Comparing ozone measurements taken from ACE-MAESTRO's ultraviolet- and visible-range spectrometers, and studying ozone trends as observed by ACE-MAESTRO

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Date: April 8, 2021

Photo Credit: www.darksky.org

Background: What is ACE-MAESTRO?

ACE-MAESTRO: "Atmospheric Chemistry Experiment - Measurement of Aerosol Extinction in the Stratosphere and Troposphere Retrieved by Occultation"

- Launched on the SCISAT satellite (with ACE - Fourier Transform Spectrometer (FTS)) in August 2003.
- ACE Mission objectives:
    1. to better evaluate/quantify the chemical/dynamical processes impacting the distribution of O_3 in the stratosphere and upper troposphere;
    2. to examine the relationship between atmospheric chemistry and global climate change;
    3. to study how burning biomass affects the free troposphere; and
    4. to establish/verify aerosol and cloud properties, and their effects on the global energy balance.
- ACE-MAESTRO was added to collect aerosol extinction data in the 400-1010 nm range, and to measure O_3 and NO_2 profiles with a higher vertical resolution than ACE-FTS does.
- Two independent diode-array grating spectrometers:
    - UV spectrometer: measures from 285-565 nm with 1.5 nm resolution
    - VIS spectrometer: measures from 515-1015 nm with 2 nm resolution

Background: What is ACE-MAESTRO?

- Measurements obtained by solar occultation (sunset and sunrise).
- An occultation measurement sequence consists of approximately 60 spectra taken at tangent heights from 0-100 km, and 20 spectra collected from the thermosphere for calculation of a Sun reference spectrum. 80 spectra are collected when the Sun is below the horizon (before sunrise or after sunset),to use in the calculation of detector dark current.
- Most measurements do not reach below 5–10 km because of clouds.
- A number of versions of the processed data have been released; ie: **v.1.2 and v.3.13.**
- Measurements come as ozone profiles in ppv.

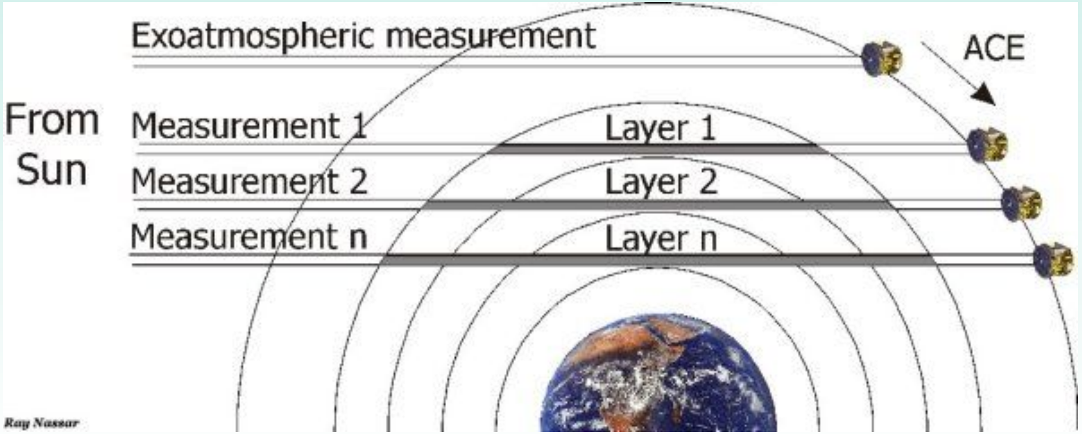


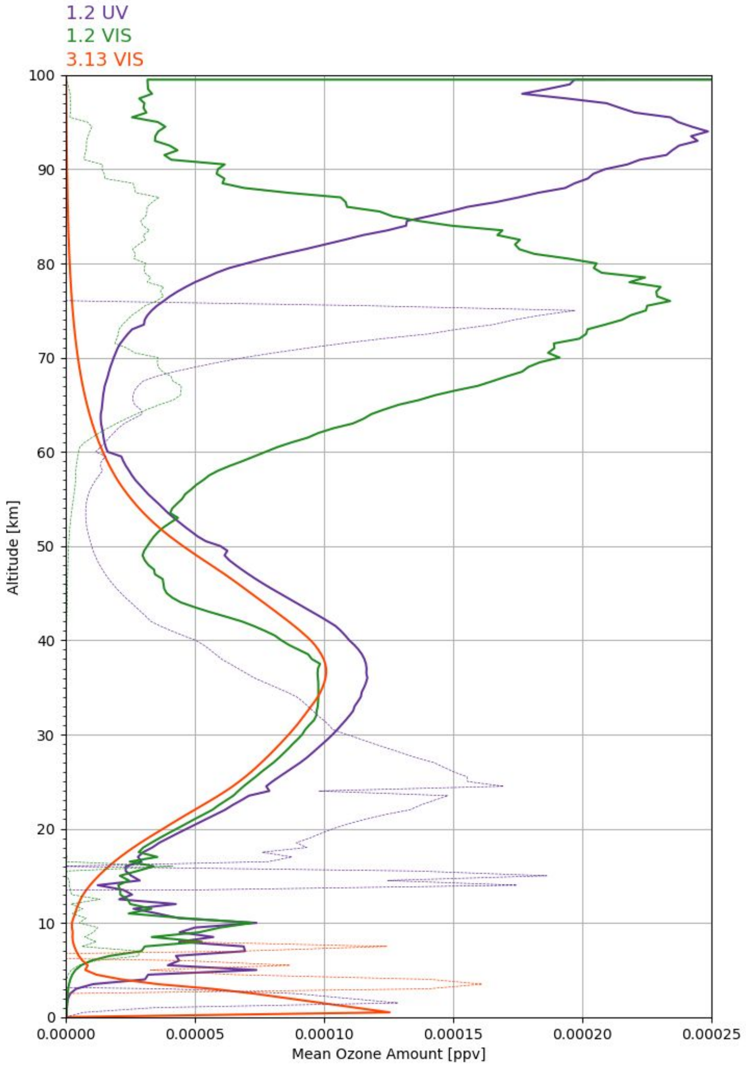
Figure 1. How measurements are made by solar occultation.

