National Centre for Radio Astrophysics

Internal Technical Report

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Lightning Analysis for the GMRT Using IITM Data: Studying Antenna Problems Due to Lightning

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Objective: Using the IITM lightning data from 2018 to 2022 years, this report aims to recommend the optimum sampling time-interval for consecutive lightning detection and constraints on geographical area to be considered for the lightning detection that can be used in the planned lightning Warning & Alarm tool for the safety of GMRT antennas. Also, this report estimates the possible average time-lost of GMRT operation time associated with a optimum temporal and spatial parameters recommended for the Lightning warning & alarm tool.

Revision	Date	Modification/ Change
Ver. 9	2024/03/21	Initial Draft Version
Ver 1.0	2024/07/02	Jun 19, 2024 TGC Bi-weekly meeting discussion – Radial distance and CG only lightning study included with Recommendation

Executive Summary

Purpose of the Report :

Occasional failures in one or many sub-systems at the antenna-base such as Front-end/Common-Box, Sentinel, Electrical, and Servo have been reported commonly in many antennas due to the lightning and thunder-storms in last couple of years. The existing GMRT Lightning arrester systems have been working reliably since the last ~20 years or so. However, when the upgraded BAND-2 feed is directed towards sky, it's dual ring structure in the vicinity of GMRT antenna arresters is suspected to induce the lightning current and causing the malfunctioning of receiver-chain electronic and other antenna-base systems. Therefore, to avoid possible damage of antenna-base subsystems due to the lightning and thunder, a Lightning Warning and Alarm tool is planned to be used for the GMRT. This tool can raise and notify the risk alarms so that the BAND-2 feed can be focused towards a parabolic dish prior to heavy lightning.

At present, the GMRT uses a LLN (*Lightning Location Network*) data based lightning monitoring ***web-tool*** *provided by the* ***Indian Institute of Tropical Meteorology***, ***Pune***. This web-tool graphically shows a spatial-temporal indication of the lightning detection (Intra-cloud, and Cloud to Ground) using a geographical Earth-map. But decision of whether to focus the BAND-2 feed towards a dish to avoid a probable damage due to the lightning is taken by observing the LLN web-tool for lightning flashes and strikes over & surrounding the GMRT areas, and watching the direction of lightning cloud movement (whether it's towards GMRT area or away from it). Along with the web-tool for the lightning monitoring, the IITM also provided a real-time ***Data-Feed*** at the GMRT which gives a real-time lightning data with detailed parameters such as the lightning time, location, intensity, and types of lightning (Intra-cloud or cloud-to-ground). Hence, it is planned to develop a LLN Data-feed based real-time Lightning Warning and Alarm tool which can predict the lightning risk specific to the GMRT .

In view of estimating the probable lightning risk for a GMRT , a study of lightning data of past five years from **2018 to 2022**[1] was targeted with following ***objectives*** :

(i) Optimum time interval and geographical boundaries : Find the optimum sampling time interval for detecting the consecutive lightning strikes, and optimum geographical boundaries so that maximum lightning detection reported by the IITM data-feed can be covered to estimate the warning and risk alarms for the GMRT. Calculate possible time-lost of operation for the GMRT observatory associated with a optimum temporal and spatial parameters under consideration for rising the warning and alarm.
(ii) Statistics on Lightning data : Report statistical analysis to know about how many days on an average lightning occurs per year in the GMRT area, know the ratio of intra-cloud (IC) to cloud-to-ground (CG) lightning, know the lightning counts per day and year, and know the average observed intensity of lightning (positive or negative) in K Amp.
(iii) A study of GMRT antenna problems due to the Lightning : Study the correlation of Lightning occurred within a 400 meters radial distance from the individual GMRT antennas and antennae problems noted during the lightning period with a detailed analysis such as Feed focused at the antenna and receiver settings etc.

1 In 2023 the LLN IITM up-gradation work was in progress which completed and IITM data feed was provided in April 2024. **We acknowledge and thanks to the Indian Institute of Tropical Meteorology, Pune personnel Prof. Sunil Pawar, Mr. Manoj Domkawale, and Mr. Gopalkrishnan.**

Lightning Data Selection Criteria :

- As per the lightning safety education facts mentioned by the ***National Weather Service***[2], successive lightning flashes are ***3-4 Km*** distance apart. But new data shows that at least ***10 to 13 km*** distance from the previous flash shall be considered relatively safe. Also, positive lightning strike can occur ***~ 10 miles (16 km)*** from the edge or upper part(s) of the thunder storm clouds called blue bolts which is comparatively stronger in current intensity than the negative lightning.

- Empirical GMRT data when correlated with lightning occurrence shows that the central-square (1 km x 1 km) antennas are more affected than the arm antennas. This is because on an average arm antennas are sparsely located 2 to 3 km distance apart from each other in each arm (South,West,and East direction). From the **C03** antenna location, last arms antennas aerial distance is around 13 to 14.3 km. Hence, assuming the GMRT antenna locations and known standards for successive lightning flashes occurrence, the lightning data of 2018 to 2022 years is geographically resampled for the lightning detection occurring within a **4 x 4 KM^2** area and 4**0 X 40 KM^2** area centered at the C03 antenna. The data sets of *4 x 4 and 40 x 40 Km-sq* area are used for studying the overall general statistics like total number of days of lightning occurrence per year, ratio of IC to CG, maximum intensities of the lightning in K Amp etc.

- In case of finding the optimum time sampling interval for consecutive lightning, the data analysis was done in two sets, one data set where lightning occurrence is within a **500 meter** radial distance from individual GMRT antennas, and other data set is having **5 km** radial distance. Both the data sets were analyzed for total lightning (IC+GC) and cloud-to-ground strikes separately.

Results :

To get the optimum sampling time interval (**ΔT)** for the successive lightning (*IC+CG or CG only*) detection, time sampling parameter to detect consecutive lightning occurring within a given **ΔT** is varied from 1, 5, 10, 15, 20 , 30, and 60 minutes. And total consecutive lightning (IC+CG or CG only) occurring with respect to each interval for a given day and then for a complete year is calculated for ***4 x 4 , 40 x 40 Km-square area*** and ***0.5 - 5 km radial distance from the individual GMRT antennas*** . Maximum percent of lightning detected for each interval with respect to the total lightning occurring (*with a continuous time i.e. independent of* ***ΔT*** **)** for each year is calculated.

It is found from data sets of "***40 x 40 km-square area***" and "***within a 5 km Radial distance of individual GMRT antennas***" that on an average ***85 to 98 %*** of lightning is detected over a complete day for a maximum selected Lightning sampling interval (**ΔT)** of ***1 hour***. If we considered the CG Lightning only for both the data sets, then ***80 to 85 %*** lightning is detected for the radial distance of 5 km, and ***85 to 95 %*** of lightning detected within 40 x 40 km-square area.

(i) *Considering the detection range from 5 to 10 % of the maximum percentage of lightning detected at 1 hours of selected sampling interval, the optimum time of sampling interval* ***(ΔT)*** *is converging to* ***~15 minutes*** *in all data sets.* ***(ii)*** *As compared to 40 x 40 km-square area, 5 km Radial distance from individual antennas seems to be preferred option because the operation time-lost of the observatory for total lightning detection is* ***22.11 hrs*** *which is less than half of value 48.8 hrs with respect to 40 x 40 km-square area.* ***(iii)*** *We considered total lightning instead of CG*

2 National Oceanic and Atmospheric Administration, US Dept of Commerce.

lightning only because electric charges in the atmosphere causing the Intra-cloud lightning may cause the CG lightning by helping to build a step leader process for the lightning . i.e. the presence of intra-cloud lightning can be indicative of the storm's intensity and the potential for more severe weather, including cloud-to-ground lightning strikes.

- *Therefore, for the lightning warning and alarm tool, the 15 minutes of sampling time interval for the consecutive lightning detection with a radial distance of 5 km from individual GMRT antennas seems to be optimum solution for detection and prediction of successive lightning.*
- It can be noted that the overall percentage of maximum lightning detection for 4 x 4 km-sq area or 0.5 km radial distance from individual antennas is reduces to less than 83 % (*40 to 83 percentage*) in case of total lightning (IC+CG), and 30 to 35 % in case of the CG only, hence these options are not considered for the optimum solution.
- It is worth to note that even if 40 x 40 km-square area is consider to improve the successive lightning prediction estimation for warning and alarming, the total lost-time of operation for the observatory is around average value of 48 hrs (i.e. ~2 days only) in a given year.

Recommendations for the Lightning Warning & Alarm tool :

As per the *National Weather Service* station data, successive lightning flashes/strikes can be 3-4 km distant apart from the old data and 10-13 km distant apart from the new data. And strong positive lightning can occur up to ~16 km from the edge of clouds where potential intra-cloud lightning is detected which can contribute for the positive lightning. Also, considering the empirical GMRT study of lightning occurrence and antenna problem noticed specific to central-square antenna, we recommend the radial distance of 5 km from the individual GMRT antennas for the lightning detection and warning which covers almost overlapped circular ~ 157 km^2 area for each antenna. The advantage of considering 5 km radial distance from each individual GMRT antenna is also a geographically optimum solution because it can possibly reduce the operation lost-time of the observatory by half of period as compared to overall 40 x 40 km square area.

In all cases ***4 x 4 and 40 x 40 km sq-area*** or ***500 meter to 5 km radial distance*** from the individual GMRT antennas, the optimum time of sampling interval **(ΔT)** is converging to ***~15 minutes*** which can detect 5 to 10 % of the maximum percentage of lightning that is detected at an hour. The optimum value of sampling time interval doesn't change with the total lightning and only CG lightning.

- **Lightning is a complex phenomenon :**

(I) In view of giving warning and risk alarms for the safety of GMRT antenna and it's sub-systems with a conservative approach for the safety first, the warning and alarm tool for the GMRT shall consider total lightning because the presence of intra-cloud lightning can be indicative of the storm's intensity and the potential for more severe weather causing 25 % of cloud-to-ground lightning strikes out of total lightning.
(II) The intensity of consecutive Lightning seems to be a non-linear or unpredictable factor, hence intensity of the Lightning strike shall be omitted while raising the warnings and risk alarms for the GMRT antenna.
(III) The total lightning strikes count varies randomly per year ranging from ~ 2126 to 10755. Hence, no significant common average of lightning per year can be predicted.
(IV) Although the mean CG Lightning occurrence is around ~ 4 to 7 days per year in the central-square. Sometimes, IC Lightning can also affect in the central square antennas due to close spacing.

Even if the Band-5 and Band-4 feeds are in focus and Band-3 and Band-2 feeds are horizontally positioned, central-square antennas can be affected (Data of April 2024).
(V) The lightning affecting area from the ***April 2024*** seems to be cover ~ 1 km central-square area where first Arm antennas like W01, S02, and E02 antennas are not affected.

Therefore, for the lightning warning and alarm tool, the 15 minutes of sampling time interval with a radial distance of 5 km from individual GMRT antennas seems to be a optimum solution for detection and prediction of successive lightning.

- ***Discussion in TGC Bi-weekly meeting on Jun 19th 2024 (Wednesday), inputs from Shri Anil Raut and Prof. Ishwara Chandra On Jun 21st, 2024 (Thursday)***

Considering that the lightning is a complex phenomenon, and the Lightning detection, warning and alarm tool shall raise the alarm(s) with a conservative approach of first observatory safety because total time-lost in operation due to the lightning warning and alarms may take only one or two days in a year. Note that with a inductive reasoning based on the IITM lightning data analysis from 2018 to 2022 years, we recommend the following SOP for the audio lightning warning and alarm tool which may need timely changes after implementation of the tool :

Step 1 Warning Alarm : *On the first occurrence of IC lightning is detected within a 5 km radial distance of individual GMRT antennas, the lightning tool will raise a warning alarm only.*

Step-2 Risk Alarm : *If the subsequent consecutive lightning occurring (IC or CG) within a 15 minutes of previous lightning occurrence is detected at the same antenna within a 5 km radial distance then it will raise a* **Risk-Alarm** *to recommend action of rotating Feed to Band-2 and park the antenna.*
If CG Lightning is happening within a 5 km distance as a first occurrence then also Feed will be asked to move to Band-2.

Step-3 System Release for the Operation : *If the consecutive Lightning is not occurring within a next 15 minutes of previous occurrence within a 5 Km of Radial distance of any antenna, then system will declare audio message to release the GMRT telescope to resume in operation.*

Lightning Analysis for the GMRT Using IITM Data: Studying Antenna Problems Due to Lightning

$ version 1.0 July , 2024 , J. Kodilkar , A. Raut, Ishwara Chandra $
$ version 0.9 May-June , 2024 , J. Kodilkar, A. Raut, Ishwara Chandra $

1. INTRODUCTION :

Occasional failures in one or many sub-systems at the antenna-base such as Front-end/Common-Box, Sentinel, Electrical, and Servo have been reported commonly in many antennas due to the lightning and thunder-storms in last couple of years. The existing GMRT Lightning arrester systems have been working reliably since the last ~20 years or so. However, when the upgraded BAND-2 feed is directed towards sky, it's dual ring structure in the vicinity of GMRT antenna arresters is suspected to induce the lightning current and causing the malfunctioning of receiver-chain electronic and other antenna-base systems. Therefore, to avoid possible damage of antenna-base subsystems due to the lightning and thunder, a Lightning Warning and Alarm tool is planned to be used for the GMRT. This tool can raise and notify the risk alarms so that the BAND-2 (150 MHz) feed can be focused towards a parabolic dish prior to heavy lightning.

At present, the GMRT uses a LLN (*Lightning Location Network*) data based lightning monitoring ***web-tool*** *provided by the* ***Indian Institute of Tropical Meteorology***, ***Pune***. This web-tool graphically shows a spatial-temporal indication of the lightning detection (Intra-cloud, and Cloud to Ground) using a geographical Earth-map. But decision of whether to focus the BAND-2 feed towards a dish to avoid a probable damage due to the lightning is taken by observing the LLN web-tool for lightning flashes and strikes over & surrounding the GMRT areas, and watching the direction of lightning cloud movement (whether it's towards GMRT area or away from it). Along with the web-tool for the lightning monitoring, the IITM also provided a real-time ***Data-Feed*** at the GMRT which gives a real-time lightning data with detailed parameters such as the lightning time, location, intensity, and types of lightning (Intra-cloud or cloud-to-ground). Hence, it is planned to develop a LLN Data-feed based real-time Lightning Warning and Alarm tool which can predict the lightning risk specific to the GMRT .

In view of estimating the probable lightning risk for a GMRT , a study of lightning data of past five years from **2018 to 2022**[3] was targeted with following ***objectives*** :

(i) Optimum time interval and geographical boundaries : Find the optimum sampling time interval for detecting the consecutive lightning strikes, and optimum geographical boundaries so that maximum lightning detection reported by the IITM data-feed can be covered to estimate the warning and risk alarms for the GMRT. Calculate possible time-lost of operation for the GMRT observatory associated with a optimum temporal and spatial parameters under consideration for rising the warning and alarm.
(ii) Statistics on Lightning data : Report statistical analysis to know about how many days on an average lightning occurs per year in the GMRT area, know the ratio of intra-cloud (IC) to cloud-to-ground (CG) lightning, know the lightning counts per day and year, and know the average observed intensity of lightning (positive or negative) in K Amp.
(iii) A study of GMRT antenna problems due to the Lightning : Study the correlation of Lightning occurred within a 400 meters radial distance from the individual GMRT antennas and antennae problems noted during the lightning period with a detailed analysis such as Feed focused

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at the antenna and receiver settings etc. Also, document the Lightning incidents occurred in ***Sep 2022***, and ***April 2024*** which affected the major GMRT antennas.

- **Methodology for the Data analysis :**

The IITM Data :

As per the MoU between NCRA and the IITM, the IITM shared the lightning data from 2018 to 2022 which occurred within a ***100 x 100 KM^2*** area of the GMRT. This data was provided in July 2023. The Lightning data consist of the *date and time (in UTC), location of the lightning strike (longitude, latitude), type of lightning strike (Intra-cloud or cloud to the ground), and the amplitude of current (Amp) that flowed through lightning i.e. lightning intensity.* The data was given in five files i.e. per year in one file. Note that the IITM data contains only lightning flashes or strikes which is nothing but collection of pulses close in space and time that approximates the continuous ionized channels of a complete bolt of lightning. The pulse-density is assumed over 10 km sq-area with pulse occurrence within a time interval of ~600 milli seconds.

Lightning Data Selection Criteria :

As per the lightning safety education facts mentioned by the ***National Weather Service***[4], based on the old data successive lightning flashes are ***3-4 Km*** distance apart. But new data shows that at least ***10 to 13 km*** distance from the previous flash shall be considered relatively safe. Also, positive lightning strike can occur ***~ 10 miles (16 km)*** from the edge or upper part(s) of the thunder storm clouds which is comparatively stronger in current intensity than the negative lightning. Empirical GMRT data when correlated with lightning occurrence shows that the central-square (1 km x 1 km) antennas are more affected than the arm antennas. This is because on an average arm antennas are sparsely located 2 to 4 km distance apart from each other in each arm (South,West,and East direction). From the **C03** antenna location, last arms antennas aerial distance is around 13 to 14.3 km. Hence, assuming the GMRT antenna locations and known standards for successive lightning flashes occurrence, the lightning data of 2018 to 2022 years is geographically resampled for the lightning detection occurring within a **4 x 4 KM^2** area and **40 x 40 KM^2** area centered at the C03 antenna. The data sets of 16 *and 1600 Km-sq* area are used for studying the overall general statistics like total number of days of lightning occurrence per year, ratio of IC to CG, maximum intensities of the lightning in K Amp etc. But in case of finding the optimum time sampling interval for consecutive lightning, the data analysis was done in two sets, one data set where lightning occurrence is within a **500 meter** radial distance from individual GMRT antennas, and other data set is having **5 km** radial distance. Both the data sets were analyzed for total lightning (IC+GC) and cloud-to-ground strikes separately.

