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Dependence of Some Features of VLF Sferics on Source and Propagation Parameters

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Abstract. The paper deals with some features of Integrated Field Intensity of Sferics (IFIS) at 21.5 kHz recorded over Tripura (Lat. 23° N, Long. 91.4° E), the hilly place of North-East India. The data are critically analyzed with respect to the variation of seasons. The results have been explained on the basis of the source parameter and propagation parameter of sferics.

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1 Introduction

The electromagnetic energy radiated due to lightning discharges extends over a wide bandwidth from a few hertz to many tens of mega hertz, although most of the radiated energy lies in VLF (3–30 kHz) and ELF (3–3000 Hz) bands. Previous experiments showed that the peak of the Fourier components lies in very low frequency (VLF) range [1,2].

These impulse-like signals known as sferics, are reflected by the lower ionosphere and ground and hence, propagate between the two boundaries (Earth-ionospheric waveguide) in a guided fashion several thousand kilometers before its strength decays to noise level. Number, amplitude and waveform of detectable sferic-signals depend primarily on the kind of discharge, distance between source and detector and conditions of transmission in the atmosphere [3].

It is very difficult to study the characteristics of ionospheric D-region, because of small electron densities (10^9 m^{-3}) and high electron-neutral collision frequencies (10^6 s^{-1}). But the VLF waves are well reflected by the D-region and this fact made VLF waves as a tool to gather information regarding this improperly explored region. Diurnal, seasonal and transient variations in the structure of the lower ionosphere that are controlled directly by solar conditions can cause large amplitude and phase variations in the VLF sferics field at a given location. Diurnal and annual variations of VLF radio noise have been studied earlier, but with no seasonal behaviour [3,4].

A continuous record of VLF sferics is going on in the north-eastern hilly state Tripura (Lat. 23° N, Long. 91.4° E). Observed Sferics waveforms radiated from lightning and received at long distances (> 1000 km) from the source contain information about the state of the ionosphere along the propagation path. The present work is a detail analysis of VLF sferics (21.5 kHz) over the premonsoon, monsoon, post-monsoon and winter period. The diurnal and seasonal variation of Integrated Field Intensity of Sferics (IFIS) yielded information about the propagation of the signal through the waveguide in relation to the position of the sun.

2 Instrumentation

The schematic diagram for the experimental arrangement is shown in Figure 1. An inverted L-type antenna has been used to receive the vertically polarized atmospherics in the VLF band from near and far sources. The induced voltage in the antenna is fed to the input buffer and filtered through the next stage using a low pass filter. The filtered output is then amplified accordingly and the output of this stage is fed to the high Q tuned circuit having a resonant frequency 21.5 kHz. The gain of the amplifier is so adjusted such that the maximum voltage induced in the antenna should not bring it to the saturation level. Then output envelope is detected using a diode detector. The time constant of the detector circuit is taken to be 0.22 s so as to get records of even small variations in sferics level. In the next stage of the receiver, a logarithmic amplifier is used to squeeze the voltage

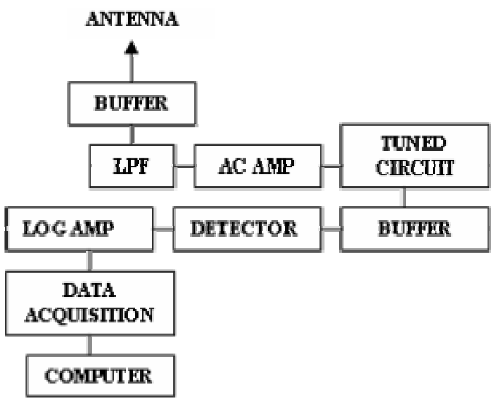

Figure 1. Block diagram of the receiver to record IFIS at 21.5 kHz.

and care is taken to maximize the dynamic range of the signal. At the output, a potential divider is used so that final output fed into the Data Acquisition System safely lies within 5 V. A capacitor is used at the output to cut-off very rapid insignificant fluctuations in dc level resulting in a total time constant of about 10 s. The overall band width is 1 kHz.

3 Data Collection for IFIS 21.5 kHz

The data of Integrated Field Intensity of Sferics (IFIS) have been recorded at Tripura (Lat. 23° N, Long. 91.4° E) on a diurnal basis. The data collection has been disturbed occasionally due to power failure in the locality. The data collection has been kept away while servicing and calibrating the instruments. The numbers of data collection over a period from 2002 to 2005 are shown in Table 1.

