03-Solar Radiation & the Greenhouse Effect

ECEGR 4530

Renewable Energy Systems

Overview

- Irradiance
- Solar Spectrum
- Atmospheric Effects
- Greenhouse Gases
- Global Warming
- Global Warming Impacts

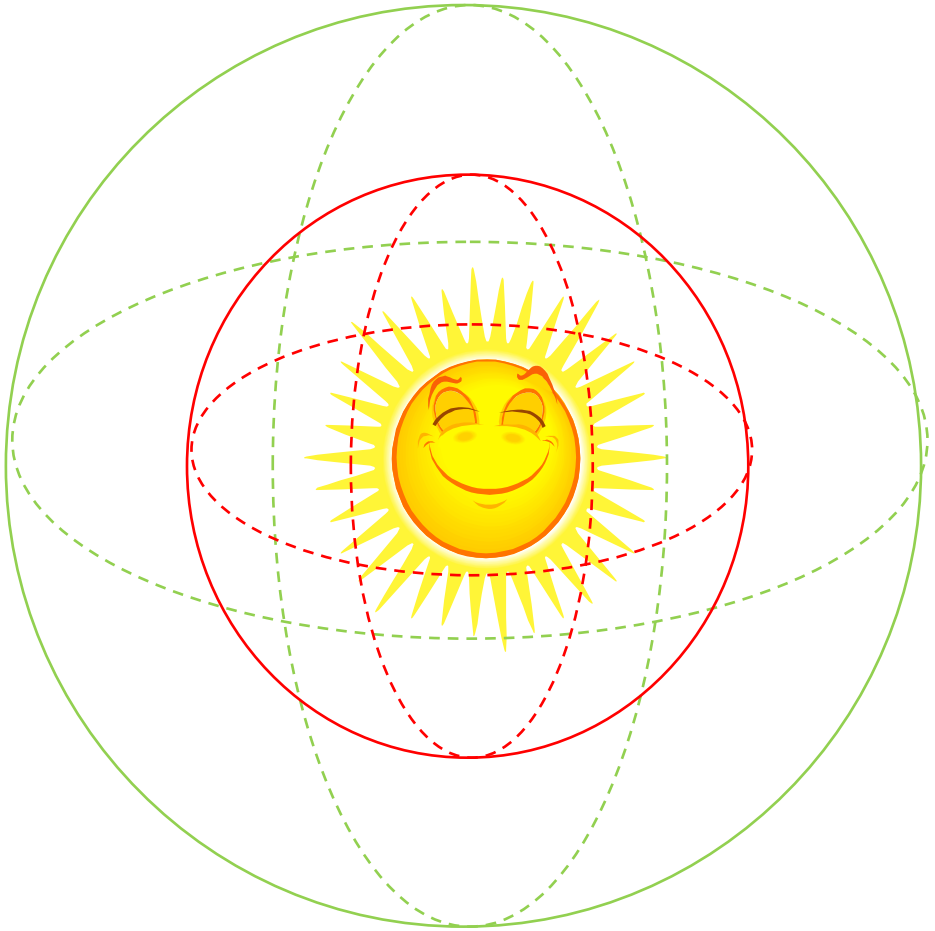
Irradiance

Irradiance

- Sun radiates energy through space to Earth
- Rate of energy arriving, per square meter, is known as irradiance (watts per square meter, also written as W/m^2 or $W\ m^{-2}$)
  - 1 square meter (m^2) is about the area of an office desk
  - Surface area of human skin is about 1.5 m^2

Irradiance

- Irradiance at the surface of the sun
  - $G_{sun} = 6.3 \times 10^7 \, W/m^2$ (63 million watts per square meter, MW/m^2)
- As we move away from the sun, the irradiance decreases
  - the sunlight is spread over larger areas, so it is less intense



