Microwave Sounding

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What is Microwave Sounding?

Passive sensor in the microwave to measure temperature and water vapor

Technique was pioneered by Ed Westwater (c. 1978)
### Microwave

- **Gamma**
- **X-Rays**
- **Ultraviolet**
- **Visible**
- **Infrared**

**Microwave (and beyond):**

<table>
<thead>
<tr>
<th>CLASS</th>
<th>FREQUENCY</th>
<th>WAVELENGTH</th>
<th>ENERGY</th>
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<td>1 pm</td>
<td>1.24 MeV</td>
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<td>124 keV</td>
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<tr>
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<tr>
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Main Purpose

- Measure total integrated water content in an atmospheric column (both vapor and liquid)
- Measure a (coarse) vertical profile of atmospheric water
We will begin with ground-based microwave radiometers
Vocabulary

- Total column water vapor = precipitable water
- Total column liquid water (in a cloud) = liquid water path (LWP)
Why do we care about column water vapor?
Why do we care about column water vapor?

- Water vapor is the most abundant greenhouse gas in the atmosphere
- Essential for weather forecasting models
- Atmospheric propagation delays
Why do we care about column liquid water?
Why do we care about column liquid water?

- In a cloud, the amount of liquid water is very important in determining optical depth.
Optical Depth

\[ I_\lambda = I_{\lambda,0} e^{-\tau_\lambda m} \]

\( I_{\lambda,0} \) = incident solar radiation (at the top of the atmosphere)
\( I_\lambda \) = solar radiation that reaches the surface
\( \tau_\lambda \) = optical depth
\( m \) = atmospheric mass (how much of the atmosphere the radiation is passing through)

Optical depth describes the attenuation of solar radiation as it passes through the atmosphere.
Understanding optical depth is ESSENTIAL to understanding the radiation budget.
Until Westwater invented the technique of microwave sounding, we were using radiosondes to determine atmospheric humidity
Problems with Radiosondes
Problems with Radiosondes

- Radiosondes tend to drift (move with the wind)
- Radiosondes are not released often enough
- Radiosonde measurements of humidity are sometimes suspect
Passive Microwave Radiometers

- VERY accurate in determining column integrated water quantities
- Get complete measurements every 20 minutes
- Operate in nearly all conditions, regardless of weather
Passive Microwave Radiometers

- Can also be used to give vertical profiles of liquid water and water vapor, albeit at very poor resolution
Resonant Frequency
(of water)

- Frequency at which vibration can be induced in water molecules
- 22.235 GHz
Procedure

• Point the radiometer in a given direction and calculate atmospheric mass

• Measure the amount of radiation at the frequency to which you tune the radiometer

• Plug it into a simple radiative transfer equation which gives you total optical depth in the column
Merged Sounding

- Pioneered by Dr. Miller (and colleagues)
- Take the column profiles and feed them into the weather forecasting model run by the European Center for Medium Range Weather Forecasting (ECMWF)
- Use this to correct radiosonde data
Humidity Profiling
Large peak at 22.235 GHz
Radiation at 22.235 GHz

Microwave Radiometer tuned to 22.235 GHz
The microwave radiometer will not see much of molecule A

This is not a good way to design a profiler
Radiation at frequency higher than 22.235 GHz

Water molecule A

Water molecule B

Microwave Radiometer tuned to different frequency
The microwave radiometer at this frequency DOES see molecule A

We do this at multiple frequencies, and we can get a vertical profile
Weighting Functions

Each channel (frequency) has a function that tells it how much to weight each elevation.

Deriving these is as much an art as a science and requires a lot of experience doing this sort of thing.
Weighting Functions

HIRS WATER VAPOR AND LONGWAVE WINDOW CHANNELS
What frequencies are used?

- Most microwave radiometers have 5 channels devoted to water
- Each group has their own preference as to which frequencies they use
- Most important ones: 20.6 GHz, 22.235 GHz, and 31.65 GHz
Line Width

All instruments are imperfect and have an aperture of some kind. If you want to measure, say, 22.235 GHz, you cannot measure exactly that frequency and no others. You might actually measure something like 22.235±0.5 GHz. This 0.5 GHz is called the line width. The line width affects the shape of the absorption curve.
20.6 GHz frequency is relatively insensitive to line width

Fig. 1. Calculations of water vapor mass absorption coefficient for $\pm 10\%$ change of line width constant $\Delta v_0$. 1 = line width increased by 10%, 2 = original line width, 3 = line width decreased by 10%. For details, see text.
If we measure at 20.6 GHz, we can be sure that the line width is not introducing a source of error into our measurements.

