Review for Midterm

EES 3310/5310

Global Climate Change

Jonathan Gilligan

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Outline of Semester

Heat and Temperature

- Temperature is stable when $Q_{in} = Q_{out}$ (balance of heat)
- Radiative equilibrium:
  - Q_{in} is shortwave light from sun
  - Q_{out} is longwave light from earth
    - Where on earth does Q_{out} come from?
  - Why is Q_{in} shortwave and Q_{out} longwave?
  - Equations (in W/m^2):

$$Q_{\text{in}} = \frac{(1-\alpha) I_{\text{solar}}}{4} \quad \text{(Absorption)}$$

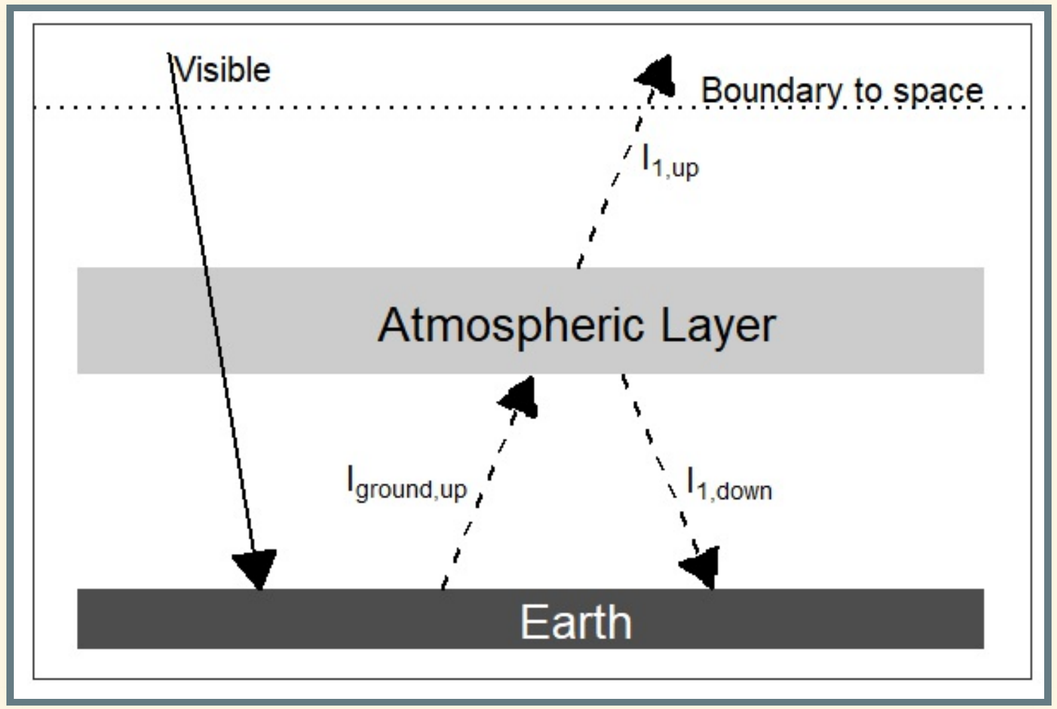
$$Q_{\text{out}} = \varepsilon \sigma T_{\text{skin}}^4 \quad \text{(Stefan-Boltzmann Law)}$$

