

Ozone trends in the UTLS using Equivalent latitude potential temperature coordinates



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Introduction

Quantifying ozone trends in the upper troposphere and lower stratosphere (UTLS) region is essential for understanding its impacts not only for surface UV, but also on climate and air quality.

Despite decades of measurements from the ground, balloons, aircraft, and satellites, estimating ozone trends in the UTLS remains challenging because it is a transition region between the ozone-poor troposphere and the ozone-rich stratosphere. UTLS ozone exhibits large spatio-temporal variability, primarily driven by dynamical fluctuations in the tropopause and the UTLS jets locations.

As part of the Observed Composition Trends and Variability in the UTLS (OCTAV-UTLS) activity within Atmospheric Processes and their Role in Climate (APARC), we have studied UTLS ozone trends binned in geographic (latitude–pressure and latitude–altitude) and EqL– θ coordinates to assess how the choice of coordinate system influences the representation of ozone variability and trends.

Methodology

We use Aura MLS version 5 (Fig1a) and ACE-FTS version 5.3 (Fig1b) ozone data, applying their recommended quality screening.

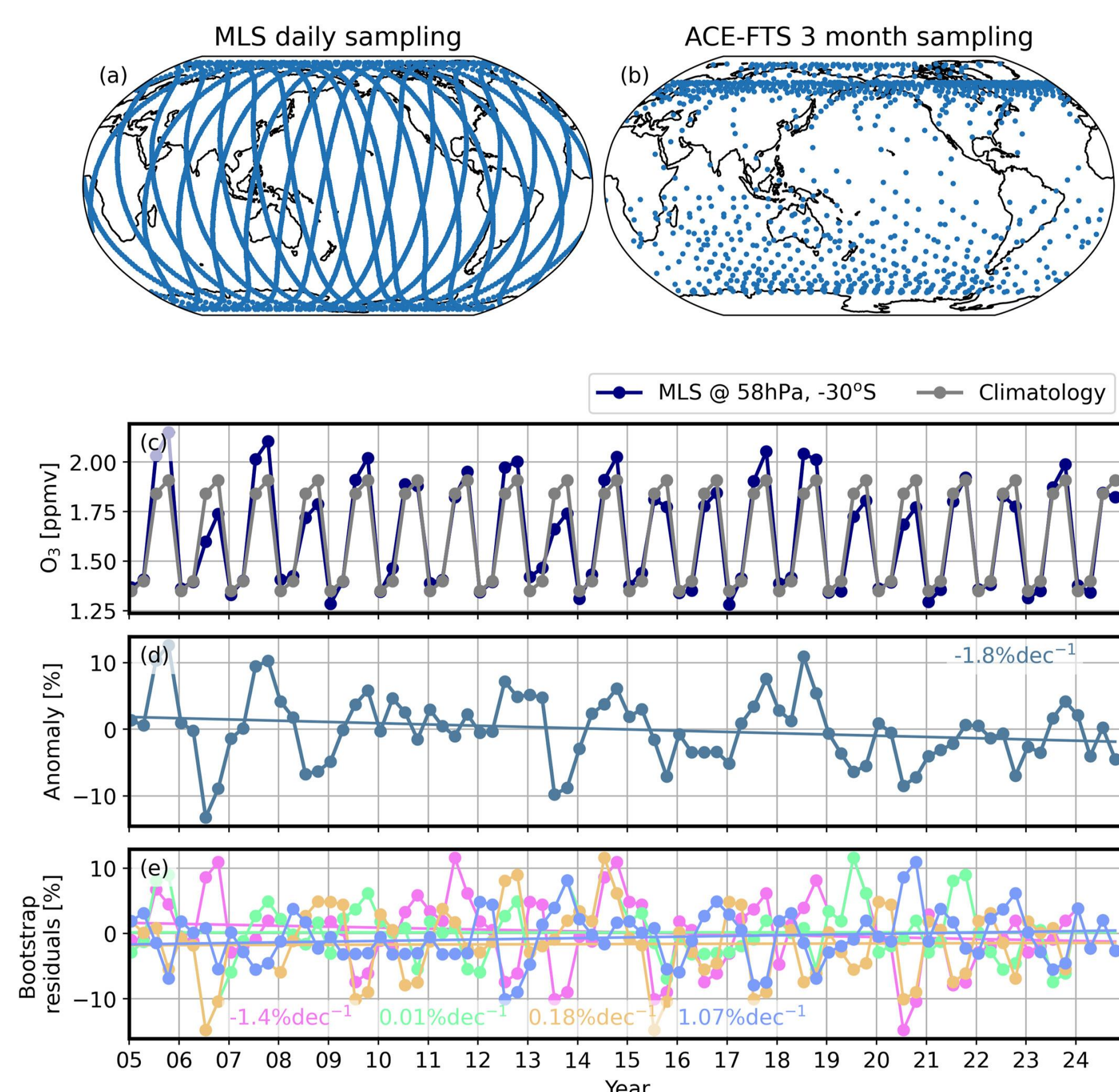
To map these ozone observations into different coordinate systems, we use the JET and Tropopause Products for Analysis and Characterization (JETPAC) algorithms (e.g. Manney et al 2011, Millán et al 2023).

