

Effect of Environmental RF Propagation Impairments on Satellite Communication Link and Prediction of Cloud Attenuation using Machine Learning Algorithms

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Abstract

Satellite communication networks is advocating the usage of millimeter wave (mmWave) frequencies to cater to the growing demand for high data rates, broader bandwidths, and reliable communication links. However, these high-frequency bands are increasingly prone to propagation impairments, particularly those originating from atmospheric conditions such as rain, clouds, and ionospheric disturbances. Among these, cloud attenuation faces a notable challenge due to its extended duration and periodic occurrence, specifically in tropical regions like India. Low-level clouds, such as cumulonimbus, present significantly to signal degradation due to their dense water content. This research focuses on the importance of understanding and predicting cloud attenuation and its effect on satellite link reliability. To this end, machine learning algorithms—linear regression, decision trees, and multiple regression—are employed to estimate cloud-related parameters such as cloud cover, derived from atmospheric temperature, humidity, and pressure data. Furthermore, in the absence of fully developed cloud attenuation measurement systems in many tropical regions, predictive attenuation models serve as indispensable tools for system design and planning. This work reviews existing models, discusses their limitations, and explores ways to adapt them to local climatic conditions to ensure effective and flexible satellite communication.

1. INTRODUCTION

The rapidly increasing demands in high data rates, high bandwidths and communication links availability requirements are forcing to deploy millimeter wave frequency in satellite communication networks that can meet these requirements. The presence of atmospheric abnormalities and severe weather conditions may adversely affect the transmission performance of earth-satellite communication links operating in the millimeter band range which leads to link outage. When a RF signal propagates through rain or clouds, then it suffers from power loss due to hydrometer scattering. This research work describes different types of propagation impairments and how it affects communication links.

This work considers cloud attenuation as a serious impairment among all propagation impairments. Because in terms of time intervals cloud attenuation occupies longer durations than rain. Cloud attenuation occurs hours and days together. Therefore it is important to investigate the impact of cloud attenuation on satellite communication links as well as to predict cloud attenuation statistics with high frequencies. Clouds are distinguished by the heights above ground level at which they form. They are classified as high level, medium level and low level clouds. Among all these clouds low level clouds like cumulonimbus having huge water molecules can lead to remarkable attenuation throughout the year. In order to investigate how low level clouds feedback process can affect climate sensitivity, an initial step is to recognize frequent changes in the cloud cover. The cloud cover is obtained by integrating the saturated part of the temperature, humidity and pressure.

2. Overview of satellite communication

A satellite is an object that has been deliberately positioned into space. These are called artificial satellites to separate them from characteristic satellites, for example, earth's moon. As it is known that satellite correspondence utilizes satellites set above the earth by VSATs set on the earth. It is likewise utilized for television broadcasting. Satellites utilize microwave frequencies for correspondence with one another utilizing satellite connections and with earth stations or VSATs. There are various sorts of satellite depending on the applications and their orbits. Satellite frameworks can give inclusion to remote spots where the terrestrial one's comes up short. For correspondence between remote territories (hilly landscapes, island and so forth) and the fundamental land satellite correspondence is the cost practical choice. The high-frequency radio waves utilized for broadcast communications joins travel by the view are impeded by the bend of the Earth.

The motivation behind correspondences satellites is to hand-off the signal around the bend of the Earth permitting correspondence between generally isolated geological focuses. Without the assistance of satellites, we can't anticipate climate. Satellites have the greatest commitment to making expectations about climate change by considering the few worldwide situations. Climate gauging is done through fitting extraordinary instruments and incredible cameras in the satellites which screen different atmosphere factors, for example, air temperature, pressure and humidity. The greater part of the correspondence links is overseen by means of satellite since they are a lot more secure from assault by foes.

2.1 Overview of propagation impairments

The spreading impairments relating to entire planet-space connections stem primarily mostly in troposphere and ionosphere. At the point when a microwave signal spreading through the downpour, clouds, snow, hail, or ice beads, radio waves experience the ill effects of intensity loss due to hydrometeor dissipating. This comprises the fundamental impediment of working at the RF frequencies such as Ku, K, Ka recurrence groups. At higher frequencies more noteworthy than 10 GHz the climate impacts turn out to be progressively serious and the most significant lessening factor at the Ku and Ka groups is basically brought about by downpour and cloud.

The fast development of satellite administrations utilizing higher frequency groups, for example, the Ka-band has featured a requirement for evaluating the impact of various proliferation debilitations. After Rain, the next large debilitation is cloud weakening. It makes unsettling influence for the longer-term as opposed to rain constriction. In beacon estimations, the varieties of the signal level are deciphered as propagation impairments. The serious Propagation weakness factors considered are: cloud attenuation, vaporous assimilation, Downpour constriction melting layer lessening, tropospheric shines, and low-angle blurring.

2.2 Effect of propagation impairments on satellite communications

Satellite correspondence frameworks definitely go up against proliferation disabilities during signal transmissions between the satellite and earth stations in the framework. Such impedances must be considered in the plan of any satellite correspondence framework that is obliged to meet indicated execution objectives [12]. Propagation impairments should in this way be assessed and obliged, in business correspondence frameworks that offer types of assistance to clients anticipating a guaranteed degree of connection accessibility. Current satellite correspondence frameworks show quick advancement in an assortment of uses that contrast from the traditional uses of trunk phone. Accessibility and quality rules for novel administrations may vary significantly from those of set up frameworks, forcing significant prerequisites for new radio wave proliferation data. For instance, the development of little margin, low-accessibility business administration's has animated a lot of enthusiasm for propagation debilitations, for example, cloud attenuation and tropospheric glitter that may cause low degrees of path fading for a noteworthy level of the time.

For some new administrations, for example, those gave by very small aperture terminal (VSAT) and business-administration systems, restricted power margins are accessible. For such frameworks, propagation debilitations may exist at moderate levels for most of the time. New media transmission satellite administrations are being worked on, new framework prerequisites are being planned, and propelled techniques for adaptively reacting to signal debilitations are being acquainted with conquering different framework restrictions, particularly power impediments stood up to in microwave and millimeter-wave frameworks. L-band administrations are venturing into the land versatile satellite territory, expanding the requirement for data on shadowing and multipath impairments [12]. It is notable that the most serious spread disabilities in such out-door frameworks are created by downpour and cloud. To alleviate such hindrances it is imperative to explain the level of connection execution corruption and to assess its relief methods quantitatively [13]. In the microwave range, various meteorological variables consolidate to drive various proliferation disabilities [14]. A precise appraisal of the impedances influencing satellite connections is basic for a legitimate structure of the physical layer and for the exhibition assessment of the system [15].

2.3 Types of propagation impairments

Propagation impairments are broadly categorized into five types. Those are Rain attenuation, Cloud attenuation, Oxygen and water vapor attenuation, Scintillation effects, Ice crystal depolarization.

2.3.1 Rain Attenuation on Satellite Communications

In areas with heavy rainfall, earth stations are designed to operate at high transmission power so as to compensate the effects of nature. When rain droplets fall on electromagnetic signals propagating through atmosphere, the resulting interference is called rain attenuation. This leads to weakening of transmission of signal as the rain

drops absorb and scatter it. Signal transmissions at 6/4 GHz frequency ranges shall undergo less attenuation, while signal that are transmissions at the frequencies of 14/12 GHz will experience greater attenuation. The signal transmissions at 6/4 GHz signals shall have attenuation effect by rain storms approaching hurricane conditions. 6/4 GHz frequency is having a wavelength of 7 centimeters & 14/12 GHz frequency is having a wavelength 2 centimeters. It means if there is a signal which nears half the wavelength in diameter, rain in its propagation path would lead to attenuation of the signal. The duration for which a transmission might be affected and the depth of attenuation depend on total rain.

When satellite services and equipment functioning are designed, care must be taken to incorporate rain fade margin such that effect of attenuation is reduced. The rain fade margin can be defined as the amount of excess power given to the strengthen signal by satellite in compensating the possibility of rain attenuation. External factors can affect transmissions. Hence, satellite engineer must include link and power margin in the calculations while designing satellite link services related to signal transmissions. This is to ensure that during normal rainfall, attenuation won't affect the service.

2.3.2 Cloud attenuation

To carry message channels separately on single radio path at same frequency, orthogonally polarized signals can be used. For example, in terrestrial links that operate at less than 10 GHz [20]. The attenuation due to rainfall and some types of clouds determine how reliable the links for earth-space communication are above 10 GHz frequency. This is important in system planning/designing [17]. Satellite communication systems are being used extensively in millimeter wavelength region of radio spectrum. The result is – increased interest in studying how clouds affect propagation [23]. Although there are no acute effects as those of rain, cloud is located for a greater amount of time [23].

