Agronomy 406
World Climates

April 5, 2018

Human-induced causes of climate change:

- Changes to atmospheric composition.
- Changes to land use.

Bring IPCC Fifth Assessment Report Summary for Policymakers to class again on Tuesday.

Poster session

When and where: April 24 and 26 (Tuesday and Thursday) during our regular class time, in the Agronomy Commons, second floor of Agronomy Hall.

Formatting and guidelines: See "AGRON 406 Poster Guidelines" in the Pages section of Canvas.

Printing: You can have your poster printed wherever you like, as long as it is ready on time.

Peer review: Each poster will be reviewed by at least two people in the class. Evaluation forms will be distributed (also in Files section on Canvas).

Attendance: You are expected to attend each day of the poster session and take notes on the posters. The poster sessions also will be open to the public.

A long-term stabilizer of climate:
The CO_2 – rock weathering "thermostat"

Basic ideas:

Over long times **volcanoes add large amounts of CO_2** to the atmosphere.

CO_2 is removed from by **weathering of rocks**: CO_2 reacts with rock material and the dissolved products are carried away.

Both processes **usually** are slow (~500,000+ years).

What controls the thermostat?

Effects on removal of CO_2:

Removal rate depends on CO_2 concentration itself: the higher is CO_2, the faster the reaction rate (basic chemistry).

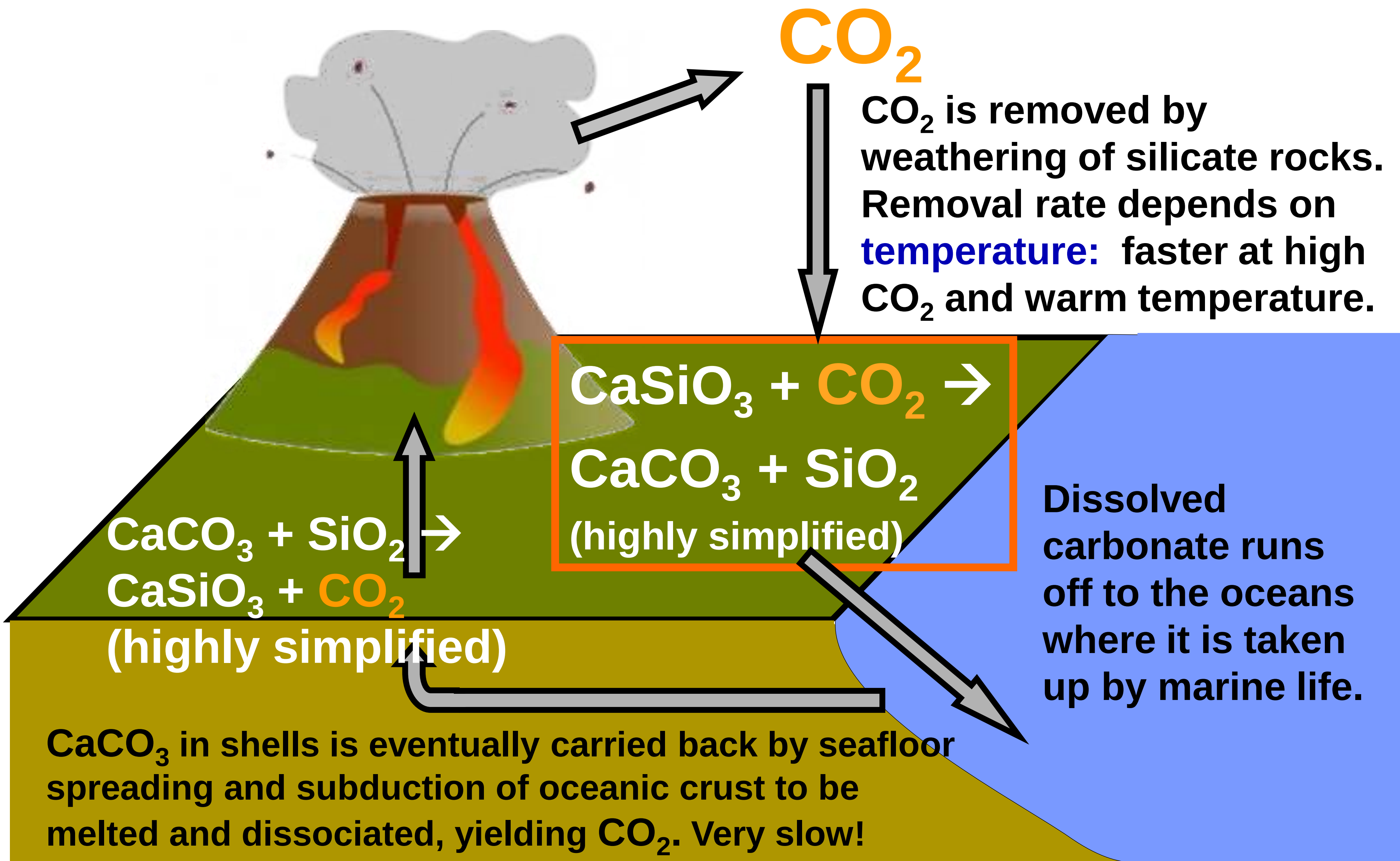
Reaction rates are higher at warm temperatures (also basic chemistry).

Warmer climates have more precipitation, which increases the rate of physical weathering (e.g., erosion) and helps flush out the reaction products.

