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DEPARTMENT OF PHYSICS

Project Report on

VERTICAL VARIATION OF ATMOSPHERIC REFRACTIVE INDEX STRUCTURE PARAMETER (Cn^2) OVER COCHIN

Submitted by

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This is to certify that, I SUJATHA, pursuing master of science in space science 2022-24 at BHARATA MATA COLLEGE, THRIKKAKARA, hereby declare that this report of work on “VERTICAL VARIATION OF ATMOSPHERIC REFRACTIVE INDEX STRUCTURE PARAMETER (Cn^2) OVER COCHIN” has been completed by me during MARCH 2024-MAY 2024, in Advanced Centre for Atmospheric Radar Research (ACARR), Cochin University of Science and Technology (CUSAT), Cochin under the valuable guidance of scientist Dr. MANOJ M G in partial fulfillment of the requirements for the award of the master’s degree in Space Science and that no part of this work has been submitted earlier for the award of any degree.

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This is to certify that this project work titled "VERTICAL VARIATION OF ATMOSPHERIC REFRACTIVE INDEX STRUCTURE PARAMETER (Cn^2) OVER COCHIN" is a record of bonafide work done by SUJATHA (Register Number: 220011023287) in partial fulfillment of the requirements for the award of the master's degree in Space Science from MAHATMA GANDHI UNIVERSITY and no part of this work has been submitted earlier for the award of any degree.

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EXTERNAL EXAMINER

DECLARATION

I hereby declare that the project work with the title" VERTICAL VARIATION OF ATMOSPHERIC REFRACTIVE INDEX STRUCTURE PARAMETER (Cn^2) OVER COCHIN" is my own work and that all data and sources I have used and quoted have been indicated and acknowledged by means of complete references.

SUJATHA

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ABSTRACT

The project is an investigation analysis of the refractive index structure parameter, Cn^2 in relation to atmospheric parameters such as temperature pressure, humidity, wind speed, etc. The refractive index structure parameter (Cn^2) is the basic parameter that explains atmospheric turbulence. Because it shows the strength of the expected scintillation at the obtained optical waves, the optical refractive index structure parameter is of interest to hobbyists in free-space optics and ground-based total optical astronomy. One of these effects, known as optical turbulence, results from air turbulence's random variations in the refractive index. Cn^2 estimation plays an important role in meteorological studies, aviation fields and free space communication also. In this work the vertical profiles of Cn^2 over the cochin region are studied with the help of Radiosonde.

After obtaining the values of refractive index structure paramteres, vertical variations of the same can be analyzed by plotting Cn^2 against altitude. For that the data containing the parameters such as temperature pressure humidity wind speed as well as wind direction at different heights of the atmosphere. Using these parameters we can calculate the Refractive index Structure Parameter Cn^2 using the value of Cn^2 a graph is plotted against altitude. From the graph, we can understand the characteristics of Cn^2 in the troposphere and hence turbulence in the troposphere. This study is beneficial for the analysis of atmospheric turbulence in the troposphere and hence the results can be applied in meteorology to explore new ideas about the topic, and in aviation fields to help aircrafts to take safety measures when turbulence is present in the flight path.

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CHAPTER 1

GENERAL INTRODUCTION

1.1 INTRODUCTION

Even in the absence of clouds and all kinds of atmospheric parameters used for backscattering, there is always a presence of air molecules in the atmosphere. Also this atmosphere is not uniform everywhere but has significant variations in temperature and pressure with altitude. And this defines a number of atmospheric layers with altitudes are as follows;

- Exosphere: The outermost layer of the Earth's atmosphere, extending from 700 to 10,000 km (440 to 6200 miles) above the Earth's surface.
- Thermosphere: Located 80 to 700 km (50 to 440 miles) above the Earth's surface, this layer is known for its high temperatures due to the absorption of solar radiation.
- Mesosphere: Situated 50 to 80 km (31 to 50 miles) above the Earth's surface, this layer is characterized by decreasing temperatures with altitude.
- Stratosphere: Found 12 to 50 km (7 to 31 miles) above the Earth's surface, the stratosphere contains the ozone layer, which absorbs and protects from harmful ultraviolet radiation.

Troposphere: The lowest layer of the Earth's atmosphere, extending from 0 to 12 km (0 to 7 miles) above the Earth's surface, where weather phenomena and human activities occur.All weather phenomena occurs in the lowest region of the earth’s atmosphere known as Troposphere. The troposphere as a whole is characterized by a constant decrease of both temperature and pressure as altitude increases. Due to variation in humidity and uneven heating of earth’s surface cause small turbulence or eddies to be formed. Mostly we send radio waves to estimate the wind speed and also we cannot demand that every time clouds would be there to get reflection back, sometimes clear sky conditions also occurs. So under such conditions the mechanism that gives reflection is known as **Refractive Index Fluctuations.**

1.2 EARTH'S ATMOSPHERE

The atmosphere of Earth is distinct. The gases that comprise the Earth's atmosphere and the mechanisms that govern their conditions are vital to human survival. According to temperature, the atmosphere is thought of as a thin band of air composed of multiple layers. Since it shields us from the sun's heat and radiation and holds the oxygen we breathe, life on Earth could not exist without this protective layer. NASA states that the exosphere, or uppermost layer of the earth's atmosphere, reaches a distance of 6,200 miles (10,001 km), beyond which the atmosphere and space merge. The Earth's atmosphere is structured into five primary layers, namely, the troposphere, stratosphere, mesosphere, thermosphere, and exosphere, arranged from the lowest to the highest. With each ascending layer, the atmosphere progressively thins out until the gases disperse into space.

Altitude causes a drop in air pressure. Pressure likewise drops with height because there are less air molecules above a surface. Gravity keeps the majority of the molecules in the atmosphere near to the surface of the planet. As a result, at greater altitudes, air pressure lowers more slowly after first decreasing quickly. Air pressure is typically a determining factor in temperature. The higher the pressure, the higher will be the temperature, since atmospheric pressure is greatest at sea level, under comparable weather conditions. The higher ones climbs, the further the temperature sinks, due to the decreasing air pressure.

The relative humidity continuously decreases with height in the troposphere and is close to zero in the stratosphere. It is because the relative humidity changes with a change in the temperature and altitude of a particular region. As we know that relative humidity is all about describing the atmospheric moisture so, the altitude of a place increases, the air gets thin and the moisture holding capacity of the air decreases (low atmospheric pressure) which results in reduced humidity. However changes in weather phenomena causes variation in humidity and uneven heating of earth's surface. As a result the air in the troposphere is always constant. This constant motion causes small turbulence or eddies to be formed resulting the bouncing of aircraft entering the turbulent area of the atmosphere.

Remote sensing is one of the efficient method that can be used to detect objects, measure distance to the objects etc. Also RADAR is one of the main remote sensing technique in which radiowaves are transmitted to detect objects. When radio signals are transmitted into the atmosphere, the refractive index fluctuation in the layer cause scattering of transmitted waves due to inhomogeneity of the refractive index of the air. From the data collected from the returned signals, we can measure the intensity of the turbulence in that layer by finding a parameter called refractive index structure parameter.

1.2 PRINCIPLE OF RADAR

RADAR ”RAdio Detection And Ranging”, is a digital gadget used to generate electromagnetic waves in the transmitter, radiates them via antenna, receives the scattered alerts returning from the goal, measures the positions, movement of the target and many others. Commonly , the same antenna is used for transmission of electromagnetic waves and reception of return indicators. The target position is acquired consistent with the course where the scattered alerts returns to the antenna, and to the distance calculated by the lapse of time that the electromagnetic waves make in the round ride among radar and target. As for the objectives that scatter electromagnetic waves, numerous styles of scatters are known, e.g., isolated items which includes aircrafts and ships, minute distributed debris consisting of precipitation and clouds, perturbations of radio refractive index because of atmospheric turbulence. The atmospheric radars generally make observations at excessive elevation angles whereas meteorological radars experiment the atmosphere at relatively low elevation angles. Meteorological radars use parabolic reflector antenna while atmospheric radar use phased array antenna. Atmospheric radar are known mesospheric stratospheric-tropospheric (MST) radar, stratospheric tropospheric (ST) radar, tropospheric (T) radar or boundary layer radar(BLR) in step with the observable regions for the radar .