1.1 Python Program to calculate the GMRT boundaries and distance from the Antenna for the Lightning :

A python data-analysis program '***parselightning.py***[5]' is developed which can extract the time-series and day-wise analysis of the lightning data. The usage of program is as follows :

parselightning -f *<IITM-Data file>* [**Optional Arguments**] **-t** time-series | **-d** daywise statistics

Optional Arguments :

4 National Oceanic and Atmospheric Administration, US Dept of Commerce.

5 ***Parselightning.py***, ***DatapassLatLong.py, and distanceCheck.py*** *Modules written by J. Kodilkar*

-s DD-MM-YYYY -e DD-MM-YYYY *# Start/stop date*
-i <abs-min:abs-max> *# Intensity range in Amp*
-l LAT:LONG:Distance *# Select Antenna based on, Lat:Long (Degree):distance in km*
-c <Minutes**>** # Continous Interval in Min to count Lightning Time
-g *# Only Cloud2Ground*

1.1.1 Latitude and Longitude boundaries of Square Area :

'Parselightning.py' program uses a ***DatapssLatLong.py*** module and ***distanceCheck.py*** Modules for data selection. The lightning data from the year-wise IITM files were extracted using '*DatapassLatLong.py*' based on ***4 x 4 KM²*** area for the Central-square and ***40 x 40 KM²*** area for the complete GMRT with centre of C03 antenna location (*Longitude 74.0469, Latitude 19.0944 degrees*).

The desired area boundaries in terms of the Longitude and Latitude from the C03 is calculated using the ***inverse of the Haversine formula***[6] which is given below.

Latitude_point = asin (sin(*latitude_C03***) * cos(***distance / radius***)**
+ cos(*latitude_c03***) * sin(***distance / radius***) * cos(***bearing***))**

Longitude_point= *longitude_C03* +
atan2 (sin(*bearing***)*sin(***distance/radius***) * cos(***latitude_C03***) ,**
cos(*distance / radius***) - sin(***latitude_c03***) * sin(***Longitude_point***))**

Latitude_boudry = degrees(*Latitude_point***)**
Longitude_boundry = degrees (*Longitude_point* **)**

Where :

latitude_C03 : *Latitude in radians*
Longitude_C03 : *Longitude in radians*
Distance : *Distance from the C03 in KM (* **= 2 and 20 KM from the C03***)*
radius **=** *6371.0 Earth Radius in Km*

bearing : *The bearing represents the direction from one point to another on the Earth's surface, measured in degrees clockwise from north.*
= 0 degrees (or 360 degrees): North
= 90 degrees: East
= 180 degrees: South
= 270 degrees: West

Latitude_boundary : *Latitude of boundary in Degrees*
Longitude_boundary : *Longitude of boundary in Degrees*

- **For the Longitude and Latitude of 40 x 40 km-square area boundaries are deduced using the above formula :**

6 https://www.geeksforgeeks.org/haversine-formula-to-find-distance-between-two-points-on-a-sphere/

East-South Point-1	74.237	18.914
East-North Point-2	74.237	19.274
West-North Point-3	73.856	19.274
West-South Point-4	73.856	18.914

- **For the Longitude and Latitude of 4 x 4 km-square central area boundaries are deduced using the above formula :**

East-South Point-1	74.0659	19.0764
East-North Point-2	74.0659	19.1123
West-North Point-3	74.0278	19.1123
West-South Point-4	74.0278	19.0764

1.1.2 Latitude and Longitude Distance from the Antenna Coordinates (Longitude-Latitude) :

 # Haversine formula:

$a = \sin^2(\Delta\varphi/2) + \cos\varphi_1 \cdot \cos\varphi_2 \cdot \sin^2(\Delta\lambda/2)$
$c = 2 \cdot \text{atan2}(\sqrt{a}, \sqrt{(1-a)})$
$d = R \cdot c$

where φ *is latitude,* λ *is longitude,* R *is earth's radius (mean radius = 6,371km);*[7]
note that angles need to be in radians to pass to trig functions!

// Python Implementation

```
lat1, lon1, lat2, lon2 = map(radians, [lat1, lon1, lat2, lon2])

# Haversine formula
dlon = lon2 - lon1
dlat = lat2 - lat1
a = sin(dlat/2)**2 + cos(lat1) * cos(lat2) * sin(dlon/2)**2
c = 2 * atan2(sqrt(a), sqrt(1-a))
# Radius of the Earth in kilometers
radius = 6371
distance = radius * c
```

The ***Haversine*** formula is used to calculate the shortest distance between two points on a sphere using their latitudes and longitudes measured along the surface. The resultant distance from the GMRT antennas at 400 Meter also verified using the Haversine PyPackage available in the python which show matching values for the distance.

7 http://www.movable-type.co.uk/ Advice, Design and Development - Information Systems & Database-driven Websites

1.2 The IITM Lightning Data Analysis :

Using the python programs using the Haversine formulae described in ***section 1.1***, the following data extracted for the Lightning :

(a) Extract the time-series of Lightning occurrence which falls (Intra-cloud and Cloud to Ground) within a 4 x 4 KM sq-area and 40 x 40 KM sq-area with C03 antenna as a center. Also, 40 x 40 KM sq-area is re-sampled for radial distance of 5 KM and 500 Meter from the individual antennas.

(b) The statistics for the Lightning data per year from 2018 to 2022 is used to estimate :

- Statistically measure the consecutive lightning strikes occurrence count within a sampling time interval of 1, 5, 10, 15, 20, 30, 60 minutes. Know the percentage of lightning detection counts for each sampling time interval with respect to the overall lightning detection count which is a continuous in time as and when occur (i.e independent of sampling interval) .

- What is a optimum sampling time interval for detecting the maximum consecutive lightning? and how much observatory's possible time can be lost associated with optimum sampling time interval under consideration?

- Calculate the total days per year for the lightning strike (Both IC + CG) occurrence within the GMRT 40 x 40 KM-square area. And how many days the CG Lightning is occurring per year?

- What is the maximum positive and negative Lightning intensity (the current that flow through the lightning discharge in Ampere) for a given year? What is the average intensity of lightning strike for 4 x 4 and 40 x 40 KM square area over a 2018 to 2022 year?

(c) Lightning Statistics per day for a given year :

- For a given year, calculate the total lightning (IC+CG) per day, and only total CG counts per day detected within a 4 x 4 , 40 x 40 Km-square area centered at the C03, and 0.5-5 km radial distance from individual GMRT antennas.

- Show the lightning detection maps for the central-square and Arm antennas over the geographical area in Latitude and Longitude.

2. LIGHTNING DATA ANALYSIS PER YEAR FROM 2018 TO 2022 :

2.1 Optimum Time interval to detect the Maximum Lightning strikes and possible Observatory time Lost :

The IITM data provides year-wise lightning strike data with date-time stamp, lightning strike location (Longitude & Latitude), classification of Intra-cloud (value=1), and cloud to ground (value=0) ,and Lightning intensity in Ampere. The data analysis method for the **Figures 1-A to 1-E** is as follows :

(i) The ***continuous time-series*** data extracted from the year-wise IITM-data file for the strikes that occurred within 4 x 4 and 40 x 40 KM-square area for the central-square and arm-antennas

respectively. To study the optimum solution, the lightning strikes detected within a 5 km and 500 meter radial distances from individual antennas are also sampled.

(ii) From the ***continuous time-series*** data, ***total consecutive strike*** occurrence counts in a given time interval **(ΔT)** calculated per day. ***i.e.*** *If the next lightning occurrence is happened within a given time interval from the time of previous lightning occurrence , then that lightning is counted. But if there is a time gap (or interval) for the next consecutive lightning occurrence from the previous time of the lightning which is greater than the given* **ΔT** *time interval sample (i.e. 1, 5, 10, 15, 20, 30, and 60 minutes), then that lightning strike is omitted from the count until the condition of lightning strike detected within a specified time-interval sample* **ΔT** *of previous one is fulfilled.*

(iii) Along with this, the number of total strikes (IC + CG and CG only) per day irrespective of given time-interval and the maximum intensities of the lightning (negative and positive) per day are also noted.

(iv) The total successive lightning occurrence count (ICs +CG and CG only) within a given time interval over a complete total year is summed from a count of complete day is calculated ***to know the % detection and associated time-lost.***

D_count = Total lightning count per Day = ∑ **Count** =
{ **C =** (Next Consecutive lightning time – previous Lightning time) | **(C ≤ ΔT** }
where, **ΔT** is Time interval - 1,5,10, 15, 20, 30 , and 60 Minutes

Y_count = Total Lightning count detected within a given **ΔT** over ***a complete year***
= $\sum_{year}$ **D_Count**

% of Lightning detected within a ΔT = (100 × Y_count) / T_count

where, T_count is *Total Lightning count within a Year irrespective of time-interval.*

- **Data Analysis Results :**

To get the optimum sampling time interval (**ΔT)** for the successive lightning (IC+CG or CG only) detection, time sampling parameter to detect consecutive lightning occurring within a given **ΔT** is varied from 1, 5, 10, 15, 20 , 30, and 60 minutes. And total consecutive lightning (IC+CG or CG only) occurring with respect to each interval for a given day and then for a complete year is calculated. Maximum percent of lightning detected for each interval with respect to the total lightning occurring (*with a continuous time i.e. independent of* ***ΔT*** **)** for a given year is calculated.

Figure 1-A, 1-C and ***Figure 1-E, 1-G*** show the percentage of consecutive lightning detection in given sampling interval (**ΔT)** with respect to a total lightning detected with a continuous time over a year within a geographical boundaries. The percentage of consecutive lightning is plotted for the 4 x 4 and 40 x 40 km-square area with total lightning (IC+CG) , and for only Cloud-to-Ground (CG) lightning. Similarly, it is also plotted for the radial distance of 500 meter and 5 Km from the individual GMRT antennas. The GMRT's operation time-lost is estimated as a total time of consecutive lightning occurrence under a selected sampling time interval. The time-lost in hrs for each sampling interval are plotted in ***Figure 1-B, 1-D*** and ***Figure 1-F, 1-G*** which indicates 4 x 4 – 40 x 40 km sq-area, 500 m – 5 km radial distance with total lightning (IC+CG) and only CG.

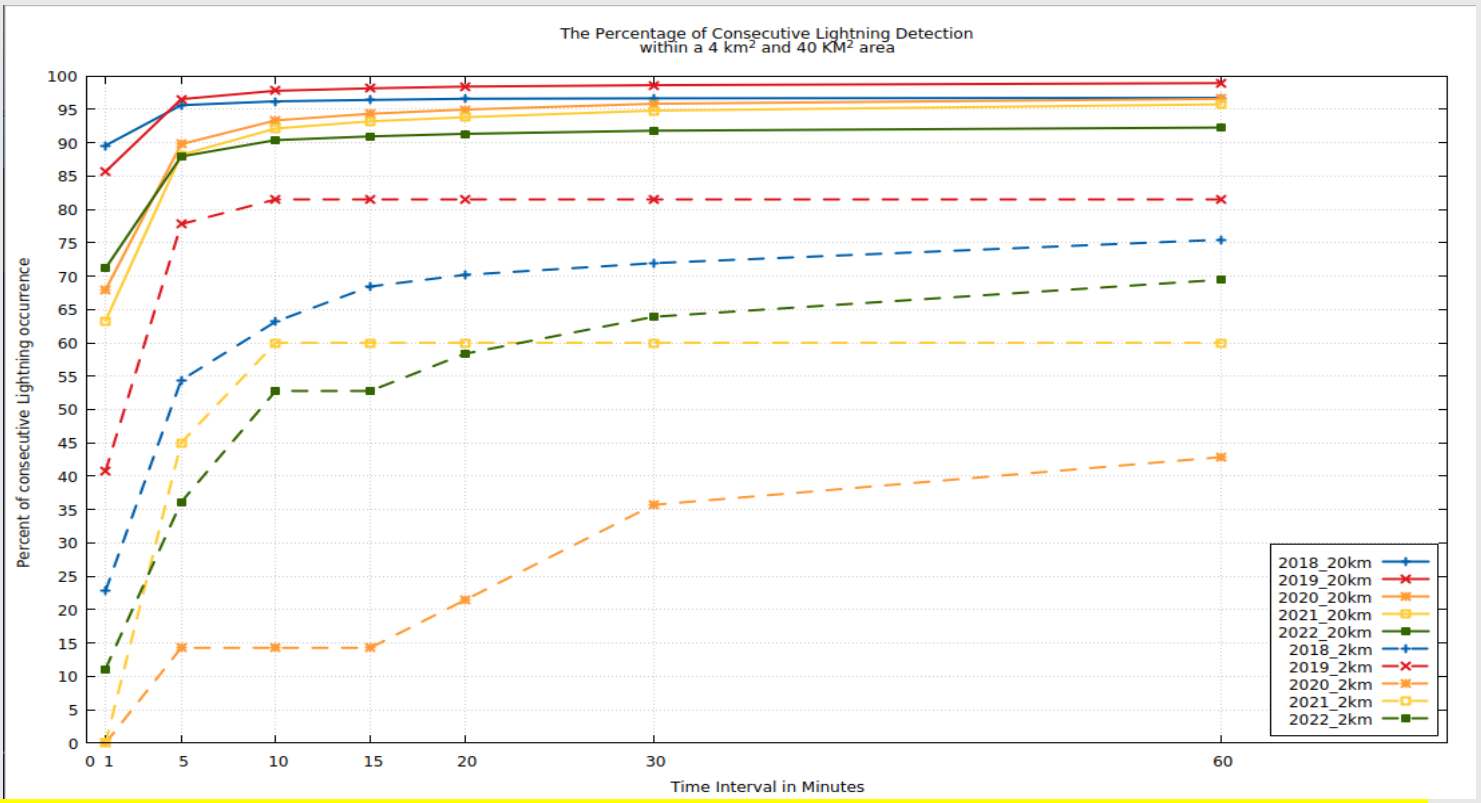

Figure 1-A (4 x 4 and 40 x 40 KM-square area): The percentage of Consecutive Lightning detection of total Lightning for a given time Interval (ΔT)

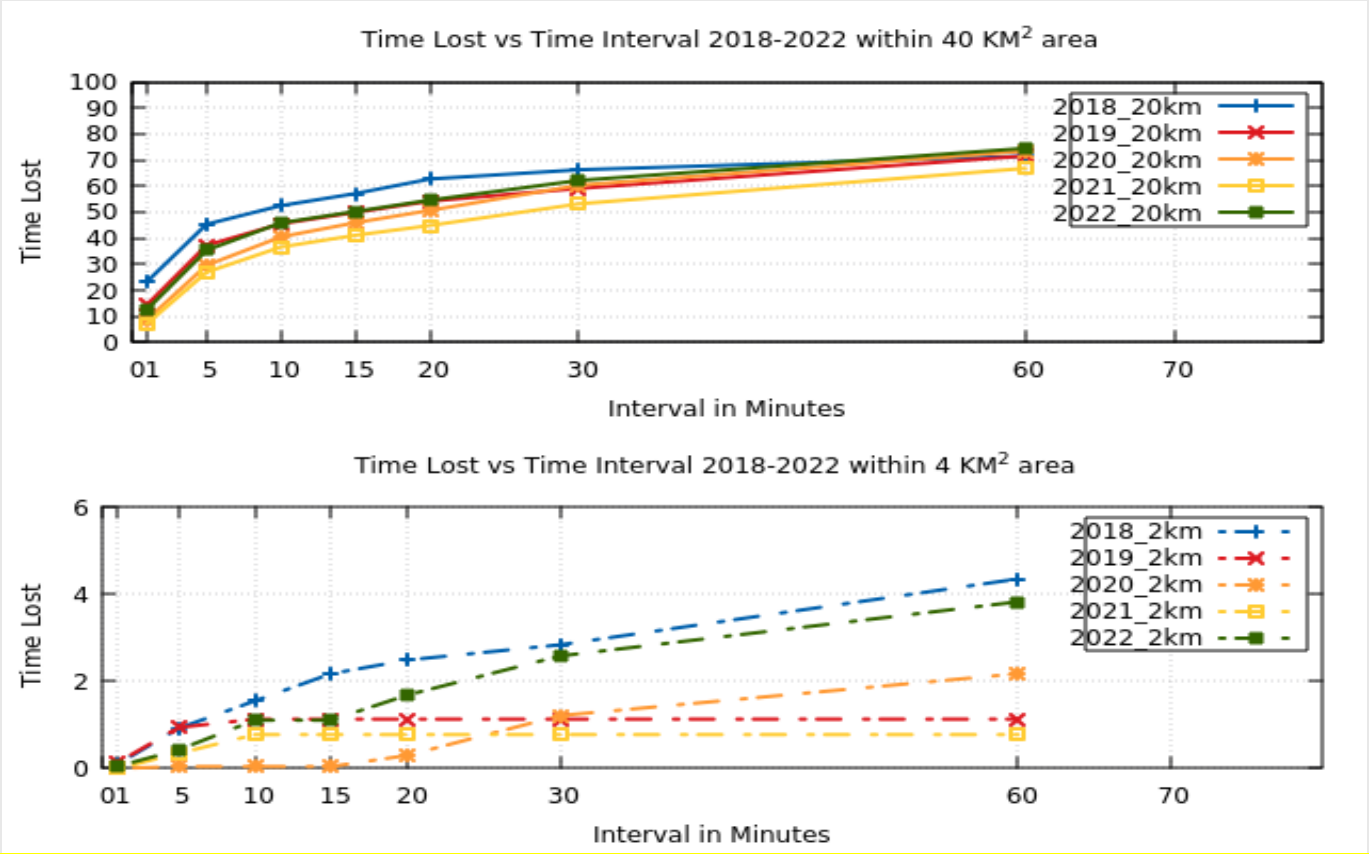

Figure 1-B (4 x 4 and 40 x 40 KM-square area) : Total Time Lost in Hours for the Given Time interval (ΔT) of Consecutive Lightning Detection

