Lecture 17.

Course Summary:

Remote sensing applications, principles and techniques for studying the atmosphere and oceans

Clouds:

Cloud amount/coverage (cloud mask)

Visible+ IR => Lecture 13 and Lab 5

Principles: based on a combination of thresholds for solar reflectivity and brightness temperature (in the IR)

Active (CALIPSO, CloudSat) => Lab 11

Cloud liquid water content (column integrated)

Microwave => Lecture 11 and Lab 7

Cloud type

ISCCP classification => Lecture 13

Cloud particle size distribution and optical depth

MODIS retrieval technique => Lecture 13 and Lab 9

CloudSat => Lab 11

Cloud thermodynamic phase

MODIS retrieval technique => Lecture 13

Cloud–top pressure

O_2 absorption technique and “CO_2 slicing technique” = > (see textbook)

Cloud height and cloud detection

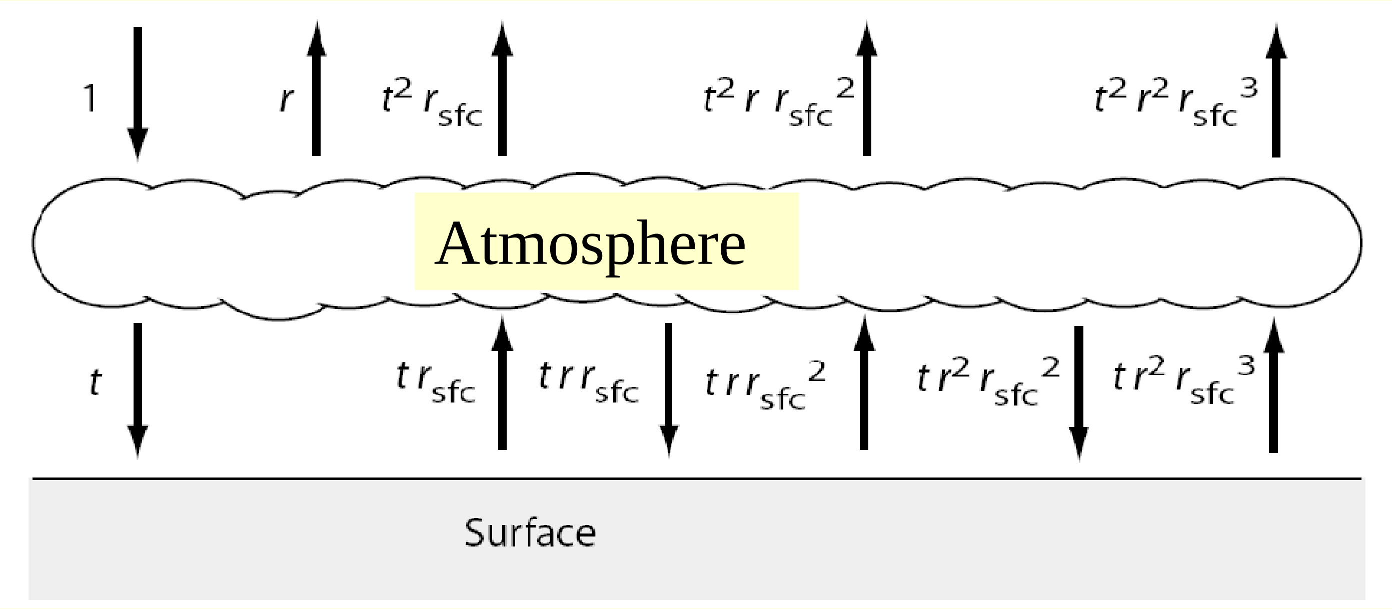
Lidars/Radars => Lectures 14-15 and Lab 11

Problem solving example

You analyze a satellite image of two clouds with one appearing brighter at the visible wavelengths. In general, would you expect more, less, or unknown infrared radiance emitted by the brighter-looking cloud?

