 EFFECT OF STACK EXIT VELOCITY

Stack exit velocity is another factor that might influence the ambient air pollutant concentration. So a part of this thesis work was intended to verify the effect of stack exit velocity on the ambient pollutant concentration. Change in ambient concentrations at a certain location with the stack exit velocity is shown in Figure 4.19. Data for this curve is listed in Table A-04. Here the model was run for the gaseous pollutant SO_2.

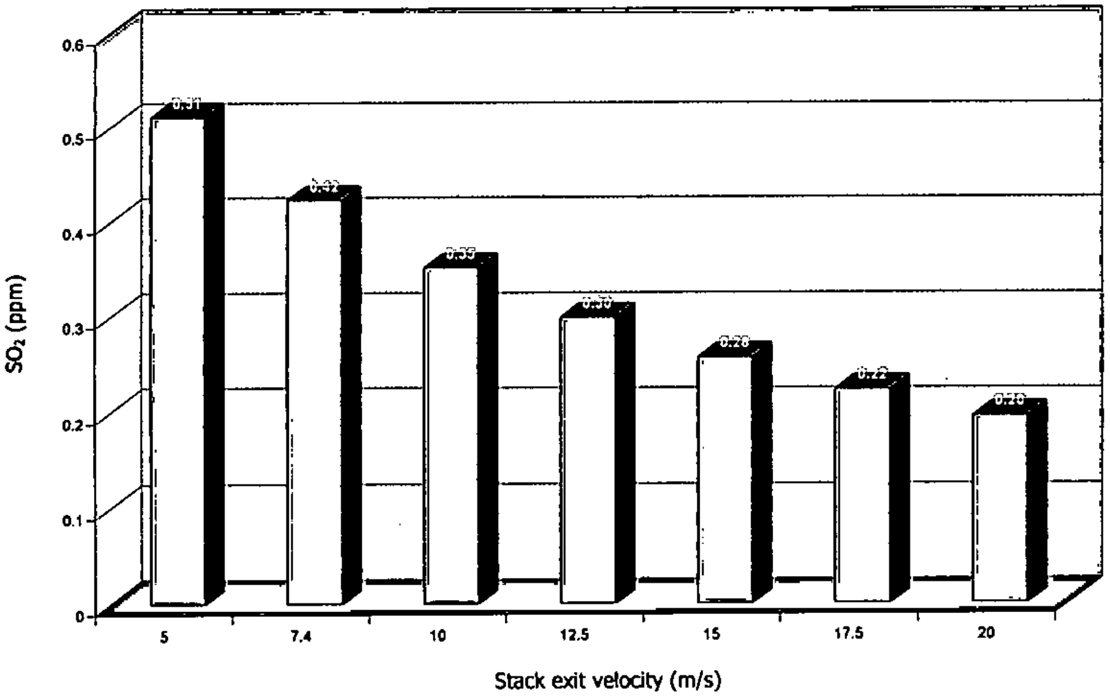

Figure 4.19: Change in SO_2 concentration at the centre of the cluster with stack exit velocity

In Figure 4.19 it is quite clear that the pollutant concentration at the centre of the cluster is significantly affected by the stack exit velocity. When the stack exit velocity was 5 m/s, the ambient concentration of SO_2 at the centre of the cluster was 0.51 ppm. It decreases with the increasing stack exit velocity. When the stack exit velocity was 20 m/s then the ambient concentration of SO_2 at the centre was found to be 0.20 ppm. This shows that higher the stack exit velocity, the lower is the pollutant concentration at the centre of the cluster. This can be explained by the concept of plume rise phenomenon. During emission from the stack, the exit gas with pollutants go directly upward until the counter forces of gravity and wind flow nullify the force. After that it starts to disperse into the atmosphere and reaches the surroundings. When the stack exit velocity is very high the plume reaches a greater height and dispersion starts at a higher elevation. So the concentration at its base becomes very low. On the other hand when the velocity is low the plume can't rise very high and disperses from a lower elevation. Therefore, due to deposition and nearness from the base, concentration at the kiln base becomes higher.

However, this phenomenon is not true for everywhere. Effect of stack exit velocity on ambient concentration was not prominent at a place distant from the source. In Figures 4.20 to 4.23 it is seen that the iso-concentration profiles were more or less same for different stack exit velocities. These curves are contour diagrams which show the points of equal concentration through contours. Data for these contours are shown in Tables A-06 to A-09. Unlike the centre concentration, concentrations at the points far from the sources did not change with different stack exit velocities. These contours were drawn for the concentration level as low as 100 microgram/m^3 (0.038 ppm) and found to be very similar irrespective of the stack exit velocities. Though ppm was used as concentration unit for gaseous pollutants, these curves were drawn for microgram/m^3 for visual clarity. All the curves have similar shape and size. The only difference is the concentration level near the centre of the sources. As discussed earlier, concentration level at the centre of the pollutant sources increases as the stack exit velocity decreases. So effect of stack exit velocity on ambient concentration is vital at the centre but not at a distant location from the source.

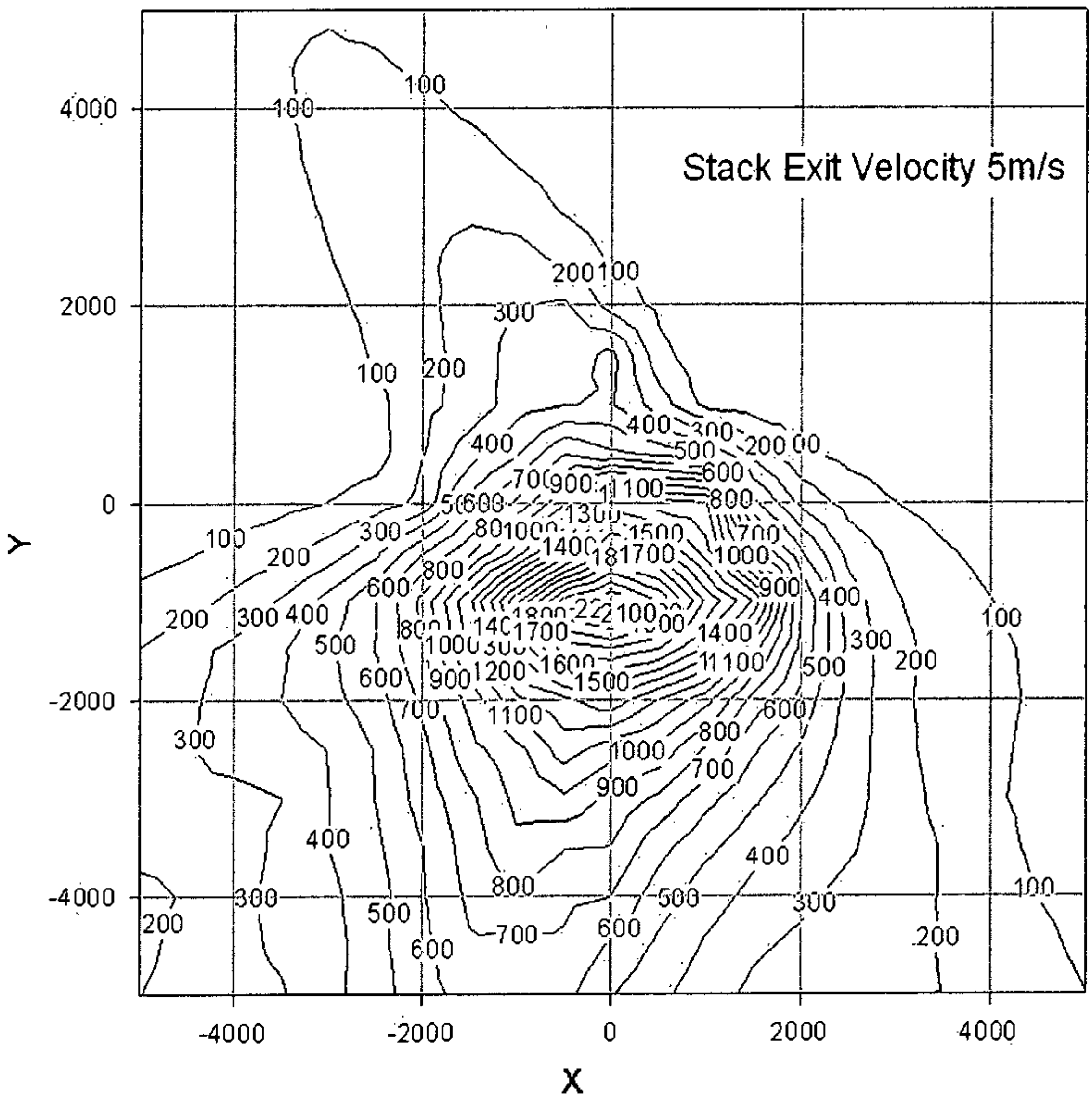

Figure 4.20: Contour of SO_2 concentrations in μ gm/m^3 around the brickfield cluster for stack exit velocity 5m/s

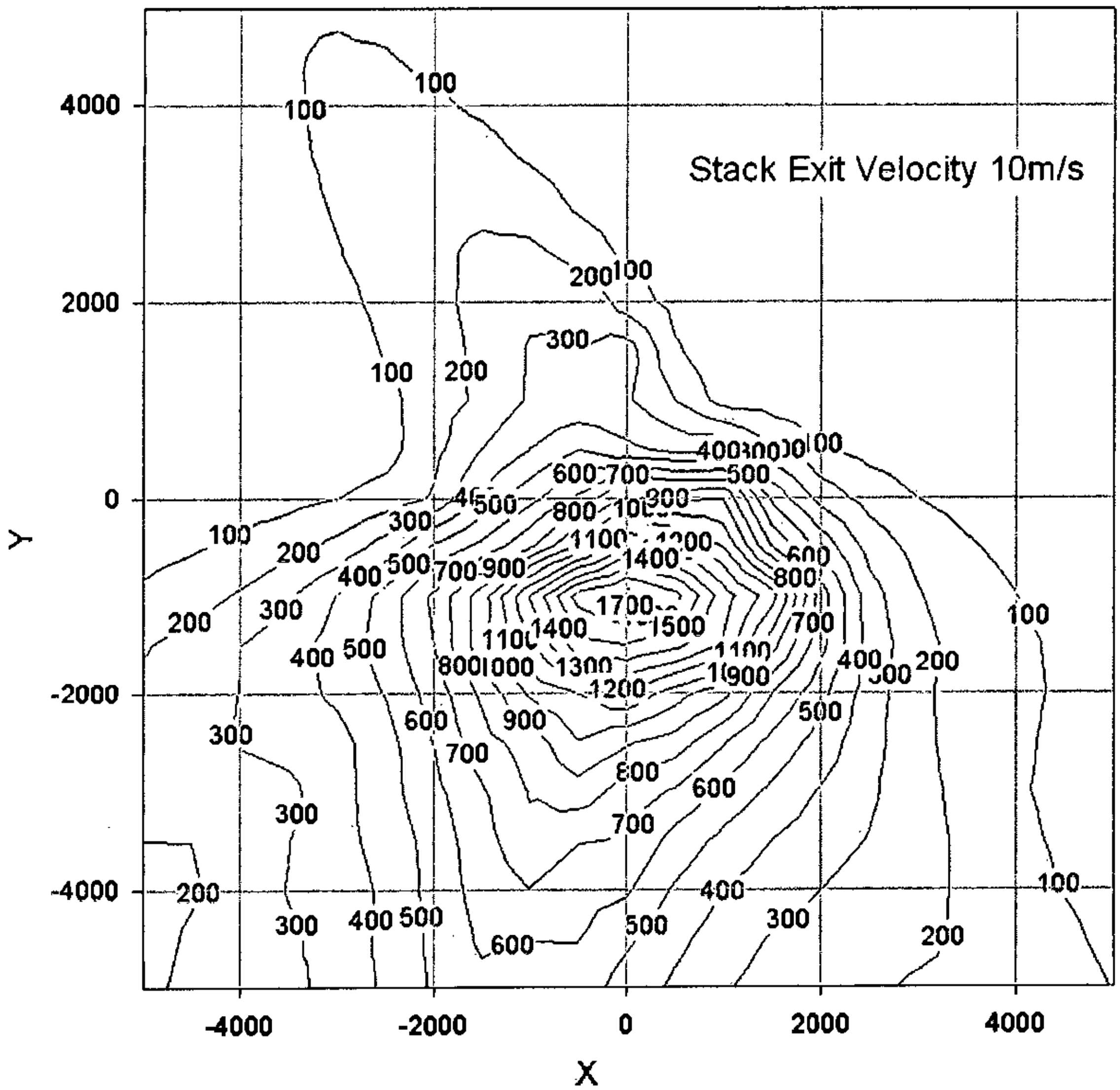

Figure 4.21: Contour of SO_2 concentrations in μ gm/m^3 around the brickfield cluster for stack exit velocity 10m/s

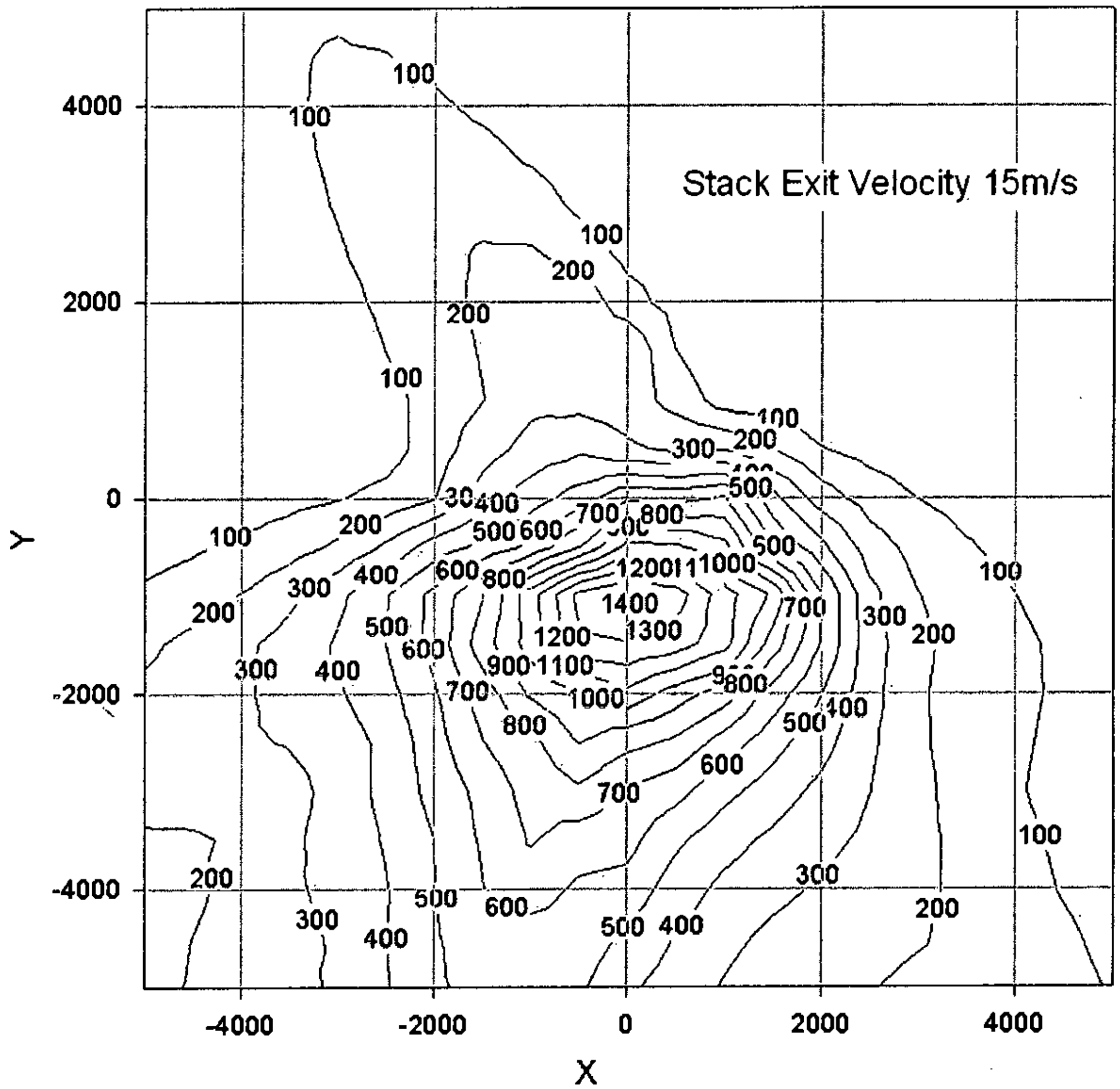

Figure 4.22: Contour of SO_2 concentrations in μ gm/m^3 around the brickfield cluster for stack exit velocity 15m/s

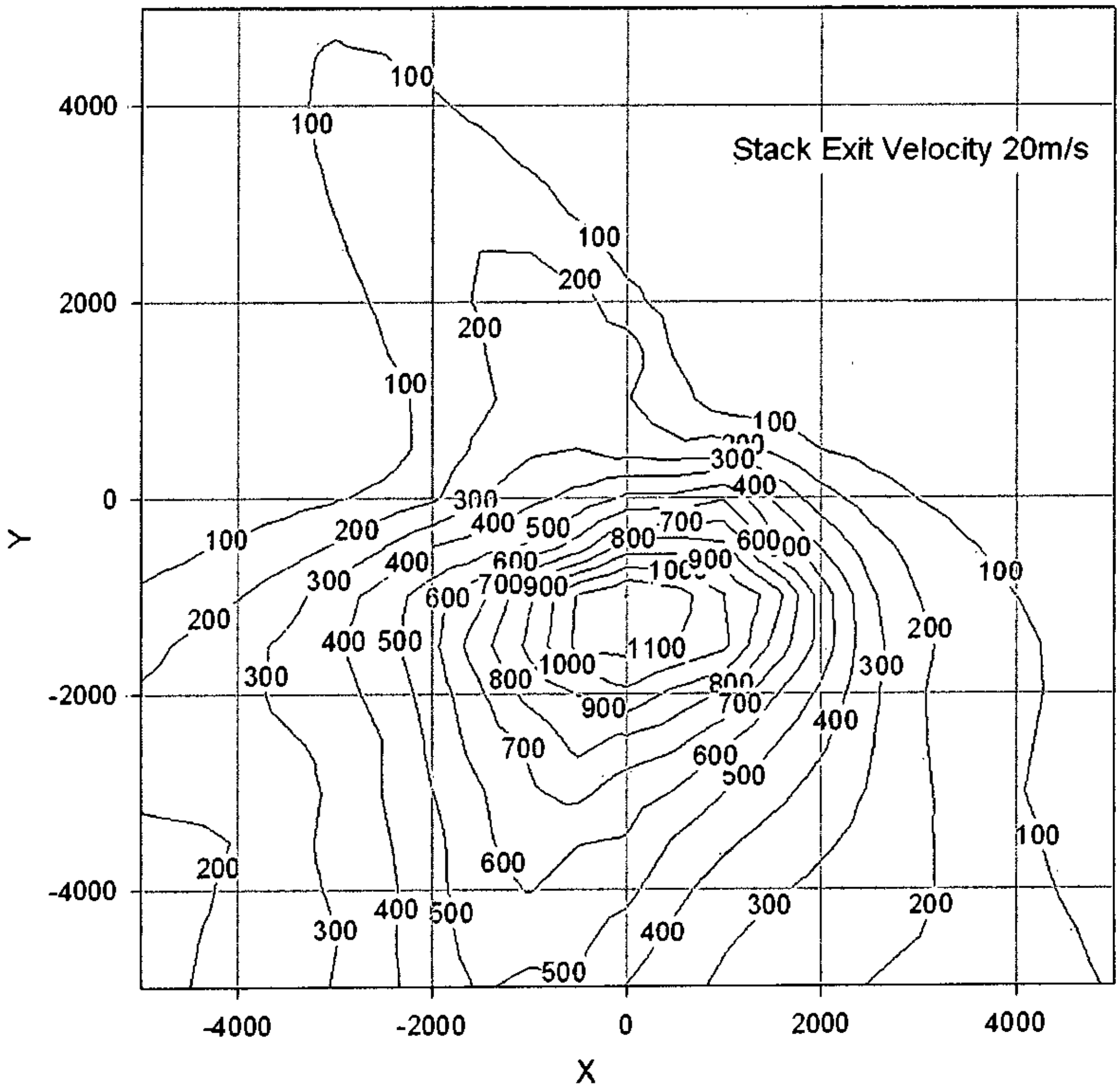

Figure 4.23: Contour of SO_2 concentrations in μ gm/m^3 around the brickfield cluster for stack exit velocity 20m/s

This trend is also expressed by the bar chart for a certain point far from the sources in Figure 4.24. Data for this diagram is listed in Table A-04. For a high stack exit velocity like 20m/s an ambient concentration of 0.151 ppm was found whereas for a very low stack exit velocity such as 5 m/s, ambient concentration of 0.193 ppm was found. So the change was not too significant to be considered compared to the changes at the centre of the cluster. This happened because of the strong effect of wind velocity on the dispersion mechanism. Pollutants had to reach the distant locations by dispersion through the atmosphere and this dispersion was completely dependent on the wind velocity and direction. Initially when the exit gas left the stack it went upward with its velocity. Then the wind velocity and gravity counterbalanced its upward flow and it started to disperse as mentioned earlier. In that case, the effect of exit velocity was no more a factor for the pollutant concentration level far from the sources. At that point the distant location concentration became independent of this stack exit velocity. Though this was not totally independent as seen in the figure but the dependence was not that significant. Total concentration level was then influenced by only the dispersion mechanism. So at a distant place the pollutant concentration was not effected significantly by the stack exit velocity.

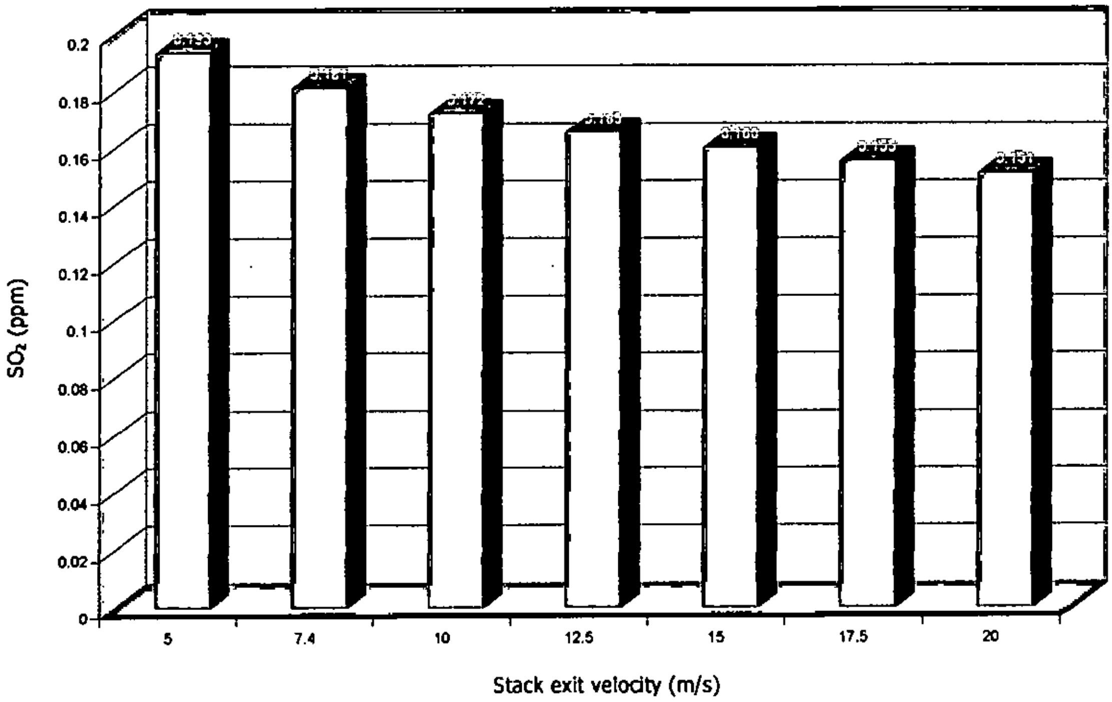

Figure 4.24: Change in SO_2 concentration at the outside of the cluster with stack exit velocity

Modeling of air quality near a cluster of brick field can be done successfully by using Industrial Source Complex (ISC) model as shown in the earlier sections. In the first section, effectiveness of this model was proved by comparing with practical data. In spite of several limitations and possibilities of errors, the results were found to be quite satisfactory. Considering ISC3 model as an efficient one for brick kiln pollutions in Bangladesh condition, it was utilized for several case studies in the subsequent sections. Effects of meteorological conditions, stack height and stack exit velocity on the ambient concentration were also successfully established for multiple pollution sources over a long period of time. Reasons behind some discrepancies and unusual behavior were explained with the help of different physical and mathematical principles. In brief, effectiveness of this air quality model was established and its different utilizations were revealed successfully in this work.

