

Simultaneous Ka-Band Site Characterization: Goldstone, CA, White Sands, NM, and Guam, USA

R. Acosta¹, J. Morse¹, M. Zemba¹, J. Nessel¹, D. Morabito², and A. Caroglanian³,

¹NASA Glenn Research Center
Cleveland, Ohio 44135

Phone: (216) 433-6640, Fax: (216) 433-6371, Email: racosta@grc.nasa.gov

²NASA Jet Propulsion Laboratory
Pasadena, California 91109

Phone: (818) 354-2424, Email: David.D.Morabito@jpl.nasa.gov

³NASA Goddard Spaceflight Center
Greenbelt, Maryland 20771

Phone: (301) 286-4340, Email: armen.caroglanian-1@nasa.gov

Abstract

To statistically characterize atmospheric effects on Ka-band links at NASA operational sites, NASA has constructed site test interferometers (STI's) which directly measure the tropospheric phase stability and rain attenuation. These instruments observe an unmodulated beacon signal broadcast from a geostationary satellite (e.g., Anik F2) and measure the phase difference between the signals received by the two antennas and its signal attenuation. Three STI's have been deployed so far: the first one at the NASA Deep Space Network Tracking Complex in Goldstone, California (May 2007); the second at the NASA White Sands Complex, in Las Cruces, New Mexico (February 2009); and the third at the NASA Tracking and Data Relay Satellite (TDRS) Remote Ground Terminal (GRGT) complex in Guam (May 2010). Two station-years of simultaneous atmospheric phase fluctuation data have been collected at Goldstone and White Sands, while one year of data has been collected in Guam. With identical instruments operating simultaneously, we can directly compare the phase stability and rain attenuation at the three sites. Phase stability is analyzed statistically in terms of the root-mean-square (*rms*) of the tropospheric induced time delay fluctuations over 10 minute blocks. For two years, the time delay fluctuations at the DSN site in Goldstone, CA, have been better than 2.5 picoseconds (ps) for 90% of the time (with reference to zenith), meanwhile at the White Sands, New Mexico site, the time delay fluctuations have been better than 2.2 ps with reference to zenith) for 90% of time. For Guam, the time delay fluctuations have been better than 12 ps (reference to zenith) at 90% of the time, the higher fluctuations are as expected from a high humidity tropical rain zone. This type of data analysis, as well as many other site quality characteristics (e.g., rain attenuation, infrastructure, etc.) will be used to determine the suitability of all the sites for NASA's future communication services at Ka-band.

I. Introduction

As NASA progresses into the 21st century, its communications network systems (e.g., Deep Space, and Near Earth Networks) are expected to transition into the use of the Ka-band spectrum. These systems will be required to provide services with a system availability higher than 99% (currently at 90%) and gigabit data rates (currently ~ megabit rates). However, the atmospheric phase stability (time delay fluctuations) and attenuation empirical distribution functions of a particular site must be

well characterized before implementation of Ka-band ground systems can proceed. A statistical knowledge of the atmospheric fluctuations will potentially lead to mitigation techniques that further improve system margin and reduce cost.

Atmospheric phase instability arises because the earth's upper atmosphere (troposphere) contains large amounts of inhomogeneous distributions of water vapor exposed to turbulent air flow conditions. This property induces variations in the precipitable water vapor content, which changes the refractivity of the medium on spatiotemporal scales, and directly leads to variations in the effective electrical path length of an electromagnetic wave propagating through this layer of the atmosphere (See **Figure 1**). Such variations are seen as 'randomly modulated phase noise' by radio arrays and will inherently degrade the antenna system performance (e.g., effective isotropic radiated power) [1, 2].

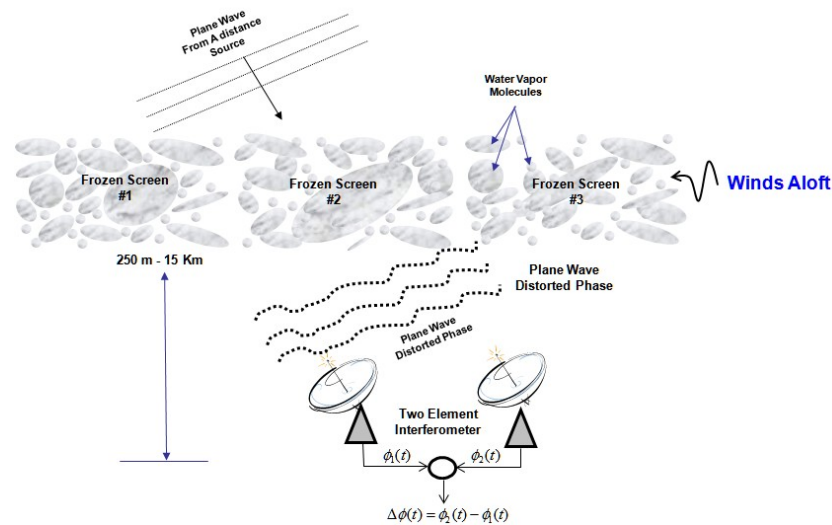


Fig. 1. Water vapor is contained in screens (a defined volume of water vapor molecules) of various sizes, which are affected across the two-element interferometer antennas. The motion of the screens causes phase fluctuations in radio waves passing through them.

