POLLUTION IN THE ARCTIC

GEOG/ENST 3331 – Lecture 16

Last lecture

- Acidity and acid rain
- Impacts of acid rain
- Sources and mitigation

Pollution in the Arctic

- **Arctic haze**
  - **Climatology**
  - **Sources**
  - **Impacts and remediation**
- Persistent organic pollutants
  - POP examples
  - Long range transport
  - Remediation

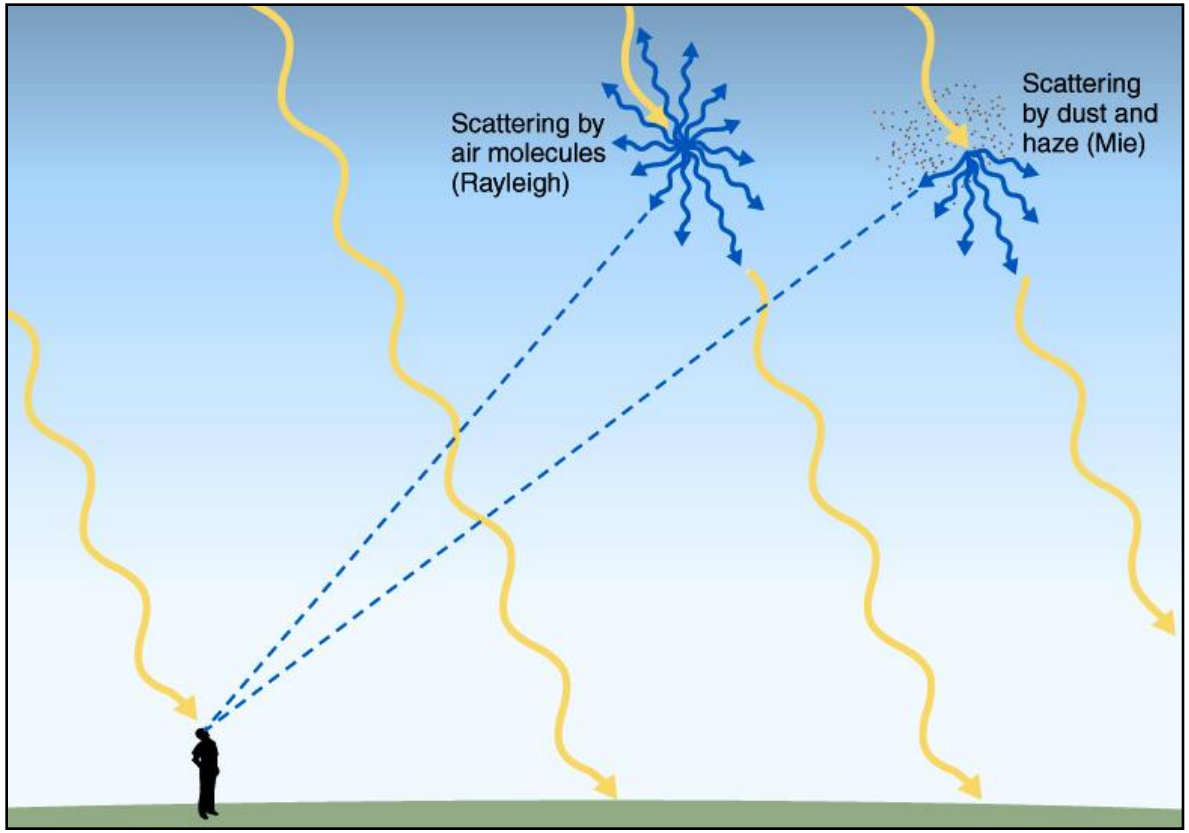
History of Arctic haze

- First noted in the 1950s by aircraft pilots
- Appears grayish or brownish in colour
- Seasonal variation – peaking in spring
- Pooling appears to occur

Scattering

When incoming radiation encounters small particles the radiation is deflected in all directions.

