Friday 29 September 2017
10:30-11:30
Class#14

Final Key Chemicals Relevant for Climate

Topics for today

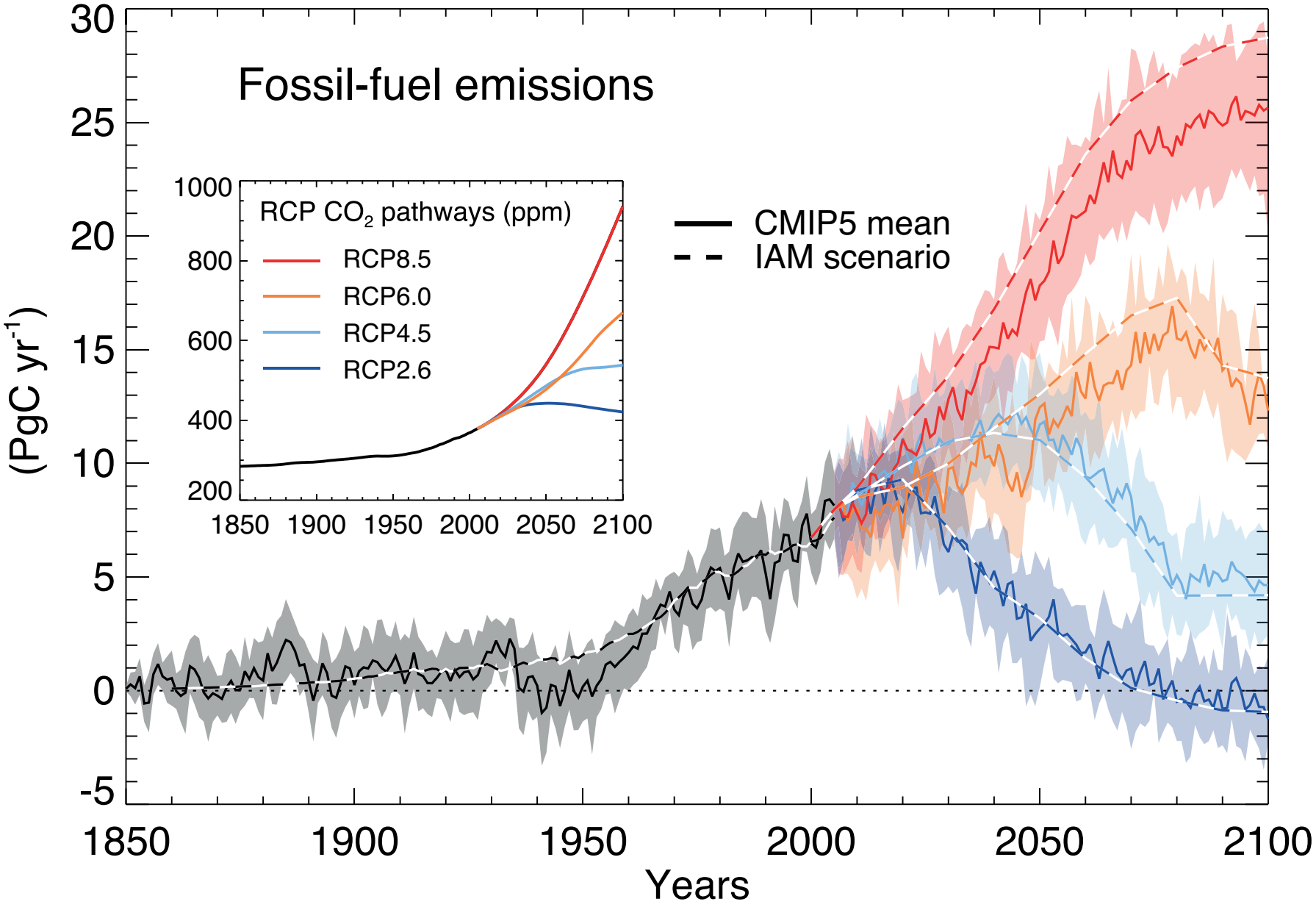
- **RCP Scenarios**
- **Ozone hole**
- **Tropospheric Aerosols**
- **Black Carbon**