Greenhouse Effect

- No greenhouse gases: Bare-rock model

$$T = \sqrt[4]{\frac{(1-\alpha)I_{\text{solar}}}{4\varepsilon\sigma}}$$

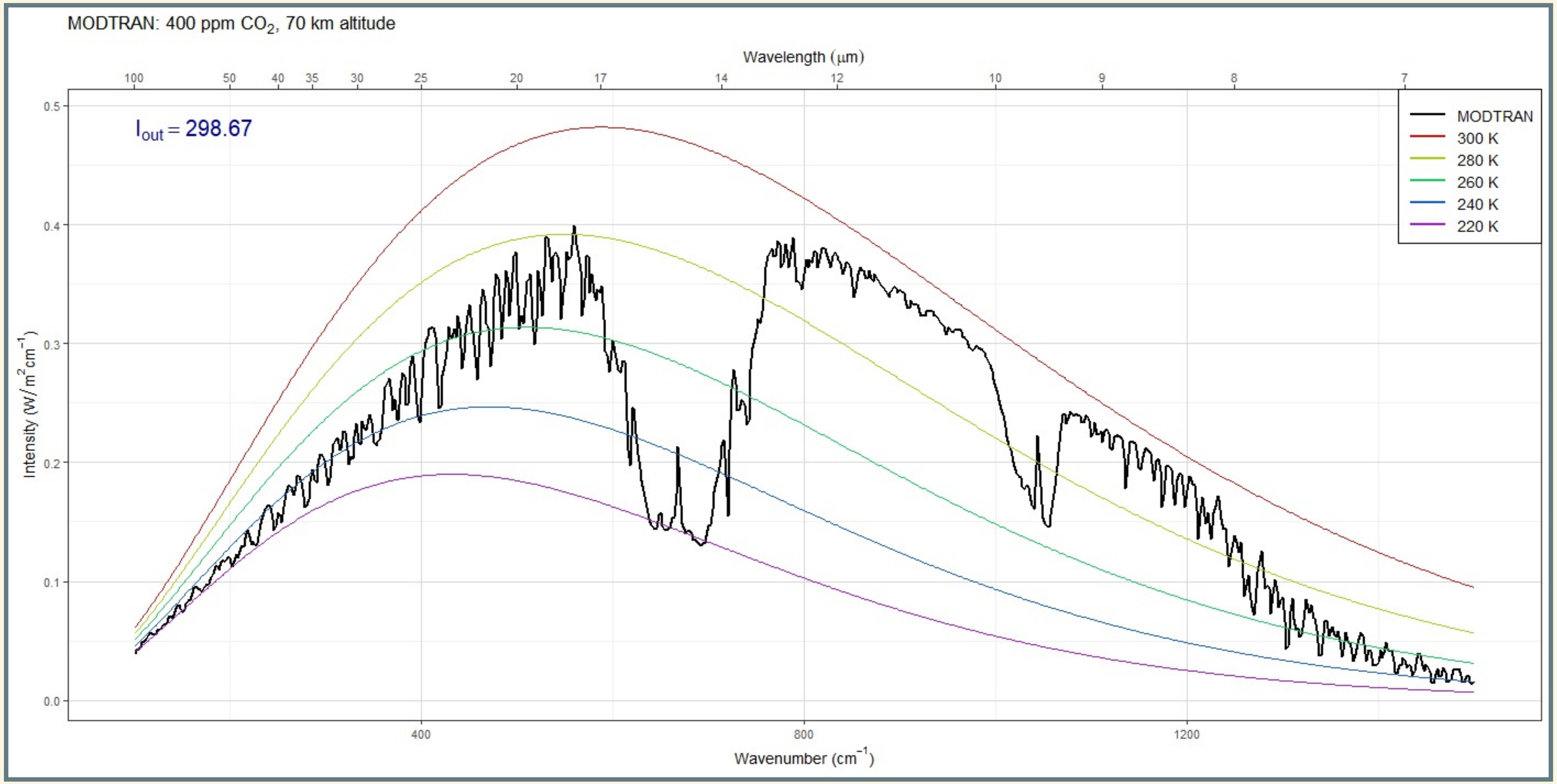
- Add greenhouse gases:
  - Simple model: Layer model ($\varepsilon = 1$ for all wavelengths)



