ATM S 111: Global Warming
Climate Forcings

Jennifer Fletcher
Day 5: June 28 2010

Climate Forcings vs Climate Feedbacks

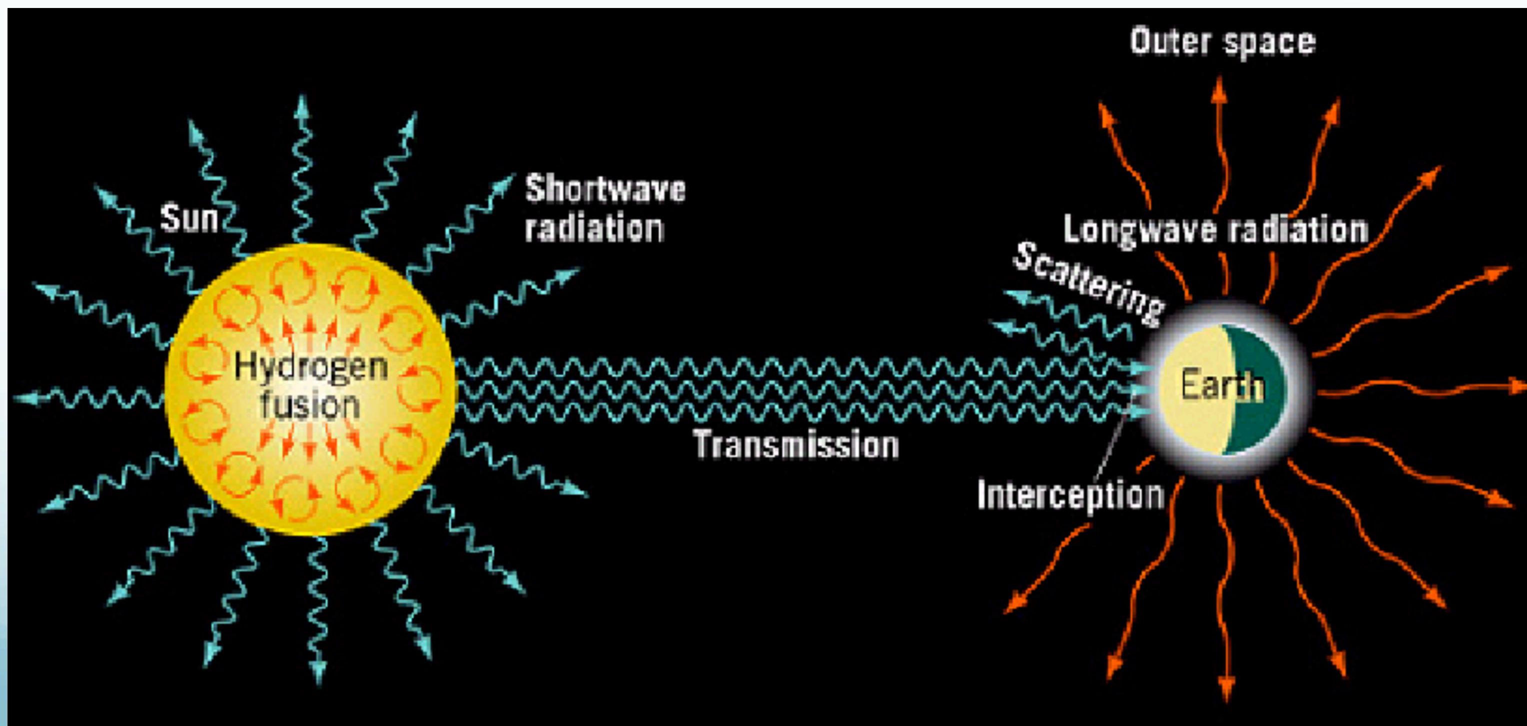
- Climate forcings:
  - Things that can change global temperatures directly
  - Examples: intensity of sunlight, atmospheric CO_2 concentration
  - Will focus on these today
- Climate feedbacks:
  - Things that respond to temperature changes, but themselves affect temperature too
  - Example: Ice sheet extent on Greenland and Antarctica
  - Will focus on these tomorrow and Wednesday

Climate Forcings

- Climate forcings directly change global temperatures
- Examples:
  - Changes in strength of **the Sun**
  - Changes in **greenhouse gas** concentrations (water vapor is an exception, as we will see)
  - **Volcanic eruptions** (which block out the Sun)
- We need a way to put these on equal footing in terms of how much warming they cause
  - Let's recall how the Earth is heated/cooled

Heating/Cooling of the Earth

- Solar radiation in, longwave radiation out
  - The Earth is heated by shortwave radiation from the Sun
  - The Earth cools by longwave radiation



Radiative Forcing

- **Radiative forcing** is calculated as the **change in shortwave in** or **longwave out** due to the particular climate forcing
  - Measured in **Watts per square meter (W/m^2)**
- Recall energy balance: $E_{in} = E_{out}$
  - Positive radiative forcing = increased shortwave in or decreased longwave out, so that $E_{in} > E_{out}$.
  - Negative radiative forcing = decreased shortwave in or increased longwave out, so that $E_{in} < E_{out}$.
  - In response to a positive radiative forcing, the climate must warm

