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ATMO 170A1 Online

Air Pollution Primary & Secondary Pollutants Particulate Matter Photochemical Smog Pollution Weather

Hazy skies over Tucson

What is Air Pollution?

AMS Glossary of Meteorology

air pollution—The presence of substances in the atmosphere, particularly those that **do not occur naturally**.

These substances are generally contaminants that substantially alter or degrade the quality of the atmosphere.

The term is often used to identify undesirable substances produced by human activity, i.e. <u>anthropogenic</u> air pollution.

Air pollution usually designates the collection of substances that adversely affects human health, animals, and plants; deteriorates structures; interferes with commerce; or interferes with the enjoyment of life.

Beijing on the day after a rainy day and on a sunny but smoggy day



Economic growth—but at what environmental cost?

Some of the slides that follow are courtesy of Prof. C. Castro, ATMO

Brief History: London Death Fog



Some of the worst events in the last two centuries occurred in London. 1952 Event resulted in 4000 deaths!



Key ingredients: calm winds, fog, smoke particles from coal burning.

Motivated parliament to pass a Clean Air Act in 1956.

Air pollution from burning of coal



Much of the air pollution in the eastern part of the United States was *and is still* from burning coal.

Many of the coal plants today are located on or near the Ohio River Why might that be?

Other places with a similar story: Rhine River Valley in Germany Northern China (Manchuria)

The U.S. passed its air pollution control act in 1955.

But this act left out one VERY BIG thing!

SMOG SMoke + fOG

Pollution from vehicle transportation sources was a rapidly growing problem

It was a new kind of pollution, different from the traditional smog of London or U.S. eastern cities.

And the worst place for it in the U.S. was (and still is) Los Angeles

By Ozone

#1: Los Angeles-Long Beach, CA #2: Visalia-Porterville-Hanford, CA #3: Bakersfield, CA #4: Fresno-Madera, CA #5: Sacramento-Roseville, CA #6: Houston-The Woodlands, TX #7: Modesto-Merced, CA #8: Washington-Baltimore-Arlington, DC-MD-VA-WV-PA #8: Dallas-Fort Worth, TX-OK #10: Las Vegas-Henderson, NV-AZ 11: Phoenix-Mesa-Scottsdale, AZ #12: New York-Newark, INT-INJ-CT-PA #13: St. Louis-St. Charles-Farmington, MO-IL #14: Tulsa-Muskogee-Bartlesville, OK #15: Cincinnati-Wilmington-Maysville, OH-KY-IN #16: Philadelphia-Reading-Camden, PA-NJ-DE-MD #17: El Centro, CA #18: Louisville-Jefferson County-Madison, #16: Birmingham-Hoover-Talladega, KY-IN #19: Oklahoma City-Shawnee, OK #20: Chicago-Naperville, IL-IN-WI #21: Pittsburgh-New Castle-Weirton, PA-OH-WV #22: Fort Collins, CO #23: Birmingham-Hoover-Talladega, AL #24: Sheboygan, WI #24: Cleveland-Akron-Canton, OH

By Year Round Particle Pollution #1: Fresno-Madera, CA #2: Visalia-Porterville-Hanford, CA #3: Los Angeles-Long Beach, CA #3: Bakersneid, CA #5: Modesto-Merced, CA #6: Pittsburgh-New Castle-Weirton, PA-OH-WV #7: El Centro CA #8: Phoenix-Mesa-Scottsdale, AZ #8: St. Louis-St. Charles-Farmington, MO-IL #8: El Paso-Las Cruces, TX-NM #11: Cincinnati-Wilmington-Maysville, #11: Logan, UT-ID OH-KY-IN #11: Philadelphia-Reading-Camden, PA-NJ-DE-MD #13: New York-Newark, NY-NJ-CT-PA #13: Louisville-Jefferson County-Madison, KY-IN #15: Macon-Warner Robins, GA #16: Cleveland-Akron-Canton, OH AL #18: Atlanta-Sandy Springs, GA #19: Wheeling, WV-OH #20: Indianapolis-Carmel-Muncie, IN #20: Chicago-Naperville, IL-IN-WI #22: Columbus-Auburn-Opelika, GA-ALIN-MI #23: San Diego-Carlsbad, CA #23: Dayton-Springfield-Sidney, OH