1.3 WIND PROFILER RADAR

Doppler radars operating in the VHF-UHF band (30MHz–3GHz) are generally referred to as "wind profilers." These radars measure the line-of-sight Doppler shift of scattered signals, or "Bragg scattering," from variations in the refractive index brought on by turbulence. By identifying minute aberrations in backscattered signals brought on by turbulence-induced refractive index inhomogeneities, UHF and VHF Doppler radar systems are able to assess wind speed and direction. Humidity variations in the lower troposphere are the primary cause of refractive index inhomogeneities. The mean radial velocity along the radar beam can be directly measured using the clear air Doppler shift. A UHF wind profiler typically has a beam width of 8.5 degrees and operates at 1290 MHz or 915 MHz with a peak power of 3.5kW. In any weather, it is capable of measuring wind profiles. Wind profile radars use the power, mean Doppler shift, and Doppler spectral width of the returned signal to assess other atmospheric factors in addition to the wind vector. These quantities consist of the following: drop-size distributions and precipitation rates (from scatter from hydrometeors), atmospheric momentum flux, virtual temperature and heat flux (using the RASS technique), and strength of turbulence (parameterized by the refractive index structure constant Cn2).

A minute amount of energy is dispersed in all directions when an electromagnetic wave comes into contact with a refractive index imperfection. When there are irregularities the size of half the incident wave's wavelength or less, energy will preferentially scatter back towards its point of origin (Bragg condition). The majority of wind profilers operate at frequencies significantly lower than those of traditional weather radars, and these anomalies range in size from a few centimeters to many meters.

1.4 RADIOSONDE

While temperature, humidity, and height data are used to compute pressure data using the hypsometric equation, certain radiosondes do not measure pressure. Temperature, humidity, wind direction, and pressure profiles are produced as a function of height, pressure, and location using data gathered from radiosonde observation devices. The instrument is carried by the wind as it climbs, therefore location is crucial. In certain instances, information is gathered both when the device is ascending and descending. While temperature, humidity, and height data are used to compute pressure data using the hypsometric equation, certain radiosondes do not measure pressure. Temperature, humidity, wind direction, and pressure profiles are produced as a function of height, pressure, and location using data gathered from radiosonde observation devices. The instrument is carried by the wind as it climbs, therefore location is crucial. In certain instances, information is gathered both when the device is ascending and descending.

CHAPTER 2

ATMOSPHERIC PARAMETERS

2.1 TEMPERATURE

Temperature is a fundamental atmospheric parameter that influences weather patterns, climate dynamics, and atmospheric processes. By measuring temperature at different altitudes, radiosondes help meteorologists and climatologists understand how temperature changes with height, which is essential for predicting weather conditions and studying atmospheric phenomena. While the troposphere is most effectively 8–9 km thick at the regions closest to the two poles, it is already 18 km thick over the equator. Troposphere temperature typically drops with a peak on the standard lapse rate of 6.5°C per kilometer. The troposphere contains almost all of the water vapor in the atmosphere; as a result, common meteorological phenomena like clouds, fog, rain, and snow occur most frequently in that particular layer.

The stratosphere is located between 10 and 50–55 kilometers above the ground. The temperature is fairly constant, or grows very slightly at the top, within the lower component that reaches 30-35 kilometers from the troposphere's pinnacle. The temperature will undoubtedly rise above 35 kilometers, peaking at an average rate of 5°C each kilometer. The air drift in this layer is continuous because very little dust or water vapor from the ground will reach the stratosphere. Because the ozone layer absorbs part of the sun's UV radiation, the upper stratosphere experiences an increase in temperature.

The mesosphere, spanning roughly 50-80 kilometers above the Earth’s surface, get progressively colder with increasing altitude. Temperatures at the mesosophere,s top can plunge to -95 degree celcius or even lower. Interestingly, the mix of gases in this region, except for water vapour and ozone, remains fairly constant compared to the layer below it. This consistent composition throughout the lower region is why it’s called the homosphere.

Sitting above the mesosphere, the thermosphere flips the temperature trend. Here, as altitude increases, so does the temperature. (Sun activity permitting, this layer can stretch up to 400 kilometers high). The lower region of the thermosphere contains very thin air, making it easy for the air particles to become ionized, resulting in an abundance of free electrons. This layer is commonly referred to as the ionosphere and is highly efficient in reflecting radio waves.

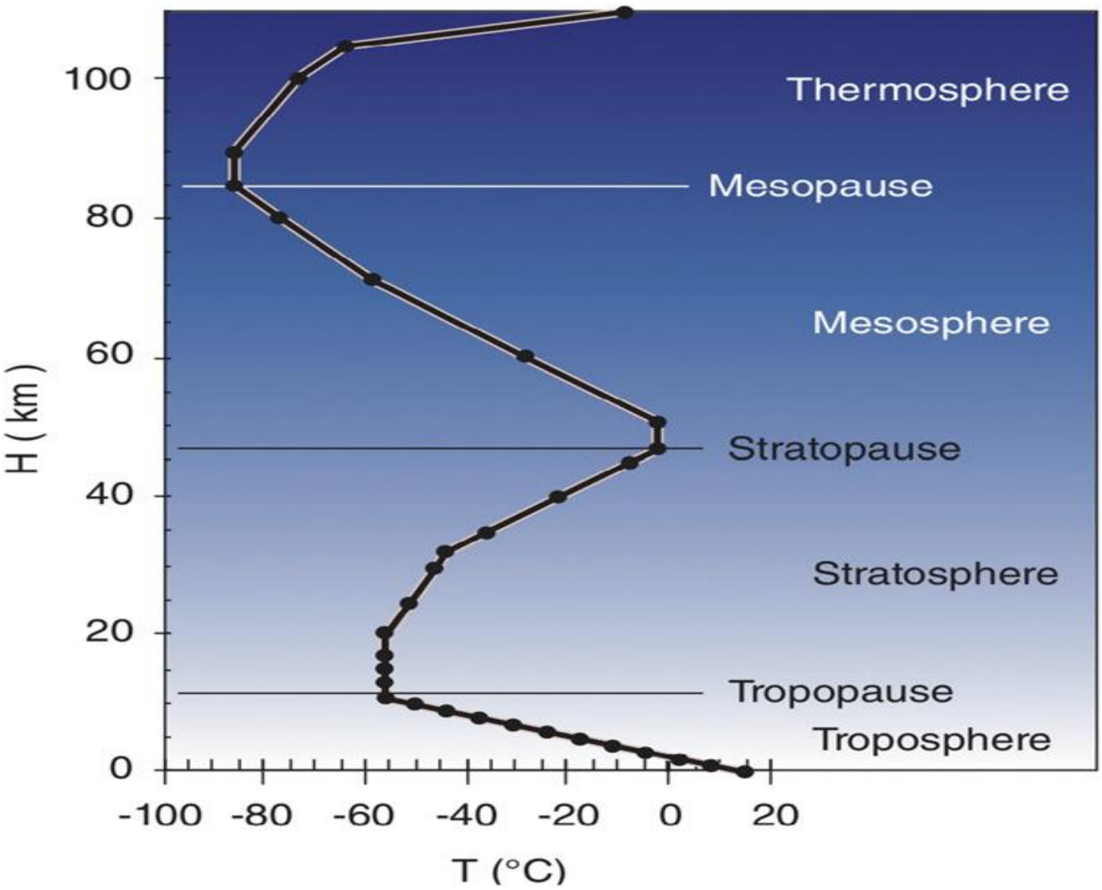
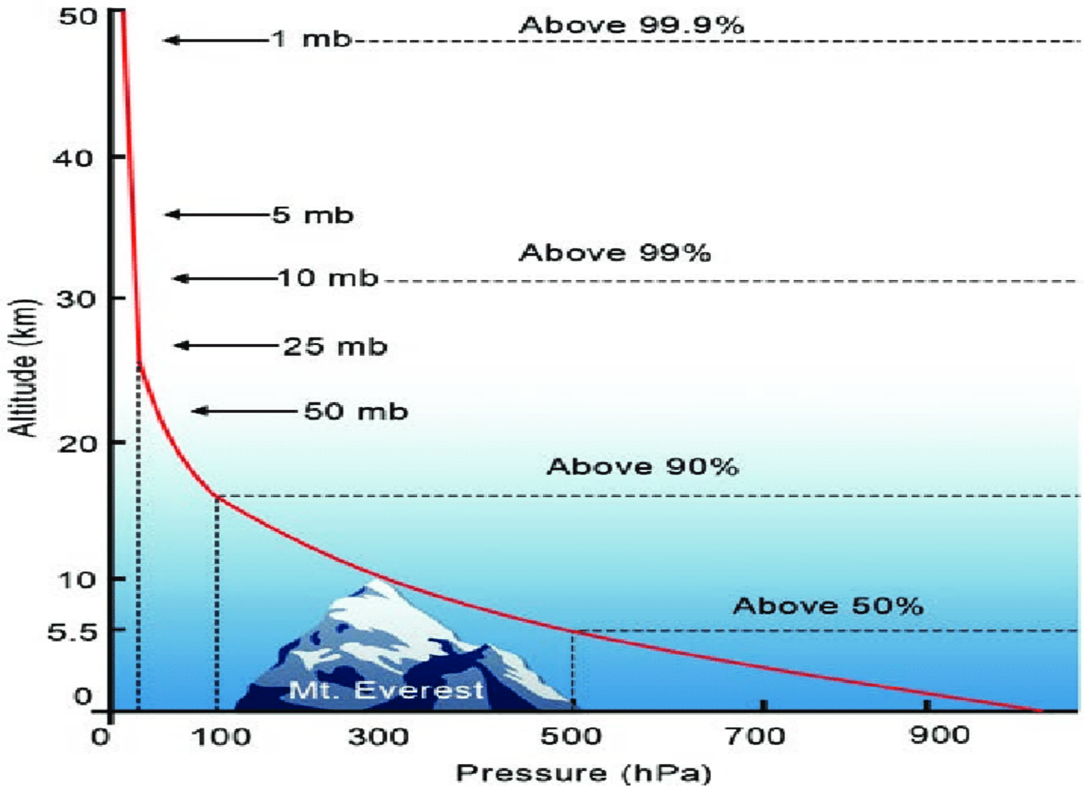


