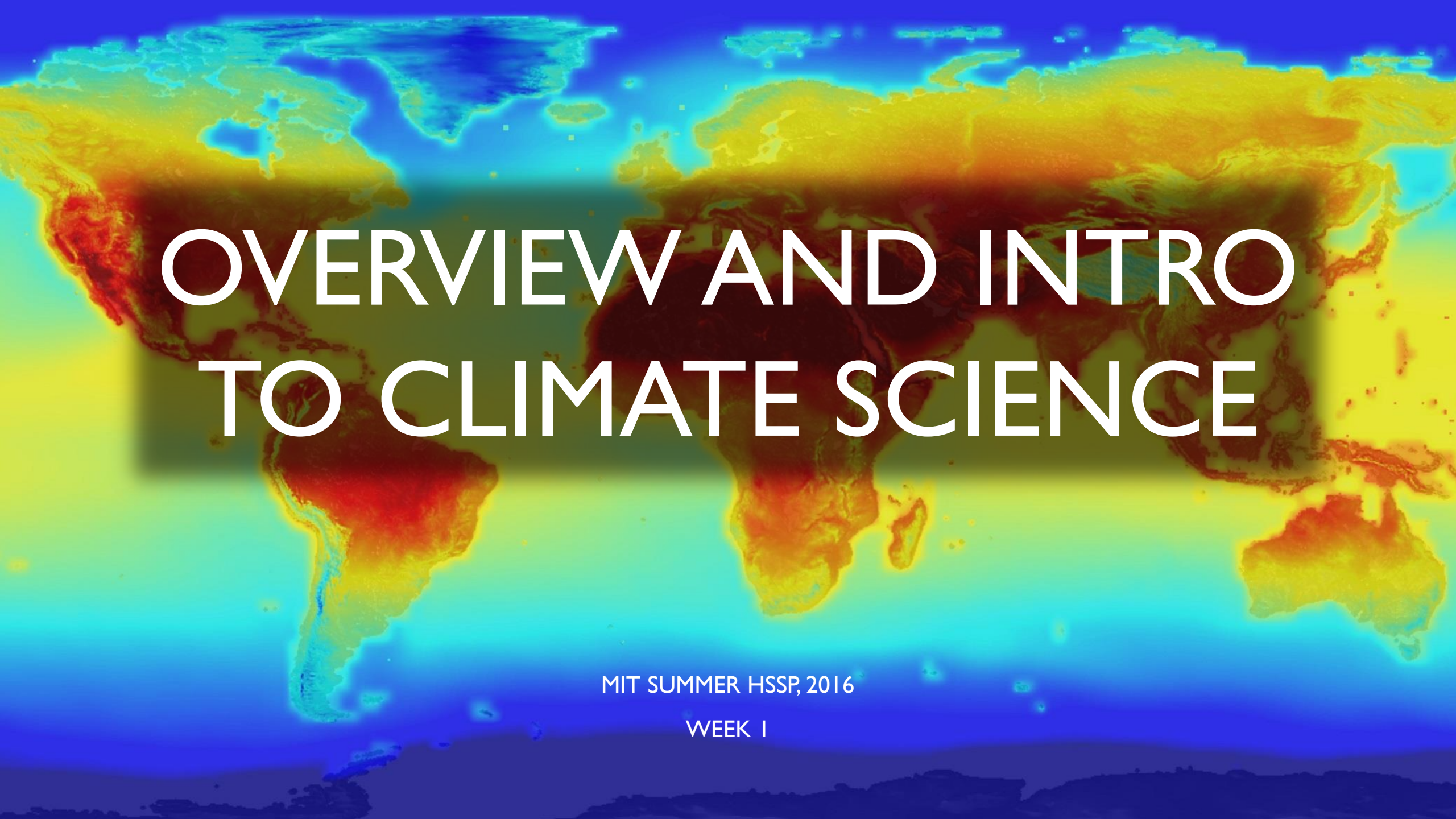


OVERVIEW AND INTRO TO CLIMATE SCIENCE

MIT SUMMER HSSP, 2016

WEEK 1

COURSE OVERVIEW

THIS IS GOING TO BE FUN (I HOPE…)

JOSH'S BACKGROUND

- **MIT:**
  - 2nd Year Ph.D. Student
  - Researching Atmospheric Chemistry

- **U.C. Berkeley:**
  - B.S. in Chemical Engineering, 2015
  - Concentration in Biotechnology
  - Researched Atmospheric Chemistry

CLASS FORMAT

- Taking notes will be helpful for when we do the mock intergovernmental scenario
  - I'll post all of the powerpoints on the website, but they won't contain everything I say
- Please ask a lot of questions!
  - This class may be more fast-paced than you are used to
- There will be optional reading assigned as homework
  - The only mandatory reading will be as preparation for the intergovernmental scenario

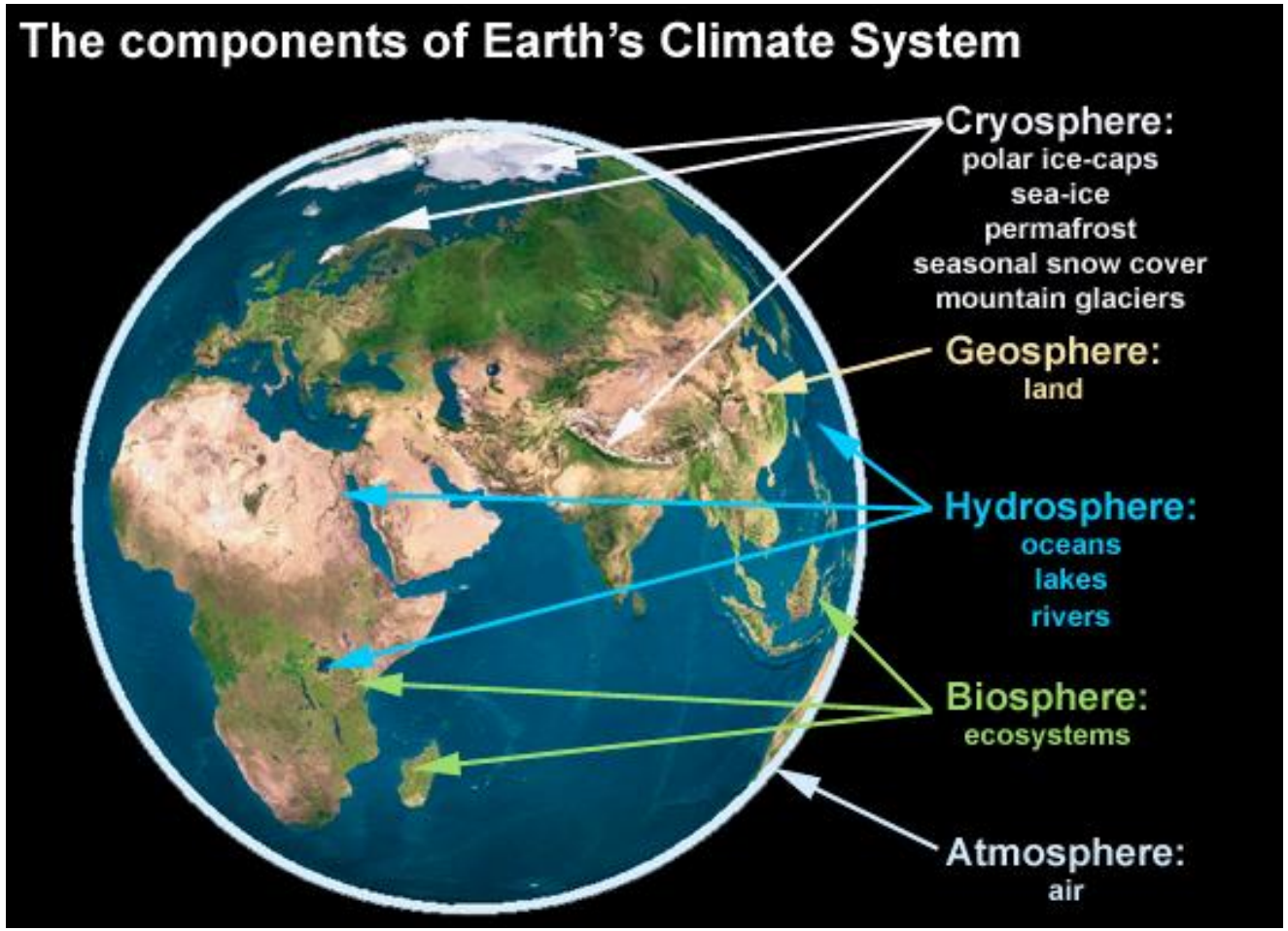
CLASS SCHEDULE

Week	Topic
1	Introduction and General Scientific Background
2	Atmospheric Chemistry and Climate Change
3	Climate Modelling and Measurements
4	Mitigation Strategies and New Energy Sources
5	Why is Climate Change a Political Issue?
6	Geoengineering: Crazy or Necessary?
7	Mock Intergovernmental Scenario

CLIMATE CHANGE OVERVIEW

MILDLY APOCALYPTIC AND SOMEWHAT PREVENTABLE

THE EARTH-CLIMATE SYSTEM



- All components of the system interact with each other over long and short timescales
- Many components interact in multiple ways with each other
- The balance between the components of this system is highly complex and not fully understood

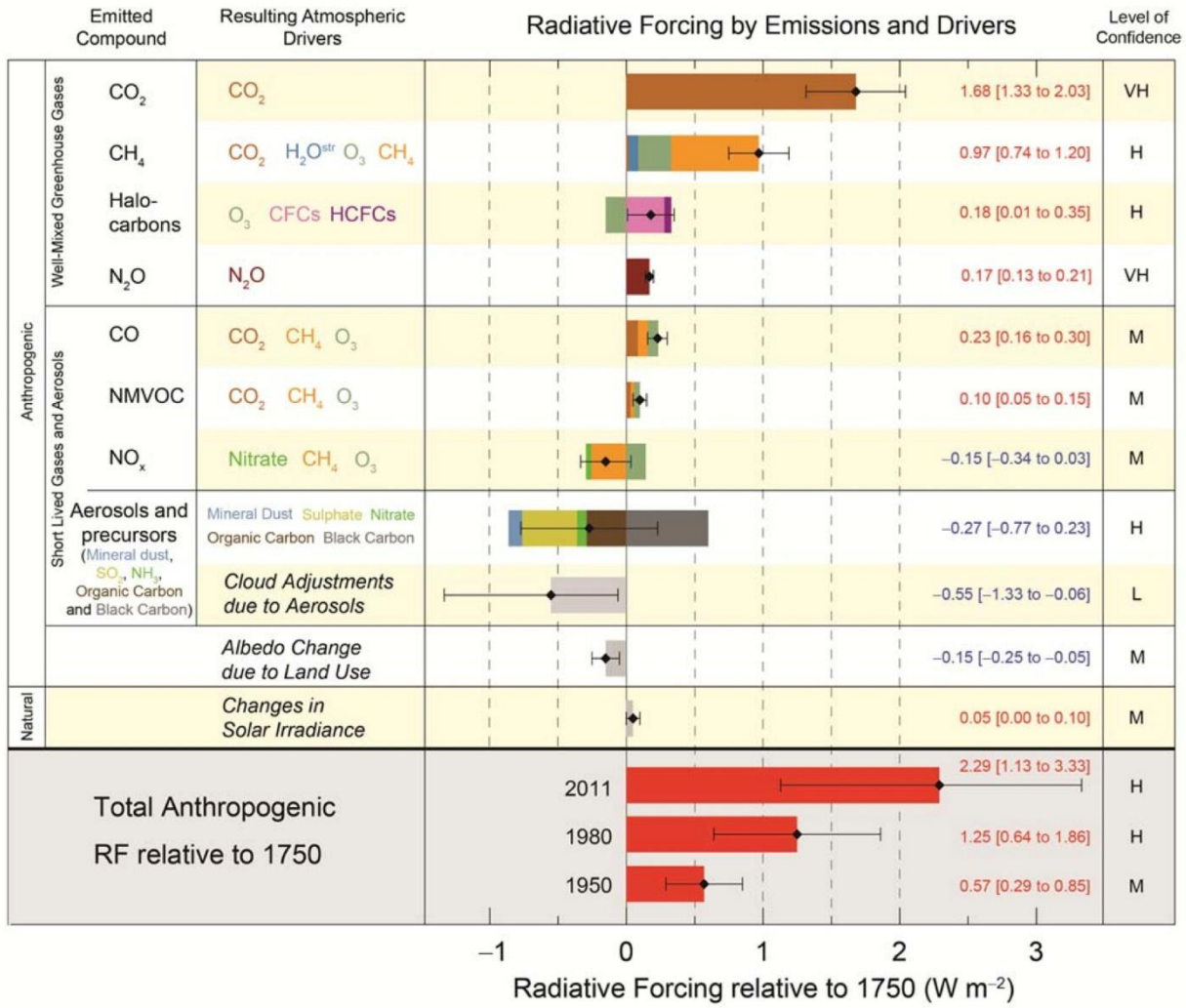
WHAT IS CLIMATE CHANGE?

- Climate change is the changes in the patterns of weather and environmental factors such as extreme storms, temperature, and rainfall

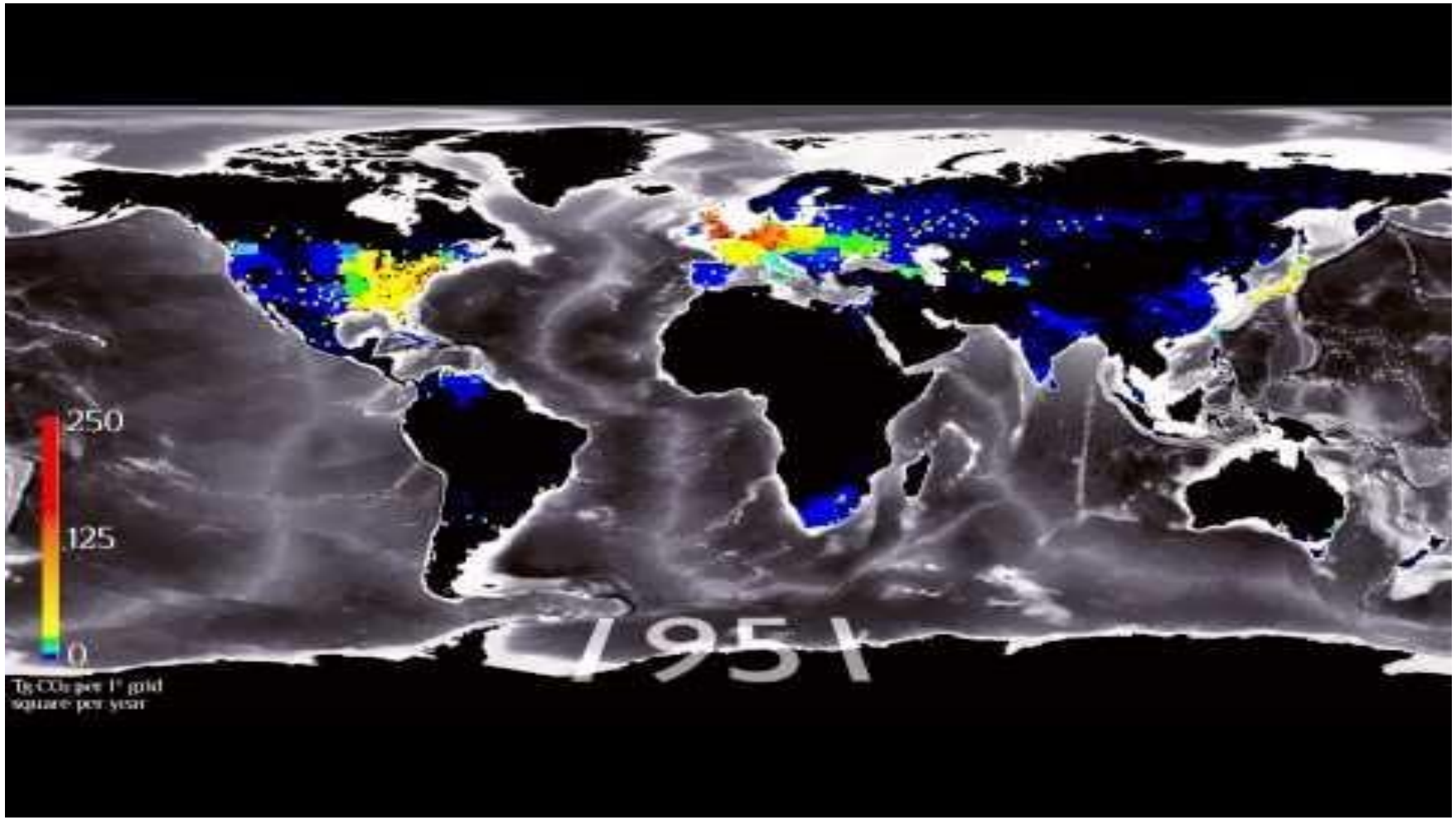
- Weather ≠ Climate
  - Weather: Short-term, immediate responses
  - Climate: Longer term weather patterns and environmental conditions

HOW DO HUMANS AFFECT CLIMATE?

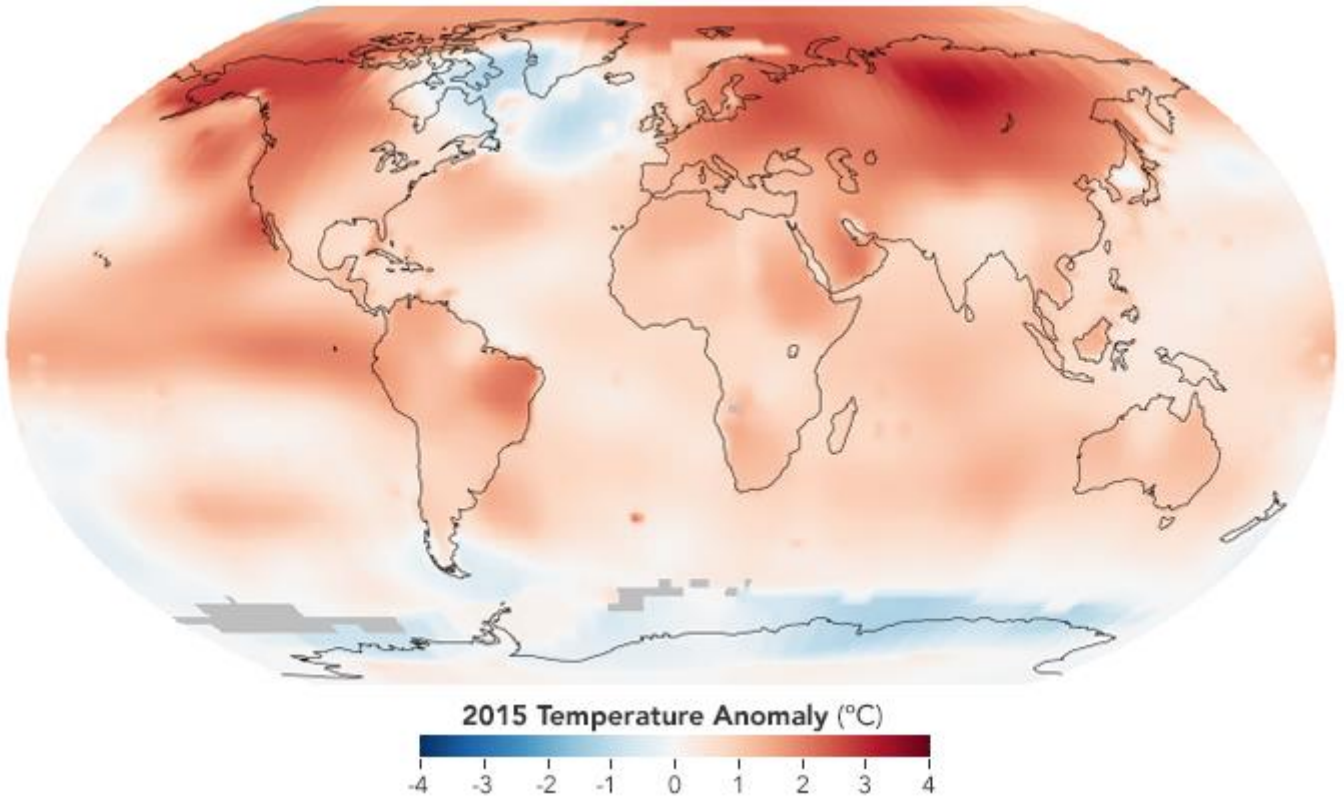
- Radiative Forcing:
  - the difference in the intensity of incoming solar radiation absorbed by the Earth and energy radiated back to space
  - If it's positive, the Earth will warm
- Greenhouse Gases (GHGs) are strongest radiative forcers
- Aerosols, clouds, and land use changes are also important for their absorptive and reflective properties

