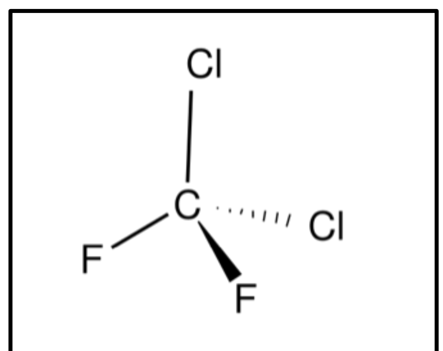
EVS341

Evaluating Significance of Environmental Pollution: Air Exposure



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Air Pollution in the News

https://www.theguardian.com/environment/2017/oct/19/global-pollution-kills-millions-threatens-survival-human-societies

Recap of Last Week's Lecture

Terminology:

concentration
exposure
dose
aerosol deposition efficiency

Exposure assessment technology:

indoor and outdoor monitoring
static and mobile monitors
active/passive/real-time personal exposure monitors
measurements and/or modelling

Exposure assessment practicalities:

cost
logistics
scientific needs

Today's Lecture Outline

AIR POLLUTION:

- **Sources**
- **Processing**
- **Sinks**
- **Description and impacts of types air pollution:**
  - Fine particles ($PM_{2.5}$)
  - Ozone
  - Smog
  - Acid Rain
  - Eutrophication
  - POPs
  - Heavy Metals
  - CFCs
- **Cost-benefit analysis**

Air Pollution Sources

Definition: Origin of a pollutant (primary versus secondary)

Primary:
Directly emitted (NO_x, SO_2, NH_3, VOCs)

Source strength represented as a **flux**: rate of emission of pollutant over a specified space and time

In models databases of primary sources is called an **emission inventory**.

Pollution sources classified by **type**:
- Natural
- Anthropogenic

Pollution sources classified by **location**:
- Point or stationary
- Mobile
- Area

Secondary Sources:
Formed from chemical reactions (nitrate, sulfate, NH_4, formaldehyde)

Air Pollution Sources

Test Your Knowledge

Are the following:

(a) natural or anthropogenic sources?

(b) mobile, stationary or area sources?

Air Pollution Processing

Includes **physical transport** and **chemical reactions**.

Transport involves movement of pollution in 3-dimensions.

The longer the lifetime of the pollutant, the further it can travel.

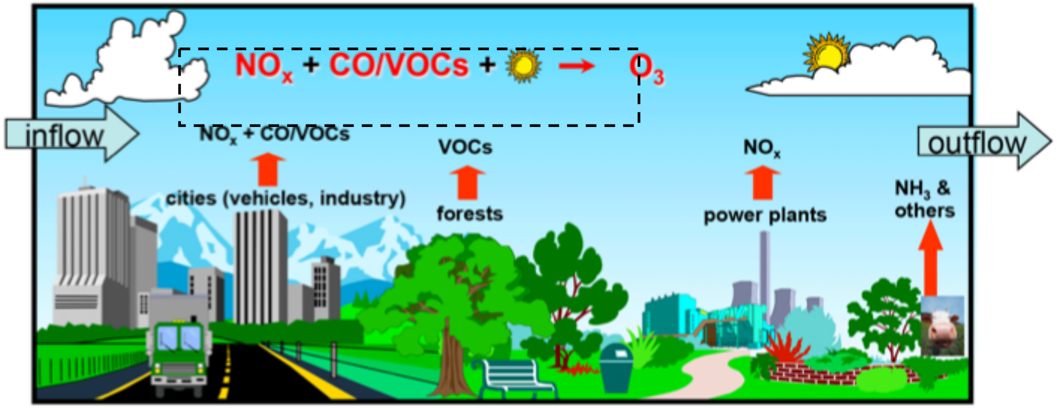
Examples:

1. Carbon monoxide (CO) lifetime is 2 months (cross-continental transport)
2. $PM_{2.5}$ lifetime is shorter (a few days at most) (regional transport)

Chemical processing to form secondary pollutants.

Examples:

1. VOCs (primary, cars) react with NO_x (primary, cars) in the presence of sunlight to form ozone (secondary)
2. NH_3 (primary, agriculture) partitions from the gas phase to the aerosol phase to form NH_4 (secondary) in the particle phase to contribute to $PM_{2.5}$.



Air Pollution Sinks

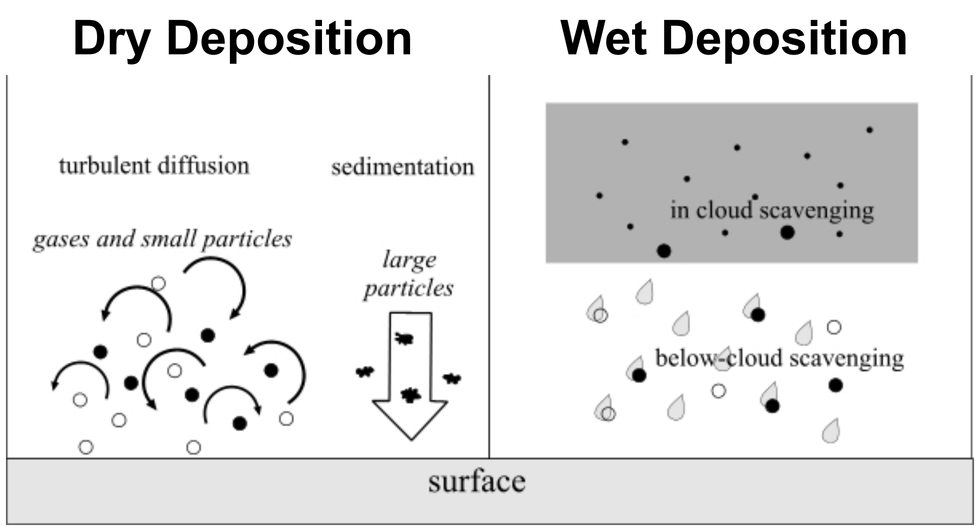
<u>Definition:</u> Removal of pollutant from the atmosphere

Can determines the impact of air pollutants on an ecosystem.

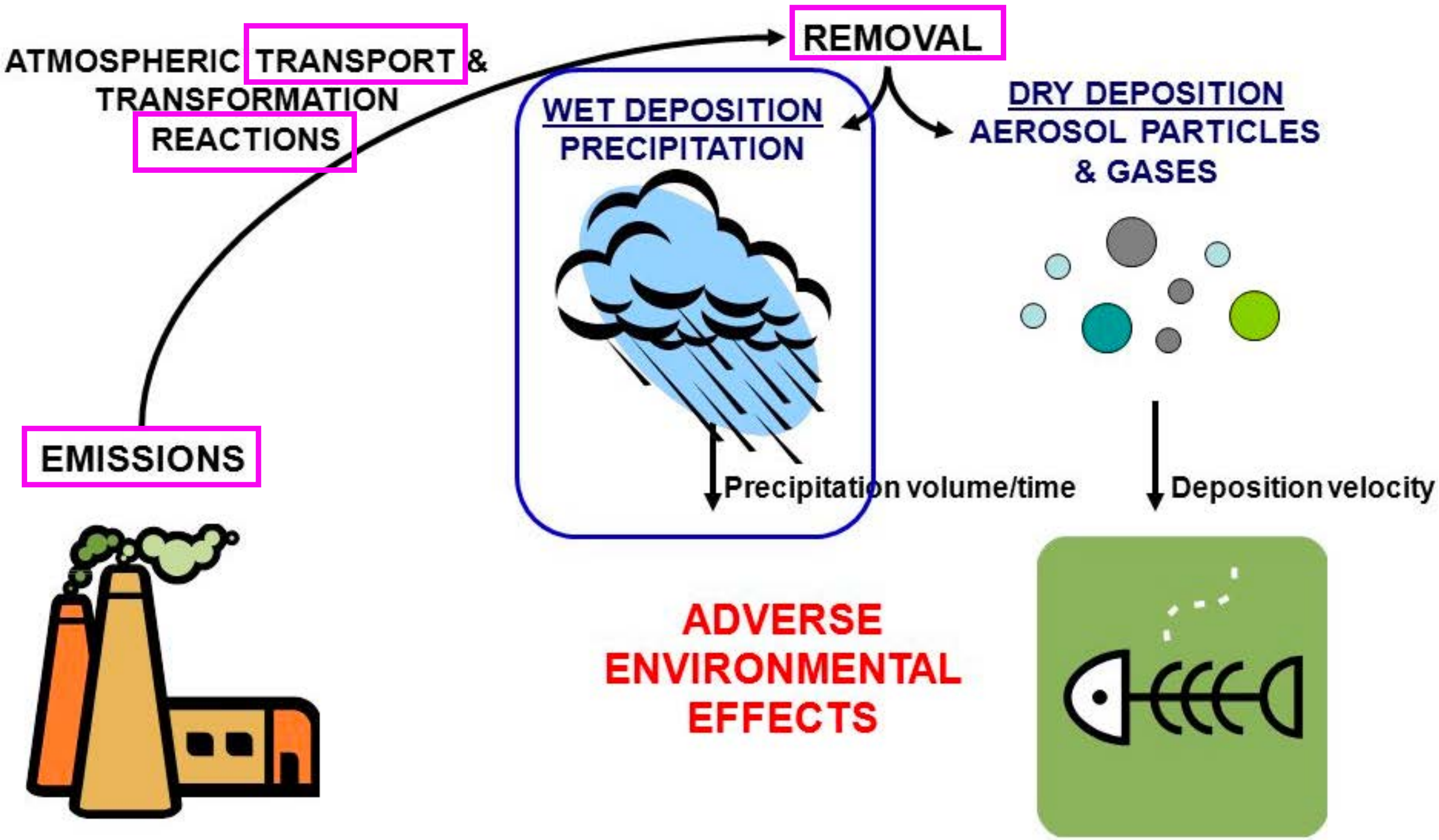
Terminal fates of air pollutants include:

