Review of the Greenhouse Effect

EES 3310/5310

Global Climate Change

Jonathan Gilligan

Class #7: Wednesday, Sept. 5 2018

Notes on Labs

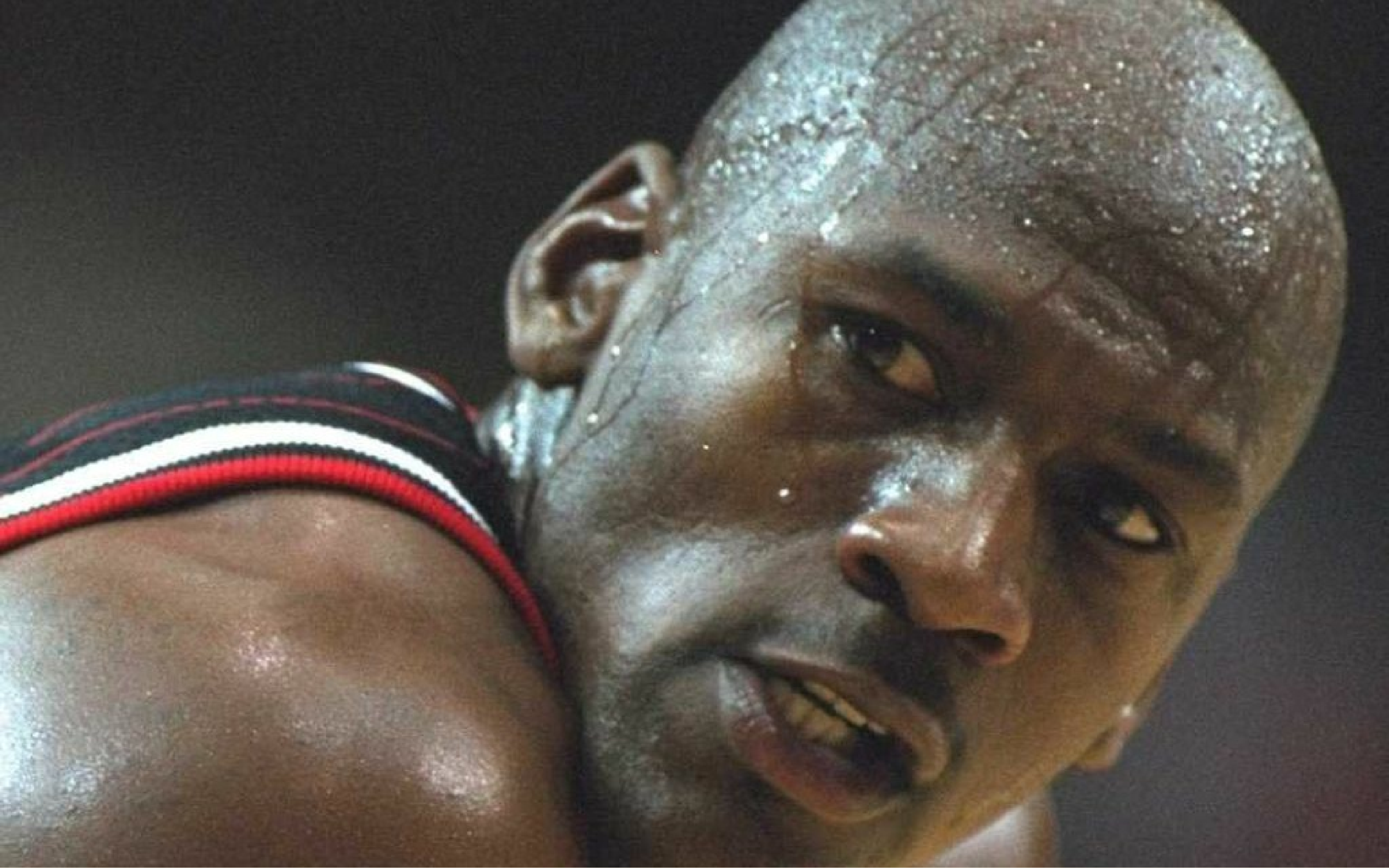
- Check frequently whether you can knit your document.
  - If you have trouble, ask for help
    - Office hours or Email both me and Kelsea
    - Remember to put “EES 3310” or “EES 5310” in the subject line
- Remember that either PDF or Word documents are acceptable for turning in your work, so if you have trouble knitting to PDF, knit to a Word document.
  - It should only take a one-time set-up to be able to knit smoothly to PDF. Kelsea and I are happy to help you set up your computer to knit to PDF.

Vertical Structure of the Atmosphere

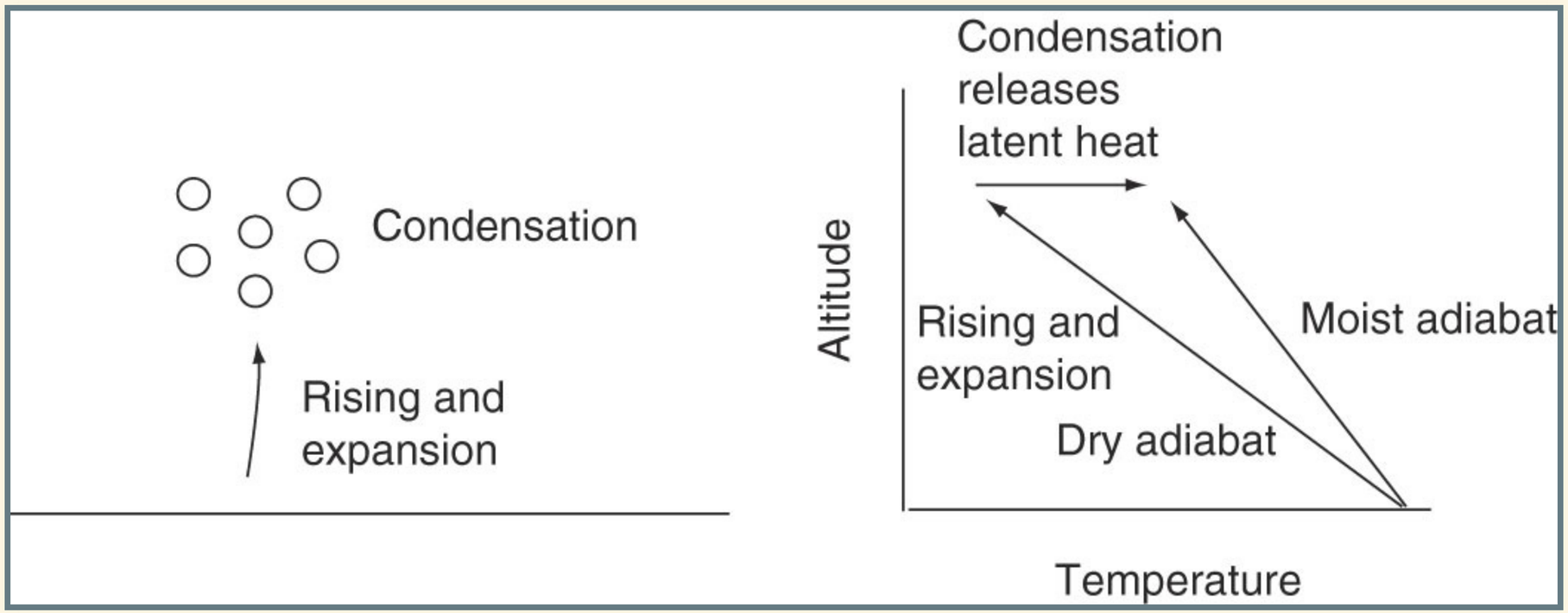
Terminology

- **Environmental Lapse**
  - Measured temperature of actual atmosphere at a single time
  - Compares one bit of air at one height with another bit at another height.
  - Environmental lapse is different from one time or place to another.
- **Adiabatic Lapse**
  - Change in a single parcel of air as it moves up or down

