# Do transient cosmic ray decreases cause changes in the global cloud cover?

**A Thesis**

submitted to

Indian Institute of Science Education and Research Pune

in partial fulfillments of the requirements for the

BS-MS Dual degree programme

by

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# Certificate

This is to certify that this dissertation entitled study of correlation between Forbush decrease and the global cloud cover towards the partial fulfilment of the BS-MS dual degree programme at the Indian Institute of Science Education and Research, Pune represents work carried out by Aman Kumar at the Indian Institute of Science Education and Research, Pune under the supervision of Dr Prasad Subramanian, professor, Department of Physics, during the academic year 2017-2018.

Dr Prasad Subramanian

Committee:

Dr Prasad Subramanian

Dr Sunil Gupta

This thesis is dedicated to my Parents, Teachers and my dear friends.

# Declaration

I hereby declare that the matter embodied in the report entitled study of correlation between Forbush decrease and the global cloud cover are the results of the work carried out by me at the Department of Physics, Indian Institute of Science Education and Research, Pune under the supervision of Dr Prasad Subramanian and the same has not been submitted elsewhere for any other degree.

Aman Kumar

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It has been a great journey for me throughout this project. I came to learn many new things.

Firstly, I would like to thank Dr. Prasad Subramanian for giving me this opportunity to carry out this project under his supervision. He has been very friendly and guided me very well throughout my project.

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# 1 Abstract

It has often been speculated that the atmospheric cloud cover might be affected by the flux of cosmic rays incident on the earth's atmosphere. The basis for this speculation is that cosmic rays (which are essentially charged particles incident on the Earth) can act as cloud condensation nuclei. It is well known that the cosmic ray flux is a sensitive function of the solar activity. Eruptions in the solar corona, called coronal mass ejections (CME) cause transient dips in the cosmic ray intensity observed at the earth, called Forbush decreases (FD).

In this work, we investigate if FD events can be correlated with changes in the global cloud cover. We use the high energy cosmic ray data from the GRAPES 3 experiment operated by the Tata Institute of Fundamental Research (TIFR) at Ooty, India and look for correlations with global cloud properties such as Ice and Liquid cloud effective radius, Optical thickness, Water path in addition to Cloud fraction and the precipitation rate.

While some of the correlations are suggestive, we conclude that it is difficult to claim an unambiguous causal link between cosmic rays and global cloud cover based on an overall examination of all the data.

# 2 Introduction

The main theme of this thesis concerns possible links between cosmic rays incident on the earth and the atmospheric cloud cover. We therefore begin with a brief introduction to cosmic rays, transient decreases in the cosmic ray flux (called Forbush decreases) and their origin.

## 2.1 Cosmic Rays

These are very energetic particles having energies up to the order of $10^{18}$-$10^{20}$ eV and are thought to originate from within our galaxy.

They are of two types: a) Galactic Cosmic rays(GCR) b) Solar Cosmic rays(SCR).

GCR's have the source of origin from far away galaxies which travels a great distance to reach towards the earth.

These cosmic rays mainly comprise of 90% protons, 9% alpha particles. The remaining 1% are the nuclei of heavy elements. They reach into the earth's atmosphere and then interacts with the atmospherics elements (mainly oxygen and nitrogen) to produce the secondary particles shower having muons, pions, neutrons, electrons some of which reach the surface of the earth which we can observe and analyze through the various detection instruments available.

## 2.2 Coronal mass ejection(CME)

CME's are events where the release of large amount of matter and electromagnetic radiation form the corona of the sun is seen. These often originate from active regions of the sun's surface. CME's are essentially magnetized plasma comprising of mainly electrons and protons. CME's are thought to be caused by the sudden arrangement of the magnetic field lines where two oppositely directed magnetic field comes in close contact leading to the magnetic reconnection. Sunspots are known to migrate from the high latitude towards the equator over an 11 years cycle.

It twists the magnetic field lines and as it become more twisted it releases a greater amount of energy which propels CMEs through the heliosphere.

## 2.3 Forbush Decrease(FD)

Earth directed CME's often cause transient decreases in the cosmic ray flux incident on earth. Such decreases called Forbush decreases (FD), last for few hours to a few days. They are caused by the magnetic fields bounding CME's shielding the ambient cosmic rays (**K. P. Arunbabu et al, 2013).**

FD's are usually observed by particle detectors which measure the count rate of the produced secondary particles. Whenever there is a significant decrease in the intensity of the GCR it is noted. These decreases usually take place over a few hours. After a few days the flux gets back to its present levels. (**Arun Babu , 2014**).

FD's affect the atmosphere in various ways such as change in the ionization rate and maybe the cloud cover etc.

There is a term called **Rigidity (R)** which plays an important role in the above event. It is an effect of magnetic field on the charged particles defined as R= pc/Ze, where 'p' is the momentum of the particle and 'e' is the charge which means the higher the momentum the higher is the resistance to the deflection by a magnetic field that's why the effect varies globally due to the different cut-off Rigidities at each altitude and latitude but the bigger events are seen globally. The rigidity dependence of FD has been observed at the earth (**J.A.Lockwood, W.R. Webber, 1991 )** (**Arun Babu , 2014**).

## 3 About the Project

We are motivated by the work of (**Svensmark.et al, 2016)** work which concludes that there is a significant correlation between the FD events and low-level clouds. It envisages the following causative chain:

FD with fewer cosmic rays → less atmospheric ionization → less aerosol nucleation → fewer formed cloud condensation nuclei (CCN) → fewer cloud droplets → larger cloud droplets, decrease in cloud fraction and in cloud emissivity.

This project is carried out to find the correlation (if any) is between various cloud cover properties and FD events using GRAPES-3 data from 2001-2005. The events which has been covered in this work are short-term FD events which exhibit a sudden decrease and gradual recovery comprising of nearly one-week period. FD event also changes the ionization rate in the atmosphere which in turn regulates the other parameters as well.

There has been a lot of work done on this topic by various researchers and they have their own view over this matter. One such work of (**Laken et al, 2012)** states that some weak but statistically significant relationship may exist at regional scales. However, he concluded that there is no robust evidence of widespread link between the cosmic rays flux and the clouds.

Another work by (**Todd & Kniveton, 2001)** concludes that there is a small but significant decline in the global proportion of cloud cover in response to FD's. He further concluded that there is substantial reduction in the high-level clouds over the polar regions.

The work by (**Kniveton, 2004)** analyzes data from the regions of rainfall and heavy rainfall free regions. They observe that in the regions of thicker cloud cover the cloud cover is reduced after the FD event whereas over the oceans, where there is thinner cloud cover it tends to increase.

## 3.1 Data:

We use muon data from the GRAPES-3, telescope at Ooty situated at 11.4 ∘ N latitude, 76.7 ∘ E longitude, and 2200 m of altitude). It facilitates the high statistics and directional study of muon count rate with greater efficiency. The threshold energy of the telescope is 1GeV for the muons arriving from the vertical direction.

The paper by (**K.P.Arunbabu et al, 2017)** states that due to the geographical location of the above observatory it is seen that the seasonal variation observed over the area is small as compared to the variations seen at the high latitude observatories.

The cut-off rigidities for the 9 different directions taken for the study at the observatory point of cosmic data is as follows:

| Direction | Rigidity(GV) |
|---|---|
| NW | 15.7 |
| N | 18.7 |
| NE | 24 |
| W | 14.3 |
| V | 17.2 |
| E | 22.4 |
| SW | 14.4 |
| S | 17.6 |
| SE | 22.4 |

The above 9 directions stand for:

NW- North West

N- North

NE- North East

V- Vertical

and similarly, for the south direction.

The Cloud data is from the Goddard Interactive Online Visualization ANd aNalysis Infrastructure (GIOVANNI), NASA which is the MODIS (Moderate Resolution Imaging Spectroradiometer) TERRA and AQUA satellite global daily average data.

TERRA's orbit around the earth is such that it passes from north to south along across the equator in the morning, whereas, the AQUA passes from south to north across the equator in the afternoon.

## 3.2 Clouds

When air becomes saturated as a result of being cooled to its dew point due to the addition of moisture, adiabatic cooling occurs causing air containing the water vapor to rise and cool. As it is cooled to its dew point and become saturated, water vapor condenses to form cloud droplets which happens on the cloud condensation nuclei (CCN).

There are various phenomena which affect cloud cover on the day to day basis. Clouds are responsible for regulating the global temperature. It is seen that the behaviour of the clouds also varies according to the altitude at which they are located such as Low-level clouds, Mid-level clouds and High-level clouds.

The cloud properties which has been taken into this project for study are as follows:

**1)** Cloud drop effective radius (CER)

It is the weighted mean of the size distribution of the cloud droplets.

**2)** Cloud Fraction (CF)

The cloud model data is divided into the various latitudes and longitudes grids. In each grid box the proportion of area which is covered by the clouds is termed as the cloud fraction.

**3)** Cloud Optical thickness (COT)

It is the measure of the degree to which the cloud layer prevents the light to pass through it.

4) Cloud water path (CWP)

It is the measure of the total amount of the liquid water or ice for the ice clouds present between the two points in the atmosphere.

5) Precipitation rate (Pr)

It indicates the amount of rainfall occur over a particular time period like /hour or /min.

# 4 Methods

## 4.1 Sorting of FD events

The hourly muon count rate percentage deviation from the mean of 28 days count rate for nine different directions from the Ooty muon telescope data is plotted for the duration of 2001-2004. So, the plotted data is actually: $\delta n = ((N_i - N_m)/N_m) * 100$. where Nm is the 28 days averaged count rate.

Total of 69 events are sorted based on the average magnitude of each event. Some of the events plotted are shown in the results section.

## 4.2 Magnitude of the event

The global minima from the above graph for each event is identified which is called the FD minima of our event and it is traced back to obtained the onset time of the event. Since the resolution in the data is such that the points around the onset time and the FD minima which comes within the deviation of 0.01% are taken and averaged in the calculation of the magnitude of each event. The magnitude is calculated as:

**M = (pre-event intensity- intensity at the minima**)

The table comprising of the magnitude for each event is shown in the results section.

## 4.3 Ionization change and the fitting

The magnitude (along the y axis) and the corresponding rigidity (x axis) for each direction is plotted for each event. We have the equation: $\delta n = AP^{\gamma}$ which is fitted for the above plot where A is the amplitude and $\gamma$ is the exponent with which the count varies with the rigidity P.

Taking log on both sides, we have the following equation: $\log(\delta n) = \log(A) + \gamma \log(P)$. Now the linear fitting of this equation is done for the above graph and the parameters "A" and "γ" are obtained which would be use later on in the calculation of Ionization change in the atmosphere varying according to: $\delta q(h) = \ -\int_{P_c}^{\infty} I(P, h)\ AP^{\gamma}\ J(P) dP$

**(J.Svensmark,et,al. 2016)**

Some of these fitted graphs are shown in the results section.

## 4.4 Correlation between the FD data and the cloud data

We seek to investigate the cosmic ray- cloud cover correlations in two ways- a) over the duration of individual FD events, and b) for a cumulative 4year period spanning 2001-2005. The event wise plotting is done in a similar manner for the cloud data as well as the FD data i.e. the 28 days mean and the % deviation was found which was then plotted together with the FD data.

For the four years data the cloud data was plotted by taking the running average of 28 days continuing till the end of the 4$^{th}$ year.

After the above, the correlation between the FD data and the cloud data was calculated event wise with each of the cloud property for only vertical direction of the FD data which is presented in a tabular form for all the events. Graphs for some of the events are shown in the result section.

## 4.5 Testing the significance of the obtained correlations

We know that the obtained results need to be tested for significance. Here the student's T- test is used for testing the significance of the above obtained correlation values.

A two-tailed test at a 95% confidence interval was carried out.

Table 3 is shows the values of t- critical and t- statistic calculated for above which can be compared for each event with that of each cloud properties to test the significance of the results is shown in the results section.

## 4.6 How the significance test is done

For the obtained correlation values the t- statistic is calculated as: $\mathbf{t_s = r}\ \sqrt{(\boldsymbol{n-2})/(\boldsymbol{1-r^2})}$

Where ‘r’ is the correlation coefficient, ‘n’ is the no of pairs of data points in the graph.

‘-2’ is done in “n-2” as we have the two data sets for each graph.

The two-tailed t- test is performed at 95% confidence interval to which from the distribution table we can get the t critical values for the given degrees of freedom and the alpha value. Now, this obtained t critical value is compared with that of the above calculated t statistic value.

The null hypothesis is taken to be that there is no correlation between the two, i.e. there is zero correlation and then after comparing the t- statistic and t- critical values such as: if from the negative side the t- static is less or from the positive side the t- statistic is more than the t- critical value obtained then the null hypothesis is discarded and the correlation is found to be significant otherwise we can’t discard the null hypothesis and the conclusion is made that the obtained correlation values are not significant .

