ATMOS 5140
Lecture 10 – Chapter 8

- Atmospheric Emission
  - Schwarzschild's Equation
  - Applications

Credit to Dr. Simon Carn at Michigan Tech for several slides used in this lecture.

Schwarzschild's Equation

- So the net change in radiant intensity is:

$$dI = dI_{abs} + dI_{emit} = \beta_a (B - I)\, ds$$

$$\frac{dI}{ds} = \beta_a (B - I)$$

NB. All quantities represent a single wavelength!

- Schwarzschild's equation is the most fundamental description of radiative transfer in a *nonscattering* medium (applies to remote sensing in the thermal IR band)
- Radiance along a particular direction either increases or decreases with distance, depending on whether $I(s)$ *is less than or greater than* $B[T(s)]$, *where* $T(s)$ *is the temperature at point* s.

Radiative transfer equation for a nonscattering atmosphere

- Some manipulation of Schwarzschild's Equation yields:

$$I(0) = I(\tau')e^{-\tau'} + \int_0^{\tau'} B e^{-\tau} d\tau$$

Basis for understanding of radiative transfer in a nonscattering atmosphere

1. I(0) is the radiance observed by a sensor at $\tau = 0$

2. Radiance I at position $\tau = \tau'$ multiplied by the *transmittance* [$t(\tau') = e^{-\tau'}$ between the sensor and τ`].
For a down-looking satellite sensor, this could represent *emission from the Earth's surface attenuated by transmission along the line-of-sight*

3. Integrated thermal emission contributions $Bd\tau$ from each point along the line of sight between the sensor and τ`, also attenuated by the path transmittances between the sensor and $\tau$`.

Radiative transfer equation for a nonscattering atmosphere

Substitute in:

$t(\tau') = e^{-\tau}$

$$I(0) = I(\tau')\, t(\tau') + \int_{t(\tau')}^{1} B\, d\tau$$

Basis for understanding of radiative transfer in a nonscattering atmosphere

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Ground-based sensor looking up

• For a *sensor located at the surface (z = 0), viewing downward emitted radiation from the atmosphere*, the appropriate form of the radiative transfer equation is:

$$I^{\downarrow}(0) = I^{\downarrow}(\infty)t^{*} + \int_{0}^{\infty} B(z)W^{\downarrow}(z)dz$$

• where z = ∞ is the 'top-of-the-atmosphere' (TOA), t^* is the transmittance from the surface to the TOA, and $B(z)$ is the Planck function applied to the atmospheric temperature profile $T(z)$.

• W(z) is the *emission weighting function*:

