National Aeronautics and Space Administration

Keeping the universe connected.

www.nasa.gov

GRC RF Propagation Studies

Glenn Research Center

ESA Information Exchange

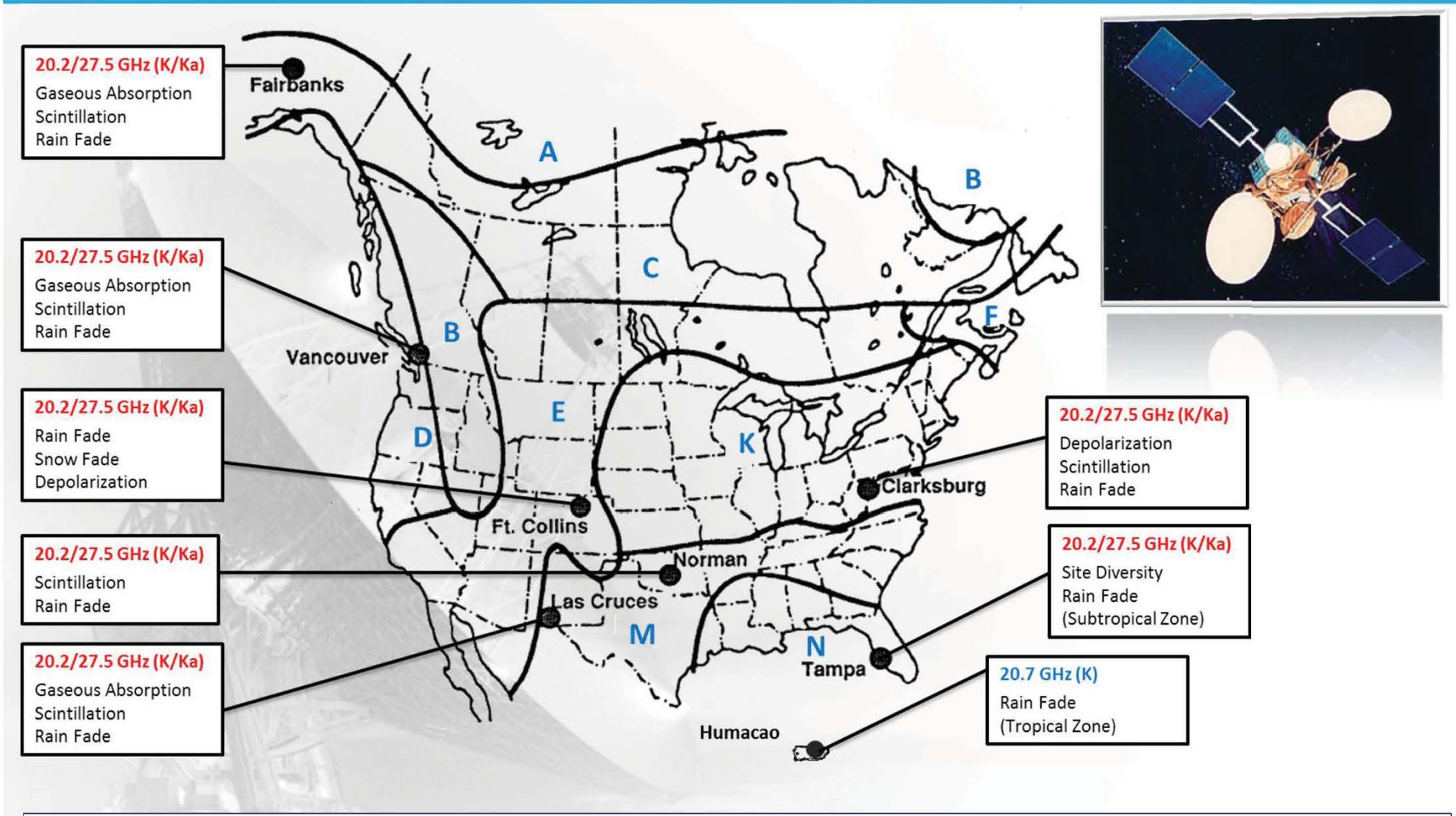
PI: James Nessel

October 1, 2013

Outline

- Historical Perspective: ACTS
- Ka-band Site Characterization of NASA Networks
  - Ka-band Propagation Studies for the Deep Space Network: Goldstone
  - Ka-band Propagation Studies for the Space Network: White Sands
  - 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



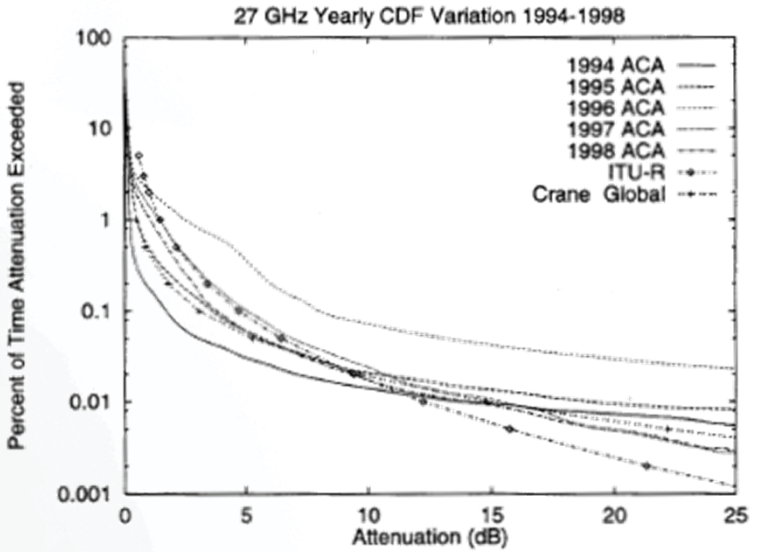
NASA helped open up the Ka band spectrum through propagation characterization in the 1990's through the Advanced Communications Technology Satellite (ACTS) program.

ACTS Impact

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

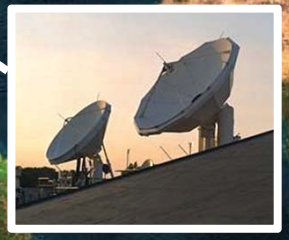
Current NASA Network Characterization Sites

In the post-ACTS era, NASA propagation activities have primarily focused on site characterization of NASA operational networks throughout the world.

Goldstone, CA
- Gaseous Absorption
- Rain Fade
- Phase

Madrid, Spain
- Phase

Svalbard
- Gaseous Absorption
- Brightness Temperature



GRC Testbed
Cleveland, OH

White Sands, NM
- Gaseous Absorption
- Rain Fade
- Phase

Guam
- Gaseous Absorption
- Rain Fade
- Phase
- Site Diversity

Canberra, Australia
- Phase

GRC Propagation Terminal Development

ACTS Propagation Terminal

Operational Frequency: 20.7/27.5 GHz
Dynamic Range: 20 dB
Sampling Rate: 1 Hz/10 Hz
Resolution: <0.3 dB rms accuracy

Hardware-based FFT Receiver

Goldstone Interferometer

Operational Frequency: 20.2 GHz
Dynamic Range: 50 dB
Sampling Rate: 1 Hz
Resolution: <0.1 dB rms accuracy

Software-based FFT Receiver

White Sands/Guam Terminal

Operational Frequency: 20.2 GHz
Dynamic Range: 60 dB
Sampling Rate: 1 Hz/10 Hz
Resolution: <0.1 dB rms accuracy

Software-based FFT Receiver

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.

