

Ozone variations pertaining to dry and wet monsoon seasons over Indian region

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सार — शुष्क और आर्द्र मानसून वर्षों के दौरान टी.सी.ओ. वितरण का अध्ययन करने के लिए भारतीय क्षेत्र में वर्ष 1982, 1983, 1987 एवं 1988 के कुल कॉलम ओजोन (टी.सी.ओ.) के मासिक औसत का उपयोग किया गया है। इस शोध-पत्र में उक्त वर्षों के भारत के 13 स्टेशनों के टी.सी.ओ. आंकड़ों का अध्ययन किया गया है। शुष्क और आर्द्र मानसून वर्षों के दौरान टी.सी.ओ. वितरण की तुलना से यह पता चला है कि टी.सी.ओ. के मान आर्द्र वर्षों की तुलना में शुष्क वर्षों में अधिक पाए गए हैं। टी.सी.ओ. में परिवर्तन होना शुष्क एवं आर्द्र वर्षों के दौरान संवहनीय गतिविधि में भिन्नता को माना जा सकता है। शुष्क (आर्द्र) वर्षों के दौरान संवहन में कमी (वृद्धि) टी.सी.ओ. की मात्रा को बढ़ाती घटाती है। शुष्क एवं आर्द्र वर्षों के बीच के मानसून के महीनों के दौरान टी.सी.ओ. के महत्व की जाँच करने के लिए सांख्यिकीय टी.-टेस्ट का प्रयोग किया गया है। यह अंतर दमदम को छोड़कर अन्य सभी स्टेशनों के लिए सांख्यिकीय दृष्टि से 5 प्रतिशत तक महत्वपूर्ण है। ऐसा कहा जा सकता है कि भारत में ग्रीष्मकालीन मानसून महीनों के दौरान ओ.एल.आर. तथा टी.सी.ओ. के बीच अच्छे संबंध रहे हैं क्योंकि इस अवधि के दौरान संवहन काफी प्रबल रहा है।

ABSTRACT. Monthly mean total column ozone (TCO) over Indian region for the years 1982, 1983, 1987 and 1988 has been utilized to study the TCO distribution during dry and wet monsoon years. TCO data for 13 Indian stations for the above years have been considered in the study. Comparison of TCO distribution during dry and wet monsoon years suggested that TCO values are found higher during dry years than those in wet years. The changes in TCO may be attributed to difference in convective activity during dry and wet years. The suppressed (enhanced) convection during dry (wet) years may lead to increase (decrease) in TCO. The statistical *t*-test is applied to test the significance of TCO difference during monsoon months between dry and wet years. The difference is statistically significant at 5% level of confidence for all stations except Dumdum. It can be said that the relation between OLR and TCO holds good during Indian summer monsoon months, as convection is stronger during this period.

Key words – TCO, Dry and wet monsoon years, Convection, Indian summer monsoon.

1. Introduction

The mean distribution of the global total ozone has a minimum in the equatorial belt and an increasing trend towards both the poles. An extensive research work on ozone has explored the ozone variability on different time scales of days to decades, which is governed by atmospheric dynamics and chemistry (Londhe *et al.*, 2003). The total column ozone (TCO) variability is governed by annual cycle (Londhe *et al.*, 2003), Quasi-Biennial Oscillation (QBO) (Randel and Cobb, 1994), El Nino-Southern Oscillation (ENSO) (Shiotani, 1992) and solar cycle (Chandra and McPeters, 1994). The intra-seasonal variability of TCO over Indian region has been studied by Londhe *et al.* (2005). They found three intra-seasonal modes of TCO variability with periods 3-8 days (weekly), 10-20 days (quasi-bi weekly) and 30-60 days (Madden Julian Oscillation). Similar type of modes of variability was observed in Indian Summer Monsoon Rainfall (ISMR) (Krishnamurti and Bhalme, 1976;

Chowdary *et al.*, 1988; Hartmann and Michelson, 1989; Hartmann *et al.*, 1992; Singh *et al.*, 1992).