Correct answer: unknown

Atmosphere-underlying surface system



$$r_{as} = r + r_s \frac{t^2}{1 - r\, r_s}$$

Problem solving example

Consider a cloud with temperature of 220 K overlying a surface with T=285 K. Assume that the atmosphere above and below the cloud is transparent to the radiation at 11 μm.

A) If the cloud emissivity is 1, what is the brightness temperature that will be measured by a nadir looking satellite radiometer at **11 μm?**

B) If the cloud emissivity is 0, what is the brightness temperature that will be measured by a nadir looking satellite radiometer at **11 μm?**

Solution: Use the following Eq., and then find BT from I by inverting the Planck function :

$$I_{\lambda}^{\uparrow}(0;\mu) = B_{\lambda}(T_{sur})T_{\lambda}(\tau^{*},\mu) + B_{\lambda}(T_{\text{cloud}})[1 - T_{\lambda}(\tau^{*},\mu)]$$

Aerosols:

Aerosol detection

TOMS/OMI Aerosol Index (UV remote sensing) => Lecture 10

Aerosol optical depth/particle size distribution/Angstrom exponent

Sunphotometers (AERONET) => Lecture 6 and Labs 3, 6

Principles: based on measurements of direct solar radiation that permit to retrieve the aerosol optical depth

Visible-near IR satellite remote sensing (MODIS, MISR, AVHRR, SeaWiFS) => Lecture 8 and Lab 6

Principles: based on measurements of reflected solar radiation and look-up tables for pre-defined aerosol models (size distribution and refractive index)

Vertical profile of backscattering and optical depth (lidars) =>Lecture 15

Assuming no surface reflection (dark surface), the upwelling intensity at the level Z (or τ) is

$$I^{\uparrow}(\tau,\mu,\varphi)=\int_{\tau}^{\tau^*} J(\tau',\mu,\varphi)\exp[-(\tau'-\tau)/\mu]d\tau'/\mu$$

Substituting in the source function

$$I^{\uparrow}(\tau,\mu,\varphi)=\frac{\omega_0}{4\pi}F_0P(\Theta)\int_{\tau}^{\tau^*} \exp[-(\tau'-\tau)/\mu-\tau'/\mu_0]d\tau'/\mu$$

Satellite sensor measures

$$I^{\uparrow}(0,\mu,\varphi)=\frac{\omega_0}{4\pi}F_0P(\Theta)\frac{\mu_0}{\mu+\mu_0}[1-\exp(-(\frac{1}{\mu_o}+\frac{1}{\mu})\tau^*)]$$

In the single scattering approximation when **τ* <1**:

$$\boxed{I^{\uparrow}(0,\mu,\varphi)=\frac{\omega_0}{4\pi}F_0P(\Theta)\frac{\tau^*}{\mu}}$$

Ozone and trace gases (NO_2, SO_2, BrO, OClO):

Ozone amount

UV downlooking spectrometer (TOMS) => Lecture 10

Differential Optical Absorption Spectroscopy (DOAS) => Lecture 10

Dobson's method = >Lecture 10

Ozone profile

Sounding => Lectures 10 and 12

Other gases => see Table 17.1 below and Lecture 4, Table 4.6

Gases:

Absorption (emission):
- **depends on molecular structure (dipole!)**
- **wavelength-selective**

Scattering:
- **a point dipole approach – Rayleigh scattering**
- **~ wavelength $^{-4}$ => important in UV-vis**
  negligible in IR-microwave

