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Role of air pollutants emitted from coal power plant and meteorology in climate change

Ganesh Chandra Kisku[1☼], **Markandeya**[1,2]

1.Environmental Monitoring Laboratory and Environmental Toxicology Group, CSIR-Indian Institute of Toxicology Research, M.G. Marg, Lucknow-226001, U.P., India; E-mail address: kiskugc1@rediffmail.com
2.Department of Civil Engineering, Institute of Engineering and Technology, Sitapur Road, Lucknow-226021, U.P., India: E-mail address: mktiwariiet@gmail.com

☼**Corresponding Author:**
Environmental Monitoring Laboratory and Environmental Toxicology Group,
CSIR-Indian Institute of Toxicology Research,
M.G. Marg, Lucknow-226001,
U.P., India;
E-mail address: kiskugc1@rediffmail.com

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ABSTRACT

Coal, a fossil fuel is the largest source of energy for the generation of electricity in India. The total of 301.56 billion tonnes of coal reserves is estimated by the Geological Survey of India as of April 1st, 2014. It was mined at 229 million tonnes in year 2013, ranking 4th largest coal producing nation in the world. India consumed about 700 million tonnes of coal in 2013, out of which 324 million tonnes were used for power generation which is 3rd largest nation in the world. Power is considered to be a core industry as it facilitates development across various sectors of the Indian economy, such as manufacturing, agriculture, commercial enterprises and railways. The monthly mean temperature and relative humidity varied from 6.9 to 47.7°C with an average of 37.4°C and 16.5 to 99.0% with an average of 97.5% during the study period. The concentrations of particulate matter, SO_2, NOx, CO and Pb were found 179, 360, 237, 218 and 1.21 mg/Nm^3 in Captive Power, CP-unit-I and 215, 355, 241, 210 and 1.17 mg/Nm^3 in CP-unit-II respectively while Hg concentration in CP-unit-I 0.94 and in CP-unit-II 1.13 (µg/m3) respectively. Keeping in view of climate change; the most important parameter is CO_2 in the flue gas of a power plant. The percentage of CO_2 ranged inbetween 11.45 to 13.67%. Meteorological conditions play a crucial role in determining the concentrations of the pollutants by affecting both directly and indirectly the emissions, transport, formation and deposition of air pollutants. Atmospheric stability determines the extent to which vertical motions mix up the pollution in the upper atmosphere, although a major chunk of pollution build up at the ground surface. Our study concluded that coal power plant is one of the key players which govern the local as well as global climate change.

Keywords: Coal Power Plant, stack emission, pollutants, meteorology, climate change

1. INTRODUCTION

Coal is world's primary source of energy. About 1444 coal based thermal power plants are present in global out of which 143 (9.9%) are in India. The consumption of coal was 324 million tonnes for power generation during 2013 (BP Statistical Review of World Energy June, 2014).

The CO_2 emission was 35094.4 metric tonne in the year of 2013 which was also 2.1% changed over 2012. The emissions of carbon reflect only those through consumption of oil, gas and coal and are based on standard global average conversion factors (Ashwini A Waoo et al. 2015). This emission does not allow for any carbon that is confiscated, for other sources of carbon emissions or for emissions of other green-house gases (Shalin Shah, 2015; Medha Kumar and Varun Dutt, 2015). The basis of carbon content in fuel oil 73,300 kg CO_2 per terajoule (3.07 tonnes per tonne of oil equivalent); natural gas 56,100 kg CO_2 per terajoule (2.35 tonnes per tonne of oil equivalent); coal 94,600 kg CO_2 per terajoule (3.96 tonnes per tonne of oil equivalent). The generation of electricity was 23127.0 terawatt-hr in 2013 which was 2.5% changed over 2012.

Coal based thermal power plants generated lots of black carbon and often loft it high into the atmosphere as emissions from tall stack (~275 m) (Kisku et al., 2012, Forster and Taylor, 2006). These power plants are not only releasing aerosols but also flue gases in huge amounts. Tiny particles of black carbon or soot are a major component of flue gases. Pollutant gases such as sulfur dioxide (SO_2) and oxides of nitrogen (NO_x) which are emitted by coal combustion and a variety of industrial processes are transformed to secondary aerosols. Chemical reactions convert these gases into solid aerosols or liquid droplets. During this process, SO_2 combines with water vapour and transform into sulfuric acid droplets, a liquid aerosol that cause acid rain. Sulfuric acid in turn combines with gaseous ammonia (NH_3) to form a solid ammonium salt, ammonium sulfate [$(NH_4)_2$ SO_4] (Kamra et al., 2009, Chung et al., 2005; Dhara, 2003).

