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SPECIFYING THE CONSPICUOUS FEATURES OF THE OZONE LAYER DEPLETION FOR PAKISTAN'S ATMOSPHERIC REGION

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Events such as the huge industrial emissions of Chlorofluoro Carbons (CFCs) provide almost visible example of man-made atmospheric pollution and global unbalance of the natural ecology. Among other scientific and socio-economic fallouts from this, the phenomenon of ozone layer depletion (OLD) is particularly disturbing. It has already attracted wide attention throughout the globe by way of 1987 Montreal protocol. This paper looks into the effectiveness of autoregressive model and predicts the menacing influence of the OLD. As such, with reference to the data for stratospheric region of Pakistan, this communication presents the confidence interval for the population mean of OLD for a significant level of probability. Then it considers the estimation of autoregressive model of order one for forecasting time series on monthly basis from 1970 to 1994, by identifying a set of related predictors. Autoregressive technique produces fairly accurate results as compared to the least squared estimate. We also consider the issue of validating the model by displaying predicted and observed data, by residual analysis, and by autocorrelation functions.

Keywords : Ozone layer depletion, Atmospheric region of Pakistan, Autoregressive modeling, Stratospheric ozone modulations, Coefficient of variation

1. Introduction

The production of hundreds of thousands of anthropogenic substances, 'unnatural' chemicals dubbed xenobiotics that are foreign to living organisms have adverse effects. Many of these have found their way into the biosphere and have been classified as toxic. Such a toxicity bestows potential hazards to the entire living environment [1].

Chlorofluoro Carbons (CFCs) and Chlorobromo Carbons (CBrCs) have in particular perturbed biosphere wherein the ozone layer depletion (OLD) is considered in the first place [2]. Due to the annihilation of O_3 shield and the resulting artificial climatic change - global warming [3] - we are facing abnormally high incidences of UV-B radiation on the earth [4-5]. Destructive impacts of UV-B radiation due to OLD have been examined on marine organisms [6-13].

In 1987, Montreal Protocol imposed conditions on ozone layer depleters such as freezing CFC consumption to certain extent and reducing the production of chlorinated and brominated hydrocarbons. It is obvious that the total emissions are expected to increase in the near future

A significant paramour between CFCs and the Antarctic O_3 hole has been established for a basic and decisive role that belongs to understand the question is as to what the effects of OLD are in regions other than that of Antarctic itself, such as Pakistan's atmosphere. But what does seem to have generally been done so far in connection with this seemingly severest "anthropogenic" pollution problems is half-baked attempts at constructing future projections via mere aritmeticisation of the crude instrumental records of OLD. That an appropriate mathematisation ought to be one of the basic objectives of the OLD analysis is supported by so many motivations [14-17].

This investigation supports earlier communications of ours — based on data developed via observational programmes on the global O_3 detection network conducted under the auspices of World Meteorological Organization (WMO) - and introduces here the problem of studying the recent conspicuous features of O_3 contents of the earth's stratosphere [18-21]. This

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study aims to examine the nature of OLD. Then we describe the problem of estimating the distribution parameters, and try to specify successfully the salient formulation of OLD. Finally, we summarise the communication, indicating some open problems that could be dealt in the context of OLD.

2. Inspecting the Nature of Stratospheric O_3 Modulations

We will base our considerations here on the O_3 time events to be able to relate the empirical expression with the mathematisation,

$$\{X_i\}, \quad (i \in \{1, 2, \cdots, 296\}), \tag{1}$$

This paper consists of monthly observations for Pakistan covering a period from January 1970 to August 1994. The plot of the modulation of O_3 depths with respect to time clearly depicts that there is an immediate confirmation (see Fig. 1) that the depletion far exceeds the restoration of O_3 in the earth's stratosphere. To tackle the problem of fitting a law to process (1), we first try to look into the nature of this 'process'. We assume that the 296 observations possess statistical independence, though they may not share the same probability distribution. Because of its more powerful character (e.g. over that of the familiar χ^2-test) and its suitability even for small sample sizes, we next apply the Kolmogorov-Smirnov (KS) goodness-of-fit test for comparing the observed sample space (1) with the theoretical distribution [22].