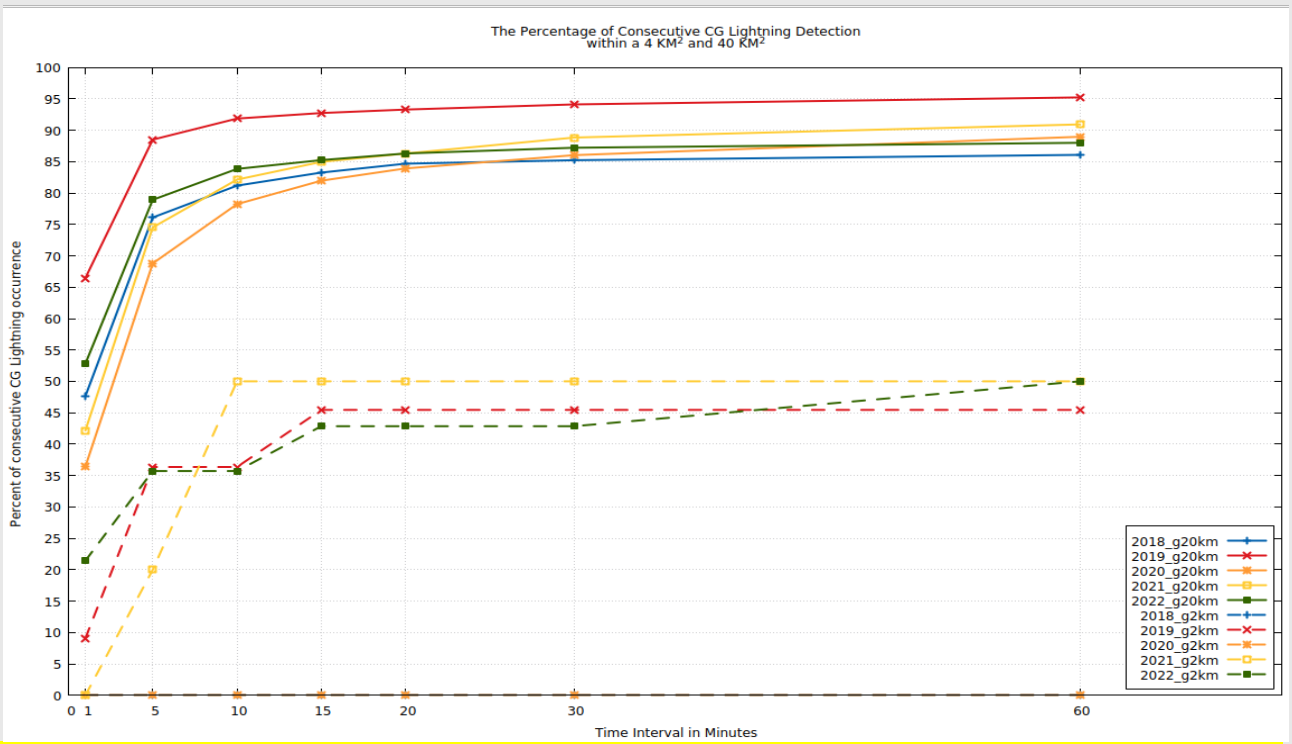

Figure 1-C (4 x 4 and 40 x 40 Km-sq area, CG Only) : The percentage of Consecutive Lightning 'CG' detection of total Lightning for a given time Interval (ΔT)

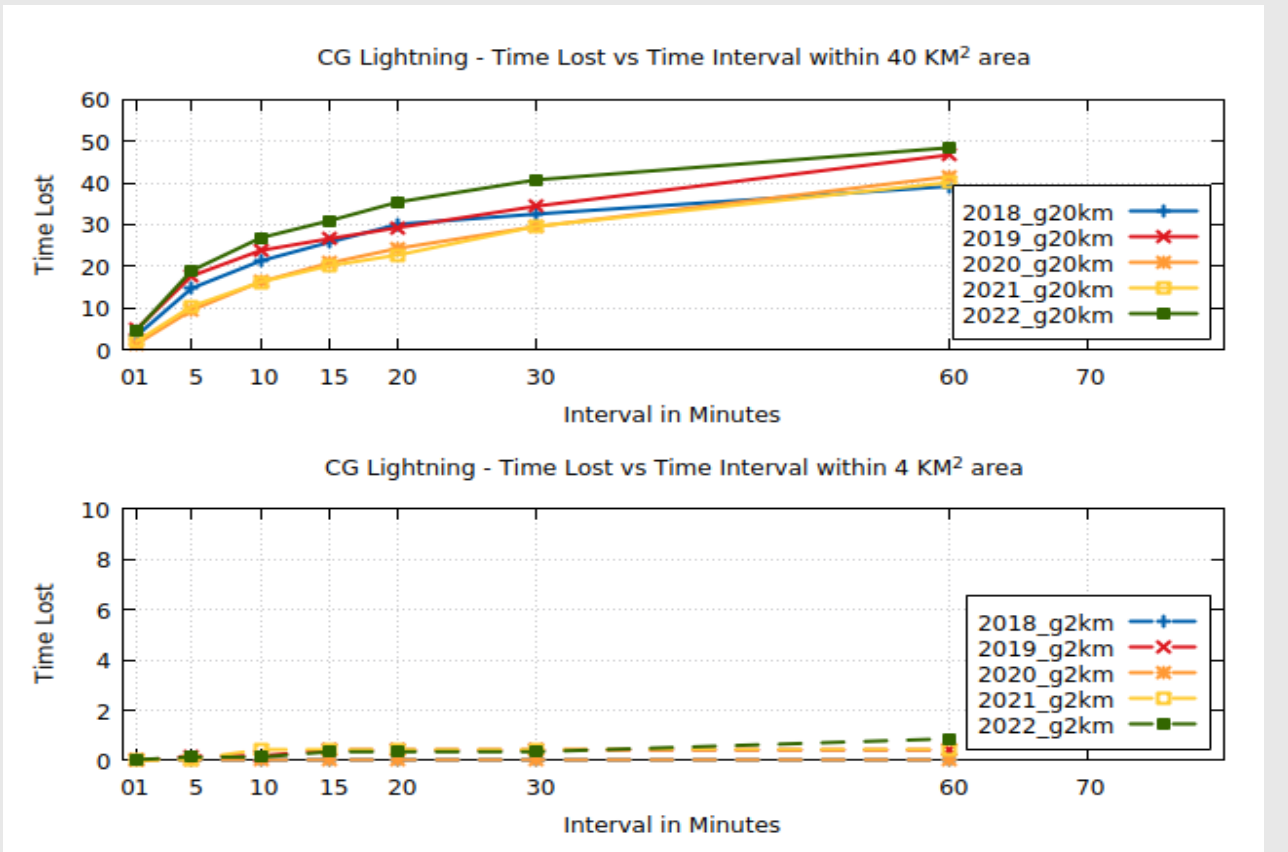

Figure 1-D (4 x 4 and 40x 40 KM-sq area, CG Only) :Total Time Lost in Hours for the Given Time interval (ΔT) of Consecutive 'CG' Lightning Detection

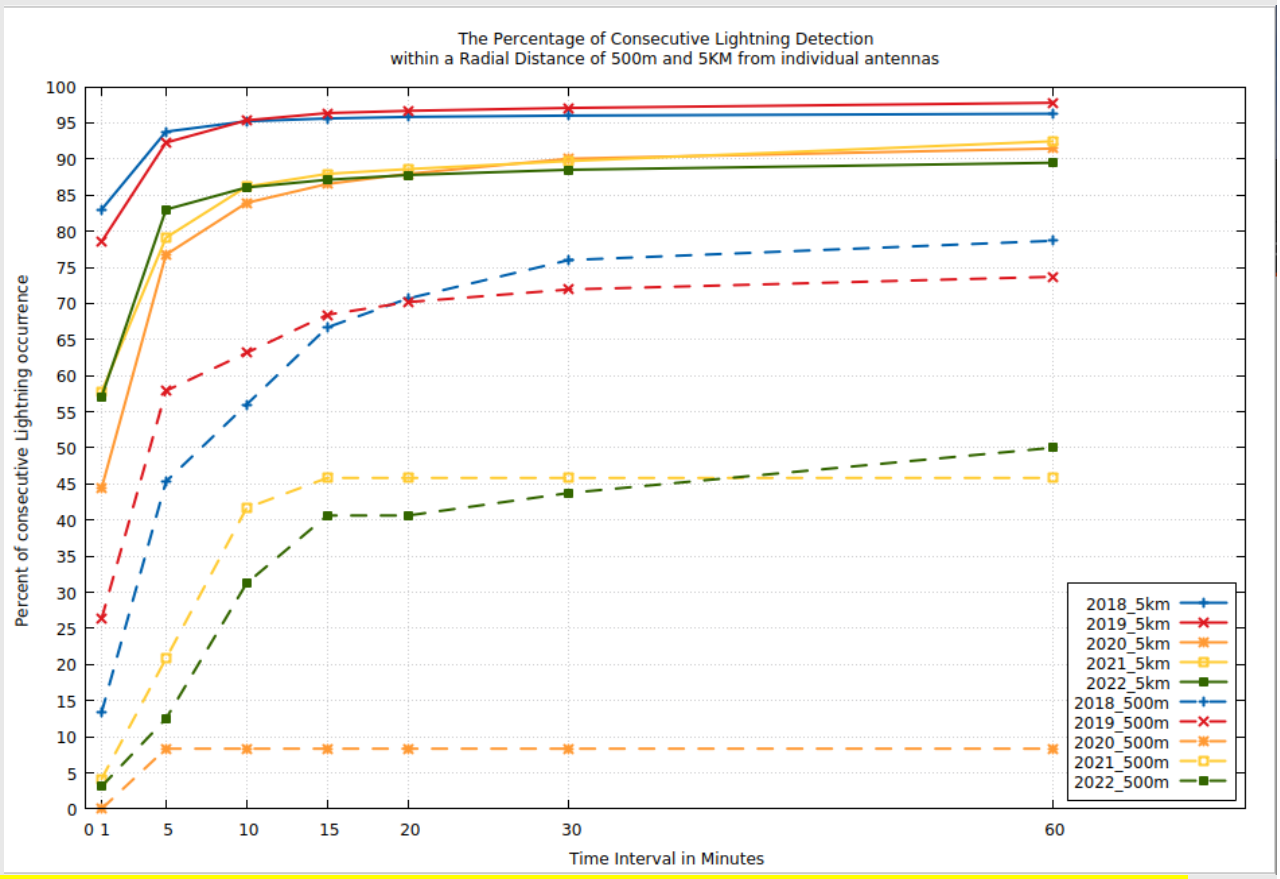

Figure 1-E (500 m and 5 Km Radial distance) : The percentage of Consecutive Lightning detection of total Lightning for a given time Interval (ΔT)

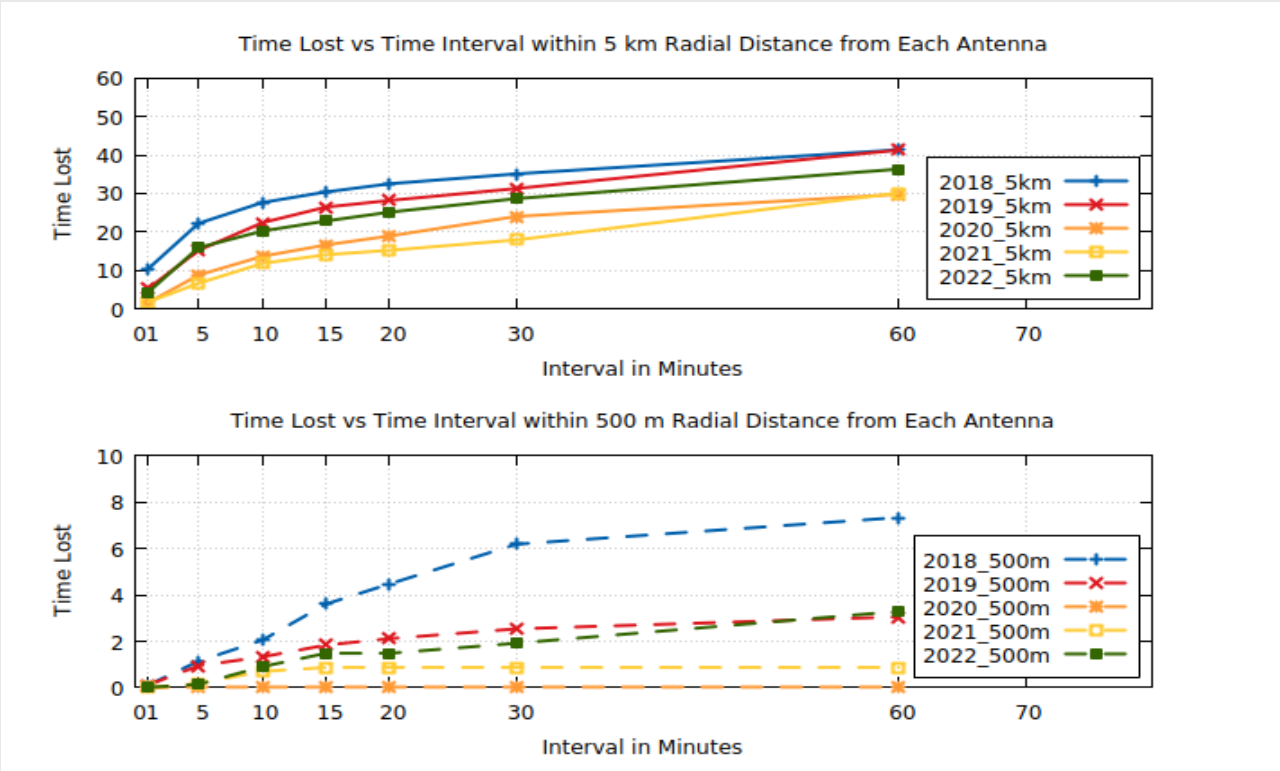

Figure 1-F (500 m and 5 Km Radial Distance) : Total Time Lost in Hours for the Given Time interval (ΔT) of Consecutive Lightning Detection