Besides its use in power plants, coal is commonly used for cooking and heating. India is world's sixth largest energy consumer, accounting for 3.4% of global energy consumption (https://en.wikipedia.org/wiki/2011). In India, electricity has increased from 1362 MW in 1947 (pre-independence) to 228,721.7 MW in 2013 installed capacity as on 2013. About 143 coal based power plants are consuming 523.52 metric tonnes (54.51%) of coal while 46.3 metric tonnes (7.78%) by gas based thermal power plants, 175.2 metric tonnes (29.46%) by diesel oil based thermal power plants, 29.8 metric tonnes (5.05%) by hydro electric power and 7.5 metric tonnes (1.27%) by nuclear power reactor 11.7 metric tonne (1.97%) by renewable energy sources (BP Statistical Review of World Energy June, 2014). Whereas electricity generating capacity is 228,721.7 MW in 2013 comprising of thermal 155,969 MW (68.2%), hydro 39,788 MW (17.4%), nuclear 4,780 MW (2.1%) and renewable 28,184.4 MW (12.3%). During this power generation process huge amount of coal is burned and all sorts of hazardous and toxic air pollutants viz. coarse/ fine and ultra fine inhalable particulate matter, CO, CO_2, SO_2, NO_x, H_xC_y, PAHs, hot steam, metal oxides, more than 20 metals like heavy, light, alkaline and alkaloid including As and Hg are being discharged from the power plants (Willoughby et al., 2014). Population explosion, modern lifestyles and fast-paced India's economic growth have rocketed the energy demand and the total demand for electricity is expected to cross 950,000 MW from 155,969 MW by 2030.

Most of the Indian has low grade quality coal with high ash content (35–50%) and low calorific value (2800 kcal/kg). Major share of the coal mines are located in the eastern parts of the country and requires transportation over long distance to cater power stations, mostly by diesel trains. Majority of the coal is of anthracite, bituminous and sub-bituminous type. In the Southern part of India, there are some lignite (brown coal) deposits which are better than black coal. Moreover, the best quality of coal is used by the metallurgical industry instead of coal power plant (Maricq, 2007; Talukdar and Swihart, 2004). Based on composition and calorific values, Indian coals are classified into six different categories. It discharges huge quantity of inhalable aerosol in the form of fly ash i.e. particulate matters. Epidemiology studies stated that the elevated concentrations of chemically coated metal bearing fine-particulates (PM_{10}, $PM_{2.5}$ and nano particles) are associated with mortality and morbidity, especially in children and elderly people (Sarkar et al. 2006). A series of adverse health impaired caused by these aerosols in turn carry high economic costs to society.

The aims of present investigation is to determine the quality and quantity of pollutants present in the flue gas emitted though stack of a power plant and to fulfil the above objective, an integrated approach is involved to understand the aspects of atmospheric chemistry of pollutants and meteological conditions which having a main role in climate change.

2. MATERIALS AND METHODS

2.1. Sampling Procedure

The concerned factory has a Captive Power Plant, an integrated small scale power plant consists of 2 units each with 25 MW production capacity. It produces power only for its factory consumtion. These two units were monitored to quantify the different pollutants released with flue gases. Stack samples were collected from the sampling port at 2.5 m above the ground in the respective stack using Stack Monitoring Kit (Model APM-615, Envirotech make, New Delhi) (IS:11255, 1985). Particulate matter was collected isokinetically in pre-weighed microglass thimble and quantified gravimetrically whereas SO_2, NO_x, O_2%, CO, CO_2%, CxHx, stack gas temperature were directly measured with the help of Automatic Flue Gas Analyzer (Model KM-9106, Germany Made). The stack gas velocity was measured using Pitot tube of stack kit which record the deflection of manometer. Mercury analysed by cold vapour digestion method and Pb analysed through nitric and perchloric acid digestion mixture after digestion measured by AAS (APHA, 1977).