Table 1. Data collection for ARNFS at 21.5 kHz over various months

Month	Year				Total
	2002	2003	1904	2005	
January	11	11	13	12	**47**
February	10	09	13	13	**45**
March	11	12	14	17	**54**
April	11	13	14	15	**53**
May	12	11	13	14	**50**
June	13	12	14	16	**55**
July	12	13	16	16	**57**
August	11	13	14	16	**54**
September	11	11	13	14	**49**
October	12	13	14	15	**54**
November	13	13	14	13	**53**
December	13	12	16	16	**57**
Total	**140**	**143**	**168**	**177**	**628**

Table 1 exhibits that: (i) During 2002-2003, data collection could have been made for 39% of the days of the months; (ii) During 2004, it is around 46% of the total days; (iii) During 2005, it is slightly higher than 48% of the total days.

4 Experimental Observations

4.1 Diurnal behavior and its month-wise variation

The IFIS at 21.5 kHz shows characteristic variation over a day, and it is almost repeated in two successive days in the absence of severe local cloud activity. The record of a typical day is shown in Figure 2. The IFIS has been shown in Figire 2

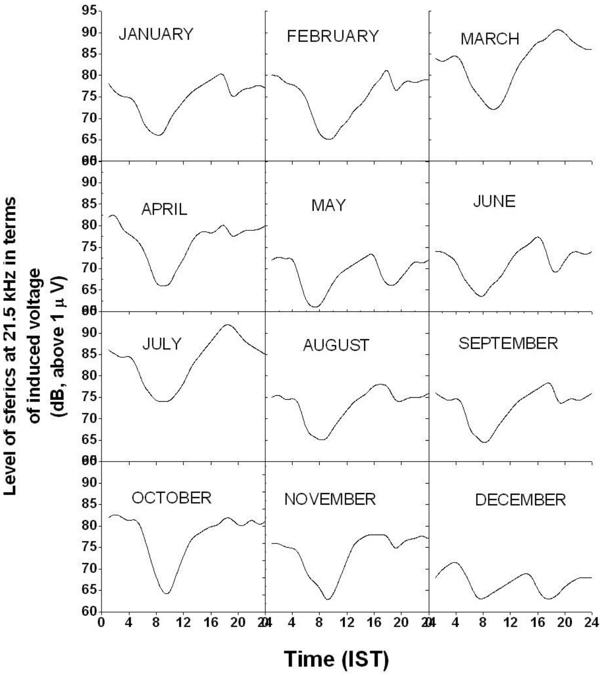

Figure 2. Diurnal variation of Integrated Field Intensity of Sferics at 21.5 kHz for various months. The ordinate represents the value in terms of induced voltage at the antenna in dB above 1 μV.

in terms of induced voltage at the antenna in dB above 1 μV for four years from 2002 to 2005. The ordinate represents the amplitude in terms of induced voltage in dB above 1 μV and the abscissa represents the time in hour (Indian Standard Time, IST).

The level of IFIS exhibits decrease during the sunrise. This fall in IFIS during sunrise is the sunrise effect. It is also called sunrise fade. In general, this kind of fall is obtained in meteorologically clear days. The sunrise effect is characterized by 2 or 3 small step falls. The magnitude of sunrise fades lies between 9–17 dB. It is worth mentioning that during severe local rain, the sunrise effect disappears. Sometimes, effect is observed without the steps. The magnitude of sunrise fade is dependent on season. The fall is found maximum during March to October. The sunrise effect is comparatively low from November to February. After sunrise effect, the level of IFIS remains low for half an hour to one hour. After that the level increases gradually. It shows a maximum during afternoon period.