Irradiance is greater around the red sphere than the green sphere

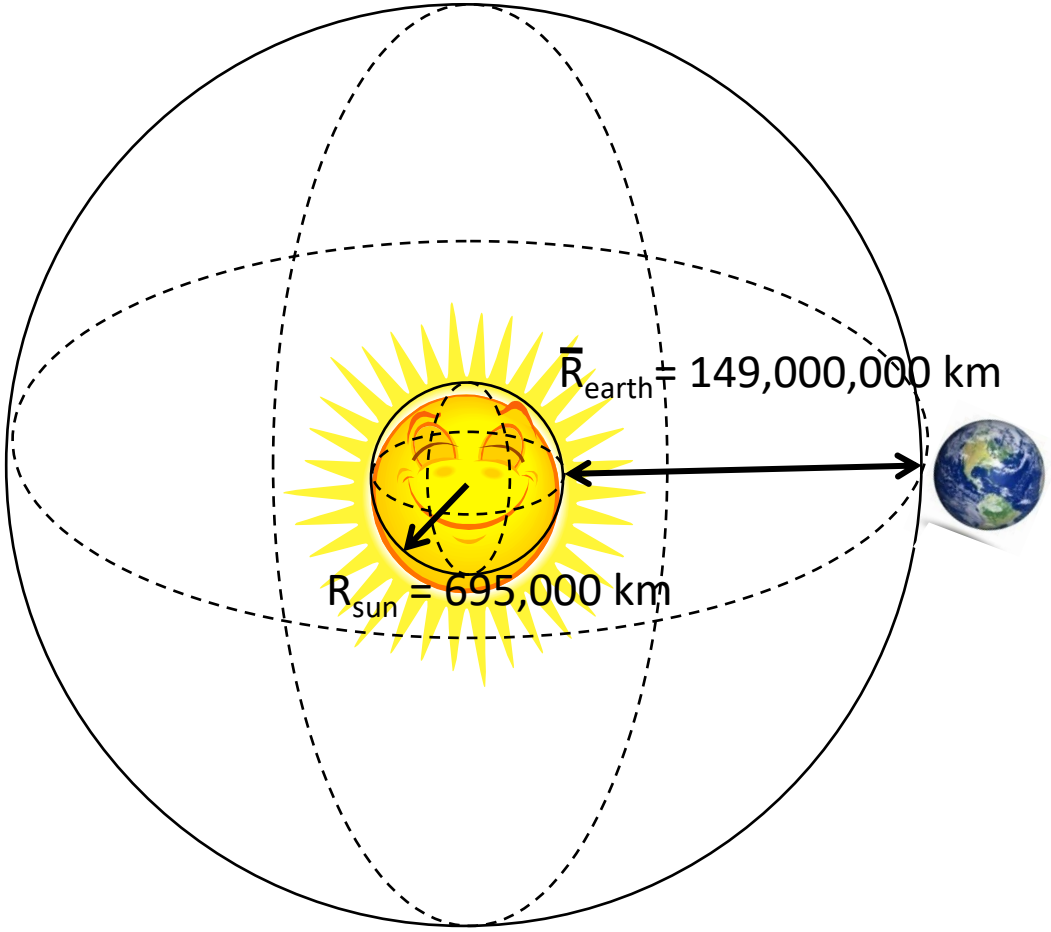
Irradiance

- Surface area of a sphere $A = 4\pi r^2$
  - r: radius of the sphere (m)
- Radius of the sun: R_{sun} = 695,000 km
- G at any distance R from the sun is:

$$G = G_{sun}\left(\frac{4\pi R_{sun}^2}{4\pi R^2}\right) = G_{sun}\left(\frac{R_{sun}^2}{R^2}\right)$$

Ratio of surface areas

Extraterrestrial Irradiance



*not to scale

Extraterrestrial Irradiance

- What is the extraterrestrial (top of the atmosphere) irradiance at the Earth?
- Average distance from Earth to sun:
  - R_{earth} = 149,000,000 km
- Solving:

$$G = G_{sun}\left(\frac{4\pi R_{sun}^2}{4\pi \bar{R}_{earth}^2}\right) = G_{sun}\left(\frac{R_{sun}^2}{\bar{R}_{earth}^2}\right) = 6.3\times 10^7\left(\frac{(695,000)^2}{(149,000,000)^2}\right) = 1370 \text{ W/m}^2$$

Solar Spectrum

- What is the frequency of solar radiation?
  - Determined by Planck's Law
  - Relates temperature to energy at each frequency

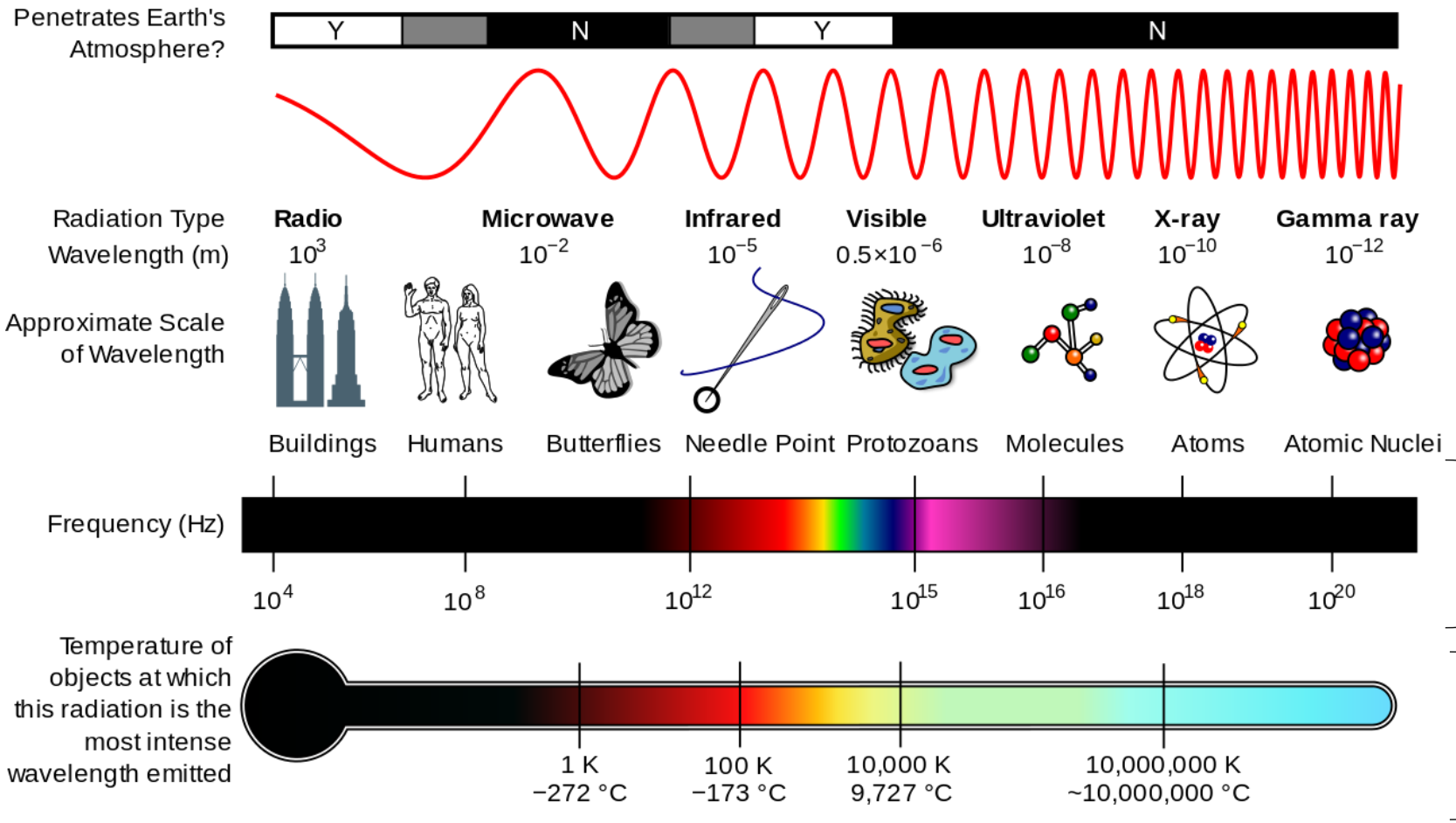
Radiation Spectrum

Radiation Spectrum

- Irradiance alone isn't enough to fully describe the radiation from the sun
- We are also interested in the spectrum of the radiation---the wavelengths (frequencies) of the radiation, and the intensity at each wavelength
- All matter emits radiation---even you!---the spectrum depends on the temperature (and properties of the surface)