More Realistic Greenhouse Effect

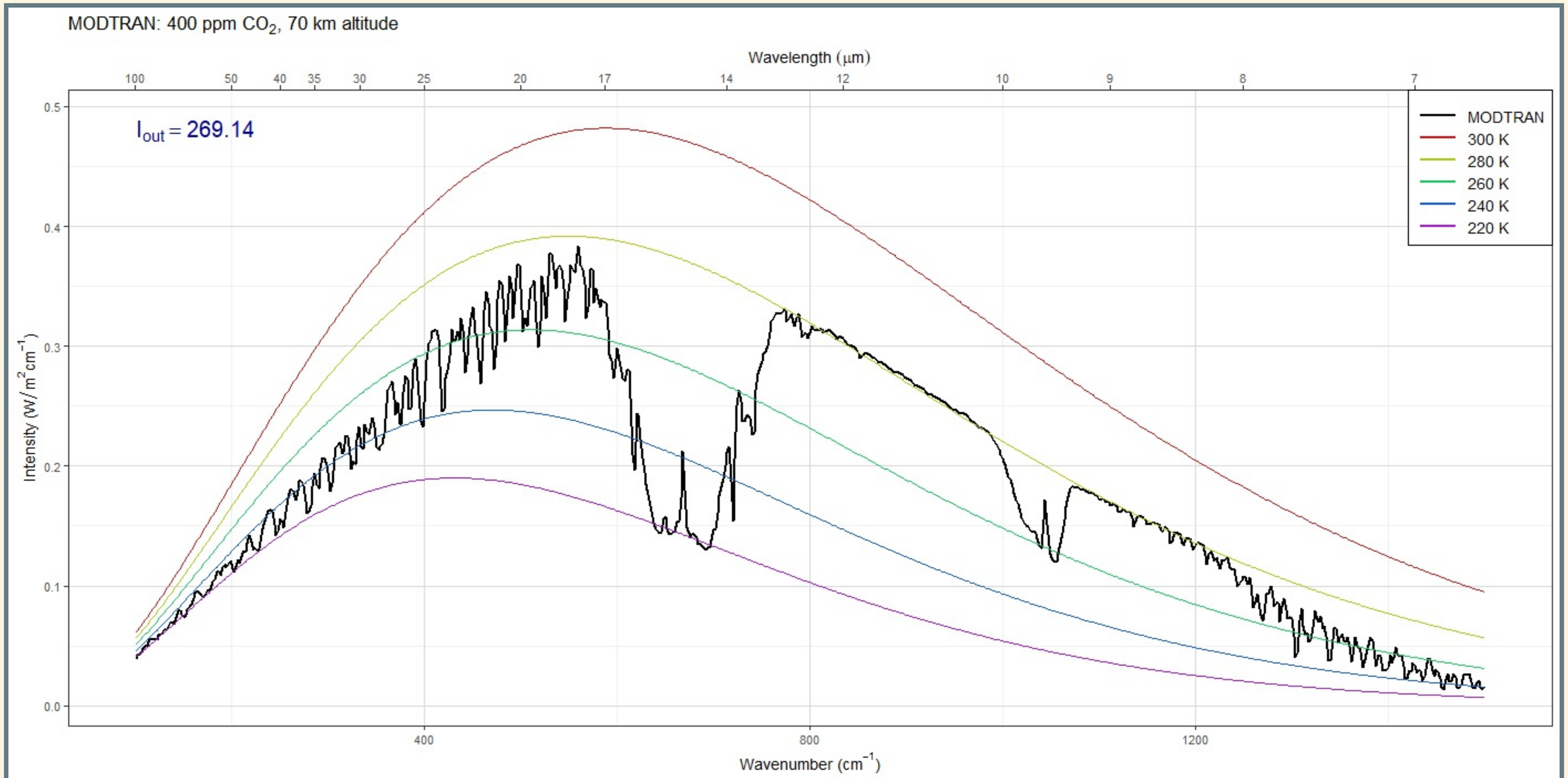
More Realistic Greenhouse Effect

- With real greenhouse gases, ε varies with wavelength:



Question:

- What do you suppose causes this?

