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Effect of El Niño on inter-annual variability of ozone during the period 1978–2000 over the Indian subcontinent and China

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Abstract. The paper details the ozone trend over the Indian subcontinent and China inferred from multi-satellite sensors. The present study utilizes data from Nimbus-7, Earth Probe-Total Ozone Mapping Spectrometer (TOMS) and the more recently launched Global Ozone Monitoring Experiment (GOME) sensors. The inter-annual variability of total ozone column (TOC) has been analysed for two periods, from 1979–1993 measured by TOMS and 1996–2000 measured by TOMS and GOME for different Indian cities and Lhasa in Tibet and Beijing in China. The trend was found to be declining over all the major cities with different rates over the period 1979–1993, whereas over the period 1996–2000 the trend was found to increase. The effect of El Niño in 1997–98 on TOC is discussed in light of the prevailing sea surface temperature (SST) anomaly over the Indian Ocean and the Arabian Ocean.

1. Background

The role of ozone in absorbing ultraviolet solar radiation is well known. Ozone makes a significant contribution to the radiative balance of the upper troposphere and lower stratosphere, such that changes in the distribution of ozone in these atmospheric regions will affect the radiative forcing of climate (Munro *et al.* 1998). Numerous studies have been carried out throughout the world to study the trend of ozone at various places to understand the impact on human activities and the coupling between the ozone layer and the climate system (Jiang and Yung 1996, WMO 1998). From these studies decreases in global ozone amounts have been detected over the last two decades using various ground-and satellite-based measurement techniques (Stolarski *et al.* 1991, 1992, Cracknell and Varotsos 1994, Cracknell *et al.* 1994, Herman *et al.* 1996, 1997, Varotsos *et al.* 2000). The total ozone column (TOC) data obtained by Nimbus-7/Meteor-3 TOMS and Solar Backscattered Ultra Violet (SBUV) have shown decreasing trends at mid-latitudes of the northern hemisphere (Hollandsworth *et al.* 1995, Chandra *et al.* 1996, McPeters *et al.* 1996, Varotsos *et al.* 2000). No detailed sensor-based approach has been undertaken so far to understand the TOC variations from an Indian perspective

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apart from work (Chakrabarty *et al.* 1998) largely based on ground-based Dobson spectrophotometers at major Indian cities. In the last five years, India, being a developing nation, has undergone rapid industrialization, and as a result pollution is increasing. Such situation may lead to an increase of tropospheric ozone which may deplete the stratospheric ozone.

Developed nations have made efforts to control some of the harmful emissions after seeing the trends in ozone depletion. For the Indian region, no trend analysis of total ozone concentrations have been previously been made. This paper presents an analysis of TOC data measured by TOMS onboard various satellites and GOME on the ERS-2 satellite during the period 1978–1993 and 1996–2000. The strong El Niño of 1997–1998 is found to influence the TOC over the Indian subcontinent, leading to an increase in TOC. The effect of sea surface temperature (SST) on the TOC has been further investigated and is found to have some close relation with the increasing ozone trend during the strong El Niño period of 1997–1998.

2. Sensors and dataset

The dataset has been taken from two different voyages of the instrument TOMS developed by NASA/GSFC. The TOMS instrument was designed to enable long-term daily mapping of the global distribution of the Earth's atmospheric ozone apart from aerosols and sulfur dioxide. There have been four such missions so far and this present study deals with data obtained from Nimbus-7 and Earth Probe (EP) mission of TOMS and ERS-2 GOME.

The monthly datasets for various places on the Indian subcontinent were obtained from TOMS web site (toms.gsfc.nasa.gov) maintained by NASA GSFC. The ERS-2 GOME data was obtained from DLR, Germany in HDF format. The monthly means have been plotted against time to give annual variations of TOC. Linear regression models have been fitted to the curves to give an estimate of the long-term TOC trend.

3. Results and discussion

The TOMS (1978–1993; 1996–2000) data available from TOMS web site have been plotted for various cities. Figures 1(a) and 1(b) show some of the plots of major cities, although similar behaviours have been observed over other cities, which have not been shown. The overall trend in TOC for most cities is found to be decreasing for the period 1979–1993 (figure 1(a)), but increasing for the period 1996–1999 (figure 1(b)). The monthly average TOC for mid- to high-latitude cities show higher values during winter (January–March) with the highest value reached around February–March every year, while for the lower-latitude cities (Madras, Trivandrum, Kodaikanal, etc.), TOC peaks occur around June–August. The TOC is found to decrease at the start of spring and reach a minimum value during July-September of every year for cities lying in middle latitudes (Delhi, Srinagar, Lhasa, Beijing) while further towards the equator the minima is reached around December-February of each year.

