MODELING AIR POLLUTION

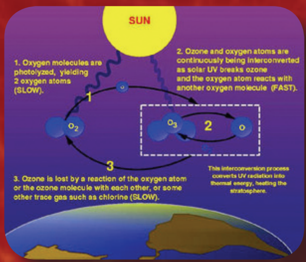
IN THE INDIAN REGION

A REPORT ON SURFACE OZONE CONCENTRATIONS

IMPACT ON HEALTH

IMPACT ON AGRICULTURAL PRODUCTIVITY

CONTENTS



Dr. Moti Mittal (pictured)

Investigators:

M.L. Mittal, Sr. Scientist
Ohio Supercomputer Center,
Columbus, Ohio (USA)

C. Sharma
National Physical Laboratory,
New Delhi (India)

OSC
Innovations in computing, networking, and education

For more information, please contact
Dr. Moti Mittal at moti@osc.edu or visit www.osc.edu/research/pcrm/

Air-pollutant Ozone in the Indian Region

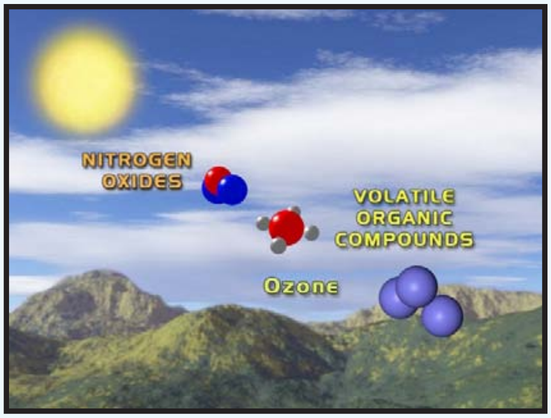
Air pollution in Asian cities has grown and will continue to grow with further industrialization and urbanization. The regions most affected are China and the South Asian Region, which includes the Indian subcontinent (India, Pakistan, Bangladesh, Nepal and Bhutan) as well as Sri Lanka and Maldives. Three fourths of this region's population live in rural areas, and approximately one third of these inhabitants are living in poverty.

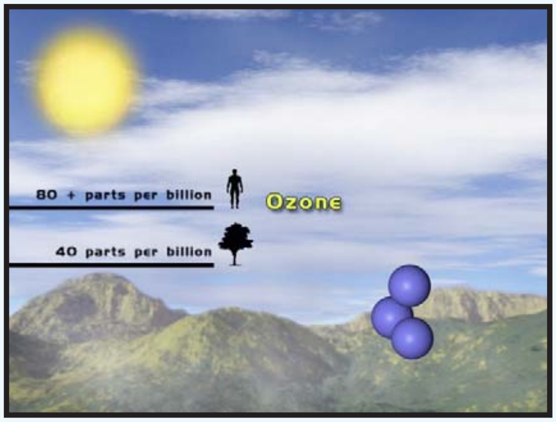
Ozone (O_3) is the most dangerous air pollutant in terms of damage to crop plants and human health. O_3 constitutes of three oxygen atoms and is a light blue gas. It is rare in the atmosphere, but has significant bearing on both physical and biological properties of the Earth's environment. O_3 is a highly reactive and toxic substance that absorbs infrared radiations from the lower atmosphere and thus contributes to the greenhouse effect.

O_3 is found in two regions of the Earth's atmosphere. Most O_3 (about 90 %) resides in the upper atmosphere (approximately 10 kilometers to 50 kilometers), also known as stratosphere. This layer provides protection from exposure to ultraviolet radiation to the Earth's inhabitants. Remaining O_3 in the lower atmosphere is known as tropospheric ozone (also surface ozone).

Tropospheric ozone is formed in the atmosphere from photochemical reactions of volatile organic compounds (VOC) and oxides of nitrogen (NOx) in the presence of sunlight. VOC and NOx are the precursor gases in the ozone formation. O_3 combines with water to form hydroxyl radical OH, which helps in cleansing the atmosphere from toxic gases.

Surface ozone is also known as bad ozone because it oxidizes biologically active molecules. Surface ozone has harmful effects on crop production, forest growth, and human health. Hotspots exist at one or several locations in a city, at places where the conditions are ripe for its formation and/or transportation. The life cycle of surface ozone is typically 5 to 8 days.





O_3 concentration greater than 40 parts per billion by volume (ppbv) persisted over a period of 8 hours, is considered harmful to crop plants. The United States Environmental Protection Agency (USEPA) has estimated that due to ambient O_3 concentrations, the yields of about one-third of US crops decreased by 10%. Similar studies for Europe estimate the yield losses ranging between 5% and 10%. Another study estimates 1 -9 % loss in yields of wheat, rice, and corn and 23-27% loss in the yields of soybeans in China, Japan, and South Korea in 1990 due to the prevailing levels of O_3.

O_3 concentration greater than 80 ppbv is considered harmful to human health. The National Institute of Environmental Health Sciences (USA) reports a 5 to 10% reduction in lung capacity occurred in volunteers engaged in moderate exercise for 6.5 hours at 80 ppbv. O_3 reacts with molecules in the lining of our airways. There is clinical evidence that exposure to ozone and particles, significantly increases the frequency of occurrence of symptoms, increases the

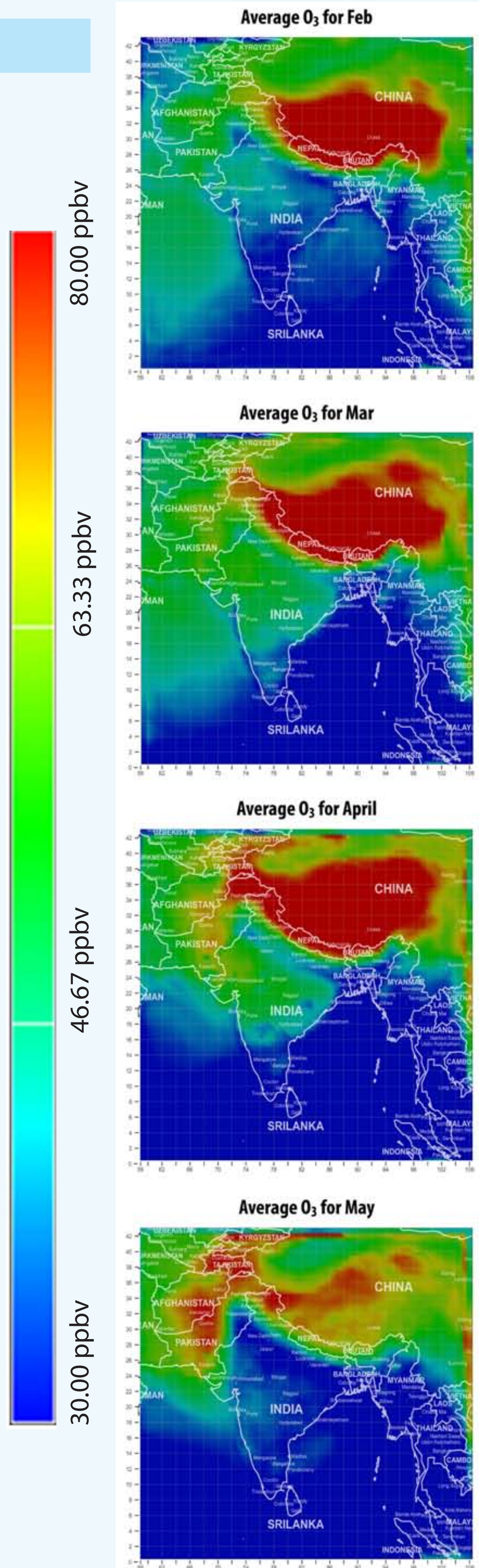
(continued on reverse side)