From the above data representations and discussions it is obvious that this type of models can be used as an effective tool for determining the effect of any pollution source prior to its establishment. That would certainly help the authority in issuing license for that establishment. More importantly, because of its ease of handling and availability, it can be utilized to revise the Environmental protection rule and regulations of any region for any hypothetical adverse situation.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Verification of an air pollution model for brickfield pollution in Bangladesh condition and different utilization of that model were the main concerns of this thesis work. There were some significant observations made through this thesis work and these are as follow:

- Industrial Source Complex (ISC3) model was found to be acceptable for modeling the ambient air pollution in Bangladesh, especially for Brickfield pollution.
- Ambient air pollutant concentration was significantly affected by the different meteorological conditions in Bangladesh and ambient TSP concentration was found very high in the cluster area compared to the Bangladesh standard.
- Average ambient concentrations of the pollutants were found lower with the increase of the brick kiln stack height. However, beyond a certain stack height, change in ambient pollutant concentration with the increase of stack height was found to be insignificant. So only increase in stack height to reduce the ambient concentration cannot be the ultimate solution.
- Stack exit velocity did not have significant influence on the ambient air quality at the surroundings of the sources but it affected the ambient concentration in the cluster area.

Ambient air quality data generated through ISC3 model were found to be in agreement with the experimental values of different ambient pollutant concentration caused by brickfields. Small discrepancy between experimental values and modeling data was the strong evidence of the applicability of this model. Though U.S. Environmental Protection Agency (EPA) has already recommended it as one of the most effective models for ambient air quality modeling, the agreement found in the work supports their recommendation. ISC3 model was found to perform very well both for the gaseous pollutants and the particulate matters with an acceptable accuracy level in Bangladesh condition especially for brickfield pollution. Percentage of error for modeling particulate matter was found 5-10% only on average. For gaseous pollutant percentage of error was little high but that was also acceptable considering the error margin of the Gastec tubes.

There were significant effects of meteorological conditions on the ambient air quality. Even after keeping all the pollutant sources and concentrations unchanged over the observation period, remarkable change in ambient concentration was observed for different months. That was because of different meteorological conditions in different months. For the first few months of dry season (November, December & January), meteorological condition was more or less similar. Thus dispersion of pollutant was found to follow a fixed trend over that period. However, later when the meteorological conditions were fluctuating, ambient pollutant concentrations were also changing with time and the pollutant dispersed into a wide area rather than some specific region. That was the reason why ambient pollutant concentration was decreasing with time for any specific region during the later months as shown in Table 5.01. As generally the wind blows from the north to the south during the dry season, ambient pollutant concentrations were high at the southern areas of the brickfield cluster.

Table 5.01: Ambient concentration in different months at a specific point at the surrounding

Month	SO_2 Concentration (ppm)	CO Concentration (ppm)	SPM Concentration (μg/m^3)
November	0.86	0.031	1424
December	0.76	0.028	1285
January	0.67	0.023	1052
February	0.51	0.021	959
March	0.24	0.012	535

The taller the brick kiln stack the lesser the ambient pollutant concentration was seen near the sources. This was established when the effect of brick kiln stack height on the ambient air quality was studied. When the stack height was less, ambient concentration near the stacks was found very high but the ambient concentration of a point far from the source was not significant. However, when the stack height was high the ambient concentration near the source was found lower compared to the previous case and concentration at a point far from the source was also significant. For higher stack height pollutant was found over a larger area but lower in concentration. So it was clear that average ambient air quality could be made better

Table 5.02: Change in 5-month averaged ambient concentration with stack height at centre of the cluster

Stack Height (m)	SO_2 Concentration (ppm)	CO Concentration (ppm)	TSP Concentration (μg/m^3)
5	1.289	0.040	1845
10	0.998	0.036	1676
15	0.788	0.031	1423
20	0.639	0.027	1228
25	0.527	0.023	1069
30	0.440	0.021	937
38	0.334	0.017	766
45	0.266	0.014	649
50	0.227	0.013	580

by increasing the stack height. However, this statement was found to be valid up to certain range of stack height. From the modeling data as shown in Table 5.02 it was observed that after a certain stack height effect of increased stack height was not significant and thus that couldn't reduce the ambient pollutant concentration much. So increasing stack height could be a temporary solution to reduce average ambient pollutant concentration but other measures should be taken to combat air pollution permanently.

Another interesting finding was the effect of stack exit velocity on the ambient air quality. Initially it was thought that higher stack exit velocity would contribute to higher ambient concentration to the regions far from the sources but it turned out to be something different. When the stack exit velocity was high ambient concentration near the sources was found low compared to the other conditions. This concentration was found very high for lower stack exit velocity. On the other hand for the area far from the sources, the effect was very insignificant. Whatever the velocity was, ambient pollutant concentration was found more or less same for all the time. Reasons behind this are also discussed in the previous section. Though the ambient concentration at a point far from the source was decreasing very little with the increase in stack exit velocity but that was insignificant compared to that near the sources. So it can be summarized that stack exit velocity didn't have significant influence on the ambient air quality at the surroundings of the sources.

Industrial Source Complex (ISC3) model was found very effective and appropriate both for gaseous pollutants and particulate matter for brickfield pollution in Bangladesh. It has different utilizations of which few were successfully practiced during this thesis work. This can be utilized more in the wider arena of environmental analysis and can be proved to be a successful tool to predict pollution load in different conditions.

5.2 RECOMMENDATIONS FOR FUTURE WORKS

Ambient air quality modeling is a very felicitous and efficient way to predict the pollutant load even prior to pollutant emission. As different sources of pollution are now increasing near the locality day by day, it can be used to predict pollution load from multiple type of sources for large scale (i.e. Dhaka city). Different proposed way to reduce air pollution can be verified using this model prior to implementation which can help modifying Environmental Rules and Regulations. Moreover, for better performance and in presence of complex terrain or complicated sources, some other advanced models such as AERMOD and CALPUFF can also be adopted.

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APPENDIX - A

CALCULATION FOR SPM CONCENTRATION

For the data of Day 1:

Average air flow rate through the filter paper: 1.202 m^3/min

Operating time of high volume Sampler: 7hr 25 min = 445 min

Total volumetric flow: $\frac{1.202\,m^3}{min} \times 445\,min = 534.89\,m^3$

Weight of conditioned Filter paper: 4.217 g

Weight of conditioned Filter paper with dust: 4.6346 g

Total amount of dust: (4.6346 – 4.217)g = 0.4176 g

Total Suspended particulate matter (SPM) = $\frac{0.4176\,g}{534.89\,m^3} \times \frac{10^6\,\mu g}{1\,g} = 780.72\ \mu g/m^3$

For the data of Day 2:

Average air flow rate through the filter paper: 1.16 m^3/min

Operating time of high volume Sampler: 6hr 35 min = 395 min

Total volumetric flow: $\frac{1.16\,m^3}{min} \times 395\,min = 458.2\ m^3$

Weight of conditioned Filter paper: 4.2453 g

Weight of conditioned Filter paper with dust: 4.8821 g

Total amount of dust: (4.8821 – 4.2453)g = 0.6368 g

Total Suspended particulate matter (SPM) = $\frac{0.6368\,g}{458.2\,m^3} \times \frac{10^6\,\mu g}{1\,g} = 1389.8\ \mu g/m^3$

For the data of Day 3:

Average air flow rate through the filter paper: 1.079 m^3/min

Operating time of high volume Sampler: 6hr 5 min = 365 min

Total volumetric flow: $\frac{1.079\,m^3}{min} \times 365\,min = 393.84\ m^3$

Weight of conditioned Filter paper: 4.2912 g

Weight of conditioned Filter paper with dust: 4.5781 g

Total amount of dust: (4.5781 – 4.2912)g = 0.2869 g

$$\text{Total Suspended particulate matter (SPM)} = \frac{0.2869\,g}{393.84\,m^3} \times \frac{10^6\,\mu g}{1\,g} = 728.5\ \mu g/m^3$$

DATA FOR GRAPHICAL REPRESENTATIONS

Table A-01: Monthly average ambient concentration of different pollutants

Month	At the centre of the cluster			At the Worst point		
	SO_2 (ppm)	CO (ppm)	SPM ($\mu g/m^3$)	SO_2 (ppm)	CO (ppm)	SPM ($\mu g/m^3$)
November 2004	0.3307	0.0185	852.89	0.860	0.0308	1424
December 2004	0.4233	0.0179	822.76	0.760	0.0279	1285
January 2005	0.3125	0.0149	687.60	0.670	0.0229	1052
February 2005	0.2855	0.0159	737.92	0.510	0.0207	959
March 2005	0.3154	0.0157	729.17	0.240	0.0115	535
November'04 – March'05	0.3341	0.0166	765.86	0.860	0.0308	1424

Table A-02: Data for effect of stack height on 1 month averaged ambient concentration

Stack height (m)	At the centre of the cluster			At the Worst point		
	SO_2 (ppm)	CO (ppm)	SPM ($\mu g/m^3$)	SO_2 (ppm)	CO (ppm)	SPM ($\mu g/m^3$)
5	1.3571	0.0378	1730.33	2.2744	0.0596	2725.68
10	1.1080	0.0349	1601.54	1.8882	0.0543	2488.53
15	0.9096	0.0303	1391.27	1.5439	0.0464	2126.99
20	0.7594	0.0267	1227.37	1.2914	0.0406	1863.86
25	0.6406	0.0237	1091.44	1.0976	0.0361	1659.65
30	0.5442	0.0212	975.46	0.9451	0.0325	1494.42
38	0.4233	0.0179	822.76	0.7610	0.0279	1285.14
45	0.3420	0.0155	715.76	0.6416	0.0247	1139.01
50	0.2944	0.0142	651.79	0.5728	0.0228	1049.35

Table A-03: Data for effect of stack height on 5 month averaged ambient concentration

Stack height (m)	At the centre of the cluster			At the Worst point		
	SO_2 (ppm)	CO (ppm)	SPM ($\mu g/m^3$)	SO_2 (ppm)	CO (ppm)	SPM ($\mu g/m^3$)
5	1.2894	0.0402	1844.87	1.9336	0.0508	2326.11
10	0.9980	0.0364	1676.31	1.5816	0.0461	2118.07
15	0.7877	0.0309	1422.77	1.2756	0.0391	1795.82
20	0.6390	0.0266	1228	1.0547	0.0340	1561.49
25	0.5272	0.0232	1069.32	0.8879	0.0300	1379.91
30	0.4397	0.0212	936.71	0.7589	0.0268	1233.99
38	0.3341	0.0166	765.86	0.6060	0.0228	1049.68
45	0.2657	0.0140	648.88	0.5085	0.0200	921.6
50	0.2267	0.0126	580.07	0.4530	0.0183	843.52

Table A-04: Data for effect of stack exit velocity on monthly averaged ambient concentration

Stack exit velocity (m/s)	Concentration of SO_2 (ppm)	
	At the centre of the cluster	At the Worst point
5	0.5113	0.1931
7.4	0.4233	0.1810
10	0.3520	0.1720
12.5	0.2995	0.1652
15	0.2578	0.1598
17.5	0.2241	0.1552
20	0.1965	0.1510

Table A-05: Locations of highest 50 ambient monthly concentration of different pollutants

SO_2			CO			SPM		
X (m)	Y (m)	Ambient Conc. (ppm)	X (m)	Y (m)	Ambient Conc. (ppm)	X (m)	Y (m)	Ambient Conc. (μg/m^3)
0	-1000	0.8561	0	-1000	0.0310	-500	-500	2437.38
500	-1000	0.7849	0	-1000	0.0279	0	-1000	2345.12
500	-1500	0.7615	500	-1000	0.0273	2000	1000	2337.74
0	-1000	0.7610	-500	-1000	0.0257	0	-2000	2255.66
-500	-1000	0.7535	500	-1000	0.0249	-1000	0	2251.92
0	-1500	0.7298	0	-500	0.0245	1500	1000	2242.23
-500	-1000	0.7118	-500	-1000	0.0241	-1500	-500	2235.57
1000	-1000	0.7088	1000	-1000	0.0235	-1500	-1000	2217.97
500	-1000	0.7001	500	-500	0.0234	-1000	-1000	2187.75
500	-1000	0.6767	0	-500	0.0231	0	-1500	2177.05
-500	-1500	0.6740	0	-1000	0.0229	-1500	0	2171.15
0	-1000	0.6659	0	-1500	0.0229	-1000	-1000	2147.26
1000	-1500	0.6315	-500	-1500	0.0215	-500	-500	2135.90
0	-500	0.6272	500	-500	0.0213	-1000	-500	2131.35
0	-1500	0.6198	500	-1500	0.0211	-500	-500	2125.42
-500	-1000	0.6116	-500	-500	0.0210	1000	500	2097.79
500	-500	0.6055	0	-1000	0.0208	-1500	-1000	2093.85
-500	-1500	0.6039	-500	-500	0.0206	-1500	0	2081.12
500	-1500	0.5929	-500	-1000	0.0204	0	-1000	2072.92
0	-2000	0.5891	1000	-1000	0.0199	-500	1500	2067.57
-500	-2000	0.5742	0	-1500	0.0196	-2000	0	2051.35
0	-500	0.5723	-500	-500	0.0189	500	500	2045.01
1000	-1000	0.5711	-500	-1000	0.0189	2500	1500	2044.53
0	-1500	0.5697	500	0	0.0188	-2000	-1000	2037.40
500	-2000	0.5633	1000	-1000	0.0186	0	-1000	2013.12
-1000	-1000	0.5621	0	-500	0.0186	-2000	-1500	2008.21
500	-500	0.5563	-500	-500	0.0186	-2500	-1000	1999.88
500	-1500	0.5462	0	0	0.0185	-2500	-1500	1990.58
1500	-1000	0.5436	500	-500	0.0184	0	-1000	1988.62
500	-500	0.5393	-500	1500	0.0184	-1000	-500	1988.08
-1000	-1500	0.5296	500	1000	0.0183	-500	-2000	1986.74
1000	-1500	0.5243	0	-500	0.0183	0	-1500	1983.04
-1000	-1000	0.5175	-1000	1000	0.0180	-2000	-1000	1977.08
0	-1000	0.5102	0	0	0.0179	0	-1000	1976.29
-500	-1500	0.4991	500	1000	0.0178	-1000	-500	1968.10
1000	-500	0.4988	500	-500	0.0175	-500	-1000	1965.29
-1000	-1500	0.4899	0	2000	0.0174	-500	-1000	1959.99
0	-2500	0.4876	-1000	1500	0.0172	0	-2500	1959.04
500	-1000	0.4851	-500	2000	0.0170	-500	-1000	1949.15
-500	-2500	0.4850	0	1500	0.0168	-2000	0	1947.92
1000	-1500	0.4832	500	1500	0.0163	500	-1000	1933.74
0	-2000	0.4828	-1000	1000	0.0162	1500	500	1930.56
-1000	-2000	0.4800	500	-500	0.0161	0	-1000	1924.27
1500	-1000	0.4796	-500	1500	0.0160	0	-1000	1922.58
1000	-2000	0.4734	500	0	0.0160	0	-2000	1915.59
500	-500	0.4697	0	0	0.0159	-500	-1500	1906.42
0	-500	0.4686	-1000	1000	0.0159	1000	0	1903.17
0	-1500	0.4670	0	0	0.0157	-500	-1500	1898.64
-500	-500	0.4606	500	2000	0.0156	1500	-500	1885.33
1000	-1000	0.4589	1000	1500	0.0154	-1500	-500	1883.58

Table A-06: Data for contour diagram for stack exit velocity 5 m/s

X (m)	Y (m)	SO_2 (µg/m³)	X (m)	Y (m)	SO_2 (µg/m³)	X (m)	Y (m)	SO_2 (µg/m³)
-5000	-5000	197.72505	-3500	-3500	324.58731	-2000	-2000	719.90149
-4500	-5000	236.40079	-3000	-3500	398.4549	-1500	-2000	931.64642
-4000	-5000	271.33234	-2500	-3500	480.95532	-1000	-2000	1176.0564
-3500	-5000	292.01782	-2000	-3500	595.90741	-500	-2000	1279.0415
-3000	-5000	368.71744	-1500	-3500	749.01703	0	-2000	1370.13965
-2500	-5000	454.84155	-1000	-3500	877.46674	500	-2000	1197.88782
-2000	-5000	565.20599	-500	-3500	805.75757	1000	-2000	1040.83044
-1500	-5000	636.32727	0	-3500	798.12817	1500	-2000	764.57922
-1000	-5000	611.52118	500	-3500	634.80969	2000	-2000	565.29681
-500	-5000	633.13269	1000	-3500	527.73511	2500	-2000	372.9263
0	-5000	507.41766	1500	-3500	433.5112	3000	-2000	228.00272
500	-5000	427.41876	2000	-3500	366.23206	3500	-2000	158.75365
1000	-5000	345.34958	2500	-3500	314.66434	4000	-2000	116.74737
1500	-5000	279.1571	3000	-3500	246.52362	4500	-2000	90.39732
2000	-5000	244.87662	3500	-3500	194.1275	5000	-2000	73.73102
2500	-5000	225.1008	4000	-3500	127.71535	-5000	-1500	204.40787
3000	-5000	202.07422	4500	-3500	84.49928	-4500	-1500	266.21823
3500	-5000	199.29276	5000	-3500	67.21053	-4000	-1500	326.59891
4000	-5000	162.95569	-5000	-3000	265.48056	-3500	-1500	388.82812
4500	-5000	139.30077	-4500	-3000	281.42862	-3000	-1500	482.95956
5000	-5000	101.13608	-4000	-3000	269.918	-2500	-1500	603.18665
-5000	-4500	175.94426	-3500	-3000	299.39365	-2000	-1500	788.10529
-4500	-4500	230.02512	-3000	-3000	398.00729	-1500	-1500	1113.77686
-4000	-4500	278.1886	-2500	-3000	503.10086	-1000	-1500	1401.07458
-3500	-4500	312.8244	-2000	-3000	639.8609	-500	-1500	1736.74377
-3000	-4500	356.03259	-1500	-3000	777.65936	0	-1500	1789.34229
-2500	-4500	466.94675	-1000	-3000	925.70386	500	-1500	1698.72424
-2000	-4500	574.57886	-500	-3000	981.99152	1000	-1500	1483.67041
-1500	-4500	687.73785	0	-3000	872.19843	1500	-1500	1052.22009
-1000	-4500	676.43311	500	-3000	779.00647	2000	-1500	677.37036
-500	-4500	684.50305	1000	-3000	635.56451	2500	-1500	378.44812
0	-4500	587.50586	1500	-3000	520.04077	3000	-1500	235.9951
500	-4500	481.17514	2000	-3000	418.76202	3500	-1500	158.66202
1000	-4500	389.78809	2500	-3000	335.74326	4000	-1500	115.01654
1500	-4500	317.38193	3000	-3000	252.76779	4500	-1500	88.19459
2000	-4500	280.20911	3500	-3000	171.95551	5000	-1500	69.60921
2500	-4500	246.79042	4000	-3000	109.5327	-5000	-1000	122.39658
3000	-4500	231.24532	4500	-3000	84.29631	-4500	-1000	161.38214
3500	-4500	197.01619	5000	-3000	67.84999	-4000	-1000	226.77524
4000	-4500	162.06198	-5000	-2500	249.5509	-3500	-1000	313.35321
4500	-4500	124.0642	-4500	-2500	292.64435	-3000	-1000	439.0076
5000	-4500	79.58515	-4000	-2500	340.42401	-2500	-1000	594.83429
-5000	-4000	183.67088	-3500	-2500	365.29044	-2000	-1000	834.13318
-4500	-4000	205.01411	-3000	-2500	402.55716	-1500	-1000	1183.24768
-4000	-4000	270.78473	-2500	-2500	504.72949	-1000	-1000	1683.34949
-3500	-4000	330.4827	-2000	-2500	673.85608	-500	-1000	2148.41162
-3000	-4000	374.28247	-1500	-2500	866.55157	0	-1000	2303.6814
-2500	-4000	458.6463	-1000	-2500	967.33997	500	-1000	2095.57495
-2000	-4000	591.86816	-500	-2500	1151.05103	1000	-1000	1687.63135
-1500	-4000	720.99579	0	-2500	1050.55139	1500	-1000	1394.10352
-1000	-4000	787.53107	500	-2500	975.98572	2000	-1000	708.37299
-500	-4000	722.02515	1000	-2500	790.6571	2500	-1000	354.62967
0	-4000	701.81323	1500	-2500	617.98022	3000	-1000	210.69954
500	-4000	549.92664	2000	-2500	489.49597	3500	-1000	141.5349
1000	-4000	446.86026	2500	-2500	353.56943	4000	-1000	101.56797
1500	-4000	374.71649	3000	-2500	242.5972	4500	-1000	75.38711
2000	-4000	321.37772	3500	-2500	151.69707	5000	-1000	57.41801
2500	-4000	272.55954	4000	-2500	112.14474	-5000	-500	69.23058
3000	-4000	248.2487	4500	-2500	87.12656	-4500	-500	91.30447
3500	-4000	194.01122	5000	-2500	70.75072	-4000	-500	125.91507
4000	-4000	154.14899	-5000	-2000	260.97604	-3500	-500	170.04669
4500	-4000	98.88496	-4500	-2000	287.50284	-3000	-500	243.91293
5000	-4000	68.68916	-4000	-2000	327.99228	-2500	-500	375.4787
-5000	-3500	215.96875	-3500	-2000	400.24643	-2000	-500	591.06592
-4500	-3500	215.74318	-3000	-2000	461.68524	-1500	-500	777.82349
-4000	-3500	243.40495	-2500	-2000	560.0545	-1000	-500	1050.05127

-500	-500	1403.43225
0	-500	1757.98047
500	-500	1634.94116
1000	-500	1348.1217
1500	-500	836.54175
2000	-500	512.95264
2500	-500	268.77887
3000	-500	164.37138
3500	-500	109.32595
4000	-500	76.27686
4500	-500	55.34111
5000	-500	41.65914
-5000	0	35.38162
-4500	0	43.47122
-4000	0	55.21233
-3500	0	73.0725
-3000	0	102.52162
-2500	0	148.18646
-2000	0	230.63187
-1500	0	536.37463
-1000	0	717.68854
-500	0	989.92993
0	0	1343.25928
500	0	1233.4314
1000	0	1202.25757
1500	0	522.43634
2000	0	276.38055
2500	0	161.1685
3000	0	100.90846
3500	0	67.57141
4000	0	47.96147
4500	0	35.74605
5000	0	27.76798
-5000	500	16.00094
-4500	500	18.44823
-4000	500	21.89448
-3500	500	27.08214
-3000	500	36.16186
-2500	500	62.87253
-2000	500	196.52557
-1500	500	358.6413
-1000	500	491.4386
-500	500	692.40149
0	500	617.43945
500	500	560.5174
1000	500	498.9545
1500	500	257.80905
2000	500	112.74258
2500	500	66.38103
3000	500	46.15377
3500	500	34.89796
4000	500	27.56775
4500	500	22.34867
5000	500	18.4984
-5000	1000	6.20273
-4500	1000	6.69158
-4000	1000	7.46658
-3500	1000	10.07703
-3000	1000	21.80355
-2500	1000	72.63579
-2000	1000	173.80405
-1500	1000	237.17021
-1000	1000	353.16919
-500	1000	396.87106
0	1000	409.8143
500	1000	248.25797
1000	1000	72.28774
1500	1000	44.33343
2000	1000	30.35271
2500	1000	23.69119
3000	1000	19.95683

