Airborne Water Vapor Science, Radiometer Requirements, and Capabilities

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Key Points

- Airborne radiometric profiling of water vapor requires:
  - At least one (183 GHz) and up to four key direct-sensing H$_2$O$_v$ bands, and
  - At least one (50-57 or 118 GHz) and up to three key O$_2$ bands for temperature profiling
  - At least one (90 GHz) and up to five window bands for cloud/precipitation sensing and correction

- Retrieval methods and achievable vertical resolutions in clear air are well established.
  - Improvements are yet possible using hyperspectral channel sets and by improving stability and calibration precision.

- Systems for the above require moderately large apertures and correspondingly heavy aircraft or large bays. Such systems (e.g. PSR) are mature.
  - Lighter aircraft or w/o large bays would benefit from compact integrated systems (e.g. PRACO).
Clear-Air Opacity Spectrum

Key tropospheric water vapor ($\text{H}_2\text{O}_v$) and temperature ($\text{O}_2$) bands


Vertical Responses
- Clear Air -

Clear-air incremental weighting functions

$O_2$
118.750 GHz
424.763 GHz

$H_2O$
183.310 GHz
380.197/340 Hz

Klein & Gasiewski,
JGR-ATM,
July 2000
118.75-GHz Temperature Profiling

MTS 7-channel airborne instrument

Some improvement possible in:
- Use of hyperspectral channel sets
- Receiver stability/calibration

* Gasiewski and Johnson, *TGARS*, 1993
Nonlinear Iterative Humidity Profiling

*Kuo and Staelin, *TGARS*, 1994

A priori STD
Linear $D$-matrix
Nonlinear Iterative

Some improvement possible in:
- Use of larger channel sets (7x 183 GHz channels)
- Receiver stability/calibration
- Neural net algorithms

*Kuo and Staelin, *TGARS*, 1994
Scattering and absorption by hydrometeors need to be considered for radiometric water vapor or temperature profile measurements:
Frequency Selection Issues

**NAST-M Convective Cells Observed from 20 km altitude over ocean**

<table>
<thead>
<tr>
<th>Frequency (GHz)</th>
<th>Brightness Temperature Perturbation [Kelvin]</th>
</tr>
</thead>
<tbody>
<tr>
<td>52.6-53.0</td>
<td><img src="image1" alt="" /></td>
</tr>
<tr>
<td>118.75 ± 2.05</td>
<td><img src="image2" alt="" /></td>
</tr>
<tr>
<td>183.31 ± 1.8</td>
<td><img src="image3" alt="" /></td>
</tr>
<tr>
<td>424.76 ± 3.25</td>
<td><img src="image4" alt="" /></td>
</tr>
</tbody>
</table>

Aircraft data tells us:

The 50-GHz band responds only to very strong convection in cell centers; partial beamfilling yields weak/no response.

Combined frequencies yield particle sizes, convective strength; cell diameters $\propto 1/f$.

Even 425 GHz sees through cirrus to convective outflow.

Small-cell sensitivity is proportional to (cell diameter/ant diam.) $\propto f^2$.

Diameter ratio: $\frac{D_{\text{cell}}}{D_{\text{beam}}} \propto f^{-1} \propto f^2$

From Surussavadee and Staelin, April 2007
SMMW Precipitation Cell Spectra

Maritime convection observed at 20 km altitude

Redundant information?

Nonlinear Karhunen-Loeve (KL) mode decomposition: MIR 150, 220, & 325±9 GHz channels

(Gasiewski 1996, unpublished)
* Evans, et al., 1998

NASA GSFC SMMW Imaging Radiometer

Submillimeter Wave Cloud Ice Sensing

**Figure:**

a) Brightness Temperature (K) over time (UTC hour)

b) Ice Water Path (g/m²) over time

c) Median Mass Equivalent Diameter (µm) over time
MM5/DO Hurricane Bonnie 424.763±4GHz
26 August 1998 00:15 UTC

Vertical X-section \( \delta T_b/\delta (ln \kappa_a) \) at 33° N
min = -21.20, max = 0.00