Project summary revisions due Monday Class

Review

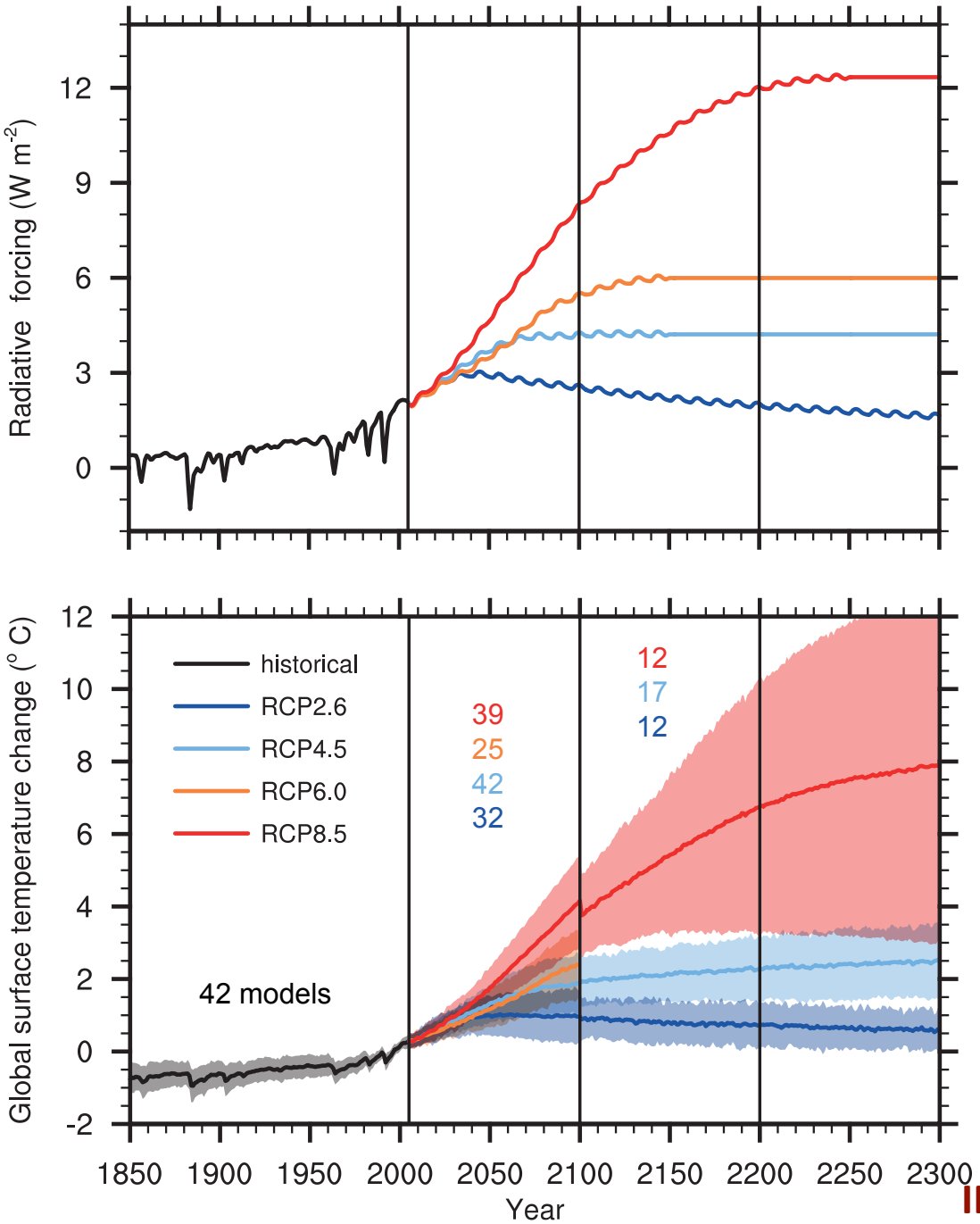
-

Emissions from different scenarios



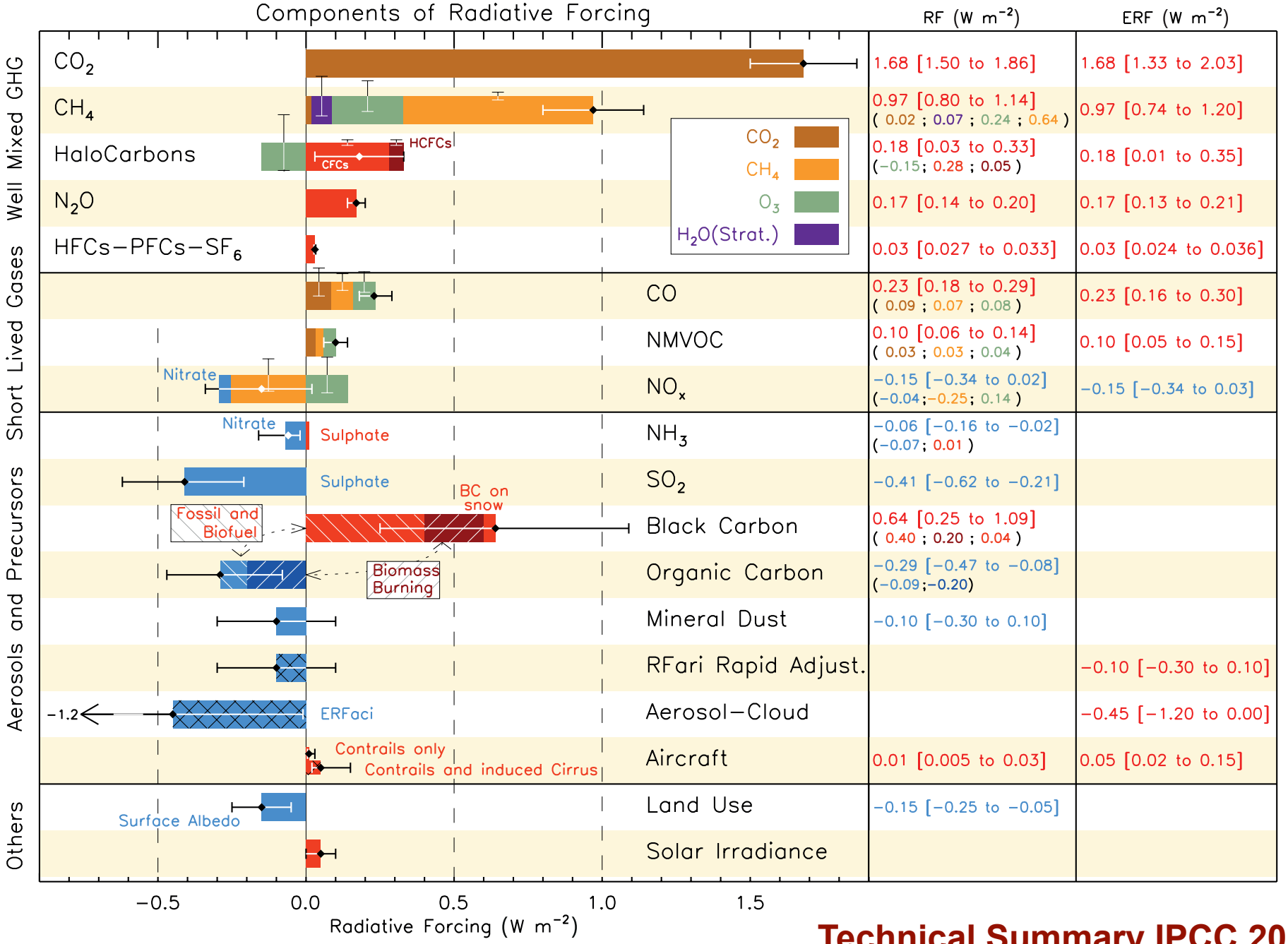
IPCC 2014 Fig TS.19 Technical Summary

Projected Temperatures from different scenarios



IPCC 2014 Fig TS.15 Technical Summary

IPCC summary of Radiative forcing



Technical Summary IPCC 2014

Ozone

- Ozone is a reactive oxygen molecule, O_3
- Ozone is formed when O_2 is hit by UV-C and breaks up into 2 O's. These O's find O_2 to make O_3.
- O_3 absorbs UV-B (less energetic than UV-C) to reduce what we receive at the surface, which is good since UV-B causes skin cancer and sunburn.
- Ozone is depleted by chlorine-bearing compounds (CFCs), used in refrigerants. The decrease of ozone was predicted but not the hole.
- Only Nobel Prize to atmospheric sci. was for Ozone chemistry (Crutzen, Molina, and Rolands)
- Antarctic winter, nitric acid clouds, convert chlorine to reactive form that consumes ozone when the sun comes up again

Ozone hole mechanism

nitric acid & water clouds

N and H_2O particles settle

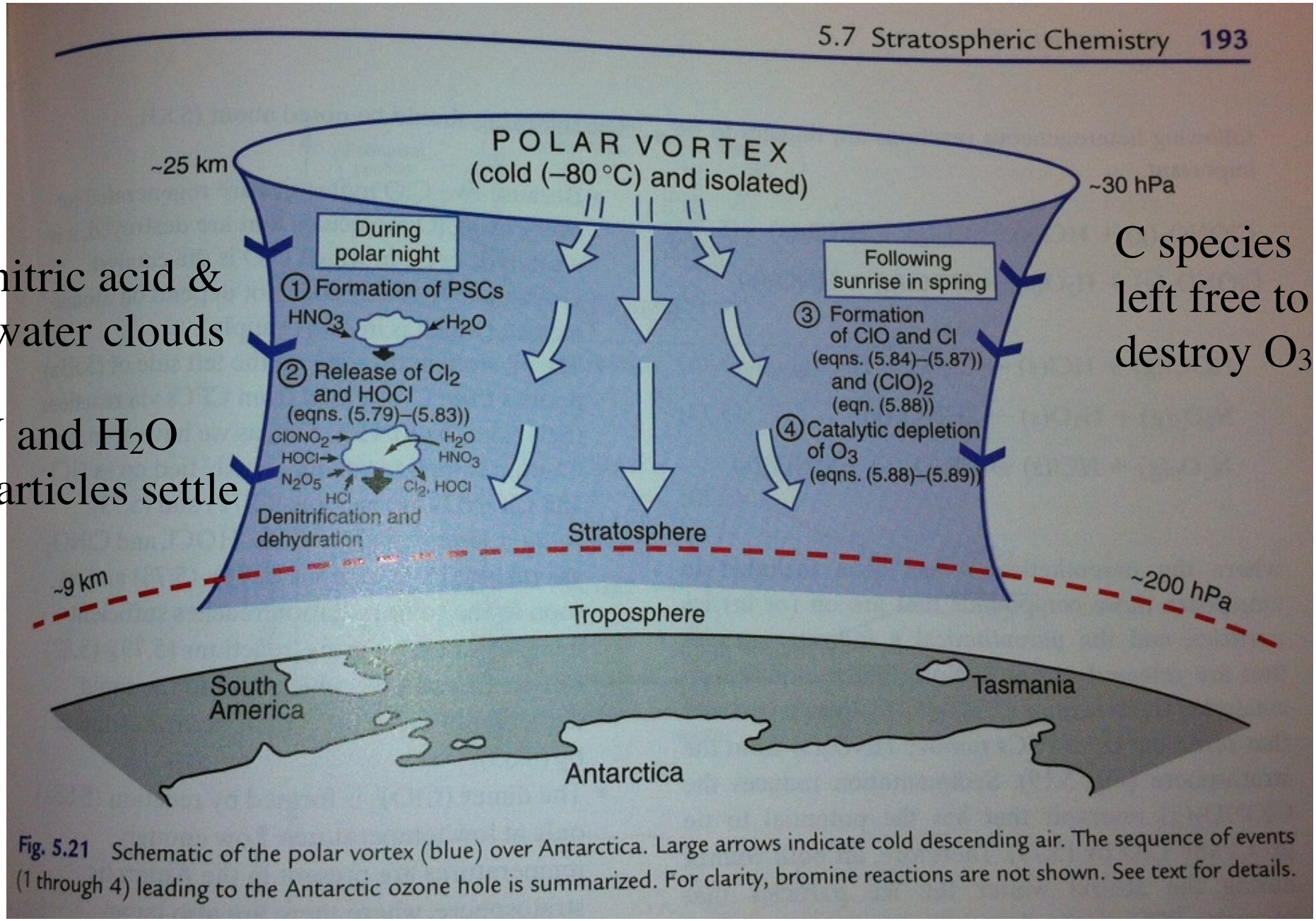


Fig. 5.21 Schematic of the polar vortex (blue) over Antarctica. Large arrows indicate cold descending air. The sequence of events (1 through 4) leading to the Antarctic ozone hole is summarized. For clarity, bromine reactions are not shown. See text for details.

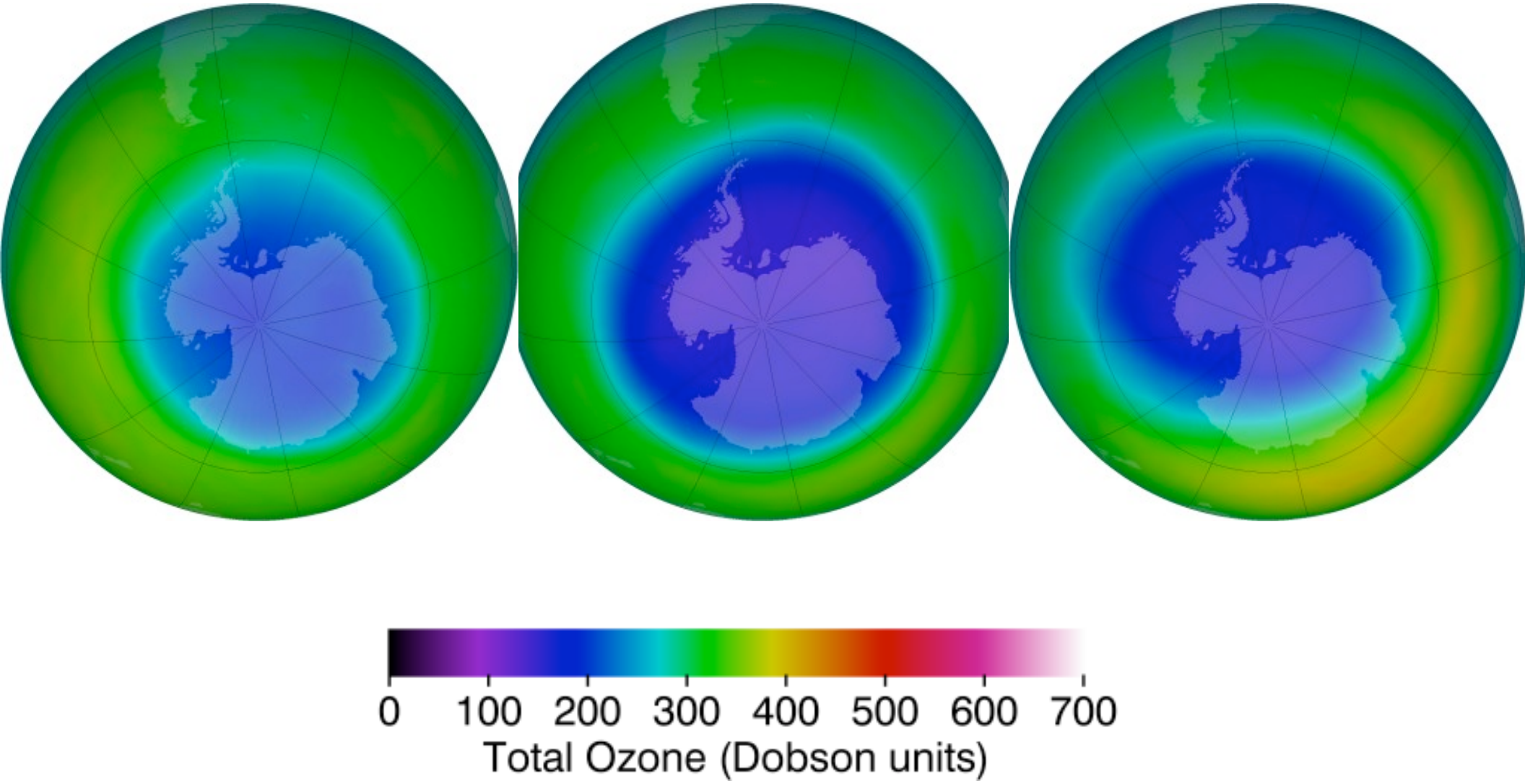
C species left free to destroy O_3.