- *Rayleigh scattering* by gases.
- *Mie scattering* by aerosols



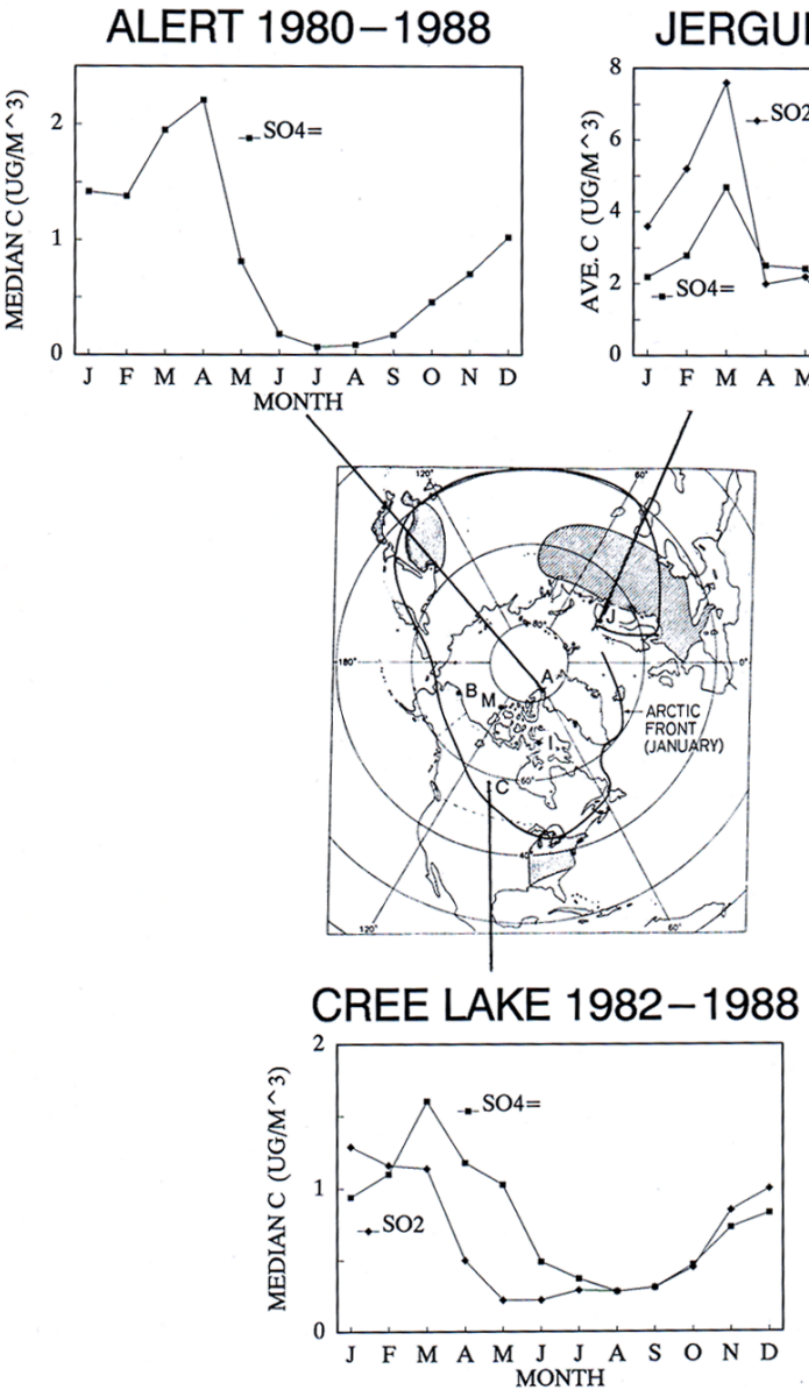
A&B: Figure 3-3

Arctic Haze

Sulfur dioxide and sulphate loading

$\mu m/m^3$

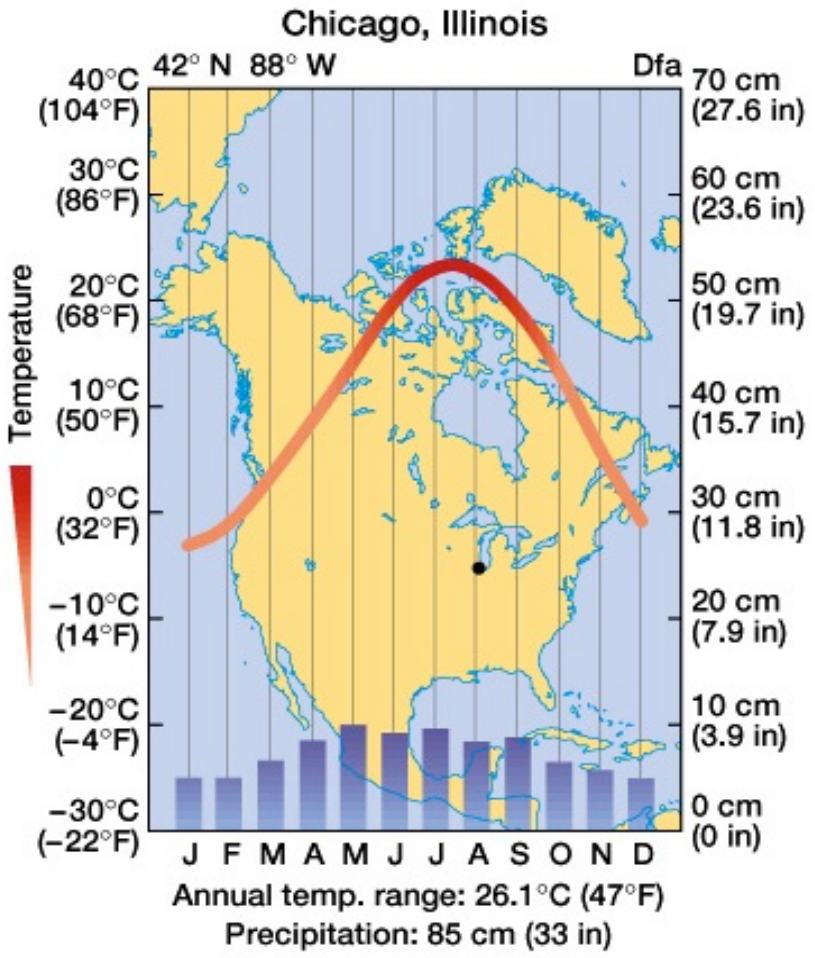
Seasonal cycle

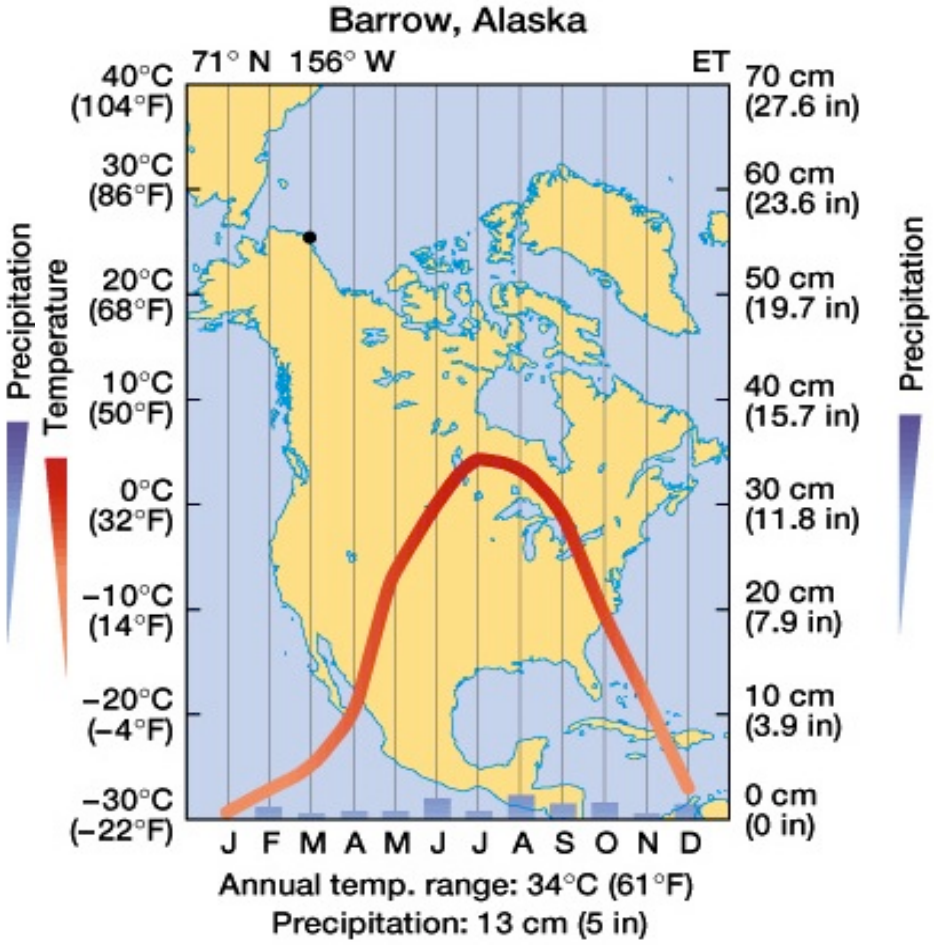


Arctic climate

- Winter
  - Very cold: average temperature -40°C
  - No sunlight; no surface heating
  - Air warmer than surface
    - Temperature inversion
- Low precipitation
  - Canadian archipelago: 20-50 cm / year
  - More in summer than in winter