Air-pollutant Ozone in the Indian Region *(continued)*

requirement for medication and adversely affects lung function. O_3 also triggers asthma and may aggravate other respiratory illnesses such as pneumonia and bronchitis. Children with asthma are especially vulnerable to adverse health effects from high levels of O_3 and children's vulnerability to ozone's ill effects provokes great concern. People spending much of their time outdoors to earn a living, such as, vendors, construction workers, rickshaw pullers, traffic police, cyclists, two-wheeler users and the likes, are most likely to have high risk of exposure to bad ozone

This study, sponsored by USAID/India's Office of Environment, Energy and Enterprise, demonstrates the gridded concentration of ozone and other air pollutants over the Indian region for a four month period. Risk assessment of the pollutants requires a complete understanding of the gridded concentrations of the primary and secondary pollutants, unavailable until now for the Indian sub-continent. Computer model MM5 is used to compute meteorological fields (temperature, pressure, wind velocity etc.) and a chemistry transport model HANK to obtain ozone (O_3) and other chemical species (CO, NO_x etc.). The territory covers the Indian sub-continent from Afghanistan in the west, to parts of Southeast Asian countries in the east, parts of China in the north, and to Sri Lanka in the south. Supercomputer CRAY X1 at The Ohio State University/Ohio Supercomputer Center is used for these simulations.

This is the first study that estimates surface ozone over the entire Indian subcontinent. The Figure on the right panel shows the average daytime O_3 levels during the months of February, March, April and May. O_3 values are averaged over an 8-hour period and for each month. Ozone hot spots (most affected regions in India) are shown on the separate sheets. This study makes it possible to quantify the productivity losses from surface ozone by estimating the losses in agricultural yields and increase in respiratory diseases.



For further information and comments, contact Moti Mittal at moti@osc.edu

Fact Sheet 1 of 10: Hotspots - Ahmedabad

The Ahmedabad region covers the area between 20º N to 25º N and 70º E to 75º E. This region covers parts of Gujarat, Rajasthan, and a small part of Pakistan. Population density in this region is: Gujarat – 258 persons/km^2 and Rajasthan – 165 persons/km^2.

This figure shows the number of days when the average daytime ozone concentration during January 15 to May 29, 2000 (135 days) was higher than 60 ppbv in the region. The whole region is divided into 100 parts of 60 x 60 km area. Blue numbers indicate the number of days that the daytime average ozone concentration was between 80 and 89 ppbv; green refers to the number of days that the daytime average was between 70 and 79 ppbv; and purple expresses the number of days that the daytime average was between 60 and 69 ppbv.

In the space between 22.5º N to 23º N and 72.5º E to 73º E, which includes Ahmedabad (3.6 million population), there were 5 days when the daytime average ozone concentration was between 60-69 ppbv, and 1 day when the concentration reached 70-79 ppbv. In the space between 20.5º N to 21º N and 72º E to 72.5º E, which includes Daman (Gujarat) and the Gulf of Khambat, there were 20 days when the daytime average ozone concentration was between 60-69 ppbv, and 5 days when the concentration reached 70-79 ppbv. Similarly in the region between 24º N to 24.5º N and 73.5º E to 74º E, which includes Udaipur (Rajasthan), there were 6 days when the daytime average ozone concentration was between 60-69 ppbv. Ozone levels are highest in the area between 22º N to 23.5º N and 72.5ºE to 75º E and on the adjacent oceanic areas .

Main crops in this area are wheat, maize, groundnut, and cotton. All these crops are affected by exposure to high levels of ozone. There has not been any scientific analysis or study to determine the exact loss in these crops from exposure to high levels of ozone in this area. Based on the laboratory experiments, a 10-35% loss in wheat, 10 -65% loss in cotton, and 20-40% loss in groundnut crops is expected. Similarly, no studies are available on number of people affected by exposure to high levels of ozone or severity in their respiratory illnesses.

Legend:
(60-69) ppbv (70-79) ppbv (80-89) ppbv (90+) ppbv

Days with Surface Ozone greater than 60 ppbv (Ahmedabad Region)

Latitude \ Longitude	70–70.5	70.5–71	71–71.5	71.5–72	72–72.5	72.5–73	73–73.5	73.5–74	74–74.5	74.5–75
24.5–25	1	1	1	2	3	4	5	7	10	12
24–24.5	1	2	1		3	4	6	6	9	10
23.5–24		1	2		3	7	8	8	8	8 1
23–23.5			4	3	5	7	7 1	8 1	8 1	9 2
22.5–23			3	5	4	5 1	7	9 1	10 1	11 1
22–22.5		2	5	6	5	6	9	9 1	10 1	10 1
21.5–22	2	5	7	8 1	20 1	5	6	11	12	14
21–21.5	1	7	5 1	5 1	17 6	6	8	12	13	12
20.5–21	9 4	9 3 1	11 4 1	11 6	20 5	7	9	12	15	16
20–20.5	7 6 1	9 6 2	15 6 2	14 6 1	17 8	8	13	15	20	25

