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Original Article

Modeling and Simulating the Effects of Ozone Layer Depletion on Climate Change at Pakistan Air Space

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Abstract: Ozone is a minor constituent of atmosphere that can shield UV-B radiation right from the solar radiation. Climate refers to the mean behaviour of the weather over some appropriate averaging time. Moreover, the condition of the atmosphere at a particular location and time is its weather that includes winds, clouds, precipitation, temperature and relative humidity. In contrast to weather, the climate of a region is the condition of the atmosphere over many years, as described by long term averages of the same properties that determine weather. The variability in the climatic conditions can enhance the temperature of the region where the ozone is depleted. Due to this increase in the temperature, climatic conditions are changed. We have found some correlational structures for determining the variations in climate on the basis of ozone layer depletion. A model has been developed for evaluating sea surface temperature using stratospheric ozone filter. This filter has been formulated taking into account the ozone layer depletion (OLD) strategy for Pakistan atmospheric regions. For making predictions of fluctuations in the temperatures that in turn create climate change in the region, stochastic analysis is implemented here for observing future conjecture of the incoming radiation. These forecasts are useful for public, private and government organizations.

Keywords: Climate change, ozone layer depletion, stratopsheric phenomenon, simulation of the effects of ozone

1. INTRODUCTION

Ozone in the stratosphere acts to protect our biosphere from harmful ultraviolet (UV) radiation from the sun. UV radiation to human and other animals can cause sunburn, cell damage, skin cancers and promotion of AIDS viruses. Plants and other simpler organisms such as phytoplankton are also susceptible to UV damage reducing their productivity rates [1, 2, 3, 4].

The average pattern of weather at a particular place is measured and recorded over a specific long period of time. This pattern is influenced by the relative position of the oceans and continents, latitude, local conditions, altitude and the impact of human activities. Our earth's climate changes over time because of several factors. These factors include: (a) variations in the sun's activities such as sunspots, solar flares, solar magnetic storms that affect the amount of radiation reaching the earth's surface, (b) changes in the composition of the atmosphere brought about by sulfur oxides (SO_x) gases thrown out by volcanic eruptions, (c) burning of fossil fuels, and (d) release of chlorofluorocarbons (CFCs) that influences the type of intensity of radiation reaching the earth's surface. Some of these effects may be long term, others will probably produce much short lived variations. While some of these may lead to the cooling of the earth and some are likely to raise its temperature. Almost all the investigators working in the field know that the climate change will

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occur due to these forms that create reasonable intensity [5–8].

Ozone layer in the stratospheric region may not be having the same effects as in the tropospheric ozone. This low level ozone at the ground level formed from the vehicle emissions and in photochemical smog is a potent oxidizing agent and damaging to health. Albeit there are some connections between climate change and the ozone layer depletion.

CFCs that cause ozone depletion are greenhouse gases but destruction of the ozone reduces greenhouse effects slightly as the ozone also acts as a greenhouse gas. Increasing CO_2 can increase ozone depletion [9]. It has been observed that if the ozone destruction were to become serious enough to reduce the productivity of the phytoplankton and forest ecosystems as a result of UV damage, this would affect climate change in reducing these sinks for atmospheric CO_2. A series of chemical reactions are mentioned in the literature regarding the ozone formation and annihilation. The ozone holes appear to have deteriorated more rapidly than hoped or expected particularly in the Artic. It is thought that this may be due to a feedback with climate change [10, 11]. CO_2 is being released into the atmosphere as a result of burning fossil fuel for which the anthropogenic climate change occurs [12, 13].

Reduction in the stratospheric ozone and increase in the greenhouse gas concentration also appear to enhance the meridional temperature gradient in the lower stratosphere leading to a strong polar vortex this becomes colder and stronger. The atmospheric response to strong tropical volcanic eruptions provide some evidence for a stratospheric influence on the earth's surface climate [1, 7].

In this communication the variability has been studied in the sea surface temperature (SST) using the process of the filtration of solar UV radiation through constructed ozone filter and constructing a mathematical model for sea surface temperature to determine the variation in the temperature. Using temperature variations, the variations in the climate structures will be discussed. Probabilistic and stochastic models can also be implemented for a more accurate study. This study is important from the point of view of monitoring OLD effects on climate change that will affect our future economy [13].

1.1. Illustration of Probability Theory for the Depth of Ozone

This illustration manifests the probability of each value of the depth of ozone in terms of its calculated volume for the period from 1960 to 1998 for Pakistan's air space.