Figure credit: http://www.ace.uwaterloo.ca/

Average Ozone Profiles

Figure 2. Average O3 profiles from ACE-MAESTRO versions 1.2 (UV and VIS) and 3.13 (VIS), from 2004 - 2011.

- Standard deviations of the averages increase significantly above 60 km and below 20 km due to data sparseness and clouds.
- Peak in ozone layer around 35 km for each data version.



Purpose: Studying Atmospheric Ozone

- An increase in athropogenic emissions of ozone-depleting substances (ODS) (ie, chlorofluorocarbons) enhanced the destruction of atmospheric ozone on polar stratospheric clouds, leading to an increase in UV radiation reaching the Earth's surface.
- Studying/tracking atmospheric ozone is highly relevant, especially since the Montreal Protocol in 1987.

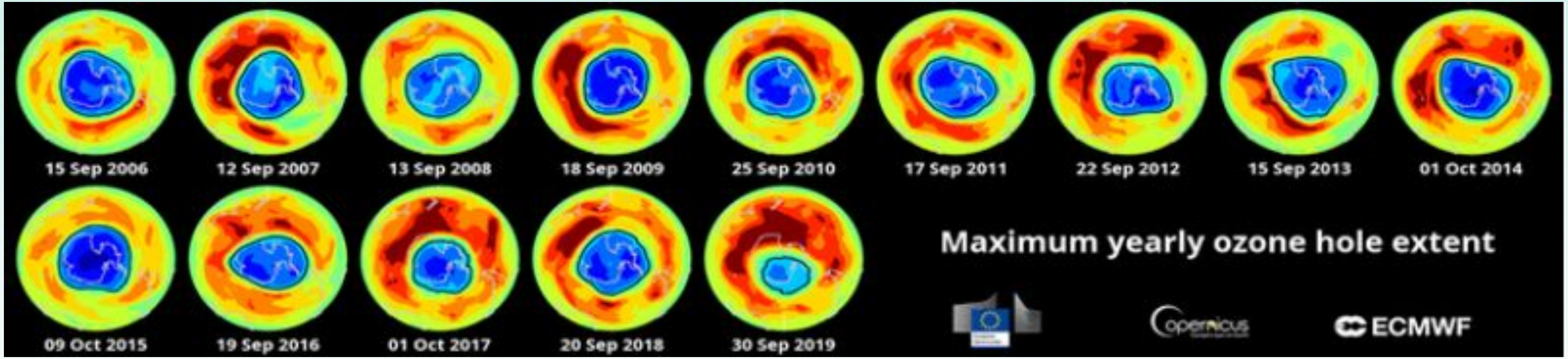


Figure 3. Maximum yearly ozone hole extent from 2006-2019.
Figure adapted from: https://www.eea.europa.eu/

Objectives

1. Compare ACE-MAESTRO data versions 1.2 and 3.13

   * Version 1.2 measurements from the UV and VIS spectrometers range from **2004-2011**.

   * Version 3.13 measurements from the VIS spectrometer range from **2004-2020**.

2. Examine global trends in atmospheric ozone, as observed by ACE-MAESTRO.

   * Model the evolution of ozone in space and time, as a linear drift with added oscillating components, for each data version.

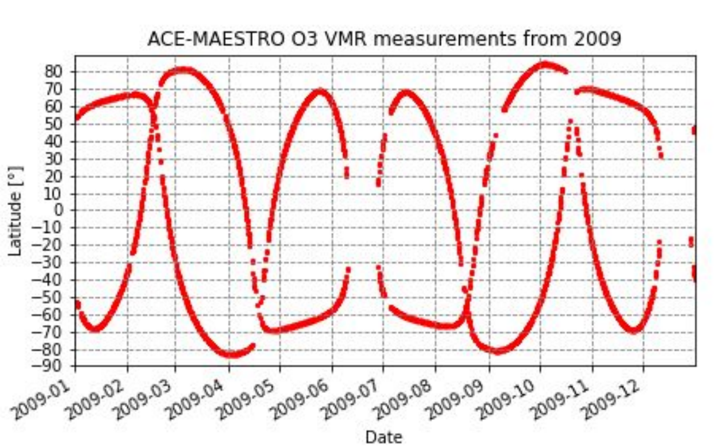


Figure 4. An example of the latitudinal distribution of measurements from ACE-MAESTRO in a year.

