Sounders & Thermodynamics in CPEX

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“Using aircraft and satellite sensors to determine the role of thermodynamics at multiple scales in the initiation and organization of tropical convection”
**High Altitude MMIC Sounding Radiometer**

- Built under IIP-98 in 2001
- Pre-ATMS prototype
- Currently most accurate/sensitive MW sounder
  - Upgraded under AITT in 2010
- Flies on multiple platforms
  - Global Hawk
  - ER-2
  - DC-8
- Data transmitted from Global Hawk in R/T
  - Products displayed in R/T
  - V. useful for situational awareness

**Past and current campaigns**

- **CAMEX-4/Florida**: Hurricanes 2001
- **TCSP/Costa Rica**: Hurricanes 2005
- **NAMMA/Cape Verde**: Hurricanes 2006
- **GRIP/California**: Hurricanes 2010
- **WISPAR/California**: 2011
  - Atmospheric rivers
  - Pacific winter storms
  - Arctic science
- **HS3/Virginia**: Hurricanes 2011-2015
- **CalWater2/California**: Atmospheric rivers 2015
- **SHOUT/CA, VA**: Severe weather 2015-2016
- **CPEX** 2017

**Measurements**

- Observations under all weather conditions
- Thermodynamic state of atmosphere
  - T(z), q(z), CLW
- Precipitation
- Convective structure
  - Reflectivity from hydrometeors
- Applications:
  - Hurricanes
  - Atmospheric rivers
  - Storms
Direct measurements:

- **Brightness temperatures**
  - 25 channels
  - ~ 0.5 K cal. accuracy

Derived vertical profiles:

- Surface to aircraft altitude
- 1-2 km vertical resolution
- 1-2 km horizontal resolution
- Super-critical sampling

- Temperature profiles
  - Dual bands (50 & 118 GHz)

- Water vapor profiles
  - More accurate than AMSU-B

- Liquid water profiles
  - 3 bands \( \Rightarrow \) V. profile

- Reflectivity profiles
  - Experimental product

HAMSR Instrument Specs

HAMSR provides a 3D picture of the thermodynamic environment, convective structure & precipitation

### Three spectral bands

- Band I
  - Center freq. (GHz): 118.75
  - Offset (GHz): -5.500
  - Bandwidth (MHz): 1500
  - WT-func.: Surface

- Band II
  - Center freq. (GHz): 50.30
  - Offset (GHz): 0
  - Bandwidth (MHz): 180
  - WT-func.: Surface

- Band III
  - Center freq. (GHz): 183.31
  - Offset (GHz): -17.0
  - Bandwidth (MHz): 4000
  - WT-func.: Surface

### Weighting functions

- Band I
  - Liquid (\( \sigma = 0.5 \text{ g/m}^3 \))
  - \( \rho_0 \)

- Band II
  - \( \rho_0 \)

- Band III
  - \( \rho_0 \)

### Cross-track scanner

- Scan direction
- Angle direction

CPEX STM 06/08/2017

Lambrigtsen
Sounders are normally used to determine thermodynamic structure:

- Retrieval of 3-D atmospheric temperature, water vapor and cloud liquid water profiles using optimal estimation inversion approach
- Good agreement with dropsonde observations
- Vertical resolution (averaging kernels) is 2-3 km

50 dropsonde comparisons during HS3 over a wide variety of atmospheric conditions

Dropsonde profiles smoothed vertically to match HAMSR vertical resolution

HAMSR website contains validation reports for each flight

Reports include comparison to MERRA and dropsondes T,q,RH

Mean: -0.03 mm
σ = 3.0 mm

Mean: -0.1K
σ = 2 K

Mean: -0.5 %
σ = 16.5 %
Reflectivity: Poor man’s radar

HIWRAP - H. Karl, 0644 UTC 9/17/2010

Perfect space-time match since both sensors are on same aircraft

HIWRAP reproduces all major structures, but at lower spatial resolution
- including cloud top structure
- including eye/eyewall structure

HAMSR has reduced sensitivity near surface

HAMSR has reduced sensitivity through stratiform structures

Vertical profiles of reflectivity across the full scan swath
- Resolution: 1-2 km; Precision: ~ 4 dBZ; Sensitivity: ~ 0 dBZ

