Early Passive Microwave Observations from Aircraft: Soil Moisture, Snow and Sea Ice

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Background

• NASA was scheduled to fly radiometers on the Nimbus-5 s/c in 1972 and needed to know what they could observe over land.
  - ESMR: Electrically Scanned Microwave Radiometer at 19 GHz
  - NEMS: Nimbus-E Microwave Sounder
  - A/C flights organized by Bill Nordberg
    • Late winter 1971 - 73
    • Collaborators: Tom Wilheit & Per Gloersen and Bill Campbell on the ice
Background: Sites

• Soil moisture: 4 Targets
  - Imperial Valley, Southern California
  - Phoenix, Arizona: Salt River Project
  - Weslaco, Texas: Rio Grande Valley
  - Little Washita, Oklahoma
Background: Sites

- **Snow: 3 Targets**
  - Yampa Valley near Steamboat Springs, Colorado: 80 cm snow over wet soil
  - Bear Lake, Utah: 15 cm snow over 25 cm ice over water
  - Cascade Glacier, Washington: 5 m snow over ice

- **Sea Ice**
  - AIDJEX: Ice island north of Barrow, Alaska
    - Mixture of First year and multi-year sea ice
NASA CV-990 Aircraft
1971 - 73 Flights

Over Arctic at < 100m
From Bill Campbell

Over NASA Ames
Moffett Field, CA
NASA CV-990 Aircraft
1971 - 73 Flights

Interior with equipment racks.
# Radiometers on CV-990

## Table I

<table>
<thead>
<tr>
<th>Frequency (GHz)</th>
<th>Wavelength (cm)</th>
<th>Pointing Relative to Nadir</th>
<th>3 db Beam Width</th>
<th>Integration Time (seconds)</th>
<th>RMS Temp. Sens.</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.42</td>
<td>21</td>
<td>0°</td>
<td>15°</td>
<td>0.1</td>
<td>5°K</td>
<td>Edgerton (1970)</td>
</tr>
<tr>
<td>2.69</td>
<td>11</td>
<td>0°</td>
<td>27°</td>
<td>1.0</td>
<td>0.5°K</td>
<td>Gray (1971)</td>
</tr>
<tr>
<td>4.99</td>
<td>6.0</td>
<td>0°</td>
<td>5°</td>
<td>0.1</td>
<td>15°K</td>
<td>Edgerton (1970)</td>
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<tr>
<td>10.69</td>
<td>2.8</td>
<td>0°</td>
<td>7°</td>
<td>2.0</td>
<td>1.5°K</td>
<td>Wilheit (1972)</td>
</tr>
<tr>
<td>19.35 H</td>
<td>1.55</td>
<td>SCANNER</td>
<td>2.8°</td>
<td>0.025</td>
<td>1.5°K</td>
<td>Wilheit (1972)</td>
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<tr>
<td>31.4</td>
<td>0.96</td>
<td>180°</td>
<td>10°</td>
<td>1.0</td>
<td>0.9°K</td>
<td>Wilheit (1972)</td>
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<tr>
<td>37 V</td>
<td>0.81</td>
<td>45°</td>
<td>5°</td>
<td>0.1</td>
<td>3.5°K</td>
<td>Wilheit (1972)</td>
</tr>
<tr>
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<td>0.81</td>
<td>45°</td>
<td>5°</td>
<td>0.1</td>
<td>3.5°K</td>
<td>Wilheit (1972)</td>
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<tr>
<td>94 V</td>
<td>0.32</td>
<td>45°</td>
<td>5°</td>
<td>0.1</td>
<td>7°K</td>
<td>Meeks (1971)</td>
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<td>0.32</td>
<td>45°</td>
<td>5°</td>
<td>0.1</td>
<td>7°K</td>
<td>Meeks (1971)</td>
</tr>
<tr>
<td>INFRARED</td>
<td>10 Microns</td>
<td>14°</td>
<td>&lt;1°</td>
<td>0.1</td>
<td>&lt;1°K</td>
<td>Kuhn (1971)</td>
</tr>
</tbody>
</table>
Sea Ice Image: Clear Day