Ahmadabad

Longitude

Latitude

For further information and comments, contact Moti Mittal at moti@osc.edu

Surface Ozone Concentrations in the Indian Region

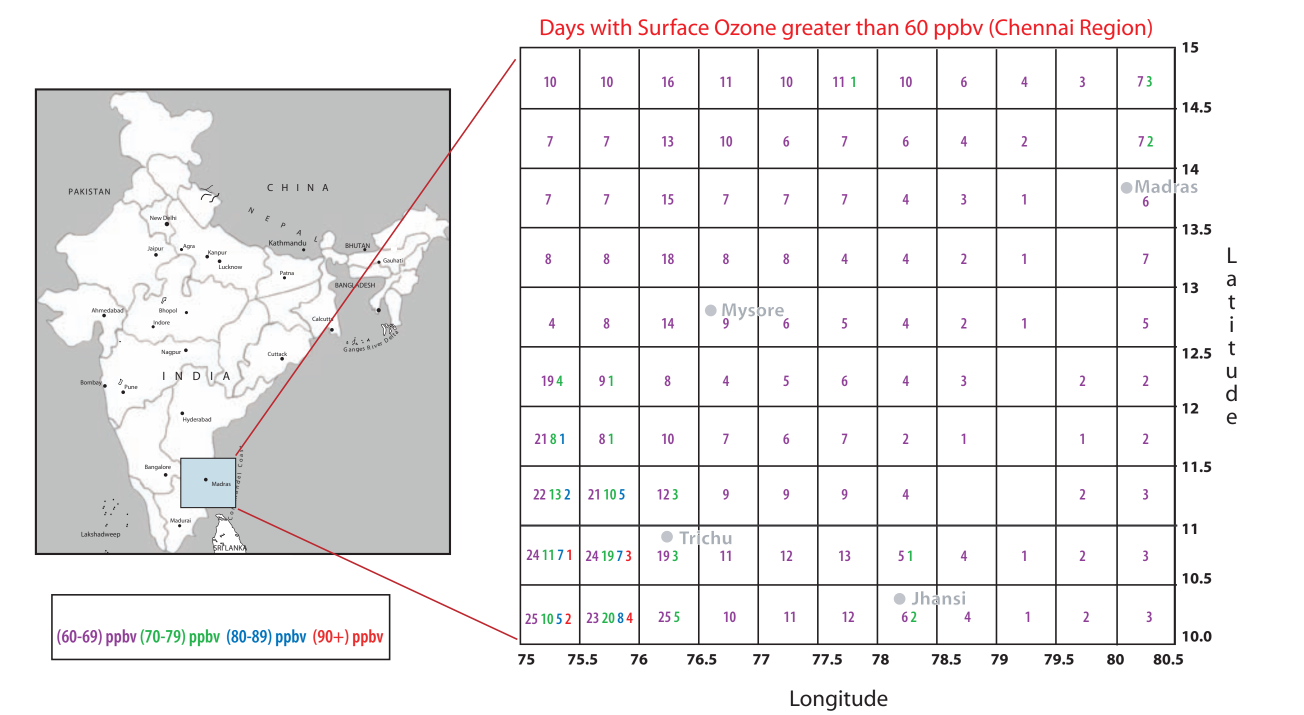
Fact Sheet 2 of 10: Hotspots - Chennai

The Chennai region indicates the area in India between 10ºN to 15ºN and 75º E to 80.5º E. This region covers parts of Tamil Nadu (TN), Karnataka, Kerala and parts of the Arabian Sea and the Bay of Bengal. Population density in this region is TN – 478 persons/km^2, Karnataka – 275 persons/km^2, and Kerala – 819 persons/km^2.

This figure shows the number of days that the average daytime ozone concentration during January 15 to May 29, 2000 (135 days) was higher than 60 ppbv in the region. The whole region is divided into 110 parts of 60 x 60 km area. Blue numbers indicate the number of days when the daytime average was between 80 and 89 ppbv; green refers to the number of days when the daytime average was between 70 and 79 ppbv; and purple expresses the number of days when daytime average was between 60 and 69 ppbv.

The square representing 10.5º N to 11º N and 76º E to 76.5ºE, which includes Trichu in Kerala state (population 2-3 million) shows that the ozone concentration in surface air was between 60-69 ppbv on 19 separate days in the 135 day period, and there were only 3 days when concentration reached 70-79 ppbv. In the area between13.5º N to 14º N and 80º E to 80.5ºE which includes Chennai (Madras) with more than 3 million people had only 6 days during January 16 to May 29, 2000, when ozone levels were greater than 60 ppbv. In the area that includes Mysore in Karnataka, population between 2 -3 million, there were 9 days when ozone concentration was between 6- 69 ppbv during this period. Compared to land ozone levels were higher in the coast of Kerala. In the region between between10.5º N to 11º N and 75.5º E to 76ºE in the Arabian Sea, there were 24 days when the daytime average ozone concentration was between 60-69, 19 days when the concentration reached 70-79; 7 days when ozone levels were between 80-89 ppbv, and also, there were 3 days when the ozone concentration was greater than 90 ppbv

Main crops in this area are rice, maize, ragi, and cotton. All these crops are affected by exposure to high levels of ozone. There has not been any scientific analysis or study to determine the exact loss in these crops from exposure to high levels of ozone in this area. Based on the laboratory experiments, 10 -65% loss in cotton and 20-40% loss in rice crop is expected. Similarly, no studies are available on number of people affected by exposure to high levels of ozone or severity in their respiratory illnesses.



Fact Sheet 3 of 10: Hotspots - Delhi

The Delhi region is spread over all the land between 25° N to 30° N and 75° E to 79.5° E. This region covers parts of Uttar Pradesh (UP), Haryana, and Rajasthan. Population density in this region is Delhi – 9294 persons/km^2, Haryana – 384 persons/km^2, Rajasthan – 165 persons/km^2, and Uttar Pradesh – 472 persons/km^2.

This figure shows the number of days when the average daytime ozone concentration during January 15 to May 29, 2000 (135 days) was higher than 60 ppbv in the region. The whole region is divided into 100 parts of 60 x 60 km area. Blue numbers indicate the number of days that the daytime average ozone concentration was between 80 and 89 ppbv; green refers to the number of days that the daytime average was between 70 and 79 ppbv; and purple expresses the number of days that the daytime average was between 60 and 69 ppbv.

In the space between 28° N to 28.5° N and 77° E to 77.5° E, which includes Delhi (13 million population), there were 17 days when the daytime average ozone concentration was between 60-69 ppbv, and there were 8 days when the concentration reached 70-79 ppbv. In the space between 27° N to 27.5° N and 75.5° E to 76° E, which includes Jaipur (more than 3 million population), there were 41 days when the daytime average ozone concentration was between 60-69 ppbv, and there were 6 days when the concentration reached 70-79 ppbv; also, there was 1 day when the ozone concentration reached 80-89 ppbv. Similarly in the region between 27° N to 27.5° N and 78° E to 78.5° E, which includes Agra (between 3 and 4 million population), there were 31 days when the daytime average ozone concentration was between 60-69 ppbv, and there were 10 days when the concentration reached 70-79 ppbv; also, there was 1 day when the ozone concentration reached 80-89 ppbv. Ozone levels are highest in the area between 25° N to 28° N and 77.5°E to 80° E (UP). In this area there are days when ozone levels are above 80 ppbv, and this is considered harmful for human health also.

Main crops in this area are wheat, rice, maize, different kinds of beans, and sugar cane. All these crops are affected by exposure to high levels of ozone. There has not been any scientific analysis or study to determine the exact loss in these crops from exposure to levels of ozone in this area. Based on the laboratory experiments, a 10-30% loss in wheat, 10 -35% loss in beans, and 20-40% loss in rice crop is expected. Similarly, no studies are available on number of people affected by exposure to high levels of ozone or severity in their respiratory illnesses.

Legend:
(60-69) ppbv (70-79) ppbv (80-89) ppbv

Days with Surface Ozone greater than 60 ppbv (Delhi Region)

Latitude \ Longitude	75–75.5	75.5–76	76–76.5	76.5–77	77–77.5	77.5–78	78–78.5	78.5–79	79–79.5	79.5–80
29.5–30	25 1	18	18	13	13	13	23	36 3	60 4	60 5
29–29.5	26 4	23 2	20 1	11 1 11	10 1 1	13	10	12	18	15
28.5–29	37 5	37 3	28 3	18 3	15 3	12 2	12 2	10	11	10
28–28.5	45 5	39 5	47 2	25 3	17 8	12 5 1	12 6 1	13 4	12 1	15 2
27.5–28	40 10 1	46 5 1	41 9	36 5	33 6 1	23 10	16 6 2	13 7 1	17 3	18 4
27–27.5	36 12 1	41 6 1	45 4 1	41 10	47 14 1	47 7 1	31 10 1	24 10 1	19 5 1	20 5 2
26.5–27	29 11 1	32 12 1	41 8 2	49 11 1	49 10 2	49 12	42 14	40 12	36 10	32 12
26–26.5	32 8	31 14	37 14	48 10	53 9 3	53 11 2	49 12 2	49 14 1	51 10 1	60 12 2
25.5–26	35 5	38 7	41 9	46 9	51 11	53 13 1	62 10	56 14 1	56 11 2	56 12 3
25–25.5	27 2	39 8	55 9	41 12	54 9	61 8 1	63 12 1	70 16 2	67 20 3	65 25 2