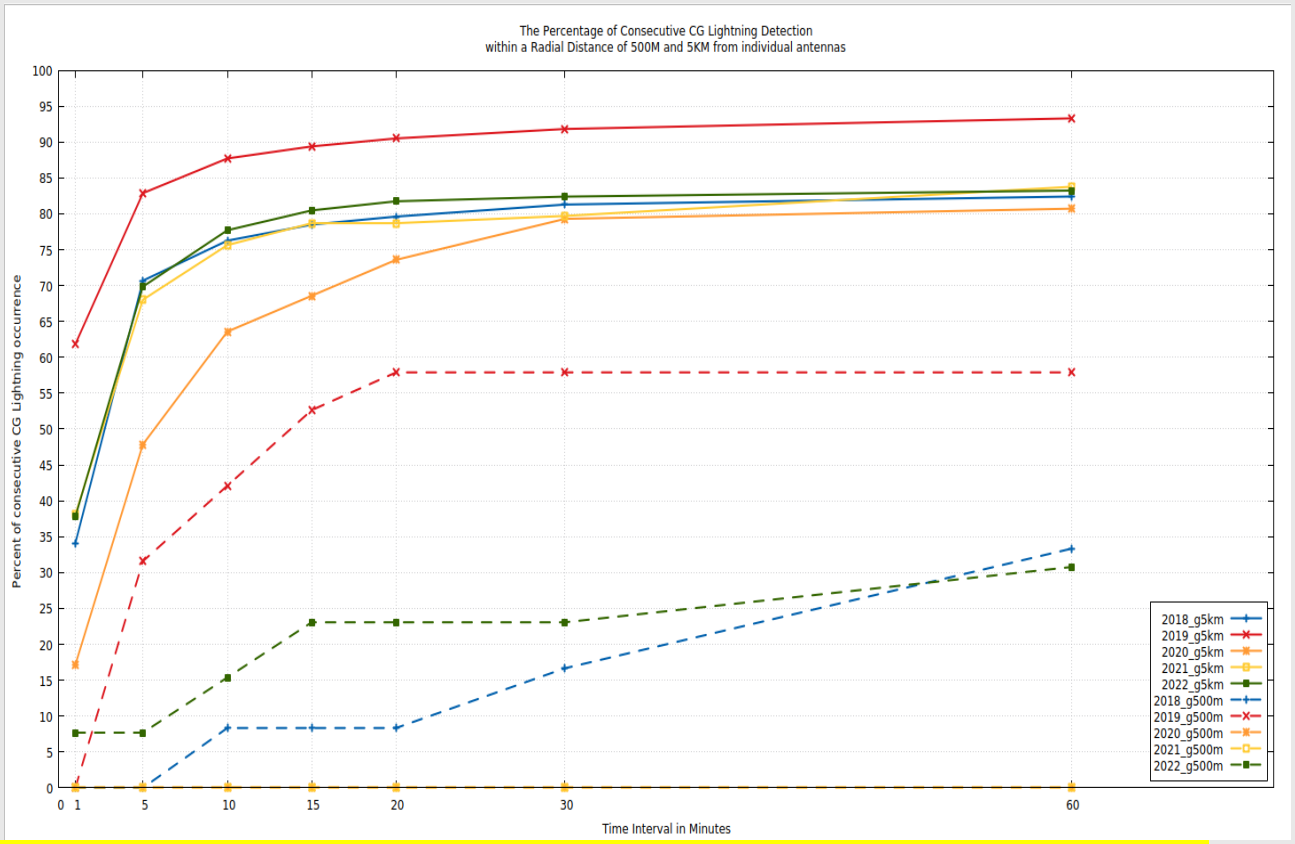

Figure 1-G (500 m and 5 KM Radial Distance, CG Only) : The percentage of Consecutive Lightning detection of total Lightning 'CG' for a given time Interval (ΔT)

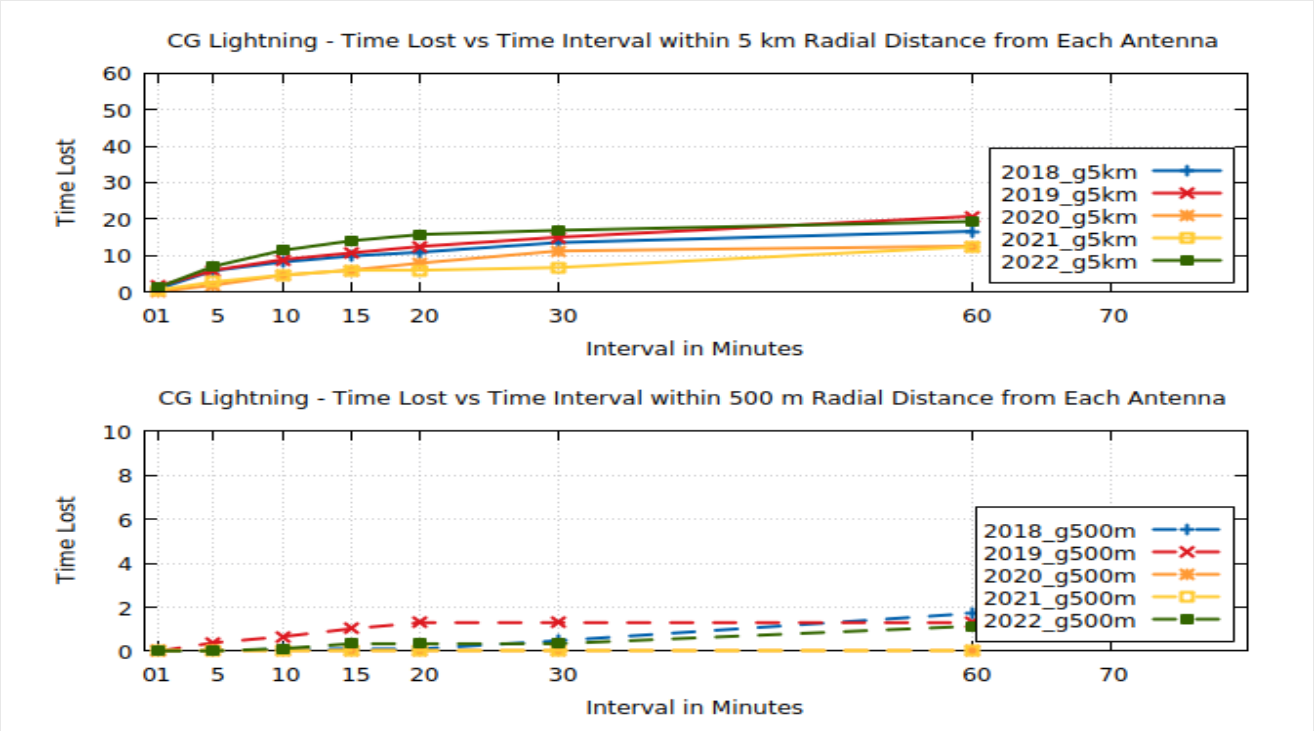

Figure 1-H (500m and 5 KM Radial Distance, 'CG' only) : Total Time Lost in Hours for the Given Time interval (ΔT) of Consecutive Lightning 'CG' Detection

All resultant parameters and optimized solutions for each data set are tabulated in Table-1 given below.

It is found from data sets of "***40 x 40 km square area***" and "***within a 5 km Radial distance of individual GMRT antennas***" that on an average ***85 to 98 %*** of lightning is detected year-wise for a maximum selected Lightning sampling interval of 1 hour. If we considered the ***CG*** Lightning only for both the data sets, then ***80 to 85 %*** lightning is detected for the radial distance of 5 km, and ***85 to 95 %*** of lightning detected within 40 x 40 km square area.

Table-1 : Result optimized solutions for Maximum Lightning detection and Time Lost

Lightning Data set (Area / Radial Distance in km)	Lightning Type	Maximum % of Lightning Detection Range in 1 hours	(% of detection at 1 hrs) – (% of detection at the 'optimum time')		Time Lost in Hrs
			Optimum Time (Minutes)	Difference in Detection Range in %	
40 x 40 KM-sq area	Total	90 to 98	15	5	**48.8**
	CG	85 to 95	15 to 20	5	**26.62**
5 km Radial	Total	85 to 97	15	5	**22.11**
	CG	80 to 85	15 to 20	5	**10.3**
4 x 4 KM-sq area	Total	60 to 83	20	5 to 13	**1.28**
	CG	43 to 50	15	5 to 8	**0.23**
0.5 km Radial	Total	40 to 45	15	5 to 10	**1.56**
	CG	30 to 35	20 to 30	5 to 25	**0.38**

Thus, considering the detection range from 5 to 10 % of the maximum percentage of lightning detected at 1 hours of selected sampling interval, in all cases the optimum time for selected sampling interval ***(ΔT)*** *is converging to ~15 minutes (Refer* ***Figure 1 A to H****, and* ***Table-1****) . Other sampling time intervals less than the optimum sampling time interval of 15 minute show less percentage of detection, and sampling time greater than optimum sampling time interval do not significantly change in detection percentage.*
As compared to 40 x 40 km-square area, ***5 km Radial distance*** *from individual antennas seems to be preferred option because the operation time-lost of the observatory for total lightning detection is* ***22.11 hrs*** *which is less than half of value* ***48.8 hrs*** *with respect to* ***40 x 40 km square area****.* The total lightning shall be considered instead of CG lightning only because electric charges in the atmosphere causing the Intra-cloud lightning may cause the CG lightning by helping to build a steped leader process for the lightning (Stepped leaders are negative charged tend to branch out as they seek a connection with the positive charge on the ground and typical length is of 50 meter).

- ***Therefore, for the lightning warning and alarm tool, the 15 minutes of sampling time interval for the consecutive lightning detection with a radial distance of 5 km from individual GMRT antennas seems to be a optimum solution for detection and prediction of successive lightning.***
- It can be noted from the ***Table-1*** that overall percentage of maximum lightning detection for 4 x 4 km-sq area or 0.5 km radial distance from individual antennas is reduces to less than 83 % (40 to 83 percentage) in case of total lightning, and 30 to 35 % in case of the CG only, hence these options are not considered for the optimum solution.
- It is worth to note that even if 40 x 40 km-square area is consider to improve the successive lightning prediction estimation for warning and alarming, the total lost-time of operation for the observatory is around 48 hrs (~2 days only) in a given year.

2.2 Number of Lightning days in a year :

Over 2018 to 2022 years where lightning statistics may vary per year, it is worth to know on an average how many days per year the lightning strike occurring in the 16 – 1600 km-square area (*centered at C03, within of ~ 4 x 4 , ~40 x 40 km-sq*). The number of days for occurrence of lightning strikes are also calculated for the radial distance of 500 meter and 5 km from the individual GMRT antennas. This information is useful to estimate the possible number of days in which observing session can be affected.

The **Figure 2-A and 2-B** show the total Lightning days per year which includes (IC+CG), and separate cloud to ground lightning total days as well.

Table 2 : Average number of days of lightning occurrence

Lightning Type	Avg. days of Lightning strikes in a Square area		Avg. days of Lightning strikes in Radial distance from each GMRT antenna	
	40 x 40 Km^2	4 x 4 Km^2	5 Km	500 meter
Total (IC+CG)	50	10	34	12
CG only	39	4	24	6

Table-2 *shows averaged number of days of lightning strikes over a five years. It can be observed that the total lightning strikes in a given year can be 50 days for 40 x 40 Km^2 area and 34 days for 5 km radial distance. In both the cases the CG lightning is less than ~10 days of the total lightning occurrence days.*
For the 4 x 4 Km^2 area and 500 meter radial distance from individual antennas, the total lightning and CG do not show much difference because 500 meter radial distance from the individual GMRT antenna mostly the same area comparatively for the central-square. And in sparsely located arm antennae, lightning strikes chances are rare within a 500 meter.

2.3 Intra-cloud (IC) to Cloud to ground (CG) Lightning Ratio per Year :

Although there is not a direct relationship between intra-cloud lightning and cloud to ground lightning in-spite of both products of the same atmospheric processes within a thunderstorm, the presence of intra-cloud lightning can be indicative of the storm's intensity and the potential for more severe weather, including cloud to ground lightning strikes.

Thus, in highly electrified storms with frequent intra-cloud lightning, the possibility of cloud to ground strikes may increase simply because there is more electrical activity overall. The **Figure 3** shows ***the Cloud to Ground (CG) lightning occurrence ratio per year which vary from few percentage (10 %) to maximum 30 % on an average for the lightning that occurred within a 40 x 40 KM-square area*** (or 20 KM distance from the C03 antenna). And for the central-square area of the GMRT, the CG lightning ratio is varying nearly 30 % up to maximum 50 % occasionally.

It can be noted from the **Figure-3** that ***the total lightning strikes count varies randomly per year ranging from ~ 2126 to 10755, no significant common average of lightning per year can be predicted. The ~ 10 to 30 % CG Lightning as compared to the IC Lightning corroborate the standard ratio of CG to IC of ~25 % Lightning in General as per the literature.***

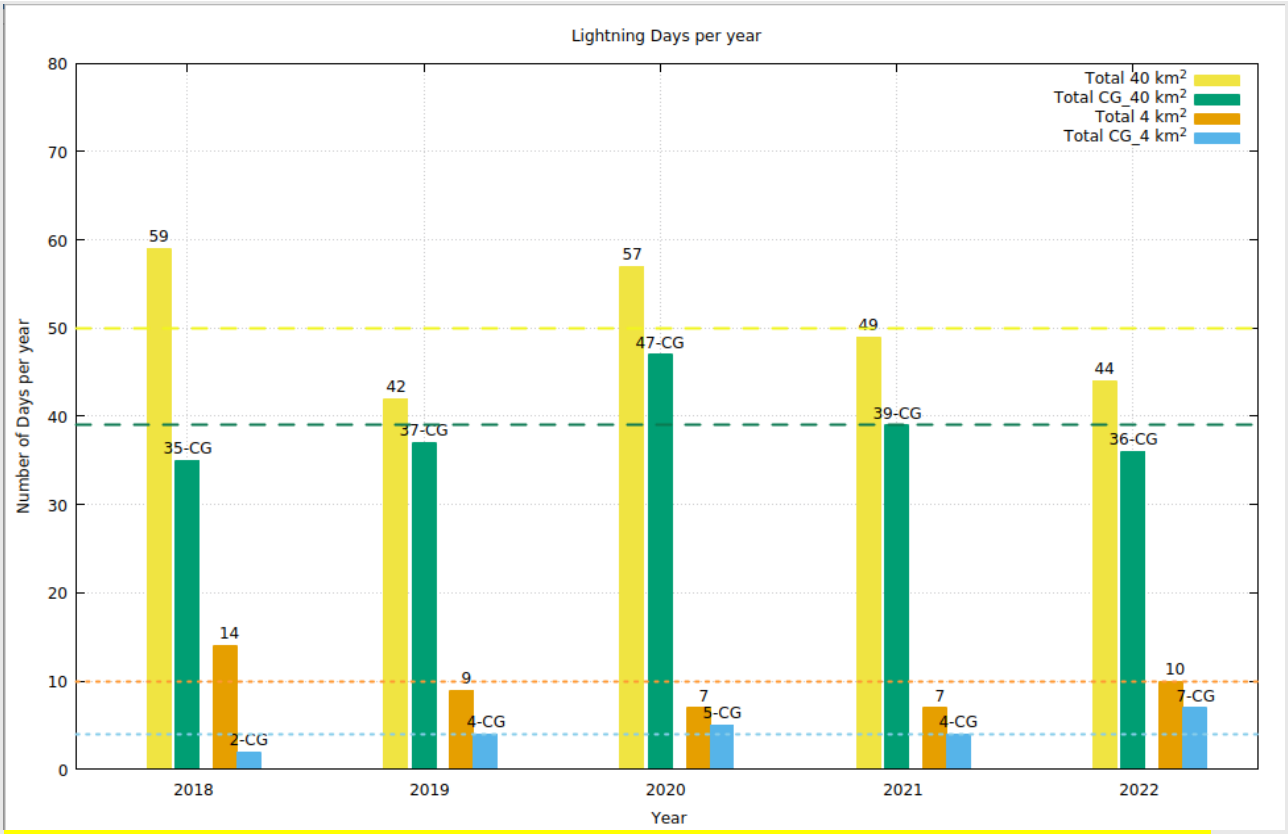

Figure 2-A (4 x 4 and 40 x 40 Km-sq area) : Lightning strikes total (IC+GC) and GC only occurrence days per year

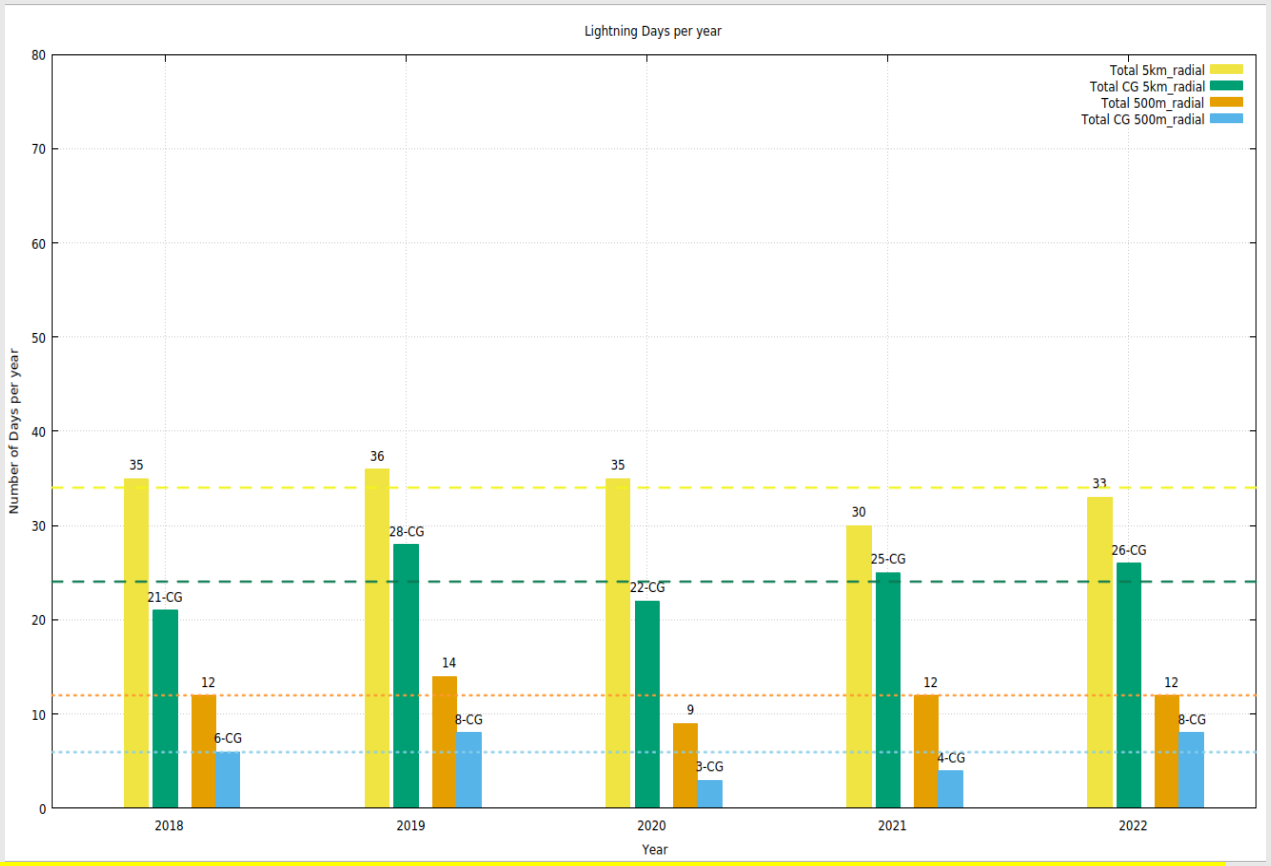

Figure 2-B (0.5 and 5 km Radial distance) : Lightning strikes total (IC+GC) and GC only occurrence days per year

2.4 Maximum Intensity of the Cloud to Ground (CG) Lightning :

Thunderstorms have very turbulent environment where strong updrafts (upper air-current) transport small liquid water droplets from the lower regions of storms to heights between ~10 to 20 km. And downdrafts transport heavy ice, hail from the frozen upper regions of the storm. The friction between water droplets and ice-particles keep outer part of the ice and hail slightly warmer which is called "soft hail" or "***graupel***" forms. When *graupel* collides with additional water droplets and ice, particles electrons are sheared off of the ascending particles and get collected on the descending particles. Because electrons carry a negative charge, the result is a storm cloud with a negatively charged at a base and a positively charged at the top. Thus ***negative lightning*** is the transfer of negative charges from the cloud to ground and typically comes from lightning formed at the base of the cloud. Whereas ***Positive lightning*** originates in the upper parts of the cloud (*cirrus anvil*) or from outer edges of cloud and is the transfer of positive charges to the ground.