[Wallace and Hobbs 2006]

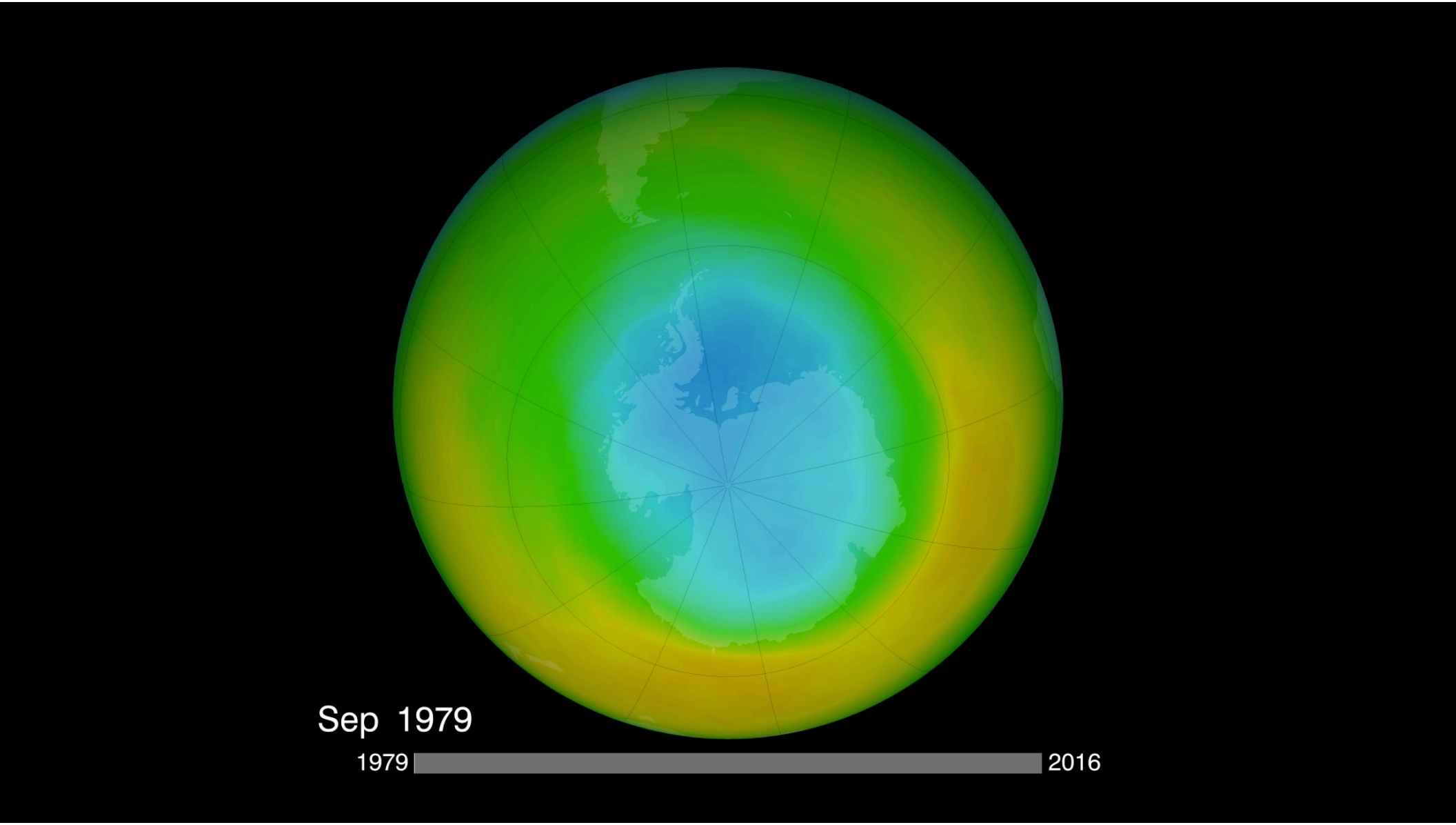
MOVIE: https://vimeo.com/104321114

Ozone hole evolution

Sept 1985 Sept 2006 (record low) Sept 2013



http://ozonewatch.gsfc.nasa.gov/

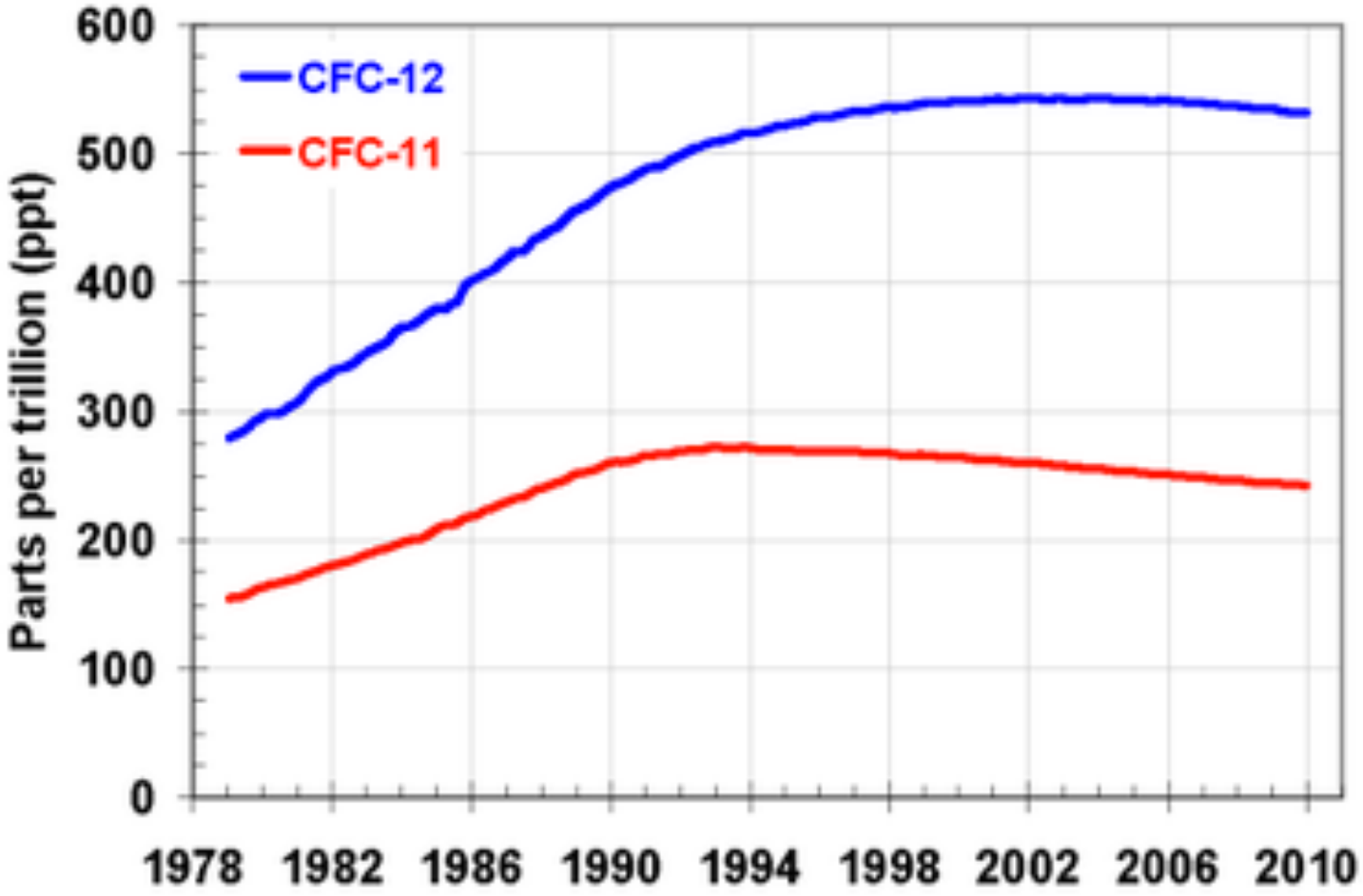

Sep 1979
1979
2016

Ozone Hole discovered and dealt with!

- Mid-1980's British Antarctic Survey scientists noted the ozone decline in surface data. Satellite data issue...
- Montreal Protocol of 1987 signed to reduce emissions. SUCCESS for environmental policy.