Fig 2.1Variation of temperature with altitude

2.2 PRESSURE

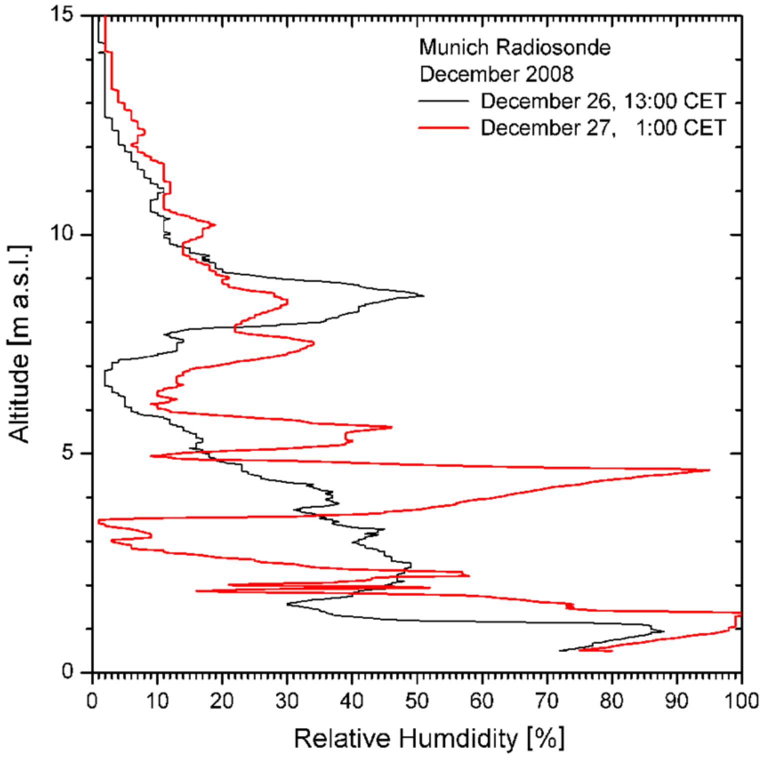
The atmospheric pressure on Earth varies significantly, and understanding these fluctuations is critical for comprehending weather and climate patterns. Atmospheric pressure is the force exerted by the air in the atmosphere on a specific area. As altitude increases, air pressure decreases. This is due to the majority of air molecules being held near the Earth's surface by gravity, resulting in a slower decrease in air pressure at higher altitudes after an initial rapid drop. The atmosphere undergoes a significant change below 5.5 km, where over half of its molecules are concentrated. This causes a rapid 50% reduction in atmospheric pressure, resulting in a pressure of about 50 mb. While the pressure continues to decrease as we ascend above 5.5 km, it does so at a slower pace. Further ascent into the stratosphere and mesosphere leads to even greater reductions in pressure.



. Fig 2.2 Variation of pressure with altitude

2.3 VARIATION OF HUMIDITY AND DENSITY WITH HEIGHT

Absolute humidity is a comprehensive measure of the total water content in the atmosphere, irrespective of the percentage of saturation. On the other hand, humidity indicates the specific amount of water vapor present in the air. As altitude increases, the atmosphere becomes thinner due to a decrease in air pressure. Consequently, the total quantity of water vapors that the atmosphere can potentially hold diminishes. Higher humidity levels can make the air feel more saturated and damper. It's important to note that when air is uplifted, both the water vapor and the air expand proportionately, leading to a reduction in the moisture content within a specific volume. As a result, with increasing altitude, the absolute humidity decreases as the air is lifted. The ability of air to keep moisture decreases upwards as temperature typically rises. Condensed moisture from higher atmospheric levels is removed during the precipitation process and is deposited onto the surface. Every now and then, horizontal flow at intermediate altitudes above might bring in moist air, changing the typical trend of moisture decrease with height. Much of the summer thunderstorm activity throughout much of the west is caused by this kind of flow. The sinking air above has extremely low absolute humidity. Originating close to the troposphere's summit, this dry air gradually descends to lower altitudes. It may cause a rapid rise in the risk of a fire and extremely low humidity close to the surface if it falls to the ground or is mixed downhill.



2.4 ATMOSPHERIC TURBULENCE

The atmospheric turbulence can be described as the dissipation of mechanical energy to internal energy occurring by an energy cascade process through a series of Fourier modes of the velocity field, in which large scale eddies break up, subdividing into smaller eddies until they disappear by means of heat dissipation through molecular viscosity d(Nath et al., 2010). The nonlinear breaking and critical level interactions of upward propagating gravity waves are one of the main reason for the generation of Turbulence in the atmosphere. And simply we can say that turbulence is caused by convection, wind shear and wind over objects. Due to the presence of winds, thermal current etc. which create eddy air currents implies that the normal state of the atmosphere is a turbulent one.

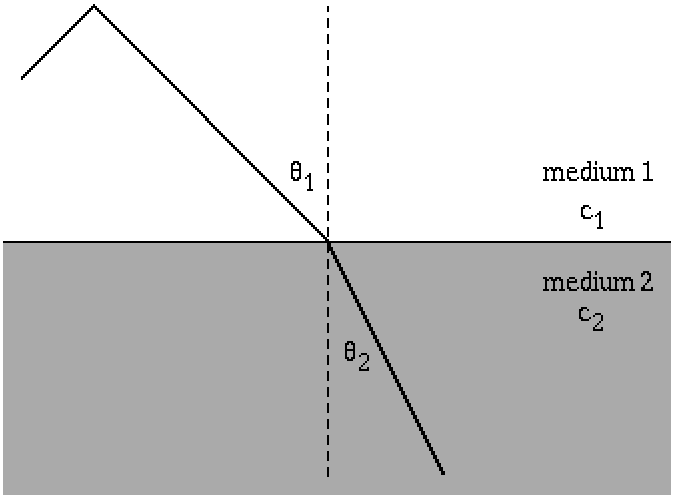
Atmosphere is considered as the large number of regions of various dimensions called eddies. Each eddy is then looked as a turbulent blob, over which the temperature, refractive index etc. deviates from the average. In general turbulent effects are considered to be isotropic for eddy sizes less than some value L_0 called outer scale of turbulence.

Eddies in the atmosphere create turbulence, and they get their energy mainly from wind shear and heat from the Earth. When these eddies become unstable and reach a certain energy level, they break up into smaller eddies. This process continues until the eddies become so small that their energy is wasted due to viscous effects. When eddies are very small, viscous dissipation begins.

In the turbulent atmosphere, the refractive index varies randomly with position and time. As an optical beam travels through this medium, it interacts with eddies, leading to random fluctuations in both amplitude and phase of the signal. These variations can ultimately degrade the performance of the optical system.

2.5 REFRACTIVE INDEX

The degree to which the speed of light is slowed down within a medium is indicated by its refractive index, also known as its index of refraction. When light beams move from air to a substance, this phenomenon causes them to bend; this idea is used in lens design. Moreover, surfaces with a refractive index different from their surroundings reflect light somewhat.



