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Variation of stratospheric ozone with relative humidity and sharp depletion of absolute humidity associated with Nor'wester over Kolkata

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Abstract : The paper presents the variation of stratospheric ozone concentration with relative humidity over Kolkata. Analysis confirms that there is close correlation between them. The relative humidity in general, increases during commencement of severe thunderstorm. As drop in temperature occurs during thunderstorms, absolute humidity decreases during the onset of thunderstorm. The sharp depletion of absolute humidity at the time of starting of Nor'wester over Kolkata has been studied in the present paper. Possible explanations of such type of variation of humidity are presented. One possible method of forecasting of severe thunderstorm is also offered.

Keywords : Relative humidity, absolute humidity, stratosphere, troposphere, Nor' wester.

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1. Introduction

Interrelation between stratospheric O_3 concentration and different environmental parameters is now well established. Dobson *et al* [1] reported that average temperature of earth is directly related to ozone concentration of stratosphere and fall in ozone content in the stratosphere takes place over England before the arrival of warm front at the ground surface. They also reported that the rise in ozone content in the stratosphere takes place when cold front reaches near the ground level. Midya *et al* [2] showed that maximum surface temperature of Kolkata is directly related with stratospheric ozone concentration over

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Kolkata. Besides these, Mitra [3] mentioned that there is a close relation between barometric height, tropospheric weather and ionospheric parameters of the upper atmosphere. It was observed that minimum height of F region and average E ionization tend to follow the variation of barometric height. Mitra [3] also mentioned that correlation was observed between the lowest virtual height of E region and ground temperature at Standford, California, U.S.A. Bates [4] and Mackay *et al* [5] concluded that variation of solar UV radiation due to fall of stratospheric ozone concentration can influence tropospheric climate in many ways. This paper presents the variation of stratospheric ozone with relative humidity and sharp depletion of absolute humidity related with Nor'wester over Kolkata. Possible explanation based on physical considerations and chemical kinetics is offered.

2. Observation

Data for relative humidity is collected from Alipore. In the absence of ozone data over Alipore, that of Dumdum station which is very near to Alipore is taken from internet website (http://jwocky.gsfc.nasa.gov).The variation of ozone with relative humidity is nearly straight lines. A few selected variations of ozone concentration for particular time and year (1991, 1992, 1993, 1994) are shown in Figure 1.It is clear from this figure that the stratospheric ozone concentration increases with the increase of relative humidity over

