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Variability of Solar Flare Duration and Its Effects on Ozone Concentration at Pakistan Air Space

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Abstract: In this communication we have presented the existence of solar flares and their variability along with the correlation structure of ozone concentration. This can be accomplished by analyzing the data of solar flare duration and ozone content. The supremacy of gradual flares in depletion of ozone was recognized. Exploratory Data Analysis approach has been utilized to find the contribution of solar flares in ozone layer depletion.

Keywords: Exploratory data analysis (EDA), gradual flares, impulsive flares, mixed flares, ozone layer depletion (OLD)

INTRODUCTION

Ozone is formed primarily by chemical process involving the dissociation of O_2 by solar UV radiation. Thus there is a need for observational and theoretical study of the relationship of O_3 concentration to variations in solar activity [1]. Albeit the anthropogenic factors are the major contributors of the ozone layer depletion (OLD), it is important to study the natural events as well. Solar flares are the most important in this respect. They occur when strong magnetic fields extending high into the sun's atmosphere, suddenly collapse and then recombine into simpler structures [2]. The electrically charged particles emitted by some flares represent a potential hazard to man during space flights to the moon and the planet. These particles are greatly increased following the appearance of some large flares [3]. Most of the destruction (~ 70 %) of ozone rate is due to catalytic cycle involving N_2O, which is most likely to produce at the time of major flares [4 - 5].

Satellite measurements in the stratosphere and mesosphere indicate a possible correlation of ozone with 27-day variations in solar activity [6].

The opening of magnetic field lines initiates by an eruptive flare is connected with ejection of material called coronal mass ejection (CME). It has been known that the real agent that causes geomagnetic storms is CME, which can also originate in quiet parts of the sun. But it is misleading to jump to a conclusion that flares are not important any more in solar terrestrial relations. Flares are excellent indicators of coronal storms and the largest geomagnetic storms are caused by fast CME which usually are associated with flares, while moderate or small storms mostly have no association with flares [7]. Nearly 40 % of CME are accompanied by solar flares that occur about the same time and place [8]. A large solar flare also called solar proton event (SPE), can destroy 20 % of the earth's ozone in a matter of few days as was in August 1972 [9 -10].

MATERIALS AND METHODS

Exploratory data analysis is one of the statistical techniques adopted in analyzing the behavior of solar flare on ozone, for the period of 1972-2006. Solar flare activities at ionosphere have been recorded by Digisonde which is installed at SUPARCO HQ, Karachi. Another remote sensing device is Dobson Spectrophotometer, which is monitoring ozone contents at stratosphere in Dobson unit and being working at GC, Quetta. These data screening convey the fundamental properties about the nature of the data and the physical process following them

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which is easy to communicate and helpful in further investigation.

According to duration solar flares are separated as impulsive and gradual modes i.e. less than and greater than 1 hour respectively. As in nature both of them exist arbitrarily, therefore we term a third category of flares called mixed flares. It is important to study their behavior in solar terrestrial relationship separately.

RESULTS AND DISCUSSION

Test of Normality

A small departure from normality is found in all three data series of SFD as shown in Fig 1-3. This is also supported by their KS-values in Table1. Their P-values confirm it with 90 % confidence interval. However Fig.4 of these measures supported with KS value is in favor to recognize ozone series as normally distributed. The P-value defines this with 95 % confidence interval [13 -14].

The role of central limit theorem is emphasizing in assessing the normality of data. It assures us that regardless the shape of the population distribution as the sample size increased the distribution approaches a normal distribution very rapidly. A large sample approaches infinity but in practice, is generally taken as a sample size of 30 or more [15, 18].

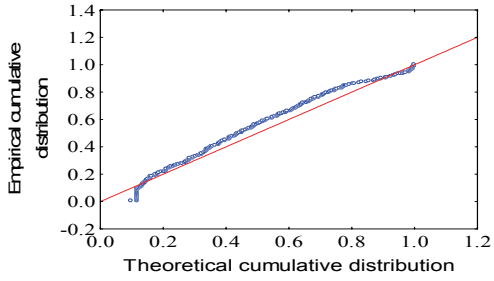

Fig. 1. Probability plot specify nature of data series for mixed flares.

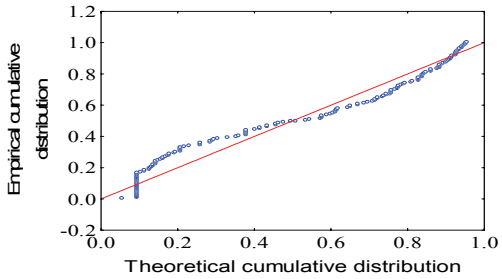

Fig. 2. Probability plot specify nature of data series for impulsive flares.