Bhadra, New Delhi, Moradabad, Jaipur, Mathura, Agra, Farrukhabad, Bhind, Jhansi

Longitude

Latitude

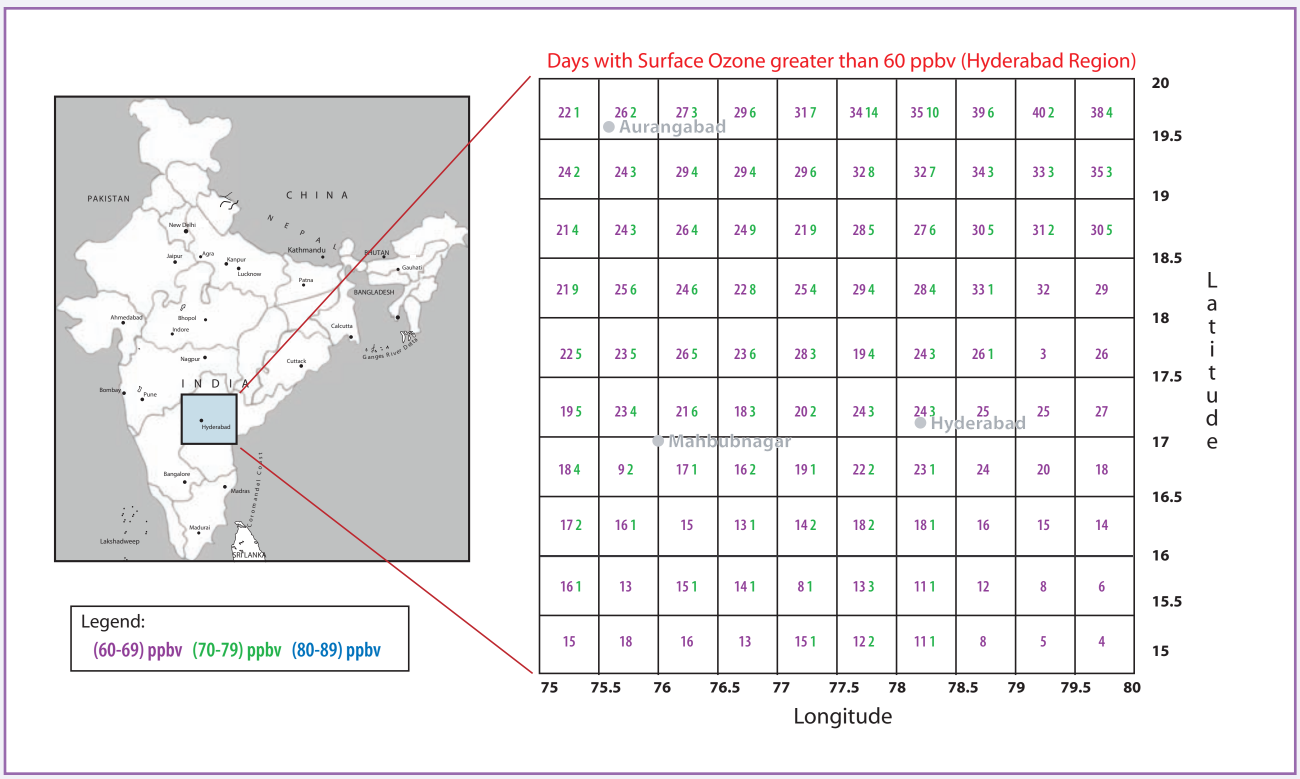
Fact Sheet 4 of 10: Hotspots - Hyderabad

The Hyderabad region covers the land between 15º N to 20º N and 75º E to 80º E. This region covers parts of Andhra Pradesh (AP), Karnataka, and Maharastra. Population density in this region is AP – 275 persons/km^2, Karnataka – 275 persons/km^2, and Maharastra – 314 persons/km^2.

This figure shows the number of days when the average daytime ozone concentration during January 15 to May 29, 2000 (135 days) was higher than 60 ppbv in the region. The whole region is divided into 100 parts of 60 x 60 km area. Blue numbers indicate the number of days that the daytime average ozone concentration was between 80 and 89 ppbv; green refers to the number of days that the daytime average was between 70 and 79 ppbv; and purple expresses the number of days that the daytime average was between 60 and 69 ppbv.

In the space between 17º N to 17.5º N and 78º E to 78.5º E, which includes Hyderabad (3.8 million population), there were 24 days when the daytime average ozone concentration was between 60-69 ppbv, and there were 3 days when the concentration reached 70-79 ppbv. In the space between 16.5º N to 17º N and 75.º E to 75.5º E, which includes Bijapur (Karnataka), there were 18 days when the daytime average ozone concentration was between 60-69 ppbv and 4 days when the concentration reached 70-79 ppbv. Similarly in the region between 19.5º N to 20º N and 78º E to 78.5º E, area near Chandrapur Thermal Power Station in Maharastra, there were 35 days when the daytime average ozone concentration was between 60-69 ppbv, and 10 days when the concentration reached 70-79 ppbv. Ozone levels are highest in the area between 17.5º N to 20º N and 77.5ºE to 80º E.

Main crops in this area are wheat, rice, and cotton. All these crops are affected by exposure to high levels of ozone. There has not been any scientific analysis or study to determine the exact loss in these crops from exposure to levels of ozone in this area. Based on the laboratory experiments, a 10-35% loss in wheat, 10-65% loss in cotton, and 20-40% loss in rice crop is expected. Similarly, no studies are available on number of people affected by exposure to high levels of ozone or severity in their respiratory illnesses.