All three of these mean that **CO_2 is removed faster in warmer climates.**

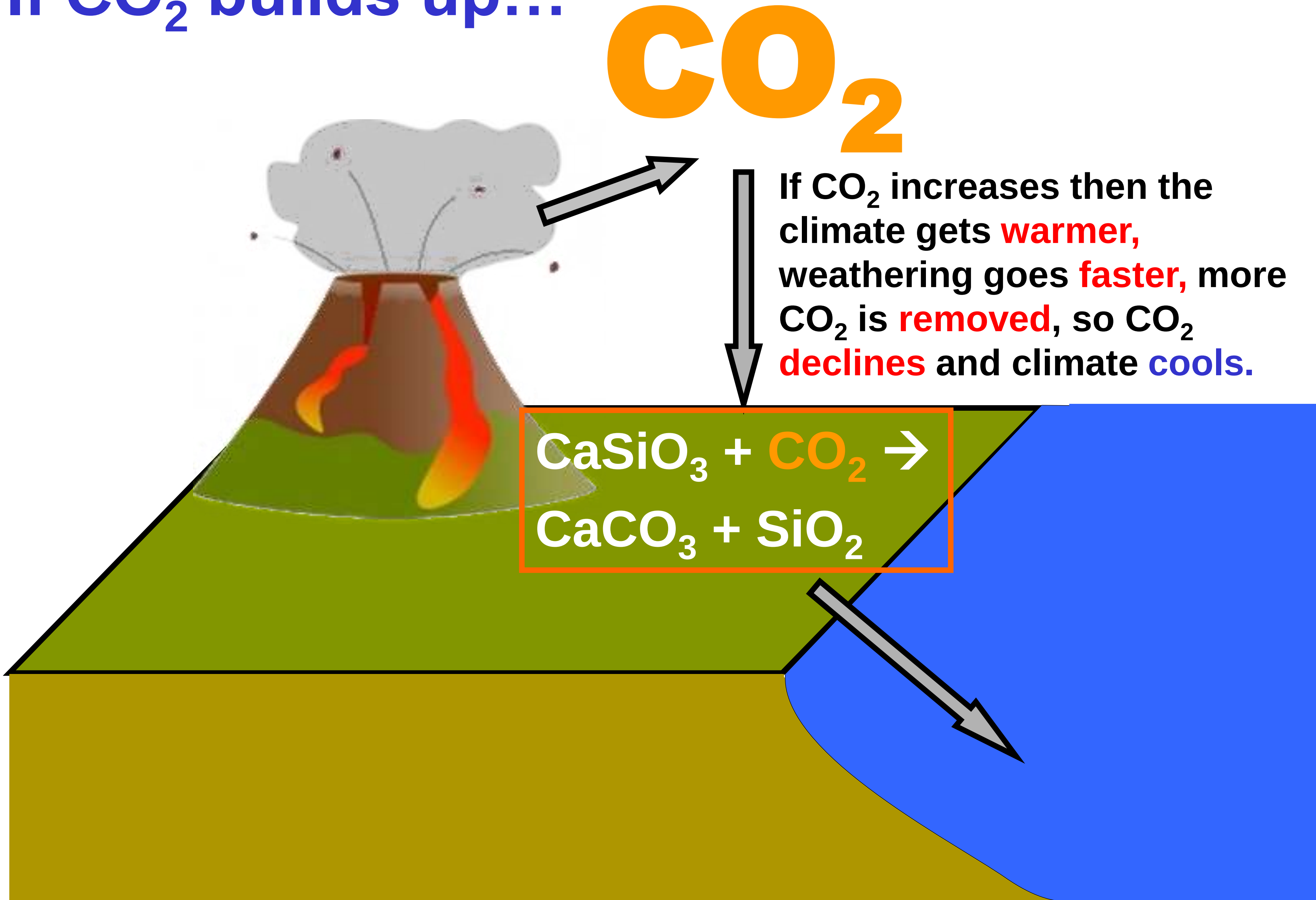
image from basc.pnnl.gov

How the CO2 – silicate rock weathering "thermostat" works

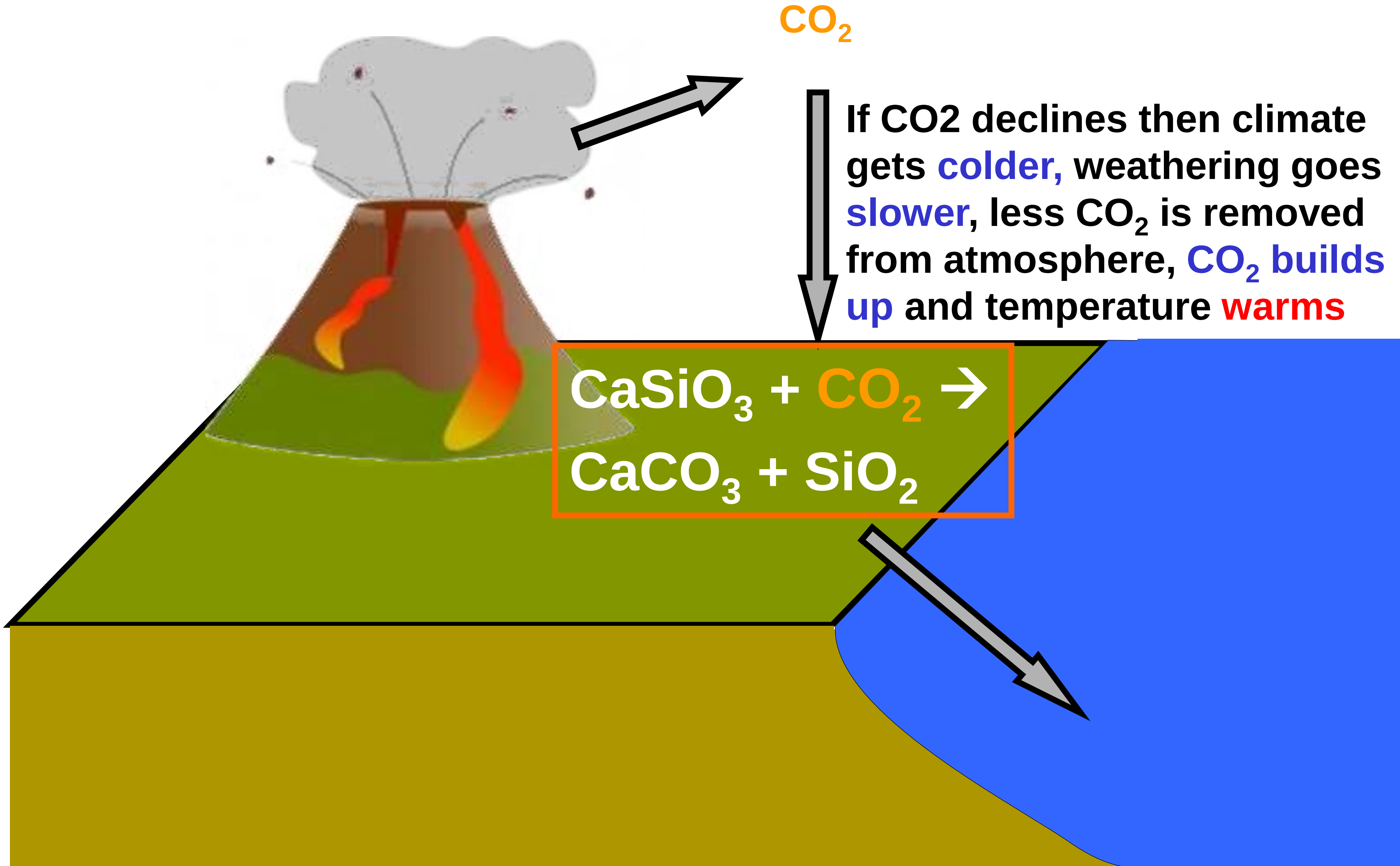


If CO_2 builds up…

If CO_2 increases then the climate gets warmer, weathering goes faster, more CO_2 is removed, so CO_2 declines and climate cools.



If CO_2 is depleted…



If CO2 declines then climate gets colder, weathering goes slower, less CO_2 is removed from atmosphere, CO_2 builds up and temperature warms

Anthropogenic causes of climate change

Changes in atmospheric composition:

Changes in concentrations of long-lived gases that are radiatively active in the thermal-infrared part of the spectrum (i.e., greenhouse gases).

Changes due to aerosols (liquid or solid particles).

Changes to the land surface:

Agriculture, urbanization, deforestation, other changes.

How do greenhouse gases work?