3500	1000	17.11298
4000	1000	15.0183
4500	1000	13.35739
5000	1000	11.95934
-5000	1500	1.36759
-4500	1500	1.78234
-4000	1500	4.32372
-3500	1500	13.14418
-3000	1500	41.99004
-2500	1500	112.73392
-2000	1500	168.98015
-1500	1500	235.52127
-1000	1500	345.84064
-500	1500	340.91901
0	1500	429.61804
500	1500	130.21358
1000	1500	32.25186
1500	1500	17.67554
2000	1500	8.75673
2500	1500	5.86154
3000	1500	7.01579
3500	1500	7.53555
4000	1500	7.58459
4500	1500	7.43514
5000	1500	7.22511
-5000	2000	1.32501
-4500	2000	4.28237
-4000	2000	11.69304
-3500	2000	30.87303
-3000	2000	77.01104
-2500	2000	128.05817
-2000	2000	176.45129
-1500	2000	244.73264
-1000	2000	298.13535
-500	2000	314.93057
0	2000	165.66154
500	2000	72.94024
1000	2000	33.37398
1500	2000	25.01648
2000	2000	5.12102
2500	2000	7.67198
3000	2000	1.58641
3500	2000	2.33836
4000	2000	3.01264
4500	2000	3.5236
5000	2000	3.88586
-5000	2500	4.72752
-4500	2500	10.91611
-4000	2500	24.63614
-3500	2500	55.44564
-3000	2500	97.98486
-2500	2500	138.48653
-2000	2500	185.09459
-1500	2500	229.12746
-1000	2500	233.23444
-500	2500	175.13991
0	2500	79.76662
500	2500	63.51208
1000	2500	34.18729
1500	2500	28.68712
2000	2500	4.53569
2500	2500	11.69756
3000	2500	0.3733
3500	2500	0.48339
4000	2500	0.83381
4500	2500	1.24173
5000	2500	1.6582
-5000	3000	10.23197
-4500	3000	20.58233
-4000	3000	42.18882
-3500	3000	75.54069

-3000	3000	110.47756
-2500	3000	145.42018
-2000	3000	177.91154
-1500	3000	182.12831
-1000	3000	160.57648
-500	3000	84.49868
0	3000	52.69877
500	3000	60.38119
1000	3000	39.15484
1500	3000	30.41399
2000	3000	18.06138
2500	3000	7.49827
3000	3000	6.71619
3500	3000	0.06903
4000	3000	0.16276
4500	3000	0.31745
5000	3000	0.53265
-5000	3500	17.74104
-4500	3500	33.59351
-4000	3500	59.16539
-3500	3500	88.71201
-3000	3500	116.94208
-2500	3500	142.57996
-2000	3500	151.59332
-1500	3500	134.30251
-1000	3500	89.00479
-500	3500	49.46749
0	3500	44.07543
500	3500	53.44484
1000	3500	37.71626
1500	3500	34.14264
2000	3500	25.27241
2500	3500	6.90701
3000	3500	16.12554
3500	3500	0.27662
4000	3500	0.02333
4500	3500	0.06072
5000	3500	0.1304
-5000	4000	27.67468
-4500	4000	47.25805
-4000	4000	71.59288
-3500	4000	95.50005
-3000	4000	116.69291
-2500	4000	128.22197
-2000	4000	118.08399
-1500	4000	84.02708
-1000	4000	49.41066
-500	4000	36.20665
0	4000	40.38454
500	4000	47.34928
1000	4000	37.65195
1500	4000	34.93515
2000	4000	25.17375
2500	4000	18.50607
3000	4000	11.83717
3500	4000	5.85636
4000	4000	0.00531
4500	4000	0.00899
5000	4000	0.02507
-5000	4500	38.48451
-4500	4500	58.20262
-4000	4500	78.70837
-3500	4500	97.04938
-3000	4500	109.08669
-2500	4500	105.74609
-2000	4500	81.70884
-1500	4500	47.87743
-1000	4500	31.29813
-500	4500	30.51411
0	4500	38.09231
500	4500	42.89707

1000	4500	33.3893	-4500	5000	65.28771	500	5000	40.53952
1500	4500	32.11207	-4000	5000	81.58891	1000	5000	28.09375
2000	4500	28.44339	-3500	5000	93.4302	1500	5000	29.09577
2500	4500	30.50567	-3000	5000	94.52513	2000	5000	27.98055
3000	4500	9.04798	-2500	5000	79.1665	2500	5000	31.05192
3500	4500	16.61526	-2000	5000	51.29979	3000	5000	17.88627
4000	4500	0.37658	-1500	5000	27.64433	3500	5000	15.75543
4500	4500	0.00107	-1000	5000	23.00733	4000	5000	5.02072
5000	4500	0.00388	-500	5000	27.56954	4500	5000	0.00935
-5000	5000	47.77091	0	5000	36.38523	5000	5000	0.00049

Table A-07: Data for contour diagram for stack exit velocity 10 m/s

X (m)	Y (m)	SO_2 ($\mu g/m^3$)	X (m)	Y (m)	SO_2 ($\mu g/m^3$)	X (m)	Y (m)	SO_2 ($\mu g/m^3$)
-5000	-5000	182.76701	2000	-4500	262.92203	-1500	-3500	662.58588
-4500	-5000	218.60606	2500	-4500	232.79877	-1000	-3500	771.32794
-4000	-5000	251.26857	3000	-4500	217.15335	-500	-3500	705.52716
-3500	-5000	271.03491	3500	-4500	185.19257	0	-3500	693.99316
-3000	-5000	338.54611	4000	-4500	152.80432	500	-3500	563.35638
-2500	-5000	415.27353	4500	-4500	117.99596	1000	-3500	473.90521
-2000	-5000	513.20941	5000	-4500	77.58633	1500	-3500	400.54007
-1500	-5000	573.22058	-5000	-4000	171.0132	2000	-3500	343.26074
-1000	-5000	547.84644	-4500	-4000	190.05023	2500	-3500	295.44266
-500	-5000	562.69769	-4000	-4000	248.69028	3000	-3500	232.32504
0	-5000	451.8681	-3500	-4000	303.4856	3500	-3500	182.71545
500	-5000	382.23212	-3000	-4000	342.81412	4000	-3500	122.75331
1000	-5000	312.17352	-2500	-4000	417.5376	4500	-3500	83.30214
1500	-5000	257.78729	-2000	-4000	531.83026	5000	-3500	66.71571
2000	-5000	229.714	-1500	-4000	642.70599	-5000	-3000	240.23991
2500	-5000	212.29642	-1000	-4000	697.0661	-4500	-3000	255.21442
3000	-5000	191.32745	-500	-4000	634.43011	-4000	-3000	248.05319
3500	-5000	186.71664	0	-4000	615.07684	-3500	-3000	275.64511
4000	-5000	153.78571	500	-4000	488.13702	-3000	-3000	362.65778
4500	-5000	131.62234	1000	-4000	401.91541	-2500	-3000	455.8251
5000	-5000	96.87291	1500	-4000	345.4234	-2000	-3000	571.6817
-5000	-4500	163.67178	2000	-4000	301.10037	-1500	-3000	686.31744
-4500	-4500	211.94788	2500	-4000	257.51059	-1000	-3000	807.08234
-4000	-4500	256.3782	3000	-4000	232.67719	-500	-3000	855.05225
-3500	-4500	288.46356	3500	-4000	182.83313	0	-3000	756.83936
-3000	-4500	327.811	4000	-4000	145.67052	500	-3000	688.28229
-2500	-4500	424.42535	4500	-4000	95.77801	1000	-3000	570.42035
-2000	-4500	519.34894	5000	-4000	67.91547	1500	-3000	479.68347
-1500	-4500	616.63757	-5000	-3500	200.1487	2000	-3000	393.19418
-1000	-4500	603.23315	-4500	-3500	200.2663	2500	-3000	316.47818
-500	-4500	604.367	-4000	-3500	224.89236	3000	-3000	237.77615
0	-4500	519.94739	-3500	-3500	297.02155	3500	-3000	163.89539
500	-4500	428.61023	-3000	-3500	364.345	4000	-3000	107.55898
1000	-4500	351.37726	-2500	-3500	435.41721	4500	-3000	83.54523
1500	-4500	293.22235	-2000	-3500	535.41412	5000	-3000	67.49199

-5000	-2500	227.69911
-4500	-2500	266.46069
-4000	-2500	307.67636
-3500	-2500	328.8541
-3000	-2500	365.73483
-2500	-2500	457.56271
-2000	-2500	601.89313
-1500	-2500	760.58331
-1000	-2500	842.65686
-500	-2500	993.78119
0	-2500	912.45581
500	-2500	854.28387
1000	-2500	709.85266
1500	-2500	571.57886
2000	-2500	459.13614
2500	-2500	333.79813
3000	-2500	229.63292
3500	-2500	148.16502
4000	-2500	110.91594
4500	-2500	86.58273
5000	-2500	70.52021
-5000	-2000	235.68576
-4500	-2000	262.42972
-4000	-2000	301.70166
-3500	-2000	364.72702
-3000	-2000	416.9913
-2500	-2000	503.49722
-2000	-2000	639.82971
-1500	-2000	818.40582
-1000	-2000	1014.91211
-500	-2000	1101.98962
0	-2000	1189.12622
500	-2000	1047.88367
1000	-2000	930.41034
1500	-2000	702.66687
2000	-2000	531.51556
2500	-2000	351.32101
3000	-2000	220.95769
3500	-2000	156.52347
4000	-2000	115.85542
4500	-2000	90.0182
5000	-2000	73.53786
-5000	-1500	189.54889
-4500	-1500	243.54604
-4000	-1500	298.90042
-3500	-1500	358.22247
-3000	-1500	442.79718
-2500	-1500	543.8045
-2000	-1500	699.45667
-1500	-1500	963.00201
-1000	-1500	1190.1178

-500	-1500	1462.64587
0	-1500	1494.83203
500	-1500	1435.5238
1000	-1500	1284.39148
1500	-1500	941.22137
2000	-1500	630.69415
2500	-1500	362.09006
3000	-1500	231.27913
3500	-1500	157.03775
4000	-1500	114.34142
4500	-1500	87.84585
5000	-1500	69.41109
-5000	-1000	117.77663
-4500	-1000	154.60834
-4000	-1000	213.2979
-3500	-1000	292.08127
-3000	-1000	402.25867
-2500	-1000	537.21283
-2000	-1000	718.94373
-1500	-1000	952.5368
-1000	-1000	1304.25952
-500	-1000	1643.05322
0	-1000	1759.15527
500	-1000	1633.31921
1000	-1000	1351.1665
1500	-1000	1146.297
2000	-1000	650.23566
2500	-1000	341.72147
3000	-1000	207.2365
3500	-1000	140.22632
4000	-1000	100.94147
4500	-1000	75.05371
5000	-1000	57.23227
-5000	-500	68.32355
-4500	-500	89.34583
-4000	-500	121.18797
-3500	-500	163.2973
-3000	-500	230.98376
-2500	-500	344.66721
-2000	-500	511.34955
-1500	-500	629.04626
-1000	-500	784.90283
-500	-500	1022.81049
0	-500	1302.57166
500	-500	1245.22803
1000	-500	1091.58032
1500	-500	694.15521
2000	-500	464.77042
2500	-500	260.17682
3000	-500	161.81796
3500	-500	108.27819

4000	-500	75.77351
4500	-500	55.07592
5000	-500	41.51134
-5000	0	34.98973
-4500	0	42.87155
-4000	0	54.23539
-3500	0	71.34418
-3000	0	98.64152
-2500	0	140.3002
-2000	0	212.58789
-1500	0	420.40201
-1000	0	564.24438
-500	0	718.87671
0	0	924.86359
500	0	877.04077
1000	0	889.63324
1500	0	472.17783
2000	0	261.93646
2500	0	157.32646
3000	0	99.52913
3500	0	66.96721
4000	0	47.65738
4500	0	35.5781
5000	0	27.66976
-5000	500	15.84724
-4500	500	18.23254
-4000	500	21.57337
-3500	500	26.56309
-3000	500	35.19291
-2500	500	60.06299
-2000	500	172.90396
-1500	500	303.43503
-1000	500	402.27615
-500	500	497.02698
0	500	423.67822
500	500	373.13815
1000	500	372.34534
1500	500	223.23994
2000	500	107.82584
2500	500	64.98212
3000	500	45.58545
3500	500	34.61749
4000	500	27.41178
4500	500	22.25539
5000	500	18.44051
-5000	1000	6.14637
-4500	1000	6.61792
-4000	1000	7.36363
-3500	1000	9.88714
-3000	1000	21.13754
-2500	1000	67.92818

-2000	1000	159.89719
-1500	1000	216.85133
-1000	1000	312.04025
-500	1000	318.71222
0	1000	313.84747
500	1000	197.79716
1000	1000	60.06636
1500	1000	40.81613
2000	1000	28.45753
2500	1000	23.37883
3000	1000	19.78718
3500	1000	17.01216
4000	1000	14.95406
4500	1000	13.31479
5000	1000	11.9307
-5000	1500	1.35534
-4500	1500	1.762
-4000	1500	4.25755
-3500	1500	12.85482
-3000	1500	40.3898
-2500	1500	107.22219
-2000	1500	160.30679
-1500	1500	221.42014
-1000	1500	310.42023
-500	1500	303.63431
0	1500	352.9787
500	1500	113.40798
1000	1500	28.01138
1500	1500	15.58181
2000	1500	7.06396
2500	1500	5.80998
3000	1500	6.98147
3500	1500	7.50867
4000	1500	7.56414
4500	1500	7.41973
5000	1500	7.21369
-5000	2000	1.31262
-4500	2000	4.23343
-4000	2000	11.51291
-3500	2000	30.13051
-3000	2000	74.57556
-2500	2000	123.7016
-2000	2000	169.86177
-1500	2000	232.61423
-1000	2000	277.86972
-500	2000	289.43048
0	2000	151.34396
500	2000	64.3252
1000	2000	27.88796
1500	2000	19.62104
2000	2000	3.74363

2500	2000	5.52659
3000	2000	1.58122
3500	2000	2.33254
4000	2000	3.00688
4500	2000	3.51847
5000	2000	3.88164
-5000	2500	4.68653
-4500	2500	10.79281
-4000	2500	24.22978
-3500	2500	54.238
-3000	2500	95.61082
-2500	2500	134.88702
-2000	2500	179.35983
-1500	2500	219.85374
-1000	2500	221.93221
-500	2500	165.77126
0	2500	73.29867
500	2500	55.22968
1000	2500	28.61891
1500	2500	22.41304
2000	2500	3.37408
2500	2500	8.30752
3000	2500	0.33441
3500	2500	0.48245
4000	2500	0.83255
4500	2500	1.2403
5000	2500	1.6568
-5000	3000	10.14341
-4500	3000	20.33454
-4000	3000	41.52284
-3500	3000	74.17965
-3000	3000	108.34155
-2500	3000	142.24443
-2000	3000	173.18364
-1500	3000	176.69151
-1000	3000	154.47006
-500	3000	80.60794
0	3000	48.36604
500	3000	52.15003
1000	3000	32.53015
1500	3000	24.29558
2000	3000	13.11083
2500	3000	5.61997
3000	3000	5.00878
3500	3000	0.06884
4000	3000	0.16257
4500	3000	0.31715
5000	3000	0.53229
-5000	3500	17.57788
-4500	3500	33.19319
-4000	3500	58.34675

-3500	3500	87.38139
-3000	3500	115.01277
-2500	3500	139.85948
-2000	3500	148.36508
-1500	3500	131.18848
-1000	3500	86.11726
-500	3500	46.8608
0	3500	40.44398
500	3500	47.11663
1000	3500	32.11436
1500	3500	27.33305
2000	3500	18.95794
2500	3500	5.32971
3000	3500	12.26464
3500	3500	0.21574
4000	3500	0.02331
4500	3500	0.06067
5000	3500	0.13034
-5000	4000	27.4173
-4500	4000	46.74204
-4000	4000	70.73517
-3500	4000	94.25642
-3000	4000	114.99507
-2500	4000	126.15907
-2000	4000	116.09362
-1500	4000	82.53193
-1000	4000	47.73669
-500	4000	34.01232
0	4000	37.11232
500	4000	42.4886
1000	4000	32.36378
1500	4000	28.57762
2000	4000	19.4387
2500	4000	14.22053
3000	4000	9.27053
3500	4000	4.59991
4000	4000	0.00474
4500	4000	0.00898
5000	4000	0.02506
-5000	4500	38.14507
-4500	4500	57.63338
-4000	4500	77.87461
-3500	4500	95.92658
-3000	4500	107.71286
-2500	4500	104.35117
-2000	4500	80.64988
-1500	4500	47.19051
-1000	4500	30.06963
-500	4500	28.54159
0	4500	35.11397
500	4500	39.03307

1000	4500	29.41828	-4500	5000	64.71256	500	5000	37.1577
1500	4500	26.87284	-4000	5000	80.81446	1000	5000	25.40504
2000	4500	22.33593	-3500	5000	92.47952	1500	5000	24.78964
2500	4500	23.91517	-3000	5000	93.52252	2000	5000	22.49383
3000	4500	7.2613	-2500	5000	78.33307	2500	5000	24.80587
3500	4500	13.24044	-2000	5000	50.80853	3000	5000	14.37426
4000	4500	0.30359	-1500	5000	27.28016	3500	5000	12.77716
4500	4500	0.00107	-1000	5000	21.98584	4000	5000	4.09009
5000	4500	0.00388	-500	5000	25.76689	4500	5000	0.00771
-5000	5000	47.3825	0	5000	33.6563	5000	5000	0.00049

Table A-08: Data for contour diagram for stack exit velocity 15 m/s

X (m)	Y (m)	SO_2 ($\mu g/m^3$)	X (m)	Y (m)	SO_2 ($\mu g/m^3$)	X (m)	Y (m)	SO_2 ($\mu g/m^3$)
-5000	-5000	173.19075	1500	-4500	278.67569	-2500	-3500	407.62827
-4500	-5000	207.44887	2000	-4500	252.19566	-2000	-3500	498.83289
-4000	-5000	238.90129	2500	-4500	223.87071	-1500	-3500	611.93207
-3500	-5000	258.07999	3000	-4500	208.10101	-1000	-3500	709.26636
-3000	-5000	320.20175	3500	-4500	177.3963	-500	-3500	648.30994
-2500	-5000	391.03137	4000	-4500	146.41904	0	-3500	634.99304
-2000	-5000	481.32849	4500	-4500	113.71583	500	-3500	522.0459
-1500	-5000	535.23773	5000	-4500	76.05316	1000	-3500	442.77737
-1000	-5000	510.13327	-5000	-4000	162.35876	1500	-3500	379.94427
-500	-5000	521.57715	-4500	-4000	180.12172	2000	-3500	328.30902
0	-5000	419.78549	-4000	-4000	234.6413	2500	-3500	282.77713
500	-5000	356.04218	-3500	-4000	286.48965	3000	-3500	222.76318
1000	-5000	293.05402	-3000	-4000	323.56812	3500	-3500	174.80164
1500	-5000	245.1042	-2500	-4000	392.37924	4000	-3500	119.07702
2000	-5000	220.53241	-2000	-4000	495.88885	4500	-3500	82.1997
2500	-5000	204.28438	-1500	-4000	596.14062	5000	-3500	66.19135
3000	-5000	184.37108	-1000	-4000	643.9198	-5000	-3000	224.47903
3500	-5000	178.65482	-500	-4000	584.2937	-4500	-3000	238.44922
4000	-5000	147.56326	0	-4000	565.59473	-4000	-3000	233.41907
4500	-5000	126.29215	500	-4000	452.63507	-3500	-3000	259.73111
5000	-5000	93.83295	1000	-4000	376.24463	-3000	-3000	340.03625
-5000	-4500	155.47974	1500	-4000	327.58743	-2500	-3000	426.06876
-4500	-4500	200.41589	2000	-4000	288.31729	-2000	-3000	530.16913
-4000	-4500	242.67883	2500	-4000	247.56403	-1500	-3000	632.23199
-3500	-4500	273.51239	3000	-4000	222.58939	-1000	-3000	738.40106
-3000	-4500	310.42487	3500	-4000	175.21158	-500	-3000	781.92761
-2500	-4500	398.72488	4000	-4000	139.75319	0	-3000	691.48694
-2000	-4500	485.76276	4500	-4000	93.43513	500	-3000	635.28149
-1500	-4500	574.03668	5000	-4000	67.1917	1000	-3000	531.83325
-1000	-4500	560.06946	-5000	-3500	189.49066	1500	-3000	453.75424
-500	-4500	558.03638	-4500	-3500	189.69475	2000	-3000	375.69489
0	-4500	481.14505	-4000	-3500	212.60909	2500	-3000	303.30322
500	-4500	398.27649	-3500	-3500	279.51251	3000	-3000	227.38788
1000	-4500	329.40775	-3000	-3500	342.80533	3500	-3000	158.03238

4000	-3000	105.77612
4500	-3000	82.75423
5000	-3000	67.10978
-5000	-2500	214.34364
-4500	-2500	250.07326
-4000	-2500	286.85175
-3500	-2500	305.495
-3000	-2500	341.27386
-2500	-2500	426.47089
-2000	-2500	556.66205
-1500	-2500	696.37964
-1000	-2500	768.52539
-500	-2500	901.59003
0	-2500	831.55518
500	-2500	781.78833
1000	-2500	659.4198
1500	-2500	539.3385
2000	-2500	437.3577
2500	-2500	319.57156
3000	-2500	220.28152
3500	-2500	145.04605
4000	-2500	109.63201
4500	-2500	86.00699
5000	-2500	70.27474
-5000	-2000	220.65686
-4500	-2000	247.1033
-4000	-2000	284.70715
-3500	-2000	341.14746
-3000	-2000	387.01282
-2500	-2000	464.83871
-2000	-2000	586.10266
-1500	-2000	745.14374
-1000	-2000	913.24622
-500	-2000	990.8313
0	-2000	1071.96814
500	-2000	950.0799
1000	-2000	855.30316
1500	-2000	656.01001
2000	-2000	504.93652
2500	-2000	335.42352
3000	-2000	214.89317
3500	-2000	154.22388
4000	-2000	114.91599
4500	-2000	89.6146
5000	-2000	73.33183
-5000	-1500	180.22139
-4500	-1500	229.5941
-4000	-1500	281.2998
-3500	-1500	337.19
-3000	-1500	413.25339
-2500	-1500	499.72791

-2000	-1500	632.60712
-1500	-1500	854.64105
-1000	-1500	1041.92834
-500	-1500	1274.33521
0	-1500	1295.87842
500	-1500	1250.12378
1000	-1500	1141.10815
1500	-1500	855.60986
2000	-1500	593.59845
2500	-1500	348.1998
3000	-1500	226.50899
3500	-1500	155.33792
4000	-1500	113.62521
4500	-1500	87.47312
5000	-1500	69.19907
-5000	-1000	114.49774
-4500	-1000	149.66652
-4000	-1000	203.94672
-3500	-1000	276.70795
-3000	-1000	375.03815
-2500	-1000	490.56677
-2000	-1000	629.96722
-1500	-1000	795.54993
-1000	-1000	1059.95728
-500	-1000	1329.45227
0	-1000	1431.86926
500	-1000	1350.01794
1000	-1000	1147.43945
1500	-1000	983.38586
2000	-1000	601.6897
2500	-1000	329.1951
3000	-1000	203.65118
3500	-1000	138.84207
4000	-1000	100.27357
4500	-1000	74.69642
5000	-1000	57.03328
-5000	-500	67.39952
-4500	-500	87.6068
-4000	-500	117.57014
-3500	-500	157.64655
-3000	-500	220.13866
-2500	-500	319.75858
-2000	-500	449.95789
-1500	-500	529.36615
-1000	-500	625.11346
-500	-500	797.79846
0	-500	1032.67126
500	-500	1014.19684
1000	-500	934.24713
1500	-500	606.50452
2000	-500	425.46878

2500	-500	251.58768
3000	-500	159.14674
3500	-500	107.16577
4000	-500	75.23521
4500	-500	54.79146
5000	-500	41.35254
-5000	0	34.58493
-4500	0	42.253
-4000	0	53.23076
-3500	0	69.58381
-3000	0	95.07421
-2500	0	133.18875
-2000	0	196.65157
-1500	0	348.4343
-1000	0	453.88641
-500	0	547.48914
0	0	677.2868
500	0	665.92267
1000	0	706.30267
1500	0	429.17477
2000	0	248.92601
2500	0	153.40599
3000	0	98.08284
3500	0	66.32607
4000	0	47.33292
4500	0	35.39803
5000	0	27.56409
-5000	500	15.6892
-4500	500	18.01111
-4000	500	21.24478
-3500	500	26.03427
-3000	500	34.21586
-2500	500	57.31318
-2000	500	152.53925
-1500	500	258.55121
-1000	500	334.70898
-500	500	378.64734
0	500	316.90817
500	500	280.18753
1000	500	291.50717
1500	500	195.89101
2000	500	102.94987
2500	500	63.52821
3000	500	44.98591
3500	500	34.31925
4000	500	27.24536
4500	500	22.15568
5000	500	18.37839
-5000	1000	6.08854
-4500	1000	6.54255
-4000	1000	7.2588

