ATM S 212
Air Pollution: From Urban Smog to the Ozone Hole

Instructor: Professor Becky Alexander
Office hours: M and Th 11:30-12:30 in 306 ATG
Required textbook: "Earth Under Siege" by Richard Turco

Course description:
This course is an introduction to air pollution on local, regional and global scales. We will focus on the sources, transformation, and dispersion of pollutants responsible for urban smog, acid rain, climate change and the stratospheric ozone hole. We will examine the health and environmental impacts of air pollutants, as well as current (or potential) technological solutions and policy regulations.

Student learning goals
• Understand how emissions, transport, chemistry and deposition impact air pollution.
• Explain the chemical and physical mechanisms behind ozone depletion, air pollution and acid rain
• Develop skills to critically evaluate discussions of air pollution and climate change based on scientific evidence and organized knowledge
The Natural World Credit
(from the UW website)

“Courses in this Area focus on the disciplined, scientific study of the natural world. The Area can be divided into three broad categories: the mathematical sciences, the physical sciences, and the biological sciences.”

This course will utilize applications of basic math/physical science concepts to Earth science problems. Thus, there will be some math (basic algebra) and science (basic chemistry) involved. I assume you have all had algebra in high school but may need a review, and you may not have taken chemistry. Thus, Friday classes are important!

Grading policy:
Exams (4) 60%
Class participation (15%)
Papers (15%)
Poster presentation (10%)

How to do well in this class:
• Attend lectures and ask questions. Read the textbook for supplemental information.
• Attempt practice problems in advance and come to practice problem solving sessions on Fridays.
• Get started early on your final project.
• Discuss project topic with the instructor before beginning your final project.

Class Web Site:
http://www.atmos.washington.edu/academics/classes/2011Q1/212/
Class Policies

• Late assignments (papers and posters) or exams are accepted only with at least 24 hours advanced OK from the instructor (me).
• If you miss class, copy notes from a classmate. Lecture slides are available on the class web site.
• If you feel your exam was graded incorrectly, you must submit your complaint to the instructor in writing, along with your graded exam, no earlier than 24 hours, but no later than one week, after your graded exam is returned to you. Your entire exam will be re-graded.
• Questions about lectures, homework or exams should be directed to the on-line message board. Only email me for personal reasons.
• Bring a calculator to class!

Important dates

• In class exams: Fridays Jan. 14, Jan. 28, Feb. 11, and Mar. 4
• Final project papers are due on Monday, March 7.
• "W" papers: First draft due on Friday, March 4, final draft due on Friday, March 11.
• There is no class on Monday, Jan. 17 or Monday, Feb. 21 (UW holidays)
~800,000 deaths (annually) are related to urban air pollution (2000). By 2020 this could increase to 8 million avoidable deaths.

Indoor air pollution ~1.6 million deaths worldwide.

World Health Organization (WHO)
http://www.arb.ca.gov/research/health/fs/pm-03fs.pdf

Recent Research Findings:
Health Effects of Particulate Matter and Ozone Air Pollution, January 2004

Health Impacts of Air Pollution
(per year)
for California

- Premature Death (6,500)
- Non-fatal Health Effects (1,200,000)
- Hospitalizations (8,000)
- School Absences (1,300,000)
- Lost Workdays (2,800,000)

Figure from: The East Bay Children's Respiratory Health Study of Traffic-Related Air Pollution Near Busy Roads
http://www.arb.ca.gov/research/eb-kids/bc-dist.jpg

How close are you willing to live to a freeway?

Figure from: The East Bay Children's Respiratory Health Study of Traffic-Related Air Pollution Near Busy Roads
http://www.arb.ca.gov/research/eb-kids/bc-dist.jpg

Turco, Figure 7.1
Physiological response of carbon monoxide (CO)

$O_2$ in air attaches to hemoglobin in the red blood cells.