Radiative Forcings: Shortwave Forcings

Shortwave forcing is just the change in solar energy absorbed by the planet

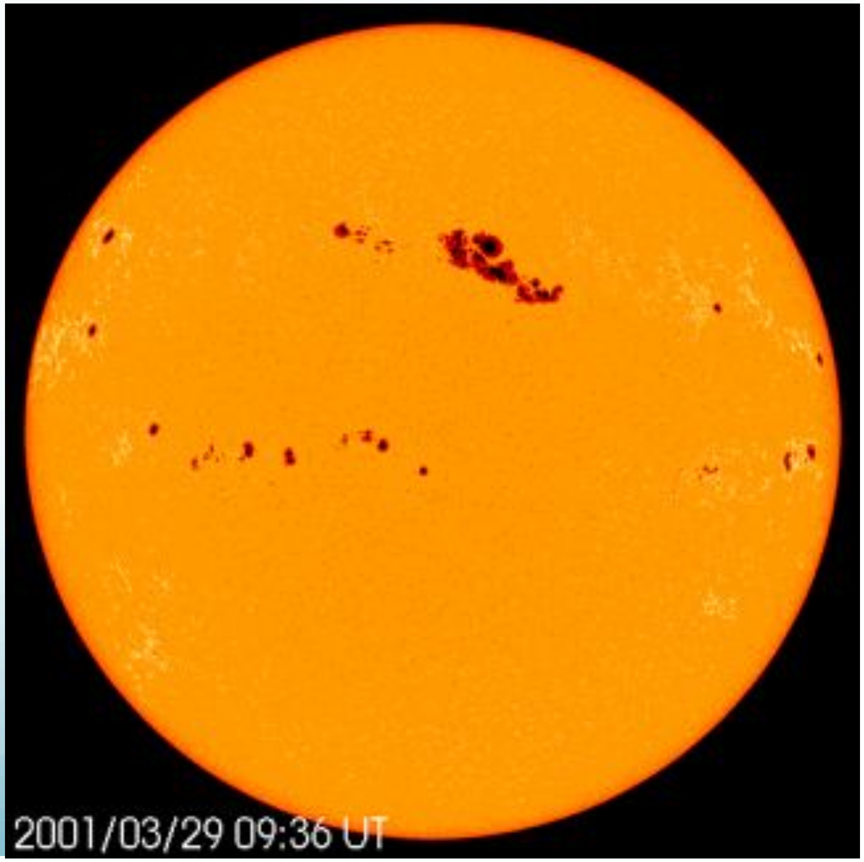
- Ex. 1: if the Sun increases in strength so 0.2 W/m^2 more is absorbed, the radiative forcing is 0.2 W/m^2
  - OK that was obvious…
- Ex. 2: if a volcano blows up and reflects back an extra 0.3 W/m^2 of the Sun's rays, the radiative forcing is -0.3 W/m^2

Shortwave Forcings

- Shortwave forcings affect how much **solar** radiation is absorbed
- Examples of shortwave forcings:
  - Changes in **strength of the Sun**
  - Changes in the **surface albedo**
    - Not changes in ice coverage – that's a feedback
  - **Volcanoes**
  - **Air pollution**
    - This falls under the more general category of "**aerosols**"
- Let's discuss each of these in more detail

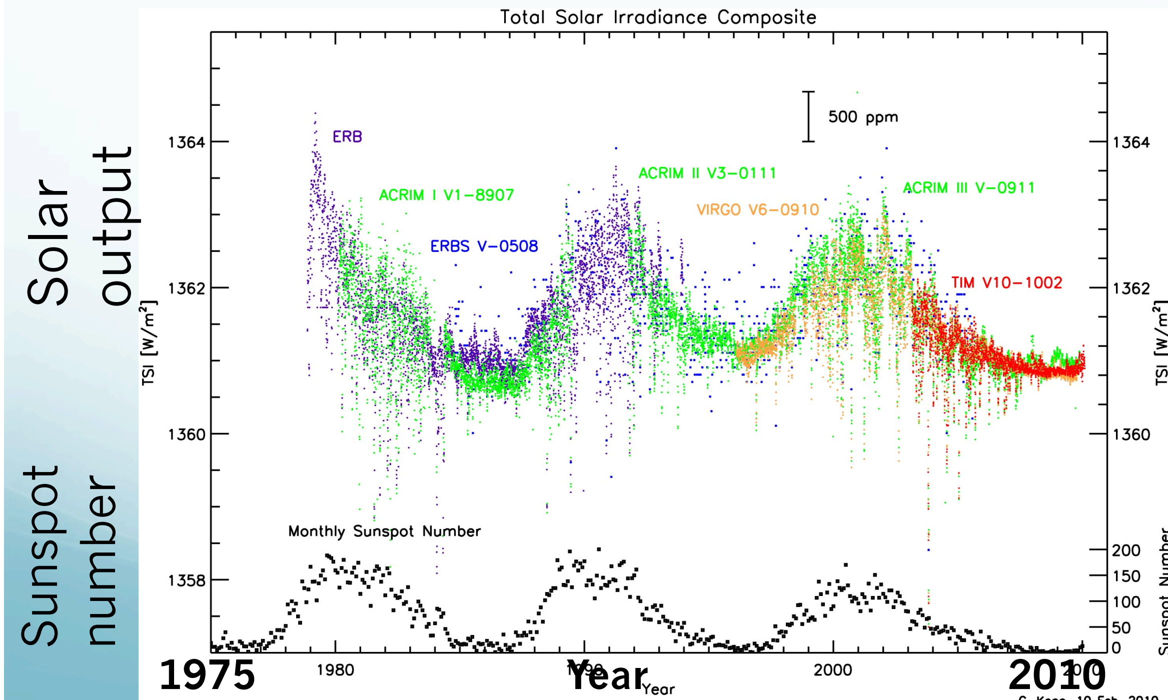
Changes in the Intensity of the Sun

- The Sun has natural variability in its strength
  - The changes are rather small though (around 0.1% since we've been measuring accurately with satellites)
- The variability of the Sun is correlated with the **sunspot cycle**
  - Sunspots are temporarily darkened regions on the Sun →



Sunspot Cycle

- Sunspots vary over an 11 year cycle
  - **More sunspots → more solar radiation** (Also more solar flares – these mess with satellites, communication systems, etc)