-3500	1000	9.69552
-3000	1000	20.47569
-2500	1000	63.39194
-2000	1000	146.7513
-1500	1000	197.86082
-1000	1000	276.4556
-500	1000	266.11276
0	1000	250.65369
500	1000	163.71964
1000	1000	51.45989
1500	1000	38.20992
2000	1000	27.29078
2500	1000	23.0565
3000	1000	19.60994
3500	1000	16.90603
4000	1000	14.88621
4500	1000	13.26971
5000	1000	11.90033
-5000	1500	1.34287
-4500	1500	1.74143
-4000	1500	4.19081
-3500	1500	12.56289
-3000	1500	38.77885
-2500	1500	101.72085
-2000	1500	151.69824
-1500	1500	207.636
-1000	1500	280.52878
-500	1500	271.5748
0	1500	297.37323
500	1500	101.01495
1000	1500	25.46107
1500	1500	14.41229
2000	1500	6.25686
2500	1500	5.76356
3000	1500	6.94654
3500	1500	7.48116
4000	1500	7.54308
4500	1500	7.4038
5000	1500	7.20184
-5000	2000	1.30009
-4500	2000	4.18373
-4000	2000	11.3291
-3500	2000	29.3681
-3000	2000	72.07843
-2500	2000	119.25275
-2000	2000	163.17017
-1500	2000	220.70514
-1000	2000	259.22882
-500	2000	266.23361
0	2000	140.06546
500	2000	59.21782

1000	2000	24.9723
1500	2000	16.86758
2000	2000	3.02208
2500	2000	4.43526
3000	2000	1.57604
3500	2000	2.3267
4000	2000	3.00108
4500	2000	3.51328
5000	2000	3.87736
-5000	2500	4.64469
-4500	2500	10.66613
-4000	2500	23.8084
-3500	2500	52.98211
-3000	2500	93.14914
-2500	2500	131.16556
-2000	2500	173.48943
-1500	2500	210.58441
-1000	2500	211.27672
-500	2500	157.43677
0	2500	69.07822
500	2500	50.54431
1000	2500	25.61767
1500	2500	19.12371
2000	2500	2.74381
2500	2500	6.52148
3000	2500	0.31305
3500	2500	0.48152
4000	2500	0.8313
4500	2500	1.23888
5000	2500	1.65541
-5000	3000	10.05202
-4500	3000	20.07629
-4000	3000	40.82509
-3500	3000	72.75484
-3000	3000	106.10999
-2500	3000	138.9391
-2000	3000	168.30368
-1500	3000	171.16011
-1000	3000	148.87064
-500	3000	77.64563
0	3000	45.71836
500	3000	47.51424
1000	3000	28.87696
1500	3000	20.93304
2000	3000	10.46797
2500	3000	4.56892
3000	3000	4.05871
3500	3000	0.06869
4000	3000	0.16237
4500	3000	0.31687
5000	3000	0.53195

-5000	3500	17.40732
-4500	3500	32.77197
-4000	3500	57.48454
-3500	3500	85.98186
-3000	3500	112.98733
-2500	3500	137.01413
-2000	3500	144.99973
-1500	3500	128.02049
-1000	3500	83.71005
-500	3500	45.13618
0	3500	38.23657
500	3500	43.41394
1000	3500	28.89051
1500	3500	23.53703
2000	3500	15.45485
2500	3500	4.42002
3000	3500	10.06895
3500	3500	0.18053
4000	3500	0.02329
4500	3500	0.06063
5000	3500	0.13027
-5000	4000	27.1459
-4500	4000	46.19642
-4000	4000	69.82881
-3500	4000	92.94357
-3000	4000	113.20508
-2500	4000	123.9897
-2000	4000	114.00567
-1500	4000	81.04403
-1000	4000	46.51124
-500	4000	32.63108
0	4000	35.10955
500	4000	39.5765
1000	4000	29.27077
1500	4000	24.90216
2000	4000	16.16152
2500	4000	11.76345
3000	4000	7.76584
3500	4000	3.86089
4000	4000	0.0044
4500	4000	0.00898
5000	4000	0.02505
-5000	4500	37.78527
-4500	4500	57.02955
-4000	4500	76.99065
-3500	4500	94.73664
-3000	4500	106.25977
-2500	4500	102.8793
-2000	4500	79.53683
-1500	4500	46.54726
-1000	4500	29.24619

-500	4500	27.31073	5000	4500	0.00388	0	4500	31.95688
0	4500	33.27449	-5000	5000	46.96921	500	5000	35.06753
500	4500	36.6742	-4500	5000	64.10048	1000	5000	23.74859
1000	4500	27.02778	-4000	5000	79.991	1500	5000	22.18544
1500	4500	23.76173	-3500	5000	91.47	2000	5000	19.22008
2000	4500	18.78241	-3000	5000	92.4594	2500	5000	21.07303
2500	4500	20.05254	-2500	5000	77.45264	3000	5000	12.26102
3000	4500	6.18691	-2000	5000	50.2925	3500	5000	10.96581
3500	4500	11.22465	-1500	5000	26.97425	4000	5000	3.52147
4000	4500	0.25953	-1000	5000	21.32571	4500	5000	0.0067
4500	4500	0.00106	-500	5000	24.63866	5000	5000	0.00049

Table A-09: Data for contour diagram for stack exit velocity 20 m/s

X (m)	Y (m)	SO_2 ($\mu g/m^3$)	X (m)	Y (m)	SO_2 ($\mu g/m^3$)	X (m)	Y (m)	SO_2 ($\mu g/m^3$)
-5000	-5000	166.65057	1000	-4500	313.53967	-3500	-3500	266.84491
-4500	-5000	199.70613	1500	-4500	267.94699	-3000	-3500	326.85187
-4000	-5000	230.0407	2000	-4500	243.8365	-2500	-3500	386.9007
-3500	-5000	248.48997	2500	-4500	216.85387	-2000	-3500	471.38004
-3000	-5000	306.47528	3000	-4500	201.05045	-1500	-3500	574.60272
-2500	-5000	372.87692	3500	-4500	171.31984	-1000	-3500	663.76965
-2000	-5000	457.52075	4000	-4500	141.39911	-500	-3500	606.53186
-1500	-5000	507.22855	4500	-4500	110.28998	0	-3500	592.35205
-1000	-5000	482.5719	5000	-4500	74.7346	500	-3500	491.82089
-500	-5000	491.84064	-5000	-4000	156.03329	1000	-3500	419.52481
0	-5000	396.74866	-4500	-4000	173.04604	1500	-3500	364.06699
500	-5000	337.34479	-4000	-4000	224.7124	2000	-3500	316.35272
1000	-5000	279.38602	-3500	-4000	274.25177	2500	-3500	272.69202
1500	-5000	235.87718	-3000	-4000	309.37546	3000	-3500	215.14113
2000	-5000	213.4953	-2500	-4000	373.48749	3500	-3500	168.51279
2500	-5000	198.04669	-2000	-4000	469.242	4000	-3500	115.99621
3000	-5000	178.91266	-1500	-4000	561.71667	4500	-3500	81.12601
3500	-5000	172.42331	-1000	-4000	605.1499	5000	-3500	65.64095
4000	-5000	142.69734	-500	-4000	547.94257	-5000	-3000	212.73628
4500	-5000	122.09369	0	-4000	530.00507	-4500	-3000	225.94531
5000	-5000	91.37999	500	-4000	427.07269	-4000	-3000	222.39165
-5000	-4500	149.71603	1000	-4000	357.45078	-3500	-3000	247.85458
-4500	-4500	192.41658	1500	-4000	314.202	-3000	-3000	323.14758
-4000	-4500	233.02478	2000	-4000	278.24689	-2500	-3000	403.45871
-3500	-4500	262.65289	2500	-4000	239.63632	-2000	-3000	498.86548
-3000	-4500	297.4238	3000	-4000	214.70149	-1500	-3000	591.75342
-2500	-4500	379.56152	3500	-4000	169.20386	-1000	-3000	687.84082
-2000	-4500	460.7738	4000	-4000	135.04422	-500	-3000	727.69928
-1500	-4500	542.52631	4500	-4000	91.4454	0	-3000	643.43488
-1000	-4500	528.51526	5000	-4000	66.47822	500	-3000	595.61578
-500	-4500	524.53375	-5000	-3500	181.39627	1000	-3000	502.25067
0	-4500	453.21719	-4500	-3500	181.82326	1500	-3000	433.19986
500	-4500	376.57275	-4000	-3500	203.68884	2000	-3000	361.33847

2500	-3000	292.50555
3000	-3000	219.04547
3500	-3000	153.17593
4000	-3000	104.0631
4500	-3000	81.92865
5000	-3000	66.70808
-5000	-2500	204.35973
-4500	-2500	237.59793
-4000	-2500	271.08209
-3500	-2500	287.9588
-3000	-2500	322.59476
-2500	-2500	402.19922
-2000	-2500	521.57428
-1500	-2500	647.1958
-1000	-2500	712.20142
-500	-2500	832.1496
0	-2500	769.93976
500	-2500	726.49023
1000	-2500	619.48346
1500	-2500	512.51331
2000	-2500	418.94678
2500	-2500	307.65338
3000	-2500	212.56586
3500	-2500	142.10324
4000	-2500	108.30337
4500	-2500	85.40356
5000	-2500	70.01591
-5000	-2000	209.69388
-4500	-2000	235.49429
-4000	-2000	271.17938
-3500	-2000	322.34552
-3000	-2000	363.25833
-2500	-2000	433.90125
-2000	-2000	542.85797
-1500	-2000	686.39862
-1000	-2000	832.96948
-500	-2000	903.33453
0	-2000	978.57709
500	-2000	871.71765
1000	-2000	793.73309
1500	-2000	616.31635
2000	-2000	481.59763
2500	-2000	322.11612
3000	-2000	209.29446
3500	-2000	151.87381
4000	-2000	113.93652
4500	-2000	89.18924
5000	-2000	73.11265
-5000	-1500	173.10045
-4500	-1500	219.00526
-4000	-1500	267.47775

-3500	-1500	319.6424
-3000	-1500	387.85651
-2500	-1500	462.36346
-2000	-1500	576.30902
-1500	-1500	765.58655
-1000	-1500	922.84894
-500	-1500	1124.83301
0	-1500	1141.82898
500	-1500	1105.12402
1000	-1500	1026.48755
1500	-1500	785.41034
2000	-1500	561.74536
2500	-1500	335.65482
3000	-1500	221.73109
3500	-1500	153.57552
4000	-1500	112.86974
4500	-1500	87.07754
5000	-1500	68.97331
-5000	-1000	111.72068
-4500	-1000	145.40083
-4000	-1000	196.12437
-3500	-1000	263.53268
-3000	-1000	351.54971
-2500	-1000	449.68234
-2000	-1000	557.28876
-1500	-1000	678.94775
-1000	-1000	884.41101
-500	-1000	1108.86121
0	-1000	1202.11682
500	-1000	1151.27148
1000	-1000	1002.70685
1500	-1000	865.46759
2000	-1000	559.84637
2500	-1000	317.11786
3000	-1000	199.96985
3500	-1000	137.38742
4000	-1000	99.56493
4500	-1000	74.31616
5000	-1000	56.82056
-5000	-500	66.44717
-4500	-500	85.92016
-4000	-500	114.32491
-3500	-500	152.35818
-3000	-500	210.05247
-2500	-500	297.54715
-2000	-500	399.97229
-1500	-500	454.2608
-1000	-500	513.85406
-500	-500	644.80267
0	-500	846.35107
500	-500	853.56726

1000	-500	819.35516
1500	-500	543.34637
2000	-500	392.67789
2500	-500	243.09686
3000	-500	156.37704
3500	-500	105.99324
4000	-500	74.66411
4500	-500	54.4884
5000	-500	41.18283
-5000	0	34.16553
-4500	0	41.61375
-4000	0	52.19711
-3500	0	67.78899
-3000	0	91.5973
-2500	0	126.38837
-2000	0	181.90439
-1500	0	296.60159
-1000	0	370.93213
-500	0	428.45633
0	0	516.34088
500	0	525.39862
1000	0	583.47296
1500	0	391.90372
2000	0	237.01619
2500	0	149.43785
3000	0	96.57567
3500	0	65.65095
4000	0	46.98869
4500	0	35.20641
5000	0	27.45153
-5000	500	15.52573
-4500	500	17.78252
-4000	500	20.90687
-3500	500	25.49394
-3000	500	33.22851
-2500	500	54.62017
-2000	500	135.06569
-1500	500	221.88344
-1000	500	281.69904
-500	500	298.74915
0	500	248.47292
500	500	222.06882
1000	500	236.29965
1500	500	173.79013
2000	500	98.16779
2500	500	62.03125
3000	500	44.35807
3500	500	34.00455
4000	500	27.06904
4500	500	22.04968
5000	500	18.31229

-5000	1000	6.02878
-4500	1000	6.46484
-4000	1000	7.1512
-3500	1000	9.50058
-3000	1000	19.81453
-2500	1000	59.06253
-2000	1000	134.44298
-1500	1000	180.24899
-1000	1000	245.49605
-500	1000	227.62067
0	1000	206.24965
500	1000	138.49641
1000	1000	44.94712
1500	1000	35.95272
2000	1000	26.35769
2500	1000	22.72432
3000	1000	19.42507
3500	1000	16.79461
4000	1000	14.8147
4500	1000	13.22201
5000	1000	11.86819
-5000	1500	1.33006
-4500	1500	1.72039
-4000	1500	4.12282
-3500	1500	12.26714
-3000	1500	37.16879
-2500	1500	96.28499
-2000	1500	143.23354
-1500	1500	194.29248
-1000	1500	254.6963
-500	1500	243.61929
0	1500	254.79906
500	1500	90.81618
1000	1500	23.51628
1500	1500	13.55563
2000	1500	5.76549
2500	1500	5.71828
3000	1500	6.91056
3500	1500	7.45268
4000	1500	7.52121
4500	1500	7.38721
5000	1500	7.18947
-5000	2000	1.28726
-4500	2000	4.13278
-4000	2000	11.14076
-3500	2000	28.58911
-3000	2000	69.54016
-2500	2000	114.74869
-2000	2000	156.43098
-1500	2000	209.08029
-1000	2000	241.80257

-500	2000	244.87198
0	2000	130.13347
500	2000	55.32475
1000	2000	22.97203
1500	2000	15.0747
2000	2000	2.56256
2500	2000	3.75453
3000	2000	1.57077
3500	2000	2.32073
4000	2000	2.99514
4500	2000	3.50795
5000	2000	3.87296
-5000	2500	4.6016
-4500	2500	10.53542
-4000	2500	23.37287
-3500	2500	51.68592
-3000	2500	90.6154
-2500	2500	127.34689
-2000	2500	167.52913
-1500	2500	201.37473
-1000	2500	200.92467
-500	2500	149.5506
0	2500	65.66628
500	2500	47.16068
1000	2500	23.56819
1500	2500	16.96526
2000	2500	2.33212
2500	2500	5.38042
3000	2500	0.29891
3500	2500	0.48059
4000	2500	0.83003
4500	2500	1.23743
5000	2500	1.654
-5000	3000	9.95731
-4500	3000	19.80764
-4000	3000	40.09838
-3500	3000	71.27316
-3000	3000	103.79498
-2500	3000	135.52556
-2000	3000	163.31049
-1500	3000	165.54366
-1000	3000	143.42662
-500	3000	74.99791
0	3000	43.6729
500	3000	44.21169
1000	3000	26.37947
1500	3000	18.6638
2000	3000	8.76106
2500	3000	3.86794
3000	3000	3.42774
3500	3000	0.06856

4000	3000	0.16218
4500	3000	0.31658
5000	3000	0.5316
-5000	3500	17.22927
-4500	3500	32.33105
-4000	3500	56.58192
-3500	3500	84.51913
-3000	3500	110.87518
-2500	3500	134.05989
-2000	3500	141.52013
-1500	3500	124.77873
-1000	3500	81.45207
-500	3500	43.72193
0	3500	36.54326
500	3500	40.6987
1000	3500	26.61924
1500	3500	20.96145
2000	3500	13.13133
2500	3500	3.79978
3000	3500	8.58742
3500	3500	0.15647
4000	3500	0.02327
4500	3500	0.06059
5000	3500	0.13021
-5000	4000	26.8608
-4500	4000	45.62286
-4000	4000	68.8764
-3500	4000	91.56621
-3000	4000	111.33142
-2500	4000	121.72546
-2000	4000	111.83197
-1500	4000	79.52651
-1000	4000	45.43909
-500	4000	31.54348
0	4000	33.57003
500	4000	37.3909
1000	4000	27.06791
1500	4000	22.34908
2000	4000	13.94045
2500	4000	10.09482
3000	4000	6.72761
3500	4000	3.34977
4000	4000	0.00417
4500	4000	0.00898
5000	4000	0.02505
-5000	4500	37.4059
-4500	4500	56.39284
-4000	4500	76.0596
-3500	4500	93.48457
-3000	4500	104.7332
-2500	4500	101.33706

-2000	4500	78.37324
-1500	4500	45.90575
-1000	4500	28.5679
-500	4500	26.3513
0	4500	31.8535
500	4500	34.86964
1000	4500	25.27916
1500	4500	21.55666
2000	4500	16.34196
2500	4500	17.38739
3000	4500	5.43148
3500	4500	9.81455

4000	4500	0.22846
4500	4500	0.00106
5000	4500	0.00388
-5000	5000	46.53225
-4500	5000	63.45374
-4000	5000	79.12144
-3500	5000	90.40525
-3000	5000	91.3404
-2500	5000	76.52756
-2000	5000	49.75201
-1500	5000	26.68418
-1000	5000	20.79769

-500	5000	23.75883
0	5000	30.63717
500	5000	33.45341
1000	5000	22.50049
1500	5000	20.31218
2000	5000	16.9297
2500	5000	18.46003
3000	5000	10.77427
3500	5000	9.68153
4000	5000	3.11691
4500	5000	0.00598
5000	5000	0.00049

** 1 $\mu g/m^3$ $SO_2 = 3.807 \times 10^{-4}$ ppm SO_2

APPENDIX - B

METEOROLOGICAL DATA USED FOR WINDROSE DIAGRAM

Table B-01: Hourly meteorological data for November 2004

Hour	Wind Vector	Wind Velocity	Hour	Wind Vector	Wind Velocity	Hour	Wind Vector	Wind Velocity
1	175.8765	2.9416	62	115.3133	2.2691	123	187.9307	2.7996
2	175.8765	2.9416	63	115.3133	2.2691	124	187.9307	2.7996
3	175.8765	2.9416	64	115.3133	2.2691	125	187.9307	2.7996
4	175.8765	2.9416	65	115.3133	2.2691	126	187.9307	2.7996
5	175.8765	2.9416	66	115.3133	2.2691	127	204.3825	2.4112
6	175.8765	2.9416	67	160.3076	3.8985	128	204.3825	2.4112
7	162.8281	1.7988	68	160.3076	3.8985	129	204.3825	2.4112
8	162.8281	1.7988	69	160.3076	3.8985	130	204.3825	2.4112
9	162.8281	1.7988	70	160.3076	3.8985	131	204.3825	2.4112
10	162.8281	1.7988	71	160.3076	3.8985	132	204.3825	2.4112
11	162.8281	1.7988	72	160.3076	3.8985	133	180.6686	1.45
12	162.8281	1.7988	73	208.7477	2.9515	134	180.6686	1.45
13	108.9411	1.7506	74	208.7477	2.9515	135	180.6686	1.45
14	108.9411	1.7506	75	208.7477	2.9515	136	180.6686	1.45
15	108.9411	1.7506	76	208.7477	2.9515	137	180.6686	1.45
16	108.9411	1.7506	77	208.7477	2.9515	138	180.6686	1.45
17	108.9411	1.7506	78	208.7477	2.9515	139	159.3553	3.5317
18	108.9411	1.7506	79	142.8846	1.4952	140	159.3553	3.5317
19	153.4707	4.8672	80	142.8846	1.4952	141	159.3553	3.5317
20	153.4707	4.8672	81	142.8846	1.4952	142	159.3553	3.5317
21	153.4707	4.8672	82	142.8846	1.4952	143	159.3553	3.5317
22	153.4707	4.8672	83	142.8846	1.4952	144	159.3553	3.5317
23	153.4707	4.8672	84	142.8846	1.4952	145	203.5559	1.9911
24	153.4707	4.8672	85	125.4721	1.6209	146	203.5559	1.9911
25	167.4272	2.157	86	125.4721	1.6209	147	203.5559	1.9911
26	167.4272	2.157	87	125.4721	1.6209	148	203.5559	1.9911
27	167.4272	2.157	88	125.4721	1.6209	149	203.5559	1.9911
28	167.4272	2.157	89	125.4721	1.6209	150	203.5559	1.9911
29	167.4272	2.157	90	125.4721	1.6209	151	355.9854	0.3455
30	167.4272	2.157	91	169.0341	3.6103	152	355.9854	0.3455
31	166.6364	1.2376	92	169.0341	3.6103	153	355.9854	0.3455
32	166.6364	1.2376	93	169.0341	3.6103	154	355.9854	0.3455
33	166.6364	1.2376	94	169.0341	3.6103	155	355.9854	0.3455
34	166.6364	1.2376	95	169.0341	3.6103	156	355.9854	0.3455
35	166.6364	1.2376	96	169.0341	3.6103	157	106.9641	0.5773
36	166.6364	1.2376	97	195.4885	2.0359	158	106.9641	0.5773
37	113.0961	1.9829	98	195.4885	2.0359	159	106.9641	0.5773
38	113.0961	1.9829	99	195.4885	2.0359	160	106.9641	0.5773
39	113.0961	1.9829	100	195.4885	2.0359	161	106.9641	0.5773
40	113.0961	1.9829	101	195.4885	2.0359	162	106.9641	0.5773
41	113.0961	1.9829	102	195.4885	2.0359	163	178.7574	3.6136
42	113.0961	1.9829	103	203.4405	1.0881	164	178.7574	3.6136
43	149.6814	3.4606	104	203.4405	1.0881	165	178.7574	3.6136
44	149.6814	3.4606	105	203.4405	1.0881	166	178.7574	3.6136
45	149.6814	3.4606	106	203.4405	1.0881	167	178.7574	3.6136
46	149.6814	3.4606	107	203.4405	1.0881	168	178.7574	3.6136
47	149.6814	3.4606	108	203.4405	1.0881	169	202.3327	2.5722
48	149.6814	3.4606	109	132.0132	1.1758	170	202.3327	2.5722
49	194.5603	1.7585	110	132.0132	1.1758	171	202.3327	2.5722
50	194.5603	1.7585	111	132.0132	1.1758	172	202.3327	2.5722
51	194.5603	1.7585	112	132.0132	1.1758	173	202.3327	2.5722
52	194.5603	1.7585	113	132.0132	1.1758	174	202.3327	2.5722
53	194.5603	1.7585	114	132.0132	1.1758	175	167.6728	0.6496
54	194.5603	1.7585	115	176.5401	4.0888	176	167.6728	0.6496
55	206.544	0.6897	116	176.5401	4.0888	177	167.6728	0.6496
56	206.544	0.6897	117	176.5401	4.0888	178	167.6728	0.6496
57	206.544	0.6897	118	176.5401	4.0888	179	167.6728	0.6496
58	206.544	0.6897	119	176.5401	4.0888	180	167.6728	0.6496
59	206.544	0.6897	120	176.5401	4.0888	181	121.5644	2.2576
60	206.544	0.6897	121	187.9307	2.7996	182	121.5644	2.2576
61	115.3133	2.2691	122	187.9307	2.7996	183	121.5644	2.2576