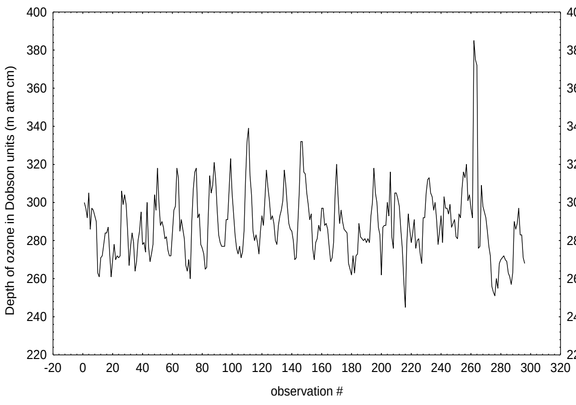

Figure 1. Monthly original time plot of OLD.

The goodness-of-fit test is used to assess how well a data set appears to come from a normal or lognormal distribution. For large sample size as in our case the distribution of the data is close enough to some theoretical distribution (say, normal distribution) and fairly accurate results may be provided by assuming that particular distribution.

The observed distribution does not differ significantly from the theoretical distribution as indicated by our null hypothesis (H_0) in the KS-test. This test may be taken to illustrate the maximum absolute difference,

$$F := \max |f_o - f_e|, \tag{2}$$

between f_e's and f_o's. Thus we calculate a cumulative expected frequency f_e expressed as a proportion of the total for each observed frequency f_o in the series (1). Notice that by Eq (2) in Table 1 we find that the O_3 depth of about 300 DU occurs at the maximum difference of about 0.0574 — recalling from Ref. [20-21], that the original data are measured in Dobson units (1 DU : = 10^{-3} cm of O_3 at standard temperature and pressure of the atmosphere). If we could argue that this absolute difference is significantly large, then we would reject the null hypothesis (H_0) and combat that the O_3 depth was from a completely normal distribution.

However, we can utilise the KS-test to obtain our F as follows: we choose to aim that, a 95% level of confidence is given by

$$\alpha = 0.05, \ 95\% = (1 - \alpha)100\% \tag{3}$$

Therefore, in view of the sample size in space (1) of O_3 concentration viz. $n \geq 50$, the F-value as calculated from KS-tables comes to be $1.36/\sqrt{296} = 0.08$. As this value exceeds the F given by Eq. (2), we accept H_0 and assume that OLD could be simulated by sampling a normal distribution with a mean, say, $\overline{X}$ and standard deviation, say, σ. That we are not wrong in accepting the hypothesis H_0 i.e. the goodness-of-fit to a normal distribution is further validated by the KS-plot shown in Fig. 2.

Similarly, the exactness of the above finding may be checked by considering the scatter of the distribution relative to the dimension of the estimated mean bared by the concept of coefficient of variation,

$$CV := \frac{\sigma}{\overline{X}} = 0.064. \tag{4}$$

We have observed that Eq. (4) depicts the sufficiently low value of the CV that shows a good

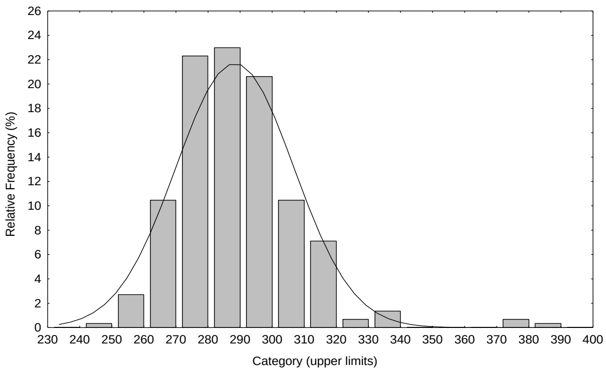

Figure 2. Kolmogorove-Smirnov goodness-of-fit appears to come from a normal distribution for OLD to assess how well the data set.

degree of normality obeyed by the different O_3 depth events. The above numerical estimate indicates that just about 6.4% of the data is non-normal.

