Results from Three Years of Ka-band Propagation Characterization at Svalbard, Norway

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• Overview of LEO Ka-band Missions
• NASA Near Earth Network
• Svalbard
  – Site Description
  – Data Calibration
  – Measurement Results
  – Comparisons with ITU Model
• Application to JPSS-1/2 System Design
• Conclusions and Future Work
NASA’s Near Earth Network (NEN)

15 NASA and commercial-owned sites comprise the Near Earth Network
**LEO Ka-band Missions**

- Past/Current LEO Ka-band communications systems (SCaN Testbed, JEM, ALOS, Envisat) rely on space-to-space links
  - TDRSS (NASA)/Artemis (ESA)/DRTS (JAXA)
- The Interagency Operations Advisory Group (IOAG) has identified several upcoming LEO missions in the 2017-2020 timeframe with planned use of the direct-to-Earth Ka-band spectrum (26GHz) to polar networks
  - Up to ~10 Gbps data rates
  - NASA has pledged to transition current near Earth operations into the Ka-band, beginning with polar network sites (i.e., Svalbard, Fairbanks, McMurdo)

<table>
<thead>
<tr>
<th>Orbit</th>
<th>Agency</th>
<th>Mission</th>
<th>Planned Launch</th>
<th>Link at 26 GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEO</td>
<td>NOAA/NASA</td>
<td>Joint Polar Satellite System (JPSS)-1</td>
<td>2017</td>
<td>Transmit: space-to-ground (Svalbard, Norway; Fairbanks, AK; McMurdo, Troll)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Transmit: space-to-space (secondary path)</td>
</tr>
<tr>
<td></td>
<td>ESA/EUMETSAT</td>
<td>EPS-SG (2 satellite configuration with 3 MetOp SG satellite pairs)</td>
<td>2020, 2022</td>
<td>Transmit: space-to-ground (Svalbard, McMurdo)</td>
</tr>
<tr>
<td></td>
<td>JAXA</td>
<td>Advanced Land Observation Satellite (ALOS)-2</td>
<td>2013</td>
<td>Transmit: space-to-space (DRTS)</td>
</tr>
</tbody>
</table>
Svalbard Site Description

Overview

Svalbard Station Polar Network

Approach

As the first Near Earth Network (NEN) site to be upgraded to operational Ka-band, NASA GRC was tasked with characterizing the propagation effects of Ka-band in a northern latitudes environment.

Measurements initiated in 2011 to measure passive radiometric attenuation in polar atmosphere to determine system planning requirements for Ka-band upgrades
## Svalbard Site Description

Radiometrics PR-2230

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calibrated Brightness Temperature Accuracy</td>
<td>$0.2 + 0.002 \cdot</td>
</tr>
<tr>
<td>Long Term Stability</td>
<td>$&lt; 1.0 \text{ K/0.5yr (typ.)}$</td>
</tr>
<tr>
<td>Resolution (dependent on integration time)</td>
<td>$0.1 \text{ to } 1 \text{ K}$</td>
</tr>
<tr>
<td>Integration Time (user selectable in 10 msec increments)</td>
<td>$0.01 \text{ to } 2.5 \text{ sec}$</td>
</tr>
<tr>
<td>Brightness Temperature Range</td>
<td>$0 - 400 \text{ K}$</td>
</tr>
<tr>
<td>Antenna System Optical Resolution and Side Lobes</td>
<td>$3^\circ / -24 \text{ dB}$</td>
</tr>
<tr>
<td>Frequency Agile Tuning Range</td>
<td>$22.0 - 30.0 \text{ GHz}$</td>
</tr>
<tr>
<td>Standard Calibrated Channels</td>
<td>21</td>
</tr>
<tr>
<td>Pre-detection Channel Bandwidth</td>
<td>$300 \text{ MHz}$</td>
</tr>
<tr>
<td>Surface Sensor Accuracy</td>
<td></td>
</tr>
<tr>
<td>Temperature (-50 to 50 °C)</td>
<td>$0.5 \text{ °C } @ 25 \text{ °C}$</td>
</tr>
<tr>
<td>Relative Humidity (0-100%)</td>
<td>2%</td>
</tr>
<tr>
<td>Barometric Pressure (800 to 1060 mb)</td>
<td>$0.3 \text{ mb}$</td>
</tr>
<tr>
<td>Infrared Thermometer (IRT)</td>
<td>$(0.5 + 0.007 \cdot \Delta T) \text{ °C}$</td>
</tr>
<tr>
<td>Calibration Systems</td>
<td>TIP method</td>
</tr>
<tr>
<td>Primary Standards</td>
<td>Noise Diode + ambient Black Body Target</td>
</tr>
<tr>
<td>Operational Standards</td>
<td></td>
</tr>
</tbody>
</table>
**Data Calibration**