- **Dry deposition** (comes into contact with and settles on a surface)
  <u>Example:</u> ozone depositing to the surface of leaves

- **Wet deposition** (scavenging/uptake by rain or cloud drops)
  <u>Example:</u> particles effectively removed from the atmosphere when it rains



Putting It All Together

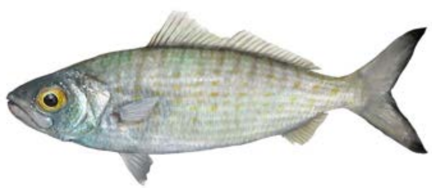


Source-Receptor

Receptor: point at which pollution is intercepted by a human or enters the surrounding environment (impact point)

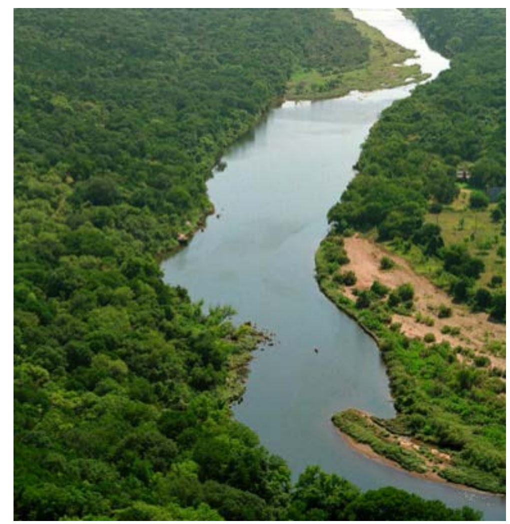
Source → Transport & Transformation → Receptor

Receptor Examples:



Fish exposed to Hg (mercury)

Human exposed to $PM_{2.5}$



River exposed to excessive nutrients (eutrophication)

Forest exposed to acid rain

Major Impacts of Air Pollution

Focus on sources, processing, fate, and impact of pollution:

- **Fine Particles ($PM_{2.5}$)**
- **Surface Ozone**
- **Acid Rain**
- **Eutrophication**
- **Persistent organic pollutants (POPs)**
- **Heavy Metals (cadmium, mercury, lead, arsenic)**
- **Chlorofluorocarbons (CFCs)**

Many others: peroxyacetyl nitrates (PAN), carbon monoxide (CO)

<u>Draw on board:</u> balanced system of inputs and outputs to a system offset by humans.

Fine particles ($PM_{2.5}$)

Fine particles with aerodynamic diameter less than 2.5 μm

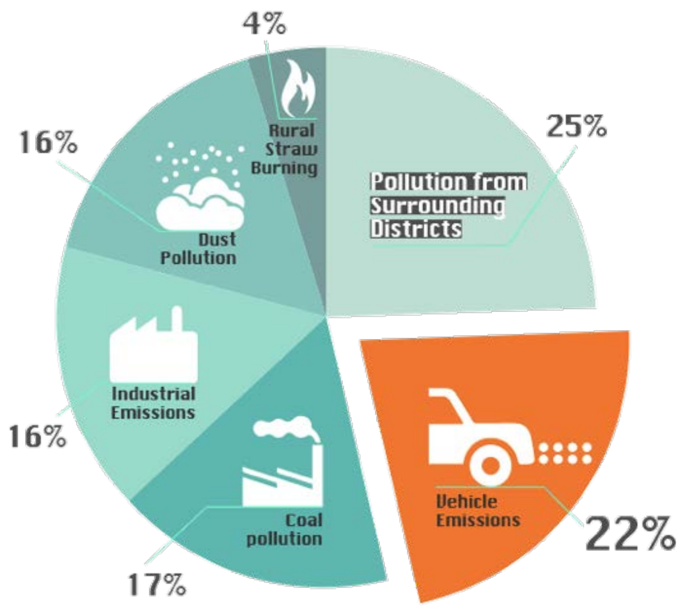
Many primary and secondary **sources**

Components: Sulfate, nitrate, ammonium, organic aerosol, black carbon, dust/soil.

Removal: Wet and dry deposition

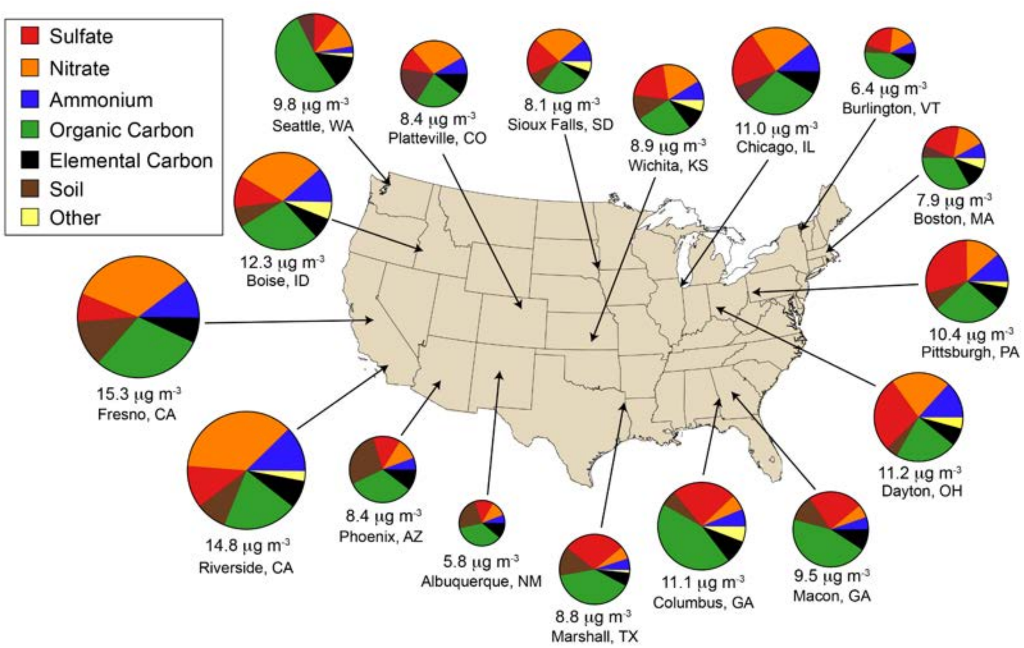
Impact: Climate, health, visibility, vegetation

Sources (Beijing)



[Source: http://www.beijingrelocation.com/]

Composition (US)



Fine particles ($PM_{2.5}$)

Climate Impact

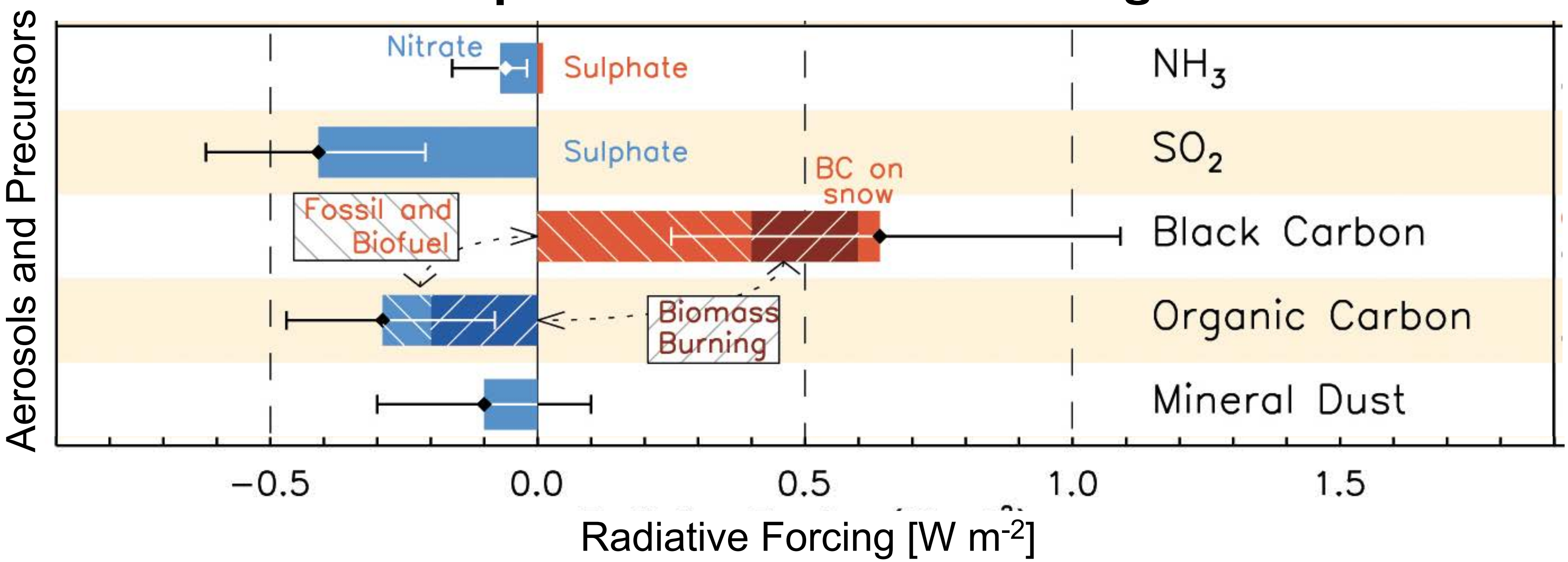
Absorb and scatter radiation

Radiative forcing: measure of change in energy (heat) balance of the Earth

Positive Radiative forcing: **warming**

Negative radiative forcing: **cooling**

Components of Radiative Forcing



[IPCC AR5, 2013]

