International Journal of Trend in Scientific Research and Development (IJTSRD)
Volume 10 Issue 5, Sep-Oct 2026 Available Online: www.ijtsrd.com e-ISSN: 2456 – 6470

Investigation of the Effects of Cloud Conditions on Satellite Signal Strength

Idakwoji Husseini[1], Bashir Sanusi Yusuf[2], Zubairu Ibrahim Dogo[3], Saki Shehu Tijani[4]

[1,4]Artificial Intelligence and Robotics Department, National Space Research and Development Agency, Abuja, Nigeria
[2]Ground Station and Mission Control Department, National Space Research and Development Agency, Abuja, Nigeria
[3]Engineering and Space Systems Department, National Space Research and Development Agency, Abuja, Nigeria

ABSTRACT

Cloud conditions can influence satellite signal strength and communication performance as electromagnetic signals propagate through the atmosphere between satellites and ground stations. This study reviews and explains the effects of cloud conditions on satellite signal strength using a review and explanatory research approach. Relevant literature on cloud attenuation, signal scattering, absorption, fading, depolarization, propagation loss, signal fluctuations, and frequency-dependent effects was examined. The study explains how cloud properties such as liquid water content, cloud thickness, droplet size, temperature, and frequency of operation can affect the received signal. The review indicates that the influence of clouds becomes more significant at higher operating frequencies and under conditions of high cloud liquid water content. Understanding these effects is important for satellite link design, signal monitoring, link-budget estimation, and maintaining reliable satellite communication services. The study provides a consolidated explanation of cloud-related effects and highlights the need to consider atmospheric cloud conditions when assessing satellite signal strength and communication performance.

KEYWORDS: *Cloud Conditions; Satellite Signal Strength; Cloud Attenuation; Signal Propagation; Satellite Communication; Atmospheric Effects.*

How to cite this paper: Idakwoji Husseini | Bashir Sanusi Yusuf | Zubairu Ibrahim Dogo | Saki Shehu Tijani "Investigation of the Effects of Cloud Conditions on Satellite Signal Strength" Published in International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Volume-10 | Issue-5, October 2026, pp.1218-1223, URL: www.ijtsrd.com/papers/ijtsrd142188.pdf

IJTSRD142188

Copyright © 2026 by author (s) and International Journal of Trend in Scientific Research and Development Journal. This is an Open Access article distributed under the terms of the Creative Commons Attribution License (CC BY 4.0) (http://creativecommons.org/licenses/by/4.0)

1. INTRODUCTION

Satellite communication has become an important part of modern communication systems, supporting television broadcasting, internet services, navigation, remote sensing, and other applications. The performance of satellite communication links depends on the reliable transmission and reception of electromagnetic signals between satellites and ground stations. However, as these signals pass through the atmosphere, they interact with atmospheric constituents and weather conditions, which can result in attenuation, scattering, fading, and variations in received signal strength. Clouds are among the atmospheric conditions that can affect satellite signal propagation, particularly at microwave and millimetre-wave frequencies. Clouds contain liquid water droplets and ice particles that can interact with electromagnetic waves travelling between a satellite and a ground station. The amount of liquid water within a cloud, its thickness, temperature, and the operating frequency of the communication system can influence the magnitude of signal attenuation.

Several researchers have examined the relationship between clouds and satellite signal propagation. Das, et al. (2013) investigated cloud attenuation at a tropical location in India and reported that cloud attenuation increased with frequency, with significant attenuation observed at Ka- and V-bands. Their measurements also showed that temperature and liquid water content influenced the observed attenuation. De and Maitra (2021) further examined cloud attenuation at 30 GHz in Kolkata and found significant attenuation during the monsoon season, which they associated with high liquid water path values.

Similarly, researchers investigating cloud characteristics and Earth-space links in India have shown that cloud liquid water content is an important

contributor to cloud attenuation, with higher-frequency systems being particularly affected. Adewusi et al. (2023) also reviewed cloud attenuation modelling for a tropical location in southwest Nigeria and emphasized the importance of considering cloud effects in satellite communication link design. More recently, Ohno et al. (2026) examined cloud attenuation using direct cloud-particle observations and reported that cloud particles can become an important source of attenuation for next-generation satellite systems operating at sub-terahertz, terahertz, and free-space optical frequencies.