Ziemke and Chandra (2003) have studied La Nina and El Nino induced variabilities of ozone in the tropical lower atmosphere during 1970-2001. During El Nino, tropospheric ozone is enhanced over the western Pacific and reduced over the eastern Pacific because of planetary-scale shifts in sea surface temperature and convection. Their study suggests that El Nino produces an east-west dipole difference in tropospheric ozone over the Pacific ranging from about 5-10 DU for weak events and up to 15-20 DU for strong events. La Nina indicates nearly opposite spatial distribution in tropospheric column ozone in the tropics compared to El Nino. Monsoon circulation induced variability in TCO and association between monsoon rainfall and TCO over Indian region has provoked us to examine the TCO distribution during dry and wet monsoon seasons.

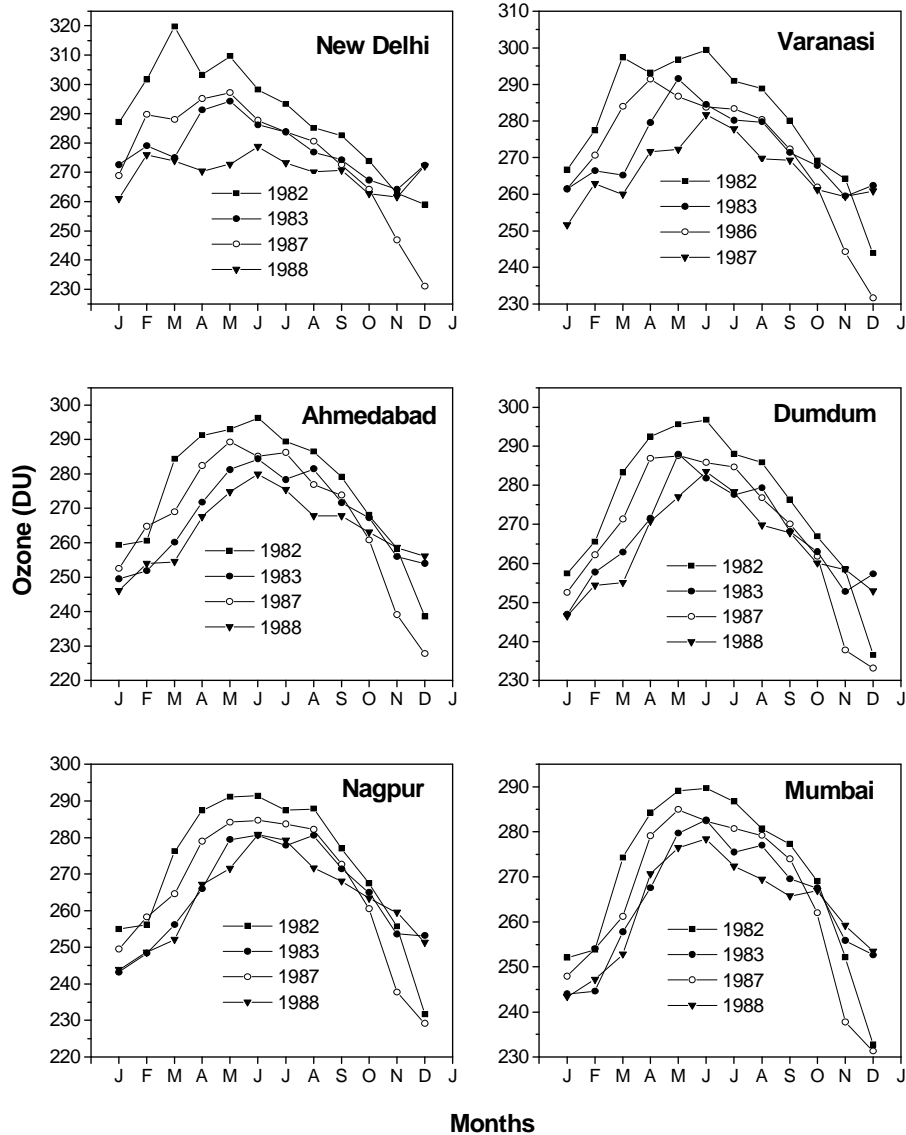


Fig. 1(a). Monthly mean TCO for the years 1982, 1983, 1987 and 1988 for the stations New Delhi, Varanasi, Ahmedabad, Dumdum, Nagpur and Mumbai