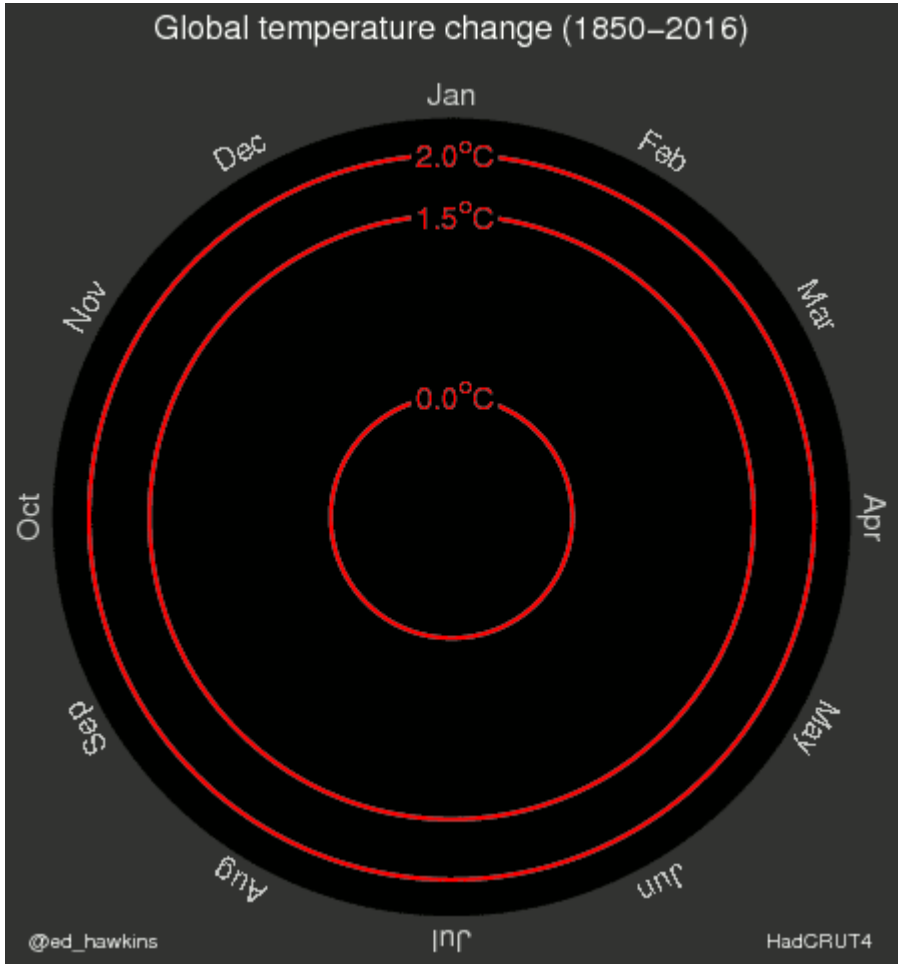


THE INDUSTRIAL REVOLUTION



MAJOR CLIMATE CHANGE EFFECTS



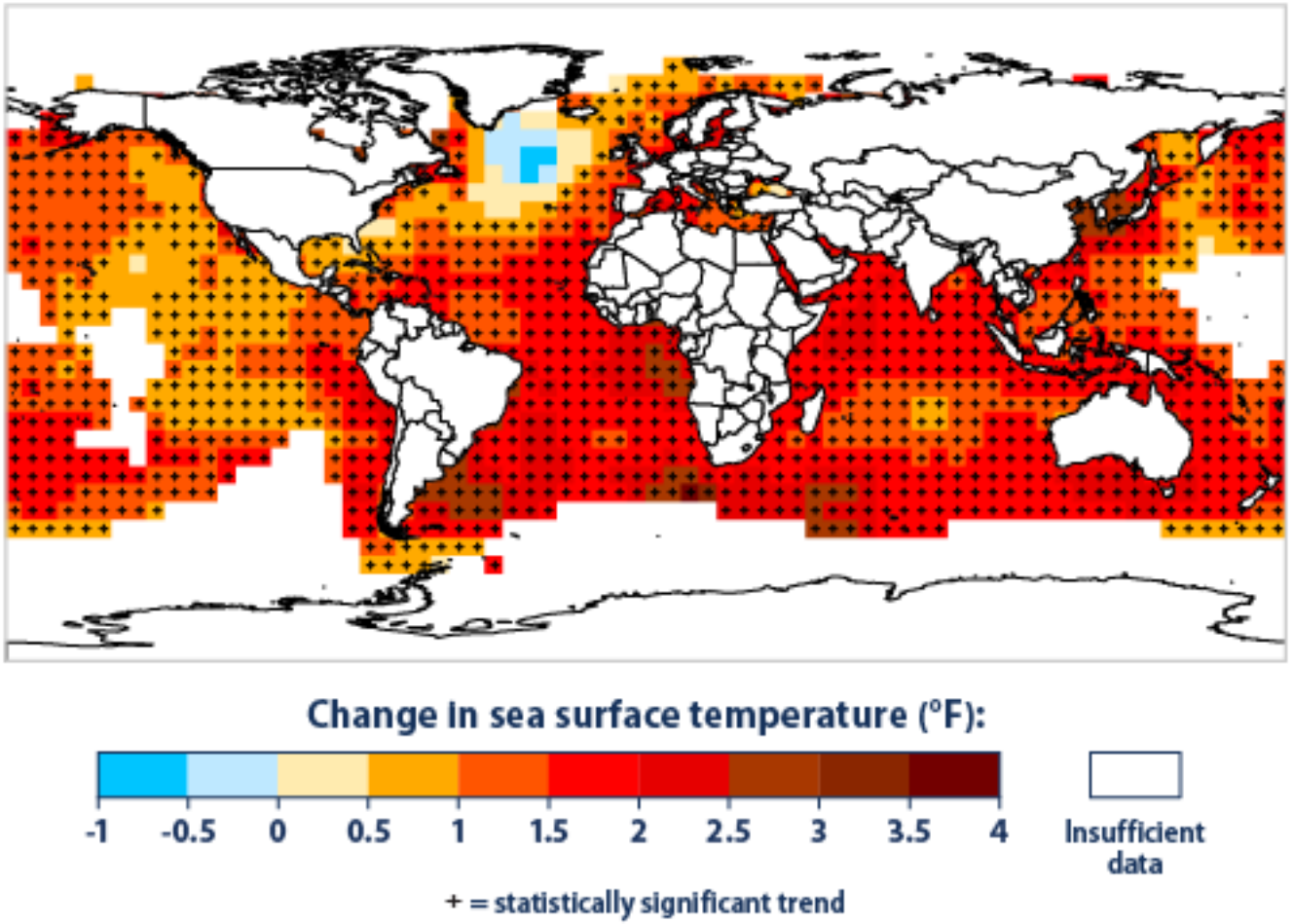


- Increasing Earth surface temperatures are the main driving effects for other climate change repercussions

MAJOR CLIMATE CHANGE EFFECTS

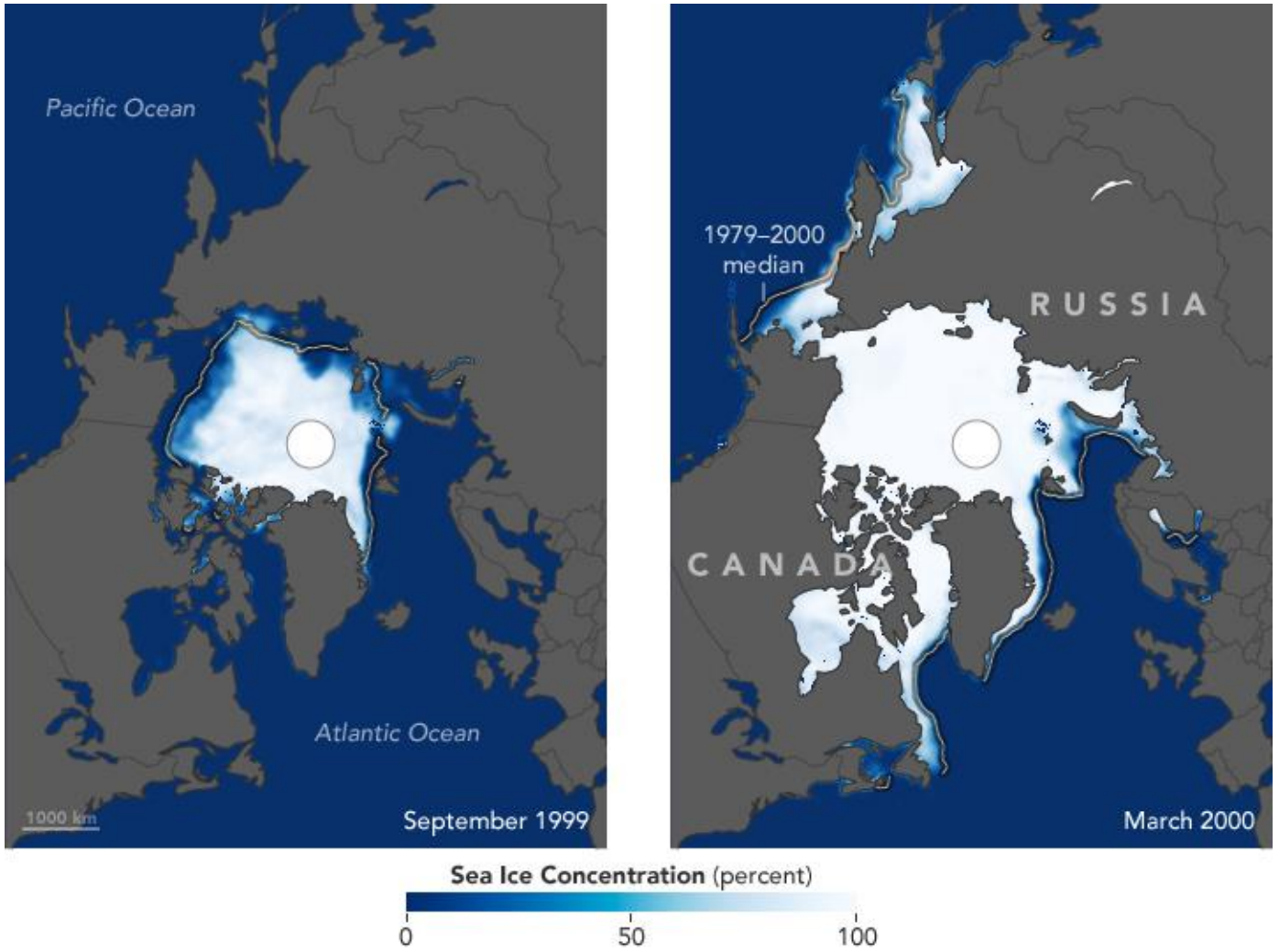
- Increasing Earth surface temperatures warm the ocean
- Note the Greenland anomaly which is most likely due to cold meltwater mixing with a weaker Gulf Stream Current from the east coast

Figure 2. Change in Sea Surface Temperature, 1901–2014

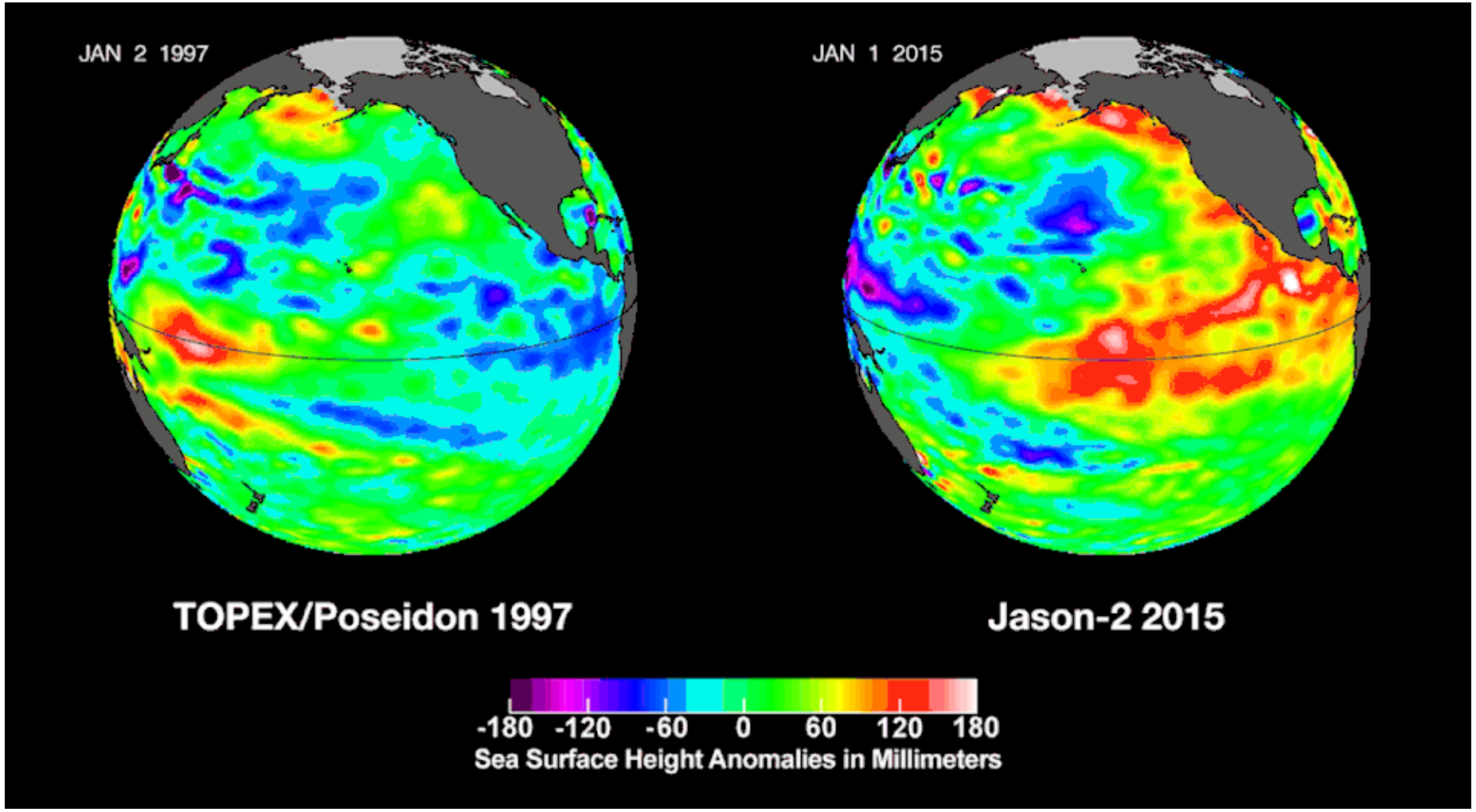


MAJOR CLIMATE CHANGE EFFECTS

- Polar ice caps are melting
- As sea and air temperatures increase, this process gets exponentially faster
- As the ice melts, sea levels rise…



MAJOR CLIMATE CHANGE EFFECTS

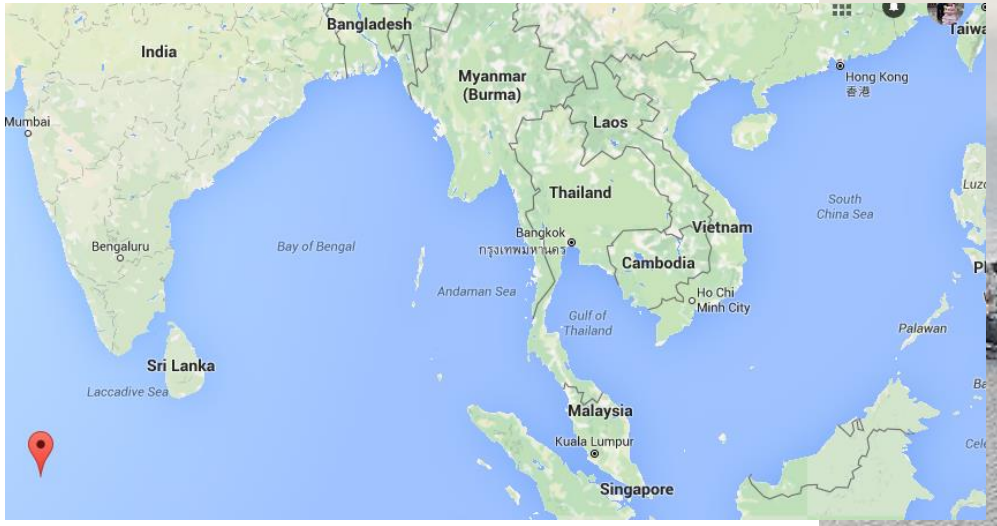


MAJOR CLIMATE CHANGE EFFECTS

- New Orleans would only be saved by levees
- This is only for a 1ft increase in sea level, but the expectation right now is for at least a one meter rise

MAJOR CLIMATE CHANGE EFFECTS

MAJOR CLIMATE CHANGE EFFECTS

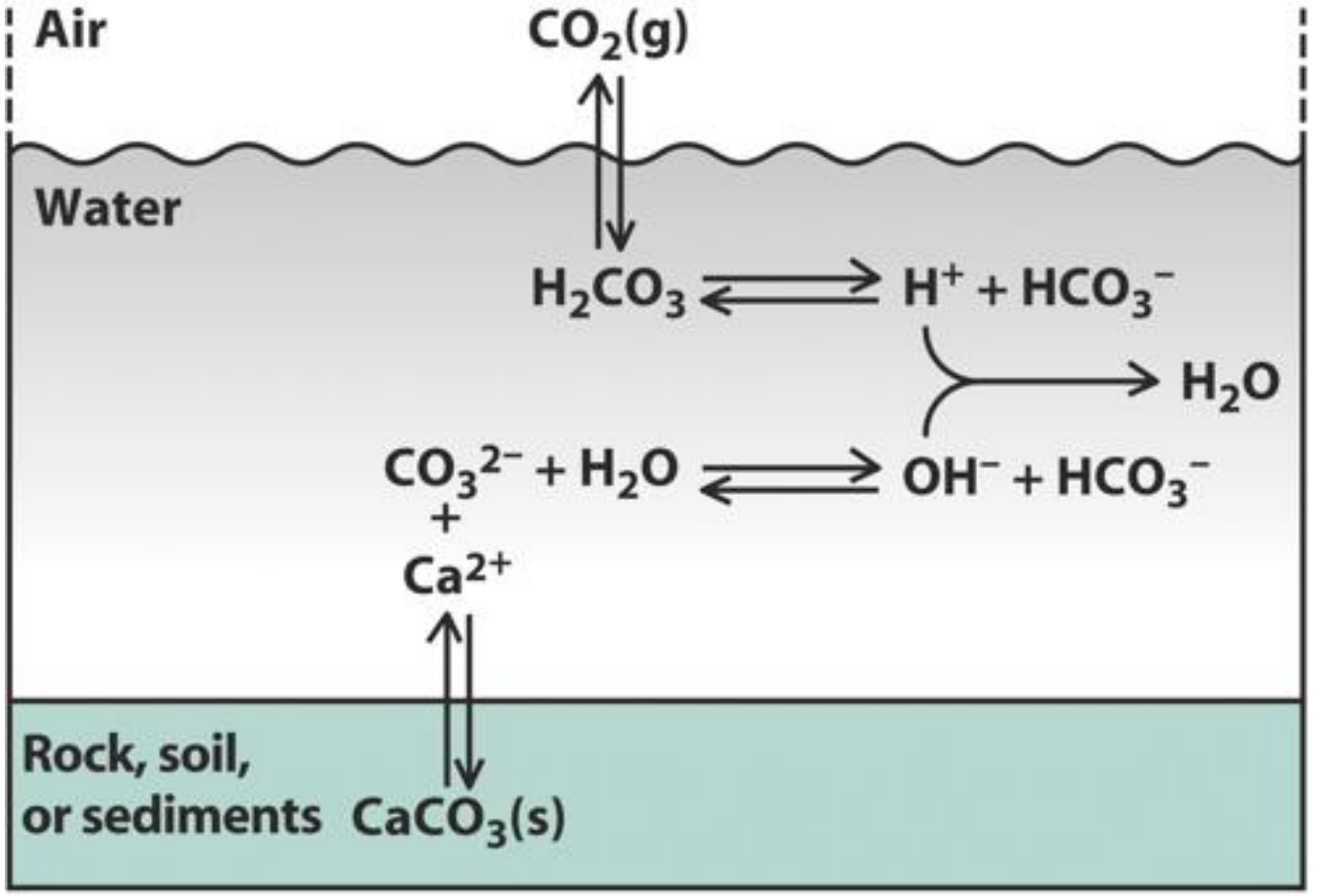


- The Maldives will no longer be a country if sea levels rise more than 1.8 meters