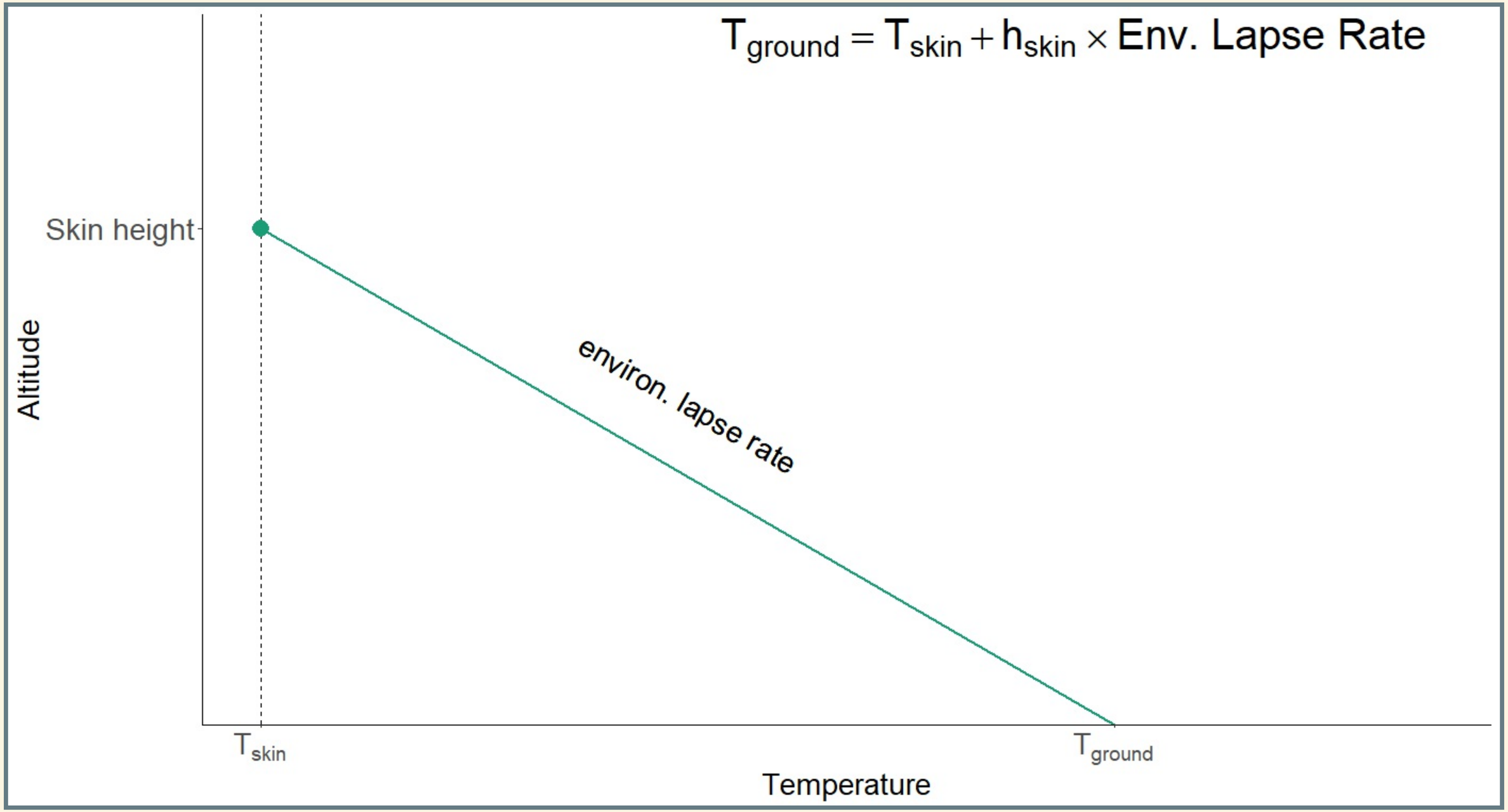


Vertical Structure of the Atmosphere

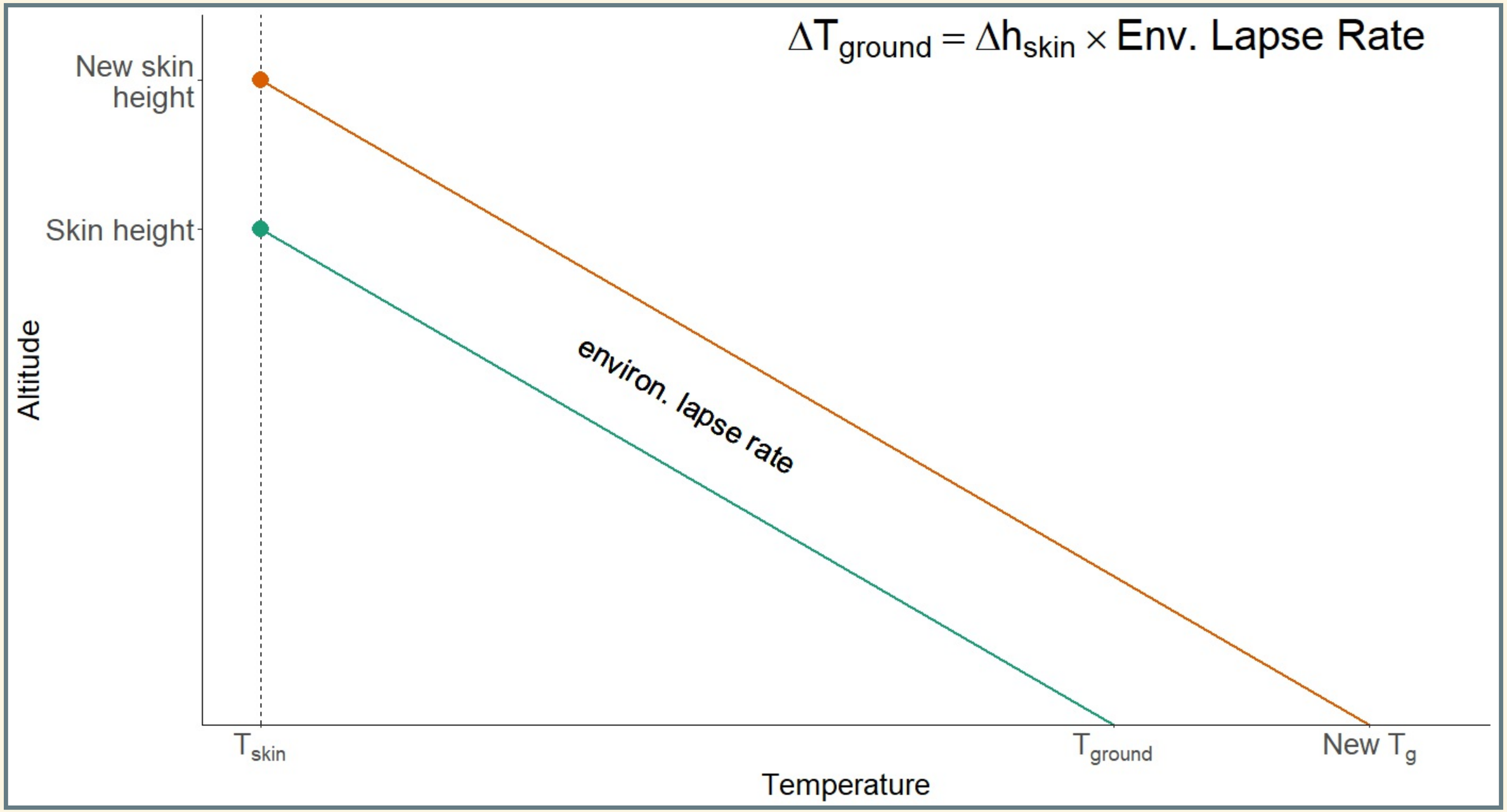
Vertical Structure of the Atmosphere

- Lapse Rate:
  - Environmental (ELR): Snapshot of actual atmosphere
  - Adiabatic (ALR): Changes as air moves up or down
  - Condition for stability: ELR < ALR
- Why does stability matter?
  - Greenhouse effect wants to make ELR very large
  - When ELR > ALR, convection happens
    - Convection moves heat around,
    - Convection reduces ELR until atmosphere becomes stable
  - Radiative-Convective Equilibrium:
    - Atmosphere is just at the edge of stability
    - Greenhouse effect wants to raise ELR
    - Convection wants to reduce ELR