Since positive lightning originates in the upper levels of a storm, the amount of air it must burn through to reach the ground is usually much greater. Therefore, electric fields associated with positive Cloud-to-Ground (CG) strikes are typically much stronger than those associated with negative strikes. The flash duration is also longer, with peak charge and potential up to ten times greater than negative CG strikes, as much as ~**300 K Amp** and **one billion volts**![8] The positive lightning can strike more than 10 miles away from a storm. Positive lightning makes up less than 5% of all strikes. The positive lightning may cause greater damage than negative lightning like power line damage, receiver-system electronics at the antenna-base, and even fires in the forest.

Therefore, a statistics of negative and positive lightning is significant in terms of knowing its average intensity from the last five years available data. **Figure 4-A** shows the maximum intensity of positive and negative lightning occurrence per day from 2018 to 2022 years within a 40 x 40 KM

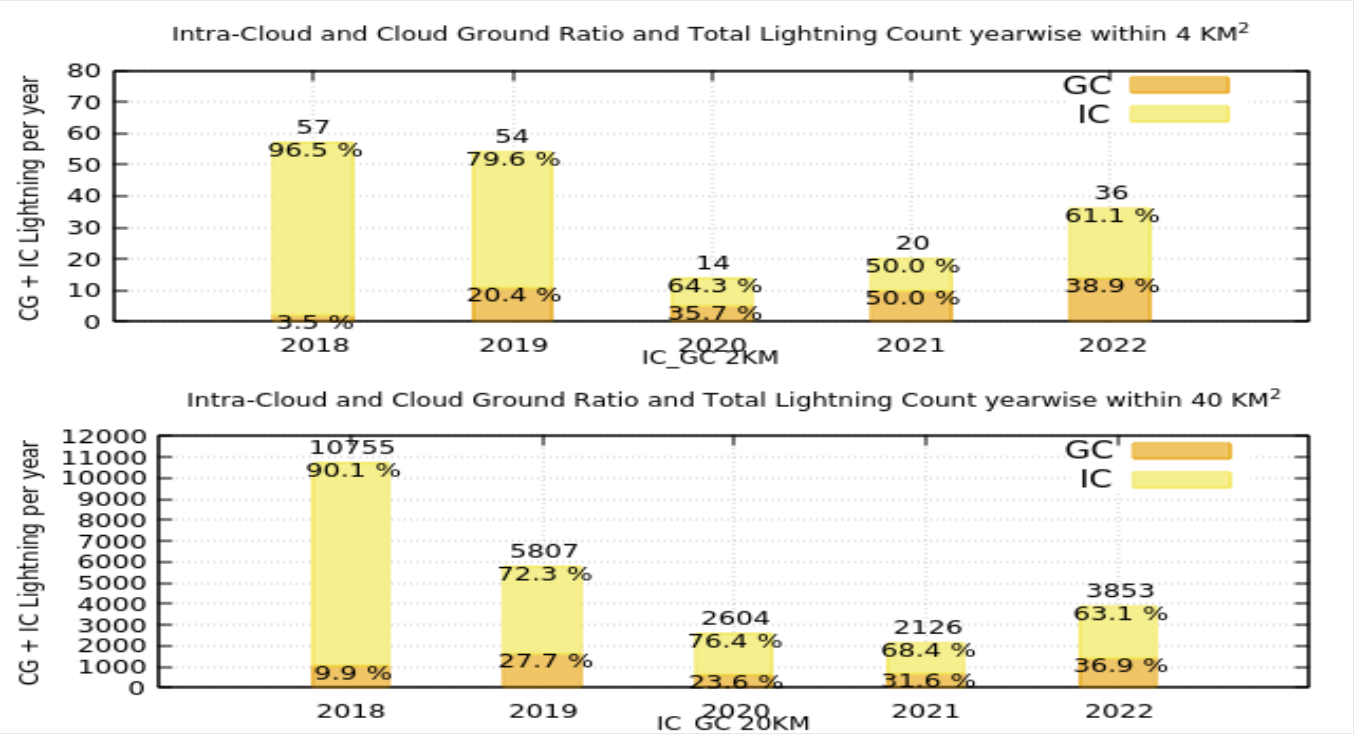

Figure 3 : Intra-cloud and Cloud to ground ratio for 2018 to 2022 Years

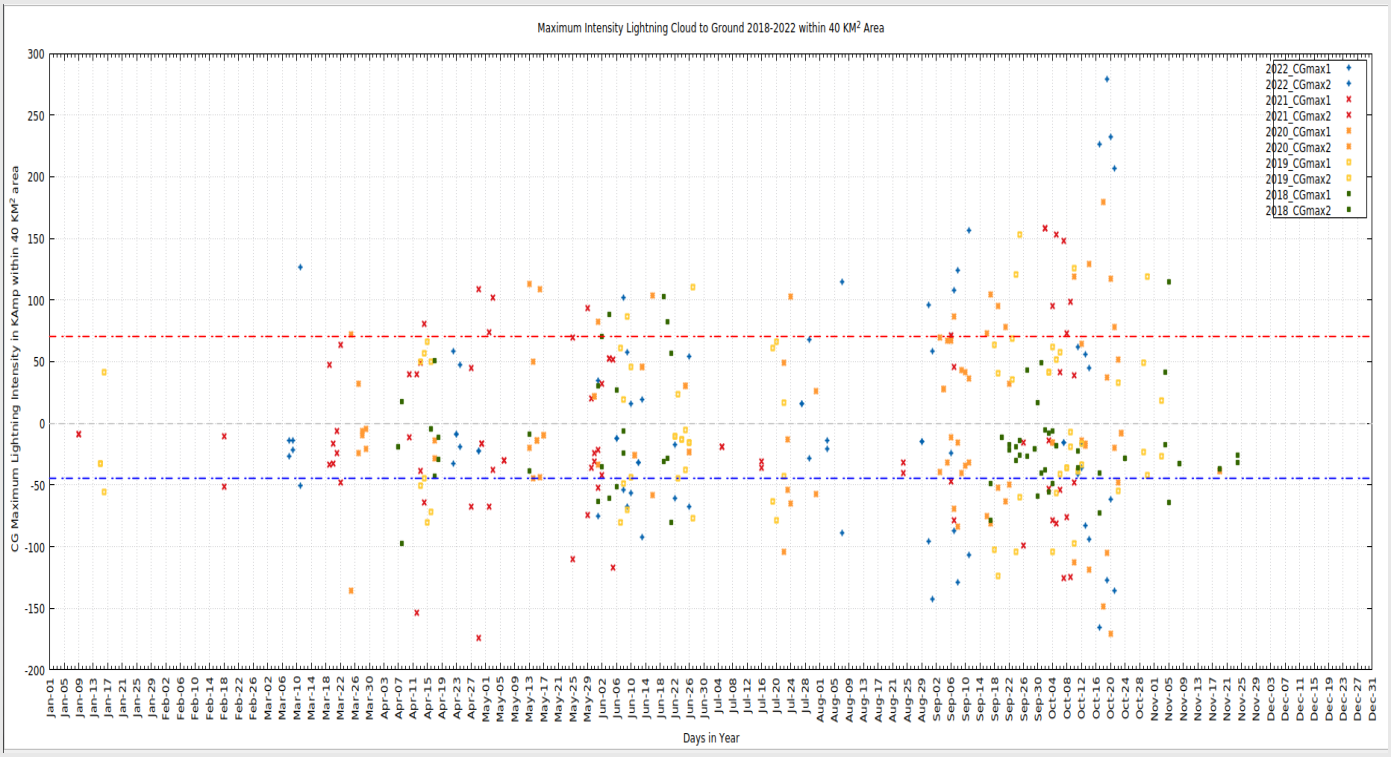

Figure 4-A : Maximum lightning intensity CG occurrence per day for years from 2018 to 2022 in 40 x 40 KM-square area of the GMRT

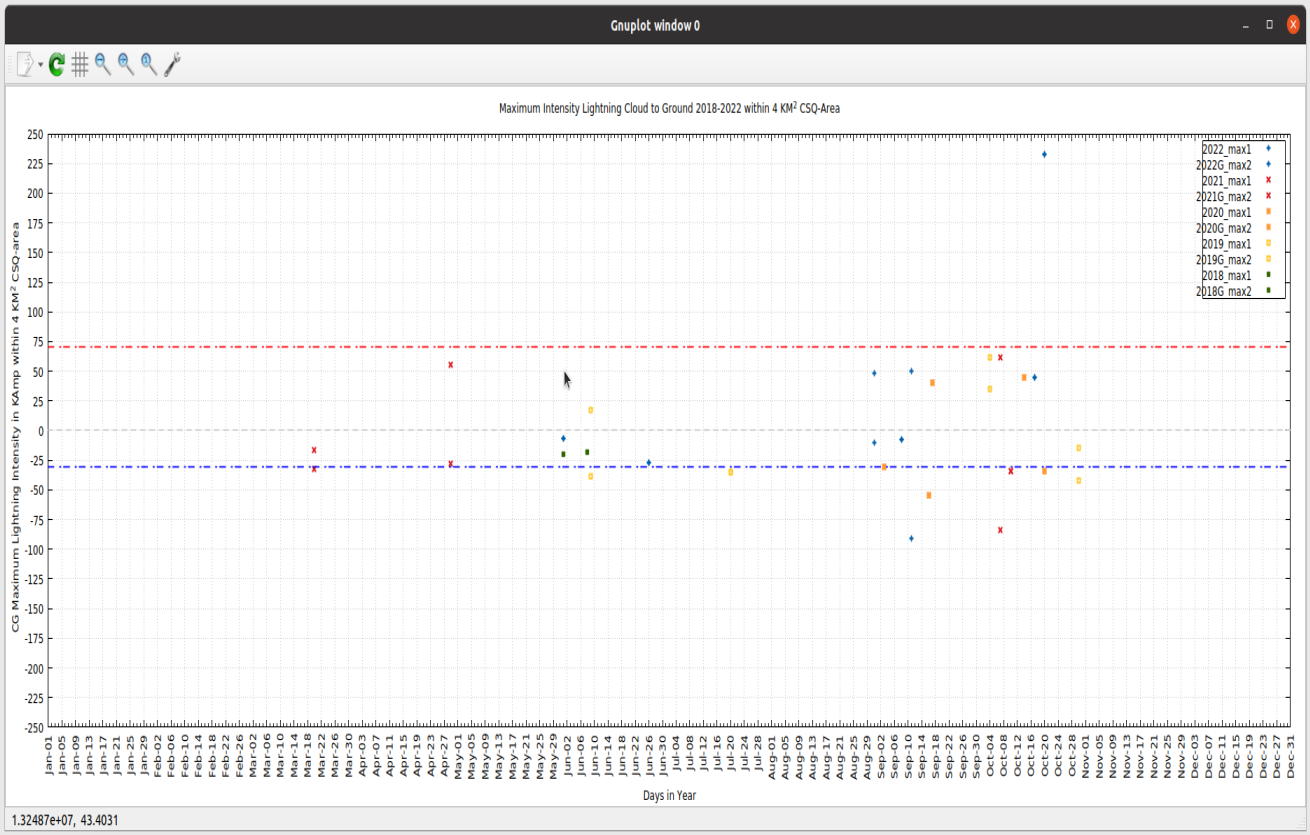

Figure 4-B : Maximum lightning intensity occurrence per day for central-square (4 x 4 km-sq area) from 2018 to 2022 years

-square area of the GMRT. Similarly **Figure 4-B** shows the maximum intensity of lightning for years from 2018 to 2022 within 40 x 40 KM-sq area.

Figure 4-A and **4-B** show that typically positive lightning intensity is more (**average +70 K amp**) as compared to negative lightning intensity which is around **- 44 K Amp.** A**lso, Figure 4 show that CG lightning intensity is more in retreating Monsoon in mid-Sep and October months every year.** Maximum positive intensity is noticed around *+232 K Amp* in central-square on Oct 20th, 2022 (where four to five antennas problems associated with temperature system and SSB box occurred), and ~ *+255 K Amp* in arm antenna areas. Hence the lightning data corroborate with the available theories of positive and negative lightning in terms of intensity.

3. GMRT ANTENNA PROBLEMS DUE TO THE LIGHTNING INCIDENTS :

The existing GMRT Lightning arrester system has been working reliably since the last ~20 years or so. However, due to the dual-ring structure of upgraded **BAND-2** feed in the vicinity of GMRT Antenna arresters may be inducing the lightning current. Hence, GMRT antennas are affected due to the lightning thunder storm mostly when Band-2 is focused towards the sky i.e. Band-3 feed (325 Mhz) is at the focus towards dish.

Using the IITM lightning data from ***2018 to 2022*** years (*recently, new data feed provided by the IITM in April 2024*), the data of CG (Cloud to ground lightning strike) flash occurrence within a 400 Meter radial distance of the GMRT Antennas are extracted. And this data is correlated with the GMRT antenna problems noted during the lightning time in the call-sheet database. Also, callsheet-data base checked for the next day of lightning occurrence as well because problem may not have observed on the same day such as the poor RF-signals or Feed not rotating. Although CG data is taken for the reference, but total lightning count (IC + CG) also noted per day (refer to ***Figures 5-A to E)*** from 2018 to 2022 so that the common problems occurrence due to the lightning can be verified. To corroborate the lightning strike occurrence within a 400 meter radial distance for individual antenna, a Latitude Vs Longitude Map also shown for the central-square antennas with CG Lightning strikes in **Appendix-I** ***Figure 6 - A to E***.

From the IITM Lighting data and correlation with the antenna problems noted in the call-sheets are described in **Table -3** , a few prominent conclusions are as follows :

(i) Even though CG Lightning noticed near arm antennas, less problems are seen with the Arm antennas and no common problem occurrence among the antennas except Arm antennas Electrical power (MSEB) is disturbed. It has seen that arm antennas are less affecting .

(ii) Central-square and Arm antennas are most probably affected whenever Band-3 feed is at focus and Band-2 (150 MHz) dual ring structure feed is directed towards sky (Sep 2022, Apr 2024).

(iii) Although the mean CG Lightning occurrence is around ~ 4 to 7 days per year. Sometimes IC Lightning can also affect in the central square antennas due to close spacing. Also, even if the Band-5 and Band-4 feeds are in focus and Band-3 and Band-2 feeds are in horizontally positioned, central-square antennas can be affected (refer to the Data of April 2024 in **Table – 1**).

3.1 Common Problem occurrence due to the Lightning Thunder storm & Rainy days :

Common problems occurring during the lightning thunder storms and rainy days are noted based on call-sheet database which are as follows :

- **ELECTRICAL :**

During the Thunder storms and heavy lightning there is a possibility of high voltage fluctuations, and 11/33 KV Power failure due breaker trip because of the earth fault (E/F) or over current (O/C).

(i) Problems occurred mainly due to the lightning are :
(a) Vacuum circuit breaker (***VCB***) vacuum bottle failed during the heaving lightning and raining has been seen (Y ph pin insulator failed, conductor rested on cross arm etc).
(b) Due to high voltage fluctuations – Individual antenna's AC stabilizer control-card faulty (cut out PCB card failed, Control fuses blown, voltage monitoring relay, R/Y/B Phase control-card found faulty etc) causes the antenna-base power failure.
AC stabilizer and control-card related problems are seen in a group of antennas after heavy lightning in a four to five incidents.