The overall decreasing trend for 1979–1993 is similar to the declining trend found over middle latitudes of the northern hemisphere (Hollandsworth *et al.* 1995, McPeters *et al.* 1996, WMO 1998). This decreasing trend may be due to meridional mixing of chemically disturbed air from the Arctic polar vortex because of cooler springs and may also depend on water vapour variations which are forced by SST change in the tropics (Randel and Wu 1995, Kirk-Davidoff *et al.* 1999).

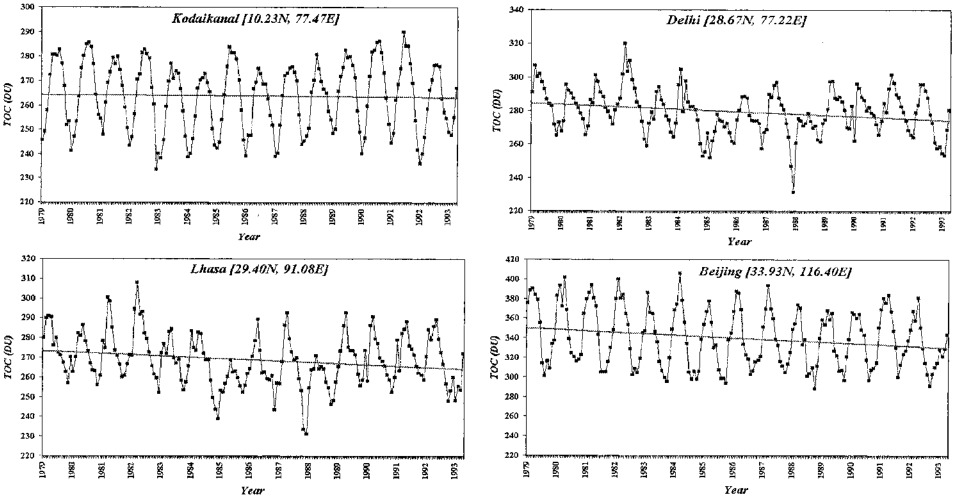

Figure 1(a). TOC trends for major cities of the Indian subcontinent, Tibet and China: derived from Nimbus-7 TOMS during the period 1979–1993.