Vertical Structure and Greenhouse Effect



Vertical Structure and Greenhouse Effect

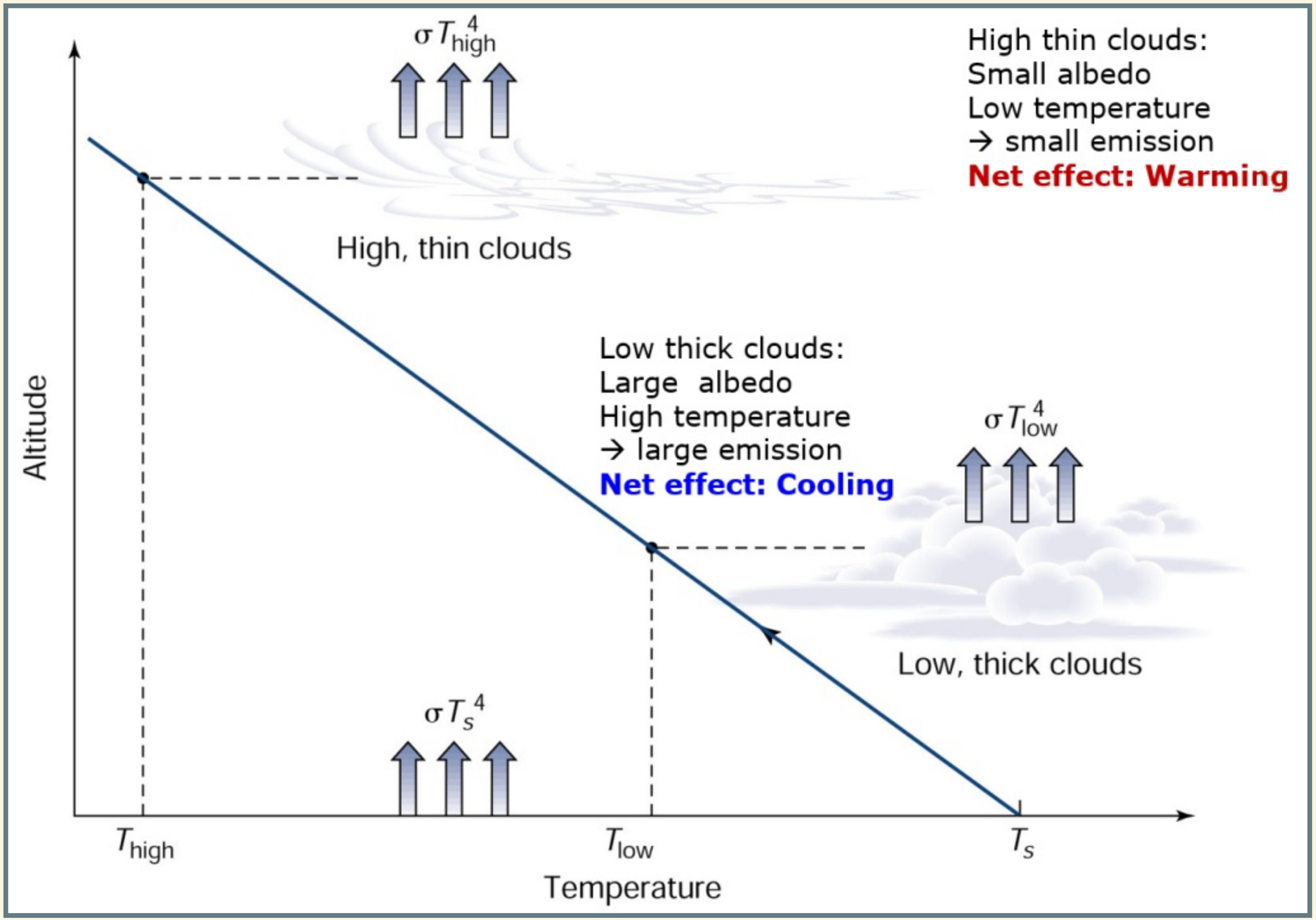


Feedbacks

Feedbacks

- Positive: amplify warming or cooling
- Negative: diminish warming or cooling
- Examples:
  - Ice-albedo
  - Water vapor
  - Clouds
  - Silicate Weathering

Cloud Feedback



Silicate Weathering

- Constant CO_2: Silicate weathering = volcanic outgassing
- Raise outgassing:
  - CO_2 rises
  - Temperature rises
  - More weathering
  - New equilibrium when weathering = new outgassing
    - Higher temperature