Methods: Comparisons

- Yearly and aggregated comparisons
- Linear regression: ordinary least squares (OLS) and reduced major axis regression (RMA), Pearson coefficient (*R*)
- Profiles of mean absolute and relative differences (Δ_{abs}, Δ_{rel})

$$\Delta_{rel} = \frac{1}{N} \sum_{i=1}^{N} \frac{(x_i - y_i)}{(x_i + y_i)/2} \cdot 100\%$$

$$\Delta_{abs} = \frac{1}{N} \sum_{i=1}^{N} (x_i - y_i)$$

$$R = \frac{\sum_{i=1}^{N} (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{N} (x_i - \bar{x})^2 \sum_{i=1}^{N} (y_i - \bar{y})^2}}$$

where x_i and y_i are the O_3 VMR measurements being compared, and $\bar{x}$ and $\bar{y}$ are their corresponding averages

Results: Comparisons of Ozone Volume Mixing Ratio

- Separating measurements by altitude reveals different patterns.
- Lowest correlation found for measurements from 0-20 km (order 1e-5).

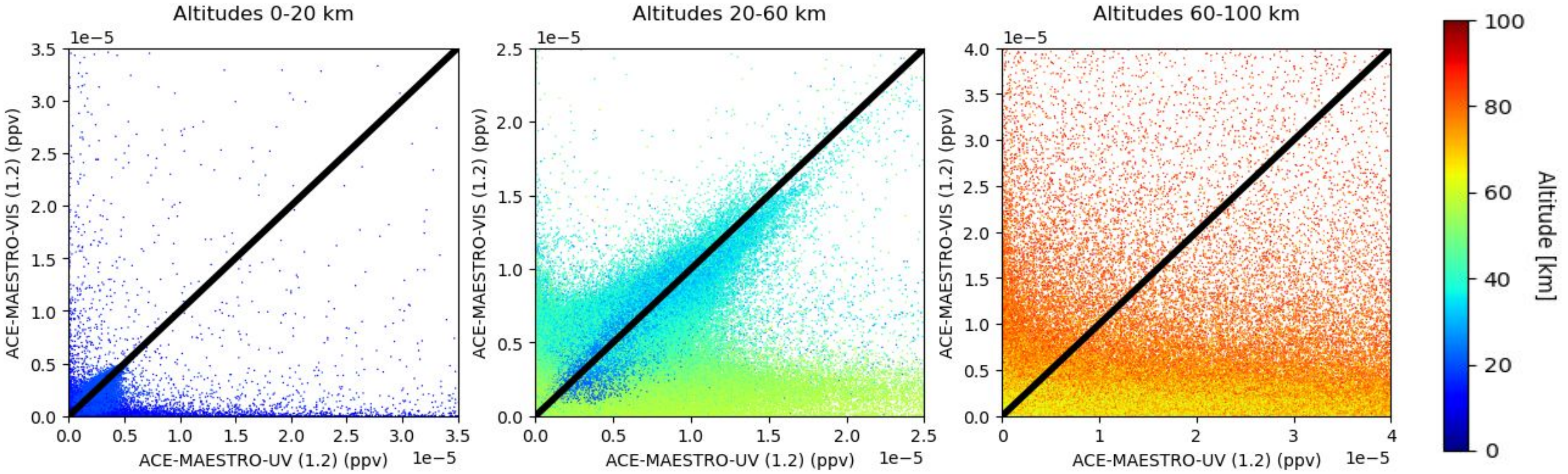


Figure 5. Correlation plots for version 1.2 measurements from the UV and VIS spectrometers (2004-2011)