Attenuation by clouds can create deep fades in this band. So it is a major factor to define attenuation margins for slant path links with higher probability of occurrence [30]. Attenuation due to clouds in millimeter & microwave segment lead to degradation of radio communication, especially for low noise receiving systems. Considering entire Indian subcontinent over the different geographical region, there is still scarcity in measurements on cloud morphology [31]. Clouds consist droplets of water. It is not only the total water content but also water in droplet form. The known fact is that before the rainfall occurs, the consideration of cloudy conditions in tropical stations across India. Clouds that are present before the rainfall occurrence purely contain rain and such clouds are having huge water particle density. So we need to measure attenuation in radio wave by cloud in a region having maximum particle density. Radio engineers of satellite communications primarily require these results [31].

2.3.3 Oxygen and Water vapor attenuation (atmospheric gaseous absorption)

As water vapor has continuous presence across atmosphere and clouds with pronounced occurrence than rainfall. The effects of both cloud and water vapor are appropriately specified and gaseous attenuation in contrast with cloud and rain attenuation are always present [29]. Water vapor contributes to losses and also influences variance in scintillation intensity of atmospheric turbulences. In order to study outcomes of attenuation rain and cloud, the effects of gases must be eliminated from the radiometer for total attenuation measurement. The oxygen attenuation is smaller than water vapor and it can be precisely designed or modeled if we know temperature and atmospheric pressures at ground levels. Oxygen attenuation can be assumed to be same at both rainy and non-rainy conditions [26].

Generally we neglect attenuation that clear-air causes for most of the applications in satellite communications at low frequencies. But it is not so at higher frequency bands like at 10GHz frequency, clear air attenuations are caused by oxygen and water vapor [27]. Atmospheric water vapor can be called as perceptible water vapor (PWV), and many a times also known as total perceptible water (TPW). The cumulative water content from ground level to the top levels of the atmosphere is called PWV in liquid form, meaning that ice is not considered [41].

2.3.4 Scintillation effects

In the amplitudes of satellite signals, several decibels of scintillation can be detected as thick cumulus clouds cross the radio path in hot summer season. Scintillations with planet satellite path using 7 m and 0.6 m resonator were typically recorded at 19GHz and 28GHz [21]. A significant fact is that in the propagation direction the start and end of the scintillation events coincide to a visible observation of beginning and finishing of clouds. The actual fluctuations in amplitude of received signal are scintillations. Thick clouds comprise large amounts of water and water vapor resulting in high refractive index values that lead to scintillation effects. These values are distinct from

the nearby clear. Dry scintillation effects are characterized by negligible average attenuation or signal absorption through the cloud. They don't have much effect [21].

When a wave travels along different media in troposphere, atmospheric irregularities in radio refractivity occur thereby causing tropospheric scintillations. The satellite signals tend to fluctuate fast with frequencies above 10GHz. The effects of fluctuations differs from region to region due to difference in weather parameters, primarily temperature and relative humidity[83][84][85][86][88][89][101]. The International Telecommunication Union claims that depending on probability of exceedance time, fade depth of tropospheric scintillation may touch few dBs.

2.3.5 Ice crystal depolarization

Ice crystals at high altitude pose as a limitation. Crystals of ice form in clouds. They form in different ambient temperature – dependent shapes around the dust particle nuclei. At temperature less than -25°C, needles prevail and in temperature between -9°C to -25°C, plate formation takes place. Single crystals in cirrus clouds may exists in un specified time.

This process gives rise to an internal structure for thunderstorms, due to presence of pure ice crystal sat the top, raindrops at the bottom ultimately leading to both of them mixing while forming a cloud [20]. Ice clouds ignored in link budget calculations due to negligible effects [22]. Ice crystals in the maritime atmosphere tend to depolarize the signal heavily and are large in size [20]. Same shapes are not found in couple ice crystal due to aerodynamic and electrostatic forces. They needn't align in the same way resulting in depolarization of the signal [20]. The depolarization ratio affiliated with water clouds is directly proportional to backscatter and is positively correlated to the optical depth [35]. Huge levels of attenuation in optical wavelength band are caused by ice particles [49].

2.4 Cloud attenuation as a serious propagation impairment

Cloud Attenuation occurs hours and days together but rain attenuation occurs only for a few minutes in a day. In terms of severity rain attenuation is high, but in terms of time intervals cloud attenuation occupies longer durations than rain. Usually probability of rain is less than 5-8% of the time in most temperate zones, where as the occurrence of clouds is 50 to 70% of the time in an year. So, the frequent occurrence of clouds leads to the link degradation for a long portion of time. Also, it is essential to observe probability of exceedance for cloud attenuation in both monsoon & winter season, because notable amount of cloud attenuation occurs during winter& monsoon seasons [48]. This cloud attenuation has notable contribution towards overall signal deterioration at many frequency bands [48]. Cloud attenuation produced in all slant paths is large for very high time percentages. A random behavior is observed in liquid water content and cloud attenuation [47].

Clouds at equatorial countries that are wet cover make up for 70% of space for a lot of time in an year [45]. Year 2012 noted the highest mean cloud cover of 71.6% over Indian ocean, because of low pressure and high temperature regions developed around the Indian sub continent during pre-monsoon periods. This high level of cloud cover leads to high amount of cloud attenuation which is a serious propagation impairment. Periodic propagation information on impairment mechanisms includes seasonal and daily variations at cloud considerations such that high quality services are provided by the design of satellite systems. Cloud attenuation for satellite links is affected by diameter of the antenna, antenna's elevation angle, operational frequency, meteorological conditions in a particular location [36][34].

3. Effect of cloud attenuation on satellite communications

The precipitation effect is profound in satellite communications, but continuous existence of cloud cover causes attenuation for longer time. For systems having low margin and operating frequency ranges of 30/20 and 50/40 GHz, cloud attenuation tends to increase very much. Earth space communication system operating at and above 10GHz are negatively affected with rain and plays a crucial role in causing high attenuation in propagating electromagnetic waves. Being rain is very serious, but in presence of rainfall across earth-space links are bounded to roughly 5% to 10% of the time across the year[104][105]. Factors like clouds causing restricted deterioration on the system but are represented by a very high likelihood in occurrence approximately 70% to 80% across the yearly time. The importance is to investigate the impact of cloud attenuation effect by electromagnetic waves as a models in predicting cloud attenuation statistics with high frequency and low elevation angles [42].

Earth space communication systems that have very high data rates are completely obstructed by clouds because micrometric droplets have high density and marked optical extinction properties [44]. cloud temperature, wavelength of the radio wave, cloud water particle density variations are the basic parameters in the calculation of radio wave attenuation [33]. In the past, some models were created for predicting cloud attenuation in receiving

as input for meteorological quantities and define empirical expressions. Other share high precision for comprehensive models for relying on some types of key features on clouds [42].

4. Formation of clouds

Clouds are produced when there is water vapor, cloud condensation nuclei (CCN), and ice nuclei (IN) [1]. Visible accumulation of smaller bubbles of water and ice crystals is termed as cloud. It floats in air and is formed when air that is moist and warm levitates to cool down. 50% of surface of Earth is covered with clouds. Thus, we can understand their influence on communication systems. A quick precipitation of water vapor creates a cloud. Two facts contribute to cloud appearance are stability of the atmosphere and increasing development of precipitation of cloud. When a cloud is being formed, atmosphere cools to a temperature less than its dew point. When excess of water vapor is present, it condenses. Clouds form when there are moisture changes from gas to liquid happens. When the ground and the air layer right above it heats up due to solar radiation, the air becomes lighter and there is an upward flow of clouds.

4.1. Types of Clouds

While preparing radiation budget of atmosphere, clouds are taken into consideration, particularly in upper and lower boundaries of the troposphere. When there is a decrease in static stability, they radiate leading to an increase in heat transfer in the upward direction. So to act and regulate the net infrared radiation budget with the surface of Earth [2]. Among the many atmospheric processes correlated tom tropical cyclones, the clouds present in these systems play a significant role for sustenance and intensification. The latent heat let out by clouds present in tropical cyclones determine their intensification and movement [3]. There are many features for clouds like shapes and spatial scales, so there are various effects on solar and infrared radiation [4]. In satellite meteorology and climatology studies, how the different types of clouds [5][6][7][8][9][10] are distributed at different altitudes is studied. Figure 1 represents the types of clouds at different altitudes.