(ii) Due to high voltage fluctuations during the lightning thunder storms , four to five incidents of Diesel Generator (DG) power not starting or MSEB Power not restoring because of DG running is continued has been seen because GEN-set controller problem, DO Fuse transformer blown off.

(iii) Due to high windy conditions, lightning and rainy seasons many times Arm antennas 11 KV line breaker tripped due to the R/Y/B phase over current (O/C) problem or Earth fault (E/F). Six to seven times breaker tripped problem have been seen.

- **SERVO :**

(i) Three times problems related to AZ Encoder card found faulty have been seen.
(ii) Three times problem related to MCB tripped (Feed not rotating) .
(iii) Due to the lightning Encoder-Transceiver gone bad (Feed Jammed).
(iv) Remote reset circuit stopped functioning. Problems in SSI – Control rack console panel EL switch not responding. BLDC Reset cct. Bypassed. Problem found in SSI. It was applying cage. so we replaced the SSI bin.

- **FECB :**

(i) April 2024 : RF is not getting set to Band2 for all central square antennas except C00. -
Replace Band-2 FE Boxes for all CSQ antennas.
(ii)Sep 2022 : ATF-54143 of LNA Gone bad for Channel-1/2 : C-00, 01, 02, 04, 05, 06, 08, 09, 10, 11, 12, 13, 14, W-01,02, 03, 04, 05, 06, and E-03,05 C02 more damaged - 7805 burned, RF SW gone bad.

- **TGC/Telemetry system :**

In two incidents, smoke/fire interlock unit or temperature monitoring unit gone bad for many central square antennas.

Table 3 : **GMRT Antenna problems noted in a call-sheet database during the Lightning period using the IITM Data**

#	IITM feed Lightning Data				Strike Near Antenna (Radial Distance =400 m)	Feed at Focus	Antenna/ Power-Line affected	**Call-sheet No. :** Problem Description
	Date Time YYYY-MM-DD HH:MM:SS	**Location (Degree) Lat Long**	**CG= 0 IC= 1**	**Intensity**				
2018								
1	2018-06-20 16:29:40	19.1112 74.09637	0	-8.55	E03	**Band-4**	-	No Problem observed
2	2018-06-20 16:52:00	19.1215 74.002	0	-10.53	W03	**Band-4**	-	No Problem observed
3	2018-06-21 13:33:48	19.134 74.16717	0	-25.289	E06	**Band-4**	-	No Problem observed
4	2018-11-05 00:57:02	19.0521 74.05017	0	-17.617	S02	**Band-4**	-	No Problem observed
2019								
5	2019-06-07 18:35:20 to 2019-06-07 20:23:16	**Total CG Lightning 109**	0	-	Arm Area	**Band-5**	**E03**	**2019.0967 :** Stow MCB was tripped.
							S, W- arm	**2019.0966 :** 11 KV Breaker tripped on R & Y phase earth fault over-current (at 19:09 S-arm , 19:13 W-arm)
6	2019-06-09 18:56:15	19.1025 74.07840	0	-9.635	**E02***	**Band-5**	**E03**	**2019.991 :** E03 (Band-5 focus) - Stow MCB was tripped.
7	2019-06-09 18:14:28	19.1238 74.14691	0	-39.154	**E05***	**Band-5**	**E06**	**2019.979 :** e06 - DG set not start after the power failure due to Gen-set controller problem.
8	2019-06-09 18:1813	19.0689 74.05493	0	-34.486	S01	**Band-5**	**S01**	**2019.096 :** AC Stabilizer cutout PCB card was failed. Card replaced and AC Unit restored. (Antenna shell Temp high due to AC failed. **2019.0990 :** Reset Cct. To BLDC was faulty. U3, U30 IC was faulty & D7 cable was short (SSI bin both

Table 3 : **GMRT Antenna problems noted in a call-sheet database during the Lightning period using the IITM Data**

#	IITM feed Lightning Data				Strike Near Antenna (Radial Distance =400 m)	Feed at Focus	Antenna/ Power-Line affected	**Call-sheet No. :** Problem Description
	Date Time YYYY-MM-DD HH:MM:SS	**Location (Degree) Lat Long**	**CG= 0 IC= 1**	**Intensity**				
								brakes not releasing).
9	2019-06-09 18:33:59	19.0817 74.04257	0	-18.488	C13	**Band-5**	-	
10	2019-06-09 18:51:51	19.0307 74.05134	0	-19.716	S03*	**Band-5**	**S04**	**2019.0997 :** Due to the lightning Encoder-Transceiver gone bad (Feed Jammed).
11	**2019-06-09**	**Total 268 CG Lightning in Arm and 5 CG in the CSQ**	**0**	**-**	CSQ/Arm	**Band-5**	**W-arm**	**2019.0976 :** 11 KV W-arm breaker tripped on R, Y phase overcurrent due to high wind
							W01	**2019.980 :** w01 - DG set not start after the power failure due to Gen-set controller problem.
12	2019-07-19 17:04:02	19.12508 74.14902	0	-24.514	E05	**Band-5**	**E05**	**2019.1279 :** ABC time out. (ABC Reset given?)
13	2019-07-20 13:56:55	19.03350 74.05676	0	-27.269	S03	**Band-5**	**S03**	**2019.1287** : Diesel Generator is ON: DO fuse of 63KVA transformer was blown off-
14	2019-07-20 14:13:38	19.09484 74.04541	0	-35.29	C04	Band-5	-	
15	2019-07-20 14:22:46	19.16803 73.97021	0	41.688	W05	Band-5	-	
16	2019-07-20 14:33:10	19.13857 73.98146	0	-44.523	W04	Band-5	-	
2020								
17	2020-09-08 14:47:11	19.16524 73.97562	0	-83.79	W05*	**Band-3**	**W-arm**	**2020.1177 :** 2020-09-08 W01 MCM 5 T.O. **2020.1178 :** 2020-09-08 West arm feeder breaker was tripped on temporary fault on R,Y & B phase O/C

Table 3 : **GMRT Antenna problems noted in a call-sheet database during the Lightning period using the IITM Data**

#	IITM feed Lightning Data				Strike Near Antenna (Radial Distance =400 m)	Feed at Focus	Antenna/ Power-Line affected	**Call-sheet No. :** Problem Description
	Date Time YYYY-MM-DD HH:MM:SS	**Location (Degree) Lat Long**	**CG= 0 IC= 1**	**Intensity**				
								(14.47 to 14.52)
18	2020-09-18 16:16:20	19.04876 74.04667	0	-46.47	S02	**Band-3**	-	
2021								
19	2021-10-07 14:29:02	19.10344 74.07453	0	-14.00	E02	Band-4	-	
20	2021-10-07 14:30:21	19.11199 74.09414	0	-23.041	E03	Band-4	-	
21	2021-10-07 19:00:40	19.08084 74.04273	0	61.742	C13*	Band-4	**S-arm**	**2021.1638 :** 11 KV S-arm feeder VCB was tripped on temporary fault (B Phase O/C,E/F) from 18:41 to 18:46 , 18:54 to 19:00 hrs).
2022								
22	2022-09-07 20:53:10	19.12199 74.00208	0	-8.05	W03*	**Band-3**	**W05**	**2022.1317 :** After lightning at 21:02 hrs., there was power glitch and W05 got dnpl flag. Tried soft reset, Hard reset (
23	2022-09-07 21:41:03	19.10876 74.09495	0	53.108	E03	**Band-3**	**E03**	**2022.1318 :** BLDC Rack was off, BLDC Reset cct. Bypassed. Problem found in SSI. It was applying cage. so we replaced the SSI bin. **2022.1322** : AC stabilizer's control card was faulty-
24	2022-09-07 21:47:13	19.11138 74.09733	0	33.232				
25	2022-09-07	**Total : 152 Lightning (CG : 56**	-	-	CSQ+ARM*	**Band-3**	**C11**	**2022.1315 :** MOSFET PIU 6Amp MCB was a trip (Feed not rotating)

Table 3 : **GMRT Antenna problems noted in a call-sheet database during the Lightning period using the IITM Data**

#	IITM feed Lightning Data				Strike Near Antenna (Radial Distance =400 m)	Feed at Focus	Antenna/ Power-Line affected	**Call-sheet No. :** Problem Description
	Date Time YYYY-MM-DD HH:MM:SS	**Location (Degree) Lat Long**	**CG= 0 IC= 1**	**Intensity**				
		in Arm-area). IC=6 in Central Sq.					**C08**	**2022.1320 :** SSI was not responding - The control rack Console panel EL switches were not responding. Power on reset given to control-card.
							S-arm	**2022.1316 :** South arm power failure at 21:02. South Arm 11kv line temporary fault R phase Over current and Earth fault.
26	2022-09-11 18:41:36	19.09344 74.04792	0	-91.151	C03*	**Band-3**	**C09**	**2022.1348 :** C09 Servo AZ brakes not releasing - After lightning & Power failure AZ Encoder card found faulty, replaced card.
27	2022-09-11	**Total CG Lightning : Arm area = 61, CSQ = 7** High intensity strike near C03.	0		CSQ Near C03	**Band-3**	**C02**	**2022.1340 :** Smoke/Fire interlock unit damaged.
							C14	**2022.1342 :** Temperature Monitor unit and Smoke/fire interlock unit damaged.
							C11	**2022.1341 :** MCM-14 Control PIU Faulty
							C05	**2022.1347 :** Remote Reset cct stop functioning
	Total CG Lightning : Arm area = 61, CSQ = 7. Total 17 CALLSHEETS High intensity strike near C03.						**C09**	**2022.1348 :** AZ Encoder card found faulty
							W01	**2022.1350 :** AZ Encoder card gone bad
							W02	**2022.1353 , 1359:** AC Voltage stabilizer R Phase control card faulty. Servo Stabilizer B Phase card found

Table 3 : **GMRT Antenna problems noted in a call-sheet database during the Lightning period using the IITM Data**

#	IITM feed Lightning Data				Strike Near Antenna (Radial Distance =400 m)	Feed at Focus	Antenna/ Power-Line affected	**Call-sheet No. :** Problem Description
	Date Time YYYY-MM-DD HH:MM:SS	**Location (Degree) Lat Long**	**CG= 0 IC= 1**	**Intensity**				
	[2022-09-11 18:29:13 19.08267 74.06413 0 49.771] [2022-09-11 18:36:17 19.08615 74.03515 1 13.377] [2022-09-11 18:41:36 19.09344 74.04792 0 -91.151] ***--- problema Near C03*** [2022-10-17 23:53:56 19.08779 74.05447 0 45.187] [2022-10-20 00:26:59 19.08492 74.04123 0 232.315 *]							faulty
							E,W,S-Arm	**(1) 2022.1343 (18:24:01 – East arm), 2022.1344 (18:28 W, S arm) :** VCB Y Pole vaccum bottle failed during heaving lightning and raining. *E41-Y ph pin insulator failed, conductor rested on cross arm.* **(2) 2022.1355 :** East Arm running on DG Set power even after 11 KV Power restored [On pole E41 – Y Ph pin insulator was failed.
							Central Square	**(1) 2022.1351,1352,1354** : C00, C01, C02,C10,C11,C12,C13,C14,S01 - Electrical Problem : LMC Not pinging. ***Down due to failure control fuses, voltage monitoring relay & AC stabilizer. Restored one by one C.Sq. antennae by electrical team members.*** ***(2) 2022.1345,1346 CMN - 33KV antenna power failure- Antenna T.O. C00, C01, C02, C11, C10,C12,C14, S01 (Temp High). R-phase gone E03, C10. MCM-14 T.O. - c09,c10***
2024								
28	2024-04-16 19:39:09	+19.1255 +074.146	0	-2.854	E05	Band-4	**E05**	**2024.0524 :** feed not focused - Feed gearbox and FPS motor are replaced

Table 3 : **GMRT Antenna problems noted in a call-sheet database during the Lightning period using the IITM Data**

#	IITM feed Lightning Data				Strike Near Antenna (Radial Distance =400 m)	Feed at Focus	Antenna/ Power-Line affected	**Call-sheet No. :** Problem Description
	Date Time YYYY-MM-DD HH:MM:SS	**Location (Degree) Lat Long**	**CG= 0 IC= 1**	**Intensity**				
29	2024-04-16 19:35:09	+19.111 +074.0488	0	-54.52	-	Band-4	**CMN**	**2024.0520 :** CMN - Electrical power failure to all antennas at 19:01 Hrs.
30	2024-04-16 19:35:09	+19.083 +074.0560	0	-35.017	Near CSQ, S01		**CSQ**	**2024.0527 , 0528, 0529 :** RF is not getting set to Band2 for all central square antennas except C00. - Replace Band-2 FE Boxes for all CSQ antennas.

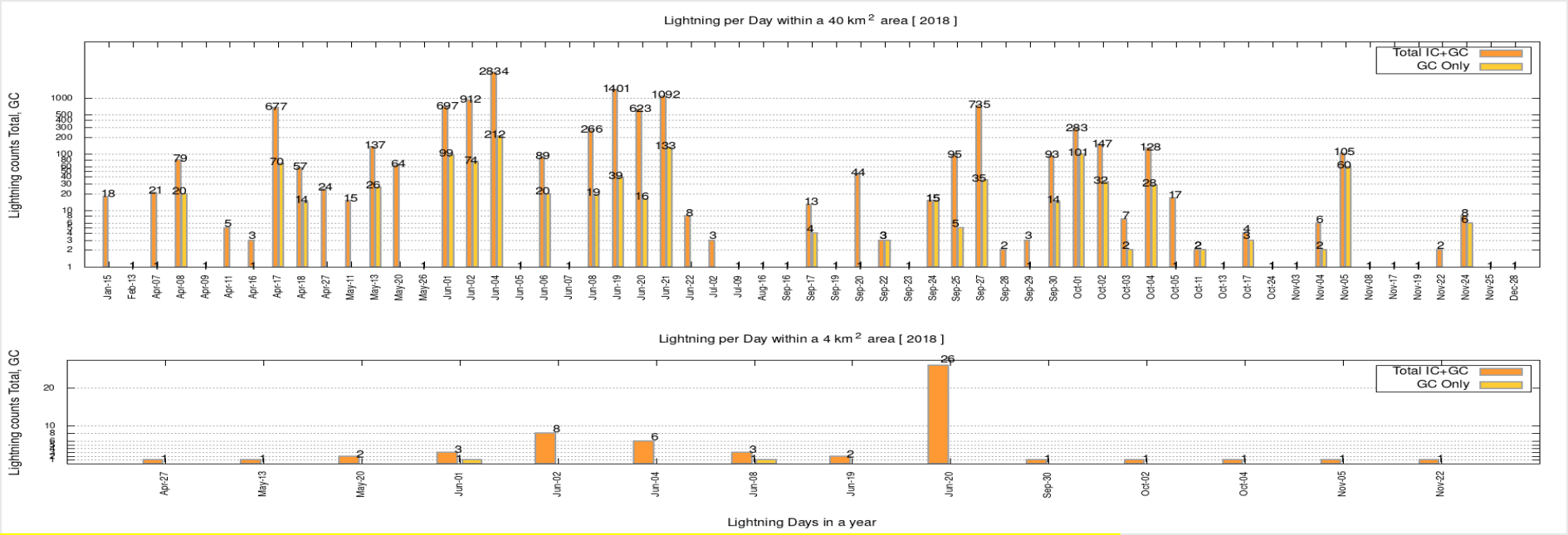

Figure 5 A : Total Lightning (IC+CG) and CG Lightning Per Day 2018, 4 x 4 and 40 x 40 km-square area

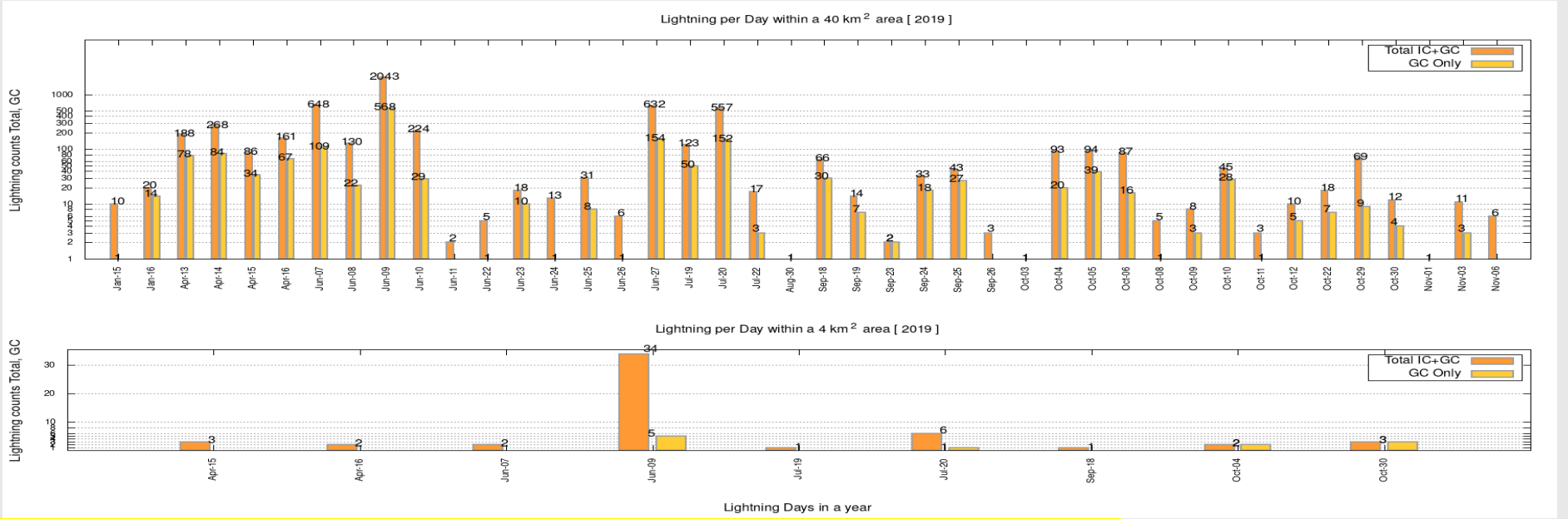

Figure 5 B : Total Lightning (IC+CG) and CG Lightning Per Day 2019, 4 x 4 and 40 x 40 km-square area