Yearly Profiles of Differences

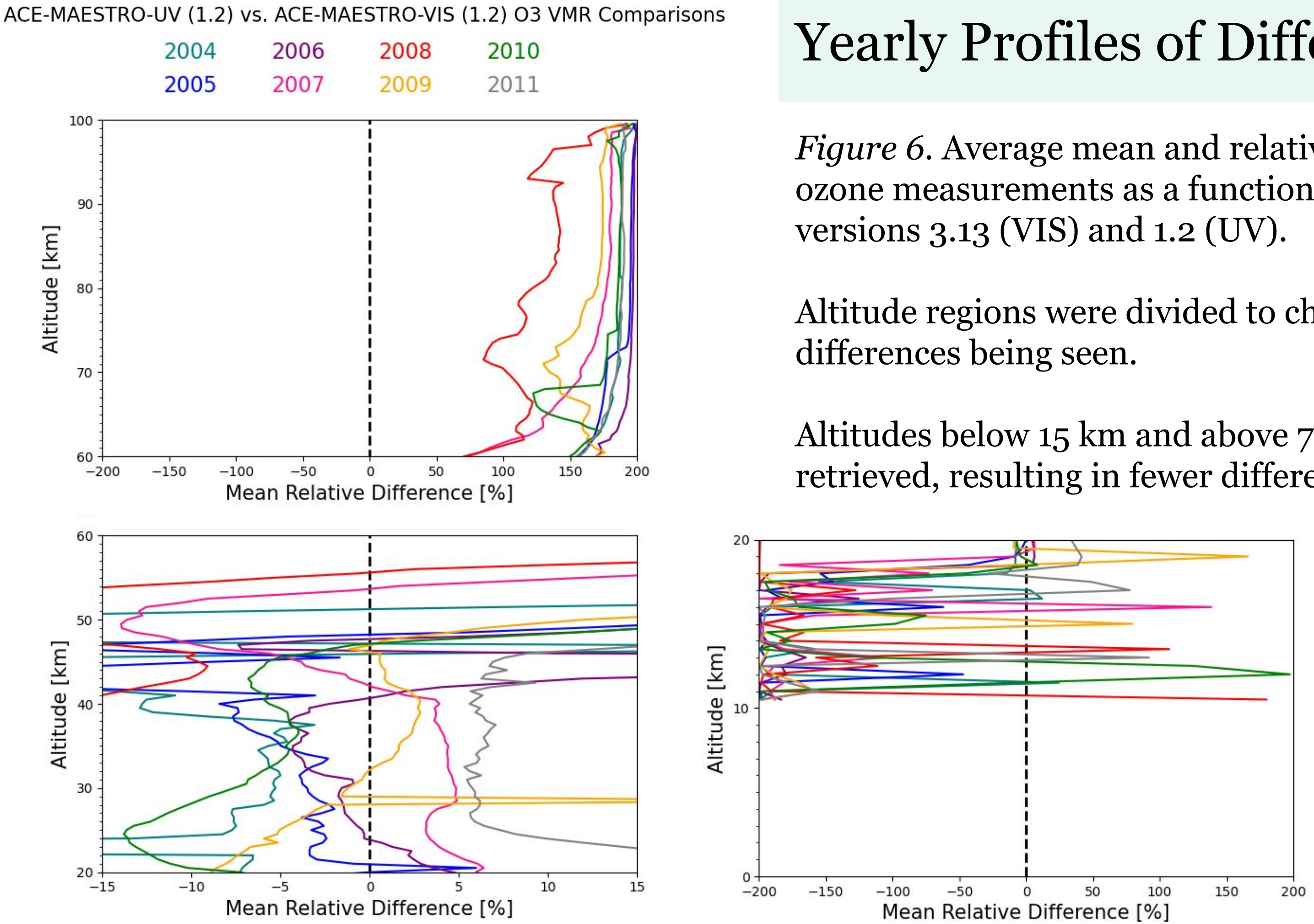


Figure 6. Average mean and relative differences of ozone measurements as a function of altitude for versions 3.13 (VIS) and 1.2 (UV).

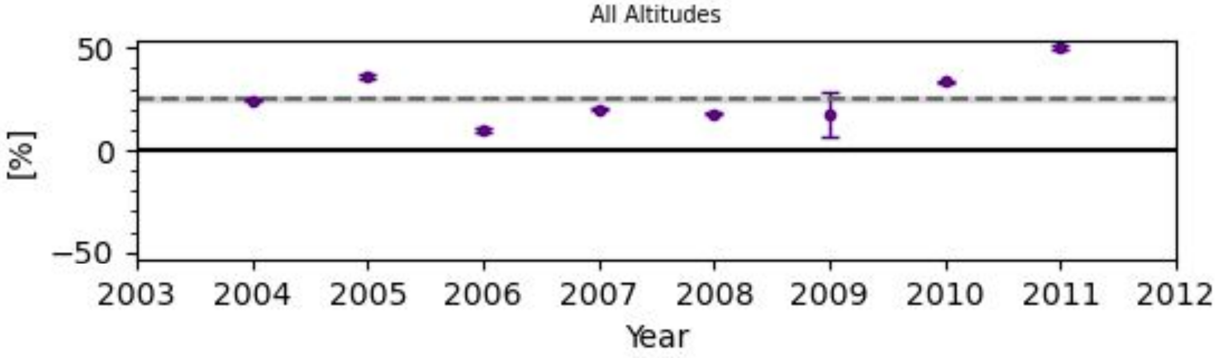
Altitude regions were divided to change the scale of the differences being seen.

Altitudes below 15 km and above 70 km are often not retrieved, resulting in fewer differences being included.

Yearly Profiles of Differences

Figure 7. Average mean and relative differences of ozone measurements for all altitudes for versions 3.13 (VIS) and 1.2 (UV).

Δ_{rel}=27.2 ± 3.5 %



Methods: Trend Analysis

- Time series of measurements of ozone from versions 1.2 (UV and VIS) and 3.13 (VIS) were constructed from monthly averages of ozone.

- Measurements were further categorized by latitude with latitudinal resolutions of 5° and 30°. Using a resolution of 30° allowed for more measurements to be included for each time series and results in a more robust fit.

$$\hat{y} = a + \omega_0 x + N_t$$

- The time series was first fit to a line with a slope of magnitude $|\omega_o|$. Eqn. (1) was used to determine the minimum number of years required to accurately estimate a linear drift of magnitude $|\omega_o|$.

$$n^* = \left[\frac{3.3\sigma_N}{|\omega_0|}\sqrt{\frac{1+\varphi}{1-\varphi}}\right]^{2/3} \qquad (1)$$