Example from GRIP
http://grip.jpl.nasa.gov
Installation

• HAMSR was installed with a slight angle
• ~ 31 degrees, was taken into account during lat/lon-calculation
• 65 usable scan angles (~ -30 to 30)
Real Time Data Overview

– netcdf-files (brightness temperatures, geolocation, t-, q- and rh- profiles, cloud liquid water, precipitable water)
– 1-hour-quicklooks available
  – (example for science flight #13 on 18UTC June 20th)
Moist outflow observed near isolated deep convection

May 31, 2017
Example for science flight #8 on June 11th:

- Show cloud liquid water column (map) and RH for nadir (curtain and 3D-flightpath)
- Only minor gaps
- Area of investigation:
  - around -92º/24º is covered
Transition from mid-level moist air to dry on return leg
Example for science flight #13 on June 19th:

- Shown: liquid water column (map), RH for nadir (curtain and 3D-flightpath)
- Several gaps during strong rain and problems of 54.4 (visible in curtain plot/blue areas for 3D)
- Area of investigation
  - at around -90°/27° is covered
  - But has gaps
• Example for science flight #13 on June 20\textsuperscript{th}:
  • Shown: T at 750hPa (map) and RH for nadir (curtain and 3D-flightpath)
  • Only a few gaps, possible during strong rain
  • Area of investigation
    – around -90°/26° is covered
    – Only a few gaps
Primary: RATATOUILLE

Retrieval Algorithm Testbed with A variety of Transmutable Options to Understand Impacts of Limiting components and Limitations from too high Expectations

• Optimal estimation algorithm in development
• Uses CRTM
• Includes scattering, allows rain estimate
• Allows different background information (e.g. CYGNSS wind) for testing
• Allows channel selection (e.g. can eliminate 54.4 GHz after Flight #11)
• Gives error

Secondary: Neural network quick-looks, re-processed
Post-Processing Example I

- Example for science flight #8 on June 19th:
  - Shown: temperature (curtain) and qv for nadir (curtain and 3d)
  - No gaps, still a little bit noisy
  - Areas with large uncertainty are identifiable via error estimate
Post-Processing Example II

- Example for science flight #13 on June 19th:
  - Shown: liquid water column (map), Qv for nadir (curtain and 3D-flightpath)
  - No gaps, but sometimes noisy retrieval:
    - Regions with large uncertainties
    - Sometimes unrealistic profiles
  
  => Noisy channels on this day
  => Channel selection needed
Post-Processing Example III

• Example for science flight #13 on June 20\textsuperscript{th}:
  • Shown: rain water column (map), $Q_v$ for nadir (curtain and 3D-flightpath)
  • No gaps, low uncertainties during most of the flight
    – Uncertainty impacts in the first quarter and last quarter
    – Main focus area good
Post-Processing – Improvements

HAMSR allows to test the impact of “channel loss”, e.g. not using noisy channels

- Left side shows temperature-retrieval with all channels
- Right side shows the retrieval results of temperature without 54Ghz
- Bottom is the difference

=> More noise, impact on lower tropospheric retrieval
Post-Processing – Improvements

• RATATOUILLE allows the change of background conditions, like for example surface wind

• When using CYGNSS data, we can actually sometimes see an impact on the retrieval, but winds have to be strong

• Example is not CPEX flight, it is Hurricane Harvey
Post-Processing - Further Testing

- Calculate without noisy channels
- Drop sonde comparisons
- Comparisons with radar to verify, if rain is at the “right place”
- Verify, if CYGNSS-data impacts the results
MTHP in CPEX

- Microwave Temperature and Humidity Profiler (MTHP)
  - Microwave radiometer that scans forward of the aircraft at 60 and 183 GHz (temperature and water vapor)
  - New capability, ‘Humidity’ capability to be demonstrated, experimental

- First installation on the DC-8
  - Flew on ~14 of 16 flights

- Nominal Operation ~75%, many lessons learnt
  - Severe environment on the wing + operation in icing conditions (insufficient heaters)
  - Interference from the aircraft (additional filtering will be implemented)
  - Catastrophic parts failures due to operation during landing in thunderstorm (SF #6)