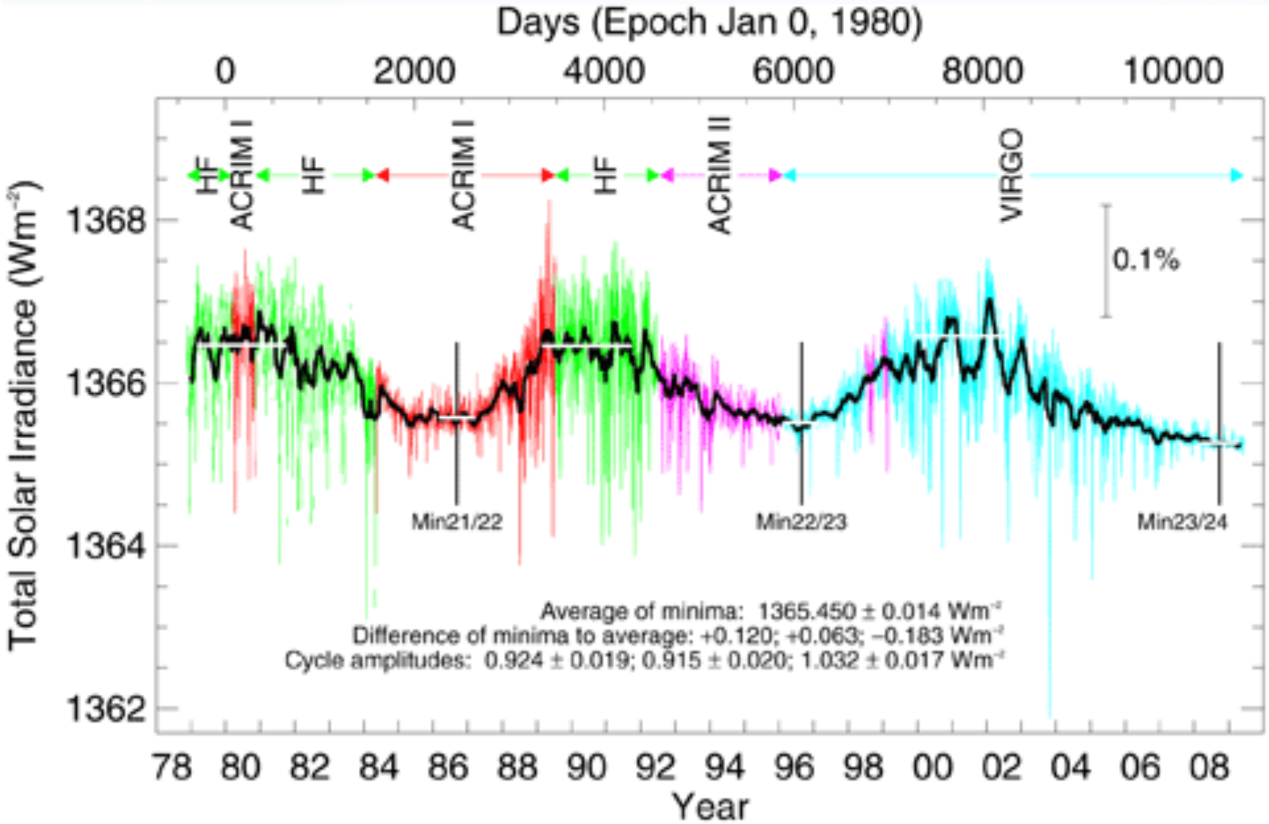


Fun Fact: Radiative forcing by the Sun
= change in solar radiation absorbed on Earth
= 0.7*(irradiance change)/4
= 0.2 W/m^2 (max to min)

(takes into account albedo and directness of radiation)

Current Solar Intensity

- We're at the end of a deep minimum of solar intensity

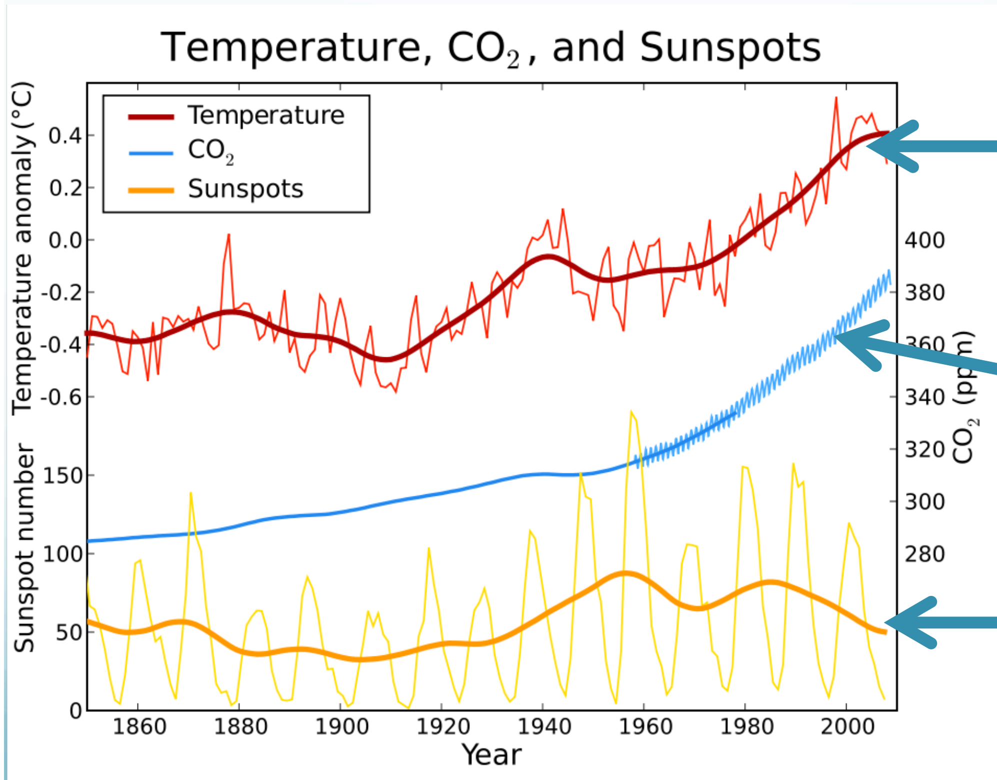


Peak to peak radiative forcing of the Sun: **0.2 W/m²**

Affects global temperatures by around **0.2º C** (research of Prof. Tung, Applied Math, UW)

Sunspot Cycles over Time

- Sunspot cycles are not the same each 11 year cycle:



Global temperature

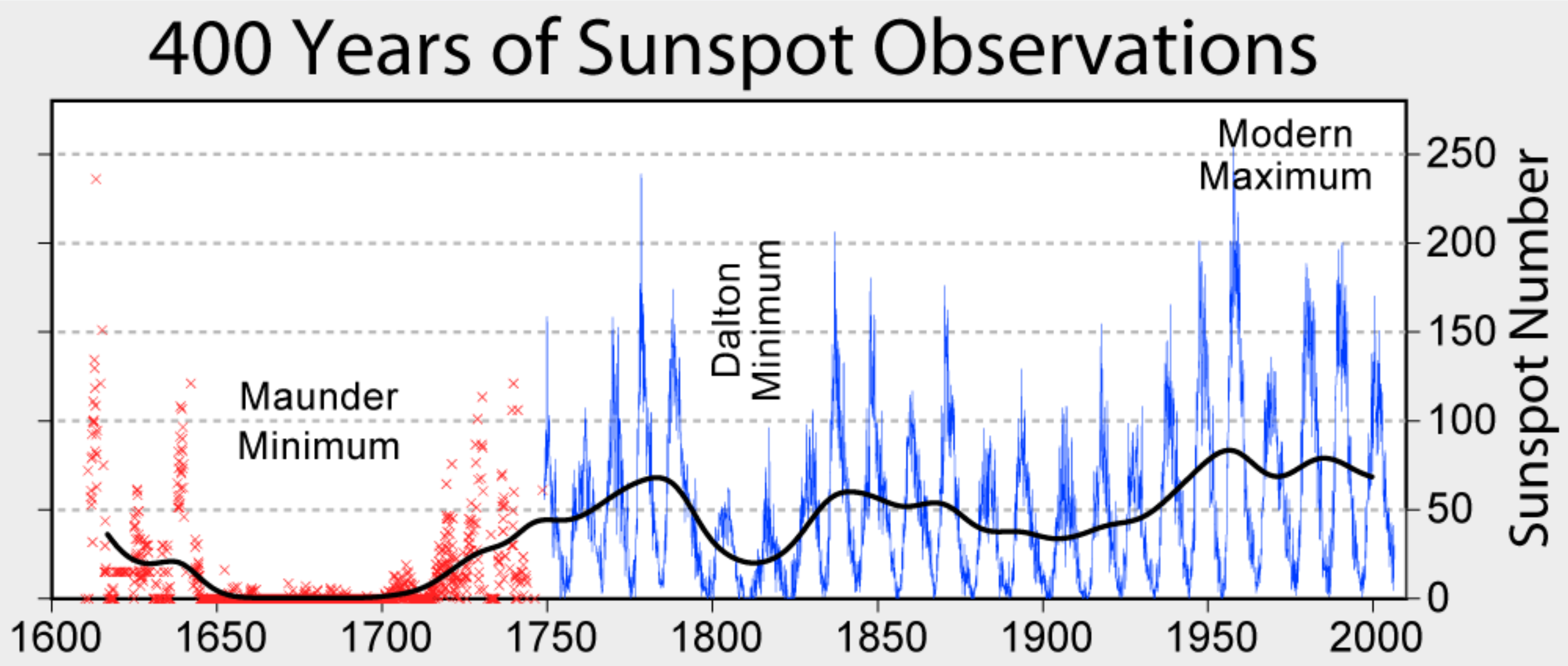
Carbon dioxide

Sunspots

Solar variability may have led to some warming in the early 20th century

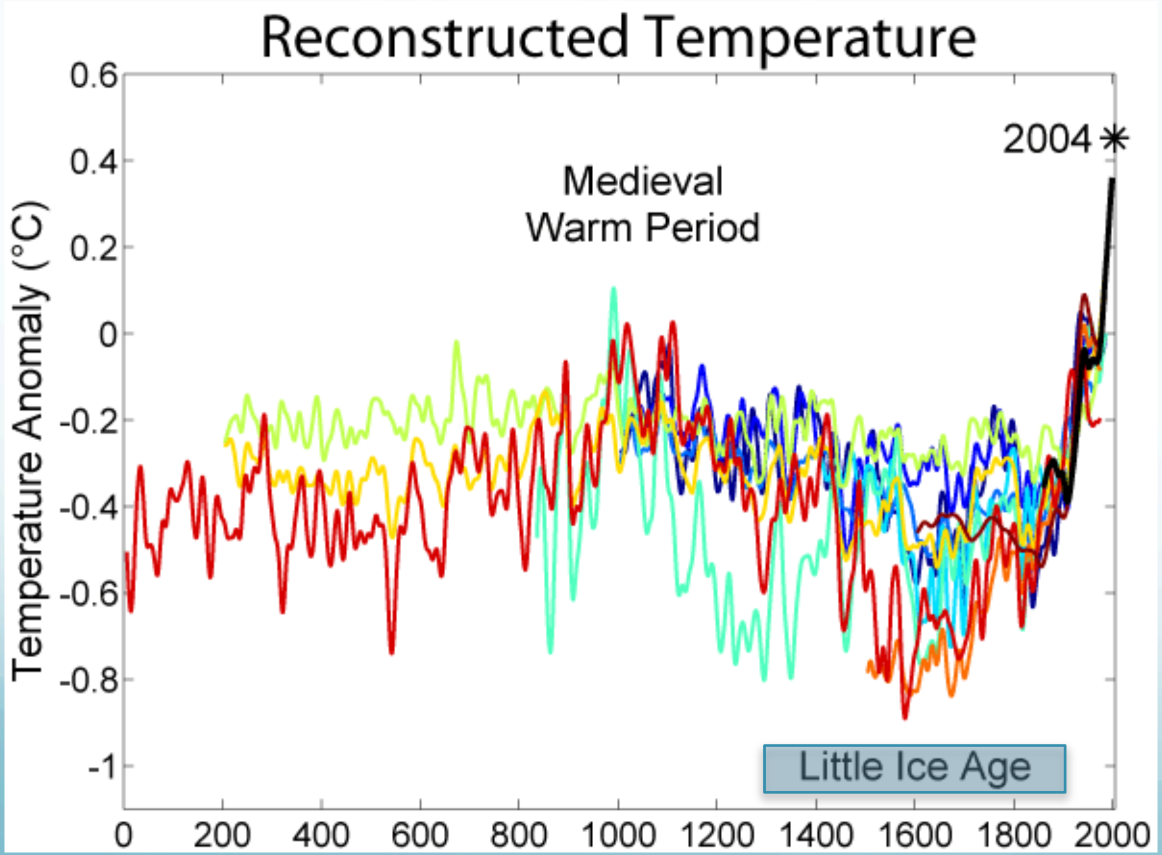
Sunspots over Last 400 Years

- Sunspots since we've been observing them:



A Preview of Some Paleoclimate

- Maunder minimum (1650-1700) coincides with "Little Ice Age":



There was also enhanced volcanic activity at this time

We'll discuss these & other periods more when we study **paleoclimate**

Other Ways to Change Absorbed Solar Radiation

- Changes in the Sun aren't the only way to change absorbed solar radiation
- We can also directly change the **albedo** of the Earth
  - Land cover
  - Soot on snow
  - Reflective particles in the air

Land Cover Changes

- Forests have low albedo (they're dark)
- **Cutting down forests** to create farmland/pastures tends to **raise the albedo**
  - This is actually a **negative** radiative forcing
    - Causes local **cooling** because there's more solar energy reflected
  - However, remember that deforestation is an important source of carbon dioxide
    - Deforestation can cause global warming but local cooling...