#23: Johnstown-Somerset, PA

Most Polluted Cities 2014

American Lung Association

By Short-Term Particle Pollution #1: Fresno-Madera, CA #2: Visalia-Porterville-Hanford, CA #3: Bakersfield_CA #4: Los Angeles-Long Beach, CA #5: Modesto-Merced, CA #6: Pittsburgh-New Castle-Weirton, PA-OH-WV #7: Fairbanks, AK #8: Salt Lake City-Provo-Orem, UT #9: El Paso-Las Cruces, TX-NM #10: San Jose-San Francisco-Oakland, CA #12: Missoula, MT #13: Davenport-Moline, IA-IL #14: Chicago-Naperville, IL-IN-WI 15: Phoenix-Mesa-Scottsdale, All #16: New York-Newark, NY-NJ-CT-PA #16: Indianapolis-Carmel-Muncie, IN #18: Lancaster, PA #18: Harrisburg-York-Lebanon, PA #20: San Diego-Carlsbad, CA #21: Seattle-Tacoma, WA #21: Yakima, WA #23: Green Bay-Shawano, WI #23: South Bend-Elkhart-Mishawaka, #25: Sacramento-Roseville, CA

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#7: Logan, UT-ID
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CA

#9: Los Angeles-Long Beach, CA

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#24: New York-Newark, NY-NJ-CT-PA #25: Medford-Grants Pass, OR

Most Polluted U.S. Cities 2016 American Lung Association

Pollution controls on vehicles

Photochemical smog, was a rapidly growing problem

This problem was especially prevalent in western U.S. cities, like Los Angeles.

Severe air pollution lead to the Clean Air act of 1970 and the establishment of the EPA.

This act and its subsequent additions placed emission control standards on vehicles that each state must meet.



Los Angeles in the 1960s

Memories, sweet memories

Even with the Clean Air Act and oversight by the EPA, air pollution is still a big problem in the U.S. today.

Reason: Although today's cars are less polluting, there are a lot more of them and people drive them farther than four decades ago.

You've got to have a car in L.A.



Current L.A. freeway system



A "Spaghetti Junction" in L.A. Figure Credit: maps.google.com

How did it get this way?

Urban mass transit systems dismantled (i.e. trolley systems).

Cities grew outward, not upward.

Freeways built but development followed—along with long commutes.

Similar story across the United States...and it still continues today!

What is the environmental consequence?

Photochemical smog (Los Angeles type smog)



<u>Photochemical smog</u>: Ozone near the ground, caused by chemical reactions involving nitrogen oxides (NO_x) and volatile organic compounds (VOC's) in the presence of sunlight. VOC's mainly come from incomplete combustion of fossil fuels.

What are the health effects of living in this? How is smog made?

But photochemical smog is not unique to Los Angeles, it occurs in every major city in the Southwest U.S.



Phoenix, Arizona



Las Vegas, Nevada



Denver, Colorado



Salt Lake City, Utah

And you can't escape it if you leave the cities either...



Grand Canyon on a clear day.

Grand Canyon on a smoggy day.

http://apollo.lsc.vsc.edu/classes/met130/notes/

Two types of air pollutants

Primary pollutants

Enter the atmosphere directly from (anthropogenic) sources.

HARMFUL EXHAUST FROM SMOKESTACKS AND TAILPIPES...

Secondary pollutant

Forms as a result of chemical reactions between primary pollutant(s) and/or some other atmospheric constituent.

Examples: photochemical smog and acid rain

OZONE POLLUTION

is smog, which is a highly irritating, but invisible gas.

YEAR ROUND PARTICLE

pollution is the avg. level of microscopic bits of solids and aerosols in the air.

SHORT TERM PARTICLE

pollution are days with spikes in those bits of pollution.



SOURCES OF POLLUTION

American Lung Association

Primary Pollutants

Particulate Matter

Solid particles and liquid droplets that are small enough to remain suspended in the air.

Particles smaller than 10 microns are more likely to lounge in the respiratory system where they can adversely affect the body.

Smaller the particle, in general the more dangers it imposes.