3. RESULTS AND DISCUSSION

In this study to understand the role of coal power plant in global climate change; Captive Power Plant of a factory consists of 2 units each 25 MW production capacity was monitored to quantify the different pollutants released with flue gases. The factory is located at Singrauli area, referred as power hub of India, producing about 1/3rd of total electricity. According to National Green Tribunal, Singrauli area is categorized as a critically polluted area. The stack emission data and analytical results are given in Table 1. The concentrations of particulate matter, SO_2, NO_x and Pb ranged from 179-215, 360-355, 237-24, 1.17-121 mg/Nm^3 while Hg ranged from 0.94-1.13 (μg/m3) respectively. The ambient temperature ranged between 313-314 (K) with an average value of 313.5 (K) while stack gas ranged from 400-412 (K) with an average value of 406 (K). The hourly volumes of CO_2 released from CP Unit-I and CP Unit-II ranged 2,67,570 i.e. 11.45% of released flue gas volume 23,36,767 Nm^3/hr and 3,35,820 i.e. 13.67% of released flue gas volume of 24,56,617 Nm^3/hr with an average valume of CO_2 301695 Nm^3/hr respectively. The Plant Load Factor ranged from 21.02 MW out of 25 MW installed capacity and 23.51 MW out of 25 MW installed capacity average 22.265 MW.

Table 1 The Analytical Results of Stack Emission

S. No.	Particulars	CP Unit – I	CP Unit – II
1.	Stack attached to	ESP outlet of Captive Power Plant	
2.	Stack height from ground (m)	75	75
3.	Type of duct	Rectangular	Rectangular
4.	Type of stack	Circular	Circular
5.	Height of sampling port from the ground (m)	3.0	3.0
6.	Dimension of duct (m)	2.48 x 2.48	2.48 x 2.48
7.	Duct area (m^2)	6.15	6.15
8.	Diameter of sampling port (mm)	100	100
9.	Load (MW) during Monitoring	21.02	23.51
10.	Quantity of fuel used (MT/hr)	19.3	21.33
11.	Ambient temperature (K)	314	313
12.	Duct/ stack temperature (K)	400	412
13.	Flue gas exit velocity (m/sec)	9.22	9.39
14.	Flue gas exhaust volume (Nm^3/hr)	2336767	2456617
15.	Concentration of pollutants (mg/Nm^3)		

SPM	179	215
SO_2	360	355
NO_x	237	241
CO_2 %	11.45	13.67
Hg (µg/m^3)	0.94	1.13
CO	218	210
Pb	1.21	1.17

The average global coal production and coal consumption between 1981 to 2013 are shown in Figure 1 and Figure 2 (BP Statistical Review of World Energy June 2014). The highest coal producing country is China (Avg 845.8 ± 465.3) followed by US (Avg 542.9 ± 43.0), Australia (Avg 153.5 ± 60.3) and India (Avg 131.2 ± 51.1) million tonnes (Figure 1). The highest coal consumption country is also China (Avg 831.6 ± 474.6) followed by US (Avg 500.1 ± 56.1) and India (Avg 148.1 ± 71.8) million tonnes (Figure 2). India secured 4th position in coal production and 3rd position in coal consumption.

