GRC RF Propagation Studies
Glenn Research Center
ESA Information Exchange
PI: James Nessel
October 1, 2013
Outline

• Historical Perspective: ACTS
• Ka-band Site Characterization of NASA Networks
  – Ka-band Propagation Studies in the Tropics: Guam
  – Ka-band Propagation Studies at the Pole: Svalbard
• Beyond Ka-band: Millimeter Wave Propagation Studies
• International Collaborative Efforts: Alphasat Aldo Payload Experiment
• NASA Online Propagation Database
• ITU Modeling Efforts
Program History – ACTS

NASA helped open up the Ka band spectrum through propagation characterization in the 1990’s through the Advanced Communications Technology Satellite (ACTS) program.
ACTS Propagation measurements have laid the foundation for the development of global attenuation prediction models used by system designers to properly account for propagation losses in communications system link budgets.

ACTS Propagation measurements identified and characterized many of the loss mechanisms associated with Ka-band systems including:

- Rain Attenuation
- Attenuation due to Gaseous Absorption
- Snow/Ice Depolarization
- Scintillation
- Wideband Dispersion
- Site Diversity
- Antenna Wetting

"Perhaps the crown jewel of the ACTS program is the exceptional body of knowledge developing from the measurements. The data in the handbook, the engineering guide, the guidelines, will be a significant enabler for all satellite communications - government, military, civil, commercial - for years to come, perhaps for decades. We should also understand that this is yet another excellent example of NASA leading the way by providing technical advantages that enhance the state of the art and the nation's leadership. This exceptional work and the commitment behind it is deserving of the highest praise. It gives me great pleasure on behalf of our industry to salute you and say, 'Well done ACTS, and many, many thanks.'"

Dr. Tom Brackey
Excerpt from Critical Perspectives on NASA’s ACTS Satellite, 2002
KA-BAND SITE CHARACTERIZATION OF NASA NETWORKS
In the post-ACTS era, NASA propagation activities have primarily focused on site characterization of NASA operational networks throughout the world.
Throughout propagation campaigns, ground station hardware has undergone evolutionary improvements in performance and autonomous operation procedures.
Current GRC Propagation Campaigns

Overview

**Goldstone, CA**
- Interferometer Data Collected (as of Sep. 2013): 5YRS 11MO

*Objective:* To statistically characterize the Goldstone DSN site to determine system impact of atmospheric turbulence on the arraying of widely distributed ground based systems for uplink arrays operating at Ka-band

**White Sands, NM**
- Interferometer Data Collected (as of Sep. 2013): 4YRS 8MO
- Microwave Profiler Data Collected (as of Sep. 2013): 1YR
- AFRL V/W Radiometer Data Collected (as of Sep. 2013): 10MO

*Objective:* To provide secondary site measurements to reference Goldstone DSN site performance. To characterize atmospheric effects in the millimeter wave.

**Guam**
- Interferometer Data Collected (as of Sep. 2013): 3YRS 4MO

*Objective:* To add tropical rain zone characterization of Ka-band for insertion to the ITU database. To determine potential for short baseline site diversity in the tropics.

**Svalbard**
- Radiometer Data Collected (as of Sep. 2013): 2YRS 4MO

*Objective:* To statistically characterize the Svalbard NEN site to determine system impact of polar atmosphere for expected Ka-band system upgrades.
Concept

Arraying of several small aperture antennas vs. single large aperture antenna provides the following advantages:

- Reduced maintenance costs
- Graceful degradation of performance of communications system
- Relative ease of meeting strict surface accuracy requirements for small apertures
- Enable new communications capabilities
- N² improvement in Effective Isotropic Radiated Power (EIRP)

\[ EIRP_{array} = \sum_{m=1}^{N} G_m \cdot \sum_{n=1}^{N} P_n \]

Assuming identical antenna elements,

\[ EIRP_{array} = G_{array} \cdot NP_0 \]

\[ \left\langle G_{array} \right\rangle = \eta D_0 \frac{1}{N} \sum_{m=1}^{N} \sum_{n=1}^{N} \sigma_{mn}^2 \]

Propagation data characterizes this value (variance in phase amongst widely distributed antenna elements)

\[ \sigma_{mn}^2 (\theta_{el}, f, r) = \sigma_{mn}^2 (\theta_0, f_0, r_0) \left( \frac{f}{f_0} \right) \left( \frac{r}{r_0} \right)^\alpha \left( \frac{\sin \theta_0}{\sin \theta_{el}} \right) \]
Site Characterization: Atmospheric Phase Distortion
Goldstone, CA (Deep Space Network)