The IFIS exhibits gradual fall followed by gradual rise during sunset. This is the sunset effect. The sunset fade lies between 4 to 9 dB. The magnitude of

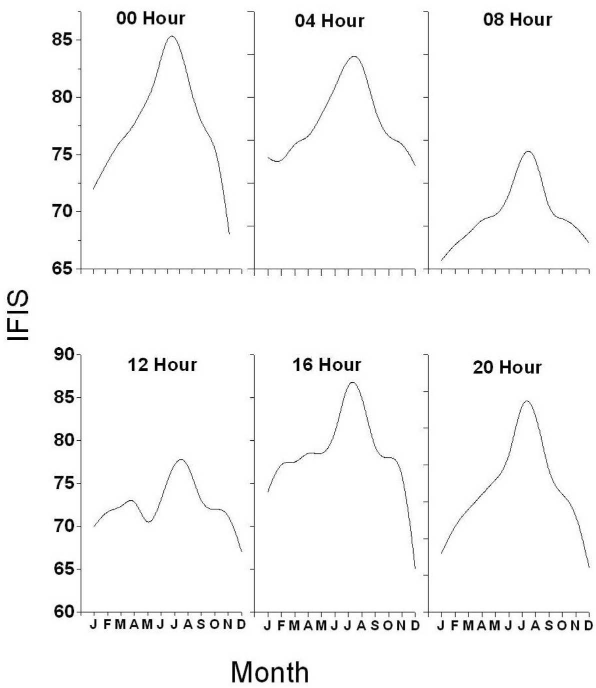

Figure 3. Monthly variation of IFIS at various hours of the day. The ordinate represents IFIS in terms of induced emf at the antenna in dB above 1 μV.

sunset effect is higher during December to May and of low value from June to November.

The monthly variations of the IFIS for six various hours, viz., 00:00, 04:00, 08:00, 12:00, 16:00 and 20:00 hours, IST, are shown in Figire 3.

The following results are obtained:

a) At all the hours, the level of IFIS is highest during July and August;

b) At 08:00 to 10:00 hour, the level is low in all months;

c) At 00:00, 12:00 and 16:00 hour, lowest IFIS levels are observed in December;

d) The December and January levels are comparable at 04:00 and 20:00 hours;

e) January level is lowest at 04:00 hour.

The IFIS shows its maximum value during afternoon or late afternoon. It is the "daily-maximum". The minimum value in a day is obtained during morning

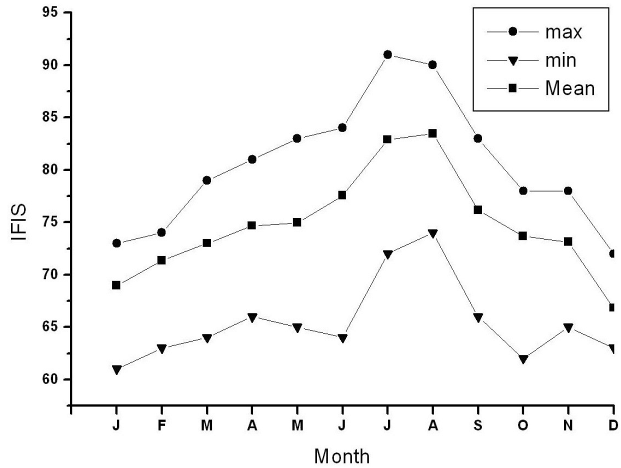

Figure 4. Graph showing the monthly variation of average level, maximum level and minimum level of IFIS of a day. The ordinate represents IFIS in terms of induced emf at the antenna in dB above 1 μV.

hours after sunrise. It is “daily-minimum”. The monthly variation of average value level, daily maximum and daily minimum are shown in Figire 4. The average level in a month is dependent on the cloud activity. From the results, it can be said that the average value of IFIS is highest in August, the value of the daily maximum is highest in July and the value of the daily minimum is highest in August. The lowest values of the average level, daily-maximum and daily minimum are observed in January and December. In the case of daily minimum, the level in October is also very low.

4.2 Seasonal variation

The monthly variation of the IFIS shows that IFIS depends on seasons. In order to study the seasonal variation, we divide a whole year into four seasons

a) Pre-monsoon (From March to Mid-June)

b) Monsoon (Mid-June to Mid-September)

c) Post-monsoon (Mid-September to November)

d) Winter (December to February).

Diurnal variations of integrated field intensity of atmospherics at 21.5 kHz for pre-monsoon, monsoon, post-monsoon and winter are shown in Figure 5. The ordinate represents the value in terms of induced voltage at the antenna in dB above 1 μV.