MLS and ACE-FTS ozone profiles are aggregated into seasonal zonal means in 5° bins (in either latitude or EqL).

Vertically, the data are binned onto uniform grids using pressure (12 levels per decade) or potential temperature (θ , 15 K spacing).

Trends are calculated by applying a linear (least squares) fit to deseasonalized data (Fig 1c,d)

Uncertainties are estimated using a yearly block bootstrap resampling method (Fig 1e).

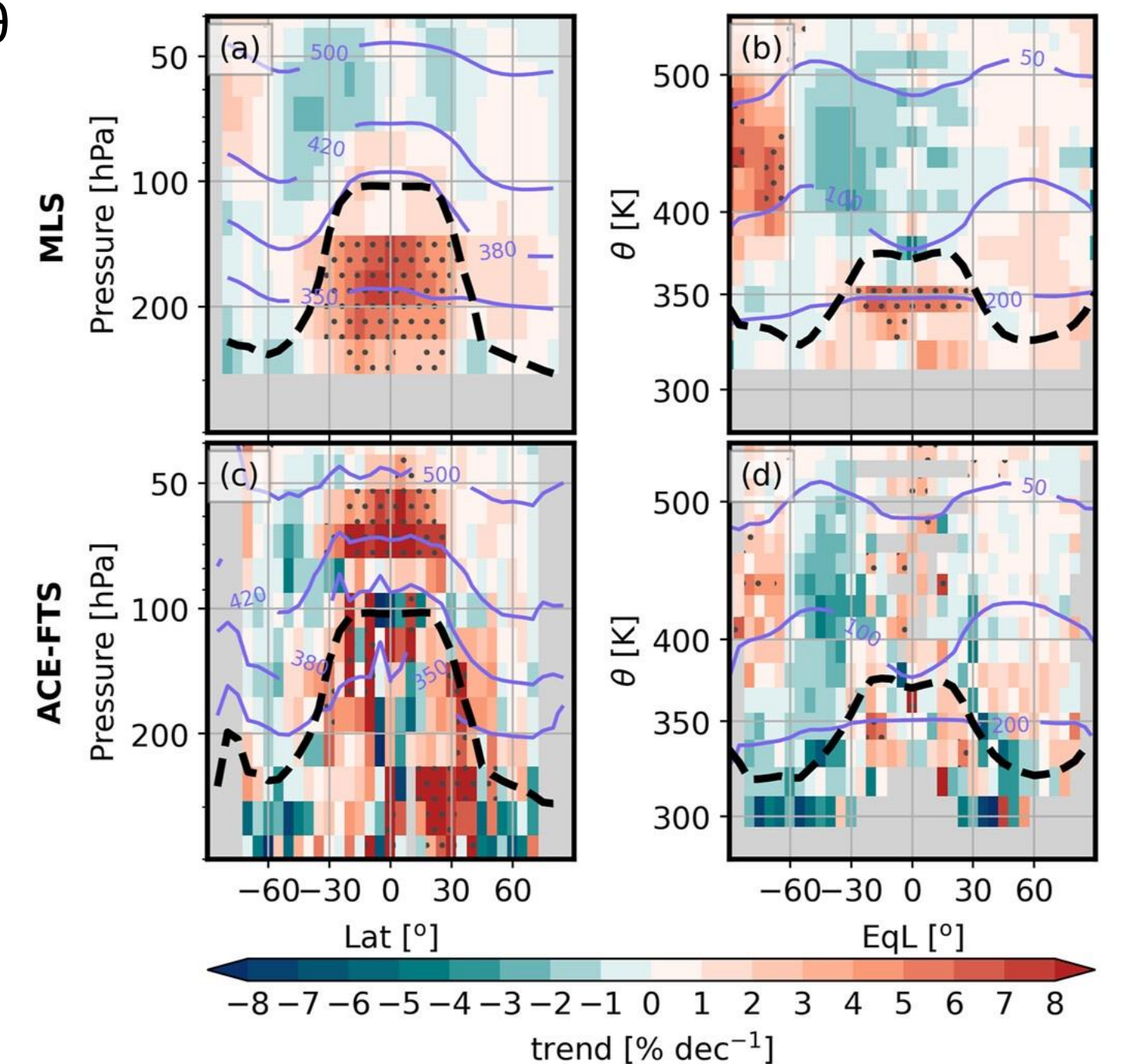