These studies demonstrate that cloud conditions can influence satellite signal strength through attenuation and other propagation effects. However, the magnitude of the effect varies according to cloud liquid water content, cloud characteristics, operating frequency, propagation path, and geographical location. A focused review is therefore useful for bringing together the findings of previous researchers and explaining the mechanisms through which clouds affect satellite signal strength. This study therefore reviews and explains the effects of cloud conditions on satellite signal strength and communication performance. Particular attention is given to cloud attenuation, scattering, absorption, fading, depolarization, propagation loss, signal fluctuations, and the influence of operating frequency. The study also examines the importance of cloud liquid water content and other cloud characteristics in determining the level of signal degradation.

2. Methodology

This study adopted a review and explanatory research approach to examine the effects of cloud conditions on satellite signal strength and communication performance. The review focused on published studies that investigated cloud attenuation, cloud liquid water content, atmospheric absorption, scattering, fading, and other cloud-related effects on satellite signal propagation. Relevant literature was obtained from scholarly sources, including peer-reviewed journal articles, conference papers, and reputable scientific publications. The literature search was conducted using keywords and combinations of terms such as **"**cloud attenuation," "cloud effects on satellite signals," "satellite signal strength," "cloud liquid water content," "satellite signal propagation," and "weather effects on satellite communication**."** Studies were selected based on their relevance to the objectives of the research, with particular attention given to studies that provided explanations, measurements, models, or observations of cloud-related signal degradation. The selected studies were examined comparatively to identify the major ways in which clouds affect satellite signal strength. Information concerning operating frequency, cloud characteristics, liquid water content, propagation conditions, and reported signal attenuation was extracted and synthesized. The explanatory component of the study was then used to describe the physical mechanisms responsible for the observed effects, including absorption, scattering, attenuation, fading, and signal fluctuations. The findings from the reviewed studies were organized according to the major cloud-related effects on satellite signals and the factors that influence their severity. Particular attention was given to differences between lower- and higher-frequency satellite communication systems and to the influence of cloud liquid water content and propagation path. No primary field measurements were conducted; therefore, the study relied on evidence and findings reported in previously published research. The approach provides a systematic explanation of existing knowledge and identifies important considerations for satellite communication link planning and signal-strength assessment under varying cloud conditions.

3. Results and Discussion

The following are some of the effects of cloud conditions on satellite signal strength.

3.1. Cloud Attenuation

Cloud attenuation is one of the major ways through which clouds affect satellite signal strength. When an electromagnetic signal travels through a cloud containing liquid water droplets, part of the signal energy is absorbed and scattered by the water particles. This results in a reduction in the power received at the ground station. The magnitude of cloud attenuation depends on factors such as operating frequency, cloud liquid water content, cloud thickness, propagation path, and elevation angle. The effect becomes increasingly important as the operating frequency increases, particularly in Ka-band and above.

Das, et al. (2013) investigated cloud attenuation using radiometric measurements at a tropical location in Kolkata, India. Their study examined cloud extent, liquid water content, and temperature profiles and found that cloud attenuation was significant at higher frequencies. The researchers reported that approximately 4 dB of attenuation at Ka-band could occur for about 0.01% of the year, demonstrating that clouds can produce measurable reductions in satellite signal strength even when rainfall is absent. Similarly, De and Maitra (2021) investigated cloud attenuation at 30 GHz using two years of ground-based microwave radiometric observations in Kolkata. They reported significant cloud attenuation

during the Indian summer monsoon, when cloud liquid water path was high. Their analysis showed that August represented a particularly severe period for cloud attenuation and that the attenuation varied according to season and cloud liquid water content. The study therefore demonstrated that cloud-related attenuation can become an important propagation impairment for high-frequency satellite links, particularly under tropical conditions.

The findings of these two studies indicate that cloud attenuation can directly reduce satellite signal strength and that its magnitude is strongly associated with cloud water content and operating frequency. This is particularly relevant to high-frequency satellite communication systems, where even a few decibels of additional attenuation can affect the available link margin.