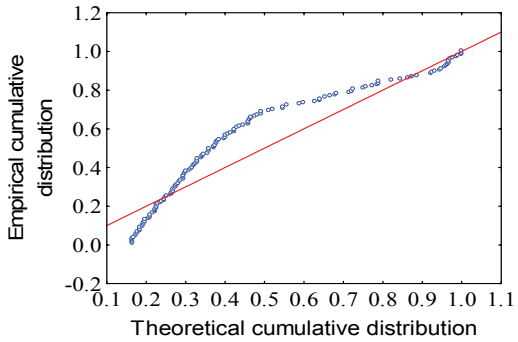

Fig. 3. Probability plot specify nature of data series for gradual flares.

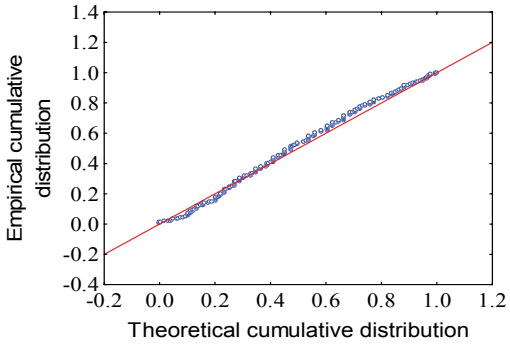

Fig..4. Probability plot specify nature of data series for ozone contents.

Pearson Index

The Pearson Index, specify that whether the distribution being analyzed is significantly skewed or consider as normally distributed.

$$PI = \frac{3(\bar{x} - median)}{s} \quad \text{---------- (1)}$$

where $\bar{x}$ is the sample mean and s the sample standard deviation.

If PI is not greater then +1 or less than −1, the distribution may not be significantly skewed. [11] The PI values for all of the four data samples in Table 1 are within this range.

Table 1. Test statistics.

	PI	KS	P-value
Mix - flares	0.43	0.09	< 0.010
Imp- flares	− 0.16	0.12	< 0.010
Grad- flares	0.98	0.19	< 0.010
Ozone	0.18	0.04	= 0.053

PI: Pearson's Index of skewness
KS: Kolmogorove-Smirnov test

Outlier Identification

An outlier may be an observation for which the value has been incorrectly recorded and so it should be removed. On the other hand, an outlier may also be an unusual item that has been correctly recorded and does belong in the data set and therefore should not necessarily be excluded [12, 15].

The Box Plot of Fig. 5 shows ten possible outliers found in the data series of solar flare duration (SFD) and six possible outliers in the data series of ozone. They are flagged with an asterisk so that these points can be checked [16].

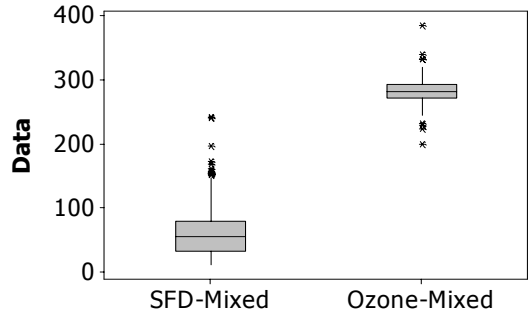

Fig. 5. Box plot identify possible outliers in the data series of SFD and ozone content.

Observations that are 2 or 3 times the IQR above the third quartile or below the first quartile are considered as outliers. [12]

Outliers $= Q_3 + 2\,(IQR)$ ---------- (2)

$= Q_1 - 2\,(IQR)$ ---------- (3)

The above measures identify three outliers in the data series of SFD and four outliers in the series of ozone content.

In the data series of ozone the outliers remains at the two extremes balance the data towards normality. On the other hand, all of the outliers of SFD exist in the right extreme makes the right tail slight heavy.

Estimation of Confidence Interval for the Population Mean of SFD

The interval estimates from the sample of solar flare duration (SFD), when the critical region is $\alpha = 0.1$ and the corresponding level of significance or the confidence interval at 90% respectively as followed.

$$\bar{x} - 1.64\frac{\sigma}{\sqrt{n}} < \mu < \bar{x} + 1.64\frac{\sigma}{\sqrt{n}}$$

$= 57.451 < \mu < 64.429$ ---------- (4)

$$\bar{x} \pm 1.64\frac{\sigma}{\sqrt{n}} = 60.94 \pm 3.49$$ --------- (5)

Testing Hypothesis

Testing the hypothesis is a procedure in which sample data are used to decide or not to reject a proposition made about the population parameter. Statistical hypothesis is a statement about a population whose validity is to be tested on the basis of a random sample drawn from the population. This statement may be an assertion about any population parameter [17].

(i) One sample test: SFD-mixed

For mixed category of flares, it would be hypothesize that gradual flares in future are more frequent then impulsive.

For sample size n = 325 with $\bar{x} = 60.94$

H_o: $\mu \geq 60$ (claim)

H_a: $\mu < 60$

Test Statistic:

$$Z = \frac{\overline{X} - \mu}{S/\sqrt{N}} = 0.44$$ ---------- (6)

Significance level = $\alpha = 0.10$; P = 0.671

Make the decision to accept the null hypothesis that the population mean of SFD either greater than or equal to 60 minutes which specify endanger of gradual flares.

