Hurricane Analysis with Microwave Sounder Observations

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The High Altitude MMIC Sounding Radiometer
HAMSRR

Summary

• Multi-function AMSU-A/B sounder in single package
  – Temperature, water vapor, cloud liq. water profile
  – Scattering & precipitation
• Multiple sounding bands, multiple channels
  – 8-channel T-sounding @ 50-60 GHz
  – 10-channel T-sounding @ 118 GHz
  – 7-channel H2O-sounding @ 183 GHz
• New technology
  – Small, low-power, low-mass
  – High performance

Development

• Developed under NASA Instrument Incubator Program, 1998-2001
• First MW sounder using MMIC receivers
  – New IC technology developed by NASA/JPL
• Other cutting-edge elements
  – Compact solid-state spectrometer/filter-bank
  – High-quality quasi-optics: dichroic diplexer
• Designed to operate from high-altitude aircraft
  – Initial plan: UAVs
  – First deployment: ER-2 (2001)
  – Also: DC-8 (2006)

Technology

<table>
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<tr>
<th>MMIC receivers</th>
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<tbody>
<tr>
<td>InP MMIC chain: LNA + Filter + LO-multiplier + Mixer + IF-amp</td>
</tr>
<tr>
<td>• Small, low power: 3”x2.5”x1”; 0.3 kg; 2 W (typical)</td>
</tr>
<tr>
<td>• High performance: wide bandwidth, low noise</td>
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<table>
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<tr>
<th>Filter banks</th>
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<tbody>
<tr>
<td>One module per band (3)</td>
</tr>
<tr>
<td>• Allows single down conversion</td>
</tr>
<tr>
<td>• Compact, low power, high performance (40 dB rejection)</td>
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<tr>
<th>Dichroic plate</th>
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<tr>
<td>Splits 183 GHz (passed) from 118 GHz (reflected)</td>
</tr>
<tr>
<td>• High precision: 1.45 mm hole spacing, 0.2 mm wall thickness</td>
</tr>
<tr>
<td>• High performance: &lt; 2% transmission loss @ 183 GHz</td>
</tr>
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<table>
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<tr>
<th>Calibration targets</th>
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<tr>
<td>One pair (hot &amp; cold) per scan reflector</td>
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<tr>
<td>• Absorber-clad cones on metal core w/thermistors embedded</td>
</tr>
<tr>
<td>• High performance: &lt; -50 dB reflectivity (&gt; 0.99999 emissivity)</td>
</tr>
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</table>
Hurricane Analysis with Microwave Sounder Observations

“HAMSR” Microwave Sounder Deployed on NASA ER-2
TCSP Hurricane Mission (2005)

- Objective: Hurricane processes, cyclogenesis
- HAMSR role: Provide core atmospheric measurements
- Deployment: Right-forward ER-2 superpod
- Field base: San Jose, Costa Rica
- Period: July 1-27, 2005
- Status: Successful flights

ER-2 payloads: Same as CAMEX, no dropsondes
Formation flying with NOAA P-3’s, no DC-8
Data are publicly available
http://tcsp.nsstc.nasa.gov/
TCSP/HAMSR Example: Hurricane Emily

- July 17, 2005
- Overflights at 0730-1200 UT
- Strength @ 0900: 938 mb/130 kt, declining (strong Cat. 4)
Hurricane Emily: Core Observations

HAMS-R-EDOP 50/118 GHz Emily 7:35 - 8:15 UTC

HAMS-R 50/118 and EDOP - Emily 8:30 - 9:00 UTC

Hurricane Emily Warm Core Anomaly
Hurricane Emily

July 17, 2005, 07:48-07:57 UTC

Flight direction

Heading: -60°

~30 km

~20 km

Fractional Tb depression [%]
Hurricane Analysis with Microwave Sounder Observations

Hurricane Emily  July 17, 2005, 08:41-08:50 UTC

Flight direction

Heading: +40°

Ch. 19 (4 km)  Ch. 20 (5 km)  Ch. 21 (6 km)  Ch. 22 (7 km)  Ch. 23 (8 km)  Ch. 24 (9 km)  Ch. 25 (10 km)

Fractional Tb depression [K]
Repeat Views of Eye
Hurricane Emily — July 17, 2005, 07:52 & 08:46 UTC

~ 07:52 UTC
(Nadir: 17.81°N, 81.65°W)

~ 08:46 UTC
(Nadir: 18.05°N, 81.95°W)