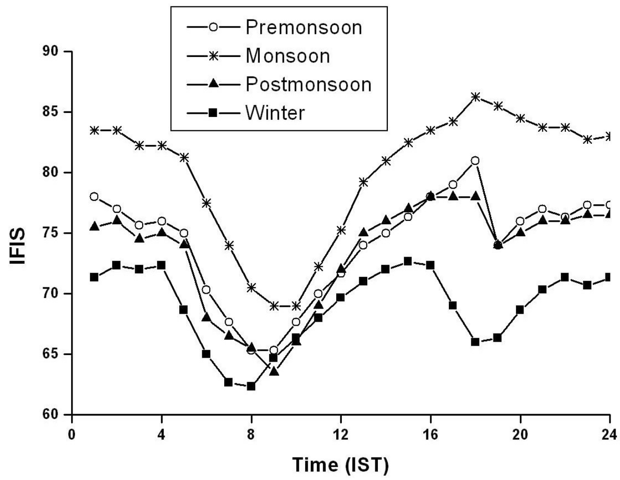

Figure 5. Diurnal variation of IFIS for various seasons. The ordinate represents the value in terms of induced voltage at the antenna in dB above 1 μV.

The following results are noticeable.

1. The daily maximum occurs during afternoon in winter and it occurs at the late afternoon periods in pre-monsoon, post-monsoon and monsoon.
2. In winter, daily minima occurs at 08:00 hour, in pre-monsoon and post-monsoon daily minimum occurs around 09:30 hour and in monsoon, it occurs at around 10:00 hour.
3. Sunset minimum occurs at the evening period in winter, pre-monsoon and post-monsoon seasons. Sunset minimum is not distinct in monsoon.
4. Variations of IFIS in post-monsoon and pre-monsoon are almost similar.

The seasonal dependence of the daily average of IFIS, the daily-maximum and the daily-minimum are shown in Figure 6.

The following results are noticeable:

1. The average of IFIS, the daily-maximum and the daily minimum are highest in monsoon.
2. The pre-monsoon level is slightly greater than post-monsoon value.
3. The daily minimum is almost same in post-monsoon and winter.

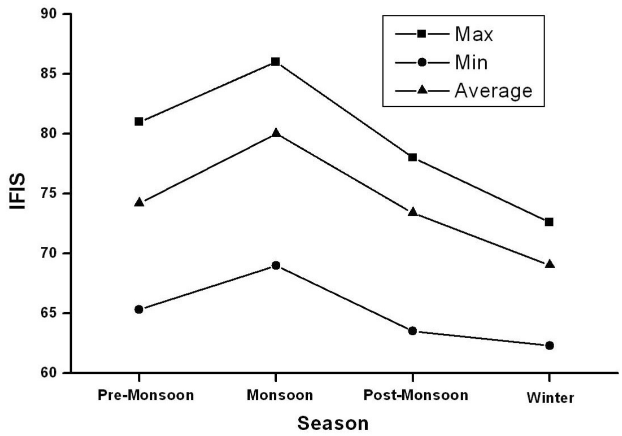

Figure 6. Seasonal variation of daily average level, level of daily-maximum and daily-minimum. The value of IFIS is in dB above 1 μV.

5 Discussion

The electromagnetic radiation of cloud discharge known as atmospherics or sferics are very much significant in regard to electric phenomenon going on in different types of cloud during meteorologically active periods. During clear period measurement of IFIS provides the study of ionospheric propagation. At Agartala we are in privileged position to study IFIS from the local cloud discharge as well as from the distant sources of Australia, Japan and Africa. The variation of electric field ΔE due to cloud discharge can be expressed by Fourier transform:

$$\Delta E(d,t) = \int a(d,\nu)\exp(i\nu t)\mathrm{d}\nu \tag{1}$$

$$a(d,\nu) = \int \Delta E(d,t)\exp(-i\nu t)\mathrm{d}t \tag{2}$$

The received Fourier component at frequency ν at distance d can be expressed as [5,6]

$$a(d,\nu) = G(\nu)W(d,\nu), \tag{3}$$

where $G(\nu)$ is the function of spectral source and $W(d,\nu)$ is the waveguide transmission function.

The electric charges separated in ordinary thunderstorm cloud (cumulonimbus) are the most common sources of lightning. Over 50% of the lightning discharges occur within the thunderstorm clouds and are called intra-cloud discharges. Cloud-to-cloud and cloud-to-air discharges are less common than intra-cloud and cloud-to-ground lightnings. All lightnings other than cloud-to-ground are often lumped together and called cloud discharges.