Based on the height at which they form, clouds are categorized into three types:

- Clouds at high altitude: These clouds occupies 20,000 feet distance above the sea. Cirrus, cirrostratus and cirrocumulus clouds comes under high altitude clouds classification.
- Clouds at mid altitude: These clouds occupies 6,000 to 20,000 feet distance above the sea. Altostratus, altocumulus and nimbostratus clouds comes under mid altitude clouds.
- Clouds at low level: These clouds occupies 6,000 feet distance above the sea. Stratus, cumulus, cumulonimbus and stratocumulus clouds comes under low level altitude clouds classification which is shown in Figure 2.

The below Figure1 shows the different positions of clouds at different altitudes.

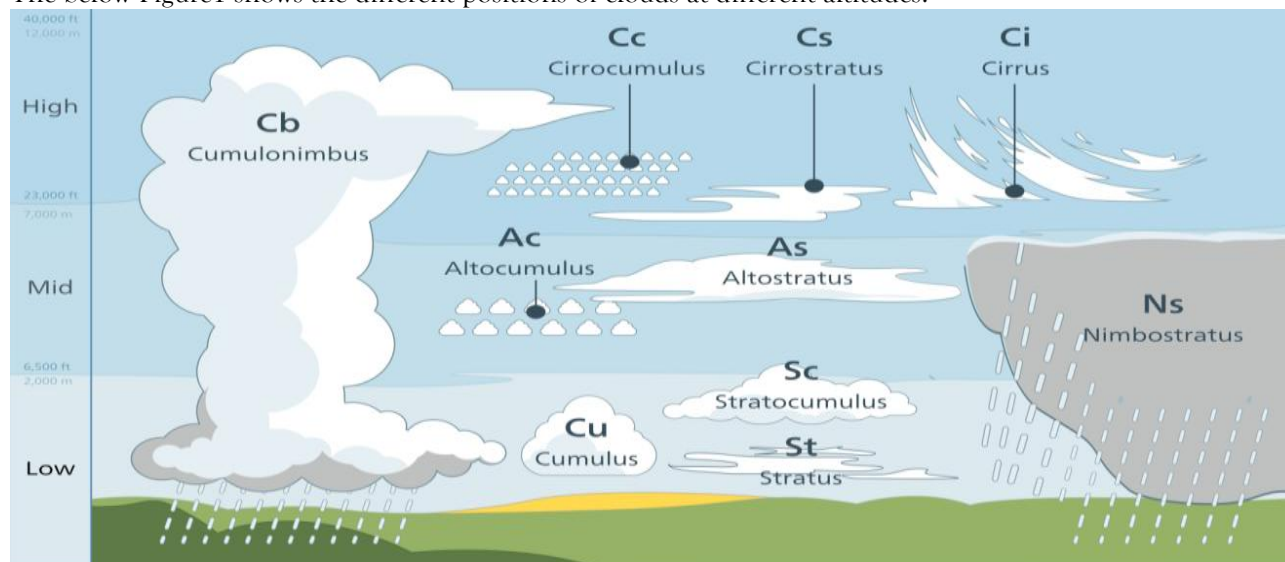


Figure1 Altitude of clouds

The below Figure 2 shows the major four types of low level altitude clouds. The following clouds are highly responsible for cloud attenuation.



Figure 2 different type of low level altitude clouds

The below Table1 gives the major characteristics like vertical extent, horizontal extent and water content of low level altitude clouds.

Table1. Characteristics of low level altitude clouds

Cloud type	Vertical extent, H_c , [Km]	Horizontal extent, L_c , [Km]	Water cont, ρ_w , [g/m ³]
Cumulonimbus	3.0	4.0	1.0
Cumulus	2.0	3.0	0.6
Nimbostratus	0.8	10.0	1.0
Stratus	0.6	10.0	0.4

5. Effects of clouds on communication system

Oxygen molecules, water droplets and ice together make a cloud. Significant attenuation can be achieved due to water molecules present in them. Couple of considerable facts confirms the appearances of cloud. One is symmetry of the atmosphere in the clouds presence and second one is increasing precipitation levels within the cloud. Free space optical communication is a fast data rate that provides links among both satellites and ground stations. But notable amount of attenuation is offered by clouds and even complete blockage of the link. Optical satellite communication systems are severely affected by the cloud coverage. As cloud makes up for almost 50% of the ground surface and has an effect on radiative transfer, influence of cloud has to be accounted for in computing processes.

Successful transmission diminishes altogether with in the height of upper cloud layer. As the cloud moves toward the surface, the optical depth(effective) turns out to be not exactly a large portion of the optical depth(true). On the off chance that cloud cover was consistent with season and year, at that point the dispersing bias would not be a factor. A huge division of the surface sign returns will be related to propagation through the transmissive cloud and aerosol. Since cloud and aerosol coverage has regular and yearly varieties. Because of the dynamic idea of clouds and their quality fluctuation at various pieces of the world and furthermore at various seasons, there is no basic method of choosing the most suitable fade mitigation procedures to use as a norm.

6. Importance of cloud physical temperature, cloud liquid water content and ice for cloud attenuation modeling

There is no static temperature for existence of clouds. When the temperature is greater than 0°C (per grid volume), the highest concentration of liquid water can exist. An inverse relation exists between latitude and physical temperature of clouds. Hence, cloud attenuation could be influenced by temperature. To understand how cloud attenuation estimation could be improved, effective temperature at frequency ranges of 20-50 GHz are analyzed. Among all clouds, cumulus and cumulonimbus have highest liquid water content. Cumulonimbus clouds have highest liquid water content a very complicated structure in comparison to other clouds. The prediction of clouds is further complicated by climatologically and depending on the liquid water content and storm structure. More humid climate results in low cloud base. Huge quantities of surface water vapor are made

of high cloud water content. During storm, high freezing levels are observed. The cumulative sum of many of these effects may arise in a crucial regional variance across the integrated liquid material pathway. Water droplets or ice crystals can make up clouds. Low density of the dielectric ice constant and small size of the constituent particles are a justification not to consider ice clouds in radio wave attenuation in the frequency range below 50GHz. It is for this reason that cirrus-type clouds are not much used for attenuation modeling.

7. Effects of cloud cover

In order to explore how cloud feedback processes influence climate sensitivity, an important step is to identify significant changes in the cloud cover [51]. Cloud cover refers to the cloud covered fraction of the sky as seen from a specific area. Cloud cover is also known as cloudiness. The cloud cover is obtained by integrating the saturated part of the temperature, humidity and pressure [55]. The amount of incoming solar radiation which reaches the earth depends on the level of cloud cover. The cloud cover is positively and significantly associated with relative humidity and negatively associated with the lapse rate [53]. Changes in overcast spread have little impact on winter temperature. The mean overcast spread increments with mean precipitation. Air temperature diminishes with expanding overcast spread.

8. Impact and importance of cloud cover

It's an important fact that clouds affect the short wave radiation tending to increase the terrestrial radiation [50]. In order to explore how cloud feedback processes influence climate sensitivity, an important step is to identify significant changes in the cloud cover [51]. As per the US Air force 3DNEPH satellite analysis, during the spring time mid latitude cloud cover raises near 900mb at 35% of cloud cover and declined to zero percent cloud cover at the point of surface [53]. Parameterization of the impact of cloud cover and total radiation of surface is a biggest problem for many cloud models [54]. Cloud cover is defined as that part of sky hidden by clouds when spotted from a particular location. Cloud cover is measured in terms of Okta. It corresponds to sunshine duration. Cloud cover is also called as cloudage/cloudiness/ cloud amount.. Clouds can simply impact the radiation stability of core earth. Because enhancement of planetary albedo leads to cooling effect. Greenhouse effect of clouds leads to heating effect [60]. The average mean cover of clouds among the oceans varies and differs from continent to continent. It is 72.4% for Pacific Ocean. Year 2012 noted the highest mean cloud cover and the year 2008 the lowest. Indian ocean has a mean cloud cover of 71.6%.Year 2010 noted the highest mean cloud cover and the year 2006 the lowest. It is 69.6% for the Atlantic Ocean. Year 2011 noted the highest mean cloud cover and the year 2003 the lowest. Arctic Ocean has a mean cloud cover of 69.3%.Year 2007 noted the highest mean cloud cover and the year 2004 the lowest. Thus it can be concluded that there was a slight increase in the cloud cover of pacific and Indian oceans [61]. The levels of radiative cooling during the night govern the amount of incoming solar radiation. These two factors which in turn depends on the quantity of moisture levels in the climate. So ,whatever the process affected by atmosphere, that compulsorily involves the water exchange [102].