By Cody.pope, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=3484188

Electromagnetic Spectrum



$$f = \frac{c}{\lambda}$$

c ← speed of light

λ ← wavelength

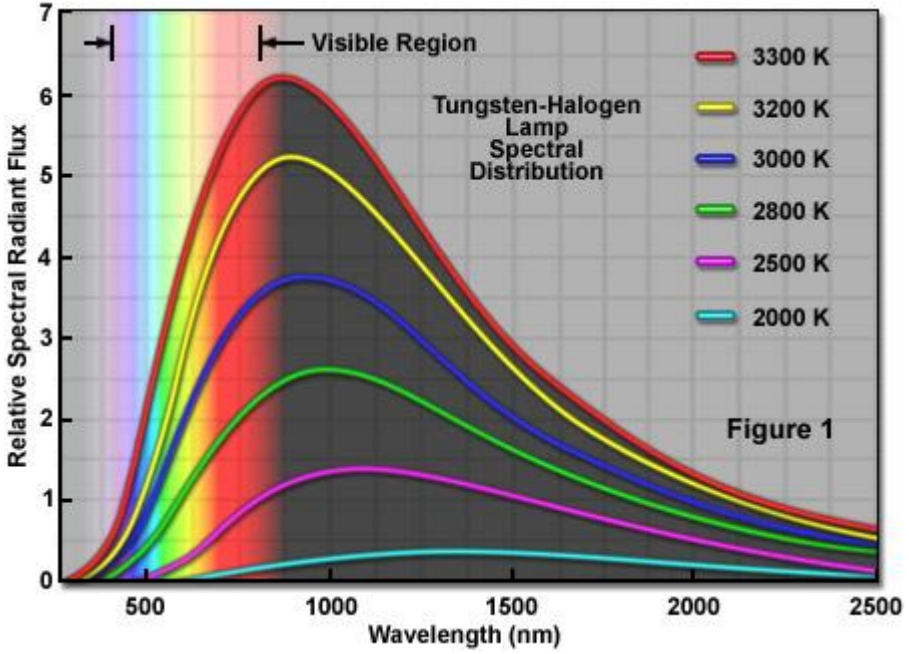
Note: frequency (Hz) and wavelength are inversely related

Note: higher temperatures correspond to shorter wavelengths

SEATTLEU

Radiation: Objects of various temperatures "glow" at different wavelengths

- Your eyes are like radiation sensors
  - Limited to wavelengths between about 380 nanometers (nm) and 740 nm
  - Radiation outside this band is not visible
- The light shown here, a typical halogen light, emits more red/yellow than blue/green
- Note that amount emitted increases with "Temperature". This represents what would be emitted by a theoretical perfect emitter—a "black body" at a given absolute temperature (in kelvins)