Moist Convection



Moist Convection



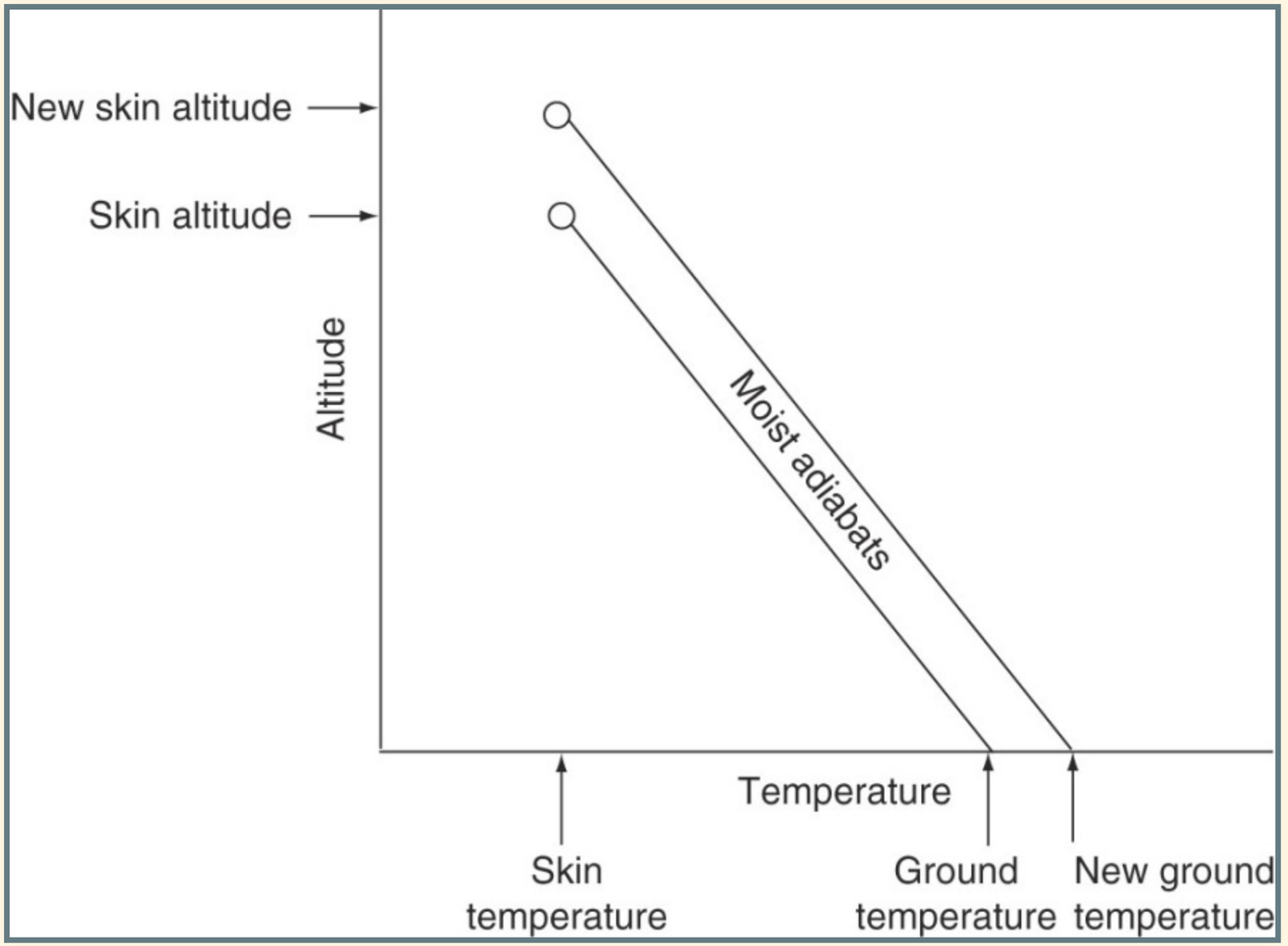
- Latent heat warms air
- Reduces adiabatic cooling
- Moist adiabatic lapse < Dry adiabatic lapse
- Smaller lapse = less stable
- **Humid air is less stable than dry air**

Perspective

- **Stable:**
  - Environmental lapse $\leq$ adiabatic lapse
- **Unstable:**
  - Environmental lapse > adiabatic lapse
- **Adiabatic lapse:**
  - Dry: 10 K/km
  - Moist: 4-8 K/km (depends on humidity)
- **Pure radiative equilibrium:**
  - Would produce lapse of **16 K/km**: unstable
- **Radiative-Convective equilibrium:**
  - Convection modifies environmental lapse
  - Normal environmental lapse is roughly **6 K/km** (typical *moist adiabatic lapse rate*)

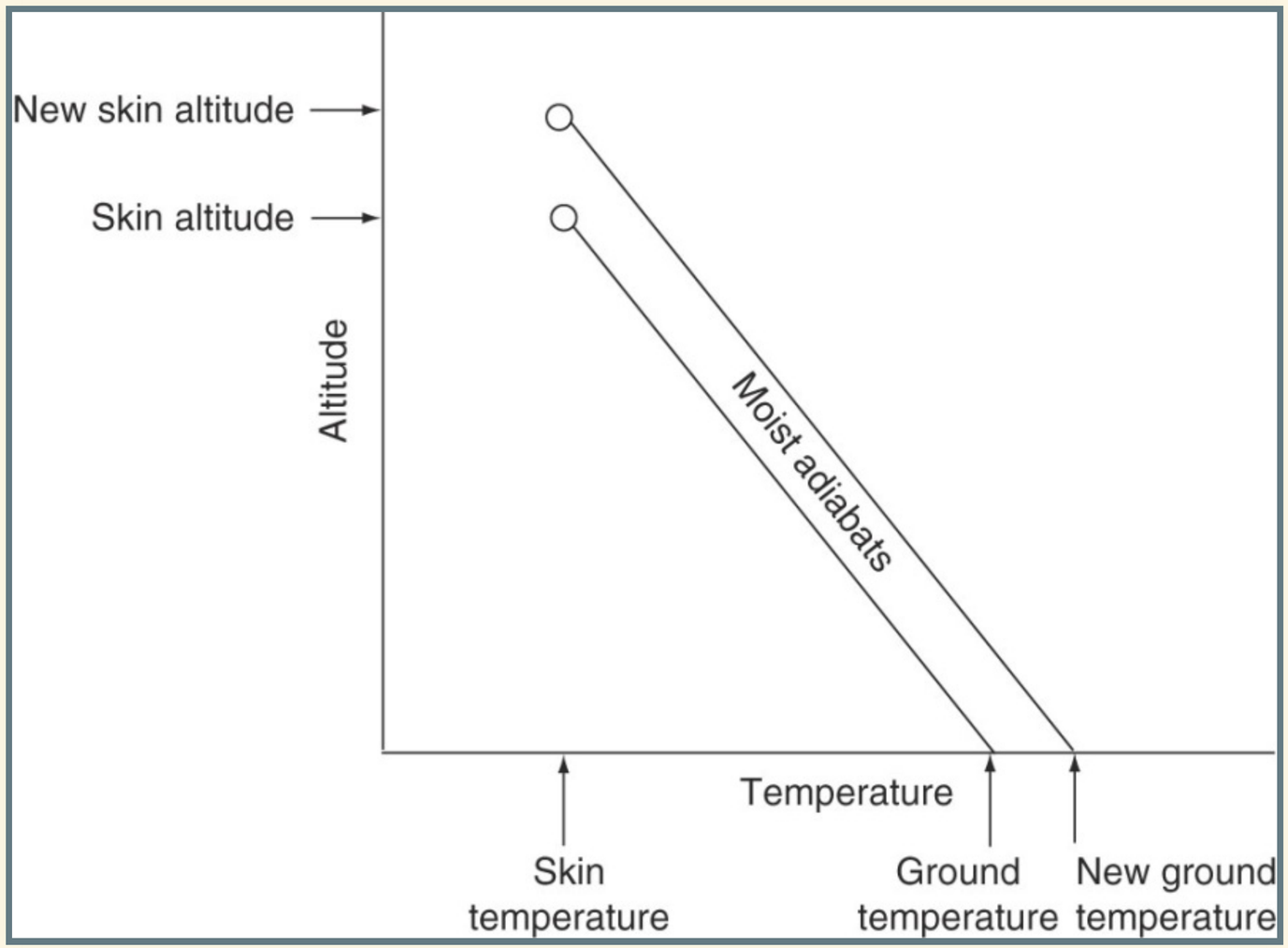
Greenhouse effect

Greenhouse effect



Greenhouse effect

1. $T_{\text{skin}} = 254\ \text{K}$
2. $T_{\text{ground}} = T_{\text{skin}} + \text{lapse rate} \times h_{\text{skin}}$
3. Increase greenhouse gases
4. Skin height rises by Δh_{skin}
5. T_{ground} rises by $\text{lapse rate} \times \Delta h_{\text{skin}}$