Climographs





Arctic haze constituents

- Sulfate levels 10 to 20 times larger than normal
- Mixed with particulate organic matter to form aerosol particles
- Also contains:
  - Soot (carbon)
  - Ammonium
  - Nitrates
  - Dust
  - NO_x
  - VOCs

Arctic haze constituents

- Trace constituents can adhere to the aerosols and pool in the Arctic air
  - Metals
  - Persistent organic pollutants (POPs)

Arctic Haze

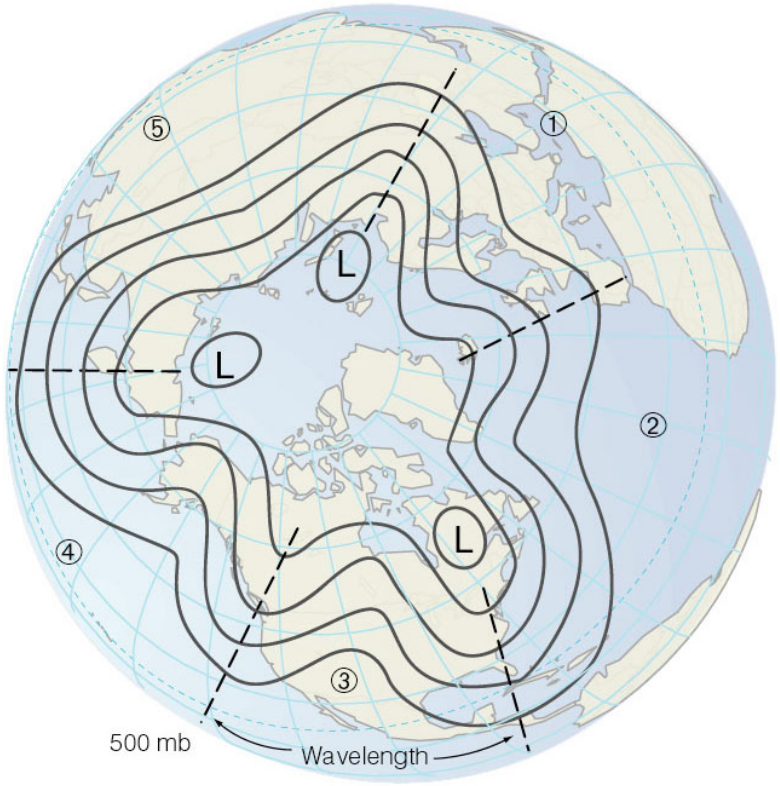
- Long range transport?
  - Occurred on a regional basis with acid rain
  - Depletion occurred due to scavenging by rain
  - Forms plume of pollutants

- 1972 – Glen Shaw – suggested long range transport as likely mechanism for source of Arctic haze
  - Presence of trace metals suggests coal burning

