Overview of Propagation Studies at NASA Glenn Research Center

James Nessel
NASA Glenn Research Center
Advanced High Frequency Branch
Outline

• Propagation Program Objectives
• Program History
• Summary of Current Propagation Campaigns
• Modeling Activities
• GRC Propagation Laboratories
• Future Plans
As NASA and the Nation move toward operations at Ka-band frequencies and above, it is desirable to characterize the site-dependent atmospheric propagation effects to manage expectations for system performance and develop improved systems at current and future potential operational sites.

**Objectives:**

- To provide a good understanding of RF propagation effects
- To develop or validate models for the prediction of propagation-related effects
- To develop techniques for the mitigation of these effects

**How to accomplish the objectives:**

- By making long-term measurements at multiple sites and analyzing the collected data
- A timely and full dissemination of results to users of propagation data
GRC possesses over 35+ station years of Ka-band propagation data collected through the Advanced Communications Technology Satellite (ACTS) program.
Overview of Current Efforts

Goldstone, CA
- Gaseous Absorption
- Rain Attenuation
- Phase

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

Albuquerque, NM
- W/V-band/Optical
- Terrestrial Link
- Rain Attenuation
- Scintillation

GRC Testbed
- Q-band
- Rain Attenuation
- Scintillation

Madrid, Spain
- Phase

Milan, Italy
- Q-band
- Rain Attenuation
- Scintillation

Svalbard
- Gaseous Absorption
- Brightness Temperature

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

Canberra, Australia
- Phase

Milan, Italy
- Phase

Canberra, Australia
- Phase
Throughout propagation campaigns, ground station hardware has undergone evolutionary improvements in performance and autonomous operation procedures.
Goldstone Campaign
Atmospheric Phase Turbulence Studies

Instrument: Two-Element Ka-Band Interferometer (20.2 GHz)
Data Collection Started: May 2007
Data Collection Completed: September 2012 (but ongoing)
Total Number of Months: 88 (7.3 Years)

Collected 7+ years of atmospheric attenuation measurements
Collected 7+ years of phase turbulence measurements
Measurements have been validated with interferometer at secondary location at DSN Complex
Instruments: Two-Element Ka-Band Interferometer (20.2 GHz)
Microwave Profiling Radiometer (22-60 GHz)
W/V-band Radiometer (82/72 GHz)

Data Collection Started: February 2009
Total Number of Months: 68 (5.7 Years)

Collected 5+ years of atmospheric attenuation measurements
Collected 5+ years of phase turbulence measurements
White Sands Campaign
Millimeter Wave Precursor Studies

Instrument: Profiler, W/V-Band Radiometer
Data Collection Started: **December 2012**
Total Number of Months: 24 (2 years)

**Collected 2+ years of W/V-band gaseous and cloud attenuation measurements**

Extrapolation of profiler measurements/absorption models to W/V-band validated with direct W/V-band radiometer measurements
Guam Campaign
Propagation Studies in the Tropics

Instrument: Two-Element Ka-Band Interferometer (20.7 GHz)
Data Collection Started: May 2010
Total Number of Months: 54 (4.5 Years)

Collected 4+ years of atmospheric attenuation measurements
Collected 4+ years of phase turbulence measurements
Collected 4+ years of site diversity measurements

Long-term average agrees with ITU-R model within 4.6%
Guam Campaign
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.
**Svalbard Campaign**

*Propagation Studies in the Polar Climate*

**Instrument**: Ka-Band Radiometer (26.5 GHz)

**Data Collection Started**: May 2011

**Total Number of Months**: 42 (3.5 Years)

*Collected 3+ years of low elevation angle gaseous absorption*

*Coordinating with ESA to install Ka-band (20.2 GHz) beacon receiver for rain attenuation/scintillation measurements*

---

Alphasat Campaign
Propagation Studies in the Q-band

Instrument: K/Q-band Beacon Receiver (20/40 GHz)
Optical Disdrometer

Data Collection Started: May 2014
Total Number of Months: 7 (0.6 Years)