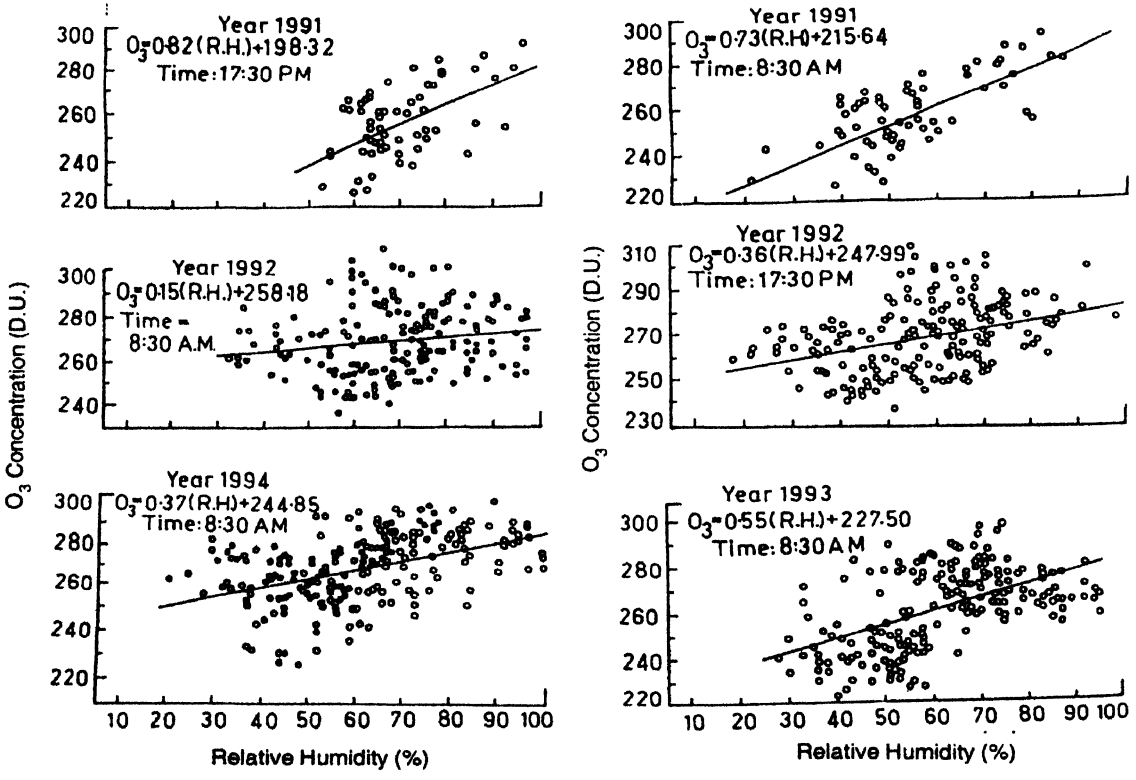

Figure 1. Variation of stratospheric ozone concentration with relative humidity for some selected dates over Kolkata.

Kolkata. We have obtained almost the same type of observations during the period 1991-1994. Detailed results are presented in Table 1.We have considered relative humidity for three times (8:30A.M., 11:30A.M., 17:30P.M.) of a particular day (03.04.1990, 18.05.1990, 14.04.1990).

Table 1. Stastical analysis of the variation of ozone concentration and relative humidity for different times of different years and their empirical relations.

Year	Time	Correlation coefficient	Empirical equations
1991	08:30 A.M.	0.39	O_3=0.73(R.H.)+215.64
1991	11:30 A.M.	0.63	O_3=0 652(R.H.)+219.66
1991	17:30 A.M.	0.55	O_3=0.818(R.H.)+198 32
1992	08:30 A.M.	0.01	O_3=0.15(R.H.)+258.18
1992	11:30 A.M.	0.64	O_3=0.498(R.H.)+238.12
1992	17:30 P.M.	0.39	O_3=0.36(R.H.)+247.99
1993	08:30 A.M.	0.39	O_3=0.55(R.H.)+227.50
1993	11:30 A.M.	0.67	O_3=0.63(R.H.)+215.13
1993	17:30 P.M.	0.52	O_3=0.708(R H.)+209.36
1994	08:30 A.M.	0.27	O_3=0.27(R.H.)+244.85
1994	11:30 A.M.	0.61	O_3=0.49(R.H.)+231.86
1994	17:30-P.M.	0.51	O_3=0.625(R.H.)+221.90

The meteorological data of the year 1990 is used to study the association of transient changes of temperature, absolute humidity and relative humidity during the occurrence of Nor'wester over Kolkata. Liebe *et al* [6] presented one empirical equation which is helpful to calculate absolute humidity of a particular Nor'wester day. To calculate the absolute humidity we consider the atmospheric temperature T (°C) and relative humidity in percentage as input parameters. Using a relative inverse temperature variable(Φ) defined as Φ=300/(T+273.15) ; and water vapor pressure (e) defined as $e = 2.408 * 10^8 * U * \Phi^4 * \exp(-22.64\Phi)$ in kPa where U represents relative humidity in percentage, we ultimately get the expression for absolute humidity as