9. Impact and importance of temperature

Temperature issues have become a first order concern for computing systems [77]. Temperature is used to express matter in hot stage and cold stage [78]. Temperature of a place mainly depends on a number of meteorological parameters viz warm/cold air masses, nature of soil, topography, solar radiation, cloud cover [98]. Temperature can be defined as a measure during the day by considering corresponding coldness and hotness. [100]. Exact predictions of different temperatures during the cold season is vital for communication channel [103]. Over the past century global mean surface temperature observed an increment of 0.75 degrees centigrade approximately [61]. Clouds have a significant effect on temperature changes [61]. One of the challenges is to accurately calculate the future course of atmosphere due to its dynamic nature and its influence on the temperature on Earth [71].

In order to plan and govern extreme climates, minimum and maximum temperatures have to be predicted periodically [71]. Most of the forecasting models provide short term predictions of just a few days, but the long-term forecasts can still be useful [75]. The data received from the Indian meteorological department are the extreme maximum temperature, low minimum temperature, maximum& minimum temperatures, 9 am & 3 pm temperatures. Results of extreme maximum temperatures are practically important due to its day time temperature issues [97]. A critical area in the field of applied meteorology is the prediction of frost events, which is nothing but low minimum temperatures [99].

Climate modeling studies suggests that halving of carbon dioxide will create an increased global mean temperature of 2 to 3 degrees centigrade [50]. High albedo and more reflectiveness leads to cooling the planet as most of the radiation is returned to space [52]. Albedo indicates how much amount of light hits a surface which is reflected without any absorption [52]. In Northern India, cold-wave and heat-wave conditions can be predicted with proper forecasts of min&max temperatures during winter and summer respectively [94]. Surface weather parameters plays a key role in satellite link design [95]. The lowest minimum level temperatures of cold season lies below zero degree centigrade. The variations in minimum temperatures are caused by the presence of variable winds due to topography [96].

10. Impact and importance of pressure

At any particular point in the atmosphere clouds form when the vapor pressure of water exceeds the vapor pressure that would be saturated w.r.t. liquid water or ice [53]. Barometer is used to measure pressure [78]. Variations of atmospheric pressure can bring out induced quasi periodic surface determinations [108]. Monsoons are characterized by huge scale seasonal reversals of pressure [107]. To estimate the atmospheric pressure at different altitudes over sea level, it is important to consider a change in density of atmosphere, water vapor practical pressure and temperature. Again diurnal pressure variations are in anti phase with temperature variations [110].

11. Impact and importance of Relative Humidity

Humidity is an integral water vapor in air [115]. For ease of computations from simple wet and dry bulb recordings, relative humidity is used [115]. RH defines the amount of moisture in the atmosphere. A low RH value adds to the drying of fuels. High RH value absorbs moisture from the atmosphere [116]. The actual vapor pressure divided by saturated vapor pressure gives the value of RH [119]. Air pressure and specific humidity affect vapor pressure and temperature of air affects saturation vapor pressure [116]. The RH data is an important information for understanding surface atmospheric and environmental issues [119]. The relative humidity raised nearby earth's surface and decreased at the top and middle of troposphere [51]. Always relative humidity of air varies with temperature. Air heating decreases the level of relative humidity [113]. Not only relative humidity but also cloudiness reduced at the upper and middle levels of troposphere [51]. Air temperature as well as humidity are the important variables in satellite meteorology [117]. Humidity arises because hot water produces steam which means water at lower temperatures such as ice also produces water vapor [119]. Specific humidity is a crucial factor during the estimation of evaporation from ocean surface. Accurate estimation of specific humidity is required [118].

12. Effect of temperature, pressure and relative humidity variations with cloud cover

Usually cloud cover can be obtained by integrating the saturated part of the temperature, humidity and pressure [55]. Cloud cover will be positively correlated with relative humidity and negatively correlated with temperature lapse rate [53]. Prediction of meteorological parameters has been one of the complex domains [78]. An analysis is performed on the aircraft thermodynamics measurements obtained from liquid clouds over the American plains to evaluate importance of humidity and temperature for cloud cover [55]. Cloud cover determines the climatology of humidity& temperature and in the warm season. Changes in frozen precipitation have more effect on winter temperature in comparison to changes in cloud cover. Reduced cloud cover is not surprisingly coupled to lower relative humidity. The mean cloud cover increases with mean precipitation. Air temperature decreases with increasing cloud cover. Air humidity level is measured using dew point temperature and relative humidity dew point temperature is defined as the temperature in which air becomes liquid water due to high concentration of water molecules.

13. Prediction of Temperature, Pressure and Relative Humidity using ML Algorithms

Machine learning is about creating computer algorithms and techniques to improve automatically through experience [63]. Inherently machine learning is a multi objective task. Any machine learning algorithm consists of training and classifying [63]. By comparing different algorithms over machine learning world is for conducting data analytics competitions [62]. Autonomous operation and intelligent decision making have been achieved through different machine learning algorithms for solving complex problems [65]. There are three types of Machine learning algorithms. First type is supervised learning in which the model approximates mapping and functioning between the input & output of the given data, commonly called classification. The second type is unsupervised learning [63] technique which is about data clustering. A data set in each subset share common similarity defined by a distance measure [63]. Reinforcement learning is the third type that involves finding a strategy for an agent to take actions that escalate aggregated rewards in a given environment [63]. All machine

learning algorithms performs parameter estimation and model selection based on one or multiple criteria [63]. In recent years, many approaches have been mentioned for classification tasks like decision trees, support vector machines, etc. Mostly Supervised learning is belongs to prediction related tasks. While unsupervised learning is internal setting to provide clusters [66]. Performance measures are always required otherwise accuracy of classification leads to a biased result [67]. In this research work we used three algorithms. Those are (i) Linear Regression (ii) Decision Tree (iii) Multiple regressions, which are discussed in the next section.

13.1 Linear Regression

Establishing a relation between dependent variable (output) and independent variables (inputs) is known as regression [70]. Linear Regression analysis is used to build possible relationships portraying the varying nature of a dataset. Linear regression equations are written using least squares estimation, instrumental variables regression, maximum likelihood estimation, adoptive estimation etc [70]. It is simple and one of the commonly used predictive models for analysis [72]. Best fit among points is found with the help of plots. Linear regression defines the relation between one dependent variable and either one or multi independent parameters [74].

13.2. Decision Tree

A decision tree uses decision support tool often used because it is simple to understand and interpret [79]. Data mining uses decision trees for data examination and to invoke the tree and its rules that will be used to make predictions [79]. Commonly used in data mining, aim is given many input parameters, target value has to be predicted using a model [81]. Decision tree follows divide & conquer approach [82] to split the problem into number of subsets [87]. In decision analysis, decisions and decision making are represented using a decision tree both visually and explicitly [83]. Solving classification problems using decision trees is very useful, particularly in many real world applications [84]. The construction of decision trees contains two common things. One is the growth of tree leads to increasing the accurate categorization of training data sets. Another one is in the pruning stage we eliminate anomalies in the training data to increase accuracy of classification [87].

13.3 Multiple Regression

Multiple regression is a powerful tool used to predict and forecast [70]. Sometimes it is difficult to explain a dependent variable with one variable. In such a situation, multiple regressions is used to predict a dependent parameter using multiple independent parameters. Major two types of multiple regression are linear and nonlinear. Multiple regressions assume a linear relationship between both dependent & independent parameters. Sometimes it also assumes no correlation among the independent variables. Multiple linear regressions can model more complex relationship which comes from various features together. When a particular variable is not noticeable enough to map the relationship between the independent and the dependent variable, multiple regression is used [92]. The reasons as to why multiple regression is used are prediction of future economic trends, determination of relationship between variables and finally effect of changes in one variable over another.

14. Cloud liquid water content:

Clouds contain few ice particles and more water droplets. Ice clouds are unable to create attenuation at microwaves in the range of 50GHz. There are couple of factors that should affect absorption from water liquid clouds i.e clouds liquid water content, temperature & path length. There are several shapes and sizes for water clouds. The density value is 1.0 when the temperature ranges of cloud water droplets is -20°C to +10°C. A decrease of temperature leads to increase in specific attenuation [28]. All cloud models are supposed to be homogeneous in terms of distributions of the liquid content [28]. When liquid water density profile is integrated, total liquid water content is obtained [37].

According to staelin, absorption can be directly related to cloud liquid and integrated water vapor [18]. Tremendous seasonal fluctuations of liquid water content in India can be obtained during June to November [37]. By using profiles of liquid water densities one can estimate the cloud attenuation over an earth-space path [37]. Small change in cloud properties result in big variations in the microwave properties of the clouds. The total liquid water quantity is mass of rain/drizzle plus the mass of non-precipitating cloud droplets [39]. Microwaves are subject to vigorous damaging effects by different impairments especially by rain that plays a dominant role at any frequency in the 10-100GHz range. However clouds because of high occurrence probability should be considered [40].