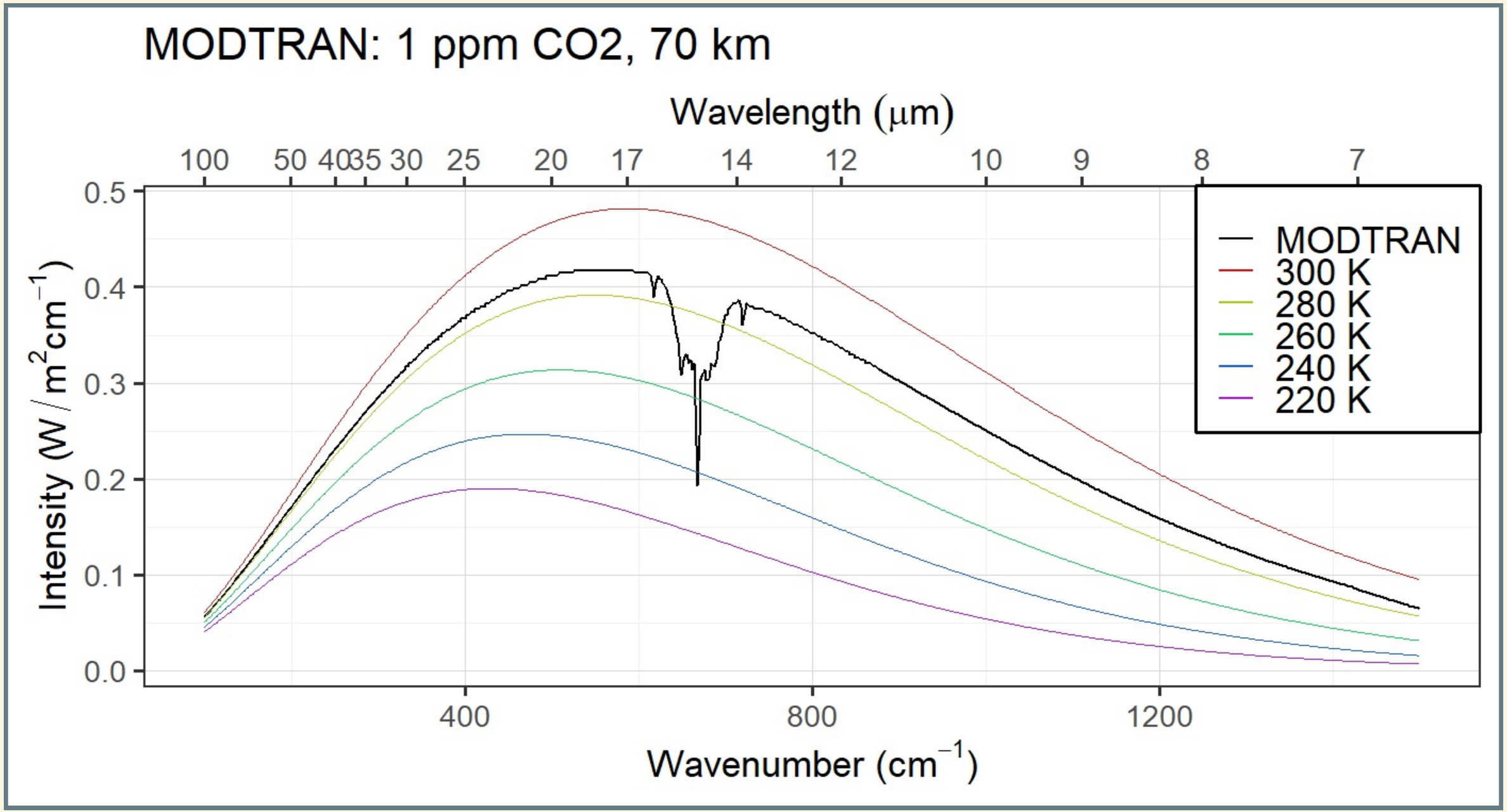
Vertical Structure and Saturation

Set up MODTRAN:

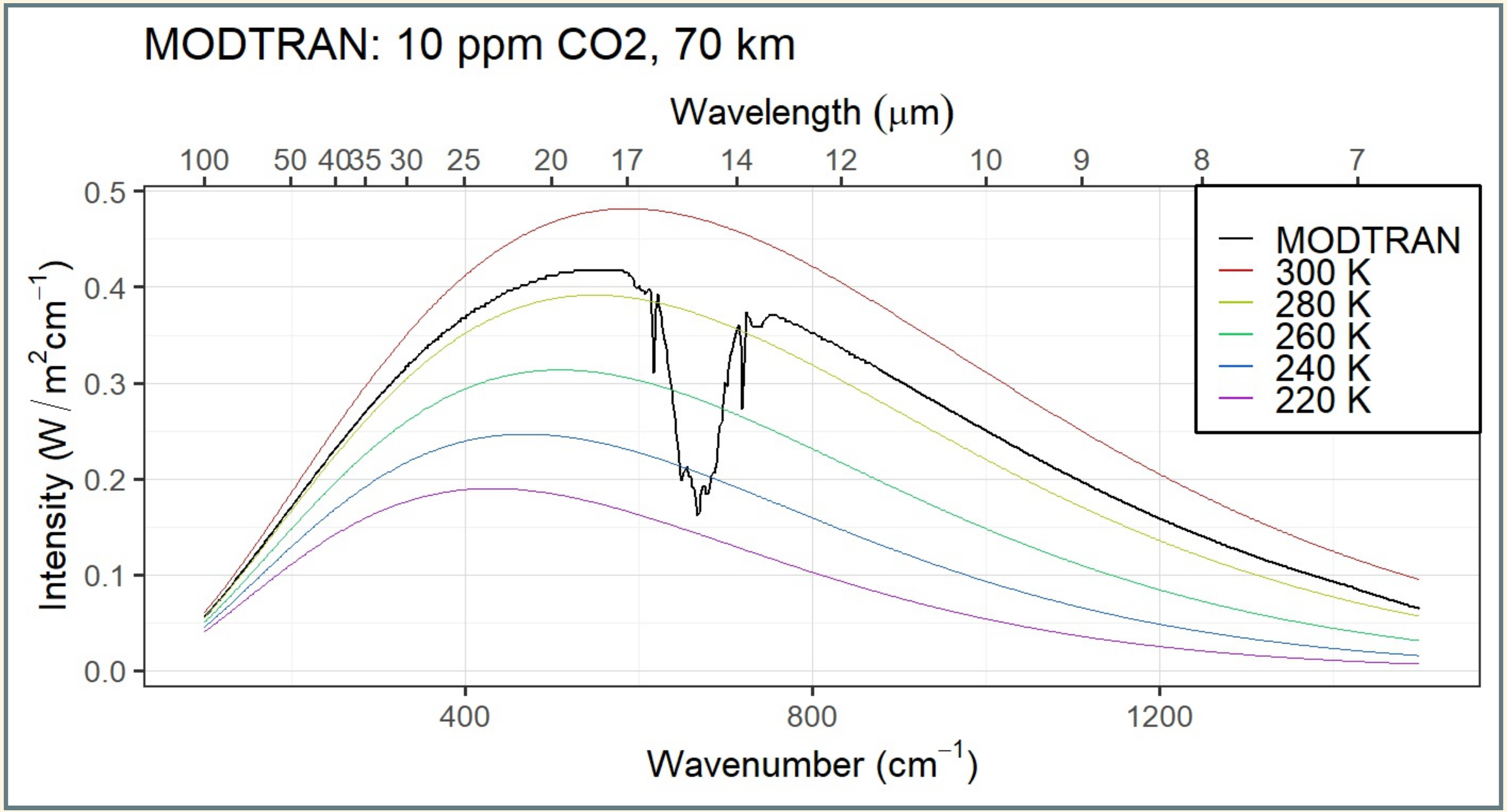
Go to MODTRAN (http://climatemodels.uchicago.edu/modtran/)

- Set altitude to **70 km** and location to “1976 Standard U.S. Atmosphere”.
- Set CO_2 to 1 ppm, all other gases to zero.
- Now increase by factors of 10 (10, 100, 1000, …)