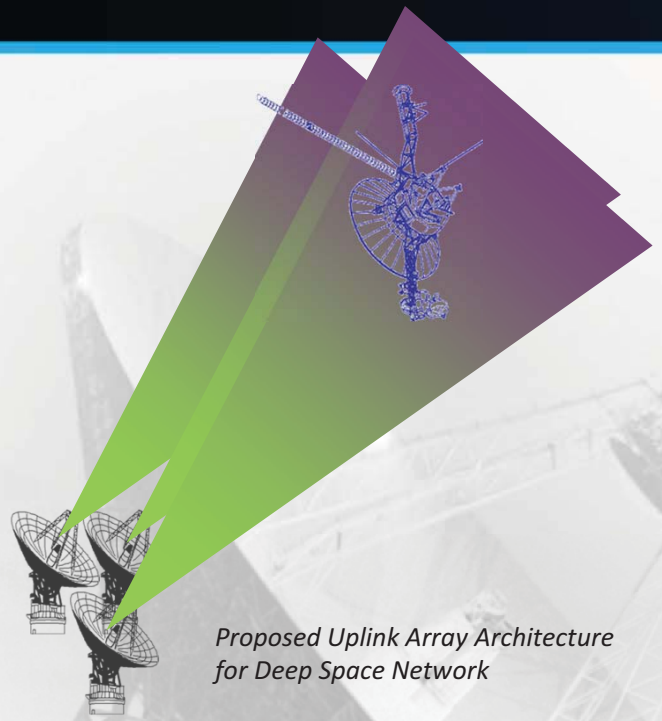
Svalbard

- 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.

Site Characterization: Atmospheric Phase Distortion

Uplink Arraying Applications



Proposed Uplink Array Architecture for Deep Space Network

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

Assuming identical antenna elements,

$$EIRP_{array} = G_{array} \cdot NP_0$$

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

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

$$\sigma_{mn}^2(\theta_{el}, f, r) = \sigma_{mn}^2(\theta_0, f_0, r_0)\left(\frac{f}{f_0}\right)\left(\frac{r}{r_0}\right)^{\alpha}\left(\frac{\sin\theta_0}{\sin\theta_{el}}\right)$$

Concept

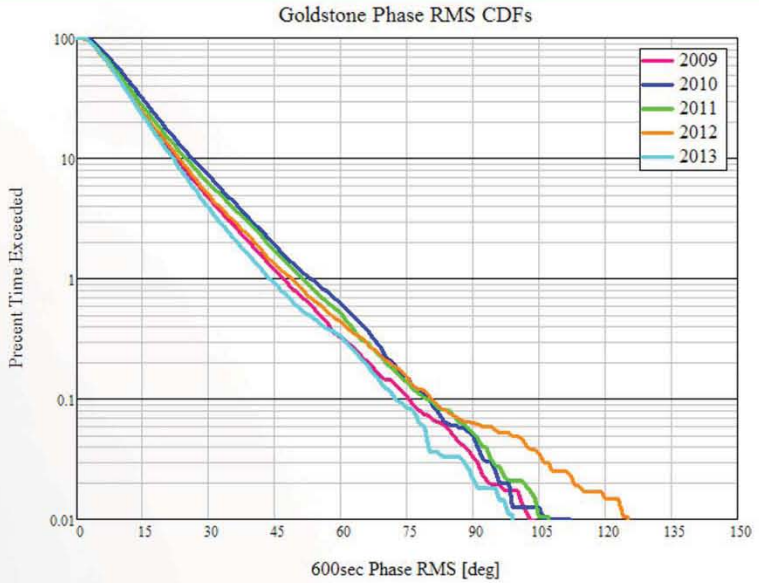
Arraying of several small aperture antennas vs. single large aperture antenna provides the following advantages:

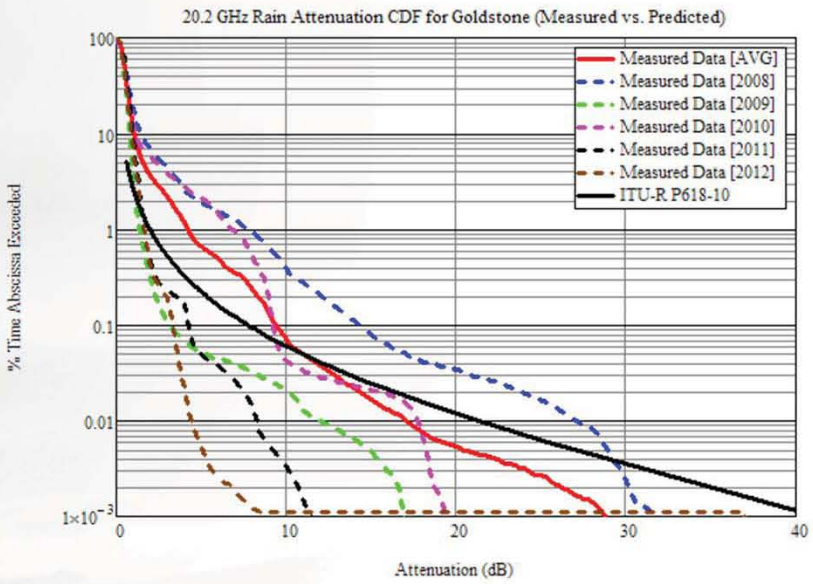
- Reduced maintenance costs
- Graceful degradation of performance of communications system
- Relative ease of meeting strict surface accuracy requirements for small apertures
- Enable new communications capabilities
- N^2 improvement in Effective Isotropic Radiated Power (EIRP)

Site Characterization: Atmospheric Phase Distortion

Goldstone, CA (Deep Space Network)

Goldstone, CA: *Current Deep Space Network Site*
Propagation program initiated in 2007

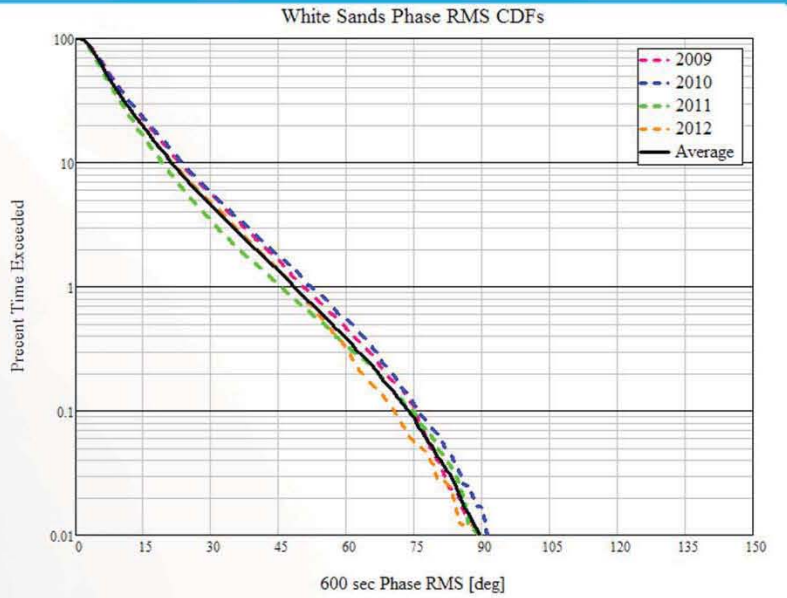


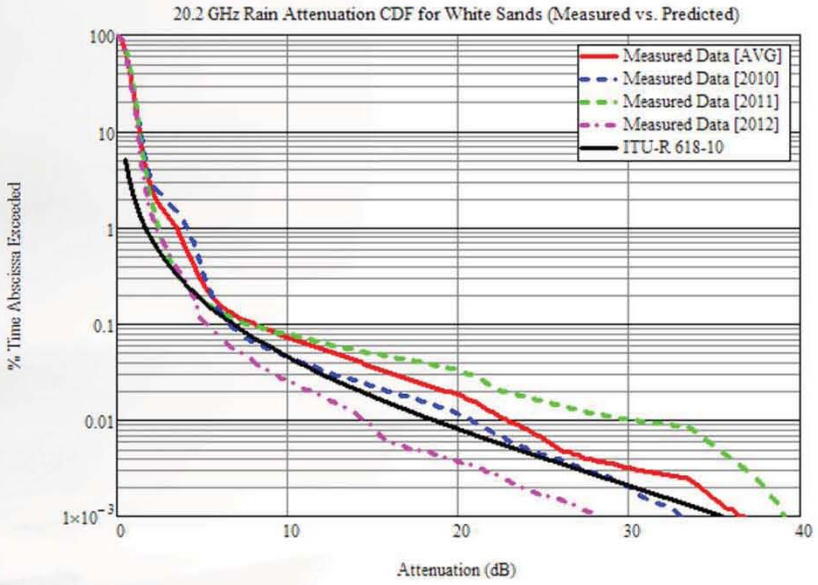


Site Characterization: Atmospheric Phase Distortion

White Sands, NM (Space Network)