φ = *autocorrelation of monthly averages*

σ_N = *standard deviation of monthly averages*

n^* = *minimum no. of years to observe a trend* $|\omega_0|$

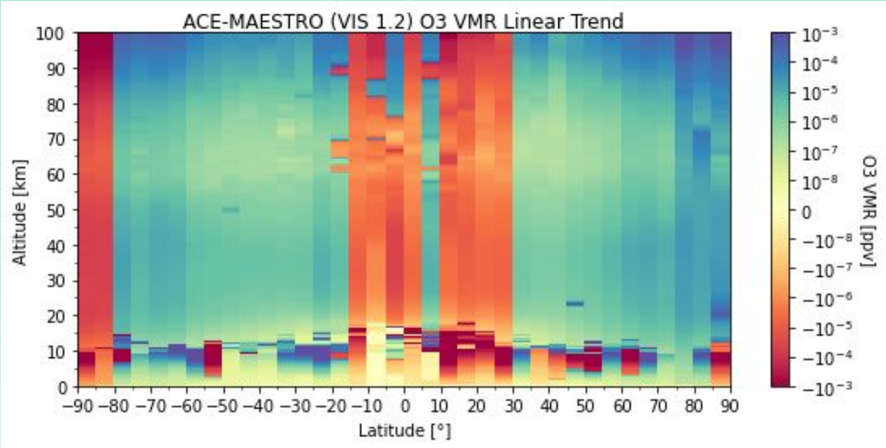
$|\omega_0|$ = *absolute linear drift*

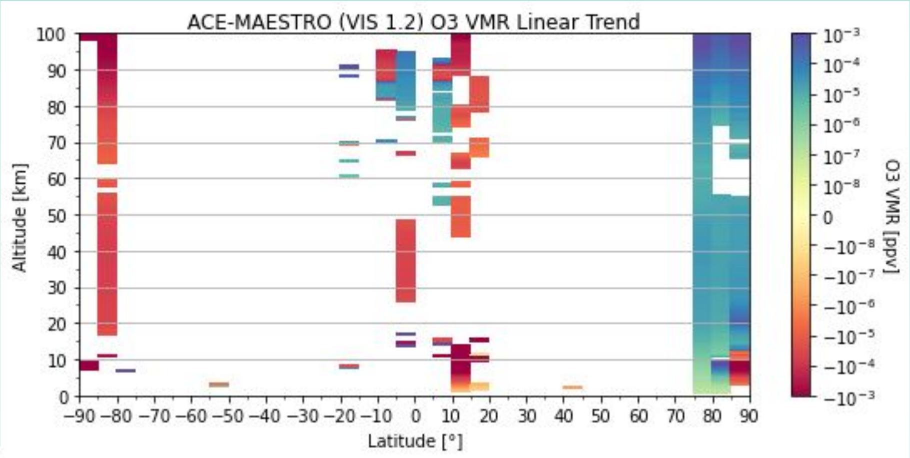
Method credit: Weatherhead et. al, 1998.

- (altitude, latitude) pairs without a sufficient number of years, or $\sigma_{|\omega|} > |\omega_o|$, were discarded.

Results: Linear Trend Analysis

- Warm: negative
- Cool: positive





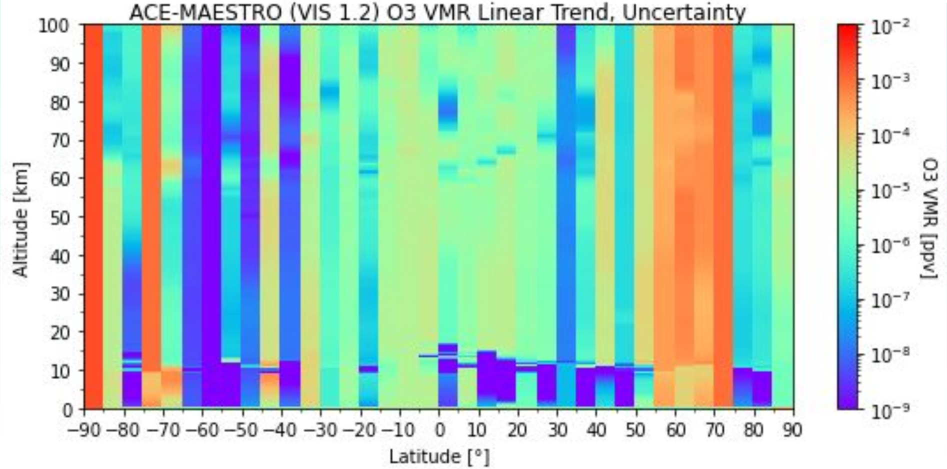


Figure 7. Linear drift determined for the three data versions on a 0.5 km, 5° latitude grid (v.1.2 measurements).

- Drifts are generally negative in tropical latitude and positive in other regions

Methods: Trend Analysis (Oscillations)

Method 1: Deseasonalise the data by subtracting the average monthly O3 quantity at each altitude, find the linear trend of the deseasonalised time series, and add the seasonal trend to the linear fit (on 30° latitude grid).

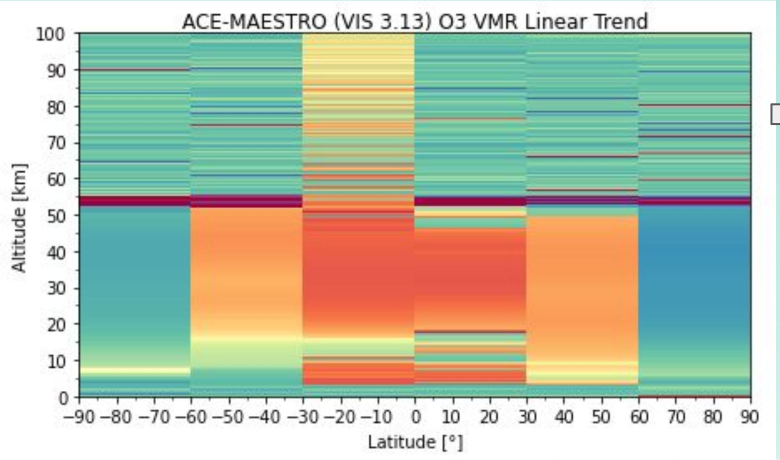
Method 2: The following matrix equations were used to determine the parameters of the linear trends (on 5° and 30° latitude grid) ☐