NASA Glenn Research Center, in collaboration with the Jet Propulsion Laboratory and Goddard Space Flight Center, has constructed and deployed three STI's (two-element site test interferometers). The first STI was deployed in Goldstone, California in May 2007; the second was deployed in White Sands, New Mexico, in February 2009 and the third in Guam, USA, in May 2010. The results of this data collection and analysis will directly determine the necessary system design parameters (e.g., system availability due to rain and its corresponding system margin) and identify possible mitigation techniques (e.g., site diversity) to optimally operate a Ka-band array system at these locations.

II. STI Measured Performance

The first interferometer at the Goldstone Deep Space Network (DSN) Complex, near Barstow, California, is located at an elevation of 3408 feet above sea level with an east-west baseline of 256 m. The second STI at the White Sands Tracking and Data Relay Satellite (TDRS) Complex, near Las Cruces, New Mexico, is located at an elevation of 4821 feet above sea level with a north-south baseline of 208 m. Both interferometers receive the Anik F2 20.2 GHz beacon signal. The third interferometer is located at an elevation of 150 ft above sea level on a north-south baseline of 600 m at the TDRS Guam Remote Ground Terminal (GRGT) complex. The Guam interferometer receives the UFO-8 GBS beacon signal at 20.7 GHz. A carrier-to-noise density ratio (CNo) of approximately 80 dB Hz^{-1} was measured at all locations. Before deployment, the performance of each instrument was

evaluated in the laboratory environment (no atmospheric contributions) and consistently showed a root-mean-square (rms) time delay fluctuation of 0.21 ps (1.5 degrees) over 600-s integration intervals.

A full year (2009) of monthly (ensembles) rms phase time series observed simultaneously by the Goldstone interferometer is depicted in **Figure 2**. These time series illustrate a typical instrument operational performance over one year.

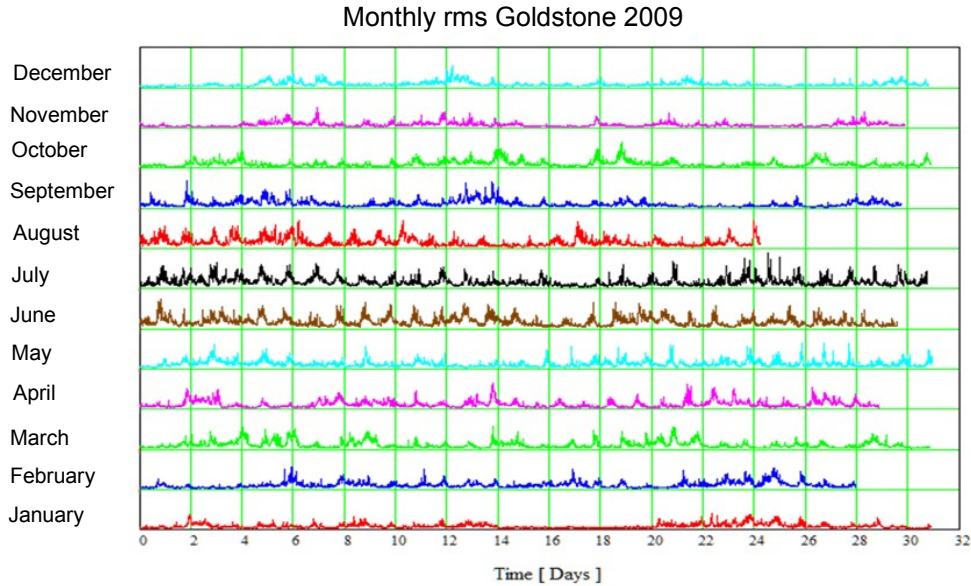


Fig. 2. One year of monthly (ensemble) rms time series of interferometer phase measurements at Goldstone, California. The rms time series are plotted with January at the bottom of the graph through December at the top of the graph.

The monthly interferometer phase rms time series are plotted in ascending order (the rms time series for January is at the lower end of the graph). Notice that the intensity of the interferometer phase rms is more pronounced in the summer months (shown in the middle of the graph) than in the winter months (at the beginning and end of the graph). This phase stability trend is common to all sites, and agrees with expectations [1].