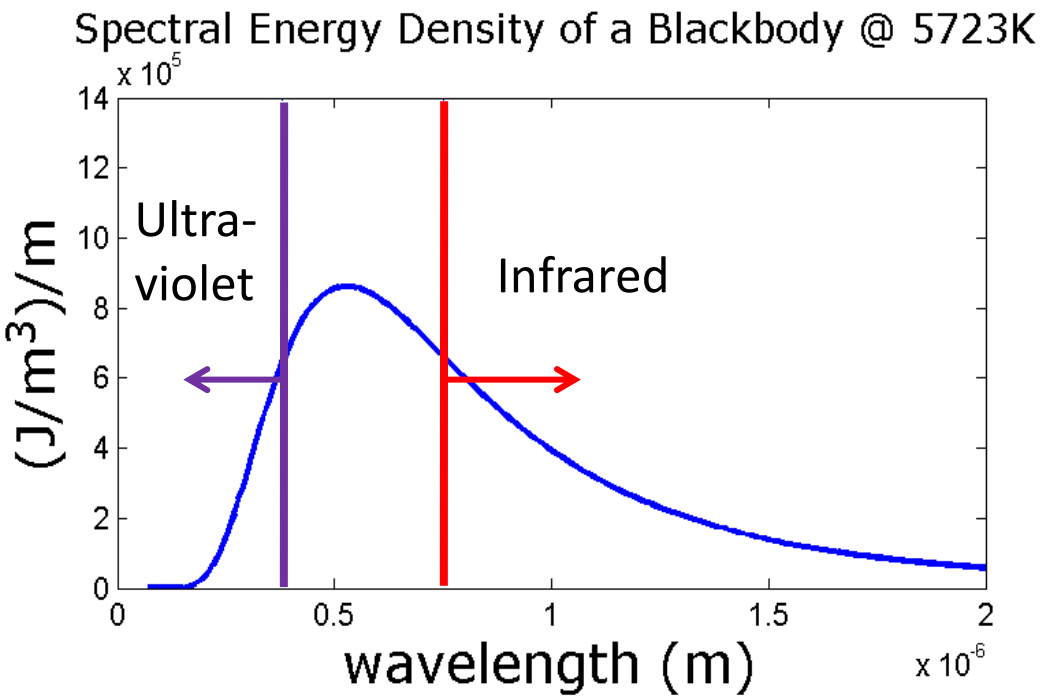


http://zeiss-campus.magnet.fsu.edu/articles/lightsources/tungstenhalogen.html

Radiation and Temperature

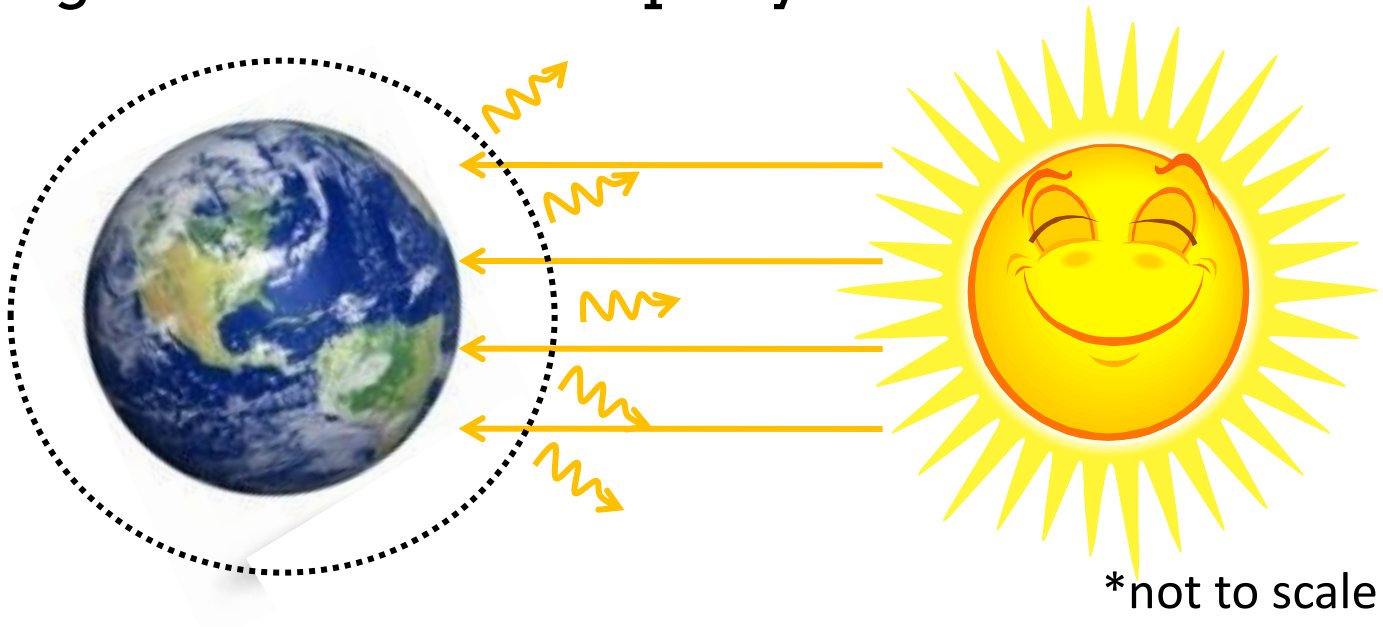
- Temperature also affects the intensity of the radiation, not just its distribution
  - Higher temperature means more power being radiated
  - Known as Stefan-Boltzmann law $F = \varepsilon\sigma T^4$
  - Relationship is not linear: power radiated increases to the fourth power of temperature (a small change in temperature leads to a large change in power being radiated)

Solar Spectrum



Atmospheric Effects

- Earth receives radiation from the sun
  - Wide range of wave lengths: 250-5000 nm
- Atmosphere reflects about 30%
  - Not all wavelengths are reflected equally



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Reflection, Transmission, Absorption

- When radiation interacts with matter, three things can occur (or a combination thereof)
  - Reflection/scattering: the radiation is returned (reflected!)
  - Transmission: the radiation passes through the matter
  - Absorption: the energy in the radiation is transferred to the matter, and it heats up (usually)
- Different matter will reflect, transmit, and absorb different wavelengths differently