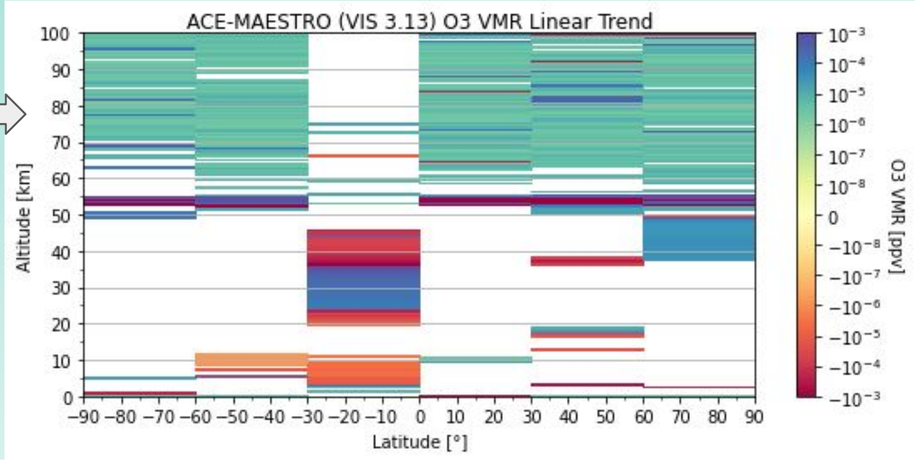
$$\hat{y}(x) = a + bx + \sum_{n=2}^{m}\left(c_n \sin\frac{2\pi x}{l_n} + d_n \cos\frac{2\pi x}{l_n}\right)$$

(l_n=*28, 12, 9, 8, 6, 4, 3*)

Method credit: vonClarmann et. al, 2010,
Eckert et. al, 2014.

AM-VIS 3.13 Fit Results: Method 1 (Deseasonalisation method)





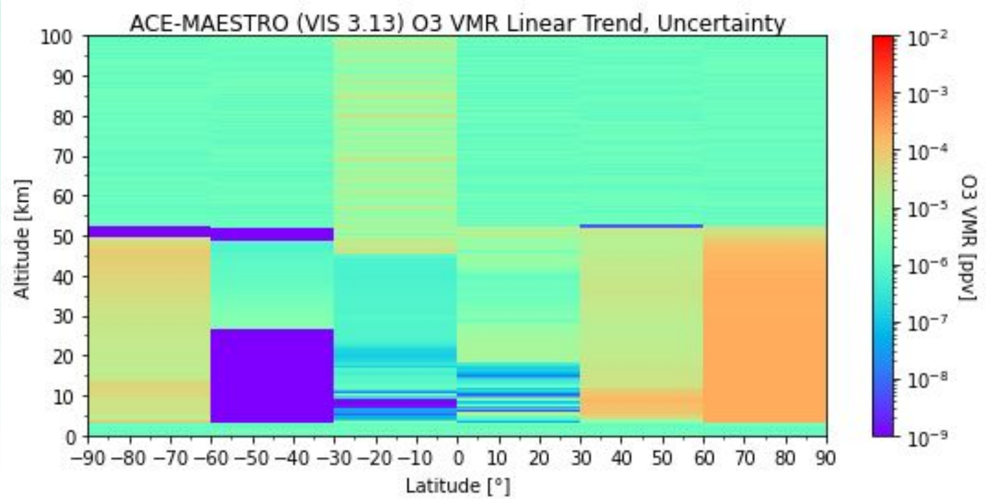
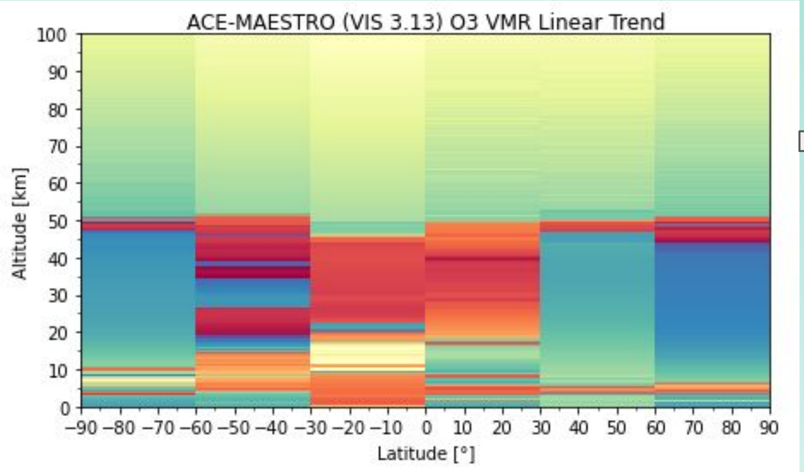
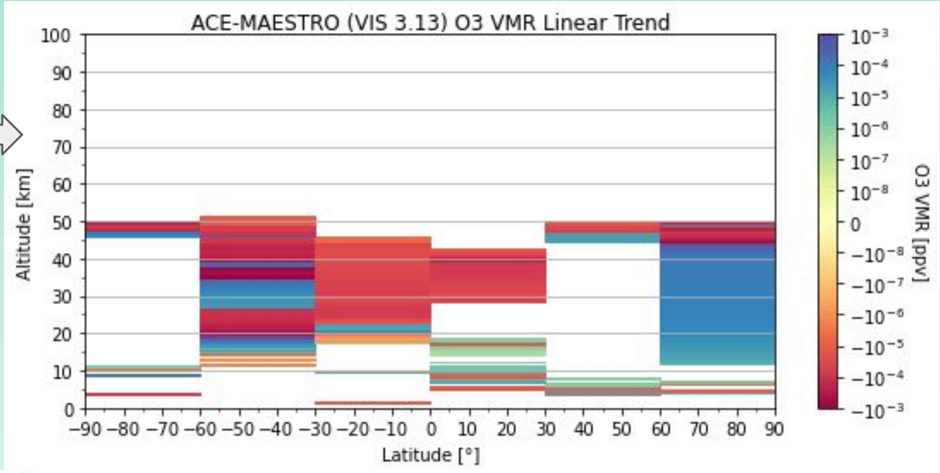