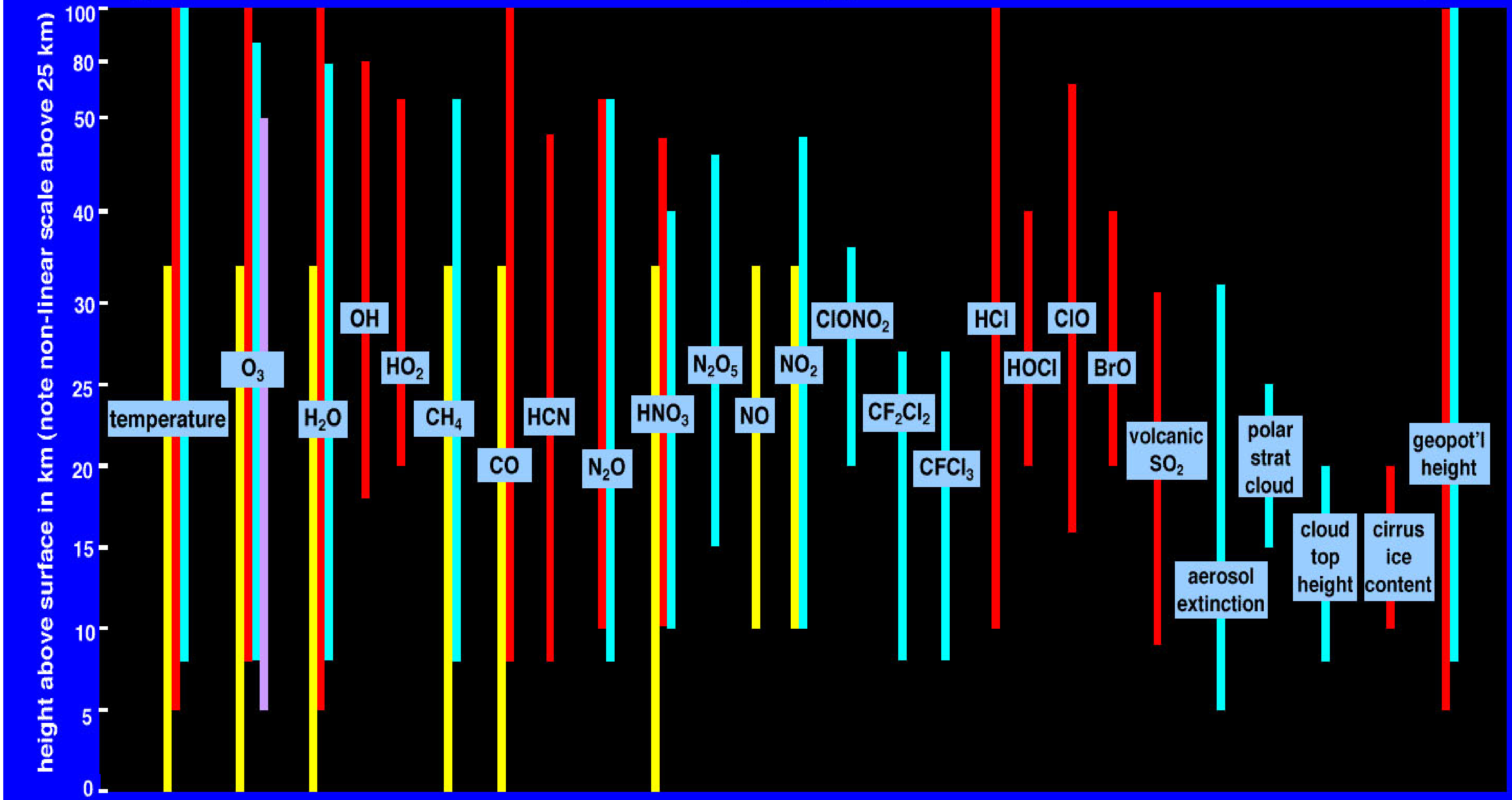
Why the limb-viewing geometry cannot provide measurements of gases in the lower atmosphere?