- Synergy on CPEX
  - Dropsondes will provide in-situ comparisons below the aircraft
  - HAMSR and MAS are similar microwave instruments will allow for performance cross-comparisons
  - MTHP only microwave instrument that scans above the aircraft
MTHP Key Capability
183 GHz Channels

• Enabling technology 35 nm InP HEMT amplifiers
  – Significant investment from NASA + others > $10 million
• Application of these technologies to instrumentation other than space
  – Both the 60 and 183 GHz channels upgraded

MTHP 183 GHz
Four Channel Radiometer

183 GHz Brightness Temperatures

<table>
<thead>
<tr>
<th>Brightness Temperature [K]</th>
<th>179</th>
<th>182.6</th>
<th>182.8</th>
<th>183.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angles (180° Zenith, 360° Nadir)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

CPEX STM 06/08/2017
Lambrigtsen
## MTP vs MTHP Performance Comparison

<table>
<thead>
<tr>
<th></th>
<th>MTP</th>
<th>MTHP</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Frequency Bands</strong></td>
<td>60 GHz Only</td>
<td>60 and 183 GHz</td>
</tr>
<tr>
<td><strong>Science</strong></td>
<td>Temperature Only</td>
<td>Temperature and Water Vapor</td>
</tr>
<tr>
<td><strong>Channels</strong></td>
<td>3</td>
<td>8 (4 + 4) Configurable and Redundant</td>
</tr>
<tr>
<td><strong>Technology</strong></td>
<td>Mixer Front End</td>
<td>Low Noise Amplifier Front End</td>
</tr>
<tr>
<td><strong>Calibration Path</strong></td>
<td>Did <em>Not</em> Include Aperture</td>
<td>Full Signal Path Including Aperture</td>
</tr>
<tr>
<td><strong>Single Scan Duration</strong></td>
<td>~13 seconds (200 ms)</td>
<td>~1.5 seconds (10 ms)</td>
</tr>
<tr>
<td><strong>Measurement</strong></td>
<td>Series</td>
<td>Parallel</td>
</tr>
<tr>
<td><strong>Angles measured</strong></td>
<td>10</td>
<td>50 to 70</td>
</tr>
<tr>
<td><strong>Scan Type</strong></td>
<td>Stop and Stare</td>
<td>Continuous</td>
</tr>
</tbody>
</table>
Cooler above
below

Warmer below

At this altitude, 2 of the channels are very similar

• ~270° is flight level (~180° zenith and 360° nadir)
• Single scan example shows a more transparent channel is necessary for sensitivity away from the aircraft, especially below the flight altitude
• 60 GHz NEDT ~0.7-0.8 K is higher than the expected 0.5 K
Data ‘Sensitivity’

- Shown is the 53 GHz channel
  - 190° near zenith upward view
  - Changes in roll significantly impact the observations
- ‘Easy’ to integrate the aircraft data to flag for ‘large’ roll values
- Issues arise due to the installation
  - MTHP on the edge of the wing, during flight there is noticeable movement and flexing
- Extra quality control must be performed on the data to ensure that the aircraft motion is accounted for or discard data if there is a suspected issue
Preliminary Curtain Plots from SF#4

- Preliminary retrievals have significant ‘excess noise’ and expected structure is ‘washed out’
- New python retrieval framework still being optimized
MTHP Next Steps

• Complete the quality control of the data with appropriate flagging of the data for the aircraft maneuvers
• Refine the retrieval process with the automated comparisons to a priori
• Compare the output data with dropsondes
• Compare the output data with HAMSR and MASC
MASC in CPEX

• Instrument has been operating continuously and collecting measurements during all the CPEX flights so far.
• Minor momentary instabilities have been observed in the 118 GHz channels. Instrument was pulled out of the pressure box to check for any loose connections or fasteners but nothing conclusive was found on May 28.
MASC Specs