Silicate Weathering

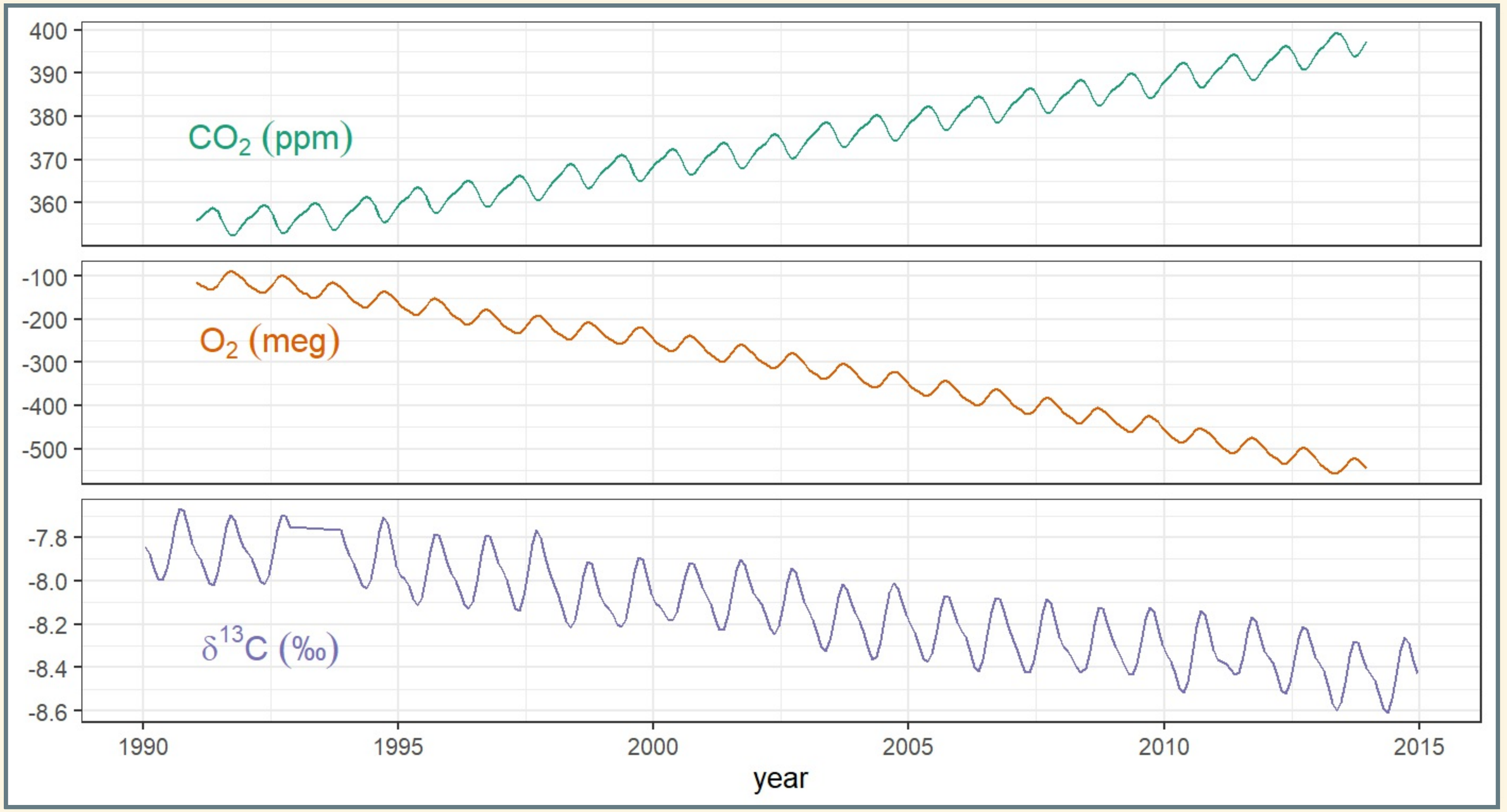
- Constant CO_2: Silicate weathering = volcanic outgassing
- One-time increase in CO_2
  - Temperature rises
  - More weathering
  - Weathering > outgassing
  - CO_2 drops
  - New equilibrium when CO_2 returns to original value:
    - *T* returns to original value
    - CO_2 back at original value
    - Weathering = outgassing

