MAUSAM, **62**, 1 (January 2011), 103-118

L E T T E R S

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GLOBAL ANALYSIS OF LONG-TERM TRENDS IN TOTAL OZONE DERIVED FROM DOBSON OR GROUND BASED INSTRUMENT DATA

1. The abundance of atmospheric ozone is determined by a combination of chemical and dynamical processes. The importance of these processes changes with time and location. These processes also act on different time scales, *e.g.*, solar cycle varies over 11 years and strong volcanic eruptions have an effect lasting a few years only. The study of long-term trend of ozone in the different regions of the globe is at the forefront of research in the atmospheric chemistry.

The long-term changes in global ozone have been studied many times in the past also and it has been observed that global total ozone values were about 3% below the pre 1980 values, which is before the occurrence of Ozone hole (WMO, 2006). It has also been observed that the reduction in the total ozone values have been observed mainly in mid and high latitudes of both hemispheres (WMO, 2006). It has also been reported that no trend of global ozone has been observed in the tropics (WMO, 2006). There are also clear differences noted in the trends of two hemispheres, a 3% decrease in the northern hemisphere and a 6% trend in the southern hemisphere has been reported earlier. (WMO, 2006).

Both dynamical and chemical processes may cause the changes in decadal lower stratospheric ozone. There seems to be no single cause and relative contributions of different processes will change with time period. The ozone loss occurring at poles may be getting transported to the mid-latitudes over a period of time and affecting the ozone there. It is also well known that a major chemical driver for long-term lower stratospheric ozone changes is increases in chlorine and bromine.

The latitudinal changes over long term have been comprehensively studied so far (WMO, 2006). In the present complimentary study the long-term changes over different longitudes has been attempted.

2. As is well known there are few hundred observatories in the world, which regularly take total ozone observations, but out of these observatories a large number are quite old and have a data record of more than 30 years that can be considered adequate for making a long term study. The standard equipment for taking reliable observations at most of the observatories is Dobson spectrophotometer which have produced a consistent data set and have been inter calibrated with the timely programs conducted by WMO. The Dobson spectrophotometer measures the ratios of the intensities of ultraviolet radiations at two pairs of wavelengths. The recent standard equipment for such observations is Brewer spectrophotometer and is also used worldwide at present. It is a standard instrument for ground–based ozone measurement and can also measure the surface UV radiation. It uses readings of five wavelengths of light from the Sun to measure the total amount of ozone overhead.

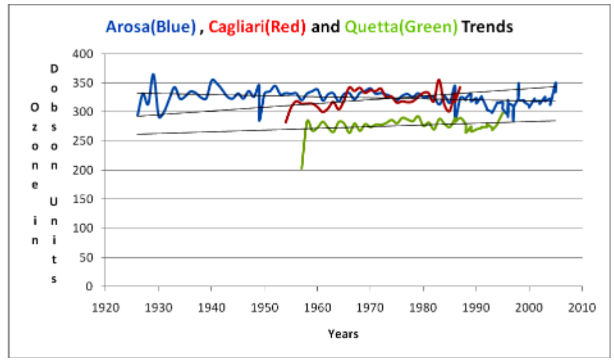

Fig. 1. Annual trend of Ozone

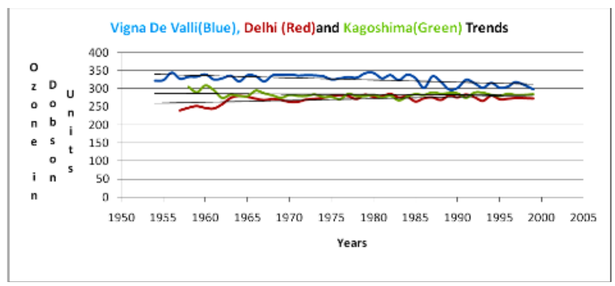

Fig. 2. Annual trend of Ozone

All countries taking ozone observations send their data to World Ozone and Ultraviolet Data Centre (WOUDC) (www.woudc.org) regularly. WOUDC in turn checks these data and after making suitable quality control makes these data available to the world community through their website. The source of data for the present study is WOUDC (www.woudc.org).