The refractive index (n) is defined as the ratio of the sine of the angle of incidence (i) to the sine of the angle of refraction (r) when a ray passes from a vacuum to a medium.; i.e.,

$$n = \frac{sini}{sinr}$$

The refractive index is also equal to the velocity of light c of a given wavelength in empty space divided by its velocity v in a substance, or

$$n = \frac{c}{v}$$

2.6 REFRACTIVE INDEX STRUCTURE PARAMETER (CN^2)

Atmospheric refractive index structure constant, simply called Cn^2 is a basic parameter which signifies the statistics of atmospheric turbulence. It gives an account of the effect that can happen with the propagation of Electromagnetic wave through atmosphere, which forms basic of a lot of communication and remote sensing systems in the world. The concept of Cn2 involves utilizing multiple standard frequencies to obtain a measurement of reflectivity, which is crucial for various research parameters. When a light beam travels through the atmosphere, its propagation is influenced by random fluctuations in the refractive index of air. These fluctuations or discontinuities lead to the occurrence of optical turbulence. The refractive index structure parameter is a quantitative measure used to assess and quantify optical turbulence.

As a part of the development of our country, aviation carries a major role therefore the importance of the study of turbulence and prediction has got much application. Turbulence leads to the energy distribution in the atmosphere. An imbalance of energy in the atmosphere can often lead to high turbulence. Measurement of turbulence is thus important in the scientific field. For the measurement of the turbulence in the atmosphere, we use the parameter known as Refractive index structure parameter (Cn^2). It gives a quantitative measurement of the turbulence.

Whenever there is turbulence in the atmosphere, various parameters such as temperature, pressure, and relative humidity undergo changes. These changes lead to variations in the refractive index at different points in the atmosphere. Normally, we expect a relatively uniform distribution of the refractive index in a specific region. However, due to the presence of turbulence in the atmosphere, the value of the refractive index deviates from this expected uniformity.

The refractive index structure parameter serves as a measurement of the change in the refractive index across different points in the atmosphere. This parameter allows us to quantify the impact of turbulence on the refractive index. Additionally, turbulence estimation can be performed based on factors such as the refractive index structure parameter, turbulent eddy dissipation rate, and turbulence or eddy diffusivity. These parameters provide valuable insights into the extent and nature of turbulence within the atmosphere.This study is carried out for studying the variation of refractive index structure parameter in the pre-monsoon, transition period from pre monsoon to monsoon, and monsoon period at a tropical coastal urban station cochin (9°58’N, 76017’E). In these seasons the weather phenomena is highly active and there is a high probability of turbulence activities. This study brings out the height distribution of Cn^2 in these three periods.

The refractive index drops monotonically with height under calm conditions, but the atmospheric medium frequently stays turbulent due to forced cooling, irregular heating of the earth's surface, and other natural or artificial disturbances. Eddies with distinct spatial and temporal scales are typically generated by these turbulent states. These eddies are related with turbulent kinetic energy (TKE), or energy per unit mass. The inertial cascade mechanism, that cause large eddies to diminish to small eddies during dissipation in the atmospheric medium, leads TKE to drop to zero. The dissipation rate is typically proportionate to the movement of energy from big to minor eddies into the medium. As a result, the atmospheric cascade process is linked to the energy transfer from the kinetic field that causes fluid abnormalities and eddies to occur. The parameter Cn2 determines the size of the abnormalities.

Understanding the lower atmospheric dynamics through the examination of Cn2 features in terms of the day and season has been emphasized in recent years. Additionally, this value is utilized to forecast quickly fluctuating radio wave attenuation and moving through a thinner atmosphere. Additionally, because lower atmospheric dynamics are so susceptible to changes in humidity, pressure, and temperature, etc. Changes in the atmospheric conditions, such as during the worst weather conditions, may affect Cn2.

The refractive index structure function's physical meaning The strength of the variations in the atmosphere's refractive index is measured by Cn2. Strong and weak turbulence are the two distinct regimes into which this parameter can be divided. Values typically range from 10–17 m–2/3 or less for the moderate turbulence regime and up to 10- 13 m–2/3 or more for the severe turbulence domain. The dimensional analysis yields the m –2/3 units.

In general, values of Cn2 have been shown to vary between approximately 10-12 and 10-16 m -2/3. Elevated Cn2 levels suggest a stormy atmosphere with significant visual blurring or picture distortion.

APPLICATIONS OF CN^2

Light signals, including those in the electro-optical (EO) and infrared (IR) range, experience intensity variations as they travel through the atmosphere. This phenomenon, known as scintillation, arises from fluctuations in the refractive index caused by atmospheric turbulence.

The severity of scintillation is directly linked to a parameter called the refractive index structure parameter (Cn2). This parameter, specifically scaled for the inertial subrange of turbulence, characterizes the variations in the refractive index.

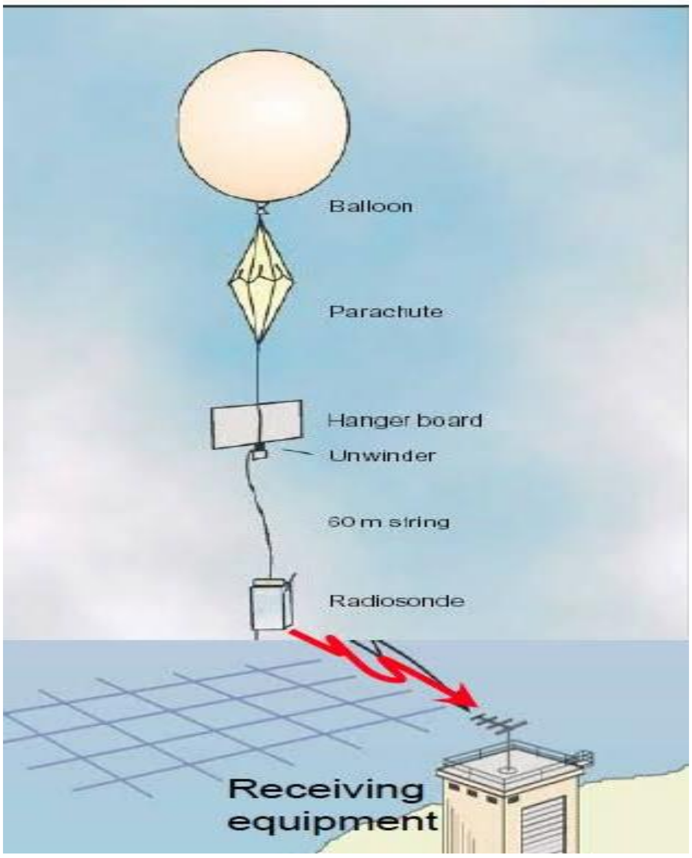
Additionally, aerosols suspended in the lower atmosphere can absorb and scatter EO/IR light. This interaction leads to attenuation (weakening) of the signal, along with potential distortions like aliasing and blurring. The following fields may be significantly impacted by atmospheric turbulence: optical ranging, terrestrial geodesy, aerial surveying, astronomical imaging, and wireless optical communication. Beam broadening, angle of arrival (AA) fluctuations, and irradiance fluctuations (scintillation) are the main consequences. For research on optical propagation, the variation (gradient and fluctuations) in refractive index present an important consequence of air turbulence. The parameter most frequently employed to characterize the intensity of air turbulence is the associated refractive index structure constant, or Cn2. In addition, Cn2 measures the atmosphere's modulation transfer function. A small Cn2 is necessary for good image quality.

The effectiveness of free-space optical communication (FSOC) systems is greatly influenced by the atmospheric conditions experienced during the transmission of the optical wave through the medium containing inhomogeneous turbulence. Atmospheric factors such as variations in temperature, humidity, and pressure, as well as the presence of aerosols and other particles, can all impact the performance of FSOC systems. These environmental factors can lead to phenomena such as scintillation, beam wander, and other forms of signal degradation, necessitating the use of appropriate mitigation techniques and adaptive systems to ensure reliable communication in FSOC applications.

CHAPTER 3

DATA AND METHODOLOGY

3.1 RADIOSONDE



A weather balloon-borne meteorological instrument set known as a radiosonde being launched into the atmosphere. It records wind speed, temperature, and humidity before sending the information to a ground receiver via radio. The majority of radiosondes run on either 403MHz or 1680MHz radio frequencies. Every day, hundreds are launched worldwide; they are a vital source of meteorological data.

