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Conclusions
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TOMS TOC time-series (1979-1993) and (1997-2005) of monthly means studied for all the stations (16) conform to the normal distribution as ascertained by Shapiro-Wilk’s Test. Earlier analysis done by others, ignored this verification of TOC data.

The seasonal (annual-cyclic) variation’s effect on the monthly mean TOC at all locations was evident for both the time-series (TS-I and TS-II). The seasonal variations were positive between April to October months for all Indian stations except for Srinagar, the magnitude of the observed variations was around ±20 DU. The annual cycle of seasonal variations also manifested a continuous increase in the phase of the cycle with increasing latitude. The pattern manifested at Srinagar stood apart from the other locations as there was a complete reversal in the sign of phase of the cycle.

For TOC TS-I, long-term trends estimate from de-seasonalized monthly mean TOC data registered statistically significant declining trends [of -0.66 to -3.60 percent per decade] for all locations; Singapore was an exception in this regard. The estimated long-term trends showed strong latitudinal dependence; decline with increasing latitude. TOC trend at Singapore was statistically invariant for TS-I.

The long-term TOC trends in de-seasonalized monthly mean TS-II manifested significant differences when compared with the estimates done for TS-I. The decline in TOC (TS-II) ranged between -0.48 to -3.25 percent per decade, but the comparison of alike locations indicated that the locations below latitude 17° N [Singapore, Trivandrum, Kodaikanal, Bangalore, Madras] reported more negative long-term trends for TS-II as compare to TS-I. The extent of the decline in the de-seasonalized monthly mean TOC in TS-II (compared to TS-I) for locations lying above latitude 13° N was less. This
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decrease in declining trend can be inferred as a sign of the recovery process in the Ozone Layer.

The season-wise long-term trends present in the de-seasonalized monthly mean TOC (TS-I), during December-January-February (DJF) and March-April-May (MAM), were higher for locations closest to the equator (Singapore and Trivandrum), when compared with the other seasons; i.e. June-July-August (JJA) and September-October-November (SON). As the locations moved away from the equator, the long-term trends in the de-seasonalized monthly mean TOC were observed to be higher during MAM (Kodaikanal, Banglore, Madras, Hyderabad, Poona and Bombay). Further shift in the locations shifted the maximal trends to JJA season (Nagpur, Dum Dum, Ahemdabad, Mount Abu, Benares, Varanasi, New Delhi and Srinagar). However, it is to be stated that except for Singapore, where the trend was positive during DJF season, at all locations the TOC trend was negative during all demarcated seasons.

For the time-series TS-II, similar pattern was observed in the long-term trends present in the de-seasonalized monthly mean TOC as a function of seasonal change. For Singapore, during DJF season the estimated long-term trend was maximal and positive. One important feature of the season-wise long-term trends in TS-II time-series was that for majority of the locations away from equator [Banglore, Madras, Hyderabad, Poona, Bombay, Nagpur, Dum Dum, Ahemdabad, Mount Abu, Benares and Varanasi] during MAM and JJA, the trends were positive; a feature not seen in TS-I time-series. It may indicate the reversal in the decreasing Total Ozone Column (TOC) trends at these locations.

It is noted from the month-wise long-term trends in the de-seasonalized monthly mean TOC TS-I that at Singapore, during the first two months of the year (January, February), the month-wise long-term trends were positive. Overall, for most of the months the long-term TOC trends were negative for all other locations. The group of months for which positive month-wise trends were observed, varied with location: (i) for Trivandrum, Kodaikanal, it was
February and March; (ii) for Bangalore, Madras, Hyderabad, Poona, Bombay and Nagpur, the positive month-wise trend spanned over February to June; and (iii) for other locations (Dum Dum, Ahmedabad, Mount Abu, Benares, Varanasi, New Delhi and Srinagar), there were no systematic cluster of months over which the TOC trends were positive.

The analysis of month-wise long-term trends estimate for TOC TS-II revealed a perceptible change in the pattern, when compared with the similar results obtained for TS-I. For instance, from January to June, at Singapore the month-wise trends in TOC were positive; the same was seen at Trivandrum, where February to March months registered positive monthly trend. Except for these two locations, all other locations registered a negative monthly trend for all months.

The magnitude of the variation in TOC (both TS-I and TS-II) explained by Inter-Annual Variations (IAV) was ± 30 DU for almost all the locations, the maximal IAV magnitude was registered at Srinagar. As we move away from the equator the strength of IAV weakened below 18° N latitude, but the same again registers an increase as latitude increased.

It is interesting to note that the time-period of dominant harmonics detected in IAV for TS-I and TS-II, coincided with the time-period of harmonic present in 30 hPa Equatorial Zonal Winds; a proxy used to detect Time-Period and Phase of the Quasi Biennial Oscillations (QBO)'. The dominant harmonic present in the proxy QBO time-series over the time span of TS-I was 30 months and the same in case of TS-II was 27 months.

It is observed that harmonic representing the QBO cycle was prominent in the IAV present in TOC at all locations for both the time-series (TS-I and TS-II). The locations closest to the Equator (Singapore) registered maximal power density for the harmonic having QBO signature. As locations move away from the equator the number of other harmonics, in addition to the one coinciding with QBO, having period less than and greater than QBO signature period emerged.

* Conceptual overview of QBO phenomenon can be grasped from Figure 6.1.
Fig. 6.1: Conceptual overview of QBO phenomenon. Figure reproduced from Baldwin et al., 2001.
It was interesting to note that the increase in the latitude from locations near equator to farther, the phase difference between QBO cycle in 30 hPa Equatorial Zonal Winds and the cycle having the same period in IAV increased substantially. Coupling Factors between harmonics representing QBO, in 30 hPa Equatorial Zonal Winds and in Inter-Annual Variations present in monthly mean TOC decreased as locations moved away from the equator was also evident in case of both TS-I and TS-II. In case of both time-series, it was equally evident that the monthly mean TOC over Delhi and Srinagar were least influenced by the QBO in Equatorial Zonal Winds. The marked difference between the locations near to equator and farther could also be observed in the steady decrease in the Harmonic Strength of dominant cycle, having time-period equivalent to QBO proxy, detected in IAV was distinct. The results suggested that the influence of QBO on TOC was stronger between 0 - 10° N, and at higher latitude the QBO effects were modulated by other short term seasonal and annual cycles. As far as the marked difference in these observations at New Delhi and more so at Srinagar was concerned, the complete reversal of phase present in the proxy QBO cycle (in 30 hPa Zonal Winds) and in the dominant cycle, having time-period equivalent to QBO proxy, detected in IAV, for both TS-I and TS-II indicated suppression of the QBO effect.

Random (white) noise with a significant magnitude of around ± 20 DU was observed in TOC for both TS-I and TS-II. This stresses the point further that there may be other unknown natural reasons/phenomenon, which could still explain the extent of the random variability detected in the white noise component of the TOC time-series.