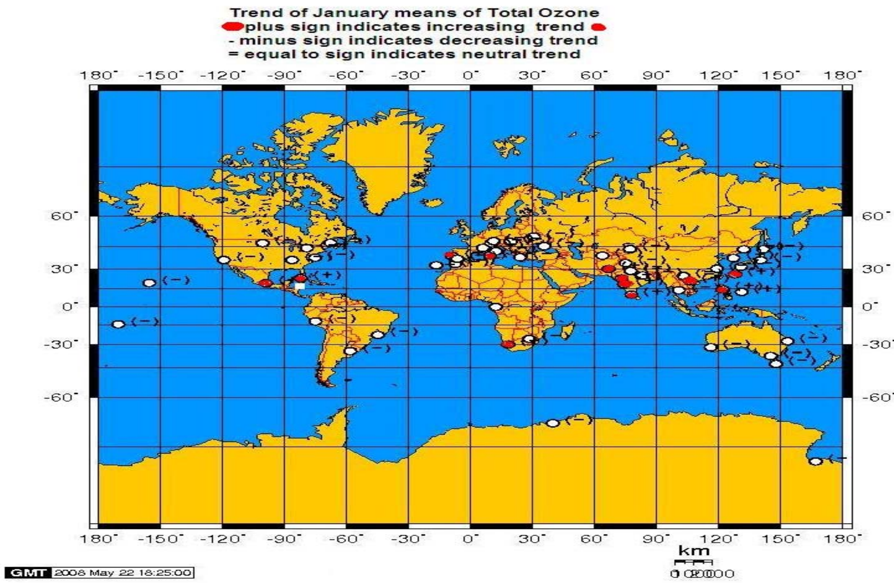

Fig. 3. Trend of January means of total ozone

In an attempt to know whether the decline in the total ozone values are uniform at all longitudes, the data of several stations in the three latitudinal zones, Tropics (0° - 30° NS), Mid-latitudes (30° - 60° NS) and higher latitudes 60° - 90° NS) were taken from the website and attempts were made to select the stations which have a long time series data sets. Although there may be some that do not have such long-term data sets and there may be few who do not have the equipment working presently and their observations are only up to few years back but these have been selected to cover the regions. This provides a grid of ozone data for a trend analysis. The plots and linear trends as computed from the computer of some of the stations are listed in Table 2, few stations which have long data sets are listed (Table 1) and the trend diagrams for six of these stations are given in Figs. 1 & 2.

In a first attempt the January means of total ozone were plotted *versus* years to just know the usefulness of the study. Since the study indicated some preliminary useful findings the annual means of the same stations were computed and were plotted against years. The increasing and decreasing trend of ozone at different stations is plotted on a world map to examine the findings at a glance. (Fig. 3 and Fig. 4).

3. (*i*) In Tropical regions (30° N to 30° S) the January means of total ozone over a number of years showed either an increasing or neutral trend on most of the stations and a smaller number of stations showed negative trend (Fig. 3). It is also noted that the number of

TABLE 1

List of stations

S. No.	Station name	Country	Period of data used
1.	Arosa	Switzerland	1926-2005
2.	Aspendale	Australia	1957-2004
3.	Bismark	USA	1957-2004
4.	Brisbane	Australia	1957-2004
5.	Cagliari	Italy	1954-1989
6.	Caribou	USA	1958-2004
7.	Mauna Loa	USA	1957-2004
8.	Sapporo	Japan	1958-2005
9.	Srinagar	India	1957-1989
10.	Tateno	Japan	1958-2005
11.	Vigna Di Valli	Italy	1954-1999
12.	Kagoshima	Japan	1957-2005
13.	Kodaikanal	India	1957-2005
14.	New Delhi	India	1957-2005
15.	Quetta	Pakistan	1957-2005