15. Related works on Cloud Attenuation

Estimation of propagation impairments effect on RF signal propagation due to clouds play a crucial role in radio propagations. Understanding the effect of atmosphere on microwave propagation, particularly in Ka-band and

above is essential as satellite services are growingly offered at higher frequencies. The simulation of microwave parameters can be obtained by physical modeling [38].

Military & Commercial applications are already being planned for these frequencies that are often referred to as EHF or V-band [24]. But with the raise of frequency, both tropospheric and ionospheric impairments effecting satellite link signals are increasing. Introduction of satellite services that employ highest frequencies requires meteorological propagation factors characterization, but those are uncertain at low frequency bandwidths. One such factor is cloud. Communication systems reliability under non-rainy conditions is determined with a combination of cloud attenuation and gaseous absorption. The point where the melting layer and rain merging with cloud attenuation is called upper end of cloud distribution. It is not a well-defined boundary and is governed by geographic location latitude and the angle of elevation [28].

The Famous Pioneer Gunn & East model is beneficial at wavelengths greater than 1mm. The drawback of Gunn and East model is, it is incapable to describe the water vapor density [120]. By using the techniques of microwave spectroscopy, based on the theoretical and practical spectrums in 1962, Staelin computed the water vapor density equation for standard atmosphere which is useful for cloud attenuation estimations [121]. Slobin carried out his primary study on microwave noise temperature and types of clouds. Slobin developed an equation for liquid water content which is the key parameter in his cloud attenuation equation [122]. K.C. Allen presented a model for the attenuation of millimeter waves by precipitating liquid water clouds [123]. So as to understand if contribution of attenuation by clouds in attenuation distribution is small or not.

Altshuler developed expression for distance of a curved earth with low elevation angles [124]. Altshuler also developed an equation for cloud attenuation with distance expression. His model is supposed to be useful for the window sections between 15GHz and 100GHz. But his model is not planned for usage in the water & oxygen absorption bands [124]. By using the concepts of Double-debye relaxation model of complex permittivity, Liebe developed [125] a model for cloud attenuation. Dintelmann developed [126] a semi empirical model for prediction of cloud attenuation. The purpose of semi empirical model is for estimating annual cumulative cloud attenuation statistics. A new and versatile method for cloud attenuation was proposed by Salonen and Uppala [127]. Salonen and Uppala together designed a method for calculating liquid water content of clouds. Salonen and Uppala's method can be applicable for climates of mid latitude with an elevation angles from 15 to 40 degrees [127]. DAH model [128] was prepared based on the average properties of four kinds of clouds which consist of huge liquid water content. The ITU-Radio communication assembly considering that attenuation due to clouds is an essential factor for microwave systems operating above 10GHz frequency [129].

ITU-R.P.840-5 recommendation provides method to predict the cloud attenuation [129]. ITU-R also recommends a procedure to calculate attenuation by oxygen & water vapor [130]. Attenuation due to water vapor and oxygen can majorly deteriorate radio wave propagation at millimeter wavelengths. Finally in this modern world, especially in this information era and technological age, we require an understanding of clouds, cloud attenuation to build and design earth-space communication links, weapons, radar systems, air planes and other systems in which clouds will encounter [131].

16. Experimental setup and for cloud attenuation measurements:

Master Control Facility-ISRO, Hassan is an important station for conducting in-orbit testing of GEOSAT space craft's built by ISRO. Master Control Facility-Hassan is an important station for the Ka-band propagation experiment. This site diversity experiment is being conducted in association with CNES and ONERA of France. The center for space studies (CNES) along with a research lab (ONERA) both situated in Europe had settled on a plan of action to perform an experiment related to a site multiplicity for identifying the space and time performance of the propagating channel in Ka-band width.

Long back an opportunity was proposed by the Space Application Center (SAC) of the Indian Space Research Organization (ISRO) to carry out a propagation experiment at Ka-band over India. For this purpose the GSAT-4 satellite boarding two propagation beacons at 20.2GHz and 30.5GHz in linear polarization. The major objectives of conducting Ka band propagation experiment are: Study of attenuation characteristics (Rain, Cloud, Gas), study of tropospheric scintillation, Polarization effects, Fade dynamics at Ka-band. The selected sites of ISRO were configured with the following equipment: Ka band beacon receivers, Radiometers, Disdrometers, Microwave Rain Radar, The tipping bucket rain gauge, Automatic Weather Station(AWS) and the data loggers.

In general, propagation measurements can be associated with meteorological centers data acquired by various instruments associated with satellites. In Ka-band propagation experiment uplink frequencies are of around

30GHz. For the downlink, number of allocations for the fixed satellite and broadcasting services are present in the 17.4-22 GHz band.

Automatic weather stations are extremely useful for meteorological sensing even in harsh environments. Below 45GHz microwave emission is insensitive to temperature structure and depends strongly on water. So measurements at the lower frequencies may be used to correct the effects of clouds [19]. Measurement of cloud attenuation is possible through radiometers which are the most responsible instruments. The measurement systems includes radiometers at the similar frequencies used to help in removing uncertainty of the measurement which is associated with derived path attenuation [28].

17.CONCLUSION

This literature survey has conducted the most recent and well known comprehensive study of the clouds, cloud attenuation models and impact of cloud attenuation on earth-space path links. This survey mentioned the affect of propagation impairments on satellite communications, types of propagation impairments, why cloud attenuation is serious propagation impairment, affect of cloud attenuation on satellite communication link and channel availability, importance of cloud attenuation modeling, need for weather forecasting, affect of cloud cover, measurement of cloud attenuation, available experimental studies and test set up for cloud attenuation measurements. It shows that cloud attenuation is the dominant affect at 30GHz frequency while water vapor attenuation is the relevant mechanism at 20GHz. The existing cloud attenuation models have been classified as statistical, empirical models based on the model development and formulation basis. According to this survey no sole prediction model can be regarded as comprehensive model to satisfy all specifications for diverse infrastructure setup related parameters, geographic locations or even climatic variations over time. Hence this survey clarifies the necessary of developing a new model.

18. REFERENCES:

- [1] Harrison, R. Giles. "Cloud formation and the possible significance of charge for atmospheric condensation and ice nuclei." *Space Science Reviews* 94.1-2 (2000):
- [2] London, Julius, Carole and J. Hahn. "Observed variations of total cloudiness and cloud types: Implications for the atmospheric radiation budget." *Atmospheric Radiation*. American Meteorological Society, Boston, 1987.459-467
- [3] Subrahmanyam, K. V., Karanam Kishore Kumar, and Natalie D. Tourville. "CloudSat observations of three-dimensional distribution of cloud types in tropical cyclones." *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing* 11.2 (2018): 339-344.
- [4] Huo, Juan, et al. "Cloud Classification and Distribution of Cloud Types in Beijing Using Ka-Band Radar Data." *Advances in Atmospheric Sciences* 36.8 (2019)
- [5] A.D. Papatsoris "Radar quantification of mid-latitude cirrus clouds at 35 and 94GHz, *Electronics Letters* Vol. 31 No. 14,1995
- [6] Sivakumar, V., et al. "Lidar observed characteristics of the tropical cirrus clouds." *Radio Science* 38.6 (2003): 2-1.
- [7] Ou, Steve SC, et al. "Retrieval of cirrus cloud properties from the atmospheric infrared sounder: the k-coefficient approach using cloud-cleared radiances as input." *IEEE transactions on geoscience and remote sensing* 51.2 (2012)
- [8] Mizuno, H., et al. "Microstructure of cirrus clouds observed by HYVIS." *Atmospheric research* 32.1-4 (1994): 115-124
- [9] AL Rangno "Classification of clouds", *Encyclopedia of atmospheric sciences*, 2nd edition, volume2, Elsevier (2015)
- [10] Tzoumanikas, P., et al. "The effect of clouds on surface solar irradiance, based on data from an all-sky imaging system." *Renewable Energy* 95 (2016): 314-322.
- [11] Dissanayake, Asoka, Jeremy Allnutt, and FatimHaidara. "A prediction model that combines rain attenuation and other propagation impairments along earth-satellite paths." *IEEE Transactions on Antennas and Propagation* 45.10 (1997): 1546-1558.
- [12] Brussaard, Gert, and David V. Rogers. "Propagation considerations in satellite communication systems." *Proceedings of the IEEE* 78.7 (1990): 1275-1282.
- [13] Fukuchi, Hajime, and Peeramed Chodkaveekityada. "Propagation impairments along satellite-to-earth path and their mitigation technologies." 2015 IEEE 4th Asia-Pacific Conference on Antennas and Propagation (APCAP).IEEE, 2015.
- [14] Green, Harry E. "Propagation impairment on Ka-band SATCOM links in tropical and equatorial regions." *IEEE Antennas and Propagation Magazine* 46.2 (2004)
- [15] Jeannin, Nicolas, et al. "Atmospheric channel simulator for the simulation of propagation impairments for Ka band data downlink." *The 8th European Conference on Antennas and Propagation (EuCAP 2014)*.IEEE, 2014.
- [16] Lai, iun, et al. "attenuation of 8.6 and 3.2 mm radio waves by clouds." (1975).
- [17] P.G.Davies, "Attenuation by cloud and rain on earth-sun paths at 12 to 71 ghz"*Electronics Letters* (1975).
- [18] Westwater, Ed R. "The accuracy of water vapor and cloud liquid determination by dual-frequency ground-based microwave radiometry." *Radio Science* 13.4 (1978)
- [19] Decker, M. T., E. R. Westwater, and F. O. Guiraud. "Experimental evaluation of ground-based microwave radiometric sensing of atmospheric temperature and water vapor profiles." *Journal of Applied Meteorology* 17.12 (1978): 1788-1795.
- [20] Bostian, C. W., and J. E. Allnutt. "Ice-crystal depolarisation on satellite-earth microwave radio paths." *Proceedings of the Institution of Electrical Engineers*. Vol. 126.No. 10.IET, 1979.