Example of (a) a Microwave Limb Sounder (MLS) daily sampling pattern and (b) an Atmospheric Chemistry Experiment-Fourier Transform Spectrometer 3-month (December–February) sampling pattern. (c) Example of an MLS ozone time series and climatology in one zonal bin. (d) Deseasonalized ozone anomalies. (e) Example bootstrapped residuals (i.e., anomalies–linear fit).

Results

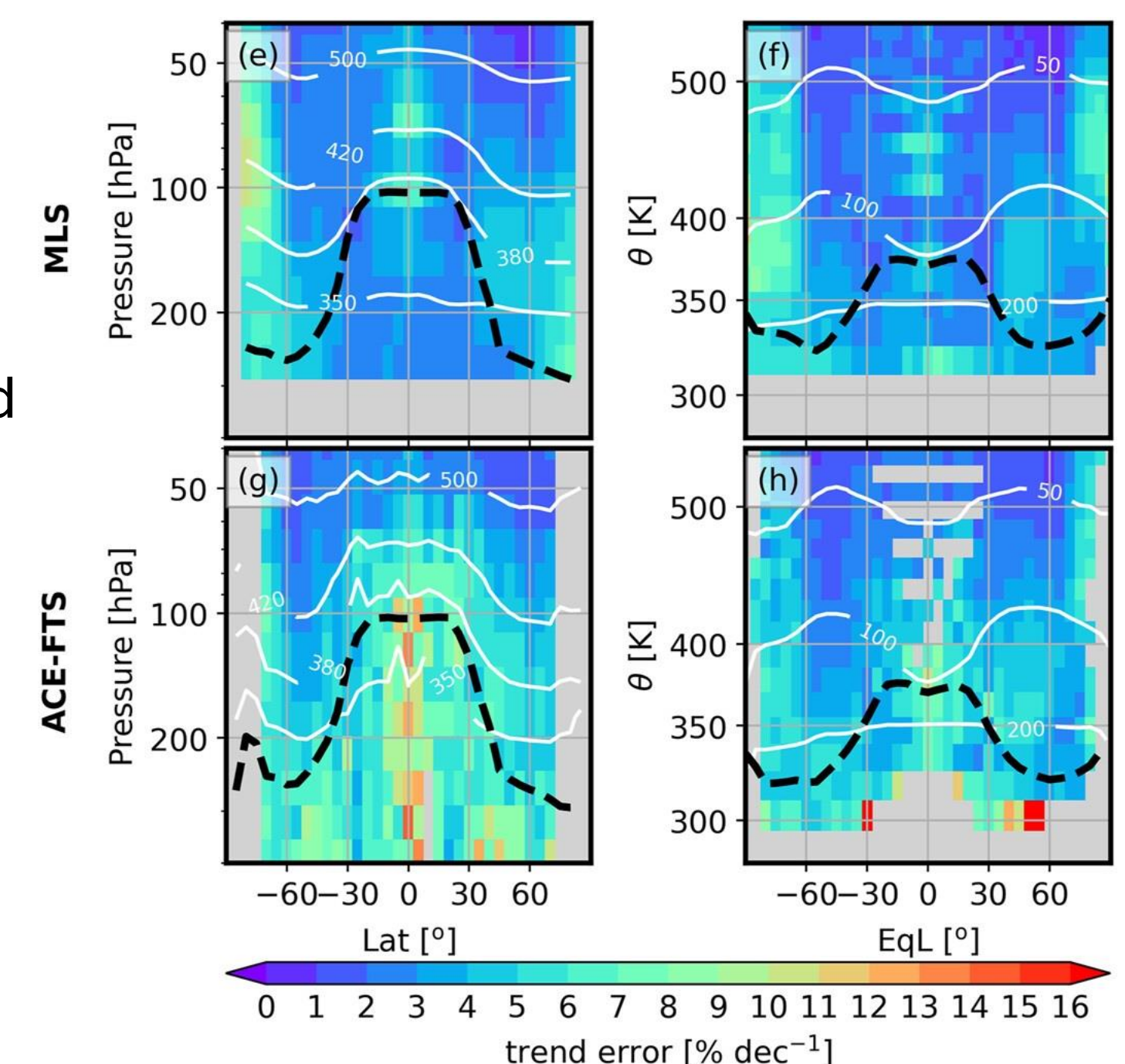
Despite the much sparser sampling of ACE-FTS, trends estimated using EqL– θ coordinates show substantially greater consistency with MLS than trends calculated in conventional latitude–pressure coordinates.

