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A global description of oscillations and trends in multi-decadal ozone from spectral analysis of zonally-averaged merged satellite data

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In the last few decades, ozone research has been strongly shaped by the observation that anthropogenic chlorofluorocarbons can deplete the ozone layer, the discovery of the ozone hole, and the signing and impact of the Montreal Protocol to limit the production and concentration of ozone-depleting substances. As we move towards ozone recovery, the focus of attention is shifting towards analysis of long-term ozone changes associated with declining halogen loads, polar ozone depletion and increases in greenhouse gases, and short-term ozone changes related to internal variability like the QBO, ENSO and NAO, or to external forcings such as volcanic signals, or the 27-day and 11-year cycles in solar variability. For all of these, accurate knowledge of the zonal latitude, altitude and seasonal/temporal structure of the ozone response is required to place constraints on possible explanations (in other words a 2D+1 spatiotemporal modeling framework). In this study we use the SBUV "Merged Cohesive" dataset of satellite ozone observations provided by the WCRP/SPARC-SI2N framework (SPARC, IO_3C, IGACO-O_3 and NDACC) which spans the latitudinal zonal range: 80N–80S in 5 degree intervals, the altitude from 50–0.5 hPa in 13 Dobson layers, and the period 11/1978 – 12/2013 with daily and monthly-averages. The dataset is of high quality, stable (trends in TOC vary by only about 1%/decade) and multi-decadal; making it suitable for the study of long-term effects. It also has the required spatial and temporal coverage for a study of short-term effects and external forcings. In this study we apply the continuous wavelet transform to each of the time series in the 2D spatial grid (latitudinal zones x Dobson layers) spanning the global domain to calculate the wavelet power spectrum and to identify statistically-significant periods for each time series. We then construct 3D grids of constant period contours in the 2+1D space to trace and study the spatiotemporal variation of individual oscillations. In parallel, we also apply singular spectrum analysis to each time series to extract non-prescribed/nonlinear trends and construct a 3D grid for studying the global long-term behaviour, transitions and temporal change-points in the data. Finally, we investigate causal interactions between oscillatory modes in the 2+1D space using advanced causal discovery algorithms in an attempt to connect them with the underlying dynamics.