~45 km displacement to NW between passes
(~50 km/h - 30 mph - 13.5 m/s)
Scattering Observations
Comparison of microwave sounder (HAMSР) with doppler radar (EDOP)

Hurricane Emily - July 17, 2005

Vertical slicing through a hurricane

Strong correlations are apparent
Physical Basis for Scattering Profiling

RTE: \( T_b = \varepsilon \cdot T_{\text{sfc}} \cdot \tau + \int T_{\text{atm}} \, d\tau \)

Opaque channels (\( \tau \approx 0 \)):
\( T_b \approx T_{\text{atm}} @ \text{w.func peak} \)

Transparent channels (\( \tau \approx 1 \)):
\( T_b \in [T_{\text{atm}}, \varepsilon \cdot T_{\text{sfc}}] \)
If \( \varepsilon \) is low, \( T_b \ll T_{\text{phys}} \)

Scattering layer acts like low-\( \varepsilon \) “surface”
Cold “\( T_{\text{sfc}} \)” replaces lower range of integral
Result is \( T_{\text{scatt}} < T_{\text{normal}} \)

\( \Delta T_b \) vs. channel => vertical distribution of scattering
\( \Delta T_b \) vs. band (wavelengths) => particle size info
for \( d < 1 \) mm (otherwise in Mie regime)
Each panel shows a scatter plot of the HAMSR Tb for a specific microwave band against the EDOP dBZ for two different vertical resolutions, 5 km and 10 km. The panels for 5 km and 10 km are paired together, with the 5 km panels on the left and the 10 km panels on the right.

- **5 km**
  - 50-GHz band
  - 118-GHz band
  - 183-GHz band

- **10 km**
  - 118-GHz band
  - 50-GHz band

Nearly all channels peaking below 150 mb contribute information, even surface channels.

**Example:**

\[ \Delta \text{Tb}(@167 \text{ GHz}) \text{ vs. dBZ}(@10 \text{ km}) \]

Correlation = 85%
Regression Model Function

EDOP Reflectivity at 10 km vs. HAMSR Regression Prediction
Hurricane Emily, July 17, 2005 (TCSP)
Hurricane Analysis with Microwave Sounder Observations

Results: Observed vs. Derived

Hurricane Emily, July 17, 2005 (TCSP campaign, Costa Rica)

Reflectivity (dBZ)

Radar (EDOP)
Observed

Sounder (HAMSR)
Derived

Soon to be published
Hurricane Emily: 3D View
Next: The View From Space
Super Typhoon Pongsona at Guam — Aqua/HSB — December 8, 2002, 03:50 UTC

150 GHz

183 ± 7 GHz

183 ± 3 GHz

183 ± 1 GHz

1200 km

Fractional Tb depression [%]
Closeup of Pongsona
Scattering-index/Convective-intensity per HSB 150-GHz channel

Large convective structures can be resolved with a 15-25 km spatial resolution.
Vertical resolution is ~ 2 km

Spatial resolution: 15 km
And Finally, The View From GEO

GeoSTAR: HAMSR/AMSU functionality from GEO

- Large aperture synthesized
- No mechanical scanning
- Continuous full-disk coverage
- Functionality similar to AMSU
  - $T(p)$ @ 50 GHz/50 km every 20 min
  - $q(p)$ @ 183 GHz/25 km every 15 min
  - Precip, convective intensity, stability
- Low sidelobes; no scan bias
- Expandable to larger apertures
- Tunable to any channels

Coming soon!
GeoSTAR to fly on “PATH”, a Decadal-Survey mission
To Be Continued...

Working hypothesis:
- HAMSR scattering index is measure of convective intensity
- Differential scattering index is measure of vertical distribution of scatterers
- 118-183 GHz difference is measure of size distribution

Next steps:
- Use more accurate scattering-anomaly references
  - E.g., with nearby retrieved profiles
- Derive more accurate differential scattering index profiles
  - Using best estimates of actual weighting functions
- Solve scattering RTE
  - Will use both “macro” approach and “micro” approach
- Determine correlations between HAMSR scattering index & radar reflectivity
- Compare HAMSR scattering obs. with microphys. obs. during NAMMA
- Derive precipitation algorithms
  - Using radar algorithms
- Derive ice water path & microphysical properties of scatterers

And then:
- Apply to space observations
  - LEO: AMSU-A/B, SSM/IS, ATMS...
  - GEO: GeoSTAR