# 5 Results & Discussion

The 69 FD events were listed out from the cosmic data (2001-2005) of 4 years. Few of those are as depicted below:

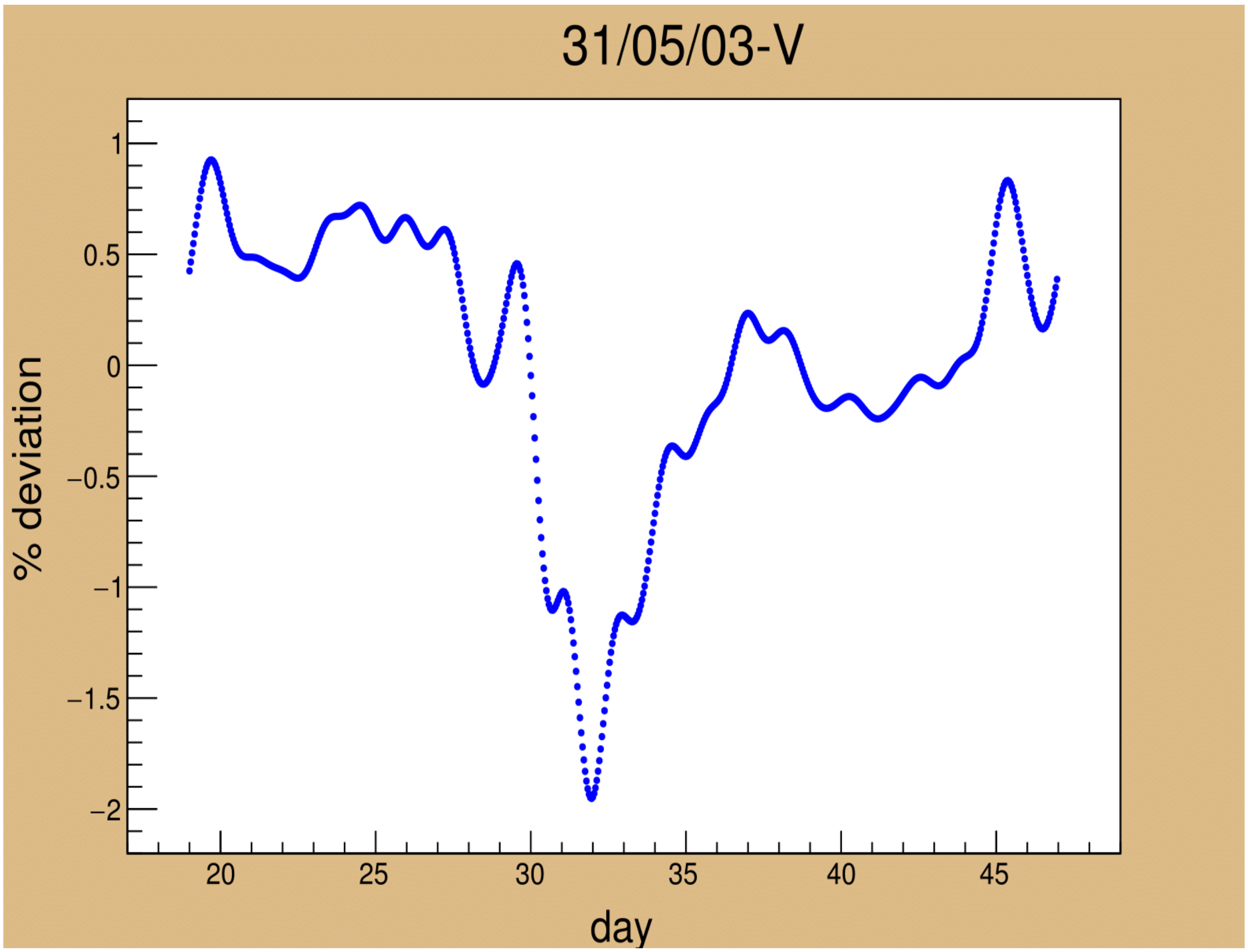


*Figure 1: FD event of 31st May,03 for the vertical direction.*

'y' axis is the % deviation in the muon count rate and the 'x' axis is the day.

We can see there is the minima occurring at $31^{st}$ May, 03.

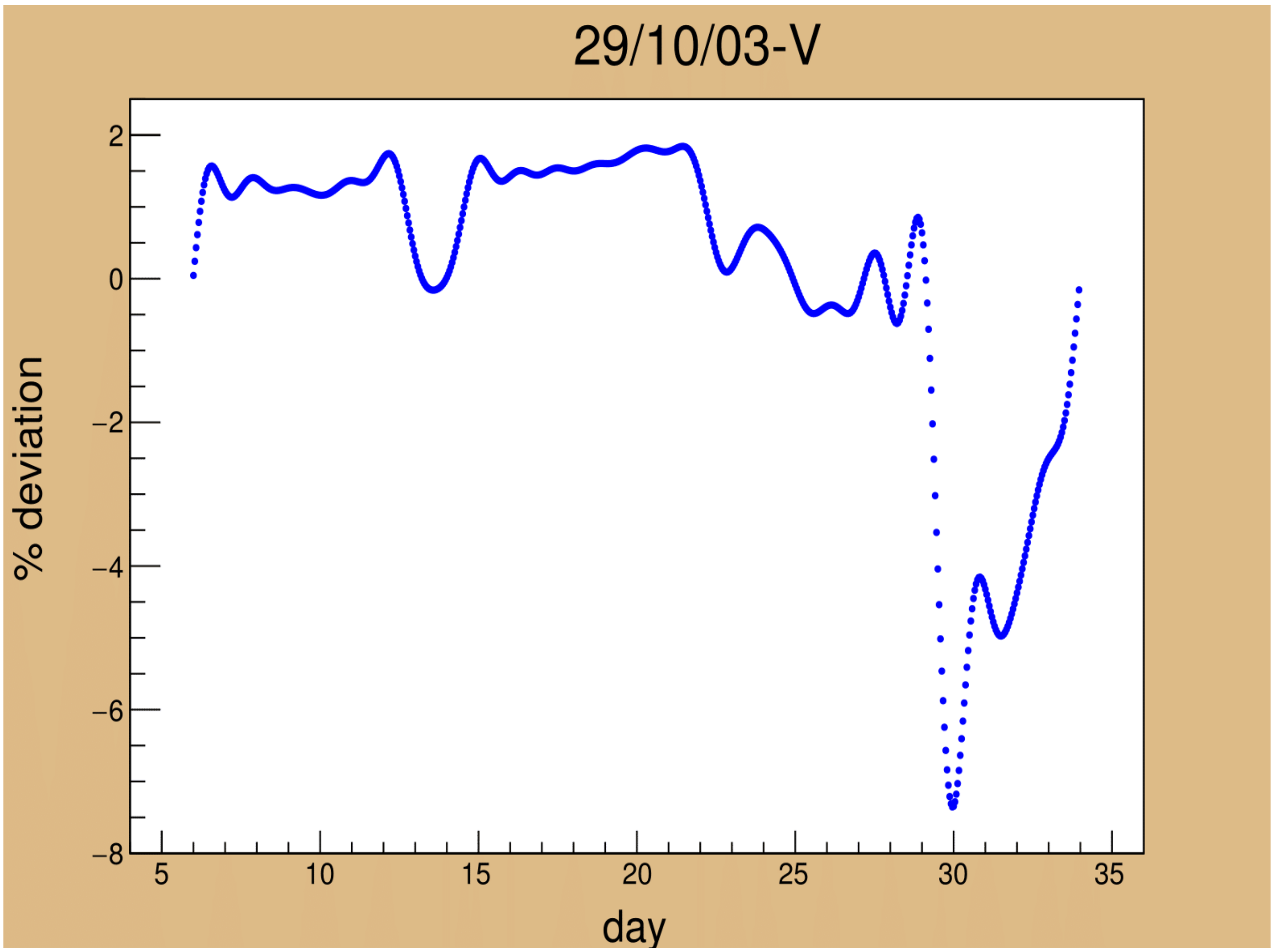


*Figure 2: FD event of 29th Oct,03 for the vertical direction.*

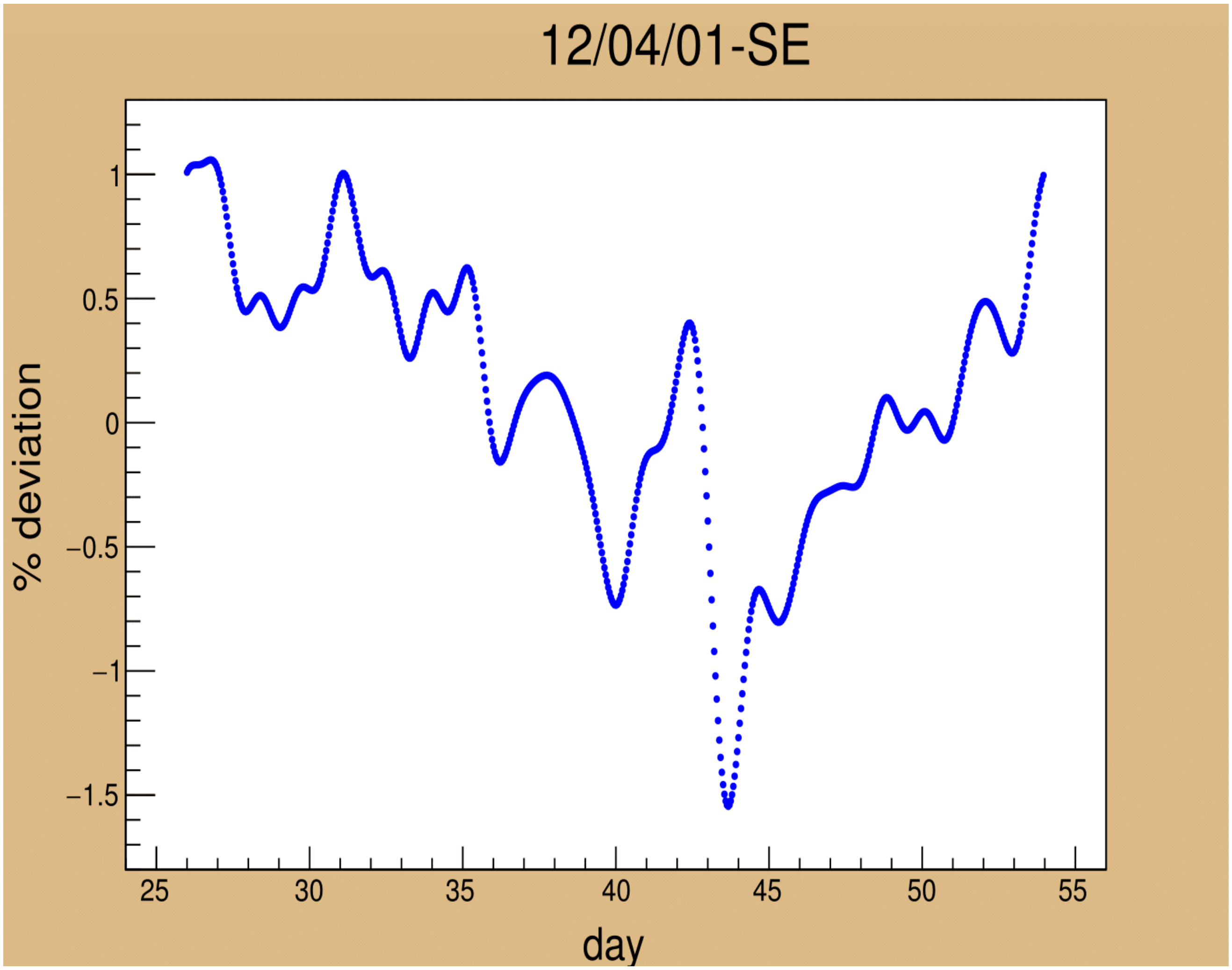


*Figure 3: FD event of 12th April,01 for the south east direction.*

The magnitude table for each event indicating the average magnitude for all the 9 nine directions is as below:

## 5.1 Table 1: Table showing the magnitude for each FD event.

| Event | Mag (% deviation) |
|---|---|
| 24/01/2001 | 0.4929 |
| 31/01/2001 | 0.9238 |
| 06/02/2001 | 1.3269 |
| 05/03/2001 | 0.6428 |
| 22/03/2001 | 0.459 |
| 28/03/2001 | 0.9818 |
| 05/04/2001 | 0.981 |
| 08/04/2001 | 0.9371 |
| 12/04/2001 | 2.515 |
| 29/04/2001 | 1.5645 |

| | |
|---|---|
| 28/05/2001 | 0.7744 |
| 18/08/2001 | 0.9779 |
| 28/08/2001 | 1.9698 |
| 26/09/2001 | 1.7249 |
| 01/10/2001 | 1.4221 |
| 12/10/2001 | 0.9827 |
| 28/10/2001 | 0.5084 |
| 06/11/2001 | 2.3306 |
| 25/11/2001 | 1.3133 |
| 04/12/2001 | 1.4627 |
| 15/12/2001 | 1.3858 |
| 31/12/2001 | 2.5966 |

| | |
|---|---|
| 11/01/2002 | 1.1268 |
| 30/01/2002 | 1.0437 |
| 05/03/2002 | 0.7227 |
| 23/05/2002 | 0.8332 |
| 12/06/2002 | 0.4823 |
| 19/06/2002 | 0.4275 |
| 20/07/2002 | 1.6465 |
| 28/08/2002 | 1.1425 |
| 01/10/2002 | 0.8341 |
| 05/10/2002 | 0.7859 |
| 20/10/2002 | 1.26 |
| 12/11/2002 | 1.5102 |

| | |
|---|---|
| 18/11/2002 | 1.5045 |
| 23/12/2002 | 0.9794 |
| 10/01/2003 | 0.6227 |
| 24/01/2003 | 0.5324 |
| 03/02/2003 | 0.7279 |
| 18/02/2003 | 0.7393 |
| 31/03/2003 | 1.0664 |
| 11/04/2003 | 0.7122 |
| 22/05/2003 | 0.6432 |
| 01/06/2003 | 1.9746 |
| 16/06/2003 | 1.1268 |
| 19/06/2003 | 0.5219 |

| | |
|---|---|
| 15/07/2003 | 0.7221 |
| 27/07/2003 | 0.4885 |
| 18/08/2003 | 0.4696 |
| 12/09/2003 | 0.6435 |
| 29/10/2003 | 7.0837 |
| 22/10/2003 | 1.5947 |
| 16/11/2003 | 0.9492 |
| 24/11/2003 | 1.0258 |
| 10/12/2003 | 0.7463 |
| 22/12/2003 | 0.9163 |
| 08/01/2004 | 1.2317 |
| 23/01/2004 | 2.0429 |

| | |
|---|---|
| 14/02/2004 | 0.942 |
| 03/03/2004 | 1.0409 |
| 12/03/2004 | 0.6781 |
| 30/03/2004 | 0.742 |
| 01/07/2004 | 0.558 |
| 27/07/2004 | 1.8571 |
| 02/09/2004 | 0.602 |
| 15/09/2004 | 0.9297 |
| 22/09/2004 | 0.5465 |
| 10/11/2004 | 1.9341 |
| 06/12/2004 | 1.1529 |

The fitted graphs of some of the FD events are shown below:

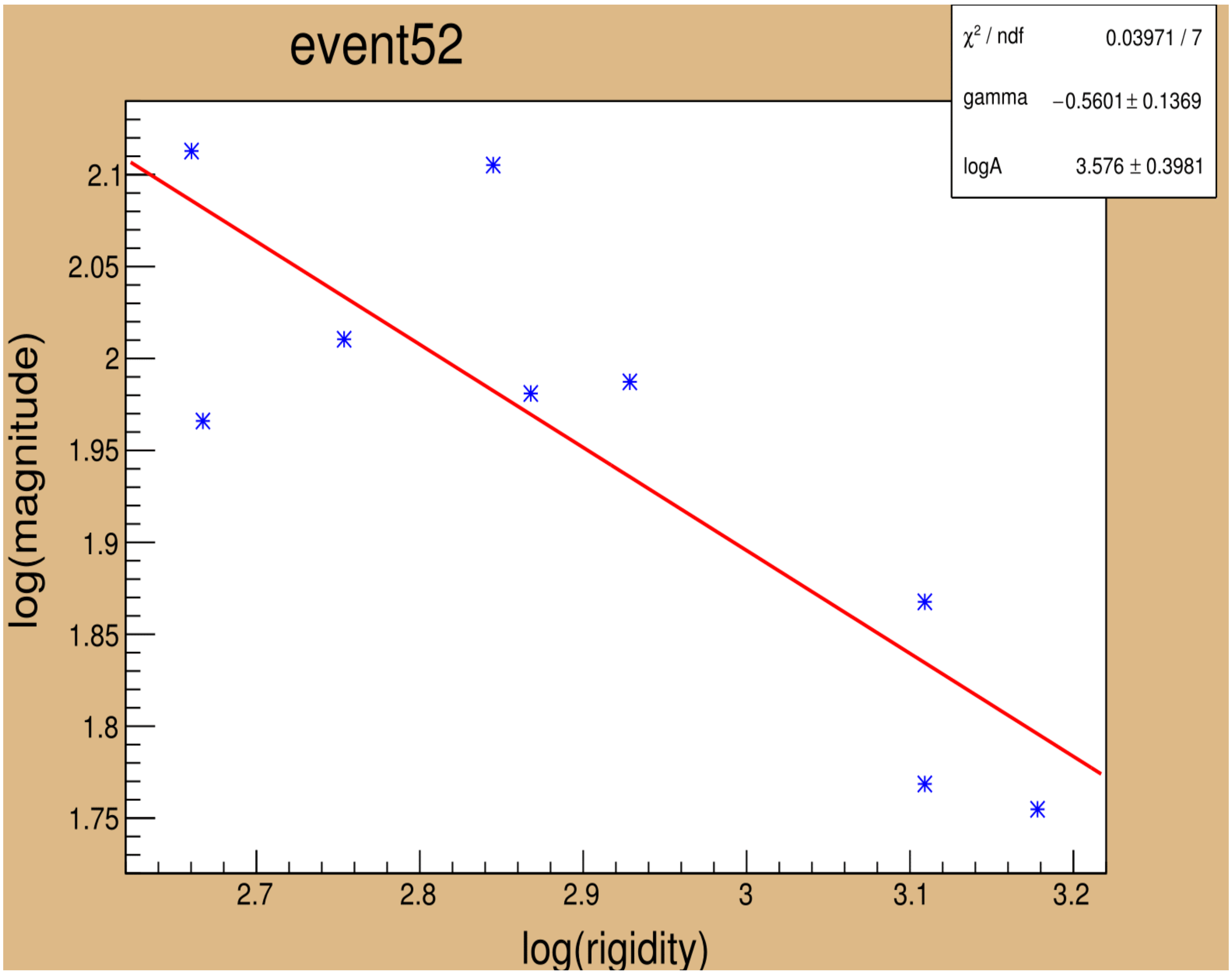


*Figure 4: FD event of 29th Oct, 2003 linear fitted to find the parameters 'A' & 'γ'.*

'y' axis is the log of magnitude of the event and the 'x' axis is the log of the rigidity for the 9 different directions.

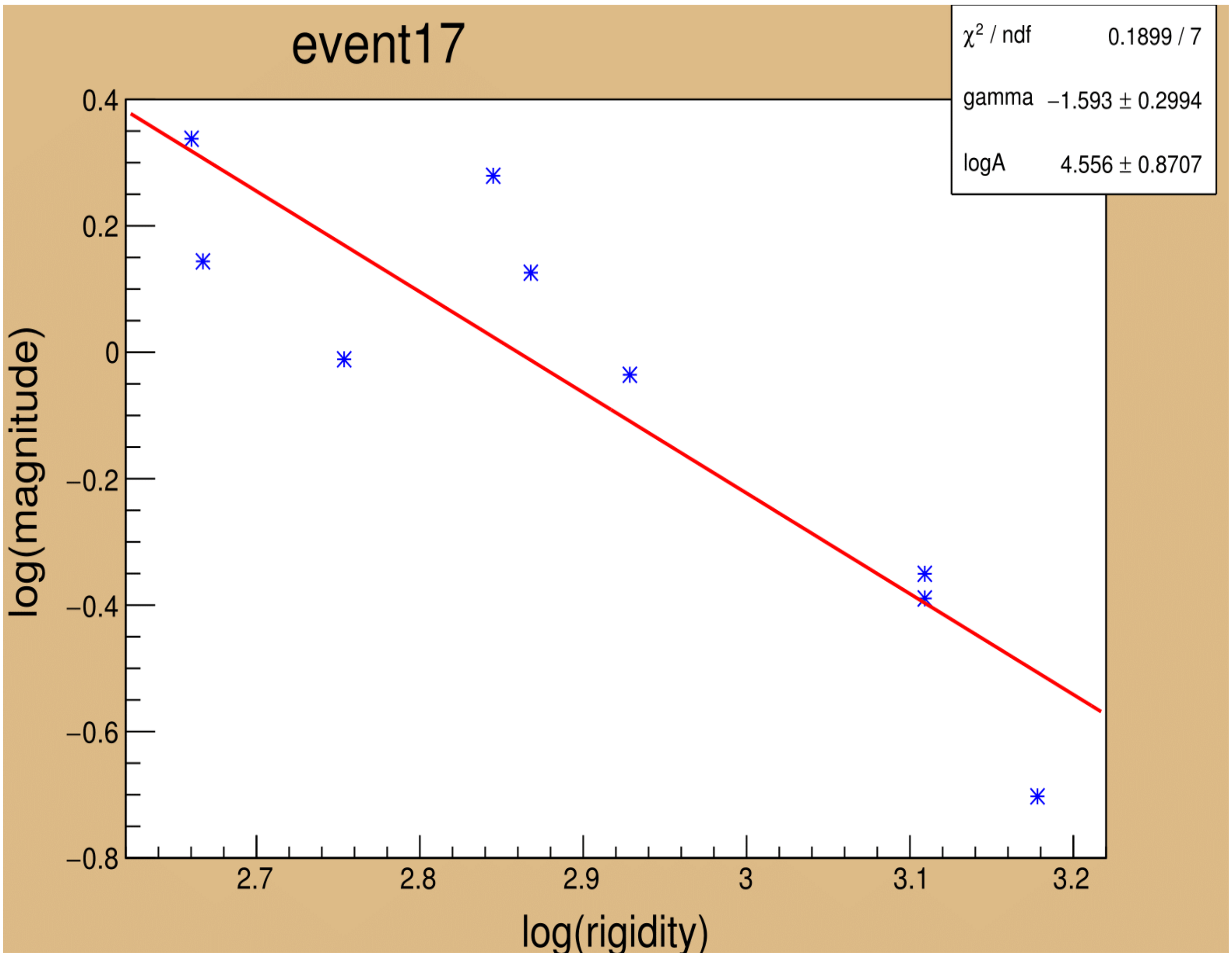


*Figure 5: FD event of 12th Oct, 2001 linear fitted to find the parameters 'A' & 'γ'.*

'y' axis is the log of magnitude of the event and the 'x' axis is the log of the rigidity for the 9 different directions.

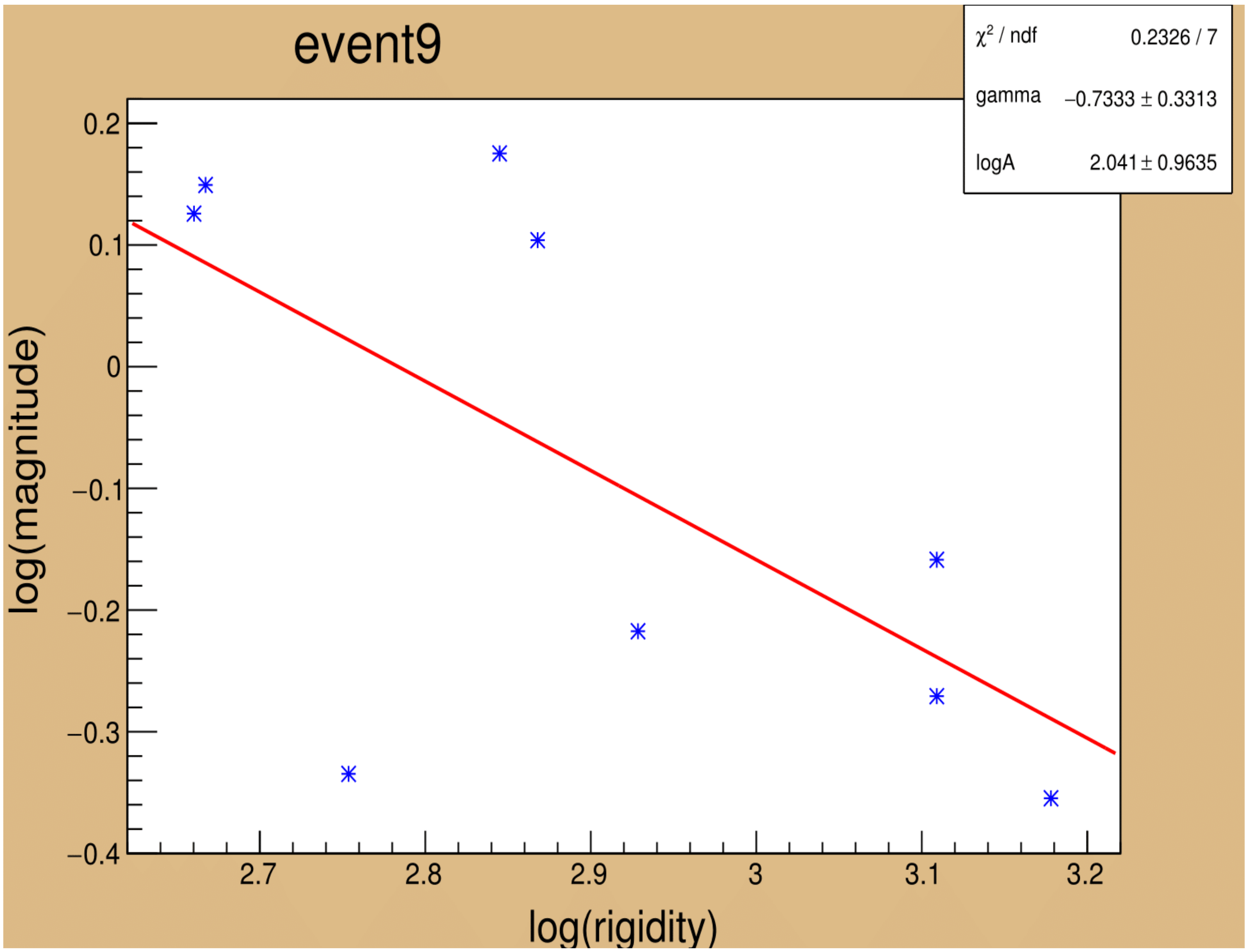


*Figure 6: FD event of 08th April, 2001 linear fitted to find the parameters 'A' & 'γ'.*

'y' axis is the log of magnitude of the event and the 'x' axis is the log of the rigidity for the 9 different directions.

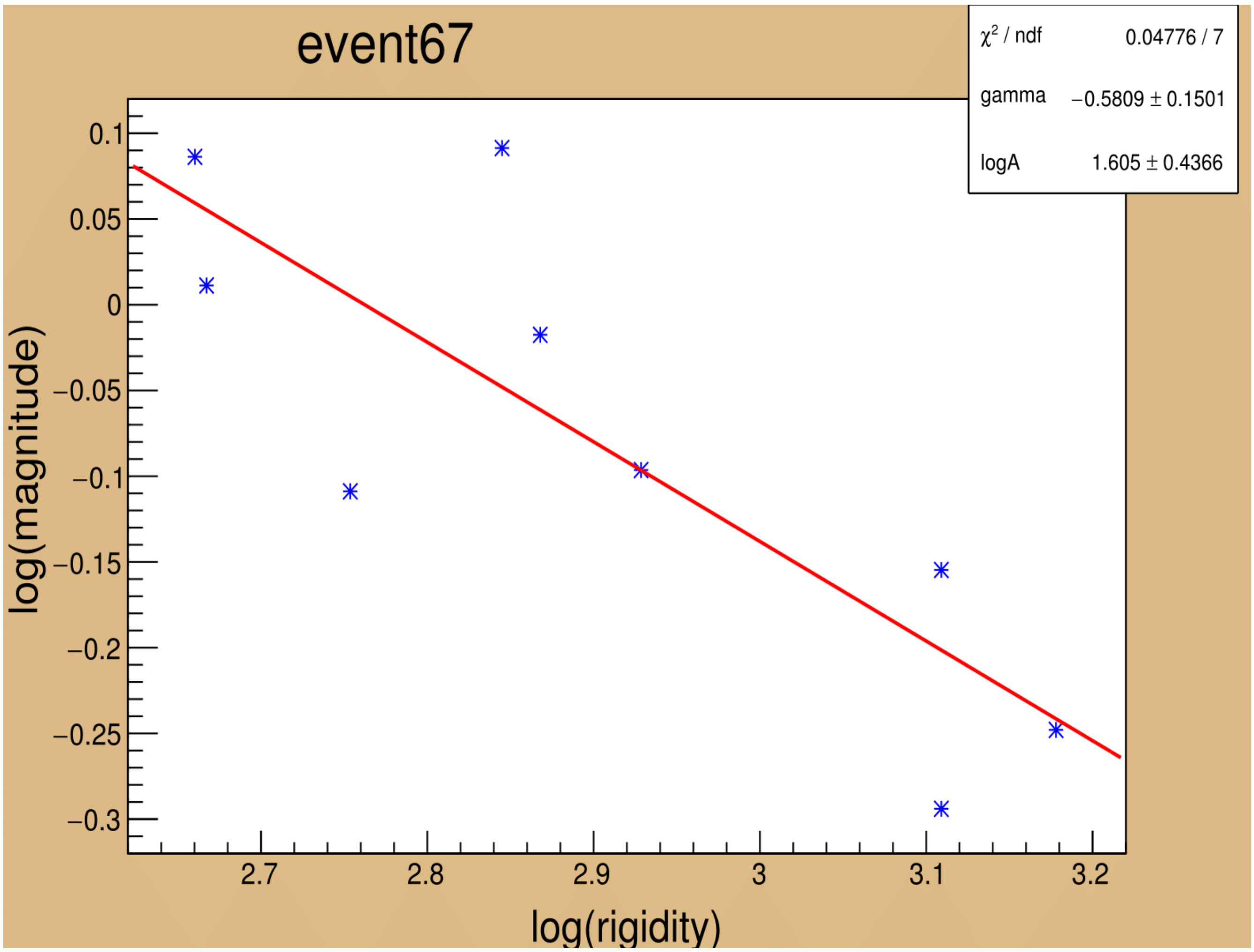


*Figure 7: FD event of 15th Sept, 2004 linear fitted to find the parameters 'A' & 'γ'.*

'y' axis is the log of magnitude of the event and the 'x' axis is the log of the rigidity for the 9 different directions.