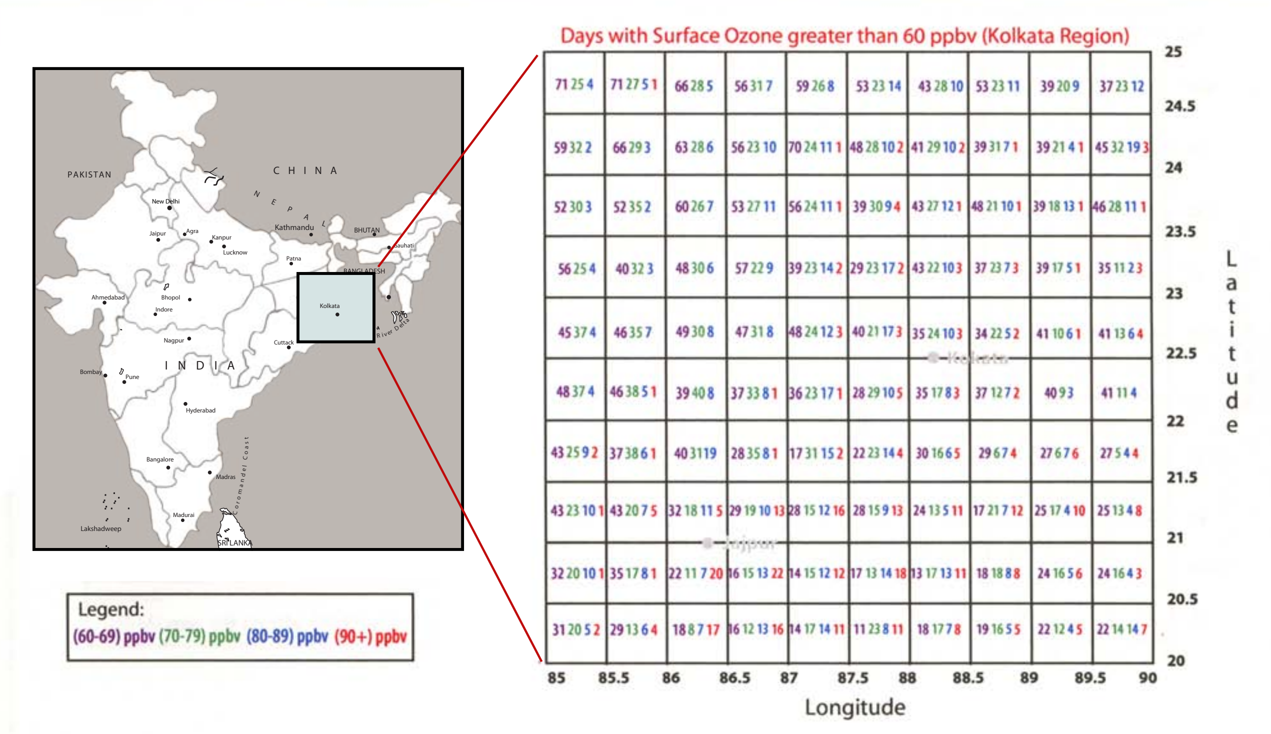
Fact Sheet 5 of 10: Hotspots - Kolkata

The Kolkata region is spread over all the land between 20° N to 25° N and 85° E to 90° E. This region covers parts of West Bengal (WB), Orissa, and Bangladesh. Population density in this region is: WB – 904 persons/km^2, Orissa - 236 persons/km^2, and Bangladesh – 1024 persons/km^2.

This figure shows the number of days when the average daytime ozone concentration during January 15 to May 29, 2000 (135 days) was higher than 60 ppbv in the region. The whole region is divided into 100 parts of 60 x 60 km area. Blue numbers indicate the number of days that the daytime average ozone concentration was between 80 and 89 ppbv; Green refers to the number of days that the daytime average was between 70 and 79 ppbv; and purple expresses the number of days that the daytime average was between 60 and 69 ppbv.

Thus, in the space between 22° N to 22.5° N and 88° E to 88.5° E, which includes Kolkata (about 13 million population), there were 35 days when the daytime average ozone concentration was between 60-69 ppbv, there were 17 days when the concentration reached 70-79 ppbv, 8 days when it was between 80-89 ppbv, and there were 3 days when the concentration reached above 90 ppbv. In the space between 22° N to 20.5° N and 85.5° E to 86° E, which includes Bhubaneswar (between 1 and 2 million population), there were 29 days when the daytime average ozone concentration was between 60-69 ppbv, there were 13 days when the concentration reached 70-79 ppbv; and 6 days when it was between 80 and 89 ppbv, also, there were 4 days when the ozone concentration reached above 90 ppbv. Similarly in the region between 23.5° N to 24° N and 88.5° E to 89° E, which includes Rajshahi (Bangladesh), there were 48 days when the daytime average ozone concentration was between 60-69 ppbv, there were 21 days when the concentration reached 70-79 ppbv; 10 days when it was between 80-89 ppbv, also, there was 1 day when the ozone concentration reached above 90 ppbv. Ozone concentration reached more than 90 ppbv for 16 times in the area between 86°E to 87° E and 20° N to 21° N.

Main crops in this area are wheat, rice, jute, and sugar cane. All these crops are affected by exposure to high levels of ozone. There has not been any scientific analysis or study to determine the exact loss in these crops from exposure to high levels of ozone in this area. Effect of ozone on the yield of jute and sugarcane has not been studied. Based on the laboratory experiments, a 10-35% loss in wheat and 20-40% loss in rice crop is expected. Similarly, no studies are available on number of people affected by exposure to high levels of ozone or severity in their respiratory illnesses.



Surface Ozone Concentrations in the Indian Region

Fact Sheet 6 of 10: Hotspots - Madhya Pradesh

The Madhya Pradesh region covers the area between 20° N to 25° N and 75° E to 80° E. This region includes parts of Madhya Pradesh (MP), and Maharastra. Population density in this region is: MP –196 persons/km^2 and Maharastra – 314 persons/km^2.

This figure shows the number of days when the average daytime ozone concentration during January 15 to May 29, 2000 (135 days) was higher than 60 ppbv in the region. The whole region is divided into 100 parts of 60 x 60 km area. Blue numbers indicate the number of days that the daytime average ozone concentration was between 80 and 89 ppbv; green refers to the number of days that the daytime average was between 70 and 79 ppbv; and purple expresses the number of days that the daytime average was between 60 and 69 ppbv.

In the space between 23° N to 23.5° N and 77° E to 77.5° E, which includes Bhopal (1.8 million population), there were 30 days when the daytime average ozone concentration was between 60-69 ppbv, and 1 day, the concentration was in the range of 70-79 ppbv. In the space between 20° N to 20.5° N and 78° E to 78.5° E, which includes Wardha (Maharastra), there were 33 days when the daytime average ozone concentration was between 60-69 ppbv, and there were 16 days when the concentration reached 70-79 ppbv; also, there was 1 day when the ozone concentration reached 80-89 ppbv. Similarly in the region between 20° N to 20.5° N and 75.5° E to 76° E, which includes Ajanta (Maharastra), there were 22 days when the daytime average ozone concentration was between 60-69 ppbv and 2 days when the concentration reached 70-79 ppbv. Ozone concentrations are higher in the region between 77.5°E to 80° E.

Main crops in this area are wheat, rice, maize, jowar, cotton, different kinds of beans, and sugar cane. All these crops are affected by exposure to high levels of ozone. There has not been any scientific analysis or study to determine the exact loss in these crops from exposure tohigh levels of ozone in this area. Based on the laboratory experiments, a 10-35% loss in wheat, 10 -35% loss in beans, 10–65% loss in cotton, and 20-40% loss in rice crop is expected. Similarly, no studies are available on number of people affected by exposure to high levels of ozone or severity in their respiratory illnesses.