Goldstone, CA: Current Deep Space Network Site
Propagation program initiated in 2007
Site Characterization: Atmospheric Phase Distortion
White Sands, NM (Space Network)

White Sands, NM: Proposed Secondary Site Characterization Propagation program initiated in 2009
Site Characterization: Ka-band in the Tropics
Guam (Space Network)

Guam: NASA Space Network ground site
Propagation program initiated in 2010
Compact, highly convective rainfall in Guam has shown evidence of rain diversity over short (600-m) antenna separation distances. Guam site diversity study indicates that meaningful diversity gain is possible within short baseline separation distances (<20 km) and is sufficient to overcome rain attenuation. Analysis results lays foundation for modeling of short baseline site diversity, which his currently lacking.

**IMPACT:** Conclude that high availability Ka-band operations in a tropical environment is possible utilizing short baseline site diversity.

Ka-band Performance Site Comparisons

Ka-band Performance Site Comparisons

### Site Comparison 600 sec Phase RMS CDF’s - Scaled to Zenith/300m Baseline

**Site** | **2-Element Array Loss** | **Site** | **Total Path Attenuation**
---|---|---|---
 | **90th Percentile** | **99th Percentile** | **90th Percentile** | **99th Percentile**
---|---|---|---|---
Goldstone | 0.17 dB | 0.94 dB | Goldstone | 1.4 dB | 3.2 dB
White Sands | 0.23 dB | 0.89 dB | White Sands | 1.6 dB | 3.9 dB
Guam | 0.62 dB | 1.62 dB | Guam | 3.9 dB | 7.8 dB

Site Characterization: Ka-band in Polar Atmosphere
Svalbard (Near Earth Network)

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*

![Cloud Index CDF](image)

- Indicates cloud cover ~70% of the time
Two-year attenuation observations at Svalbard show good agreement with attenuation statistics at Alaska.

Svalbard data collection indicates significant cloud attenuation present for high percentage of time not accounted for in model predictions (resulting in discrepancy of ~2 dB).

**IMPACT:** Ka-band propagation data results from Svalbard requires reevaluation of Ka-band system operations (reduced availability from 99% to 97%) by NEN planning team at GSFC.
BEYOND KA-BAND:
Millimeter Wave Propagation Studies
Characterization of Q/V/W-band

Instruments: Profiling Radiometer
W/V-band Radiometer
Data Collection Started: December 2012
Total Number of Months: 9

- GRC Model/Software developed to utilize outputs of microwave radiometer and profiler to develop predictions for propagation impairments at V/W-band up to ~98% availability (cannot determine rain attenuation effects)
Collaboration with AFRL and University of New Mexico (UNM) provides cost-effective opportunity to conduct immediate near-term rain fade and depolarization measurements prior to having an active W/V-band beacon for model validation and rain fade mitigation.

**IMPACT:**
- Terrestrial Line-of-Sight Experiment in W/V-band will provide immediate preliminary validation/prediction of mm-wave rain attenuation and depolarization models prior to the expected W/V-band beacon payload launch in 2017 timeframe.
INTERNATIONAL COLLABORATIONS

Alphasat Aldo Payload Experiment
Collaboration with AFRL and Politecnico di Milano (POLIMI) provides unique opportunity using the Alphasat beacon to further improve models to predict rain attenuation effects on Q/V/W-band signals (characterization up to 99.9% availability).

- NASA to provide Ka/Q-band beacon receiver and weather sensors
- AFRL to provide operations funding and V/W-band radiometer
- POLIMI to provide operations/data collection support and access to ASI propagation database

**IMPACT:** Through the concomitant characterization of passive W/V-band gaseous absorption, multiple coherent beacon frequencies (20/40 GHz), and rain drop size distributions, improved attenuation models at W/V-band frequencies can be developed to estimate system availability due to the atmosphere.

\[ A = aR^b \]

*Functions of drop size distribution*
Alphasat Beacon Experiment

Status:
- AFRL established EOARD grant with university for model development and operations of propagation terminal
- Ka/Q-band terminal fabrication completed and undergoing laboratory testing
- Relevant environment (rooftop) testing to commenced August 19, 2013
- Site survey planned during Ka-band conference in October 2013
- Installation of terminal planned for December 2013
NASA ONLINE PROPAGATION DATABASE
Overview

• For the past 20 years, NASA Glenn Research Center (in collaboration with GSFC and JPL) has collected over 100 station years of data characterizing atmospheric propagation effects at K/Ka-band frequencies.

• The RF Propagation Database is the means in which this data is disseminated to the user community to maintain public awareness of previous/current NASA efforts in this area of atmospheric propagation and to enhance the scientific return of acquired data.