- In the 1980s people were faced with the clear and present health dangers from ozone depletion, leading to widespread public support for CFC bans."There was a scary side of the ozone hole, linked to skin cancers and cataracts and so on, which immediately engaged the public," the British Antarctic Survey's Shanklin said. "The real impact of what a rapidly warming world could do is not so obviously intuitive." National Geographic Article (2010)

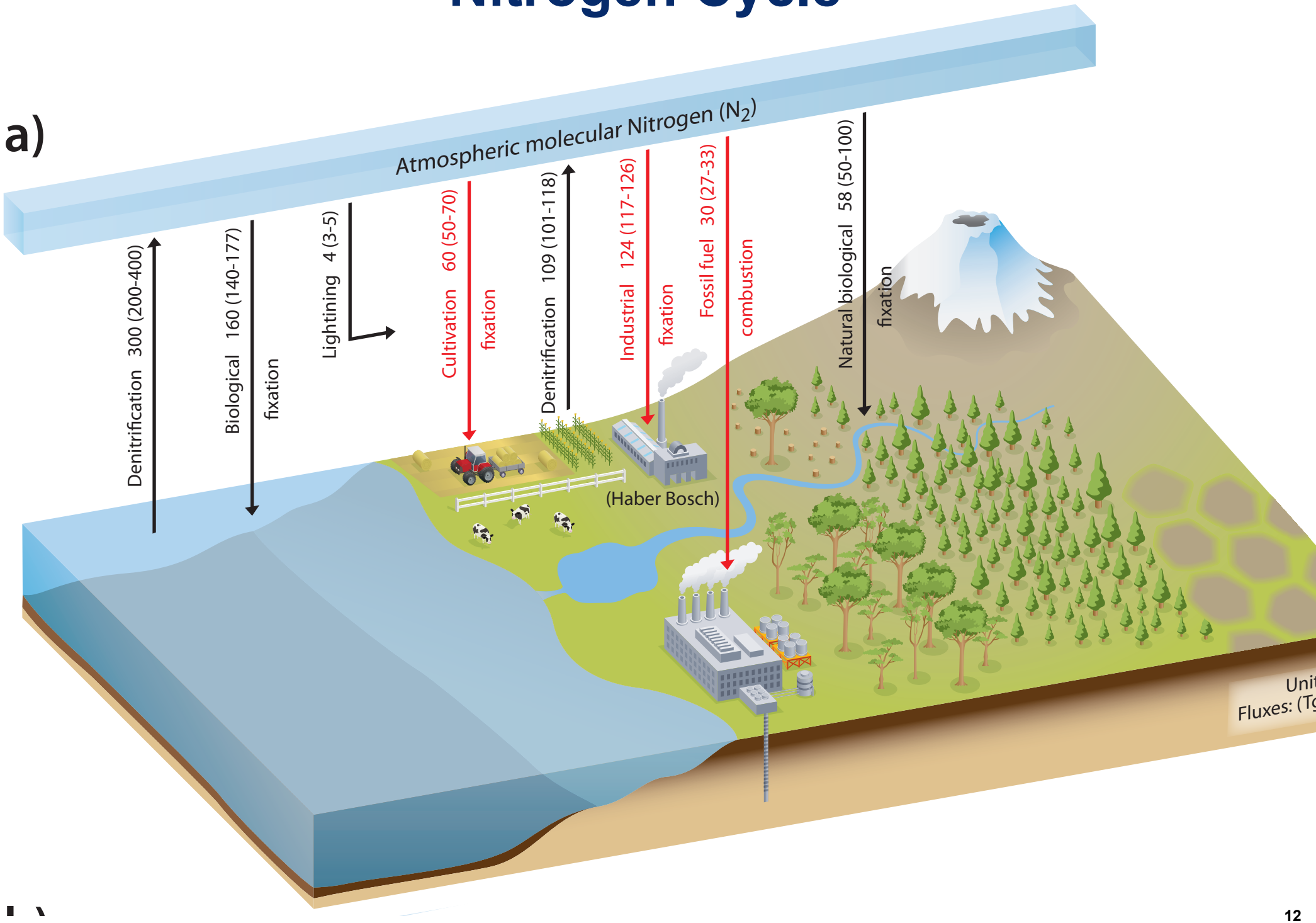
Montreal Protocol - CFCs have declined



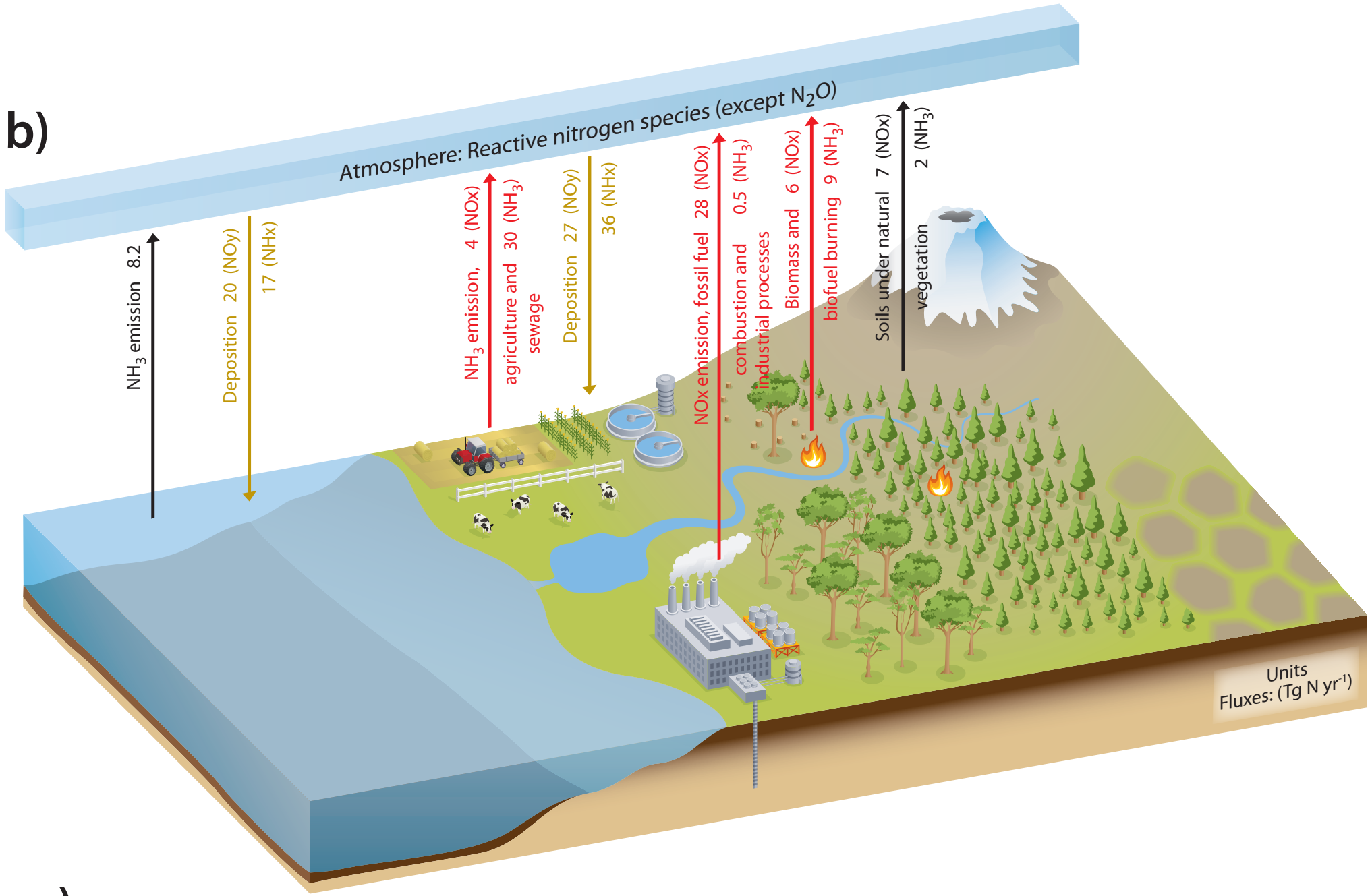
Ozone is produced in car exhaust and naturally so too much in urban air reduces safe air quality.

