Hardware Performance, Software Tools and Data Formats

Ground-Based Microwave Sounding Radiometers are prepared for Operational Networks and Data Assimilation

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Assimilation of global satellite observations revolutionized NWP
Include the ground-based perspective to „close the observational gap in the boundary layer“
A number of remote sensors are available for continuous atmospheric sounding

Microwaves radiometers ...
  - ... measure vertical temperature and humidity profiles of the entire troposphere
  - ... provide valuable measurements in cloudy and even light rain conditions
  - ... offer a high-temporal resolution (minute-scale)
  - ... are successfully/continuously operated under all environmental conditions

Operational networks used for data assimilation require more:
  - Adequate hardware performance
  - Standardized data formats
  - Software tools for automated processing, quality checking and data distribution
Towards Radiance Assimilation of Ground-based Microwave Sounders

- Error Model
- Forward Model
- Radiance Observation
- Stability
- Noise
- Accuracy
- Band-Passes
- Beam Widths
- Simulated Radiance
- Radiative Transfer (+ Jacobians)
- Assimilation
- Data Product
- Standardization
- NWP model

* De Angelis et al., Geoscientific Model Development, 2016
Microwave Sounding Radiometer: RPG-HATPRO Design

Direct Detection Filter-Bank Design
- 7 channel water vapour band (22 to 31 GHz)
- 7 channel oxygen band (51 to 58 GHz)
- all channels parallel @1 s res. (100% duty cycle)

Individual Band-Passes
200 MHz – 2000 MHz
→ optimized TB sensitivity

Elevation Scanning for enhanced information content

Network Suitable
- TCP/IP interface
- internal monitoring
- housekeeping data
- sanity checks
- automatic alerts
Microwave Sounding Radiometer: RPG-HATPRO Evolution

- First generation launched more than 15 years ago
- More than 200 deployments worldwide
- Evolution through instrument generations:
  
  Improved …
  - noise performance
  - radiometric stability
  - calibration accuracy

  … drive retrieval quality:
  - reduced RMS
  - more degrees of freedom
  - added features
# Microwave Sounding Radiometer: RPG-HATPRO Error Model

## Receiver Noise

<table>
<thead>
<tr>
<th>Int. time</th>
<th>1 s</th>
<th>10 s</th>
<th>100 s</th>
</tr>
</thead>
<tbody>
<tr>
<td>f / GHz</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22.24</td>
<td>0.070</td>
<td>0.025</td>
<td>0.010</td>
</tr>
<tr>
<td>23.04</td>
<td>0.072</td>
<td>0.030</td>
<td>0.015</td>
</tr>
<tr>
<td>23.84</td>
<td>0.068</td>
<td>0.028</td>
<td>0.013</td>
</tr>
<tr>
<td>25.44</td>
<td>0.067</td>
<td>0.026</td>
<td>0.014</td>
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<tr>
<td>26.24</td>
<td>0.070</td>
<td>0.025</td>
<td>0.013</td>
</tr>
<tr>
<td>27.84</td>
<td>0.065</td>
<td>0.026</td>
<td>0.013</td>
</tr>
<tr>
<td>31.40</td>
<td>0.083</td>
<td>0.035</td>
<td>0.020</td>
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<tr>
<td>51.26</td>
<td>0.120</td>
<td>0.050</td>
<td>0.030</td>
</tr>
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<td>0.050</td>
<td>0.025</td>
</tr>
<tr>
<td>53.86</td>
<td>0.110</td>
<td>0.050</td>
<td>0.025</td>
</tr>
<tr>
<td>54.94</td>
<td>0.110</td>
<td>0.045</td>
<td>0.028</td>
</tr>
<tr>
<td>56.66</td>
<td>0.070</td>
<td>0.030</td>
<td>0.018</td>
</tr>
<tr>
<td>57.30</td>
<td>0.060</td>
<td>0.028</td>
<td>0.015</td>
</tr>
<tr>
<td>58.00</td>
<td>0.050</td>
<td>0.025</td>
<td>0.010</td>
</tr>
</tbody>
</table>

### Receiver Stability

**23.84 GHz**

![Receiver Stability Graph](image)

- 24 h on warm load
- Integration Time / s
- ASD($\Delta T$) / K

**Calibration Accuracy**

$$\Delta T_B = \pm 0.15 \, K$$
Microwave Sounding Radiometer: RPG-HATPRO Covariance Matrix

\[ J(x) = \frac{1}{2} (x - x_b)^T B^{-1} (x - x_b) \]
\[ + \frac{1}{2} (y - F(x))^T R^{-1} (y - F(x)) \]
RPG Software Tool
Data Flow

Data Center / Server

ODIN
Observation Data Infrastructure Network

ODIN
Host-PC
SFTP
Push/Pull
NetCDF
QC

ODIN
Host-PC
SFTP
Push/Pull
NetCDF
QC

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TCP/IP
RPG Software Tool
Quality Checks

- Train spectral retrieval: $T^\text{instrument}_B = f(T^\text{measured}_B)$
- $T^\text{instrument}_B$ considers instrument characteristics (error model / band-passes / beam widths)
- Analyse spectral deviations
- Apply automatic quality checks:
  - hardware mal-functions
  - heavy rain events
  - ...

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RPG Software Tool
Data Formats

- Definition of a standard data format: **CF (1.6) compliant NetCDF files**
- Implementation by manufacturer

**Naming convention adapted to the satellite community:**

- L1B: per sensor, Microwave-TB, IRR-TB, …
- L1C: co-located on time-grid
- L1D: derived L1 like cloud-removal from TB
- L2B: retrieved products (T, Q, IWV, LWP, …)

**Meta-data section in the file header:**

- L1: covariance matrix, absolute accuracy, band-pass filters, beam widths
- L2: retrieval type, data source, RTM, …
The latest Generation-5 of HATPRO radiometers have reached maturity in precision, stability, robustness.

By joint efforts of the user community - like COST-TOPROF – microwave radiometers have been prepared for operational networks in terms of standardization, procedures and software tools.

Ground-based microwave radiometers are ready for operational networks and data assimilation to close the observational gap in the boundary layer.

Thank you very much.
Jacobians from RTTOV-gb
RPG-HATPRO Correlation Matrix

![Image of the RPG-HATPRO-G5 Correlation Matrix](image-url)
Data Flow

MIDGARD - Microwave Data Gadgets for Acquisition, Reprocessing, and Dissemination

A Client-Server code framework to acquire, collect, centralize, quality-check, post-process, retrieve, and re-distribute microwave remote sensing data

HATPRO
Fibre optical lines to connecting MWR and host
Host-PC

RAGNAR
Remote Access Gadget for Network Attached Radiometers / Radars

ODIN
Observation Data Infrastructure Network
Unix server process using agents like RAGNAR to collect data, hold it in memory, check, reject, co-locate, re-distribute ...

L.o.d.
web-page creation, graphical output for control and survey

NJOERD
Network for Joint Observations + Estimates in Realtime Distribution

LOKI
Level-0 Kernel Interface (watch-dog, restart ...)

FENRRIR
File ENcoding & Reading Infrastructure for Radiometers / Radars

IDUNN
Information Distribution User Network, NetCDF

Internal Website

WWW Website

Monitoring Tools

File-Set 1
File Sets for Post-Processing

File-Set 2

File-Set ...

Data Dissemination

Data Center
Central Server

National Weather
Service Server

... Server

Local Output File 1

Local Output File 2

Local Output File 3

Local Output File 4

Local Output File ...

FTP Push/Pull

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