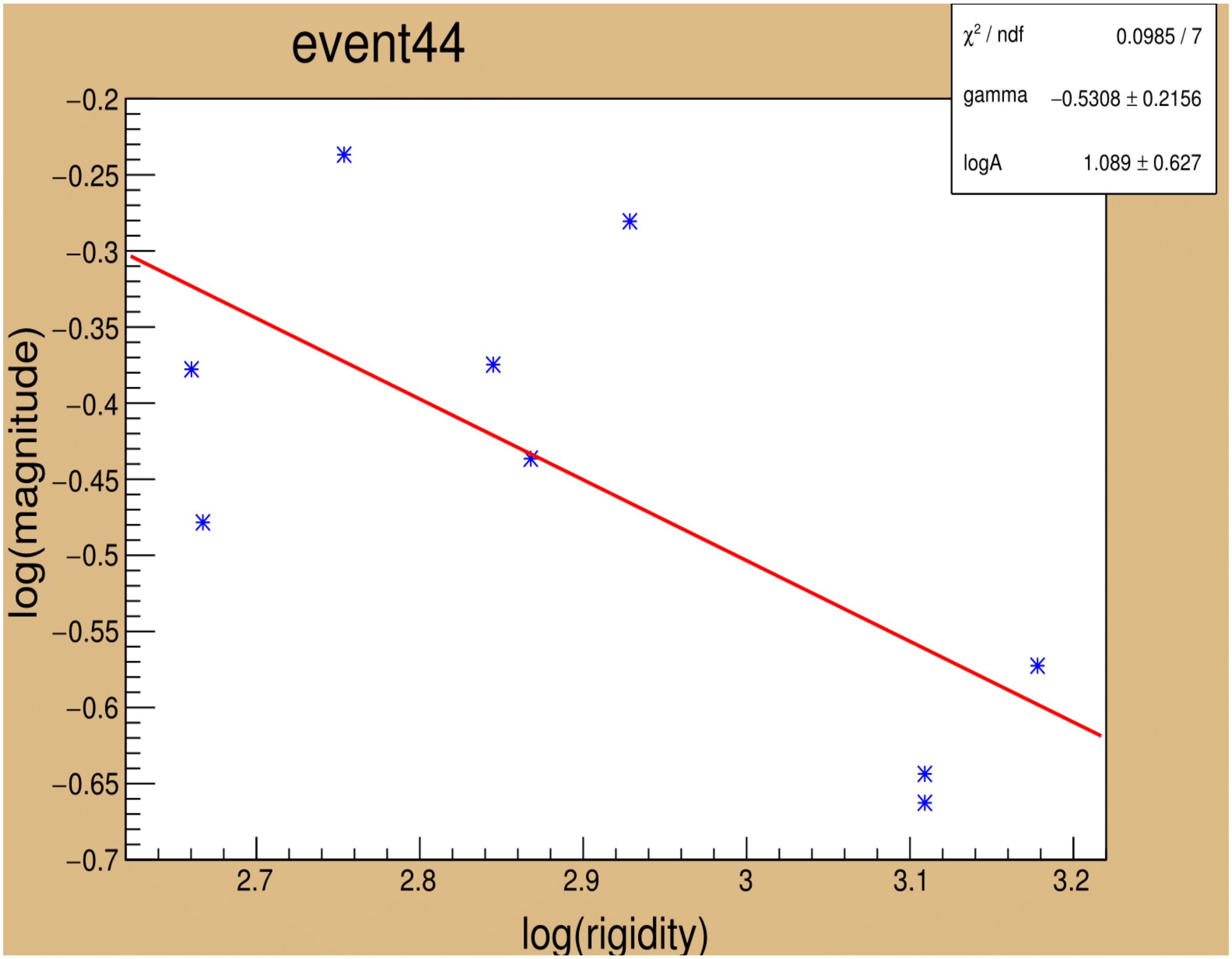


*Figure 8: FD event of 22nd May, 2003 linear fitted to find the parameters 'A' & 'γ'.*

'y' axis is the log of magnitude of the event and the 'x' axis is the log of the rigidity for the 9 different directions.

Correlation graph of the few FD events for the vertical direction with that of the various cloud properties data are shown below:

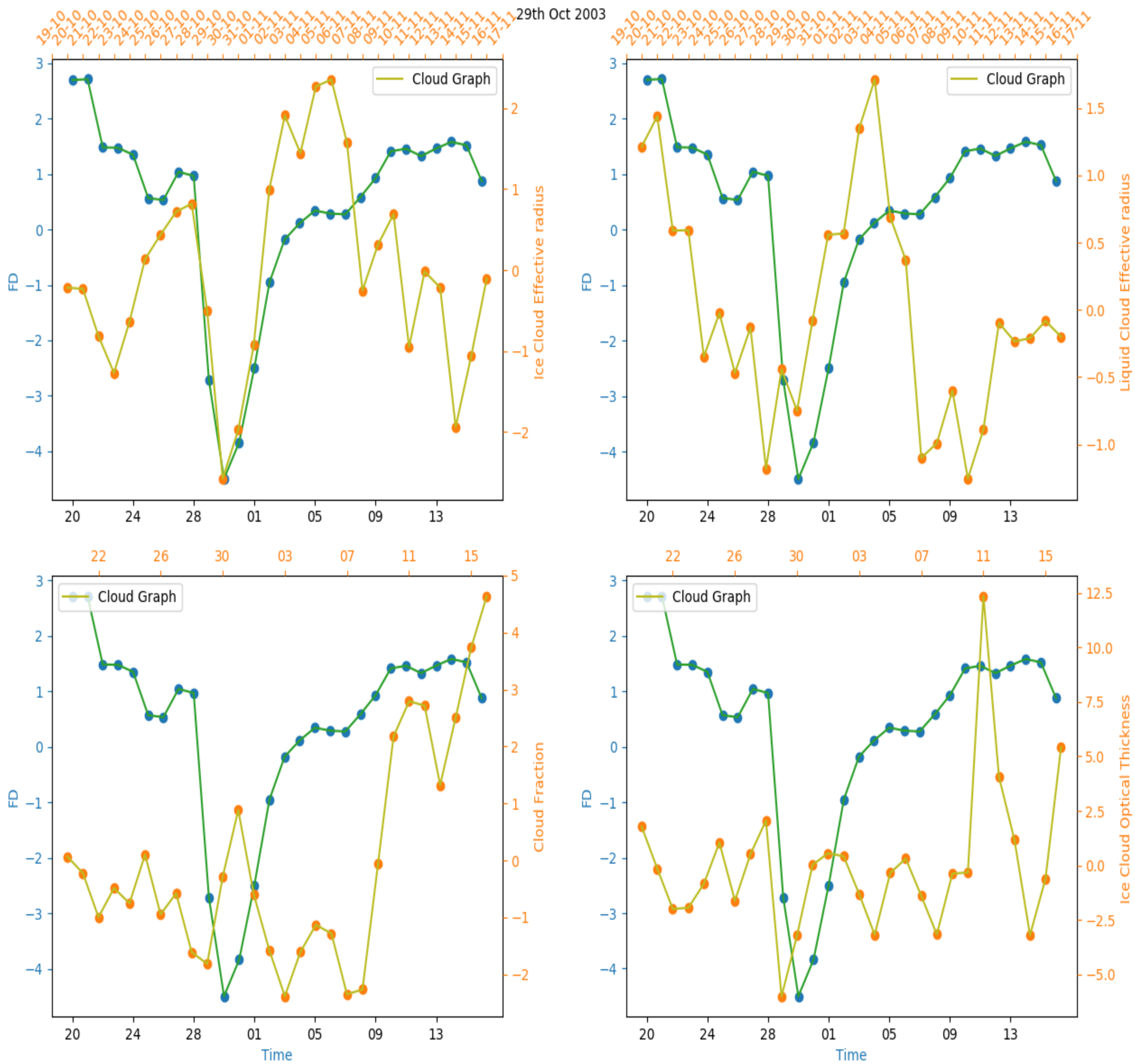


*Figure 9: FD event of 29$^{th}$ Oct, 03 plotted with the cloud properties.*

'blue' dots and labels correspond to the FD event whereas the 'orange' one represents the cloud properties ice cloud effective radius, liquid cloud effective radius, cloud fraction and ice cloud optical thickness respectively. Both the 'y' axes are in % deviation.

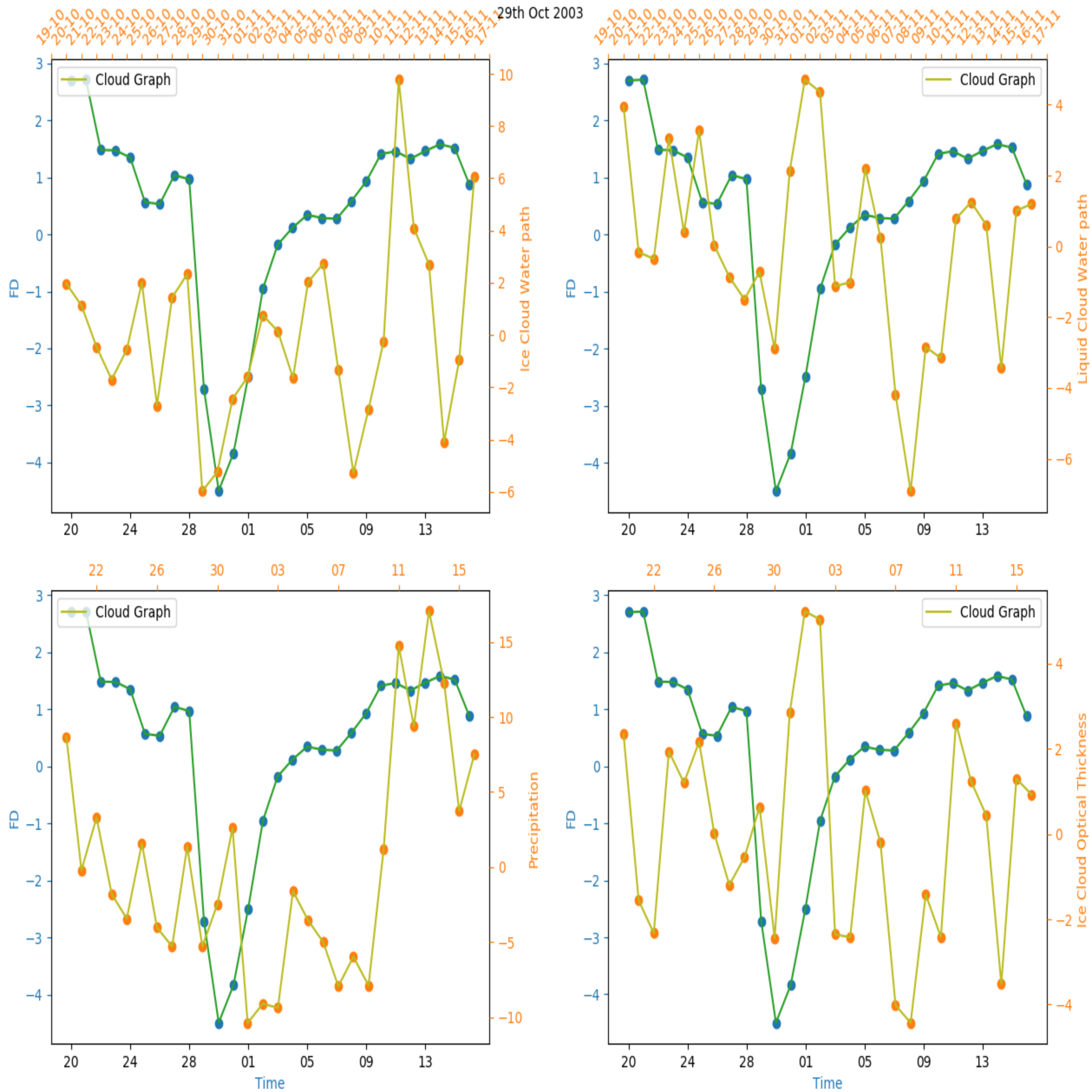


*Figure 10: FD event of 29th Oct, 03 plotted with the cloud properties*

. ‘blue’ dots and labels correspond to the FD event whereas the ‘orange’ one represents the cloud properties ice cloud water path, liquid cloud water path, precipitation and liquid cloud optical thickness respectively. Both the ‘y’ axes are in % deviation


*Figure 11: FD event of 31st March, 03 plotted with the cloud properties*

'blue' dots and labels correspond to the FD event whereas the 'orange' one represents the cloud properties ice cloud effective radius, liquid cloud effective radius, cloud fraction and ice cloud optical thickness respectively. Both the 'y' axes are in % deviation.