The IFIS consists of electromagnetic radiation from two groups of atmospheric sources, viz., the nearby and distant sources. During locally clear periods contributions to IFIS by the distant sources dominate. The electromagnetic radiation from distant sources reaches the receivers through earth-ionosphere waveguide. Considering normal electron density profile of the lower ionosphere, the daytime and the nighttime reflection heights are 70 and 90 km, respectively [7,8]. Prior to the sunrise, distant atmospherics are reflected from 90 km. At this stage, the region below 90 km acts as attenuator due to presence of electrons of very low density. After sunrise, the electron density in the absorption region gradually increases due to decrease of solar zenith angle. As a result, absorption goes on increasing until the D region is completely formed. This causes sunrise effect. In the light of waveguide mode theory, modal conversion and subsequently interference of various modes are the causes of sunrise and sunset effect [9,10].

The gradual rise of ARNFS prior to afternoon rains during pre-monsoon and monsoon are the evidences of gradual development of thunderclouds over the locality of the receiver. With the commencement of rain, the charged drops fall vertically decreasing the potential difference across the bipolar structure of the cloud. It takes 20 min. to an hour for the potential difference to fall below critical value required for cloud discharge. Present observations supports that high charge separation occurs in pre-monsoon clouds than in monsoon clouds. The severity of the phenomenon in the afternoon may be the effect of temperature and liquid water content in thunderstorm charging [11]. Laboratory studies have shown that thunderstorm charging caused by interactions of ice-crystal and graupel pallets is affected in sign and magnitude by temperature and cloud liquid-water content. All that happens is to say that charge separation mechanism is favoured by pre-monsoon atmospheric conditions.

During the months of monsoon, severe cloud activity occurs in and around the latitude (23° N), the present observing station at Agartala. The radiations from nearby sources (thunderclouds) can suppress radiations coming from distant sources. During this period, direct radiations from nearby sources are mainly due to intra-cloud and cloud-to-ground discharges. These are the main causes of highest values of $D_{\max}$ and $D_{\min}$ in monsoon. The level of VLF sferics is jointly governed by the status of cloud activity [source parameter $G(\nu)$] and propagation parameter $W(d,\nu)$. Due to high cloud activity over the Indian continent and neighbouring countries, the source parameter $G(\nu)$ is high in monsoon and waveguide parameter $W(d,\nu)$ is moderate. So the product '$G(\nu)W(d,\nu)$' is high in monsoon. Hence monsoon level of IFIS is high in all respects. In winter, $G(\nu)$ is low, but $W(d,\nu)$ is high giving moderate value of the product $G(\nu)W(d,\nu)$. Hence winter level of IFIS is moderate. In order to explain the seasonal variation of level of sferics, a model calculation has been done by assigning value of $G(\nu)$ as zero if the world-wide cloud-activity is nil and assigning a value as 8, when the whole locality is covered by cloud for the whole day. Based on this, numerical values are assigned to $G(\nu)$ for different months.

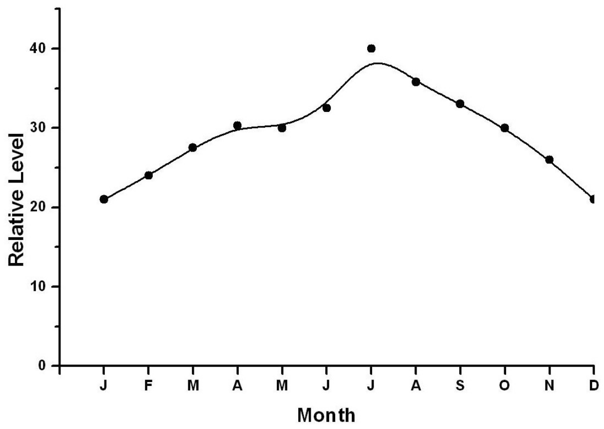

Figure 7. Graphs showing the monthly variation of relative atmospherics according to model calculation.

Similarly, $W(d,\nu)$ has been considered to be zero if the electromagnetic signal is completely absorbed by medium (null propagation) and a numerical value 8 has been assigned for propagation without absorption. Considering this, $W(d,\nu)$ have been given various values as shown in Table 2. So we calculate the product $G(\nu)W(d,\nu)$. The monthly variation of this product for various months is shown Figure 7. This Figure is in good agreement with the graphs in Figure 4.