MAJOR CLIMATE CHANGE EFFECTS

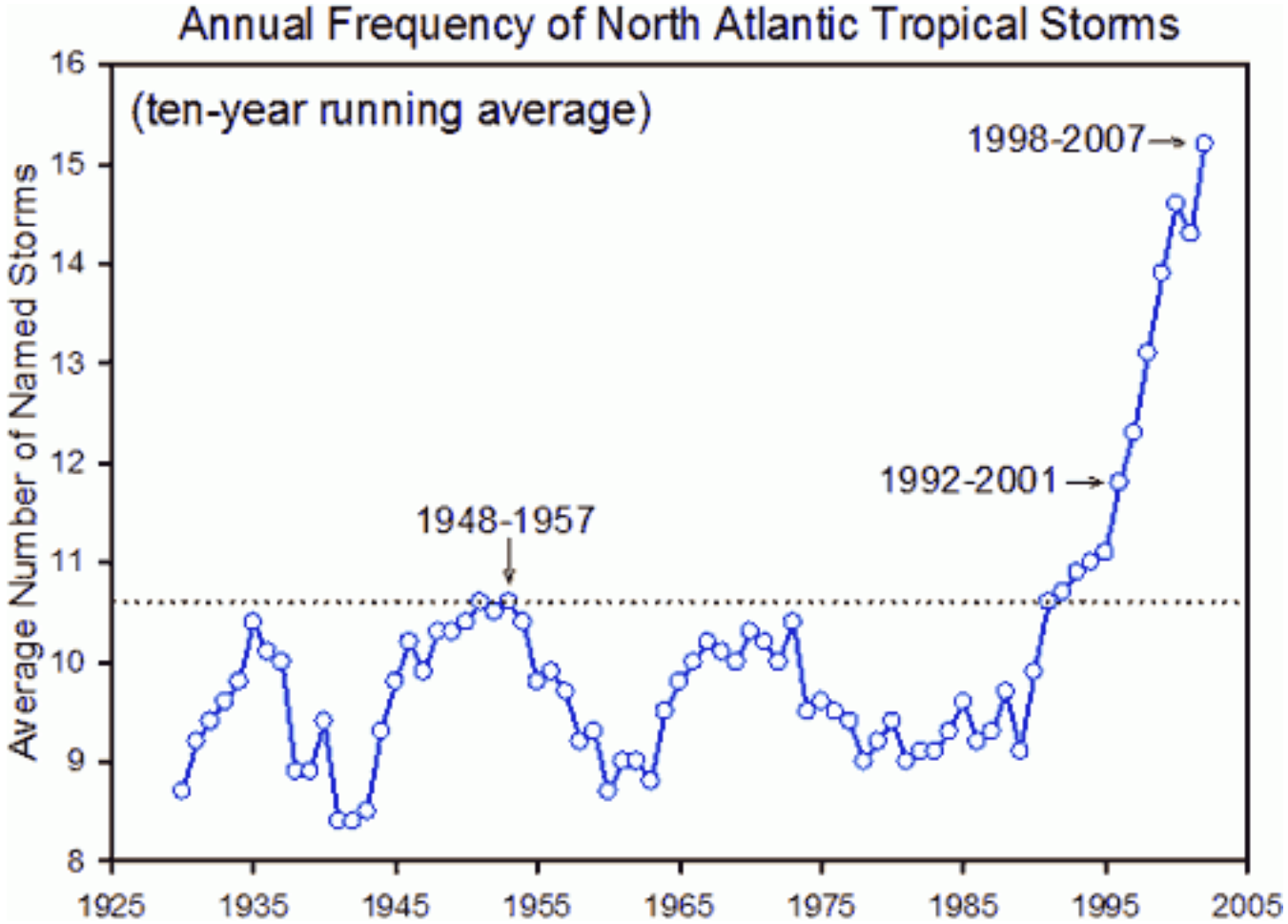
- Ocean acidification:
  - CO2 increases the acidity of the ocean

- This damages corals and many other organisms sensitive to pH
  - Dissolves the shells of mollusks and



MAJOR CLIMATE CHANGE EFFECTS

- Increasing catastrophic weather event frequency
- Hurricanes like Katrina will most likely become more frequent and damaging
- Coupled with rising sea levels, they will penetrate further inland

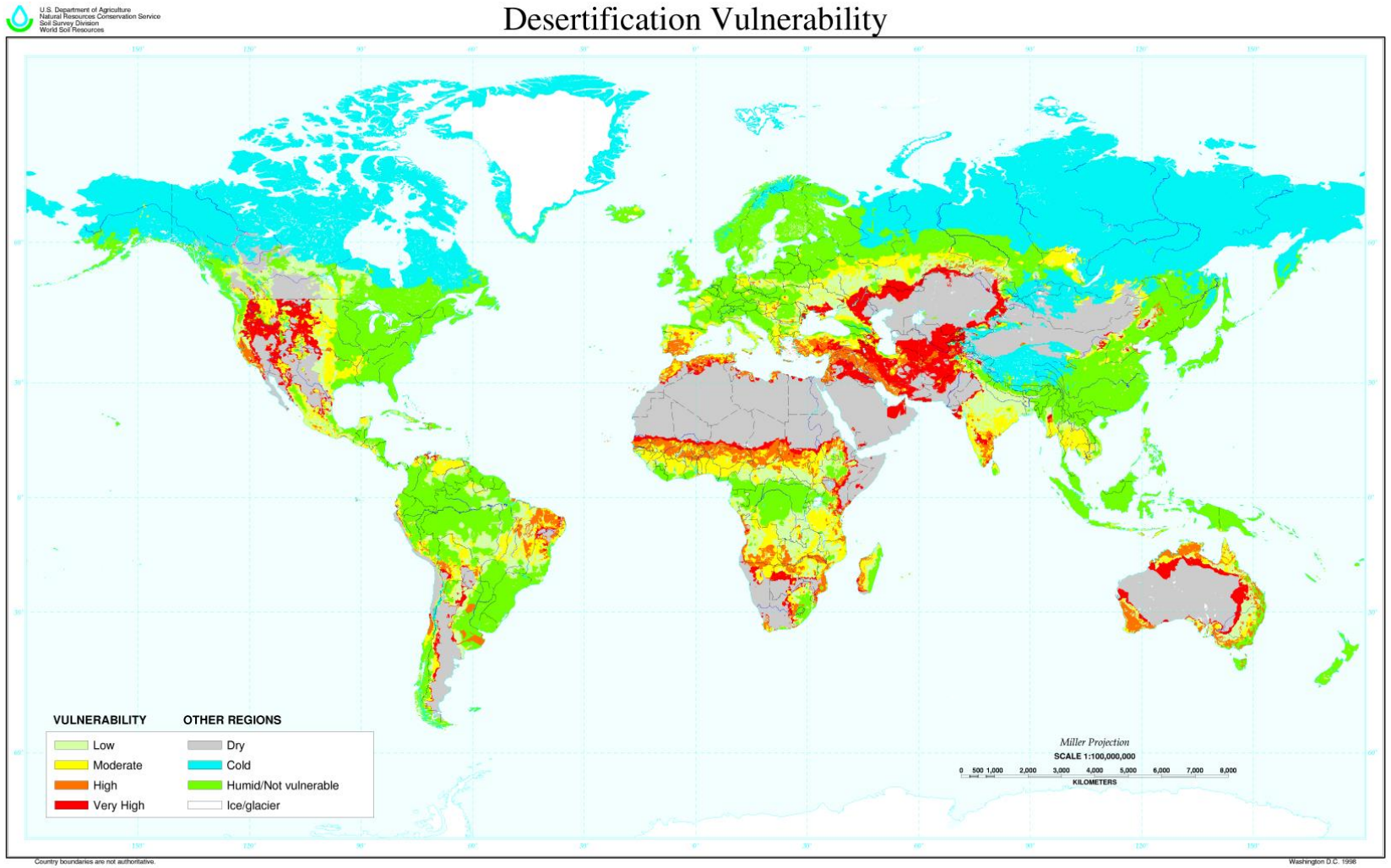


MAJOR CLIMATE CHANGE EFFECTS

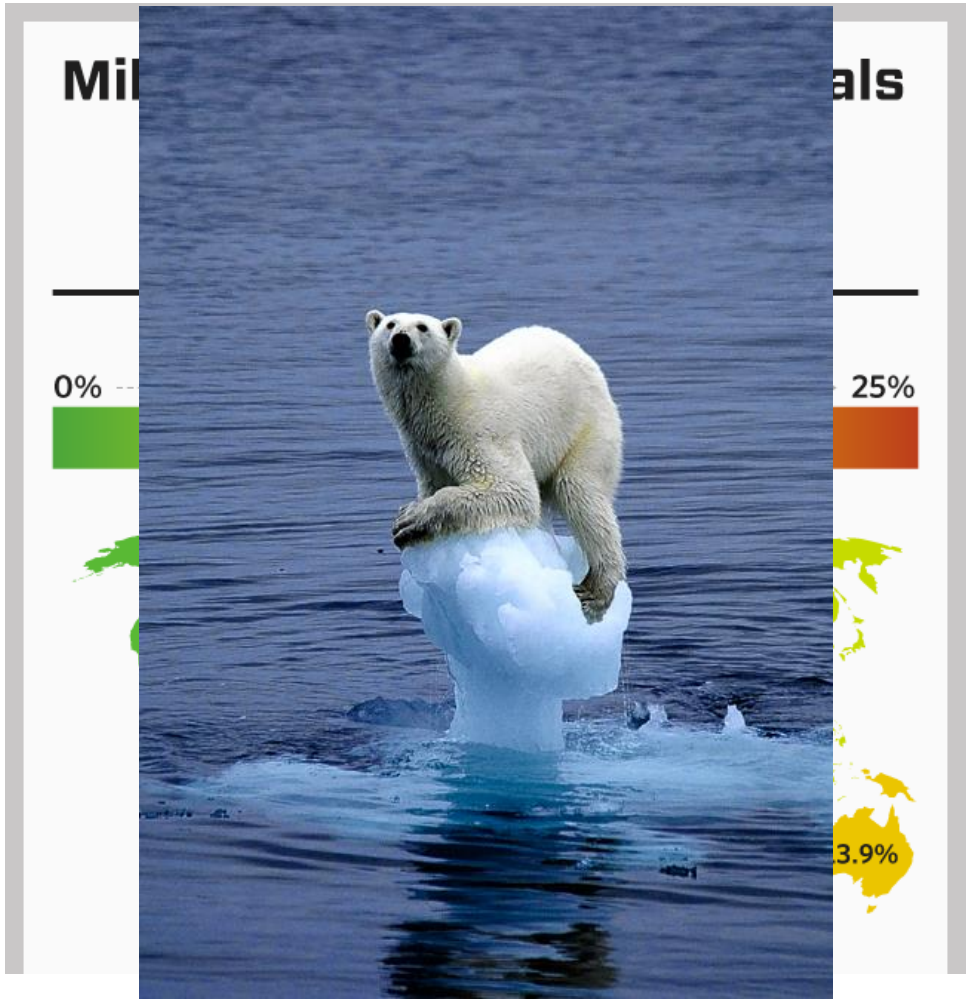
- Increased Flooding
- Miami is already dealing with bi-monthly flooding, roughly a doubling from the previous frequency
- Miami is spending millions of dollars already to revamp infrastructure

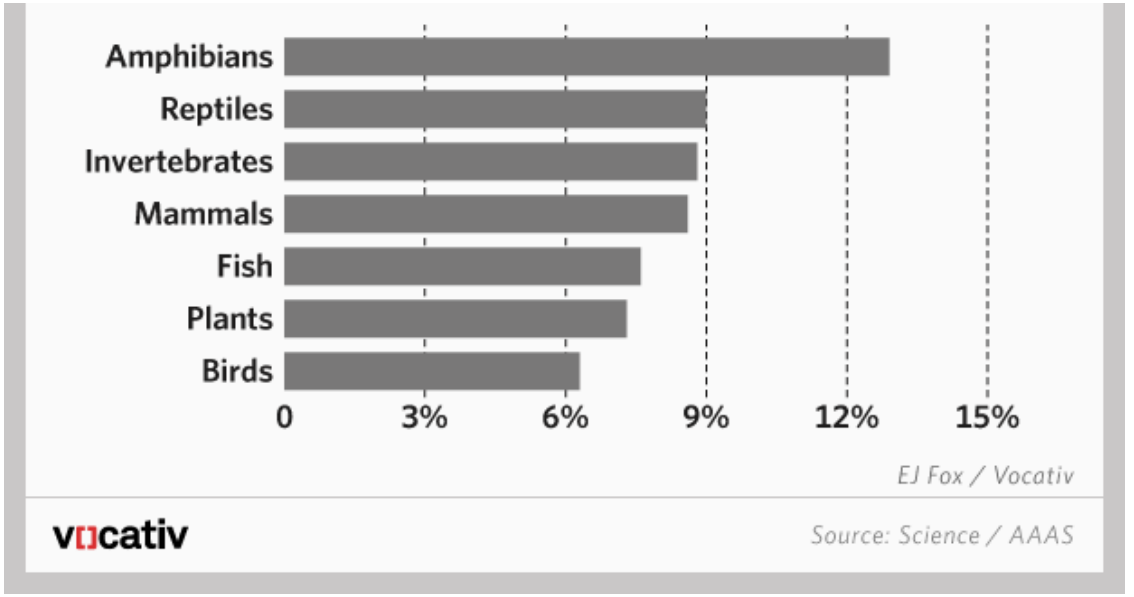
MAJOR CLIMATE CHANGE EFFECTS

- Desertification
  - Refers to making a fertile land infertile
- Climate change tends to exacerbate existing conditions
  - Wet get wetter, dry get drier



MAJOR CLIMATE CHANGE EFFECTS

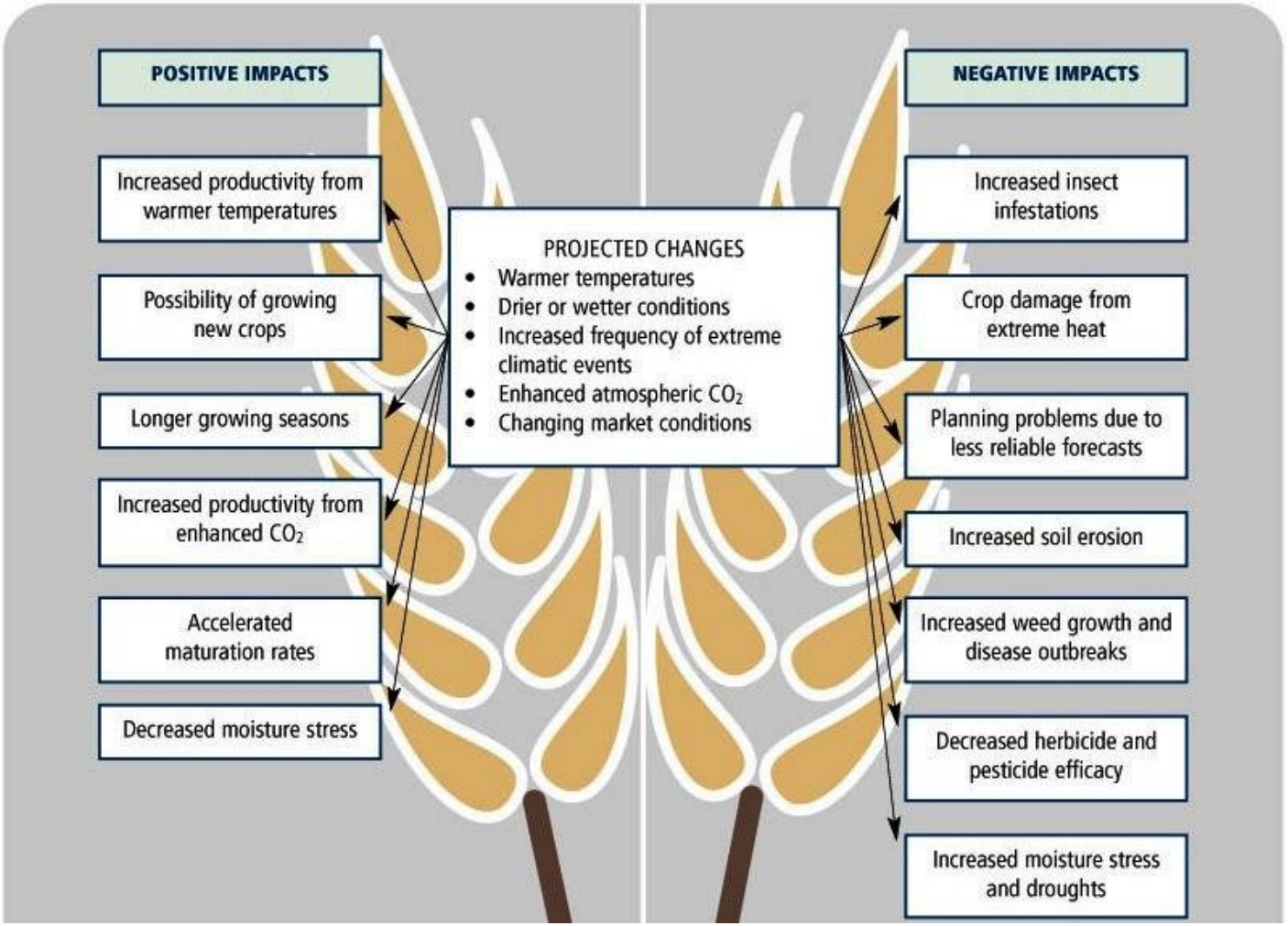




- Extinction events and loss of biodiversity will increase will habit destruction and food chain shifts
- Lower estimates predict 7.9% or approximately 632,000 plant and animal species going extinct

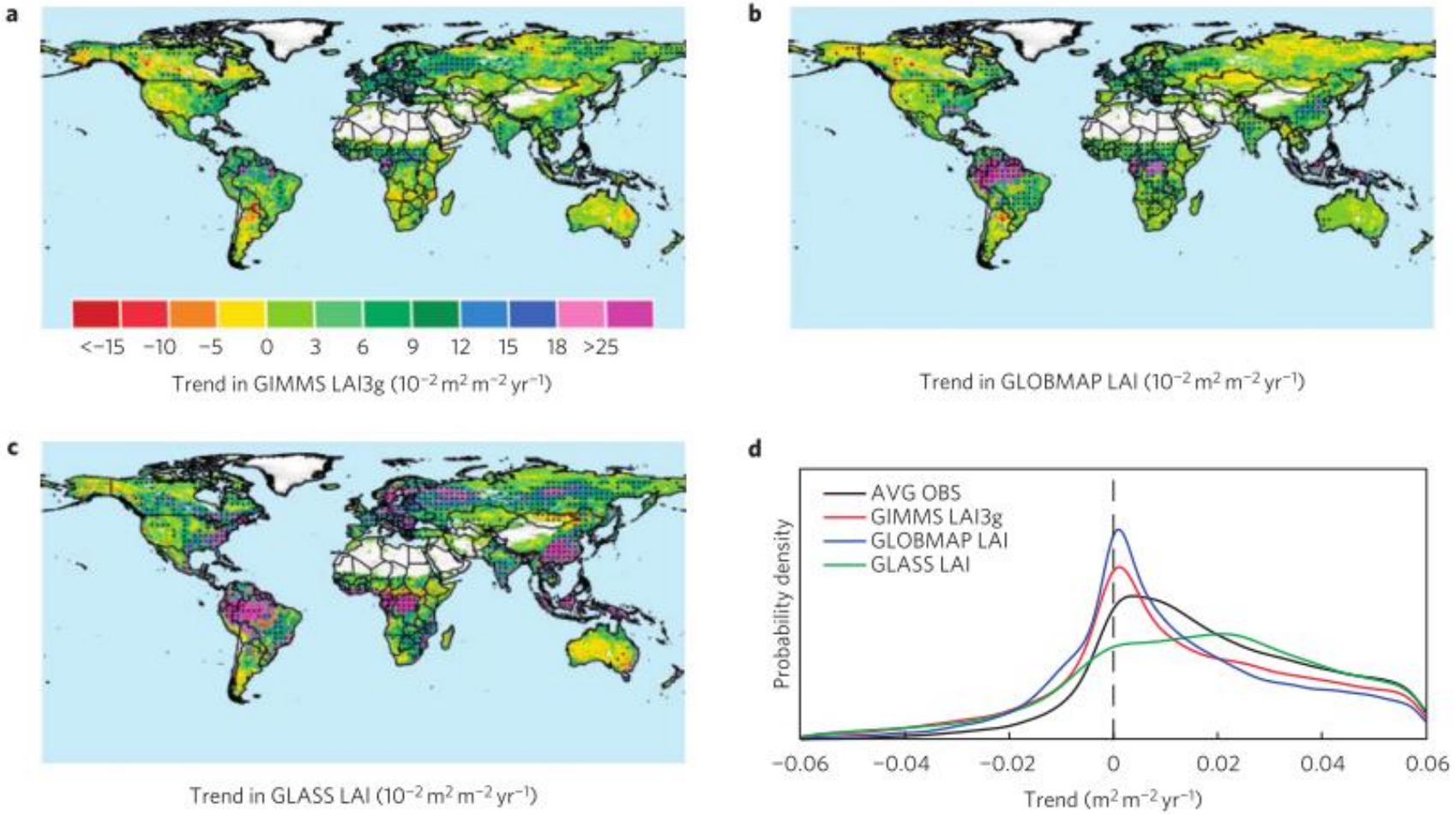
MAJOR CLIMATE CHANGE EFFECTS

- Food shortages?
- Other Positives:
  - Increased cropland availability?
- Other Negatives:
  - Increased oxidative tissue damage?
  - Changes in BVOC emissions and SOA formation?