184	121.5644	2.2576	255	124.7435	1.5971	326	164.6381	1.452
185	121.5644	2.2576	256	124.7435	1.5971	327	164.6381	1.452
186	121.5644	2.2576	257	124.7435	1.5971	328	164.6381	1.452
187	192.2589	2.761	258	124.7435	1.5971	329	164.6381	1.452
188	192.2589	2.761	259	181.0523	3.5542	330	164.6381	1.452
189	192.2589	2.761	260	181.0523	3.5542	331	200.1242	4.3978
190	192.2589	2.761	261	181.0523	3.5542	332	200.1242	4.3978
191	192.2589	2.761	262	181.0523	3.5542	333	200.1242	4.3978
192	192.2589	2.761	263	181.0523	3.5542	334	200.1242	4.3978
193	201.4438	2.3025	264	181.0523	3.5542	335	200.1242	4.3978
194	201.4438	2.3025	265	198.4333	2.3423	336	200.1242	4.3978
195	201.4438	2.3025	266	198.4333	2.3423	337	166.9343	2.1098
196	201.4438	2.3025	267	198.4333	2.3423	338	166.9343	2.1098
197	201.4438	2.3025	268	198.4333	2.3423	339	166.9343	2.1098
198	201.4438	2.3025	269	198.4333	2.3423	340	166.9343	2.1098
199	187.2666	0.4803	270	198.4333	2.3423	341	166.9343	2.1098
200	187.2666	0.4803	271	224.7593	1.6565	342	166.9343	2.1098
201	187.2666	0.4803	272	224.7593	1.6565	343	187.5987	0.9831
202	187.2666	0.4803	273	224.7593	1.6565	344	187.5987	0.9831
203	187.2666	0.4803	274	224.7593	1.6565	345	187.5987	0.9831
204	187.2666	0.4803	275	224.7593	1.6565	346	187.5987	0.9831
205	134.3339	1.757	276	224.7593	1.6565	347	187.5987	0.9831
206	134.3339	1.757	277	140.7727	2.1583	348	187.5987	0.9831
207	134.3339	1.757	278	140.7727	2.1583	349	146.054	1.6494
208	134.3339	1.757	279	140.7727	2.1583	350	146.054	1.6494
209	134.3339	1.757	280	140.7727	2.1583	351	146.054	1.6494
210	134.3339	1.757	281	140.7727	2.1583	352	146.054	1.6494
211	191.8642	3.7993	282	140.7727	2.1583	353	146.054	1.6494
212	191.8642	3.7993	283	209.048	3.7378	354	146.054	1.6494
213	191.8642	3.7993	284	209.048	3.7378	355	215.8493	3.9537
214	191.8642	3.7993	285	209.048	3.7378	356	215.8493	3.9537
215	191.8642	3.7993	286	209.048	3.7378	357	215.8493	3.9537
216	191.8642	3.7993	287	209.048	3.7378	358	215.8493	3.9537
217	183.1483	2.9154	288	209.048	3.7378	359	215.8493	3.9537
218	183.1483	2.9154	289	176.1107	2.0299	360	215.8493	3.9537
219	183.1483	2.9154	290	176.1107	2.0299	361	210.4079	2.8006
220	183.1483	2.9154	291	176.1107	2.0299	362	210.4079	2.8006
221	183.1483	2.9154	292	176.1107	2.0299	363	210.4079	2.8006
222	183.1483	2.9154	293	176.1107	2.0299	364	210.4079	2.8006
223	212.8514	1.7443	294	176.1107	2.0299	365	210.4079	2.8006
224	212.8514	1.7443	295	165.6635	1.9632	366	210.4079	2.8006
225	212.8514	1.7443	296	165.6635	1.9632	367	187.7123	0.8912
226	212.8514	1.7443	297	165.6635	1.9632	368	187.7123	0.8912
227	212.8514	1.7443	298	165.6635	1.9632	369	187.7123	0.8912
228	212.8514	1.7443	299	165.6635	1.9632	370	187.7123	0.8912
229	125.0969	1.5132	300	165.6635	1.9632	371	187.7123	0.8912
230	125.0969	1.5132	301	129.2105	1.0899	372	187.7123	0.8912
231	125.0969	1.5132	302	129.2105	1.0899	373	138.4793	1.6577
232	125.0969	1.5132	303	129.2105	1.0899	374	138.4793	1.6577
233	125.0969	1.5132	304	129.2105	1.0899	375	138.4793	1.6577
234	125.0969	1.5132	305	129.2105	1.0899	376	138.4793	1.6577
235	181.5497	2.5143	306	129.2105	1.0899	377	138.4793	1.6577
236	181.5497	2.5143	307	214.3096	4.3469	378	138.4793	1.6577
237	181.5497	2.5143	308	214.3096	4.3469	379	191.0397	4.3808
238	181.5497	2.5143	309	214.3096	4.3469	380	191.0397	4.3808
239	181.5497	2.5143	310	214.3096	4.3469	381	191.0397	4.3808
240	181.5497	2.5143	311	214.3096	4.3469	382	191.0397	4.3808
241	173.1312	1.7288	312	214.3096	4.3469	383	191.0397	4.3808
242	173.1312	1.7288	313	199.0374	2.7283	384	191.0397	4.3808
243	173.1312	1.7288	314	199.0374	2.7283	385	177.7182	2.5639
244	173.1312	1.7288	315	199.0374	2.7283	386	177.7182	2.5639
245	173.1312	1.7288	316	199.0374	2.7283	387	177.7182	2.5639
246	173.1312	1.7288	317	199.0374	2.7283	388	177.7182	2.5639
247	205.2315	2.9555	318	199.0374	2.7283	389	177.7182	2.5639
248	205.2315	2.9555	319	153.5015	0.7323	390	177.7182	2.5639
249	205.2315	2.9555	320	153.5015	0.7323	391	224.3889	1.1858
250	205.2315	2.9555	321	153.5015	0.7323	392	224.3889	1.1858
251	205.2315	2.9555	322	153.5015	0.7323	393	224.3889	1.1858
252	205.2315	2.9555	323	153.5015	0.7323	394	224.3889	1.1858
253	124.7435	1.5971	324	153.5015	0.7323	395	224.3889	1.1858
254	124.7435	1.5971	325	164.6381	1.452	396	224.3889	1.1858

397	143.4494	1.2727
398	143.4494	1.2727
399	143.4494	1.2727
400	143.4494	1.2727
401	143.4494	1.2727
402	143.4494	1.2727
403	184.9713	3.9068
404	184.9713	3.9068
405	184.9713	3.9068
406	184.9713	3.9068
407	184.9713	3.9068
408	184.9713	3.9068
409	189.6585	2.3981
410	189.6585	2.3981
411	189.6585	2.3981
412	189.6585	2.3981
413	189.6585	2.3981
414	189.6585	2.3981
415	210.3185	0.7799
416	210.3185	0.7799
417	210.3185	0.7799
418	210.3185	0.7799
419	210.3185	0.7799
420	210.3185	0.7799
421	125.3842	0.5976
422	125.3842	0.5976
423	125.3842	0.5976
424	125.3842	0.5976
425	125.3842	0.5976
426	125.3842	0.5976
427	213.0654	3.0285
428	213.0654	3.0285
429	213.0654	3.0285
430	213.0654	3.0285
431	213.0654	3.0285
432	213.0654	3.0285
433	233.41	1.5289
434	233.41	1.5289
435	233.41	1.5289
436	233.41	1.5289
437	233.41	1.5289
438	233.41	1.5289
439	357.8981	0.7208
440	357.8981	0.7208
441	357.8981	0.7208
442	357.8981	0.7208
443	357.8981	0.7208
444	357.8981	0.7208
445	115.7897	0.6096
446	115.7897	0.6096
447	115.7897	0.6096
448	115.7897	0.6096
449	115.7897	0.6096
450	115.7897	0.6096
451	245.0847	2.9802
452	245.0847	2.9802
453	245.0847	2.9802
454	245.0847	2.9802
455	245.0847	2.9802
456	245.0847	2.9802
457	222.0127	2.597
458	222.0127	2.597
459	222.0127	2.597
460	222.0127	2.597
461	222.0127	2.597
462	222.0127	2.597
463	186.1063	1.1758
464	186.1063	1.1758
465	186.1063	1.1758
466	186.1063	1.1758
467	186.1063	1.1758
468	186.1063	1.1758
469	152.8997	1.9156
470	152.8997	1.9156
471	152.8997	1.9156
472	152.8997	1.9156
473	152.8997	1.9156
474	152.8997	1.9156
475	181.1985	3.5722
476	181.1985	3.5722
477	181.1985	3.5722
478	181.1985	3.5722
479	181.1985	3.5722
480	181.1985	3.5722
481	171.2836	2.106
482	171.2836	2.106
483	171.2836	2.106
484	171.2836	2.106
485	171.2836	2.106
486	171.2836	2.106
487	185.8531	1.818
488	185.8531	1.818
489	185.8531	1.818
490	185.8531	1.818
491	185.8531	1.818
492	185.8531	1.818
493	193.4636	1.0181
494	193.4636	1.0181
495	193.4636	1.0181
496	193.4636	1.0181
497	193.4636	1.0181
498	193.4636	1.0181
499	195.2094	4.786
500	195.2094	4.786
501	195.2094	4.786
502	195.2094	4.786
503	195.2094	4.786
504	195.2094	4.786
505	234.3332	2.1475
506	234.3332	2.1475
507	234.3332	2.1475
508	234.3332	2.1475
509	234.3332	2.1475
510	234.3332	2.1475
511	252.2451	0.7526
512	252.2451	0.7526
513	252.2451	0.7526
514	252.2451	0.7526
515	252.2451	0.7526
516	252.2451	0.7526
517	220.798	0.3919
518	220.798	0.3919
519	220.798	0.3919
520	220.798	0.3919
521	220.798	0.3919
522	220.798	0.3919
523	211.1936	3.9521
524	211.1936	3.9521
525	211.1936	3.9521
526	211.1936	3.9521
527	211.1936	3.9521
528	211.1936	3.9521
529	182.2477	1.8572
530	182.2477	1.8572
531	182.2477	1.8572
532	182.2477	1.8572
533	182.2477	1.8572
534	182.2477	1.8572
535	263.4608	0.6919
536	263.4608	0.6919
537	263.4608	0.6919
538	263.4608	0.6919
539	263.4608	0.6919
540	263.4608	0.6919
541	309.3571	0.6204
542	309.3571	0.6204
543	309.3571	0.6204
544	309.3571	0.6204
545	309.3571	0.6204
546	309.3571	0.6204
547	222.4745	3.0458
548	222.4745	3.0458
549	222.4745	3.0458
550	222.4745	3.0458
551	222.4745	3.0458
552	222.4745	3.0458
553	231.9148	1.6922
554	231.9148	1.6922
555	231.9148	1.6922
556	231.9148	1.6922
557	231.9148	1.6922
558	231.9148	1.6922
559	300.1229	0.6668
560	300.1229	0.6668
561	300.1229	0.6668
562	300.1229	0.6668
563	300.1229	0.6668
564	300.1229	0.6668
565	153.5984	1.7547
566	153.5984	1.7547
567	153.5984	1.7547
568	153.5984	1.7547
569	153.5984	1.7547
570	153.5984	1.7547
571	229.1833	3.9576
572	229.1833	3.9576
573	229.1833	3.9576
574	229.1833	3.9576
575	229.1833	3.9576
576	229.1833	3.9576
577	220.5313	3.2286
578	220.5313	3.2286
579	220.5313	3.2286
580	220.5313	3.2286
581	220.5313	3.2286
582	220.5313	3.2286
583	221.9682	1.8948
584	221.9682	1.8948
585	221.9682	1.8948
586	221.9682	1.8948
587	221.9682	1.8948
588	221.9682	1.8948
589	198.7558	1.6017
590	198.7558	1.6017
591	198.7558	1.6017
592	198.7558	1.6017
593	198.7558	1.6017
594	198.7558	1.6017
595	205.2964	4.2575
596	205.2964	4.2575
597	205.2964	4.2575
598	205.2964	4.2575
599	205.2964	4.2575
600	205.2964	4.2575
601	216.9724	2.8724
602	216.9724	2.8724
603	216.9724	2.8724
604	216.9724	2.8724
605	216.9724	2.8724
606	216.9724	2.8724
607	211.8107	2.3307
608	211.8107	2.3307
609	211.8107	2.3307

610	211.8107	2.3307
611	211.8107	2.3307
612	211.8107	2.3307
613	154.6678	1.4189
614	154.6678	1.4189
615	154.6678	1.4189
616	154.6678	1.4189
617	154.6678	1.4189
618	154.6678	1.4189
619	177.7312	3.3961
620	177.7312	3.3961
621	177.7312	3.3961
622	177.7312	3.3961
623	177.7312	3.3961
624	177.7312	3.3961
625	211.2847	1.6436
626	211.2847	1.6436
627	211.2847	1.6436
628	211.2847	1.6436
629	211.2847	1.6436
630	211.2847	1.6436
631	192.0133	0.78
632	192.0133	0.78
633	192.0133	0.78
634	192.0133	0.78
635	192.0133	0.78
636	192.0133	0.78
637	119.5104	0.6349
638	119.5104	0.6349
639	119.5104	0.6349
640	119.5104	0.6349
641	119.5104	0.6349
642	119.5104	0.6349
643	201.8521	2.538
644	201.8521	2.538
645	201.8521	2.538
646	201.8521	2.538
647	201.8521	2.538
648	201.8521	2.538
649	213.733	1.9228
650	213.733	1.9228
651	213.733	1.9228
652	213.733	1.9228
653	213.733	1.9228
654	213.733	1.9228
655	167.8924	1.1149
656	167.8924	1.1149
657	167.8924	1.1149
658	167.8924	1.1149
659	167.8924	1.1149
660	167.8924	1.1149
661	96.0972	1.1885
662	96.0972	1.1885
663	96.0972	1.1885
664	96.0972	1.1885
665	96.0972	1.1885
666	96.0972	1.1885
667	189.2258	4.0776
668	189.2258	4.0776
669	189.2258	4.0776
670	189.2258	4.0776
671	189.2258	4.0776
672	189.2258	4.0776
673	221.0098	2.5002
674	221.0098	2.5002
675	221.0098	2.5002
676	221.0098	2.5002
677	221.0098	2.5002
678	221.0098	2.5002
679	160.5312	2.2989
680	160.5312	2.2989
681	160.5312	2.2989
682	160.5312	2.2989
683	160.5312	2.2989
684	160.5312	2.2989
685	140.3772	1.2361
686	140.3772	1.2361
687	140.3772	1.2361
688	140.3772	1.2361
689	140.3772	1.2361
690	140.3772	1.2361
691	180.1197	3.3102
692	180.1197	3.3102
693	180.1197	3.3102
694	180.1197	3.3102
695	180.1197	3.3102
696	180.1197	3.3102
697	208.9206	2.5974
698	208.9206	2.5974
699	208.9206	2.5974
700	208.9206	2.5974
701	208.9206	2.5974
702	208.9206	2.5974
703	221.6385	1.0746
704	221.6385	1.0746
705	221.6385	1.0746
706	221.6385	1.0746
707	221.6385	1.0746
708	221.6385	1.0746
709	153.7078	1.533
710	153.7078	1.533
711	153.7078	1.533
712	153.7078	1.533
713	153.7078	1.533
714	153.7078	1.533
715	164.3876	3.1827
716	164.3876	3.1827
717	164.3876	3.1827
718	164.3876	3.1827
719	164.3876	3.1827
720	164.3876	3.1827

Table B-02: Hourly meteorological data for December 2004

Hour	Wind Vector	Wind Velocity	Hour	Wind Vector	Wind Velocity	Hour	Wind Vector	Wind Velocity
1	204.694	2.5593	67	167.4908	4.0093	133	227.7011	1.0072
2	204.694	2.5593	68	167.4908	4.0093	134	227.7011	1.0072
3	204.694	2.5593	69	167.4908	4.0093	135	227.7011	1.0072
4	204.694	2.5593	70	167.4908	4.0093	136	227.7011	1.0072
5	204.694	2.5593	71	167.4908	4.0093	137	227.7011	1.0072
6	204.694	2.5593	72	167.4908	4.0093	138	227.7011	1.0072
7	212.2222	1.4686	73	185.2084	3.1016	139	197.0333	5.5075
8	212.2222	1.4686	74	185.2084	3.1016	140	197.0333	5.5075
9	212.2222	1.4686	75	185.2084	3.1016	141	197.0333	5.5075
10	212.2222	1.4686	76	185.2084	3.1016	142	197.0333	5.5075
11	212.2222	1.4686	77	185.2084	3.1016	143	197.0333	5.5075
12	212.2222	1.4686	78	185.2084	3.1016	144	197.0333	5.5075
13	188.2591	2.0597	79	196.3707	1.1555	145	201.5411	3.0293
14	188.2591	2.0597	80	196.3707	1.1555	146	201.5411	3.0293
15	188.2591	2.0597	81	196.3707	1.1555	147	201.5411	3.0293
16	188.2591	2.0597	82	196.3707	1.1555	148	201.5411	3.0293
17	188.2591	2.0597	83	196.3707	1.1555	149	201.5411	3.0293
18	188.2591	2.0597	84	196.3707	1.1555	150	201.5411	3.0293
19	172.1862	3.4647	85	155.3127	1.7332	151	201.855	4.1457
20	172.1862	3.4647	86	155.3127	1.7332	152	201.855	4.1457
21	172.1862	3.4647	87	155.3127	1.7332	153	201.855	4.1457
22	172.1862	3.4647	88	155.3127	1.7332	154	201.855	4.1457
23	172.1862	3.4647	89	155.3127	1.7332	155	201.855	4.1457
24	172.1862	3.4647	90	155.3127	1.7332	156	201.855	4.1457
25	187.7346	2.6514	91	185.6624	3.9786	157	114.7411	0.337
26	187.7346	2.6514	92	185.6624	3.9786	158	114.7411	0.337
27	187.7346	2.6514	93	185.6624	3.9786	159	114.7411	0.337
28	187.7346	2.6514	94	185.6624	3.9786	160	114.7411	0.337
29	187.7346	2.6514	95	185.6624	3.9786	161	114.7411	0.337
30	187.7346	2.6514	96	185.6624	3.9786	162	114.7411	0.337
31	245.5807	0.6793	97	179.3803	2.9146	163	178.3769	4.5009
32	245.5807	0.6793	98	179.3803	2.9146	164	178.3769	4.5009
33	245.5807	0.6793	99	179.3803	2.9146	165	178.3769	4.5009
34	245.5807	0.6793	100	179.3803	2.9146	166	178.3769	4.5009
35	245.5807	0.6793	101	179.3803	2.9146	167	178.3769	4.5009
36	245.5807	0.6793	102	179.3803	2.9146	168	178.3769	4.5009
37	157.1529	1.5155	103	268.9965	1.4684	169	181.6877	2.8112
38	157.1529	1.5155	104	268.9965	1.4684	170	181.6877	2.8112
39	157.1529	1.5155	105	268.9965	1.4684	171	181.6877	2.8112
40	157.1529	1.5155	106	268.9965	1.4684	172	181.6877	2.8112
41	157.1529	1.5155	107	268.9965	1.4684	173	181.6877	2.8112
42	157.1529	1.5155	108	268.9965	1.4684	174	181.6877	2.8112
43	175.2754	3.8778	109	107.909	1.3518	175	326.0584	1.1406
44	175.2754	3.8778	110	107.909	1.3518	176	326.0584	1.1406
45	175.2754	3.8778	111	107.909	1.3518	177	326.0584	1.1406
46	175.2754	3.8778	112	107.909	1.3518	178	326.0584	1.1406
47	175.2754	3.8778	113	107.909	1.3518	179	326.0584	1.1406
48	175.2754	3.8778	114	107.909	1.3518	180	326.0584	1.1406
49	190.854	2.7083	115	185.881	3.1106	181	143.3982	1.1635
50	190.854	2.7083	116	185.881	3.1106	182	143.3982	1.1635
51	190.854	2.7083	117	185.881	3.1106	183	143.3982	1.1635
52	190.854	2.7083	118	185.881	3.1106	184	143.3982	1.1635
53	190.854	2.7083	119	185.881	3.1106	185	143.3982	1.1635
54	190.854	2.7083	120	185.881	3.1106	186	143.3982	1.1635
55	156.7267	2.4841	121	199.1434	3.0858	187	195.6406	4.578
56	156.7267	2.4841	122	199.1434	3.0858	188	195.6406	4.578
57	156.7267	2.4841	123	199.1434	3.0858	189	195.6406	4.578
58	156.7267	2.4841	124	199.1434	3.0858	190	195.6406	4.578
59	156.7267	2.4841	125	199.1434	3.0858	191	195.6406	4.578
60	156.7267	2.4841	126	199.1434	3.0858	192	195.6406	4.578
61	171.7338	1.6159	127	252.446	0.6785	193	199.7753	3.0254
62	171.7338	1.6159	128	252.446	0.6785	194	199.7753	3.0254
63	171.7338	1.6159	129	252.446	0.6785	195	199.7753	3.0254
64	171.7338	1.6159	130	252.446	0.6785	196	199.7753	3.0254
65	171.7338	1.6159	131	252.446	0.6785	197	199.7753	3.0254
66	171.7338	1.6159	132	252.446	0.6785	198	199.7753	3.0254

199	321.518	0.3848	270	207.0994	3.5214	341	199.8401	2.5232
200	321.518	0.3848	271	222.0886	2.7855	342	199.8401	2.5232
201	321.518	0.3848	272	222.0886	2.7855	343	191.555	1.5923
202	321.518	0.3848	273	222.0886	2.7855	344	191.555	1.5923
203	321.518	0.3848	274	222.0886	2.7855	345	191.555	1.5923
204	321.518	0.3848	275	222.0886	2.7855	346	191.555	1.5923
205	92.1366	0.7863	276	222.0886	2.7855	347	191.555	1.5923
206	92.1366	0.7863	277	168.8759	1.9625	348	191.555	1.5923
207	92.1366	0.7863	278	168.8759	1.9625	349	133.2244	2.776
208	92.1366	0.7863	279	168.8759	1.9625	350	133.2244	2.776
209	92.1366	0.7863	280	168.8759	1.9625	351	133.2244	2.776
210	92.1366	0.7863	281	168.8759	1.9625	352	133.2244	2.776
211	202.3297	4.2146	282	168.8759	1.9625	353	133.2244	2.776
212	202.3297	4.2146	283	200.621	4.4115	354	133.2244	2.776
213	202.3297	4.2146	284	200.621	4.4115	355	191.7758	4.0056
214	202.3297	4.2146	285	200.621	4.4115	356	191.7758	4.0056
215	202.3297	4.2146	286	200.621	4.4115	357	191.7758	4.0056
216	202.3297	4.2146	287	200.621	4.4115	358	191.7758	4.0056
217	189.4768	2.6777	288	200.621	4.4115	359	191.7758	4.0056
218	189.4768	2.6777	289	190.0169	3.2031	360	191.7758	4.0056
219	189.4768	2.6777	290	190.0169	3.2031	361	186.9133	3.3653
220	189.4768	2.6777	291	190.0169	3.2031	362	186.9133	3.3653
221	189.4768	2.6777	292	190.0169	3.2031	363	186.9133	3.3653
222	189.4768	2.6777	293	190.0169	3.2031	364	186.9133	3.3653
223	255.8884	1.4836	294	190.0169	3.2031	365	186.9133	3.3653
224	255.8884	1.4836	295	237.1024	1.0127	366	186.9133	3.3653
225	255.8884	1.4836	296	237.1024	1.0127	367	217.4739	0.5664
226	255.8884	1.4836	297	237.1024	1.0127	368	217.4739	0.5664
227	255.8884	1.4836	298	237.1024	1.0127	369	217.4739	0.5664
228	255.8884	1.4836	299	237.1024	1.0127	370	217.4739	0.5664
229	193.3896	1.4575	300	237.1024	1.0127	371	217.4739	0.5664
230	193.3896	1.4575	301	121.9747	2.0418	372	217.4739	0.5664
231	193.3896	1.4575	302	121.9747	2.0418	373	147.0862	0.4187
232	193.3896	1.4575	303	121.9747	2.0418	374	147.0862	0.4187
233	193.3896	1.4575	304	121.9747	2.0418	375	147.0862	0.4187
234	193.3896	1.4575	305	121.9747	2.0418	376	147.0862	0.4187
235	191.1457	4.9341	306	121.9747	2.0418	377	147.0862	0.4187
236	191.1457	4.9341	307	175.6543	4.9067	378	147.0862	0.4187
237	191.1457	4.9341	308	175.6543	4.9067	379	192.4316	2.4529
238	191.1457	4.9341	309	175.6543	4.9067	380	192.4316	2.4529
239	191.1457	4.9341	310	175.6543	4.9067	381	192.4316	2.4529
240	191.1457	4.9341	311	175.6543	4.9067	382	192.4316	2.4529
241	216.7083	2.7003	312	175.6543	4.9067	383	192.4316	2.4529
242	216.7083	2.7003	313	180.599	3.0415	384	192.4316	2.4529
243	216.7083	2.7003	314	180.599	3.0415	385	201.488	1.8096
244	216.7083	2.7003	315	180.599	3.0415	386	201.488	1.8096
245	216.7083	2.7003	316	180.599	3.0415	387	201.488	1.8096
246	216.7083	2.7003	317	180.599	3.0415	388	201.488	1.8096
247	258.4521	1.1919	318	180.599	3.0415	389	201.488	1.8096
248	258.4521	1.1919	319	169.4118	1.1527	390	201.488	1.8096
249	258.4521	1.1919	320	169.4118	1.1527	391	200.2723	2.1939
250	258.4521	1.1919	321	169.4118	1.1527	392	200.2723	2.1939
251	258.4521	1.1919	322	169.4118	1.1527	393	200.2723	2.1939
252	258.4521	1.1919	323	169.4118	1.1527	394	200.2723	2.1939
253	203.7104	1.0215	324	169.4118	1.1527	395	200.2723	2.1939
254	203.7104	1.0215	325	108.4451	1.9712	396	200.2723	2.1939
255	203.7104	1.0215	326	108.4451	1.9712	397	147.7243	1.0713
256	203.7104	1.0215	327	108.4451	1.9712	398	147.7243	1.0713
257	203.7104	1.0215	328	108.4451	1.9712	399	147.7243	1.0713
258	203.7104	1.0215	329	108.4451	1.9712	400	147.7243	1.0713
259	213.4335	5.3861	330	108.4451	1.9712	401	147.7243	1.0713
260	213.4335	5.3861	331	174.21	3.0475	402	147.7243	1.0713
261	213.4335	5.3861	332	174.21	3.0475	403	200.7722	5.2173
262	213.4335	5.3861	333	174.21	3.0475	404	200.7722	5.2173
263	213.4335	5.3861	334	174.21	3.0475	405	200.7722	5.2173
264	213.4335	5.3861	335	174.21	3.0475	406	200.7722	5.2173
265	207.0994	3.5214	336	174.21	3.0475	407	200.7722	5.2173
266	207.0994	3.5214	337	199.8401	2.5232	408	200.7722	5.2173
267	207.0994	3.5214	338	199.8401	2.5232	409	194.8806	2.3644
268	207.0994	3.5214	339	199.8401	2.5232	410	194.8806	2.3644
269	207.0994	3.5214	340	199.8401	2.5232	411	194.8806	2.3644

