

# OZONE COLUMN TRENDS OVER ROSARIO, CENTRAL ARGENTINA, FROM 45-YEAR SATELLITE DATA SERIES

Iván Lionel Novara<sup>1</sup>; Eduardo Luccini<sup>2,3</sup>

<sup>1</sup>Instituto de Física de Rosario IFIR-CONICET, Universidad Nacional de Rosario, Rosario, S2000, Santa Fé, Argentina; <sup>2</sup>Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Centro de Excelencia en Productos y Procesos de Córdoba (CEPROCOR). Sede Santa María de Punilla, Pabellón Ceproc (X5164), Córdoba, Argentina; <sup>3</sup>Pontificia Universidad Católica Argentina, Facultad de Química e Ingeniería del Rosario. Av. Pellegrini 3314 (2000), Rosario, Santa Fe, Argentina.

Contact: ivanlionelnovara@gmail.com

## INTRODUCTION

Stratospheric ozone is crucial protecting the Earth's surface life against solar UVB radiation. Satellite total ozone column (TOC) retrievals are presently long enough for in-deep analysis. Periodic natural phenomena modulate the TOC behavior, as well as occasional events.

The stratospheric ozone depletion of anthropic origin, afforded by the Vienna Convention measures, requests continuous monitoring and long-term analysis in search of its evolution and trends. Deseasonalization methods apply.

## Objetives

1. Determine trends in the TOC measured by satellite instruments over Rosario (32.96°S, 60.62°W, 25 m a.s.l.), Argentina, during the period 1979–2024.
2. Assess the contribution of different natural periodic forcings to the observed behavior.

## METODOLOGY

Monthly-averaged TOC from daily TOMS-OMI merged datasets accessed from Google Earth Engine were analyzed for the period 1979 - 2024 excepting 1995-1996 with only partial data. Data were split into two periods : 1979 - 1994 and 1997 - 2024. Spectral methods were not able to apply to the shortest 1979 - 1994 period. The analysis was cut at 1990, because the eruption of Mount Pinatubo in 1991 impinged additional non-periodic depleting effects on the regular TOC behavior. Trend for period 1979 - 1990 was performed by subtracting the average monthly values along the year for the whole period to the original TOC data, and applying then a simple linear regression.

Two methods were applied to analyze the period 1997 - 2024: First method combines Empirical Mode Decomposition (EMD) with Fast Fourier Transform (FFT), independently of external forcings. The first six Intrinsic Mode Functions (IMFs) obtained from the EMD were subjected to FFT analysis. A second method, Multiple Linear Regression (MLR) using Trend Run Model tool, is dependent on the forcings. In each method, trends were derived by evaluating the residuals.

## RESULTS AND CONCLUSIONS:

For the 1979-1990 period, a statistical trend analysis was performed, revealing a significant negative trend of  $(-2.3 \pm 1.6 \text{ \%/decade})$  or  $(-7.4 \pm 4.9 \text{ DU/decade})$ , with respect to the pre-1980's levels consistent with the determined stratospheric ozone decline at these latitudes prior to the full implementation of the Montreal Protocol. Using the MLR approach, the separately deduced contributions of periodic phenomena are as follows: AO (73.7%), QBO (3.4%), SC (2.0%), SAO (0.84%), and ENSO (0.71%). Together, these factors account for approximately 81% of the total TOC series variability. This results in a weaker trend over this period of  $-0.39 \pm 0.16 \text{ \%/decade}$  relative to pre-1980s levels  $(-1.19 \pm 0.49 \text{ DU/decade})$  and accounting for 5.7% of the total variability over the period.

**Figures 1:** The upper figure shows the monthly time series of TOC from 1979 to 2024, and the lower figure displays the monthly anomaly, calculated by subtracting the mean values for each month, along with the linear trend over the period. The monthly anomaly is shown in blue, and the trend line is in red.

**Figure 2:** The upper figure shows two series: the monthly TOC series from 1997 to 2024, in black, and the monthly reconstructed series, in red. The reconstructed series was obtained using the MLR method, where the forcing terms (AO), (SAO), (QBO), (ENSO), (SC), and the residuals with their linear trend are combined to reconstruct the original series. The lower figure shows the residual series in blue and the linear trend fitted to the residuals in red.