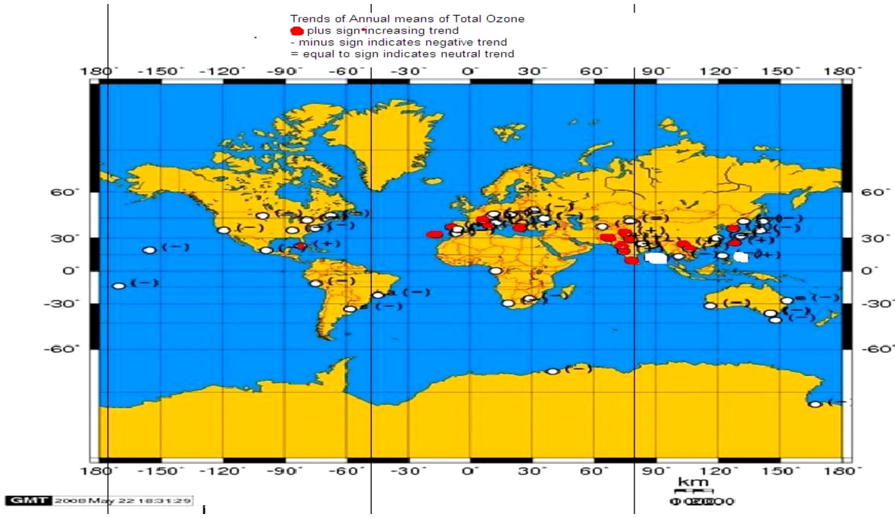

Fig. 4. Trend of annual means of total ozone

stations having positive trend lay mostly in Asia and adjacent Pacific. In America, Africa and Europe the number of stations having positive trend are very few.

In mid-latitudes (30° - 60° NS) almost all stations have negative trend except Lisbon (Portugal) and Cagliary (Italy) which have shown slight positive trend in January values over a period of more than 30 years. None of the stations in southern hemisphere have shown positive trend in mid-latitudes.

In the higher latitudes none of the stations have shown positive trend although there are only few stations making ozone observations in these areas that too mainly at Antarctica.

The January study indicates that the effect of ozone hole and chemical processes in the reduction of total ozone over tropics particularly over Asia and adjoining Pacific is very much less as is expected as these are too distant from poles. The local climate may also be the cause of the ozone trend at few stations as it is known that thunderstorm activity increases the ozone content, *e.g.*, in New Delhi and northern Indian stations as the western disturbances bring lot of ozone rich air from higher latitudes. Such studies have been made earlier also. (Gupta and Sharma, 1996). A similar cause may be responsible at other stations showing positive trend and the station remain less affected by the worldwide ozone decline.

The mid latitudes have marked affect due to ozone hole and the associated dynamics of poor ozone airflow. The southern hemisphere is completely ruled by ozone hole and the associated chemistry and dynamics while the northern hemisphere still has some isolation effect due to Arctic hole not being permanent and as pronounced as Antarctic ozone hole.

(*ii*) The results of trends of annual means of total ozone (Fig. 4) are mostly similar to that of January means but at some of the stations the results are either enhanced or inverse. New Delhi has shown a positive trend in annual mean compared to neutral trend in January mean, Mexico City has also shown a negative trend in annual mean as compared to a positive trend in January mean. Kunming (China) has also shown a positive trend as compared to neutral trend and Springbok, South Africa has shown a slightly negative trend as compared to positive trend in January. With this, in tropics, the number of stations having positive trend further increase in Asia and adjoining Pacific and decreases over other continents.

In mid latitudes the number of stations having positive trend has increased while annual mean trends are seen. Srinagar (India), Funchal (Portugal), Athens (Greece), Haute Province (France) have also shown positive trend and Budapest-Lorinc (Hungary), Alma ATA (Kazakhstan). Bolshayanaya Elan (Russia), and Linan (China) have shown neutral trend compared to negative trend in January analysis. This means the annual trends over any station may not be much affected by the