Atmospheric Effects

top of the atmosphere

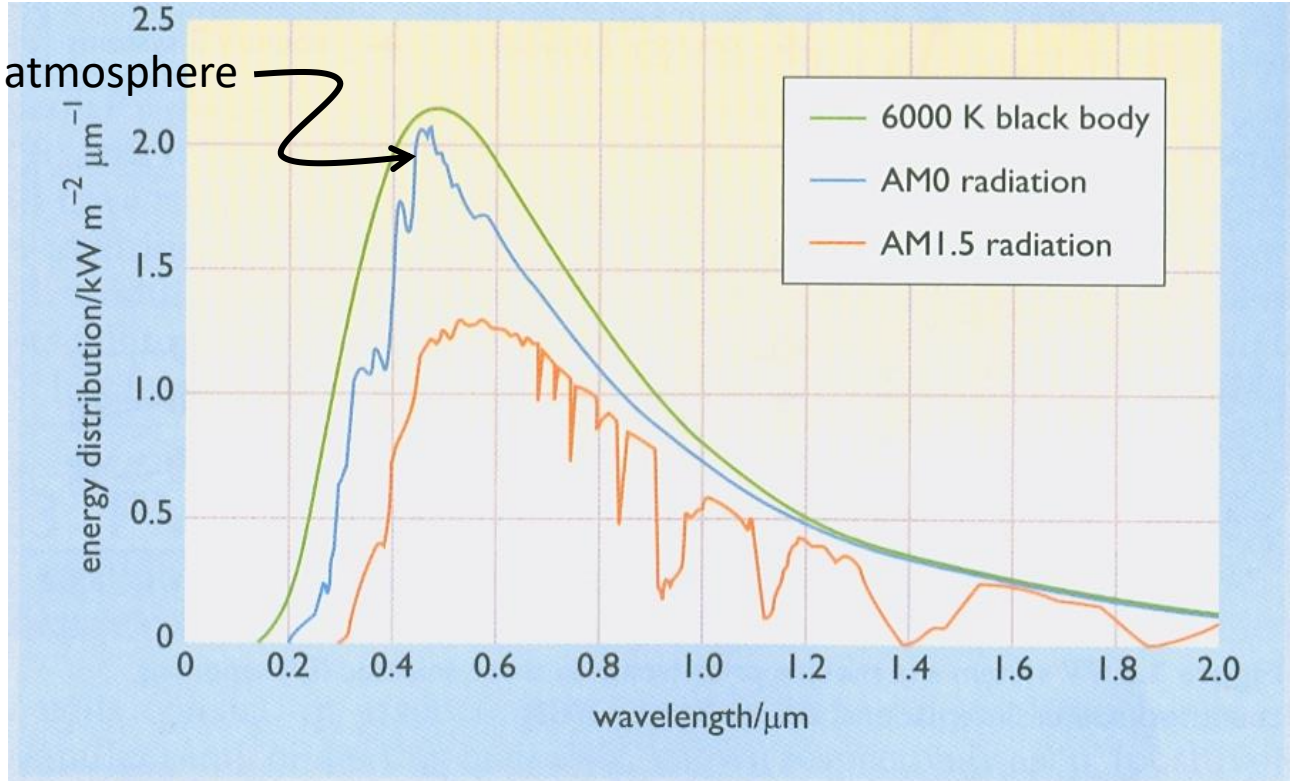


Figure 3.8 The spectral power distributions of solar radiation corresponding to Air Mass 0 and Air Mass 1.5. Also shown is the theoretical spectral power distribution that would be expected, in space, if the sun were a perfect radiator (a 'black body') at 6000 °C

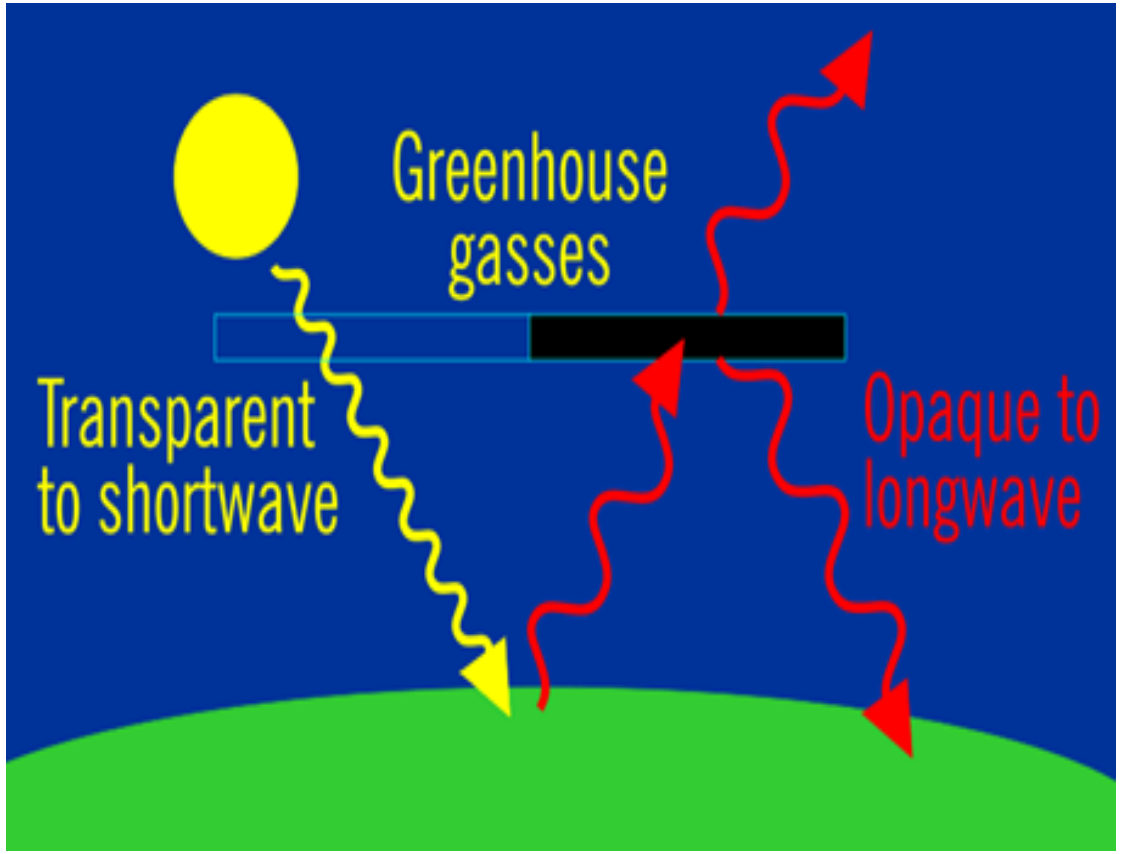
Source: Renewable Energy: Power for a Sustainable Future, G. Boyle

Reflection, Transmission, Absorption

- Windshield glass is an excellent transmitter for most of the visible spectrum of radiation (we can see through it!)
- Our skin absorbs most wavelengths, which is why sunlight warms us
- The reflection, transmission, and absorption properties of the gases that make up Earth's atmosphere at different wavelengths play a crucial role in the greenhouse effect

Greenhouse Effect

- Naturally occurring process in the atmosphere where gases trap in heat.
- Like a blanket covering planet
- Without it, Earth would be COLD
- Known about for over a century



Source:http://www.niwa.co.nz/our-science/climate/information-and-resources/clivar/models

Greenhouse Gases

- Greenhouse gases: atmospheric gases that keep the longwave infrared radiation from escaping