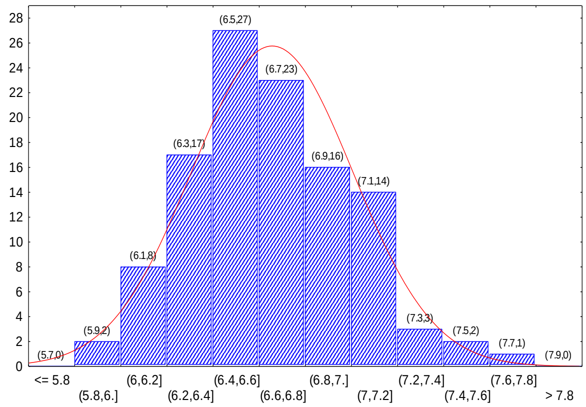

Fig. 1. Various number of observations of volume of ozone contents.

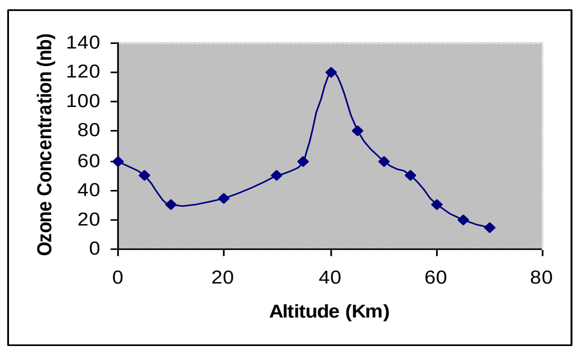

Fig. 2. Ozone levels as a function of altitude.

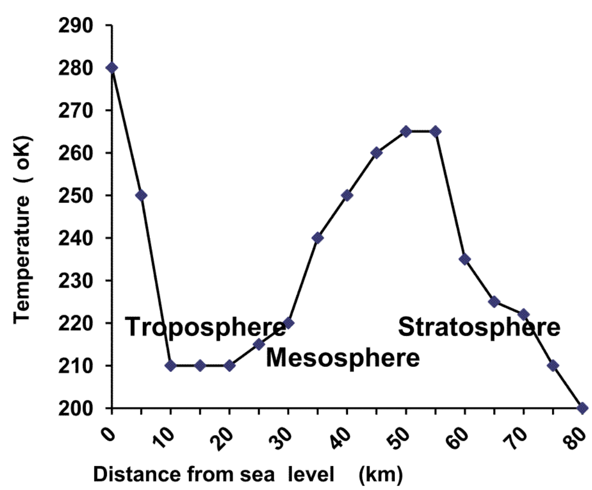

Fig. 3. Thermal structure of the atmosphere.

In Fig. 1, the ozone contents have been illustrated in Pakistan atmospheric regions. In Fig. 2 and 3 different levels and the layers of atmosphere have been exhibited, respectively. The abundance of ozone is found at stratospheric location of the atmosphere.

1.2. Modeling Variability of OLD with respect to Atmospheric Abundances of CFCs

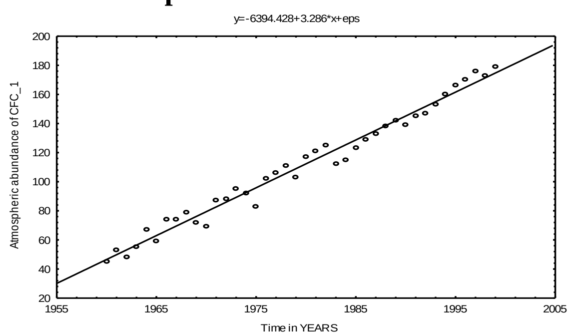

Fig. 4. Temporal variations of CFCs.
X-axis = time in months
Y-axis = atmospheric abundance

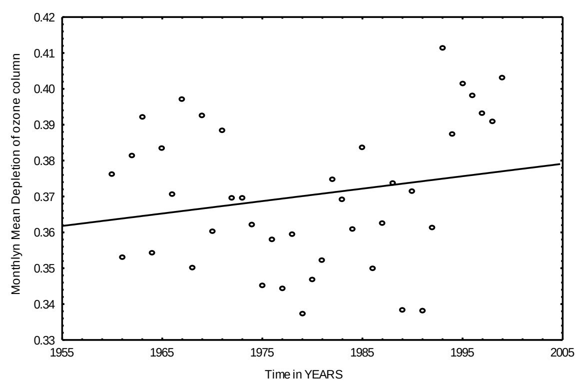

Fig. 5. Temporal variation of ozone depletion.