- [21] Cox, D. C., H. W. Arnold, and H. H. Hoffman. "Observations of cloud-produced amplitude scintillation on 19-and 28-GHz earth-space paths." *Radio Science* 16.5 (1981): 885-907.
- [22] Papatsoris, A. D. "Effect of ice clouds on millimetre-wave aeronautical and satellite communications." *Electronics Letters* 33.21 (1997): 1766-1768.
- [23] Davies, O. T., R. G. Howell, and P. A. Watson. "Measurement and modelling of cloud attenuation at millimetre wavelengths." *Electronics Letters* 34.25 (1998).
- [24] Wrench, C. L., P. G. Davies, and J. Ramsden. "Global predictions of slant path attenuation on earth-space links at EHF." *International journal of satellite communications* 17.2-3 (1999): 177-186.
- [25] Davies, O. T., and P. A. Watson. "GPS phase-delay measurement: Technique for the calibration and analysis in millimetre-wave radio propagation studies." *IEE Proceedings-Microwaves, Antennas and Propagation* 146.6 (1999): 369-373.
- [26] Konefal, T., et al. "Prediction of monthly and annual availabilities on 10-50 GHz satellite-Earth and aircraft-to-aircraft links." *IEE Proceedings-Microwaves, Antennas and Propagation* 147.2 (2000): 122-127.
- [27] Ortgies, G., F. Rucker, and F. Dintelmann. "Statistics of clear-air attenuation on satellite links at 20 and 30 GHz." *Electronics letters* 26.6 (1990): 358-360.
- [28] Dissanayake, Asoka, Jeremy Allnutt, and FatimHaidara. "Cloud attenuation modelling for SHF and EHF applications." *International journal of satellite communications* 19.3 (2001): 335-345.
- [29] Ventouras, S., and C. L. Wrench. "ITU-R total attenuation predictions in comparison with slant path measurements in southern England." *Electronics Letters* 38.18 (2002): 1058-1059.
- [30] Al-Ansafi, K., et al. "One-year cloud attenuation results at 50 GHz." *Electronics Letters* 39.1 (2003): 136-137.
- [31] Sarkar, S. K., Iqbal Ahmad, and M. M. Gupta. "Statistical morphology of cloud occurrences and cloud attenuation over Hyderabad, India." 92.60 Nv; (2005).
- [32] Sarkar, S. K., et al. "Cloud morphology over three Indian tropical stations for Earth space communication." *International journal of infrared and millimetre waves* 27.7 (2006): 1005-1017.
- [33] Kumar, Anil, and S. K. Sarkar. "Cloud attenuation and cloud noise temperature over some Indian eastern stations for satellite communication." (2007).
- [34] Sarkar, S. K., and Anil Kumar. "Recent studies on cloud and precipitation phenomena for propagation characteristics over India." 92.60. (2007).
- [35] Cho, Hyoun-Myoung, et al. "Depolarization ratio and attenuated backscatter for nine cloud types: analyses based on collocated CALIPSOlidar and MODIS measurements." *Optics Express* 16.6 (2008): 3931-3948.
- [36] Mandeep, Jit Singh, Joseph Sunday Ojo, and L. D. Emiliani. "Statistics of annual and diurnal cloud attenuation over equatorial climate." *IET communications* 3.4 (2009): 630-635.
- [37] Maitra, Animesh, and Swastika Chakraborty. "Cloud liquid water content and cloud attenuation studies with radiosonde data at a tropical location." *Journal of Infrared, Millimeter, and Terahertz Waves* 30.4 (2009): 367-373.
- [38] Mattioli, V., et al. "Analysis and improvements of cloud models for propagation studies." *Radio Science* 44.02 (2009): 1-13.
- [39] Ellis, Scott M., and Jothiram Vivekanandan. "Liquid water content estimates using simultaneous S and K a band radar measurements." *Radio Science* (2011).
- [40] Luini, Lorenzo, C. Riva, and Carlo Capsoni. "Reduced liquid water content for cloud attenuation prediction: the impact of temperature." *Electronics letters*(2013)
- [41] Suen, Jonathan Y., Michael T. Fang, and Philip M. Lubin. "Global distribution of water vapor and cloud cover,sites for high-performance THzapplications." *IEEE Transactions on Terahertz Science and Technology* 4.1 (2014): 86-100.
- [42] Luini, Lorenzo, and Carlo Capsoni. "Efficient calculation of cloud attenuation for earth space applications." *IEEE Antennas and Wireless Propagation Letters*(2014)
- [43] FET, NSHM. "Attenuation of signal at a tropical location with radiosonde data due to cloud." *International Journal of Smart Home* 8.1 (2014): 15-22.
- [44] Luini, Lorenzo, and Carlo Capsoni. "Scaling cloud attenuation statistics with link elevation in earth-space applications." *IEEE Transactions on Antennas and Propagation* 64.3 (2016): 1089-1095.
- [45] Al-Saegh, Ali M., et al. "Channel measurements, characterization, and modelling for land mobile satellite terminals in tropical regions at Ku-band." *IEEE Transactions on Vehicular Technology* 66.2 (2016): 897-911.
- [46] Kokab, Ahmed Ali Rais, and HalaAldawEdreis. "Attenuation (Fading) Due To Clouds South Kordofan (Sudan)."
- [47] Lyras, Nikolaos K., Charilaos I. Kourogiorgas, and Athanasios D. Panagopoulos. "Cloud attenuation statistics prediction from Ka-band to optical frequencies: Integrated liquid water content field synthesizer." *IEEE Transactions on Antennas and Propagation* 65.1 (2016): 319-328.
- [48] De, Arijit, RohitChakraborty, and AnimeshMaitra. "Radiometric measurements of cloud attenuation over Earth-space path at a tropical location." 2017 XXXIInd General Assembly and Scientific Symposium of the International Union of Radio Science (URSIGASS).IEEE, 2017.
- [49] Luini, Lorenzo, and Andrea Quadri. "Investigation and modeling of ice clouds affecting earth-space communication systems." *IEEE Transactions on Antennas and Propagation* 66.1 (2017): 360-367.
- [50] Henderson-Sellers, "Cloud changes in a warmer Europe." *Climaticchange*(1986).
- [51] Wetherald, R. T., and SyukuroManabe. "An investigation of cloud cover change in response to thermal forcing." *Climatic Change* 8.1 (1986): 5-23.
- [52] Vokrouhlický, David, and LadislavSehnal. "Cloud coverage aspects of the albedo effect." *Celestial Mechanics and Dynamical Astronomy* 57.3 (1993): 493-508.
- [53] Walcek, Chris J. "Cloud cover and its relationship to relative humidity during a springtime midlatitude cyclone." *Monthly weather review* 122.6 (1994)