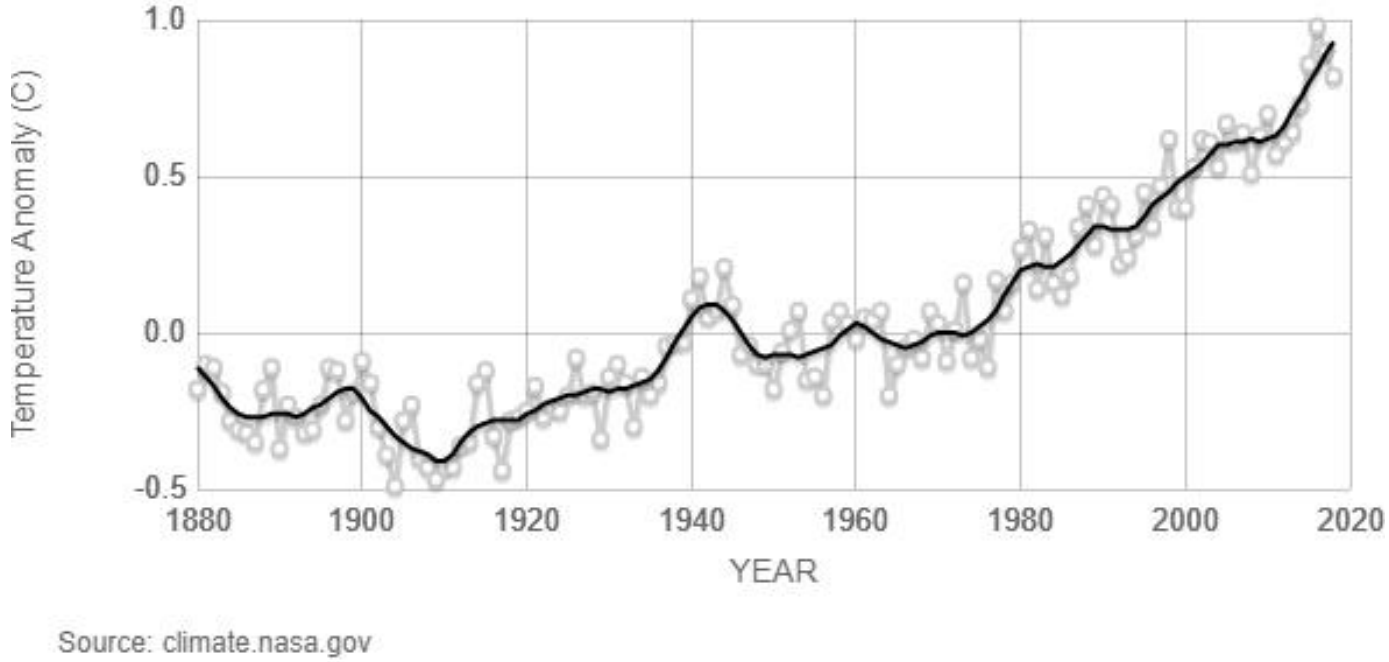
- Common Greenhouse gases (GHG)
  - Water vapor (responsible for 60-80% of greenhouse effect)
  - Carbon dioxide (CO_2)
  - Methane
  - N_2O
  - Ozone

Greenhouse Gases

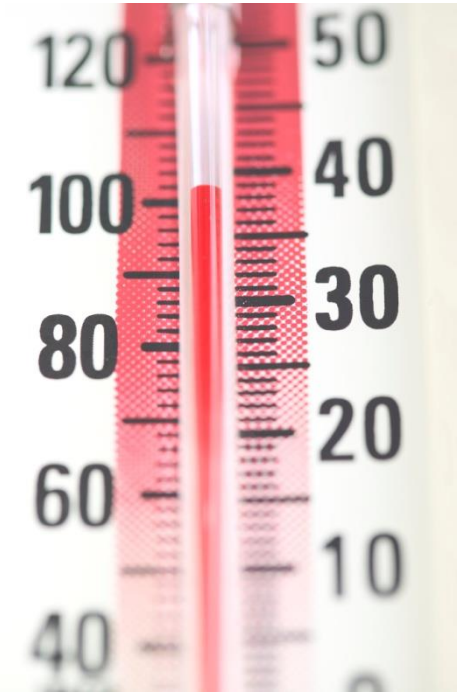
- Current CO_2 concentration ~ 400 ppm (parts per million)
  - increasing
  - 18th Century ~ 280 ppm
- Burning fossil fuels releases previously sequestered (buried) carbon into the atmosphere
  - Concentration of CO_2 increases

Global Warming

Global warming is a generalization in both space and time used to describe the rising trend in mean global temperature evident in many but not all analyses of near-surface temperature data-Timothy Casey