CO can also attach to hemoglobin forming carboxyhemoglobin (CO-hb)

$\rightarrow$ reduces the availability of $O_2$ to the body

Physiological effects of human exposure to CO

<table>
<thead>
<tr>
<th>Exposure (hr)</th>
<th>Percent carboxyhemoglobin</th>
</tr>
</thead>
<tbody>
<tr>
<td>600 ppmv CO</td>
<td>100%</td>
</tr>
<tr>
<td>300 ppmv CO</td>
<td>50%</td>
</tr>
<tr>
<td>100 ppmv CO</td>
<td>10%</td>
</tr>
<tr>
<td>30 ppmv CO</td>
<td>1%</td>
</tr>
<tr>
<td>15 ppmv CO</td>
<td>0.5%</td>
</tr>
</tbody>
</table>

Physiological effects:
- No symptoms
- Headache, reduced mental acuity
- Throbbing, headache
- Vomiting, collapse
- Coma
- Death

Turco, Table 7.1

<table>
<thead>
<tr>
<th>Substance</th>
<th>Concentration (ppm)</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic (As)</td>
<td>0.5</td>
<td>Cancer of the lungs, liver, and skin, genotoxic</td>
</tr>
<tr>
<td>Cadmium (Cd)</td>
<td>0.2</td>
<td>Accumulation in the kidneys, lungs, and heart, symptoms like Wilson's disease, 10 ppm fatal within 1 hour, genotoxic</td>
</tr>
<tr>
<td>Chromium (Cr)</td>
<td>1.0</td>
<td>Skin rashes, lung cancer (after continued exposure), carcinogenic</td>
</tr>
<tr>
<td>Iron (Fe)</td>
<td>10.0</td>
<td>Siderosis, or red lung disease</td>
</tr>
<tr>
<td>Lead (Pb)</td>
<td>0.15</td>
<td>Nerve damage, and brain and heart anoxia, paralysis of limbs</td>
</tr>
<tr>
<td>Manganese (Mn)</td>
<td>5.0</td>
<td>Aching limbs and back, drowsiness, loss of bladder control, mental blunting</td>
</tr>
<tr>
<td>Mercury (Hg)</td>
<td>0.04</td>
<td>Central nervous system attack, tremors and neuropsychiatric disturbance</td>
</tr>
<tr>
<td>Nickel (Ni)</td>
<td>1.0</td>
<td>Skin rashes, cancer of the esophagus (after continued exposure), exposure to 0.001 ppm of nickel causes loss of taste, vomiting, and possible death</td>
</tr>
<tr>
<td>Vanadium (V)</td>
<td>0.5</td>
<td>Arterial spasm of the bronchial arteries</td>
</tr>
<tr>
<td>Zinc (Zn)</td>
<td>5.0</td>
<td>Fever, muscular pain, nausea, and vomiting</td>
</tr>
</tbody>
</table>

The table includes toxic metals and their concentrations, effects, and possible health impacts. The threshold concentrations are given in parts per million (ppm).
Health effects of air pollutants

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Exposure level (ppm)</th>
<th>Immediate effects</th>
<th>Long-term effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particulate matter</td>
<td></td>
<td>Inhalation symptoms</td>
<td>Decrease in respiratory function, increase in hospital admissions</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>20</td>
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<td>60</td>
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<td></td>
<td>150</td>
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<td></td>
<td>600</td>
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</tr>
<tr>
<td>Ozone</td>
<td>0.08 - 0.1</td>
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<td>0.1</td>
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<td>0.5</td>
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<td></td>
<td>1.0</td>
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<tr>
<td>Nitrogen dioxide</td>
<td>0.1</td>
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<td></td>
<td>0.5</td>
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<td>1.0</td>
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World Health Organization, Health aspects of air pollution, 2004

Healthy vs. Smoker Lung

Non-smoker lung - from a 47 year old city-dweller. The black spots are caused by carbon particles from air pollution

Blackened lung of a smoker. Whitish area is the developing area of lung cancer

Turco, Table 7.2

<table>
<thead>
<tr>
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<th>Long-term effects</th>
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<tbody>
<tr>
<td>CO</td>
<td>10 - 30</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>100</td>
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<td>150</td>
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<tr>
<td>O3</td>
<td>0.02</td>
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<td>1.0</td>
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<td>SO2</td>
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<td></td>
<td>1.5</td>
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</table>

Time delay (hypersensitive) | Headache (100 ppm) | Nausea, collapse (300 ppm) | Death

Respiratory impact (long-term exposure genotoxic damage) | Breathing difficulty | Asthma bronchitis |

Oder threshold | Nose and throat irritation in sensitive people |
| | General nose and throat irritation |
| | Airway irritation, headaches |
Long-term exposure leads to premature aging of lung tissue |

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World Health Organization (WHO)

http://www.arb.ca.gov/research/health/fs/pm-03fs.pdf

AMERICAN LUNG ASSOCIATION of California

Recent Research Findings: Health Effects of Particulate Matter and Ozone Air Pollution, January 2004