- [54] Hurley, Peter, and Reinout Boers. "The effect of cloud cover on surface net radiation: simple formulae for use in mesoscale models." *Boundary-layer meteorology* 79.1-2 (1996): 191-199.
- [55] Tompkins, A. M. "Impact of temperature and humidity variability on cloud cover assessed using aircraft data." *Quarterly Journal of the Royal Meteorological Society: A journal of the atmospheric sciences, applied meteorology and physical oceanography* 129.592 (2003): 2151-2170.
- [56] Volkova, E. V., and A. B. Uspensky. "Detection and assessment of cloud cover and precipitation parameters using data of scanning radiometers of polar-orbiting and geostationary meteorological satellites." *Izvestiya, Atmospheric and Oceanic Physics* 52.9 (2016): 1097-1109.
- [57] Betts, Alan K., et al. "Climate coupling between temperature, humidity, precipitation, and cloud cover over the Canadian Prairies." *Journal of Geophysical Research: Atmospheres* 119.23 (2014): 13-305.
- [58] Kim, Bu-Yo, et al. "Cloud cover retrieved from skyviewer: A validation with human observations." *Asia-Pacific Journal of Atmospheric Sciences* 52.1 (2016): 1-10.
- [59] WĄSZEK, K. I. N. G. A., et al. "Sensitivity study of cloud cover and ozone modeling to microphysics parameterization." *Geo informatics and Atmospheric Science*. Birkhäuser, Cham, 2018. 33-52.
- [60] Zhang, Xiao, Saichun Tan, and Guangyu Shi. "Comparison between MODIS-derived day and night cloud cover and surface observations over the north china plain." *Advances in Atmospheric Sciences* 35.2 (2018): 146-157.
- [61] Mao, Kebiao, et al. "Changes in Global Cloud Cover Based on Remote Sensing Data from 2003 to 2012." *Chinese geographical science* 29.2 (2019): 306-315.
- [62] Sajda, Paul, et al. "A data analysis competition to evaluate machine learning algorithms for use in brain-computer interfaces." *IEEE Transactions on neural systems and rehabilitation engineering* 11.2 (2003): 184-185.
- [63] Jin, Yaochu, and Bernhard Sendhoff. "Pareto-based multi objective machine learning: An overview and case studies." *IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews)* 38.3 (2008): 397-415.
- [64] Fernández, Alberto, et al. "Genetics-based machine learning for rule induction: state of the art, taxonomy, and comparative study." *IEEE Transactions on Evolutionary Computation* 14.6 (2010): 913-941.
- [65] Wang, Shouyi, WanprachaChaovaitwongse, and Robert Babuska. "Machine learning algorithms in bipedal robot control." *IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews)* 42.5 (2012): 728-743.
- [66] Stimpson, Alexander J., and Mary L. Cummings. "Assessing intervention timing in computer-based education using machine learning algorithms." *IEEE Access* 2 (2014): 78-87.
- [67] Lee, Taehyung, Ki Bum Lee, and Chang Ouk Kim. "Performance of machine learning algorithms for class-imbalanced process fault detection problems." *IEEE Transactions on Semiconductor Manufacturing* 29.4 (2016): 436-445.
- [68] Hashem, Somaya, et al. "Comparison of machine learning approaches for prediction of advanced liver fibrosis in chronic hepatitis C patients." *IEEE/ACM transactions on computational biology and bioinformatics* 15.3 (2017): 861-868.
- [69] Liang, Tiankai, et al. "An unsupervised user behavior prediction algorithm based on machine learning and neural network for smart home." *IEEE Access* 6 (2018): 49237-49247.
- [70] Özbalta, TürkanGöksal, AlperSezer, and Yusuf Yıldız. "Models for prediction of daily mean indoor temperature and relative humidity: education building in Izmir, Turkey." *Indoor and Built Environment* 21.6 (2012): 772-781.
- [71] Ramesh, K., R. Anitha, and P. SelvaGopal. "Linear Regression Based Lead Seven Day Maximum and Minimum Air Temperature Prediction in Chennai, India." *Research Journal of Applied Sciences, Engineering and Technology* 7.11 (2014): 2306-2310.
- [72] Gupta, Sanyam, K. Indumathy, and GovindSinghal. "Weather prediction using normal equation method and linear regression techniques." *IJCSIT International Journal of Computer Science and Information Technologies* 7.3 (2016) .
- [73] Massie, Darrell R., and Mark A. Rose. "Predicting daily maximum temperatures using linear regression and Eta geo potential thickness forecasts." *Weather and forecasting* 12.4 (1997): 799-807.
- [74] Prabakaran, S., P. Naveen Kumar, and P. Sai Mani Tarun. "Rainfall prediction using modified linear regression." *ARPN Journal of Engineering and Applied Sciences* 12 (2017): 3715-3718.
- [75] Jacobson, Teresa, Josh James, and Neil C. Schwertman. "An example of using linear regression of seasonal weather patterns to enhance undergraduate learning." *Journal of Statistics Education* 17.2 (2009).
- [76] Qasem, Sultan Noman, et al. "Estimating daily dew point temperature using machine learning algorithms." *Water* 11.3 (2019): 582.
- [77] Upton, Dan, and Kim Hazelwood. "Evaluating linear regression for temperature modeling at the core level." *Workshop on Duplication, Deconstructing, and Debunking*. 2011.
- [78] Prasad, Narasimha, Prudhvi Kumar Reddy, and Mannava Munirathnam Naidu. "A Novel Decision Tree Approach for the Prediction of Precipitation Using Entropy in SLIQ." *2013 UKSim 15th International Conference on Computer Modelling and Simulation*. IEEE, 2013.
- [79] Petre, Elia Georgiana. "A decision tree for weather prediction." *PP* 77 (2009): 82.
- [80] Gupta, Deepti, and UdayanGhose. "A comparative study of classification algorithms for forecasting rainfall." *2015 4th International Conference on Reliability, Infocom Technologies and Optimization (ICRITO)(Trends and Future Directions)*. IEEE, 2015.
- [81] Kumar, Rajesh. "Decision tree for the weather forecasting." *International Journal of Computer Applications* 76.2 (2013): 31-34.
- [82] Graham williams, "Data Science with R Decision Trees", Copyright © 2013-2014 Graham@togaware.com Module: DTrees, 2014
- [83] Mandale, Ms Ashwini, and B. A. Jadhawar. "Weather forecast prediction: a data mining application." *Int J Eng Res Gen Sci* 3.2 (2015).
- [84] Bhatkande, Siddharth S., and Roopa G. Hubballi. "Weather Prediction Based on Decision Tree Algorithm Using Data Mining Techniques." *International Journal of Advanced Research in Computer and Communication Engineering* 5.5 (2016)