With identical instruments operating simultaneously, we can directly compare the phase stability and rain attenuation characteristics at Goldstone, White Sands, and Guam. With only one year of data collected in Guam, however, it is early to draw any firm conclusions about how the site compares with the Goldstone and White Sands locations. Simultaneous measurements extending over several years (a minimum of five years) are required to accurately characterize the sites and provide a solid basis for comparison. However, general expectations of system performance on a relative scale can be established in shorter time frames. The Goldstone, White Sands, and Guam interferometers receive the satellite signal at three different elevation angles (51.8, 48.5 and 38 deg., respectively). Therefore, to more accurately compare the time delay fluctuations of the three sites, it is necessary to extrapolate the measured phase rms results to a zenith observation angle (90 deg). The rms phase fluctuation arising from water vapor scale linearly with frequency, hence the conversion from the interferometer readings into an rms path length fluctuation is given by equation 1

$$L_{rms} = \lambda \frac{\sigma_{rms}}{2\pi} \quad (1)$$

where λ is operating wavelength (0.015 m), and σ_{rms} is an estimated rms phase (over 10 minute blocks) from the measured interferometer phase collected every second. The time delay fluctuations are obtained by dividing the rms path length in equation 1 by the speed of light (3×10^8 m/sec).

In order to reference the rms to zenith we need to divide the phase delay fluctuations by the air mass towards the observation satellite which is given by equation 2.

$$\tau_{rms}|_{zenith} = \frac{\left(\frac{L_{rms}}{c}\right)^{\frac{1}{2}}}{\left(\frac{1}{\sin(\theta_{sat})}\right)^{\frac{1}{2}}} \quad (3)$$

where θ_{sat} is the elevation angle and $\tau_{rms}|_{zenith}$ is the atmospheric time delay.

It should be noted that while a common zenith reference for all sites provides some measure of site performance comparison, a true direct comparison of the phase delay fluctuations for each site will involve a comparison for a common baseline, as well, which is beyond the scope of this paper.

III. Data Processing

Before the data can be statistically analyzed, the phase fluctuations induced by the atmosphere must be isolated from those introduced by the system (i.e., diurnal motion of the satellite and slow varying system thermal drift). The foundation for (and validation of) this calibration procedure can be found in [3], and a summary of the steps is provided below.

First, the recorded data (1-s) is unwrapped (the interferometer records relative phase within a ± 180 deg. range), so that a continuous differential phase curve is established. The 24-hour data are then divided into 144 blocks of 600 sec (10 min) intervals. Blocks containing bad data (e.g., data recorded during maintenance visits, system-induced phase jumps, etc.) are removed. Within each good 10 minute block, a 2nd order polynomial is fitted to the data using a least mean square approach and subtracted. The final result of this process is the phase fluctuations due solely to the atmosphere and system noise over 10 minute intervals in a given 24-hour period.

IV. Statistical Results

The overall cumulative distribution functions (CDF) of the time delay derived from the phase fluctuations (*rms*) at all three sites for one year is presented in **Figure 3**. The CDF is derived from a histogram of observations that includes the time delay *rms*.

The distributions are referenced to zenith and represent an evaluation of the first-order statistics at each site. The one year average 90th percentile was 2.5 ps, 2.2 ps, and 12 ps for the Goldstone, White Sands, and Guam sites respectively.

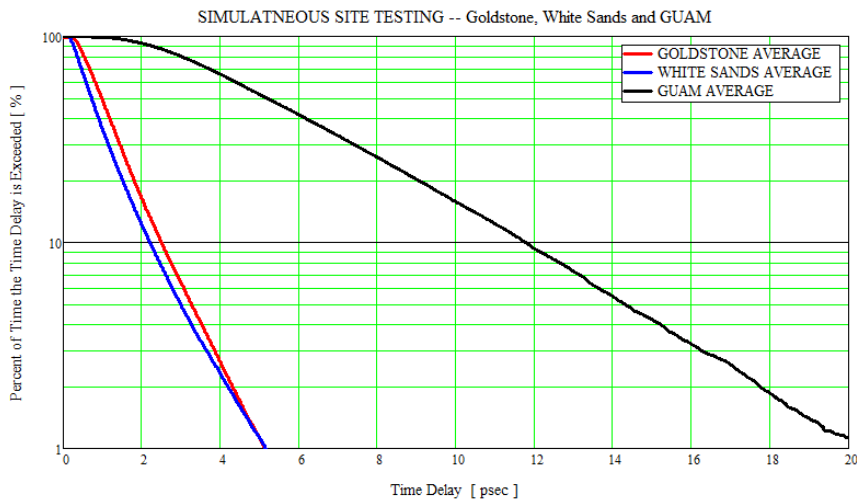


Fig. 3. Cumulative Distribution Function (CDF) for *rms* Time Delay fluctuations (reference to zenith) at Goldstone, White Sands and Guam.