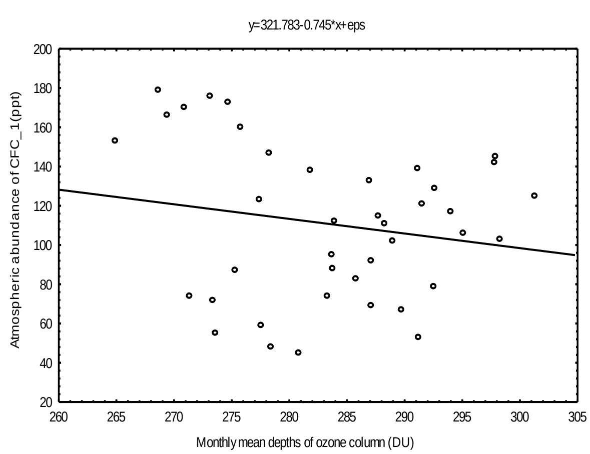

Fig. 6. Variation of CFCs with respect to monthly mean depth of ozone at Pakistan. atmospheric region.

1.3. Filtration of Solar UV Radiation through Ozonosphere

The change in ozone concentration, in turn alters the change in temperature. The direct radiative effect of gases comes about via absorption of solar radiation and absorption and emission of long wave radiation also referred to as thermal, terrestrial, or infrared.

The temperature does refer to heat intensity. For a discrete body, the temperature is proportional to the average kinetic energy of the component molecules. Solar radiation reaching the sea level consists of broad range of wavelengths or frequencies. Among this radiation, the optical wavelengths are entirely responsible for heating the earth's atmosphere, land surface and oceans.

The chemical reactions for the formation and annihilation of ozone in the stratosphere are given below:

$$O_2 + h\nu\ (\lambda < 240\ \text{nm}) \rightarrow O + O \quad \text{Slow} \qquad (1)$$

$$O + O_2 + M \rightarrow O_3 + M \quad \text{Fast} \qquad (2)$$

In which M is an un-reactive third molecule (such as N_2 and O_2) required to absorb or to carry off excess energy of the association process.

$$O_3 + h\nu(\lambda < 310\ \text{nm}) \rightarrow O + O_2 \quad \text{Fast} \qquad (3)$$

$$O + O_3 \rightarrow O_2 + O_2 \quad \text{Slow} \qquad (4)$$

Overall reaction is as follows:

$$O + O_3 \rightarrow 2\,O_2 \qquad (5)$$

Calculations of the variation of temperature can provide information about the chemical reactions taking place in the stratospheric region [11].

1.4. Quantification of Ultraviolet Flux

Volume of ozone column at the stratosphere of Pakistan can be determined using the total volume of maximum ozone column in the stratosphere V_t for Pakistan' atmospheric region. This volume can be computed using the area of air space of Pakistan(S) and the depth of ozone layer (*h*).

$$\mathbf{V}_t = \mathbf{S} \times \boldsymbol{h}_t\ (O_3\ \text{in DU}) \qquad (6)$$

DU is Dobson Unit for total amount of Ozone per cm^2 above sea level. The equivalent depth for total ozone at STP. (1 DU = 10^{-3} cm of ozone at STP)