The particular year ' i ' is categorized as dry/wet depending on rainfall $R(i)$ in that year if

$$R(i) < \bar{R} - \sigma \text{ / } R(i) > \bar{R} + \sigma$$

where \bar{R} is long term ISMR normal (852 mm) and σ is standard deviation of ISMR (80mm) [Parthasarathy *et al.*, 1992]. This criterion has been adopted to select the dry and wet monsoon years. The years 1982 and 1987 are dry monsoon years as the rainfall was deficient by -13.4% and -17.9% respectively, while 1983 and 1988 are wet monsoon years as the rainfall was excess by $+12.5\%$ and $+13.2\%$ respectively.

2. Data

The daily Total Ozone Mapping Spectrometer (TOMS) data over 13 Indian stations (Table 1) for the years 1982, 1983, 1987 and 1988 have been utilized for the study. TOMS (Nimbus7) data have been collected from the following website: http://jwocky.gfsc.nasa.gov/eptoms/EPTOMS_V7_Ovp.N. The daily TCO values were utilized to derive the mean monthly TCO and these mean monthly TCO values were used for the analysis. The seasonal mean (June through September) Outgoing Longwave Radiation (OLR) data for the above years have been taken from NCEP/NCAR Reanalysis data.

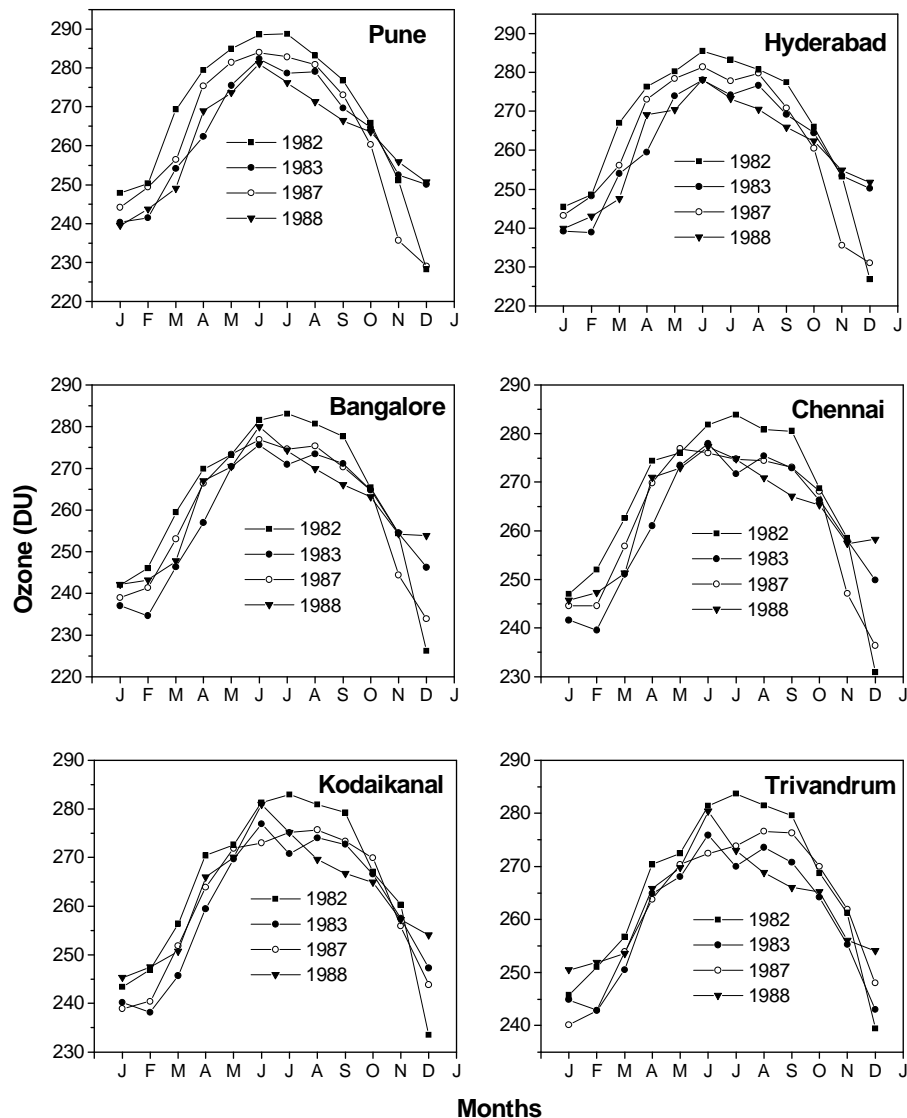


Fig. 1(b). Same as Fig. 1(a) but for the stations Pune, Hyderabad, Bangalore, Chennai, Kodaikanal and Trivandrum

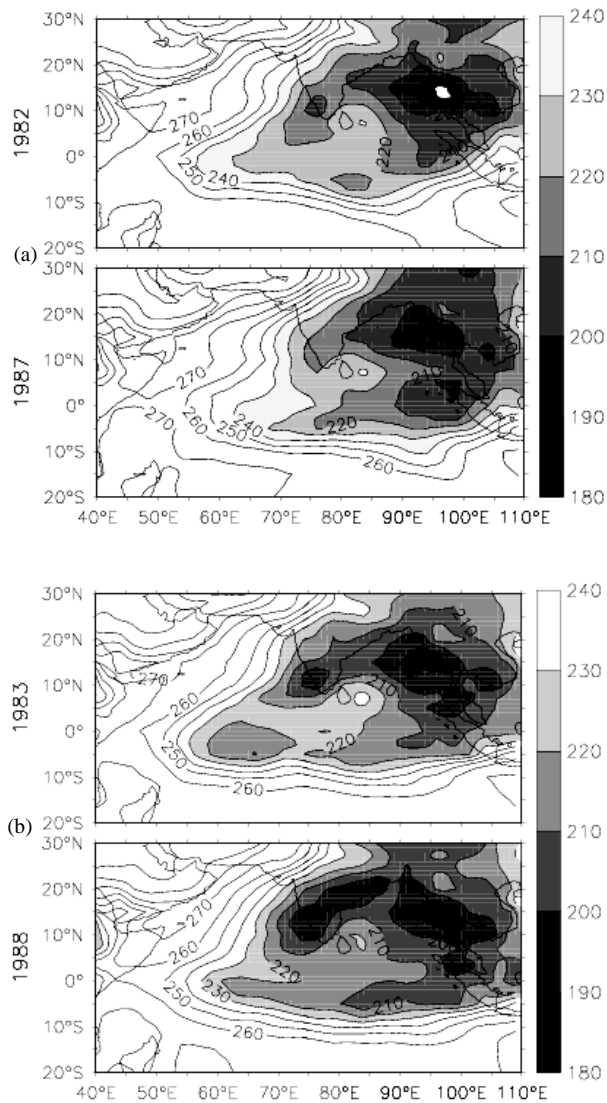
3. Results and discussions

The monthly mean TCO for the years 1982, 1983, 1987 and 1988 for the twelve Indian stations were depicted in Figs. 1(a&b). It is seen from the figures that TCO values on an average are higher during the years 1982 and 1987 for almost all the stations as compared to those in the years 1983 and 1988. The years 1982 and 1987 were dry years while the years 1983 and 1988 were wet years. Thus the ozone values are comparatively higher during dry years than the wet years.