- [85] Samya, R., and R. Rathipriya. "Predictive analysis for weather prediction using data mining with ANN: A study." *International Journal of Computational Intelligence and Informatics* 6.2 (2016).
- [86] Sheikh, Fahad, et al. "Analysis of data mining techniques for weather prediction." *Indian Journal of Science and Technology* 9.38 (2016).
- [87] kolluru, venkatanagendra, and maligelaussenaiah. "a survey on classification techniques used for rainfall forecasting." *international journal of advanced research in computer science* 8.8 (2017).
- [88] Kalaiselvi, P., and D. Geetha. "Weather prediction using J48, EM and K-Means clustering algorithms." *International Journal of Innovative Research in Computer and Communication Engineering* 4.12 (2016): 20889-20895.
- [89] Kalaiyarasi, P., and Mrs A. Kalaiselvi. "Data Mining Techniques Using To Weather Prediction."
- [90] Palinggi, Denny Asarias. "Predicting soccer outcome with machine learning based on weather condition." (2019).
- [91] Amit Kumar Agarwal, Manish Shrimali, SukanyaSaxena, AnkurSirohi, Anmol Jain "Forecasting using Machine Learning" *International Journal of Recent Technology and Engineering (IJRTE)* ISSN: 2277-3878, Volume-7 Issue-6C, April 2019 .
- [92] Cai, Qi, Wenbiao Wang, and Siyuan Wang. "Multiple Regression Model Based on Weather Factors for Predicting The Heat Load of A District Heating System in Dalian, China:A Case Study." *The Open Cybernetics & Systemic Journal*(2015)
- [93] Parthasarathy, B., K. Rupa Kumar, and N. A. Sontakke. "Surface and upper air temperatures over India in relation to monsoon rainfall." *Theoretical and applied climatology* 42.2 (1990): 93-110.
- [94] Mohanty, U. C."Forecasting minimum temperature during winter and maximum temperature during summer at Delhi." *Meteorological Applications*(1997)
- [95] Maini, Parvinder, et al. "Forecasting maximum and minimum temperatures by statistical interpretation of numerical weather prediction model output." *Weather and forecasting* 18.5 (2003): 938-952.
- [96] Dimri, A. P., and U. C. Mohanty. "Location-specific prediction of maximum and minimum temperature over the western Himalayas." *Meteorological Applications: A journal of forecasting, practical applications, training techniques and modelling* 14.1 (2007): 79-93.
- [97] Alfaro, Eric J., Alexander Gershunov, and Daniel Cayan. "Prediction of summer maximum and minimum temperature over the central and western United States: The roles of soil moisture and sea surface temperature." *Journal of Climate* 19.8 (2006): 1407-1421.
- [98] Chakraborty, TAPANKANTI. "Prediction of winter minimum temperature of Kolkata using statistical model." *Mausam* 57.3 (2006): 451.
- [99] Emmanouil, G.G. Galanis, "Statistical methods for the prediction of night-time cooling and minimum temperature." *Meteorological Applications*(2006).
- [100] Husaini, Noor Aida, et al. "Jordan pi-sigma neural network for temperature prediction." *International Conference on Ubiquitous Computing and Multimedia Applications*. Springer, Berlin, Heidelberg, 2011.
- [101] Abhishek, Kumar, et al. "Weather forecasting model using artificial neural network." *Procedia Technology* 4 (2012): 311-318.
- [102] Hanlon, H. M., et al. "Near-term prediction of impact-relevant extreme temperature indices." *Climatic Change* 132.1 (2015): 61-76.
- [103] Tiwari, P. R., et al. "Seasonal prediction skill of winter temperature over North India." *Theoretical and applied climatology* 124.1-2 (2016): 15-29.
- [104] Ma, Gang, Ary A. Hoffmann, and Chun-Sen Ma. "Daily temperature extremes play an important role in predicting thermal effects." *Journal of Experimental Biology* 218.14 (2015): 2289-2296.
- [105] Lyla, Mehta, et al. "Climate change and uncertainty from 'above' and 'below': perspectives from India." (2019).
- [106] Nezhad, Elham Fahimi, Gholamabbas Fallah Ghalhari, and Fateme Bayatani. "Forecasting Maximum Seasonal Temperature Using Artificial Neural Networks "Tehran Case Study". " *Asia-Pacific Journal of Atmospheric Sciences* 55.2 (2019)
- [107] Parthasarathy, B., K. Rupa Kumar, and A. A. Munot."Surface pressure and summer monsoon rainfall over India." *Advances in atmospheric sciences*(1992)
- [108] Sun, H.P., B. Ducarme, and VéroniqueDehant."Effect of the atmospheric pressure on surface displacements." *Journal of Geodesy* 70.3 (1995): 131-139.
- [109] Bogdanov, M. B., A. N. Surkov, and A. V. Fedorenko."Effect of cosmic rays on atmospheric pressure under mountain conditions." *Geomagnetism and Aeronomy* 46.2 (2006): 254-260.
- [110] Ivanov, V. V. "Seasonal and diurnal variations in atmospheric pressure." *Izvestiya, Atmospheric and Oceanic Physics* 43.3 (2007): 323-337.
- [111] Conrath, Barney J. "On the estimation of relative humidity profiles from medium-resolution infrared spectra obtained from a satellite." *Journal of Geophysical Research* 74.13 (1969): 3347-3361.
- [112] Ali, Shamshad."Effect of temperature and humidity on the development and fertility-fecundity of *Aeridaexaltata* Walk." *Proceedings: Animal Sciences* (1982)
- [113] Okland, Hans. "Modelling the height, temperature and relative humidity of a well-mixed planetary boundary layer over a water surface." *Boundary-Layer Meteorology* 25.2 (1983): 121-141.
- [114] Vermaas, H. F. "Measuring the relative humidity of dry kiln air above 100° C." *HolzalsRoh-und Werkstoff* 43.6 (1985): 237-241.
- [115] Adebayo, Y. R. "Day-time effects of urbanization on relative humidity and vapour pressure in a tropical city." *Theoretical and applied climatology* 43.1-2 (1991): 17-30.
- [116] Peng, Guangxiong, et al. "High-resolution surface relative humidity computation using MODIS image in Peninsular Malaysia." *Chinese Geographical Science* 16.3 (2006): 260-264.
- [117] Li, Long, and Yong Zha."Mapping relative humidity, average and extreme temperature in hot summer over China." *Science of the Total Environment* 2018
- [118] Tomita, H., T. Hihara, and M. Kubota."Improved satellite estimation of near-surface humidity using vertical water vapor profile information." *Geophysical Research Letters* 45.2 (2018): 899-906.

- [119] Ramírez-Beltrán, Nazario D., et al. "A satellite algorithm for estimating relative humidity, based on GOES and MODIS satellite data." *International Journal of Remote Sensing* 40.24 (2019): 9237-9259.
- [120] Gunn, Kenrich Lewis Stuart, and Thomas William Russell East. "The microwave properties of precipitation particles." *Quarterly Journal of the Royal Meteorological Society* 80.346 (1954): 522-545.
- [121] Staelin, David H. "Measurements and interpretation of the microwave spectrum of the terrestrial atmosphere near 1-centimeter wavelength." *Journal of Geophysical Research* 71.12 (1966): 2875-2881.
- [122] Slobin, Stephen D. "Microwave noise temperature and attenuation of clouds: Statistics of these effects at various sites in the United States, Alaska, and Hawaii." *Radio Science* 17.6 (1982): 1443-1454.
- [123] Allen, Kenneth C. "Attenuation of millimeter waves on earth-space paths by rain clouds." *STIN* 84 (1983): 17471.
- [124] Altshuler, Edward E., and Richard A. Marr. "Cloud attenuation at millimetre wavelengths." *IEEE Transactions on antennas and propagation* 37.11 (1989)
- [125] Liebe, Hans J. "MPM—An atmospheric millimeter-wave propagation model." *International Journal of Infrared and millimeter waves* 10.6 (1989)
- [126] Dintelmann, F., and G. Orgies. "Semi empirical model for cloud attenuation prediction." *Electronics Letters* 25.22 (1989): 1487-1488.
- [127] Salonen, E., and S. Uppala. "New prediction method of cloud attenuation." *Electronics Letters* 27.12 (1991): 1106-1108.
- [128] Dissanayake, Asoka, Jeremy Allnutt, and Fatim Haidara. "A prediction model that combines rain attenuation and other propagation impairments along earth-satellite paths." *IEEE Transactions on Antennas and Propagation* 45.10 (1997)
- [129] Radio communication sector of ITU-R, "Attenuation due to clouds and fog", International Telecommunication Union, 2012
- [130] Action, C. O. S. T. "Radio wave propagation modeling for SatCom services at Ku band and above." *COST 255 Final Rep* (2002).
- [131] Gerace, G. C., and E. K. Smith. "A comparison of cloud models (EM wave scattering)." *IEEE Antennas and Propagation Magazine* 32.5 (1990): 32-38.
- [132] Rathnakara, K., D. Ravindranath, and M. Y. S. Prasad. "In-orbit testing of satellite communication payloads." *IETE Technical Review* 20.5 (2003): 447-462.
- [133] Boulanger, Xavier, Frédéric Lacoste, and Laurent Castanet. "Small and large scale site diversity experiment at Ka-band in the south of France." *International Journal of Satellite Communications and Networking* 36.1 (2018): 14-28.
- [134] Dasgupta, K. S., et al. "A new propagation campaign in tropical areas: The Ka-band propagation experiment over India with the GSAT-4 satellite." *2009 3rd European Conference on Antennas and Propagation. IEEE, 2009.*
- [135] Beaver, John D., and V. N. Bringi. "The application of S-band polarimetric radar measurements to Ka-band attenuation prediction." *Proceedings of IEEE* (1997)
- [136] Brown, Shannon T., et al. "On the long-term stability of microwave radiometers using noise diodes for calibration." *IEEE Transactions on Geoscience and Remote Sensing* 45.7 (2007): 1908-1920.
- [137] García-Rubia, José Miguel, et al. "Propagation in the Ka band: Experimental characterization for satellite applications." *IEEE Antennas and Propagation Magazine* 53.2 (2011): 65-76.
- [138] Mener, Simon, Raphael Gillard, and LangisRoy. "A dual-band dual-circular-polarization antenna for Ka-band satellite communications." *IEEE antennas and wireless propagation letters* 16 (2016): 274-277.
- [139] Cesarini, Daniel, et al. "AENEAS: An energy-aware simulator of automatic weather stations." *IEEE Sensors Journal* 14.11 (2014): 3932-3943.
- [140] Munandar, Aris, et al. "Design of real-time weather monitoring system based on mobile application using automatic weather station." *2017 2nd International Conference on Automation, Cognitive Science, Optics, Micro Electro-Mechanical System, and Information Technology (ICACOMIT). IEEE, 2017.*