White Sands, NM: *Proposed Secondary Site Characterization*
Propagation program initiated in 2009

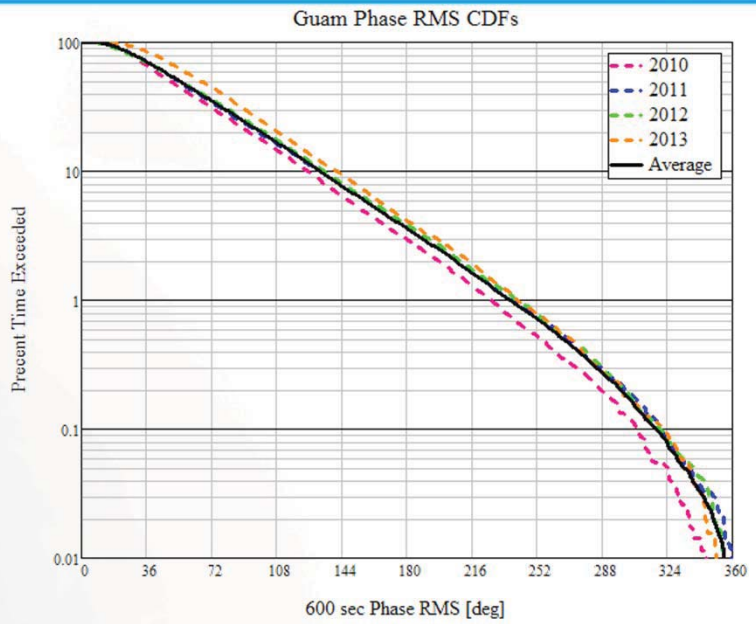


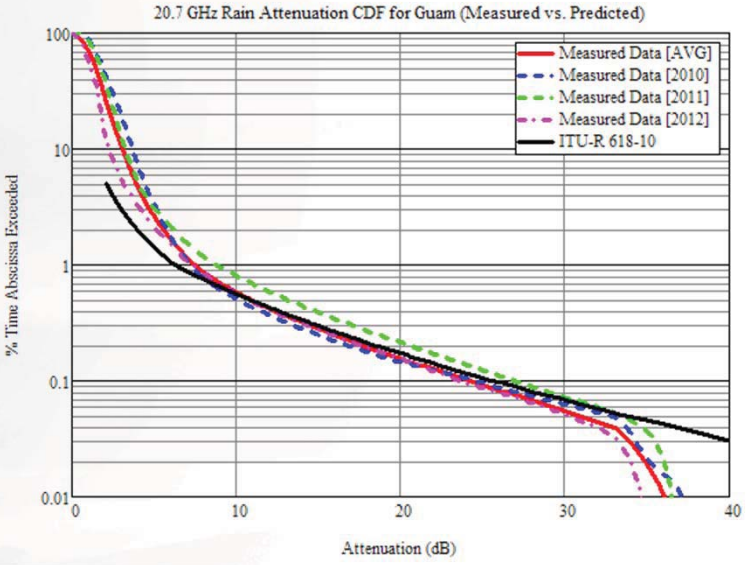


Site Characterization: Ka-band in the Tropics

Guam (Space Network)

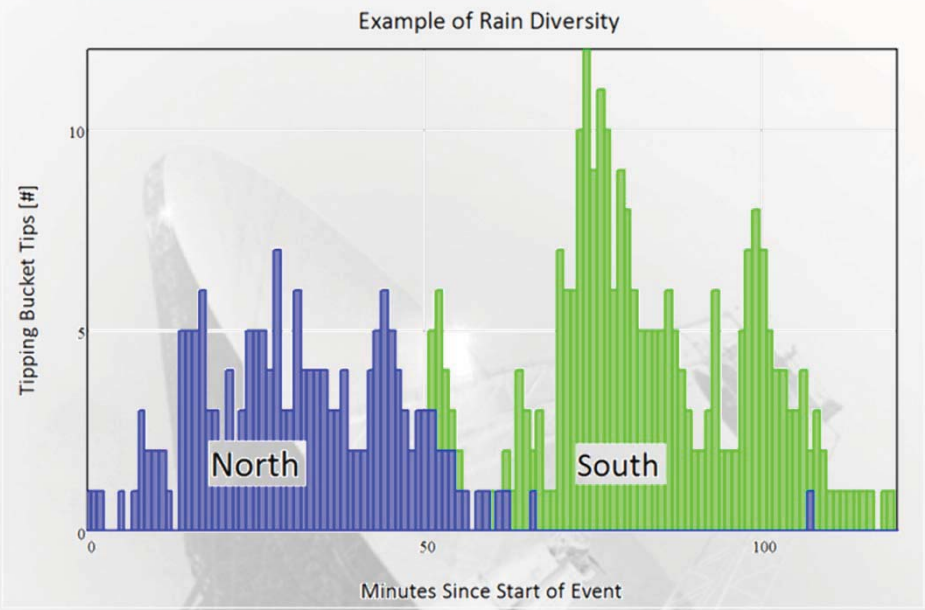
Guam: *NASA Space Network ground site*
Propagation program initiated in 2010

