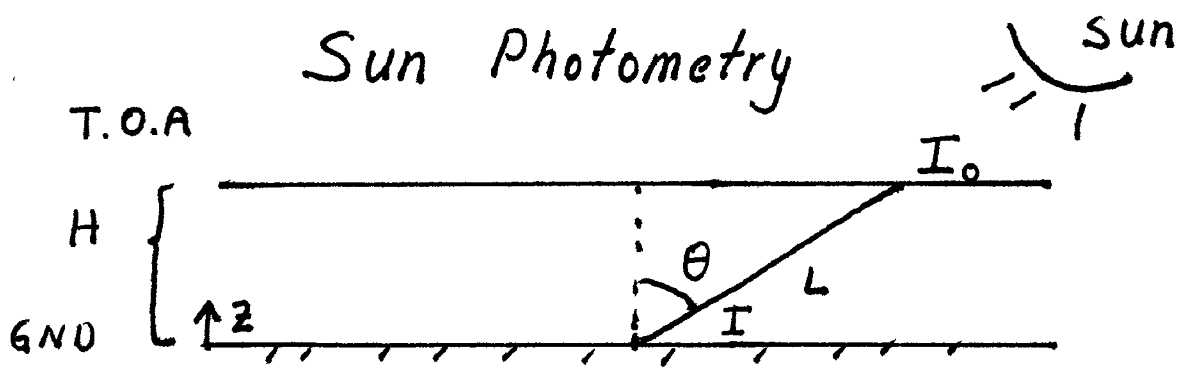
Sun Photometry



Let

H = "height" of atmosphere

L = Pathlength of sunlight through atmosphere.

θ = Solar Zenith Angle

Then $\cos\theta = \frac{H}{L}$, $L = \frac{H}{\cos\theta}$

Let

$m = 1/\cos\theta$ = Air Mass , $m \geq 1$

$m = 1$ Sun overhead

$m = 10$ Sunrise or sunset

$I_o = I_o(\lambda)$ = T.O.A Solar irradiance

$I(\lambda)$ = GND solar irradiance

τ = optical depth - dimensionless quantity (when the sun is overhead)

Then

Direct Beam

(no multiple scattering)

$$I(\lambda) = e^{-\frac{\tau(\lambda)}{\cos\theta}} I_o(\lambda)$$

Sunlight at surface

Sunlight at top of atmosphere

So $I(\lambda) = e^{-m\tau(\lambda)} I_0(\lambda)$

Idea: 1. Measure $I(\lambda)$ at the ground at different times, so with different m values.

2. The sun output $I_0(\lambda)$ at the top of of the atmosphere remains the same.

3. Unknown: $\tau(\lambda)$ Solve for it, learn about the atmosphere with it.

Here's how:

$$\tau(\lambda) = \tau_{gas}(\lambda) + \tau_{aerosol}(\lambda) + \tau_{cloud}(\lambda)$$

$$\tau_{gas}(\lambda) \Rightarrow \tau_{gas}^{scattering}(\lambda) + \tau_{gas}^{absorption}(\lambda)$$

Rayleigh Scattering (Blue Sky) O_2, N_2, $= \frac{a}{\lambda^4}$

Absorption by gases like water vapor, O_2, Ozone (O_3), Nitrogen dioxide (NO_2)

$$\tau_{aerosol}(\lambda) = \tau_{aerosol}^{scattering}(\lambda) + \tau_{absorption}^{aerosol}(\lambda)$$

$\sim \frac{b}{\lambda^2}$ Sulfates, Nitrates, Sea Salt, Organic Carbon, Dust, Black Carbon

$\sim \frac{c}{\lambda}$ Black Carbon (Soot), Dust (UV wavelengths)

Example: Rayleigh Scattering by O_2, N_2

$$\frac{\text{Blue}\quad \tau_{gas}^{scattering}(\lambda = 400nm)}{\text{Red}\quad \tau_{gas}^{scattering}(\lambda = 600nm)} = \left(\frac{600}{400}\right)^4 = \frac{81}{16} \approx 5$$

Conclusion: Scattering in blue by gases is 5 x scattering in Red.