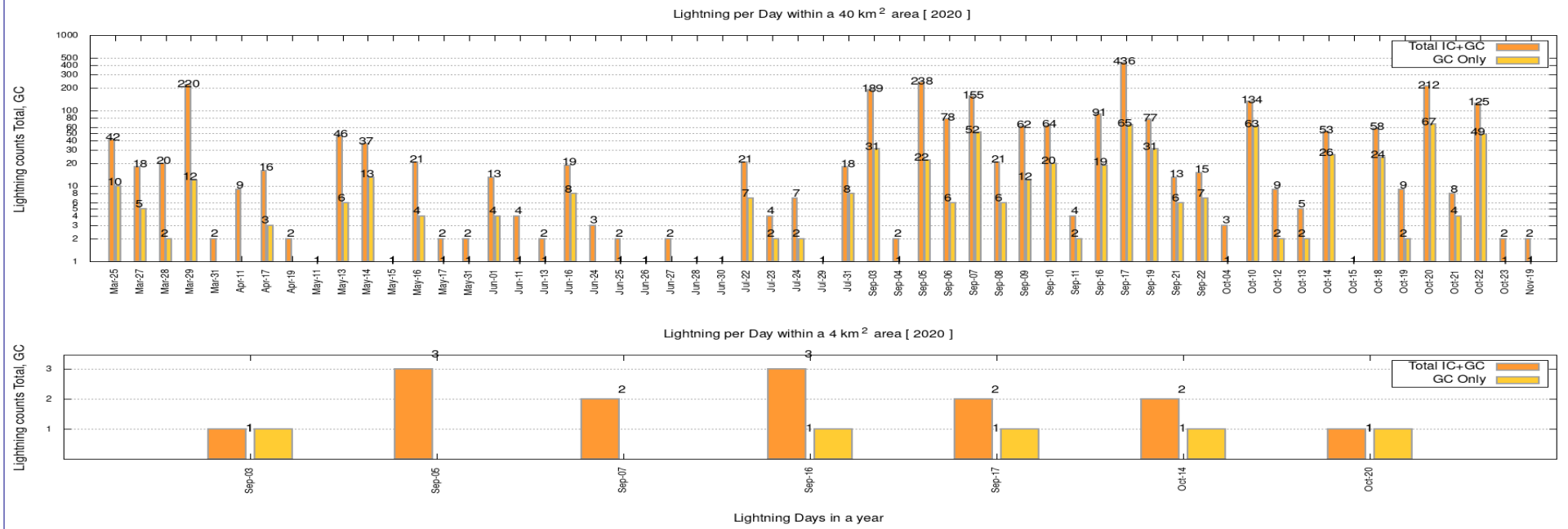

Figure 5 C : Total Lightning (IC+CG) and CG Lightning Per Day 2020, 4 x 4 and 40 x 40 km-square area

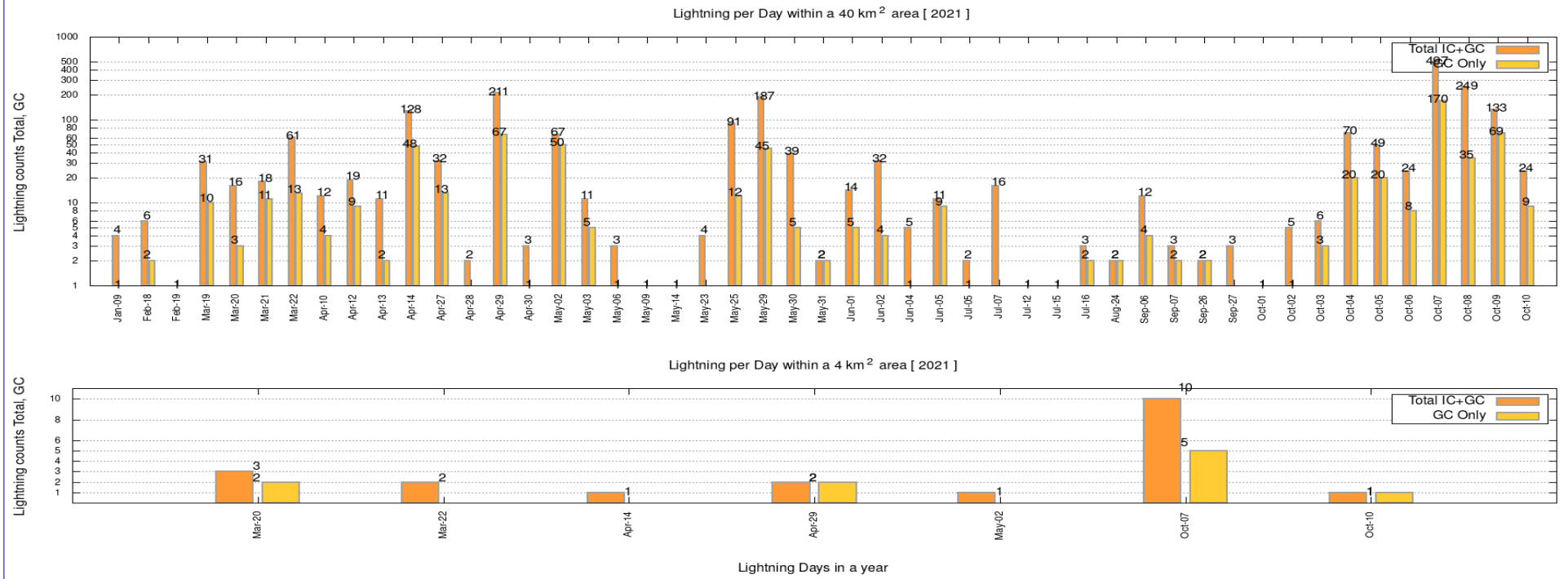

Figure 5 D : Total Lightning (IC+CG) and CG Lightning Per Day 2021, 4 x 4 and 40 x 40 km-square area

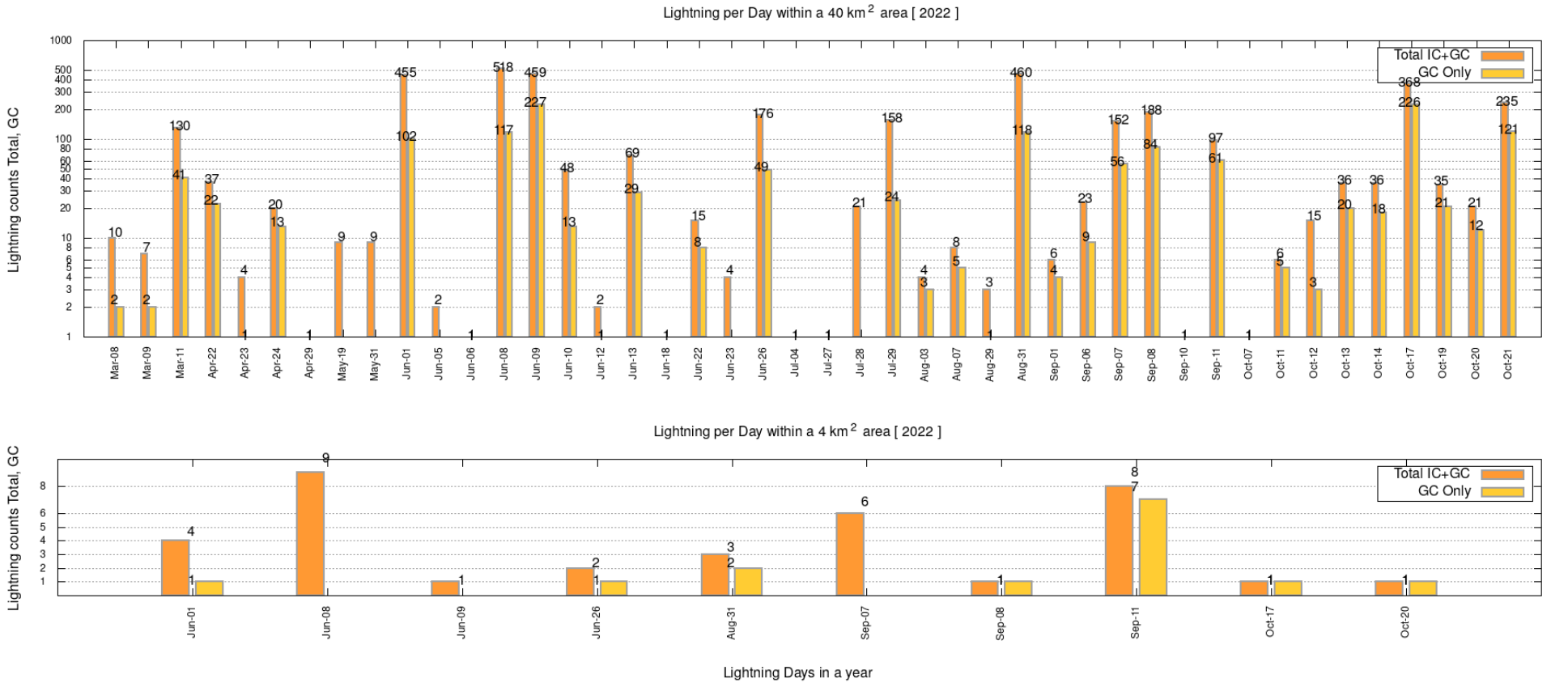

Figure 5 E : Total Lightning (IC+CG) and CG Lightning Per Day 2022, 4 x 4 and 40 x 40 km-square area

5. SUMMARY AND CONCLUSION :

1. Optimum Time interval for successive Lightning and the Time-lost :

To get the optimum sampling time interval (**ΔT)** for the successive lightning (*IC+CG or CG only*) detection, time sampling parameter to detect consecutive lightning occurring within a given **ΔT** is varied from 1, 5, 10, 15, 20 , 30, and 60 minutes. And total consecutive lightning (IC+CG or CG only) occurring with respect to each interval for a given day and then for a complete year is calculated for ***4 x 4 , 40 x 40 Km-square area*** and ***0.5 - 5 km radial distance from the individual GMRT antennas*** . Maximum percent of lightning detected for each interval with respect to the total lightning occurring (*with a continuous time i.e. independent of* ***ΔT*** **)** for each year is calculated.

It is found from data sets of "***40 x 40 km-square area***" and "***within a 5 km Radial distance of individual GMRT antennas***" that on an average ***85 to 98 %*** of lightning is detected over a complete day for a maximum selected Lightning sampling interval (**ΔT)** of ***1 hour***. If we considered the CG Lightning only for both the data sets, then ***80 to 85 %*** lightning is detected for the radial distance of 5 km, and ***85 to 95 %*** of lightning detected within 40 x 40 km square area.

(i) *Considering the detection range from 5 to 10 % of the maximum percentage of lightning detected at 1 hours of selected sampling interval, in all cases the optimum time of sampling interval* ***(ΔT)*** *is converging to* ***~15 minutes*** *in all data sets.* ***(ii)*** *As compared to 40 x 40 km-square area, 5 km Radial distance from individual antennas seems to be preferred option because the operation time-lost of the observatory for total lightning detection is* ***22.11 hrs*** *which is less than half of value with respect to 40 x 40 km-square area.* ***(iii)*** *The total lightning shall be considered instead of CG lightning only because electric charges in the atmosphere causing the Intra-cloud lightning may cause the CG lightning by helping to build a step leader process for the lightning . i.e. the presence of intracloud lightning can be indicative of the storm's intensity and the potential for more severe weather, including cloud-to-ground lightning strikes.*

- ***Therefore, for the lightning warning and alarm tool, the 15 minutes of sampling time interval for the consecutive lightning detection with a radial distance of 5 km from individual GMRT antennas seems to be optimum solution for detection and prediction of successive lightning.***
- It can be noted that the overall percentage of maximum lightning detection for 4 x 4 km sq-area or 0.5 km radial distance from individual antennas is reduces to less than 83 % (*40 to 83 percentage*) in case of total lightning (IC+CG), and 30 to 35 % in case of the CG only, hence these options are not considered for the optimum solution.
- It is worth to note that even if 40 x 40 km-square area is consider to improve the successive lightning prediction estimation for warning and alarming, the total lost-time of operation for the observatory is around average value of 48 hrs (i.e. ~2 days only) in a given year.

2. Number of days per year for Lightning occurrence :

- The Lightning data analysis shows that on an average 50 days of total lightning and 39 days of CG- only lightning can occur in 40 x 40 km-sq area.
- If we considered the radial distance of 5 km from individual antenna, then on an average ~34 days of total lightning and 24 of days CG-only lightning can happened over a year.
- In case of 4 x 4 km sq-area and 500 meter radial distance from each antenna, the lightning occurrence is 10 to 12 days of total lightning, and 4 to 6 days of CG lightning per year.

3. CG to IC Ratio :

- *The Cloud-to-Ground (CG) lightning occurrence ratio with respect to the Intra-cloud (IC) lightning occurrence per year vary from a few percentage (10 %) to maximum 30 % on an average for the lightning that occurred within a 40 x 40 KM-square area*. And for the central-square area of the GMRT, the CG lightning ratio is varying nearly 30 % up to maximum 50 % occasionally. ***The ~ 10 to 30 % CG Lightning as compared to the IC Lightning corroborate the standard ratio of CG to IC of ~25 % Lightning in General as per the literature.***
- ***The total lightning strikes count varies randomly per year ranging from ~ 2126 to 10755, no significant common average of lightning per year can be predicted.***

4. Maximum intensities of the Lightning :

The negative lightning is a transfer of negative charges from the cloud to ground and typically comes from lightning formed at the base of the cloud. Whereas Positive lightning originates in the upper parts of the cloud (cirrus anvil) or from outer edges of cloud and is the transfer of positive charges to the ground.
The lightning data analysis of 2018 to 2022 show that typically positive lightning intensity is more (**average +70 K amp**) as compared to the negative lightning intensity which is around **- 44 K Amp. Also, it is observed from the data that CG lightning intensity is more in retreating Monsoon in mid-Sep and October months every year.** Maximum positive intensity is noticed around *+232 K Amp* in central-square on Oct 20th, 2022, and ~ *+255 K Amp* in arm antenna areas.

5. Conclusions on common GMRT problems due to the lightning :

The CG (Cloud to ground lightning strike) flashes/strikes occurrence within a 400 Meter radial distance of the GMRT Antennas are extracted from the IITM data from 2018 to 2022, and April 2024 (given by the IITM data-feed). And this data is correlated with the GMRT antenna problems noted during the lightning time in the call-sheet database. Conclusions from the lightning data with antenna problems during the lightning as follows :

(i) Even though the CG Lightning noticed near arm antennas, less problems are seen with arm antennas. This is may be because arm antennas are sparsely located in isolation (~2 to 3 km distant apart). No common problems are noticed among the arm antennas except Electrical power (MSEB) is disturbed.
(ii) Central-square and Arm antennas are most probably affected whenever Band-3 feed is at focus and Band-2 (150 MHz) dual ring structure feed is directed towards sky (Data of Sep 2022 and Apr 2024).
(iii) Although the mean CG Lightning occurrence is around ~ 4 to 7 days per year in the central-square. Sometimes, IC Lightning can also affect in the central square antennas due to close spacing.
(iv) Even if the Band-5 and Band-4 feeds are in focus and Band-3 and Band-2 feeds are in horizontally positioned, central-square antennas can be affected (Data of April 2024).

5.1 Proposed Lightning Detection and Alarm tool Criteria :

As per the *National Weather Service* station data, successive lightning flashes/strikes can be 3-4 km distant apart from the old data and 10-13 km distant apart from the new data. And strong positive lightning can occur up to ~16 km from the edge of clouds where potential intra-cloud lightning is

detected which can contribute for the positive lightning. Also, considering the empirical GMRT study of lightning occurrence and antenna problem noticed specific to central-square antenna, we recommend the radial distance of 5 km from the individual GMRT antennas for the lightning detection and warning which covers almost overlapped circular ~ 157 km^2 area for each antenna. The advantage of considering 5 km radial distance from each individual GMRT antenna is also a geographically optimum solution because it can possibly reduce the operation lost-time of the observatory by half of period as compared to overall 40 x 40 km square area.