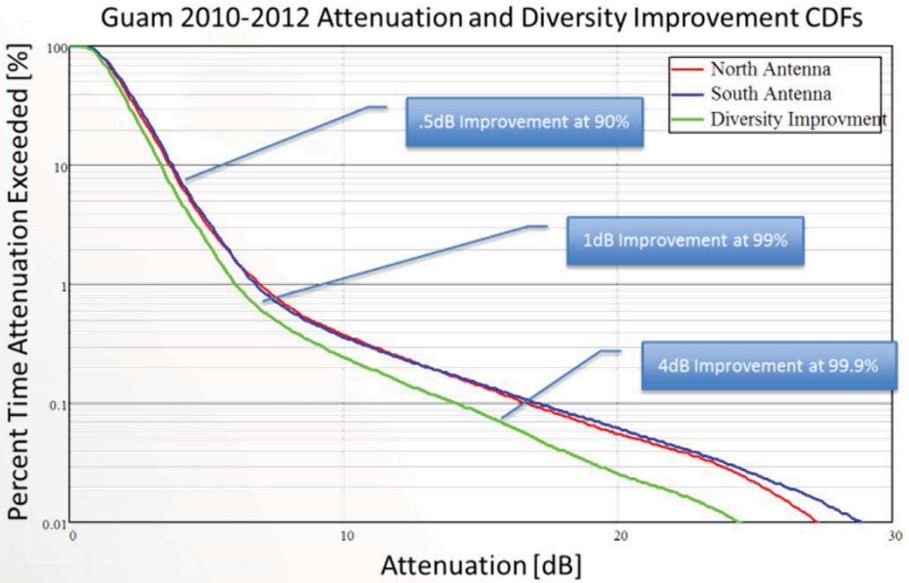




Site Characterization: Ka-band in the Tropics

Site Diversity Analysis

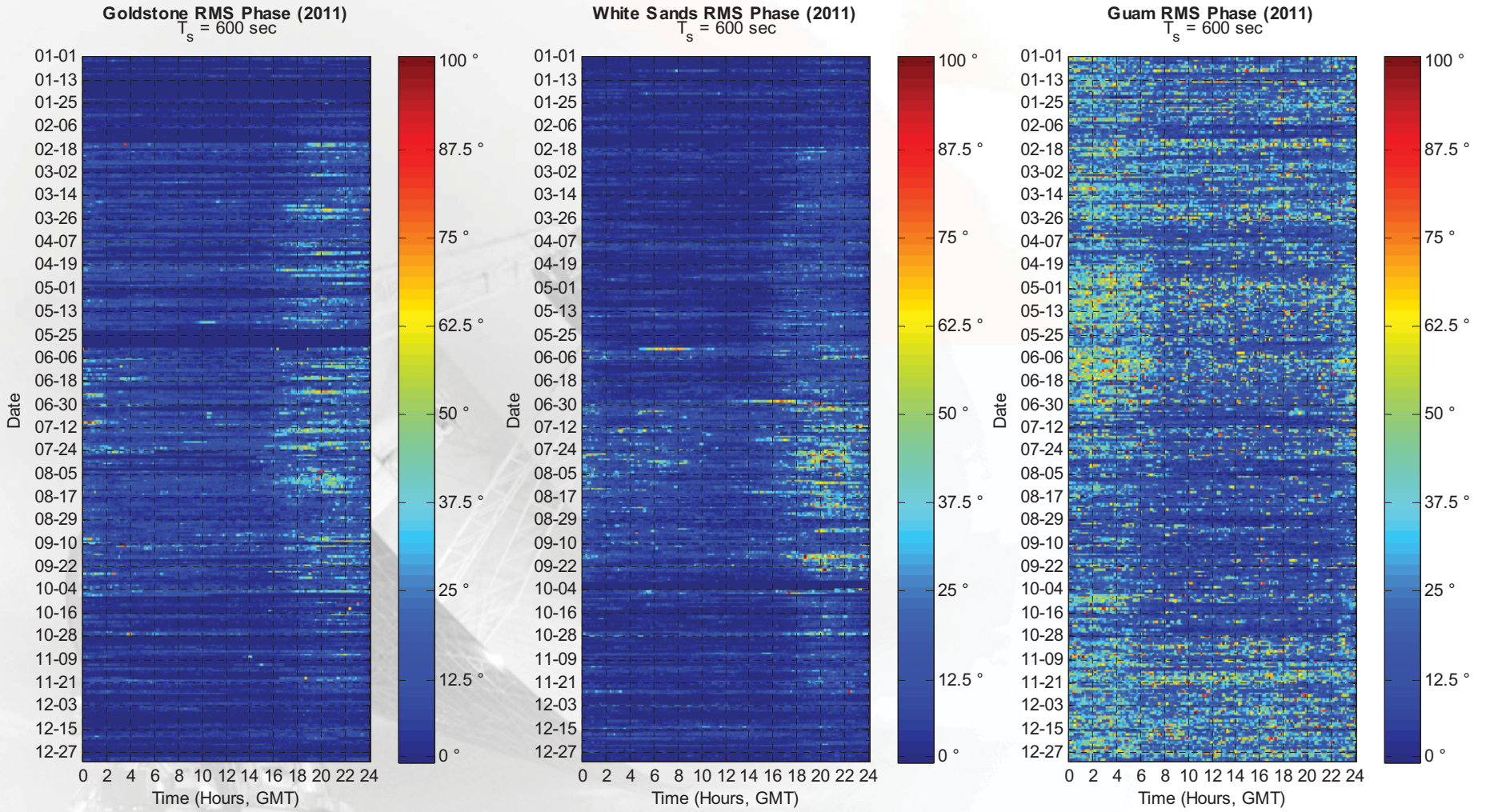




- Compact, highly convective rainfall in Guam has shown evidence of rain diversity over short (600-m) antenna separation distances.
- Guam site diversity study indicates that meaningful diversity gain is possible within short baseline separation distances (<20 km) and is sufficient to overcome rain attenuation
- 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**

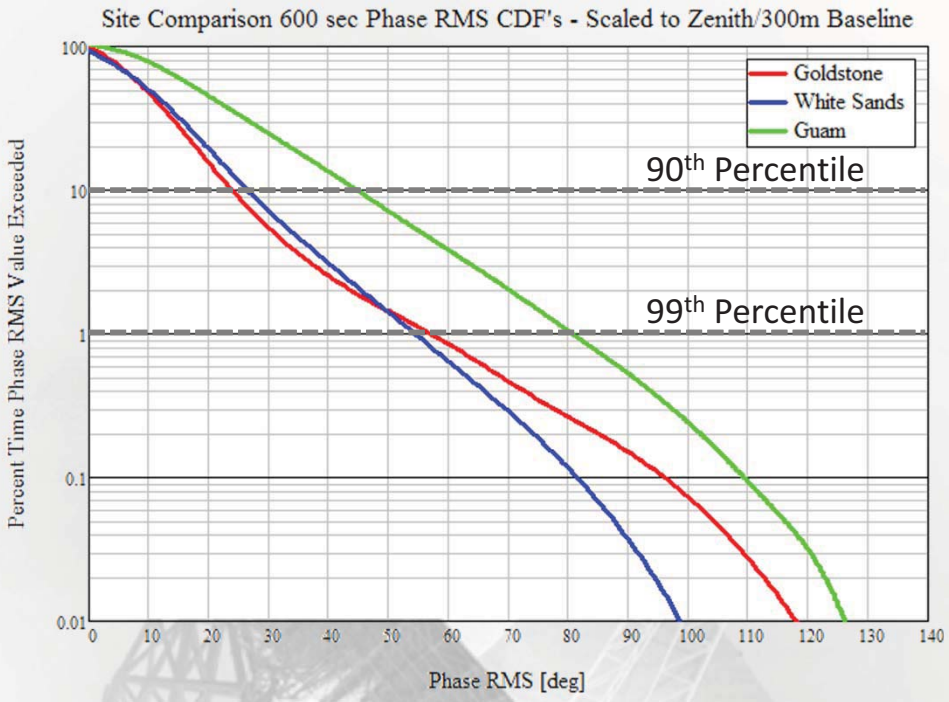
[4] R. Acosta, J. Morse, M. Zemba, J. Nessel, "Two Years of Site Diversity Measurements in Guam," 18th Ka and Broadband Communications Conference, Ottawa, Canada, Sep. 24-27, 2012

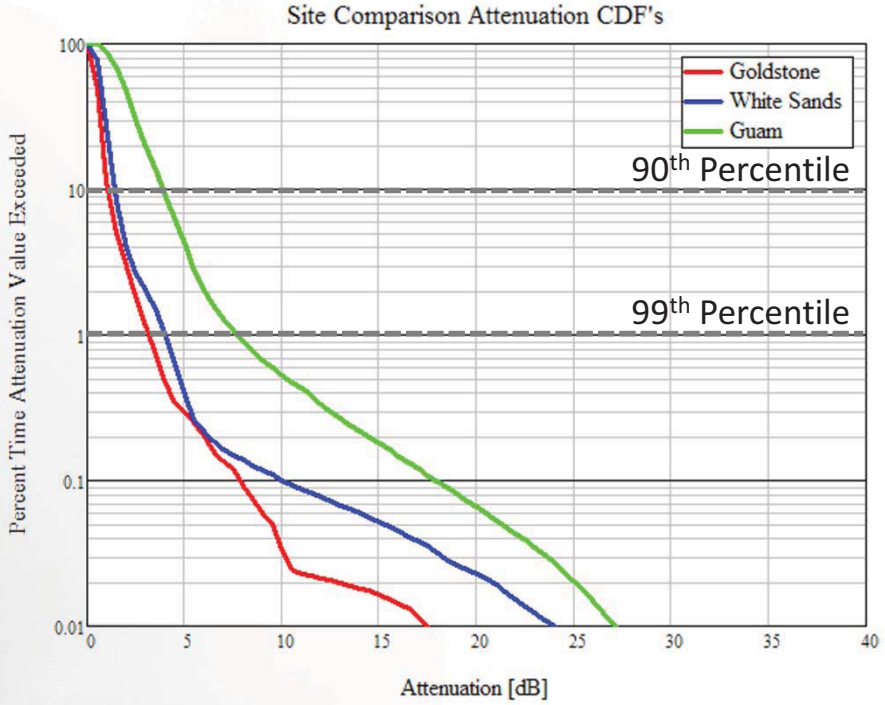
Ka-band Performance Site Comparisons



[3] 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

Ka-band Performance Site Comparisons





Site	2-Element Array Loss	
	90th Percentile	99th Percentile
Goldstone	0.17 dB	0.94 dB
White Sands	0.23 dB	0.89 dB
Guam	0.62 dB	1.62 dB