Radiosonde measurements include the launching of meteorological balloons which are equipped with GPS units along with sensors which is capable of measuring the atmospheric parameters during their free flight ascent from ground level up to 30Km. Hydrogen or

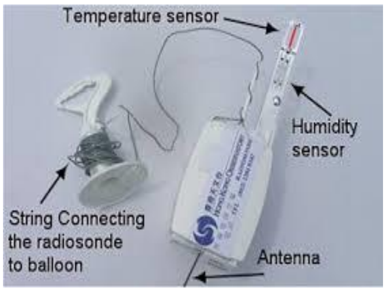
Helium are used for filling the balloons and has a flight speed of 5 to 6 m/s upward. The experiment is conducted on 17:30Hrs on selected days of the month at the above specified location prior to the location from ATC. For this experiment GRAW Radiosonde Upper Air Sounding system DFM-09 is used This system provides accurate and dependable readings for several key environmental factors, including temperature, humidity, air pressure, and wind direction. It even offers detailed information about the sensors themselves and their operational status. All the systems including software are equipped on the ground station in CUSAT campus. The GRAW offers a well-developed user friendly software GRAWMET is used for sounding and simulation process. The data are received within a time difference of 5 seconds. Figure 1 shows the detailed block diagram of the radiosonde system used. (Courtesy: GRAW documentation)

Applications

Altitude, pressure, temperature, relative humidity, wind (both wind speed and wind direction), Geographical position (Latitude/Longitude)

Advantages

- Automatic data collection
- Stratosphere and troposphere measurements (30 km altitude)



The device provides measurements of vertical temperature structure ranging up to 30km with good vertical resolution. The dataset required for the study is collected from high-resolution radiosonde observation from CUSAT campus, which is regularly operated at approximately 15:00 IST.

3.2 DATA ANALYSIS

DATA	PERIOD	TIME OF OBSERVATION	RESOLUTION
GRAW Radiosonde upper air sounding system DFM-09	Pre monsoon and monsoon season for the year 2018 and 2019	17:30 IST	20m

Radiosonde DFM-09 – Technical Data

Weight	<90g, ready to start
Size	200×42×60mm
Battery	Lithium
Battery operating time	>140 min
Wind finding	GPS(48 channels)
Transmission- rate	One full data set per second
Bandwidth	<10khz
Frequency deviation	+/- 3kHz
Modulation	FSK
Output power telemetry	100mW, typical
Error correction telemetry	Code-spreading, interleaving
Windfinding options	C/A code GPS
Temperature resolution	0.1°C
Temperature random error	<0.2°C
Humidity resolution	1%rH
Humidity random error	<4%rH
Pressure accuracy	<0.3hPa
Geopotential height accuracy	<10m
Wind speed accuracy	<0.2 m/s
Accuracy horizontal position	<5m

3.3 METHODOLOGY

In this section, the methodology adopted for the work is presented. High resolution Radiosonde data are obtained from the series of experiments conducted which is mentioned earlier. We briefly introduce one of the turbulent parameters, i.e., refractive index structure parameter (cn^2), which is an important parameter used to measure strength or intensity of turbulence. Here, the methodology adopted to find the seasonal variation of cn^2 is presented. In order to quantify turbulence, cn^2 can be calculated for individual radiosonde launches. From the values of cn^2 mean and standard deviation can be found from which we can get the plot of the seasonal variation of the refractive index structure parameter for the pre-monsoon, monsoon and post monsoon seasons. A radio transmitter with sensors to detect pressure, temperature, humidity, wind direction, and speed at various atmospheric altitudes from the surface to around 30 km is included in the RS. A free-flying balloon with a spherical shape that is launched from the surface lifts the complete transmitter and sensor equipment into the air.A radio transmitter with sensors to detect pressure, temperature, humidity, wind direction, and speed at various altitudes is included in the RS.

The atmosphere from the surface down to around thirty kilometers. A free-flying balloon with a spherical shape that is launched from the surface lifts the complete transmitter and sensor equipment into the air.

Initially for the estimation of turbulence and the initial study of phenomenon, the Raynolds number are calculated using the equations (1) and (2) respectively. Reynolds number, which is dimensionless number, gives an account of flow, whether it is laminar or turbulent. The reference value for the Reynolds number is 10^6,10^7 a change in this value yields the transition of flow in the medium (turbulent, laminar or chaotic).

$$\text{Reynolds number, Re} = \frac{Vxl}{v} \quad \text{……………..(1)}$$

Where, V- wind speed

L – characteristic length, for atmosphere it is equal to resolution from the radiosonde measurements.

v – Kinematic viscosity dependent on temperature, which is equal to $1.1\times 10^{-5}\ m^2\ s^{-1}$

An estimation of the data to get considered for the turbulence estimation has to be done initially. Richardson number gives the measure of how the turbulent layer is. Taking this into account calculation of Richard's number is done for each reading using the equation (2)

Richardson number $Ri = \frac{|g|(\Delta Tv + \gamma a \Delta z)\Delta z}{Tv.[(\Delta U)^2 + (\Delta V)^2]}$ ………… (2)

Where g – gravitational acceleration (9.8 ms-1)

Tv – Virtual temperature

γa – Adiabatic rate of decrease of temperature which is equal to 0.0098 Km-1

z- the height

dU and dV the components of wind

The Richardson number is used to assess the stability of a flow in terms of shear instability. A smaller Richardson number indicates less stability in the flow. The commonly accepted value for the onset of shear-induced turbulence is between 0.15 and 0.5, usually set at Ricr= 0.25. Once turbulence is established within a shear layer, it should be sustained as long as Ri < 1.0. The impact of using either 0.25 or 0.5 for the critical Richardson number was evaluated, and no significant differences were found between the two values. In order to compute the Refractive index structure parameter (cn2), the Potential refractive index gradient (M) has to be calculated. For the estimation of M value, we use the following equation.

$$M = -\frac{79.10^{-6}.P}{T2}\left(1+\frac{15500.q}{T}\right)\left[\frac{dT}{dz} + \gamma a - \frac{7800}{\left(1+\frac{15500.q}{T}\right)}\frac{dq}{dz}\right] \ldots\ldots\ldots\ldots (3)$$

Where T – Temperature in kelvin

P – Pressure in Pascal

Q – Specific humidity

Sometimes referred to as the humidity ratio, specific humidity, also known as moisture content, is the ratio of the mass of water vapor in the air parcel to its entire mass, which includes its dry mass. The "mixing ratio," which is the ratio of the mass of water vapor in an air parcel to the mass of dry air for the same parcel, is roughly equivalent to specific humidity. Equation is used to compute specific humidity.

$$q = \frac{0.622 * e}{p} \dots\dots\dots\dots..(4)$$

Where, e is the water vapor pressure. The vapor pressure of water is the pressure at which water vapor is in thermodynamic equilibrium with its condensed state. It is given by

$$e = \frac{u.es}{100} \qquad \dots\dots(5)$$

Where, u is the humidity and es is the saturation vapor pressure. es is technically the pressure of water vapor above a surface of water. It is given by the equation

$$es = \exp((a/T)+b+(c.T)+d.T^2+e.\log(T)) \quad \dots\dots..(6)$$

The values of constants are

a = -6096.938

b = 21.2409642

c = -2.711193e-2

d = 1.673952e-5

e = 2.433502

From the M value the cn2 is calculated using the formulae

$$Cn^2 = a^2 A L_o^{4/3} M^2 \quad \dots\dots\dots\dots\dots..(7)$$

Where a^2 is a universal constant which is taken as 2.8, A is the ratio of thermal to momentum diffusivity and varies slightly with atmospheric stability but is taken as unity, L_0 is the outer scale length of turbulence spectrum and is given as 5 and M is the vertical gradient of the potential refractive index. The potential refractive index gradient is vertical, M is related to the strength of turbulence.

By substituting the value of refractive index gradient (M) in equation (7), we find the values of Cn^2 for each height level. Cn^2 profile is then drawn. In this analysis a plot of the seasonal variation of refractive index structure parameter (Cn^2) can be made by taking the data of the required seasons with LOG Cn^2 in the x- axis and altitude on y-axis.

Finally, the given radiosonde data are delimited and opened in excel file. Calculations have been done using excel function. Graphs are plotted using PYTHON program.