Arctic

Source: *CIA World Factbook*

Rossby Waves



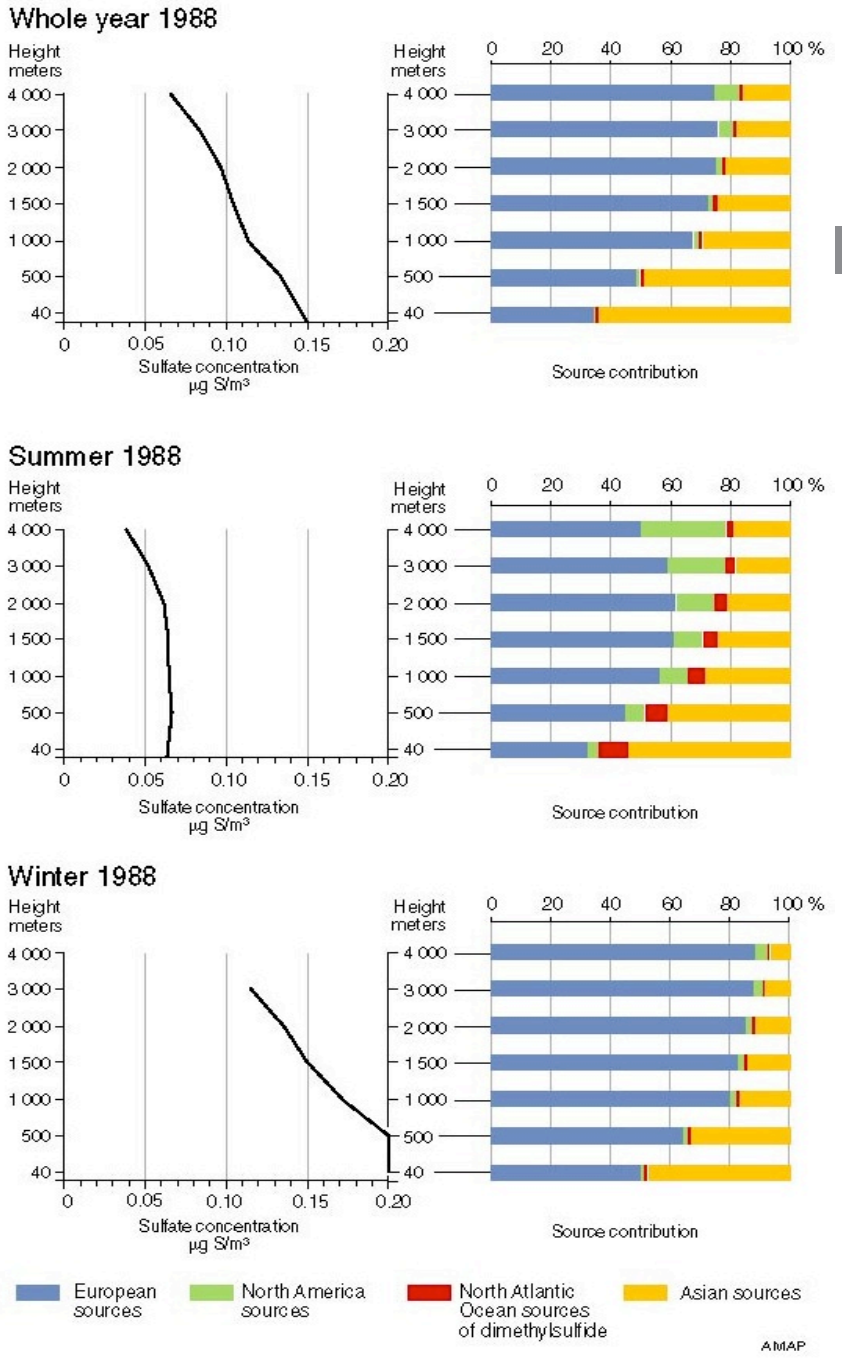
Arctic Haze

- Pollutants pool in the Arctic winter
  - Stable atmosphere – temperature inversion
  - Little precipitation
- Disperse in summer
  - Solar radiation destroys temperature inversion
    - Vertical dispersion
  - Greater precipitation (slightly) to wash out pollutants

Vertical distribution

Sulfur loading in Barrow, Alaska

Source: AMAP



Impacts of Arctic haze

- Warmer temperatures
- Reduced visibility, especially in spring
- Ozone production
  - NO_x and VOCs
- Contamination of snow, ice and Arctic waters
  - Haze brings with it heavy metals and other toxins
- *Bioaccumulation* of toxins
  - Ingestion is greater than excretion

Remediation

- Coal based emissions
- Solutions easy to identify, difficult to implement
- Reduction of coal emissions, especially in Eurasia


Transport of pollutants into the Arctic
Primary sources of air pollution
Major rivers flowing into Arctic Ocean
Surface ocean currents
Winter air circulation
H High-pressure cell (clockwise flow)
L Low-pressure cell (counterclockwise flow)
Prevailing winds
CHINA
INDIA
U. S. S. R.
CANADA
U. S. A.
GREENLAND
ALERT
PACIFIC OCEAN
ARCTIC OCEAN
ATLANTIC OCEAN
ARCTIC CIRCLE
Beijing
Seoul
Tokyo
Novosibirsk
Omsk
Chelyabinsk
Sverdlovsk
Kuybyshev
Salekhard
Norilsk
Lena River
Moscow
Arkhangel'sk
Chernobyl
Leningrad
FINLAND
Warsaw
SWEDEN
Berlin
NORWAY
Geneva
Paris
London
ICELAND
Ellesmere I.
Axel Heiberg I.
Alaska (U.S.A.)
Mackenzie River
Baffin I.
Broughton Island
Iqaluit
Rankin Inlet
Hudson Bay
Ungava Bay
St. Lawrence River
Montreal
Toronto
Chicago
Detroit
New York
Pittsburgh
St. Louis
Atlanta
Mexico City
75°
60°
45°
30°
15°

Lecture outline

- Arctic haze
  - Climatology
  - Sources
  - Impacts and remediation
- **Persistent organic pollutants**
  - **POP examples**
  - **Long range transport**
  - **Remediation**

Persistent Organic Pollutants

- POPs
- Long living organic compounds that become concentrated as they move through the food chain
  - Hydrophobic and lipophilic
  - Bioaccumulation and biomagnification
  - Risk to biota health

Persistent Organic Pollutants

- Examples
  - PCBs
  - DDT
  - Chlordane
  - Heptachlor
  - Lindane
  - PAHs (polycyclic aromatic hydrocarbons)

PCBs

- Polychlorinated biphenyls
  - Group of over 200 chlorinated compounds
- Used as coolants and lubricants in electronic equipment
- Links to skin conditions and liver damage

- Production and import ceased in 1977
  - Still in use, however

PCBs in the Environment

- PCBs are hydrophobic (do not bond with water)
- PCBs released in the Great Lakes:
  - Go into the sediment
  - Bioaccumulate
    - Great Lakes food chain bio-magnifies PCBs to dangerous levels
    - Concerns for pregnant women, native populations with high fish diets
  - Volatilize readily into the atmosphere

DDT

- Dichlorodiphenyltrichloroethane
- 1939 introduced as an insecticide in WWII
  - Combating malaria, typhus
  - Eventually saw widespread agricultural use
  - 675,000 tons applied in US
- Extremely hydrophobic and lipophilic
  - Affects bird reproduction; especially problematic for predatory birds (e.g. bald eagles) due to biomagnification
  - Highly toxic to aquatic life, especially fish

DDT

- Conditionally banned in US in 1972
  - Banned in Canada in 1990
  - Stockholm Convention (2001): 98 countries agreed to eliminate DDT except for public health crises
  - *Still has some usage, especially in the tropics, for control of malaria and other insect-borne disease*

- Classified as a "probable carcinogen" by US EPA
  - Studies of the extent that it is toxic or carcinogenic in humans have been inconclusive; some controversy about its 'ban'