Factor of 1.2

Site	Total Path Attenuation	
	90th Percentile	99th Percentile
Goldstone	1.4 dB	3.2 dB
White Sands	1.6 dB	3.9 dB
Guam	3.9 dB	7.8 dB

Factor of 2.5

[3] 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

Site Characterization: Ka-band in Polar Atmosphere

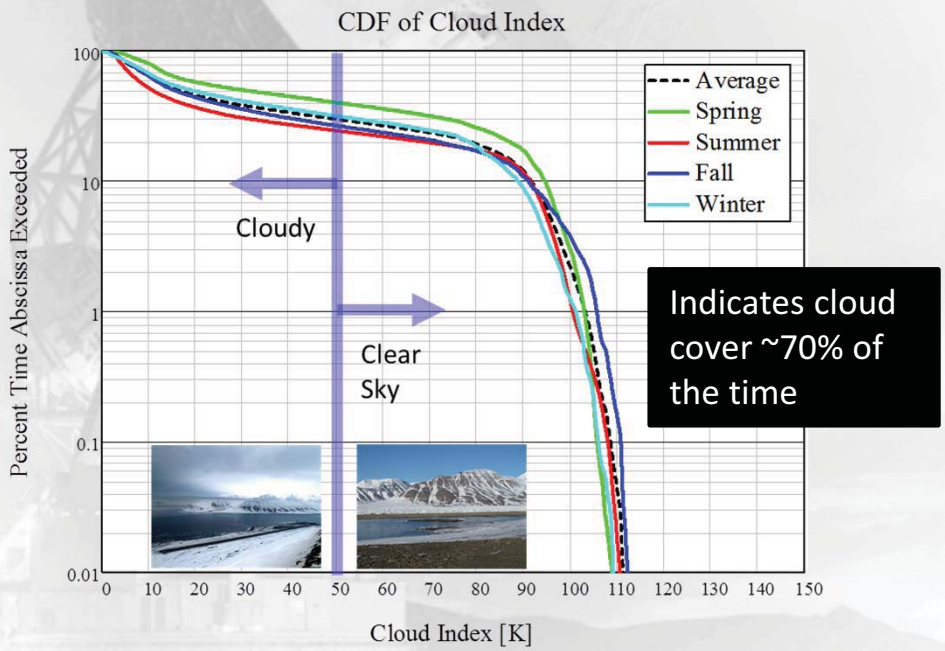
Svalbard (Near Earth Network)

Svalbard Station Polar Network

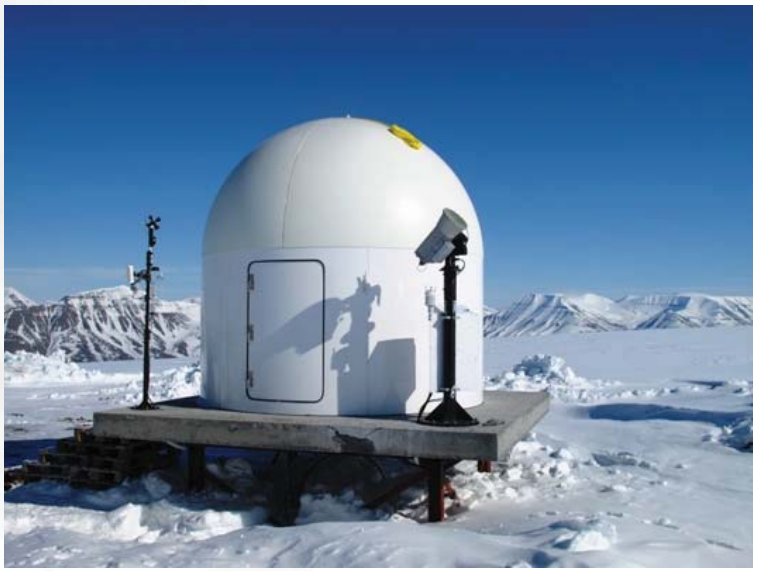
<u>Approach</u>

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



Indicates cloud cover ~70% of the time

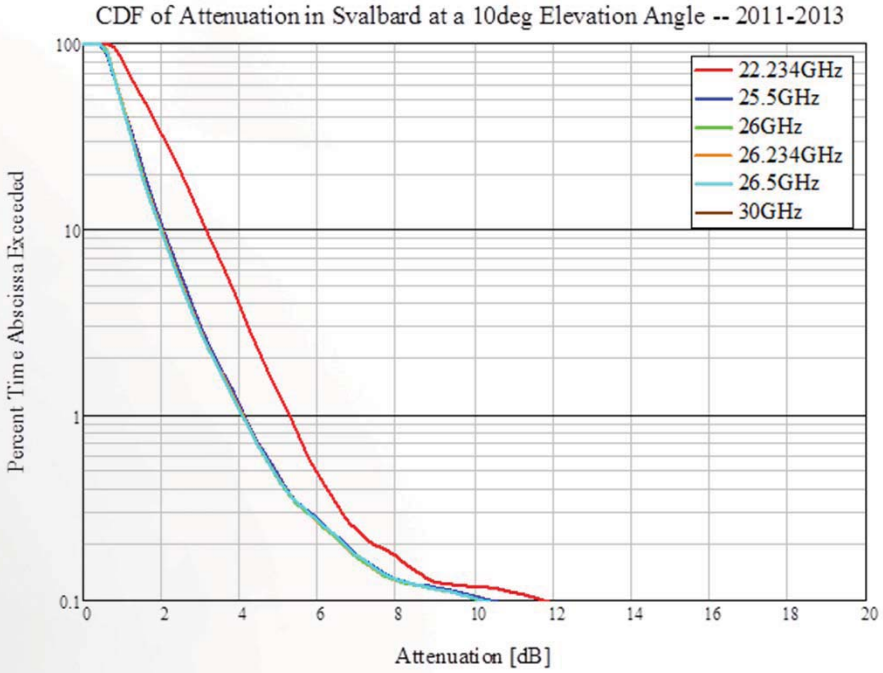


Site Characterization: Ka-band in Polar Atmosphere

Svalbard (Near Earth Network)

Model vs. Measurement		95% Availability Attenuation	97% Availability Attenuation	99% Availability Attenuation
Fairbanks, Alaska	Model (Expected)	1.72 dB @ 10° elevation	2.09 dB @ 10° elevation	3.39 dB @ 10° elevation
	Measured (Actual)	2.8 dB @ 10° elevation	3.2 dB @ 10° elevation	4.8 dB @ 10° elevation
Svalbard, Norway	Model (Expected)	1.37 dB @ 10° elevation	1.56 dB @ 10° elevation	2.28 dB @ 10° elevation
	Measured (Actual)	2.5 dB @ 10° elevation	2.9 dB @ 10° elevation	4.1 dB @ 10° elevation

K. McCarthy, F. Stocklin, B. Geldzahler, D. Friedman, P. Celeste, "NASA's Evolution to Ka-band Space Communications for Near-Earth Spacecraft," AIAA SpaceOps 2010, Apr. 25-30, 2010, Huntsville, AL