3. Estimating the Dimension of Modulations in Stratospheric O_3

Of available standard approaches for parameter estimation, for our current context we may take the MLE (maximum likelihood estimator) technique because of its several useful properties discussed in the standard literature [23]. To formulate the likelihood function (L), we may assume, as per provisions made in the above section, that the random space (1) obeys the law

$$P(X_i) =, \frac{1}{\sigma\sqrt{2\pi}} \exp\left[-\frac{(x_i-\mu)^2}{2\sigma^2}\right] \quad (1 < i \leq 296) \qquad (5)$$

Thus, our likelihood function, joint (product) probability distribution of density functions (5), is

$$L(\mu, \sigma^2) = \frac{i}{(2\pi\sigma^2)^{n/2}} \exp\left[-\frac{1}{2\sigma^2}(\sum x_i - \mu)^2\right] \qquad (6)$$

Simplifying $dL/d\mu = 0$ readily yields $\sum(x_i - \mu) = 0$, giving our estimator

$$\hat{\mu} = \frac{\sum x_i}{n} \;(=: \bar{X}) = 288.36 \text{ DU}, \qquad (7)$$

which can be taken to provide an estimate of the population mean μ. Also, differentiating (6) once with respect to σ^2 and equating to zero leads to the following variance-related quantity (which we will need shortly):

$$\tilde{\sigma}^2 = \frac{\sum(x_i - \bar{X})^2}{n} \qquad (8a)$$

And substituting values in Eq. (8a), we see that the standard deviation may be taken as

$$\tilde{\sigma} = 18.39 \text{ DU} \qquad (8b)$$

The above point estimate for μ is of little value unless we know how accurate the estimate is likely to be. According to the central limit theorem we know that, for sufficiently large n (as is the case with us, here n being 296), the sampling distribution of the sample mean $\bar{X}$ is approximately normal with

$$E(\bar{X}) = \mu, \; V(\bar{X}) = \sigma^2/n \qquad (9)$$

Notice that $\bar{X}$ may be considered as the best estimator of μ in view of the first of the relations (9) and because it is easy to show that $\bar{X}$ has the smallest variance among all unbiased estimators of μ. Now, as $\bar{X}$ is approximately normal, one way to ascertain the accuracy of our $\hat{\mu}$ consists of constructing a large-sample $(1 - \alpha)100\%$ classical confidence interval (CI) for the population mean. Inserting

$$\hat{\mu} = \bar{X}, \; \sigma_{\bar{X}} = \sigma/\sqrt{n} \qquad (10)$$

into the usual expression for calculating the confidence interval gives

$$\bar{X} \pm z_{\alpha/2}\sigma_{\bar{X}} \approx \bar{X} \pm z_{\alpha/2}\left(\frac{\sigma}{\sqrt{n}}\right), \qquad (11)$$

where $z_{\alpha/2}$ is the value of the standardised normal variable z that locates an area of $\alpha/2$ to its right. As $n \geq 50$ in our case, the approximation (11) for CI is quite satisfactory. In fact, when the value of population standard deviation, say, s is unknown, the sample standard deviation σ may be used to approximate s in Eqs. (11) for the CI.

Now, using normal distribution tables, we find that the area to the left of z-value κ viz. $\psi(\kappa) \equiv (1-\alpha/2) = 0.975$ yields $\kappa = 1.96$, so that z lies between −1.96 and 1.96. In other words, 95 % of OLD sample of size *n* being considered lies between confidence limits given by the following range:

$$\overline{X} - 1.96\frac{\sigma}{\sqrt{n}} < \mu < \overline{X} + 1.96\frac{\sigma}{\sqrt{n}}, \quad (12)$$

In view of Eq. (8b), the population mean μ lies thus in the interval

$$\overline{X} \pm 1.96 \times 18.39/\sqrt{296} \equiv \overline{X} \pm 2.1 \quad (13)$$

Notice that the confidence limits (13) are universal in that they differ from sample to sample. For the specific O_3 depth sample (1), for which $\overline{X}$ = 288.36, the confidence limits are given by

$$286.26 < \mu < 290.46, \quad (14)$$

with the probability of such an occurrence of the population mean being

$$P(\overline{X} - 2.1 < \mu < \overline{X} + 2.1) = 0.95 \quad (15)$$

We also know that our given sample has 95% probability that the population mean μ will lie between the implied confidence limits. Notice that Eq. (7) lends acceptance to a physical picture of the time events (1) as a stationary process in that Fig. 1 shows a prevalence of time events alike our $\hat{\mu}$. This, in turn, necessitates a search for the possibility of further conformity pattern, which we take up in the next section.