$$W^{\downarrow}(z) = -\frac{dt(0,z)}{dz} = \frac{\beta_a(z)}{\mu}t(0,z)$$

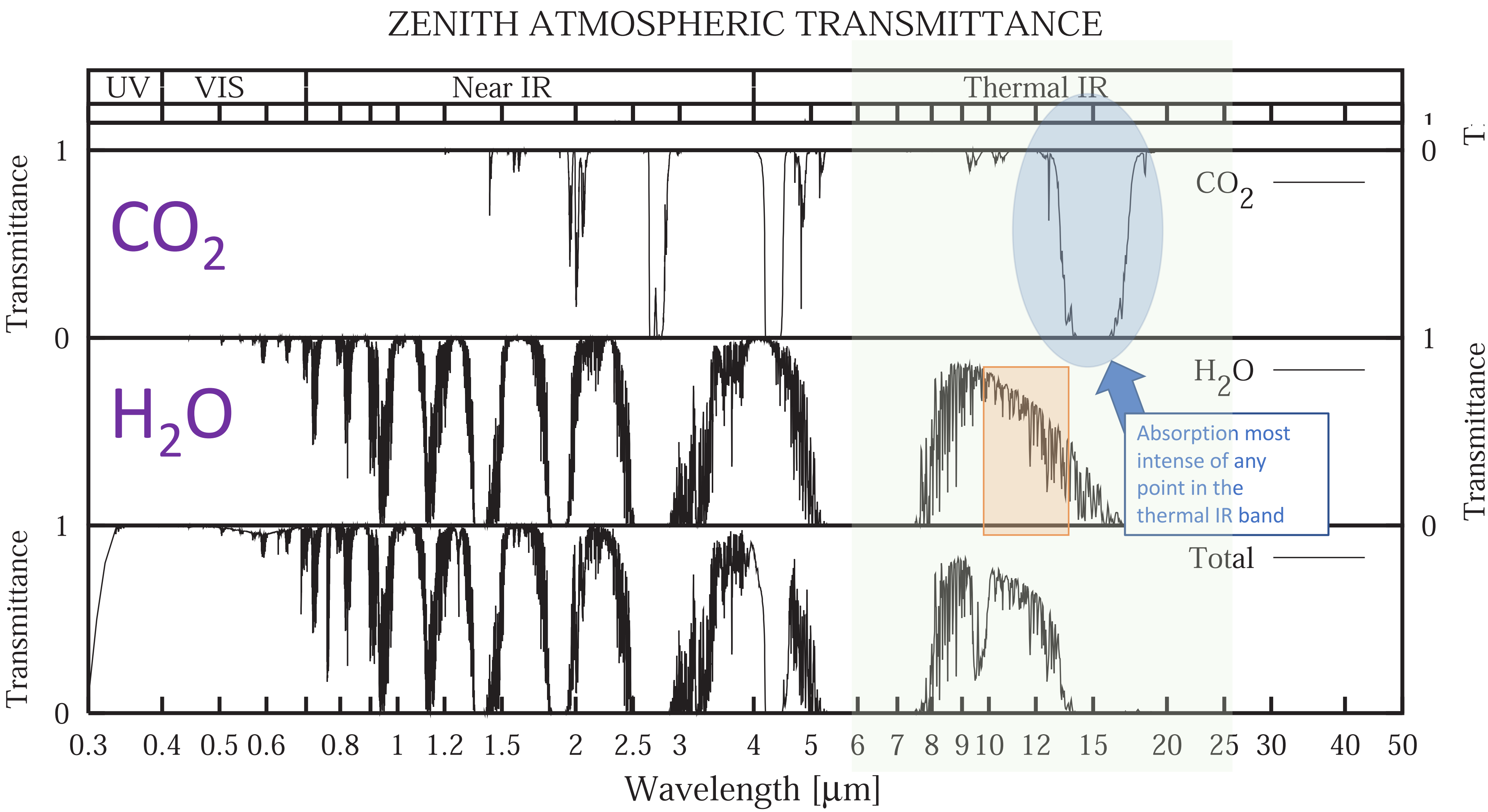
Satellite-based sensor looking down

- For a *sensor located in space (z = ∞), viewing upward emitted radiation from the atmosphere*, the appropriate form of the radiative transfer equation is:

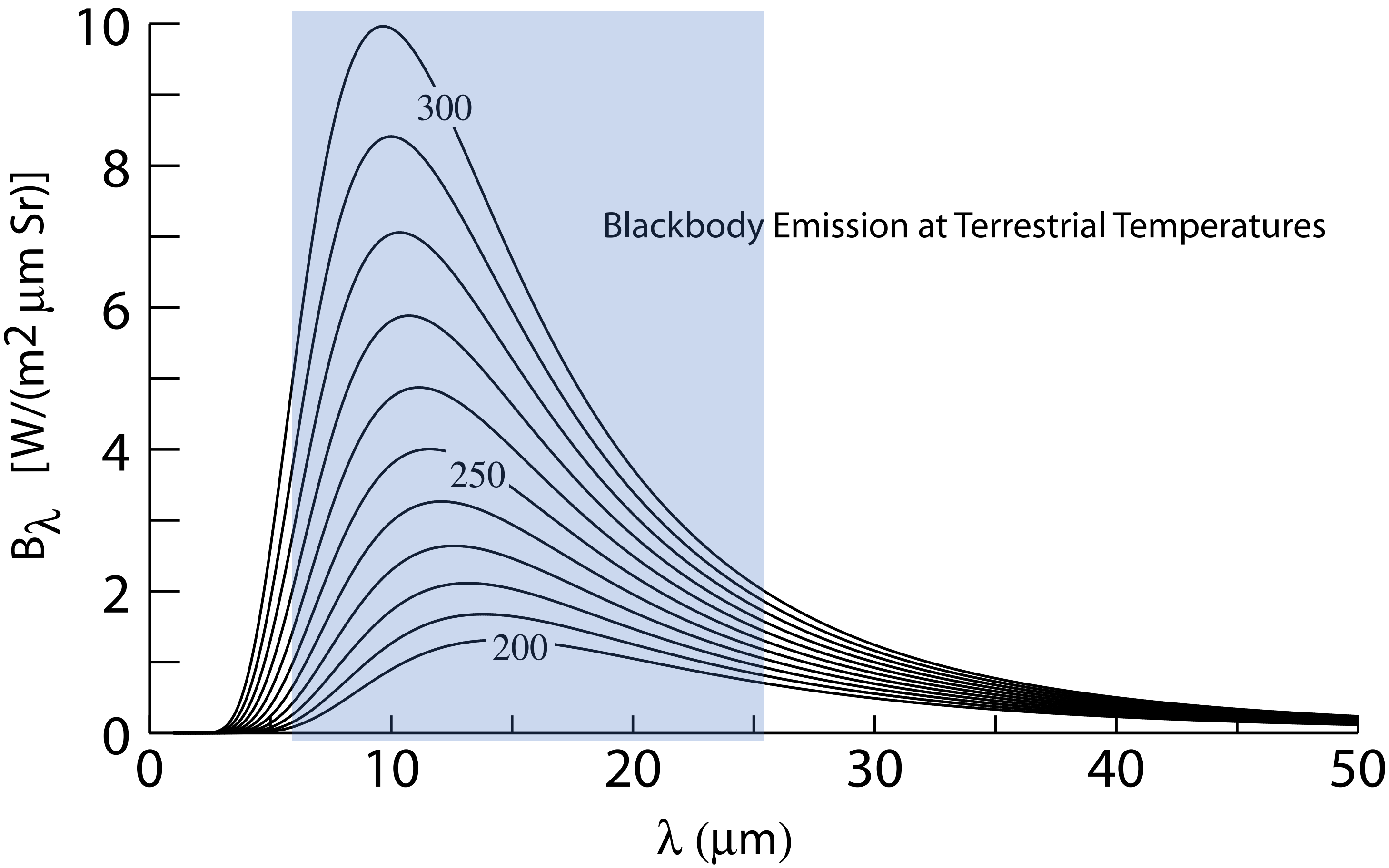
$$I^{\uparrow}(\infty) = I^{\uparrow}(0)t^{*} + \int_{0}^{\infty} B(z)W^{\uparrow}(z)dz$$

- W(z) is the *emission weighting function for upwelling radiation*:

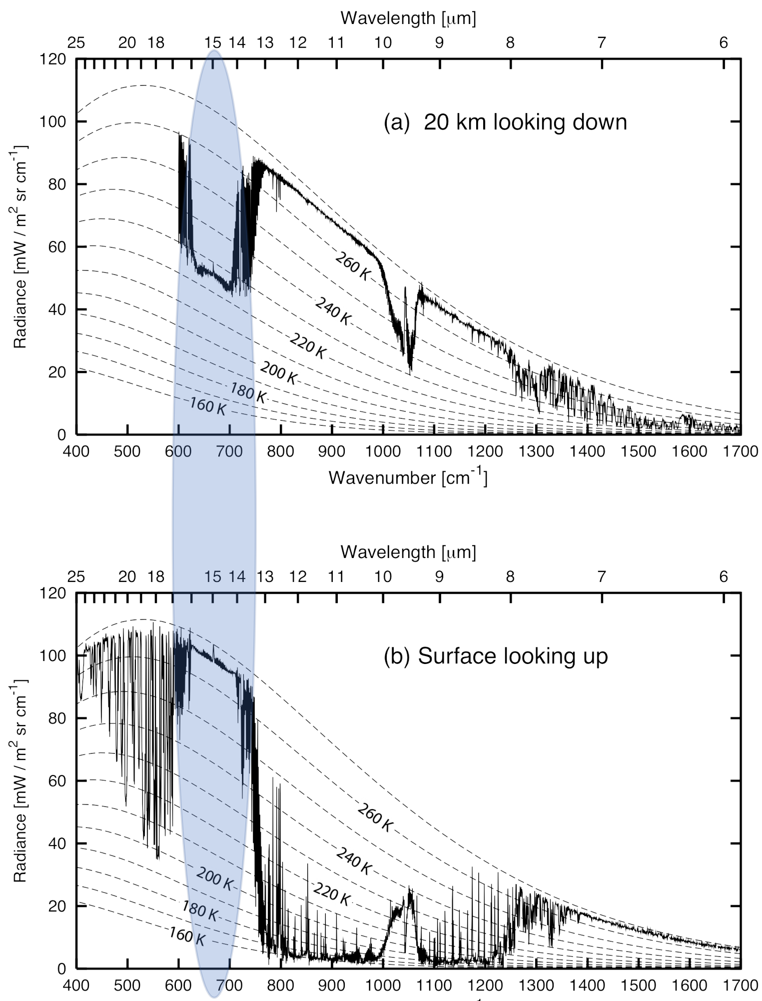
$$W^{\uparrow}(z) = \frac{dt(z,\infty)}{dz} = \frac{\beta_a(z)}{\mu}t(z,\infty)$$



ZENITH ATMOSPHERIC TRANSMITTANCE
UV
VIS
Near IR
Thermal IR
Transmittance
CO2
H2O
Total
Absorption most intense of any point in the thermal IR band
0.3 0.4 0.5 0.6 0.8 1 1.2 1.5 2 2.5 3 4 5 6 7 8 9 10 12 15 20 25 30 40 50
Wavelength [μm]


Blackbody Emission at Terrestrial Temperatures
300
250
200
B_λ [W/(m^2 μm Sr)]
λ (μm)
0
2
4
6
8
10
0
10
20
30
40
50

Problem 8.8



Looking down over the polar ice sheet

What is the approximate temperature of the ***surface*** *of the ice sheet?*

What is the approximate temperature of the near-surface ***air****?*

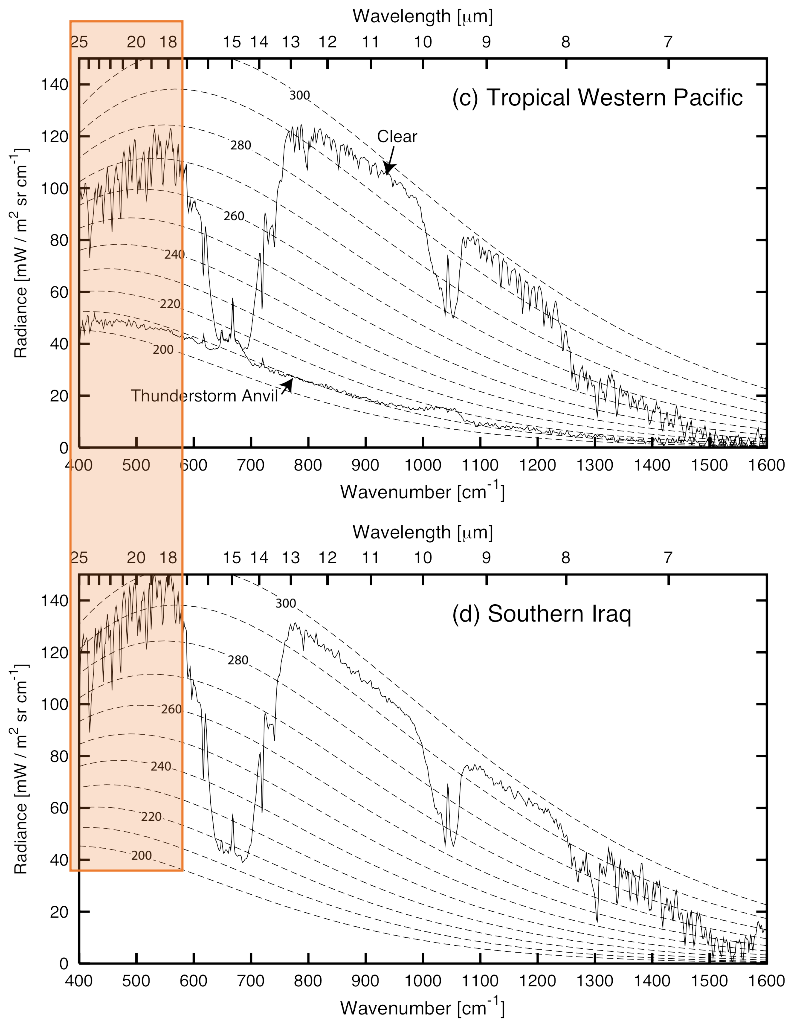
What is the approximate temperature of the ***air*** *at the aircraft's flight altitude of 20 km?*