Soot on Snow

- A tiny amount of soot (AKA black carbon) in pure white snow can change the albedo dramatically!
  - Currently a very active area of research (Prof. Warren, Atmos Sci)

Fresh snow over Greenland from high above

Other Ways to Change Albedo

- Can change albedo **in the atmosphere** as well
- *Aerosols* (fine particles suspended in air) make a large contribution to reflection of sunlight
  - Volcanoes!
  - Pollution (from coal burning or other types of burning)
  - Dust (e.g., from the Sahara)
  - And others

Volcano Effects on Climate

- Volcanoes can have a large climate impact
  - Certain big ones cause a temporary **cooling** of the climate

Mount Pinatubo, Philippines, erupted June 1991, resulted in more than **0.5° C** (0.9° F) global temperature **decrease**

Direct heating of atmosphere by volcanoes is small.

CO_2 emission by volcanoes is <1% of anthropogenic emission.

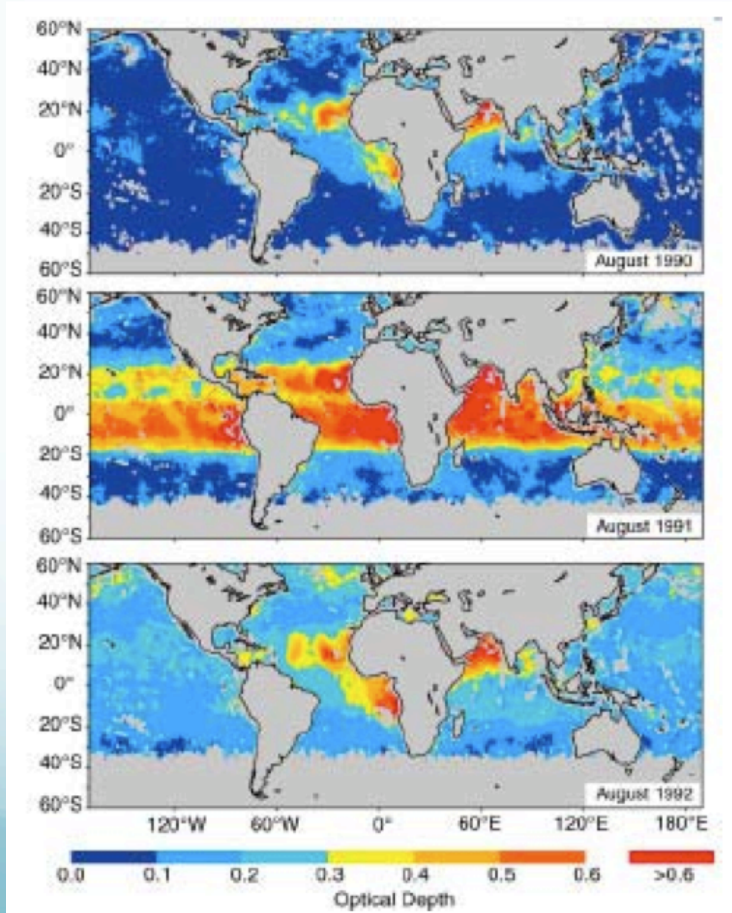
Volcano Impacts on Climate

- Dust and sulfates from volcanoes **block out the Sun**

Before the Pinatubo eruption →

2 months after →

14 months after →



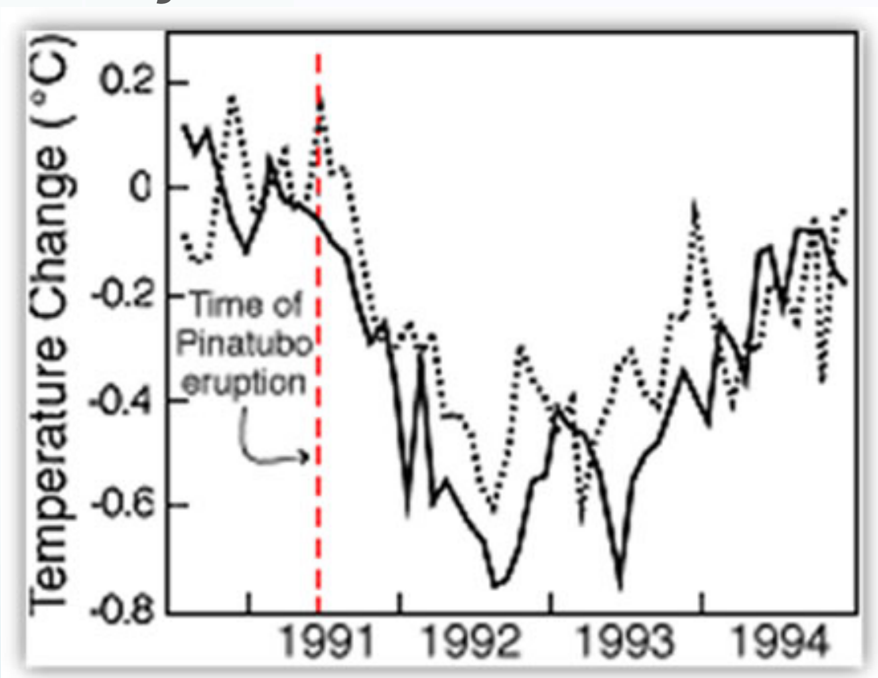
Volcanic material spreads quickly around the same latitudes as the eruption