IT'S NOT ALL BAD…

- CO2 is the primary nutrient that fuels plant growth
- Increasing CO2 levels increases plant Net Primary Productivity (NPP)
- CO_2 fertilization accounts for 70% of the observed greening of the Earth



WHY SHOULD HUMANS CARE?

- Increased flooding
- Increased droughts
  - Food supply changes
- Increased extreme weather events
- Large population displacements from sea level rise
- Loss of biodiversity
- Air and water quality change
  - Ozone pollution
  - Water-borne diseases spread farther and faster
- Mental health risks
- Large costs of dealing with all of these preventable outcomes

WHY YOU SHOULD CARE!

- Conflicting information can be confusing and misleading

theguardian

Five Pacific islands lost to rising seas as climate change hits

Tuesday 10 May 2016 09.02 EDT

Last modified on Tuesday 10 May 2016 09.36 EDT

Headlines 'exaggerated' climate link to sinking of Pacific islands

Tuesday 10 May 2016 08.50 EDT

Last modified on Wednesday 11 May 2016 07.28 EDT

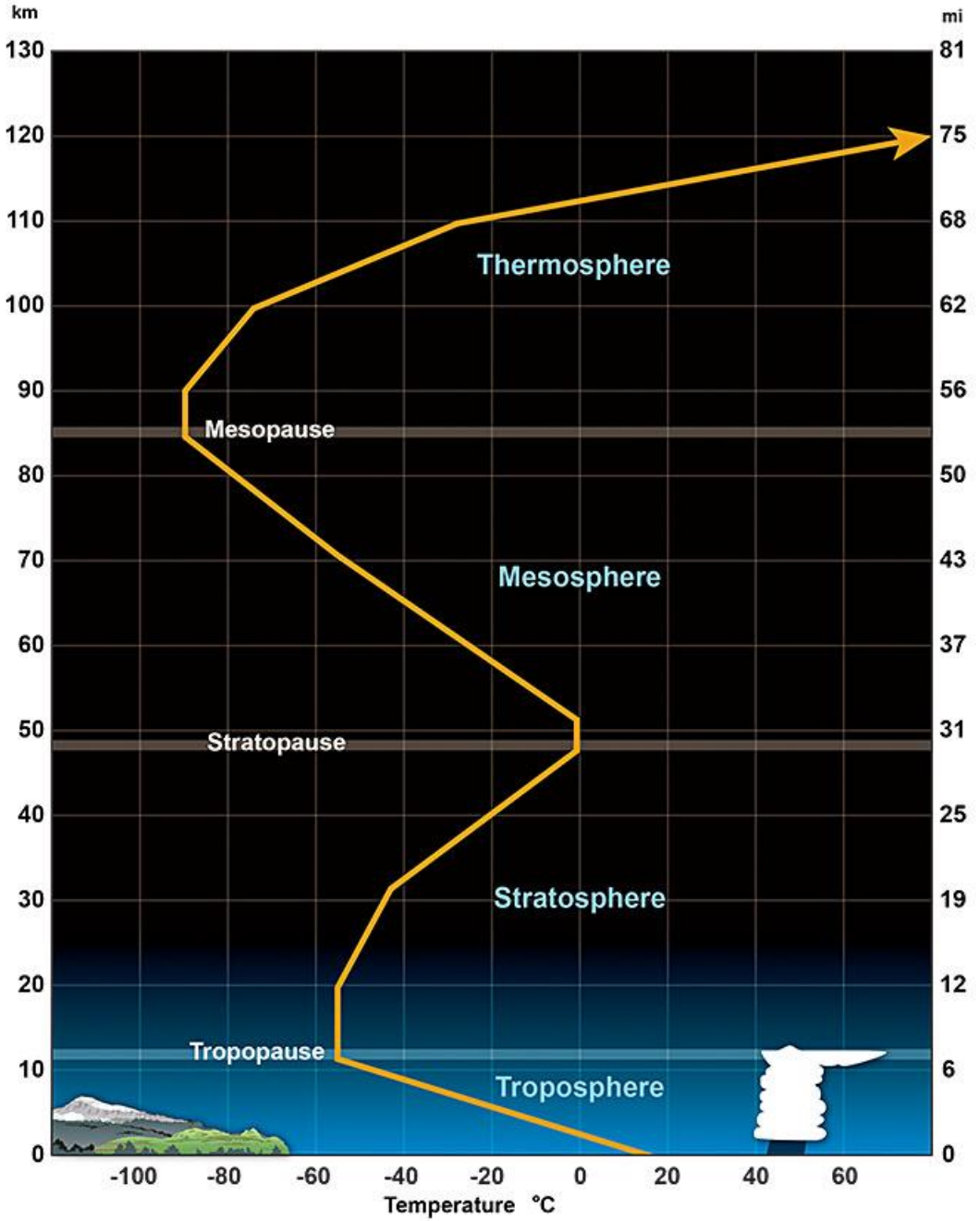
- Must be able to analyze basic data for yourselves!

THE ATMOSPHERE

MY FAVORITE OF ALL THE SPHERES

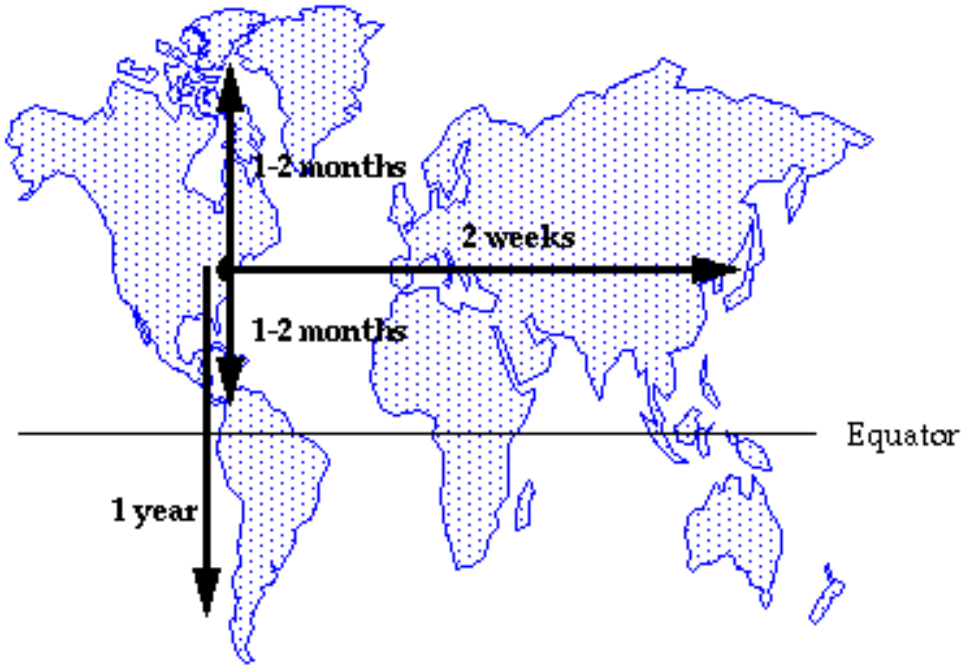
THE STRUCTURE OF THE ATMOSPHERE

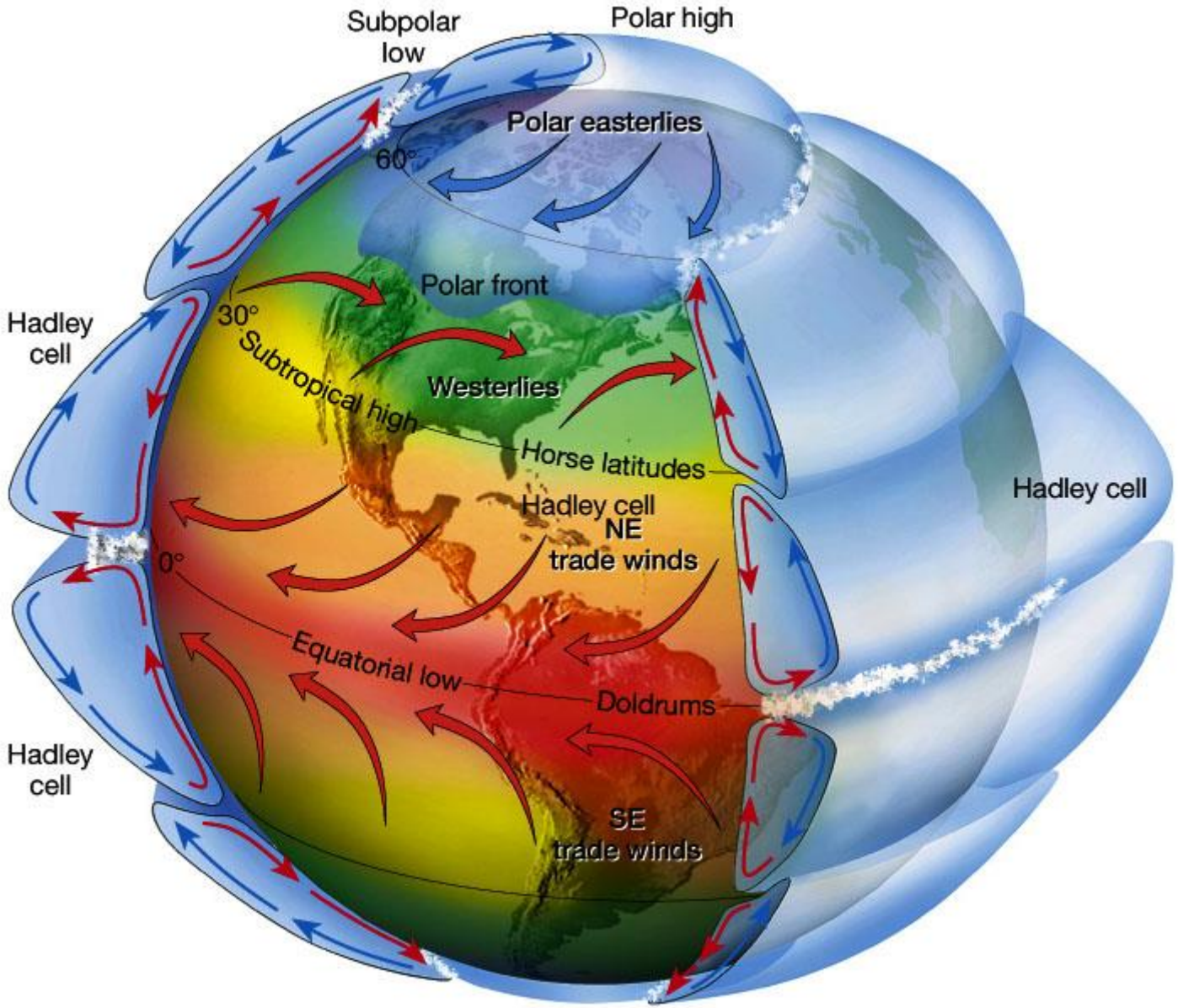
- 90% of the mass of the atmosphere is in the troposphere
  - This is where we live ad where the warming will occur
- The stratosphere contains the ozone layer
  - Ozone in the stratosphere protects the surface from damaging UV radiation
  - Stratosphere will cool as troposphere heats
- Higher up layers are much less important and impacted by climate change



ATMOSPHERIC DYNAMICS

- In general, warm air rises near the equator, cools, and then falls at the poles





UNITS OF CONCENTRATION

- Concentration = amount of stuff / volume

- Mixing ratio
  - Independent of temperature and pressure, but not humidity

  - ppm – part per million
    - The number of molecules per million total molecules
  - ppb – part per billion
    - The number of molecules per billion total molecules

ATMOSPHERIC COMPOSITION

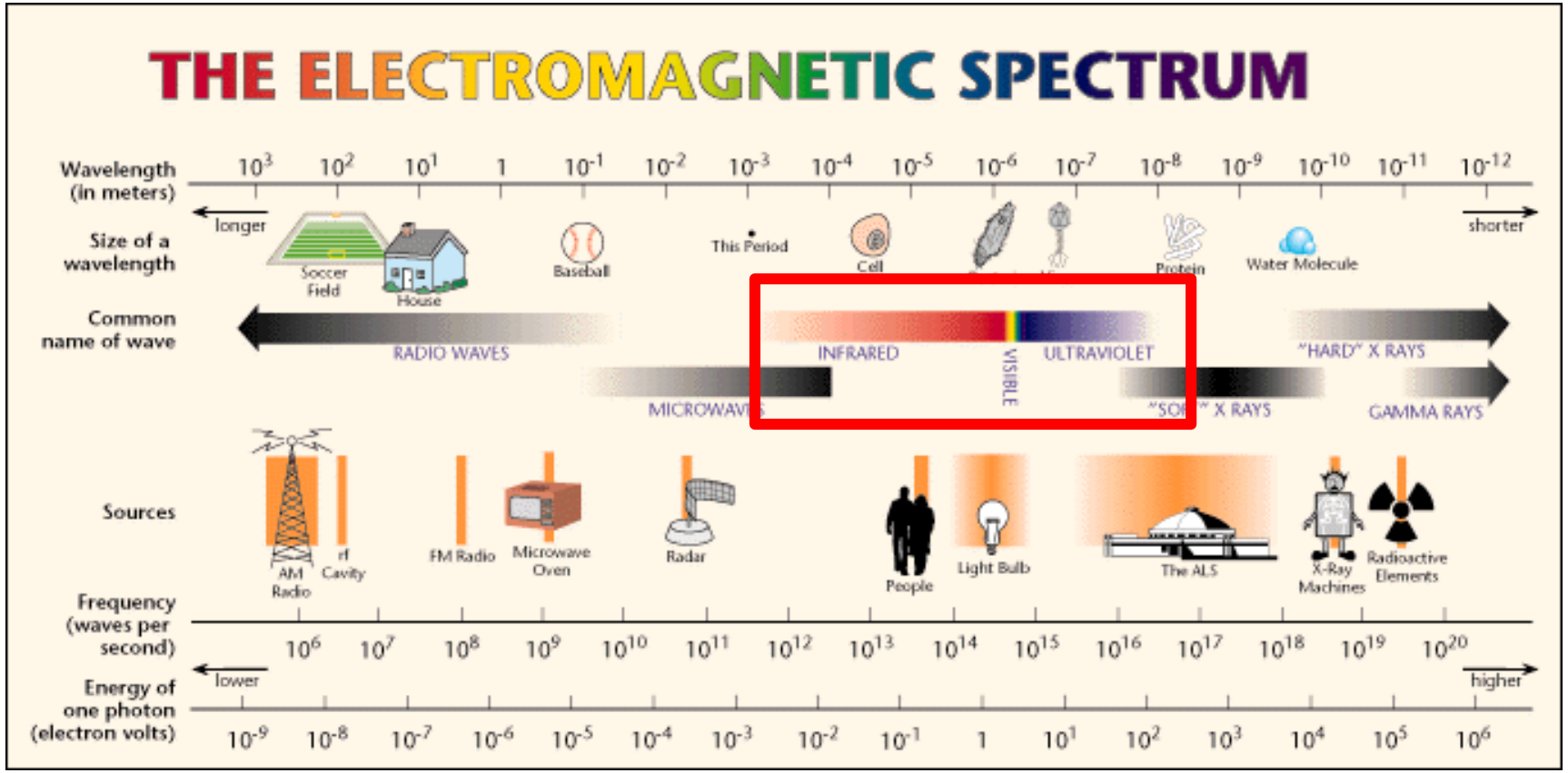
- Thousands of other species like ozone, and biogenic and anthropogenic emissions are very important to the chemistry of the atmosphere

Constituent	Percent by Volume	Concentration in Parts Per Million (PPM)
Nitrogen (N_2)	78.084	780,840.0
Oxygen (O_2)	20.946	209,460.0
Argon (Ar)	0.934	9,340.0
Carbon dioxide (CO_2)	0.036	360.0
Neon (Ne)	0.00182	18.2
Helium (He)	0.000524	5.24
Methane (CH_4)	0.00015	1.5
Krypton (Kr)	0.000114	1.14
Hydrogen (H_2)	0.00005	0.5