Vertical X-section \( \delta T_b/\delta T \) at 33° N
min = 0.00, max = 0.62

424+/−4 GHz Simulations – 3 hour time steps
424 +/- 4 GHz Simulations - 15 min time steps

MM5/DO Hurricane Bonnie 424.763 +/- 4 GHz
26 August 1998 00:15 UTC

Vertical X-section $\delta T_b / \delta (ln \kappa)$ at 33° N
min = -21.20, max = 0.00

Vertical X-section $\delta T_b / \delta (ln \kappa)$ at 33° N
min = -2.53, max = 17.60

Vertical X-section $\delta T_b / \delta T$ at 33° N
min = 0.00, max = 0.62

Brightness Temperature (K)
Polarimetric Scanning Radiometer (PSR) System

**PSR/L:**
1.4 GHz

**PSR/S**
V, IR
18/21, 50-57, 37, 89, 118, 183, 340, 380, 424 GHz

**PSR/A:**
10.7, 18.7, 21.5, 37, 89 GHz
Polarimetric

**PSR/CX:**
6-7.3, 10.6-10.8 GHz
Polarimetric
with Interference Mitigation

**PSR/S**
CU CET Passive Microwave Vertical Sounder

CET spectrometer modules with internal fast-switched absolute calibration.

Above spectrometers (plus two more under development) provide full AMSU-A/B and NPOESS CMIS and ATMS tropospheric sounding compatibility.

Microwave sounders as installed in PSR/S airborne radiometer sensor head
Airborne Imaging Radiometry

PSR installs on NASA DC-8, P-3B, WB-57F, ER-2, Altair, Navy P-3C, NRL P-3.
Altair Integrated Package

First UAV-based passive microwave vertical sounding sensor
Atmospheric River Sounding
- Weak Atm River Penetrated on May 9, 2005 -

55 GHz

89 GHz

183 GHz

10 um IR
Comparison of Precipitable Water Vapor Retrievals from the ARM MWR, the CET GSR, and Vaisala RS92 radiosondes launched during RHUBC on Julian Day 65, 2007.
10.7H GHz emission-based rain rate retrieval algorithm
Data from CAMEX-3, DC-8 overflights of Hurricane Bonnie
High-Resolution MCS and Hurricane Rainband Imaging

PSR/A 10.7H GHz Rain Rate vs TRMM TMI (2A12)

CAMEX3 - Hurricane Bonnie near landfall, August 26, 1998
Hurricane Bonnie at Landfall
Airborne Microwave Imagery

PSR/A 10.7H GHz imagery from aircraft overpasses of hurricane Bonnie at 1400-1425 GMT (August 26, 1998).

High-resolution airborne imagery clearly reveals - over a limited region - many submesoscale details of rainband precipitation structure absent in satellite imagery.
Regional SM Images - SMEX02
Central Iowa - Loam / Flat Topography

June 25

June 27

June 29

July 1

July 4

July 8

July 9

July 10

July 11

July 12

Legend: 

440000 460000 480000

4620000

4640000

4660000

4680000

4700000

4720000

4740000

4760000

4780000

4800000
Sea Ice Mapping
- Multi-Year Ice - Beaufort Sea, March 19, 2003-

Filamentary structure from pressure ridging observed at ~5 km scale

~350 m resolution

~100 km
Ocean Surface
Azimuthal Emission Harmonics

Wind Direction Harmonics for LS97.DF007.M0075.SLH 970304

Vertical Polarization

Horizontal Polarization

Third Stokes Parameter

W = 10 m/s
Microwave Wind Vector Imaging
Labrador Sea Cold Cyclone - PSR/D - March 7, 1997

Full-scan passive microwave wind vector retrievals during two crossings of a cold cyclone centered in the Labrador Sea.

Retrieved wind vectors are overlaid onto PSR and SSM/I 37H GHz imagery. Blue arrows are wind data from the NOAA/NCEP Eta analysis, dropsondes are orange arrows.

Tight cyclonic rotation of the retrieved and model wind fields about the center of rotation is revealed.
Summary

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