Geochemical Carbon Cycle

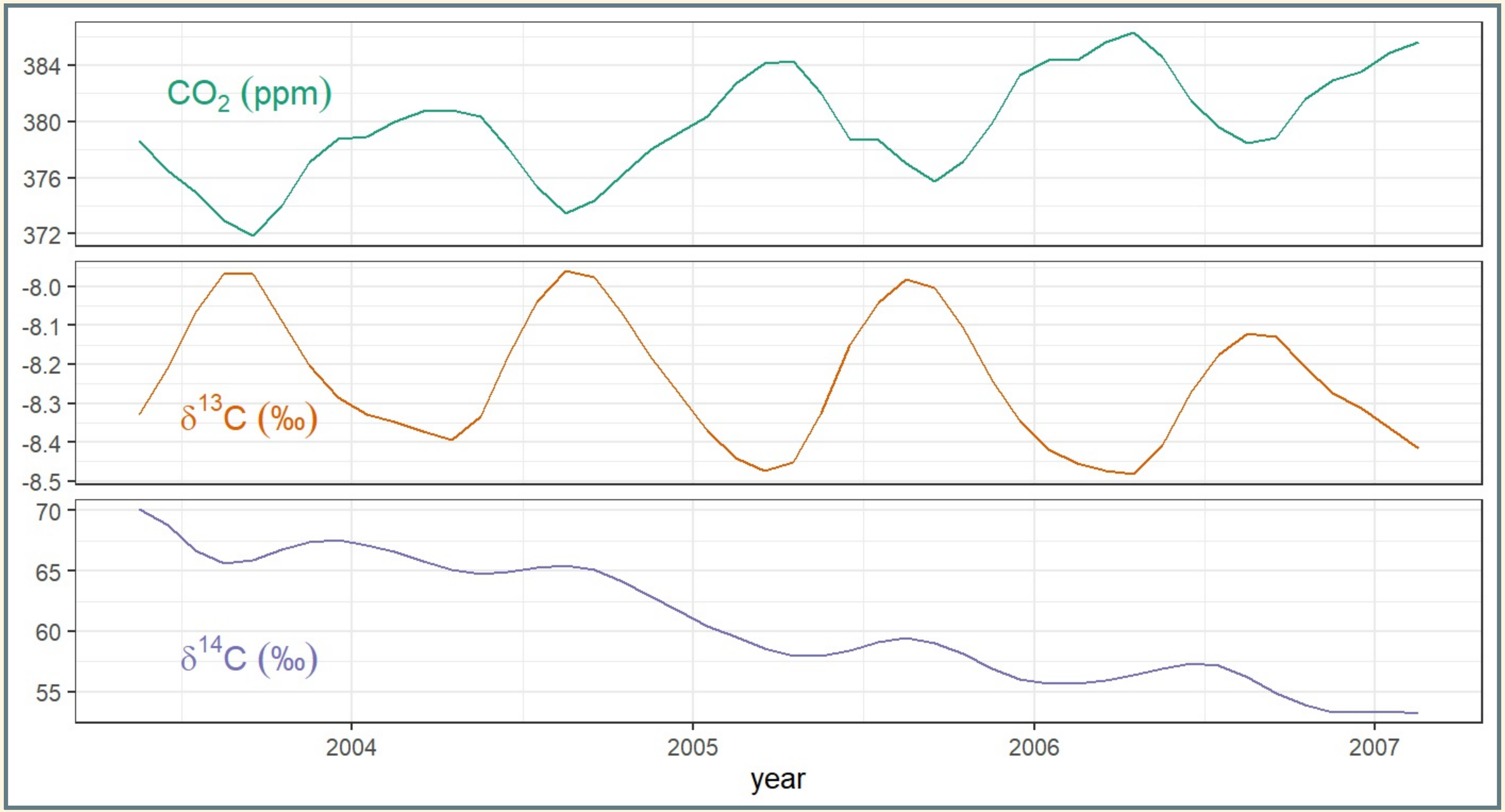
Carbon

- Oxidized vs. Reduced Carbon
- Isotopes:
  - ^{12}C, ^{13}C, ^{14}C
  - What do they tell us?
- Evidence that rising CO_2 comes from fossil fuels