Legend:
(60-69) ppbv (70-79) ppbv (80-89) ppbv

Days with Surface Ozone greater than 60 ppbv (MP Region)

Latitude \ Longitude	75–75.5	75.5–76	76–76.5	76.5–77	77–77.5	77.5–78	78–78.5	78.5–79	79–79.5	79.5–80
24.5–25	13	16	25 1	28	30 3	35 7	36 5	43 6	48 8	50 9
24–24.5	10	14	21	23 1	26 2	32 2	32 6	40 6	46 5	45 6
23.5–24	13 2	23 2	23 4	33 4	31 2	31 3	37 3	38 5	42 5	44 5
23–23.5	22 1	26 2 (Indore)	27 5	29 2	30 1 (Bhopol)	30 4	33 4 (Sagar)	40 3	40 4	43 6
22.5–23	16 1	22 1	24 2	33	29 2	28 4	35 3	36 3	41 3	42 4
22–22.5	14 1	20 4	27 2	31 1	31 4	34 4	34 4	34 4	34 4	40 7
21.5–22	15	23 2	27 3	29 4	34 4	33 7	32 7	33 6	35 6	38 6
21–21.5	17 1	23 1	24 3	29 2	31 4	32 7	33 9	36 7 (Nagpur)	38 7	40 7
20.5–21	20	18 2	25 3	28 4	22 4	30 8 1	34 12 1	28 7	44 5	48 6
20–20.5	22	28 2	28 2	28 4	31 5	31 9 1	33 16 1	40 6	44 10	45 11

Longitude: 75, 75.5, 76, 76.5, 77, 77.5, 78, 78.5, 79, 79.5, 80

Latitude: 25, 24.5, 24, 23.5, 23, 22.5, 22, 21.5, 21, 20.5, 20

Fact Sheet 7 of 10: Hotspots - Mumbai

The Mumbai region rests in the area between 15º N to 20º N and 70º E to 74.5º E. This region covers parts of Maharastra, Goa, and the Arabian Sea. Population density in this region is Maharastra – 314 persons/km^2, Goa – 363 persons/km^2.

This figure shows the number of days when the average daytime ozone concentration during January 15 to May 29, 2000 (135 days) was higher than 60 ppbv in the region. The whole region is divided into 100 parts of 60 x 60 km area. Blue numbers indicate the number of days that the daytime average ozone concentration was between 80 and 89 ppbv; Green refers to the number of days that the daytime average was between 70 and 79 ppbv; and purple expresses the number of days that the daytime average was between 60 and 69 ppbv.

In the area between 18.5º N to 19º N and 72.5º E to 73º E, which includes Mumbai (more than 18 million population), there were 16 days when the daytime average ozone concentration was between 60-69 ppbv. In the space between 18º N to 18.5º N and 73.5º E to 74º E, which includes Pune (more than 4.5 million population), there were 19 days when the daytime average ozone concentration was between 60-69 ppbv and 6 days when the concentration reached 70-79 ppbv. Ozone concentrations are higher over the water of the Arabian Sea than over the adjoining land. In the area between 18º N to 18.5º N and 72º E to 72.5º E, near the Murud town, there were 17 days when the daytime average ozone concentration was between 60-69 ppbv, 14 days when the concentration reached 70-79 ppbv; and 4 days when it was between 80-89 ppbv, also, there were 2 days when the ozone concentration reached 90+ ppbv.

Main crops in this area are wheat, rice, cotton, and sugar cane. All these crops are affected by exposure high levels of ozone. There has not been any scientific analysis or study to determine the exact loss in these crops from exposure to high levels of ozone in this area. Based on the laboratory experiments, a 10-35% loss in wheat, 10-65% loss in cotton, and 20-40% loss in rice crop is expected. No studies are available on the effects of exposure to high ozone concentrations on sea food. Similarly, no studies are available on number of people affected by exposure to high levels of ozone or severity in their respiratory illnesses.

Legend:
(60-69) ppbv (70-79) ppbv (80-89) ppbv (90+) ppbv

Days with Surface Ozone greater than 60 ppbv (Mumbai Region)

13 4 2	15 4 2	15 5 2	11 6 2	14 10	11	19	20	22	23	20
16 3 3	16 4 3	13 5 3	15 5 3	15 12	16	19	21	23 2	24 2	19.5
17 4 3	17 3 3	15 4 4	15 10 3	18 12 3	18	20	22 4	19 5	20 5	19
16 3 3	16 3 4	12 7 4	12 8 7	17 14 4 2	14 4	17 5	19 6	22 5	25 6	18.5
16 3 3	15 6 3	13 9 5	14 10 2 2	17 14 6 2	24 16 3 2	14 5	19 5	23 4	23 5	18
14 3 4	12 9 4	14 8 8	16 13 4 3	16 20 5	26 16 8 1	15 3	19 6	21 4	22 4	17.5
13 5 3	13 9 4	17 11 5	20 12 5 2	21 19 4 2	27 13 8 1	13 5	15 7	16 5	20 5	17
13 8 3	18 12 2	17 15 3	22 18 3 1	25 15 7	27 14 9	17 3	16 5	15 3	15 5	16.5
14 3 2	21 9 3	22 16 3	19 17 5	20 17 5	25 20 3	34 11 3	18 2	13 1	14 2	16
11 10 2	16 10 4	19 13 3	22 15 3	24 17 3	22 19 3	28 17 1 1	12	15	18	15.5

15

70 70.5 71 71.5 72 72.5 73 73.5 74 74.5 75

Longitude

Latitude

Mumbai
Pune
Kolhapur

Fact Sheet 8 of 10: Hotspots - Orissa

The Orissa region is somewhat larger, spanning 15º N to 20º N and 80º E to 85º E. This region covers parts of Andhra Pradesh (AP), Orissa, and the Bay of Bengal. Population density in this region is AP – 275 persons/km^2 and Orissa – 236 persons/km^2.

This figure shows the number of days when the average daytime ozone concentration during January 15 to May 29, 2000 (135 days) was higher than 60 ppbv in the region. The whole region is divided into 100 parts of 60 x 60 km area. Blue numbers indicate the number of days that the daytime average ozone concentration was between 80 and 89 ppbv; green refers to the number of days that the daytime average was between 70 and 79 ppbv; and purple expresses the number of days that the daytime average was between 60 and 69 ppbv.

In the space between 19º N to 19.5º N and 83.5º E to 84º E, which includes Ramagiri-Udayagiri (Orissa), there were 22 days when the daytime average ozone concentration was between 60-69 ppbv, 14 days when the concentration reached 70-79 ppbv, also, there was 1 day when the ozone concentration reached 80-89 ppbv. In the space between 17.5º N to 18º N and 83º E to 83.5º E, which includes Vishakhapatnam (AP), there were 14 days when the daytime average ozone concentration was between 60-69 ppbv, 12 days when the concentration reached 70-79 ppbv; also, there were 5 days when the ozone concentration reached 80-89 ppbv. Similarly in the region between 17º N to 17.5º N and 81.5º E to 82º E, which includes Rajahumundry (AP), there were 14 days when the daytime average ozone concentration was between 60-69 ppbv, 2 days when the concentration reached 70-79 ppbv; also, there was 1 day when the ozone concentration reached 80-89 ppbv

In the area between 18º N to 18.5º N and 84º E to 84.5º E, which covers water of the Bay of Bengal, ozone concentration reached above the 90 ppbv mark a total of 3 times over the 135 day period, and 7 times in the 80-89 ppbv range. This area also had ozone levels in the 70-79 ppbv range for 11 days, and the 60-69 ppbv range for 21 days. The area within Orrisa with the highest prevalence of hotspots in the 135 day time period fell between 83.5º E to 85º E and 17.5º N to 18.5º N..

Main crops in this area are wheat, rice, ragi, and jowar. All these crops are affected by exposure to high levels of ozone. There has not been any scientific analysis or study to determine the exact loss in these crops from exposure to high levels of ozone in this area. Based on the laboratory experiments, a 10-35% loss in wheat and 20-40% loss in rice crop is expected. Similarly, no studies are available on number of people affected by exposure to high levels of ozone or severity in their respiratory illnesses.