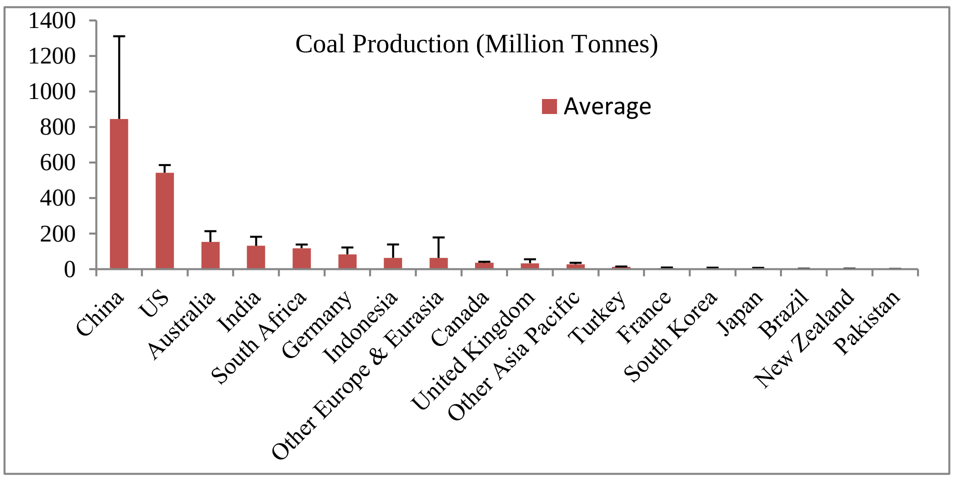

Figure 1 The average Globally coal production between 1981 to 2013

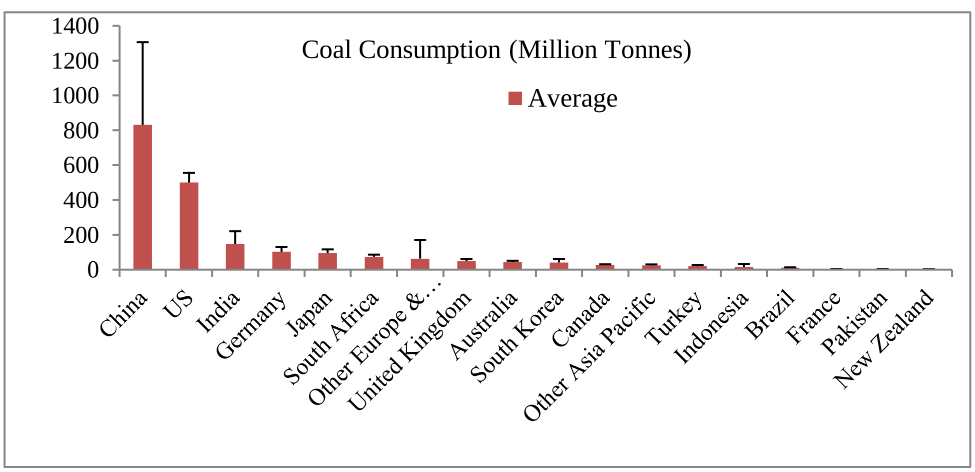

Figure 2 The average globally coal consumption between 1981 to 2013

The variation of temperature profile is given in Table 2 and Figure 3. The monthly minimum temperature varied between 6.9-28.6°C with an average of 20.0 ± 8.05°C. The monthly maximum temperature varied between 28.5-47.7°C with an average of 40.0 ± 6.93°C. The monthly mean temperature varied between 17.0-37.4°C with an average of 29.3 ± 7.47°C. The monthly minimum relative humidity varied between 6.9-28.6% with an average of 20.0 ± 8.05%. The monthly maximum relative humidity varied between 28.5-

47.7% with an average of 40.0 ± 6.93%. The monthly mean relative humidity varied between 17.0-37.4% with an average of 29.3 ± 7.47%.

Table 2 Daily Minimum, Maximum, Average Temperature and Relative humidity

Date	Temperature (°C)			Relative Humidity (%)		
	Minimum	Maximum	Average	Minimum	Maximum	Average
January 2014	6.9	28.5	18.4	33.5	94.8	70.1
February 2014	13.2	28.7	20.1	34.0	99.0	78.8
March 2014	18.0	41.7	28.0	17.0	97.0	53.3
April 2014	23.2	45.8	34.8	16.5	59.0	35.5
May 2014	27.5	47.7	37.3	19.6	87.7	57.0
June 2014	27.9	46.8	37.4	23.4	92.3	50.7
July 2014	26.5	43.2	34.6	44.5	98.6	70.3
August 2014	28.6	42.5	34.7	52.6	95.3	97.5
September 2014	26.5	42.1	33.2	53.6	92.2	76.4
October 2014	20.7	41.5	31.6	45.0	87.5	68.6
November 2014	13.8	41.0	24.8	19.0	94.9	59.8
December 2014	7.2	29.9	17.0	24.9	99.0	58.9
Minimum	6.9	28.5	17.0	16.5	59.0	35.5
Maximum	28.6	47.7	37.4	53.6	99.0	97.5
Average	20.0	40.0	29.3	32.0	91.4	64.7
SD	8.05	6.93	7.47	13.93	10.95	15.91