(ii) Two samples test: ozone-imp Vs ozone-grad

This would be hypothesizes that ozone column on average would not remain identical during the two phases of impulsive and gradual flares. At $\alpha = 0.05$, the evidence to support the claim can be analyzed by using t-test. Therefore the series of SFD which designate as mixed flares have been separated into two series of impulsive and gradual flares according to their duration and ozone column corresponding to that period assigned as ozone-imp and ozone –grad. The two means are then compare as independent populations.

Table 2. Ozone statistics during two phases of solar flares.

	N	Mean	St.Dev	SE Mean
Ozone-Imp	178	281.57	25.16	1.89
Ozone-Grad	147	286.66	17.88	1.47

Ozone-Imp: Ozone during impulsive flares
Ozone-Grad: Ozone during gradual flares

H_o: $\mu_1 = \mu_2$
H_a: $\mu_1 \neq \mu_2$ (claim)
Test Statistic:

$$t = \frac{\overline{x}_1 - \overline{x}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} = -2.06 \text{ ----------} \quad (7)$$

Significance level = α = 0.05; P = 0.040
95 % Confid. Interval = (−9.95, 0.22)

Make the decision to accept the alternate hypothesis that the two series of ozone column during impulsive and gradual phase of flares are not identical.

Linear Regression Approach

Regression analysis is the measure of the relationship between two or more variables in terms of the original units of the data [17].

Linear regression technique for each of the three data series of SFD with respective ozone content are represented in Fig 6-8. Their model equations are respectively as follows.

$$y = 278.57 + 0.074x \text{ ----------} \quad (8)$$

$$y = 275.14 + 0.185x \text{ ----------} \quad (9)$$

$$y = 290.57 - 0.042x \text{ ----------} \quad (10)$$

Table 3. Model validation parameters.

	F-value	P-value	R^2
Mix - flares	8.15	0.005	2.5 %
Imp- flares	2.15	0.145	1.2 %
Grad- flares	0.92	0.339	0.6 %

R^2: Coefficient of determination.

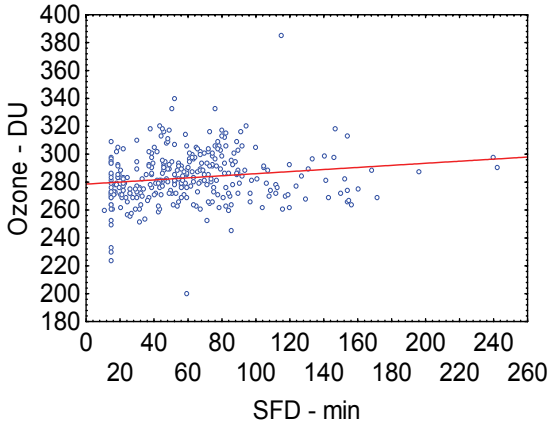

Fig. 6. Mixed flares show positive variation in ozone content.

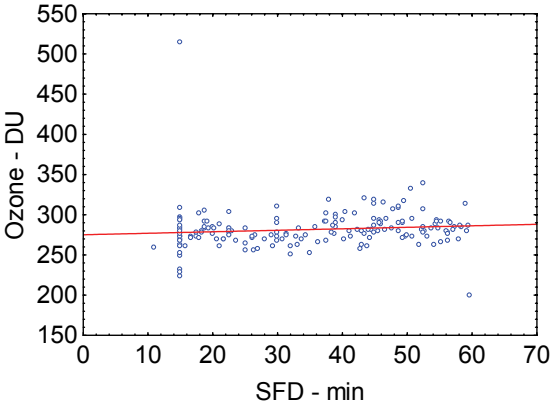

Fig. 7. Impulsive flares again show a minimal change in ozone content.

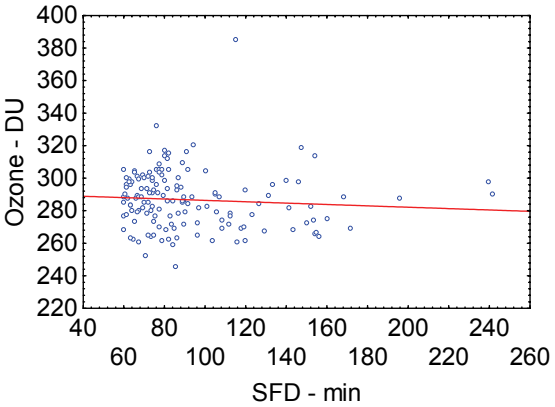

Fig. 8. Gradual flares shows decline in ozone content.

Among the three linear regression models it specifies that during gradual flares there is depletion in the ozone column. This trend is small but negative.

CONCLUSION

In this communication four samples are tested and found normally distributed. The least square estimate predicts ozone layer depletion (OLD) during gradual phase of solar flares. Mixed and impulsive categories of flares are found positively correlated with ozone concentration. Therefore Sun is responsible for both formation and annihilation of ozone. As the correlations are weak, the more improved results can be recorded using more sophisticated approach.

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