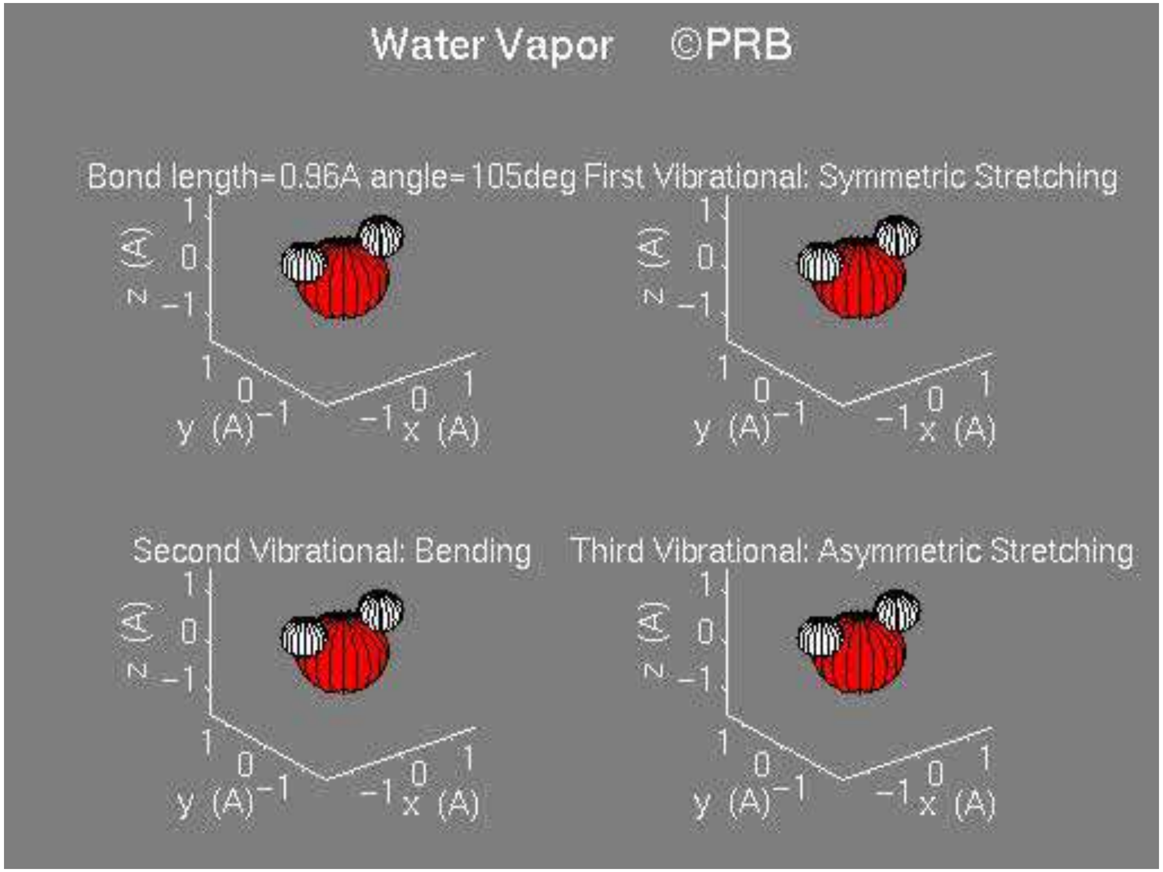
Greenhouse gases work by absorbing and emitting electromagnetic radiation in **the range of wavelengths at which Earth emits radiation** (about 10 microns).

This absorption and emission involves changes related to a molecule's **distribution of electrical charges**.

> Then **only molecules that have the possibility for a change in distribution of electrical charges** can be greenhouse gases.

Different gases absorb and emit radiation in specific frequency bands, related to specific ways of moving when they are energized.

Example: Stretching and bending modes of water molecules (H_2O)



Hydrogen tends to be **positively** charged.

Oxygen tends to be **negatively** charged.

When the molecule bends or stretches, this change in relative position of the H and O atoms **changes its distribution of electrical charges.**

Animations: http://www.ems.psu.edu/~bannon/moledyn.html

Major greenhouse gases

Water vapor: atmospheric lifetime about **9 days.**

- Very short lifetime makes H_2O a **feedback** rather than a **forcing.**

Carbon dioxide: atmospheric lifetime ~ century++

- Has a complex variety of sources and sinks, so there is **not a single, well-defined CO_2 lifetime.**

Methane: atmospheric lifetime about 10 years.

- Many sources, mostly biological (not necessarily "natural").

These were identified as greenhouse gases by John Tyndall in 1859-1862.

Other significant greenhouse gases

Nitrous oxide: atmospheric lifetime ~120 years

Sources are mostly biological. Tropical soils produce about 75%.

Main source from human activity is fertilizer manufacture and application.

Halocarbons: lifetimes vary, few years to centuries

Carbon combined with fluorine, chlorine and/or bromine.

Commonly used as refrigerants and solvents.

Ozone:

Don’t confuse ozone’s role in long-wave radiation (greenhouse effect) with its absorption of ultraviolet radiation (e.g., concern over the "ozone hole").

Team question: Which gases matter?

Radiative forcing is the change in net radiation at the tropopause over some period.

In the IPCC reports, radiative forcing usually is defined relative to values in 1750, around the start of the Industrial Revolution.

In the IPCC Fifth Assessment Report:

What are the values of radiative forcing associated with emissions of **carbon dioxide, methane, halocarbons, and nitrous oxide?**

What are the percentages of each of these relative to the **total anthropogenic radiative forcing?**

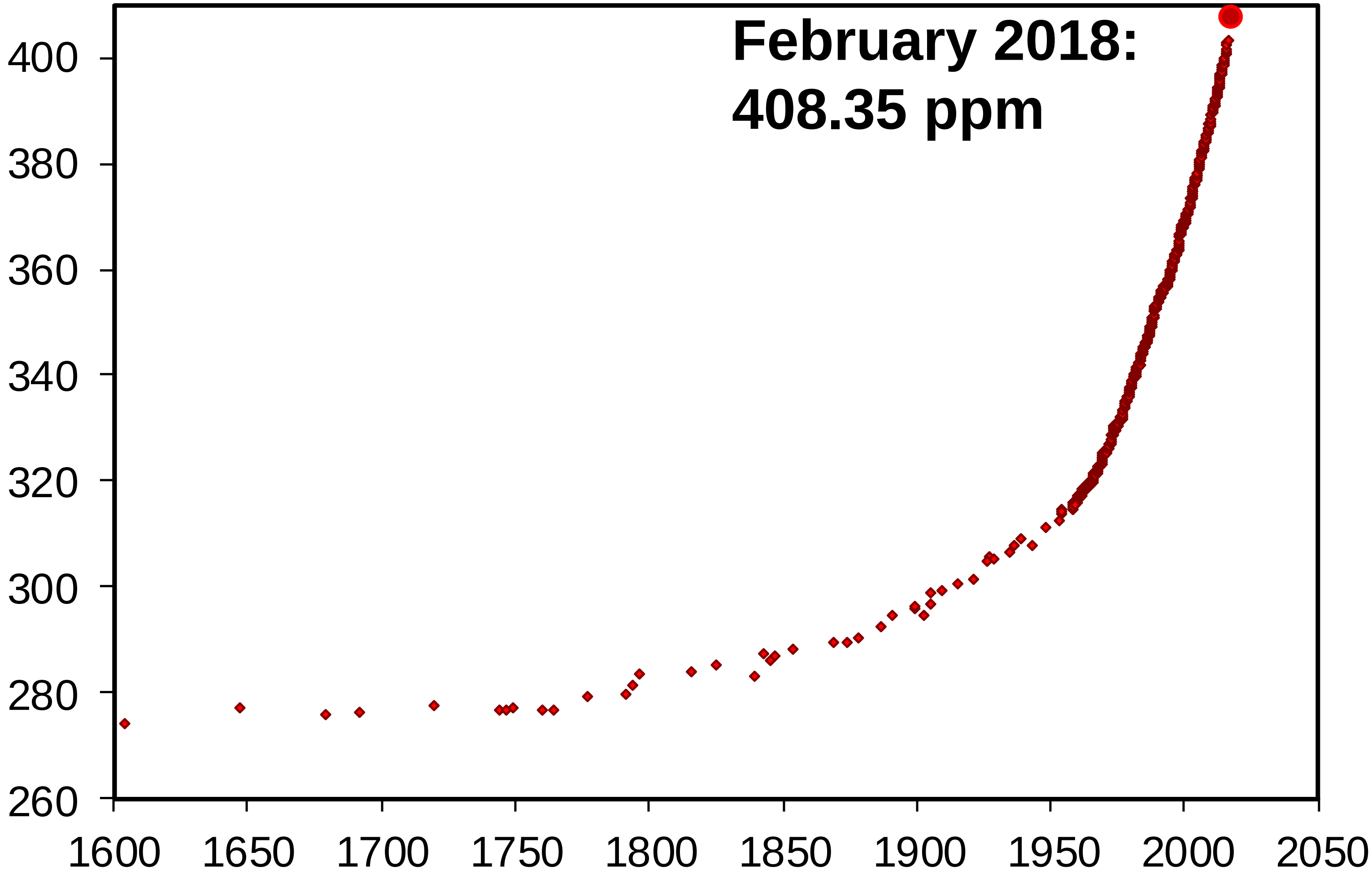
Fraction of human-caused radiative forcing due to emissions of major greenhouse gases