412	194.8806	2.3644	483	0.4975	2.5661	554	209.824	3.1775
413	194.8806	2.3644	484	0.4975	2.5661	555	209.824	3.1775
414	194.8806	2.3644	485	0.4975	2.5661	556	209.824	3.1775
415	155.3868	0.4116	486	0.4975	2.5661	557	209.824	3.1775
416	155.3868	0.4116	487	359.4986	2.5361	558	209.824	3.1775
417	155.3868	0.4116	488	359.4986	2.5361	559	171.0547	0.841
418	155.3868	0.4116	489	359.4986	2.5361	560	171.0547	0.841
419	155.3868	0.4116	490	359.4986	2.5361	561	171.0547	0.841
420	155.3868	0.4116	491	359.4986	2.5361	562	171.0547	0.841
421	161.8727	1.3736	492	359.4986	2.5361	563	171.0547	0.841
422	161.8727	1.3736	493	76.43	2.0727	564	171.0547	0.841
423	161.8727	1.3736	494	76.43	2.0727	565	130.875	2.5536
424	161.8727	1.3736	495	76.43	2.0727	566	130.875	2.5536
425	161.8727	1.3736	496	76.43	2.0727	567	130.875	2.5536
426	161.8727	1.3736	497	76.43	2.0727	568	130.875	2.5536
427	224.0984	5.6034	498	76.43	2.0727	569	130.875	2.5536
428	224.0984	5.6034	499	248.3769	0.3212	570	130.875	2.5536
429	224.0984	5.6034	500	248.3769	0.3212	571	180.2185	4.0578
430	224.0984	5.6034	501	248.3769	0.3212	572	180.2185	4.0578
431	224.0984	5.6034	502	248.3769	0.3212	573	180.2185	4.0578
432	224.0984	5.6034	503	248.3769	0.3212	574	180.2185	4.0578
433	203.575	2.5587	504	248.3769	0.3212	575	180.2185	4.0578
434	203.575	2.5587	505	235.05	1.2675	576	180.2185	4.0578
435	203.575	2.5587	506	235.05	1.2675	577	239.4012	3.135
436	203.575	2.5587	507	235.05	1.2675	578	239.4012	3.135
437	203.575	2.5587	508	235.05	1.2675	579	239.4012	3.135
438	203.575	2.5587	509	235.05	1.2675	580	239.4012	3.135
439	221.0907	0.9605	510	235.05	1.2675	581	239.4012	3.135
440	221.0907	0.9605	511	322.8255	0.9878	582	239.4012	3.135
441	221.0907	0.9605	512	322.8255	0.9878	583	193.5047	1.1432
442	221.0907	0.9605	513	322.8255	0.9878	584	193.5047	1.1432
443	221.0907	0.9605	514	322.8255	0.9878	585	193.5047	1.1432
444	221.0907	0.9605	515	322.8255	0.9878	586	193.5047	1.1432
445	156.1178	1.2599	516	322.8255	0.9878	587	193.5047	1.1432
446	156.1178	1.2599	517	104.7919	1.3582	588	193.5047	1.1432
447	156.1178	1.2599	518	104.7919	1.3582	589	150.8211	1.3216
448	156.1178	1.2599	519	104.7919	1.3582	590	150.8211	1.3216
449	156.1178	1.2599	520	104.7919	1.3582	591	150.8211	1.3216
450	156.1178	1.2599	521	104.7919	1.3582	592	150.8211	1.3216
451	220.9956	3.1272	522	104.7919	1.3582	593	150.8211	1.3216
452	220.9956	3.1272	523	222.4018	3.7829	594	150.8211	1.3216
453	220.9956	3.1272	524	222.4018	3.7829	595	153.4966	2.1593
454	220.9956	3.1272	525	222.4018	3.7829	596	153.4966	2.1593
455	220.9956	3.1272	526	222.4018	3.7829	597	153.4966	2.1593
456	220.9956	3.1272	527	222.4018	3.7829	598	153.4966	2.1593
457	215.2368	2.6619	528	222.4018	3.7829	599	153.4966	2.1593
458	215.2368	2.6619	529	141.8338	2.0955	600	153.4966	2.1593
459	215.2368	2.6619	530	141.8338	2.0955	601	145.2292	1.3672
460	215.2368	2.6619	531	141.8338	2.0955	602	145.2292	1.3672
461	215.2368	2.6619	532	141.8338	2.0955	603	145.2292	1.3672
462	215.2368	2.6619	533	141.8338	2.0955	604	145.2292	1.3672
463	327.8383	1.6659	534	141.8338	2.0955	605	145.2292	1.3672
464	327.8383	1.6659	535	249.1982	1.666	606	145.2292	1.3672
465	327.8383	1.6659	536	249.1982	1.666	607	132.3696	0.6595
466	327.8383	1.6659	537	249.1982	1.666	608	132.3696	0.6595
467	327.8383	1.6659	538	249.1982	1.666	609	132.3696	0.6595
468	327.8383	1.6659	539	249.1982	1.666	610	132.3696	0.6595
469	108.7518	0.6438	540	249.1982	1.666	611	132.3696	0.6595
470	108.7518	0.6438	541	124.2132	2.6238	612	132.3696	0.6595
471	108.7518	0.6438	542	124.2132	2.6238	613	114.8875	2.0655
472	108.7518	0.6438	543	124.2132	2.6238	614	114.8875	2.0655
473	108.7518	0.6438	544	124.2132	2.6238	615	114.8875	2.0655
474	108.7518	0.6438	545	124.2132	2.6238	616	114.8875	2.0655
475	23.6979	1.4042	546	124.2132	2.6238	617	114.8875	2.0655
476	23.6979	1.4042	547	232.8284	4.1951	618	114.8875	2.0655
477	23.6979	1.4042	548	232.8284	4.1951	619	186.7907	2.393
478	23.6979	1.4042	549	232.8284	4.1951	620	186.7907	2.393
479	23.6979	1.4042	550	232.8284	4.1951	621	186.7907	2.393
480	23.6979	1.4042	551	232.8284	4.1951	622	186.7907	2.393
481	0.4975	2.5661	552	232.8284	4.1951	623	186.7907	2.393
482	0.4975	2.5661	553	209.824	3.1775	624	186.7907	2.393

625	203.1525	2.5271	685	145.5578	1.5623
626	203.1525	2.5271	686	145.5578	1.5623
627	203.1525	2.5271	687	145.5578	1.5623
628	203.1525	2.5271	688	145.5578	1.5623
629	203.1525	2.5271	689	145.5578	1.5623
630	203.1525	2.5271	690	145.5578	1.5623
631	216.7239	1.1132	691	213.168	3.5286
632	216.7239	1.1132	692	213.168	3.5286
633	216.7239	1.1132	693	213.168	3.5286
634	216.7239	1.1132	694	213.168	3.5286
635	216.7239	1.1132	695	213.168	3.5286
636	216.7239	1.1132	696	213.168	3.5286
637	141.7542	3.1451	697	201.9254	2.835
638	141.7542	3.1451	698	201.9254	2.835
639	141.7542	3.1451	699	201.9254	2.835
640	141.7542	3.1451	700	201.9254	2.835
641	141.7542	3.1451	701	201.9254	2.835
642	141.7542	3.1451	702	201.9254	2.835
643	182.2155	5.5522	703	311.0531	1.7101
644	182.2155	5.5522	704	311.0531	1.7101
645	182.2155	5.5522	705	311.0531	1.7101
646	182.2155	5.5522	706	311.0531	1.7101
647	182.2155	5.5522	707	311.0531	1.7101
648	182.2155	5.5522	708	311.0531	1.7101
649	168.3799	4.2794	709	334.0084	0.4188
650	168.3799	4.2794	710	334.0084	0.4188
651	168.3799	4.2794	711	334.0084	0.4188
652	168.3799	4.2794	712	334.0084	0.4188
653	168.3799	4.2794	713	334.0084	0.4188
654	168.3799	4.2794	714	334.0084	0.4188
655	178.9016	1.3939	715	227.4957	4.9358
656	178.9016	1.3939	716	227.4957	4.9358
657	178.9016	1.3939	717	227.4957	4.9358
658	178.9016	1.3939	718	227.4957	4.9358
659	178.9016	1.3939	719	227.4957	4.9358
660	178.9016	1.3939	720	227.4957	4.9358
661	126.1542	1.6139	721	164.7558	2.8935
662	126.1542	1.6139	722	164.7558	2.8935
663	126.1542	1.6139	723	164.7558	2.8935
664	126.1542	1.6139	724	164.7558	2.8935
665	126.1542	1.6139	725	164.7558	2.8935
666	126.1542	1.6139	726	164.7558	2.8935
667	222.99	4.3966	727	248.0716	0.6327
668	222.99	4.3966	728	248.0716	0.6327
669	222.99	4.3966	729	248.0716	0.6327
670	222.99	4.3966	730	248.0716	0.6327
671	222.99	4.3966	731	248.0716	0.6327
672	222.99	4.3966	732	248.0716	0.6327
673	191.8641	2.9258	733	152.4029	0.7766
674	191.8641	2.9258	734	152.4029	0.7766
675	191.8641	2.9258	735	152.4029	0.7766
676	191.8641	2.9258	736	152.4029	0.7766
677	191.8641	2.9258	737	152.4029	0.7766
678	191.8641	2.9258	738	152.4029	0.7766
679	235.0942	0.1253	739	219.3564	4.8486
680	235.0942	0.1253	740	219.3564	4.8486
681	235.0942	0.1253	741	219.3564	4.8486
682	235.0942	0.1253	742	219.3564	4.8486
683	235.0942	0.1253	743	219.3564	4.8486
684	235.0942	0.1253	744	219.3564	4.8486

Table B-03: Hourly meteorological data for January 2005

Hour	Wind Vector	Wind Velocity	Hour	Wind Vector	Wind Velocity	Hour	Wind Vector	Wind Velocity
1	180.3346	3.7253	67	221.9105	6.1344	133	123.9084	1.545
2	180.3346	3.7253	68	221.9105	6.1344	134	123.9084	1.545
3	180.3346	3.7253	69	221.9105	6.1344	135	123.9084	1.545
4	180.3346	3.7253	70	221.9105	6.1344	136	123.9084	1.545
5	180.3346	3.7253	71	221.9105	6.1344	137	123.9084	1.545
6	180.3346	3.7253	72	221.9105	6.1344	138	123.9084	1.545
7	221.0656	3.1358	73	204.3374	4.3045	139	193.8604	5.1548
8	221.0656	3.1358	74	204.3374	4.3045	140	193.8604	5.1548
9	221.0656	3.1358	75	204.3374	4.3045	141	193.8604	5.1548
10	221.0656	3.1358	76	204.3374	4.3045	142	193.8604	5.1548
11	221.0656	3.1358	77	204.3374	4.3045	143	193.8604	5.1548
12	221.0656	3.1358	78	204.3374	4.3045	144	193.8604	5.1548
13	152.1627	2.5117	79	221.5249	3.166	145	181.347	1.9227
14	152.1627	2.5117	80	221.5249	3.166	146	181.347	1.9227
15	152.1627	2.5117	81	221.5249	3.166	147	181.347	1.9227
16	152.1627	2.5117	82	221.5249	3.166	148	181.347	1.9227
17	152.1627	2.5117	83	221.5249	3.166	149	181.347	1.9227
18	152.1627	2.5117	84	221.5249	3.166	150	181.347	1.9227
19	204.7665	5.8691	85	173.0246	1.8762	151	180.6843	1.0616
20	204.7665	5.8691	86	173.0246	1.8762	152	180.6843	1.0616
21	204.7665	5.8691	87	173.0246	1.8762	153	180.6843	1.0616
22	204.7665	5.8691	88	173.0246	1.8762	154	180.6843	1.0616
23	204.7665	5.8691	89	173.0246	1.8762	155	180.6843	1.0616
24	204.7665	5.8691	90	173.0246	1.8762	156	180.6843	1.0616
25	209.8591	3.8545	91	202.6185	5.4938	157	170.0675	2.032
26	209.8591	3.8545	92	202.6185	5.4938	158	170.0675	2.032
27	209.8591	3.8545	93	202.6185	5.4938	159	170.0675	2.032
28	209.8591	3.8545	94	202.6185	5.4938	160	170.0675	2.032
29	209.8591	3.8545	95	202.6185	5.4938	161	170.0675	2.032
30	209.8591	3.8545	96	202.6185	5.4938	162	170.0675	2.032
31	188.4262	1.3064	97	188.1812	4.8715	163	186.6812	3.8833
32	188.4262	1.3064	98	188.1812	4.8715	164	186.6812	3.8833
33	188.4262	1.3064	99	188.1812	4.8715	165	186.6812	3.8833
34	188.4262	1.3064	100	188.1812	4.8715	166	186.6812	3.8833
35	188.4262	1.3064	101	188.1812	4.8715	167	186.6812	3.8833
36	188.4262	1.3064	102	188.1812	4.8715	168	186.6812	3.8833
37	150.6274	1.9386	103	181.0222	2.159	169	210.1329	3.1965
38	150.6274	1.9386	104	181.0222	2.159	170	210.1329	3.1965
39	150.6274	1.9386	105	181.0222	2.159	171	210.1329	3.1965
40	150.6274	1.9386	106	181.0222	2.159	172	210.1329	3.1965
41	150.6274	1.9386	107	181.0222	2.159	173	210.1329	3.1965
42	150.6274	1.9386	108	181.0222	2.159	174	210.1329	3.1965
43	206.4456	2.3621	109	141.919	2.6589	175	175.3711	1.4399
44	206.4456	2.3621	110	141.919	2.6589	176	175.3711	1.4399
45	206.4456	2.3621	111	141.919	2.6589	177	175.3711	1.4399
46	206.4456	2.3621	112	141.919	2.6589	178	175.3711	1.4399
47	206.4456	2.3621	113	141.919	2.6589	179	175.3711	1.4399
48	206.4456	2.3621	114	141.919	2.6589	180	175.3711	1.4399
49	226.2288	3.5478	115	193.4291	5.4534	181	121.1641	3.4104
50	226.2288	3.5478	116	193.4291	5.4534	182	121.1641	3.4104
51	226.2288	3.5478	117	193.4291	5.4534	183	121.1641	3.4104
52	226.2288	3.5478	118	193.4291	5.4534	184	121.1641	3.4104
53	226.2288	3.5478	119	193.4291	5.4534	185	121.1641	3.4104
54	226.2288	3.5478	120	193.4291	5.4534	186	121.1641	3.4104
55	212.405	2.4811	121	203.1856	3.4902	187	183.048	4.8491
56	212.405	2.4811	122	203.1856	3.4902	188	183.048	4.8491
57	212.405	2.4811	123	203.1856	3.4902	189	183.048	4.8491
58	212.405	2.4811	124	203.1856	3.4902	190	183.048	4.8491
59	212.405	2.4811	125	203.1856	3.4902	191	183.048	4.8491
60	212.405	2.4811	126	203.1856	3.4902	192	183.048	4.8491
61	180.9541	0.8209	127	185.9328	1.9593	193	167.9695	3.7321
62	180.9541	0.8209	128	185.9328	1.9593	194	167.9695	3.7321
63	180.9541	0.8209	129	185.9328	1.9593	195	167.9695	3.7321
64	180.9541	0.8209	130	185.9328	1.9593	196	167.9695	3.7321
65	180.9541	0.8209	131	185.9328	1.9593	197	167.9695	3.7321
66	180.9541	0.8209	132	185.9328	1.9593	198	167.9695	3.7321

199	175.7417	2.3046	270	203.9773	2.5723	341	267.5942	2.5022
200	175.7417	2.3046	271	123.4815	1.2598	342	267.5942	2.5022
201	175.7417	2.3046	272	123.4815	1.2598	343	296.7235	1.2049
202	175.7417	2.3046	273	123.4815	1.2598	344	296.7235	1.2049
203	175.7417	2.3046	274	123.4815	1.2598	345	296.7235	1.2049
204	175.7417	2.3046	275	123.4815	1.2598	346	296.7235	1.2049
205	139.2905	2.7923	276	123.4815	1.2598	347	296.7235	1.2049
206	139.2905	2.7923	277	159.8315	2.3153	348	296.7235	1.2049
207	139.2905	2.7923	278	159.8315	2.3153	349	256.8606	1.4235
208	139.2905	2.7923	279	159.8315	2.3153	350	256.8606	1.4235
209	139.2905	2.7923	280	159.8315	2.3153	351	256.8606	1.4235
210	139.2905	2.7923	281	159.8315	2.3153	352	256.8606	1.4235
211	186.1004	5.2473	282	159.8315	2.3153	353	256.8606	1.4235
212	186.1004	5.2473	283	194.2253	5.5692	354	256.8606	1.4235
213	186.1004	5.2473	284	194.2253	5.5692	355	224.6857	4.0569
214	186.1004	5.2473	285	194.2253	5.5692	356	224.6857	4.0569
215	186.1004	5.2473	286	194.2253	5.5692	357	224.6857	4.0569
216	186.1004	5.2473	287	194.2253	5.5692	358	224.6857	4.0569
217	197.4885	6.5135	288	194.2253	5.5692	359	224.6857	4.0569
218	197.4885	6.5135	289	187.5967	2.8757	360	224.6857	4.0569
219	197.4885	6.5135	290	187.5967	2.8757	361	218.886	2.5008
220	197.4885	6.5135	291	187.5967	2.8757	362	218.886	2.5008
221	197.4885	6.5135	292	187.5967	2.8757	363	218.886	2.5008
222	197.4885	6.5135	293	187.5967	2.8757	364	218.886	2.5008
223	170.8769	3.2718	294	187.5967	2.8757	365	218.886	2.5008
224	170.8769	3.2718	295	133.9607	0.4228	366	218.886	2.5008
225	170.8769	3.2718	296	133.9607	0.4228	367	247.4088	1.7341
226	170.8769	3.2718	297	133.9607	0.4228	368	247.4088	1.7341
227	170.8769	3.2718	298	133.9607	0.4228	369	247.4088	1.7341
228	170.8769	3.2718	299	133.9607	0.4228	370	247.4088	1.7341
229	149.5558	2.3503	300	133.9607	0.4228	371	247.4088	1.7341
230	149.5558	2.3503	301	88.9676	1.8629	372	247.4088	1.7341
231	149.5558	2.3503	302	88.9676	1.8629	373	124.6161	1.5619
232	149.5558	2.3503	303	88.9676	1.8629	374	124.6161	1.5619
233	149.5558	2.3503	304	88.9676	1.8629	375	124.6161	1.5619
234	149.5558	2.3503	305	88.9676	1.8629	376	124.6161	1.5619
235	200.2072	5.6615	306	88.9676	1.8629	377	124.6161	1.5619
236	200.2072	5.6615	307	215.5062	3.1011	378	124.6161	1.5619
237	200.2072	5.6615	308	215.5062	3.1011	379	212.4884	4.2142
238	200.2072	5.6615	309	215.5062	3.1011	380	212.4884	4.2142
239	200.2072	5.6615	310	215.5062	3.1011	381	212.4884	4.2142
240	200.2072	5.6615	311	215.5062	3.1011	382	212.4884	4.2142
241	193.087	3.1238	312	215.5062	3.1011	383	212.4884	4.2142
242	193.087	3.1238	313	287.918	1.6391	384	212.4884	4.2142
243	193.087	3.1238	314	287.918	1.6391	385	234.502	2.5849
244	193.087	3.1238	315	287.918	1.6391	386	234.502	2.5849
245	193.087	3.1238	316	287.918	1.6391	387	234.502	2.5849
246	193.087	3.1238	317	287.918	1.6391	388	234.502	2.5849
247	202.458	3.1392	318	287.918	1.6391	389	234.502	2.5849
248	202.458	3.1392	319	21.8142	2.8157	390	234.502	2.5849
249	202.458	3.1392	320	21.8142	2.8157	391	228.6042	1.9261
250	202.458	3.1392	321	21.8142	2.8157	392	228.6042	1.9261
251	202.458	3.1392	322	21.8142	2.8157	393	228.6042	1.9261
252	202.458	3.1392	323	21.8142	2.8157	394	228.6042	1.9261
253	149.6049	1.2336	324	21.8142	2.8157	395	228.6042	1.9261
254	149.6049	1.2336	325	111.1761	0.9934	396	228.6042	1.9261
255	149.6049	1.2336	326	111.1761	0.9934	397	149.4892	1.0911
256	149.6049	1.2336	327	111.1761	0.9934	398	149.4892	1.0911
257	149.6049	1.2336	328	111.1761	0.9934	399	149.4892	1.0911
258	149.6049	1.2336	329	111.1761	0.9934	400	149.4892	1.0911
259	189.7992	4.7846	330	111.1761	0.9934	401	149.4892	1.0911
260	189.7992	4.7846	331	262.4631	4.6674	402	149.4892	1.0911
261	189.7992	4.7846	332	262.4631	4.6674	403	228.8636	5.1727
262	189.7992	4.7846	333	262.4631	4.6674	404	228.8636	5.1727
263	189.7992	4.7846	334	262.4631	4.6674	405	228.8636	5.1727
264	189.7992	4.7846	335	262.4631	4.6674	406	228.8636	5.1727
265	203.9773	2.5723	336	262.4631	4.6674	407	228.8636	5.1727
266	203.9773	2.5723	337	267.5942	2.5022	408	228.8636	5.1727
267	203.9773	2.5723	338	267.5942	2.5022	409	203.717	3.0682
268	203.9773	2.5723	339	267.5942	2.5022	410	203.717	3.0682
269	203.9773	2.5723	340	267.5942	2.5022	411	203.717	3.0682