There is a similar feature at 24.4 GHz.
relative minimum at 31.65 GHz
The 31.65 GHz frequency shows a drop-off of absorption. This reduction of absorption is greater for water vapor than for liquid water. By measuring at this frequency, we can differentiate between water vapor and liquid water.
Resolution

The resolution of microwave humidity profilers is about 1 km. This is not at all useful for a large majority of clouds.
We’ve discussed the 5 channels in the 20-32 GHz range.

Most microwave radiometers have 12 channels total.

There are 7 more channels in the 48-71 GHz range.
Oxygen

OXYGEN ABSORPTION SPECTRUM

Notice the reduction in absorption with height
Absorption of microwave energy by oxygen is very dependent upon temperature.

We can use these 7 channels to profile temperature.
For very dry conditions, the 31.65 GHz channel is not very good at distinguishing water vapor from liquid water. For this reason, some radiometers also take measurements at 183 GHz. This frequency is very sensitive to liquid water.
Atmospheric microwave spectra

Modelled microwave spectra at different altitudes

Brightness Temperature [K]

Frequency [GHz]

- Oxygen ($O_2$)
- Water Vapor ($H_2O$)

- Pink line: sea level
- Blue line: 4000 m
- Red line: 8000 m
Calibration

- Microwave radiometers have a strong tendency to drift
- They need to be calibrated quickly and often
Atmospheric Mass

To a good approximation, \( m \approx \sec(\theta) \)

\( \theta = \text{zenith angle} \)

As zenith angle increases (moves away from the vertical), so does atmospheric mass.
Tipping Angle

Distance to top of atmosphere increases with zenith angle, so the amount of atmosphere between the radiometer and the sun grows with angle.

\( \theta = 0^\circ \Rightarrow m = 1 \)

\( \theta = 90^\circ \Rightarrow m = \infty \)
Atmospheric Mass

- We define that for $m=0$, $\tau$ should equal 0
- We can’t actually measure anything for $m<1$
- To get $\tau$ for $m=0$, we use the Langley plot and extrapolate backwards to $m=0$
Calibration

• Usually, $\tau \neq 0$ at $m=0$

• This tells us how much we need to correct our measurements

• This is how we calibrate the radiometer
Space-based microwave radiometers
NASA has had microwave sounders in orbit since 1978 (MSU, which flew on TIROS-N)

Microwave sounders have given us a very long satellite-based temperature record

Resolution and number of channels has dramatically improved since then

Using microwave sounders to measure temperature and humidity is an idea that is losing currency with the advent of GPS radio occultation (which we’ll talk about later in the class)
AMSU

• Advanced Microwave Sounding Unit

• Onboard Aqua

• 15 channels in the range 23.8-89 GHz (AMSU-A) and 5 channels in the range 89-183 GHz (AMSU-B)

• AMSU-A: 45 km spatial resolution at nadir, used for water and temperature sounding

• AMSU-B: 15 km, used for moisture sounding
AMSU-B has since been replaced by the Microwave Humidity Sounder (MHS) which basically does the same thing - some of the frequencies have been slightly altered.
Resolution
Weighting Functions

![Weighting Functions Graph]

- Height (km)
- Weighting Function (km⁻¹)
- AMSU-A1
- Nadir
- Clear Sky

Curves for different C-series:
- C14
- C13
- C12
- C11
- C10
- C9
- C8
- C7
- C6
- C5
- C4
- C3
- C15
Weighting Functions

![Graph showing Weighting Functions for AMSU-B with different curves for Nadir, Clear Sky, and Water Cloud at various heights and weighting functions.](image)
AMSU-B/MHS

Figure 3.4.1-1. Microwave Characteristics of the Atmosphere.
Data!

http://amsu.cira.colostate.edu/AMSU_Data_Status.html
More Data!

- [http://amsu.cira.colostate.edu/browse.html](http://amsu.cira.colostate.edu/browse.html)
- [http://amsu.cira.colostate.edu/TPW/default.htm](http://amsu.cira.colostate.edu/TPW/default.htm)