Total anthropogenic radiative forcing is 2.29 W m^{-2}.

Gas	Radiative forcing, W m^{-2}	Fraction
Carbon dioxide	1.68	73%
Methane	0.97	42%
Halocarbons	0.18	8%
Nitrous oxide	0.17	7%

Notice the sum is more than 100%! This is because some other processes cause **negative** radiative forcing.

Atmospheric CO2 since 1600



Values before 1958 are from Antarctic ice cores.

Values 1958-present are from Mauna Loa observatory.

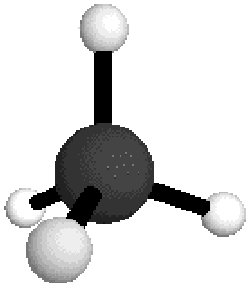
Methane (CH_4)

Atmospheric concentration is much lower than CO_2.

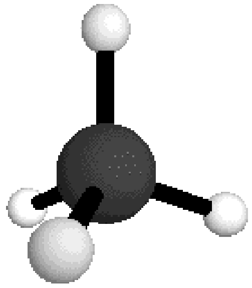
At current concentrations, methane is a much stronger greenhouse gas on a molecule-for-molecule basis.

Concentration has increased about 160% since 1750 (from 700 to 1800 ppb).

wavelength 3.3 μm

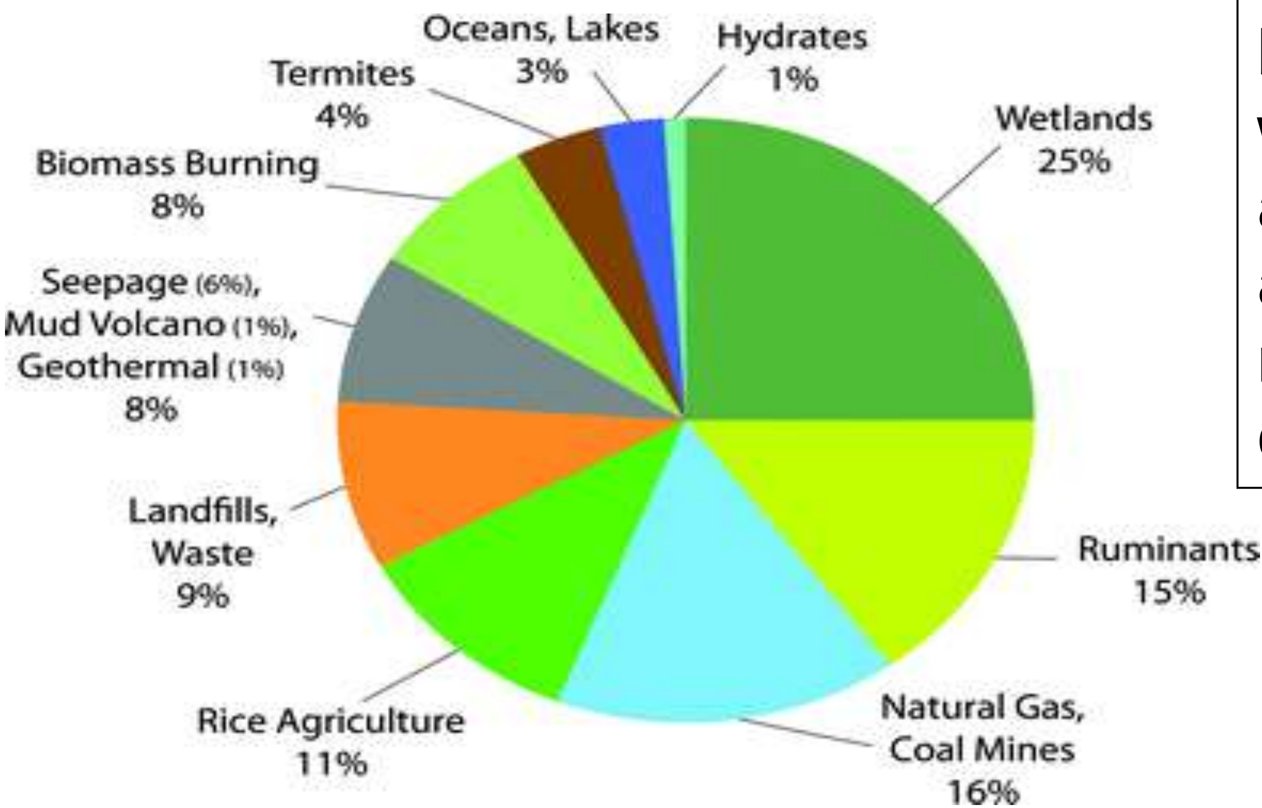


wavelength 7.7 μm



vibrational mode animations from
http://www2.ess.ucla.edu/~schauble/MoleculeHTML/CH4_html/CH4_page.html