- First 40 GHz propagation data collected by NASA
- GRC receiver recognized as highest-performing receiver of all Alphasat experimenters (>40 dB dynamic range)
- Collaboration with ASI for 20km site diversity measurements
MODEL DEVELOPMENT
Model for Phase Turbulence Statistics (TBD):

$$\sigma_\phi = f(\text{Nwet}, v, \theta, \nu)$$

Derivation of Cn2 from Interferometric Measurements:

$$C_n^2 = 0.043D_{\Delta H}(\infty) \Lambda_1^{-1}d^{-\beta}H^{-1}$$
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)

**EIRP** array is given by:

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

Assuming identical antenna elements,

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

$$\langle G_{\text{array}} \rangle = \eta D_0 \frac{1}{N} \sum_{m=1}^{N} \sum_{n=1}^{N} e^{\frac{\varphi_{mn}^2}{2}}$$

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

$$\sigma_{mn}^2(\theta, f, r) = \sigma_{mn}^2(\theta_0, f_0, r_0) \left( \frac{f}{f_0} \right) \left( \frac{r}{r_0} \right)^\alpha \left( \frac{\sin \theta}{\sin \theta_0} \right)$$
Array Loss at Goldstone due to Atmospheric Phase Noise: 90%-99% Availability (10 min timescales)

- **X-band (7.2 GHz)**
  - 99% availability
- **Ka-band (32 GHz)**
  - 99% availability
  - 90% availability
Atmospheric Optical Scintillation Modeling

Preliminary Analysis of Optical Performance at White Sands

Modified Structure Parameters:

\[ C_n^2(T, U, \Delta t) = \frac{4[(T(r) - T(r+U\Delta t))^2]}{k_U^{-2/3}} \left[ 0.57722 + \log(U\Delta t) + \frac{3}{2} \log\left(2k_U^{2/3}\right) + \frac{1}{2} \frac{v^2}{U^2} \right] \]

\[ C_n^2 = \left( \frac{77.689 \langle P \rangle}{\langle T \rangle^2} \right)^2 C_T^2(T, U, \Delta t) \]

Coherence radius, \( r_0 = 0.423 \left( \frac{2\pi}{\lambda} \right)^2 \int C_n^2(h) dh, \lambda = 1550\text{nm} \)
Rapid assessment of the operation of an optical communications link anywhere within the solar system as well as within GEO/LEO orbits

Dynamic evaluation of optical link operation, accounting for the locations of deleterious noise sources with respect to the link and their impact on, e.g., achievable data rate during these periods

Provides temporal and data rate connectivity throughout the lifetime of a mission yielding calculations for potential total data throughput of a mission

Tool can be directly interfaced with the Satellite Tool Kit (STK) from which it gets its dynamic capability.

Software configuration of tool allows extensive reporting capabilities as well as the flexibility to add ‘modules’ new optical detector types, new modulations schemes, etc.

Optical tool can be employed for the simulation of entire relay satellite system when used with an attendant tool for RF.
PROPAGATION LABORATORIES
RF Propagation Laboratory

Bldg. 55 Rooftop radiometer testing

Bldg. 55 Propagation Laboratory used for component/system level testing and integration

NASA Ground Station (NGS) 5.5-m beam waveguide antenna for receiver system testing/check-out

Feed horn system upgrade completed to transition ground station for operation to Ka/Q/V/W bands
Presently transitioning test equipment to millimeter wave:

- Spectrum Analyzer (up to 90 GHz)
- Vector Network Analyzer (up to 110 GHz)
- Laboratory Investment Fund proposal in place to procure Signal Generator (up to 110 GHz)
FUTURE PLANS

Activities in the Millimeter Wave
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.

Measurement equipment to include:
- Beacon Transmitter on Sandia Peak (72/84 GHz)
- Beacon Receiver at UNM
- V/W-band Microwave Radiometer at UNM
- Optical Transmitter/Receiver for concomitant measurements along path
- Multiple Optical Disdrometers along path for rain drop size distribution measurements
- Multiple weather stations along path for path profiling information
- Super Doppler Radar for path profiling information

**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 2018 timeframe.
- Will provide a testbed for prototype propagation terminals to reduce experiment risk.
AFRL W/V-band Satellite Communications Experiment (WSCE)
- Conduct ACTS-like CONUS propagation campaign at V/W bands
- Expected payload launch date in 2018
THANK YOU!