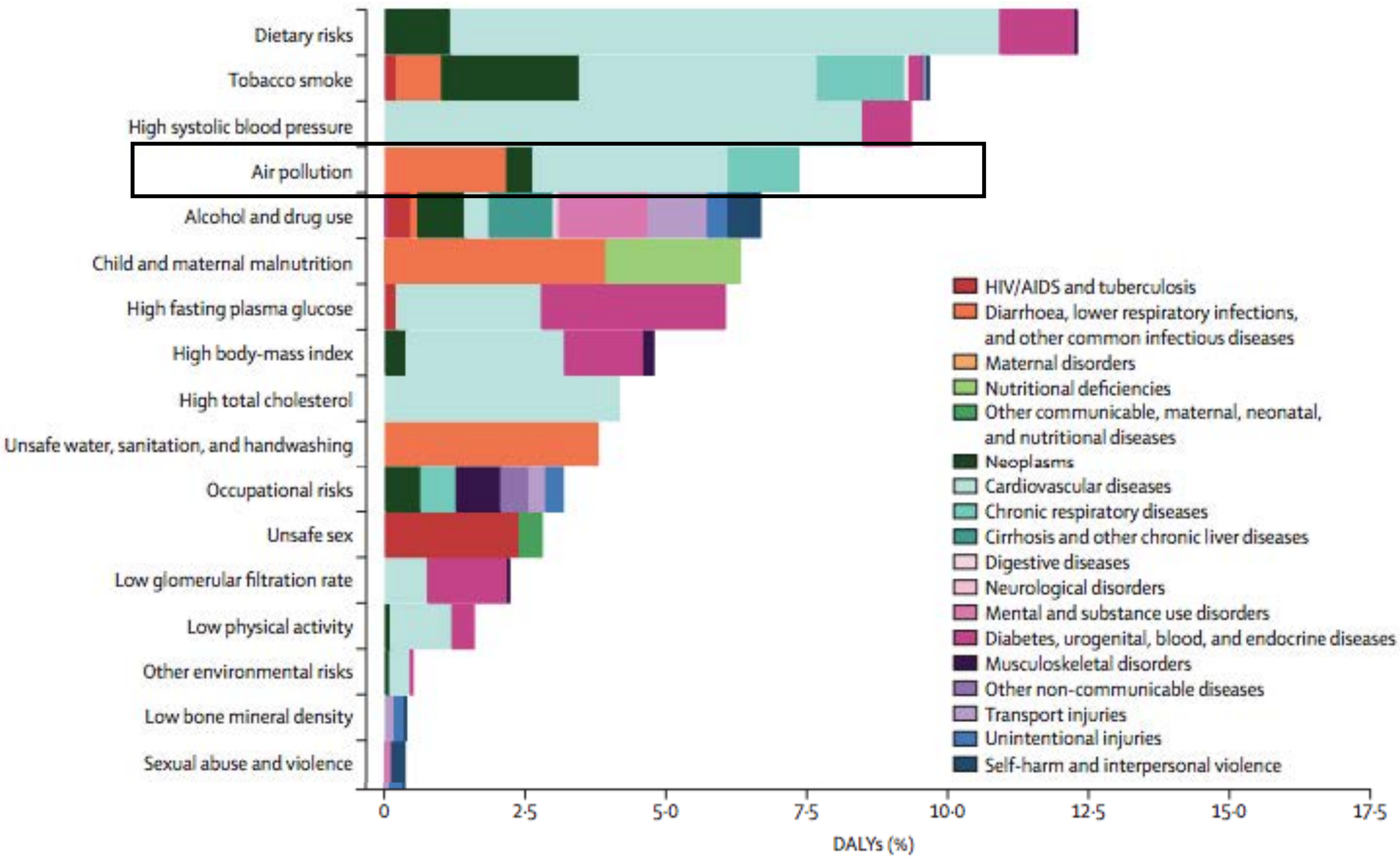
Fine particles ($PM_{2.5}$)

Health Impact

Acute health endpoints: stroke, upper respiratory infections

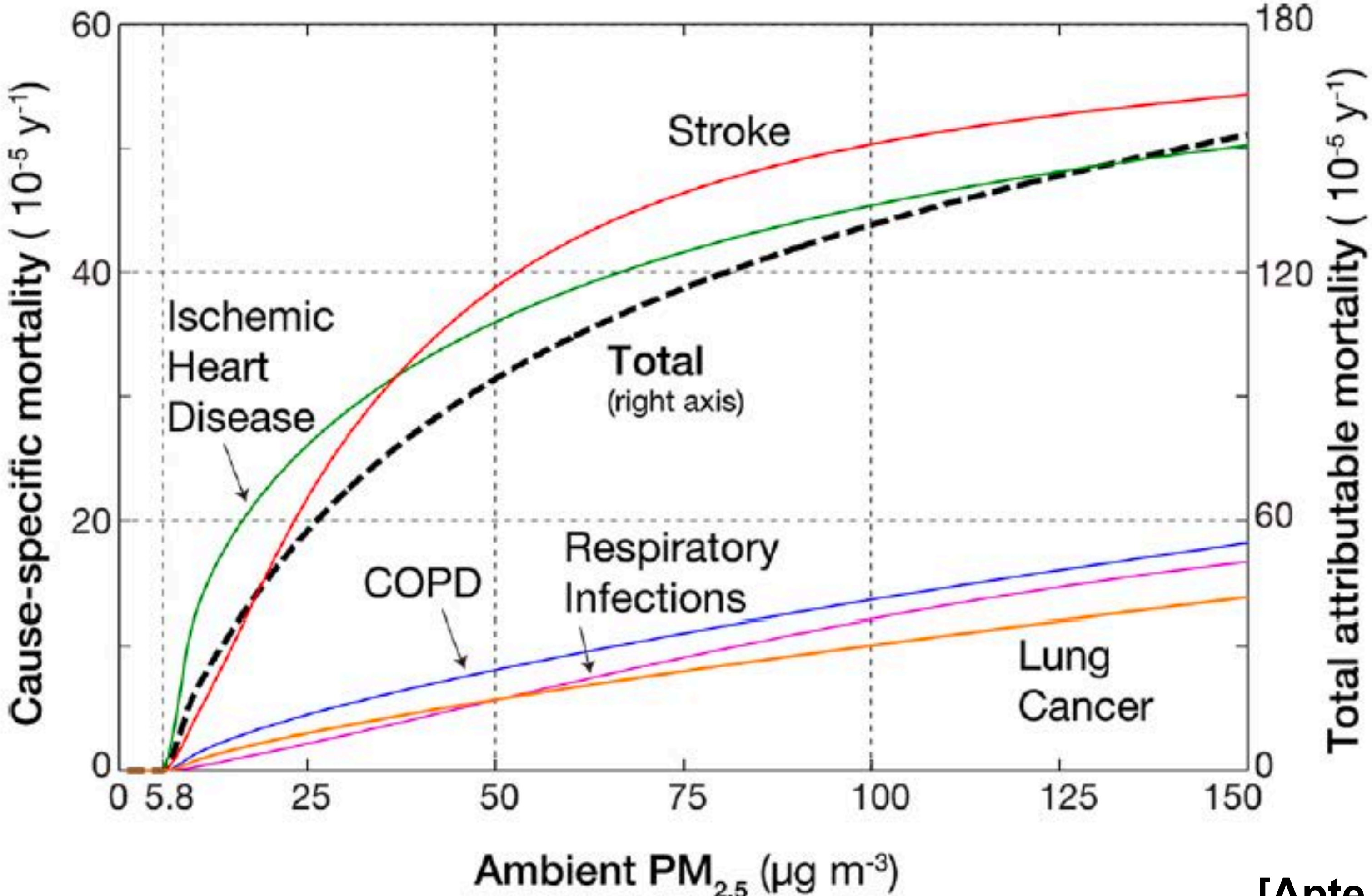
Chronic: respiratory disease, lung cancer, heart disease

4th highest health risk (Global Burden of Disease (GBD), 2015):



Fine particles ($PM_{2.5}$)

Relating exposure to mortality



Y-axes: per-capita mortality

X-axis: annual average $PM_{2.5}$

[Apte et al., 2015]