<= microns =>

https://en.wikipedia.org/wiki/Particulates

Particle deposition in the lungs

Coarse particles	 Deposit in the upper respiratory tract and large airways (nose and throat) and are cleared out. 		
Fine particles	 Penetrate deep into the lungs and reach terminal bronchioles and alveoli. Stay there longer periods of time. PM2.5 		
Ultra-fine particles	 Enter the blood and travel through out the body. < 0.1 μm 		

Particle size is the most important factor for target tissue deposition

Credit: B. Victor

PM2.5 concentration for 2011-2006



NASA aerosols animation 200602910

Green: Biomass Burning Red/Orange: Dust White: Sulfites (from coal primarily) Blue: Salt

More Anthropogenic Primary Pollutants

Carbon monoxide (CO)

Forms from incomplete combustion of carbon containing fuels. Can be lethal in high concentrations because it replaces oxygen in the hemoglobin of the blood.

Sulfur Dioxide (SO₂)

Colorless gas that comes primarily from burning of coal and oil.

<u>Nitrogen oxides</u> (NO_X)

Gases that form when some of the nitrogen in the air reacts with oxygen during fuel combustion process. Can be harmful to respiratory and cardiovascular systems and is carcinogenic.

Volatile organic compounds (VOCs)

Mainly complex hydrocarbon compounds mostly from incomplete combustion of fuel and biomass burning.

TO CREATE PHOTOCHEMICAL SMOG AS A SECONDARY POLLUTANT YOU NEED NITROGEN OXIDES AND VOLATILE ORGANIC COMPOUNDS.

Emissions and sources of primary pollutants in the U.S.



EPA estimates

How do nitrogen oxides (NO_x) and volatile organic compounds (VOCs) make photochemical smog?

Ozone Production

Motor vehicle exhaust contains the nitrogen dioxide (NO₂) and nitric oxide (NO), the NO_x gases.

At the high temperatures of internal combustion, nitrogen and oxygen from the air react to form nitric oxide (NO), a colorless gas:

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Step 1: N_2 + O_2 + heat \rightarrow 2NO Creates nitric oxide.
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Some of the nitric oxide (NO) reacts with oxygen to form nitrogen dioxide (NO₂), a toxic brown gas:

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Step 2: 2NO + O_2 \rightarrow 2NO_2 + O Creates nitrogen dioxide.
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When the nitrogen dioxide (NO₂) concentration is well above clean air levels and there is plenty of sunlight, an oxygen atom splits off from the nitrogen dioxide molecule: **Step 3:** NO₂ + *sunlight* \rightarrow NO + O **Creates atomic oxygen**.

This oxygen atom (O) can react with molecular oxygen (O₂) in the air to form ozone (O₃): Step 4: $O + O_2 \rightarrow O_3$ Creates ozone.

Nitric oxide can remove ozone by reacting with it to form nitrogen dioxide (NO₂) and oxygen (O₂): Step 5: NO + O₃ \rightarrow NO₂ + O₂ Removes ozone.

When the ratio of NO₂ to NO exceeds 3, production of ozone dominates. Maximized at 8. If the ratio is less than 3, then the nitric oxide reaction destroys the ozone at about the same rate as it is formed, keeping the ozone concentration below harmful levels.

Ozone causes breathing difficulties, headaches, fatigue and aggravates respiratory problems.

Favorable factors for ozone air pollution in Southwest U.S.

Big metropolitan areas with a lot of vehicles

Long commutes

Lots of sunshine

Meteorological conditions

City	% Sunshine	Hours of Sun	Clear Days
Phoenix, Arizona	85	3872	211
Las Vegas, Nevada	85	3825	210
Sacramento, California	78	3608	188
Los Angeles, California	73	-	147
Miami, Florida	70	3154	74
Denver, Colorado	69	3107	115
Oklahoma City, Oklahoma	68	3089	139
San Diego, California	68	3055	146
Salt Lake City, Utah	66	3029	125
San Francisco, California	66	-	160
Tampa, Florida	66	2927	101

that "trap" the air over a metro area for a long time. Most ideal combination:

> Weak winds City located under an inversion City situated in a basin or valley surrounded by mountains

VIRTUALLY ANY MAJOR CITY WESTERN U.S. FITS THIS DESCRIPTION SOMETIME DURING THE YEAR!



Cool Sea Dependence of the L.A. Basin

Topographic influence



Los Angeles is located in a basin.

Cool afternoon sea breezes.

When the winds are weak, the mountains are a physical barrier that prevent pollution from escaping.

Phoenix is a LOT like Los Angeles!



Satellite image of Phoenix area.

But if you think it is bad in the U.S., other parts of the world are worse, a WHOLE LOT worse

Meet Mexico City: THE WORST place for air pollution in North America



Smog in Mexico City

Factors

Located at high elevation surrounded by very high mountains on three sides

A dry and sunny winter under a ridge of high pressure most of the time.