4. Synchronism of Stratospheric O_3 Modulations

The modulation in depths of O_3 column, emergence from its interaction with various atmospheric processes and measured at different points of time during the years 1970-1994, can be thought of at least in part (!) — having decided, for mathematical tractability, to ignore 'fractality',.as emerging from randomness, as a particular realisation of a stochastic process. The question is how to grade the intricacy of the stratospheric resident O_3 , its perplexing steps of restitution and depletion, in order to understand the inherent stochastic character, discovering interesting structural properties of OLD? The trend set by newer developments such as simulation, symbol dynamics, chaos research, etc. in atmospheric sciences, meteorology and the like suggest that we supplicate the idea of a controlled model, the notion of simpler repeatable representation, to help us define and crystallise the realistic situation of the present 'process'. For an illustration, such an attempt at inferencing from a realisation to the process, the physical mechanism generating the series of O_3 events, may be partially likened to the inferencing from a sample to a population – in the setting of classical statistical analysis [23-25].

For the sake of convenience, we may treat the process (1) as a linear phenomenon rather than a nonlinear one. Thus, in keeping with the spirit behind the most general as also the prime example of ab initio mathematical formulation of a process viz. generalised linear modelling, an immediate candidate seems to be multiple regression format but one in which some or all the explanatory variables are 'lagged' values of a 'time-dependent' random variable X_t . Thus, taking into account the mutually regressive relationship between random variables X_t — defining the space (1) — arising from the temporal inter-dependence of X_t on its predecessor X_{t-1} , we naturally land on a formulation of X_t as a linear combination of its two immediately preceding values, which in turn readily yields the following special case of a generic multiple regression model :

$$X_t = \alpha_t + \beta_1 X_{t--1} + \beta_2 X_{t-2} + \cdots + \beta_s X_{t-k} + \gamma_t \quad (16)$$

where we may obviously dub *k* as the order of the ansatz (16) and designate the value x_{t-k} (of the random variable X_{t-k}) as the lagged value of *x* at time (t – k), taking γ_t to stand for the possible white noise over the main signal represented by other terms in Eq. (16). For mathematisation for the sake of saving the process (1) from further imposition of constraints such as the imposition of the assumption of moving-average hypothesis), we ignore here other terms in Eq. (16) and settle down to an ansatz equation

$$X_t = \beta_1 X_{t-1} + \alpha_t \quad (17)$$

for the description of the time-dependent history of O_3 depths. As regards acute assumptions for our ansatz (17), other than those already indicated, α_t's at different *t* are independent i.e. α_t is independent of α_{t-1} , α_{t-2} , ⋯. This, in turn, implies that α_t is independent of X_{t-2} , X_{t-3} , ⋯ too (this being an expression of the fact that Eq. (17) is self-regressive of order 1).

Our ansatz (17) is a kind of conditional regression in that at time $t - 1$, when X_{t-1} is fixed, Eq. (17) is a regression model. In addition to the completely dependent constituent (given by $\beta_1 X_{t-1}$) of X_t in the ansatz (17), we have another constituent of X_t which happens to be independent of X_{t-1} (given by α_t). At time $t - 1$, as X_t is an unknown random variable, so is α_t , obeying a certain distribution. As soon as X_t is observed and known at time t, α_t no longer remains a random variable but gets fixed, which can then be computed by

$$\alpha_t = X_t - \beta_1 X_{t-1} \tag{18}$$

Clearly, Eq. (18), is a different form of our ansatz (17), resulting from a consideration of the 'orthogonal decomposition' that provides us with an suitable interpretation. As $\{X_t\}$ is a dependent series and α_t is an independent one, we may consider the ansatz (17) as a device to reduce a dependent dataset into an independent one (accomplished by removing from X_t the part that depends on X_{t-1}). An immediate implication is that the assumption of independence reserved at the start of the previous section is honoured by our ansatz (17).

Similarly, we must worry ourselves with the task of estimating parameters reckoning in our ansatz (17). For concreteness, we may assume that α_t possesses a normal distribution:

$$\alpha_t \sim \mathrm{NID}(0, \sigma_a^2), \tag{19}$$

where NID stands for the phrase 'normally independent distributed'. As the ansatz (17) is just a conditional regression, we can conjure the technique of conditional least squares to get estimates of β_1 and σ_a^2 [24]

$$\hat{\beta}_1 = \frac{\sum_{t=2}^{n} X_t X_{t-1}}{\sum_{t=2}^{n} X^2{}_{t-1}} = 0.716, \tag{20a}$$

$$\hat{\sigma}_a^2 = \frac{\text{residual sum of squares}}{\text{number of residuals}} = 81.77 \tag{20b}$$

