

# Long-Term Trends in Space-Ground Atmospheric Propagation Measurements

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**Abstract**—Propagation measurement campaigns are critical to characterizing the atmospheric behavior of a location and efficiently designing space-ground links. However, as global climate change affects weather patterns, the long-term trends of propagation data may be impacted over periods of decades or longer. Particularly, at high microwave frequencies (10 GHz and above), rain plays a dominant role in the attenuation statistics, and it has been observed that rain events over the past 50 years have trended toward increased frequency, intensity, and rain height. In the interest of quantifying the impact of these phenomena on long-term trends in propagation data, this paper compares two 20 GHz measurement campaigns both conducted at NASA’s White Sands facility in New Mexico. The first is from the Advanced Communication Technology Satellite (ACTS) propagation campaign from 1994 – 1998, while the second is amplitude data recorded during a site test interferometer (STI) phase characterization campaign from 2009 – 2014.

## I. INTRODUCTION

The Intergovernmental Panel on Climate Change (IPCC) notes that, among other climate change phenomena, it is likely that the past several decades have seen an increase in precipitation and humidity in the mid-latitudes of the northern hemisphere as well as a warming of the troposphere. It is also observed that “the number of heavy precipitation events has increased in more regions that it has decreased” [1]. Given that rain is a dominant factor in link attenuation, particularly above 10 GHz, it is worthwhile to investigate whether such changes in weather patterns may play a role in the long-term stability of propagation measurements. Studies on rain rate statistics over time have shown that rain rates have significantly increased over the past 20 years, with the most notable trends presenting at the 99.9% availabilities and above [2]. Prior studies on propagation data over the long-term have compared the inter-annual variability over ten years [3], and seven years [4], but there remains a need to assess longer time-scales in which climate change phenomena may affect availability.

Attenuation data collected at NASA’s White Sands Ground Terminal in New Mexico offers a unique opportunity to characterize trends in propagation statistics over the past two decades, given that there have been two measurement campaigns conducted at the same location, spanning 20 years total (with an 11 year gap between), which may provide an indication of the impact of climate change phenomena on satellite communication system design.

## II. RECEIVER DESIGN

The first dataset used in this analysis was collected at the White Sands facility during the propagation campaigns of the Advanced Communication Technology Satellite (ACTS) from 1994 - 1998. The ACTS terminal employed a digital beacon receiver design, observing the unmodulated Ka-band beacon onboard the ACTS satellite at 20.2 GHz with a 20 dB dynamic range and 1 sample per second recording standard [5].

The second dataset was collected via a two-element site test interferometer (STI) installed to characterize the same site’s phase stability from 2009 to the present, with attenuation data also being recorded from each element of the interferometer. This terminal is located less than 400m from the location of the original ACTS receiver at White Sands. The design of the STI is presented in Fig. 1 from the front end to the analog-to-digital converter (ADC). The STI employs a similar approach to the ACTS design, with upgrades to the components to reduce noise figure and improve dynamic range. Each channel observes a 20.2 GHz beacon onboard the ANIK F2 communications satellite and down-converts to 70 MHz directly at the feed. Following this, the signals from both channels are fed to a common intermediate frequency (IF) stage and further down-converted to 455 kHz, at which point they are sampled by the ADC with a sampling rate of 3.64 MHz and integrated over 144 ms. The attenuation of each channel is then stored at 1 second intervals (1 Hz). The system was characterized to have

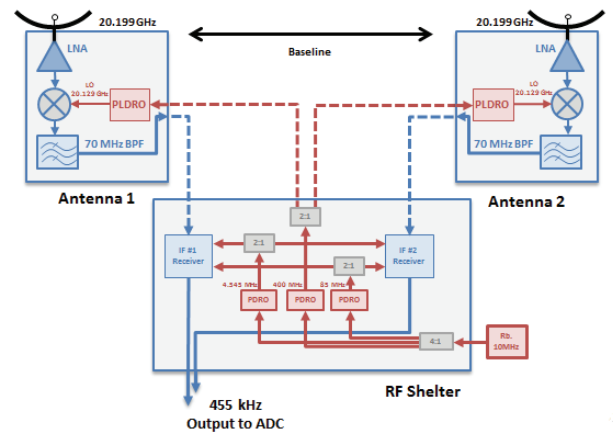


Fig. 1. Block diagram of the site test interferometer (STI) design used in the 2009 campaign. The 1994 ACTS terminal was comparable but with only a single element and a smaller dynamic range.

a dynamic range of 30 dB. Only one channel is used for the comparison to the ACTS measurements as both channels are highly similar in attenuation.