THE GREENHOUSE EFFECT

ACTUALLY NOT ABOUT GREENHOUSES AT ALL

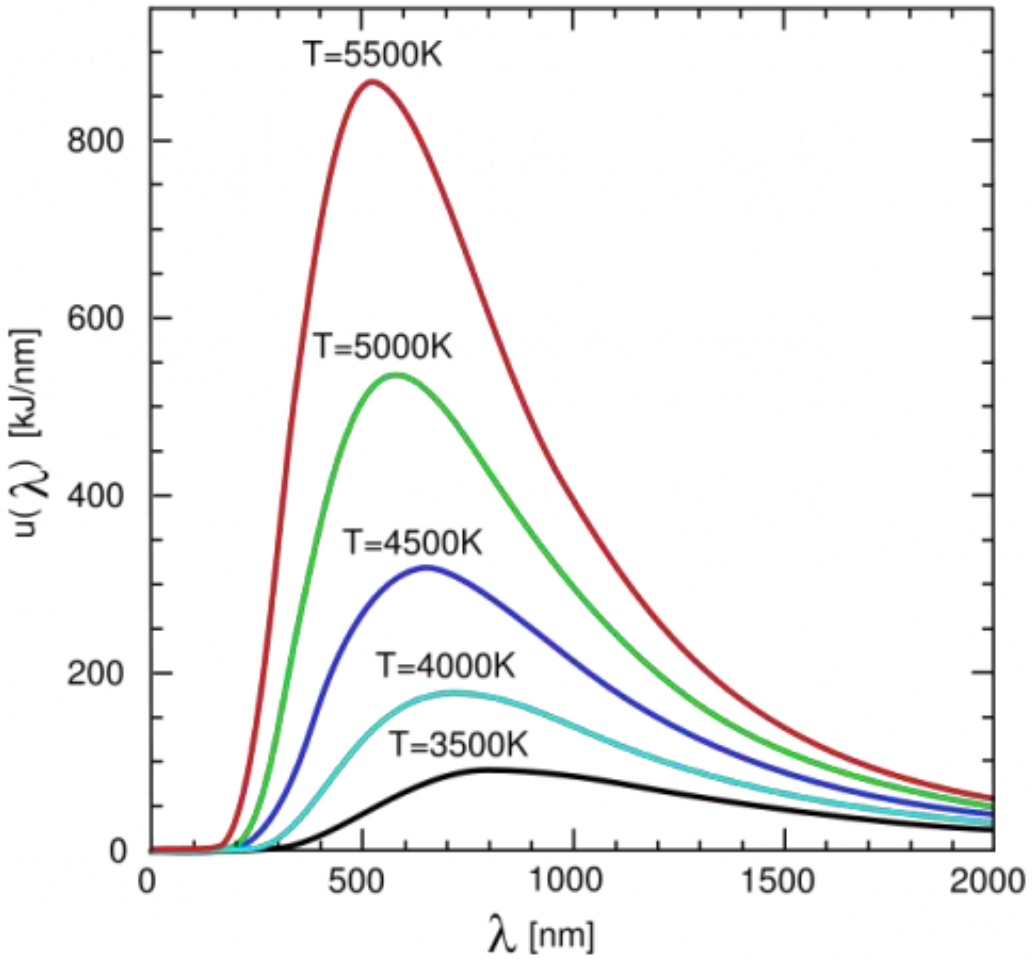
THE ELECTROMAGNETIC SPECTRUM



- Light is also known as electromagnetic radiation

BLACK BODY RADIATION

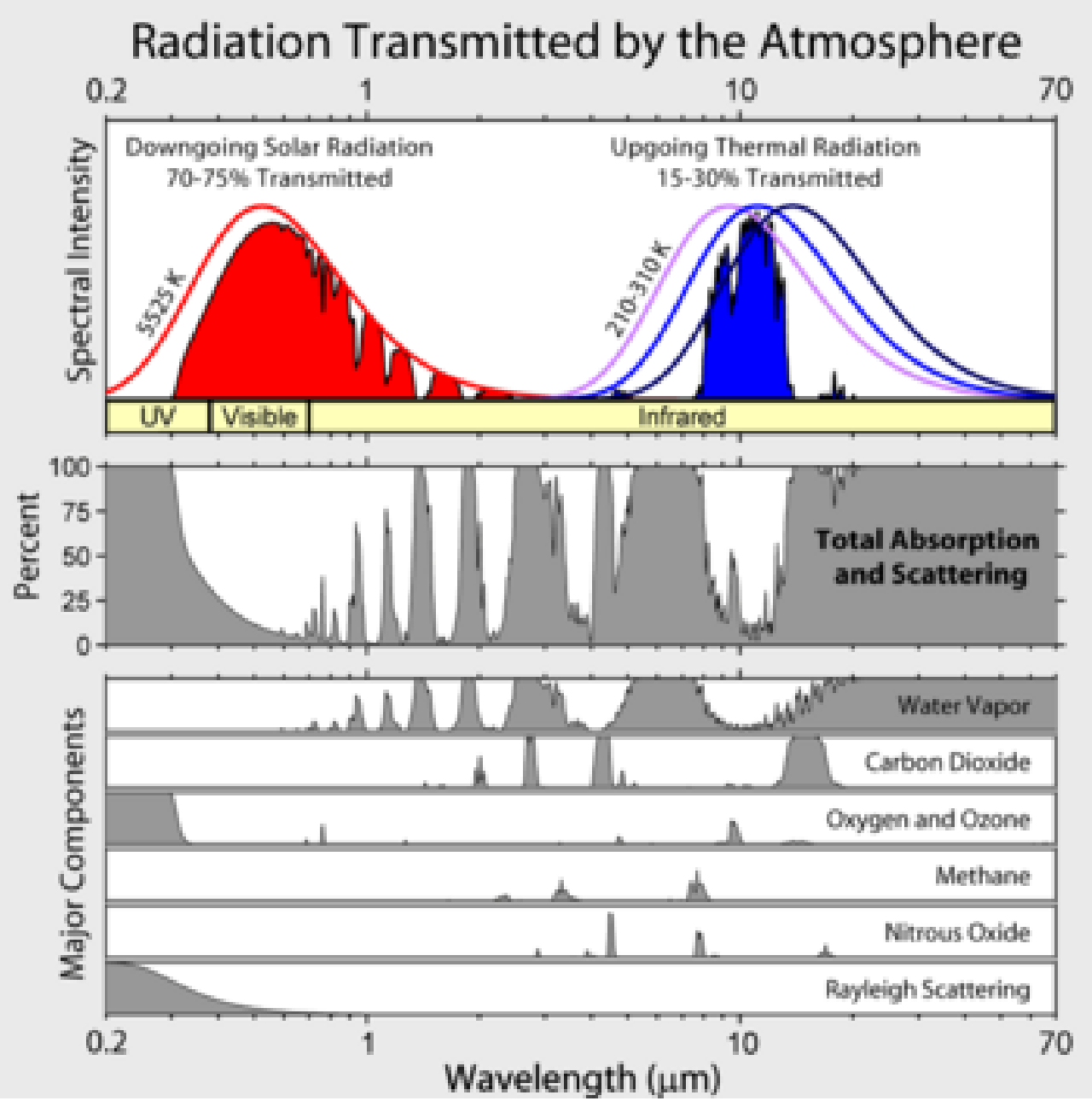
$$I(\nu, T) = \frac{2h\nu^3}{c^2} \frac{1}{e^{\frac{h\nu}{kT}} - 1}$$



- Black body: an opaque object that emits thermal radiation
- The Planck equation governs the intensity (I or u here) of the outgoing radiation
- Warmer objects tend to emit more intense and high energy (lower wavelength) light

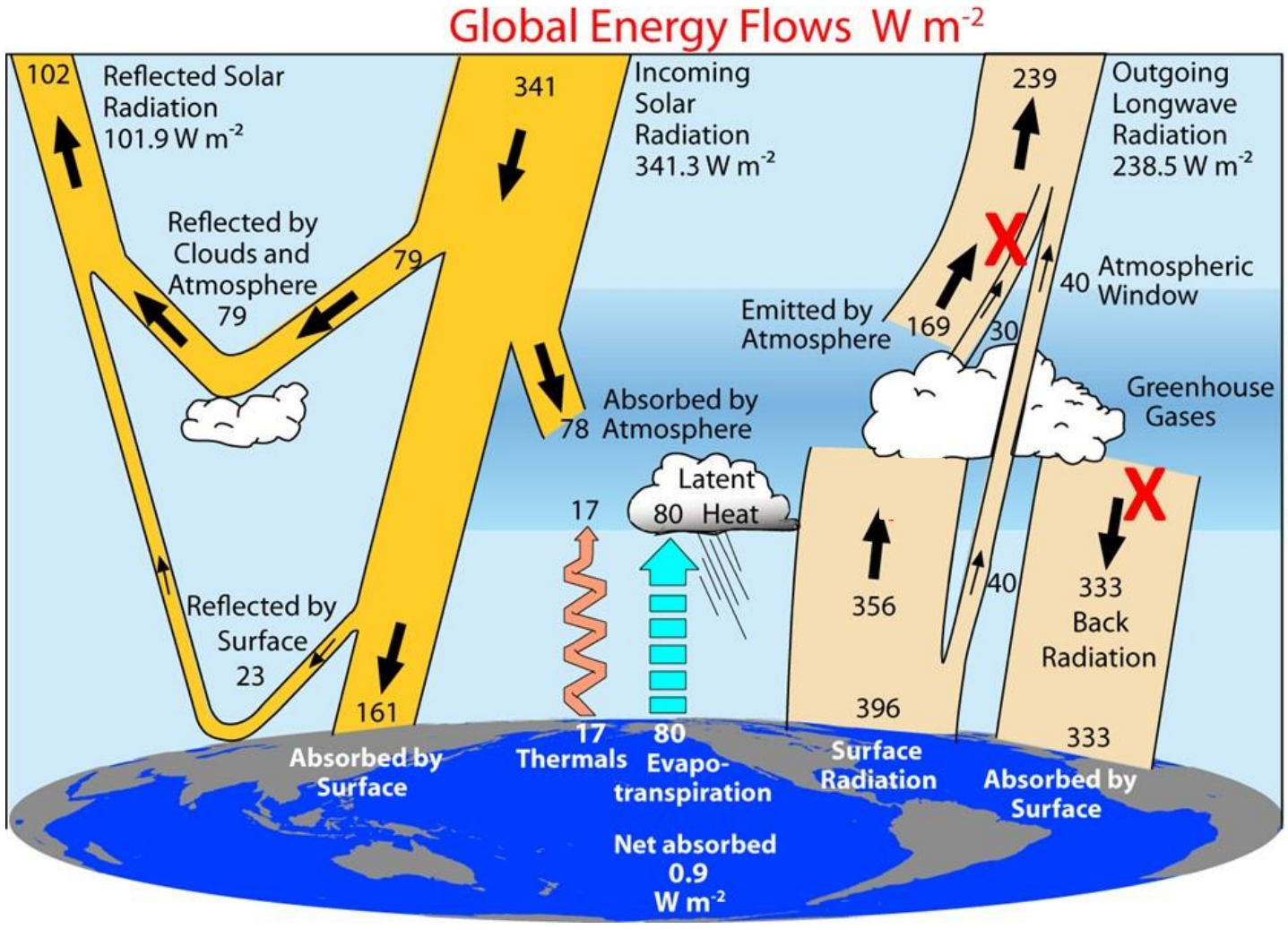
THE GREENHOUSE EFFECT

- The Sun and Earth act as black bodies
- The sun is much warmer than Earth, so it's peak radiation is in the visible spectrum
- Earth is cooler and emits mostly infrared light
- Greenhouse gases absorb infrared radiation in the atmosphere and re-emit it



THE GREENHOUSE EFFECT

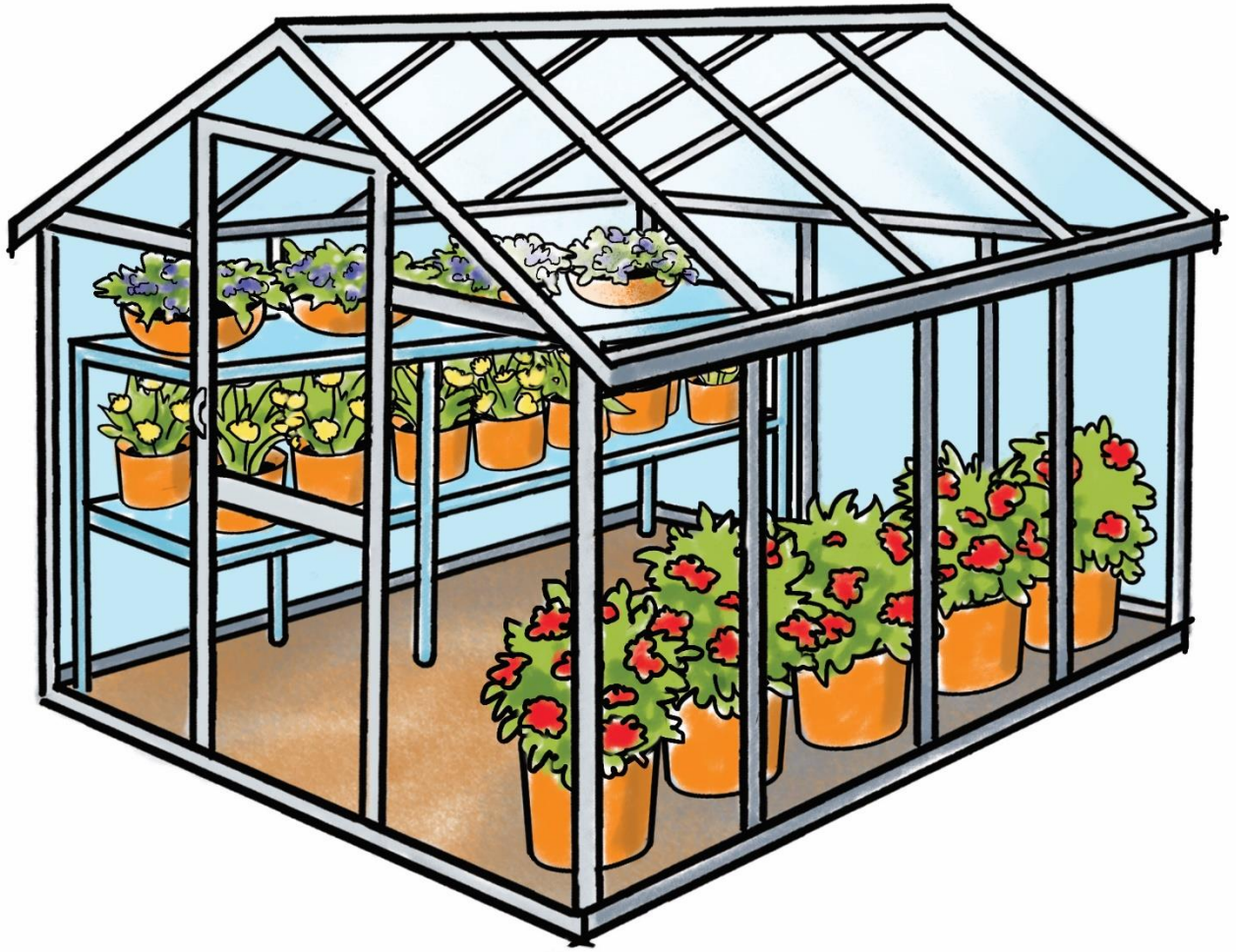
- Incoming solar radiation is mostly in the UV and visible spectrum
- Light that makes it to the surface is converted to IR light
- IR light is absorbed by GHG's



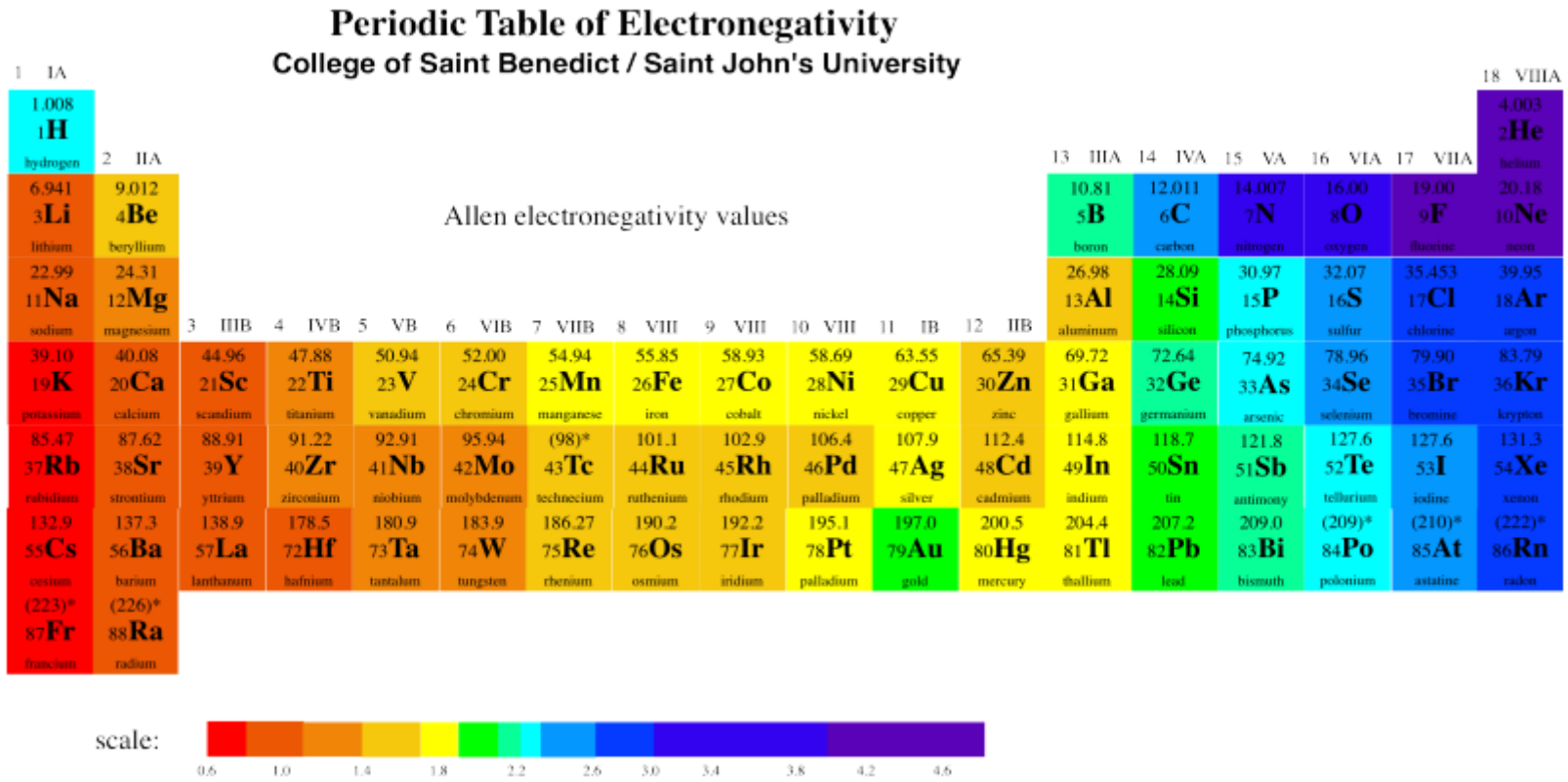
Infrared energy flows marked "X" would not exist without greenhouse gases

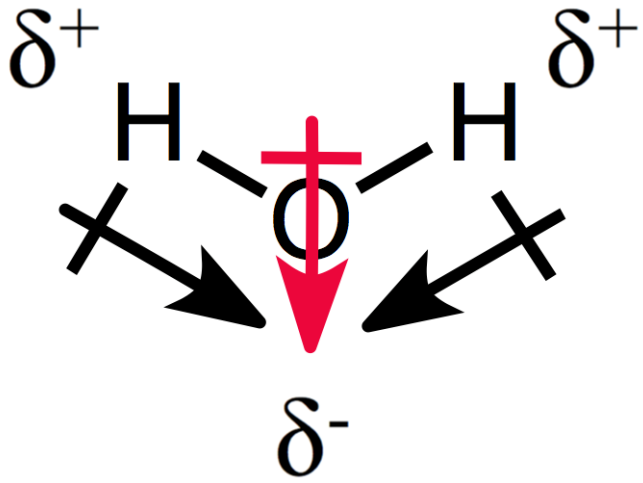
HOW AN ACTUAL GREENHOUSE WORKS

- Greenhouses take advantage of the Earth turning UV and visible light into IR radiation
- IR heats the air in the greenhouse
- Heated air is trapped in the glass enclosure leading to a localized warming



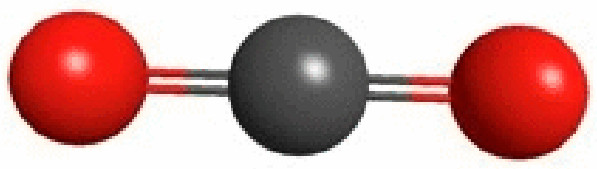
BOND DIPOLES AND ELECTRONEGATIVITY

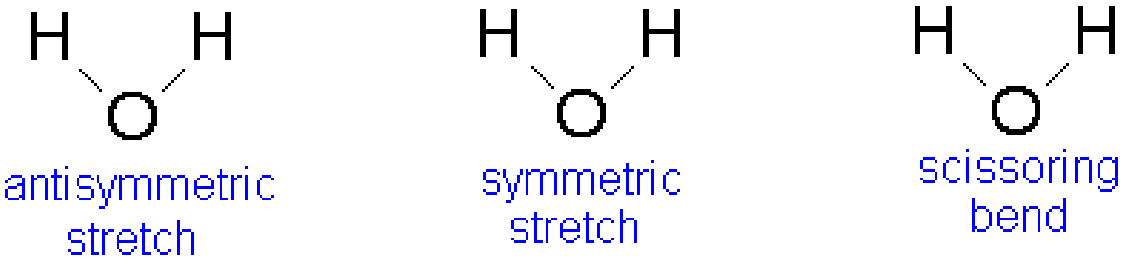




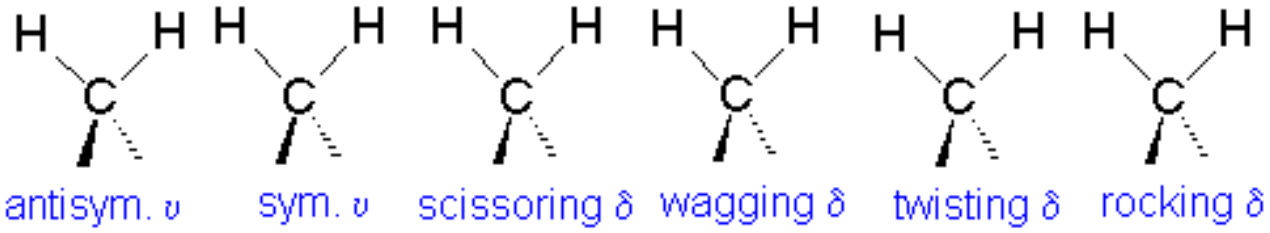
- Each bond has a dipole vector (an asymmetric distribution of electrons) which can be summed to find the net dipole for the molecule

WHAT MAKES A GHG A GHG?





