Fundamentals of air pollution and climate change

Daniel J. Jacob

Vasco McCoy Family Professor of Atmospheric Chemistry & Environmental Engineering
School of Engineering & Applied Science, Dept. of Earth & Planetary Science
Science & engineering undergraduate education in the US: some important differences with China

1. The teaching culture strongly favors inductive over deductive reasoning

2. Education is much more focused on applications than on math

3. Applied sciences and engineering are introduced very early in curriculum, viewed as a good way to learn science because they excite curiosity.

4. There is emphasis on creativity and experimentation through lab courses, design projects, research

China, Europe: deductive reasoning

Mathematics → Fundamental science → Applied science & engineering

US: inductive reasoning
Three ways to major in environmental science at Harvard

1. Environmental Science and Engineering
   - engineering degree (very popular at Harvard)
   - design project

2. Earth & Planetary Sciences
   - includes broader Earth science perspective
   - yearly field trip

3. Environmental Science and Public Policy
   - lighter science load, more courses in government, economics...
   - great preparation for law school

In all cases you are likely to take (from Harvard course catalog):

ENG-SCI 133 - Atmospheric Chemistry or return to Course Catalog Search

156496 - Section 001
School  Department  Faculty
Faculty of Arts and Sciences  Engineering Sciences  Daniel Jacob

Term  Day and Time  Location
Spring 2017-2018 (show academic calendar)  TuTh 11:30 a.m. - 12:59 p.m.  Geological Museum 102 (FAS)

Credits  Credit Level
4 (show credit conversion for other schools)  Graduate and Undergraduate

Description

Prerequisite(s)
Recommended: Physical Sciences 1, 2, Mathematics 1b; or equivalents.

Notes
This course, when taken for a letter grade, meets the General Education requirement for Science of the Physical Universe. ES 133 is also offered as EPS 133. Students may not take both EPS 133 and ES 133 for credit. Engineering students should enroll in ES 133.
Atmospheric chemistry: understand composition of Earth’s atmosphere and its implications

Multidisciplinary science:
- Chemistry
- Meteorology
- Geography
- Ecology & biology
- Computer & data science

Air pollution
Acid rain

Ozone hole
Climate change
Observations and modeling: foundation of atmospheric chemistry

- Atmospheric chemistry problems involve hundreds of chemical species transported by turbulent winds on all scales – grand computational challenge!

- Models simplify the mathematical system to make it computationally tractable - explain observations and make predictions
Satellite observations of atmospheric CO₂
Modeling of atmospheric CO$_2$
EQUILIBRIUM CLIMATE OF THE EARTH:
BALANCE BETWEEN SOLAR AND TERRESTRIAL RADIATION

SOLAR RADIATION (visible)
30% reflected by clouds, ice...

TERRESTRIAL RADIATION (infrared)
WARMING OF EARTH’S SURFACE BY GREENHOUSE GASES

Solar radiation (visible)

Terrestrial radiation (infrared)

30% reflected by clouds, ice...

Greenhouse gases in atmosphere absorb infrared radiation, re-emit it both upward and downward

Water and CO₂ are the two most important greenhouse gases
Global surface temperature trend

Global Mean Estimates based on Land and Ocean Data

[Graph showing global temperature anomalies from 1880 to 2020 with a focus on 2015-2017]
CO₂ increase because of fossil fuels

Surface observations since 1958
Mauna Loa, Hawaii
South Pole

2017: 405 ppm

10 billion tons of carbon per year (2017)

Ice core records for past 1,000 years

IPCC [2007, 2014]
Only half of the emitted CO$_2$ remains in atmosphere

- 50% of emitted CO$_2$ is taken up by surface ocean and vegetation within a few decades;
- another 30% goes into the deep ocean within a few centuries;
- getting rid of the final 20% takes thousands of years
Future projections of CO$_2$ emissions

Intergovernmental Panel on Climate Change
There is hope: CO\textsubscript{2} emission increase is slowing down, decreasing in developed countries.
The industrial revolution and air pollution

US in the 1940s
London fog: first evidence of air pollution deaths

Fine particulate matter (PM$_{2.5}$) from domestic+industrial coal combustion

“Killer fog” of December 1952 caused 10,000 deaths in 4 days
Los Angeles smog: first evidence of ozone air pollution
Respiratory problems, vegetation damage due to high surface ozone

- Troposphere (~ 10 km)
- Stratosphere (~ 1 km)
- Temperature inversion
- Ozone
- Nitrogen oxides (NOx ≡ NO + NO2)
- Organic compounds
- Sunlight
- Ozone (O3)
- PM
- Radicals

vehicles, industry, vegetation

produced by photolysis of oxygen (O2)
AIR POLLUTION TODAY:
Ozone and fine particulate matter (PM$_{2.5}$) are the major pollutants

US population exposed to air pollutants in excess of national ambient air quality standards, 2015
M = millions

- Ozone: 108M, 70 ppb (8-h average)
- PM$_{2.5}$: 31M, 12 µg m$^{-3}$ (annual), 35 µg m$^{-3}$ (24-h)
- PM$_{10}$: 11M
- SO$_2$: 5M
- Lead: 1M
- CO: 0
- NO$_2$: 0

Million environmental deaths per year worldwide

- PM$2.5$: 1.5
- Ozone: 1
- Water supply: 2
- Indoor air: 2.5
- Malaria: 0.5

2010 data

US EPA [2017], OECD [2012]
Particulate matter (PM$_{2.5}$) observed from satellite

US air quality standard

China air quality standard

http://www.nasa.gov/topics/earth
Particle pollution in China

Aggressive control of SO_2 and soot emissions from coal has achieved a lot of success, still much more to be done.

Shixian Zhai, Harvard
Ozone pollution in China

Ozone is getting worse – Why?
Decrease in particle pollution may cause increase in ozone

2013-2017 decrease in PM pollution may have increased radicals available for ozone production

Ke Li, Harvard
GEMS: geostationary satellite for observing air pollution in Asia

Planned for launch in 2019 by Korean Space Agency

Geostationary orbit will allow continuous observation:
• Monitoring emissions
• Detecting episodes
• Forecasting air quality

Interpreting these observations is a next grand challenge for atmospheric chemists
I look forward to your questions!

djacob@fas.harvard.edu