- 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.**

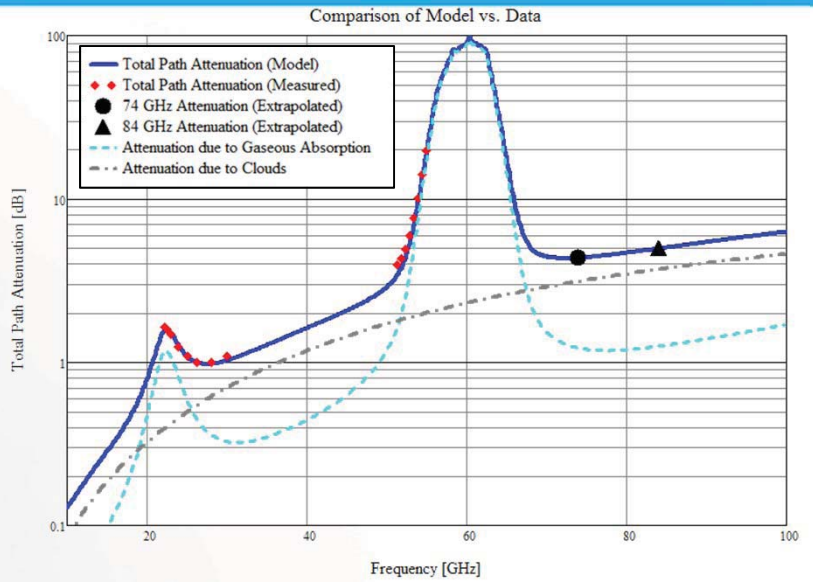
BEYOND KA-BAND:

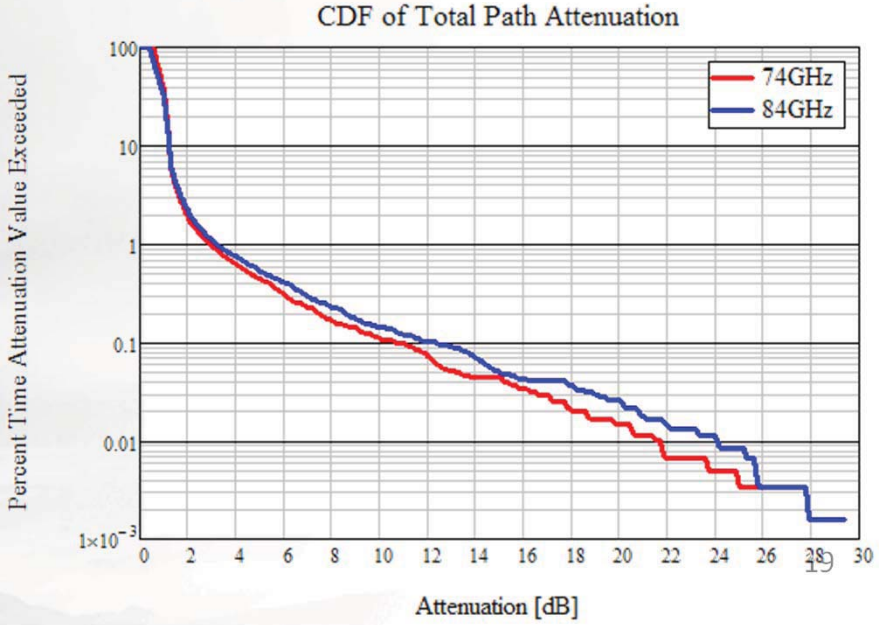
Millimeter Wave Propagation Studies

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)





V/W-band Terrestrial Link Experiment

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.

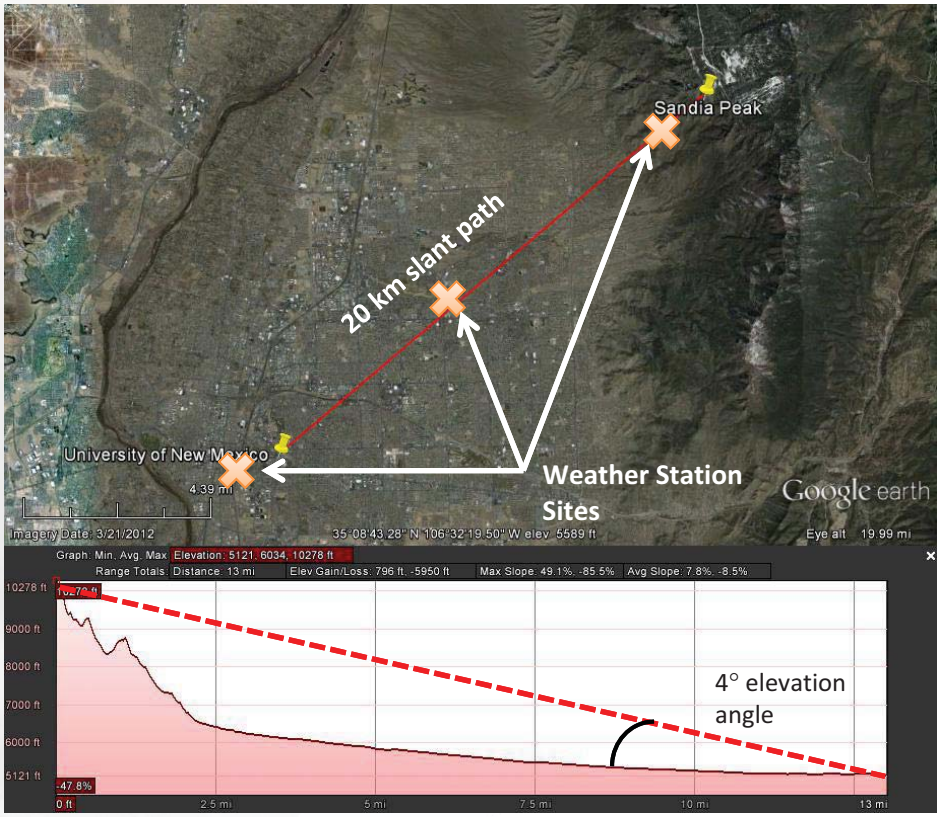
NASA to provide V/W-band beacon receiver and weather sensors

AFRL to provide V/W-band transmitter and operations funding

UNM to provide graduate student operations/data collection support

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

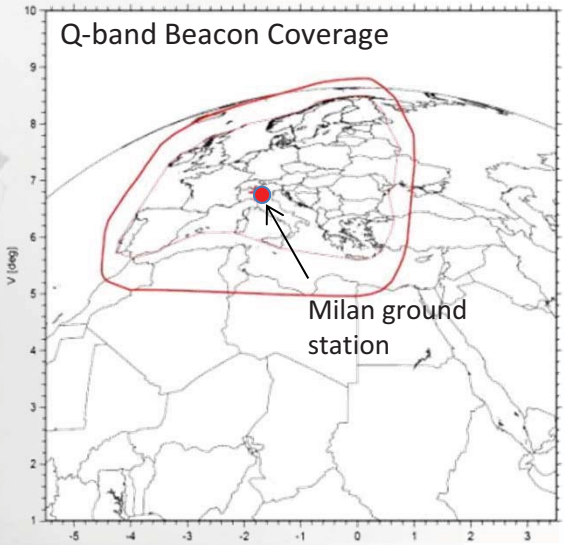
Alphasat Beacon Experiment

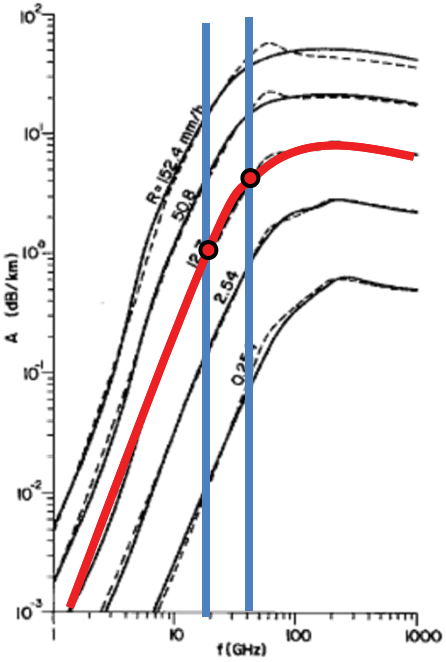
Collaboration with AFRL and Politecnico di Milano (POLIMI) provides unique opportunity using the Alphasat beacon to further improve models to predict rain attenuation effects on Q/V/W-band signals (characterization up to 99.9% availability)