$$V = 7.223 * e * \Phi \text{ in gm/m cube.}$$

A typical record of the relative humidity, temperature and absolute humidity variations during two Nor'westers occurring on 03.04.1990 and 18.05.1990 are shown in Figure 2. Figure 3 shows the variation of the said parameters on a normal day 14.04.1990, with no report of thunderstorm. Comparison of the figures confirm the dip of absolute humidity at 1430 IST on 03.04.1990 and at 1370 IST on18.051990 on two selected Nor'wester days around the time of onset of the thunderstorm. The drop in temperature is monotonic, showing no sharp dip, while the relative humidity also increases monotonically at the

same time. During the period of consideration, there were 26 cases of prominent Nor'westers of these 23 cases show a sharp drop of absolute humidity. Moreover, regarding the relative humidity variation during Nor'wester, it is generally monotonic and having no correlation with absolute humidity variations. From analysis we get the following results

(i) Concentration of stratospheric O_3 increases with the increase of relative humidity over Kolkata (Figure 1)

(ii) The rate of increase of O_3 concentration depends on time of a particular day (Table 1)

(iii) Observations confirms a fall of temperature and a sharp drop in absolute humidity during the onset of a Nor'wester over Kolkata

3. Discussion

O_3 is a minor constituent of the atmosphere. It is mainly distributed in the stratosphere Maximum concentration of O_3 occurs around 25 km altitude [7]. Ozone is formed in the