COPD:
chronic obstructive pulmonary disease

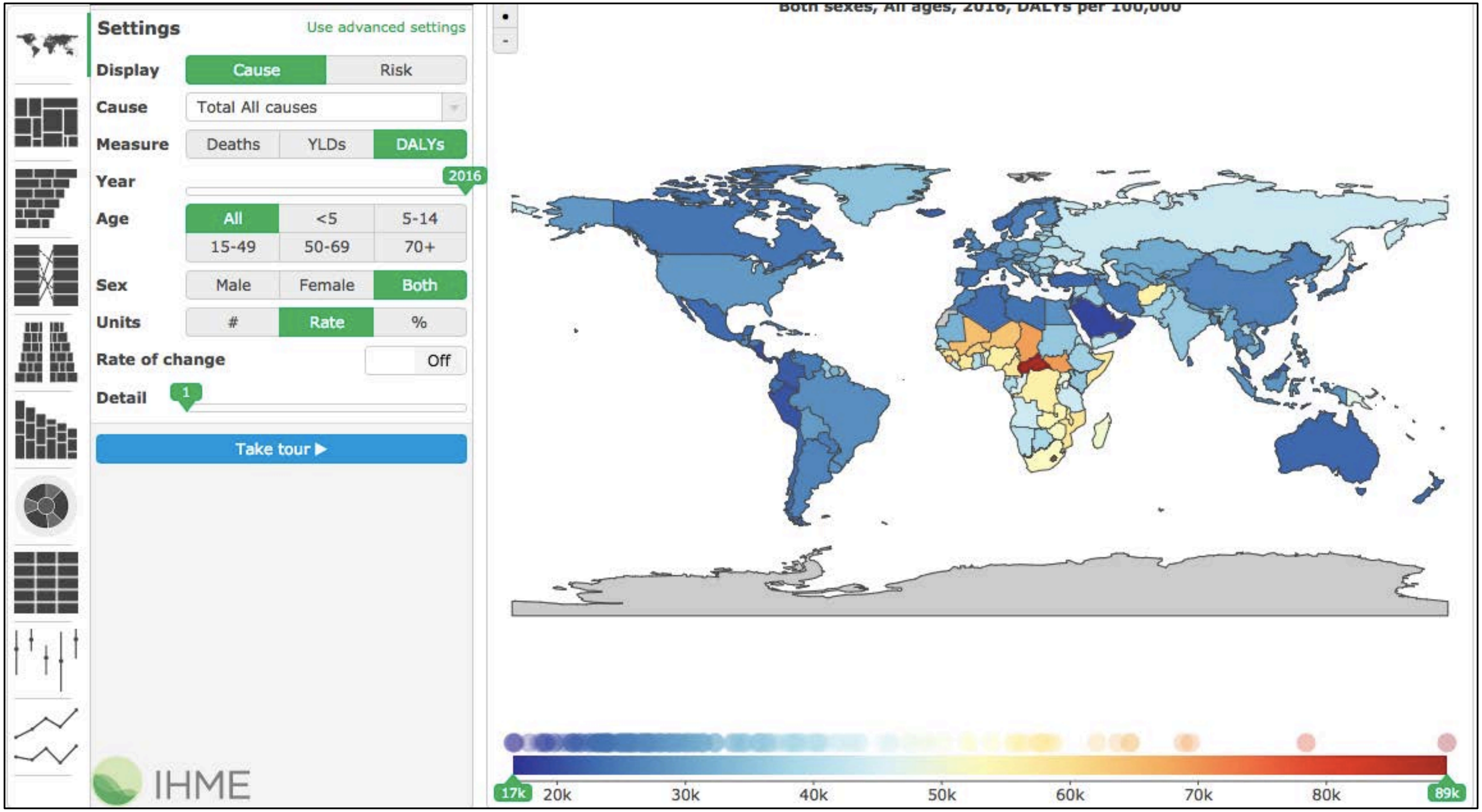
Fine particles ($PM_{2.5}$)

Worked Example

Estimate the number of premature deaths in 2010 in Birmingham due to exposure to $PM_{2.5}$. Calculate mortality for individual and the total end points. Total population in 2010 was 1.1 million people and annual average $PM_{2.5}$ was 11 $\mu g\ m^{-3}$.

How does premature deaths in Birmingham compare to that in Beijing in 2010? Annual average $PM_{2.5}$ was 95 $\mu g\ m^{-3}$ and the population was 24.9 million.

Global Burden of Disease Tool



https://vizhub.healthdata.org/gbd-compare/

Global Burden of Disease Tool

Worked Example

How many people died due to exposure to ambient $PM_{2.5}$ and ozone in the **UK** in 2016? How does this compare to **India**? To **China**? And to **Nigeria**?

With this tool you could start to answer additional curiosities:

→ How does ambient (outdoor) air pollution compare to deaths due to exposure to indoor air pollution?

→ How different are 2016 and 2000 ambient air pollution deaths for these countries?

→ How many people died due to exposure to ambient air pollution in the West Midlands?

Exposure to black carbon (BC) in London

Behavioural patterns and personal exposure to a $PM_{2.5}$ component

BC exposure video:

https://www.theguardian.com/environment/video/2014/aug/12/london-air-pollution-public-transport-video

Surface Ozone

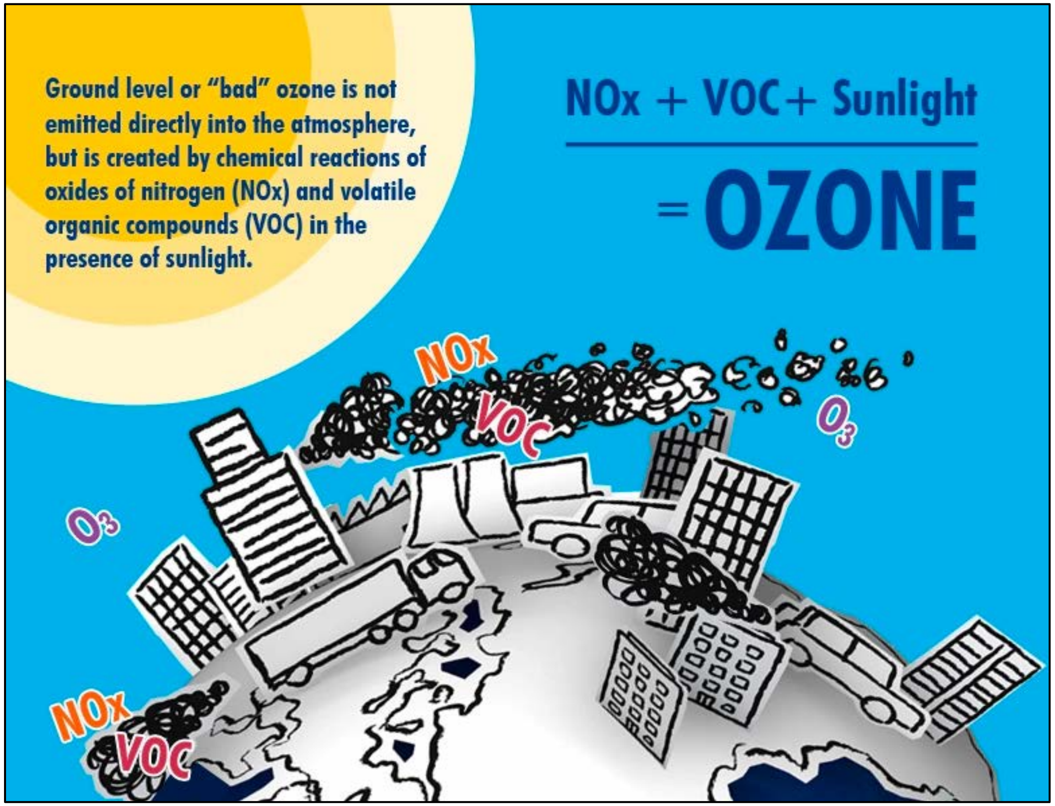
Why specifically "**surface ozone**"?