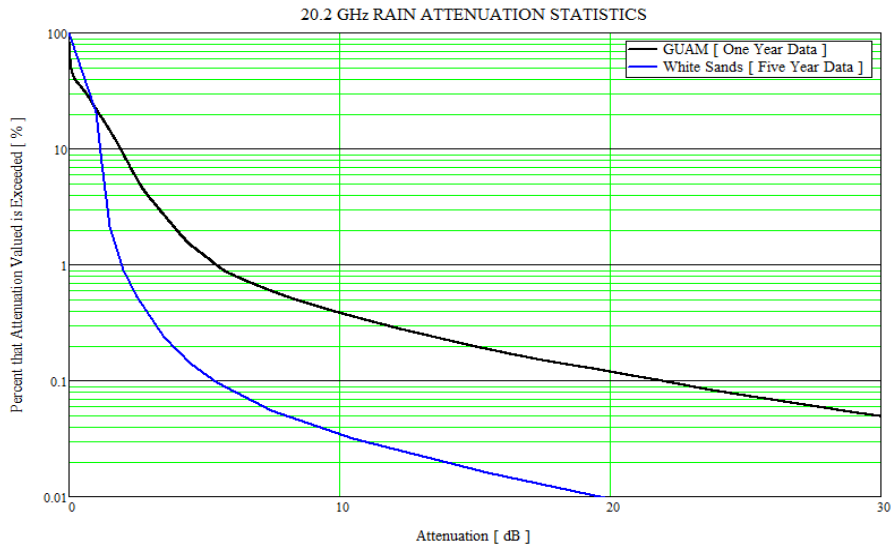


Fig. 4. Cumulative Distribution Function (CDF) for Attenuation with respect to free space (includes rain, gaseous absorption and clouds).

The overall cumulative distributions derived from the measured attenuation values due to rain, gaseous absorption and clouds at the White Sands and Guam sites are presented in **Figure 4**. Notice that at the 99th percentile, 6 dB of rain margin will be needed for Guam while White Sands will require only 2 dB, this is due to the stark contrast of the two climates.

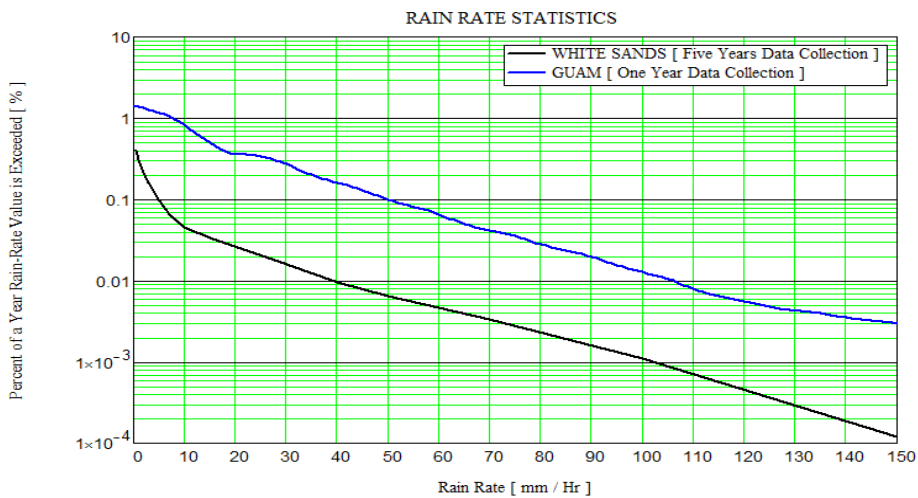


Fig. 5. Cumulative Distribution Function (CDF) for Attenuation with respect to free space (Includes rain, Gaseous absorption and clouds).

The distributions of the rain rates at Guam (a tropical rain zone) and White Sands (a dry desert zone) are presented in **Figure 5**. The 0.01% probability point values of rain rates for White Sands and Guam are 40 mm/h and 105 mm/h, respectively. These are typical values for a tropical rain zone and for a desert type zone. Notice that it only rains in White Sands an average of 0.4% of the year while Guam experiences rain 1.2% percent of per year.

V. Conclusive Remarks and Future Work

Reviewing the statistical analysis of the phase fluctuations at all three sites has lead to a noticeable trend in the phase stability. The phase fluctuations (rms) at all sites tend to be the worst during the summer months, best during winter months, and generally worse during the day than during the nights. A statistically meaningful comparison between these three sites is not possible with only one year of data collection at Guam, but preliminary results indicate that the Goldstone and White Sands sites appear to have similar atmospheric phase stability (time delay) characteristics which are very different from Guam, whose stability is worse by almost a factor of six. Similarly the attenuation statistics at White Sands and Goldstone are very similar, while Guam will require at least 4 dB more margin due to rain and clouds. A more comprehensive comparison will be done after several years of simultaneous data collection.

VI. References

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