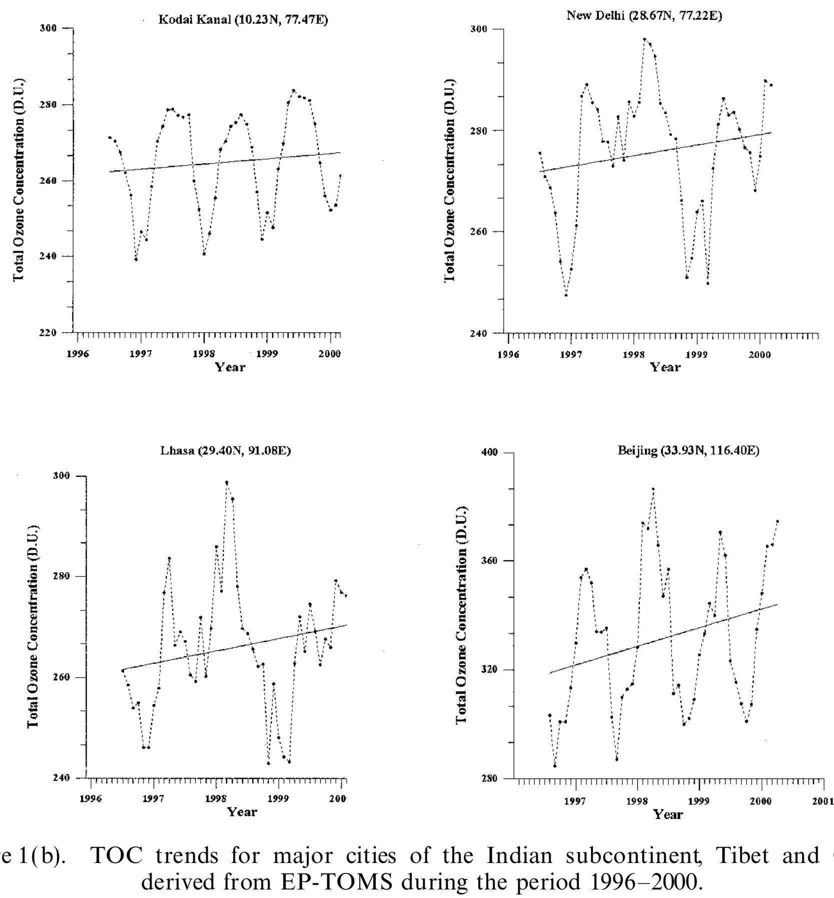

Figure 1(b). TOC trends for major cities of the Indian subcontinent, Tibet and China: derived from EP-TOMS during the period 1996–2000.

The decadal decreasing trend with standard deviation for various cities is shown in table 1, which shows a continuous increase from low to high latitude except at Lhasa (figure 1(a) and table 1). The yearly increasing rate for the period 1996 (July)–2000 (March) shows no such dramatic regularity albeit a decrease in the rate of increasing trend can be seen as one approaches the equator. Similar results have also been found by Chakrabarty *et al.* (1998) for few Indian cities using ground data and Nimbus-7 TOMS data. Over the period 1996–2000, almost all the cities in low and middle latitude zones show an increasing trend (figure 1(b)). An anomalous high TOC is found at most mid-latitude cities (figure 1(b) shows this only for New Delhi, Lhasa in Tibet and Beijing in China).

3.1. *GOME data*

The GOME data over the Indian subcontinent have been extracted from the global dataset, which was made available by DLR, Germany. We have considered GOME data over the Indian subcontinent in two latitude ranges: a lower latitude (6°N–26°N) and mid-latitude (26°N–42°N) and have deduced monthly TOC from the daily measurements. Figure 2 shows the TOC observed on the ground using a Dobson spectrophotometer at Ahmedabad station (23.02°N, 72.65°E), which lies in a low-latitude region, along with GOME averaged TOC at low latitude. The ground-observed TOC at Ahmedabad is found to have a one-to-one relation with the minima and maxima peaks, however, the ground-observed TOC is found to be higher than the GOME data. During 1998, the TOC observed at Ahmedabad is found to be higher than earlier years (1996–1997) (figure 2).

3.2. *GOME versus TOMS data (1996–2000)*

The TOC deduced from GOME for mid-latitude is shown in figure 3, and are compared with the TOMS data observed over Delhi (28.67°N, 77.22°E) in India, Beijing (33.93°N, 116.40°E) in China and Lhasa (29.40°N, 91.08°E) in Tibet. The overall behaviour of TOMS observed at Delhi, Beijing and Lhasa is found to be qualitatively similar. The TOC observed by TOMS for Beijing is found to be higher

Table 1. Decadal (1979–1993) and yearly (1996–2000) rates.

Major cities (from high to low latitude)	1979–1993 ~Decadal rate % (Nimbus 7) ±St. Dev.	1996 (July)–2000 (March) ~Yearly % (EP-TOMS) ±St. Dev.
Beijing (33.93°N, 116.40°E)	−8.6 ±0.6	15.3±0.1
Srinagar (34.06°N, 74.51°E)	−6.0 ±0.3	5.8±0.11
Lhasa (29.40°N, 91.08°E)	−3.8 ±0.4	5.4±0.1
Delhi (28.67°N, 77.22°E)	−4.4 ±0.3	4.4±0.1
Benares (25°N, 83°E)	−2.8 ±0.3	4.3±0.1
Ahmedabad (23.02°N, 72.65°E)	−2.7 ±0.3	3.9±0.1
Dum Dum (Calcutta) (22.65°N, 88.45°E)	−2.0 ±0.2	3.3±0.1
Pune (18.53°N, 73.85°E)	−1.7 ±0.2	4.1±0.1
Hyderabad (17.2°N, 78.3°E)	−1.5 ±0.1	3.8±0.1
Madras (13.08°N, 80.17°E)	−1.3 ±0.1	3.1±0.1
Bangalore (12.98°N, 77.58°E)	−0.9 ±0.1	2.6±0.1
Kodaikanal (10.23°N, 77.47°E)	−0.6 ±0.0	2.8±0.1
Trivandrum (8.48°N, 76.95°E)	0.02±0.0	3.1±0.1