Ozone is a secondary pollutant

Source: Chemical reaction: CO/VOCs + NO_x + sunlight → ozone

Removal: Dry deposition

Impact: Climate, health, food security, vegetation



Surface Ozone

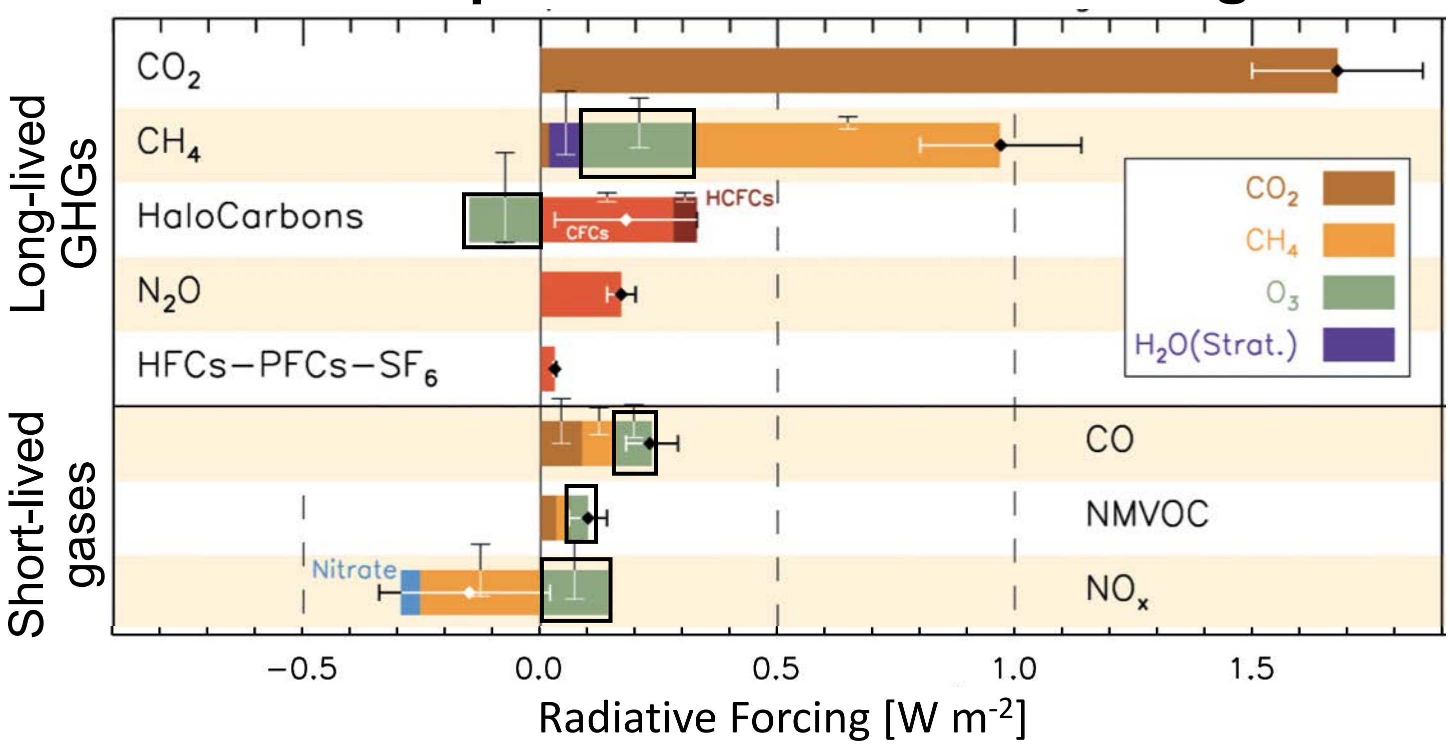
Climate Impact

Absorb radiation

Radiative forcing: measure of change in energy (heat) balance of the Earth

Radiative forcing shown in terms of the chemicals that form (CH_4, CO, NMVOCs, NO_x) and deplete (halocarbons) ozone.

Components of Radiative Forcing



Surface Ozone

Health Impact

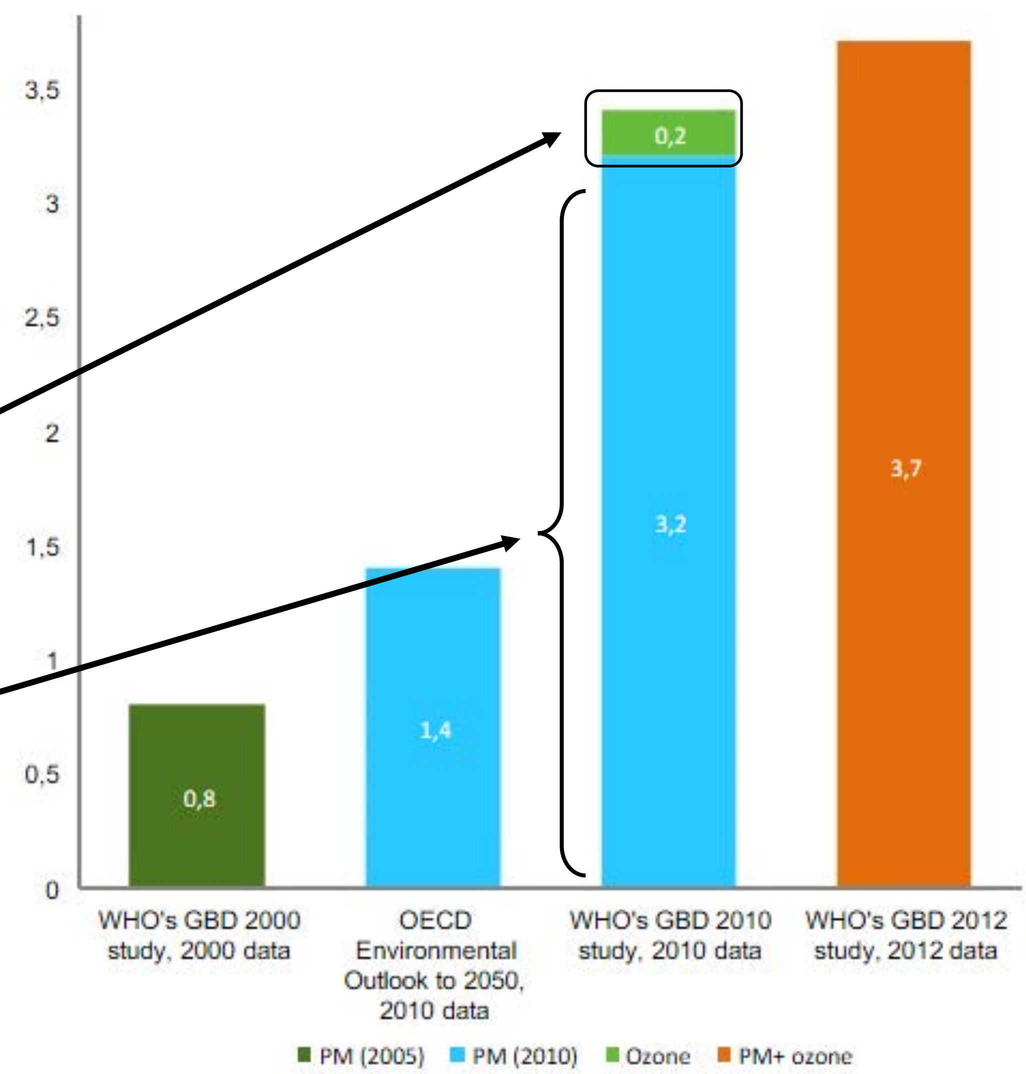
Greatest impact on the vulnerable (elderly, young, existing health issues)

Much smaller contribution to air pollution deaths than $PM_{2.5}$ (~6% of total in 2010).

OZONE (O_3)

$PM_{2.5}$

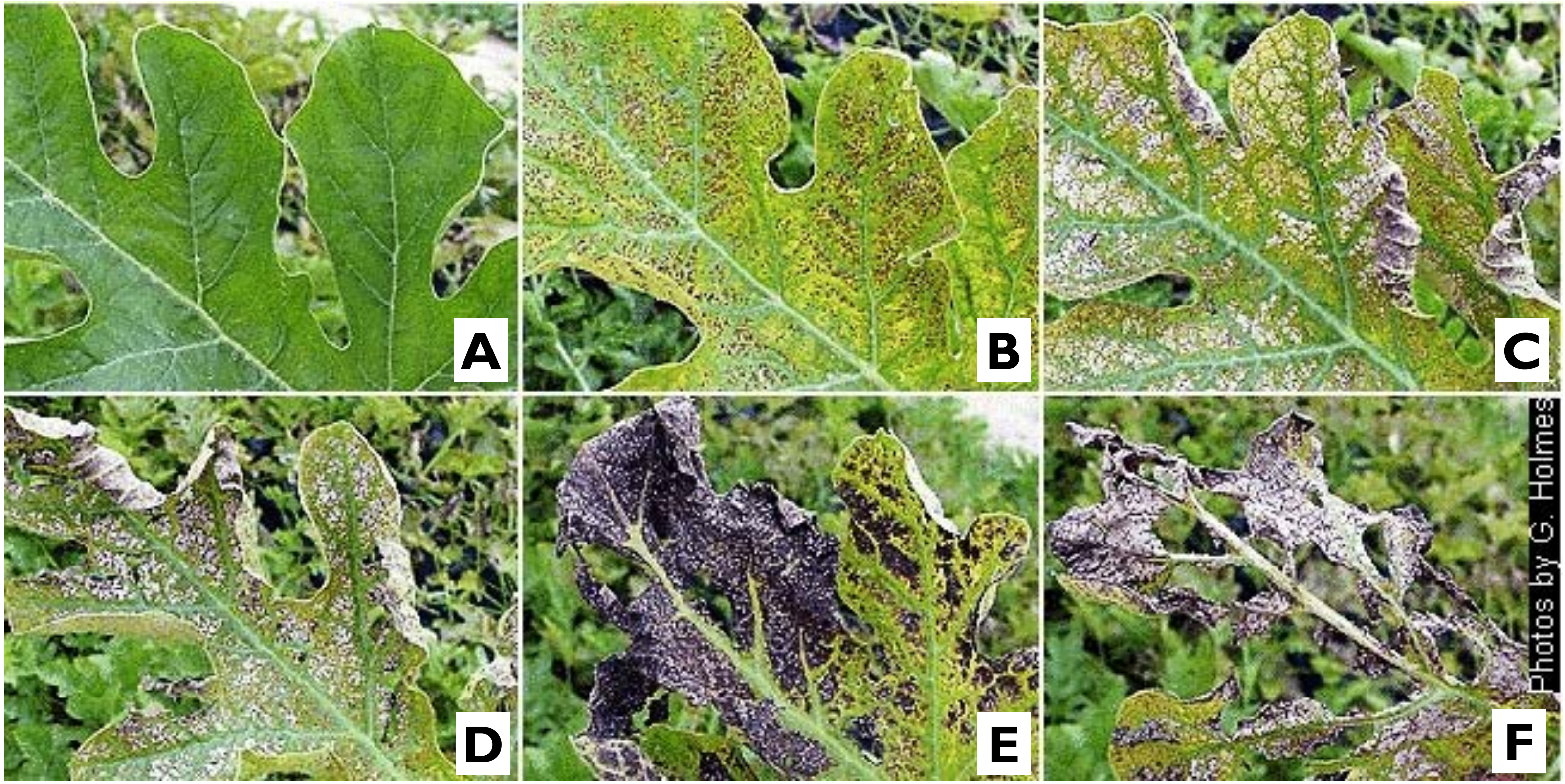
Figure 2: **Deaths caused by outdoor air pollution** (in millions)