Chlordane

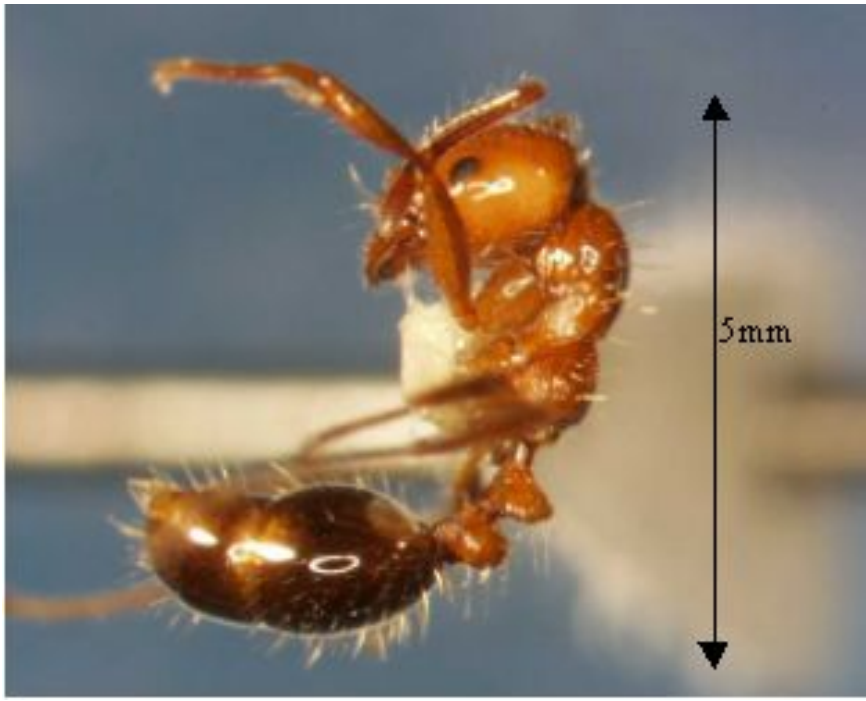
- $C_{10}H_6Cl_8$ Octachlorodihydrodicyclopentadiene
- Insecticide – used from 1948 to 1983
- Linked to disorders of the nervous system and digestive system
- Canada: banned in 1995
- US: banned in 1988, except for fire ant control in power transformers
  - Production for export ceased in 1997

Heptachlor

- $C_{10}H_5Cl_7$ Heptachlorodicyclopentadiene
- Insecticide (termiticide)
- White powder (smells like mothballs)
- Linked to damage to the nervous system
- Canada: banned in 1985
- US: banned in 1988 except for use for fire ants in power transformers

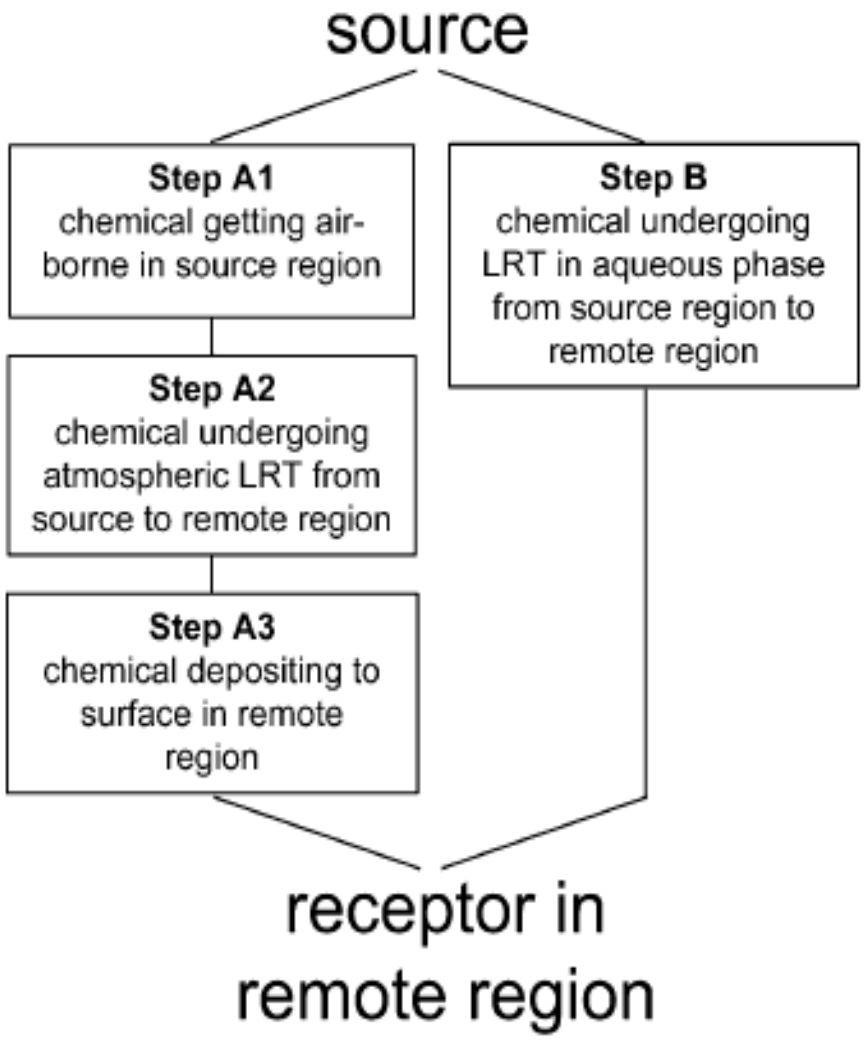
Fire Ants?

- 1930s – red fire ants imported to Alabama (accidentally) from South America
- Since then the ants have invaded 260 million acres of land in the southern US
- Still spreading (Arizona, California)
- Painful sting
- Attracted to electrical fields



POP Transport

- Chemistry
- Dynamics



Wania and Mackay (1993)

- Examination of pollutant concentration data in air, snow, fish, seals
  - Creation of a chemical fate model to explain high concentrations
- Conclusions from review:
  - No local sources
  - Ban of POPs has not resulted in any significant reduction

Yoho National Park, B.C.

Global distillation

- Distillation:
  - Separating mixtures based on volatility
  - E.g. alcohol, petroleum
- Global distillation:
  - Volatile compounds deposit in colder climates