Looking up from the polar ice sheet

What is the feature seen between 9 and 10 μm in both spectra?

Can you see any evidence for a temperature inversion in the spectra?

IR spectra observed by a satellite spectrometer



Well mixed gases

- E.g. O_2, CO_2 (throughout the troposphere and stratosphere)
- Present at constant mass ratio to other constituents
- If you know the density profile of the atmosphere then:

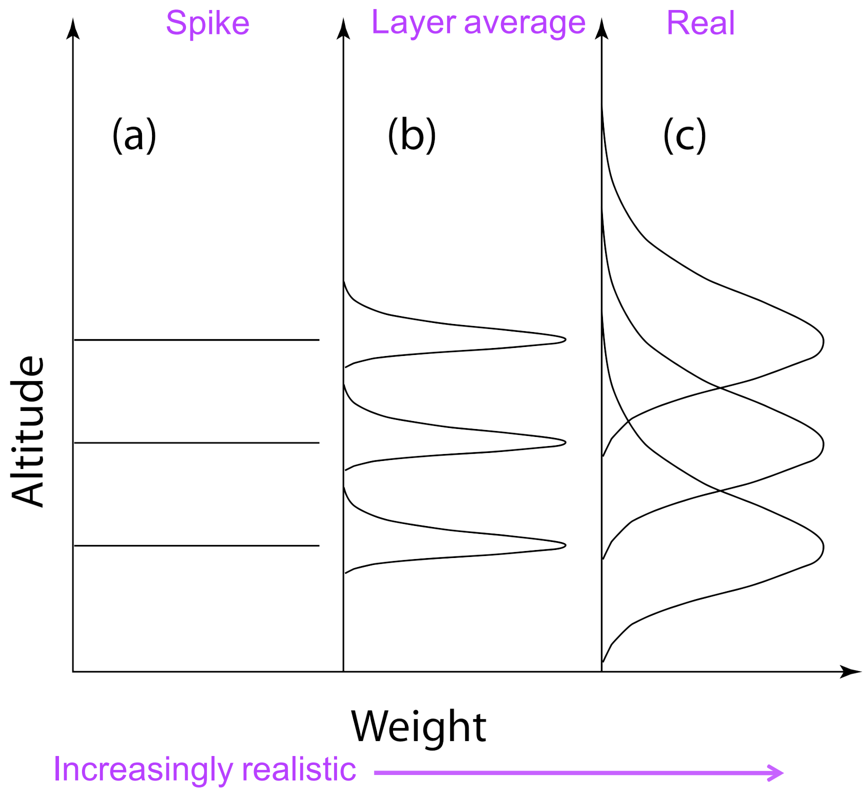
$$\rho'(z) = w\rho(z), where\ w = mass\ ratio\ of\ well\ mixed\ gas$$

$$\beta_a = \rho k_a$$

Recall

- So, if you know $k_a(z)$, then you can calculate the optical depth $\tau(z)$, and thus the emission weighting function $W^{\uparrow}(z)$

Satellite retrieval of temperature profiles



Requirements:

Strong absorption band that renders the atmosphere opaque over a range of wavelengths.