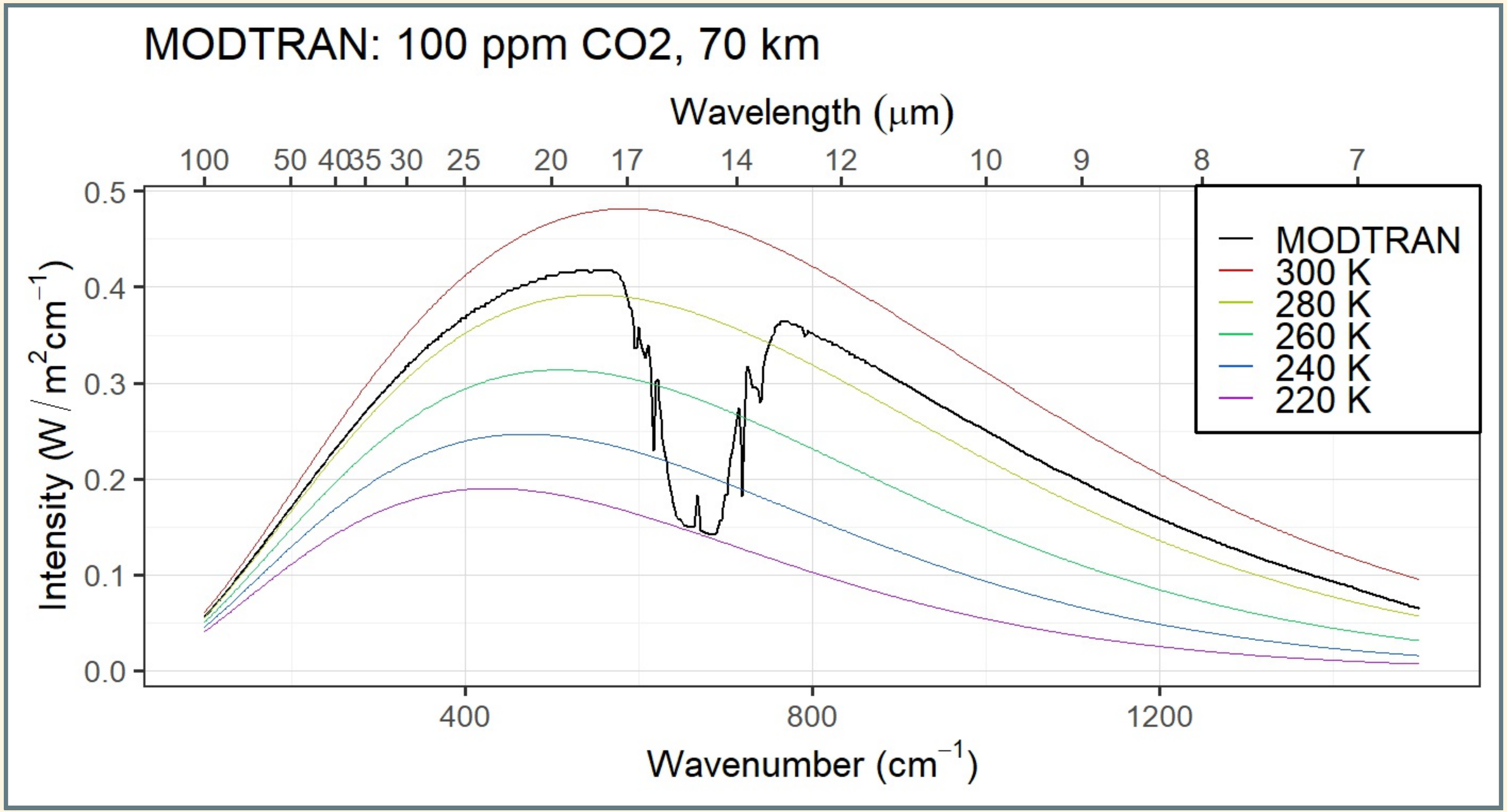
1 ppm CO_2


MODTRAN: 1 ppm CO2, 70 km
Wavelength (μm)
100
50
40
35
30
25
20
17
14
12
10
9
8
7
0.5
0.4
0.3
0.2
0.1
0.0
Intensity (W / m2cm−1)
MODTRAN
300 K
280 K
260 K
240 K
220 K
400
800
1200
Wavenumber (cm−1)

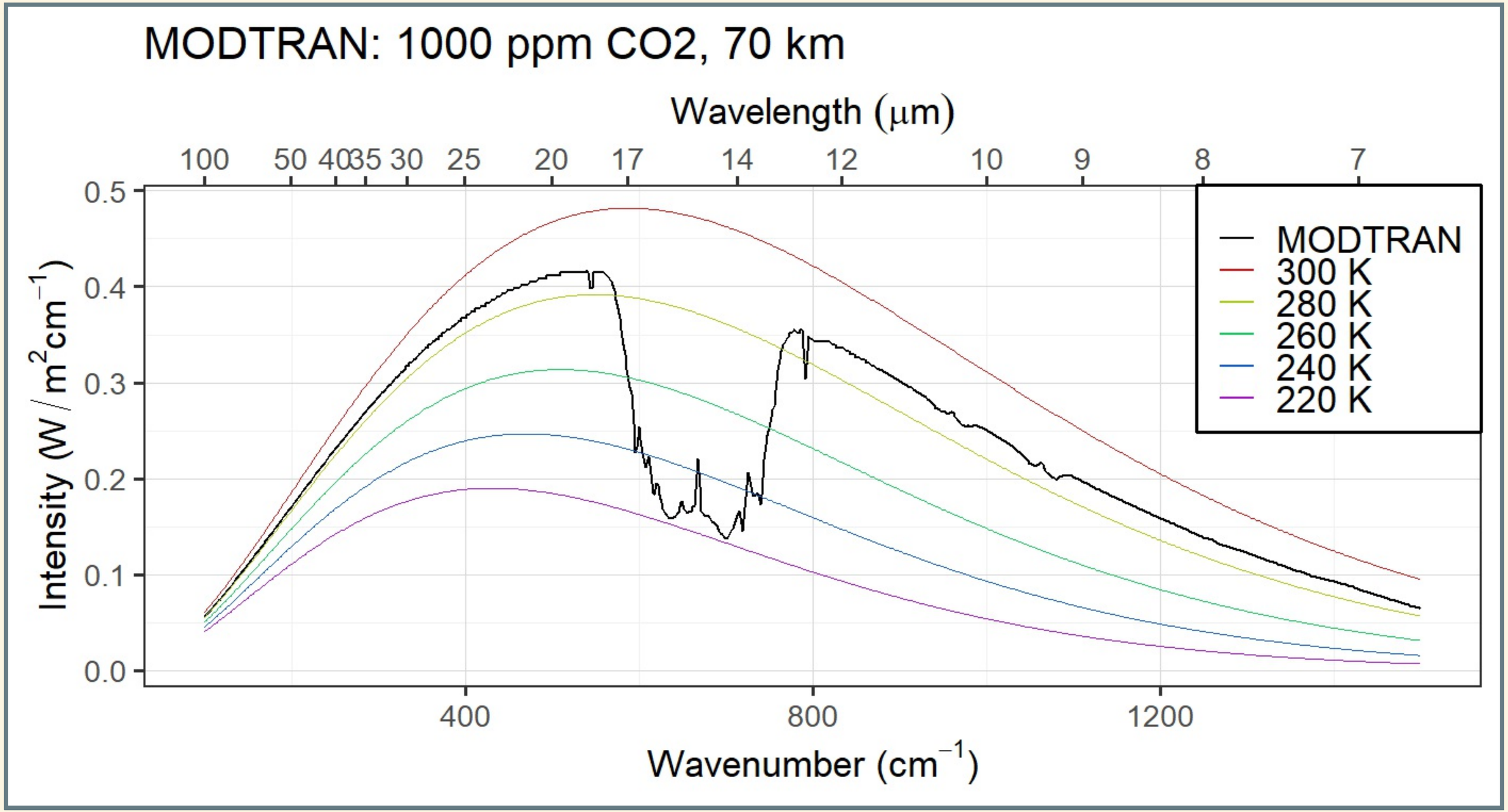
10 ppm CO_2


MODTRAN: 10 ppm CO2, 70 km
Wavelength (μm)
100
50
40
35
30
25
20
17
14
12
10
9
8
7
0.5
0.4
0.3
0.2
0.1
0.0
Intensity (W / m2cm−1)
MODTRAN
300 K
280 K
260 K
240 K
220 K
400
800
1200
Wavenumber (cm−1)