Health Impacts of Air Pollution (per year) for California

- Premature Deaths (6,550)
- Hospitalizations (10,000)
- Respiratory issues including asthma (1,700,000)
- School Absences (1,300,000)
- Lost Workdays (2,800,000)

Killer Smog in London

Turco Figure 6.1
Human Impact

- Humans appear around 1 Million years ago
  - hunters / gatherers

- Human settlements
  - ~ 5000 - 10000 yrs ago

Early Human Impact (3000-1000 years ago)

- Agriculture
  - cultivation of land
  - burning of woods
  - animal waste

- Heating
  - open wood fires indoors
  - burning of coal

- Manufacturing:
  - metals: copper, bronze, iron, etc.
  - leather tanning

But: world population small

- ~300 million people

individuals did not use as much energy

"As soon as I had gotten out of the heavy air of Rome and from
the stink of smoky chimneys thereof, which, being stirred, poured
fresh whatever pestilential vapors and soot they had enclosed
in them, I felt an alteration of my disposition."

Seneca (Roman philosopher, dramatist, and politician), 61 AD
Industrialization

1784  Watt invents the steam engine fired by coal

Used to pump water out of mines; Energy for mills (paper, iron, flour, cotton, steel), distilleries, locomotives…

→ Hundred-fold global increase in coal combustion between 1800 and 1900.  
James Watt (1736-1819)

Edgar Fahs Smith Collection, University of Pennsylvania Library

Examples

1876 AD

Coal combustion in U.S. ~ 1900s…

Reading, Pennsylvania (c. 1909)

Youngstown, Ohio (c. 1910)

Gary, Indiana (c. 1912)

…for steel manufacturing, iron manufacturing, railway transportation
London Smog, 1900s

Claude Monet: “Waterloo Bridge, Fog Effect” (1903)

Claude Monet: “Houses of Parliament, Effects of Sunlight in the Fog” (1904)

…London, 1900s

James Tissot: “The Thames” (1876)

London Smog of 1952

Fog + smoke from coal burning
Worst single pollution episode in the UK. December 5-8 1952: 4,000 people died, another 8,000 died in the weeks-months that followed
Noontime, Donora, Pennsylvania, October 29, 1948

Pollution from steel mills and zinc smelters
Deadly episode: Oct 26-31 1948 – 20 people died, 7,000 people with respiratory illness “killer smog”

Copyright Photo Archive/Pittsburgh Post-Gazette, 2001. All rights reserved

Smog Bothers Pedestrians, Los Angeles (1950s)

Factories + cars

Hollywood Citizens News Collection, Los Angeles Public Library

Urban smog

Build-up of gases+particles in cities
Causes: Combustion products (cars, smokestacks…)+industry
Effects: Human+animal health; vegetation; structures
Scale: 10s-100s of kilometers
Time: 1850s-present


159 million people

Nonattainment areas (2000-2003) for surface ozone
Urban smog around the world today

New Delhi

Mexico City

Seoul

Beijing

Los Angeles

Acid rain

Acidification of rain

Causes: human-produced acids from combustion sources

Effects: Acidification of soils, forests, lakes (fish), structures

Scale: meters-1000s of kilometers

Time: 1850s-present

Acidified forest, Germany (1991)

Sandstone figure, Westphalia, Germany

1989-1991

Wet sulfate deposition

Getting better in the U.S.

1997-1999

... but worsening in Asia
Growth of World Population

- 300 million in 0 AD
- 1 billion in 1800
- 2 billion in 1927
- 3 billion in 1960
- 4 billion in 1974
- 5 billion in 1987
- 6 billion in 1999
- 9 billion projected in 2050?

Agriculture, industry, and technology support population growth.

Stratospheric ozone depletion

**Human-induced destruction of ozone layer in stratosphere**

**Causes:** Man-made chemicals (CFCs) used as refrigerants, solvents, sprays...

**Effects:** Increase in ultraviolet radiation reaching the ground
- Human and animal health

**Scale:** Global

**Time:** 1970s-present

Global Warming

**Retreat of the South Cascade glacier in the 20th century**

**Global climate change** (temperature, rainfall, sea level rise...)

**Causes:** Greenhouse emissions gases (combustion, deforestation, agriculture)

**Effects:** Human health (malaria); animal/plant biodiversity; $\$$ cost (sea-level rise)

**Scale:** Global

**Time:** 1850s-present
The Future

- Developed Countries:
  - high living standard
  - high per-capita resource consumption
  - more pollution per person
  - small population (~ 1 billion)
- Less developed Countries:
  - low living standard
  - low per-capita resource consumption
  - less pollution per person
  - large population (~ 5 billion)

What is going to happen when/if poorer countries reach our lifestyle?
What is an atom?