In all cases ***4 x 4 and 40 x 40 km sq-area*** or ***500 meter to 5 km radial distance*** from the individual GMRT antennas, the optimum time of sampling interval **(ΔT)** is converging to ***~15 minutes*** which can detect 5 to 10 % of the maximum percentage of lightning that is detected at an hour. The optimum value of sampling time interval doesn't change with the total lightning and only CG lightning.

- **Lightning is a complex phenomenon :**

(I) In view of giving warning and risk alarms for the safety of GMRT antenna and it's sub-systems with a conservative approach for the safety first, the warning and alarm tool for the GMRT shall consider total lightning because the presence of intra-cloud lightning can be indicative of the storm's intensity and the potential for more severe weather causing 25 % of cloud-to-ground lightning strikes out of total lightning.
(II) The intensity of consecutive Lightning seems to be a non-linear or unpredictable factor, hence intensity of the Lightning strike shall be omitted while raising the warnings and risk alarms for the GMRT antenna.
(III) The total lightning strikes count varies randomly per year ranging from ~ 2126 to 10755. Hence, no significant common average of lightning per year can be predicted.
(IV) Although the mean CG Lightning occurrence is around ~ 4 to 7 days per year in the central-square. Sometimes, IC Lightning can also affect in the central square antennas due to close spacing. Even if the Band-5 and Band-4 feeds are in focus and Band-3 and Band-2 feeds are horizontally positioned, central-square antennas can be affected (Data of April 2024).
(V) The lightning affecting area from the ***April 2024*** seems to be cover ~ 1 km central-square area where first Arm antennas like W01, S02, and E02 antennas are not affected.

Therefore, for the lightning warning and alarm tool, the 15 minutes of sampling time interval with a radial distance of 5 km from individual GMRT antennas seems to be a optimum solution for detection and prediction of successive lightning.

- ***Discussion in TGC Bi-weekly meeting on Jun 19th 2024 (Wednesday), inputs from Shri Anil Raut and Prof. Ishwara Chandra On Jun 21st, 2024 (Thursday)***

Considering that the lightning is a complex phenomenon, and the Lightning detection, warning and alarm tool shall raise the alarm(s) with a conservative approach of first observatory safety because total time-lost in operation due to the lightning warning and alarms may take only one or two days in a year. Note that with a inductive reasoning based on the IITM lightning data analysis from 2018 to 2022 years, we recommend the following SOP for the audio lightning warning and alarm tool which may need timely changes after implementation of the tool :

Step 1 Warning Alarm : *On the first occurrence of IC lightning is detected within a 5 km radial distance of individual GMRT antennas, the lightning tool will raise a warning alarm only.*

Step-2 Risk Alarm : *If the subsequent consecutive lightning occurring (IC or CG) within a 15 minutes of previous lightning occurrence is detected at the same antenna within a 5 km radial distance then it will raise a* **Risk-Alarm** *to recommend action of rotating Feed to Band-2 and park the antenna.*
If CG Lightning is happening within a 5 km distance as a first occurrence then also Feed will be asked to move to Band-2.

Step-3 System Release for the Operation : *If the consecutive Lightning is not occurring within a next 15 minutes of previous occurrence within a 5 Km of Radial distance of any antenna, then system will declare audio message to release the GMRT telescope to resume in operation.*

- **REFERENCES :**

[1] https://www.weather.gov/safety/lightning-myths *(http://www.noaa.gov)*

[2] National Centre for Earth Science Studies, Ministry of Earth Sciences, Govt. of India https://www.ncess.gov.in/research-groups/atmospheric-science-group/laboratories/lightning-detection-network.html

[3] A comparative study on Lightning Detection Alarm systems : LLN and ATStorm@v3
NCRA internal technical report by Jitendra Kodilkar and Anil Raut (March 2023).

[4]https://www.geeksforgeeks.org/haversine-formula-to-find-distance-between-two-points-on-a-sphere/

[5] http://www.movable-type.co.uk/ Advice, Design and Development - Information Systems & Database-driven Website

APPENDIX – I : Lightning MAPS for the Central Square

FIG 6-A : CSQ Lightning for 2018

FIG 6-B : CSQ Lightning for 2019

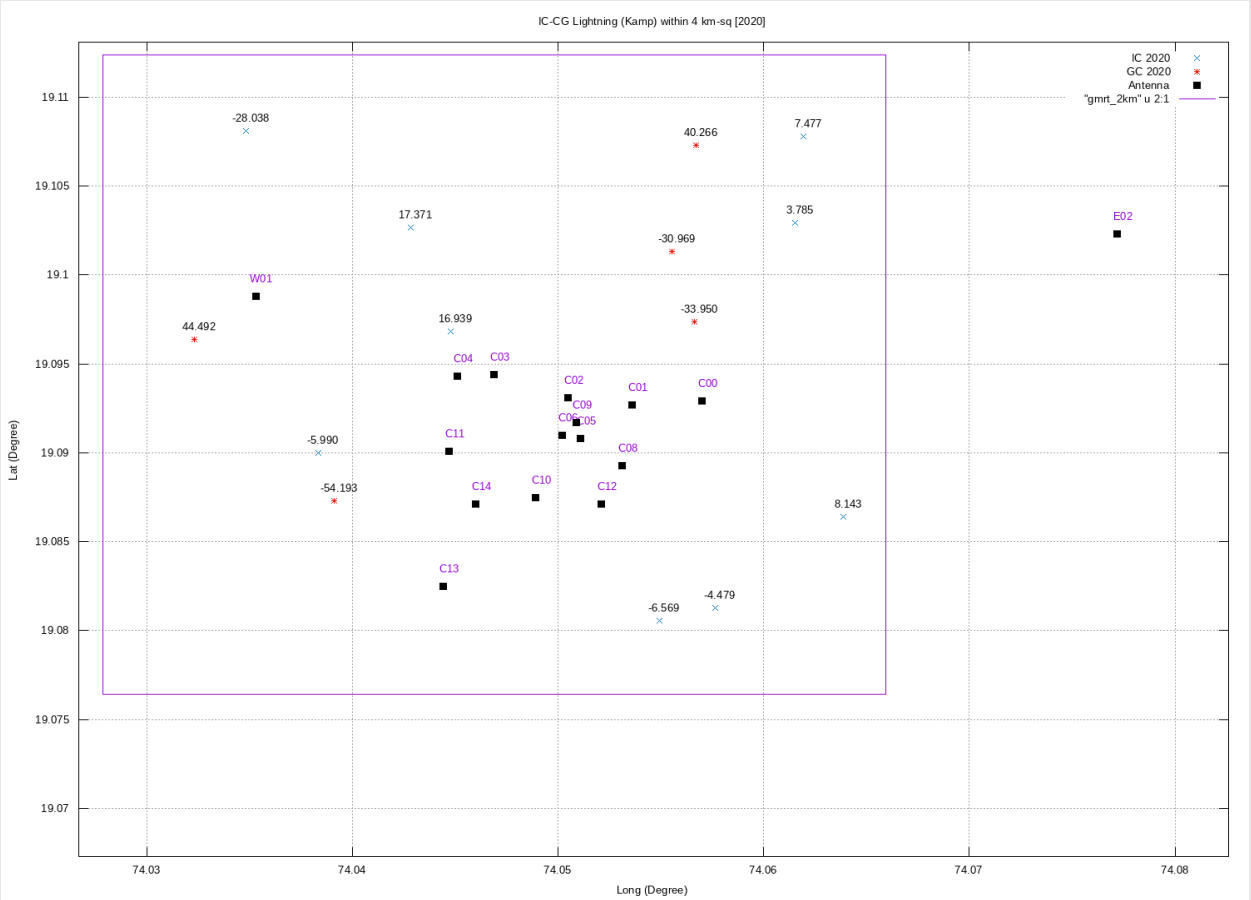

Fig 6-C : CSQ Lightning for 2020

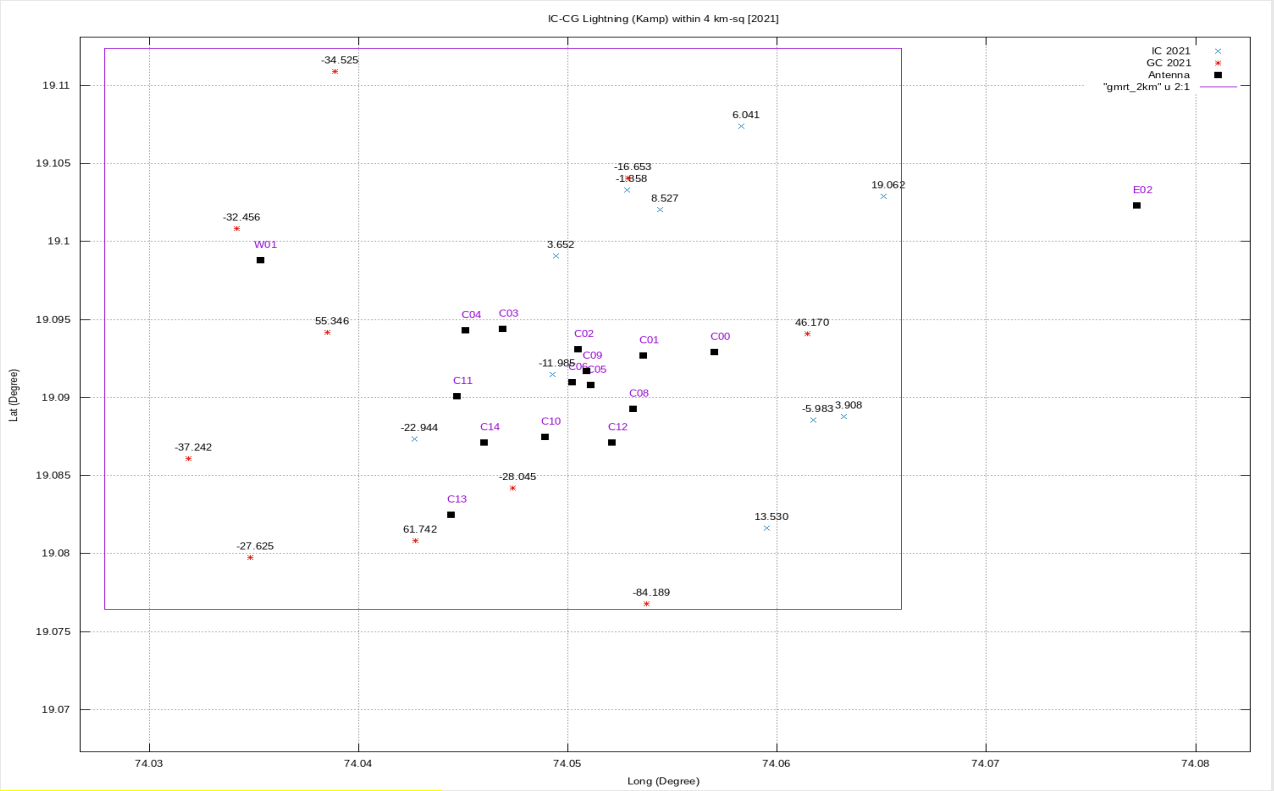

Fig 6-D : CSQ Lightning for 2021

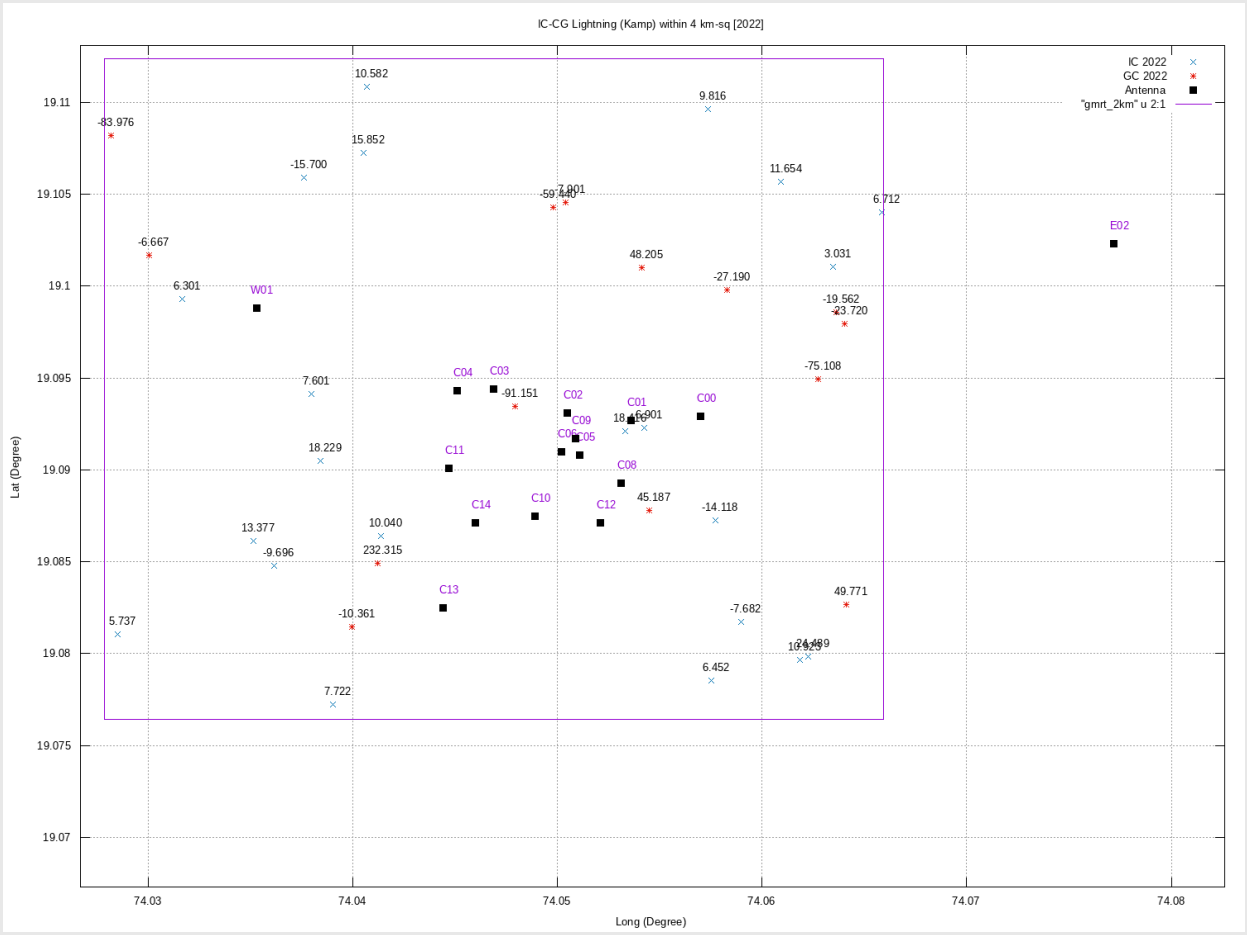

Fig 6-E CSQ Lightning for 2022

APPENDIX-II Lightning Myths and Queries :

https://www.weather.gov/safety/lightning-myths
http://www.noaa.gov/

US Dept of Commerce
National Oceanic and Atmospheric Administration
National Weather Service
About the NWS
1325 East West Highway
Silver Spring, MD 20910

(1) Myth: If it's not raining or there aren't clouds overhead, you're safe from lightning.
Fact: *Lightning often strikes more than* **three miles from the center of the thunderstorm**, *far outside the rain or thunderstorm cloud. "Bolts from the blue"* ***can strike 10-15 miles from the thunderstorm.***

(2) Myth: lightning flashes are 3-4 km apart
Fact: Old data said successive flashes were on the order of 3-4 km apart. New data shows half the flashes are about 9 km apart.

- **The National Severe Storms Laboratory report concludes:** "***It appears the safety rules need to be modified to increase the distance from a previous flash which can be considered to be relatively safe, to at least 10 to 13 km (6 to 8 miles). In the past, 3 to 5 km (2-3 miles) was as used in lightning safety education.***" *Source: Separation Between Successive Lightning Flashes in Different Storms Systems: 1998, Lopez & Holle, from Proceedings 1998 Intl Lightning Detection Conference, Tucson AZ, November 1998.*

(3) Myth: ***A High Percentage of Lightning Flashes Are Forked.***
Fact: Many cloud-to-ground ***lightning flashes*** have forked or multiple attachment points to earth. ***Tests carried out in the US and Japan verify this finding in at least half of negative flashes and more than 70% of positive flashes.*** Many lightning detectors cannot acquire accurate information about these multiple ground lightning attachments. *Source: Termination of Multiple Stroke Flashes Observed by Electro- Magnetic Field: 1998, Ishii, et al. Proceedings 1998 Int'l Lightning Protection Conference, Birmingham UK, Sept. 1998.*

(4) Myth*: Lightning Can Spread out Some 60 Feet After Striking Earth.*
Fact: ***Radial horizontal arcing has been measured at least 20 m***. from the point where lightning hits ground. Depending on soils characteristics, safe conditions for people and equipment near lightning termination points (ground rods) may need to be re-evaluated. *Source: 1993 Triggered Lightning Test Program: Environments Within 20 meters of the Lightning Channel and Small Are Temporary Protection Concepts: 1993, SAND94-0311, Sandia Natl Lab, Albuquerque NM.*