Microwave Interactions with the Atmosphere

S. L. Cruz Pol
Electrical and Computer Engineering
University of Puerto Rico

Atmosphere composition

Typical Atmosphere in %

- 21% N\textsubscript{2}
- 0.93% O\textsubscript{2}
- 78% Ar

Other components:
- Carbon dioxide (CO\textsubscript{2})
- Neon (Ne)
- Helium (He)
- Methane (CH\textsubscript{4})
- Krypton (Kr)
- Hydrogen (H\textsubscript{2})
- Water vapor (highly variable)
Introduction

- Up to now, we have assumed lossless atm.
- For $1 \text{ GHz} < f < 15 \text{ GHz}$ ~lossless
- For higher frequencies, =>absorption bands

\begin{align*}
\text{H}_2\text{O} & : 22.235 \text{ GHz, 183.3 GHz, IR & visible} \\
\text{O}_2 & : 50-70 \text{GHz, 118.7 GHz, IR & visible}
\end{align*}
Outline

I. The atmosphere: composition, profile

II. Gases: many molecules

1. Shapes \((G, VVW, L)\): below 100GHz, up to 300GHz
   e.g. \(H_2O\), \(O_2\)

2. Total Atmospheric
   Absorption \(\kappa_g\), opacity \(\tau_\theta\), and atm-losses \(L_\theta\)

3. \(T_B\): Downwelling Emission by Atmosphere
   Sky Temp = cosmic + galaxy

U.S. Standard Atmosphere

- Thermosphere (or Ionosphere) 1000-3000°F!
- Mesosphere
  no aircrafts here
  too cold ~90°F
- Stratosphere
  no \(H_2O\) or dust
  ozone absorption of UV
  warms air to ~40°F
- Troposphere - clouds, weather
  \(T = 300K\)

\(P = 1013\) mbars
\(= 1013\) HPa
Atmospheric Profiles
US Standard Atmosphere 1962

- Temperature

\[ T(z) = \begin{cases} T_0 - az & 0 \leq z \leq 11 \text{ km} \\ T_{11} & 11 \text{ km} \leq z \leq 20 \text{ km} \\ T_{11} + (z - 20) & 20 \text{ km} \leq z \leq 32 \text{ km} \end{cases} \]

- Density

\[ \rho_{\text{air}}(z) = 1.225e^{-z/H_1} \quad \text{where } H_1 = 9.5 \text{ km density scale height} \]

Or \[ \rho_{\text{air}}(z) = 1.225e^{-z/7.3}[1 + 0.3 \sin(z / 7.3)] \]

- Pressure

\[ P = nRT/V = \rho_{\text{air}}RT/M \text{ or } P_o e^{-z/H_3} \]

where \( H_3 = 7.7 \text{ km Pressure scale height} \)

Water Vapor Profile

Depends on factors like weather, seasons, time of the day. It’s a function of air temperature.
- Cold air can’t hold water
- Hot air can support higher humidities \((P \text{ dependence})\)

\[ \rho_v(z) = \rho_o e^{-z/H_4} \quad [\text{g/m}^3] \]

where \( \rho_o \) averages 7.72 in mid latitudes and the total mass of water vapor in a column of unit cross section is

\[ M_v = \int_0^\infty \rho_v(z) \, dz = \rho_o H_4 \]

where \( H_4 \) = between 2 – 2.5 km water - vapor scale height
EM interaction with Molecules

- **Total internal energy state for a molecule**
  - electronic energy corresponding to atomic level
  - vibration of atoms about their equilibrium position
  - rotation of atoms about center of molecule
  - \( \varepsilon = \varepsilon_e + \varepsilon_v + \varepsilon_r \)
- **Bohr condition**  \( f_m = (\varepsilon_m - \varepsilon_i) / h \)
- **Values for energy differences for**
  - electronic: 2 to 10 eV
  - vibrational-rotational: 0.1 to 2 eV
  - pure rotational: \( 10^{-4} \) to \( 5 \times 10^{-2} \) eV (microwaves)
Line Shapes

Line shapes

- **Lorentz**
  \[ F_L(f, f_{lm}) = \frac{1}{\pi} \frac{\gamma}{(f - f_{lm})^2 + \gamma^2} \]

- **Gross**
  \[ F_G(f, f_{lm}) = \frac{1}{\pi} \frac{4f f_{lm}}{(f_{lm}^2 - f^2)^2 + 4f^2 \gamma^2} \]

- **Van-Vleck-Weisskopt**
  \[ F_{vw}(f, f_{lm}) = \frac{1}{\pi} \left( \frac{f}{f_{lm}} \right)^2 \frac{\gamma}{(f_{lm} - f)^2 + \gamma^2} + \frac{\gamma}{(f_{lm} + f)^2 + \gamma^2} \]
Absorption Bands

- Mainly water and oxygen for microwaves

\[
\begin{align*}
\text{Brightness Temperature [K]} & \\
\text{Frequency [GHz]} &
\end{align*}
\]

Total Atmospheric

- Absorption \( \kappa_g \)

\[
\kappa_g = \kappa_{H_2O} + \kappa_{O_2}
\]

- Opacity \( \tau_\theta \)

\[
\tau_\theta = \int_0^\infty \kappa_\eta(z) \sec \theta \, dz = \sec \theta \tau_\eta
\]

- Loss factor \( L_\theta \)

\[
L_\theta = e^{\tau_\theta \sec \theta} = e^{0}
\]
Atmospheric Emission

- For clear atmosphere

\[ T_{DN} = \sec \theta \int_{0}^{\infty} \kappa_{\alpha}(z') T(z') e^{-\tau(0,z') \sec \theta} dz' \]

where

\[ \tau(0,z') = \int_{0}^{z} \kappa_{\alpha}(z) dz \]

Also there is some background radiation

\[ T_{extra} = T_{cosmic} + T_{galactic} \]

\( T_{cos} = 2.7K \) from the Big Bang and \( T_{gal} \approx 0 \) above 5GHz

Relative Humidity

<table>
<thead>
<tr>
<th>Air Temperature</th>
<th>Vapor air can hold</th>
<th>Actual Vapor in the air [gr per kg dry air]</th>
<th>Relative humidity</th>
</tr>
</thead>
<tbody>
<tr>
<td>86°F</td>
<td>27.6</td>
<td>10.83</td>
<td>39%</td>
</tr>
<tr>
<td>77°F</td>
<td>20.4</td>
<td>10.83</td>
<td>53%</td>
</tr>
<tr>
<td>68°F</td>
<td>14.9</td>
<td>10.83</td>
<td>72%</td>
</tr>
<tr>
<td>59°F</td>
<td>10.8</td>
<td>10.83</td>
<td>100%</td>
</tr>
</tbody>
</table>
AVIRIS CONCEPT

Each spatial element has a continuous spectrum that is used to analyze the surface and atmosphere.

224 spectral images taken simultaneously.