TABLE 2

List of stations and their trends/slope

S. No.	Country	Station	Latitude	Longitude	Trend	Slope Dobson/year
1.	India	Kodaikanal	10.2 N	77.5 E	Increase	0.127
2.	USA	Mauna Loa	19.5 N	155.6 W	Decrease	-0.178
3.	Australia	Darwin	12.4 N	130.9 E	Increase	0.138
4.	Australia	Huan Kayo	12.1 S	75.3 W	Decrease	-0.435
5.	American Samoa	Samoa	14.3 S	170.6 W	Decrease	-0.289
6.	Mexico	Mexico City	19.3 N	99.2 W	Decrease	-0.092
7.	Thailand	Bangkok	13.7 N	100.6 E	Decrease	-0.09
8.	Philippines	Manila	14.6 N	121.8 E	Increase	-0.227
9.	India	Varanasi	25.3 N	83.0 E	Decrease	-0.425
10.	South Africa	Spingbok	29.7 S	17.9 E	Decrease	-0.061
11.	India	New Delhi	28.6 N	77.2 E	Increase	0.450
12.	Japan	Naha	26.2 N	127.7 E	Increase	0.155
13.	China	Kunming	25.0 N	102.7 E	Increase	0.264
14.	South Africa	Irena	25.6 N	28.2 E	Decrease	-0.684
15.	Cuba	Havana	23.3 N	82.5 E	Increase	0.727
16.	Brazil	Cachoeria Paulista	22.7 N	45.0 W	Decrease	-0.521
17.	Australia	Brisbane	27.4 N	153.1 E	Decrease	-0.195
18.	India	Ahmadabad	23.0 N	72.7 E	Increase	0.521
19.	Japan	Kagoshima	31.6 N	130.6 E	Decrease	-0.086
20.	Pakistan	Quetta	30.1 N	66.6 E	Increase	0.336
21.	India	Srinagar	34.1 N	74.8 E	Increase	0.528
22.	Japan	Tateno	36.1 N	140.1 E	Decrease	-0.157
23.	Australia	Aspendale	38.0 S	141.1 E	Decrease	-0.464
24.	Italy	Cagliari	39.3 N	9.1 E	Increase	0.606
25.	Portugal	Lisbon	38.8 N	9.2 E	Increase	0.231
26.	Argentina	Buenos Aires	34.6 S	58.5 W	Decrease	-0.156
27.	USA	Nashville	36.3 N	86.6 W	Decrease	-0.525
28.	USA	Wallops Island	37.9 N	75.5 W	Decrease	-0.31
29.	Mar	Casablanca	33.6 N	7.7 W	Decrease	-1.312
30.	Australia	Perth	31.9 S	116.0 E	Decrease	-0.111
31.	Spain	EL-Arenosillo	37.1 N	6.7 W	Decrease	-0.202
32.	Korea	Seoul	37.6 N	127.0 E	Increase	0.611
33.	Australia	Melbourne	37.8 S	145.0 E	Decrease	-0.757
34.	Turkmenistan	Cardozou	39.1 N	63.6 E	Decrease	-0.412
35.	Portugal	Funchal	32.6 N	16.9 W	Increase	0.077
36.	Greece	Athens	38.0 N	23.7 E	Increase	0.683
37.	China	Linan	30.3 N	119.0 E	No change	-0.001
38.	USA	Hanford	36.3 N	119.6 E	Decrease	-0.388
39.	Kazakhstan	Alma Ata	43.2 N	76.9 E	Increase	0.048
40.	Japan	Sapporo	43.1 N	141.3 E	Decrease	-0.667
41.	Russia	Vladivostok	43.1 N	131.9 E	Decrease	-0.547
42.	USA	Bismarck	46.8 N	100.8 W	Decrease	-0.206
43.	USA	Caribou	46.9 N	68.0 W	Decrease	-0.319
44.	Switzerland	Arosa	46.8 N	9.7 E	Decrease	-0.181
45.	France	Haute Province	43.9 N	5.7 E	Increase	0.527
46.	Italy	Vigna Di Valli	42.1 N	12.2 E	Decrease	-0.505
47.	Canada	Toronto	43.8 N	79.5 W	Decrease	-0.723
48.	Ukraine	Feodosiya	45.0 N	35.4 E	Decrease	-0.094
49.	Ukraine	Kiev	50.4 N	30.4.E	Decrease	-0.374
50.	Australia	Hobart	42.8 S	147.5 E	Decrease	-0.983
51.	Germany	Hohenpeissenberg	47.8 N	11.0 E	Decrease	-0.527
52.	Hungary	Budapest-lorinc	47.4 N	19.2 E	No change	0.050
53.	USA	Amundersen-Scott	90.0 S	24.8 W	Decrease	-1.848
54.	Japan	Syowa	69.0 S	39.6 E	Decrease	-1.867
55.	USA	Mc Murdo	77.8 S	166.7 E	Decrease	-0.676

ozone decline at poles. In higher latitudes the trend remains negative in January as well as annual means.

4. We draw the following conclusions based on our present study:

The trend in ozone decline is not uniform over all latitudes; there are variations in the trend longitudinally also. The trend in tropics at most of the stations in Asia and adjoining Pacific regions are positive which shows that the dynamics and chemistry of ozone decline has not affected these regions. The observed positive trend is not likely to be solely attributed to surface ozone increase at these stations due to its less contribution. The positive trend of ozone observed at some stations could be attributed to increase in the troposphere ozone as reported earlier also by some authors Chakrabarty *et al.* (1998) and Lelieveld *et al*. (2004). This trend may be due to anthropogenic substances but nothing can be confirmed until a similar long term series of these substances at the corresponding stations is studied simultaneously. The slope of the trend line has also been computed which shows significant increase/decrease at several stations over the years.

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