Surface Ozone

Food Security Impact

Progression of ozone damage (A=none to F=severe) on watermelon foliage

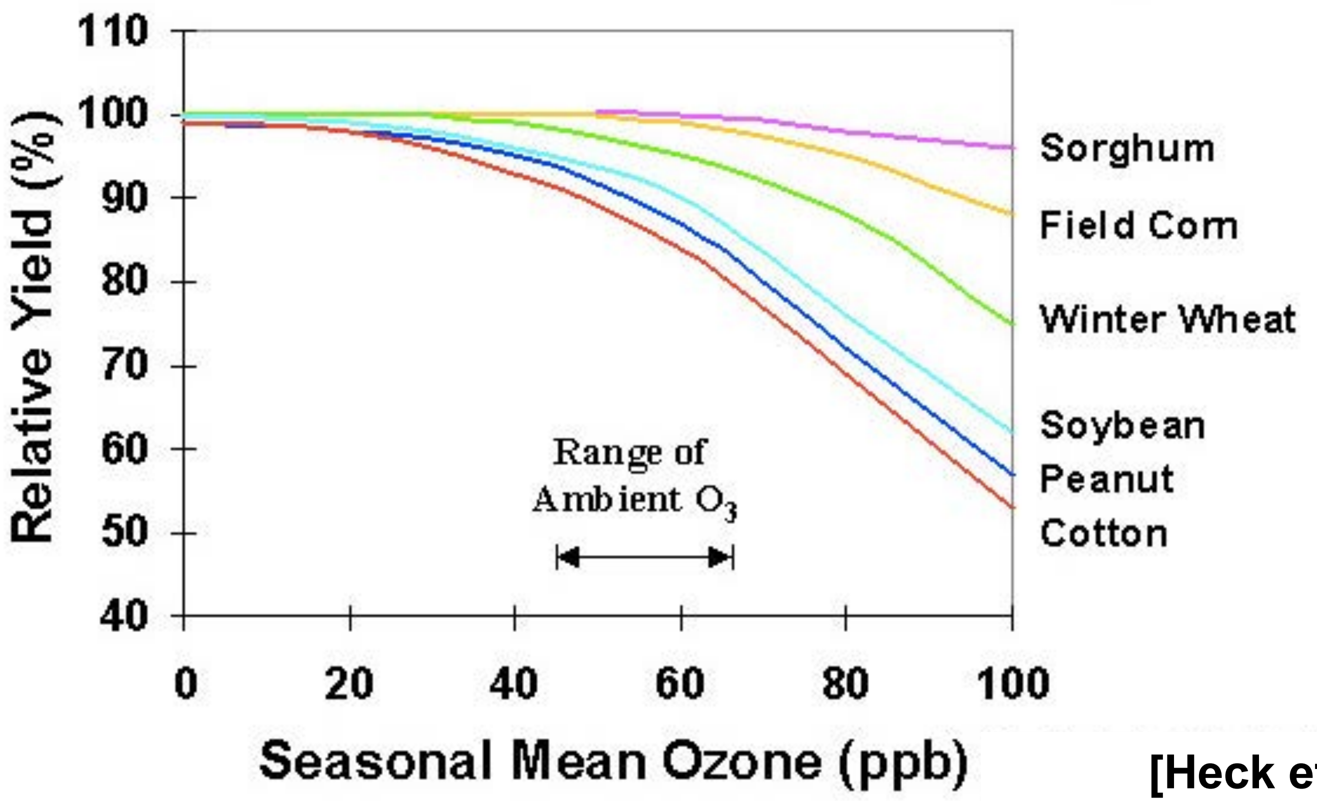


Damage occurs at relatively low ozone concentrations (**40 ppb**)

<u>Varying degrees of sensitivity</u>:
very sensitive (soybean), moderately sensitive (rice/maize), no damage (barley).

Surface Ozone

Relating exposure to crop yield losses



[Heck et al., 1983]

Relationship between ozone and crop yields is more complex than illustrated above.

Implication: ozone exposure not always equal to ozone concentration.

Surface Ozone

Worked Example

Groundnut (peanut) is a staple crop grown extensively in Nigeria (and across the African continent). Under ideal conditions groundnut yields are 2.5 tonnes per hectare (tonnes ha^{-1}). What is the yield if ozone is 60 ppb during the growing season?

$PM_{2.5}$ and Surface Ozone

Summary Comparison of the two

	$PM_{2.5}$	Surface Ozone
Sources	Primary and Secondary (1º: OA, BC, dust, soil; 2º: SO_4, NO_3, NH_4, OA)	Secondary (NO_x + CO/VOCs + sun)
Removal	Wet and dry deposition	Dry deposition
Impacts	Absorb and scatter radiation	Absorbs radiation
	Vegetation (change light availability)	Crops (damage and decrease yields)
	Health (all population)	Health (susceptible population)

NOTE: primary OA is called **POA**, secondary OA **SOA**

Photochemical Smog

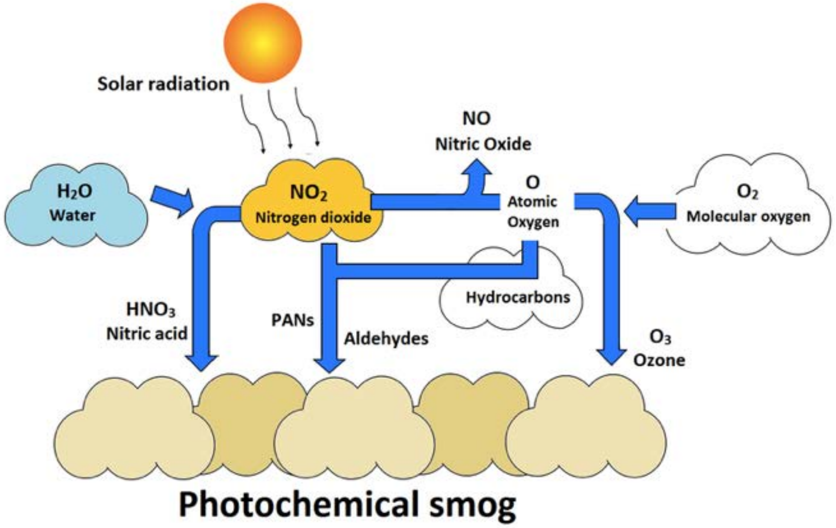
Hazy pollution layer of high levels of very reactive primary and secondary pollutants

Cause: Photochemical reactions of very large sources of VOCs, NO_x, SO_2.

Impact: health, infrastructure (buildings), ecosystems (acid rain)

Health effects: eye irritation, respiratory problems, coughing and wheezing

London Smog



PAN: peroxyacetyl nitrate
Aldehydes: types of VOCs

Acid Rain

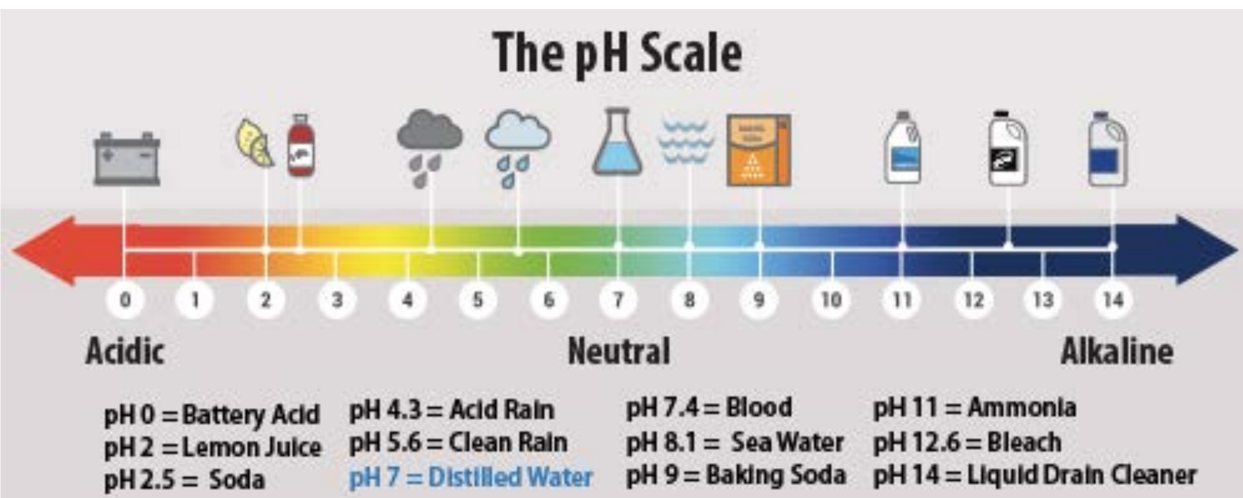
Effect: unusually acidic rain (pH < 5.6)

Sources: wet and dry deposition of secondary pollutants

Example: **Sulfates** from SO_2 oxidation and **nitrates** from NO_x oxidation increase acidity (decrease pH)

Impact: ecosystems (terrestrial and aquatic), infrastructure, leaching of soil nutrients, solubilizes harmful metals

Where does acid rain fall on the pH scale?