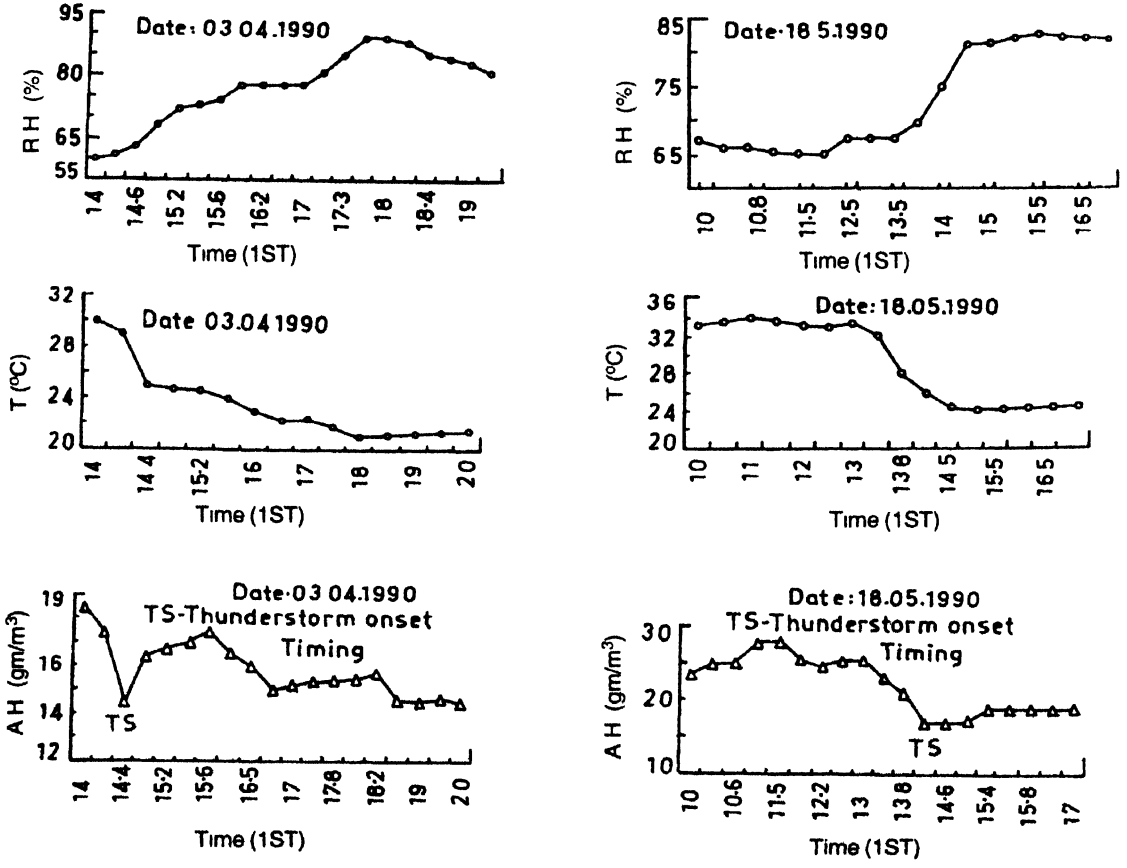

Figure 2. Variation of relative humidity, temperature and absolute humidity with time (IST) on two Nor'wester days over Kolkata

atmosphere due to the decomposition of water molecule by solar UV ray as given below [8] :

$$H_2O \rightarrow H + OH,$$

$$OH \rightarrow O + H,$$

$$O + O + M \rightarrow O_2 + M\ .$$

O_3 is formed in the atmosphere from the combination of atomic and molecular oxygen. There are also other ozone formation and destruction processes .The net results are as follows:

	Reactions			Rate Constants
1.	$O_3 + h\nu$	$\xrightarrow{labs}$	$O3^*$	labs
2.	O_3^*	$\xrightarrow{K1}$	$O_2 + O$	K_1
3.	$O + O_3$	$\xrightarrow{K2}$	$2O_2$	K_2
4.	$O + O_3^*$	$\xrightarrow{K3}$	$2O_2$	K_3
5.	$O + O$	$\xrightarrow{K4}$	O_2	K_4
6.	$O + O_2$	$\xrightarrow{K5}$	O_3	K_5

All rate constants are calculated by Midya *et al* [9] in a previous communication.

Solar UV rays contain high energy photons which decompose water molecules into atomic oxygen and OH radical. Thus we can expect that if stratospheric ozone is depleted, the high energy solar UV photons fall directly on troposphere and as a result, tropospheric water molecules are decomposed resulting the fall of relative humidity and increase of tropospheric ozone which acts as Greenhouse gas and plays important role in global warming.

Again for high stratospheric ozone concentration, ozone layer absorbs maximum of the incoming UV photons and resist falling on the lower atmospheric water molecules. Thus increase of relative humidity with the increase of stratospheric ozone concentration is expected. It is clear from the Figure 1 which is obtained from the meteorological data of Alipur and O_3 data over Kolkata. WMO bulletin [10] confirmed that O_3 is depleted everywhere in a smaller amount, but dramatic decrease of O_3 concentration takes place only over Antarctica during spring time. But for Indian regions for the latitude range 25-34^{0}N, we have shown that ozone concentration gradually increases from the month of January, attains its maximum value for the period of May and June, then gradually decreases and attains a minimum value for the month of December [11]. Thus variation stratospheric O_3 concentration with relative humidity is quite expected.

The fall in surface temperature and increase in relative humidity with thunderstorm is a normal trend. From the observations of change of surface meteorological parameters associated with thunderstorms many models have been proposed by various researchers in this field. Maddox *et al* [12] in their model postulated that low level warm and moist air from the forward sector slides over the warm and dry moving air mass during the formation