EOS Aura Atmospheric Profile Measurements

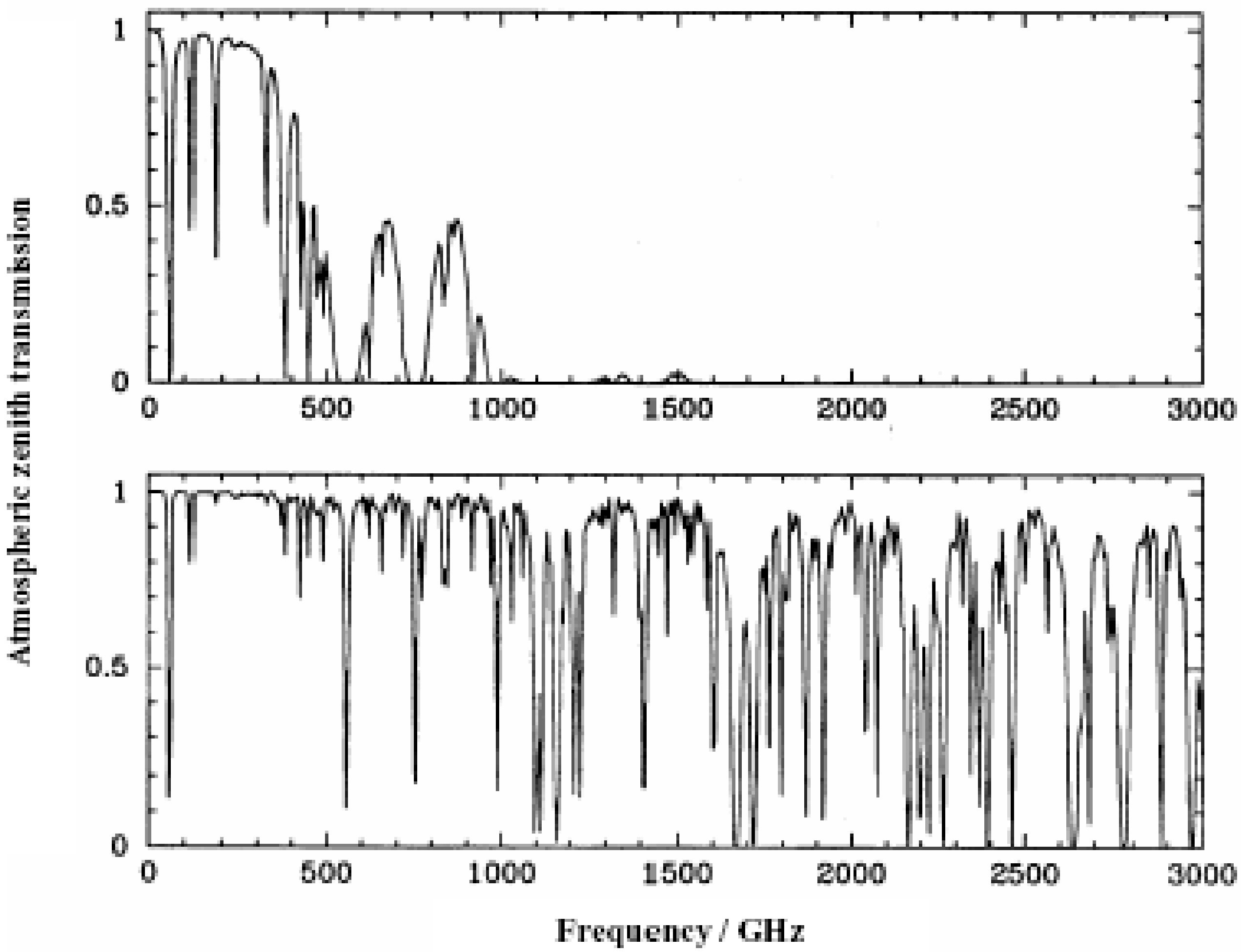
OMI also measures UVB flux, cloud top/cover, and column abundances of O_3, NO_2, BrO, aerosol and volcanic SO_2

TES also measures several additional 'special products' such as $ClONO_2$, CF_2Cl_2, $CFCl_3$, N_2O and volcanic SO_2