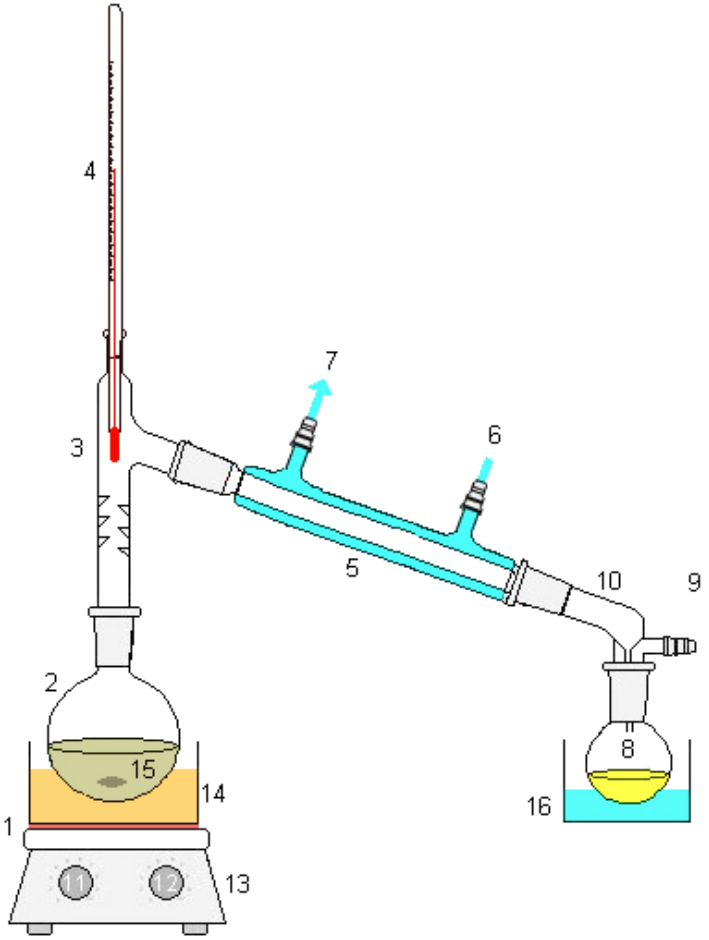


Image source: Wikipedia

Chemistry of POP transport

- POPs enter the atmosphere in gas form (*volatilize*)
- As they travel poleward, fractionation and condensation occurs due to cooler temperatures
- Phase change to liquid or solid phase

- Lower temperatures lead to direct deposition and *adsorption* on particulate matter
- Adsorption onto sulfates – transported to Arctic

Two methods of atmospheric POP transport

1. "Grasshoppering"
   - In poleward journey, deposition due to cooler temperatures takes place (especially in cooler seasons)
   - Re-volatilized in warmer seasons – airborne once again
   - Process continues until Arctic is reached

2. Sulfate adsorption provides a shortcut
   - Arctic haze

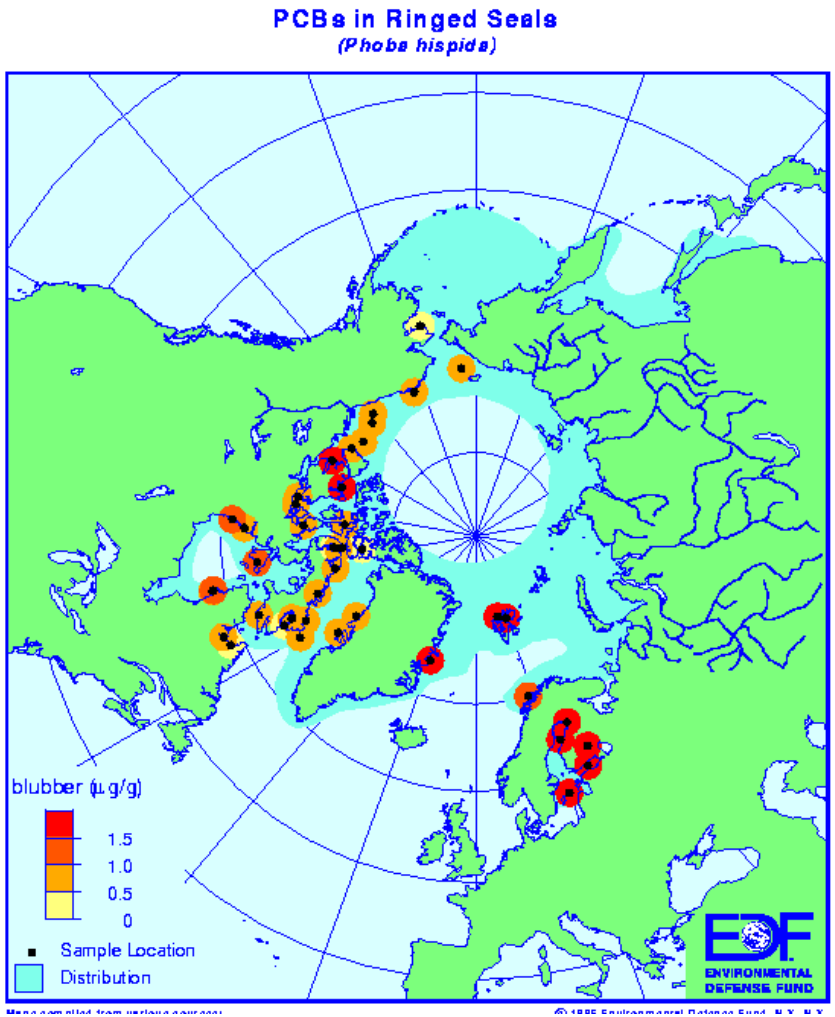
Pooling of Arctic POPs

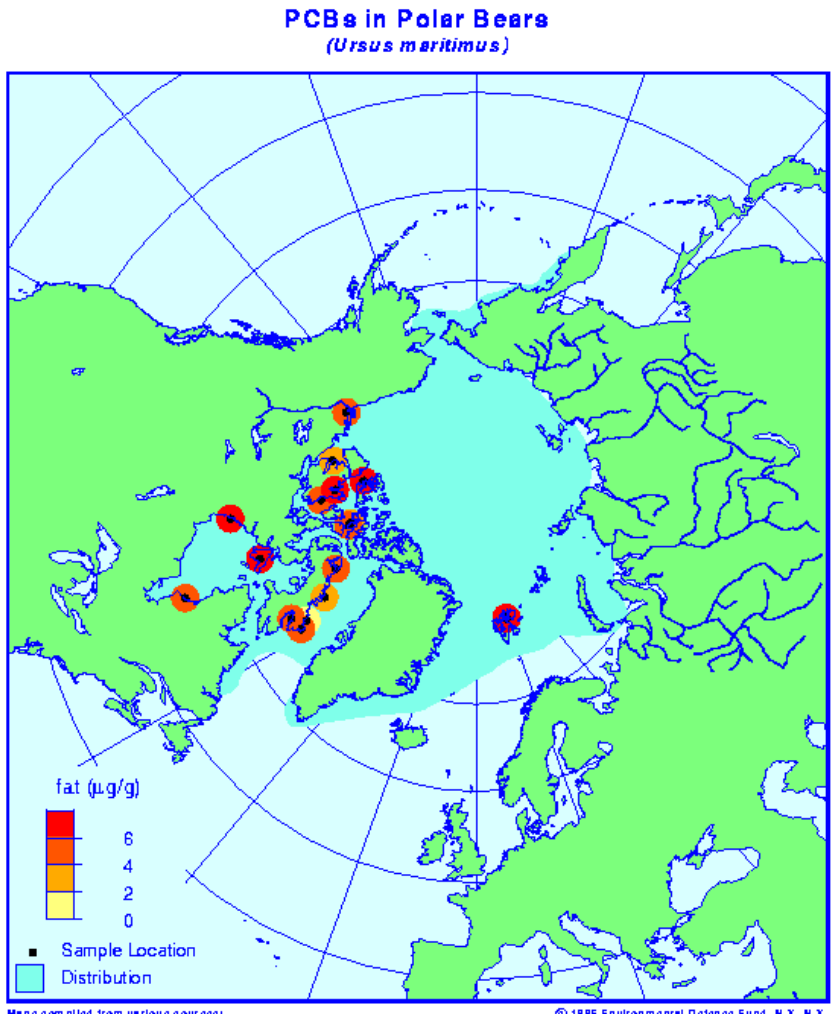
- Cold temperatures allow for phase change (condensation or deposition)
  - Removes POPs from atmosphere
- Arctic air dynamics (temperature inversion) traps pollutants (as in the case of Arctic haze)
- Chemical breakdown slowed by cold temperatures