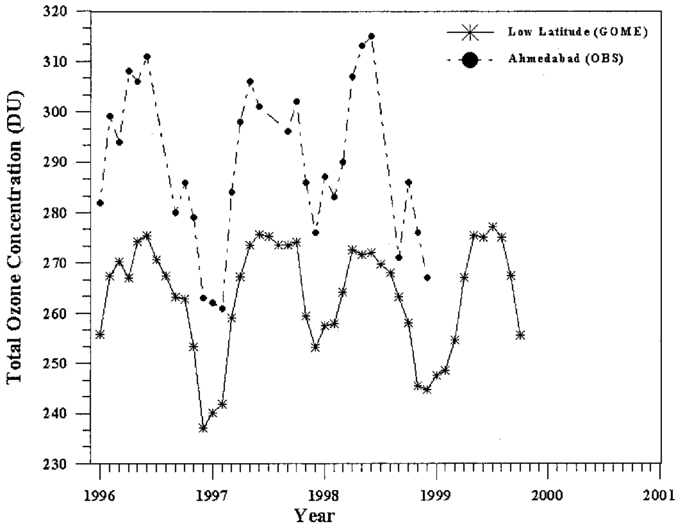

Figure 2. TOC observed at Ahmedabad and TOC observed at mid-latitude zone.

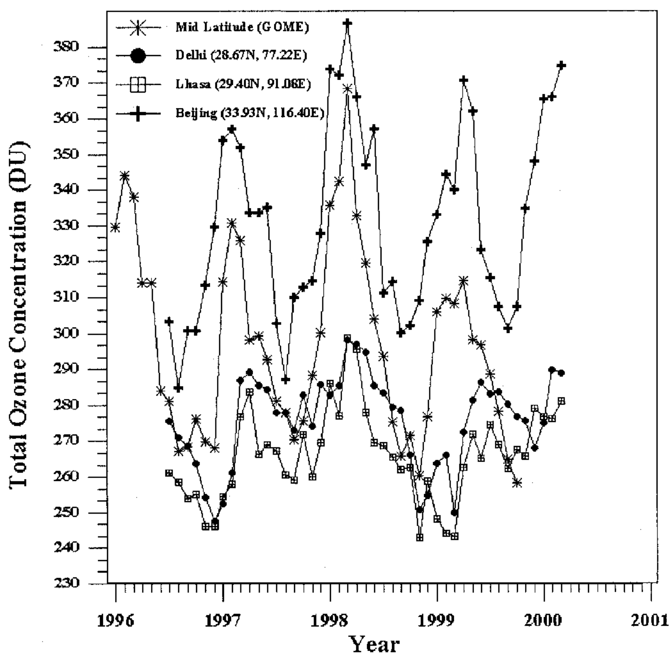

Figure 3. Comparison of TOC observed at mid-latitude from GOME data with TOC observed by TOMS over Delhi, Lhasa and Beijing.

than the GOME average; during 1998 the GOME-deduced TOC is found to be higher than the TOMS readings for all cities.

3.3. *Effect of 1997–1998 El Niño on TOC*

The two most intense El Niño episodes in more than a century occurred during the past two decades, in 1982 and 1997–1998. Relationships between El Niño and rainfall, floods and draughts are well known. Recently, Maes (2000) found an effect of the 1997–1998 El Niño on ocean salinity variability. The effect of El Niño/Southern Oscillation on TOC deduced by ground observation and satellite sensors has been studied (Chandra *et al.* 1998, Langford *et al.* 1998) on a regional scale. TOC plots for the 1996–1999 period over the Indian subcontinent show anomalous high values of TOC around January–March 1998 for cities lying in the middle to high latitudes (Delhi, Lhasa, Beijing) deduced from TOMS data, and cities at mid-latitudes deduced from GOME data (figures 1(b) and 3). This anomalous high value of TOC is found to coincide with the warmer temperature over the Indian subcontinent. The SST readings provided by the Indian Meteorological Department (IMD), Poona (India) over the equatorial Indian Ocean have also been found to be higher during first few months of 1998. By March 1998 nearly the entire Indian Ocean shows a considerably warmer SST due to the strong El Niño effect (Yu and Rienecker 1999, Rajeevan *et al.* 2000) which may have led to the higher anomalous TOC prominently seen over mid-latitude zones and mid-latitude cities (figures 1(b) and 3). In figure 4, the variations of TOC at Delhi, Lhasa and Beijing show a lag and lead relation with the SST anomaly of the Indian Ocean and the Arabian Ocean. It is seen that the SST peak anomaly over the Indian Ocean occurs about 2 months ahead of the TOC peak, however, the SST peak anomaly over the Arabian Ocean follows the TOC peak, as observed at Delhi, Lhasa and Beijing. The analysis made by Chandra *et al.* (1998) to study the influence of El Niño on satellite-deduced TOC has shown that the TOC decreases by 4–8 Dobson Units (DU) in the eastern Pacific and increases by about 10–20 DU in the Western Pacific. This ozone behaviour may be due to the eastward shift of the tropical convective activity as inferred from