<table>
<thead>
<tr>
<th></th>
<th>118 GHz</th>
<th>183 GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>System noise temperature</td>
<td>&lt; 600 K</td>
<td>&lt; 800 K</td>
</tr>
<tr>
<td>Minimum # of channels</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Minimum spectral resolution</td>
<td>350 MHz</td>
<td>350 MHz</td>
</tr>
<tr>
<td>If Channels</td>
<td>+1, +2, +7 and +8 GHz</td>
<td>-1, -2, -7 and -8 GHz</td>
</tr>
<tr>
<td>Minimum Spatial resolution</td>
<td>24 km at nadir (orbit:400 km)</td>
<td>13 km at nadir (orbit:400 km)</td>
</tr>
<tr>
<td>Minimum Beam efficiency</td>
<td>&gt;90%</td>
<td>&gt;90%</td>
</tr>
<tr>
<td>Mass</td>
<td>5 kg</td>
<td></td>
</tr>
<tr>
<td>Power</td>
<td>W</td>
<td></td>
</tr>
<tr>
<td>Volume</td>
<td>3U</td>
<td></td>
</tr>
<tr>
<td>Data Rate</td>
<td>10 kbps</td>
<td></td>
</tr>
</tbody>
</table>

Direct measurements:
- Brightness temperatures
  - 8 channels
  - ~ 0.5 K NEDT @ 5ms

Derived vertical profiles:
- Temperature profiles (118 GHz)
- Water vapor profiles (183 GHz)

Cross-track scanner
MASC Performance

- NEDT plots for all channels are similar to the plot shown above for 183.31 GHz ± 1 GHz.
- Bandwidths are 390-400 MHz for all channels.

<table>
<thead>
<tr>
<th>Channel</th>
<th>NEDT [K]@100 ms</th>
</tr>
</thead>
<tbody>
<tr>
<td>183.31±1 GHz</td>
<td>0.16</td>
</tr>
<tr>
<td>183.31±2 GHz</td>
<td>0.15</td>
</tr>
<tr>
<td>183.31±7 GHz</td>
<td>0.12</td>
</tr>
<tr>
<td>183.31±8 GHz</td>
<td>0.14</td>
</tr>
<tr>
<td>118.2±1 GHz</td>
<td>0.21</td>
</tr>
<tr>
<td>118.2±2 GHz</td>
<td>0.23</td>
</tr>
<tr>
<td>118.2±7 GHz</td>
<td>0.24</td>
</tr>
<tr>
<td>118.2±8 GHz</td>
<td>0.24</td>
</tr>
</tbody>
</table>
June 2: SCIENCE FLIGHT #4
MASC TB compared with APR-3

Courtesy of Dr. J Turk
• The MASC retrievals for June 19 measurements are shown.
• The time axis means minutes since beginning of the leg.
Served as the official project website, offering the following resources:

- Event Calendar
- Flight and Science Summaries
- Daily Forecast Reports
- Quicklook Images
- Information about aircraft and instruments
- Team contact information and campaign image gallery
- Links to related data resources – data portal, FTP server, model forecast pages, etc.
CPEX FTP Server

ftp://mwsci.jpl.nasa.gov/outgoing/cpex

- Data is organized by instruments and dates/flights, including satellite data, CPEX data, and GFS model forecasts for easy download
- Satellite is data subsetted into the CPEX domain for the campaign time period
  - AIRS L2, ASCAT Wind, MUR 1km SST, TPW from Metop-B, NOAA-18 and NOAA-19, microwave brightness temperature from AMSR2, GMI, SSMIS, AAMH Microwave sounder data product from AMSU-A and MHS, IMERG GPM, MODIS AOT from Terra, SMAP wind speed, and JPL Rain Indicator product.
- The latest CPEX science quality data is available from the instrument PIs
  - HAMSR, APR3, dropsonde, DAWN and DC8 flight tracks.
- Daily GFS forecast at 00Z for 120 hours at every 12 hours interval
  - Relative humidity, temperature, wind vectors, vertical velocity and height at different pressure levels
CPEX Data Portal
https://cpexportal.jpl.nasa.gov

- Displays NRT satellite data, model forecast, and airborne data products on a 3D global Earth using Cesium (a Google Earth-like web-based 3D Virtual Globe Platform).
- Overlays multiple types of products with opacity adjustment and separate calendars for model and data for easy comparison.
- Allows access to raw data associated with the images for interactive analysis. Subsetting tools are built in so users can select circular or rectangular areas, lines, or points on the globe.
  - MySQL and Solr databases are used to provide temporal and geospatial search to find the satellite swaths that intersect with the selected area.
- Supports data exploration and visual investigation of all the relevant data products that describe the physical processes in the CPEX domain before, during, and after the campaign.