Slight dimming seen across the globe over a year after the eruption

Red colors = atmosphere is reflecting a lot of sunlight back

Volcano Impacts on Climate

- Effects of big eruptions are felt for a couple of years



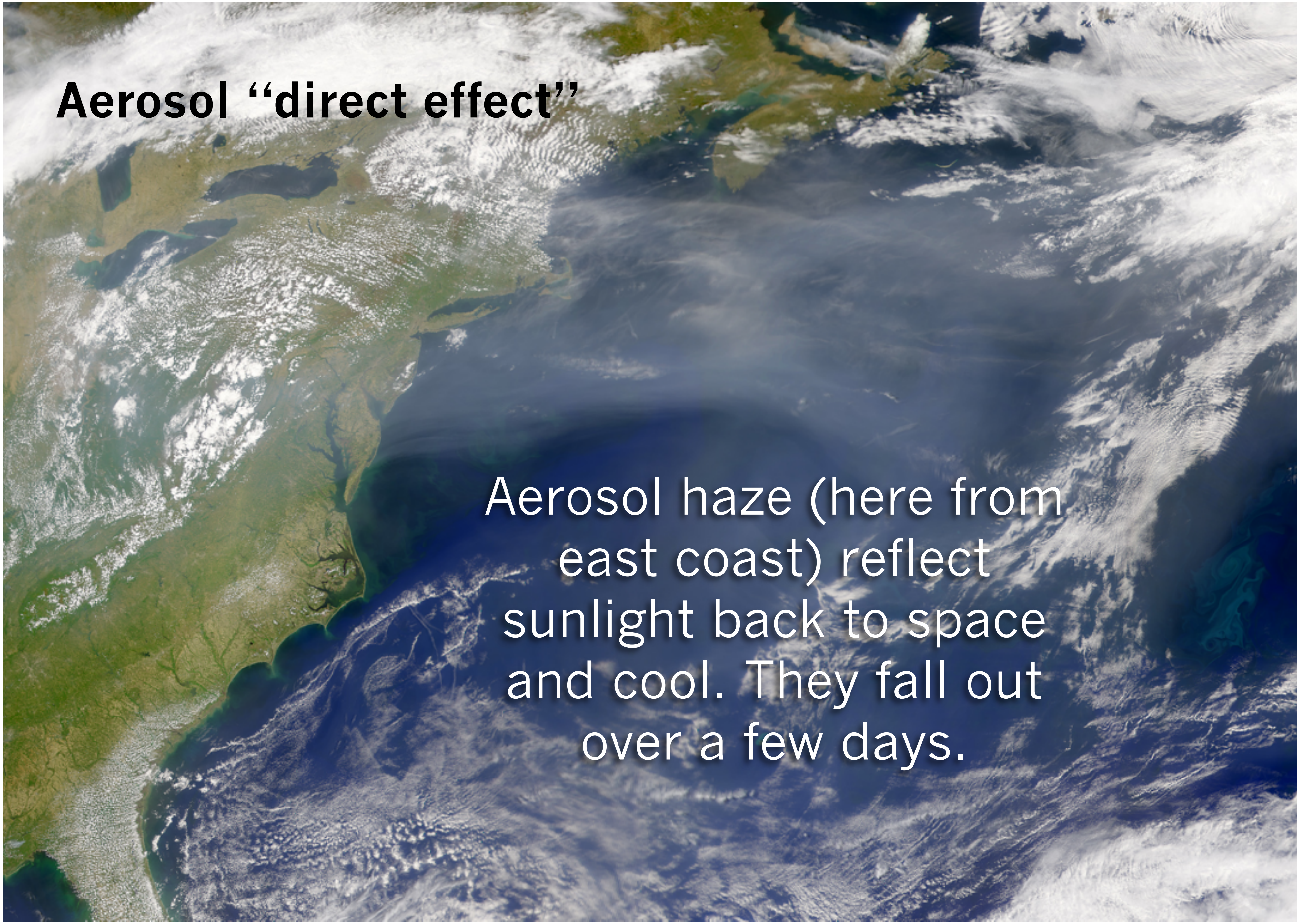
Observed (dashed) vs modeled (solid) temperature change (from Hansen et al 1996)

Temperatures were cold for around 2 years before recovering

Fun Fact: **Tropical** volcanoes that get lots of **sulfates** into the **stratosphere** have the biggest climate effect

