National Aeronautics and Space Administration
Glenn Research Center at Lewis Field

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

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Keeping the universe connected.
Outline

• 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)

Ka-band operations currently in use (SDO, LRO)

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

## Parameter Specification

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

- 2012
- 2013
- 2014
- Total

CCDF of Svalbard Barometric Pressure

- 2012
- 2013
- 2014
- Total

CCDF of Svalbard Relative Humidity

- 2012
- 2013
- 2014
- Total

CDF - Dew Point [2011-05-10 - 2014-04-01]
(2011-05-10 to 2014-04-01)

Percent of Time Value is Exceeded [%]
- 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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THANK YOU!
BACKUP CHARTS
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
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.