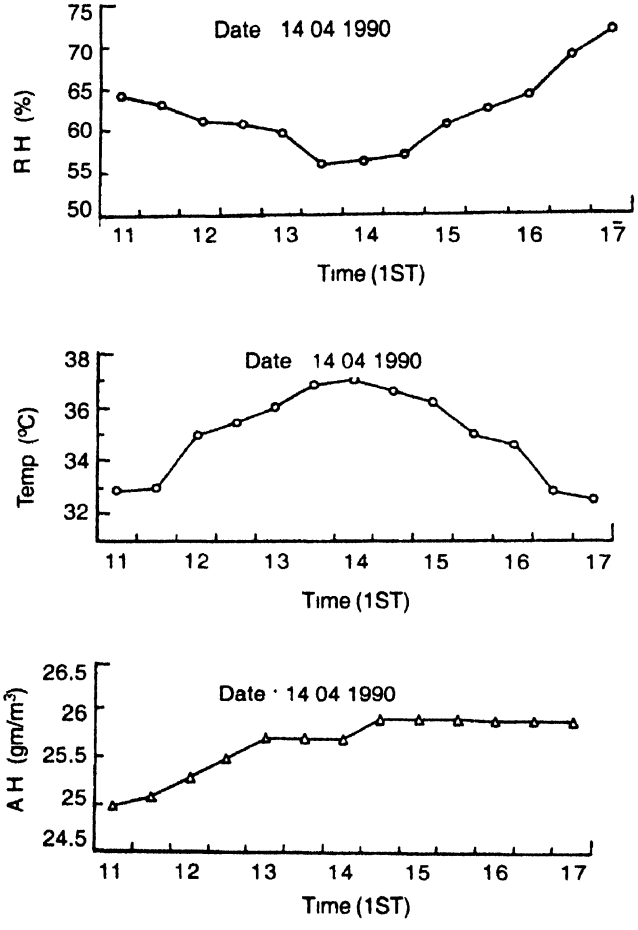

Figure 3. Variation of relative humidity, temperature and absolute humidity with time (IST) on one normal day over Kolkata

stage of thunderstorms. As the thunderstorms overtake into maturity the whole field of thunderstorm gets filled up with regions of updraft and downdraft. Doppler radar observations confirmed that downdrafts of air beginning from lower levels and not accompanied with rain exhibit weak reflectivity meaning thereby impinging precipitation free air on the surface, indicating low absolute humidity at the surface during such events.

It may be realized that at least two mechanisms operate in a moving thunderstorm for the sudden drop of absolute humidity during the onset of a thunderstorm over a station and these mechanisms may be explained as follows:

(i) The turbulence produced at the leading edge of the wind front mixes dry air at the top resulting in a drop in surface moisture.

(ii) In the initial stage of downdraft, the air is evaporating and thus cooled but devoid of any moisture.

It is felt that in the case of Nor'wester over Kolkata, both the above mechanisms were being operated causing fall in surface temperature and sharp fall in absolute humidity With the progress of thunderstorm activity the downdraft reaches the ground and is embedded with rain causing the surface air to cool with rise in relative humidity and absolute humidity

It is now well established that Doppler radar study in the thunderstorm region reveals a very complex nature of wind It has been observed that at different stages of thunderstorm, there is a shift in the location of regimes of updraft and downdraft with consequential influence on environmental condition The main point emerges from the present study is that the absolute humidity is more realizing than that of relative humidity during the occurrence of Nor'westers For the sharp drop in temperature associated with tends to increase the relative humidity while the absolute humidity really drops at much higher rate and it is absolute humidity which is more important parameter for modeling of such thunderstorms As absolute humidity starts to drop at about forty to sixty minutes before the starting time of Nor'wester, so this parameter may be utilized for the forecasting of Nor wester events Also, observing the nature of rate of fall of the absolute humidity (fast rate or slow rate), we may conclude about the different types of thunderstorms i.e squall type or ordinary thunderstorm, which may be left for our next research work It may be mentioned here that a faster response absolute humidity sensor would be more desirable for such studies and a Lyman- hygrometers with having a time constant of 15 milli-second would be ideal for this purpose It is also expected that depletion of stratospheric O_3 increases tropospheric temperature and decreases presence water molecules of the troposphere due to unabsorbed solar UV ray by the stratosphere As a result, rainfall will be decreased and nature of Nor'wester will be changed due to depletion of stratospheric ozone. Midya *et al* [13] showed that N_2O plays important role in the depletion of ozone in the stratosphere So it may be concluded that in order to maintain suitable condition of our different environmental parameters, we have to give more attention to control concentration of N_2O with respect to other ozone depleting substances (ODS)

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