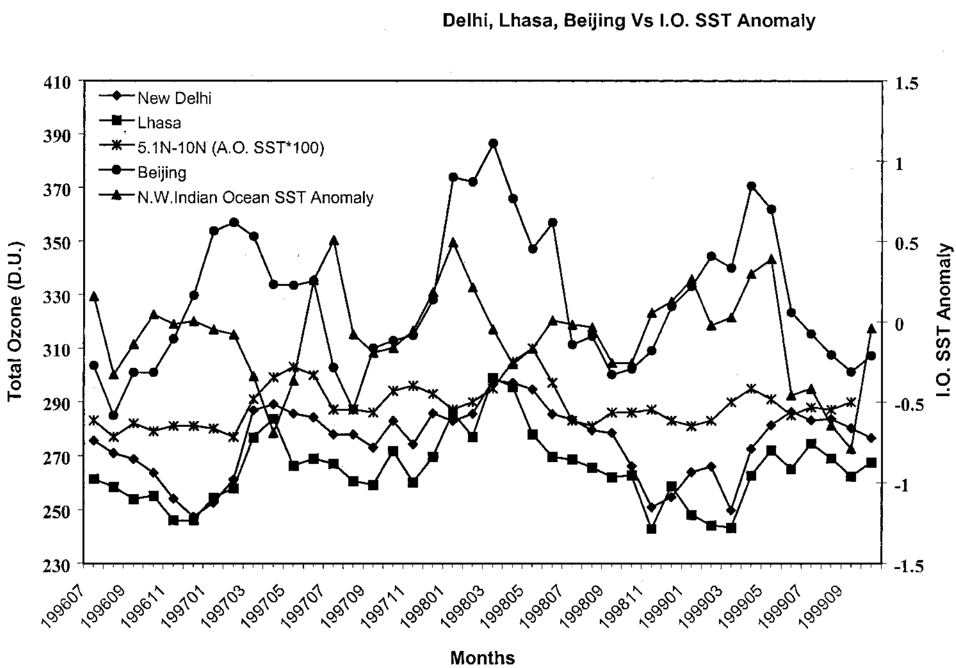

Figure 4. Relation of EP-TOMS deduced TOC over Delhi, Lhasa and Beijing with the Arabian Ocean (AO) and NW Indian Ocean SST anomaly.

National Oceanic and Atmospheric Administration (NOAA) outgoing longwave radiation data (Chandra *et al.* 1998).

4. Conclusions

The present analysis of TOC data measured by different sensors on different satellites during the periods 1979–1993 and 1996–2000 show interesting features over the Indian subcontinent and adjoining region. During the period 1978–1993, almost all the cities on the Indian subcontinent and Lhasa in Tibet and Beijing in China show declining TOC trend, as observed in many cities throughout the world. The overall decadal declining trend is found to increase with the increasing latitudes. During the period 1996–2000, an increasing TOC trend is also confirmed over the Indian sub-continent and adjoining region, which is similar to other places in the world. Anomalous TOC is found during 1998 over cities lying in the mid-latitude zone. The period 1997–1998 was known to be affected by an intense El Niño, and it is concluded that the anomalous TOC is likely due to an El Niño effect which shows a close relation with the observed SST over the Indian Ocean and the Arabian Ocean. The inter-relationship between El Niño, SST and TOC needs investigation by the scientific community in greater detail.

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References

Chakrabarty, D. K., Peshin, S. K., Pandya, K. V., and Shah, N. C., 1998, Long-term trend of ozone column over the Indian region. *Journal of Geophysical Research*, **103**, 19 245–19 251.