CHAPTER 4

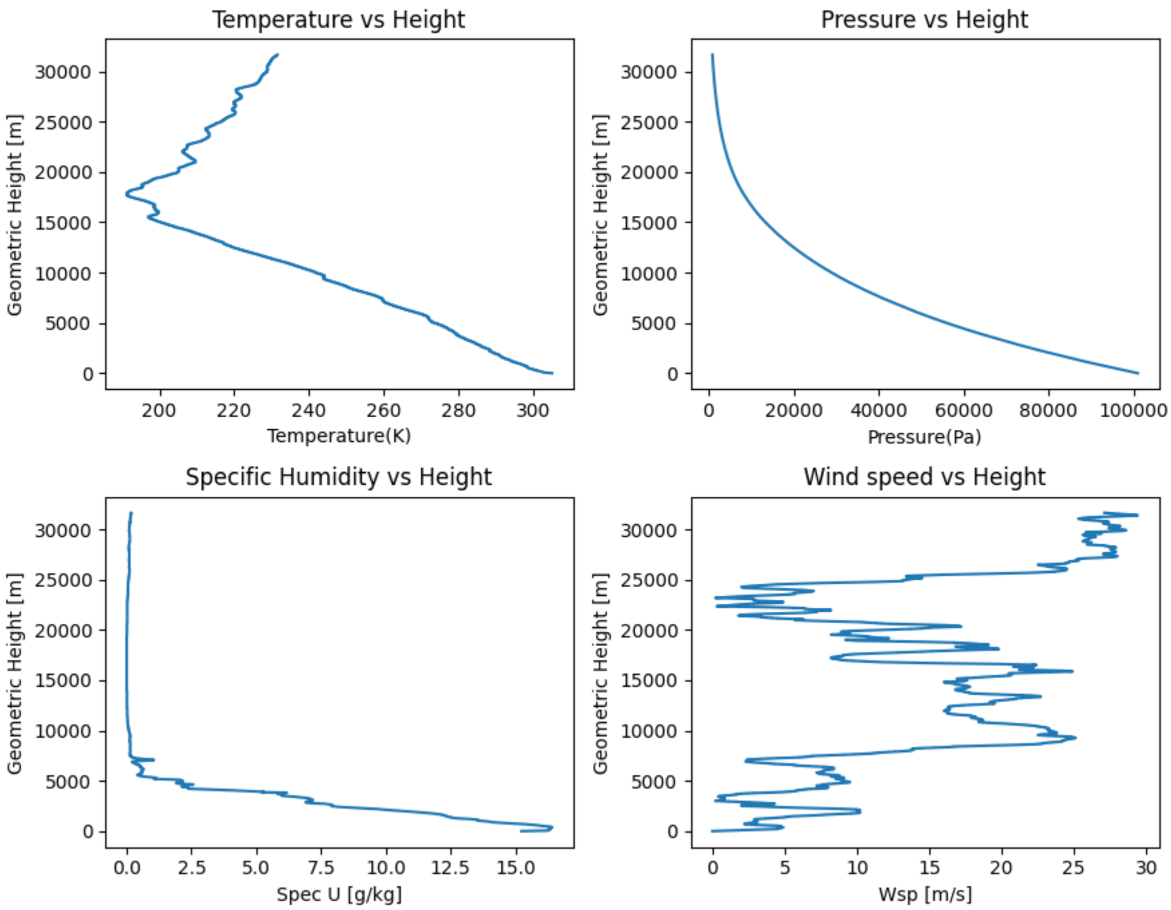
RESULTS AND DISCUSSIONS

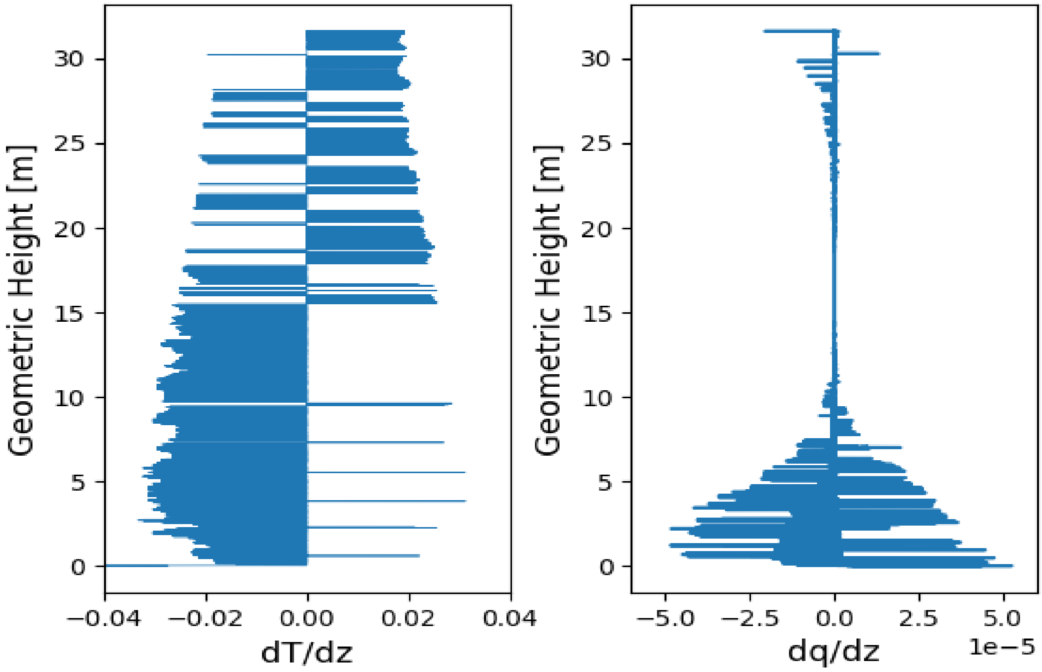
The experiments have been conducted at the Advanced Centre for Atmospheric Radar Research (ACARR) at Cochin University of Science and technology (CUSAT, main campus) in Kerala, India. The four major seasons observed at this place are winter (January), and post monsoon (July - September).

Considering the significant role played by Specific humidity, Pressure, Temperature, the gradient of temperature, the gradient of specific humidity on C_n^2, it is essential to analyze variation pattern of these parameters with height. Therefore, Specific humidity, the gradient of temperature, the gradient of specific humidity from 1 to 15 km altitude are calculated using Temperature, Pressure, Humidity data of RTS for the months of winter and post-monsoon and the typical profiles of RS variables, Specific humidity, Pressure, Temperature, the gradient of temperature, the gradient of specific humidity are shown in fig;