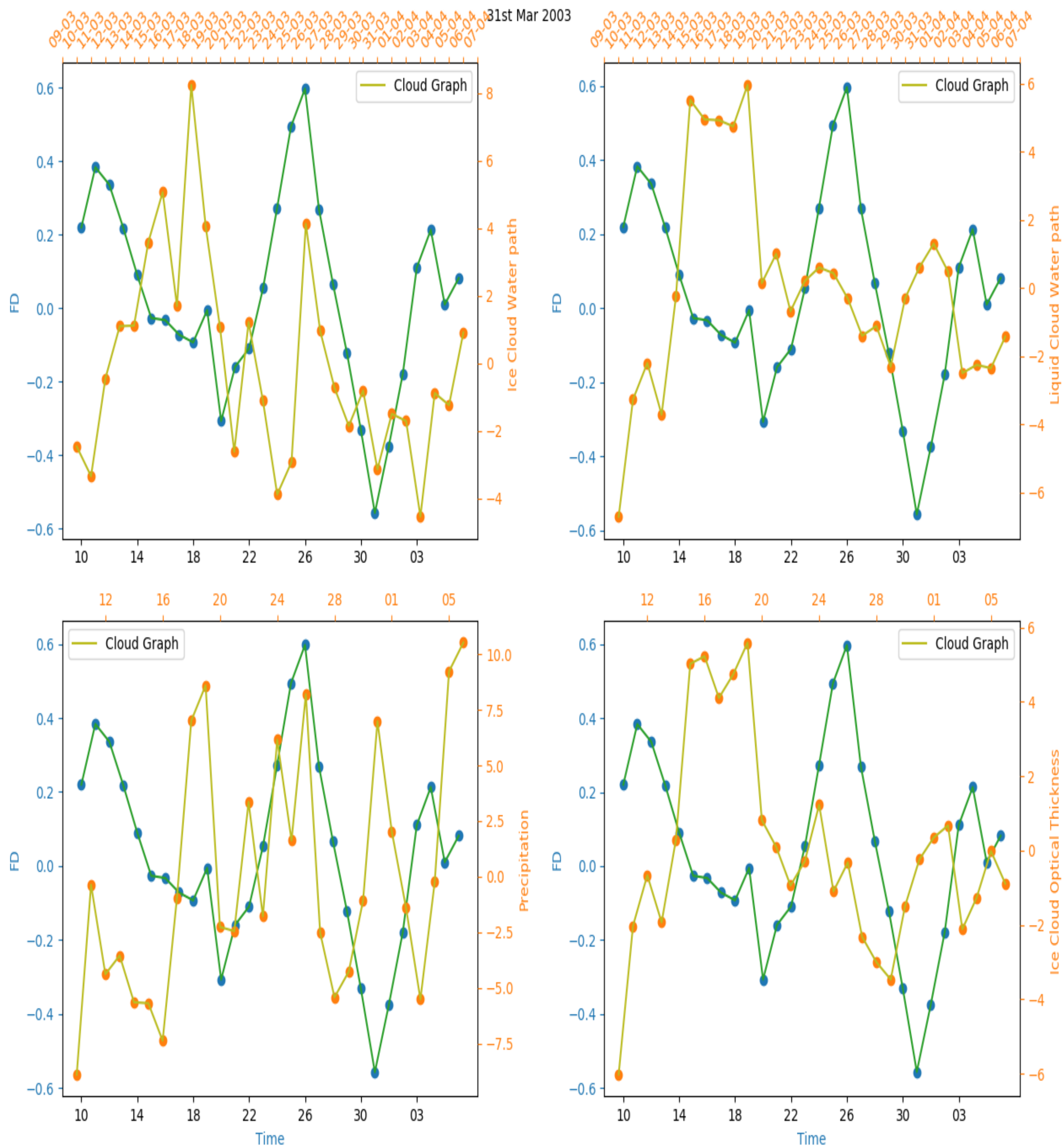


*Figure 12: FD event of 31st March,03 plotted with the cloud property.*

'blue' dots and labels correspond to the FD event whereas the 'orange' one represents the cloud properties ice cloud water path, liquid cloud water path, precipitation and liquid cloud optical thickness respectively. Both the 'y' axes are in % deviation

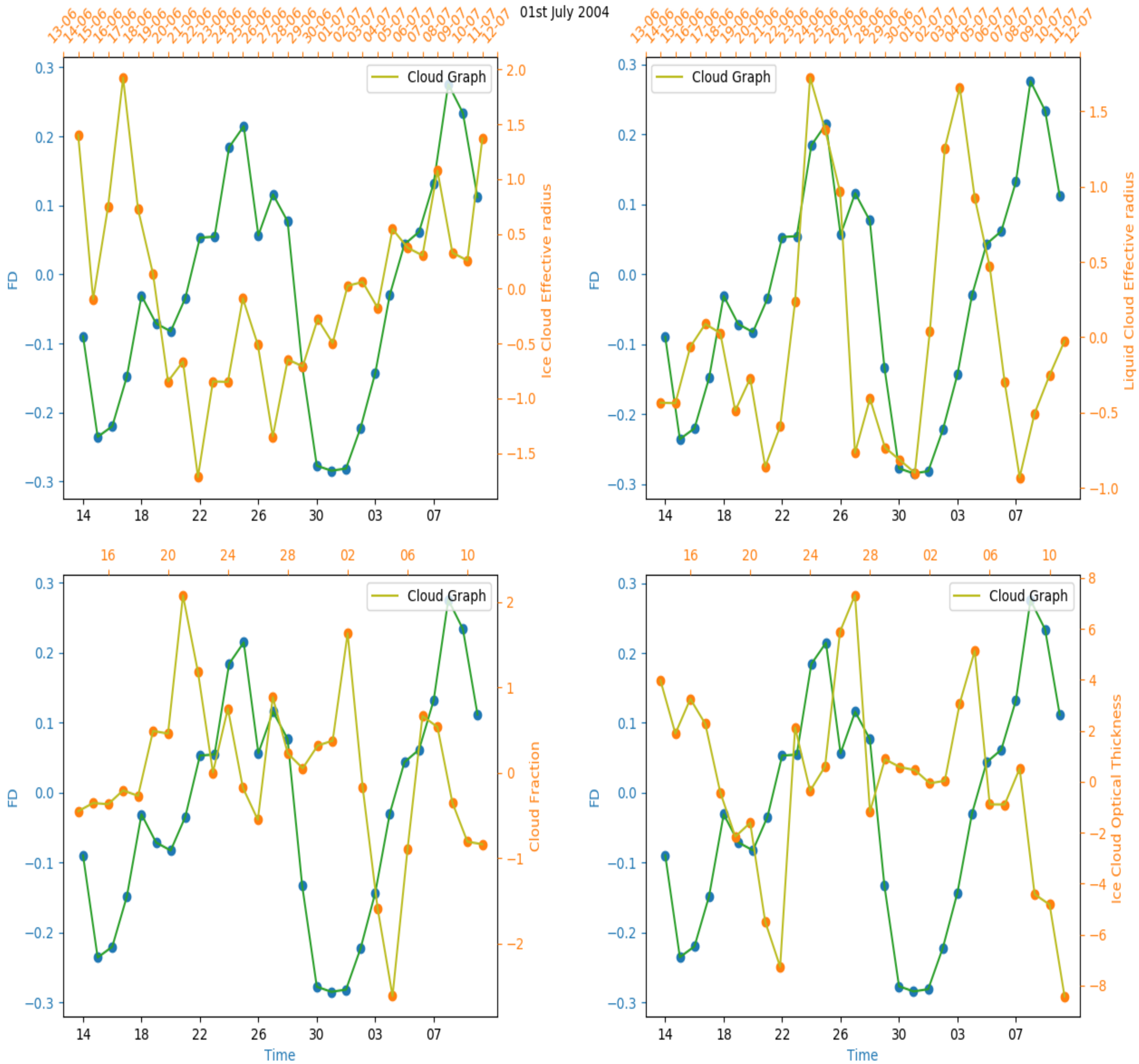


*Figure 13: FD event of 1st July, 04 plotted along with the cloud property.*

'blue' dots and labels correspond to the FD event whereas the 'orange' one represents the cloud properties ice cloud effective radius, liquid cloud effective radius, cloud fraction and ice cloud optical thickness respectively. Both the 'y' axes are in % deviation.

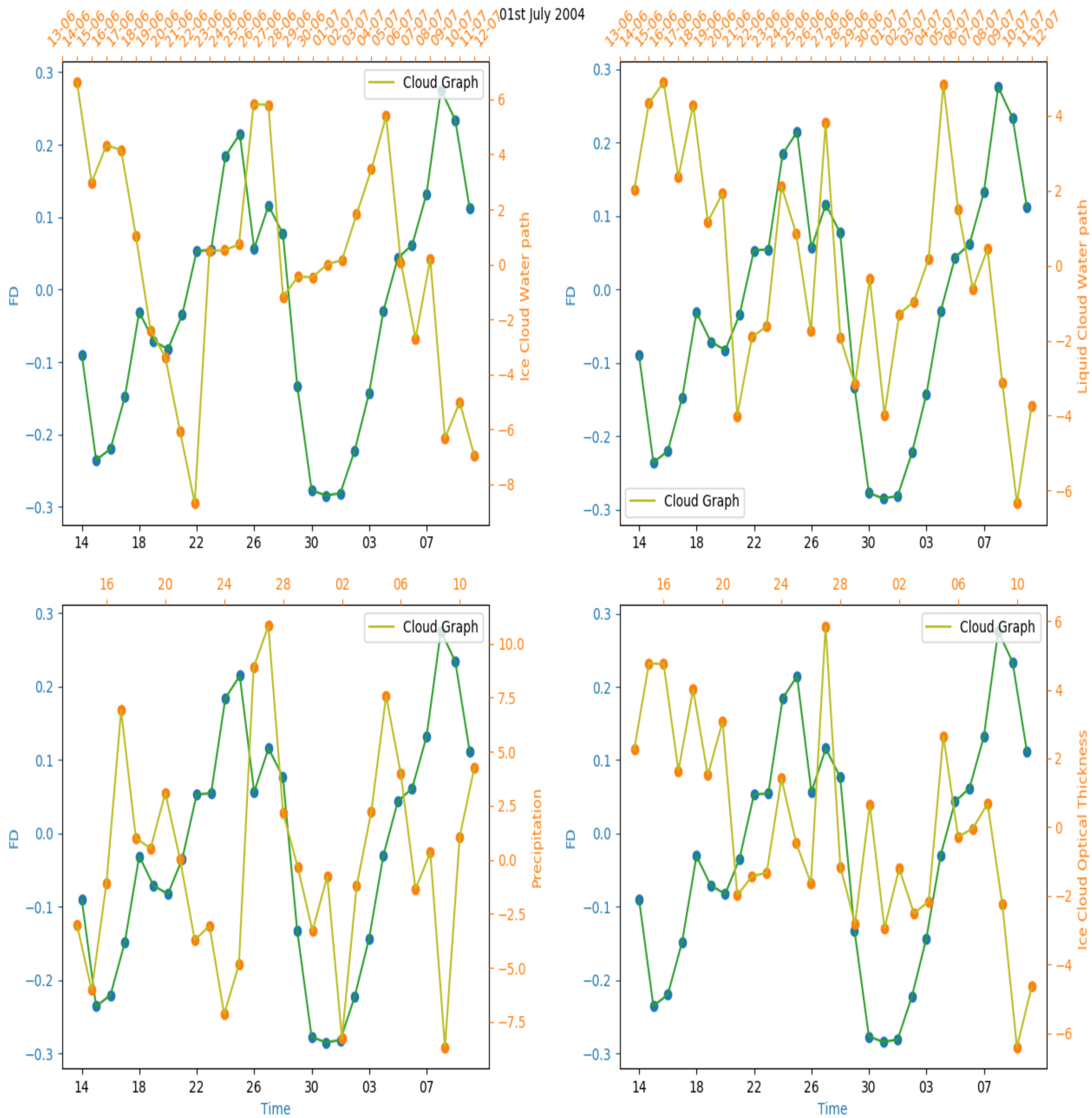


*Figure 14: FD event of 1st July, 04 plotted with the cloud property.*

'blue' dots and labels correspond to the FD event whereas the 'orange' one represents the cloud properties ice cloud water path, liquid cloud water path, precipitation and liquid cloud optical thickness respectively. Both the 'y' axes are in % deviation

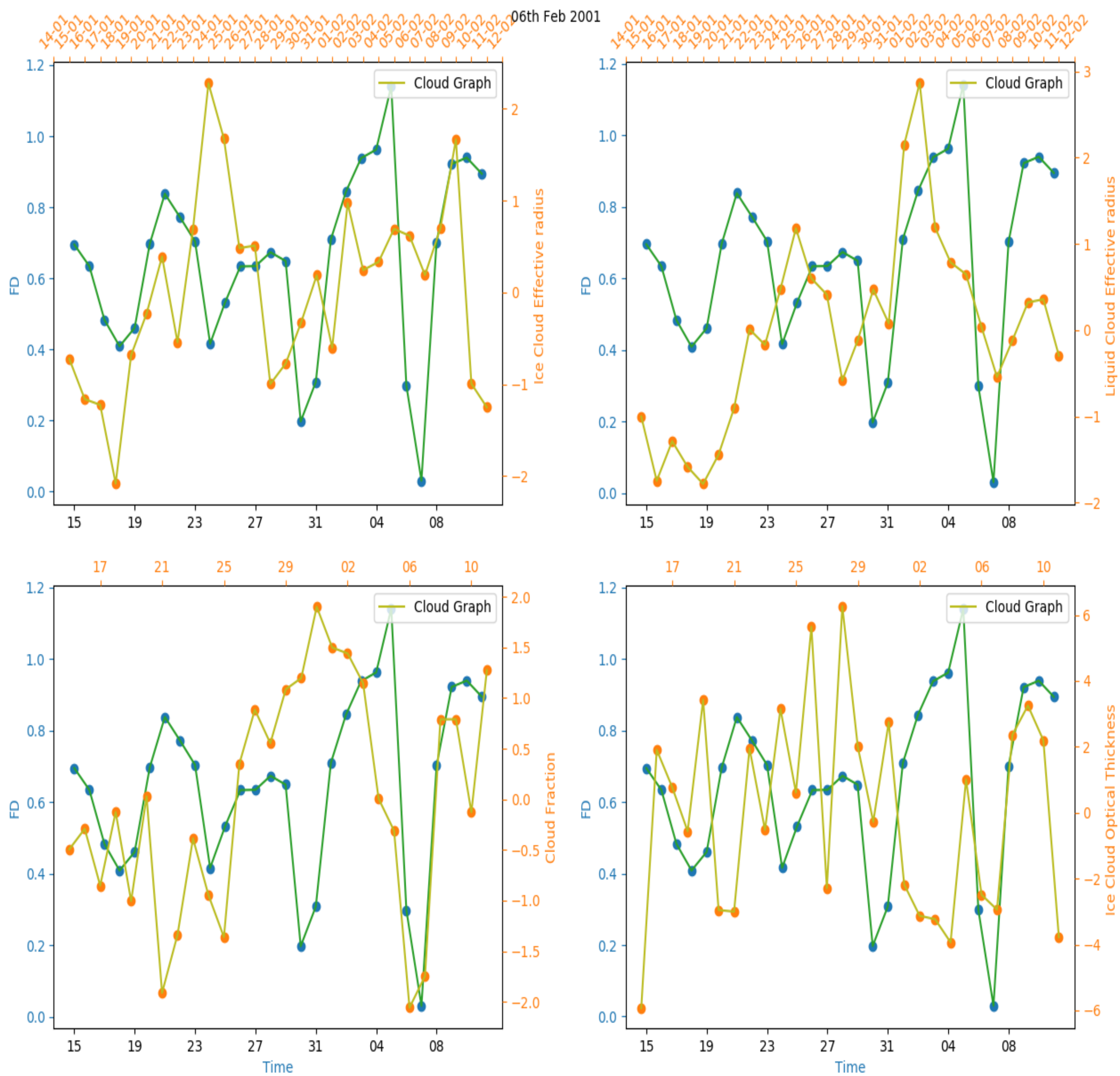


*Figure 15: FD event of 06$^{th}$ Feb, 01 plotted with the cloud property.*

'blue' dots and labels correspond to the FD event whereas the 'orange' one represents the cloud properties ice cloud effective radius, liquid cloud effective radius, cloud fraction and ice cloud optical thickness respectively. Both the 'y' axes are in % deviation.