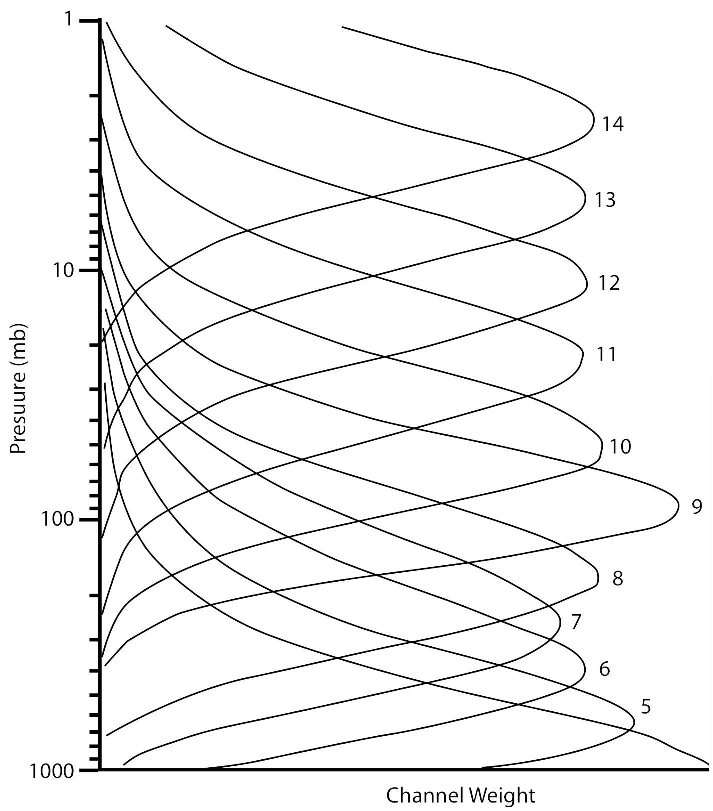
Well-mixed constituent throughout troposphere and stratosphere (i.e., constant mixing ratio)

➔ *CO_2 and O_2*

Measurements of radiant intensities for a series of closely spaced wavelengths on the edge of a strong absorption band (e.g., 15 μm CO_2)