3.2. Cloud Liquid Water Content

Cloud liquid water content (LWC) is another important factor controlling the effect of clouds on satellite signal strength. LWC refers to the amount of liquid water contained within a given volume of cloud. As LWC increases, the interaction between electromagnetic waves and cloud water droplets generally becomes stronger, resulting in greater signal attenuation. Consequently, clouds with higher liquid water content can produce greater degradation of satellite signal propagation than clouds containing relatively small amounts of liquid water.

De and Maitra (2021) examined the relationship between cloud attenuation and liquid water path using radiometric observations at 30 GHz in Kolkata. Their results showed significant cloud attenuation during the monsoon period, when liquid water path values were high. The researchers also observed seasonal and diurnal variations in cloud attenuation, demonstrating that changes in atmospheric cloud water content can produce corresponding variations in satellite signal attenuation. Also, Ohno et al. (2026) investigated cloud attenuation using direct cloud-particle observations from cloud particle sensor sondes in Okinawa, Japan. Their study considered both water droplets and ice crystals and found that the contribution of ice crystals becomes particularly important at wavelengths shorter than approximately 1 mm. The researchers noted that conventional approaches based mainly on liquid water content may not adequately represent attenuation under multilayered cloud conditions containing significant ice particles.

These findings show that cloud liquid water content is an important parameter for explaining variations in satellite signal strength, but the composition and physical characteristics of cloud particles can also become important at very high frequencies. Therefore, accurate assessment of cloud effects requires consideration of both the amount and type of water or ice particles present along the satellite propagation path.

3.3. Cloud Scattering

Cloud scattering occurs when electromagnetic waves interact with water droplets and ice particles within clouds, causing part of the signal energy to deviate from its propagation path. Its effect depends on signal frequency, wavelength, particle size, concentration, and cloud composition. At microwave frequencies, cloud attenuation is mainly associated with absorption by liquid water, while scattering becomes more relevant at higher frequencies.

Omotosho et al. (2014) examined cloud attenuation across major climatic zones in Africa and found that cloud liquid-water content and attenuation varied with atmospheric conditions. Their results also showed that conventional ITU-R estimates could underestimate cloud attenuation at higher frequencies, particularly at 30 and 50 GHz. This indicates that cloud characteristics are important when estimating satellite signal losses in African environments. Yuan et al. (2016) investigated cloud attenuation using an 18.9-GHz satellite beacon in tropical Singapore. Their findings showed that cloud conditions produced measurable signal attenuation and that cloud liquid-water content should be considered when evaluating high-frequency satellite communication links in tropical regions.

These studies indicate that cloud characteristics and operating frequency influence satellite signal propagation. Therefore, cloud effects should be considered when assessing received signal strength and satellite link performance, particularly in tropical environments.

3.4. Cloud Conditions

Cloud conditions can also produce variations or fluctuations in satellite signal strength. Changes in cloud thickness, liquid water content, cloud movement, and the distribution of water or ice particles along the propagation path can cause the amount of attenuation experienced by the signal to vary with time. Consequently, a satellite receiver may experience changes in received signal power rather than a constant level of attenuation. Such variations are important for communication systems because they can reduce the available link margin and affect the stability and availability of the communication link.

Pimienta-del-Valle et al. (2024) demonstrated the temporal and statistical variability of cloud

attenuation through five years of Q-band propagation measurements. Their analysis showed that cloud attenuation can be characterized statistically over long observation periods and that the resulting attenuation distributions are useful for evaluating satellite-link performance. Importantly, the study found that ERA5 total-column cloud liquid water produced attenuation estimates comparable with those obtained from radiosounding observations, indicating that meteorological cloud parameters can be used to assess variations in propagation conditions. Similarly, Pham, et al (2023) investigated the effect of cloud attenuation on the placement of optical satellite ground stations. Using ERA-Interim meteorological data covering Japan from 2018 to 2022, the researchers calculated monthly mean cloud attenuation and incorporated the results into a site-diversity strategy. Their simulations showed that selecting geographically separated ground stations according to cloud-attenuation conditions can achieve sufficiently high system availability. The study therefore demonstrates that spatial and temporal variations in cloud conditions can have direct implications for satellite communication availability and ground-station planning.