The kind of atom is determined by the number of protons and neutrons.

Nomenclature:

<table>
<thead>
<tr>
<th>symbol</th>
<th>protons</th>
<th>neutrons</th>
<th>name</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>1</td>
<td>0</td>
<td>hydrogen</td>
</tr>
<tr>
<td>He</td>
<td>2</td>
<td>2</td>
<td>helium</td>
</tr>
<tr>
<td>N</td>
<td>7</td>
<td>7</td>
<td>nitrogen</td>
</tr>
<tr>
<td>C</td>
<td>6</td>
<td>6</td>
<td>carbon</td>
</tr>
<tr>
<td>O</td>
<td>8</td>
<td>8</td>
<td>oxygen</td>
</tr>
</tbody>
</table>

Periodic table of elements

Atomic number = # of protons

What is a molecule?

Two or more atoms that are bound together forming one unit.

Nomenclature:

water

H₂O

number of H atoms in molecule
Other Examples

Oxygen molecule: O₂

Ozone molecule: O₃

Carbon dioxide molecule: CO₂

Chemical Reactions

O₃ + NO → NO₂ + O₂

we say:
O₃ (ozone) reacts with NO
(nitric oxide) to form NO₂
(nitrogen dioxide) and O₂
(oxygen)

What happens: (not every collision leads to a reaction)

Nomenclature of Chemical Reactions

direction of reaction

O₃ + NO → NO₂ + O₂

reactants products

4 O atoms + 1 N atom = 4 O atoms and 1 N atom

Rules:
• the number of specific atoms, for example O, N, etc. are always the same on both sides.
• in air reaction only occur with 2 reactants
• whether a reaction occurs depends on many things, that we will not discuss in this class
Concentration

C = \frac{\text{Amount of substance}}{\text{Volume}}

\text{Volume} = 1m \times 1m \times 1m = 1m^3

C = \frac{20 \text{ balls}}{1m^3} = \frac{20 \text{ balls}}{m^3}

Gas: molecules in Volume
⇒ \text{unit: molec. cm}^{-3}

Mixing Ratio (M.R.)

M.R. = \frac{\text{Amount of one substance}}{\text{Amount of all substances}}

M.R. = \frac{2 \text{ red balls}}{20 \text{ balls}} = 0.1

no unit

Mixing Ratios

<table>
<thead>
<tr>
<th>name</th>
<th>symbol</th>
<th>ratio</th>
<th>ratio description</th>
</tr>
</thead>
<tbody>
<tr>
<td>One percent</td>
<td>1%</td>
<td>10^{-2}</td>
<td>one out of each 100</td>
</tr>
<tr>
<td>One part per million</td>
<td>ppm</td>
<td>10^{-6}</td>
<td>one out of each million</td>
</tr>
<tr>
<td>One part per billion</td>
<td>ppb</td>
<td>10^{-9}</td>
<td>one out of each billion</td>
</tr>
<tr>
<td>One part per trillion</td>
<td>ppt</td>
<td>10^{-12}</td>
<td>one out of each trillion</td>
</tr>
</tbody>
</table>

Volume / Number

M.R. = \frac{\text{Amount of one substance}}{\text{Amount of all substances}}

⇒ ppmv

Mass

M.R. = \frac{\text{Mass of one substance}}{\text{Mass of all substances}}

⇒ ppmm

ppbv

ppbm
Concentration vs. Mixing Ratio

\[ C = \frac{20 \text{ balls}}{0.001 \text{m}^3} = \frac{20000 \text{ balls}}{\text{m}^3} \]

\[ \text{M.R.} = \frac{2 \text{ red balls}}{20 \text{ balls} / 0.001 \text{m}^3} = 0.1 \]

Concentration changes, M.R. not!

How can we quantify the amount of a pollutant that comes out of a smoke stack?

How do we quantify the amount of pollutant a person breathes in?

Question

One car emits $10^{12}$ molecules of carbon monoxide (CO) in 1 hour, another car emits $10^{12}$ molecules CO in 30 minutes.

Which car is the worse polluter?

A third car emits $10^{13}$ molecules per day.

Is it better or worse than the other two?