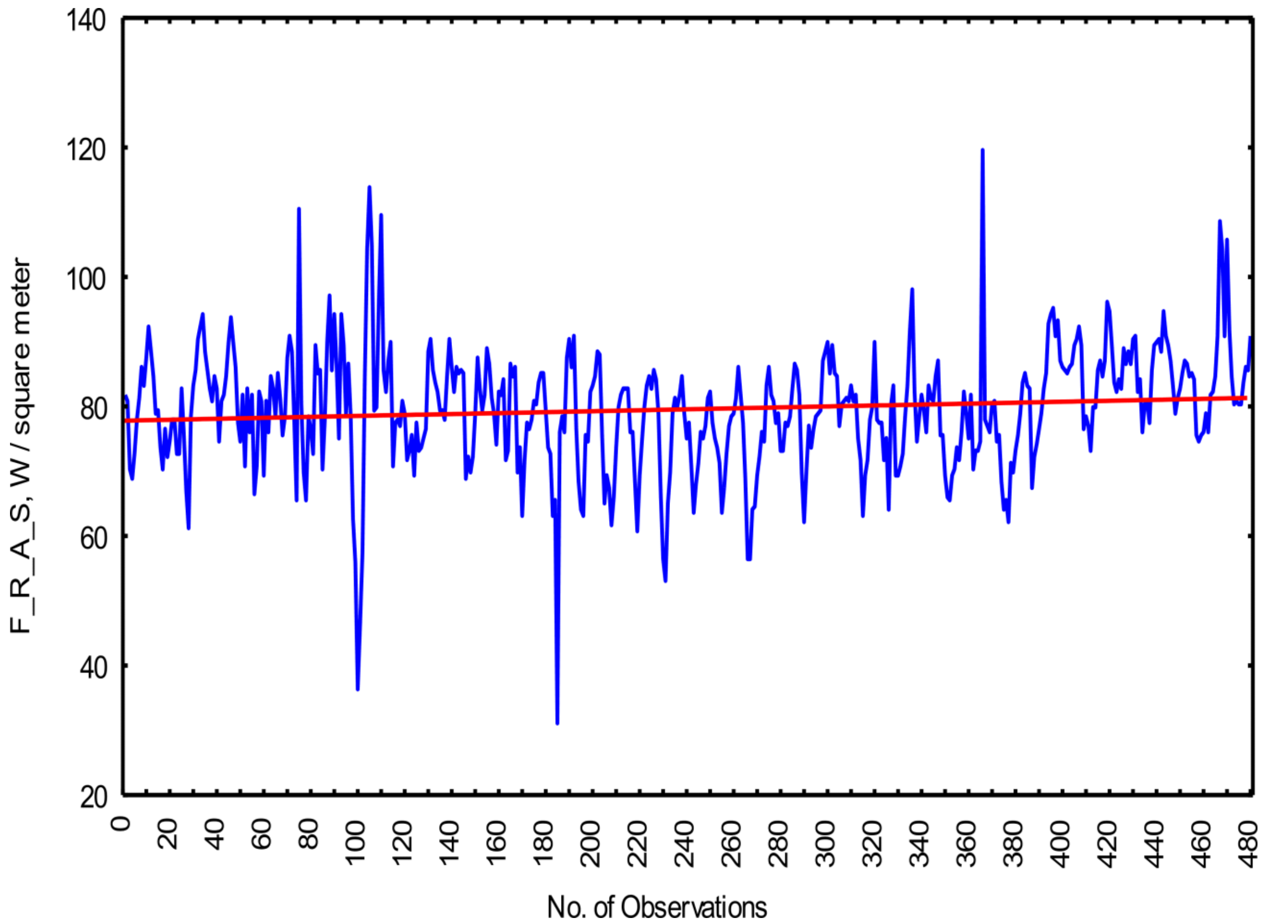

Fig. 7. Variation of UV flux versus time, depicting the enhancement and decrease of flux due to depletion of O_3 at Pakistan's stratosphere.

Area of the air space for Pakistan is 2.34×10^6 km^2 = S

Where ***h*** is the depth of ozone column measured at Geophysical Centre, Quetta for Pakistan's atmospheric region. The maximum depth of ozone h_t which has been transported from south-pole to Pakistan's atmospheric region is 400-450 m-atm cm (milli–atmosphere-centimeter, equivalent to 400- 450 DU) which is a reference depth. The total volume of ozone at Pakistan could be calculated from this depth. The volume of ozone for Pakistan's atmospheric region from the data points collected at Geophysical Centre Quetta Pakistan will be calculated using the following mathematical expression:

$$\mathbf{V}_i = \mathbf{S} \times \boldsymbol{h}_i, \ (i = 1,2,3, \ldots n), \tag{7}$$

n is # of observations

Therefore,

$$\mathbf{V_t} - \mathbf{V}_i, \quad (i = 1,2,3, \ldots n), \tag{8}$$

n is # of observations

is the absolute depletion with respect to the total ozone transported to Pakistan atmospheric regions. The relative depleted volume of ozone is calculated with the help of the following expression:

$$\mathrm{P_i} = \frac{V_t - \mathrm{V_i}}{V_t} \tag{9}$$

$$\mathrm{P_i} = \left(1 - \frac{V_i}{V_t}\right) \tag{10}$$

For *n* is the total # of observations and *i* is the observation number then the equation # (9) may be written as follows:

$$\mathrm{P}_n = \left(1 - \frac{V_n}{V_t}\right) \tag{11}$$

$$\mathrm{P}_n \times \text{Luminosity} = f_{effective} \tag{12}$$

Equation (11) characterizes the ozone filter mentioned above for different luminosities which have been calculated using the UV- Lyman flux of solar radiation. Equation (12) shows effective luminosity reaching the Arabian sea through the ozone filter. We know that stratosphere will act as the secondary source of UV radiation through the ozone filter [12-13].