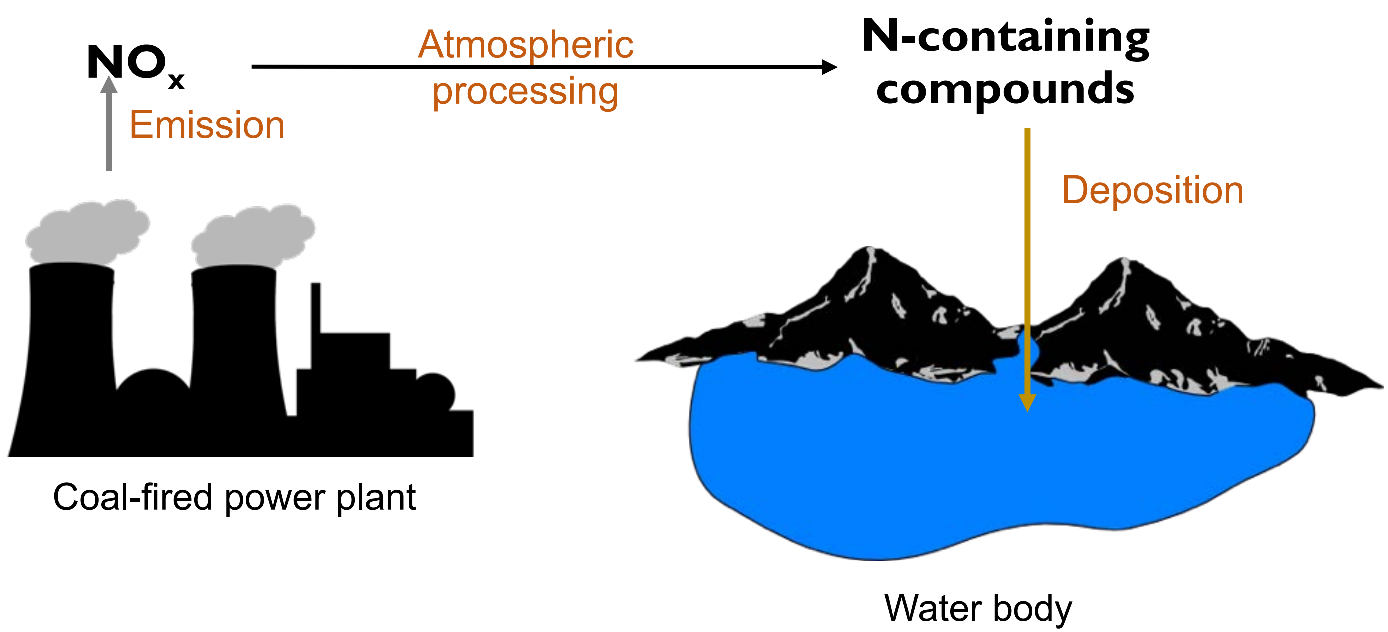
Forest damage

Eutrophication

Effect:
Excessive enrichment of nutrients in water bodies
Increase aquatic biomass and deplete oxygen

Cause: Wet and dry deposition of nitrogen from NO_x emissions (other contributors: detergents, fertilizers, sewage)

Impact: decrease biodiversity, change species composition

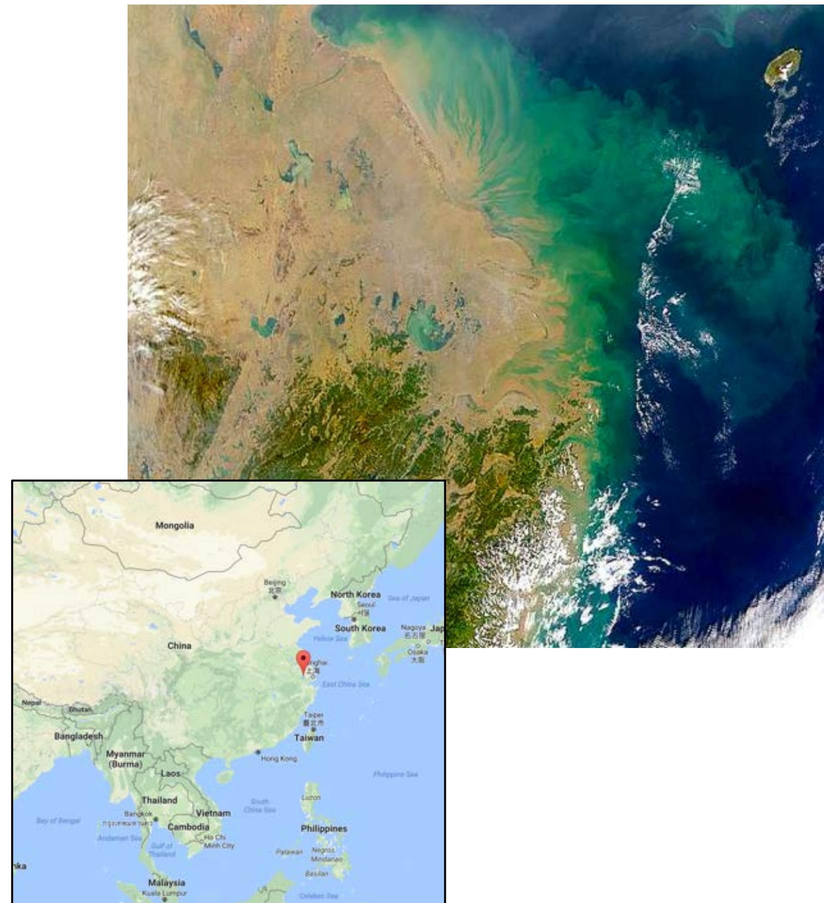


Eutrophication

Eutrophication visible from space

Black Sea

Taihu Lake and Yangtze River delta



[Source: https://visibleearth.nasa.gov/view_cat.php?categoryID=690]

Persistent Organic Pollutants (POPs)

Long-lived organic compounds

Transported long distances

Bioaccumulate / biomagnify

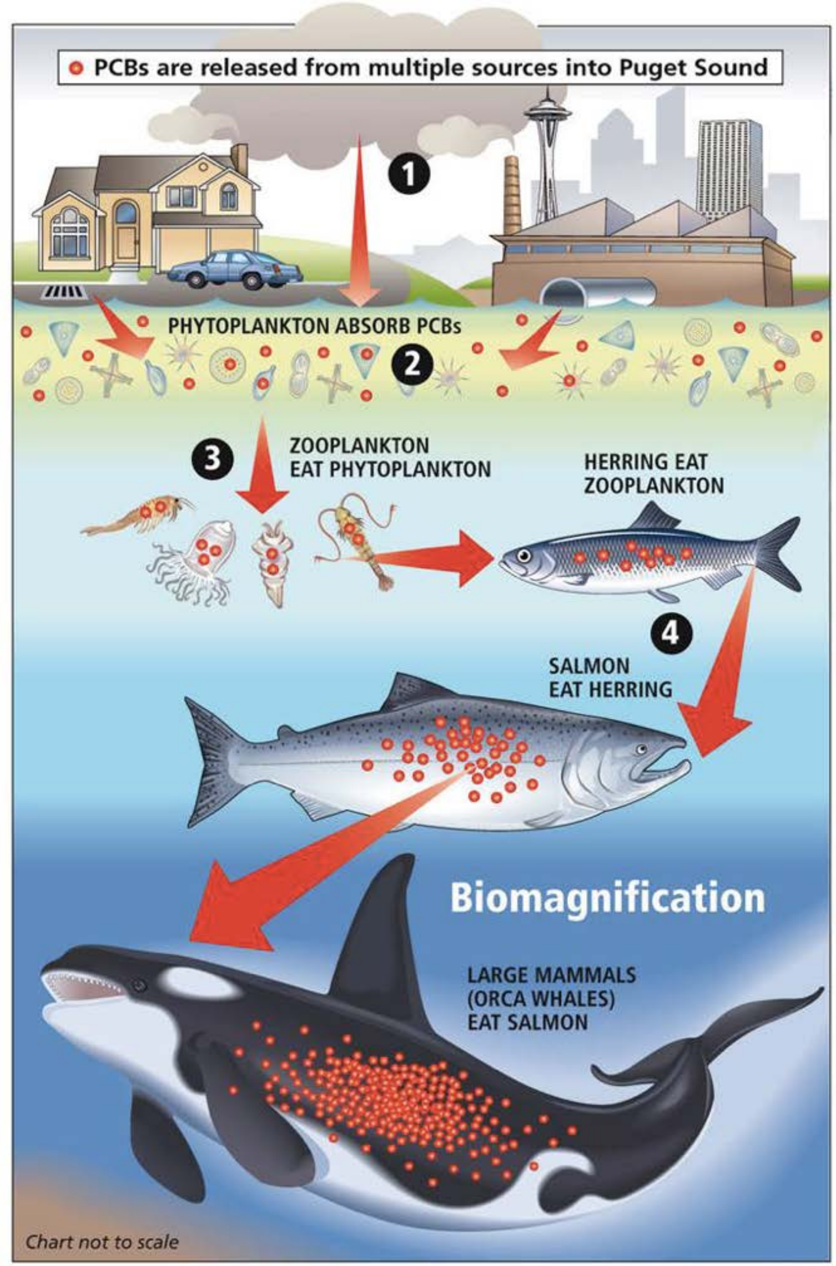
Sources: industry, wood burning, wildfires, pesticides, pharmaceuticals

Many kinds:
Polychlorinated biphenyls (PCBs)
Polycyclic aromatic hydrocarbons (PAHs)

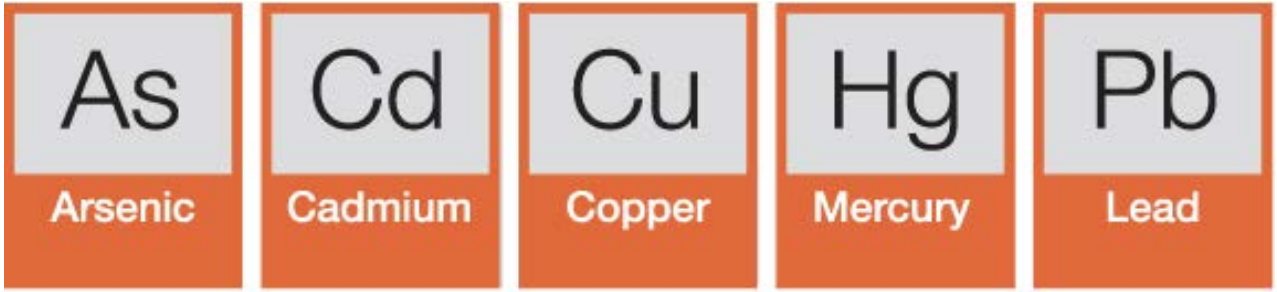
Health effects: development defects, chronic disease, death, cancer, endocrine disruptors.