For example, in the Southern polar lower stratosphere (LS) trends shift from 2% for MLS and –2% per decade for ACE-FTS to up to 5% per decade, with MLS data indicating statistical significance just poleward of 60°S.



MLS and ACE-FTS ozone trends (2005–2024) using latitude-pressure (left) and equivalent latitude-potential temperature (right). Gray regions indicate areas without measurements. The hatching represents statistical significance at the 2σ level.

Using EqL– θ yields better consistency between the MLS and ACE-FTS trend uncertainties than using conventional geographical coordinates. For example, in the polar LS, when using EqL– θ , both data sets show trend uncertainties that more effectively capture the interannual variability associated with Antarctic and Arctic vortex-related chemical depletion.



MLS and ACE-FTS ozone trends uncertainties (2005–2024) using latitude-pressure (left) and equivalent latitude-potential temperature (right). Gray regions indicate areas without measurements.

Trends were also analyzed using multiple linear regression, dynamic linear model, as well as by season (not shown).

Regardless of the method, EqL– θ improves consistency between trends across the UTLS, reduces large UT tropical uncertainties, alters the magnitude of mid-latitude trends, and, most notably, in the Southern polar lower stratosphere, reveals statistically significant trends exceeding 8% per decade during Antarctic Spring. This provides further evidence of Antarctic ozone recovery.

More information can be found at Millán et al. (2025) – doi: 10.1029/2025GL118651

Conclusions

- EqL– θ coordinates enhance robustness and interpretability of ozone trends in the UTLS (LMS), even at the tropics (although most trends remain statistically insignificant)
- EqL– θ accounts for vortex variability when grouping ozone, whereas geographical coordinates ignore it, mixing polar and mid-latitude trends
- EqL– θ reveals statistically significant trends around the Antarctic vortex in the lower stratosphere, missed in geographical coordinates, warranting further investigation.

References:

Manney et al. (2011) - doi:10.5194/acp-11-6115-2011
Millán et al (2023) – doi: 10.5194/amt-16-2957-2023