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





$$A = aR^b$$

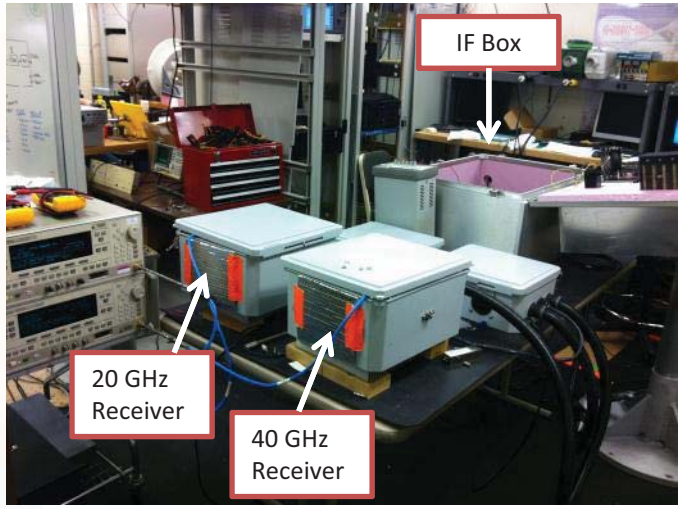
Functions of drop size distribution

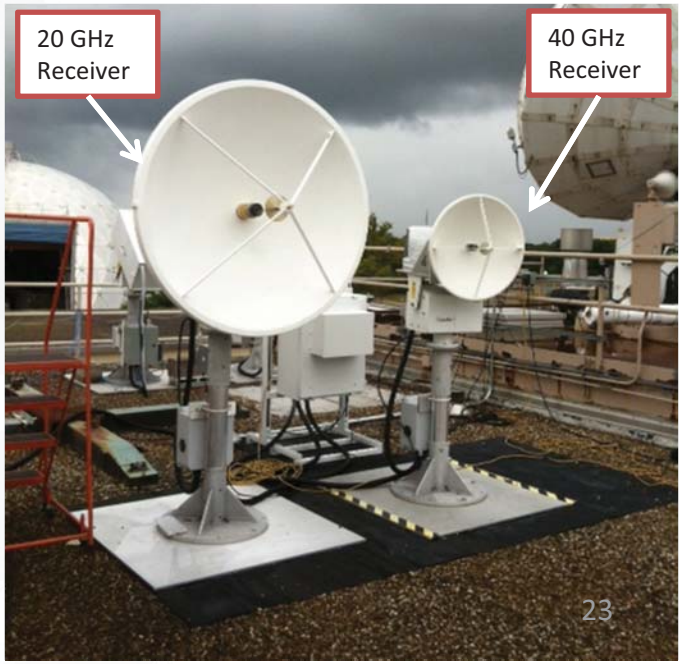
IMPACT: Through the concomitant characterization of passive W/V-band gaseous absorption, multiple coherent beacon frequencies (20/40 GHz), and rain drop size distributions, improved attenuation models at W/V-band frequencies can be developed to estimate system availability due to the atmosphere.