The model calculation has been repeated for various seasons also and numerical values assigned to two parameters in various seasons are shown in Table 3. Figure 8 resembles the experimental graphs in Figure 6.

Table 2. Values of source parameter $\Delta G(\nu)$, waveguide transmission factor $\Delta W(d,\nu)$ for various months

Month	$G(\nu)$	$W(d,\nu)$	$G(\nu)W(d,\nu)$
January	3	7	21
February	4	6	24
March	5	5.5	27.5
April	5.5	5.5	30.3
May	6	5	30
June	6.5	5	32.5
July	7	5	40
August	6.5	5.5	35.8
September	6	5.5	33
October	5	6	30
November	4	6.5	26
December	3	7	21

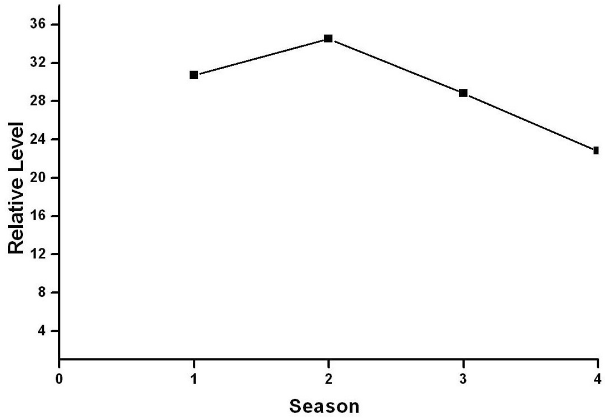

Figure 8. Graphs showing the seasonal variation of relative atmospherics according to model calculation.

The variation of IFIS over a day is jointly determined by the variation of source parameter $\Delta[G(\nu)]$, and the variation of propagation parameter $\Delta[W(d,\nu)]$. The values $\Delta[G(\nu)]$ and $\Delta[W(d,\nu)]$ over a day are dependent on seasons. The value of $\Delta[G(\nu)]$ over a day is expected to be low in winter and post monsoon. The value of $\Delta[G(\nu)]$ over a day, though not high in pre-monsoon, is appreciable (moderate) due to occasional appearance of cloud in the afternoon periods and nights. $\Delta[G(\nu)]$ over a day is high in monsoon. The value of $\Delta[W(d,\nu)]$ is expected to be high in winter and moderate in other seasons. The seasonal variation of $D_{\max} - D_{\min}$ is explained in Table 4.

Table 3. Values of source parameter $G(\nu)$, waveguide transmission factor $W(d,\nu)$ in various seasons

Season	$G(\nu)$	$W(d,\nu)$	Level
Pre-monsoon	5.8	5.3	30.7
Monsoon	6.5	5.3	34.5
Post-monsoon	4.8	6	28.8
Winter	3.4	6.7	22.8

Table 4. Values of source parameter variation $\Delta G(\nu)$, waveguide transmission factor variation $\Delta W(d,\nu)$, and the variation of level of VLF atmospherics in various seasons

Season	$\Delta G(\nu)$	$\Delta W(d,\nu)$	$D_{\max}$–$D_{\min}$
Winter	Low	High	Moderate
Pre-monsoon	Moderate	Moderate	Moderate
Monsoon	High	Moderate	High
Post-monsoon	Low	Moderate	Low

July and August are the months of peak monsoon in North-East part of India. During monsoon average, cloud activity is high from mid day to afternoon period. So the high level of IFIS at these hours in the months of July and August are the indication of this fact. On the other hand, the high level at night in July and August is due to combined result of source function and propagation parameter in the VLF band. The comparatively low value in the month of August at 04:00 and 08:00 hours must be the effect of bad propagational condition.

From the graphs in Figure 4, it is seen that there are evidences of high cloud activity in July and August. In North-East part of India, the ambient level of cloud activity is comparatively high in the month of May. This is observed as highest value of daily minimum value of IFIS in this month. The actual picture is clarified if we consider the seasonal variation of IFIS.

6 Conclusions

i) The afternoon and late afternoon level of sferics at 21.5 kHz is highest in a day during all seasons.

ii) Average IFIS, the daily maximum and daily minimum are highest in monsoon.

iii) Daily minimum occurs at around 08:30 to 10:00 hour in a day.

iv) Pre-monsoon and post-monsoon levels are almost same during all the hours in a day.

v) During monsoon, sunrise minimum is not distinct.

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