412	203.717	3.0682
413	203.717	3.0682
414	203.717	3.0682
415	257.485	1.4082
416	257.485	1.4082
417	257.485	1.4082
418	257.485	1.4082
419	257.485	1.4082
420	257.485	1.4082
421	40.9626	1.2441
422	40.9626	1.2441
423	40.9626	1.2441
424	40.9626	1.2441
425	40.9626	1.2441
426	40.9626	1.2441
427	15.6594	2.3023
428	15.6594	2.3023
429	15.6594	2.3023
430	15.6594	2.3023
431	15.6594	2.3023
432	15.6594	2.3023
433	24.6139	2.6925
434	24.6139	2.6925
435	24.6139	2.6925
436	24.6139	2.6925
437	24.6139	2.6925
438	24.6139	2.6925
439	350.0786	2.4601
440	350.0786	2.4601
441	350.0786	2.4601
442	350.0786	2.4601
443	350.0786	2.4601
444	350.0786	2.4601
445	19.8501	2.1636
446	19.8501	2.1636
447	19.8501	2.1636
448	19.8501	2.1636
449	19.8501	2.1636
450	19.8501	2.1636
451	203.9563	2.9674
452	203.9563	2.9674
453	203.9563	2.9674
454	203.9563	2.9674
455	203.9563	2.9674
456	203.9563	2.9674
457	209.9985	3.6174
458	209.9985	3.6174
459	209.9985	3.6174
460	209.9985	3.6174
461	209.9985	3.6174
462	209.9985	3.6174
463	201.4411	3.6249
464	201.4411	3.6249
465	201.4411	3.6249
466	201.4411	3.6249
467	201.4411	3.6249
468	201.4411	3.6249
469	131.4171	2.7763
470	131.4171	2.7763
471	131.4171	2.7763
472	131.4171	2.7763
473	131.4171	2.7763
474	131.4171	2.7763
475	224.4405	4.4521
476	224.4405	4.4521
477	224.4405	4.4521
478	224.4405	4.4521
479	224.4405	4.4521
480	224.4405	4.4521
481	199.6716	3.0602
482	199.6716	3.0602
483	199.6716	3.0602
484	199.6716	3.0602
485	199.6716	3.0602
486	199.6716	3.0602
487	237.0379	2.6169
488	237.0379	2.6169
489	237.0379	2.6169
490	237.0379	2.6169
491	237.0379	2.6169
492	237.0379	2.6169
493	144.5224	1.3751
494	144.5224	1.3751
495	144.5224	1.3751
496	144.5224	1.3751
497	144.5224	1.3751
498	144.5224	1.3751
499	239.3259	1.0555
500	239.3259	1.0555
501	239.3259	1.0555
502	239.3259	1.0555
503	239.3259	1.0555
504	239.3259	1.0555
505	254.6716	2.4187
506	254.6716	2.4187
507	254.6716	2.4187
508	254.6716	2.4187
509	254.6716	2.4187
510	254.6716	2.4187
511	10.1851	1.8395
512	10.1851	1.8395
513	10.1851	1.8395
514	10.1851	1.8395
515	10.1851	1.8395
516	10.1851	1.8395
517	84.81	3.1161
518	84.81	3.1161
519	84.81	3.1161
520	84.81	3.1161
521	84.81	3.1161
522	84.81	3.1161
523	311.0045	3.0614
524	311.0045	3.0614
525	311.0045	3.0614
526	311.0045	3.0614
527	311.0045	3.0614
528	311.0045	3.0614
529	248.0066	2.4174
530	248.0066	2.4174
531	248.0066	2.4174
532	248.0066	2.4174
533	248.0066	2.4174
534	248.0066	2.4174
535	246.2688	1.109
536	246.2688	1.109
537	246.2688	1.109
538	246.2688	1.109
539	246.2688	1.109
540	246.2688	1.109
541	131.904	1.8214
542	131.904	1.8214
543	131.904	1.8214
544	131.904	1.8214
545	131.904	1.8214
546	131.904	1.8214
547	263.7616	2.9901
548	263.7616	2.9901
549	263.7616	2.9901
550	263.7616	2.9901
551	263.7616	2.9901
552	263.7616	2.9901
553	238.9954	1.2729
554	238.9954	1.2729
555	238.9954	1.2729
556	238.9954	1.2729
557	238.9954	1.2729
558	238.9954	1.2729
559	268.5606	0.5831
560	268.5606	0.5831
561	268.5606	0.5831
562	268.5606	0.5831
563	268.5606	0.5831
564	268.5606	0.5831
565	120.2488	1.8445
566	120.2488	1.8445
567	120.2488	1.8445
568	120.2488	1.8445
569	120.2488	1.8445
570	120.2488	1.8445
571	249.0926	4.3678
572	249.0926	4.3678
573	249.0926	4.3678
574	249.0926	4.3678
575	249.0926	4.3678
576	249.0926	4.3678
577	188.5113	2.1261
578	188.5113	2.1261
579	188.5113	2.1261
580	188.5113	2.1261
581	188.5113	2.1261
582	188.5113	2.1261
583	152.5168	1.5767
584	152.5168	1.5767
585	152.5168	1.5767
586	152.5168	1.5767
587	152.5168	1.5767
588	152.5168	1.5767
589	146.0059	3.4938
590	146.0059	3.4938
591	146.0059	3.4938
592	146.0059	3.4938
593	146.0059	3.4938
594	146.0059	3.4938
595	191.1253	5.5505
596	191.1253	5.5505
597	191.1253	5.5505
598	191.1253	5.5505
599	191.1253	5.5505
600	191.1253	5.5505
601	218.9865	4.3262
602	218.9865	4.3262
603	218.9865	4.3262
604	218.9865	4.3262
605	218.9865	4.3262
606	218.9865	4.3262
607	182.4585	1.6541
608	182.4585	1.6541
609	182.4585	1.6541
610	182.4585	1.6541
611	182.4585	1.6541
612	182.4585	1.6541
613	130.9442	2.9593
614	130.9442	2.9593
615	130.9442	2.9593
616	130.9442	2.9593
617	130.9442	2.9593
618	130.9442	2.9593
619	147.1624	2.4382
620	147.1624	2.4382
621	147.1624	2.4382
622	147.1624	2.4382
623	147.1624	2.4382
624	147.1624	2.4382

625	183.3644	3.3397	685	154.4682	2.0948
626	183.3644	3.3397	686	154.4682	2.0948
627	183.3644	3.3397	687	154.4682	2.0948
628	183.3644	3.3397	688	154.4682	2.0948
629	183.3644	3.3397	689	154.4682	2.0948
630	183.3644	3.3397	690	154.4682	2.0948
631	202.1755	1.1687	691	229.395	4.9754
632	202.1755	1.1687	692	229.395	4.9754
633	202.1755	1.1687	693	229.395	4.9754
634	202.1755	1.1687	694	229.395	4.9754
635	202.1755	1.1687	695	229.395	4.9754
636	202.1755	1.1687	696	229.395	4.9754
637	106.445	3.0059	697	215.8788	3.8138
638	106.445	3.0059	698	215.8788	3.8138
639	106.445	3.0059	699	215.8788	3.8138
640	106.445	3.0059	700	215.8788	3.8138
641	106.445	3.0059	701	215.8788	3.8138
642	106.445	3.0059	702	215.8788	3.8138
643	187.7334	4.8239	703	191.2395	1.4094
644	187.7334	4.8239	704	191.2395	1.4094
645	187.7334	4.8239	705	191.2395	1.4094
646	187.7334	4.8239	706	191.2395	1.4094
647	187.7334	4.8239	707	191.2395	1.4094
648	187.7334	4.8239	708	191.2395	1.4094
649	212.7494	2.8077	709	149.1029	2.2834
650	212.7494	2.8077	710	149.1029	2.2834
651	212.7494	2.8077	711	149.1029	2.2834
652	212.7494	2.8077	712	149.1029	2.2834
653	212.7494	2.8077	713	149.1029	2.2834
654	212.7494	2.8077	714	149.1029	2.2834
655	178.8294	1.9757	715	208.5193	3.3655
656	178.8294	1.9757	716	208.5193	3.3655
657	178.8294	1.9757	717	208.5193	3.3655
658	178.8294	1.9757	718	208.5193	3.3655
659	178.8294	1.9757	719	208.5193	3.3655
660	178.8294	1.9757	720	208.5193	3.3655
661	129.8992	3.3678	721	219.6786	3.5213
662	129.8992	3.3678	722	219.6786	3.5213
663	129.8992	3.3678	723	219.6786	3.5213
664	129.8992	3.3678	724	219.6786	3.5213
665	129.8992	3.3678	725	219.6786	3.5213
666	129.8992	3.3678	726	219.6786	3.5213
667	184.4391	4.2051	727	242.982	2.0909
668	184.4391	4.2051	728	242.982	2.0909
669	184.4391	4.2051	729	242.982	2.0909
670	184.4391	4.2051	730	242.982	2.0909
671	184.4391	4.2051	731	242.982	2.0909
672	184.4391	4.2051	732	242.982	2.0909
673	175.6257	4.0603	733	134.456	2.0054
674	175.6257	4.0603	734	134.456	2.0054
675	175.6257	4.0603	735	134.456	2.0054
676	175.6257	4.0603	736	134.456	2.0054
677	175.6257	4.0603	737	134.456	2.0054
678	175.6257	4.0603	738	134.456	2.0054
679	218.4018	5.0208	739	263.1831	2.4644
680	218.4018	5.0208	740	263.1831	2.4644
681	218.4018	5.0208	741	263.1831	2.4644
682	218.4018	5.0208	742	263.1831	2.4644
683	218.4018	5.0208	743	263.1831	2.4644
684	218.4018	5.0208	744	263.1831	2.4644

Table B-04: Hourly meteorological data for February 2005

Hour	Wind Vector	Wind Velocity	Hour	Wind Vector	Wind Velocity	Hour	Wind Vector	Wind Velocity
1	239.8846	2.5213	66	102.5243	3.1413	131	237.1192	1.673
2	239.8846	2.5213	67	203.1628	5.6625	132	237.1192	1.673
3	239.8846	2.5213	68	203.1628	5.6625	133	56.568	0.5675
4	239.8846	2.5213	69	203.1628	5.6625	134	56.568	0.5675
5	239.8846	2.5213	70	203.1628	5.6625	135	56.568	0.5675
6	239.8846	2.5213	71	203.1628	5.6625	136	56.568	0.5675
7	197.5142	1.1151	72	203.1628	5.6625	137	56.568	0.5675
8	197.5142	1.1151	73	194.407	2.9012	138	56.568	0.5675
9	197.5142	1.1151	74	194.407	2.9012	139	224.1636	1.7963
10	197.5142	1.1151	75	194.407	2.9012	140	224.1636	1.7963
11	197.5142	1.1151	76	194.407	2.9012	141	224.1636	1.7963
12	197.5142	1.1151	77	194.407	2.9012	142	224.1636	1.7963
13	118.3199	1.6666	78	194.407	2.9012	143	224.1636	1.7963
14	118.3199	1.6666	79	165.4079	1.7178	144	224.1636	1.7963
15	118.3199	1.6666	80	165.4079	1.7178	145	241.2145	1.8988
16	118.3199	1.6666	81	165.4079	1.7178	146	241.2145	1.8988
17	118.3199	1.6666	82	165.4079	1.7178	147	241.2145	1.8988
18	118.3199	1.6666	83	165.4079	1.7178	148	241.2145	1.8988
19	193.484	2.4658	84	165.4079	1.7178	149	241.2145	1.8988
20	193.484	2.4658	85	103.0346	4.2405	150	241.2145	1.8988
21	193.484	2.4658	86	103.0346	4.2405	151	234.3354	1.994
22	193.484	2.4658	87	103.0346	4.2405	152	234.3354	1.994
23	193.484	2.4658	88	103.0346	4.2405	153	234.3354	1.994
24	193.484	2.4658	89	103.0346	4.2405	154	234.3354	1.994
25	225.8298	2.0058	90	103.0346	4.2405	155	234.3354	1.994
26	225.8298	2.0058	91	176.6104	2.5911	156	234.3354	1.994
27	225.8298	2.0058	92	176.6104	2.5911	157	140.0643	2.7626
28	225.8298	2.0058	93	176.6104	2.5911	158	140.0643	2.7626
29	225.8298	2.0058	94	176.6104	2.5911	159	140.0643	2.7626
30	225.8298	2.0058	95	176.6104	2.5911	160	140.0643	2.7626
31	136.3711	1.4619	96	176.6104	2.5911	161	140.0643	2.7626
32	136.3711	1.4619	97	207.6188	1.8726	162	140.0643	2.7626
33	136.3711	1.4619	98	207.6188	1.8726	163	205.2716	5.7956
34	136.3711	1.4619	99	207.6188	1.8726	164	205.2716	5.7956
35	136.3711	1.4619	100	207.6188	1.8726	165	205.2716	5.7956
36	136.3711	1.4619	101	207.6188	1.8726	166	205.2716	5.7956
37	141.1001	3.9251	102	207.6188	1.8726	167	205.2716	5.7956
38	141.1001	3.9251	103	187.3544	1.5771	168	205.2716	5.7956
39	141.1001	3.9251	104	187.3544	1.5771	169	184.4711	3.0027
40	141.1001	3.9251	105	187.3544	1.5771	170	184.4711	3.0027
41	141.1001	3.9251	106	187.3544	1.5771	171	184.4711	3.0027
42	141.1001	3.9251	107	187.3544	1.5771	172	184.4711	3.0027
43	174.4305	4.5217	108	187.3544	1.5771	173	184.4711	3.0027
44	174.4305	4.5217	109	125.8628	1.9391	174	184.4711	3.0027
45	174.4305	4.5217	110	125.8628	1.9391	175	168.9678	2.4601
46	174.4305	4.5217	111	125.8628	1.9391	176	168.9678	2.4601
47	174.4305	4.5217	112	125.8628	1.9391	177	168.9678	2.4601
48	174.4305	4.5217	113	125.8628	1.9391	178	168.9678	2.4601
49	157.9562	2.4837	114	125.8628	1.9391	179	168.9678	2.4601
50	157.9562	2.4837	115	256.8063	3.7688	180	168.9678	2.4601
51	157.9562	2.4837	116	256.8063	3.7688	181	148.6415	3.483
52	157.9562	2.4837	117	256.8063	3.7688	182	148.6415	3.483
53	157.9562	2.4837	118	256.8063	3.7688	183	148.6415	3.483
54	157.9562	2.4837	119	256.8063	3.7688	184	148.6415	3.483
55	144.9983	2.8121	120	256.8063	3.7688	185	148.6415	3.483
56	144.9983	2.8121	121	198.6419	1.5475	186	148.6415	3.483
57	144.9983	2.8121	122	198.6419	1.5475	187	210.2692	6.2989
58	144.9983	2.8121	123	198.6419	1.5475	188	210.2692	6.2989
59	144.9983	2.8121	124	198.6419	1.5475	189	210.2692	6.2989
60	144.9983	2.8121	125	198.6419	1.5475	190	210.2692	6.2989
61	102.5243	3.1413	126	198.6419	1.5475	191	210.2692	6.2989
62	102.5243	3.1413	127	237.1192	1.673	192	210.2692	6.2989
63	102.5243	3.1413	128	237.1192	1.673	193	185.0563	3.6031
64	102.5243	3.1413	129	237.1192	1.673	194	185.0563	3.6031
65	102.5243	3.1413	130	237.1192	1.673	195	185.0563	3.6031

196	185.0563	3.6031
197	185.0563	3.6031
198	185.0563	3.6031
199	195.2912	3.2553
200	195.2912	3.2553
201	195.2912	3.2553
202	195.2912	3.2553
203	195.2912	3.2553
204	195.2912	3.2553
205	140.1929	4.9727
206	140.1929	4.9727
207	140.1929	4.9727
208	140.1929	4.9727
209	140.1929	4.9727
210	140.1929	4.9727
211	169.413	5.8822
212	169.413	5.8822
213	169.413	5.8822
214	169.413	5.8822
215	169.413	5.8822
216	169.413	5.8822
217	178.8686	3.8391
218	178.8686	3.8391
219	178.8686	3.8391
220	178.8686	3.8391
221	178.8686	3.8391
222	178.8686	3.8391
223	208.7742	0.9842
224	208.7742	0.9842
225	208.7742	0.9842
226	208.7742	0.9842
227	208.7742	0.9842
228	208.7742	0.9842
229	127.8628	2.463
230	127.8628	2.463
231	127.8628	2.463
232	127.8628	2.463
233	127.8628	2.463
234	127.8628	2.463
235	203.8194	4.2152
236	203.8194	4.2152
237	203.8194	4.2152
238	203.8194	4.2152
239	203.8194	4.2152
240	203.8194	4.2152
241	218.8808	2.72
242	218.8808	2.72
243	218.8808	2.72
244	218.8808	2.72
245	218.8808	2.72
246	218.8808	2.72
247	209.5828	1.8439
248	209.5828	1.8439
249	209.5828	1.8439
250	209.5828	1.8439
251	209.5828	1.8439
252	209.5828	1.8439
253	158.0898	1.4519
254	158.0898	1.4519
255	158.0898	1.4519
256	158.0898	1.4519
257	158.0898	1.4519
258	158.0898	1.4519
259	199.6526	5.0201
260	199.6526	5.0201
261	199.6526	5.0201
262	199.6526	5.0201
263	199.6526	5.0201
264	199.6526	5.0201
265	207.9667	3.976
266	207.9667	3.976
267	207.9667	3.976
268	207.9667	3.976
269	207.9667	3.976
270	207.9667	3.976
271	173.8374	4.0734
272	173.8374	4.0734
273	173.8374	4.0734
274	173.8374	4.0734
275	173.8374	4.0734
276	173.8374	4.0734
277	145.3606	3.5748
278	145.3606	3.5748
279	145.3606	3.5748
280	145.3606	3.5748
281	145.3606	3.5748
282	145.3606	3.5748
283	186.99	5.2156
284	186.99	5.2156
285	186.99	5.2156
286	186.99	5.2156
287	186.99	5.2156
288	186.99	5.2156
289	185.3663	2.3802
290	185.3663	2.3802
291	185.3663	2.3802
292	185.3663	2.3802
293	185.3663	2.3802
294	185.3663	2.3802
295	177.012	2.6336
296	177.012	2.6336
297	177.012	2.6336
298	177.012	2.6336
299	177.012	2.6336
300	177.012	2.6336
301	151.499	4.2534
302	151.499	4.2534
303	151.499	4.2534
304	151.499	4.2534
305	151.499	4.2534
306	151.499	4.2534
307	147.0326	4.6668
308	147.0326	4.6668
309	147.0326	4.6668
310	147.0326	4.6668
311	147.0326	4.6668
312	147.0326	4.6668
313	171.674	2.0536
314	171.674	2.0536
315	171.674	2.0536
316	171.674	2.0536
317	171.674	2.0536
318	171.674	2.0536
319	138.05	1.7419
320	138.05	1.7419
321	138.05	1.7419
322	138.05	1.7419
323	138.05	1.7419
324	138.05	1.7419
325	88.1149	2.5804
326	88.1149	2.5804
327	88.1149	2.5804
328	88.1149	2.5804
329	88.1149	2.5804
330	88.1149	2.5804
331	165.6431	3.3488
332	165.6431	3.3488
333	165.6431	3.3488
334	165.6431	3.3488
335	165.6431	3.3488
336	165.6431	3.3488
337	234.8889	1.7845
338	234.8889	1.7845
339	234.8889	1.7845
340	234.8889	1.7845
341	234.8889	1.7845
342	234.8889	1.7845
343	39.5932	0.6907
344	39.5932	0.6907
345	39.5932	0.6907
346	39.5932	0.6907
347	39.5932	0.6907
348	39.5932	0.6907
349	135.6338	3.5895
350	135.6338	3.5895
351	135.6338	3.5895
352	135.6338	3.5895
353	135.6338	3.5895
354	135.6338	3.5895
355	214.6899	4.2729
356	214.6899	4.2729
357	214.6899	4.2729
358	214.6899	4.2729
359	214.6899	4.2729
360	214.6899	4.2729
361	238.094	1.766
362	238.094	1.766
363	238.094	1.766
364	238.094	1.766
365	238.094	1.766
366	238.094	1.766
367	217.2222	2.2804
368	217.2222	2.2804
369	217.2222	2.2804
370	217.2222	2.2804
371	217.2222	2.2804
372	217.2222	2.2804
373	144.4437	2.7754
374	144.4437	2.7754
375	144.4437	2.7754
376	144.4437	2.7754
377	144.4437	2.7754
378	144.4437	2.7754
379	175.2335	3.6975
380	175.2335	3.6975
381	175.2335	3.6975
382	175.2335	3.6975
383	175.2335	3.6975
384	175.2335	3.6975
385	211.9687	2.9299
386	211.9687	2.9299
387	211.9687	2.9299
388	211.9687	2.9299
389	211.9687	2.9299
390	211.9687	2.9299
391	160.7215	3.3212
392	160.7215	3.3212
393	160.7215	3.3212
394	160.7215	3.3212
395	160.7215	3.3212
396	160.7215	3.3212
397	149.3394	2.9201
398	149.3394	2.9201
399	149.3394	2.9201
400	149.3394	2.9201
401	149.3394	2.9201
402	149.3394	2.9201
403	213.9679	5.2077
404	213.9679	5.2077
405	213.9679	5.2077
406	213.9679	5.2077
407	213.9679	5.2077
408	213.9679	5.2077

409	169.6449	3.2791	480	200.1992	2.5654	551	213.752	3.9544
410	169.6449	3.2791	481	172.7509	2.8961	552	213.752	3.9544
411	169.6449	3.2791	482	172.7509	2.8961	553	160.0157	2.2915
412	169.6449	3.2791	483	172.7509	2.8961	554	160.0157	2.2915
413	169.6449	3.2791	484	172.7509	2.8961	555	160.0157	2.2915
414	169.6449	3.2791	485	172.7509	2.8961	556	160.0157	2.2915
415	197.699	1.6566	486	172.7509	2.8961	557	160.0157	2.2915
416	197.699	1.6566	487	198.2461	1.5401	558	160.0157	2.2915
417	197.699	1.6566	488	198.2461	1.5401	559	291.755	0.3183
418	197.699	1.6566	489	198.2461	1.5401	560	291.755	0.3183
419	197.699	1.6566	490	198.2461	1.5401	561	291.755	0.3183
420	197.699	1.6566	491	198.2461	1.5401	562	291.755	0.3183
421	116.4824	1.9617	492	198.2461	1.5401	563	291.755	0.3183
422	116.4824	1.9617	493	137.5447	3.7266	564	291.755	0.3183
423	116.4824	1.9617	494	137.5447	3.7266	565	97.6102	4.2437
424	116.4824	1.9617	495	137.5447	3.7266	566	97.6102	4.2437
425	116.4824	1.9617	496	137.5447	3.7266	567	97.6102	4.2437
426	116.4824	1.9617	497	137.5447	3.7266	568	97.6102	4.2437
427	190.3955	0.6983	498	137.5447	3.7266	569	97.6102	4.2437
428	190.3955	0.6983	499	184.4355	4.3285	570	97.6102	4.2437
429	190.3955	0.6983	500	184.4355	4.3285	571	229.4631	2.7515
430	190.3955	0.6983	501	184.4355	4.3285	572	229.4631	2.7515
431	190.3955	0.6983	502	184.4355	4.3285	573	229.4631	2.7515
432	190.3955	0.6983	503	184.4355	4.3285	574	229.4631	2.7515
433	237.3789	2.1275	504	184.4355	4.3285	575	229.4631	2.7515
434	237.3789	2.1275	505	198.4695	2.4309	576	229.4631	2.7515
435	237.3789	2.1275	506	198.4695	2.4309	577	215.3449	2.2151
436	237.3789	2.1275	507	198.4695	2.4309	578	215.3449	2.2151
437	237.3789	2.1275	508	198.4695	2.4309	579	215.3449	2.2151
438	237.3789	2.1275	509	198.4695	2.4309	580	215.3449	2.2151
439	18.2771	1.2884	510	198.4695	2.4309	581	215.3449	2.2151
440	18.2771	1.2884	511	142.4378	0.7811	582	215.3449	2.2151
441	18.2771	1.2884	512	142.4378	0.7811	583	182.4912	1.2128
442	18.2771	1.2884	513	142.4378	0.7811	584	182.4912	1.2128
443	18.2771	1.2884	514	142.4378	0.7811	585	182.4912	1.2128
444	18.2771	1.2884	515	142.4378	0.7811	586	182.4912	1.2128
445	48.7753	2.0006	516	142.4378	0.7811	587	182.4912	1.2128
446	48.7753	2.0006	517	98.2096	2.4836	588	182.4912	1.2128
447	48.7753	2.0006	518	98.2096	2.4836	589	113.5318	3.0129
448	48.7753	2.0006	519	98.2096	2.4836	590	113.5318	3.0129
449	48.7753	2.0006	520	98.2096	2.4836	591	113.5318	3.0129
450	48.7753	2.0006	521	98.2096	2.4836	592	113.5318	3.0129
451	299.0593	3.7069	522	98.2096	2.4836	593	113.5318	3.0129
452	299.0593	3.7069	523	234.3387	0.6216	594	113.5318	3.0129
453	299.0593	3.7069	524	234.3387	0.6216	595	205.5556	3.8774
454	299.0593	3.7069	525	234.3387	0.6216	596	205.5556	3.8774
455	299.0593	3.7069	526	234.3387	0.6216	597	205.5556	3.8774
456	299.0593	3.7069	527	234.3387	0.6216	598	205.5556	3.8774
457	250.1397	2.6671	528	234.3387	0.6216	599	205.5556	3.8774
458	250.1397	2.6671	529	259.1808	1.5754	600	205.5556	3.8774
459	250.1397	2.6671	530	259.1808	1.5754	601	223.6739	2.7204
460	250.1397	2.6671	531	259.1808	1.5754	602	223.6739	2.7204
461	250.1397	2.6671	532	259.1808	1.5754	603	223.6739	2.7204
462	250.1397	2.6671	533	259.1808	1.5754	604	223.6739	2.7204
463	358.8948	2.134	534	259.1808	1.5754	605	223.6739	2.7204
464	358.8948	2.134	535	136.5735	3.4206	606	223.6739	2.7204
465	358.8948	2.134	536	136.5735	3.4206	607	180.7357	1.3014
466	358.8948	2.134	537	136.5735	3.4206	608	180.7357	1.3014
467	358.8948	2.134	538	136.5735	3.4206	609	180.7357	1.3014
468	358.8948	2.134	539	136.5735	3.4206	610	180.7357	1.3014
469	121.1605	1.1268	540	136.5735	3.4206	611	180.7357	1.3014
470	121.1605	1.1268	541	110.6014	3.8462	612	180.7357	1.3014
471	121.1605	1.1268	542	110.6014	3.8462	613	105.5302	2.1142
472	121.1605	1.1268	543	110.6014	3.8462	614	105.5302	2.1142
473	121.1605	1.1268	544	110.6014	3.8462	615	105.5302	2.1142
474	121.1605	1.1268	545	110.6014	3.8462	616	105.5302	2.1142
475	200.1992	2.5654	546	110.6014	3.8462	617	105.5302	2.1142
476	200.1992	2.5654	547	213.752	3.9544	618	105.5302	2.1142
477	200.1992	2.5654	548	213.752	3.9544	619	190.1556	3.3182
478	200.1992	2.5654	549	213.752	3.9544	620	190.1556	3.3182
479	200.1992	2.5654	550	213.752	3.9544	621	190.1556	3.3182