The difference observed in the ozone distribution during wet and dry years may be attributed to the difference in the convective activity during these two

extremes. During wet years convection is more compared to dry years, which may affect the total column ozone by transport of tropospheric ozone into stratosphere. The Indian summer monsoon rainfall (period June through September) is essentially convective in nature and the ascending motions within the areas of rainfall have compensating divergence motions outside such areas (Ananthkrishnan and Pathan, 1971; Rao, 1976; Webster *et al.*, 1998).

Convective activity is inferred using NCEP/NCAR derived OLR flux. The OLR data have been extensively used for the study of interannual and intraseasonal variability of tropical convection (Lau and Chan, 1988). Change in OLR is a good indicator of changed distribution



Figs. 2(a&b). Contour plot of seasonal mean (June through September) OLR flux for (a) dry monsoon years 1982 and 1987 and (b) wet monsoon years 1983 and 1988

of deep atmospheric convection. Low (high) values of OLR indicate the presence of strong (weak) convection (Chandra *et al.*, 1998). The contour plots of seasonal mean OLR flux (average of June – September) for dry years (1982, 1987) and wet years (1983, 1988) are shown in Figs. 2(a&b). It is seen from the figure that OLR values during the years 1982 and 1987 are higher than in years 1983 and 1988 over Indian region. The higher OLR flux means weak convection. Thus, it is confirmed that during dry years (1982, 1987) convection is suppressed. The OLR flux during dry years is more by 10-20 W/m^2 than in wet years. Northwestward shift in OLR flux during wet

TABLE 1

Selected thirteen Indian stations and their Latitudes and Longitudes

S. No.	Station	Latitude	Longitude
1.	New Delhi	28° 40' N	77° 13' E
2.	Varanasi	25° 27' N	83° 01' E
3.	Mt. Abu	24° 36' N	72° 43' E
4.	Ahmedabad	23° 01' N	72° 39' E
5.	Dumdum	22° 38' N	88° 26' E
6.	Nagpur	21° 06' N	79° 03' E
7.	Mumbai	19° 07' N	72° 50' E
8.	Pune	18° 31' N	73° 50' E
9.	Hyderabad	17° 22' N	78° 28' E
10.	Chennai	13° 04' N	80° 10' E
11.	Bangalore	12° 58' N	77° 34' E
12.	Kodaikanal	10° 13' N	77° 28' E
13.	Trivandrum	08° 19' N	76° 36' E

years has been observed. During dry years TCO as well as OLR flux are more and in wet years both are less. Therefore the present study indicates the in phase relation between OLR and TCO which is in consistency with the results obtained by Chandra *et al.*, 1998 and Willams and Toumi, 2001.

Convection is deep and maximum over the Indian land mass region during the summer monsoon season (June – September) (Meehl, 1987). Rainfall is associated with convection, therefore, rainfall amount can be considered as the convenient indicator of the convective activity. Kulkarni and Verma (1993) have studied the relation between tropopause height over India and the Indian summer monsoon activity. They noticed that all India mean tropopause height shows statistically higher value in the composites of good monsoon years than the value in bad monsoon years for the months May through September. Steinbrecht *et al.*, 1998 have examined the correlation between tropopause height and total ozone. They suggested that a high tropopause is correlated with low total ozone and low tropopause with high total ozone. Independent of season, total ozone decreases by 16 DU per km increase in tropopause height. Simple analysis of about 15 years of monthly total ozone data has been carried out in the tropical and sub tropical regions of northern hemisphere by Hingane and Patil 1996. They observed the pronounced maximum (~17.5 km) in the tropopause height and well-marked trough in total ozone during the months of July and August over the most humid part of the region, which comes under the influence of monsoon circulation. It appears that the occurrence of