$$F = \frac{f_{effective}}{4\pi R^2_{Arabiansea}}. \quad (13)$$

Equation (13) gives the values of UV-B flux reaching Arabian Sea. Fig. 7 depicts the variation of UV-B. Along the y-axis, the abbreviations F.R.A.S. stands for Flux Reaching Arabian Sea in watts / meter square

1.5. Computation of Sea Surface Temperature Using the Flux Reaching Arabian Sea

Here a very simple and applied meteorological model that concerns the estimation of the planetary temperature using the calculated flux reaching the Arabian sea via the ozone filter has been constructed for Pakistan air space. Albeit it is very crude assumption, let us approximate our earth a black body radiator. On this assumption the consideration of Stefan Boltzmann law leads to the flux emitted by earth as $\pi D^2 \sigma T^4$. This can be equated with the flux obtained from the calculation of OLD made earlier. This leads towards the following empirical model which can yield temperature variability between two instants of time as shown in Fig. 8. Though, our assumption of the earth being a black body radiator is very crude, however, the temperature calculated on this assumption and provides us a kind of handle on atmospheric issues in particular in weather and climate prediction [12-13].

The total radiant energy flux from the sun, just outside the earth's atmosphere is 1.353 kW m^{-2}.

The total heat inflow to earth from the sun =

$$\frac{\pi}{4} D^2 .Flux \quad (14)$$

$$\text{The total heat outflow} = \pi D^2 \sigma T^4 \quad (15)$$

where $\sigma = 5.672 \times 10^{-11}$ kW / m^2 K^4, and D is the diameter of the earth considered to be 12.75×10^6 m.

The total heat radiated to outer space would be the amount of heat given by (14) plus the amount of heat produced on earth by nuclear decay and tidal friction with the moon, which together are less than 0.1 percent of the solar energy inflow and can be safely ignored. The outward radiation is calculated using the surface area rather than the projected area. Then *T* can be determined by equating the expressions of heat inflow and heat outflow as follows:

Heat in flow = $\frac{\pi}{4} D^2 .Flux$ = heat out flow = $\pi D^2 \sigma T^4$

$$T = \left(\frac{Flux}{4\sigma}\right)^{0.25} \quad (16)$$

where the flux in Equation (13) is the flux reaching the Arabian sea through ozone filter. Using Equation (16) the approximate value of the temperature of the earth's surface can be computed.

1.6. Assessing Stochasticity in the Sea Surface Temperature

The constructed AR(1) model that has been regarded as stochastic model for OLD data is shown that below:

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

is the most adequate for OLD study. β_1 is parameter that depicts the autoregressive nature of the process. Now this model is used to study sea surface temperature. Here $\hat{\beta}_1$ comes out to be 0.69 ± 0.035 that is the predicted value or estimate of the parameter β_1.and the Mean Sum of Squared Errors (MSSE) $\hat{\sigma}_a^2$ appears as 11.64 ± 1.9, $\hat{\rho}$ (α_t and α_{t-1}) and $\hat{\rho}$ (α_t and X_{t-2}) comes out to be –0.015 and 0.0012 respectively.

There may exist temporal and spatial limitations of our model in Equation (17) as a representation of the real stratospheric atmosphere [7-9]. O_3 depth fluctuations seem to be transported along with seasonal variations as shown in Fig. 8. to Pakistan's atmospheric regions. Moreover, the O_3 layer variability forms an O_3 filter in the passage of UV-B that also gives a variation in the temperature.