Methane sources

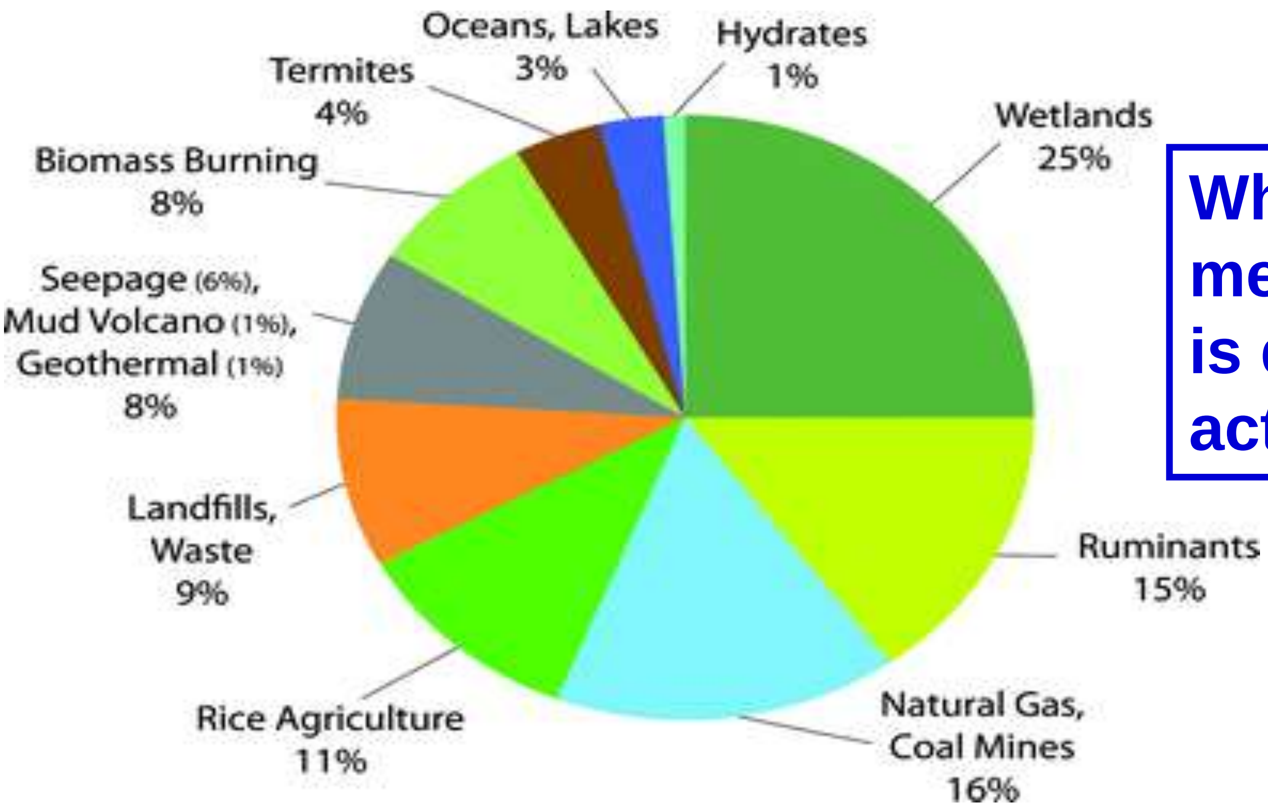


Sources are mostly biological: wetlands, ruminant animals, termites, and rice farming make up about 54% of emissions.

The main sink is oxidation by hydroxyl radicals (OH) in the troposphere.

from Atreya (2010), DOI: 10.1039/c005460g

How much is anthropogenic?



What fraction of methane emissions is due to human activities?

from Atreya (2010), DOI: 10.1039/c005460g

Aerosols and dust

Tropospheric aerosols have two kinds of effects:

- **Direct effect:** Shading of the surface.
- **Indirect effect:** Effect on **clouds.** Aerosols serve as cloud condensation nuclei. Higher aerosol concentrations cause more and smaller droplets, making clouds longer-lasting and more reflective.

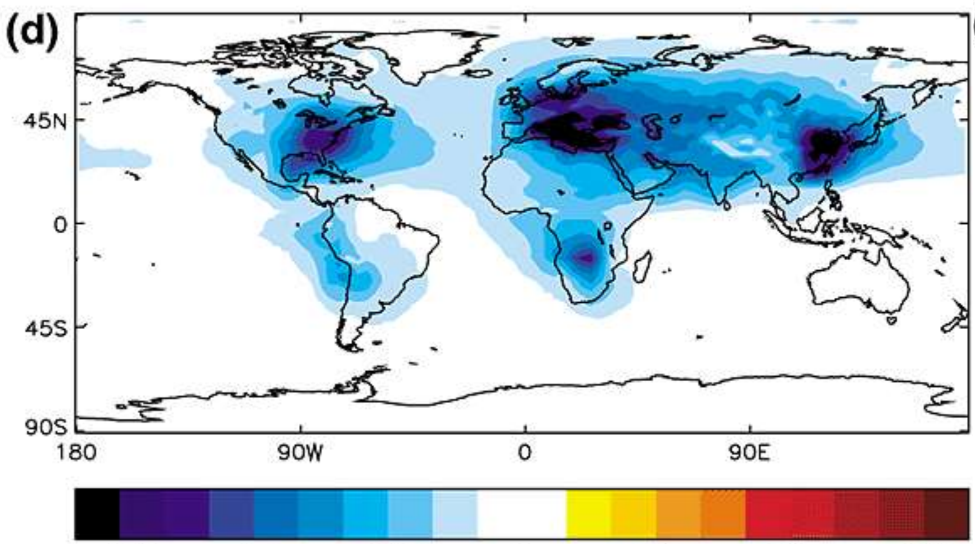
Aerosol effects are less certain than greenhouse gas effects. Some reasons:

- Harder to measure aerosols.
- Large spatial variations (short lifetime).
- "Clouds are hard." (Isaac Held, NOAA GFDL)
- Effects depend on aerosol size and composition as well as concentration.

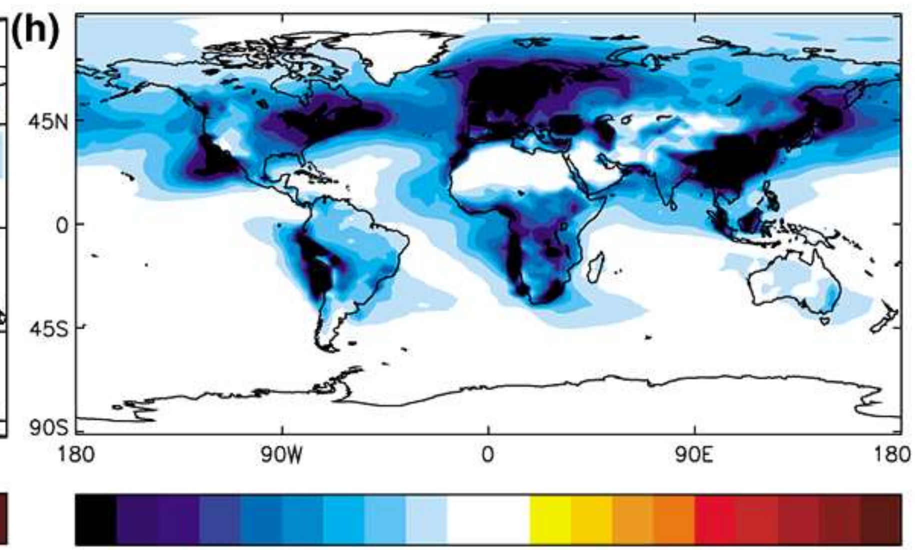
The aerosol indirect effect is larger and more extensive than the direct effect

What patterns can you see in the direct effect? In the indirect effect? How do they differ?

direct effect



indirect effect



note 2x difference in scale

Changes to land use

Strongest effects are **local to the region where land use is changed.** Can affect global energy balance if changes are extensive enough, or if similar changes happen in multiple regions.