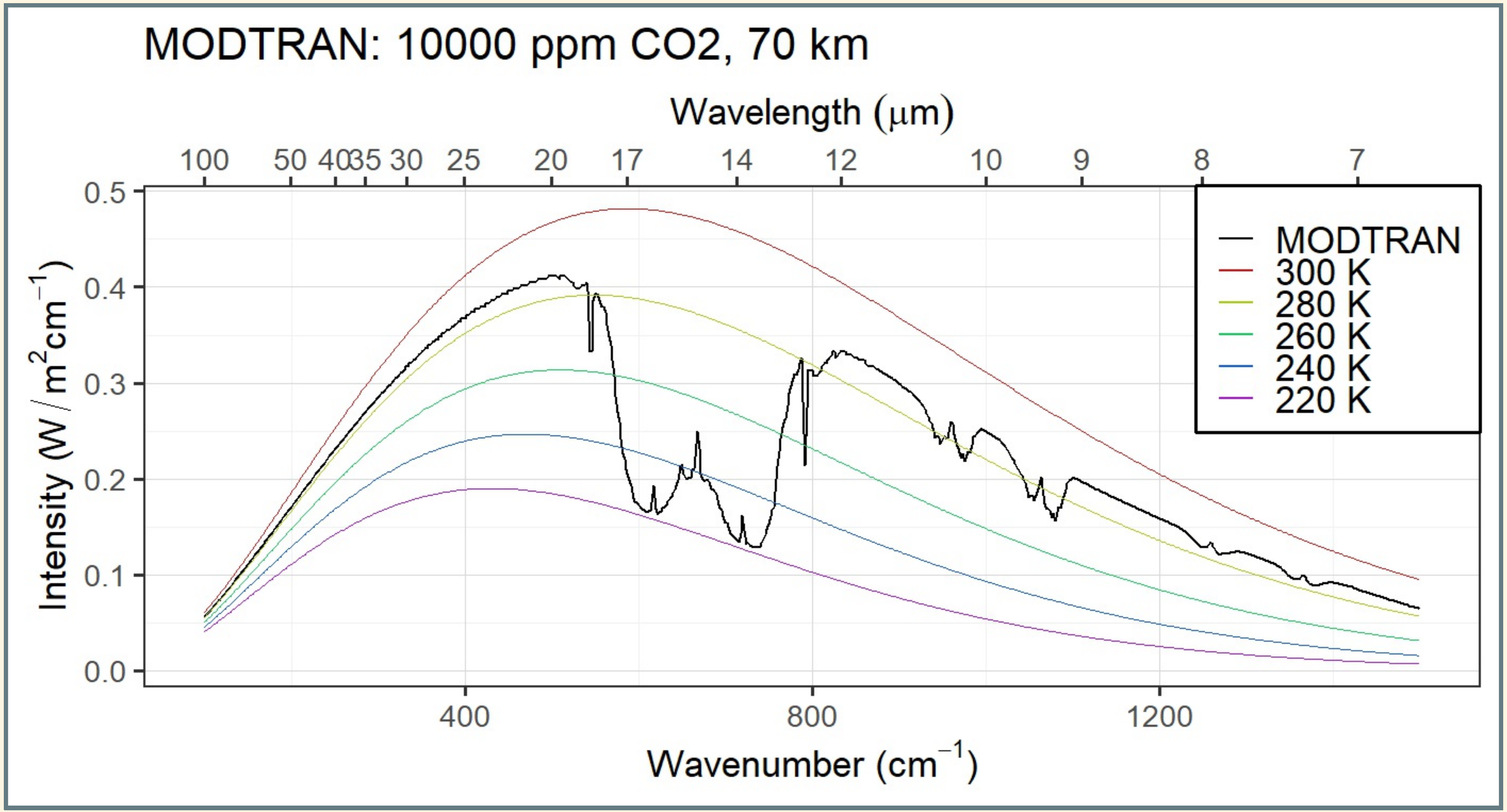
100 ppm CO_2


MODTRAN: 100 ppm CO2, 70 km
Wavelength (μm)
100
50
40
35
30
25
20
17
14
12
10
9
8
7
0.5
0.4
0.3
0.2
0.1
0.0
Intensity (W / m2cm-1)
MODTRAN
300 K
280 K
260 K
240 K
220 K
400
800
1200
Wavenumber (cm-1)

1000 ppm CO_2


MODTRAN: 1000 ppm CO2, 70 km
Wavelength (μm)
100
50
40
35
30
25
20
17
14
12
10
9
8
7
0.5
0.4
0.3
0.2
0.1
0.0
Intensity (W / m² cm⁻¹)
MODTRAN
300 K
280 K
260 K
240 K
220 K
400
800
1200
Wavenumber (cm⁻¹)

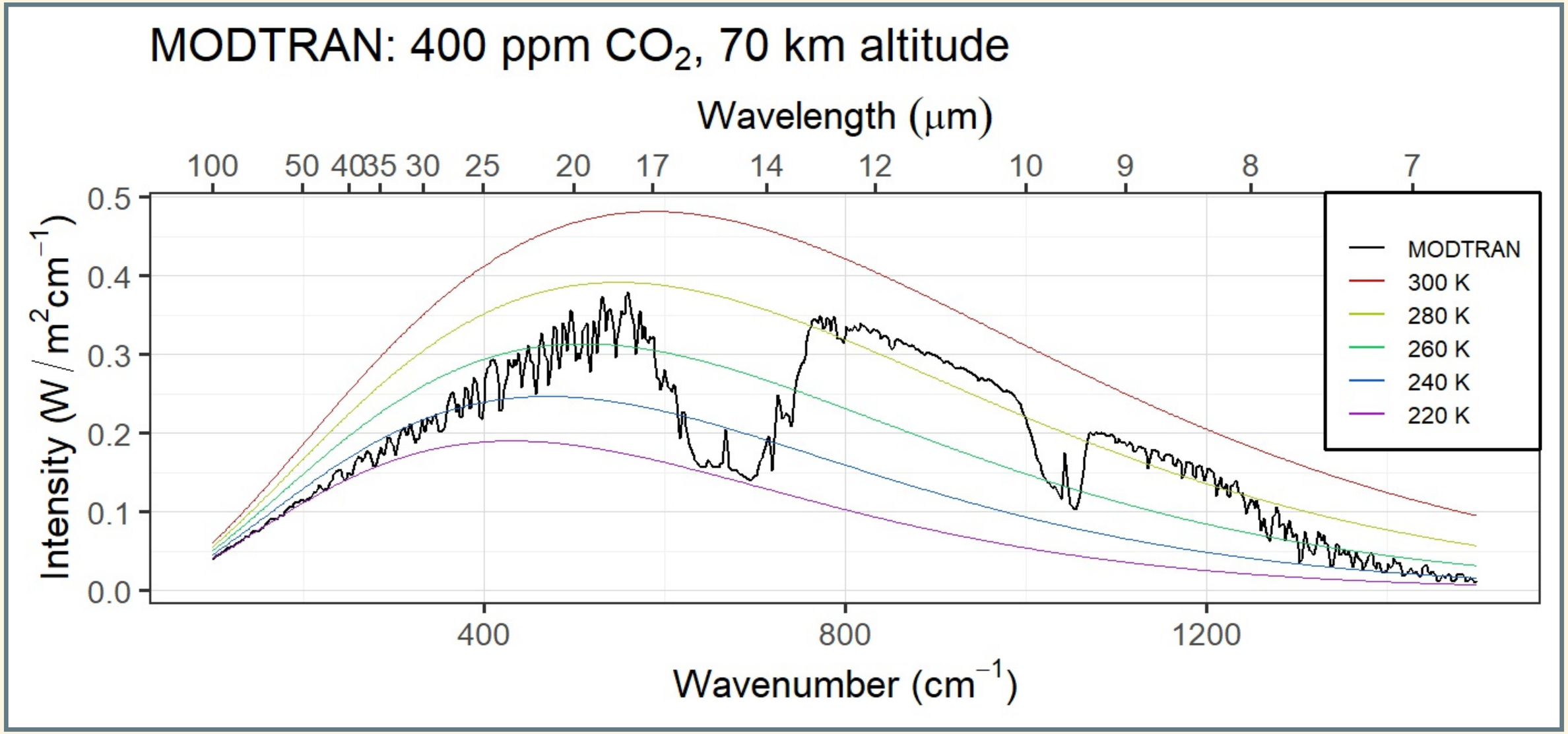
10,000 ppm CO_2



Question

Why do we see the spike in the middle of the CO_2 absorption feature?