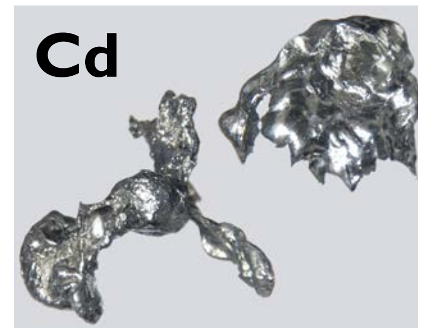
International treaty to restrict production and use of POPs:

Stockholm Convention on persistent organic pollutants (POPs)



Heavy Metals





Many desirable properties:
Lustre (shine)
Good conductors of electricity
Non-degradable
Malleable: reformed into thin sheets
Ductile: drawn into wires

Sources: forestry, mining, fossil fuel combustion, waste incineration, smelting, metallurgical industries

Target vital organs:
As → liver (hepatotoxic)
Hg/Pb → brain (neurotoxic)
Cd → kidney/lungs (nephrotoxic/pulmonotoxic)

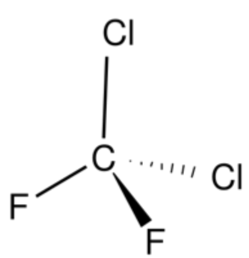
Bioaccumulate if react with organic compounds to form organometallics (e.g. methyl mercury).

Chlorofluorocarbons (CFCs)

<u>Effect:</u> Long-lived gases that deplete stratospheric ozone

<u>Sources:</u> fridges, air conditioners, spray cans, insulation material

<u>Impact:</u> increase harmful UV radiation reaching the Earth's surface

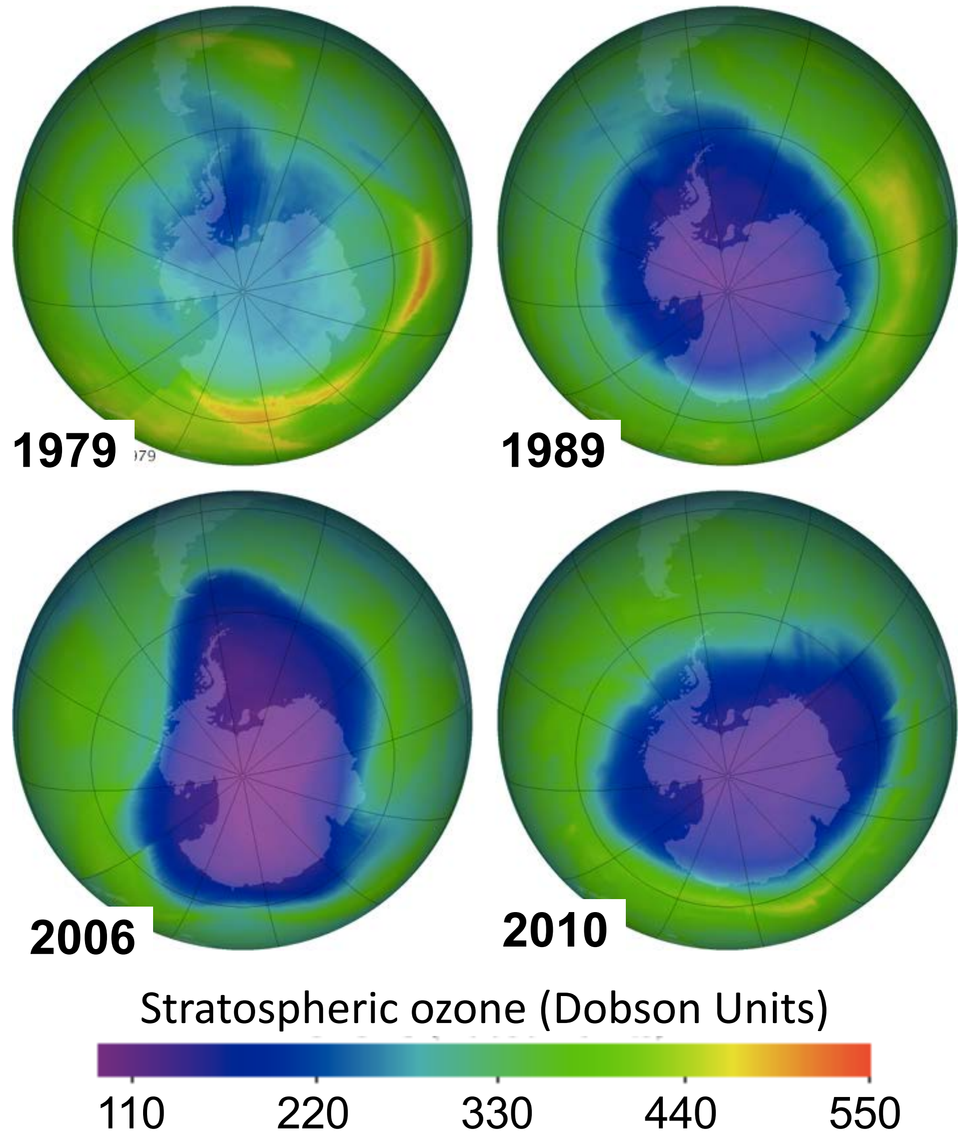


Dichlorodifluoromethane

Cl: chlorine

F: fluorine

Progression of the Ozone Hole



1 Dobson Unit = 2.69 x 10^{16} molecules cm^{-2}

CFCs and the Montreal Protocol

International treaty that led to the successful phase-out of CFCs

The treaty is 30 years young

Video: https://www.youtube.com/watch?v=6ezl0ky45CQ

Success of the Montreal Protocol features prominently in the debate about how to implement international cooperative **climate change policy**.

Pollution Sources Summary

Pollution	Description
Photochemical smog	Hazy layer of high concentrations of pollution
Acid rain	Unusually acidic rain that impacts ecosystems
Eutrophication	Excess nutrients to ecosystems disrupting biodiversity
POPs	Long-lived organic pollutants that bioaccumulate
Heavy metals	Toxic to vital organs
CFCs	Long-lived gases that destroy stratospheric ozone

Economic Burden of Air Pollution

What are the costs of air pollution?

- Stress on the health system
- Agricultural losses
- Ecosystems losses
- Infrastructure damage
- Loss of work productivity
- Decreased quality of life

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PRESS RELEASE

Air Pollution Deaths Cost Global Economy US$225 Billion

September 8, 2016

Global Loss of Wheat Due to Ozone Pollution (CEH report)

	2000	2020
Loss in production (t)	26.9 million	16.5 million
Loss in value[1]	3.2 billion Euro	1.96 billion Euro
Area at risk of losses[2]	24.5 million ha	24.5 million ha

Cost-Benefit Analysis (CBA)

Information required for a cost-benefit analysis:

Cost to regulate?

Examples:

Scrubber in a coal-fired power plant (industry-level)

Switch from fossil fuel to renewable energy (country-level)

Cost to comply?

Frequent checks (e.g. annual MOT)

Benefits?

Examples:

Reduced urban pollution: increase visibility, appeal of city, sustainability of city, house prices

Reduced rural pollution: increase food security, food production and revenue for farmers

Benefits can be challenging to quantify. How to value a healthy forest, access to viable green spaces, a nutrient balanced water body?

Cost-Benefit Analysis (CBA)

Aim: Do benefits of an intervention exceed the cost?

Inputs:
Health: Mortality or morbidity or life lost metrics (YLL or DALYs or QALYs).
Agriculture: crop yield losses

Calculate (using a model):
Cost of mitigation strategy
Benefit to health, wellbeing, food security

Primary output:
benefit-cost-ratio (< 1: costs exceed benefits; > 1 benefits exceed costs)

Other outputs:
Economic internal rate of return (return on investment)
Net present value (net gain in currency units of the base/start period)
Break-even point (when economic benefits = resource investment)

Tools are available (e.g. from US EPA) to estimate costs and benefits

Lecture Summary

Sources, atmospheric processing, ultimate fate of pollutant types

Types of air pollution and air pollutants

Impacts of air pollution:

human health, food security, climate, infrastructure, vegetation, ecosystem health

Cost-benefit analysis:

Benefits must outweigh costs

Worked Example

Thought Experiment

Task: The Birmingham City Council seeks the services of your Consultancy company to determine personal exposure to roadside pollution at a bus stop along the A4040.

Questions following Week 4:

What monitors would you use? (Week 3)

What pollutants would you measure? (Week 4)

Is there additional information you need to effectively assess roadside pollution exposure?