**Figure 3:** The upper figure shows the FFTs of each of the six IMFs generated by the EMD method. The values of the functions were normalized to unity to better visualize which periods correspond to the peaks in the functions. The lower figure displays the residuals from this method and the linear trend fitted to the residuals. According to the color of each function, they can be associated with different forcing factors based on the periods of their peaks. We plotted the FFT of IMF3 with dashed lines to distinguish it from IMF2, due to their overlap.

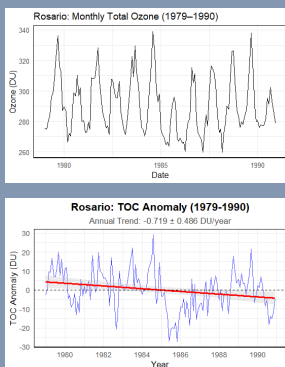


Figure 1

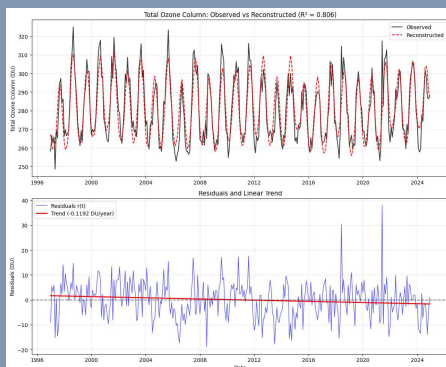
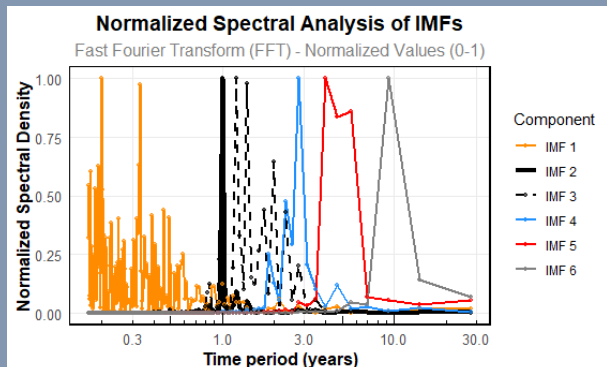


Figure 2



Figures 3

## RESULTS AND CONCLUSIONS:

Using the EMD approach for Period 1997–2024: The nonlinear decomposition of the time series yields the first six IMFs; IMFs beyond the sixth do not have physical significance. **Figure 3** attempts to interpret the physical meaning of each IMF. The FFT analysis of each IMF is interpreted as follows: The FFT of IMF1 shows a peak at a period of 3 months, suggesting the possible presence of the SAM (Southern Annular Mode). The trend is fitted to this residual function, whose slope corresponds to a negative trend of  $-0.37\%$ . There is a close similarity between the slopes obtained from both methods: the forcing-dependent method and the EMD method, which is independent of external forcings.

The FFT of IMF5 displays a signal associated with ENSO, given its well-defined period of approximately 4 to 5 years. The FFT of IMF6 shows a clear periodicity corresponding to the solar signal, with a cycle of about 11 years. This structured decomposition allows for a more nuanced understanding of the underlying physical drivers in the time series.

The residual function in this method is defined as:  $r(t) = TOC(t) - \sum_{i=1}^6 IMF_i$

The trend is fitted to this residual function, whose slope corresponds to a negative trend of  $-0.37 \pm 0.01 \text{ \%/decade}$  with respect to the pre-1980's levels  $(-1.13 \pm 0.03 \text{ DU/decade})$ . There is a close similarity between the slopes obtained from both methods: the forcing-dependent method and the EMD method, which is independent of external forcings.

One possible discussion point is, instead of applying FFT to each IMF separately, to perform the analysis by frequency bands in the Fourier frequency space. This could yield clearer components in terms of their periods, particularly for the QBO.