Notice that the estimate of the parameter β, figuring in our ansatz (17) and given by Eq. (20a), shows that

$$|\hat{\beta}_1| < 1 \neq 0 \tag{21}$$

Thus the extent of the dependence of X_t on X_{t-1} (as measured by this parameter) is weak (β is small, for $|\hat{\beta}_1| < 1$). Nevertheless, Eq. (20*a*), does demonstrate a relationship between X_t and X_{t-1} ($|\hat{\beta}_1| \neq 0$). In other words, the process depicted by our O_3 time events (1) is not just statistical but also not uncorrelated i.e. is stochastic, as we assumed here above. Again, Eq. (20) (small but nonzero β) also shows that the process (1) is stationary – of course, corresponding to an stipulation of some suitable restrictions related to the white noise γ_t and the general terms in the original Eq. (16).

This stationarity has the important characteristic that mean, variance and correlation (covariance, in the language of usual statistical analysis) of the individual O_3 events in the process (1) remain the same for all t [24,25]. This information is encoded in the autocorrelation function

$$\rho_k := \lim_{n\to\infty} \hat{\rho}_k , \tag{22a}$$

where

$$\hat{\rho}_k := \frac{\sum_{t=k+1}^{n} X_t X_{t-k}}{\sum_{t=k+1}^{n} X^2{}_{t-k}} \tag{22b}$$

is the estimate of the autocorrelation at k lags, $\hat{\rho}_1$ being the autocorrelation (giving an estimate of the relation or dependence between values of X_t) one lag apart or at lag one.

As a further check for adequacy, we may note that there is no evidence against the basic assumption of independence behind our ansatz (17), this being confirmed by the correlation between α_t and α_{t-1} and α_t and X_{t-2} :

$$\hat{\rho}\,(\alpha_t \text{ and } \alpha_{t-1}) = \frac{\sum_{t=3}^{n} \alpha_t \alpha_{t-1}}{\sum_{t=3}^{n} \alpha^2{}_{t-1}} = -0.072 \tag{23}$$

In a definite affirmation of our argument at the beginning of this section, the line spectrum (periodogram) constructed in Fig. 3. identifies the randomness in the O_3 depletion process (1). It is worth mentioning for a seasonality (or trend) among the given time events. Moreover, our line spectrum exhibits a predominance of positive over negative autocorrelations, i.e. a dominance of low-frequency amplitudes over high frequency ones. In other words, there is taking place a damping of O_3 concentration over time. Thus the spectrum reinforces the allegation made at the beginning of last section.

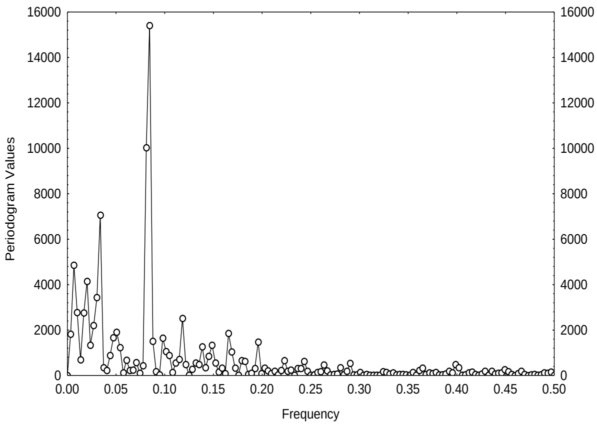

Figure 3. Periodogram is shown, used to identify randomness in the OLD data .

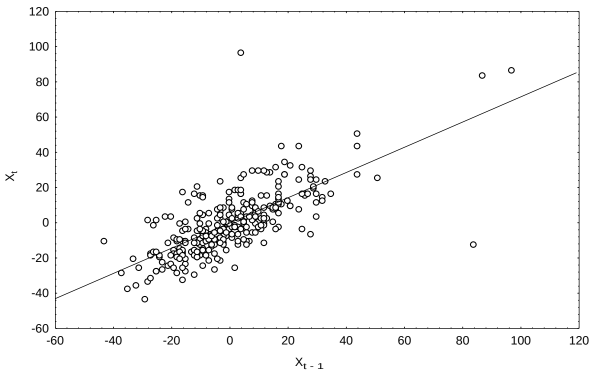

Figure 4. Scatter diagram of X_{t-1} versus X_t showing a rather complicated dependence of the future on the past.