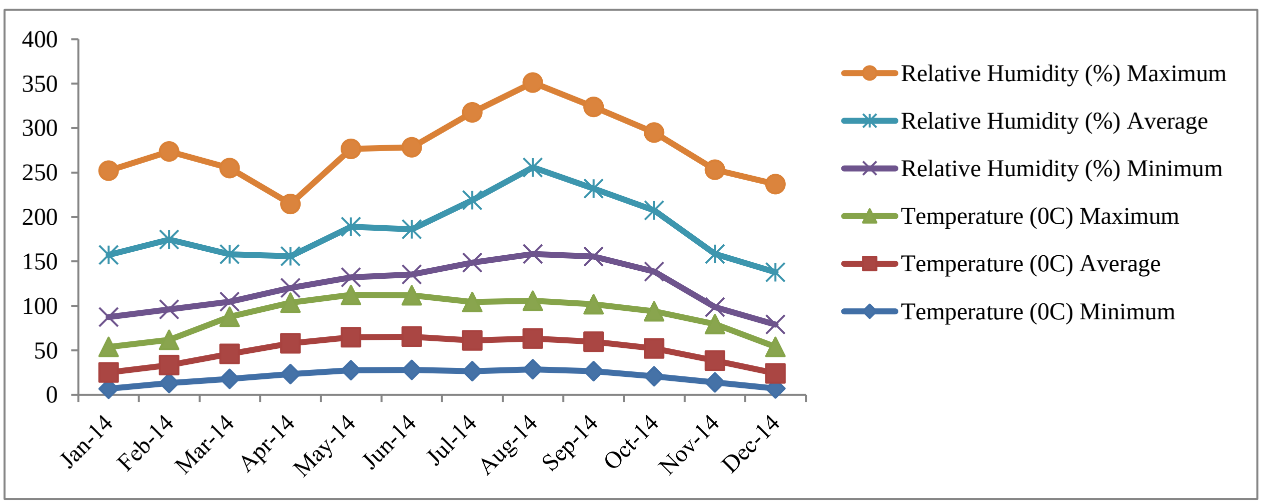

Figure 3 The monthly variation of temperature and relative humidity during Jan 2014-Dec 2014

It is found that once pollutants released from tall stack there is tendency to miwed up with the upper atmosphere. Coarse particles settled down to the surface within 3 to 5 days while fine and lighter aerosols remains in suspended form for long time. Gaseous pollutants can transform into bigger molecules. These particles and gaseous pollutants are being the cause of climate change. Chemical reactions involving, aerosols can generate new substances that influence climate or they can diminish the amounts of certain other chemicals in the atmosphere, again altering the existing balance. Reactions can cause aerosols to grow in size, altering their ability to absorb or scatter light or other electromagnetic radiation. Usually, tonnes of aerosols are escaped from the power plant in the upper atmosphere through stacks. These aerosols range from 0.1 nm to >100 μm in size and in varying shapes. Aerosols have a major impact in Earth's climate. Different aerosols interact with sunlight and other electromagnetic radiation in various ways. All aerosols, including sulphate and nitrate aerosols, scatter light to some extent. Therefore, aerosols of different types can influence climate in one or more ways (Koukouzas et al., 2006). However, aerosols that also absorb sunlight especially black carbon effectively increase albedo (both directly and indirectly via clouds) warming the atmosphere in their vicinity when they reradiate the absorbed energy. Such absorption and heating may occur near Earth's surface or high above it in the stratosphere and that the location of that heating can make a big difference in terms of the overall effect on climate (Andreae and Gelencser, 2006). Aerosols alter Earth's energy budget (some scatter or reflect light, while others are strong absorbers of solar energy) and cause changes to the water cycle. The overall effects of aerosols are complex phenomena. The chemical composition and properties of pollutants can play a large role in their abilities to influence climate. Some are relatively inert, others are highly reactive and some react strongly only with certain substances. Aerosols play a critical role in cloud and rain-drop formation. Clouds formed as parcels of cool moist air and the water vapor in them condenses, forming small liquid droplets of water. The particles around which cloud droplets coalesce are called Cloud Condensation Nuclei (CCN) or sometimes "cloud seeds". Amazingly, in the absence of CCN, air containing water vapor needs to be "supersaturated" to a humidity of about 400% before droplets spontaneously form. So, in almost all circumstances, aerosols play a vital role in the formation of clouds. As humidity accumulates on the particles droplets are formed, which later develop into clouds.