622	190.1556	3.3182
623	190.1556	3.3182
624	190.1556	3.3182
625	230.8817	3.0571
626	230.8817	3.0571
627	230.8817	3.0571
628	230.8817	3.0571
629	230.8817	3.0571
630	230.8817	3.0571
631	53.8446	0.4141
632	53.8446	0.4141
633	53.8446	0.4141
634	53.8446	0.4141
635	53.8446	0.4141
636	53.8446	0.4141
637	92.5954	3.1139
638	92.5954	3.1139
639	92.5954	3.1139
640	92.5954	3.1139
641	92.5954	3.1139
642	92.5954	3.1139
643	288.9937	0.5102
644	288.9937	0.5102
645	288.9937	0.5102
646	288.9937	0.5102
647	288.9937	0.5102
648	288.9937	0.5102
649	357.9092	2.1094
650	357.9092	2.1094
651	357.9092	2.1094
652	357.9092	2.1094
653	357.9092	2.1094
654	357.9092	2.1094
655	24.0041	3.5019
656	24.0041	3.5019
657	24.0041	3.5019
658	24.0041	3.5019
659	24.0041	3.5019
660	24.0041	3.5019
661	53.7009	3.497
662	53.7009	3.497
663	53.7009	3.497
664	53.7009	3.497
665	53.7009	3.497
666	53.7009	3.497
667	287.0321	3.0094
668	287.0321	3.0094
669	287.0321	3.0094
670	287.0321	3.0094
671	287.0321	3.0094
672	287.0321	3.0094
673	314.4555	0.3412
674	314.4555	0.3412
675	314.4555	0.3412
676	314.4555	0.3412
677	314.4555	0.3412
678	314.4555	0.3412
679	41.2794	3.2603
680	41.2794	3.2603
681	41.2794	3.2603
682	41.2794	3.2603
683	41.2794	3.2603
684	41.2794	3.2603
685	61.8031	3.8594
686	61.8031	3.8594
687	61.8031	3.8594
688	61.8031	3.8594
689	61.8031	3.8594
690	61.8031	3.8594
691	343.9499	2.4813
692	343.9499	2.4813
693	343.9499	2.4813
694	343.9499	2.4813
695	343.9499	2.4813
696	343.9499	2.4813

Table B-05: Hourly meteorological data for March 2005

Hour	Wind Vector	Wind Velocity	Hour	Wind Vector	Wind Velocity	Hour	Wind Vector	Wind Velocity
1	18.0116	3.0936	67	195.4754	2.5227	133	110.9979	2.3308
2	18.0116	3.0936	68	195.4754	2.5227	134	110.9979	2.3308
3	18.0116	3.0936	69	195.4754	2.5227	135	110.9979	2.3308
4	18.0116	3.0936	70	195.4754	2.5227	136	110.9979	2.3308
5	18.0116	3.0936	71	195.4754	2.5227	137	110.9979	2.3308
6	18.0116	3.0936	72	195.4754	2.5227	138	110.9979	2.3308
7	47.9272	4.8647	73	239.4921	3.8523	139	62.0242	0.1649
8	47.9272	4.8647	74	239.4921	3.8523	140	62.0242	0.1649
9	47.9272	4.8647	75	239.4921	3.8523	141	62.0242	0.1649
10	47.9272	4.8647	76	239.4921	3.8523	142	62.0242	0.1649
11	47.9272	4.8647	77	239.4921	3.8523	143	62.0242	0.1649
12	47.9272	4.8647	78	239.4921	3.8523	144	62.0242	0.1649
13	78.4002	4.1899	79	344.7173	0.7088	145	237.8807	0.584
14	78.4002	4.1899	80	344.7173	0.7088	146	237.8807	0.584
15	78.4002	4.1899	81	344.7173	0.7088	147	237.8807	0.584
16	78.4002	4.1899	82	344.7173	0.7088	148	237.8807	0.584
17	78.4002	4.1899	83	344.7173	0.7088	149	237.8807	0.584
18	78.4002	4.1899	84	344.7173	0.7088	150	237.8807	0.584
19	52.601	3.2233	85	87.9565	3.4596	151	119.8733	0.9557
20	52.601	3.2233	86	87.9565	3.4596	152	119.8733	0.9557
21	52.601	3.2233	87	87.9565	3.4596	153	119.8733	0.9557
22	52.601	3.2233	88	87.9565	3.4596	154	119.8733	0.9557
23	52.601	3.2233	89	87.9565	3.4596	155	119.8733	0.9557
24	52.601	3.2233	90	87.9565	3.4596	156	119.8733	0.9557
25	308.2957	1.9498	91	0.9902	2.352	157	265.3801	1.8037
26	308.2957	1.9498	92	0.9902	2.352	158	265.3801	1.8037
27	308.2957	1.9498	93	0.9902	2.352	159	265.3801	1.8037
28	308.2957	1.9498	94	0.9902	2.352	160	265.3801	1.8037
29	308.2957	1.9498	95	0.9902	2.352	161	265.3801	1.8037
30	308.2957	1.9498	96	0.9902	2.352	162	265.3801	1.8037
31	52.3739	2.1503	97	278.4992	1.4786	163	212.5232	6.0618
32	52.3739	2.1503	98	278.4992	1.4786	164	212.5232	6.0618
33	52.3739	2.1503	99	278.4992	1.4786	165	212.5232	6.0618
34	52.3739	2.1503	100	278.4992	1.4786	166	212.5232	6.0618
35	52.3739	2.1503	101	278.4992	1.4786	167	212.5232	6.0618
36	52.3739	2.1503	102	278.4992	1.4786	168	212.5232	6.0618
37	87.6545	2.4152	103	54.6557	1.5949	169	219.3107	3.7721
38	87.6545	2.4152	104	54.6557	1.5949	170	219.3107	3.7721
39	87.6545	2.4152	105	54.6557	1.5949	171	219.3107	3.7721
40	87.6545	2.4152	106	54.6557	1.5949	172	219.3107	3.7721
41	87.6545	2.4152	107	54.6557	1.5949	173	219.3107	3.7721
42	87.6545	2.4152	108	54.6557	1.5949	174	219.3107	3.7721
43	67.2428	2.2176	109	99.0651	3.5025	175	218.9022	1.9738
44	67.2428	2.2176	110	99.0651	3.5025	176	218.9022	1.9738
45	67.2428	2.2176	111	99.0651	3.5025	177	218.9022	1.9738
46	67.2428	2.2176	112	99.0651	3.5025	178	218.9022	1.9738
47	67.2428	2.2176	113	99.0651	3.5025	179	218.9022	1.9738
48	67.2428	2.2176	114	99.0651	3.5025	180	218.9022	1.9738
49	234.3896	1.7606	115	38.6726	3.4398	181	176.6417	4.2733
50	234.3896	1.7606	116	38.6726	3.4398	182	176.6417	4.2733
51	234.3896	1.7606	117	38.6726	3.4398	183	176.6417	4.2733
52	234.3896	1.7606	118	38.6726	3.4398	184	176.6417	4.2733
53	234.3896	1.7606	119	38.6726	3.4398	185	176.6417	4.2733
54	234.3896	1.7606	120	38.6726	3.4398	186	176.6417	4.2733
55	102.5092	2.4669	121	312.9718	1.3321	187	191.7815	7.1119
56	102.5092	2.4669	122	312.9718	1.3321	188	191.7815	7.1119
57	102.5092	2.4669	123	312.9718	1.3321	189	191.7815	7.1119
58	102.5092	2.4669	124	312.9718	1.3321	190	191.7815	7.1119
59	102.5092	2.4669	125	312.9718	1.3321	191	191.7815	7.1119
60	102.5092	2.4669	126	312.9718	1.3321	192	191.7815	7.1119
61	90.187	3.1503	127	50.555	2.5263	193	170.6582	4.2193
62	90.187	3.1503	128	50.555	2.5263	194	170.6582	4.2193
63	90.187	3.1503	129	50.555	2.5263	195	170.6582	4.2193
64	90.187	3.1503	130	50.555	2.5263	196	170.6582	4.2193
65	90.187	3.1503	131	50.555	2.5263	197	170.6582	4.2193
66	90.187	3.1503	132	50.555	2.5263	198	170.6582	4.2193

199	206.7043	1.5147	270	221.4508	2.7121	341	201.1602	2.4501
200	206.7043	1.5147	271	209.0156	1.5216	342	201.1602	2.4501
201	206.7043	1.5147	272	209.0156	1.5216	343	143.8003	1.0183
202	206.7043	1.5147	273	209.0156	1.5216	344	143.8003	1.0183
203	206.7043	1.5147	274	209.0156	1.5216	345	143.8003	1.0183
204	206.7043	1.5147	275	209.0156	1.5216	346	143.8003	1.0183
205	121.9245	1.5861	276	209.0156	1.5216	347	143.8003	1.0183
206	121.9245	1.5861	277	107.8296	1.8347	348	143.8003	1.0183
207	121.9245	1.5861	278	107.8296	1.8347	349	105.8523	2.8055
208	121.9245	1.5861	279	107.8296	1.8347	350	105.8523	2.8055
209	121.9245	1.5861	280	107.8296	1.8347	351	105.8523	2.8055
210	121.9245	1.5861	281	107.8296	1.8347	352	105.8523	2.8055
211	165.1439	3.7098	282	107.8296	1.8347	353	105.8523	2.8055
212	165.1439	3.7098	283	190.5159	4.2472	354	105.8523	2.8055
213	165.1439	3.7098	284	190.5159	4.2472	355	184.7921	3.4211
214	165.1439	3.7098	285	190.5159	4.2472	356	184.7921	3.4211
215	165.1439	3.7098	286	190.5159	4.2472	357	184.7921	3.4211
216	165.1439	3.7098	287	190.5159	4.2472	358	184.7921	3.4211
217	121.1315	2.8387	288	190.5159	4.2472	359	184.7921	3.4211
218	121.1315	2.8387	289	243.8642	1.4968	360	184.7921	3.4211
219	121.1315	2.8387	290	243.8642	1.4968	361	190.2997	0.3371
220	121.1315	2.8387	291	243.8642	1.4968	362	190.2997	0.3371
221	121.1315	2.8387	292	243.8642	1.4968	363	190.2997	0.3371
222	121.1315	2.8387	293	243.8642	1.4968	364	190.2997	0.3371
223	167.5045	1.662	294	243.8642	1.4968	365	190.2997	0.3371
224	167.5045	1.662	295	154.9929	0.409	366	190.2997	0.3371
225	167.5045	1.662	296	154.9929	0.409	367	45.0423	1.6902
226	167.5045	1.662	297	154.9929	0.409	368	45.0423	1.6902
227	167.5045	1.662	298	154.9929	0.409	369	45.0423	1.6902
228	167.5045	1.662	299	154.9929	0.409	370	45.0423	1.6902
229	207.7535	3.0445	300	154.9929	0.409	371	45.0423	1.6902
230	207.7535	3.0445	301	110.5177	2.0542	372	45.0423	1.6902
231	207.7535	3.0445	302	110.5177	2.0542	373	80.3701	2.593
232	207.7535	3.0445	303	110.5177	2.0542	374	80.3701	2.593
233	207.7535	3.0445	304	110.5177	2.0542	375	80.3701	2.593
234	207.7535	3.0445	305	110.5177	2.0542	376	80.3701	2.593
235	195.0352	3.5532	306	110.5177	2.0542	377	80.3701	2.593
236	195.0352	3.5532	307	184.4579	3.7844	378	80.3701	2.593
237	195.0352	3.5532	308	184.4579	3.7844	379	206.0809	2.0623
238	195.0352	3.5532	309	184.4579	3.7844	380	206.0809	2.0623
239	195.0352	3.5532	310	184.4579	3.7844	381	206.0809	2.0623
240	195.0352	3.5532	311	184.4579	3.7844	382	206.0809	2.0623
241	187.4594	2.1703	312	184.4579	3.7844	383	206.0809	2.0623
242	187.4594	2.1703	313	181.1964	1.5783	384	206.0809	2.0623
243	187.4594	2.1703	314	181.1964	1.5783	385	258.2915	1.578
244	187.4594	2.1703	315	181.1964	1.5783	386	258.2915	1.578
245	187.4594	2.1703	316	181.1964	1.5783	387	258.2915	1.578
246	187.4594	2.1703	317	181.1964	1.5783	388	258.2915	1.578
247	142.2717	1.6766	318	181.1964	1.5783	389	258.2915	1.578
248	142.2717	1.6766	319	148.4256	0.9299	390	258.2915	1.578
249	142.2717	1.6766	320	148.4256	0.9299	391	328.1607	1.8043
250	142.2717	1.6766	321	148.4256	0.9299	392	328.1607	1.8043
251	142.2717	1.6766	322	148.4256	0.9299	393	328.1607	1.8043
252	142.2717	1.6766	323	148.4256	0.9299	394	328.1607	1.8043
253	130.4017	1.5241	324	148.4256	0.9299	395	328.1607	1.8043
254	130.4017	1.5241	325	140.5538	3.4047	396	328.1607	1.8043
255	130.4017	1.5241	326	140.5538	3.4047	397	35.9397	1.168
256	130.4017	1.5241	327	140.5538	3.4047	398	35.9397	1.168
257	130.4017	1.5241	328	140.5538	3.4047	399	35.9397	1.168
258	130.4017	1.5241	329	140.5538	3.4047	400	35.9397	1.168
259	193.4989	3.6864	330	140.5538	3.4047	401	35.9397	1.168
260	193.4989	3.6864	331	203.8603	2.8033	402	35.9397	1.168
261	193.4989	3.6864	332	203.8603	2.8033	403	166.1277	1.8472
262	193.4989	3.6864	333	203.8603	2.8033	404	166.1277	1.8472
263	193.4989	3.6864	334	203.8603	2.8033	405	166.1277	1.8472
264	193.4989	3.6864	335	203.8603	2.8033	406	166.1277	1.8472
265	221.4508	2.7121	336	203.8603	2.8033	407	166.1277	1.8472
266	221.4508	2.7121	337	201.1602	2.4501	408	166.1277	1.8472
267	221.4508	2.7121	338	201.1602	2.4501	409	276.2843	3.3893
268	221.4508	2.7121	339	201.1602	2.4501	410	276.2843	3.3893
269	221.4508	2.7121	340	201.1602	2.4501	411	276.2843	3.3893

412	276.2843	3.3893
413	276.2843	3.3893
414	276.2843	3.3893
415	293.8041	0.9576
416	293.8041	0.9576
417	293.8041	0.9576
418	293.8041	0.9576
419	293.8041	0.9576
420	293.8041	0.9576
421	57.2983	2.8518
422	57.2983	2.8518
423	57.2983	2.8518
424	57.2983	2.8518
425	57.2983	2.8518
426	57.2983	2.8518
427	186.829	1.1999
428	186.829	1.1999
429	186.829	1.1999
430	186.829	1.1999
431	186.829	1.1999
432	186.829	1.1999
433	277.4007	0.8838
434	277.4007	0.8838
435	277.4007	0.8838
436	277.4007	0.8838
437	277.4007	0.8838
438	277.4007	0.8838
439	339.0994	1.5841
440	339.0994	1.5841
441	339.0994	1.5841
442	339.0994	1.5841
443	339.0994	1.5841
444	339.0994	1.5841
445	40.1212	3.312
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447	40.1212	3.312
448	40.1212	3.312
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450	40.1212	3.312
451	293.2692	1.7517
452	293.2692	1.7517
453	293.2692	1.7517
454	293.2692	1.7517
455	293.2692	1.7517
456	293.2692	1.7517
457	331.7133	1.5485
458	331.7133	1.5485
459	331.7133	1.5485
460	331.7133	1.5485
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462	331.7133	1.5485
463	6.2538	5.103
464	6.2538	5.103
465	6.2538	5.103
466	6.2538	5.103
467	6.2538	5.103
468	6.2538	5.103
469	25.041	2.74
470	25.041	2.74
471	25.041	2.74
472	25.041	2.74
473	25.041	2.74
474	25.041	2.74
475	307.6202	2.4884
476	307.6202	2.4884
477	307.6202	2.4884
478	307.6202	2.4884
479	307.6202	2.4884
480	307.6202	2.4884
481	17.6261	1.0572
482	17.6261	1.0572
483	17.6261	1.0572
484	17.6261	1.0572
485	17.6261	1.0572
486	17.6261	1.0572
487	352.576	4.4475
488	352.576	4.4475
489	352.576	4.4475
490	352.576	4.4475
491	352.576	4.4475
492	352.576	4.4475
493	13.358	5.3885
494	13.358	5.3885
495	13.358	5.3885
496	13.358	5.3885
497	13.358	5.3885
498	13.358	5.3885
499	5.1917	3.5157
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504	5.1917	3.5157
505	326.9311	4.3243
506	326.9311	4.3243
507	326.9311	4.3243
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509	326.9311	4.3243
510	326.9311	4.3243
511	9.1003	6.3997
512	9.1003	6.3997
513	9.1003	6.3997
514	9.1003	6.3997
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516	9.1003	6.3997
517	23.627	5.468
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519	23.627	5.468
520	23.627	5.468
521	23.627	5.468
522	23.627	5.468
523	356.783	5.5974
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527	356.783	5.5974
528	356.783	5.5974
529	327.4547	4.398
530	327.4547	4.398
531	327.4547	4.398
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533	327.4547	4.398
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535	6.0099	4.5349
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540	6.0099	4.5349
541	7.762	5.229
542	7.762	5.229
543	7.762	5.229
544	7.762	5.229
545	7.762	5.229
546	7.762	5.229
547	340.1626	4.4095
548	340.1626	4.4095
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552	340.1626	4.4095
553	279.5628	2.0351
554	279.5628	2.0351
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557	279.5628	2.0351
558	279.5628	2.0351
559	5.3942	4.4444
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561	5.3942	4.4444
562	5.3942	4.4444
563	5.3942	4.4444
564	5.3942	4.4444
565	30.7957	4.4918
566	30.7957	4.4918
567	30.7957	4.4918
568	30.7957	4.4918
569	30.7957	4.4918
570	30.7957	4.4918
571	338.4856	4.5481
572	338.4856	4.5481
573	338.4856	4.5481
574	338.4856	4.5481
575	338.4856	4.5481
576	338.4856	4.5481
577	338.3278	2.6616
578	338.3278	2.6616
579	338.3278	2.6616
580	338.3278	2.6616
581	338.3278	2.6616
582	338.3278	2.6616
583	21.6211	4.8598
584	21.6211	4.8598
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586	21.6211	4.8598
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588	21.6211	4.8598
589	21.7248	4.5098
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601	355.1751	3.6851
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612	0.3058	4.1909
613	47.1343	3.9069
614	47.1343	3.9069
615	47.1343	3.9069
616	47.1343	3.9069
617	47.1343	3.9069
618	47.1343	3.9069
619	359.5941	5.2566
620	359.5941	5.2566
621	359.5941	5.2566
622	359.5941	5.2566
623	359.5941	5.2566
624	359.5941	5.2566

625	13.0718	1.5033
626	13.0718	1.5033
627	13.0718	1.5033
628	13.0718	1.5033
629	13.0718	1.5033
630	13.0718	1.5033
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634	67.9685	3.2969
635	67.9685	3.2969
636	67.9685	3.2969
637	54.8746	4.2199
638	54.8746	4.2199
639	54.8746	4.2199
640	54.8746	4.2199
641	54.8746	4.2199
642	54.8746	4.2199
643	101.1922	1.1849
644	101.1922	1.1849
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646	101.1922	1.1849
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648	101.1922	1.1849
649	2.7794	3.4655
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654	2.7794	3.4655
655	46.1118	4.5567
656	46.1118	4.5567
657	46.1118	4.5567
658	46.1118	4.5567
659	46.1118	4.5567
660	46.1118	4.5567
661	51.048	5.0895
662	51.048	5.0895
663	51.048	5.0895
664	51.048	5.0895
665	51.048	5.0895
666	51.048	5.0895
667	18.6973	3.8433
668	18.6973	3.8433
669	18.6973	3.8433
670	18.6973	3.8433
671	18.6973	3.8433
672	18.6973	3.8433
673	25.5026	2.1679
674	25.5026	2.1679
675	25.5026	2.1679
676	25.5026	2.1679
677	25.5026	2.1679
678	25.5026	2.1679
679	25.6643	2.766
680	25.6643	2.766
681	25.6643	2.766
682	25.6643	2.766
683	25.6643	2.766
684	25.6643	2.766
685	33.6429	3.8147
686	33.6429	3.8147
687	33.6429	3.8147
688	33.6429	3.8147
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692	308.3281	1.76
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695	308.3281	1.76
696	308.3281	1.76
697	279.5225	1.7934
698	279.5225	1.7934
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700	279.5225	1.7934
701	279.5225	1.7934
702	279.5225	1.7934
703	47.6217	2.2026
704	47.6217	2.2026
705	47.6217	2.2026
706	47.6217	2.2026
707	47.6217	2.2026
708	47.6217	2.2026
709	75.7206	4.77
710	75.7206	4.77
711	75.7206	4.77
712	75.7206	4.77
713	75.7206	4.77
714	75.7206	4.77
715	266.3139	2.3723
716	266.3139	2.3723
717	266.3139	2.3723
718	266.3139	2.3723
719	266.3139	2.3723
720	266.3139	2.3723
721	263.4597	1.7288
722	263.4597	1.7288
723	263.4597	1.7288
724	263.4597	1.7288
725	263.4597	1.7288
726	263.4597	1.7288
727	52.3666	2.7166
728	52.3666	2.7166
729	52.3666	2.7166
730	52.3666	2.7166
731	52.3666	2.7166
732	52.3666	2.7166
733	42.2314	3.8097
734	42.2314	3.8097
735	42.2314	3.8097
736	42.2314	3.8097
737	42.2314	3.8097
738	42.2314	3.8097
739	134.1187	0.8262
740	134.1187	0.8262
741	134.1187	0.8262
742	134.1187	0.8262
743	134.1187	0.8262
744	134.1187	0.8262