The scatter plot of X_{t-1} against X_t (see Fig. 4) also reveals, as expected, a rather complicated dependence of the future on the past, again as sustained at the outset of this section. Clearly, there may exist serious temporal and spatial limitations of our ansatz (17) as a representation of the real stratospheric atmosphere. However, given this, the eddy diffusion in the ansatz may be thought of as a radial diffusion of the O_3 towards stratospheric region in question (such as Pakistan). In other words, the ansatz (17) may be interpreted as a special case of the random walk [24-25] mode of transportation of O_3 flux. This nicely ties up with the critical geographical position of Pakistan — it roughly covering the South Asia between $\varphi \in$ [23.45°N, 36.75°N] and $\lambda \in$ [61°E, 75.5°E] — and the large positive correlation between the potential vorticity deviations and O_3 mixing ratios in the stratosphere [26-27]. O_3 depth modulations seem to be thrilled alongwith seasonal variations (cf. Fig. 3) to Pakistan's atmospheric regions [20, 21]. Moreover, the O_3 layer variability forms an O_3 filter in the passage of UV-B. This O_3 filter appears to be transported to Pakistan via a vertical lifting followed by a horizontal mixing of O_3 contents.

Our ansatz (17) is further vindicated by various evidences. The residual analysis for Eq. (17) graphed in. Fig. 5 adequately demonstrates that the constructed ansatz is reasonably

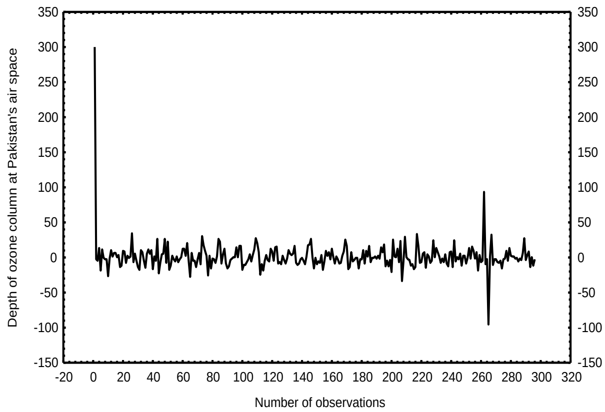

Figure 5. Plot of residuals showing the adequacy of the constructed model for OLD for atmospheric region of Pakistan.

commensurate. Moreover, the correlational structure of the O_3 process (1) (its correlation with itself) — determined by the autocorrelation function (22a) and (22b) between the i^{th} observation and the $(i + m)^{th}$ at various lags of 1, 2, or more periods show a sufficiently high degree of correlation (see Fig. 6), the high orders of our ansatz (17) depicting in turn a good fit of Eq. (17) to the temporal or transient process (1). Furthermore, the error structure unveiled by the autocorrelation for residuals of the O_3 depth events exhibits a rather neat serial correlation (vide Fig.7).

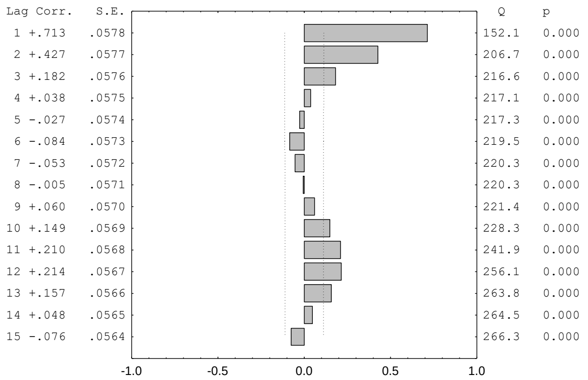

Figure 6. Autocorrelation function for OLD between the i^{th} observation and the $(i + m)^{th}$ giving high correlation.

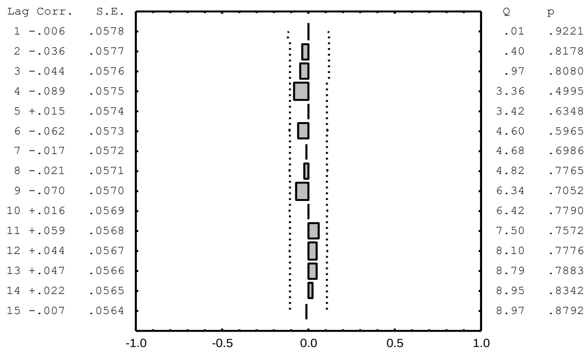

Figure 7. Autocorrelations for the residuals of OLD, evincing the presence of high serial correlation between observational and model values.