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





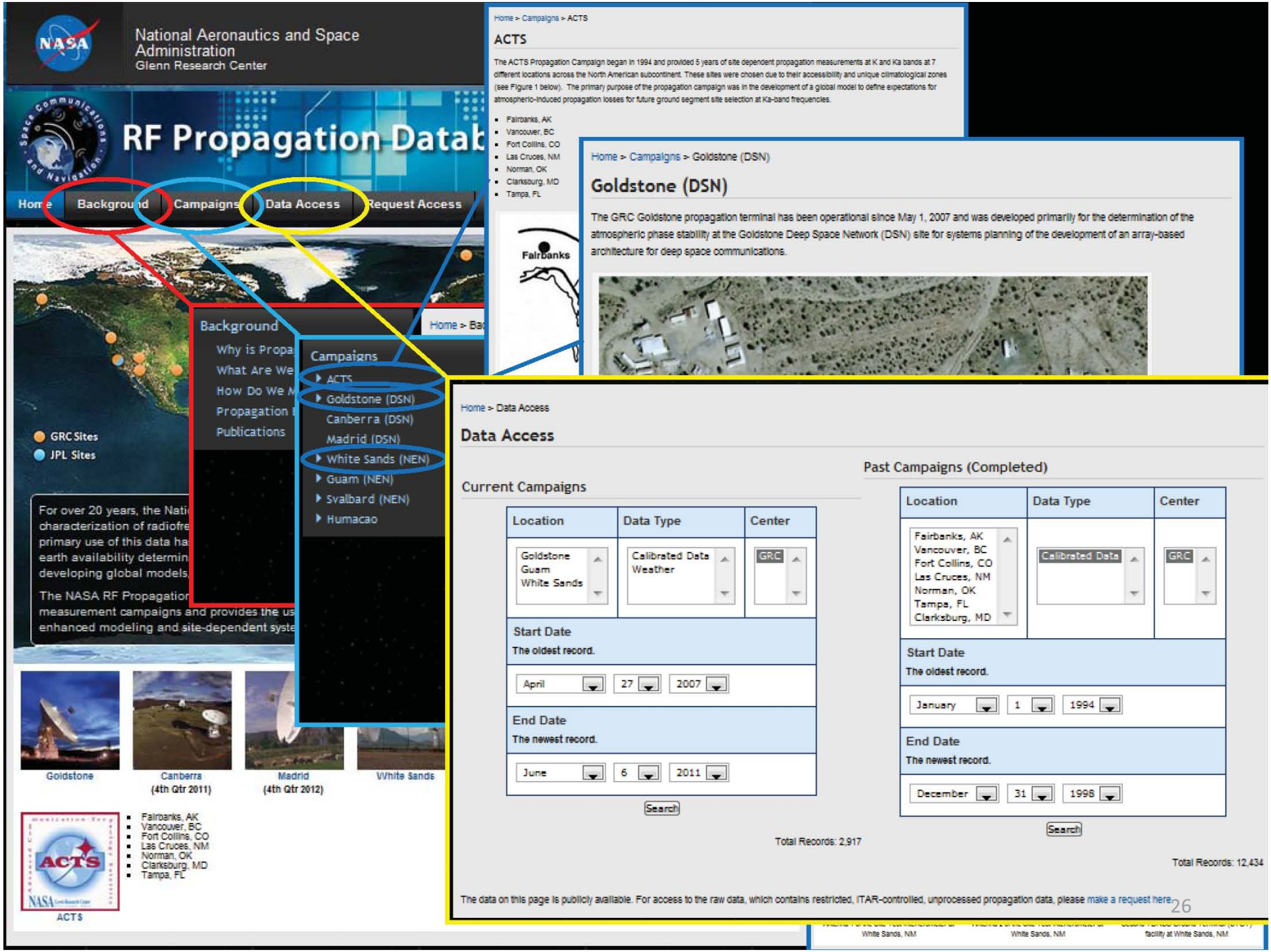
NASA ONLINE PROPAGATION DATABASE

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


National Aeronautics and Space Administration
Glenn Research Center
RF Propagation Datab
Home
Background
Campaigns
Data Access
Request Access
GRC Sites
JPL Sites
Background
Why is Propa
What Are We
How Do We M
Propagation
Publications
Campaigns
ACTS
Goldstone (DSN)
Canberra (DSN)
Madrid (DSN)
White Sands (NEN)
Guam (NEN)
Svalbard (NEN)
Humacao
Goldstone
Canberra
(4th Qtr 2011)
Madrid
(4th Qtr 2012)
White Sands
ACTS
Fairbanks, AK
Vancouver, BC
Fort Collins, CO
Las Cruces, NM
Norman, OK
Clarksburg, MD
Tampa, FL
Home > Campaigns > ACTS
ACTS
The ACTS Propagation Campaign began in 1994 and provided 5 years of site dependent propagation measurements at K and Ka bands at 7 different locations across the North American subcontinent. These sites were chosen due to their accessibility and unique climatological zones (see Figure 1 below). The primary purpose of the propagation campaign was in the development of a global model to define expectations for atmospheric-induced propagation losses for future ground segment site selection at Ka-band frequencies.
Fairbanks, AK
Vancouver, BC
Fort Collins, CO
Las Cruces, NM
Norman, OK
Clarksburg, MD
Tampa, FL
Home > Campaigns > Goldstone (DSN)
Goldstone (DSN)
The GRC Goldstone propagation terminal has been operational since May 1, 2007 and was developed primarily for the determination of the atmospheric phase stability at the Goldstone Deep Space Network (DSN) site for systems planning of the development of an array-based architecture for deep space communications.
Fairbanks
Home > Data Access
Data Access
Current Campaigns
Location
Data Type
Center
Goldstone
Guam
White Sands
Calibrated Data
Weather
GRC
Start Date
The oldest record.
April
27
2007
End Date
The newest record.
June
6
2011
Search
Total Records: 2,917
Past Campaigns (Completed)
Location
Data Type
Center
Fairbanks, AK
Vancouver, BC
Fort Collins, CO
Las Cruces, NM
Norman, OK
Tampa, FL
Clarksburg, MD
Calibrated Data
GRC
Start Date
The oldest record.
January
1
1994
End Date
The newest record.
December
31
1998
Search
Total Records: 12,434
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.

LOGIN

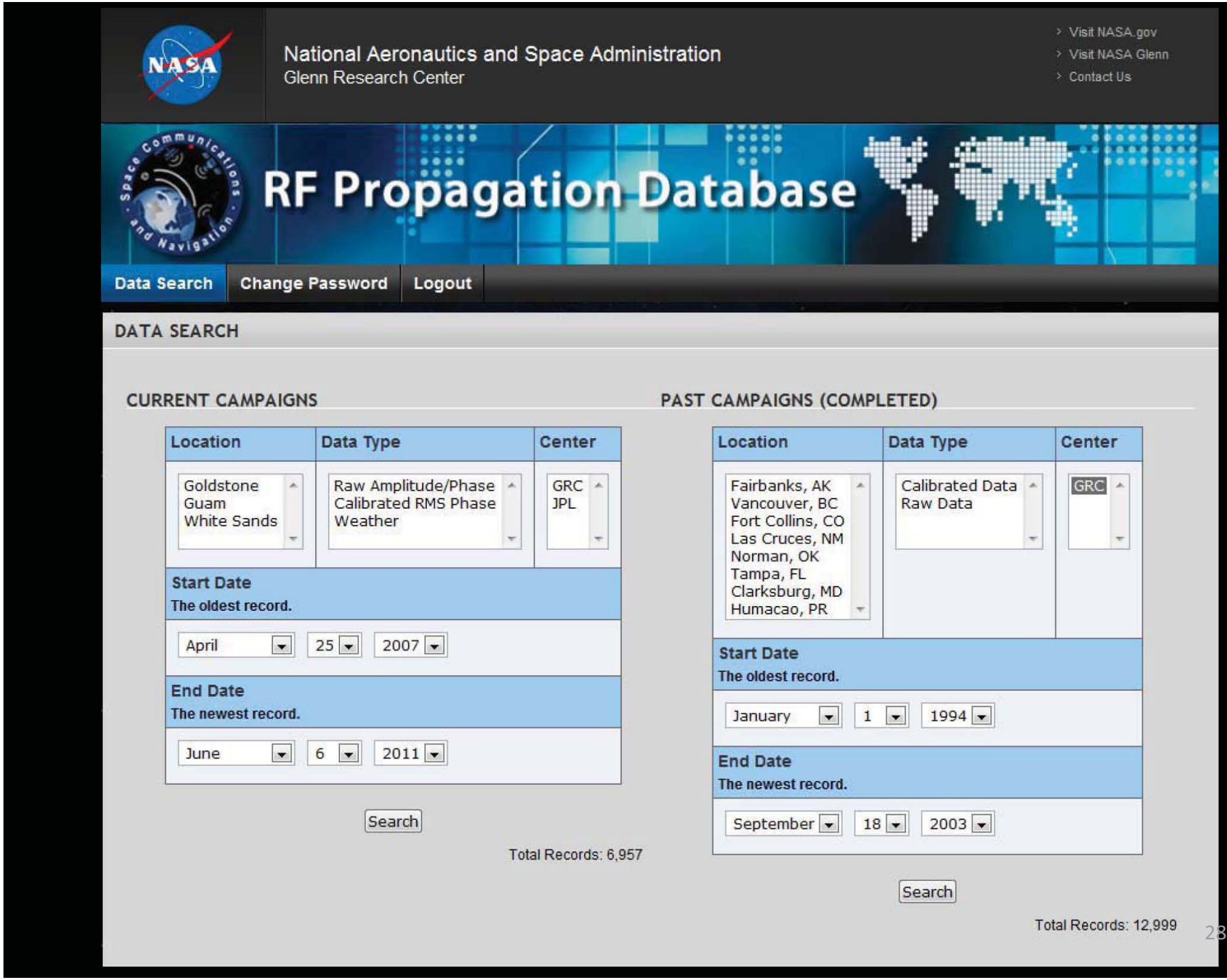
Please login to view this site.

Username

jnessel

Password

Login


National Aeronautics and Space Administration
Glenn Research Center
Visit NASA.gov
Visit NASA Glenn
Contact Us
RF Propagation Database
Data Search
Change Password
Logout
DATA SEARCH
CURRENT CAMPAIGNS
Location
Data Type
Center
Goldstone
Guam
White Sands
Raw Amplitude/Phase
Calibrated RMS Phase
Weather
GRC
JPL
Start Date
The oldest record.
April
25
2007
End Date
The newest record.
June
6
2011
Search
Total Records: 6,957
PAST CAMPAIGNS (COMPLETED)
Location
Data Type
Center
Fairbanks, AK
Vancouver, BC
Fort Collins, CO
Las Cruces, NM
Norman, OK
Tampa, FL
Clarksburg, MD
Humacao, PR
Calibrated Data
Raw Data
GRC
Start Date
The oldest record.
January
1
1994
End Date
The newest record.
September
18
2003
Search
Total Records: 12,999

ITU MODELING EFFORTS

ITU Modeling Efforts

In Progress…

- 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

- J. Nessel, R. Acosta, "Predicting Sparse Array Performance From Two-Element Interferometer Data," IEEE Transactions on Antennas and Propagation, Vol. 60, No. 2, pg. 886-894, Feb. 2012

International Conference Publications

- J. Rosello, A. Martellucci, R. Acosta, J. Nessel, L.E. Braten, C. Riva, "26 GHz data downlink for LEO satellites," 6th European Conference on Antennas and Propagation, Prague, Czech Republic, March 2012.
- R. Acosta, R. Simons, J. Morse, J. Budinger, J. Nessel, M. Zemba, "Q/V/W-Band RF Propagation Experiment Design," 18th Ka and Broadband Communications Conference, Ottawa, Canada, Sep. 24-27, 2012
- 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, R. Acosta, "Development of a Q-band Propagation Campaign in the United States," 18th Ka and Broadband Communications Conference, Ottawa, Canada, Sep. 24-27, 2012
- D. Morabito, L. D'Addario, R. Acosta, J. Nessel, "An Inter-Comparison of Two Independent Site Test Interferometer Located in Goldstone, CA: Initial Study Results," 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]

- R. Acosta, "NASA Ka-Band RF Propagation Studies," European Cooperation in the Field of Scientific and Technical Research (COST Action ICO802) Management Committee Meeting (MCM7), Portsmouth, London, April 16, 2012