Question

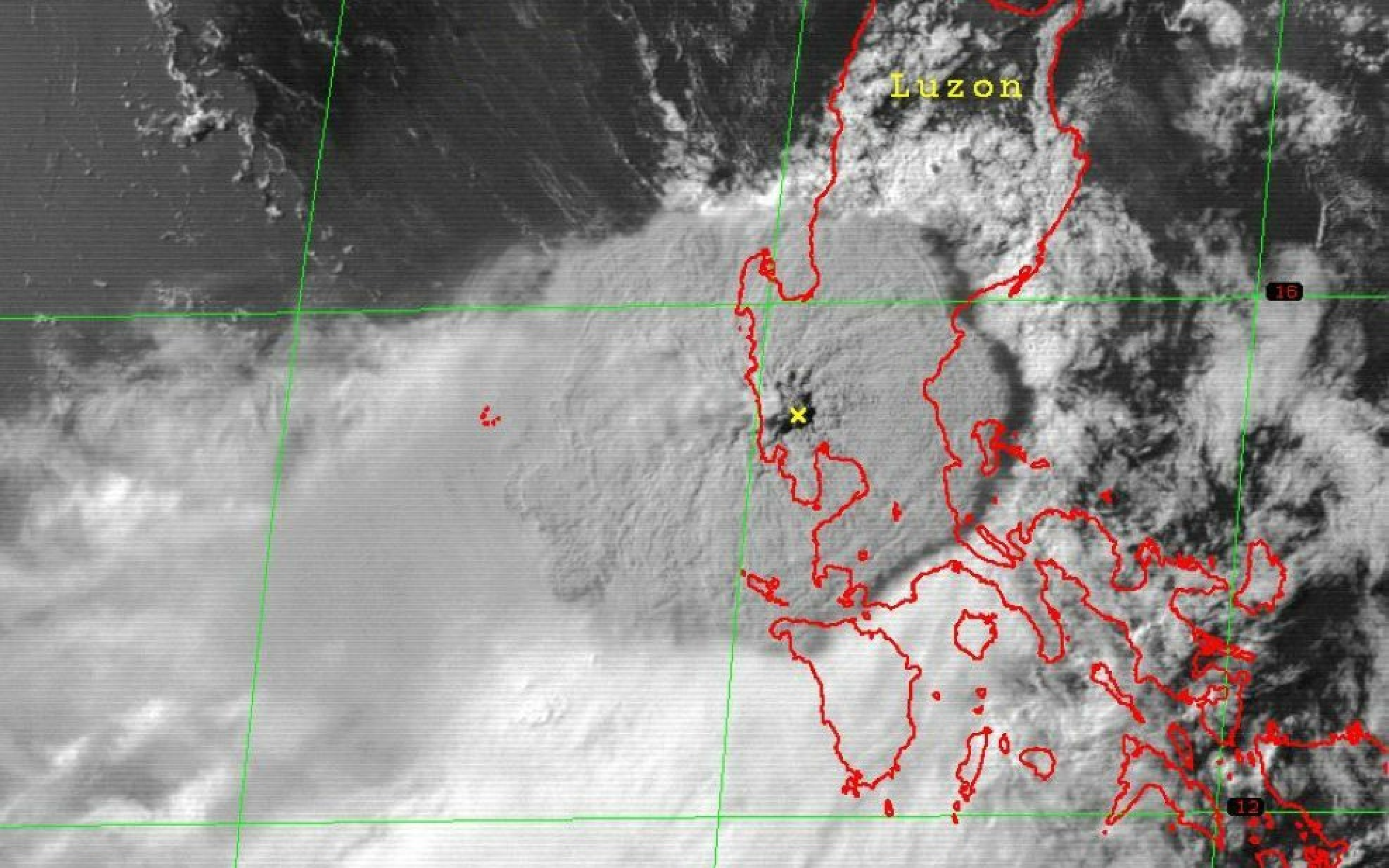


- Water vapor absorption is completely saturated.
  - Why does water vapor emit at warmer temperatures than CO_2?