Satellite retrieval of temperature profiles

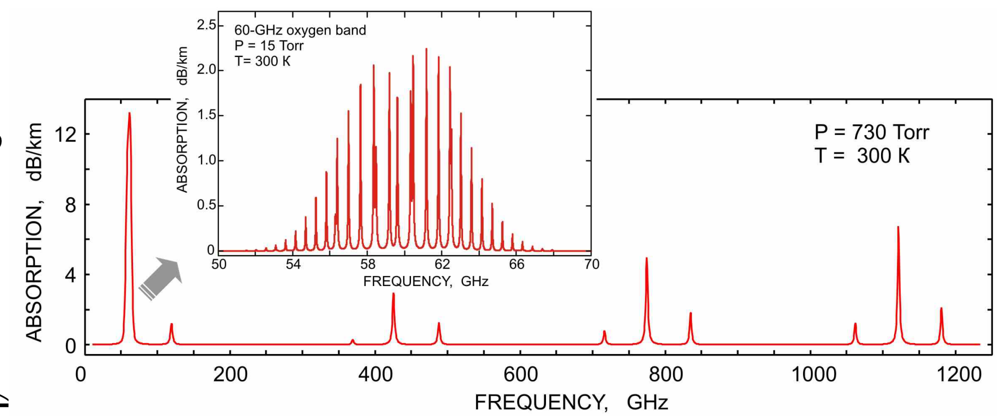
Active Sensor

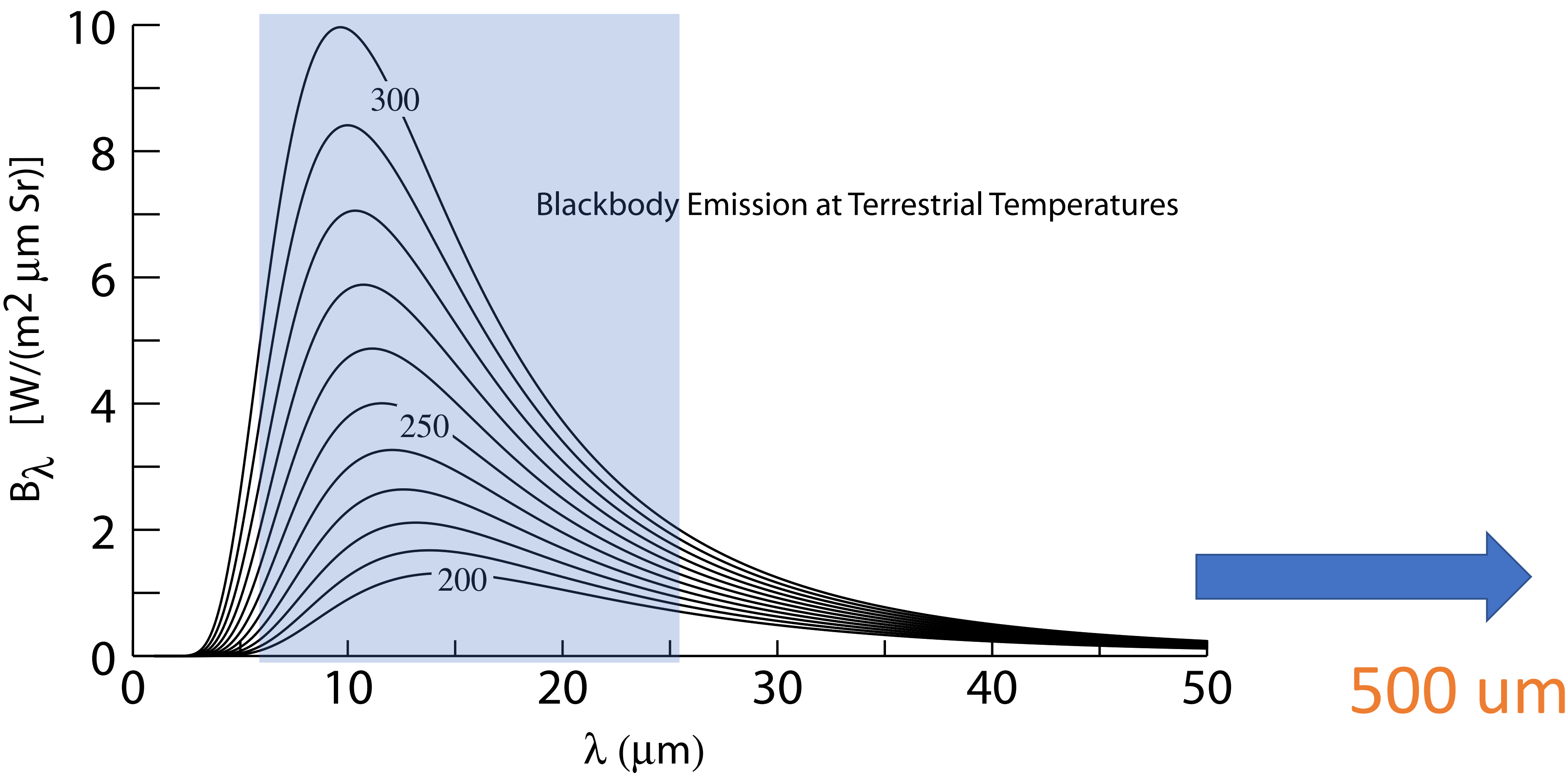


Actual weighting functions for channels 4-14 of the Advanced Microwave Sounding Unit (AMSU)

Located on the edge of the strong O_2 absorption band at 60 GHz (~5mm)

Essential for weather forecasting!





Blackbody Emission at Terrestrial Temperatures
300
250
200
B_λ [W/(m^2 µm Sr)]
λ (µm)
0
2
4
6
8
10
0
10
20
30
40
50
500 um