A population of about 9 million people.

Lower environmental standards than U.S.

SIMILAR STORY IN SANTIAGO, CHILE, AND SAO PAULO, BRAZIL

And Mexico City can't hold a candle to

World's most polluted cities

Annual mean concentration of particulate matter with diameter of 2.5 microns or less. Micrograms per cubic metre



National Ambient Air Quality Standards

• TABLE 18.2					
The National Ambient Air Quality Standards					
POLLUTANT	AVERAGING PERIOD	PRIMARY NAAQS	SECONDARY NAAQS		
Ozone (O ₃)	1-hour 8-hour	0.12 ppm 0.8 ppm	0.12 ppm 0.8 ppm		
Carbon Monoxide (CO)	1-hour 8-hour	35 ppm 9 ppm	_		
Sulfur Dioxide (SO ₂)	3-hour 24-hour Annual	0.14 ppm 0.030 ppm	0.5 ppm 		
Nitrogen Dioxide (NO ₂)	Annual	0.053 ppm	0.053 ppm		
Respirable Particulate Matter (10 μm or less) PM 10	24-hour Annual	150 μg/m³ 50 μg/m³	150 μg/m³ 50 μg/m³		
Respirable Particulate Matter (2.5 µm or less) PM 2.5	24-hour Annual	65 μg/m³ 15 μg/m³	65 μg/m³ 15 μg/m³		
Lead (Pb)	Calendar Quarter	1.5 μg/m ³	1.5 μg/m³		
			Ahrens		

These are the EPA's federal standards for air pollution measurements.

If pollution levels exceed these standards, then the area is designated the status "Non-Attainment"

Non-Attainment Counties



6 Pollutants: CO, Pb, NO₂, O₃, PM, SO₂

www.epa.gov

Health Effects of Polluted Air

AQI = 100% (ratio of actual/acceptable) levels

• TABLE 18.3				
The Air Quality Index (AQI)				
AQI VALUE	AIR QUALITY	GENERAL HEALTH EFFECTS	RECOMMENDED ACTIONS	
0-50	Good	None		
51-100	Moderate	There may be a moderate health concern for a very small number of individuals. People unusually sensitive to ozone may experience respiratory symptoms.	When O ₃ AQI values are in this range, unusually sen- sitive people should consider limiting prolonged outdoor exposure.	
101-150	Unhealthy for sensitive groups	Mild aggravation of symptoms in suscepti- ble persons.	Active people with respiratory or heart disease should limit prolonged outdoor exertion.	
151-200	Unhealthy	Aggravation of symptoms in susceptible per- sons, with irritation symptoms in the healthy population.	Active children and adults with respiratory or heart disease should avoid extended outdoor activities; everyone else, especially children, should limit pro- longed outdoor exertion.	
201-300	Very Unhealthy	Significant aggravation of symptoms and decreased exercise tolerance in persons with heart or lung disease, with widespread symptoms in the healthy population.	Active children and adults with existing heart or lung disease should avoid outdoor activities and exertion. Everyone else, especially children, should limit out- door exertion.	
301-500 Ahrens	Hazardous	Significant aggravation of symptoms. Premature onset of certain diseases. Premature death may occur in ill or elderly people. Healthy people may experience a de- crease in exercise tolerance.	Everyone should avoid all outdoor exertion and minimize physical outdoor activities. Elderly and persons with existing heart or lung disease should stay indoors.	



Current/Forecast AQI

Our environmental record shows

Most emissions are better. But some are not...PM2.5

SO WHAT'S THE SOLUTION?





SOME GOOD NEWS FOR THE U.S...SOME BAD NEWS TOO.

Smaller environmental footprint per person...but... Americans have one of the highest footprints in the world.

Summary of Air Pollution

Primary air pollutants include particulate matter PM, sulfur dioxide SO_2 , carbon monoxide CO, nitrogen oxides NO_X , sulfur dioxide SO_2 , and volatile organic compounds VOC. These are largely the result of fuel combustion processes.

Pollution knows no boundaries. Global problem.

London-type smog is caused by particles and sulfur from coal burning. It is more prevalent in the eastern U.S.

Photochemical smog (or L.A.-type smog) is caused by chemical reactions involving nitrogen oxides and volatile organic compounds that produce ozone O_3 . It is found in regions with sunny climates since sunlight is necessary for the ozone creation.