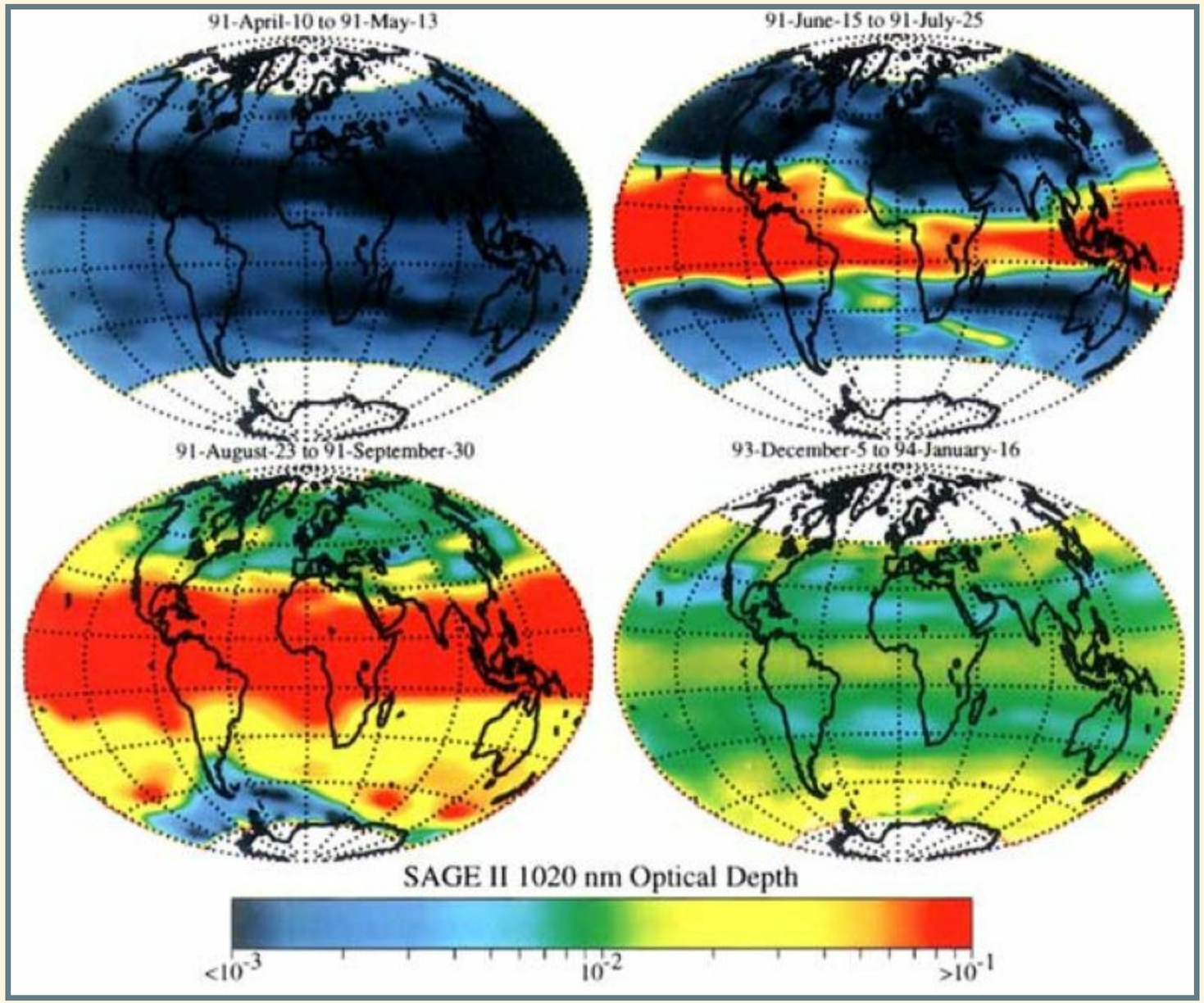
Review Perspective

Review Perspective

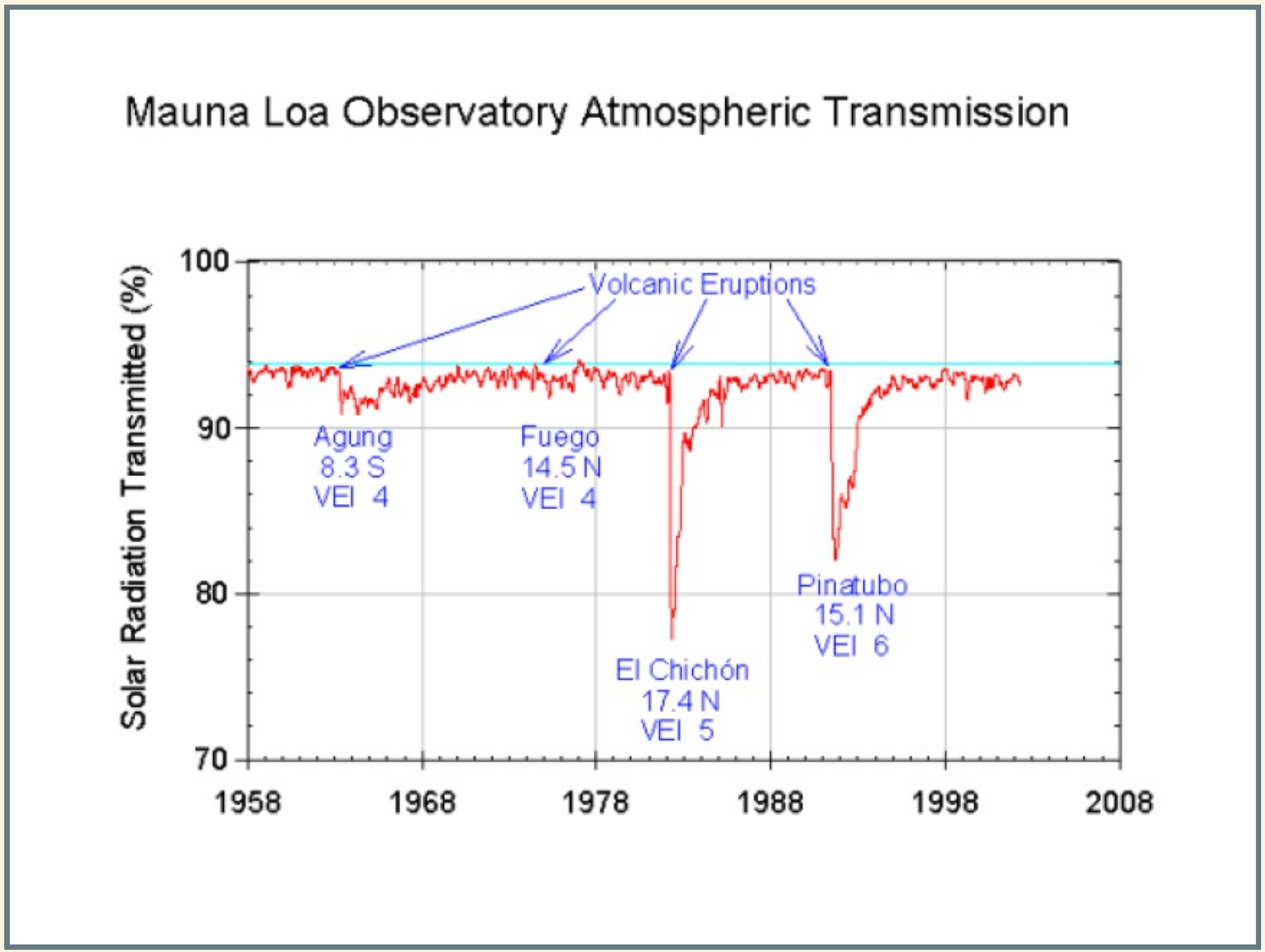
1. **Start with bare-rock temperature**
   - This becomes skin temperature
2. **Add simple atmosphere:**
   - Completely absorbs longwave radiation
   - Top of atmosphere: skin temperature (same as bare-rock)
   - Atmosphere insulates surface $\Rightarrow$ surface heats up
   - More layers $\Rightarrow$ bigger greenhouse effect
3. **Realistic longwave absorption:**
   - Atmosphere is not a black body
4. **Radiative-Convective equilibrium:**
   - Pure radiative equilibrium would have *huge* lapse
   - Big lapse is unstable $\Rightarrow$ convection
     - Convection mixes hot & cold air $\Rightarrow$ modifies environmental lapse
     - Reduces greenhouse effect