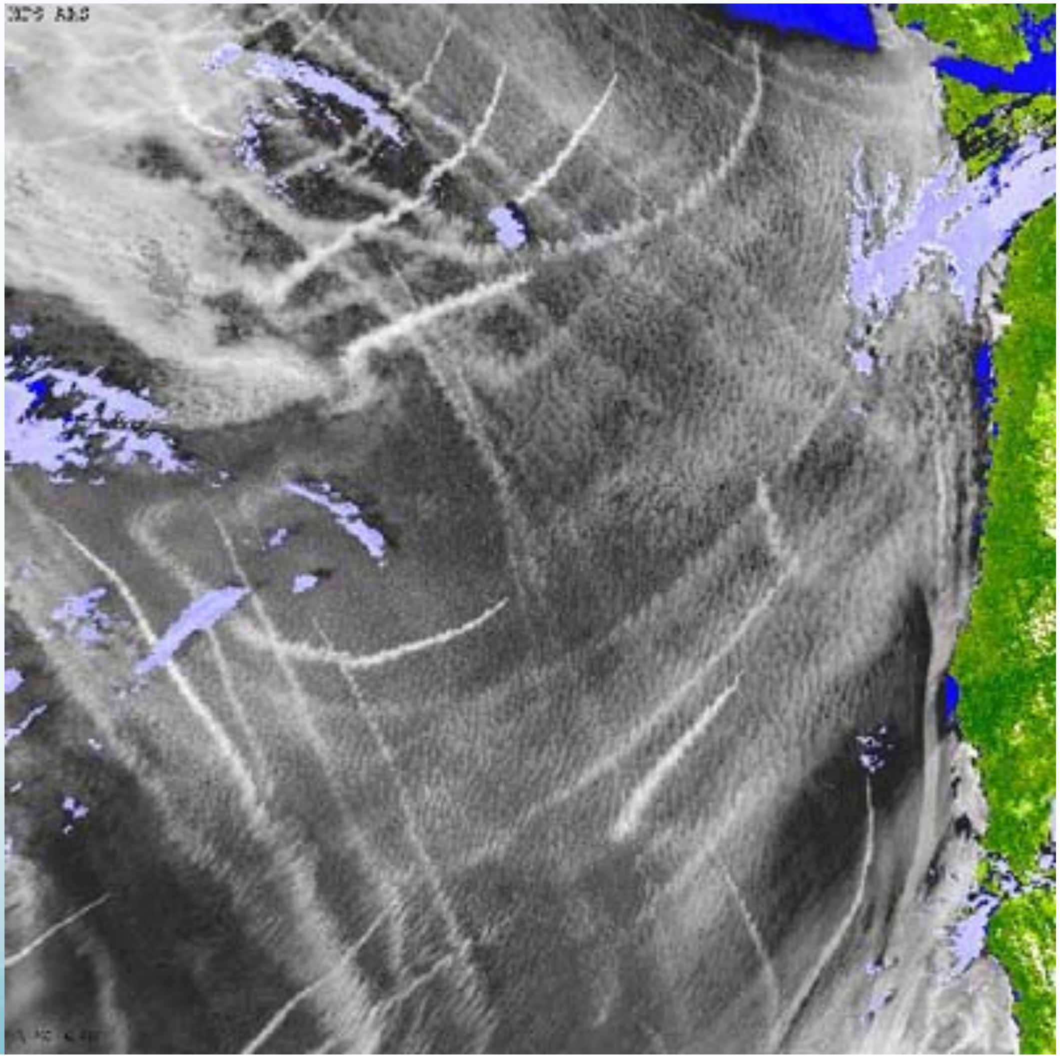
Air Pollution Aerosols

- Air pollution particles block out sunlight too
  - Sulfates from dirty coal burning are particularly important (**sulfate aerosols**)
    - This is the same stuff that causes acid rain
  - These are a **big effect**
    - One of the **main uncertainties** in our understanding of climate


Aerosol "direct effect"
Aerosol haze (here from east coast) reflect sunlight back to space and cool. They fall out over a few days.

Aerosol "Indirect Effect"

- Aerosols also affect cloud formation
- Ship tracks can be seen as brighter clouds follow the ships' smokestacks

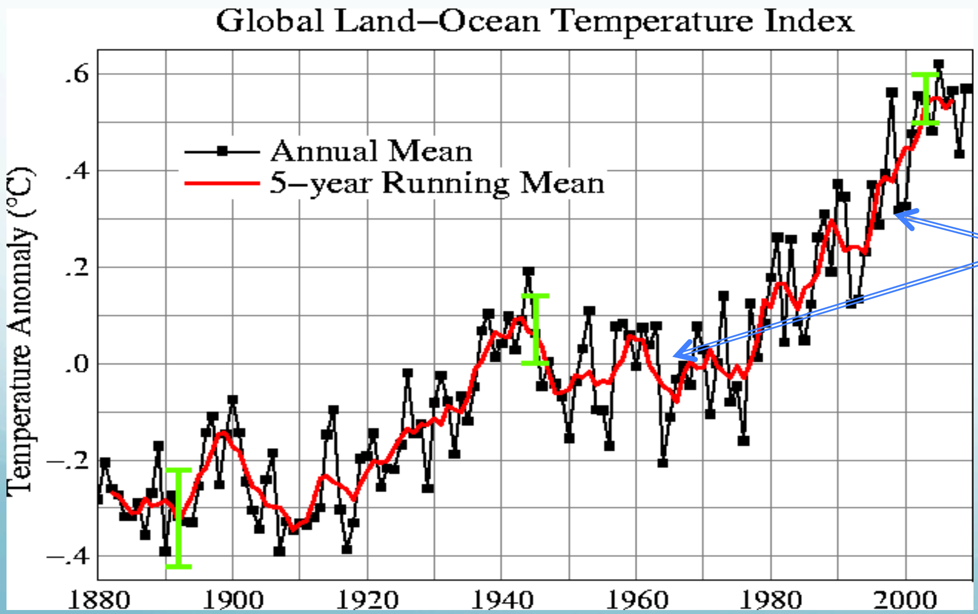


“Global Dimming”

- Solar radiation reaching the Earth’s surface **declined** by ~4% from 1961-1990
  - This has coexisted with large increases in the global temperature. Why?
- Increased **aerosol** concentrations partially to blame
  - Both direct reflection and indirect cloud changes are thought to be important
- Trend has reduced since 1990s (likely due to Clean Air Act and similar laws in Europe)

Aerosol Effects on Climate

- Air pollution thus is another strange issue:
  - Sulfate aerosols **reflect** away sunlight so itself causes cooling
  - Cleaning up pollution has had great benefits for air quality, human health, acid rain, etc
  - However it has likely led to **additional warming**



Aerosol increases/cleanup is likely partially to blame for the small warming from 1950-1970, and the rapid warming since then

Another twist: China is pumping out lots of dirty coal emissions now

Summary of Shortwave Climate Forcings

- Shortwave radiative forcings can come from:
  - Changes in strength of the Sun
  - Changes in albedo at the surface
  - Changes in albedo of the atmosphere

Summary of Shortwave Climate Forcings

- **Radiative forcings** for shortwave agents in current climate vs preindustrial:
  - **Solar** radiation changes +0.12 W/m^2
  - **Land** cover changes -0.20 W/m^2
  - **Soot** on snow +0.10 W/m^2
  - **Aerosol direct** effect -0.50 W/m^2
  - **Aerosol indirect** effect (clouds) -0.70 W/m^2
- All of the above have significant scientific **uncertainty** associated with them.
  - We just don't know these values very accurately.
  - This is because we don't have enough data on the amount of aerosols in the atmosphere.