- 🟦 HIRDLS: High Resolution Dynamics Limb Sounder
- 🟪 OMI: Ozone Monitoring Instrument
- 🟥 MLS: Microwave Limb Sounder
- 🟨 TES: Tropospheric Emission Spectrometer

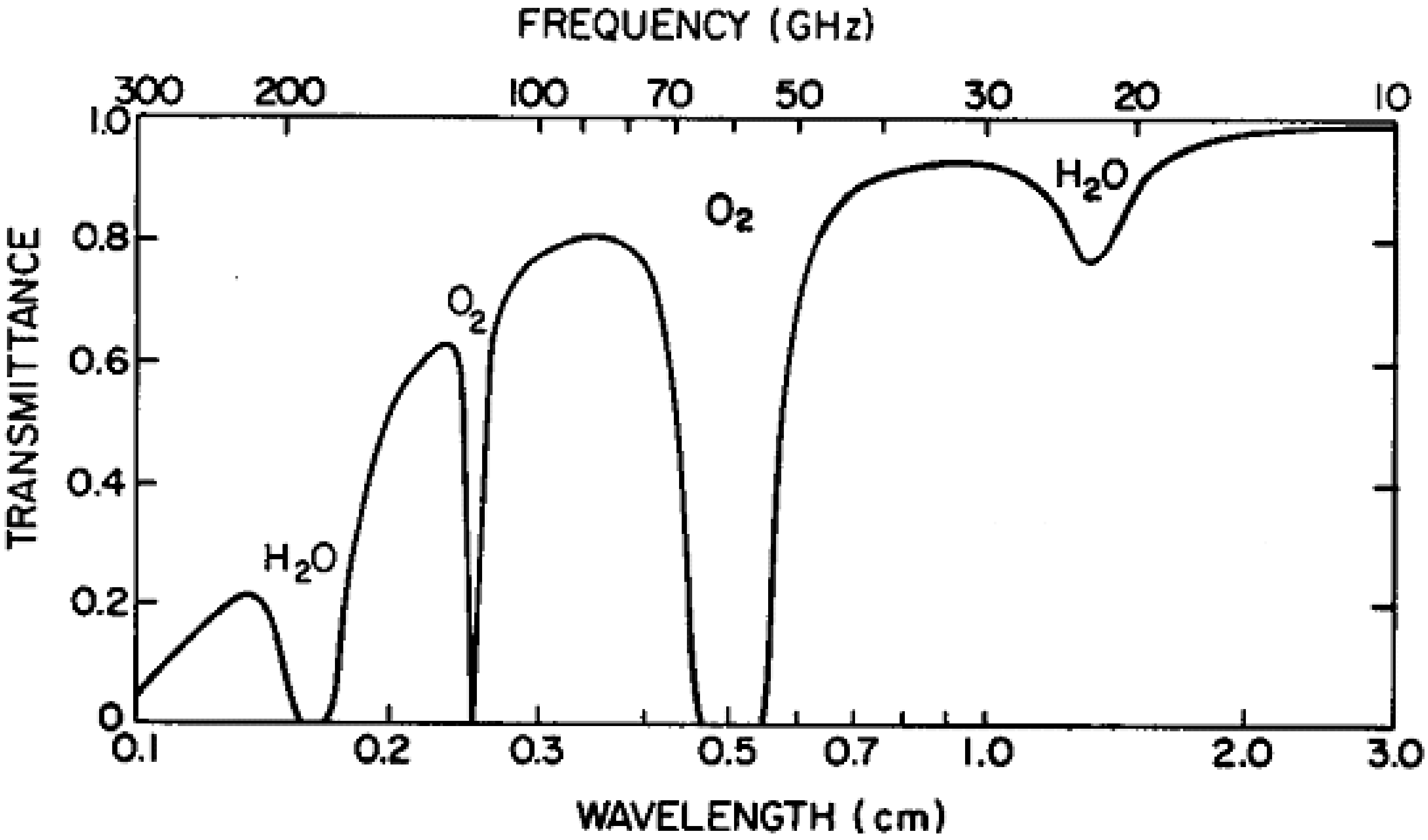


Explain the difference in atmospheric zenith transmission above a 4 km high mountain (top) and above an aircraft at 12 km (bottom).