Figure 8. Linear drift determined for the three data versions on a 0.5 km, 30° latitude grid (v.3.13 measurements) (method 1).

AM-VIS 3.13 Fit Results: Method 2 (Matrix Method)





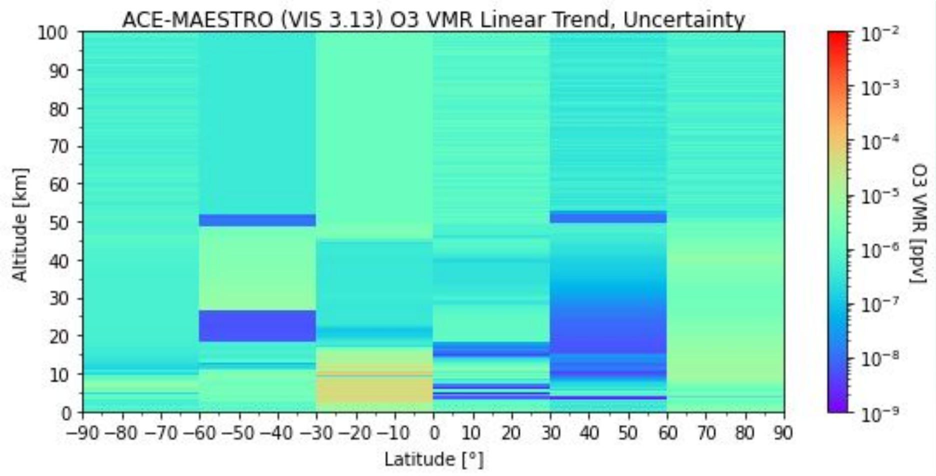


Figure 8. Linear drift determined for the three data versions on a 0.5 km, 30° latitude grid (v.3.13 measurements) (method 2).