Longwave Climate Forcings

- **Shortwave** forcings affect the amount of solar (shortwave) radiation that Earth **absorbs.**
- **Longwave** forcings affect how much infrared (longwave) radiation that Earth **emits**.
- What are longwave forcings?
- **Greenhouse gases**

Climate Forcing of CO_2

- Radiative forcing of CO_2 for current value versus preindustrial (year 1750) value: 1.66 W/m^2
- This means that, if everything else stayed the same since 1750 (temperature, other greenhouse gases, etc), the extra CO_2 in the atmosphere would prevent an extra 1.66 W/m^2 radiation from escaping to space.
- Radiative forcing for doubling CO_2: around 3.7 W/m^2
  - And the radiative forcing increase gets less as CO_2 increases more.
  - Why?

Radiative Forcing of Other Greenhouse Gases

- These are all current values vs preindustrial values

Carbon dioxide:	**1.66 W/m^2**
Methane:	**0.48 W/m^2**
Nitrous oxide:	**0.16 W/m^2**
CFCs:	**0.32 W/m^2**

  - But CFCs are **decreasing** now (everything else is increasing)
- These numbers give the percentages of the anthropogenic greenhouse effect from last lecture…
- Recall that average solar radiation absorbed by Earth is 240 W/m^2, so these are small but important perturbations.

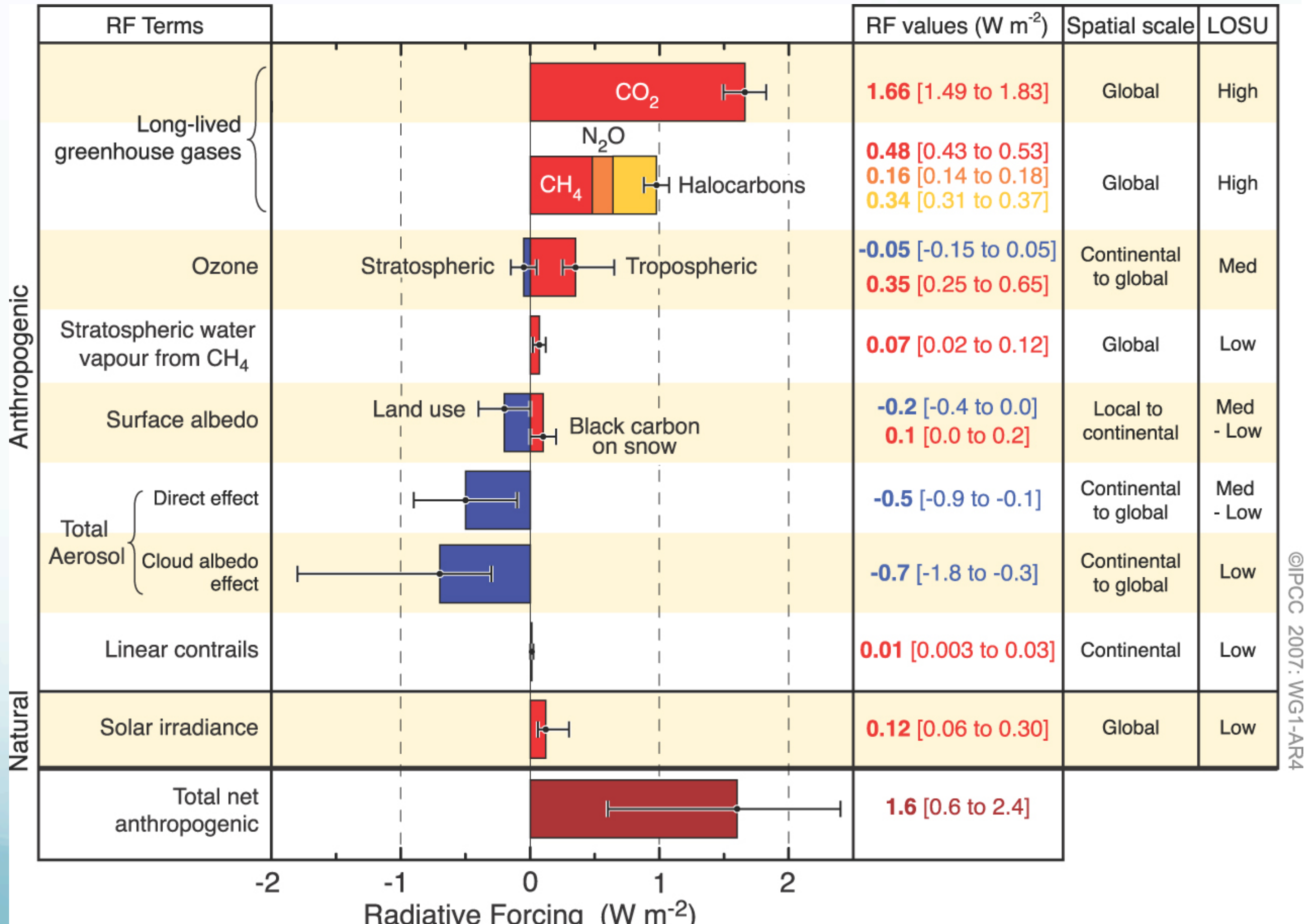
Radiative Forcings all Plotted Together

- Red = warming, blue = cooling
- Longwave and shortwave together here

Radiative forcing of present climate vs Preindustrial, with uncertainties

Aerosols (air pollution) are the biggest uncertainty

IPCC AR4 SPM



Climate Forcings Summary

- Climate forcings either change shortwave radiation or longwave radiation
  - Longwave forcings are greenhouse gases and include:
    - Carbon dioxide
    - Methane
    - Nitrous oxide
    - Ozone
  - Shortwave forcings include:
    - Changes in solar radiation
    - Changes in surface albedo by land use and soot on snow
    - Volcanoes
    - Aerosols

Local Aspects of Many Climate Forcings

- CO_2 is still the main problem
  - And it is global (essentially the same concentration everywhere)
  - Hence “global warming” is an appropriate name
- Many of the other climate forcings are much more localized though
  - Soot on snow, land use, aerosols all tend to be localized
  - Hence “climate change” is a better term when covering these

Summary

- Climate forcing: anything – natural or not – that can change energy balance, and hence climate, independently.
- Distinguish this from climate feedbacks, which can also change energy balance but which depend on the climate itself (tomorrow!).
- Most greenhouse gases (but not water vapor) are a form of positive climate forcing.
- Aerosols, soot, and changes in land use also represent human-caused climate forcing, and mostly would cause global cooling if there were no GHGs.