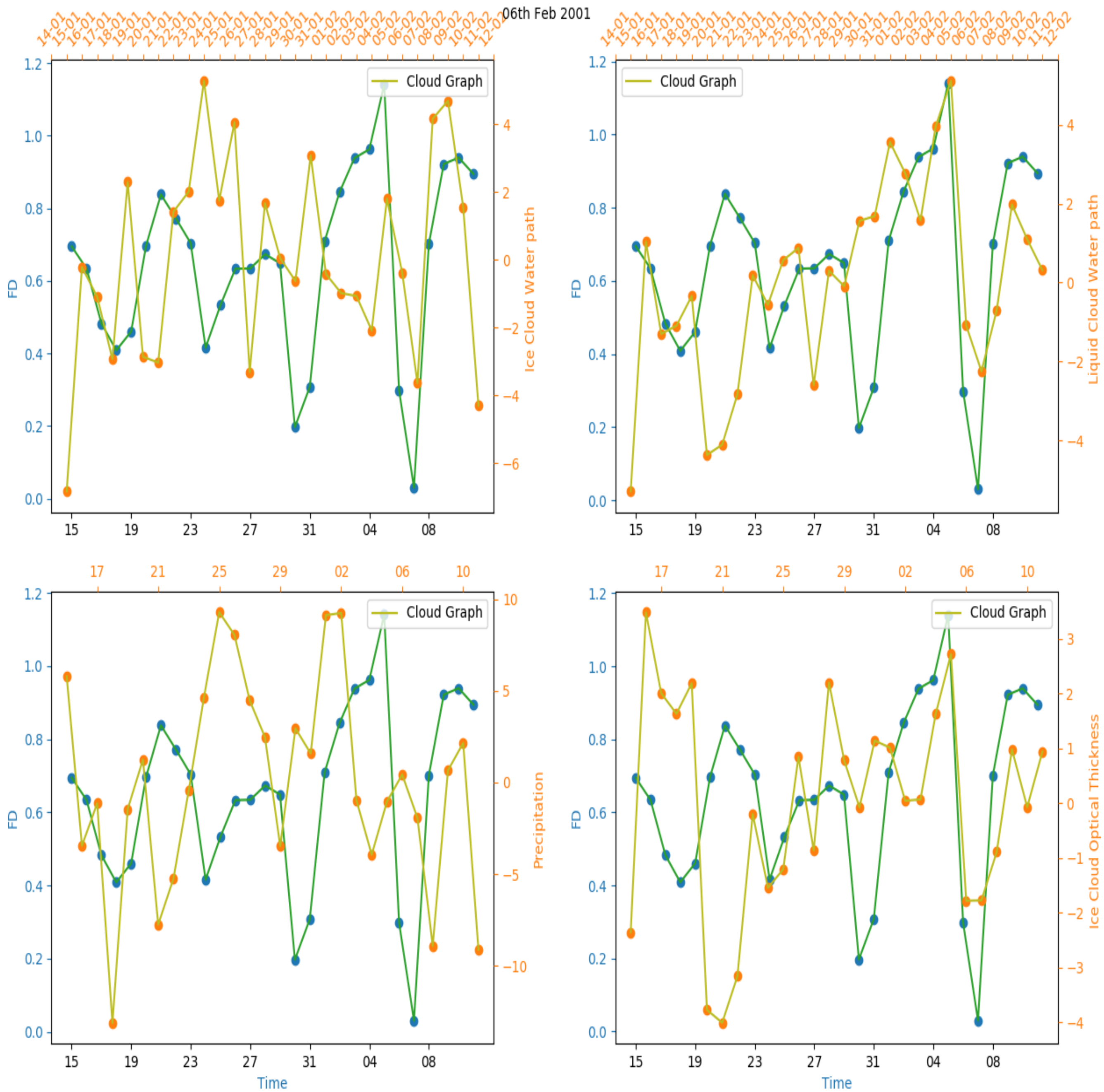


*Figure 16: FD data of 06th Feb, 01 plotted with the cloud property.*

'blue' dots and labels correspond to the FD event whereas the 'orange' one represents the cloud properties ice cloud water path, liquid cloud water path, precipitation and liquid cloud optical thickness respectively. Both the 'y' axes are in % deviation

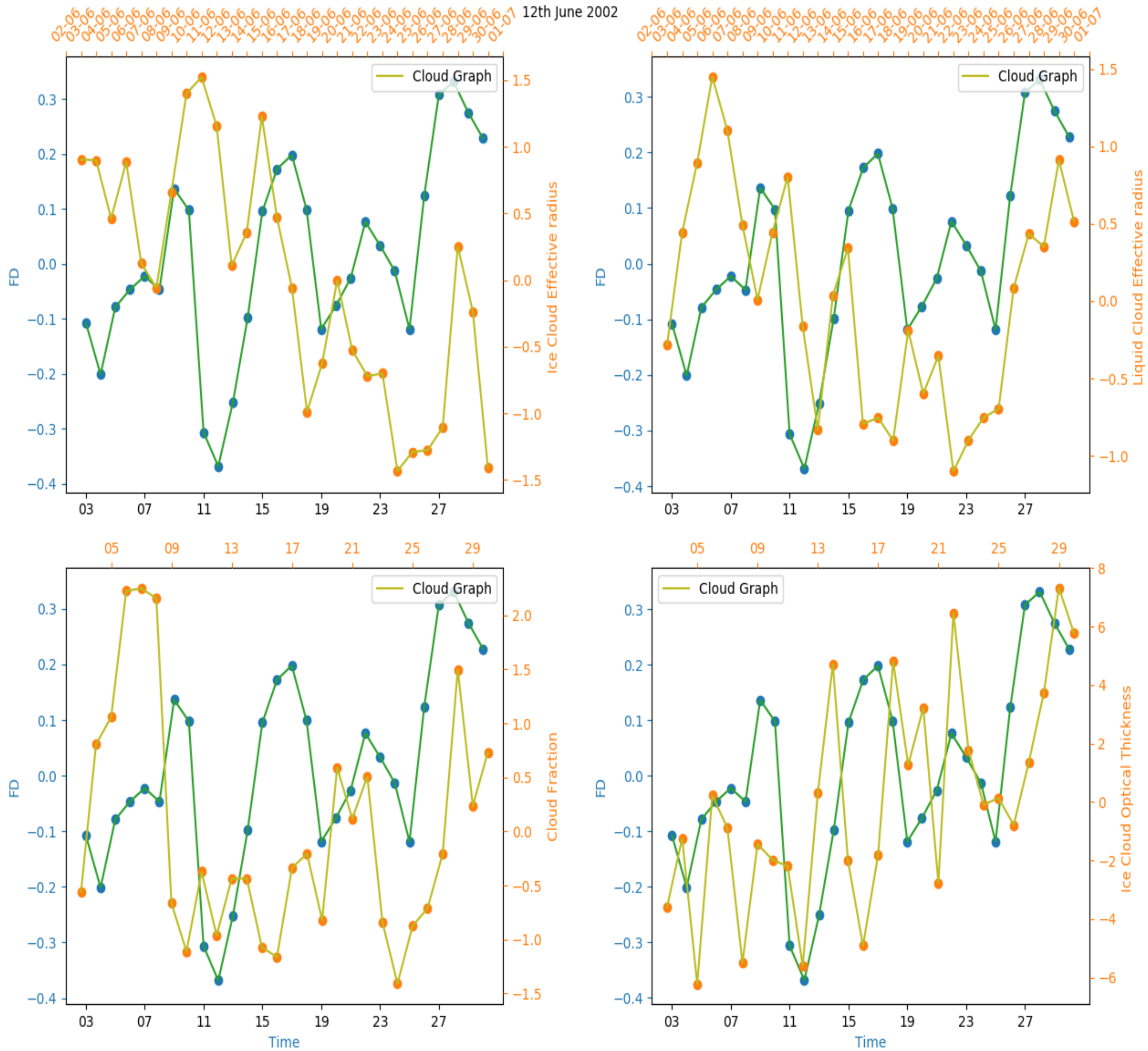


*Figure 17: FD event of 12$^{th}$ June, 02 plotted with the cloud property data.*

‘blue’ dots and labels correspond to the FD event whereas the ‘orange’ one represents the cloud properties ice cloud effective radius, liquid cloud effective radius, cloud fraction and ice cloud optical thickness respectively. Both the ‘y’ axes are in % deviation.

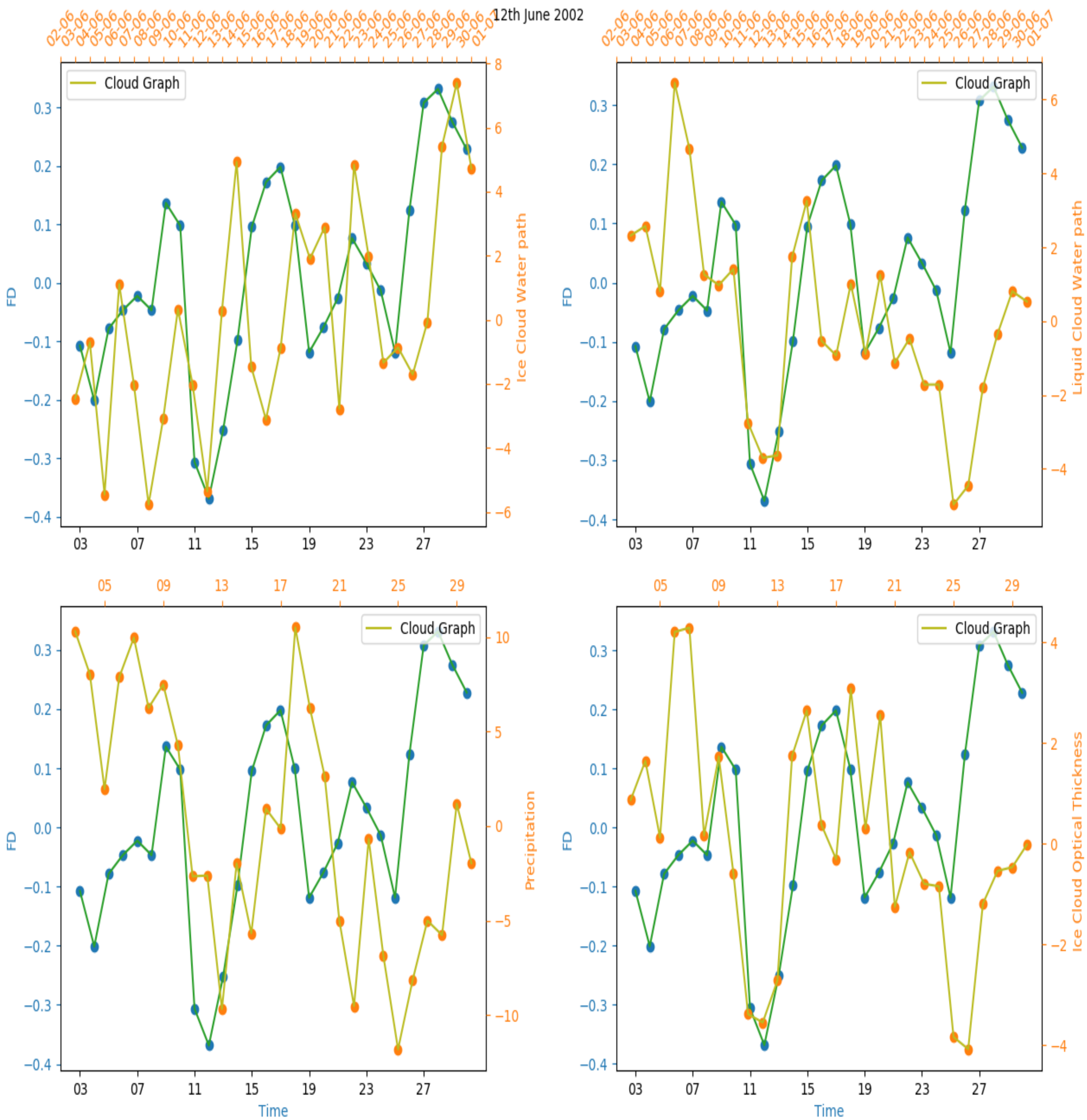


*Figure 18: FD event of 12th June, 02 plotted with the cloud property data.*

'blue' dots and labels correspond to the FD event whereas the 'orange' one represents the cloud properties ice cloud water path, liquid cloud water path, precipitation and liquid cloud optical thickness respectively. Both the 'y' axes are in % deviation

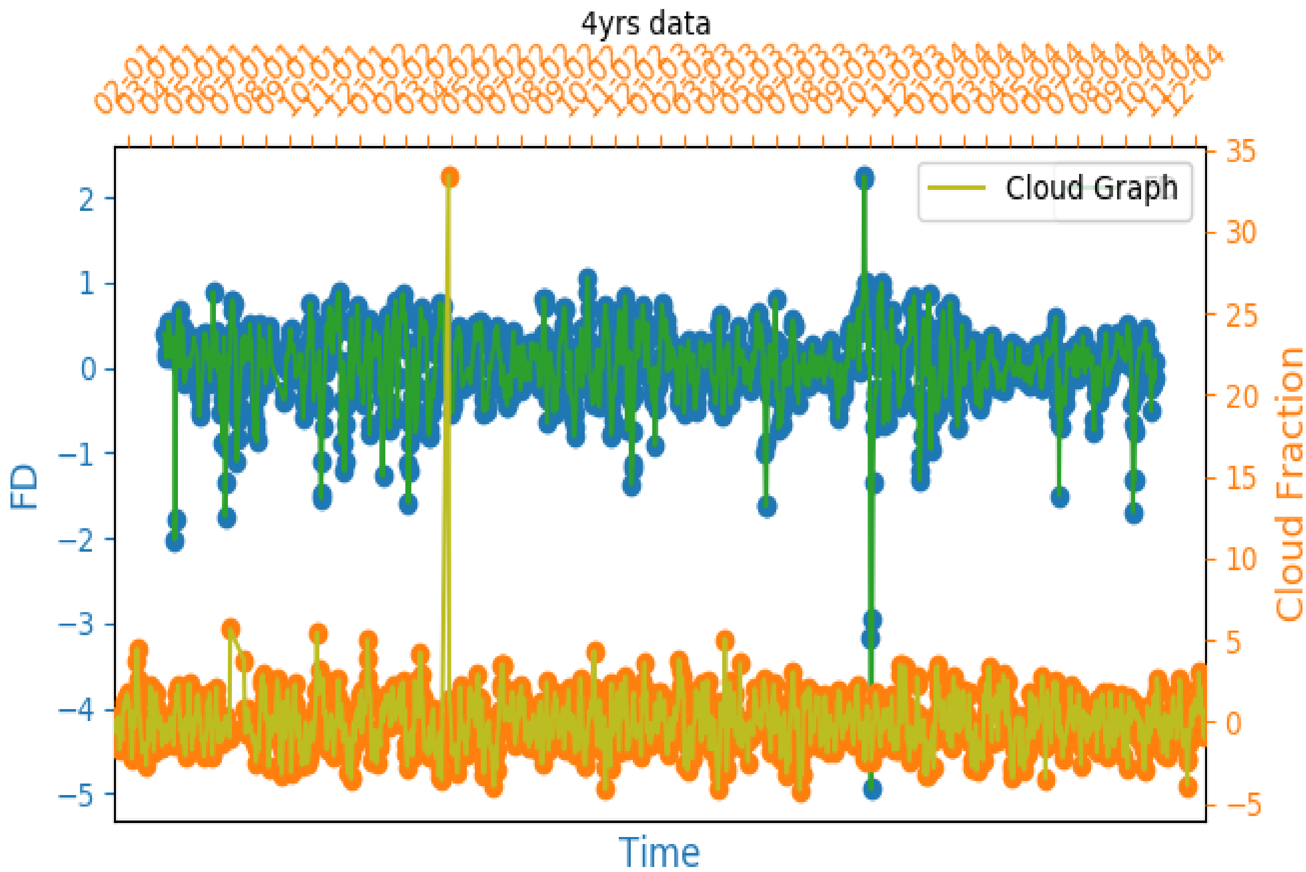


*Figure 19: Full 4 years data from 2001-2005 of cosmic data and the cloud data plotted together.*

Here the FD data is plotted with the Cloud fraction data.