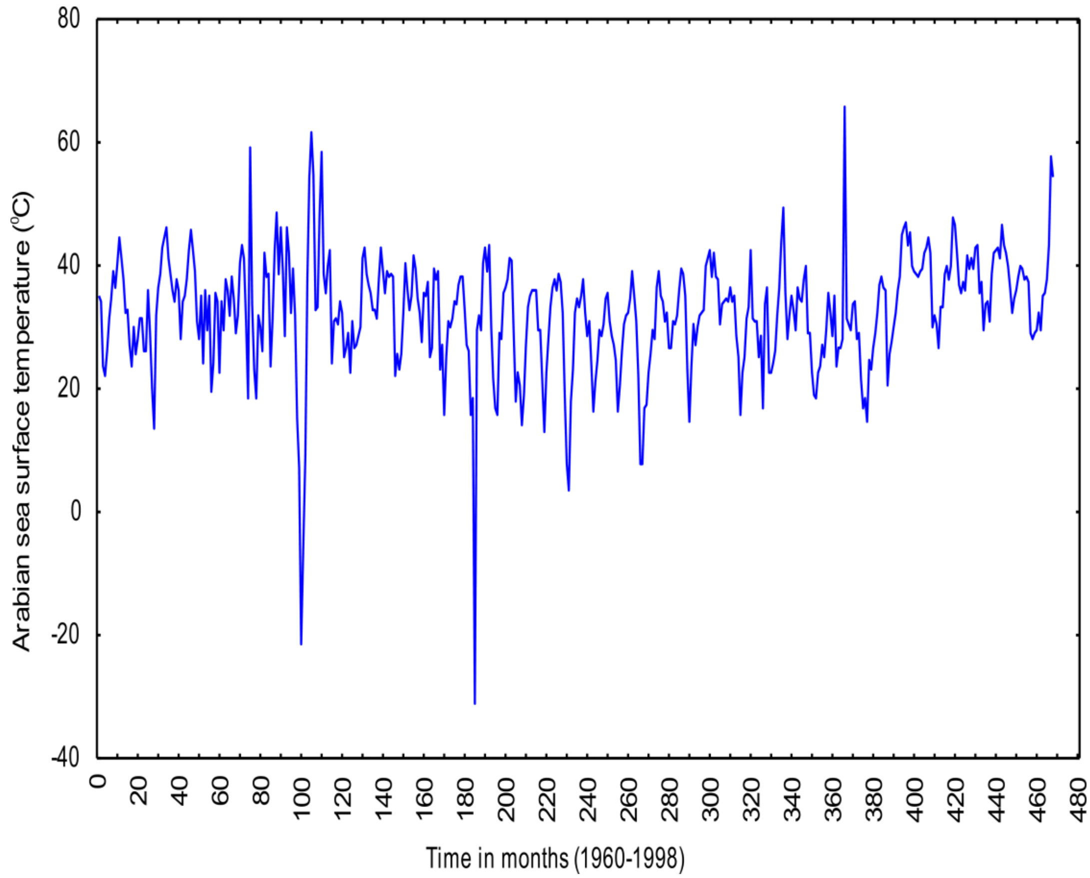

Fig. 8. The plot of Arabian Sea surface temperature against the time that exhibits the variation in temperature due to OLD.

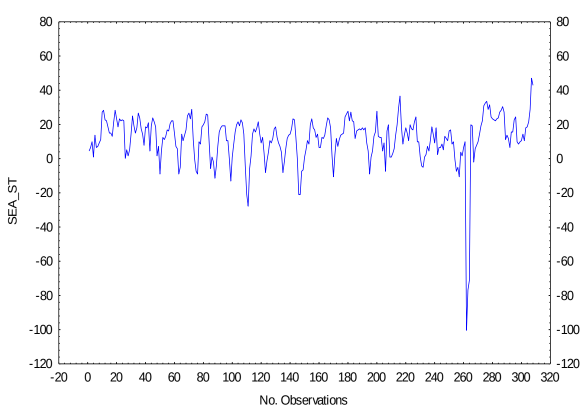

Fig. 9. Residual plot elucidating the appropriateness of the constructed model for sea surface temperature.

The residual analysis is depicted in Fig. 9 that amply demonstrates that the constructed model is reasonably adequate. The line spectrum or periodogram (cf Fig. 10.) constructed to identify the randomness in the SST due to OLD.