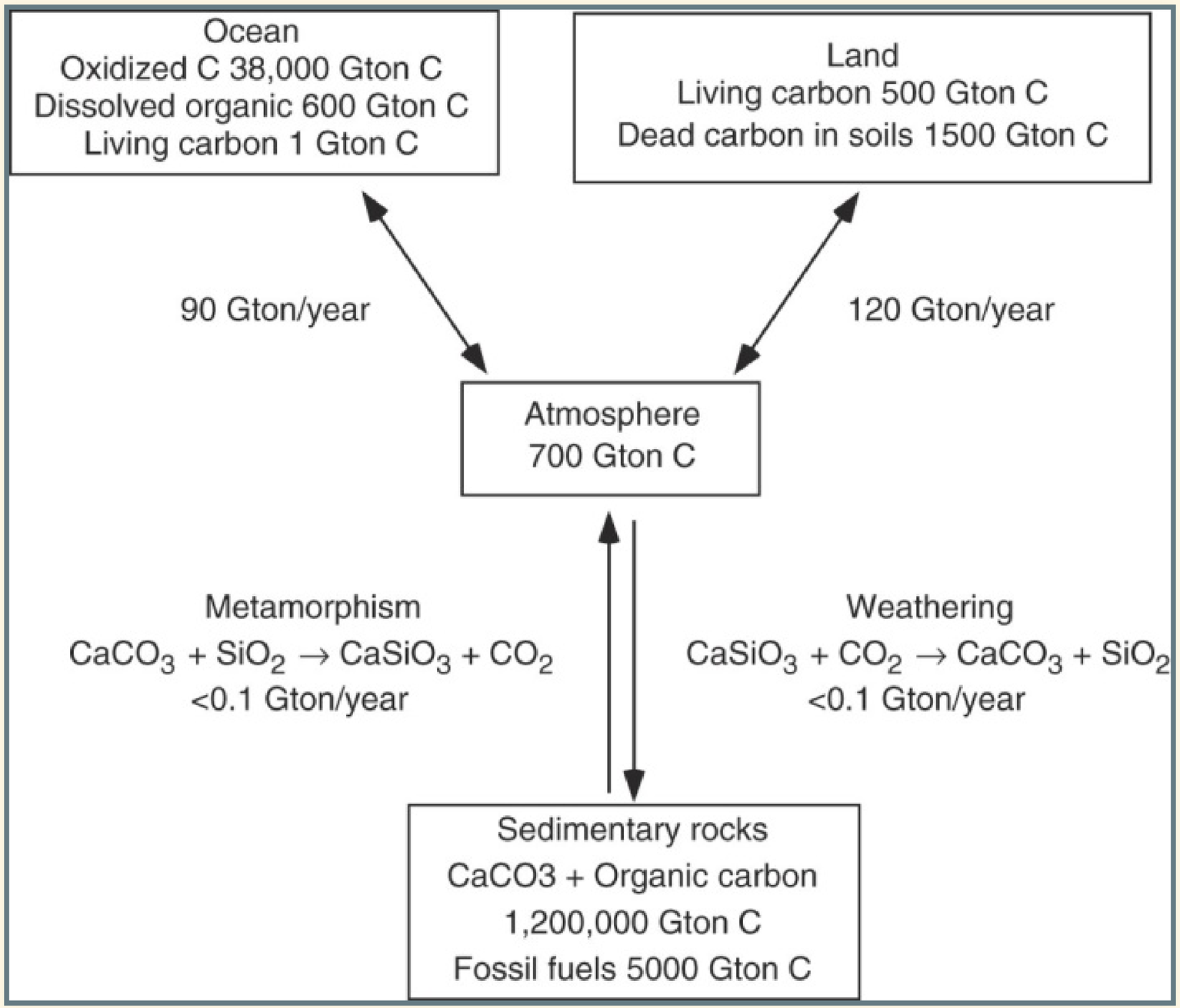
Source of CO_2: O_2 and ^{13}C



Source of CO_2: ^{13}C and ^{14}C



Where is Carbon



Carbonate/Bicarbonate Buffering

Buffering reaction

$$CO_2 + H_2O + CO_3^{2-} \rightleftharpoons 2HCO_3^-$$

Important points:

- Lots more carbonate than CO_2 in ocean
- Le Chatlier's principle
- Absorb lots more CO_2 because of buffering, carbonate
- Ocean acidification as carbonate depleted

Weathering Reactions

Silicate Weathering Reactions

- Silicate Weathering (Urey Reaction)

$$CaSiO_3 + CO_2 \leftrightharpoons CaCO_3 + SiO_2$$

  - Intermediate (in water):

$$CaSiO_3 + H_2CO_3 \leftrightharpoons Ca^{2+} + SiO_3^{2-} + 2H^+ + CO_3^{2-}$$

  - Silicate rocks dissolve into ions in water
  - Wash into ocean
  - In ocean, living organisms convert ions to $CaCO_3$ and SiO_2.
  - Net result: Convert CO_2 from atmosphere into rocks at bottom of ocean.

Carbonate Weathering Reactions

- Carbonate Weathering

$$CaCO_3 + CO_2 \leftrightharpoons CaCO_3 + CO_2$$

  - Intermediate (in water):

$$CaCO_3 + H_2CO_3 \leftrightharpoons Ca^{2+} + 2H^+ + 2CO_3^{2-}$$

  - Carbonate rocks dissolve into ions in water
  - Add carbonate ions to oceans
  - Net result: No permanent removal of CO_2 from atmosphere, but long-term storage in oceans.

Climates of the Past

Climates of the Past {past-climates}

- Paleocene-Eocene Thermal Maximum (PETM) (~55 million years ago)
- Pleistocene Ice Ages (~2.8 million to 10,000 years ago)
- Holocene (last ~10,000 years)
  - Medieval Warm Period (~1000 years ago)
  - Post-industrial warming

Paleocene-Eocene Thermal Maximum

- What was it?
- What important evidence do we see for what caused it?
- What is its relevance to today?

Pleistocene Ice Ages

- What was it?
- What important evidence do we use to study it?
- What do we know about what caused it?
- What is its relevance to today?

Post-Industrial Warming

- What do we know about what caused it?
- What are some lines of evidence that human activity is responsible?

Medieval Warm Period

- What was it?
- What is its relevance to today?

Younger Dryas

- What was it?
- What is its relevance to today?