- Greenhouse gases absorb and re-emit infrared light
- Absorption happens due to the excitation of **asymmetrical** bond vibrations which create molecular dipoles



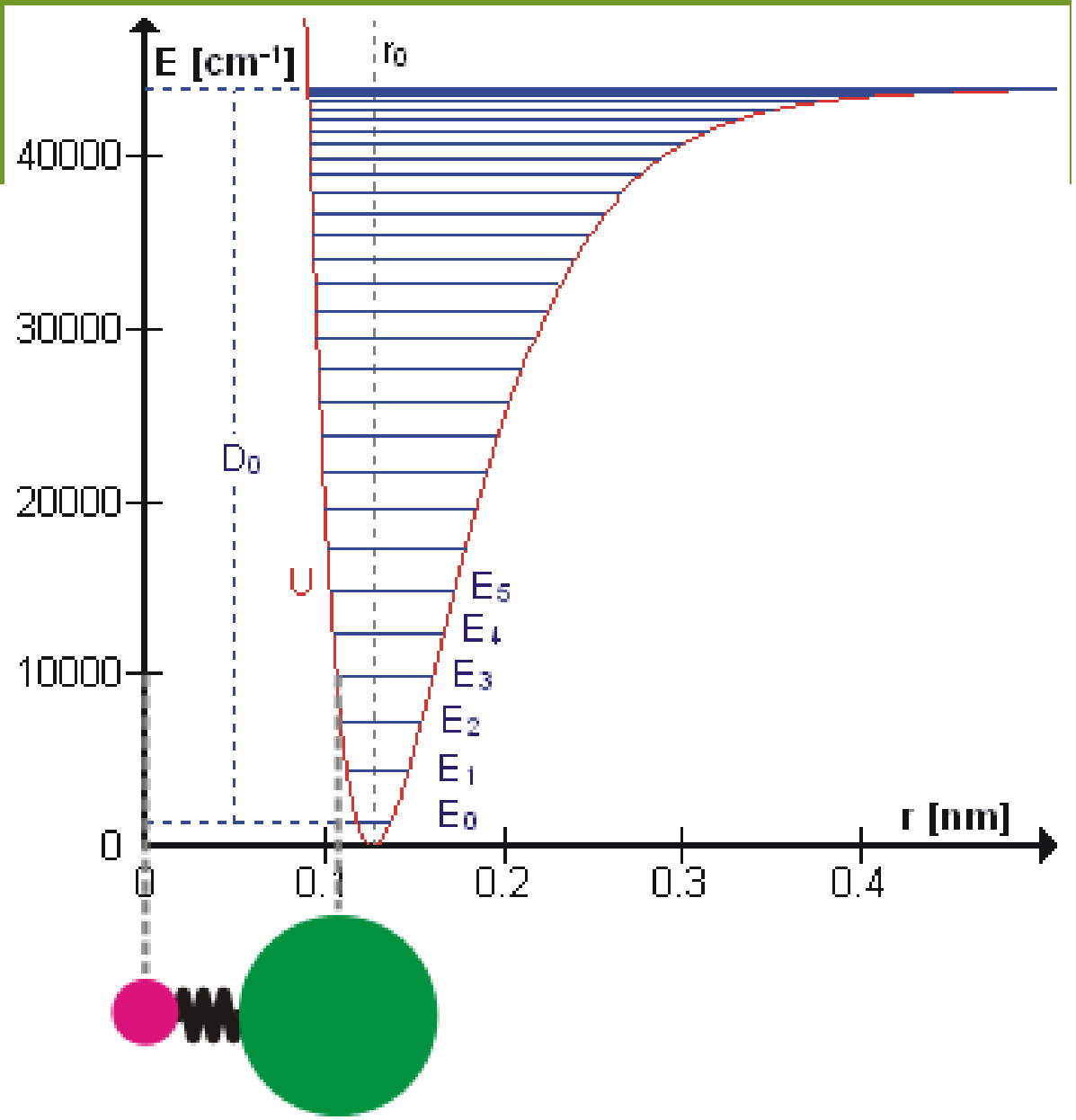
WHY DO BONDS VIBRATE?

- Quantum Mechanics!

$$E_v = \left(v + \frac{1}{2}\right) v_e - \left(v + \frac{1}{2}\right)^2 v_e x_e + \left(v + \frac{1}{2}\right)^3 v_e y_e + higher\ terms$$

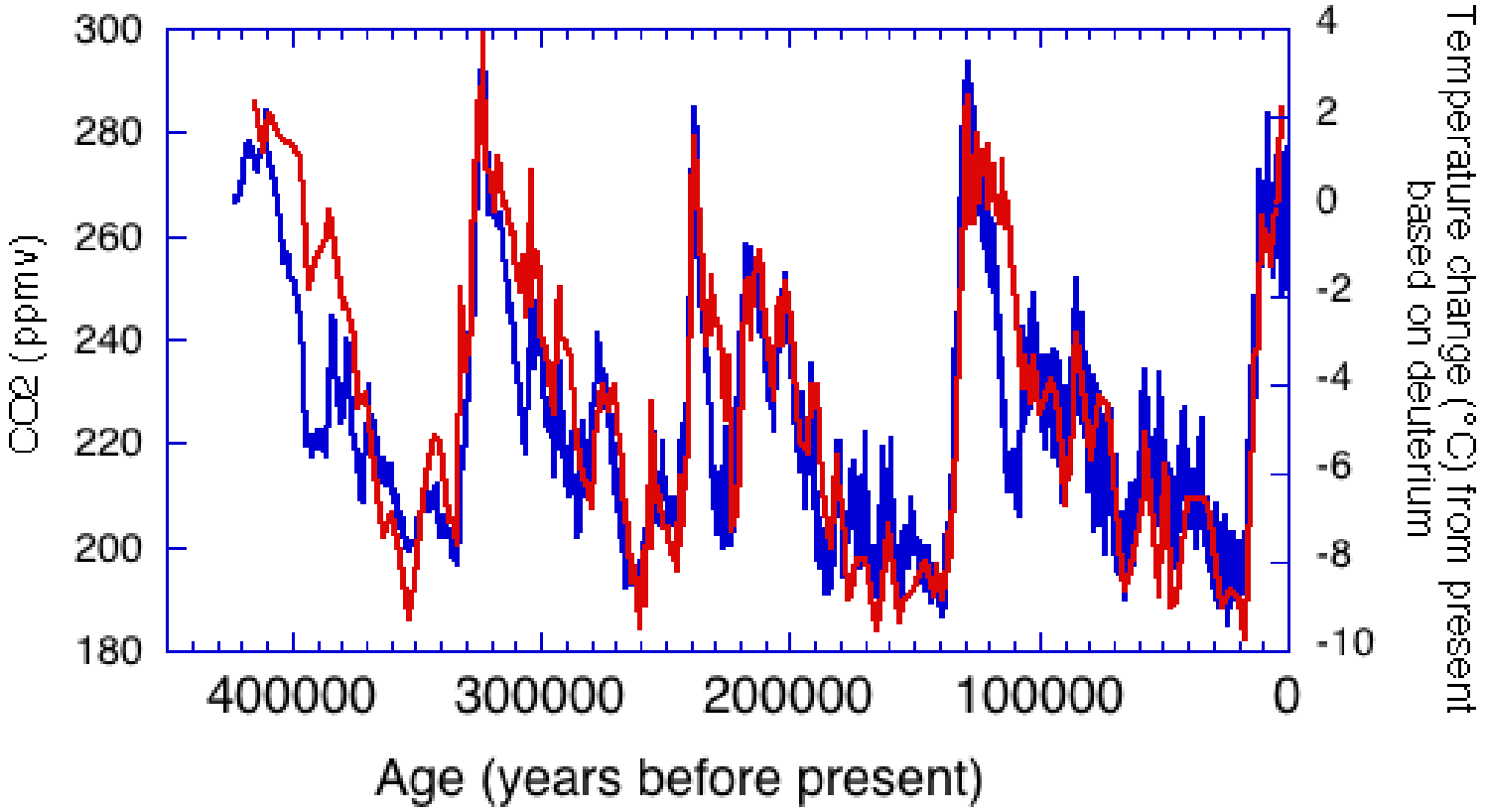
  - v – vibrational quantum number
  - x and y – anharmonicity constants

- Different wavelengths of light at different energy levels excite different type of vibrations



CARBON DIOXIDE: CO_2

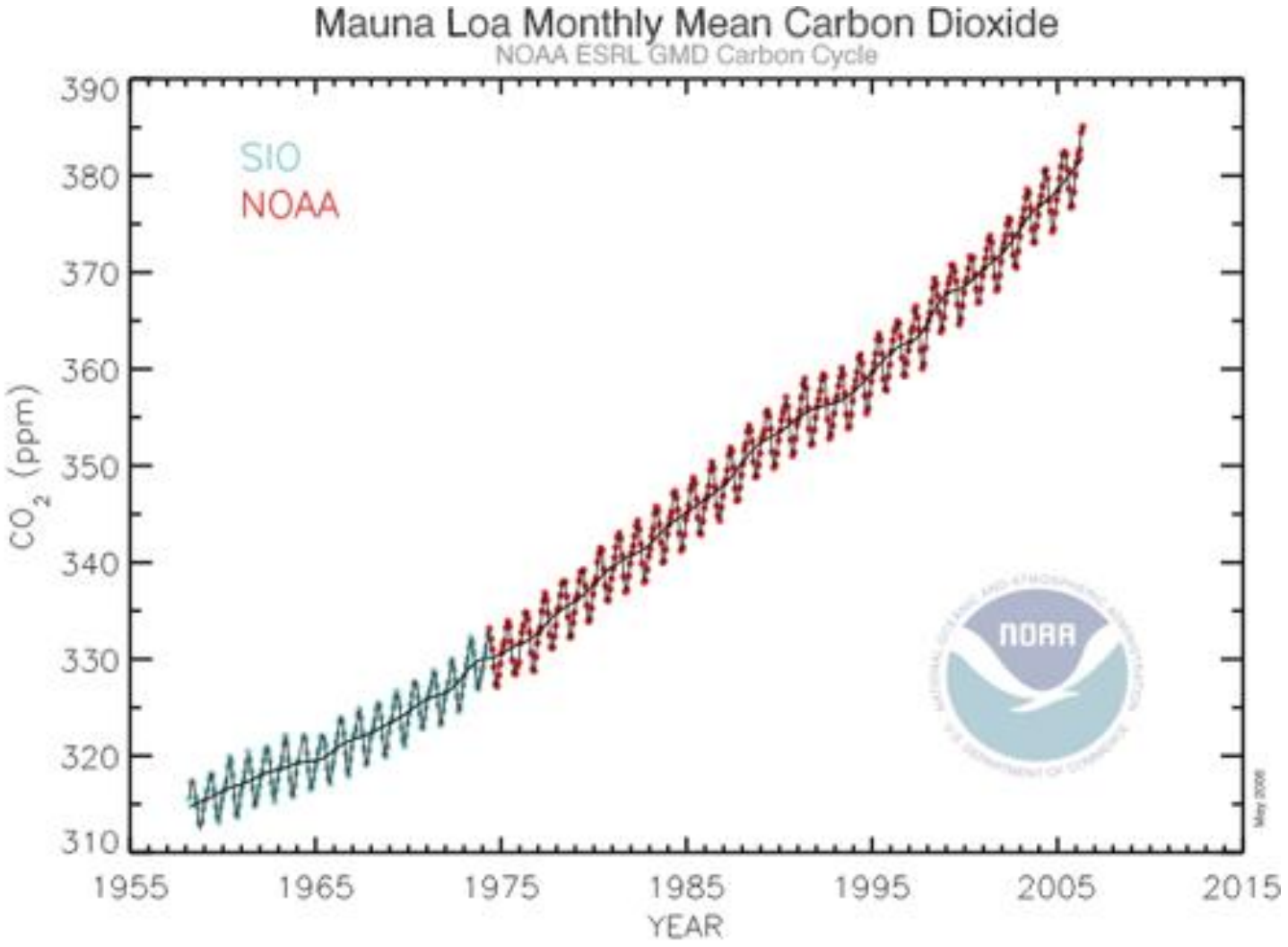
- Most well known greenhouse gas, but not the most potent or most important
- Strong correlations historically between temperature and CO_2 concentrations
- 2016 is set to be the first year on record where CO_2 levels will remain above 400ppm for the whole year



CARBON DIOXIDE: CO_2

- Preindustrial CO2 levels hovered around 250ppm

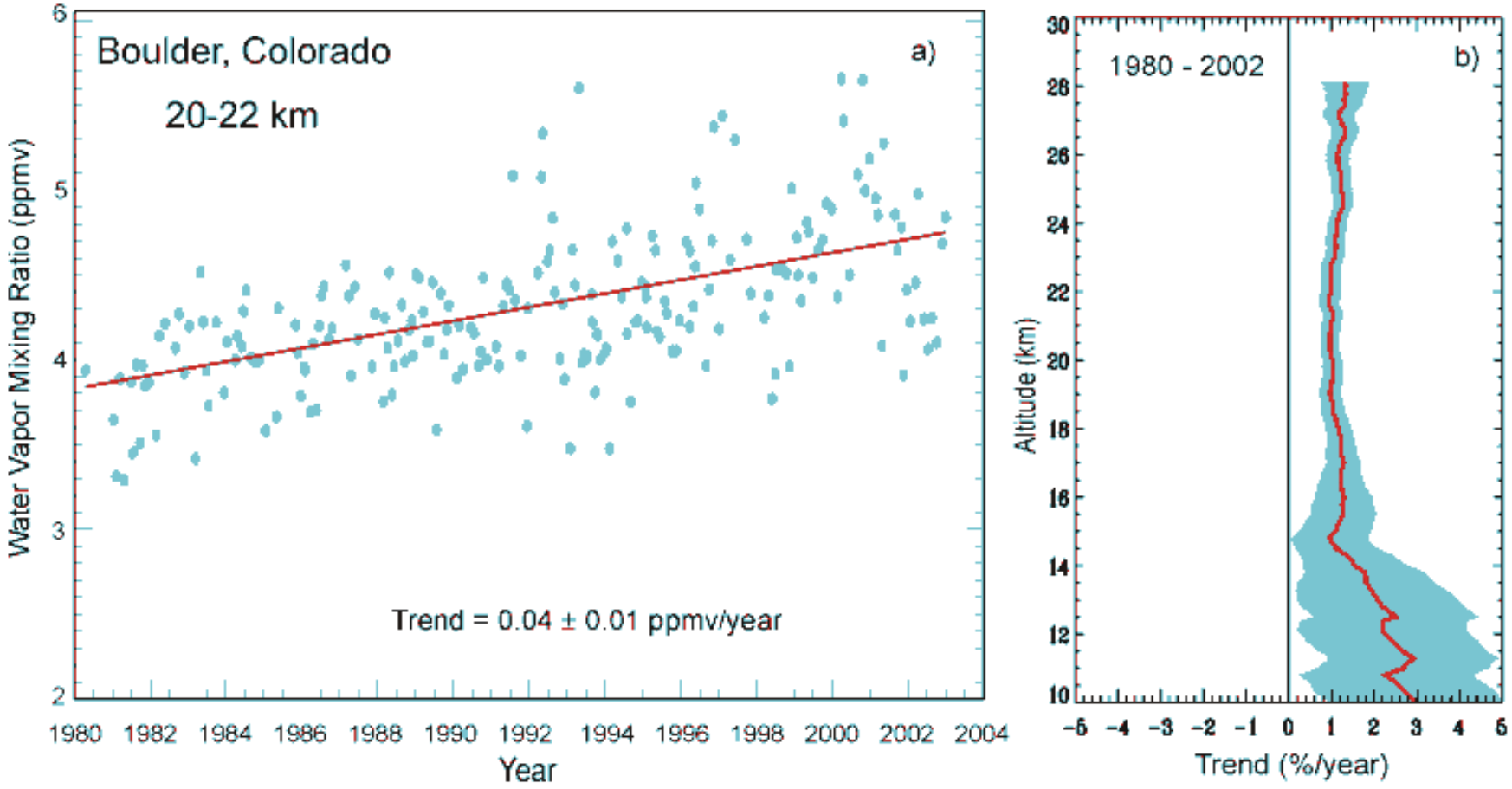
- Interesting "sawtooth" pattern has a period of 1 year, what causes it?
  - The seasons!
  - In the summer plants are taking up CO2 to grow, in the winter the plants die and their carbon is decomposed into CO2 by microbes



WATER VAPOR: H_2O

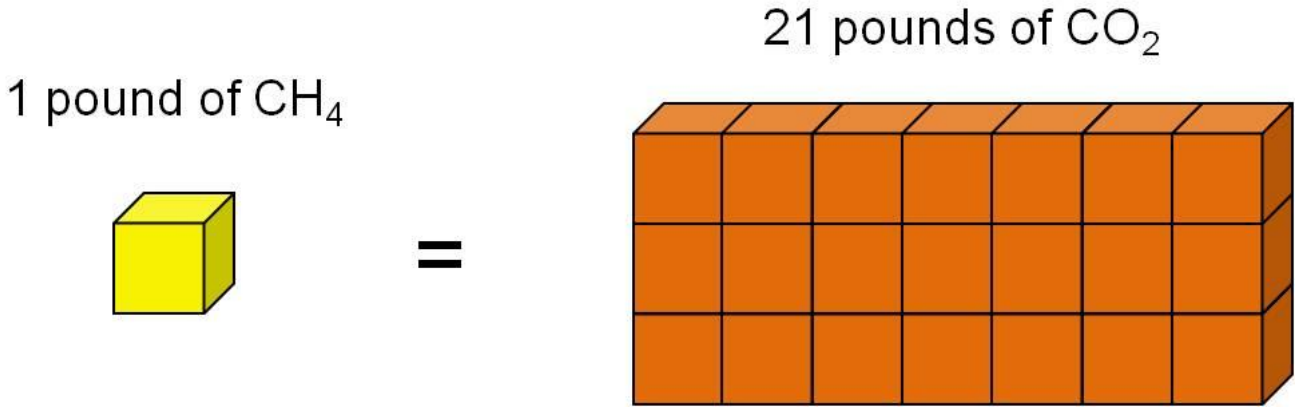
- Water vapor accounts for the largest percentage of the greenhouse effect, between 36% and 66% for clear sky conditions and between 66% and 85% when including clouds.