Source: climate.nasa.gov

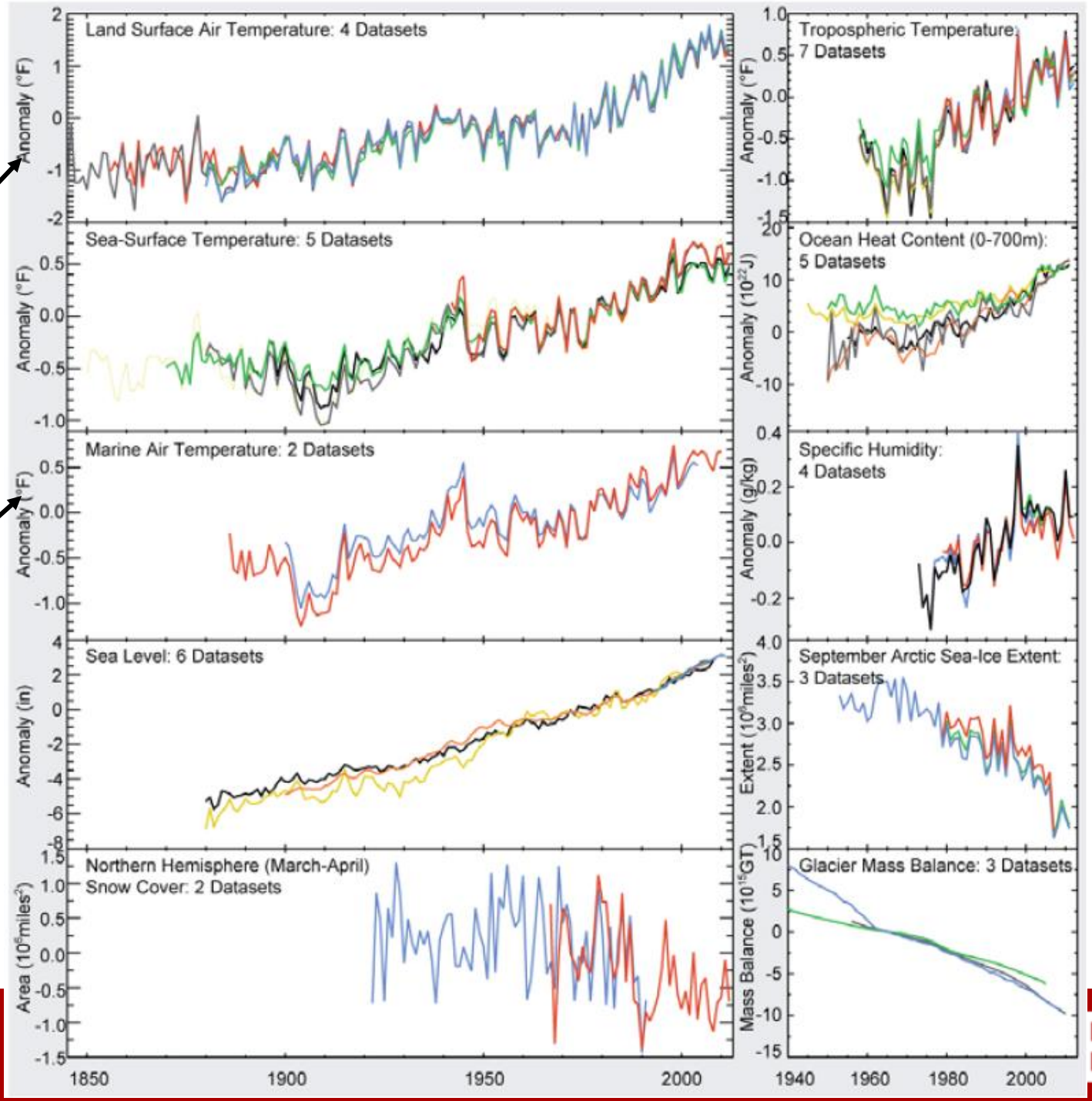


Recent climate trends show clear warming pattern

Land surface temperature increasing

Sea surface temperature increasing

Marine air temperature increasing

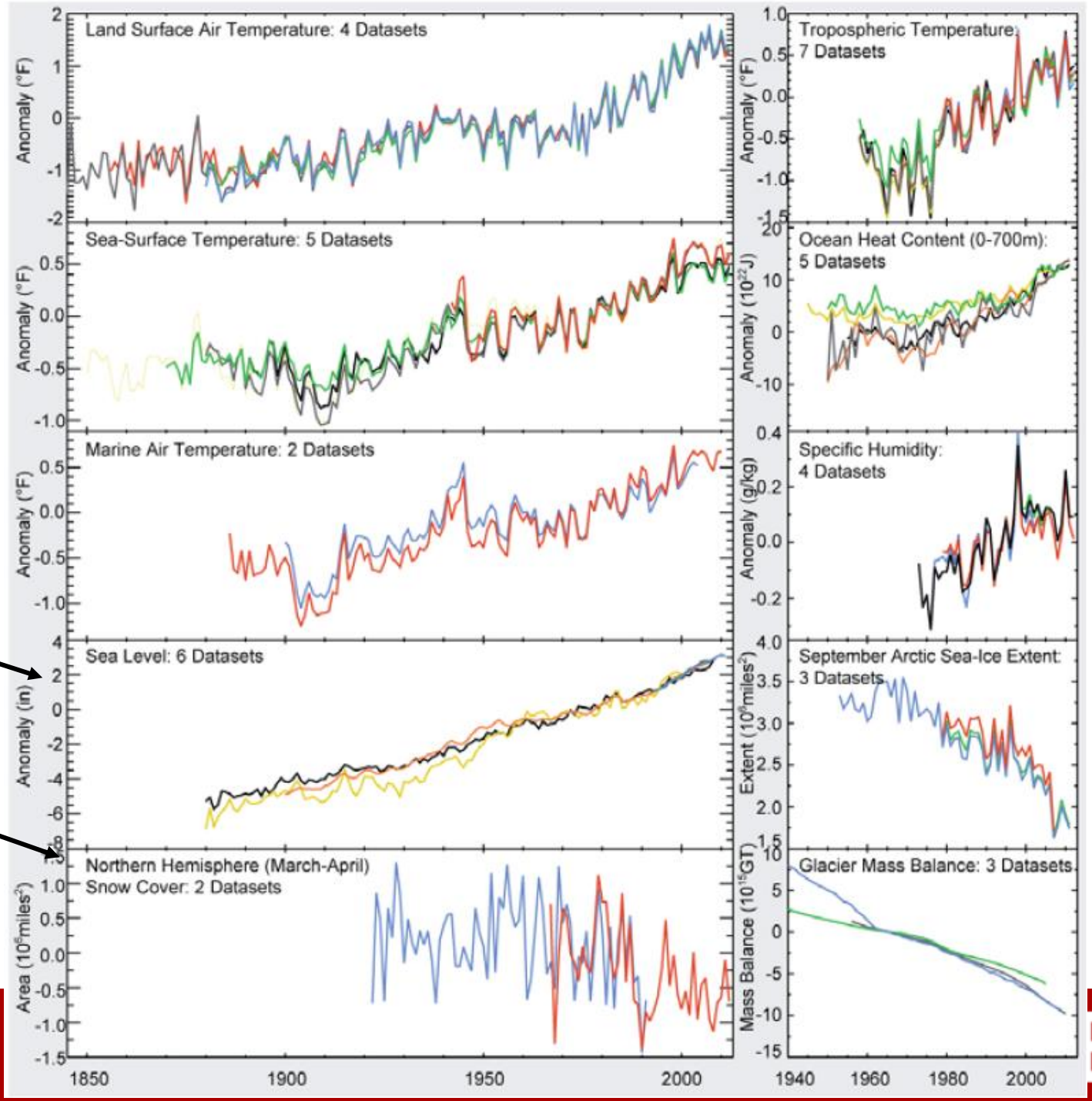


(From USGCRP 2014, Climate Change Impacts in the United States, Appendix 3)

Recent climate trends show clear warming pattern

Sea level increasing

Snow level decreasing



(From USGCRP 2014, Climate Change Impacts in the United States, Appendix 3)