http://commons.wikimedia.org/wiki/File:Major_greenhouse_gas_trends.png

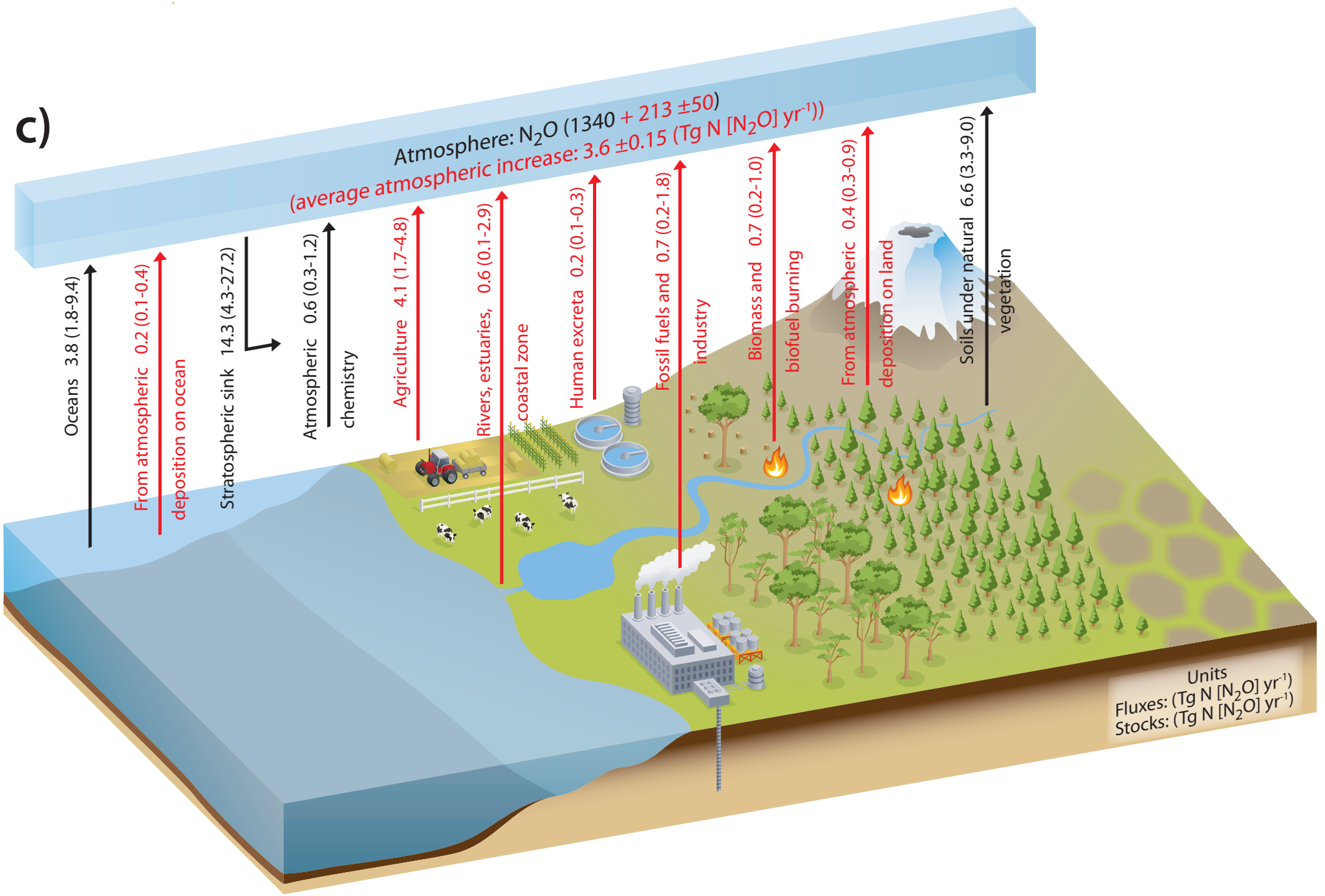
Nitrogen Cycle



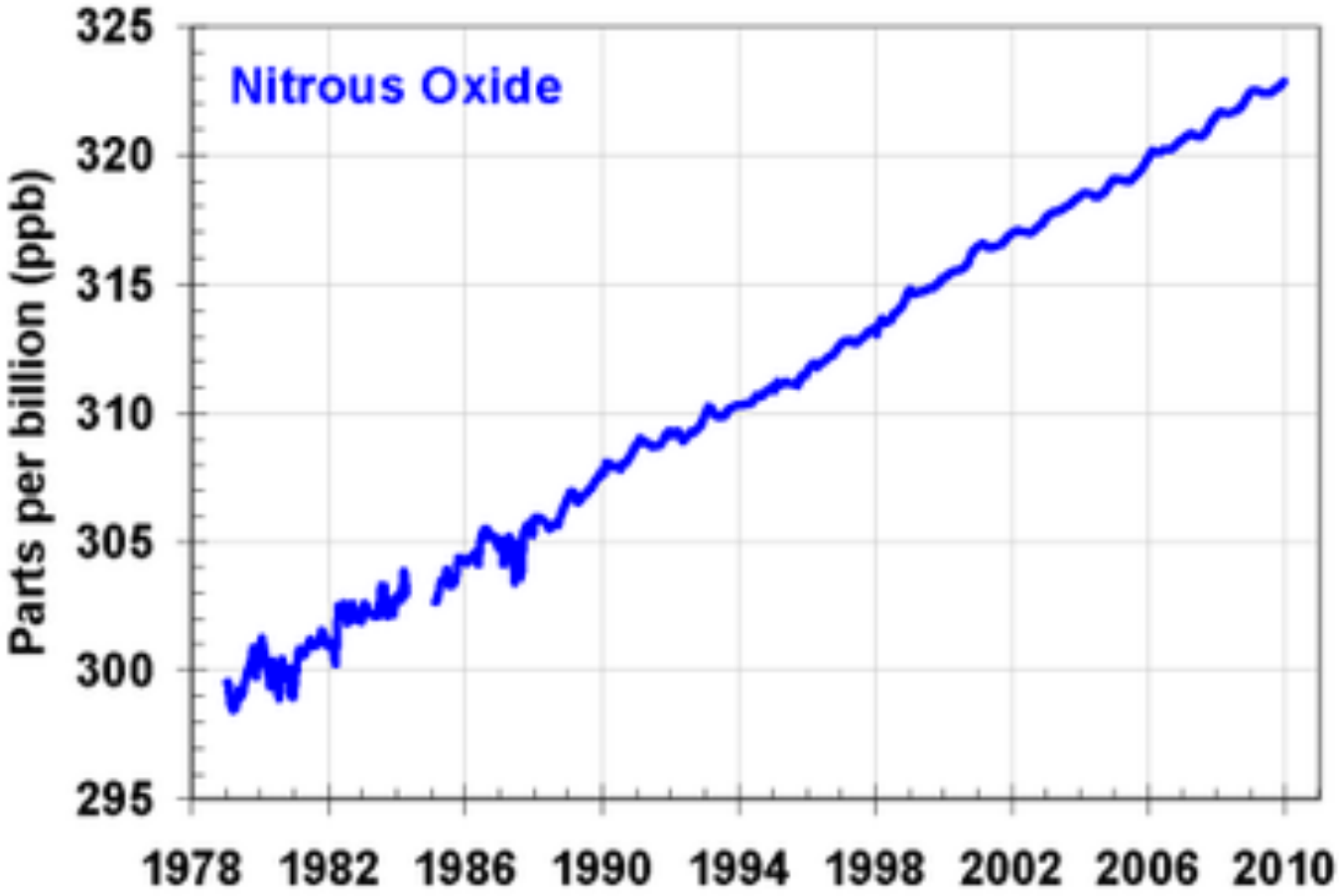
Nitrogen Cycle



Nitrogen Cycle



Nitrous Oxide N_2O



- Long lived gas
- Naturally produced by bacteria
- Agricultural fertilizers are biggest non-natural source
- Reacts with Oxygen to make NO, nitric oxide which in turn breaks down Ozone

- 1799 British upper class had laughing gas parties & helps enhance combustion in cars
- One unit of nitrous oxide is equivalent to 310 units of carbon dioxide. It is a potent greenhouse gas so regulation is desired. Warmer soils emit more nitrous oxide.

Summary

Review

- **What is the radiative forcing due to anthropogenic CO2?**
- **What is the radiative forcing due to anthropogenic methane?**
- **What is the overall impact of ozone on the radiative forcing (warming or cooling)?**
- **What is the radiative forcing due to land use change (warming or cooling)?**
- **What chemicals start off the heterogenous chemistry that is responsible for ozone hole?**
- **What other processes are key for Antarctic ozone depletion?**
- **What is the main source of anthropogenic Nitrous Oxide?**

Tropospheric Aerosols

Definition

- **Atmospheric Aerosols are suspensions of small solid and/or liquid particles (excluding cloud particles) in air that have negligible terminal fall speeds. (Wallace and Hobbs, 2011)**

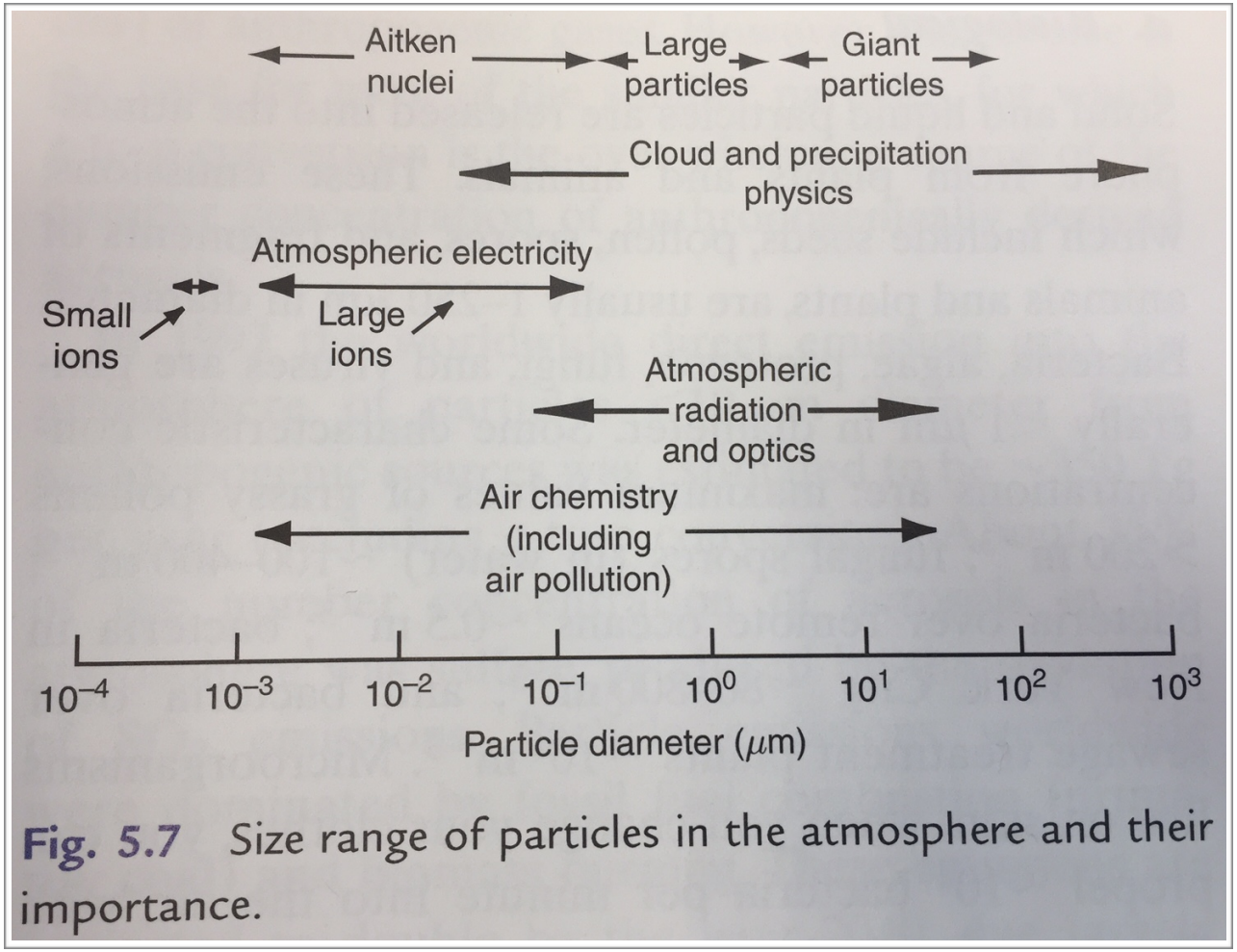


Fig. 5.7 Size range of particles in the atmosphere and their importance.