Examples:

- Agriculture and irrigation
- Overgrazing
- Large-scale deforestation
- Urbanization

Deforestation

Net loss of forest in 2000-2010 was **13 million acres per year** (about 1/3 the area of Iowa). Deforestation has slowed since the 20th century.

Land is deforested for various reasons:

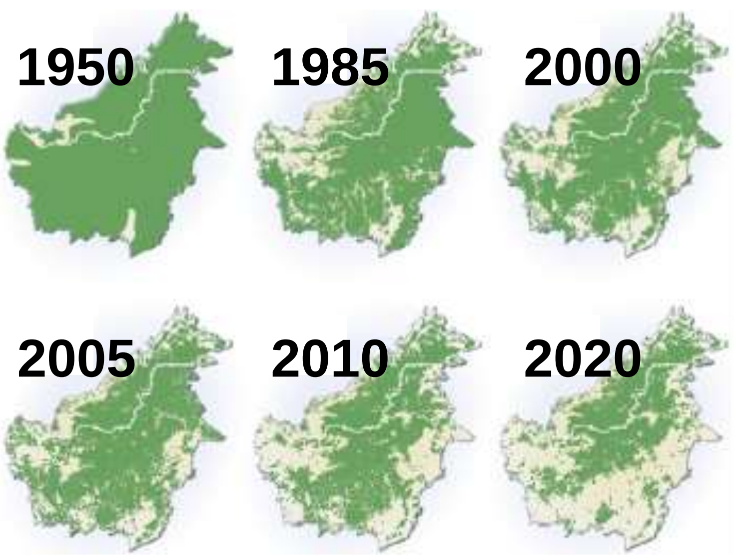
wood harvesting, urban expansion, agriculture, development of roads and other infrastructure

The largest reason for deforestation has been to clear land for agriculture:

Amazon: cattle ranching, soybean production

Borneo: palm tree plantations

Deforestation in Borneo, 1950-2020



images from WWF

Effect of deforestation on surface energy balance and climate

The surface energy balance is

$$Q^* = F_{SH} + F_{LE} + F_{cond}$$

where

Q^* = net radiation

F_{SH} = sensible heat flux

F_{LE} = latent heat flux

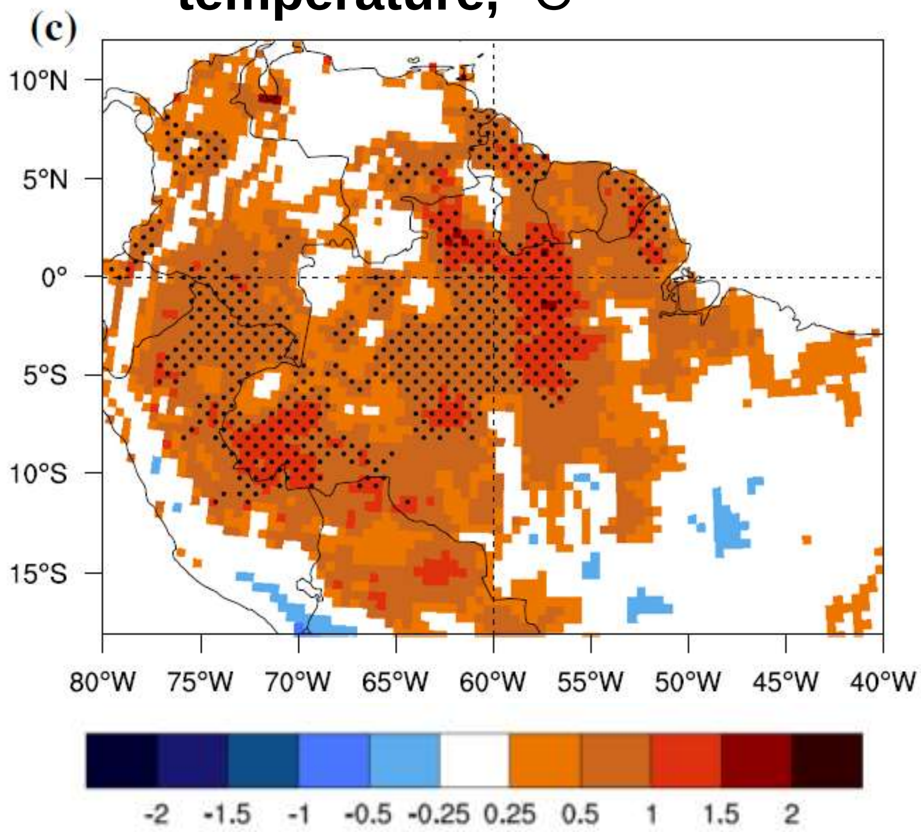
F_{cond} = conduction of heat to/from the substrate.

Given your knowledge of the surface energy balance and evapotranspiration, how would you expect deforestation to affect climate in the Amazon region?

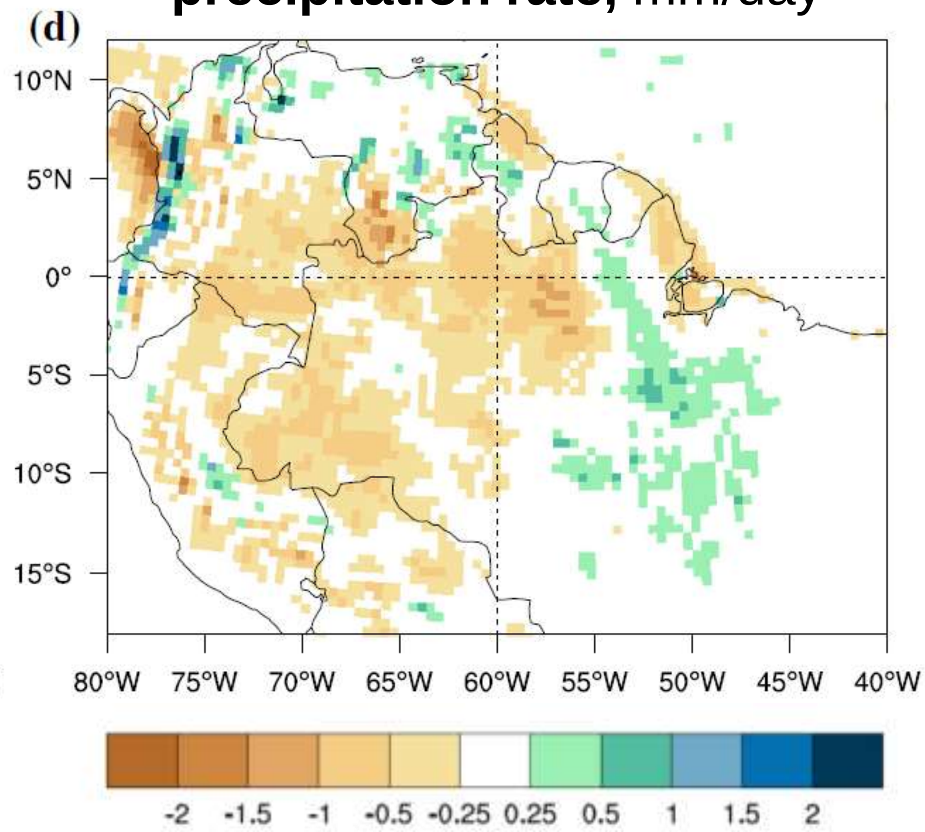
Some recent modeling results for changes due to deforestation