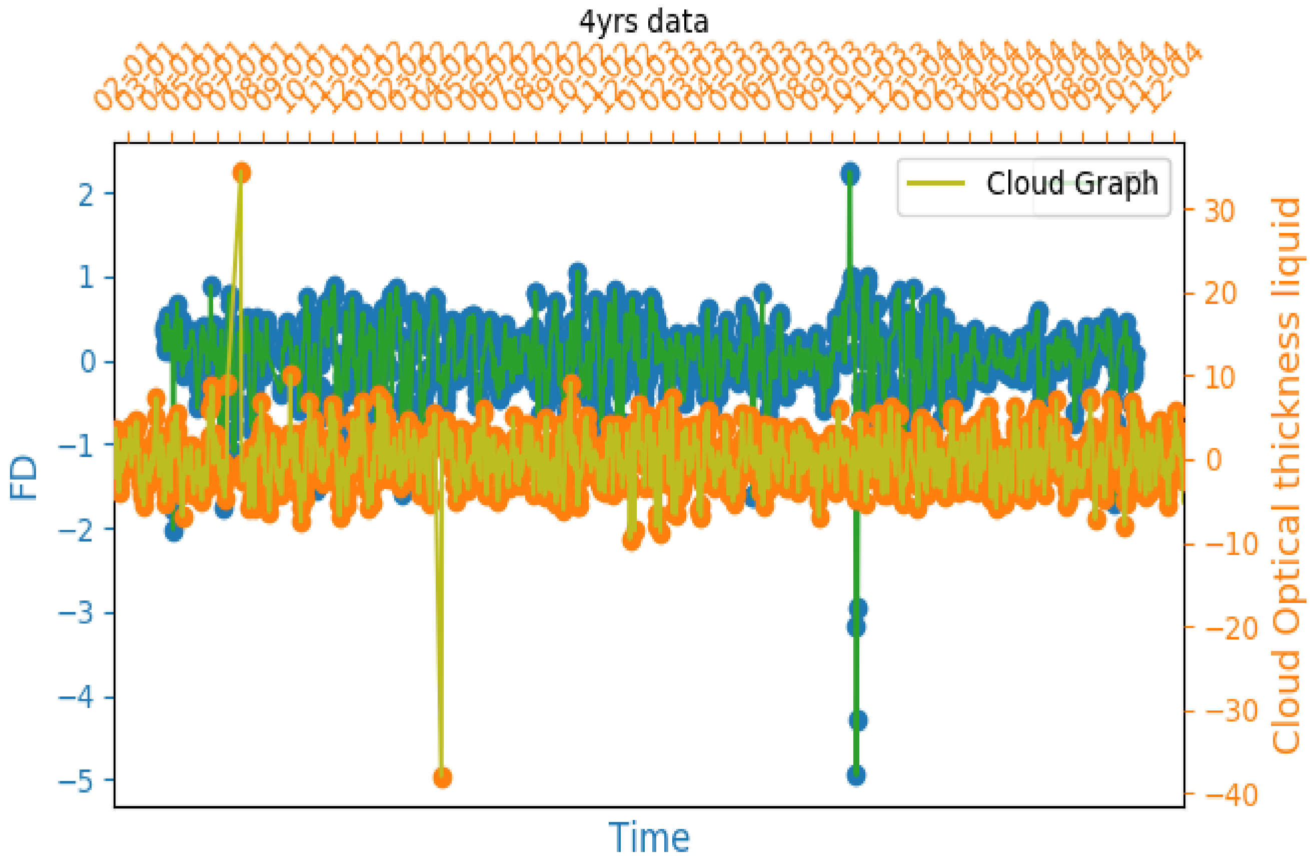


*Figure 20: Full 4 years data from 2001-2005 of cosmic data and the cloud data is plotted together.*

Here the FD data is plotted with the Cloud Optical thickness liquid.

Table showing the **correlation values** between the FD data and the various cloud properties data for 66 events below:

Abbreviations are same as stated in the cloud part of the about the project section where here I stand for the Ice cloud and L stands for the liquid cloud properties.

Abbreviations used are as follows:

**COTL**- Cloud optical thickness liquid

**CERI**- Cloud effective radius ice

**CERL**- Cloud effective radius liquid

**CF**- Cloud fraction

**COTI**- Cloud optical thickness ice

**CWPI**- Cloud water path ice

**CWPL**- Cloud water path liquid

**Pr**- Precipitation

## 5.2 Table 2: table showing the correlation values between each FD event with the cloud properties.

| Events | COTL | CERI | CERL | CF | COTI | CWPI | CWPL | Pr |
|---|---|---|---|---|---|---|---|---|
| 29-10-03 | -0.1799 | 0.2507 | 0.1173 | 0.2576 | 0.3087 | 0.4595 | -0.0416 | 0.404 |
| 31-12-01 | -0.5801 | 0.3281 | 0.2904 | -0.5129 | -0.4228 | -0.234 | -0.5093 | -0.1679 |
| 12-04-01 | 0.2688 | 0.0909 | -0.0277 | 0.0239 | 0.4111 | 0.3515 | 0.2658 | 0.2433 |
| 06-11-01 | -0.1619 | -0.3448 | -0.4417 | 0.2699 | 0.451 | 0.2902 | -0.2686 | 0.1657 |
| 23-01-04 | 0.3592 | -0.357 | -0.4144 | 0.2331 | 0.2059 | -0.0306 | 0.1209 | -0.2393 |
| 01-06-03 | 0.2098 | -0.4954 | -0.0676 | -0.18 | -0.0235 | -0.1009 | 0.1332 | 0.1172 |
| 28-08-01 | 0.2083 | 0.3005 | 0.2668 | 0.0337 | 0.3586 | 0.3835 | 0.3593 | 0.3154 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 10-11-04 | -0.4967 | 0.3111 | 0.3824 | -0.3201 | -0.1594 | -0.0317 | -0.2829 | -0.3032 |
| 27-07-04 | -0.0926 | 0.403 | -0.6508 | -0.1913 | 0.1247 | 0.3308 | 0.1893 | -0.1291 |
| 26-09-01 | -0.5571 | 0.1485 | 0.262 | -0.2512 | -0.0046 | -0.0836 | -0.5625 | -0.2983 |
| 20-07-02 | -0.3773 | -0.078 | -0.1842 | 0.0454 | -0.2163 | -0.177 | -0.2584 | 0.1016 |
| 22-10-03 | -0.3772 | 0.3093 | 0.6117 | -0.1521 | 0.2857 | 0.3894 | -0.1581 | 0.3847 |
| 29-04-01 | 0.2577 | 0.3327 | 0.506 | 0.2509 | 0.3674 | 0.3451 | 0.2218 | -0.0508 |
| 12-11-02 | 0.0137 | -0.2673 | -0.0458 | 0.1334 | -0.3217 | -0.3524 | 0.1365 | -0.2417 |
| 18-11-02 | 0.1294 | -0.4046 | -0.4674 | -0.1159 | -0.1543 | -0.1843 | 0.1613 | -0.1322 |
| 04-12-01 | 0.2395 | 0.3201 | -0.0995 | 0.3251 | 0.1622 | 0.2622 | 0.3245 | 0.3518 |
| 01-10-01 | -0.082 | -0.1242 | -0.3756 | 0.1401 | -0.3089 | -0.236 | -0.2123 | -0.1761 |
| 15-12-01 | -0.0434 | 0.2913 | -0.1077 | 0.0852 | 0.1355 | 0.2219 | 0.0661 | 0.4582 |
| 06-02-01 | 0.1235 | 0.0572 | 0.2861 | 0.2423 | -0.0903 | 0.0259 | 0.3165 | -0.0714 |
| 25-11-01 | -0.1316 | 0.0751 | 0.172 | -0.0455 | 0.1559 | 0.1411 | -0.1548 | 0.1219 |
| 20-10-02 | -0.083 | -0.5761 | 0.0081 | 0.4174 | 0.016 | -0.0627 | 0.0133 | 0.2821 |
| 06-12-04 | 0.3282 | -0.0242 | 0.3971 | -0.3774 | -0.0275 | -0.0033 | 0.4072 | 0.1402 |
| 28-08-02 | 0.1153 | -0.4124 | -0.5188 | 0.6472 | 0.278 | 0.1986 | 0.074 | -0.1679 |
| 11-01-02 | -0.49 | 0.3798 | 0.4539 | 0.2434 | -0.6052 | -0.54 | -0.2771 | -0.0501 |
| 31-03-03 | -0.2501 | -0.3492 | -0.3763 | 0.2498 | 0.1498 | -0.012 | -0.337 | -0.0349 |
| 30-01-02 | -0.0458 | -0.1203 | -0.2816 | 0.34 | -0.472 | -0.4801 | -0.0683 | 0.367 |
| 03-03-04 | -0.0543 | 0.0271 | -0.2557 | -0.6176 | 0.0654 | 0.139 | 0.0068 | -0.4634 |
| 24-11-03 | -0.2729 | 0.2552 | -0.0116 | -0.1592 | 0.1373 | 0.1132 | -0.2787 | 0.1755 |
| 12-10-01 | -0.082 | -0.1242 | -0.3756 | 0.1401 | -0.3089 | -0.236 | -0.2123 | -0.1761 |
| 28-03-01 | -0.1561 | 0.3071 | -0.3969 | -0.6672 | -0.3708 | -0.2623 | -0.0276 | -0.3501 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 05-04-01 | 0.2688 | 0.0909 | -0.0277 | 0.0239 | 0.4111 | 0.3515 | 0.2658 | 0.2433 |
| 23-12-02 | -0.6746 | -0.6447 | 0.0161 | 0.2066 | -0.6789 | -0.7078 | -0.6401 | -0.3367 |
| 18-08-01 | 0.2079 | 0.2159 | 0.1038 | 0.6724 | 0.0505 | 0.1162 | 0.1574 | 0.1931 |
| 16-11-03 | 0.4467 | -0.3827 | -0.447 | 0.3689 | 0.5687 | 0.4528 | 0.3358 | 0.3653 |
| 14-02-04 | -0.2106 | 0.3288 | 0.0647 | -0.4125 | -0.2949 | -0.2179 | -0.1676 | -0.5033 |
| 08-04-01 | 0.2688 | 0.0909 | -0.0277 | 0.0239 | 0.4111 | 0.3515 | 0.2658 | 0.2433 |
| 15-09-04 | -0.0465 | 0.131 | -0.4554 | -0.1588 | -0.3705 | -0.3852 | -0.0248 | -0.0532 |
| 31-01-01 | 0.1235 | 0.0572 | 0.2861 | 0.2423 | -0.0909 | 0.0299 | 0.3165 | -0.0714 |
| 22-12-03 | -0.2714 | -0.2766 | 0.1003 | 0.0568 | -0.0473 | -0.0267 | -0.334 | 0.2702 |
| 01-10-02 | 0.1194 | -0.0567 | -0.2992 | 0.2805 | 0.0294 | 0.2263 | 0.1633 | 0.1896 |
| 23-05-02 | -0.3321 | 0.2593 | 0.0387 | 0.456 | -0.6452 | -0.5693 | -0.362 | 0.4822 |
| 05-10-02 | 0.1194 | -0.0567 | -0.2992 | 0.2805 | 0.0294 | 0.2263 | 0.1633 | 0.1896 |
| 28-05-01 | -0.6202 | -0.1328 | -0.0024 | -0.1502 | -0.4335 | -0.3991 | -0.6733 | 0.3528 |
| 10-12-03 | 0.008 | -0.3448 | -0.0753 | 0.45 | -0.0791 | -0.1119 | -0.0223 | -0.2437 |
| 30-03-04 | 0.0038 | 0.035 | -0.1921 | 0.1638 | -0.0822 | -0.0664 | -0.0486 | -0.0111 |
| 18-02-03 | -0.3443 | 0.5336 | -0.2889 | -0.243 | -0.2862 | -0.2293 | -0.4019 | -0.0047 |
| 03-02-03 | -0.0216 | -0.2028 | -0.6757 | 0.2897 | -0.2195 | -0.3583 | -0.2783 | -0.0301 |
| 15-07-03 | 0.1278 | 0.2242 | 0.0506 | 0.3647 | 0.4484 | 0.3823 | 0.0462 | 0.2479 |
| 11-04-03 | -0.2453 | -0.1246 | -0.2856 | 0.222 | 0.0543 | -0.0174 | -0.181 | 0.0681 |
| 12-03-04 | -0.0543 | -0.0271 | -0.2557 | -0.6176 | 0.0654 | 0.139 | 0.0068 | -0.4634 |
| 12-09-03 | -0.3082 | -0.3717 | -0.0179 | 0.0859 | 0.1906 | 0.0931 | -0.303 | -0.2758 |
| 22-05-03 | 0.3165 | -0.1292 | 0.2568 | 0.088 | -0.0788 | -0.1224 | 0.2814 | 0.3138 |
| 05-03-01 | 0.111 | 0.0499 | -0.1343 | 0.6102 | 0.1198 | 0.0465 | 0.1405 | 0.3117 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 10-01-03 | 0.1409 | 0.1103 | 0.1972 | -0.4275 | 0.5031 | 0.5696 | 0.1038 | 0.1628 |
| 02-09-04 | -0.2255 | -0.4967 | -0.1432 | -0.214 | 0.1424 | -0.0548 | -0.2606 | 0.0749 |
| 01-07-04 | -0.2229 | -0.069 | 0.1304 | -0.0659 | -0.2895 | -0.343 | -0.2174 | 0.0674 |
| 22-09-04 | -0.0465 | 0.131 | -0.4554 | -0.1588 | -0.3705 | -0.3852 | -0.0248 | -0.0532 |
| 24-01-03 | 0.3538 | 0.1237 | -0.4953 | -0.0873 | -0.0647 | -0.1505 | 0.1924 | -0.4973 |
| 19-06-03 | 0.3961 | 0.1487 | -0.2419 | -0.4716 | 0.0329 | -0.0316 | 0.3018 | 0.0203 |
| 28-10-01 | 0.4196 | -0.1959 | -0.5882 | -0.2218 | 0.402 | 0.2566 | 0.0595 | 0.1677 |
| 24-01-01 | -0.273 | -0.0346 | 0.1576 | 0.0176 | -0.2826 | -0.2839 | -0.2534 | -0.106 |
| 27-07-03 | -0.3178 | -0.1267 | 0.1766 | 0.3121 | -0.14 | -0.2287 | -0.3875 | -0.457 |
| 12-06-02 | 0.1755 | -0.3702 | 0.0478 | 0.0683 | 0.4113 | 0.4223 | 0.1364 | -0.0601 |
| 18-08-03 | -0.2719 | -0.0779 | 0.23 | 0.1762 | -0.5723 | -0.582 | -0.3594 | -0.16 |
| 22-03-01 | -0.1561 | 0.3071 | -0.3969 | -0.6672 | -0.3708 | -0.2623 | -0.0276 | -0.3501 |
| 19-06-02 | 0.1755 | -0.3702 | 0.0478 | 0.0683 | 0.4113 | 0.4223 | 0.1364 | -0.0601 |

After the above process the student two tailed t test was performed on the above obtained correlation values to check for the significance of the obtained values.