Legend:
(60-69) ppbv (70-79) ppbv (80-89) ppbv (90+) ppbv

Days with Surface Ozone greater than 60 ppbv (Orissa Region)

20–19.5	36 1	37 3	36 4	37 9	34 15	34 14 1	34 14 1	30 14 1 1	27 16 1	36 13 1
19.5–19	33 1	34 1	34 4	35 5	32 9 1	33 8 1	30 9 1	22 14 1	24 11 4	17 13 2
19–18.5	36	35	37 1	31 6	31 7 1	31 4 1	29 9 1	23 9 3	17 10 1	13 10 12 12
18.5–18	31	32	30 3	30 5	30 4 1	26 6 1	25 4 1	15 6 1	21 11 7 3	14 11 11 3
18–17.5	25	20 2	23 3	23 3 1	23 6	18 5	14 12 5	16 10 6	14 14 3 3	9 16 8 1
17.5–17	18	15 1	17 2	14 2 1	14 6	15 10 2	18 8 6	16 9 6	16 10 6	13 12 6
17–16.5	11	8 1	10 1	7 1	7	12 9 3	11 11 4	15 7 4	19 7 3	18 8 2
16.5–16	3	2 1	2 1	10 6 1	15 6	17 7 2	15 9 2	19 4 2	19 4 2	13 6 1
16–15.5	3	12 1 1	11 2 1	15 5 1	14 7	15 5 1	15 4 1	14 3 1	14 2 1	10 4
15.5–15	2	10 2	9 3 1	12 4	16 2	17 2	14 1	10 1 1	8 2	8 3

Map labels in grid: Jagdalpur, Kakinada, Machilipatnam

Latitude: 20, 19.5, 19, 18.5, 18, 17.5, 17, 16.5, 16, 15.5, 15

Longitude: 80, 80.5, 81, 81.5, 82, 82.5, 83, 83.5, 84, 84.5, 85

Fact Sheet 9 of 10: Hotspots - Punjab

The Punjab region is spread over all the land between 30º N to 35º N and 75º E to 80º E. This region covers parts of Punjab, Himachal Pradesh (HP), Jammu and Kashmir, and small parts of China. Population density in this region is Punjab – 482 persons/km^2, Himachal Pradesh – 109 persons/km^2, and Jammu and Kashmir – 99 persons/km^2.

This figure shows the number of days when the average daytime ozone concentration during January 15 to May 29, 2000 (135 days) was higher than 60 ppbv in the region. The whole region is divided into 100 parts of 60 x 60 km area. Blue numbers indicate the number of days that the daytime average ozone concentration was between 80 and 89 ppbv; green refers to the number of days that the daytime average was between 70 and 79 ppbv; and purple expresses the number of days that the daytime average was between 60 and 69 ppbv.

In the space between 30.5º N to 31º N and 75.5º E to 76º E, which includes Patiala (Punjab), there were just 5 days when the daytime average ozone concentration was between 60-69 ppbv, otherwise ozone concentration was always below 60 ppbv during this period. In the space between 32.5º N to 33º N and 77º E to 77.5º E, near Dharmsala (Himachal Pradesh), there were 38 days when the daytime average ozone concentration was between 60-69 ppbv, and there were 5 days when the concentration reached 70-79 ppbv. Similarly in the region between 34.5º N to 35º N and 78º E to 78.5º E, near Leh (Jammu and Kashmir), there were 38 days when the daytime average ozone concentration was between 60-69 ppbv, and there were 12 days when the concentration reached 70-79 ppbv. Ozone levels are highest in the area between 33º N to 35º N and 77.5ºE to 80º E. In this area there are days when ozone levels are above 80 ppbv, and this is considered harmful for human health also.

Main crops in this area are wheat, rice, maize, and sugar cane. All these crops are affected by exposure to high levels of ozone. There has not been any scientific analysis or study to determine the exact loss in these crops from exposure to high levels of ozone in this area. Based on the laboratory experiments, a 10-30% loss in wheat, 10 -35% loss in beans, and 20-40% loss in rice crop is expected. Similarly, no studies are available on number of people affected by exposure to high levels of ozone or severity in their respiratory illnesses.

Legend: (60-69) ppbv (70-79) ppbv (80-89) ppbv

Days with Surface Ozone greater than 60 ppbv (Punjab Region)

Latitude \ Longitude	75–75.5	75.5–76	76–76.5	76.5–77	77–77.5	77.5–78	78–78.5	78.5–79	79–79.5	79.5–80
34.5–35	16 1	21 1	26 1	31 2	40 3	42 8	28 12	39 19	41 17 2	45 20 4
34–34.5	11 1	19 1	27 1	31 2	37 4	36 9	41 12	41 13 2	39 18 2	43 15 3
33.5–34	4 1	12 1	23 1	32 2	44 5	44 10	41 12 1	38 16 2	36 20 1	40 20 2
33–33.5	5	7	20 1	32 2	40 6	39 16	38 19	34 22	31 22	35 25 1
32.5–33	6	13 1	11	24 1	38 5	36 13	34 19	31 21	31 19	32 22 1
32–32.5	4	7	8	16	30 3	35 6	36 12	33 14	31 15	34 20 2
31.5–32	4	6	4	11	25	31 3	30 6	37 6	33 14	35 15 1
31–31.5	6	5	5	5	18	22 1	28 4	31 6	32 6 3	33 8 4
30.5–31	10	5	5	8	8	13	16	23 2	31 4	35 5
30–30.5	14	8	5	7	9	7	9	18	22 3	25 3

Leh, Dharmsala, Simla

Longitude

Latitude

Fact Sheet 10 of 10: Hotspots - Varanasi

The Varanasi region is spread over all the land area between 25º N to 30º N and 80º E to 85º E. This region covers parts of Uttar Pradesh (UP), Nepal, and part of China's Himalayan region. Population density in this region is: Uttar Pradesh – 472 persons/km^2, Nepal - 402 persons/km^2, and China - 140 persons/km^2.

This figure shows the number of days that the average daytime ozone concentration during January 15 to May 29, 2000 (135 days) was higher than 60 ppbv in the region. The whole region is divided into 100 parts of 60 x 60 km area. Blue numbers indicate the number of days that the daytime average was between 80 and 89 ppbv; green refers to the number of days that the daytime average was between 70 and 79 ppbv; and purple expresses the number of days where daytime average was between 60 and 69 ppbv.

In the space between 25º N to 25.5º N and 82.5º E to 83º E, which includes Varanasi (between 3 and 4 million population), there were 55 days when the daytime average ozone concentration was between 60-69, there were 30 days when the concentration reached 70-79, and 1 day when the concentration was between 80-89 ppbv. In the space between 26º N to 26.5º N and 80º E to 80.5º E, which includes Kanpur (more than 4 million population), there were 57 days when the daytime average ozone concentration was between 60-69, 14 days when the concentration reached 70-79; also, there was 1 day when the ozone concentration reached 80-89 ppbv. Similarly in the region between 28.5º N to 29º N and 84º E to 84.5º E, which is part of Nepal (23.1 million population), there were 43 days when the daytime average ozone concentration was between 60-69, and there were 32 days when the concentration reached 70-79; also, there were 5 days when the ozone concentration reached 80-89 ppbv, and there was 1 day when ozone levels were above 90 ppbv. Ozone levels are highest in the area between 28.5º N to 30º N and 82.5ºE to 85º E (Nepal and part of China).