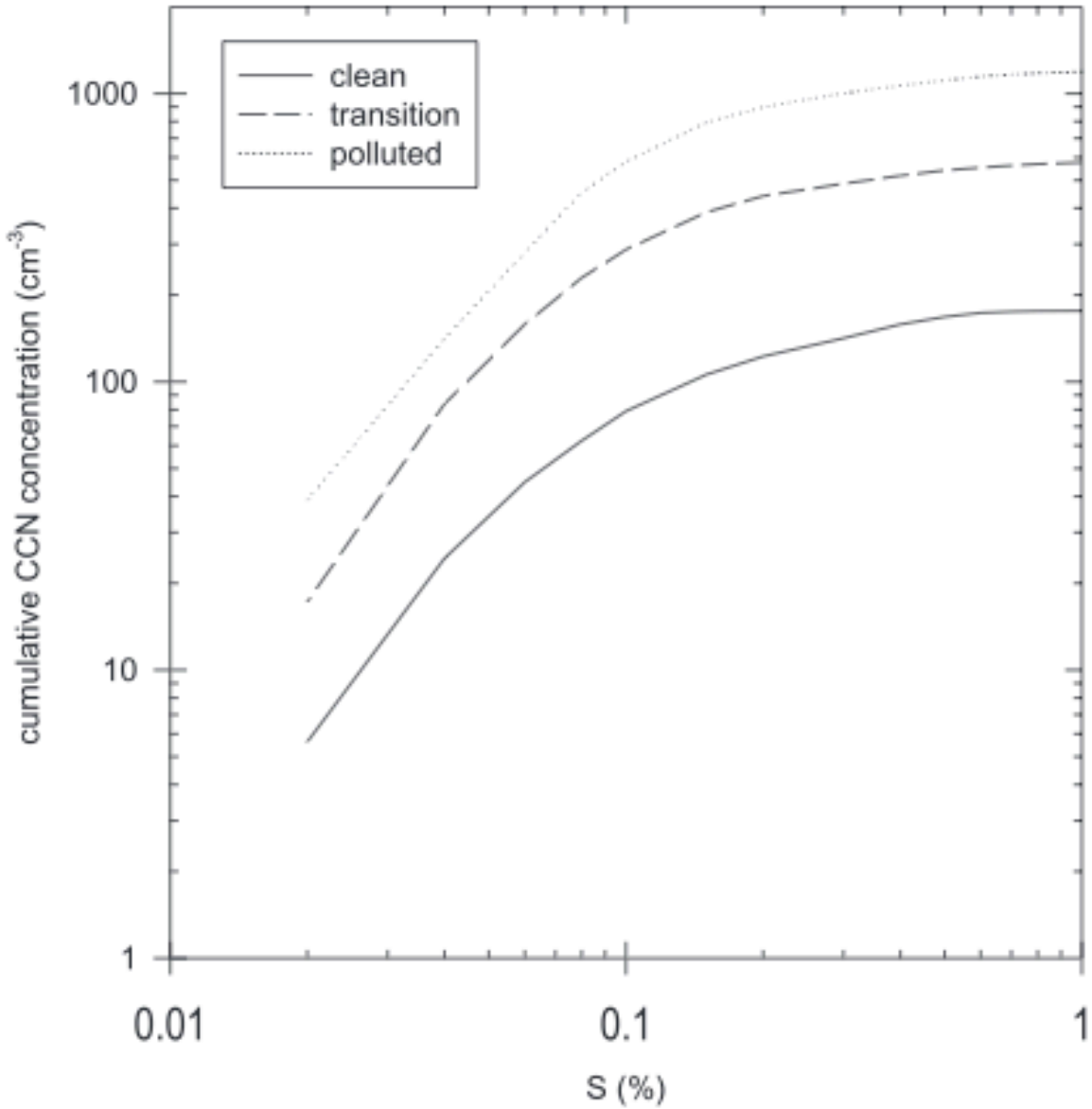
[Wallace and Hobbs 2011]

Cloud Condensation Nuclei

- In order for water droplets to grow they must first attach to a CCN. Aerosols serve as CCN on which water vapor condenses and then grows into a drop that is large enough to be able to fall to the earth.
- Cloud in a jar experiment

- Some types of particles are better than others at being CCN. The larger the particle, the more easily it is wetted by water and can more easily serve as a CCN site.
- We do not know the global distribution of CCN but near the earth's surface there are more over land than over the ocean.

Cloud Condensation Nuclei Numbers Vary



Azores polluted air

Florida Marine air

Clean Arctic air

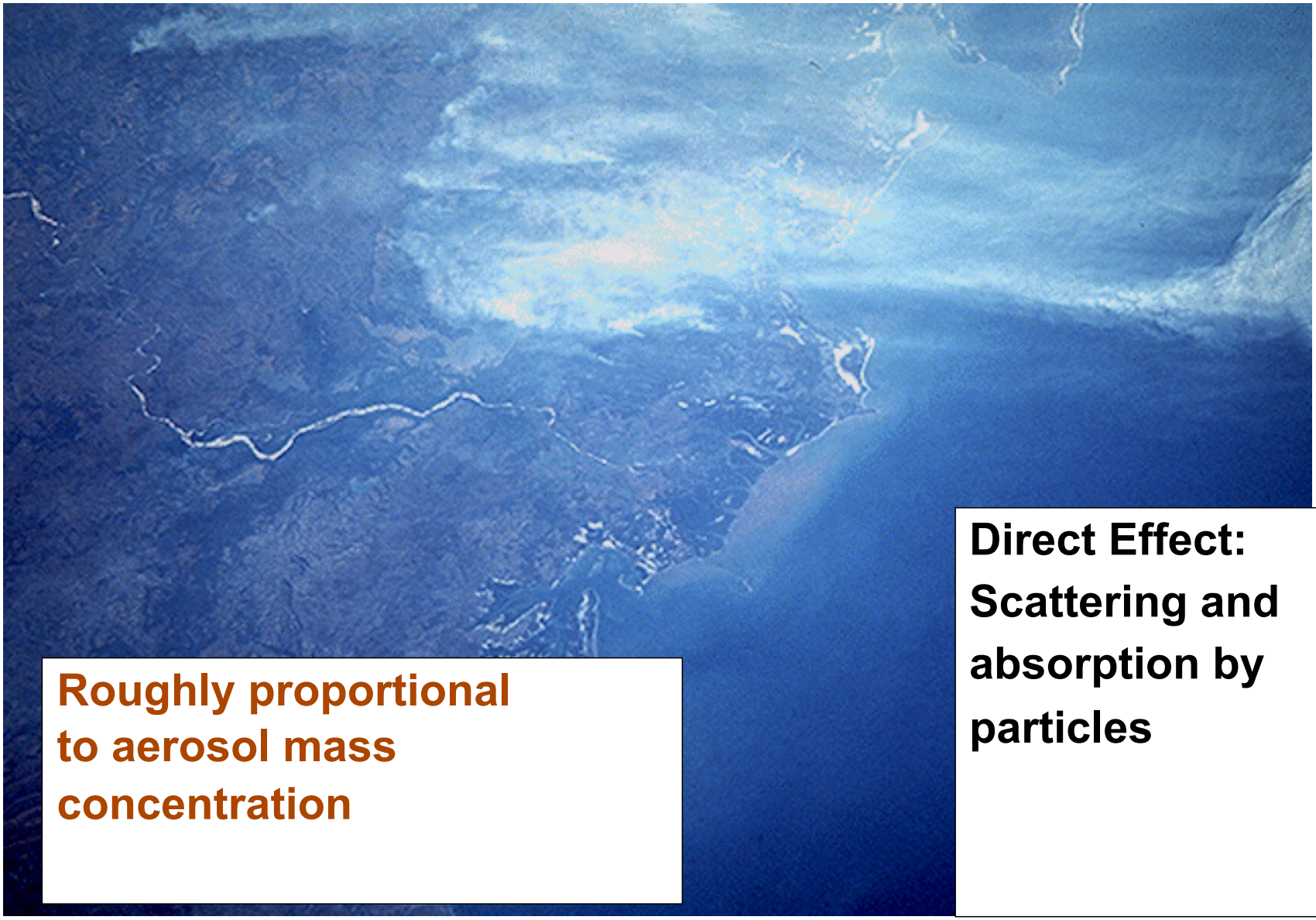
Figure 2. Average boundary layer CCN spectra in polluted, clean, and transition air masses for the three gradient flights considered here.

Hudson and Yun, 2001

Sources of CCN

- Forest Fires are a major source of aerosols. Organic compounds and elemental carbon are small particles.
- Bacteria from vegetation may nucleate ice in clouds
- Idling diesel engines, dust from roads, fossil fuel combustion (burning coal)
- Sea salt, but not dominant since big it falls out fast
- gas-to-particle conversions, ex: chemical reactions such as the oxidation of SO_2 to sulfuric acid. This makes up about 1/3 of global emissions of particles below 10μ.
- Organic sulfates (in form of DMS, dimethyl sulfide or MSA, methane sulfonic acid provide CCN sources.
- Much is still not known about this topic! In 20th century anthropogenic sources were smaller than natural sources BUT this is projected to become equal around mid-21st century.