From the t distribution table, the t- critical value was obtained to be compared with the calculated t- statistic values with the following parameters:

Degree of freedom for the sample data was df= 28 'alpha' value chosen is at the 95% confidence interval. t- critical is: $\mathbf{t_c = 2.0484}$ for the +ve direction and -2.0484 for the -ve direction as it is the two-tailed test.

Below is the table showing the values of the t- statistic calculated for each correlation values obtained. Its in the same order of events as above.

Below abbreviations used in the table of cloud properties are same as that in the Table: 2.

## 5.3 Table 3: Table showing the t- statistic values calculated for each of the above obtained correlation values.

| COTL | CERI | CERL | CF | COTI | CWPI | CWPL | Pr |
|---|---|---|---|---|---|---|---|
| -0.9325 | 1.3205 | 0.6023 | 1.3594 | 1.6549 | 2.638 | -0.2123 | 2.252 |
| -3.6314 | 1.771 | 1.5474 | -3.0465 | -2.379 | -1.2272 | -3.0176 | -0.8685 |
| 1.423 | 0.4654 | -0.1413 | 0.1219 | 2.2995 | 1.9145 | 1.4059 | 1.279 |
| -0.8366 | -1.873 | -2.5104 | 1.4293 | 2.5766 | 1.5463 | -1.4218 | 0.8568 |
| 1.9625 | -1.9488 | -2.3218 | 1.2223 | 1.0729 | -0.1561 | 0.621 | -1.2567 |
| 1.0941 | -2.908 | -0.3455 | -0.9331 | -0.1199 | -0.5171 | 0.6853 | 0.6018 |
| 1.0859 | 1.6065 | 1.4116 | 0.1719 | 1.9588 | 2.1174 | 1.9632 | 1.6947 |
| -2.9181 | 1.6691 | 2.1103 | -1.7228 | -0.8233 | -0.1617 | -1.5039 | -1.6224 |
| -0.4742 | 2.2453 | -4.3707 | -0.9938 | 0.6408 | 1.7874 | 0.983 | -0.6638 |
| -3.4207 | 0.7657 | 1.3843 | -1.3233 | -0.0235 | -0.4278 | -3.469 | -1.5936 |
| -2.0774 | -0.3989 | -0.9556 | 0.2317 | -1.1297 | -0.917 | -1.3639 | 0.5208 |
| -2.0768 | 1.6584 | 3.9428 | -0.7847 | 1.5202 | 2.1557 | -0.8164 | 2.1251 |
| 1.3599 | 1.7989 | 2.9913 | 1.3216 | 2.0143 | 1.8749 | 1.1599 | -0.2594 |
| 0.0699 | -1.4144 | -0.2338 | 0.6863 | -1.7324 | -1.9201 | 0.7026 | -1.2701 |
| 0.6654 | -2.256 | -2.6959 | -0.595 | -0.7963 | -0.9561 | 0.8334 | -0.6801 |
| 1.2578 | 1.7228 | -0.5099 | 1.7529 | 0.8382 | 1.3854 | 1.7493 | 1.9163 |
| -0.4195 | -0.6382 | -2.0665 | 0.7215 | -1.6561 | -1.2383 | -1.1078 | -0.9122 |
| -0.2215 | 1.5527 | -0.5524 | 0.436 | 0.6973 | 1.1604 | 0.3378 | 2.6285 |
| 0.6346 | 0.2921 | 1.5225 | 1.2734 | -0.4623 | 0.1321 | 1.7013 | -0.365 |
| -0.6769 | 0.384 | 0.8903 | -0.2322 | 0.8048 | 0.7267 | -0.799 | 0.6262 |
| -0.4247 | -3.5939 | 0.0413 | 2.3421 | 0.0816 | -0.3203 | 0.0678 | 1.4993 |
| 1.7716 | -0.1234 | 2.2062 | -2.078 | -0.1403 | -0.0168 | 2.2733 | 0.722 |
| 0.5919 | -2.3083 | -3.0944 | 4.329 | 1.4757 | 1.0332 | 0.3784 | -0.8685 |
| -2.8662 | 2.0935 | 2.5974 | 1.2796 | -3.8764 | -3.2715 | -1.4705 | -0.2558 |
| -1.3171 | -1.9002 | -2.071 | 1.3154 | 0.7726 | -0.0612 | -1.8251 | -0.1781 |
| -0.2338 | -0.6179 | -1.4964 | 1.8435 | -2.73 | -2.7907 | -0.3491 | 2.0117 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| -0.2773 | 0.1382 | -1.3487 | -4.004 | 0.3342 | 0.7157 | 0.0347 | -2.6665 |
| -1.4464 | 1.3458 | -0.0592 | -0.8223 | 0.7068 | 0.5809 | -1.4797 | 0.909 |
| -0.4195 | -0.6382 | -2.0665 | 0.7215 | -1.6561 | -1.2383 | -1.1078 | -0.9122 |
| -0.8058 | 1.6454 | -2.2049 | -4.5673 | -2.0358 | -1.386 | -0.1408 | -1.9058 |
| 1.423 | 0.4654 | -0.1413 | 0.1219 | 2.2995 | 1.9145 | 1.4059 | 1.279 |
| -4.6598 | -4.3003 | 0.0821 | 1.0767 | -4.7148 | -5.109 | -4.2482 | -1.8233 |
| 1.0838 | 1.1275 | 0.5322 | 4.632 | 0.2578 | 0.5965 | 0.8127 | 1.0035 |
| 2.5459 | -2.1122 | -2.548 | 2.0238 | 3.5254 | 2.5895 | 1.8178 | 2.001 |
| -1.0985 | 1.7753 | 0.3306 | -2.3089 | -1.5737 | -1.1384 | -0.8669 | -2.9699 |
| 1.423 | 0.4654 | -0.1413 | 0.1219 | 2.2995 | 1.9145 | 1.4059 | 1.279 |
| -0.2374 | 0.6738 | -2.6083 | -0.8201 | -2.0339 | -2.1284 | -0.1265 | -0.2717 |
| 0.6346 | 0.2921 | 1.5225 | 1.2734 | -0.4654 | 0.1525 | 1.7013 | -0.365 |
| -1.4378 | -1.4676 | 0.514 | 0.2901 | -0.2415 | -0.1362 | -1.8068 | 1.431 |
| 0.6132 | -0.2896 | -1.5989 | 1.4901 | 0.15 | 1.1846 | 0.844 | 0.9846 |
| -1.7953 | 1.369 | 0.1975 | 2.6126 | -4.3061 | -3.5309 | -1.9801 | 2.8066 |
| 0.6132 | -0.2896 | -1.5989 | 1.4901 | 0.15 | 1.1846 | 0.844 | 0.9846 |
| -4.0314 | -0.6832 | -0.0122 | -0.7747 | -2.4529 | -2.2194 | -4.6434 | 1.9226 |
| 0.0408 | -1.873 | -0.385 | 2.5694 | -0.4046 | -0.5742 | -0.1137 | -1.2813 |
| 0.0194 | 0.1786 | -0.9981 | 0.8467 | -0.4206 | -0.3393 | -0.2481 | -0.0566 |
| -1.8699 | 3.2171 | -1.5387 | -1.2773 | -1.523 | -1.2012 | -2.238 | -0.024 |
| -0.1102 | -1.056 | -4.6738 | 1.5434 | -1.1472 | -1.9569 | -1.4774 | -0.1536 |
| 0.657 | 1.1731 | 0.2583 | 1.9972 | 2.558 | 2.1096 | 0.2358 | 1.3048 |
| -1.2902 | -0.6403 | -1.5196 | 1.161 | 0.2773 | -0.0887 | -0.9384 | 0.3481 |
| -0.2773 | -0.1382 | -1.3487 | -4.004 | 0.3342 | 0.7157 | 0.0347 | -2.6665 |
| -1.6519 | -2.0416 | -0.0913 | 0.4396 | 0.99 | 0.4768 | -1.6212 | -1.4631 |
| 1.7013 | -0.6644 | 1.3549 | 0.4505 | -0.4031 | -0.6288 | 1.4953 | 1.6852 |
| 0.5695 | 0.2548 | -0.6911 | 3.9273 | 0.6153 | 0.2374 | 0.7236 | 1.6727 |
| 0.7257 | 0.5659 | 1.0257 | -2.4113 | 2.9683 | 3.5337 | 0.5322 | 0.8413 |
| -1.1802 | -2.9181 | -0.7378 | -1.1171 | 0.7336 | -0.2798 | -1.3764 | 0.383 |
| -1.1659 | -0.3527 | 0.6706 | -0.3368 | -1.5422 | -1.8619 | -1.1357 | 0.3445 |
| -0.2374 | 0.6738 | -2.6083 | -0.8201 | -2.0339 | -2.1284 | -0.1265 | -0.2717 |
| 1.9288 | 0.6356 | -2.9072 | -0.4469 | -0.3306 | -0.7762 | 0.9997 | -2.9228 |
| 2.1996 | 0.7667 | -1.2712 | -2.727 | 0.1678 | -0.1612 | 1.6141 | 0.1035 |
| 2.3571 | -1.0186 | -3.7087 | -1.1599 | 2.2387 | 1.3537 | 0.3039 | 0.8674 |
| -1.447 | -0.1765 | 0.8138 | 0.0898 | -1.5022 | -1.5097 | -1.3357 | -0.5436 |
| -1.7091 | -0.6513 | 0.9149 | 1.6751 | -0.721 | -1.1979 | -2.1433 | -2.6198 |
| 0.909 | -2.032 | 0.244 | 0.3491 | 2.3009 | 2.3755 | 0.7021 | -0.307 |
| -1.4407 | -0.3984 | 1.2051 | 0.9127 | -3.5586 | -3.6494 | -1.9638 | -0.8265 |
| -0.8058 | 1.6454 | -2.2049 | -4.5673 | -2.0358 | -1.386 | -0.1408 | -1.9058 |
| 0.909 | -2.032 | 0.244 | 0.3491 | 2.3009 | 2.3755 | 0.7021 | -0.307 |

## 5.4 Discussion

From the above obtained graphs and the correlation values table we can clearly see that there isn't much of the correlation between the various cloud properties and the FD event data even for the 4years continuous data was plotted together.

We can see from the correlation table that for few higher magnitude events there is a correlation value going beyond 0.5 and 0.6 with at least one of the cloud property like for the 31st Dec 01, 27th July 04, 22nd Oct 03 and 3rd March 04.

For one of the mid- range magnitude event such as 23rd Dec 02 with four of the cloud properties it goes beyond the 0.6 value and for one of them it even reaches beyond the 0.7 but still, as a whole we find that there isn't much of the events even larger in magnitudes also which shows the clear signs of correlation.

For the events no 24, 32 and 34 in the table 2 we see that in spite of being the low correlated events they were found to be significant with most of the cloud properties whereas, for the events no 38, 39 and 40 there was not a single correlation value also among the eight correlation values corresponding to each event which was found to be significant

The significance test table too above obtained suggests that for most of the events the correlation was not found to be significant i.e. we can't discard the null hypothesis that there isn't any correlation between the two quantities for the global cloud data with that of the FD event data.

There's still a hope to see some changes in the ionization rate during these events which would be calculated from the obtained parameters values from the fitting done for the FD event data earlier.

# 6 Conclusion

The results obtained so far in this work suggests that there isn't much of correlation between the FD and the global cloud cover data either event wise or for the 4 years cumulative data as. For most of the events we see that it shows the positive correlation with the global cloud cover data during some events and negative correlation as well during the other events with the same cloud property. It seems to be inconclusive from the above study and to come up with the appropriate mechanisms or suggestions for this behaviour.

Much of the correlation values calculated was found not to be significant in the student-t test and even if there is some correlation then that is very weak for the global cloud cover data.

This area of study is such that we need to have more and more research on this to come up with the more robust conclusions as the cloud cover is affected by the various local and global factors such as El Nino, La Nina, volcanic eruptions, pollution etc so there is much noise into this system which makes it more difficult to come up with the strong conclusions.

Sometimes there is the issue in the data also so we may have some errors during the capturing of data due to various reasons one such problem which was highlighted earlier during many studies states that due to the cloud cover present in the mid- level or high- level obscures the observation for the low- cloud cover data (**Benjamin.A. Laken et.al, 2012)**.

As (**Svensmark et.al, 2016)** study shows that the FD events cause the change in the ionization in the atmosphere which in turn changes the CCN formation leading to the changes in the cloud cover. In this study the parameters have been calculated which would later be used for the calculation of changes in the ionization in the atmosphere to see if there has been any significant changes or not.

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