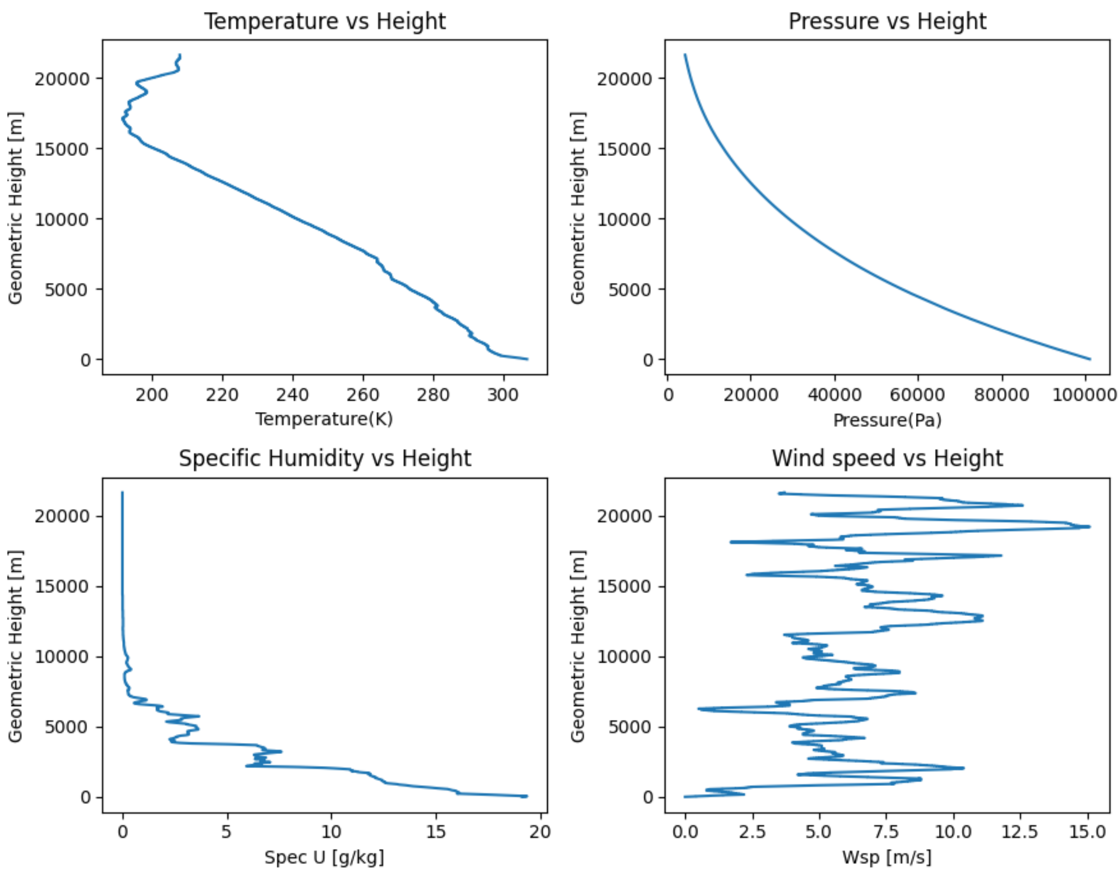
❖ Winter

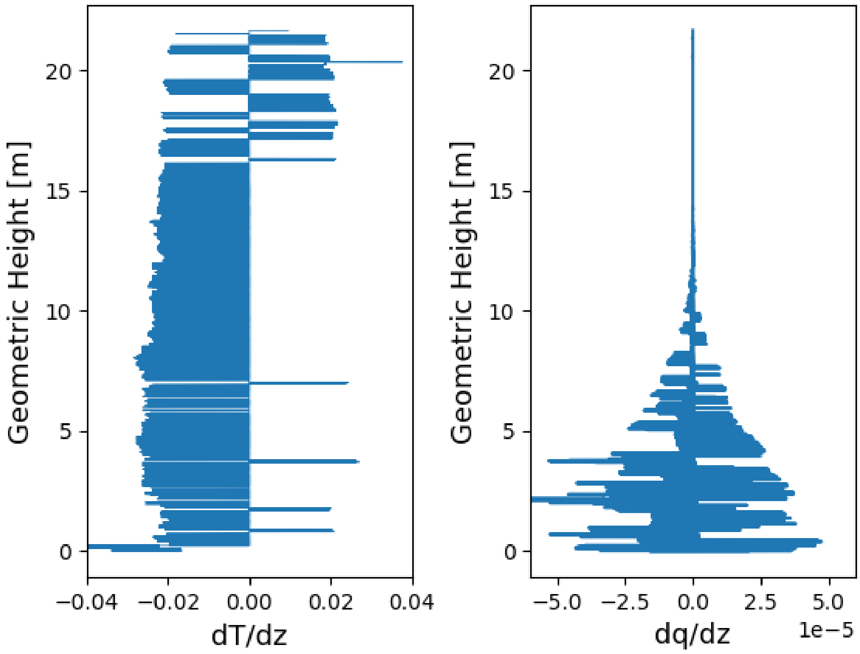
➢ JANUARY 1 2020





➢ DECEMBER 27 2019

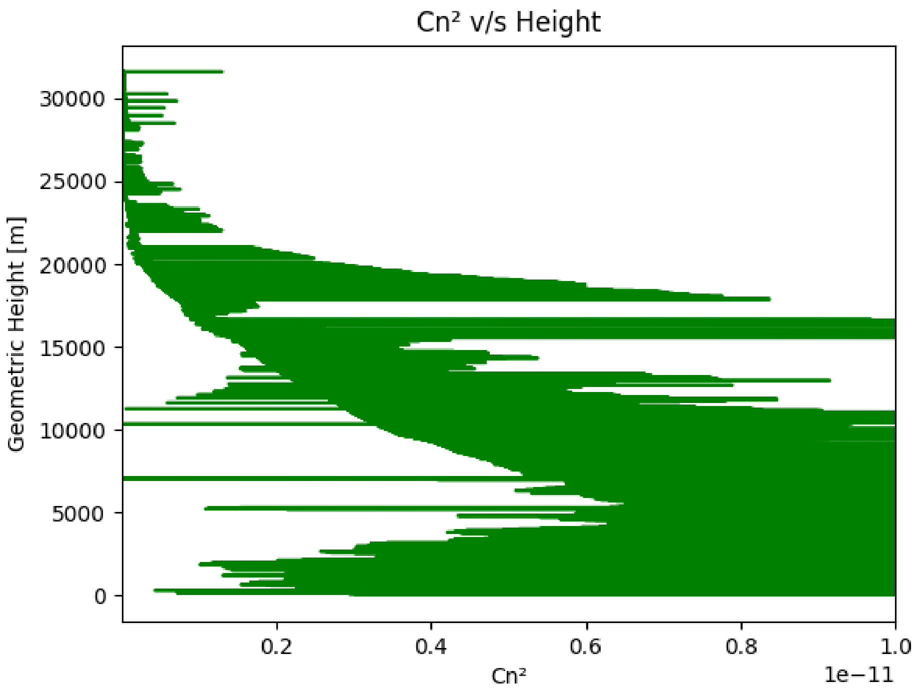




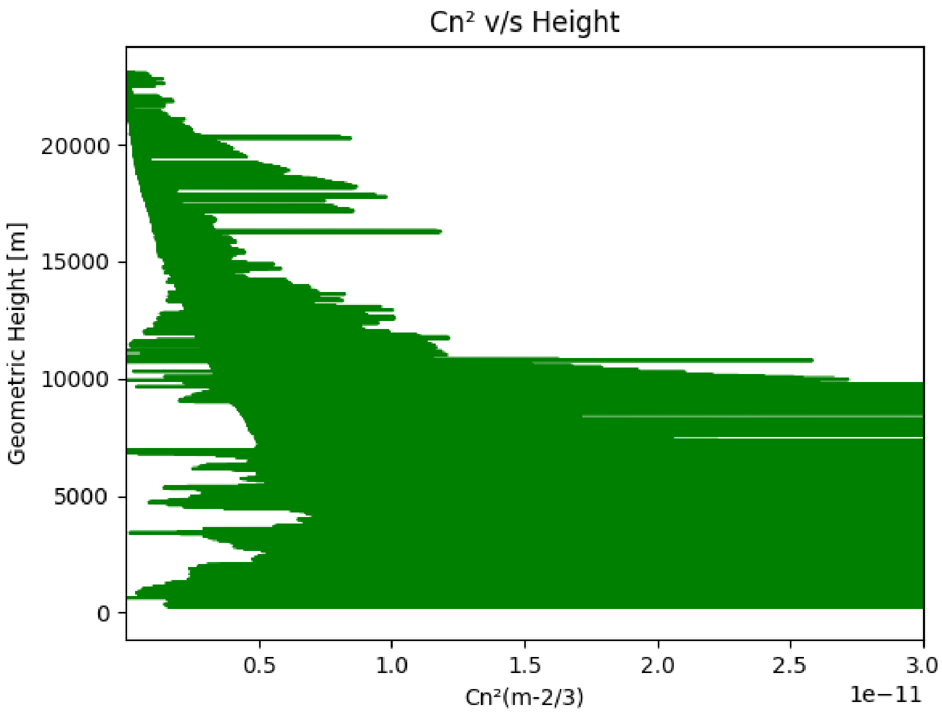
REFRACTIVE INDEX STRUCTURE PARAMETER V/S ALTITUDE

- **Winter**

January 1 2020

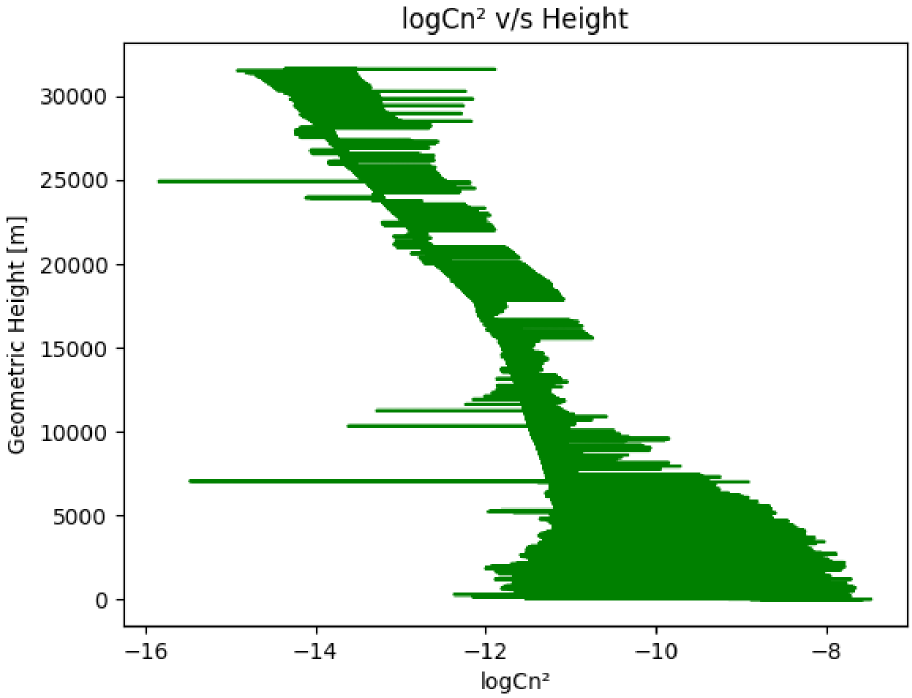


December 27 2019

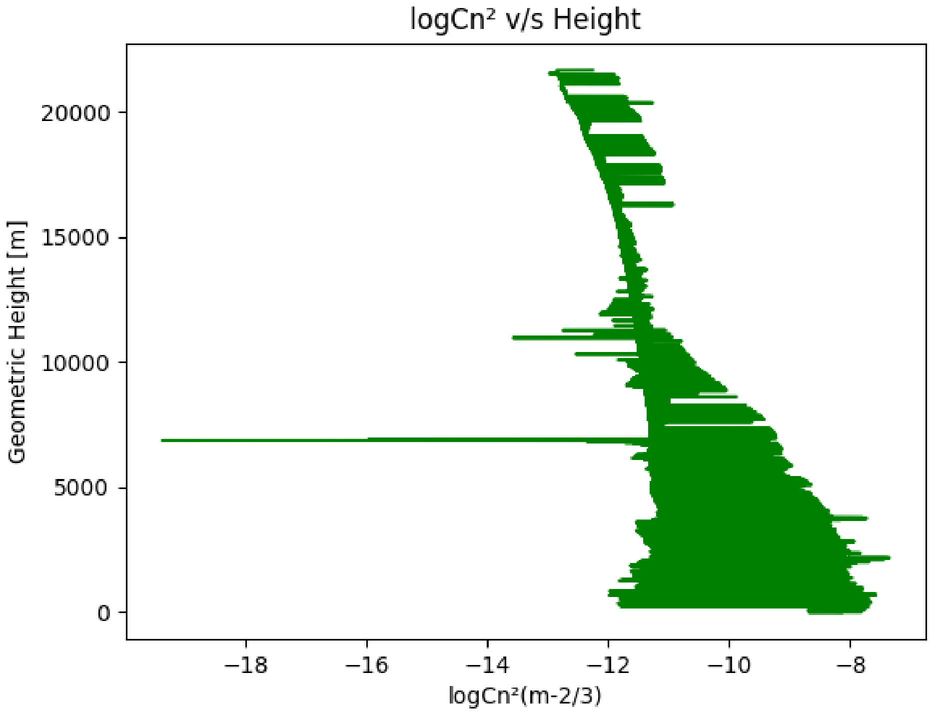


❖ $LogCn^2$ v/s Altitude

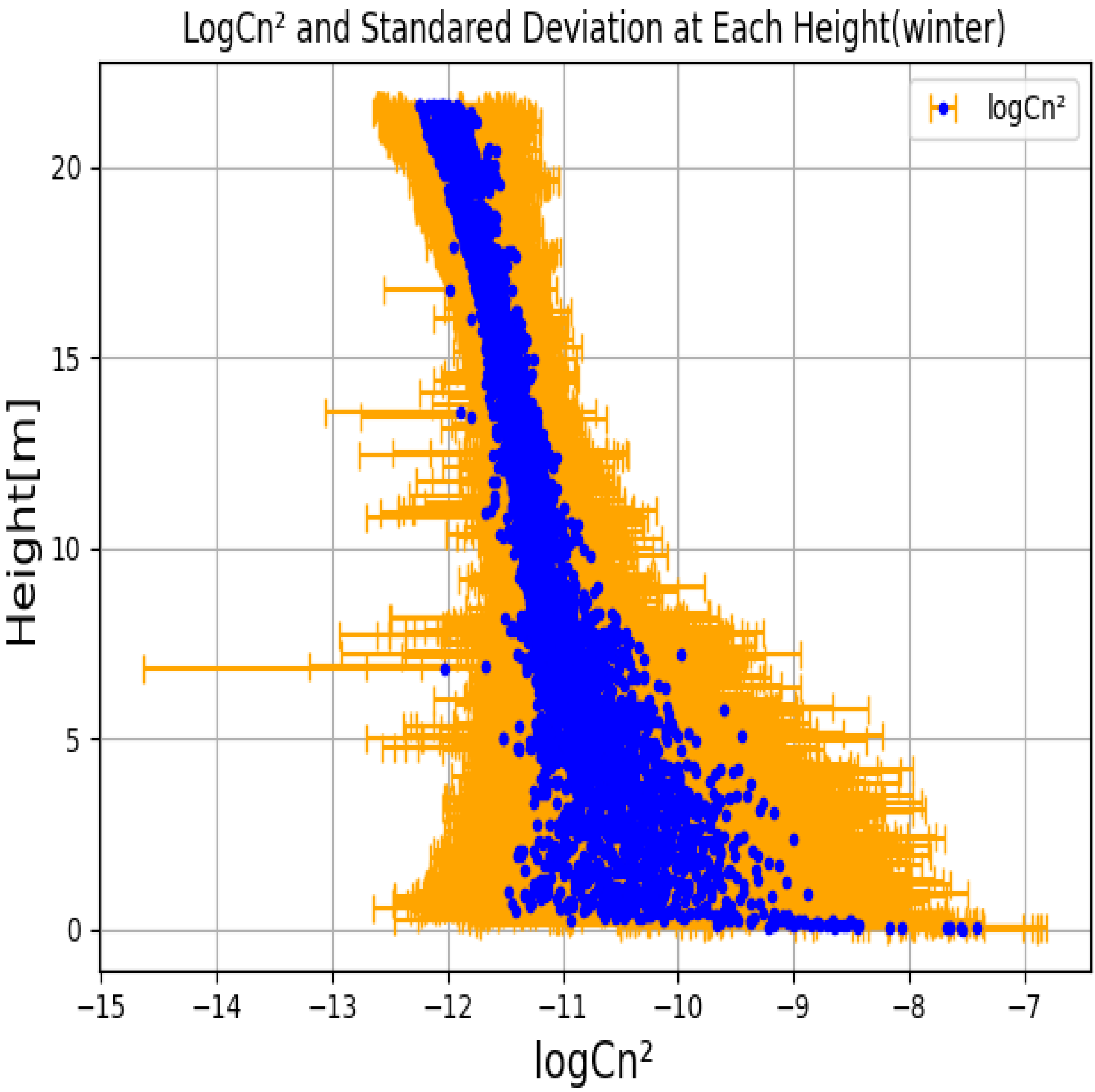
➢ January 1 2020



➢ December 27 2019



Average Standard Deviation during Monsoon and Winter



CHAPTER 5

SUMMARY AND CONCLUSION

In this project the refractive index structure parameter of both the winter as well as monsoon seasons has been estimated from the radiosonde data that has been obtained from the experiment conducted at ACARR, CUSAT, in Cochin. From these data's the variation of atmospheric parameters such as temperature, pressure, specific humidity, wind speed, gradient of temperature and humidity have been plotted against Altitude is analysed using python plots. And finally the refractive index structure parameter is calculated plotted and plotted against altitude.

According to the given data, firstly the analysed variation of Cn^2 during the winter season. And we came to the conclusion that Cn^2 has significantly a high value during the monsoon season. One of the main reason for it is that as we all know during monsoon the presence of moist air is very much higher and while during winter season there is dry air is high. So due to significant increase in atmospheric humidity, and all atmospheric parameters such as temperature, pressure, wind speed vary during these two seasons. As we know when sun rises, eventually the land will heated up and water vapors will be everywhere. Due to the formation of water vapor the air will become less denser and air density changes, as a result