These studies demonstrate that cloud conditions influence satellite signal attenuation through both temporal variability and spatial differences in cloud characteristics. Consequently, cloud effects should not be considered only as a single maximum attenuation value. Their variation over time, location, cloud liquid water content, and frequency should also be considered when evaluating received signal strength, link margin, and service availability. This is particularly important for high-frequency microwave and optical satellite systems, where cloud-induced attenuation can become a significant propagation impairment.

3.5. Seasonal and Geographical Variation

Cloud-related attenuation of satellite signals varies with geographical location and season because cloud characteristics are not uniform throughout the year. Changes in cloud liquid water content, cloud thickness, cloud occurrence, and atmospheric temperature can produce different levels of attenuation at different locations and seasons. This variation is particularly important in satellite communication because a link that experiences relatively low cloud attenuation during one season may experience greater attenuation during another season. Pugazhenthi and Lakshmi (2021) investigated cloud parameters and attenuation at five locations in India using atmospheric observations from October 2016 to September 2017. Their study considered cloud liquid water content and calculated attenuation at 6, 12.5, and 24 GHz. They found that cloud attenuation was generally higher during the southwest monsoon season, followed by the northeast monsoon, pre-monsoon, and winter seasons. The maximum calculated cloud attenuation reached 1.67 dB/km at 24 GHz in Hyderabad, showing that both location and season can influence the severity of cloud-related signal degradation. In the same way, Garcia et al. (2021) examined cloud attenuation at Ka-, Q-, and W-bands in El Alto, Bolivia, using three years of radiosonde observations. Their study emphasized that cloud attenuation is a variable atmospheric phenomenon and that its characterization should consider not only annual statistics but also seasonal and monthly variations. The researchers specifically examined attenuation at 20, 40, and 75 GHz, demonstrating the importance of geographical and seasonal information when assessing satellite link availability. The findings from these studies indicate that cloud effects on satellite signal strength cannot be assumed to be constant throughout the year or across different geographical regions. Therefore, satellite communication planning should consider local and seasonal cloud characteristics when estimating signal attenuation and link availability.

3.6. High-Frequency Satellite Communication Systems

The importance of cloud effects increases as satellite communication systems move toward higher operating frequencies. Modern satellite systems increasingly employ high-frequency bands to provide greater bandwidth and higher data transmission capacity. At these frequencies, atmospheric water droplets and other cloud particles can produce additional attenuation, making accurate characterization of cloud effects important for maintaining reliable communication. Pimienta-del-Valle et al. (2024) experimentally assessed cloud attenuation on a Q-band slant-path link using five years of measurements in Madrid, Spain. Their study developed a method for separating cloud attenuation from other propagation effects during non-rainy conditions. The researchers found that the measured cloud attenuation statistics were in good agreement with radiosounding-based models, although the ITU-R P.840 model tended to overestimate the measured attenuation. Their results demonstrate the importance of experimental observations for validating cloud attenuation models used in high-frequency satellite communication systems. In another study, Battaglia et al. (2020) developed a global climatology of attenuation caused by clouds and precipitation at Ka-band using four years of observations from the Global Precipitation Measurement (GPM) mission. Their

study demonstrated that cloud and precipitation attenuation can affect Ka-band satellite systems and examined the geographical distribution and temporal characteristics of these atmospheric losses. The authors noted that attenuation is particularly relevant to applications such as satellite communication, radar altimetry, and synthetic aperture radar systems operating at Ka-band. These studies demonstrate that cloud attenuation is increasingly important for high-frequency satellite systems. As communication systems adopt higher frequencies to achieve greater bandwidth, accurate cloud attenuation measurements and models become necessary for reliable link-budget estimation, system design, and communication availability.