Arctic POPs

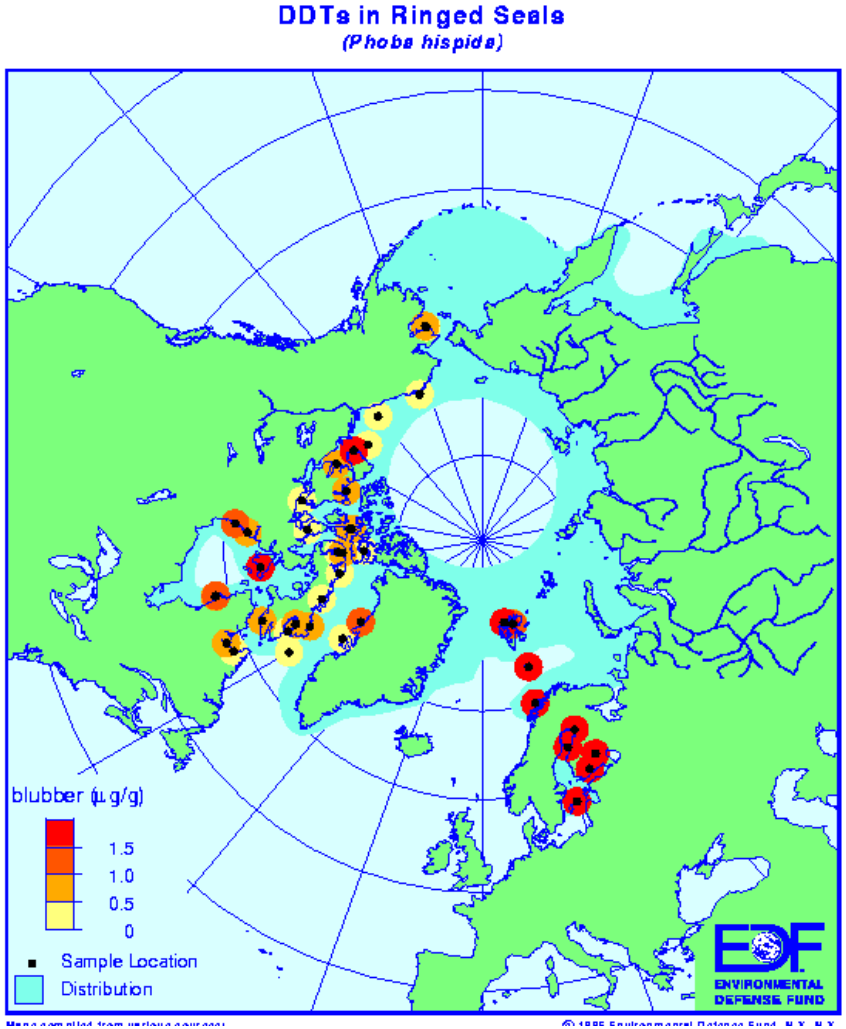
- Impacts on biota
  - Bioaccumulation of POPs
  - High levels found in Arctic polar bears
  - Polar bears feed on ringed seals which also have high levels
  - Suspected effects on immune system