**Part 1: Bad Data Removal Procedure**

- Occasionally, system instabilities, operator intervention, or physical issues (i.e., ice formation on radiometer antenna) will introduce erroneous data and requires removal
  - An automatic approach identifies and flags rms brightness temperature thresholds which exceed 10 K over a 1-min block period and removes uncorrelated channel events
  - A manual approach to validate automatic removal and visually inspect and isolate anomalous data is performed on daily files
Data Calibration
Part 2: Ground Emission Correction Procedure

- Scatterplot comparison between $T_B$ derived from ERA Interim profiles and radiometer measurements indicate common clear sky slope, but DC bias on channels.
- Bias identified as ground emission

$$\Delta T = \frac{(1 - H)T_{GND}}{H}$$

$H_{22}=0.94$
$H_{26}=0.96$
$H_{30}=0.96$

- Correction for ground emission contribution results in excellent agreement between radiometer measurement and profile-based model.
Statistical Results - Meteorology

CCDF of Svalbard Temperature

CCDF of Svalbard Barometric Pressure

CCDF of Svalbard Relative Humidity

CDF - Dew Point [2011-05-10 to 2014-04-01]
(2011-05-10 to 2014-04-01)
Model 2010 fits empirical data with an error of less than 10%.
Model 2013 is around 30% apart from the empirical data.
Discrepancy related to the latest updates of the ITU maps.
Needs to be understood (which changes and in which way they influence the results).
Application to JPSS-1 Mission

• JPSS-1 link budget designed for 5° elevation angle at 99% availability for polar network operations (~12 dB margin for atmospheric propagation + 3 dB excess margin)

• Measurements at the Fairbanks, AK, site and the Svalbard site indicate that system was overdesigned by ~4 dB for worst case conditions (5° acquisition availability) and >7 dB for best case conditions (taking into account LEO orbit)
Concluding Remarks

• ITU attenuation availability model predictions at Svalbard site do not consistently agree with measured data
  – 2010 maps show good agreement with radiometer measurements (<10%), but updated 2013 maps show increased discrepancy (>30%)
• Svalbard propagation campaign results indicate that the current JPSS-1 design margin for atmospheric attenuation is overdesigned by as much as 7 dB. Presently working with NASA/NOAA JPSS team to modify requirements for follow-on JPSS-2 mission to reduce design constraints
• Will continue to take propagation data at the Svalbard site for a minimum 2 more years...

Follow-on Work
• Validation of scintillation models at high latitudes (polar) sites has not been effectively performed by this measurement campaign
• Presently working with NASA to expand characterization activities to other NASA polar sites (i.e., Fairbanks, McMurdo Station) to ensure Ka-band availabilities for polar NEN network are realizable
Acknowledgements:
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For their contributions to the processing and validation of the radiometer data

THANK YOU!
BACKUP CHARTS
Site Characterization: Ka-band in Polar Atmosphere
Svalbard

- Clouds are the dominant attenuation mechanism at the Svalbard site, as cloud cover accounts for attenuation approximately 70% of the time.
  - Fall/Summer show slightly less cloud cover vs. Spring/Winter season
  - Distinction between type of cloud difficult to determine from IR measurements

\[ C_I = T_{surface} - T_{IR} \]
In the post-ACTS era, NASA propagation activities have primarily focused on site characterization of NASA operational networks throughout the world.
Site Characterization: Ka-band in Polar Atmosphere
Fairbanks, AK

Fairbanks Station Polar Network

During ACTS Experiment, data was collected at Fairbanks, AK from 1994-1998.

Measurement Parameters
Frequencies: 20/27.5 GHz
Elevation Angle: 8 deg

*Model discrepancy between margin requirements between measured data and models. Model prediction improves with addition of local rain rate information, but still overpredicts attenuation effects.*