Public Site:
http://propagation.grc.nasa.gov
### Background

For over 20 years, the National Aeronautics and Space Administration (NASA) has been involved in the characterization of radiofrequency propagation for various missions. The primary use of this data is to support mission planning and operations. The NASA RF Propagation Database is a comprehensive resource that supports the development of models, enhanced modeling and site-dependent system design.

The Database is accessible through the RF Propagation Database website, which provides a variety of tools and information for researchers and engineers. This includes access to past and current campaigns, which are listed in a table format.

### Campaigns

The database includes the following campaigns:

<table>
<thead>
<tr>
<th>Campaigns</th>
<th>Location</th>
<th>Data Type</th>
<th>Center</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACTS</td>
<td>Goldstone</td>
<td>Calibrated Data</td>
<td>GRC</td>
</tr>
<tr>
<td></td>
<td>White Sands</td>
<td>Weather</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Guam</td>
<td>Calibrated Data</td>
<td>GRC</td>
</tr>
<tr>
<td></td>
<td>Svalbard</td>
<td>Calibrated Data</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Humacao</td>
<td>Calibrated Data</td>
<td></td>
</tr>
</tbody>
</table>

### Current Campaigns

- **Goldstone (DSN)**: Started on April 27, 2007, ended on June 5, 2011.
- **White Sands (NEN)**: Started on January 1, 1994, ended on December 31, 1998.

### Past Campaigns (Completed)

- **Goldstone (DSN)**: Started on May 1, 2007, ended on June 30, 2011.
- **White Sands (NEN)**: Started on April 1, 2000, ended on December 31, 2005.

The data on this page is publicly available. For access to the raw data, which contains restricted, ITAR-controlled, unprocessed propagation data, please make a request here.
<table>
<thead>
<tr>
<th>Location</th>
<th>Data Type</th>
<th>Center</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goldstone</td>
<td>Raw Amplitude/Phase</td>
<td>GRC</td>
</tr>
<tr>
<td>Guam</td>
<td>Calibrated RMS Phase</td>
<td>JPL</td>
</tr>
<tr>
<td>White Sands</td>
<td>Weather</td>
<td></td>
</tr>
<tr>
<td>Fairbanks, AK</td>
<td>Calibrated Data</td>
<td>GRC</td>
</tr>
<tr>
<td>Vancouver, BC</td>
<td>Raw Data</td>
<td></td>
</tr>
<tr>
<td>Las Cruces, NM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fort Collins, CO</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Norman, OK</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tampa, FL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clarksburg, MD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Humacao, PR</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Start Date**
- The oldest record:
  - April 25 2007

**End Date**
- The newest record:
  - June 6 2011

**Search**

**Total Records:** 6,957

<table>
<thead>
<tr>
<th>Location</th>
<th>Data Type</th>
<th>Center</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fairbanks, AK</td>
<td>Calibrated Data</td>
<td>GRC</td>
</tr>
<tr>
<td>Vancouver, BC</td>
<td>Raw Data</td>
<td></td>
</tr>
<tr>
<td>Las Cruces, NM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fort Collins, CO</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Norman, OK</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tampa, FL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clarksburg, MD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Humacao, PR</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Start Date**
- The oldest record:
  - January 1 1994

**End Date**
- The newest record:
  - September 18 2003

**Search**

**Total Records:** 12,999
ITU MODELING EFFORTS
• Validation of ITU-R model with propagation data collected in wide range of climates (dessert, tropics, arctic)
• Presently working to format collected propagation data to ITU standards to include in international propagation database
• Multiple model development activities in progress
  – Short baseline site diversity modeling
  – Cloud attenuation models for V/W-band
  – Rain attenuation models for V/W-band
  – Use of radiometric profiler data in predicting optical path scintillation
Recent Publications

Journal Publications

International Conference Publications
• R. Acosta, J. Nessel, M. Zemba, J. Morse, “Two Years of Simultaneous Ka-Band Path Length Fluctuations Measurements: Goldstone, CA; White Sands, NM; Guam,” 18th Ka and Broadband Communications Conference, Ottawa, Canada, Sep. 24-27, 2012
• R. Acosta, J. Morse, M. Zemba, J. Nessel, “Two Years of Site Diversity Measurements in Guam,” 18th Ka and Broadband Communications Conference, Ottawa, Canada, Sep. 24-27, 2012
• J. Nessel, J. Morse, M. Zemba, “Results from Two Years of Ka-band Site Characterization at Svalbard, Norway,” 19th Ka and Broadband Communications Conference, Florence, Italy, Oct. 14-17, 2013

International Presentations [Invited Talks]