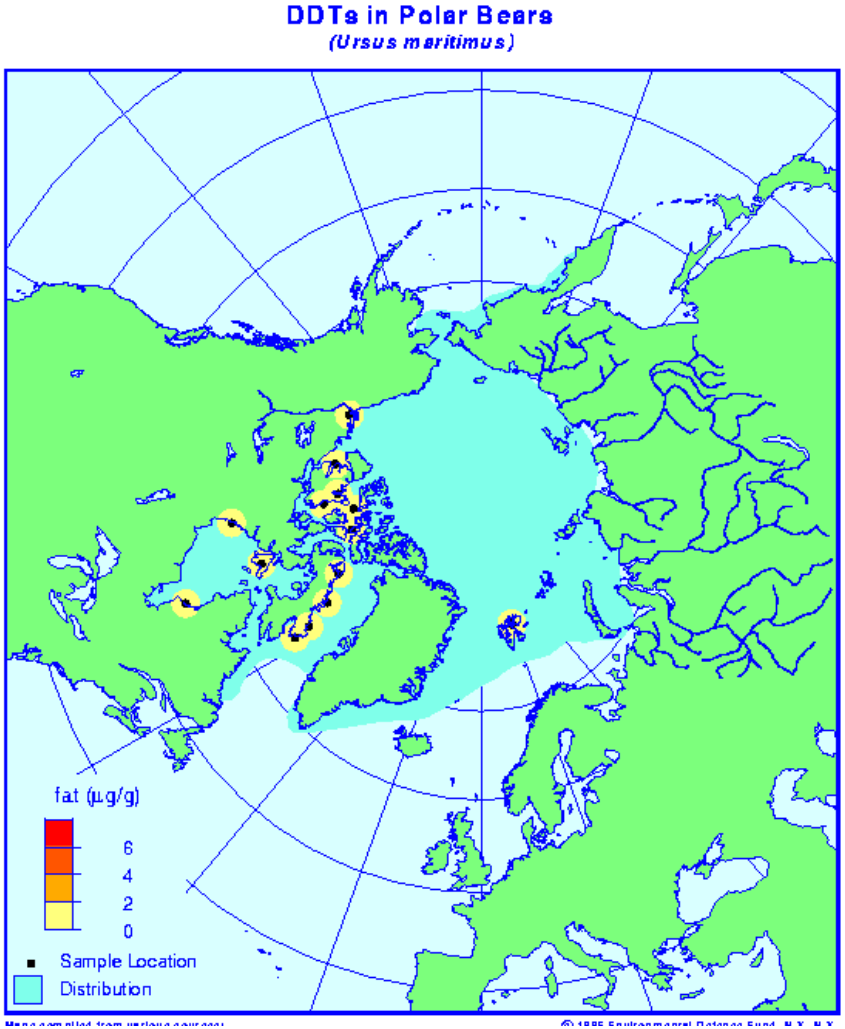
PCB Bioaccumulation





DDT Bioaccumulation





Remediation

- Many POPs have been banned from western countries
- In some cases, all production has ceased
- Stockholm Convention on Persistent Organic Pollutants (2001)

Stockholm Convention

- Stockholm Convention - global treaty to protect human health and the environment from persistent organic pollutants (POPs)

- In implementing the Convention, Governments will take measures to eliminate or reduce the release of POPs into the environment

“Dirty dozen”

- First step – elimination of the 12 most harmful POPs

Aldrin	**DDT**	**Hexachlorobenzene**
Chlordane	Endrin	Mirex
Dieldrin	Furans	**PCBs**
Dioxins	**Heptachlor**	Toxaphene

- Nine of the twelve are pesticides
- Exceptions are PCBs, dioxins and furans

“Dirty… twenty-one”

- May 2009: nine new chemicals added
  - 4 insecticides/pesticides, including **lindane**
  - 4 flame retardants
  - 1 by-product

Stockholm Convention

- Agreement finalized on May 22, 2001
- Update: 179 parties to the agreement
  - Canada signed and ratified agreement on May 23, 2001
  - US, Italy, others have signed but not ratified
  - Treaty became operational on May 26, 2004 when 50 signatories had ratified the agreement and it is now considered to be international law

Ratification in China

- August, 2004
  - Stopped producing PCBs (tonnes in storage, though)
  - Four of the POPs on the list are still produced in China
  - Seeking alternatives, international financial and technical support
- Others have ratified or acceded since:
  - E.g. Russia, UK, France, Iran

State parties to the Stockholm Convention as of 2012

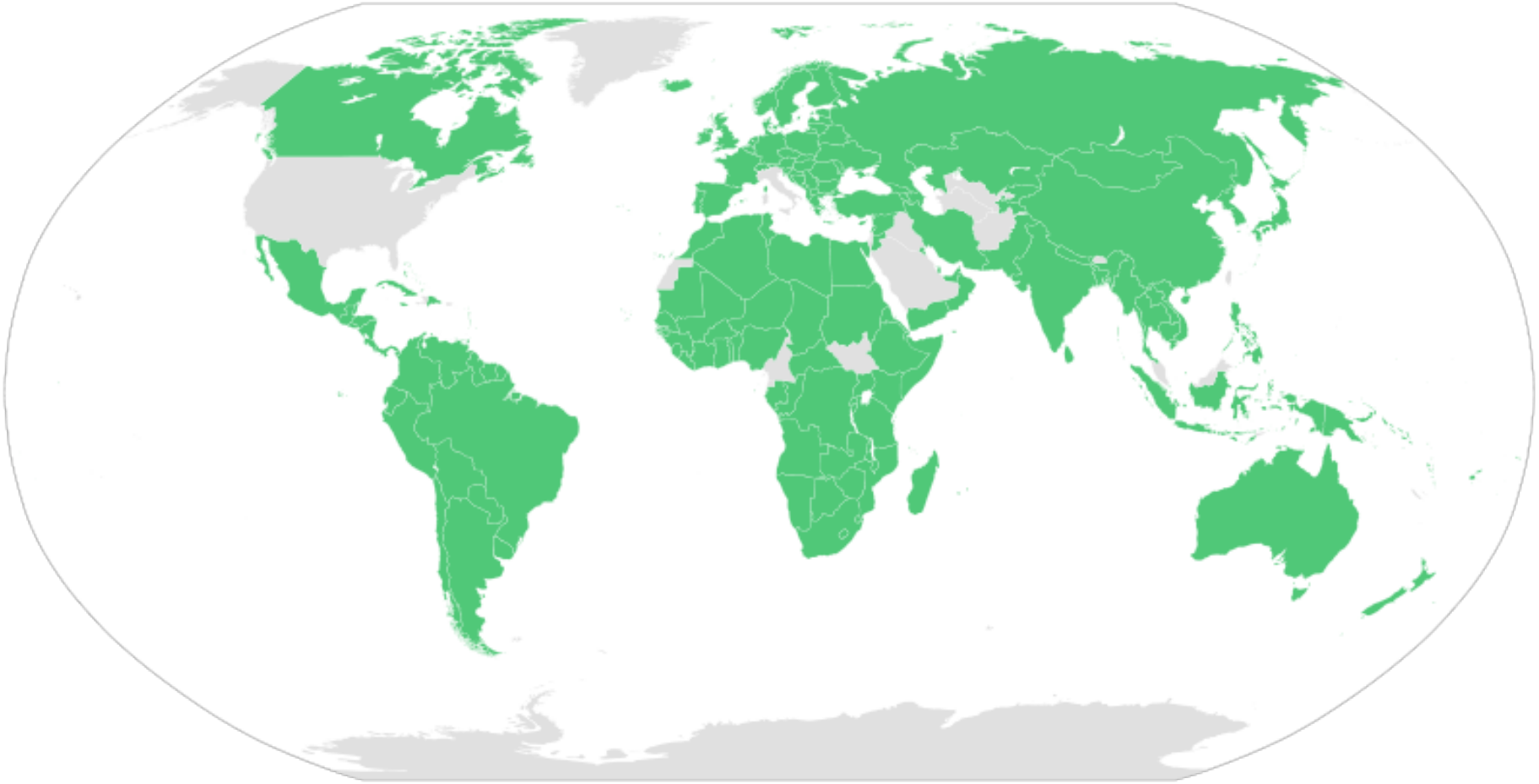


Image source: Wikipedia

Next lecture

- Urban Heat Islands