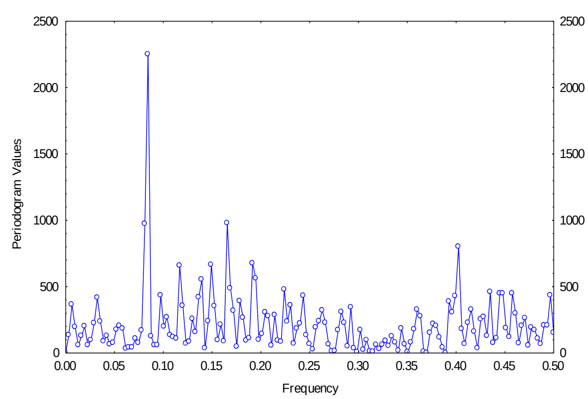

Fig. 10. Periodogram for Sea surface temperature AR(1) identifying the randomness in this temperature due to OLD.

Error structure can be revealed by the autocorrelation for residuals of the O_3 depth events exhibits a rather neat serial correlation (vide Fig. 11). With the predicted value comfortably establishes the validity of the constructed model (Fig. 11.).

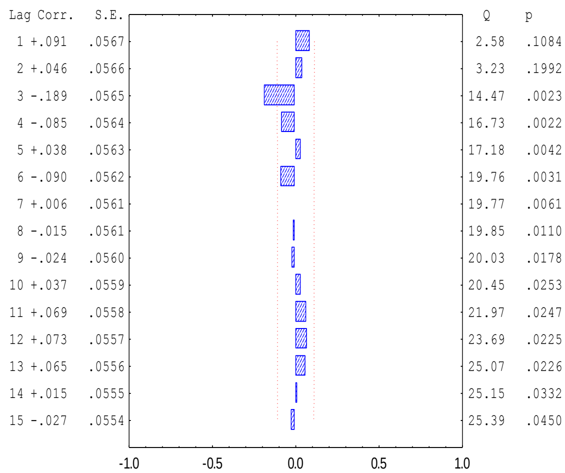

Fig. 11. Autocorrelation or serial correlation for Sea surface temperature between i[th] Observations and the (i+m)[th], exhibiting high degree of correlation.

Substituting $\alpha_t = 11.64 \pm 1.91$ in equation (17) the forecast of the sea surface temperature (SST) for the month of January 1999 is 40.62 ^{0}C. The forecast accuracy being 13.5 % as absolute percentage forecast error (APFE), which is reasonable for Pakistan's atmospheric region.

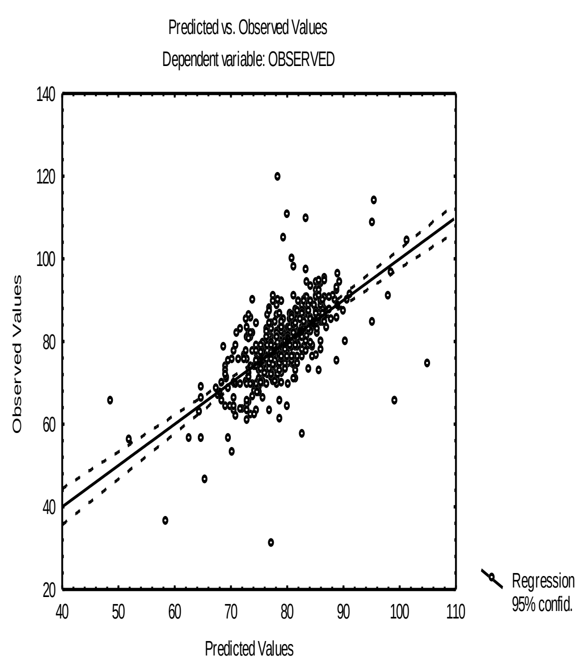

Fig. 12. Comparison of observed and predicted values of the sea surface temperature (SST) signifying the behaviour of the constructed model.

2. CONCLUSIONS

In this communication the major role of ozone layer depletion has been intimated in the stratospheric regions of Pakistan. Effects from this type of process would more than likely to be cumulative and would affect long term climatology of the region. Meteorological correlations with the CFCs and ozone depths indicate that the temperature variations are due to solar flux reaching the biosphere. The ozone layer depletion has a dual role as a barometer of the stratospheric changes on one hand and a possible driver of the atmospheric and climatic changes on the other hand.

The role of ozone layer depletion as a possible driver of atmospheric changes is of principal concern in this investigation. We have presented that the variations in the ozone depletion modulate the amount of solar UV radiation especially UV-B reaching the biosphere with a consequent variation in heating that would lead to temperature changes and attendant modulation in the atmospheric circulation patterns at Pakistan regional scenario.

3. ACKNOWLEDGEMENTS

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