Changes for projected land use at 2100 versus present

Change of annual mean **temperature,** °C



Change of annual mean **precipitation rate,** mm/day



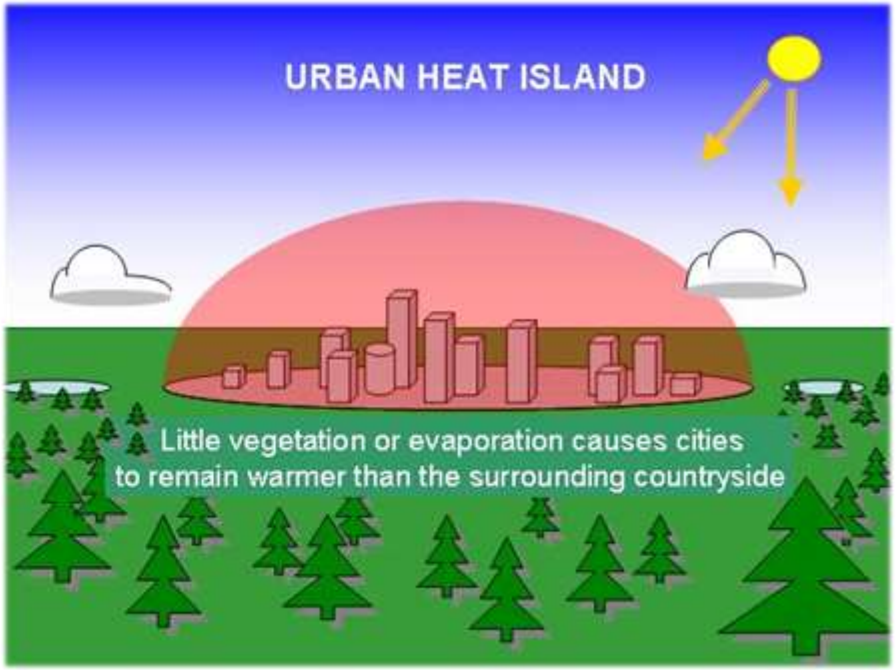
Lejeune et al. (2015)

Urban Heat Island (UHI)

Built-up area that is generally warmer than surrounding rural areas.

Difference is strongest at night:

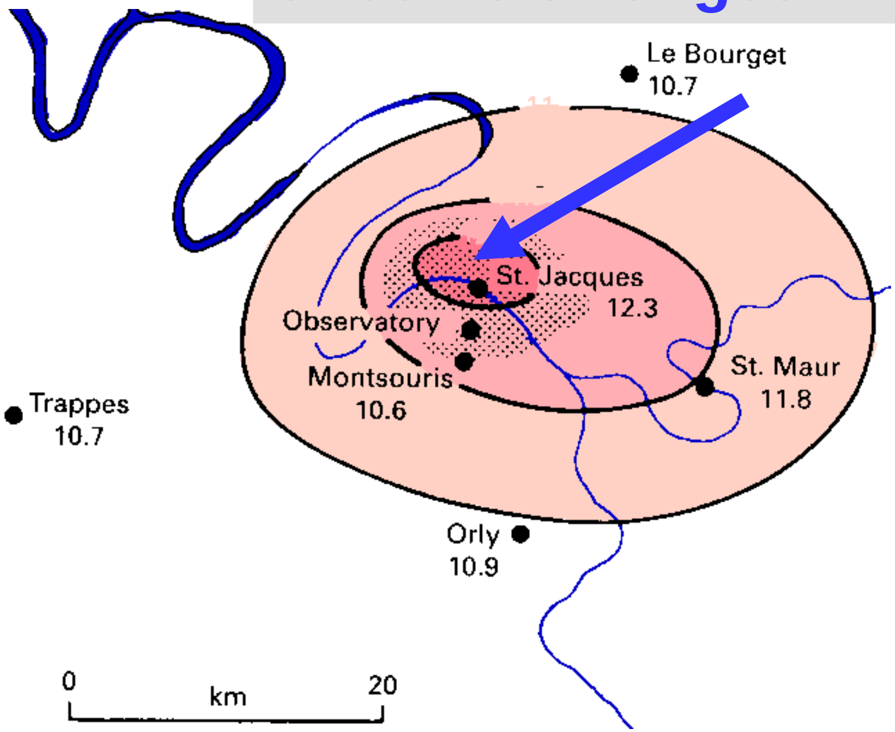
- About 2–5°F (1–3°C) warmer during the day.
- As much as 22°F (12°C) at night.