Luzon
16
12

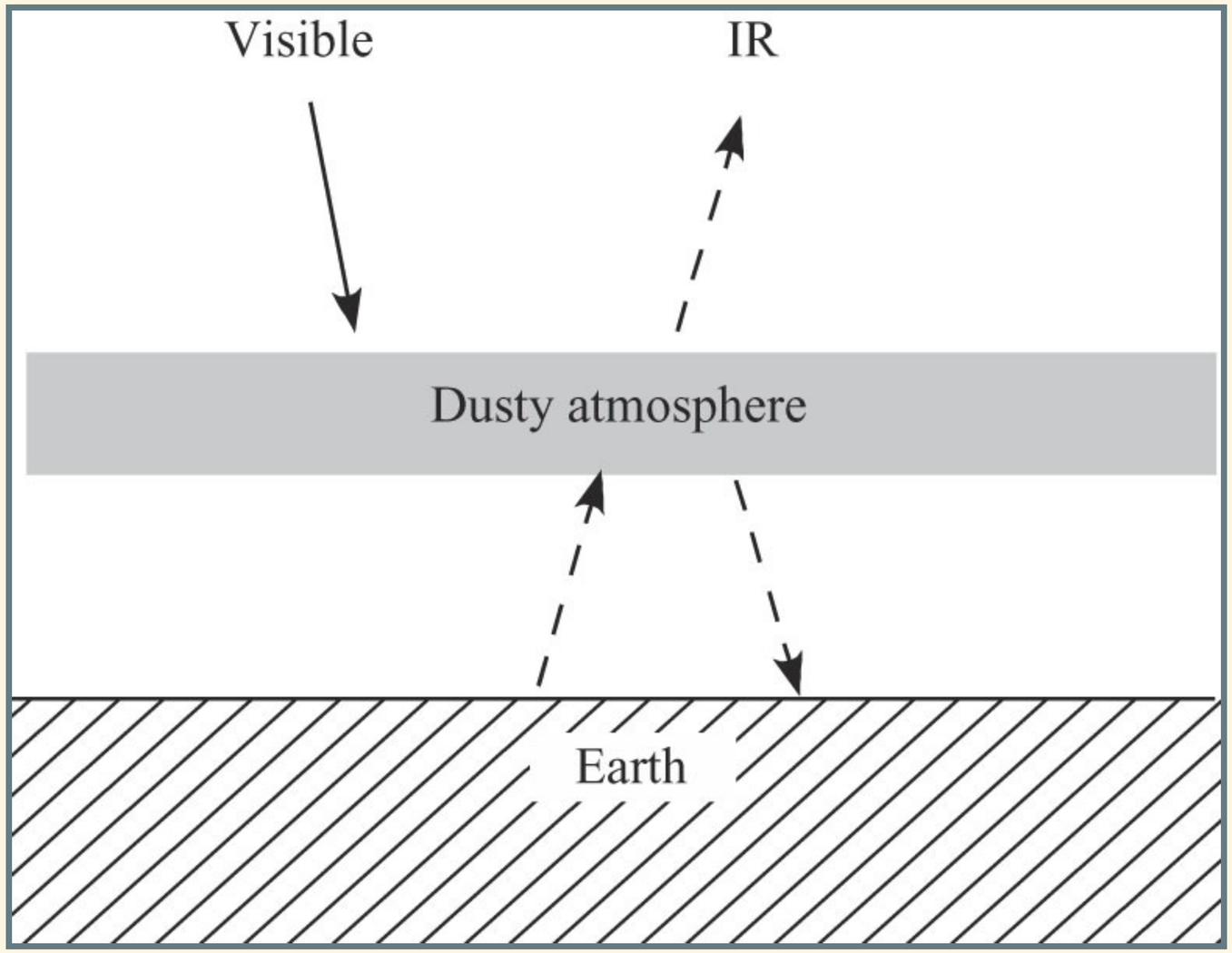
Around the planet



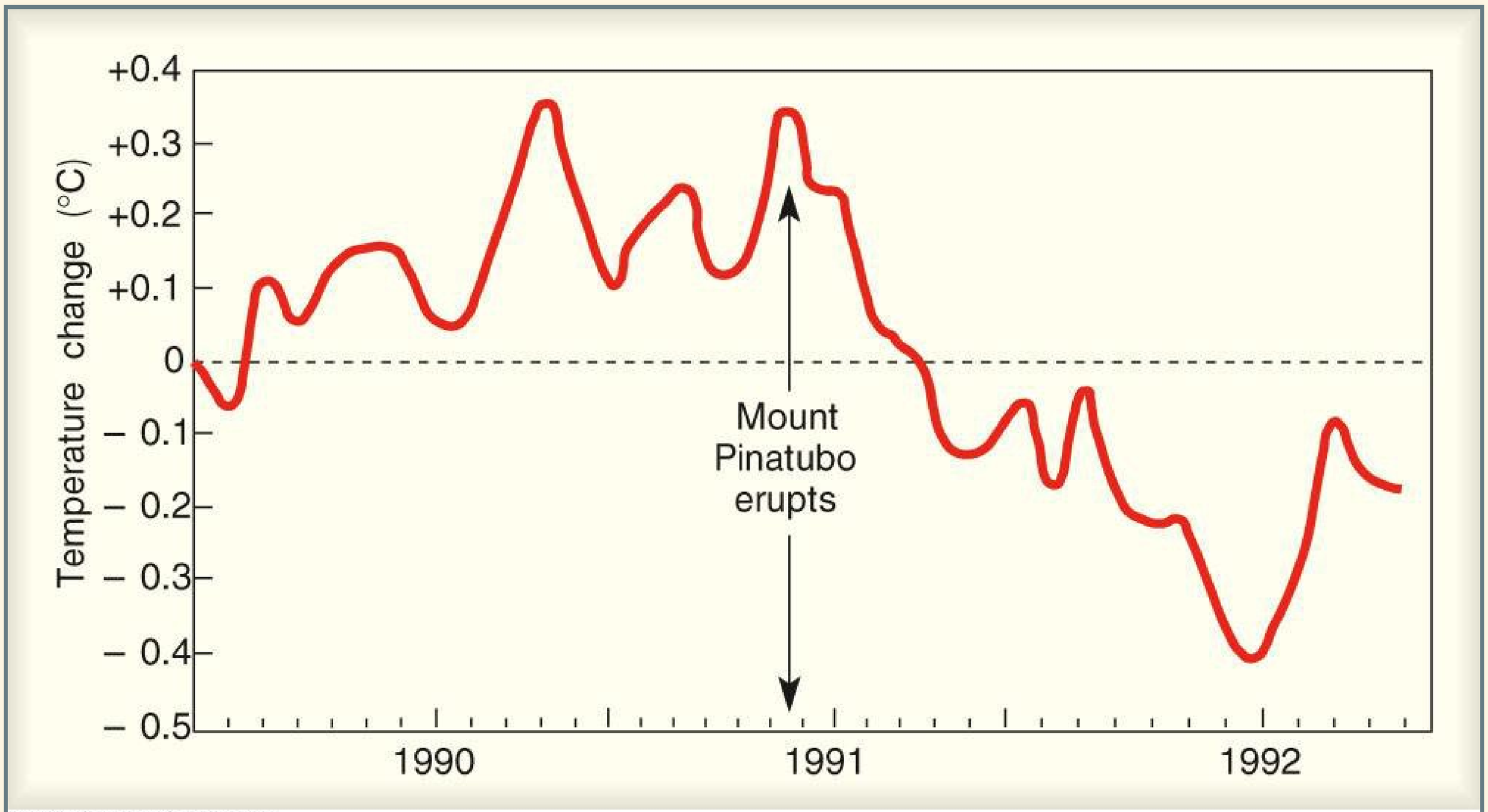
Cloud blocks sunlight



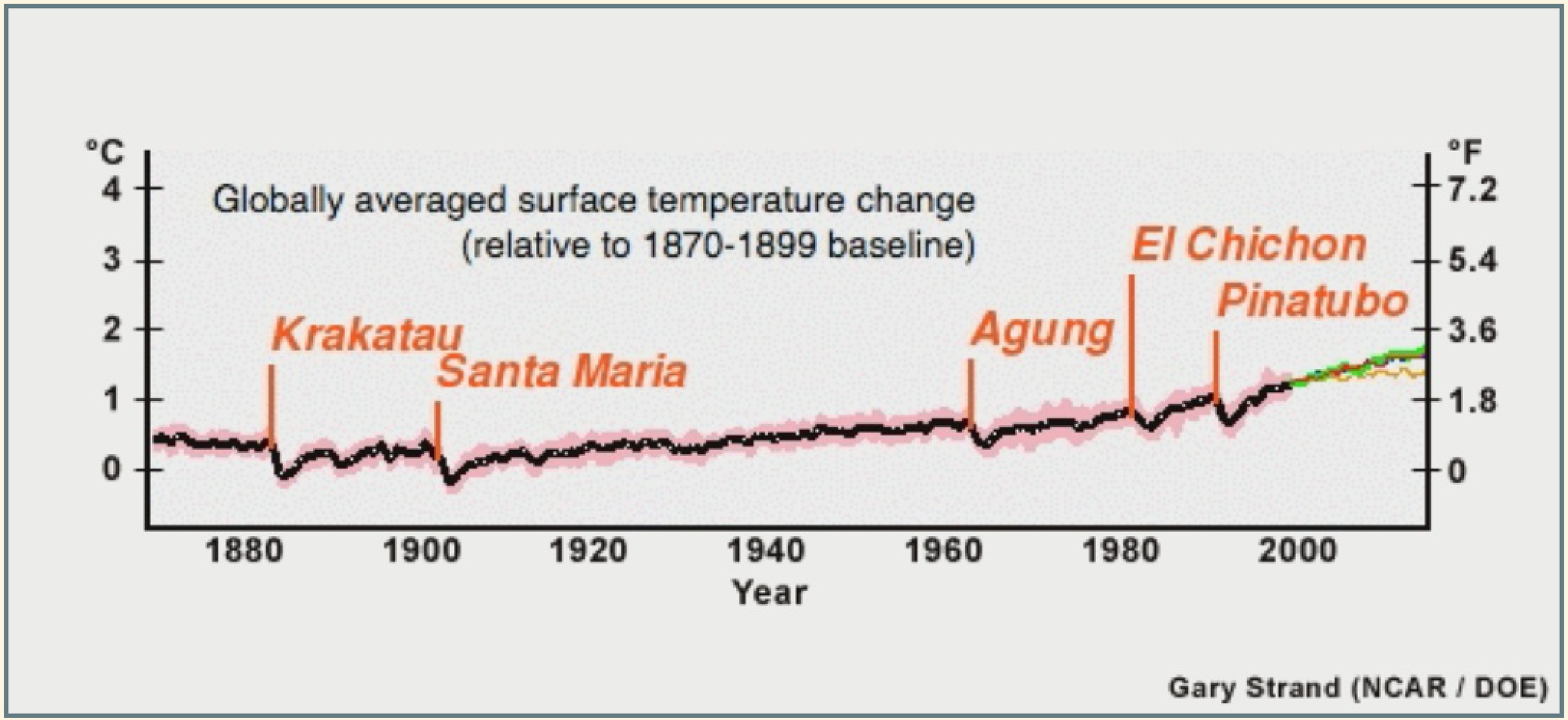
Exercise 3-3



Temperature drops



Volcanoes and Temperature



1771 REUBEN WHITTEN 1847
SON OF A REVOLUTIONARY SOLDIER
A PIONEER OF THIS TOWN. COLD SEASON OF
816 RAISED 40 BUSHILS OF WHEAT ON THIS
LAND WHITCH KEPT HIS FAMILY AND
NEIGHBOURS FROM STARVEATION.
HIS WIFE SALLEY SAWYER
1807 CALVIN ROBERTS 1849
1800 HIS WIFE MARY M. WHITTEN 1886