### III. DATA PROCESSING & NORMALIZATION

To compare the two data sets equally, both were normalized to a reference clear-sky attenuation level. This was accomplished by applying a five minute moving average to each day of data and referencing the daily minimum attenuation of the moving average to zero. This also has the effect of removing the contributions of atmospheric gaseous absorption (AGA), thusly focusing on the excess attenuation due to rain. Additionally, in the case of the STI data, there was a change in the amplitude measurement technique in June of 2012. Prior to this point, amplitude data was recorded as the peak power of the FFT which produces a scalloping pattern in the amplitude measurement as a function of frequency drift. Beyond this date, the scalloping effect was mitigated in real time through a bin-summing approach that sums the total power in the peak bin and several neighboring bins to recover a majority of the power that bleeds into nearby bins. This greatly decreases the scalloping ripple and thusly improves measurement accuracy. However, to compensate for the scalloping in the data prior to 2012, an additional low-pass filter was applied to the data before normalization.

### IV. RESULTS

Fig. 2 plots the monthly attenuation values of both campaigns at the 90<sup>th</sup>, 95<sup>th</sup>, and 99<sup>th</sup> percentiles along with a linear regression across both datasets at each percentile. At the 90<sup>th</sup> percentile, an increasing trend of 0.013 dB / decade is observed, along with a 0.010 dB / decade trend at the 95<sup>th</sup> percentile and 0.022 dB / decade at the 99<sup>th</sup>. Fig. 3 plots the complementary cumulative distribution function (CCDF) of each year along with the total for each campaign. For approximately 99.9% and below, the change from the ACTS data to the STI data does not generally exceed the inter-annual variability, indicating that on a 20 year timescale, these phenomena may be of greatest concern for availabilities at and above 99.9%. Table I summarizes the mean attenuation and standard deviation of each campaign along with the relative increase or decrease between the ACTS data and the STI data. Although the mean attenuation shows a small increase, the standard deviation is more variable, which is also evident by increase in high attenuation months in the curves of Fig. 2.

TABLE I. SUMMARY STATISTICS OF EACH CAMPAIGN

Propagation Campaign Statistics				
	Percentile	ACTS (1994 - 1998)	STI (2009 - 2014)	$\Delta$
Mean Atten.	90 <sup>th</sup>	0.3356 dB	0.3579 dB	+ 6.630%
	95 <sup>th</sup>	0.4358 dB	0.4581 dB	+ 5.120%
	99 <sup>th</sup>	0.9392 dB	0.9577 dB	+ 1.971%
Std. Dev.	90 <sup>th</sup>	0.1075 dB	0.089 dB	- 17.208%
	95 <sup>th</sup>	0.1676 dB	0.213 dB	+ 27.052%
	99 <sup>th</sup>	0.5184 dB	0.7332 dB	+ 41.438%

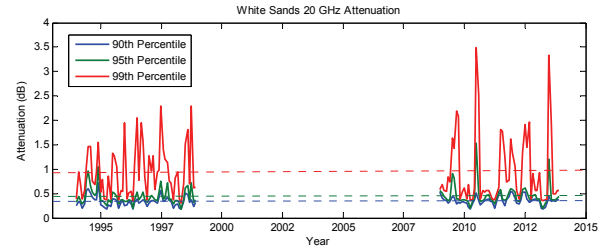


Fig. 2. The monthly attenuation during each campaign at the 90<sup>th</sup>, 95<sup>th</sup>, and 99<sup>th</sup> percentile along with linear fits across both campaigns.

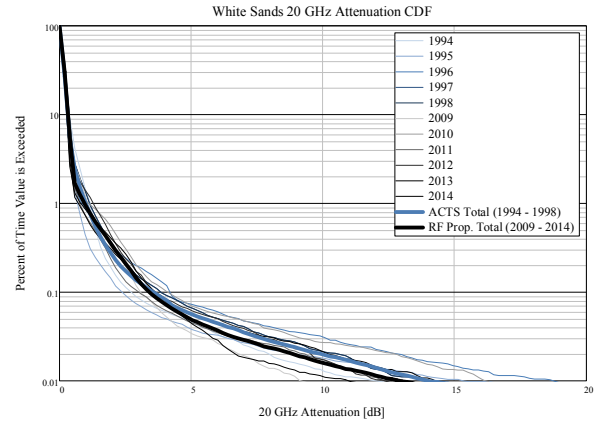


Fig. 3. Annual CCDFs of attenuation during each campaign, 1994 – 1998 and 2009 – 2014 along with the total CDFs of each campaign.

### V. CONCLUSIONS

As indicated by these statistics, there was a slight positive increasing trend in attenuation, and notable variability in standard deviation, although the impact was most pronounced at high availabilities. Given that NASA systems tend to be designed below 99.9%, these results suggest that, at least on a timescale of 20 years, the impact of climate change phenomena may be negligible unless higher availabilities are pursued. However, it should also be noted that the impacts may be more noticeable in rainier locations given that rain is the dominant mechanism. Further analysis may also consider climatological trends including the AGA, or a study over a longer period of time to shed greater insight on the relationship over timescales more comparable to those of climate change phenomena.

### REFERENCES

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