Impacts to Oceans

- pH (Acidity)—we will discuss in context of ecosystems
  - Oceans are major repository of carbon globally, much of it in the form of carbonic acid

$$H_2O + CO_2 \Leftrightarrow H_2CO_3$$

  - One of the hydrogen ions in H_2C0_3 is then "liberated", increasing the concentration of H^+ ions (decreasing pH)

$$H_2CO_3 \Leftrightarrow H^+ + HCO_3^-$$

- Polar Sea Ice and Circulation
  - Loss of polar ice and potential changes to thermohaline circulation.
- Sea level
  - Energy and melting land-based ice both end up in the ocean, leading to change in global sea level
  - Local sea level can change with winds

Impacts to Water Resource

- Precipitation will become more intense/variable
- Increased temperature leads to high chances of less runoff (but more runoff when it occurs). This can increase water stress and damage economies and ecosystems
- Locally, we expect major changes in timing of snowmelt.
- Changes in water resources systems are very location-specific and need to be evaluated in the context of a particular river system/watershed.

Questions

- How much money are you willing to pay to prevent all CO_2 from power plants from being emitted into the atmosphere?
- What happens if we do not reduce mankind's greenhouse gas emissions?
- Should the U.S. reduce its greenhouse gas emissions if China does not?

Key Points: Terrestrial Ecological Systems

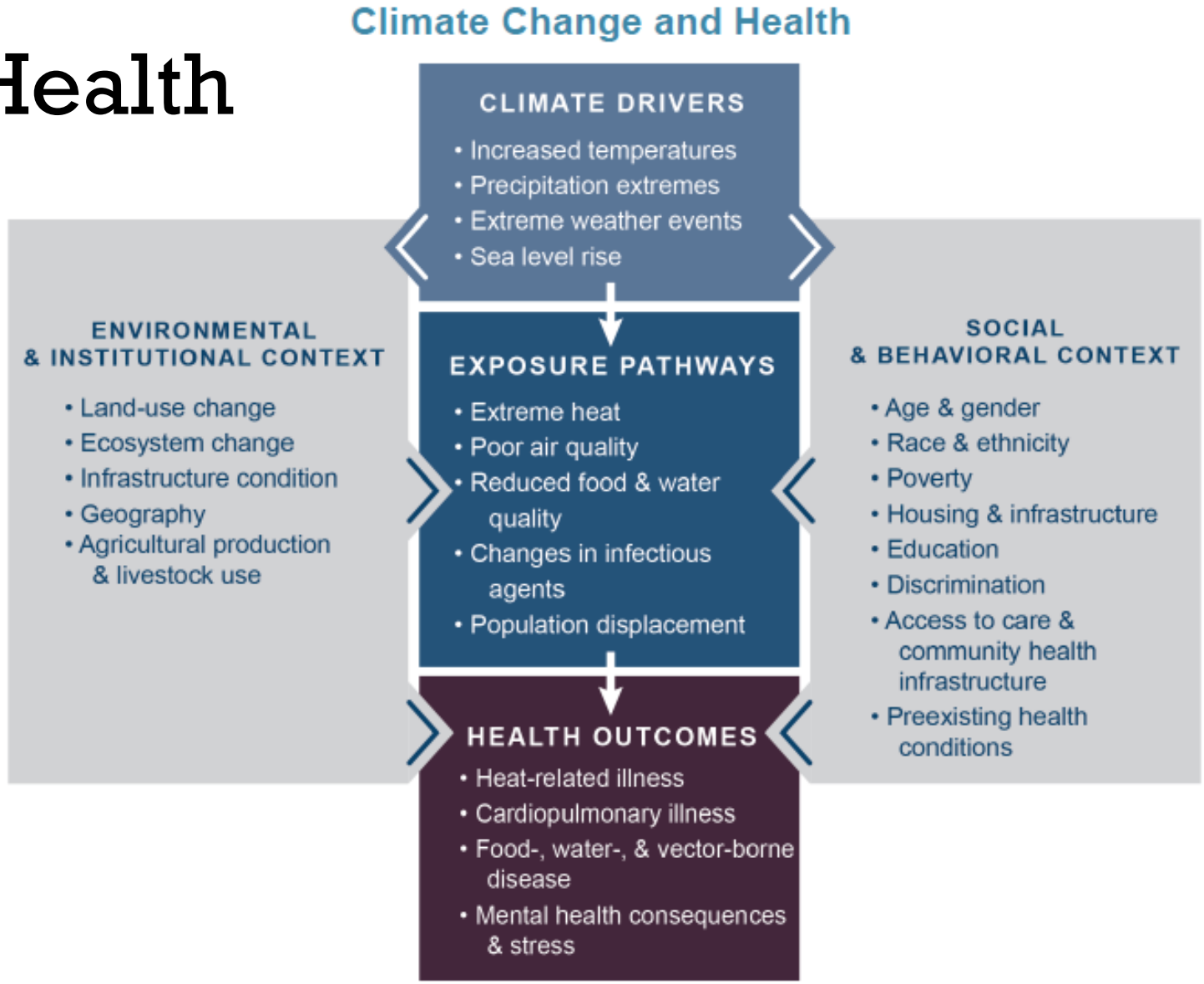
- Biomes depend on temperature/precipitation patterns, so we know they will change
  - Shifts simulated by models are
    - A) much larger than already experienced
    - B) much larger for high emission scenarios
    - C) Are generally occurring stressed systems
- Key question: Can species keep up given habitat fragmentation/barriers?
- Will existing ecological carbon sinks become carbon sources?

Impacts to Agricultural/Marine Ecosystems

- Agricultural Systems
  - CO_2 fertilization effect
  - Some winners/some losers
  - Importance of soil carbon
- Marine Systems
  - Less is known—and impacted by acidification as well as temperature
  - Stressed for many other reasons—see previous discussion of coastal zone

Impacts to Human Health

Health is complicated, but we know it depends partly on climate and will be affected by climate change



From 2018 National Climate Assessment, Chapter 14.