refractive index will also change. So as we go up in troposphere with the increase in altitude, pressure decreases and thereby a decrease in density also occurs. That is in surrounding areas there are lots of moisture and less density, and as we go up, the moisture content decreases and density becomes higher with pressure. So there is a density gradient there, and we are able to observe the bending of radiobeam. The bending will be in different angles and in very rare cases we are able to observe the beam in exactly opposite to the transmitted beams direction. So even in clear sky conditions, there is a chance of getting reflection as a result of density gradient. Other one is refractive index gradient, which can occur as a result of turbulence in the atmosphere.

Shears, or vertical propagation of air waves, are the primary way that the troposphere affects the stratosphere. It is therefore crucial to predict the presence or absence of deep clouds based on these vertical shears.

FUTURE

The refractive index structure parameter that is known as Cn2 is a physical representation of how much turbulent there is in the atmosphere. Atmospheric turbulence is a major issue, especially for imaging and energy conveyance cases. Previously, most research in this area has been largely focused to study vertical transmission path for astronomical observations and imaging. However, in recent years, attention to researching horizontal spread routes has increased. It is this change that the project to develop free-space optical communication system and, farther down, astronomizing at a lower altitude seeks.

Some Known Limitations of Severe turbulence - Large, abrupt changes in altitude and/or attitude, and large, variation in indicated airspeed. The resulting turbulence could momentary upset the control of the aircraft

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