4. Conclusion

This study reviewed and explained the effects of cloud conditions on satellite signal strength and communication performance. The reviewed studies show that clouds can contribute to signal attenuation, scattering, fading, propagation loss, and fluctuations in received signal strength. The magnitude of these effects depends mainly on cloud liquid water content, cloud characteristics, propagation path, geographical location, and operating frequency. The reviewed findings also indicate that cloud effects become more significant at higher frequencies, particularly in Ka-band, V-band, and emerging higher-frequency satellite systems. Therefore, cloud conditions represent an important atmospheric factor that should be considered when assessing satellite signal strength and designing reliable satellite communication links, especially in tropical regions.

5. Recommendation

It is recommended that satellite communication planners and engineers incorporate cloud attenuation into satellite link-budget calculations, particularly for systems operating at high frequencies. Ground-based measurements of cloud liquid water content, cloud thickness, temperature, and related atmospheric parameters should be encouraged to improve the accuracy of local cloud attenuation models. Researchers should also conduct more long-term measurements in tropical regions, including Nigeria, to establish location-specific relationships between cloud conditions and satellite signal strength. In addition, future studies should examine the combined effects of clouds, rainfall, humidity, and other atmospheric conditions to provide a more comprehensive assessment of satellite communication performance.

References

[1] Adewusi, O. M., Omotosho, T. V., Akinyemi, M. L., Akinwumi, S. A., & Ometan, O. O. (2023). Development of cloud attenuation model for satellite network links performance improvement. *Advances and Challenges in Science and Technology, 8*.

[2] Battaglia, A., Mroz, K., Watters, D., & Ardhuin, F. (2020). GPM-derived climatology of attenuation due to clouds and precipitation at Ka-band. *IEEE Transactions on Geoscience and Remote Sensing, 58*(3), 1812–1823.

[3] Das, S., Chakraborty, S., & Maitra, A. (2013). Radiometric measurements of cloud attenuation at a tropical location in India. *Journal of Atmospheric and Solar-Terrestrial Physics, 105–106*, 97–100.

[4] De, A., & Maitra, A. (2021). Cloud attenuation statistics from radiometric measurements over a tropical location Kolkata, India. *Advances in Space Research, 67*(1), 290–297.

[5] Garcia, A., Siles, G., Arciénega, J. P., & Balderrama, Y. (2021). Cloud attenuation at Ka, Q and W bands based on radiosoundings during rainy and non-rainy seasons in Central Andes: A study in El Alto, Bolivia. *Revista Investigación & Desarrollo*.

[6] Le, H. D., Pham, A. T., & Nguyen, T. V. (2021). Cloud attenuation statistical model for satellite-based FSO communications. *IEEE Antennas and Wireless Propagation Letters, 20*(5), 643–647.

[7] Ohno, T., Matsui, M., Itokawa, K., Tokuyasu, T., Ito, K., Shige, S., & Takemi, T. (2026). Cloud attenuation estimation based on cloud particle sensor sonde observations for next-generation satellite communications. *Scientific Reports, 16*.

[8] Omotosho, T. V., & Babatunde, E. B. (2010). Study of cloud impact on fixed satellite communication link at Ku, Ka and V bands in Nigeria. *Australian Journal of Basic and Applied Sciences, 4*(8), 3287–3298.

[9] Omotosho, T. V., et al. (2014). Cloud attenuation and cloud liquid water content in the tropical regions. *Annals of Geophysics, 57*(5), A0546.

[10] Pham, T. V., Yamano, H., & Ishihara, S. (2023). A placement method of ground stations for optical satellite communications considering cloud attenuation. *IEICE Communications Express, 12*(10), 568–571.

[11] Pimienta-del-Valle, D., Siles, G. A., Riera, J. M., & Garcia-del-Pino, P. (2024). Experimental

assessment of cloud attenuation in a Q-band slant-path link. *IEEE Transactions on Antennas and Propagation, 72*(2), 1772–1778.

[12] Pugazhenthi, A., & Lakshmi Sutha Kumar, S. (2021). Calculation and analysis of cloud attenuation and other cloud parameters in India for earth-space links. *Advances in Space Research, 68*(10), 3957–3970.

[13] Yuan, T., et al. (2016). Cloud attenuation measurements using an 18.9-GHz satellite beacon in Singapore. *IEEE Transactions on Antennas and Propagation*.