Comparing Different Models

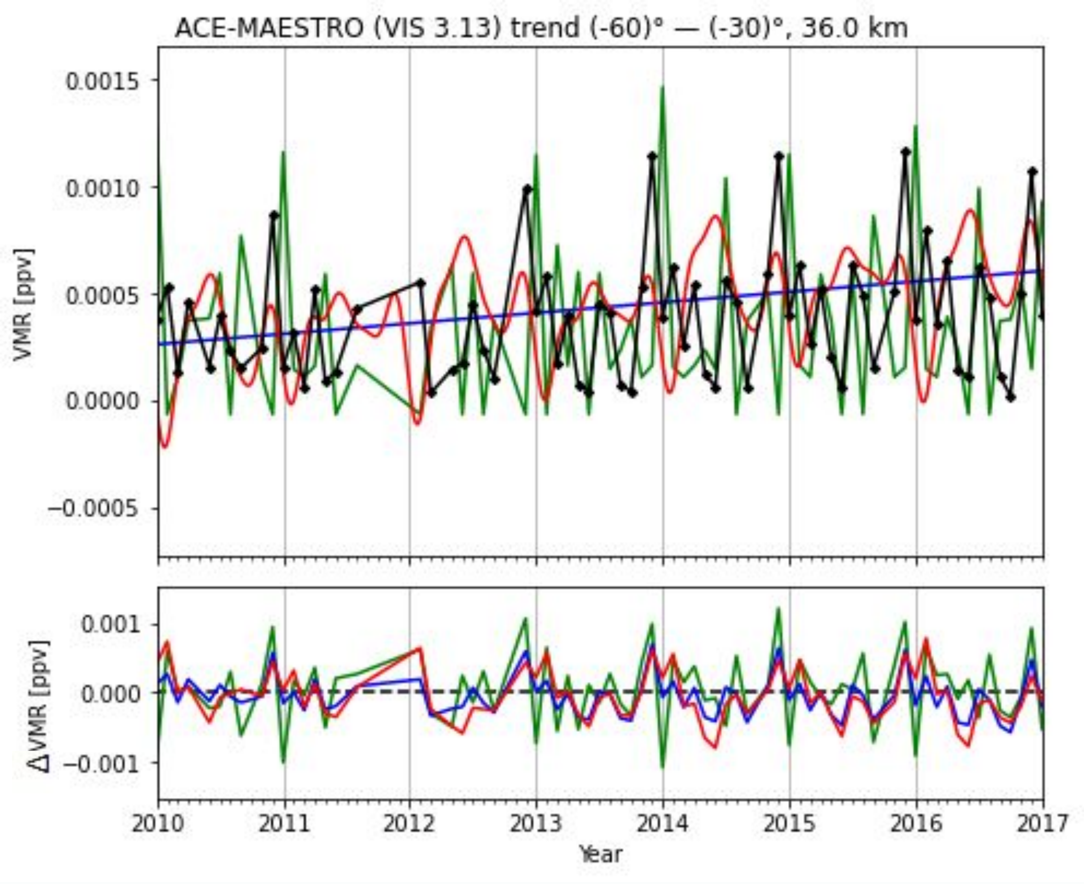


Figure 10. Different ways of modelling monthly average ozone at 60°S-30°S, 33.0 km altitude (zoomed in to 2010-2017). Below the models is a plot of the residuals for each fit.

Monthly Ozone Average
Linear Fit Using Matrix Method
Fit Using Deseasonalisation
Linear + Oscillatory Fit Using Matrix Method (Method 2)

Summary

1. Compared ACE-MAESTRO data versions 1.2 and 3.13

- The availability of data from 0-10 and 80-100 km was particularly low.
- Measurements from the VIS spectrometer were generally smaller than those from the UV spectrometer from 0-20 km and 60-100 km.

2. Examined global trends in atmospheric ozone, as observed by ACE-MAESTRO.

- Implemented different ways of modelling ozone time series.
- Uncertainty was very high for these models and in many cases there were not enough years of data to accurately model the time series.
- The models generally showed negative drifts in midlatitudes and positive drifts at polar latitudes.

Next Steps

- Implement the quasi-biennial oscillation (~28-month period) to the ozone trends using proxy data from Singapore.

  Method credit: Eckert et. al, 2014.

- Instrumental drift could be calculated by performing comparisons of measurements from ACE-MAESTRO with measurements from other instruments, fitting the aggregated measurement differences over time to a line, and adding it to the existing model.

- This would yield a model that describes how global distributions of ozone have changed; not as how ACE-MAESTRO observed it.

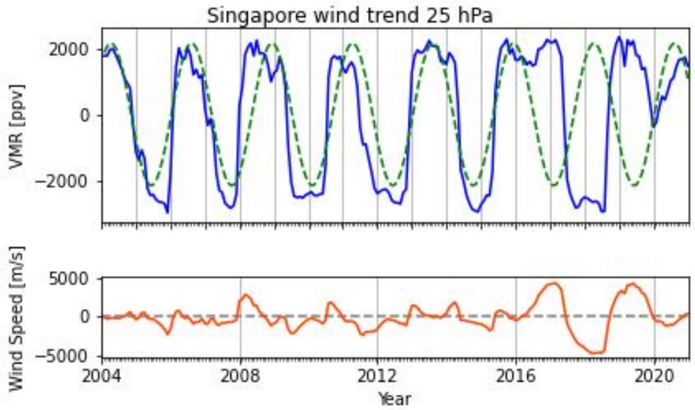


Figure 12. Fit of winds measured at 45 hPa from 2004 - 2020.

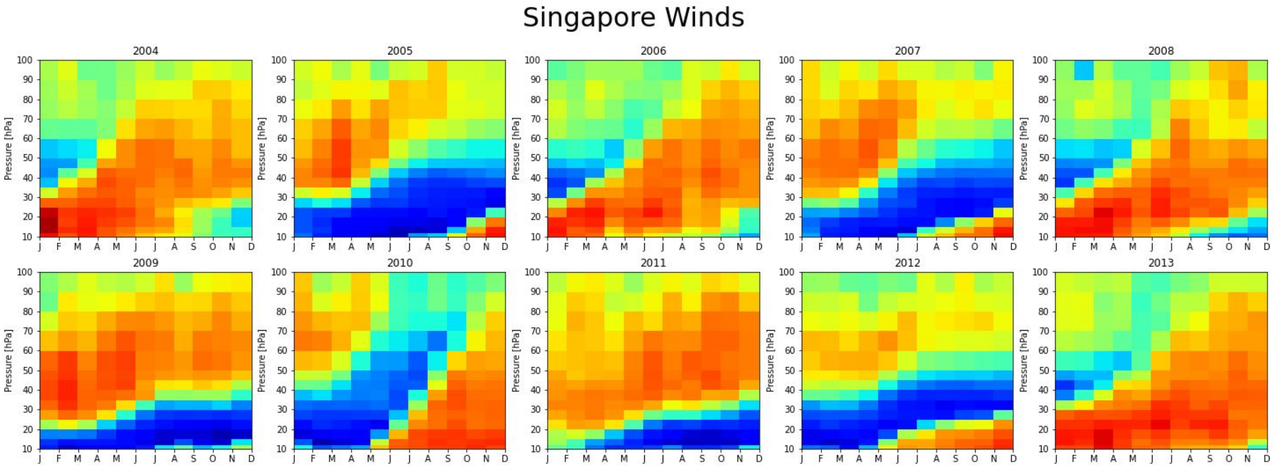


Figure 11. Monthly mean zonal wind components at Singapore (1°N, 104°E).

Thank you!
Questions?