Any disturbance to the normal mixing of aerosols, whether from natural events or from anthropogenic ones like emissions from fossil fuel burning, tends to alter the types and numbers of clouds that appear in that region or downwind of it. Changes to clouds alter solar energy input via an altered albedo, alter precipitation patterns and alter the strength of the greenhouse effect (Javaria Manzoor Shaikh, 2015). These changes affect large areas but are not uniform on a global scale. One area might see more clouds, another fewer and another changed abundance of high altitude clouds. Such changes impact climate in important but complex, ways. Global dimming may also be interfering with the water cycle. Less sunlight upon water (especially the oceans) leads to a diminished evaporation rate. This may be responsible for droughts in some regions. The increase in incident radiation, in combination with a growing greenhouse effect from the continuing emissions of greenhouse gases, may lead to an accelerated rate of global warming. It can also be stated that ‘more aerosols mean more clouds and greater albedo and hence less light at the surface and thus cooling".

3.1. Role of Meteorology in Dispersal of Pollutants and Climate Change

Meteorology, the science of the atmosphere and study of the characteristics of the weather elements and meteorological conditions including certain meteorological parameters like wind speed, wind direction, temperature, atmospheric stability, mixing height, olar radiation, atmospheric pressure, cloud cover etc. Generally, the degree to which air pollutants discharged from various sources, concentrate to a particular area depends on meteorological conditions. So, the knowledge of these meteorological parameters which influence the dispersion mechanisms of air pollutants will give certain results like whether the air pollutants will be diluted into the atmosphere or they just simply tend to concentrate onto the ground level.

Once in the environment, air pollutants may be dispersed via air, water, soil, living organisms and food. The pathways of dispersion vary greatly, depending upon both the emission source and the pollutant concerned. Rates and patterns of dispersion also depend to a large extent upon environmental conditions. Pollution dispersal in the air is affected by many factors:

- Meteorological conditions (especially wind speed, wind direction and atmospheric stability),
- Emission height (e.g. ground level sources such as road traffic or high level sources such as tall chimneys),
- Local and regional geographical features,
- Source (e.g. fixed point, such as a chimney, or a diffuse number of sources such as cars and solvents).

During dispersion pollutants undergo a wide array of changes and transfers. Dilution occurs owing to mixing into the air. Separation or accumulation of pollutants occurs on the basis of physical characteristics of the pollutant. Chemical reactions occur, breaking down the original pollutant or converting it into new compounds. Some pollutants can also be removed from the transporting medium through deposition, for example, by settling out under the effects of gravity, by rainwash or by interception (scavenging) by plants and other obstructions (Gramotnev D and Gramotnev, 2005).

Many pollutants therefore show extremely complex dispersion patterns, especially in environments such as cities and towns where there are a large number of emission sources and major variations in environmental conditions. This complexity means that it is often very difficult to model or measure pollutant patterns and trends and thus to predict levels of human exposure (Cheng et al., 2007; Kovac-Andric et al., 2009; Eludoyin, 2015).

Temporal variations in pollution levels are important. In many cases long-term trends exist, reflecting underlying changes in the rates of emission (e.g. as a result of technical or economic changes, or due to policy intervention). Superimposed upon these there may be annual variations, reflecting year-to-year differences in climate or source activity. Many pollutants also show marked seasonal, weekly and daily patterns, owing to cycles of activity and short-term climatic and other effects. Major, short-term pollution episodes may also occur as a result of sudden, accidental releases. Therefore measurements of exposure will vary according to when, where and for how long air monitoring is carried out.

4. CONCLUSIONS

Study concluded that pollutants of coal based power plant greatly influence cloud formation, the scattering of light and temperature profile. It affects the energy balance of the our planet. In recent years numbers of cyclones, heavy rains/ cloud bursts or draught occurred and vast area of a particular location or many provinces of India and other countries also. Not only human being but also all animals and plants are terribly affected. The frequency of unwanted devastating catasthrophic phenomena are gradually increasing. It could be said beyond doubt that coal power plant is playing a major factor of climate change, global warming as well as acidrain. Meteorological conditions play a crucial role determining the concentrations of the pollutants by affecting both directly and indirectly the emissions, transport, formation, and deposition of air pollutants. Atmospheric stability determines the extent to which vertical motions will mixup the pollution in the upper atmosphere, although a major chunk of pollution occurs at the ground surface.

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