Main crops in this area are wheat, rice, maize, potato, and sugar cane. All these crops are affected by exposure to high levels of ozone. There has not been any scientific analysis or study to determine the exact loss in these crops from exposure to high levels of ozone in this area. Based on the laboratory experiments, a 10-35% loss in wheat, 5 -10% loss in potato, and 20-40% loss in rice crop is expected. Similarly, no studies are available on number of people affected by exposure to high levels of ozone or severity in their respiratory illnesses.

Legend:
(60-69) ppbv (70-79) ppbv (80-89) ppbv (90+) ppbv

Days with Surface Ozone greater than 60 ppbv (Varanasi Region)

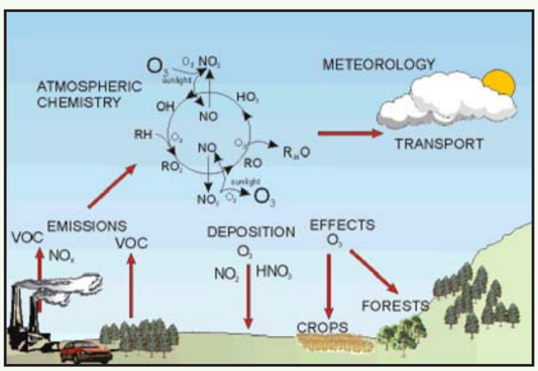
Latitude \ Longitude	80–80.5	80.5–81	81–81.5	81.5–82	82–82.5	82.5–83	83–83.5	83.5–84	84–84.5	84.5–85
29.5–30	17	28 2	40 3	53 3 1	3	4	5	7	10	12
29–29.5	11	11	17	33 1	3	4	6	6	9	10
28.5–29	11 1	9	7	15	3	7	8	8	8	8 1
28–28.5	17 3	16 1	12	14	5	7	7 1	8 1	8 1	9 2
27.5–28	22 5 1	22 4	20 1	15	4	5 1	7	9 1	10 1	11 1
27–27.5	36 14 1	36 13	33 7	22 3	5	6	9	9 1	10 1	10 1
26.5–27	48 11 2	49 14	41 16	39 6	20 1	5	6	11	12	14
26–26.5	57 14 1	56 12 2	57 15 2	39 25	17 6	6	8	12	13	12
25.5–26	53 12 2	51 20 2	48 25 1	49 29 1	20 5	7	9	12	15	16
25–25.5	47 17 1	45 18 1	48 20 1	50 27 1	17 8	8	13	15	20	25

Longitude: 80, 80.5, 81, 81.5, 82, 82.5, 83, 83.5, 84, 84.5, 85
Latitude: 25, 25.5, 26, 26.5, 27, 27.5, 28, 28.5, 29, 29.5, 30

Summary

Ozone is a pale blue gas with a strong odor. Tropospheric ozone is toxic to all living things that breathe it or come in contact with it, including human beings and plants. At the same time, tropospheric ozone is like an intercontinental traveler, crossing geographic and political boundaries. Where ozone forms and where it travels have become key concerns for health and economic policy-making.

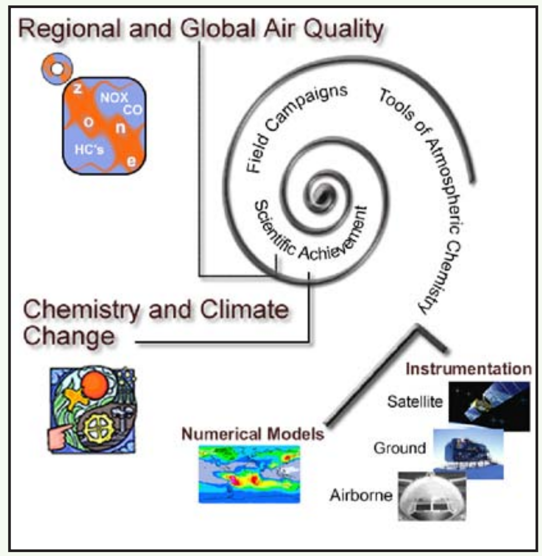
Understanding the chemical and physical dynamics of ozone and other trace gases is becoming increasingly urgent as world population rises and economic activity increases among developing nations. The lifetime of ozone precursors in the troposphere is long enough to produce ozone hundreds or even thousands of miles away. This ozone production occurs before further chemical reactions transform ozone into oxygen and other species. It is imperative that governments adopt a holistic perspective when designing a strategy to meet regional and local ambient air quality objectives.



Chemical and physical dynamics of ozone

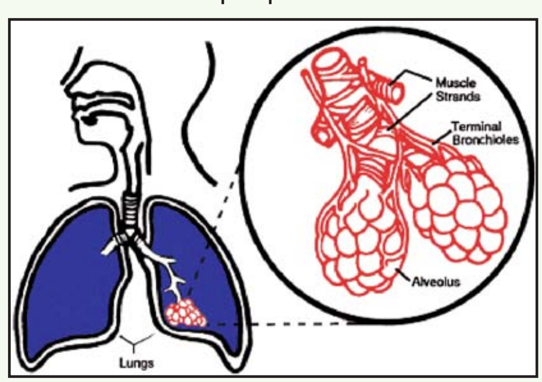
The U.S. Environmental Protection Agency (EPA) has designated ozone as one of six "criteria air pollutants". In India, recent measurement studies have shown that surface ozone levels are at critical levels and rising.

An integral part of studying complex atmosphere is using computer models where chemistry and dynamics are simulated by mathematical equations. Present research, based on computer models as described in the coversheet, has enabled us to estimate the prevailing surface ozone levels over the entire Indian region. Ozone measurements have been reported at a few sites in India, but these are mostly expedition type, except for the continuous measurements at the National Physical Laboratory, New Delhi, Indian Meteorological Department, and the Physical Research Laboratory, Ahmedabad. A systematic detailed study is needed to evaluate the effects of exposure to surface ozone on human health and crop yields.



Atmospheric Modeling

Ozone damage to human beings occurs without any noticeable signs. Otherwise healthy people can expect to experience acute but reversible effects from exposure to high levels of ozone. A database needs to be created for people with respiratory illnesses, and then the database should correlate these illnesses with the ozone levels in the area where these people live and work.



Health effects of ozone

Summary *(continued)*

A National Crop Loss Assessment Network (NCLAN) research study in India should be initiated to assess the losses from increased levels of surface ozone. Agricultural researchers in India need to study ozone's effects on major crops which include wheat, rice, cotton, soybeans, and sugarcane that are important to India's agricultural economy. Crops' exposure to ozone appears in soil and plants; overexposure specifically effects plant growth and soil fertility. Most farmers are unaware that increasing ozone concentrations can reduce their crop yields.

Leaf effected by ozone

Recommendations

- *Increase public awareness of the harmful effects of surface ozone*
- *Estimate daily surface ozone concentrations throughout the Indian region by modeling*
- *Make continuous measurements of ozone concentrations in metro-cities of India for assessing human exposure and calibration*
- *Assess losses in crop yields from exposure to ozone*
- *Assess human health vulnerability from exposure to ozone*
- *Publicize daily predictions and measured levels of surface ozone in cities and towns, particularly where ozone will be at critical levels (Ozone warning)*
- *Evolve mitigation and adaptation strategies*

For further information and comments, contact Moti Mittal at moti@osc.edu