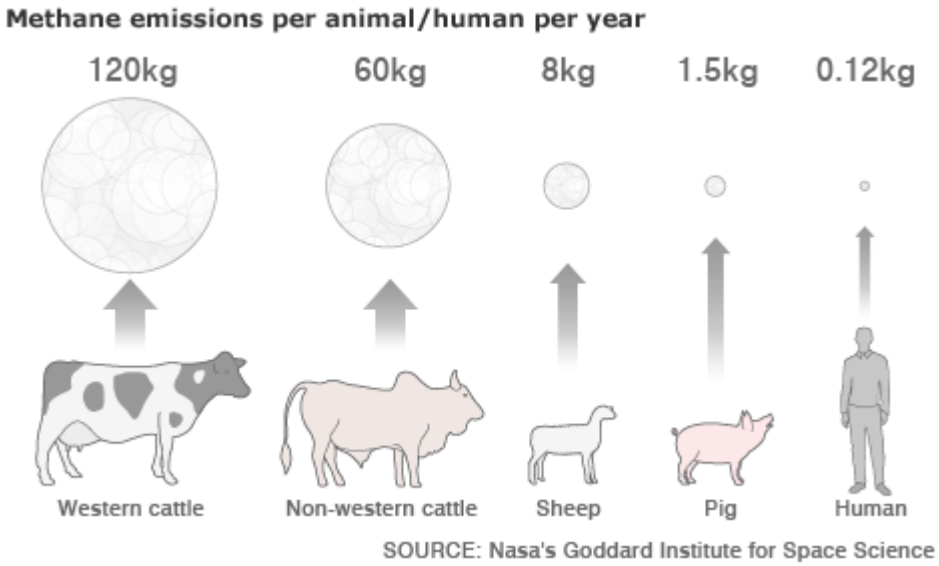
- Humans have little effect on direct water emissions

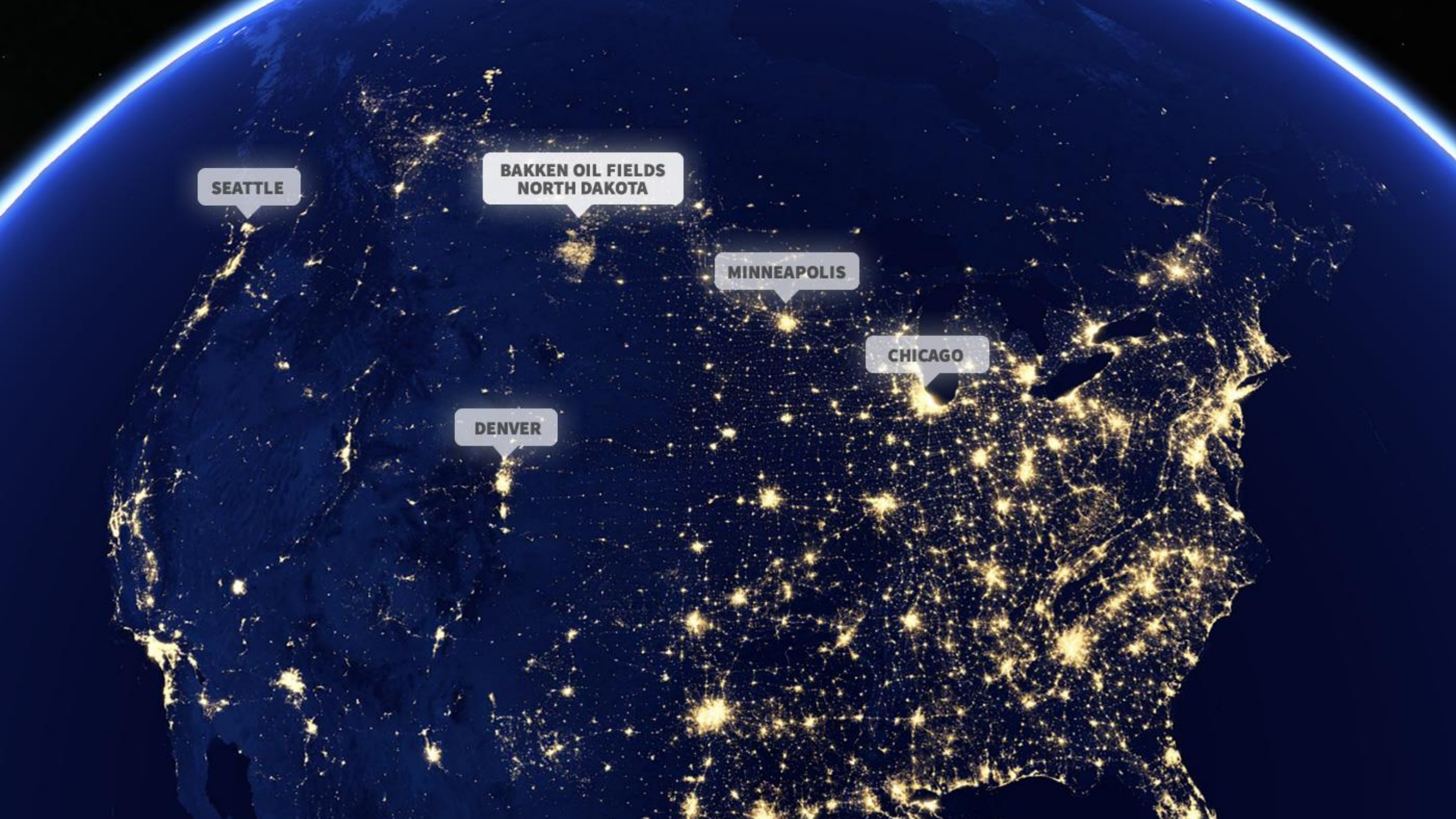


METHANE: CH_4

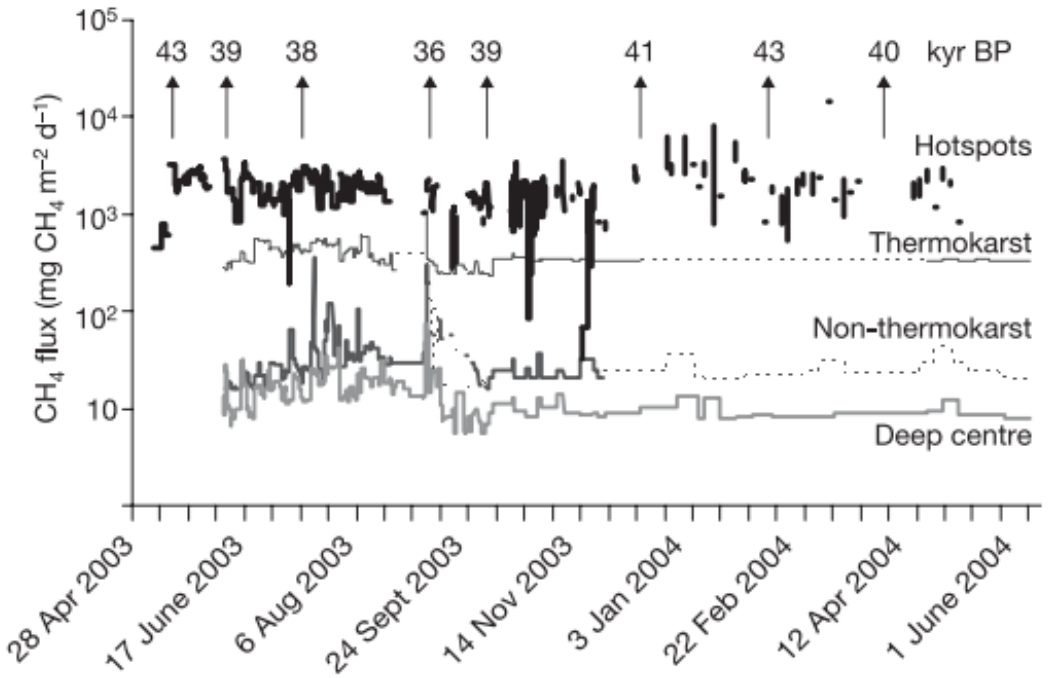
- Methane is one of the most potent greenhouse gases and is 21x more effective as a warmer than CO_2
- Methane is the primary constituent in natural gas
- Natural gas may not be a better alternative to oil and gasoline due to methane leaks during natural gas production

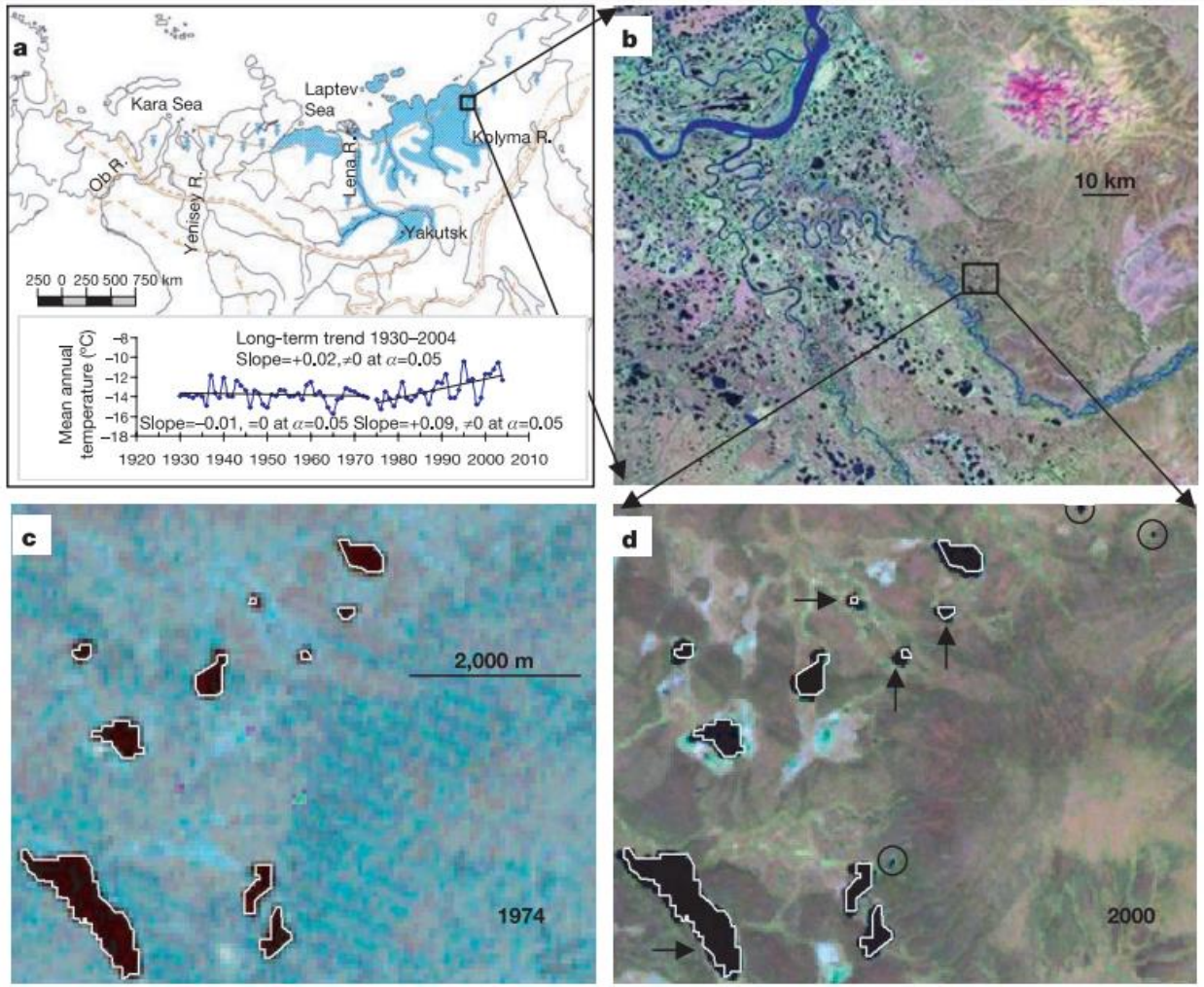





SEATTLE
BAKKEN OIL FIELDS
NORTH DAKOTA
MINNEAPOLIS
CHICAGO
DENVER

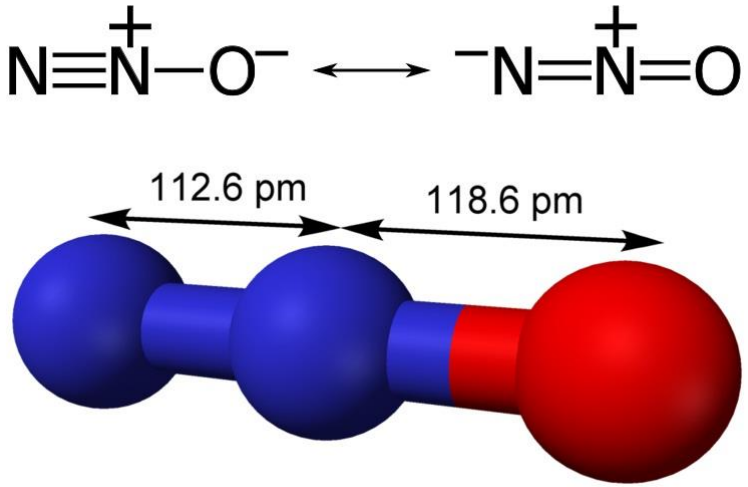
METHANE AND PERMAFROST



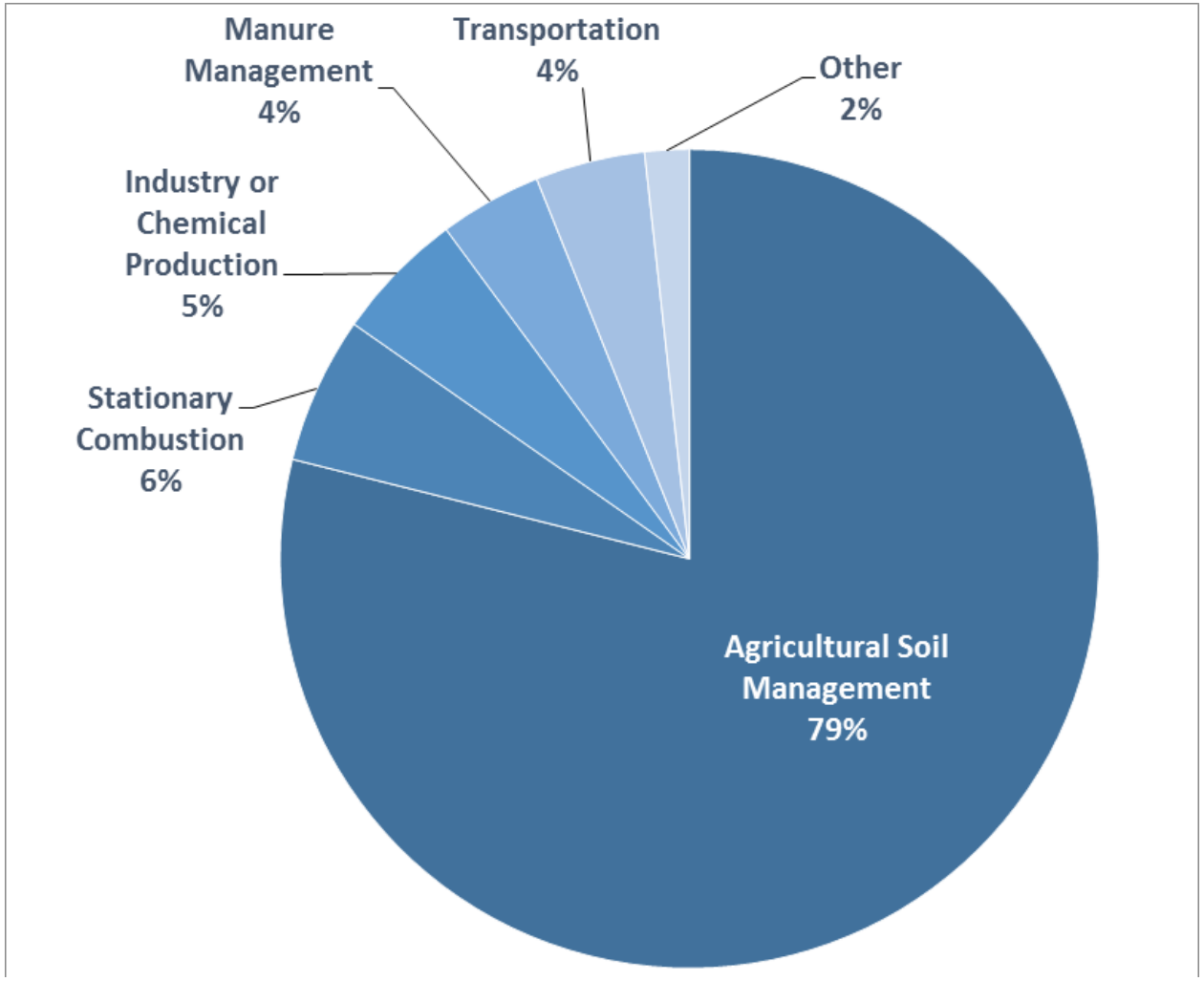


- Large deposits of methane are stored in Siberian permafrost, but if that starts to melt more…

NITROGEN DIOXIDE: N_2O

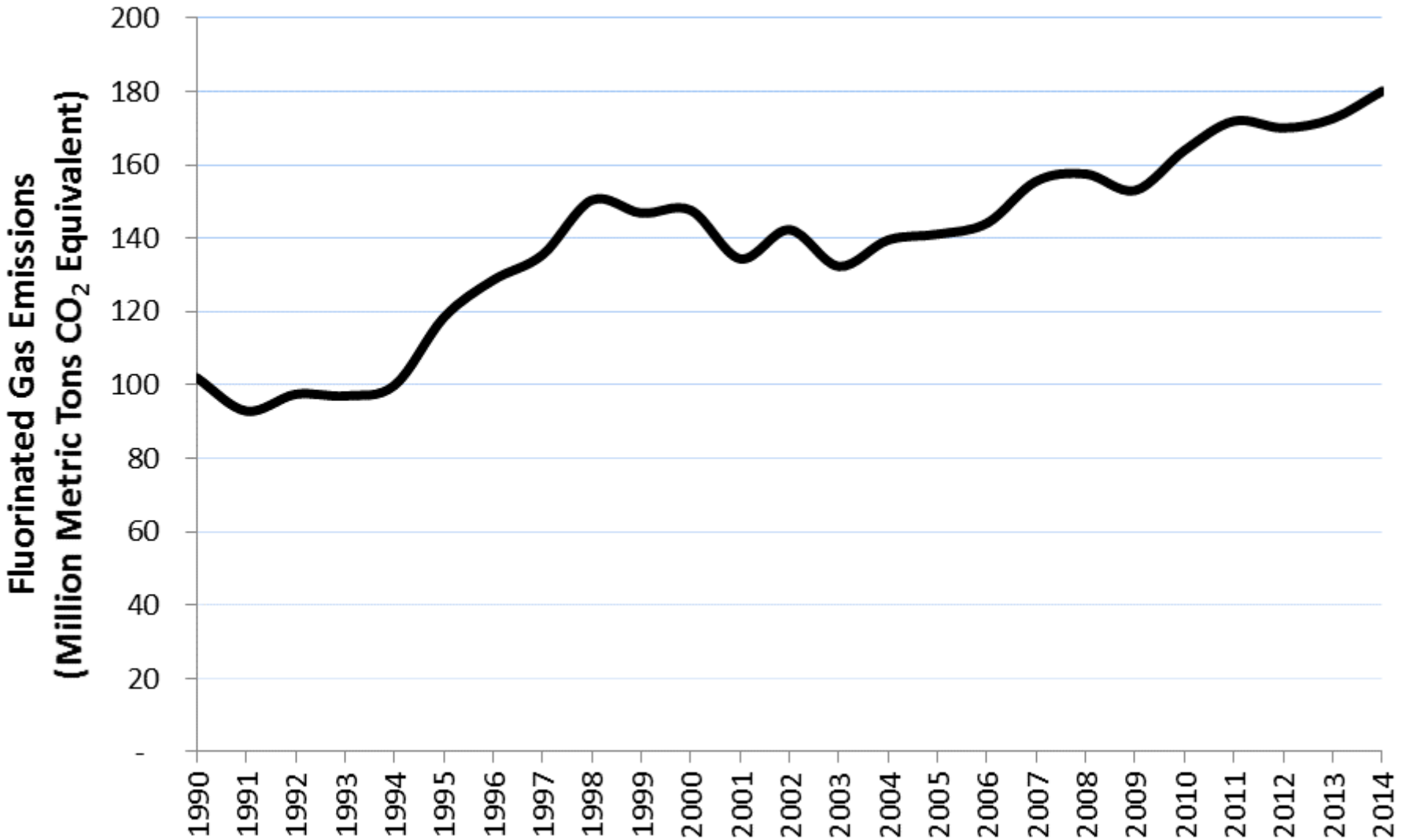


- N_2O has a GWP of 298x that of CO_2
- 40% of all N2O emissions are anthropogenic
- Accounted for 5.9% of total U.S. GHG emissions in 2014