Gloersen et al. JGR 1972
Sea Ice Image: Cloudy Day

PASSIVE MICROWAVE IMAGE OF ARCTIC SEA ICE (λ=1.55CM) (NASA CV-990 AIRCRAFT, 16 MARCH 1971—CLOUDY DAY)

Gloersen et al. JGR 1972
Sea Ice Spectra

Gloersen et al. JGR 1972
Sea Ice Model

1 - 20 cm

Snow

Brine Pockets

Frazil or Congelation Ice

Freeboard

First Year Ice

10 - 200 cm

Congelation Ice

Smooth

5 - 50 cm

Rough

Snow

Frozen Melt Ponds

Air Pockets

Recrystallized Ice

Freeboard

Multiyear Ice

50 - 500 cm

Congelation Ice

\[ S = 4 \rightarrow 16\%_o \]
\[ \rho = 0.85 \text{gm/cm}^3 \]

\[ S = 4 - 5\%_o \]
\[ \rho = 0.92 \text{gm/cm}^3 \]

\[ S < 1\%_o \]
\[ \rho = 0.7 \text{gm/cm}^3 \]

\[ S = 2 - 4\%_o \]
\[ \rho = 0.8 - 0.9 \text{gm/cm}^3 \]
SNOW SITES

- Snow: 3 Targets
  - Yampa Valley near Steamboat Springs, Colorado: 80 cm snow over wet soil
  - Bear Lake, Utah: 15 cm snow over 25 cm ice over water
  - Cascade Glacier, Washington: 5 m snow over ice
Snow Summary

![Graph showing microwave brightness temperature vs. wavelength for different snow and ice conditions, with annotations for Cascade Glacier, Bear Lake, Steamboat Springs.]
Soil Moisture Flights

- **Where**
  - Phoenix, Arizona & Imperial Valley in southern California
    - Flights in Texas and Oklahoma were not productive
  - Irrigation provided wide range of soil moistures
    - Pre-planting irrigation for cotton

- **When**
  - Late Winter 1971 - 1973

- **Multi-frequency microwave radiometers on a NASA CV 990**
  - Wavelength range 0.8 - 21 cm
Furrow Irrigation
Phoenix & Imperial Valley
ASTER Image
Imperial Valley, California - May, 2000

2 Flight lines
1971-73
Microwave & TIR Comparison
Imperial Valley, California

March, 1973
λ = 10 –12 µm
λ = 21 cm
Alt = 600m
North line
Microwave $T_B$ Image
Imperial Valley, California

1.55 cm Microwave Image of the Imperial Valley
February 8, 1973
Aircraft Altitude = 0.6 km Above Terrain

Salton Sea
$T_B = 119$ K

#1
$T_B = 264$ K
25%

#10
$T_B = 230$ K
35%

#16
$T_B = 275$ K
10%

#26
$T_B = 280$ K
3%

Desert
$T_B = 275$ K

Temperature Scale:
249 253 257 261 265 269 273 277 281 290 K
200 210 220 225 229 233 237 241 245 249 K
$T_B$ vs Soil Moisture
Phoenix & Imp Valley 1972 & 73
$T_B$ vs $\% FC$

$\lambda = 1.55$ CM

$T_B = 310.4 - (0.40 \pm 0.01) \chi$

$r = 0.876$

![Graph showing the relationship between brightness temperature (K) and field capacity as a percentage]
What did we learn

- Limited soil moisture sampling depth
  - Tried 0-15 cm samples in 1971
  - Changed to 0-1, 0-2.5 and 0-5 cm in 1972
  - A few tenths of wavelength in the soil
  - Longer wavelengths better
- Effect of soil texture
- Effects of vegetation
  - Again, longer wavelengths better
Soil Moisture Sensitivity From aircraft
Hand County, South Dakota (5/31/77)
Soil Moisture Sensitivity From aircraft
Hand County, South Dakota (5/31/77)