Aerosols and Climate: Direct Effect



Roughly proportional to aerosol mass concentration

Direct Effect: Scattering and absorption by particles

photo: SeaWifs website

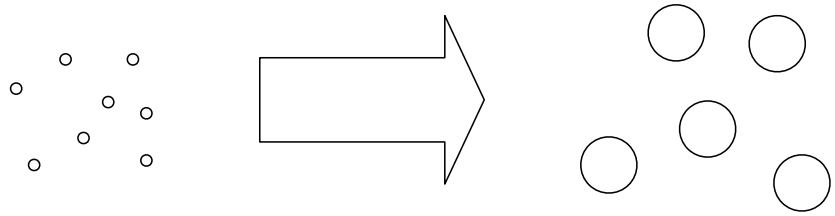
[Peter Adams, CMU]

Indirect Effect on Climate

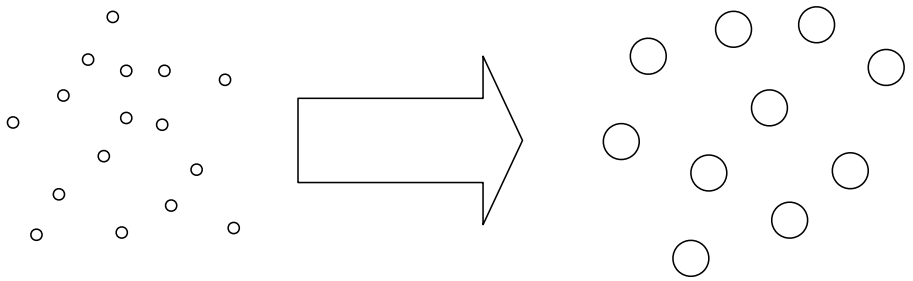
Aerosol Particles

Cloud Droplets

Clean Air



Polluted Air



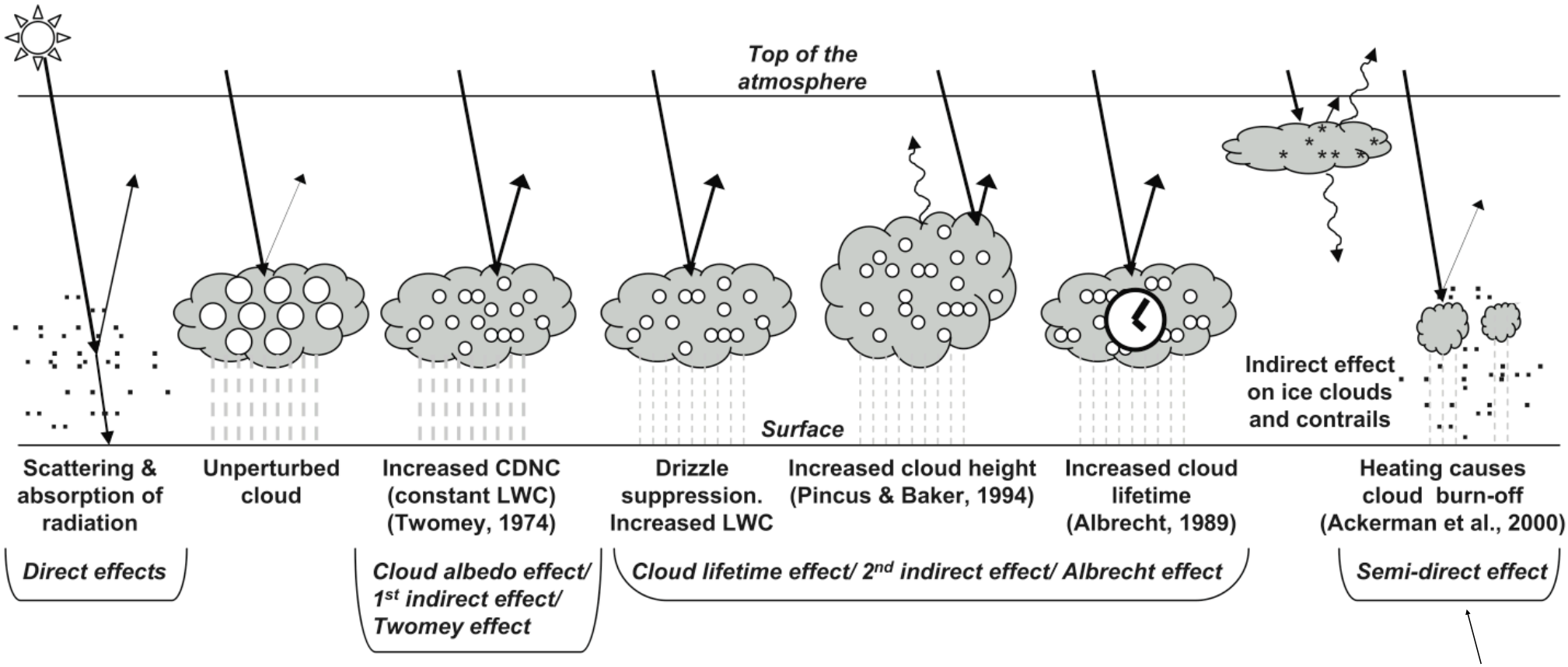
Brighter, more persistent clouds

"First" indirect effect: albedo

"Second" indirect effect: lifetime

[Peter Adams, CMU]

Aerosol effects on radiative forcing through cloud influences



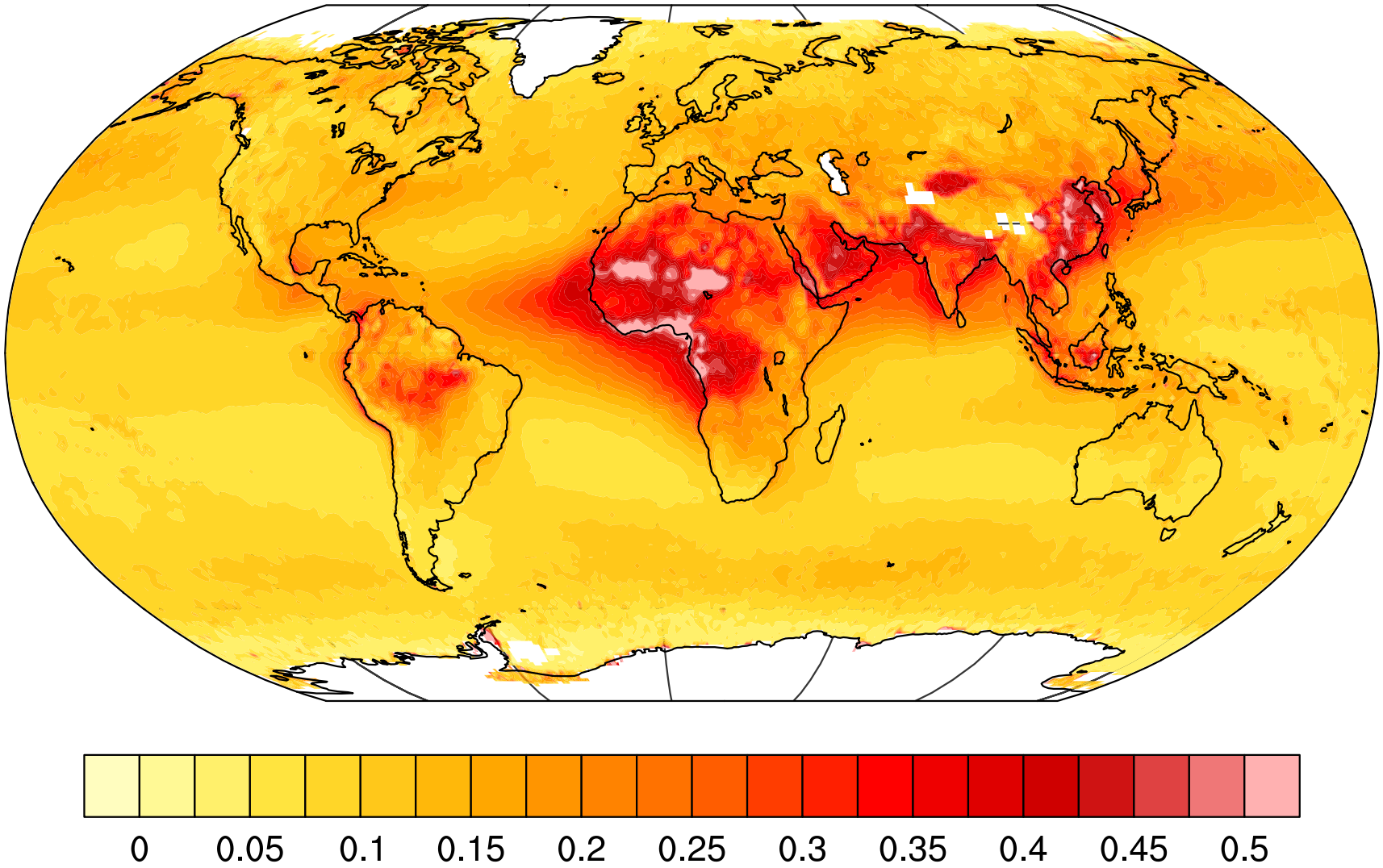
Aerosols absorb shortwave radiation and warm

Aerosol-cloud interactions not well understood and therefore not well modeled!