Microwave

$$\lambda(in\ \ cm) = \frac{30}{\tilde{\nu}(in\ \ GHz)}$$



Water vapor:

Integrated column (total precipitable water) from microwave => Lecture 11 and Lab 7

Profile from IR sounding => Lecture 12

Profile from microwave sounding => Lecture 12

Profile from Raman lidar, DIAL => Lecture 15

Precipitation

Visible/IR techniques => Lecture 13

Principles: indirect method that relates properties of clouds to precipitation

Microwave techniques => Lecture 13

Principles: direct method that relates the optical depth associated with the emitting rain drops and brightness temperature measured by a passive microwave radiometer.

Radar => Lecture 14 and Lab 10

Principles: measured backscattering from rain drops is related to the Z factor (size distribution) and then to precipitation via Z-R relationship

Problem solving example:

Precipitation is a key component of the hydrological cycle. Briefly explain the principles and discuss advantages and disadvantages of the following remote sensing techniques:

- **passive IR sensing of precipitation**
- **passive microwave sensing of precipitation**
- **active microwave sensing of precipitation**

Sea Surface Temperature

IR split-window technique => Lecture 12 and Lab 8

Microwave techniques => Lecture 12 and Lab 8

Atmospheric temperature (profile)

IR (or microwave) sounding techniques => Lecture 12 and Lab 8

Principles: multi-spectral remote sensing in the 15 μm CO2 absorbing band
(in microwave in the O2 absorbing region)

$$\tau_\nu = \int_{u_1}^{u_2} k_\nu \, du$$

$$\tau_\nu = \int_{z'}^{z} k_\nu \rho_{gas} \, dz''$$

$$T_\nu(z, z', \mu) = \exp\left(-\frac{1}{\mu} \int_{z'}^{z} k_\nu \rho_{gas} \, dz'' \right)$$

$$\frac{dT_\nu(z, z', \mu)}{dz'} = -\frac{k_\nu \rho_{gas}}{\mu} \exp\left(-\frac{1}{\mu} \int_{z'}^{z} k_\nu \rho_{gas} \, dz'' \right)$$

$$\boxed{I_\nu^\uparrow(z, \mu) = I_\nu^\uparrow(0, \mu) T_\nu(z, 0, \mu) + \int_0^z B_\nu(T(z')) \left| \frac{dT_\nu(z, z', \mu)}{dz'} \right| dz'}$$

$$\boxed{I_\nu^\uparrow(z, \mu) = I_\nu^\uparrow(0, \mu) \exp\left[-\frac{1}{\mu} \int_0^z k_\nu \rho_{gas} \, dz' \right] + \frac{1}{\mu} \int_0^z \exp\left[-\frac{1}{\mu} \int_{z'}^{z} k_\nu \rho_{gas} \, dz' \right] B_\nu(T(z')) k_\nu \rho_{gas} \, dz'}$$

Weighting functions for near-nadir sounding:

For a satellite sensor looking down:

$$I_\nu^\uparrow(\infty,\mu) = I_\nu^\uparrow(0,\mu)T_\nu(\infty,0,\mu) + \int_0^\infty B_\nu(T(z'))\left|\frac{dT_\nu(\infty,z',\mu)}{dz'}\right|dz'$$

$$\boxed{W_\nu(\infty,z,\mu) = \left|\frac{T_\nu(\infty,z,\mu)}{dz}\right| = \frac{k_\nu\rho_{gas}}{\mu}\exp(-\frac{1}{\mu}\int_z^\infty k_\nu\rho_{gas}dz)}$$