TABLE 2

Significance of the difference in mean ozone for dry and wet years by *t*-test

Station	<i>t</i> - value
Ahmedabad	2.45**
Bangalore	2.35**
Chennai	2.44**
Dumdum	1.97*
Hyderabad	2.88***
Kodaikanal	2.09**
Mumbai	2.84***
Mt.Abu	2.89***
Nagpur	2.53***
New Delhi	2.51***
Pune	2.38**
Trivandrum	2.77***
Varanasi	2.28**

* 10%; ** 5%; *** 2%

trough may be due to lifting of air mass by the intense convective activity over areas of the low level convergence, which is fed normally from the equatorial belt.

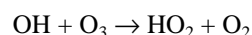
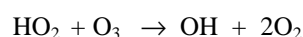
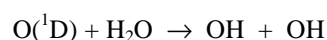
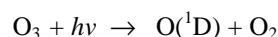
Thus, the above results together suggest that the tropopause height during wet monsoon years is more than in the dry monsoon years and the increase in tropopause height causes decrease in TCO.

The difference in TCO values between wet and dry years have been tested with *t*-test (Table 2) and it is found that the difference is significant at 2% level of confidence for the stations Hyderabad, Mumbai, Mt. Abu, Nagpur, New Delhi and Trivandrum, while it is significant at 5% level of confidence for the stations Pune, Varanasi, Bangalore, Chennai, Kodaikanal and Ahmedabad. However, the difference is significant at 10% level of confidence for the station Dumdum.

It is noticed from the present study that monsoon circulation over Indian region affect TCO variability on seasonal scale. The convective activity associated with ITCZ (Inter Tropical Convergence Zone) plays dominating role in the TCO variability. The normal position of ITCZ shows extraordinary deep intrusion over southeast Asia during monsoon months. Over India it migrates almost up to 30° N (Riehl, 1979). A strong convection is associated with ITCZ position during Asian summer monsoon season. Thus the more prominent

relation has been observed between TCO and convective activity during monsoon months over tropical and subtropical stations of India.

In addition to dynamical processes (convective activity) tropospheric H₂O chemistry may be playing a role in the redistribution of TCO. In general O₃ and H₂O are negatively correlated with high (low) O₃ and low (high) humidity in the region of enhanced (suppressed) convection (Chandra *et al.*, 1998). O₃ may be destroyed by the reaction of O(¹D) with H₂O in the following way



The enhanced convection, which is associated with rich water vapor during wet monsoon season, may be responsible for more O₃ losses than in the dry monsoon season.

4. Conclusion

Comparison of TCO distribution during dry and wet monsoon years suggested that TCO values are found higher during dry years than those in wet years. The difference in convective activity during dry and wet years may be responsible for the changes in TCO. The suppressed convection during dry years may be responsible for the increase in TCO. The TCO difference during monsoon months between dry and wet years is examined for the significance by *t*-test. The difference is statistically significant at 5% level of confidence for all stations except Dumdum. It can be said that the relation between OLR and TCO holds good during Indian summer monsoon months, as convection is stronger during this period.