[Haywood and Boucher 2000 Rev Geophys]

Aerosol optical depth from satellite measurements

(a) Satellite AOD



- 2001-2005 from MODIS
- Large biomass burning in Gulf of Guinea in J-M
- Mineral dust transport from Africa to S. America
- Industrial aerosols
- SH sea salts
- No measurements over highly reflective surfaces

[Fig 9.28 IPCC 2014]

Various Biogeochemical Feedbacks

1. **CCN over oceans, dimethyl sulfide (DMS) produced by tiny organisms in ocean Charlson et al., 1987, more particles means more cloud droplets, longer residence time in atmosphere, higher cloud albedo, cooling of earth. Magnitude and sign of feedback unknown.**
2. **Gaia - Mother Earth, single entity (Lovelock, 1979), one big feedback system that optimizes conditions for life to exist. Homeostasis - actively maintain constant conditions.** *"The Gaia hypothesis says that the temperature, oxidation state, acidity, and certain aspects of the rocks and waters are kept constant, and that this homeostasis is maintained by active feedback processes operated automatically and unconsciously by the biota." - James Lovelock, The Ages of Gaia*

[Hartmann, 1994]

Global Dimming

- **Cooling at the surface of the earth induced by reduced solar radiation reaching the surface, mainly due to sulfur aerosols**
- **Climate researcher James Hansen estimates that "global dimming" is cooling our planet by more than a degree Celsius (1.8°F) and fears that as we curb these types of air pollution, global warming may escalate to a point of no return.**
- **Beate Liepert estimated that there was globally a reduction of about 4% in solar radiation reaching the ground between 1961 and 1990.**
- **Geoengineering solution to increase aerosols to reduce global warming... The health costs are not considered here.**
- **Secondly, would a re-evaluation of the aerosol effect imply that projections to 2100 must be worse than previously suggested? No, according to Gavin Schmidt. Most extreme scenario postulated in TAR (A1F1) already has a big reduction in sulphate aerosol forcing, so no biggie.**

http://www.realclimate.org

Excellent web site for science summaries write at scientist level!

Contrails reduce daily temperature range DTR

Cooler at night and warmer during the day without contrails!

We analysed maximum and minimum temperature data from about 4,000 weather stations throughout the conterminous United States (the 48 states not including Alaska and Hawaii) for the period 1971–2000, and compared these to the conditions that prevailed during the three-day aircraft-grounding period. All sites were inspected for data quality and adjusted for the time of observation

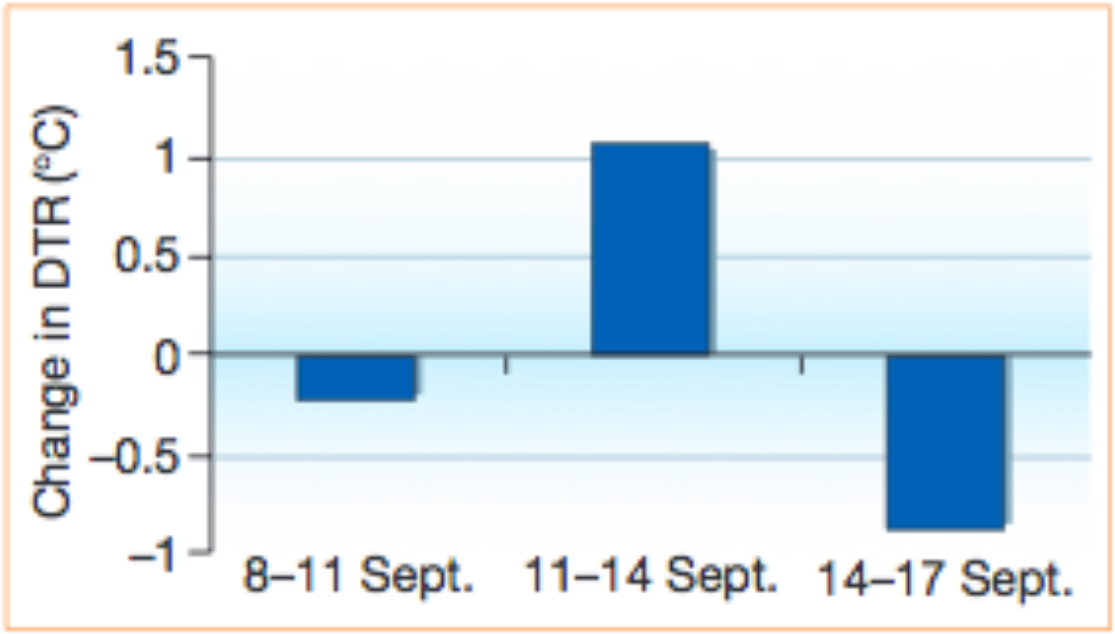


Figure 1 Departure of average diurnal temperature ranges (DTRs) from the normal values derived from 1971–2000 climatology data for the indicated three-day periods in September 2001. These periods included the three days before the terrorist attacks of 11 September; the three days immediately afterwards, when aircraft were grounded and there were therefore no contrails; and the subsequent three days.

Travis et al. Nature 2002

Black Carbon

- Bond et al. 2013, "BC is the second most important human emission in terms of its climate forcing in the present-day atmosphere", 1.1W/m2
- Black Carbon is pure carbon emitted from incomplete combustion and it is what we call soot.
- BC is important "because it absorbs solar radiation, influences cloud processes, and alters the melting of snow and ice cover."
- Large fraction due to anthropogenic emissions
- Can be removed quickly if we reduce emissions! Politics
- Black carbon undergoes regional and intercontinental transport during its short atmospheric lifetime. Atmospheric removal occurs within a few days to weeks via precipitation and contact with surfaces.

Black Carbon Sources and Processes

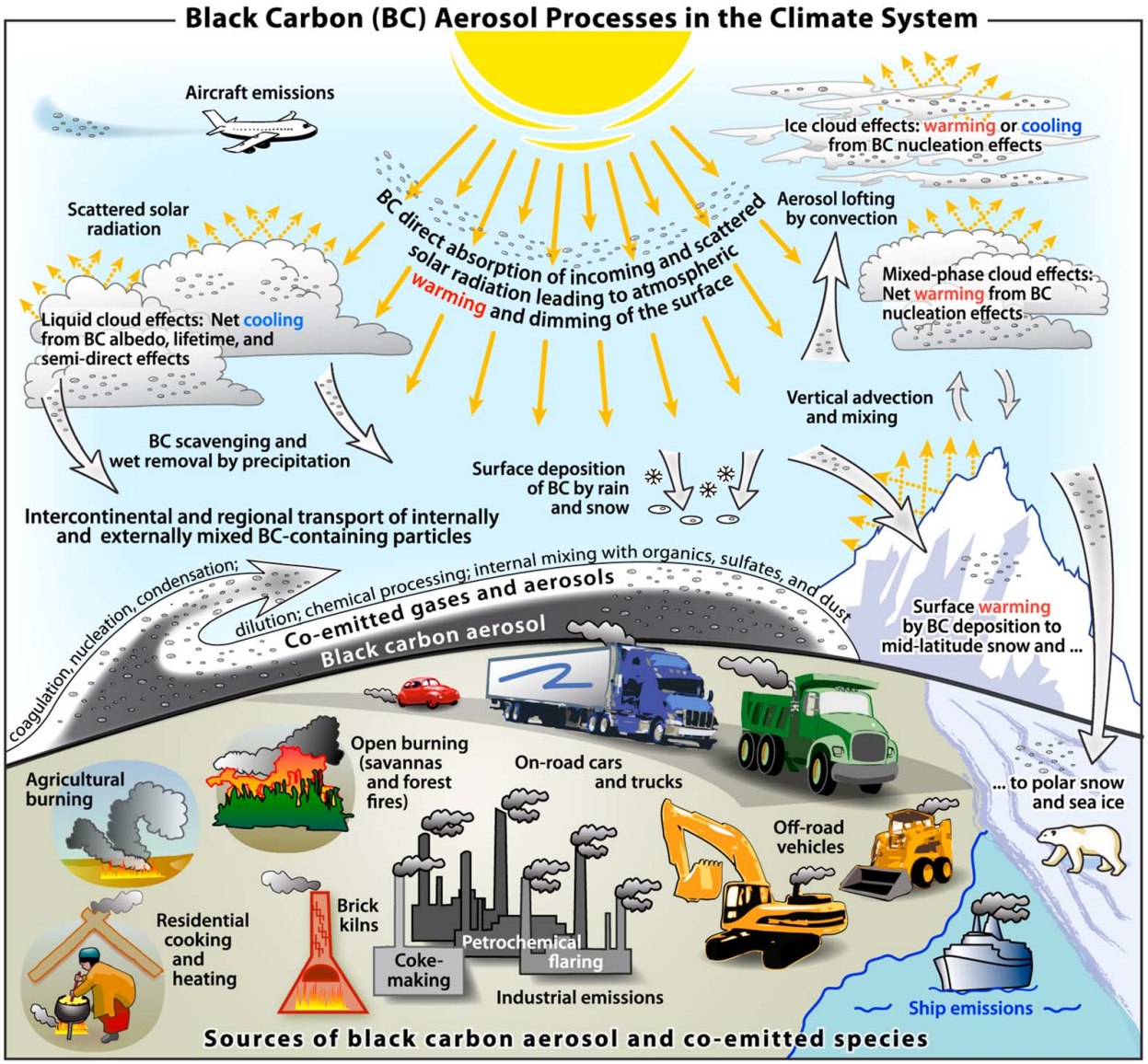


Figure 1. Schematic overview of the primary black-carbon emission sources and the processes that control the distribution of black carbon in the atmosphere and determine its role in the climate system.

[Bond et al. 2013]

Summary

- Understanding aerosol-cloud interactions is a research-priority!
- Sulfate aerosols have reduced surface warming through direct aerosol impacts.
- One of the complexities of black carbon is that the same sources of BC emit other compounds that act to cool the climate, so total impact has large uncertainty.
- BC may be very important for the Arctic and Greenland
- Climate science is becoming more and more interdisciplinary so we need to work with experts from various group to solve problems!