Aerosol: $$\tau_{aerosol}^{ext}(\lambda) = \int_0^H \int_0^\infty \sigma_{ext}(\lambda, D)\, N(D, z)\, dz\, dD$$

ext = abs + sca

Particle extinction cross section as a function of wavelength and particle size.

$N(D,z)$ = Particle Size Distribution (D = particle diameter)

<u>Gas Absorption</u>:

$$\tau_{gas}^{absorption}(\lambda) = \int_0^H C(z)\, \sigma_{abs}(z, \lambda)\, dz$$

$C(z)$: # of Absorbing Molecules / Volume

$\sigma_{abs}(z, \lambda)$: Absorption Cross Section per Molecule

Here's how to crunch the data and get information from it.

Date	Time	Lat	Long	Calculate θ	Measure $I(\lambda)$ Volts	Measure $I(\lambda)$ Dark Volts

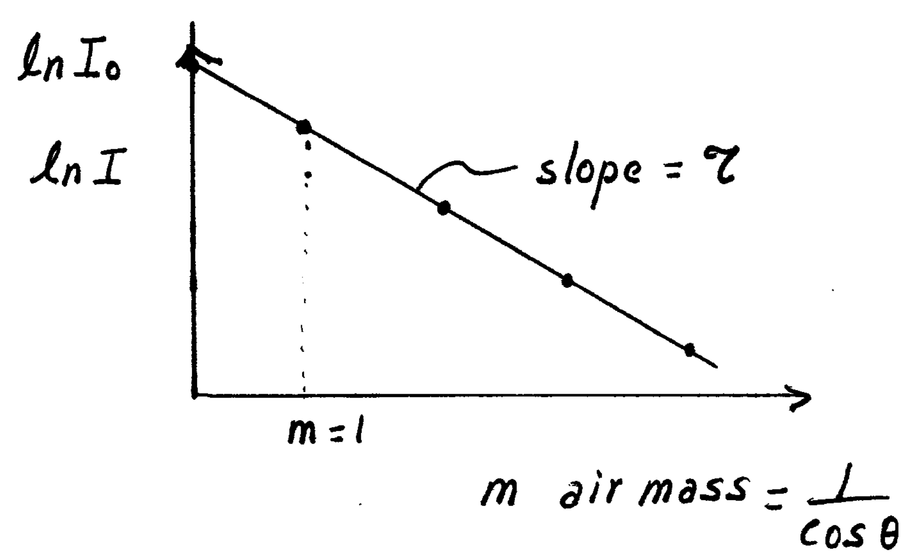
$$I(\lambda) = e^{-\tau m} I_0(\lambda)$$

Then $\ln I = \ln I_0 - m\tau$

offset (fixed, sunlight at top of Atmosphere)

independent variable

slope use to learn about atmosphere



How to process

$$\text{Slope} = \tau = \tau_{gas}^{sca} + \tau_{aerosol} + \cancel{\tau_{cloud}}$$

look up from table

aerosol amount (optical depth)

$\tau_{aerosol} \sim 0.2$ or so.

"Clear" day (No clouds)

For 940nm, also get water vapor concentration

$$\tau = \tau_{gas}^{scatt.} + \tau_{H_2O}^{absorp.} + \tau_{aerosol}$$

look up

Large when atmosphere is moist

Get from 870nm

Wavelength (nm)		Comment
430		Good for aerosol, Rayleigh scattering larger
470		
530		
660		Good for aerosol, Rayleigh modest
870	—	Good for aerosol, Rayleigh small
940	—	water vapor channel

Also, get $I_o(\lambda)$ from the offset.

$$\overset{\text{calibrated}}{I_o(\lambda)} = k(\lambda)\,\overset{\text{counts or voltage}}{I_o(\lambda)}$$

from offset

calibration factor

From satellite measurements, TABLE

$$K(\lambda) = \frac{\overset{\text{calibrated}}{I_o(\lambda)} \quad \left[\frac{\text{Watts}}{m^2 \cdot nm}\right]}{\overset{\text{counts}}{I_o(\lambda)}}$$

Raw output from spectrometer.

Use $k(\lambda)$ to calibrate any spectrum from the spectrometer.