Chandra, S., Varotsos, C., and Flynn, L. E., 1996, The mid-latitude total ozone trends in the northern hemisphere. *Geophysical Research Letters*, **23**, 555–558.

Chandra, S., Ziemke, J. R., Min, W., and Read, W. G., 1998, Effects of 1997–998 El Niño on tropospheric ozone and water vapor. *Geophysical Research Letters*, **25**, 3867-3870.

Cracknell, A. P., and Varotsos, C. A., 1994, Ozone depletion over Scotland as derived from Nimbus-7 TOMS measurements. *International Journal of Remote Sensing*, **15**, 2659–2668.

Cracknell, A. P., Varotsos, C. A., and Asimakopoulos, D. N., 1994, On the total ozone depletion over Greece derived from satellite flown and ground based instruments. *International Journal of Remote Sensing*, **15**, 3285–3293.

Herman, J. R., Bhartia, P. K., Ziemke, J., Ahmad, Z., and Larko, D., 1996, UV-B increases (1979–1992) from decreases in total ozone. *Geophysical Research Letters*, **23**, 2117–2120.

Herman, J. R., Bhartia, P. K., Torres, O., Hsu, C., Seftor, C., and Celarier, E., 1997, Global distribution of UV-absorbing aerosols from Nimbus 7/TOMS data. *Journal of Geophysical Research*, **102**, 16 911–16 922.

Hollandsworth, S. M., McPeters, R. D., Flynn, L. E., Planet, W., and Miller, A. J., 1995, Ozone trends deduced from combined Nimbus 7 SBUV and NOAA 11 SBUV/2 data. *Geophysical Research Letters*, **22,** 905–908.

Jiang, Y., and Yung, Y. L., 1996, Concentrations of tropospheric ozone from 1979 to 1992 over tropical pacific South America from TOMS data. *Science*, **272**, 714–716.

Kirk-Davidoff, D. B., Hintsa, E. J., Anderson, J. G., and Keith, D. W., 1999, The effect of climate change on ozone depletion through changes in stratospheric water vapor. *Nature*, **402**, 399–401.

Langford, A. O., O'Leary, Masters, C. D., Aikin, K. C., and Profitt, N. H., 1998, Modulation of middle and upper tropospheric ozone at Northern mid latitudes by the El Niño/Southern Oscillation. *Geophysical Research Letters*, **25**, 2667–2670.

Maes, C., 2000, Salinity variability in the equatorial Pacific Ocean during the 1993–98 period. *Geophysical Research Letters,* **27**, 1659–1662.

McPeters, R. D., Hollandsworth, S. M., Flynn, L. E., Herman, J. R. and Seftor, C. J., 1996, Long-term ozone trends derived from the 16 year combined Nimbus 7/Meteor 3 TOMS Version 7 record. *Geophysical Research Letters*, **23**, 3699–3702.

Munro, R., Siddans, R., Reburn, W. J., and Kerridge, B. J., 1998, Direct measurements of tropospheric ozone distributions from space. *Nature*, **392**, 168–171.

Rajeevan, M., De, U. S., and Prasad, R. K., 2000, Decadal variation of sea surface temperatures, cloudiness and monsoon depressions in the north Indian ocean. *Current Science*, **79**, 283–285.

Randel, W. J., and Wu, F., 1995, TOMS total ozone trends in potential vorticity coordinates, *Geophysical Research Letters*, **22** 683–686.

Stolarski, R. S., Bloomfield, P., McPeters, R. D., and Herman, J. R., 1991, Total ozone trends deduced from Nimbus 7 TOMS data, *Geophysical Research Letters*, **18**, 1015–1018.

Stolarski, R. S., Bojkov, R., Bishop, L., Zerefos, C., Staehdin, J., and Zawodny, J., 1992, Measured trends in stratospheric ozone. *Science*, **256**, 342–349.

Varotsos, C. A., Kondratyev, K. Ya., and Cracknell, A. P., 2000, New evidence for ozone depletion over Athens, Greece. *International Journal of Remote Sensing*, **21**, 2951–2955.

World Meteorological Organization, 1998, Scientific assessment of ozone depletion: WMO Global Ozone Research and Monitoring Project Report No. 44, 1994.

Yu, L., and Rienecker, M. M., 1999, Mechanism for the Indian Ocean warming during the 1997–98 El Niño. *Geophysical Research Letters*, **26**, 735–738.