CFC's,

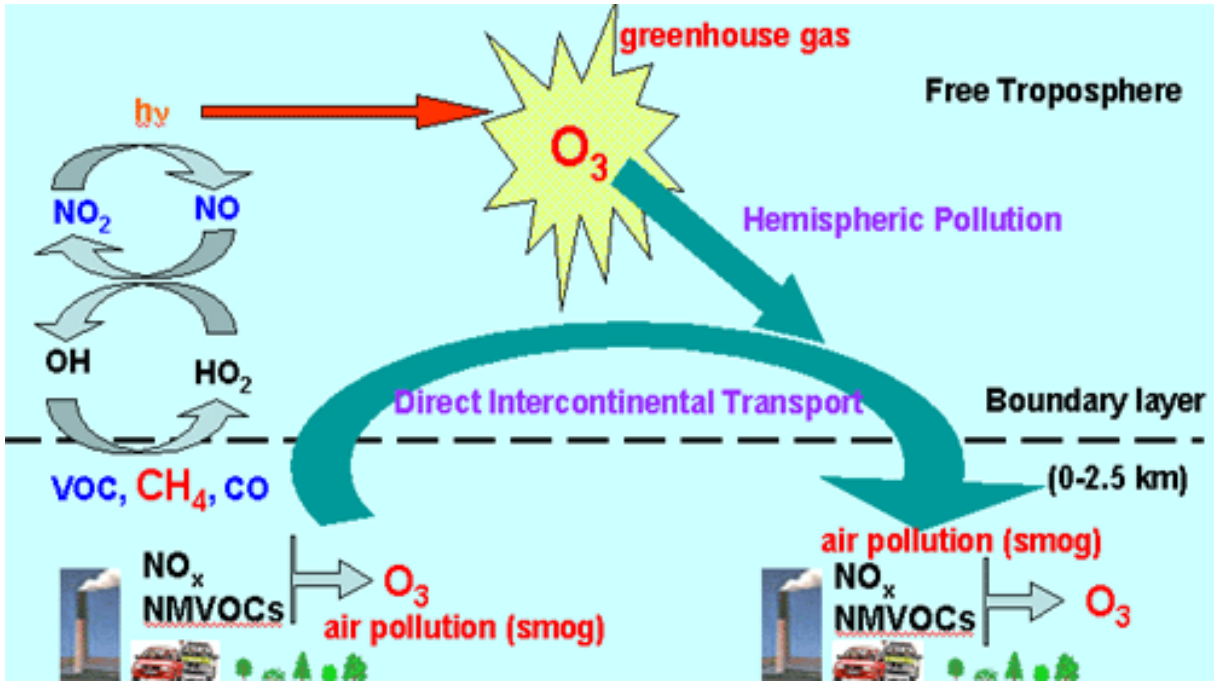
- **CFC:**
  - Ban
- **HCFC**
- **HFC:**
- **PFC:**
- **NF_3:** n
- **SF_6:** su
  - The

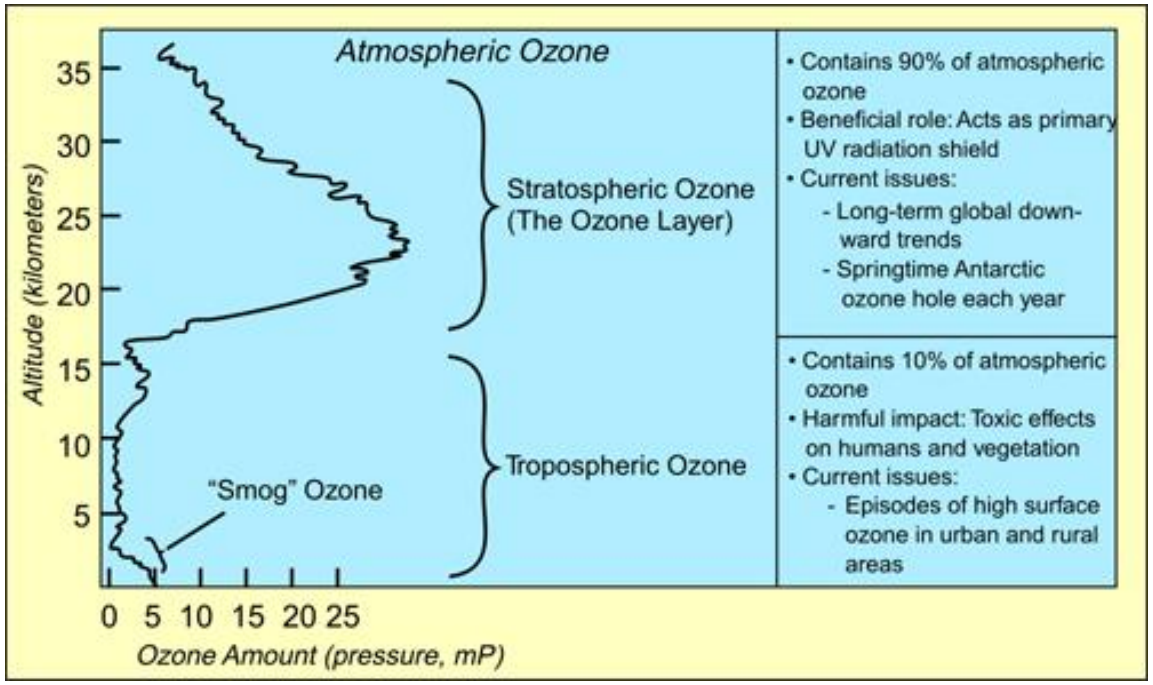


—Cl

.2

OZONE: O_3



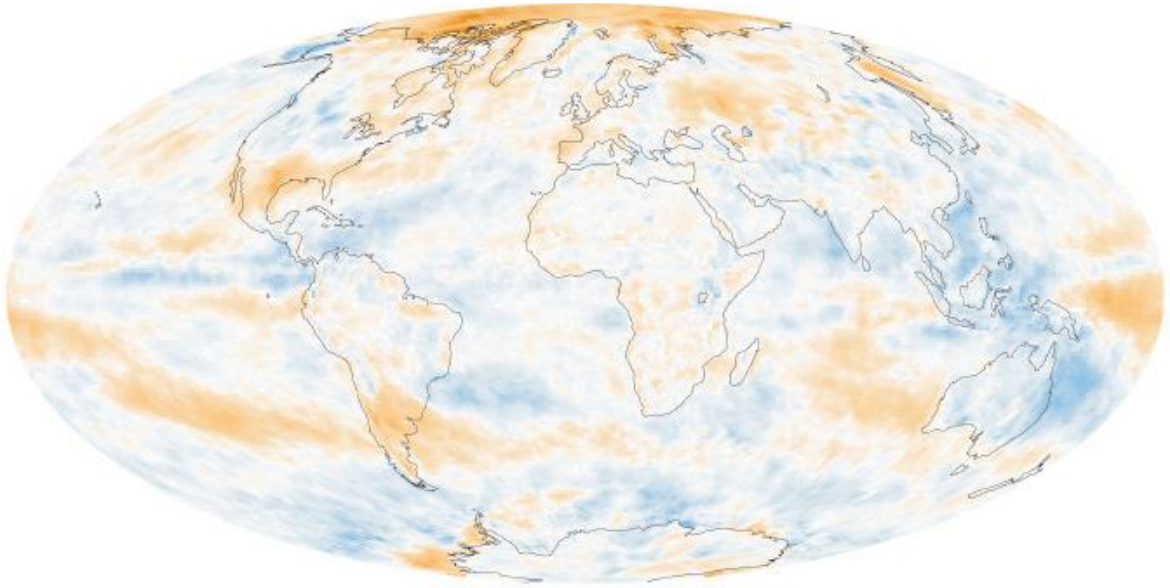


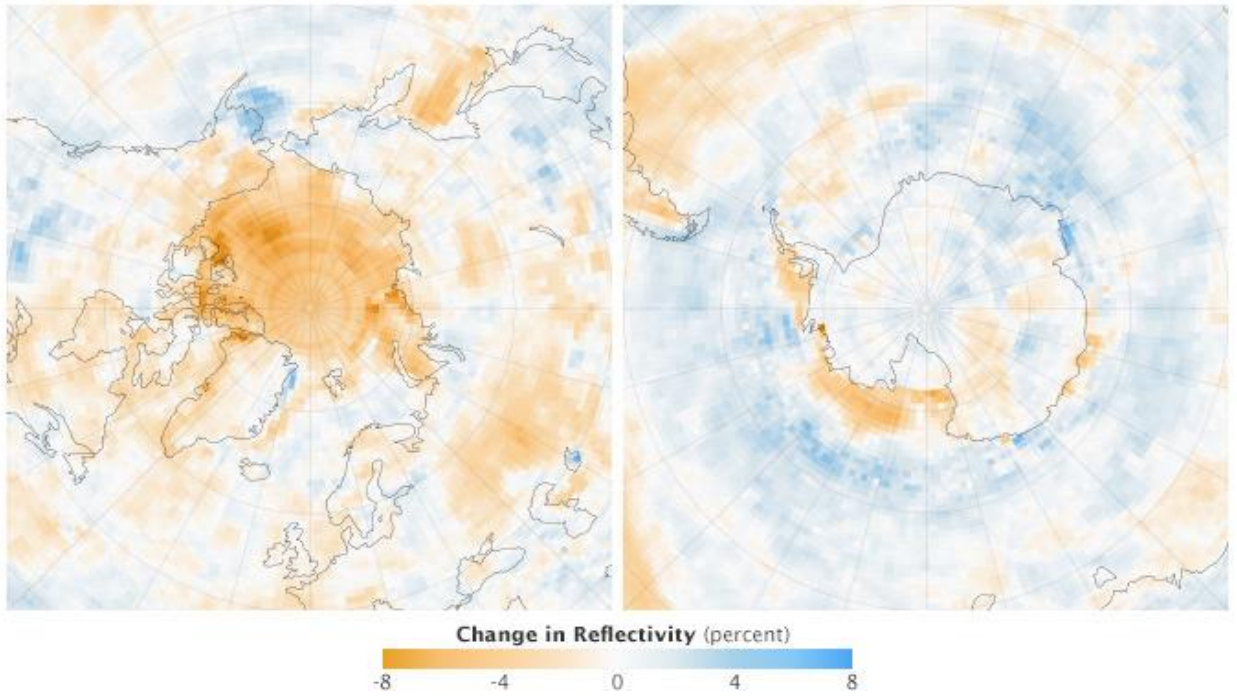
- Ozone is particularly complicated, but the harmful ozone is found in the troposphere
- Ozone is toxic to most life. In humans the most harmful effect is dissolving lung tissue

OTHER IMPORTANT FACTORS

IT'S MORE THAN JUST GREENHOUSE GASES

ALBEDO





- Albedo refers to the reflectivity of a surface
  - The higher the albedo the more reflective the surface is
- Ice and snow have high albedos, but as they melt, the albedo of the planet decreases

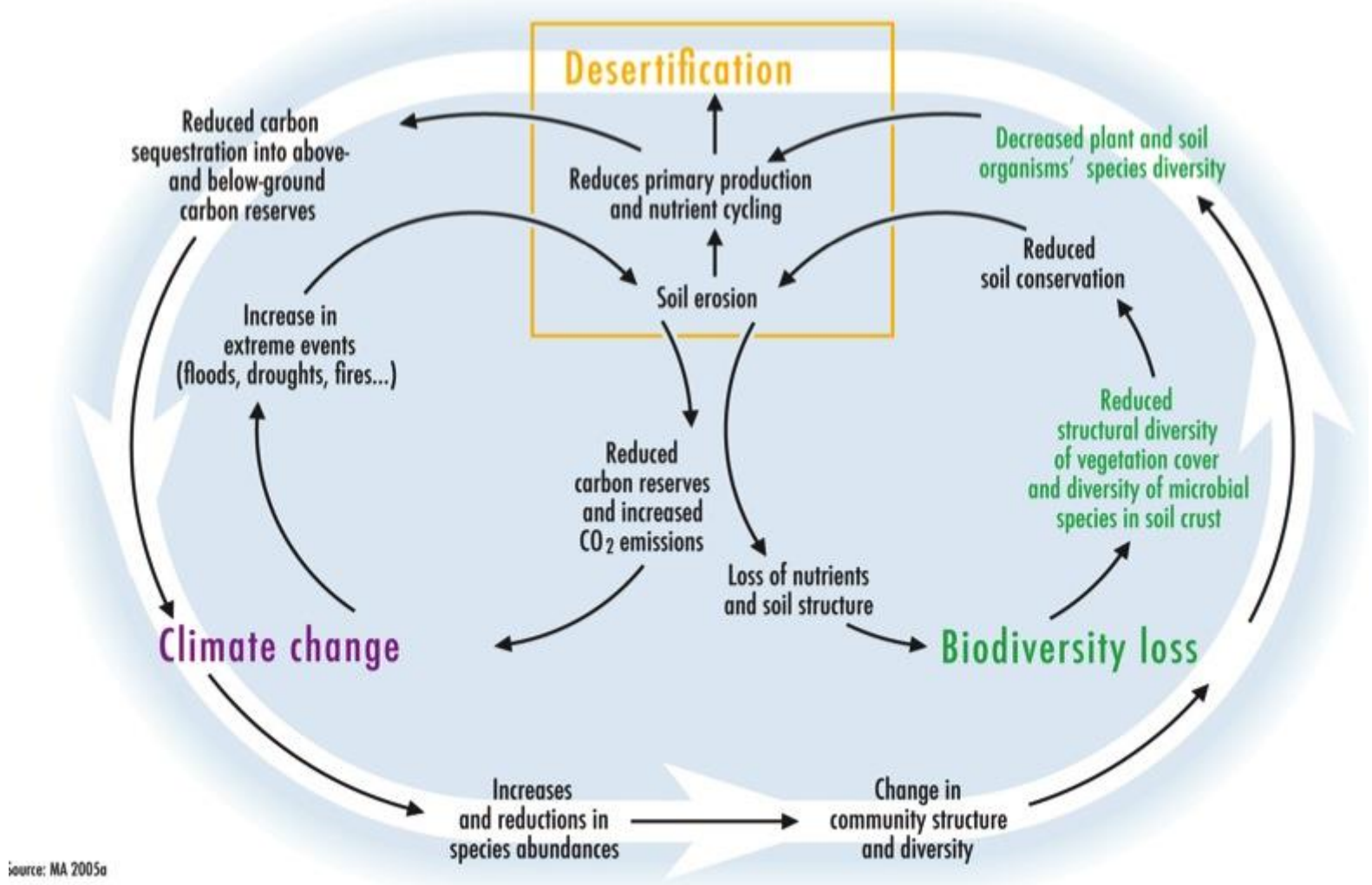
AEROSOLS

- **Aerosol**: a mixture of gases and suspended particles
- Aerosols scatter light and tend to increase the albedo relative to the surface beneath them
- Aerosol particles are important in forming clouds which are also generally more reflective
- Black carbon (soot) aerosols are highly absorptive and tend to decrease surface albedo

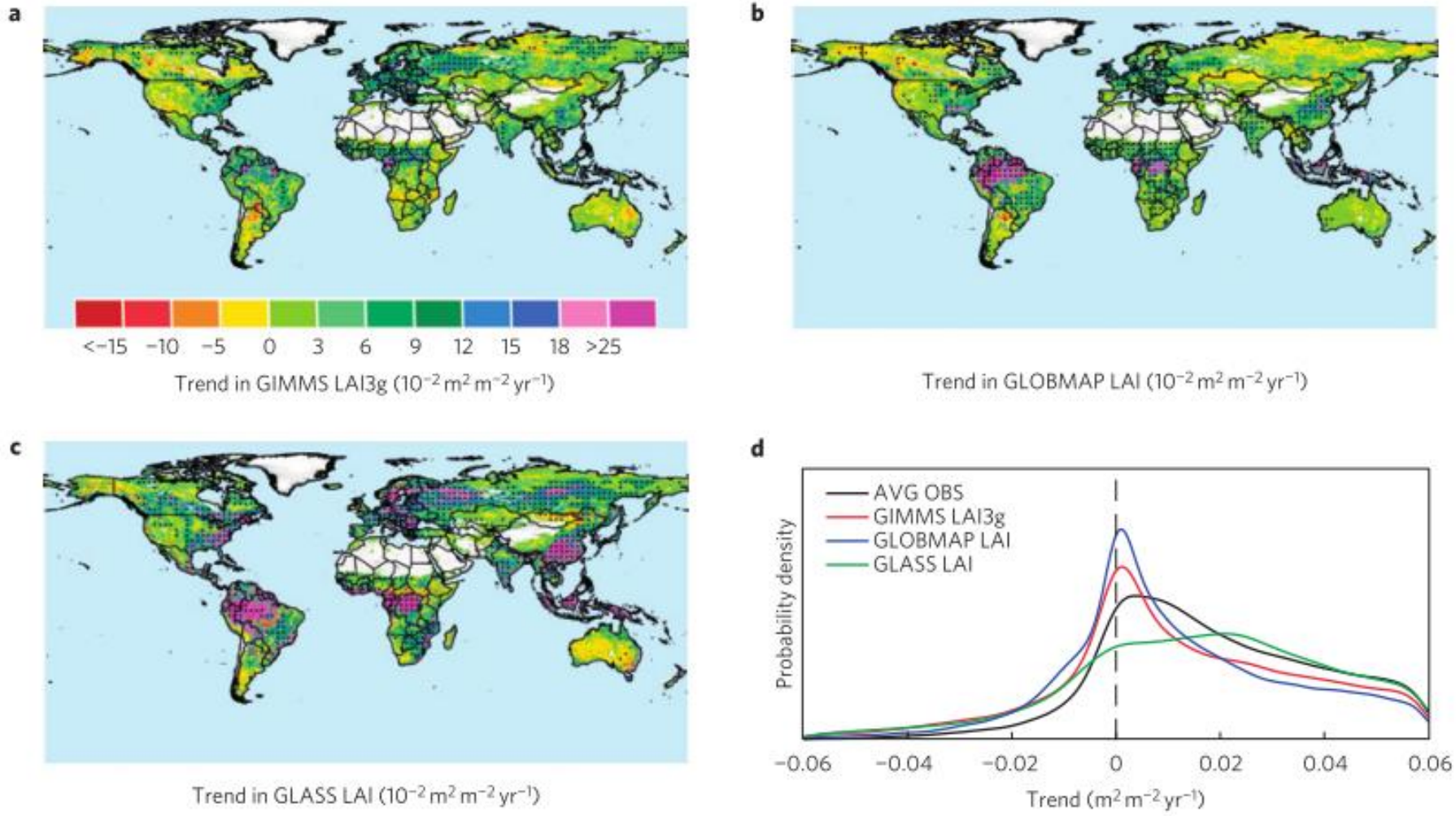
CLIMATE FEEDBACKS

POSITIVE CLIMATE FEEDBACKS

- Positive feedback loops amplify the effects of a perturbation
- This is one example of many connecting climate change to desertification and loss of biodiversity



NEGATIVE CLIMATE FEEDBACKS



VENUS AND THE GREENHOUSE EFFECT

- Venus may have had ocean(s) at one time, but they boiled off into space long ago

- This positive feedback loop is happening on Earth, but we're far enough away from the sun that we haven't had a runaway effect