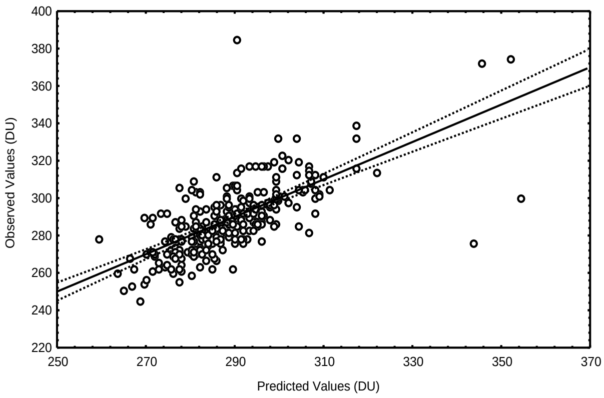

Figure 8. Comparison of observed and predicted values of OLD, establishing well the nature of onstructed model (cf. text).

Finally, a comparison of observed O_3 process described in Table 1 with the predicted one on the basis of Eq. (17) comfortably establishes the validity of the constructed ansatz (cf. Fig. 8).

Table. 1. Kolomogorov - Smirnov goodness-of-fit test.

Ozone Depth (DU)[#]	Cumulative frequency % observed	Cumulative frequency % expected
240	0.000	0.4279
250	3378	1.8509
269	3.0405	6.1548
270	13.513	15.9081
280	35.810	32.4707
290	58.783	53.5495
300[**]	79.391	73.6554
310	89.864	88.0287
320	96.959	95.7292
330	96.959	98.8205
340	98.986	99.9597
350	98.986	99.9951
360	98.986	99. 9995
370	98.986	100.000
380	99.662	100.000
390	100.00	100.000
Infinity	100.00	100.000

**indicates the depth of O_3 about 300 DU occurs at the maximum difference of 0.0574

[#] 1 DU = 10^{-3} cm.

Now substitute the estimates found above in the ansatz (17) gives

$$\hat{x}_t = 81.772 + 0.716\, x_{t-1} \tag{24}$$

So the forecast for the O_3 depth for the month of September 1994 (i.e. for the 297[th] month reckoned from January 1970) is provided by the following equation on inserting x_{296} = 268 DU in Eq. (24):

$$\hat{x}_{297} = 81.772 + 0.716\, x_{296} = 81.772 + 0.716 \times 268$$

$$\hat{x} \quad = 273.66 \text{ DU} \tag{25}$$

It can be checked that the forecast accuracy is 2.8%, which is not unwholesome.

5. Conclusions

We have shown OLD as a potential source of high incidence of UV radiation on the sea level. To recognise this immediate threat, we wish to properly assess and monitor the influence of OLD on the recent environment of our region (stratospheric region of Pakistan). As argued in this section, for a systematic handle on the problem, among other things, we need to try to understand the nature of modulations in the O_3 concentrations in the stratospheric region of any specific area. Therefore, our calculations show that the process (1) possesses a good degree of normality, which is reasonable for Pakistan's stratosphere, though raising the question of the performance of Dobson spectrophotometers being used for recording the events at detection centers, on the one hand, and of the actual configuration of the O_3 depth probability distribution, on the other. The goodness-of-fit tests are used

We have utilized linear self-regressive model for estimating the dimension of O_3 concentrations and validity of the model was checked that gave a forecast of O_3 depths for Pakistan's stratospheric region with a good forecast accuracy. In addition to specifying various features of the O_3 phenomenon as a physical process, thus strengthening our earlier findings, what is quite interesting is the fact that such a forecast computation for O_3 depths could lend insight into the very physical mechanism generating future events. The study presented here does not seem to have been undertaken in the published literature, in particular in a local/regional perspective. In fact, however, the question of O_3 depths is still unanswered in many respect. A justification in treating the conditional regression as a regression, reduction in assumptions could be made for our ansatz. We could suggest analysis of the periodicities of OLD for improving our model further due to the interactions of atmospheric fine-particles. Moreover, the modulation of UV flux due to OLD during solar active and passive periods can be studied.

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