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References

- Ananthakrishnan, R. and Pathan, J. M., 1971, "Rainfall patterns over India and adjacent seas", Scientific Report No. 144, India Meteorological Department.
- Chandra, S. and McPeters, R. D., 1994, "The solar cycle variation of ozone in the stratosphere inferred from Nimbus-7 and NOAA 11 satellites", *J. Geophys. Res.*, **99**, 20665-20671.
- Chandra, S., Ziemke, J. R., Min, W. and Read, W. G., 1998, "Effects of 1997-1998 El Nino on tropospheric ozone and water vapor", *Geophys. Res. Lett.*, **25**, 3867-3870.
- Chowdhury, A., Mukhopadhyay, R. K. and Sinha Ray, 1988, "Low frequency oscillations in summer monsoon rainfall over India", *Mausam*, **39**, 375-382.
- Hartmann, D. L. and Michelson, M. L., 1989, "Intra seasonal periodicities in Indian Rainfall", *J. Atmos. Sci.*, **46**, 2838-2862.
- Hartmann, D. L., Michelsen, M. L. and Klein, S. A., 1992, "Seasonal variations of Tropical Intraseasonal Oscillation : A 20-25 Day oscillation in the western Pacific", *J. Atmos. Sci.*, **49**, 1277-1289.
- Hingane, L. S., and Patil, S. D., 1996, "Total ozone in the most humid monsoon region", *Meteorol. Atmos. Phys.*, **58**, 215-221.
- Krishnamurti, T. N. and Bhalme, H. N., 1976, "Oscillations of monsoon system. Part I. Observational aspects", *J. Atmos. Sci.*, **33**, 1937-1954.
- Kulkarni, J. R. and Verma, R. K., 1993, "On the spatio-temporal variations of the tropopause height over India and Indian summer monsoon activity", *Advances in Atmos. Sci.*, **10**, 481-488.
- Lau, K. M. and Chan, P. H., 1988, "Intraseasonal and interannual variations of tropical convection. A possible link between 40-50 day oscillation and ENSO", *J. Atmos. Sci.*, **45**, 506-521.
- Londhe, A. L., Bhosale, C. S., Kulkarni, J. R., Padma Kumari, B. and Jadhav, D. B., 2003, "Space-time variability of ozone over Indian region for the period 1981-1998", *J. Geophys. Res.*, **108**, doi : 10.1029/2002JD002942.
- Londhe, A. L., Padma Kumari, B., Kulkarni, J. R. and Jadhav, D. B., 2005, "Monsoon circulation induced variability in total column ozone over India – A case study", *Current Sci.*, **89**, 164-167.
- Meehl, G. A., 1987, "The annual cycle and interannual variability in the tropical Pacific and Indian Ocean regions", *Mon. Wea. Rev.*, **115**, 27-50.
- Parthasarathy, B., Rupkumar, K. and Kothawale, D. R., 1992, "Indian summer monsoon rainfall indices 1871-1990", *Meteorological Magazine*, **121**, 174-186.
- Randel, W. J. and Cobb, J. B., 1994, "Coherent variations of monthly mean total ozone and lower stratospheric temperature", *J. Geophys. Res.*, **99**, 5433-5447.
- Rao, Y. P., 1976, "Southwest monsoon", Meteorological Monograph, Synoptic Meteorology, No.1, India Meteorological Department, 1-30.
- Riehl, H., 1979, "Climate and weather in the tropics", Academic Press, London, p17.
- Shiotani, M., 1992, "Annual, Quasi-Biennial and El Nino-Southern Oscillation (ENSO) Time scale variations in Equatorial Total ozone", *J. Geophys. Res.*, **97**, 7625-7633.
- Singh, S. V., Kriplani, R. H. and Sikka, D. R., 1992, "Interannual variability of the Madden Julian Oscillations in Indian summer monsoon rainfall", *J. Climate*, **5**, 973-979.
- Steinbrecht, W., Claude, H., Kohler, U. and Hoinka, K. P., 1998, "Correlations between tropopause height and total ozone: Implications for long term changes", *J. Geophys. Res.*, **103**, 19183-19192.
- Webster, P. J., Magana, V. O., Palme, T. N., Shukla, J., Tomas, A., Yanai, M. and Yasunari, T., 1998, "Monsoons: Processes, predictability and prospects for prediction", *J. Geophys. Res.*, **103**, 14451-14510.
- Williams, V. and Toumi, R., 2001, "The correlation between tropical total ozone and outgoing long-wave radiation", *Quart. J. R. Met. Soc.*, **127**, 989-1003.
- Ziemke, J. R. and Chandra, S., 2003, "La Nina and El Nino-induced variabilities of ozone in the tropical lower atmosphere during 1970-2001", *Geophys. Res. Lett.*, **30**, 10.1029/2002GL016387.