adapted from a presentation by Taleena Sines

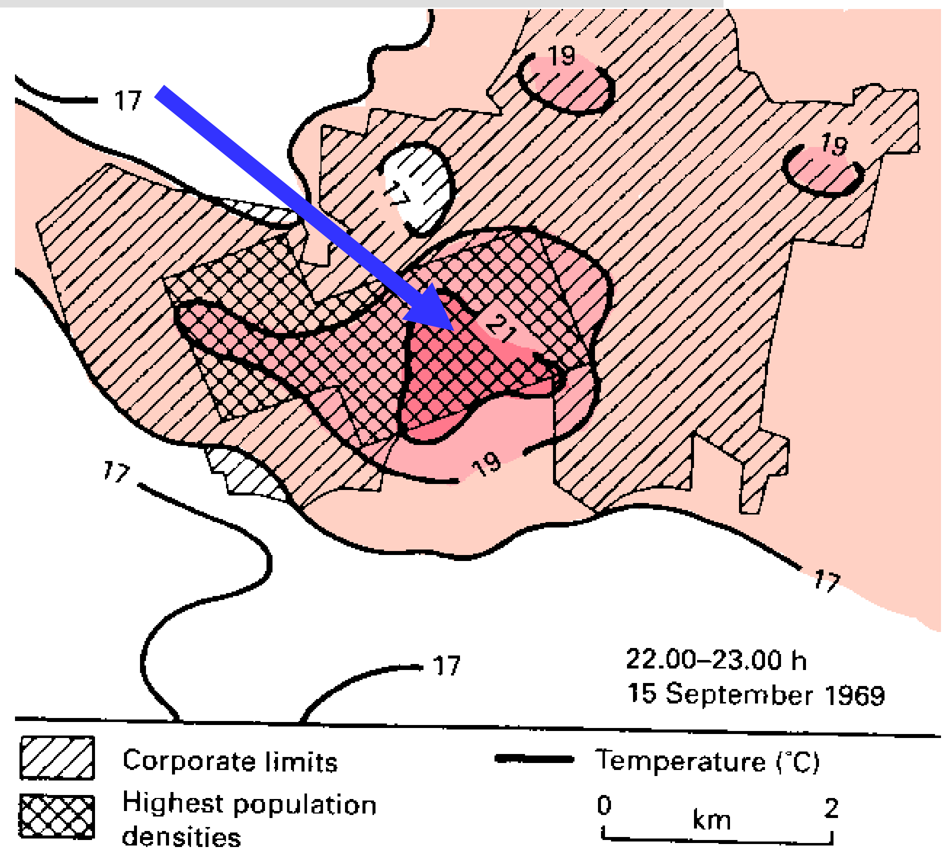
Examples of urban heat islands

Paris



Chapel Hill, NC

effect is strongest near the center of the city



adapted from Robinson and Henderson-Sellers, *Contemporary Climate*

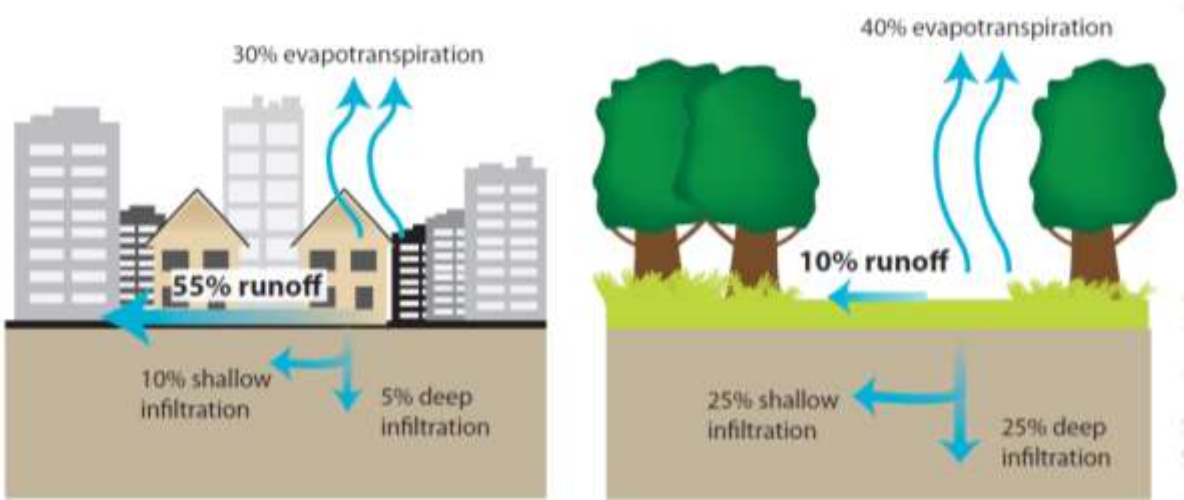
Differences of urban areas from their surroundings

Impermeable materials reduce infiltration and evapotranspiration.

Thermal properties such as albedo, thermal conductivity and heat capacity affect energy balance.

Height and spacing of buildings affect wind flow, energy absorption, and emissivity.

Anthropogenic **heat release** by air conditioning, transportation, industry etc. add to UHI (mainly in winter).



adapted from a presentation by Taleena Sines

Scale of the urban heat island

The larger the city, the greater the effect.

One approximation is:

$$\Delta T(\text{urban - rural}) \sim A \log p$$

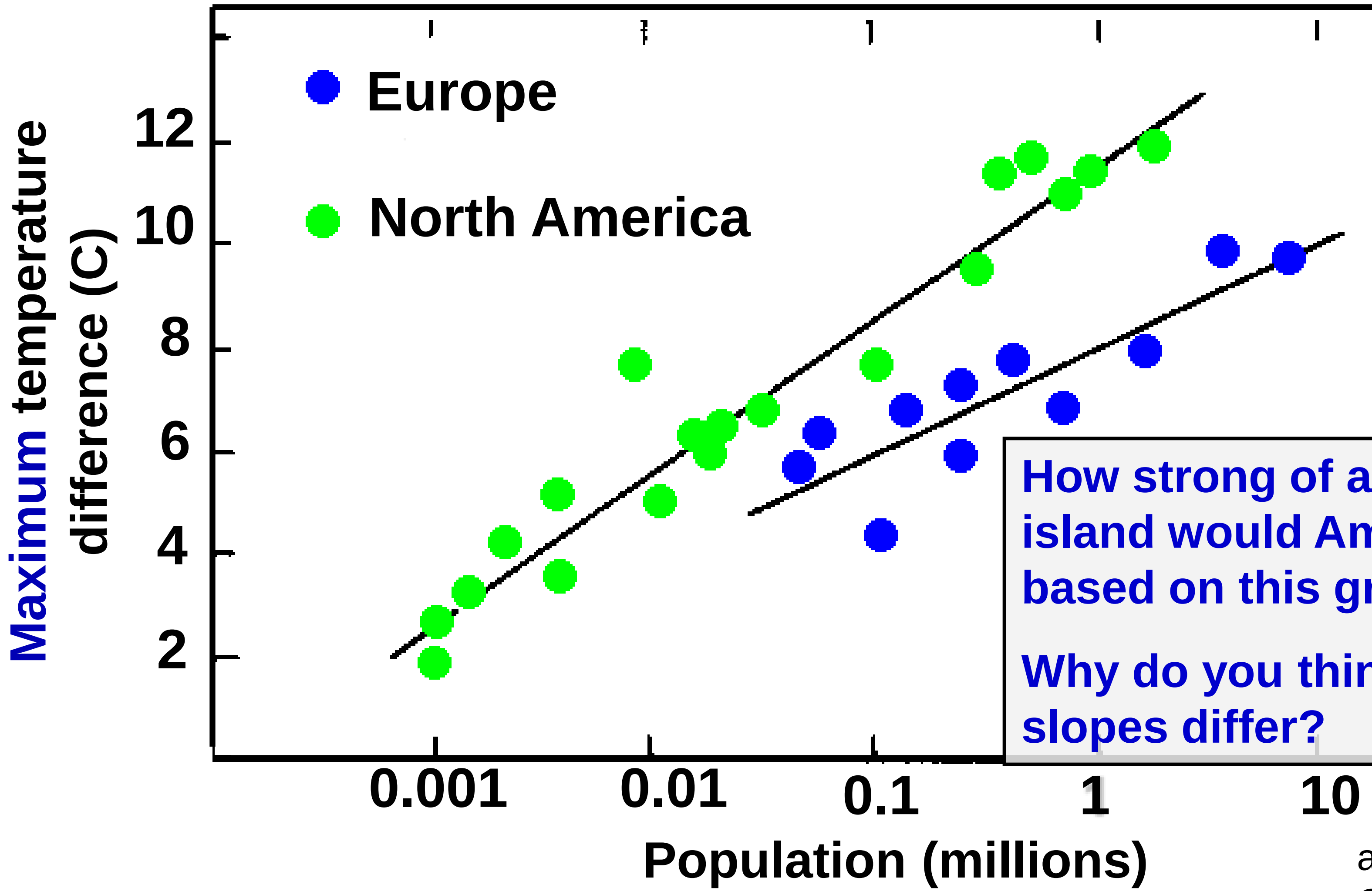
T is temperature

p is population

A is a constant

Effect per unit population (value of the constant A) differs between Europe and North America.

Urban heat island: relation to population



How strong of a heat island would Ames have, based on this graph?

Why do you think the slopes differ?

adapted from Oke (1973)