Summary of Air Pollution

Every major city in the Southwest U.S. suffers from a photochemical smog problem because of meteorological conditions that trap air over the metro areas for long periods of time. These include:

- 1) weak winds
- 2) Subsidence inversions
- 3) location in a basin or valley

Air quality standards are defined by the federal government. EPA monitors six criteria air pollutants: CO, NO_x , SO₂, O₃, PM, and Pb.

Air pollution has numerous negative effects on human health. The air quality index AQI of EPA gives a guide for the health effects of pollution and recommended actions.

Next regional-scale air pollution topic we'll cover is acid rain.

Assignment for Next Lecture Ozone Hole, Climate Change

- Reading- Ahrens
 - Pg. 438-442; Pg. 397-428
- "Questions for Review" Ahrens
 Pg. 458: 14.10, 14.11
 Pg. 428: 13.5, 13.6, 13.7, 13.8, 13.12



Ohio River coal power plant

Although London-type smog in the eastern U.S. has lessened in recent years, coal burning in the Ohio Valley and surrounding areas is associated with another problem...

ACID RAIN

Brief Review of Basic Chemistry of Acids and Bases

Acidity: Refers to the concentration of hydrogen (H+) ions.

Alkalinity: Refers to the concentration of hydroxide (OH-) ions.

The degree of acidity or alkalinity is given by the pH scale (1-14). Acids are at the low end of the scale pH of 7 is neutral Bases are at the high end of the scale

Characteristics of strong acids

Sting and burn the skin Highly corrosive Toxic

pH Scale: Degree of Acidity and Alkalinity



Pristine rain is weakly acidic (pH = 5 to 6)

Acid rain has a pH of about 4 to 4.5

The pH is scale is LOGARITHMIC, so for each numerical value lower on the scale, it is ______times more acidic.

Acid rain is about _____ times more acidic than natural rain.

pH Scale: Degree of Acidity and Alkalinity



Pristine rain is weakly acidic (pH = 5 to 6)

Acid rain has a pH of about 4 to 4.5

The pH is scale is LOGARITHMIC, so for each numerical value lower on the scale, it is <u>10</u> times more acidic.

Acid rain is about <u>10</u> times more acidic than natural rain.

Chemistry Acid Rain



http://www.dec.ny.gov/images/air_images/acidrain.gif

SO_2 and NO_X sources



Coal Burning Power Plants in U.S.

Coal-powered electric plants



There are **511** coal-powered electric plants in the U.S. They have generated **34** percent of the nation's electricity this year.

The leading fuel for electricity generation in the country, coal is most popular in the Midwest, Appalachia and the East Coast, but is also the primary source in Wyoming, Utah, Montana and Arizona. It generated the vast majority of the nation's electricity in the late 1980s but now creates one-third with natural gas gaining steadily. Coal is the chief source of electricity in 22 states and creates a majority of the electrical power in 14 states.





Acid Rain Impacts



http://people.emich.edu/mcliffo1/PollutionWebguest/AcidRain.html

1983

Damaged trees in the Great Smoky Mountains Freshwater aquatic ecosystems are particularly sensitive to changes in acidity.

Many small lakes in New York's Adirondack Park are no longer able to support fish populations.



https://commons.wikimedia.org/wiki/File:Waterspecies.gif

In many eastern U.S. forests, acid rain has lead to severe tree damage by changing the soil chemistry.

Acid Rain Effects on Buildings and Monuments



Sandstone figure in Germany 1908



Same figure 1968

Reducing Acid Rain

Main Sources: Power plants and automobiles

What can you do?

Turn off "stuff" when not in use; use only when needed. Use and demand energy efficient products. Use electronic gadgets only when you need them. Carpool, use public transportation, walk or bicycle. Drive low NO_x emissions, properly maintained cars.

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Summary of Acid Rain

Acid rain forms when sulfur dioxide and nitrogen oxides interact within a cloud water drop. It is about 5 to 10 times more acidic than normal rain.

Acid rain occurs downwind of pollution sources (mainly coal plants). It causes damage to forests, aquatic ecosystems, and buildings and monuments.

Acid rain provides damning evidence that air pollution from anthropogenic activities can affect large areas downwind of point sources of pollution. Assignment for Next Lecture Ozone Hole, Climate Change

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