

Evaluation of age of air derived from simulated infra-red satellite observations of trace gases



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1. Introduction

Following the increase of greenhouse gas emissions, atmospheric models predict a strengthening of the middle atmospheric Brewer-Dobson circulation (BDC). Changes in the BDC can be inferred from age of air (AoA) trends. While models predict an acceleration of the BDC (i.e. a decrease of AoA), in-situ balloon observations suggest the opposite, although not significantly, given the limited number of observations and the substantial uncertainties (Garny et al., 2024a). Additionally, meteorological reanalyses disagree on the sign and magnitude of AoA trends. The Changing Atmosphere Infrared Tomography explorer (CAIRT), proposed for ESA's Earth Explorer 11 was designed to measure AoA with an uncertainty of 0.5 years per profile or 0.25 years for zonal mean observations. Synthetic CAIRT profiles of six long-lived species (SF_6 , CH_4 , N_2O , CFC-11, CFC-12 and HCFC-22) are simulated by the Belgian Assimilation System for Chemical Observations (BASCOE) chemistry transport model, considering CAIRT's expected measurement errors and spatial resolution. CAIRT AoA observations, derived from the six long-lived species using the method of Voet et al. (2025), are compared to clock tracer AoA, simulated by the BASCOE model, to evaluate the

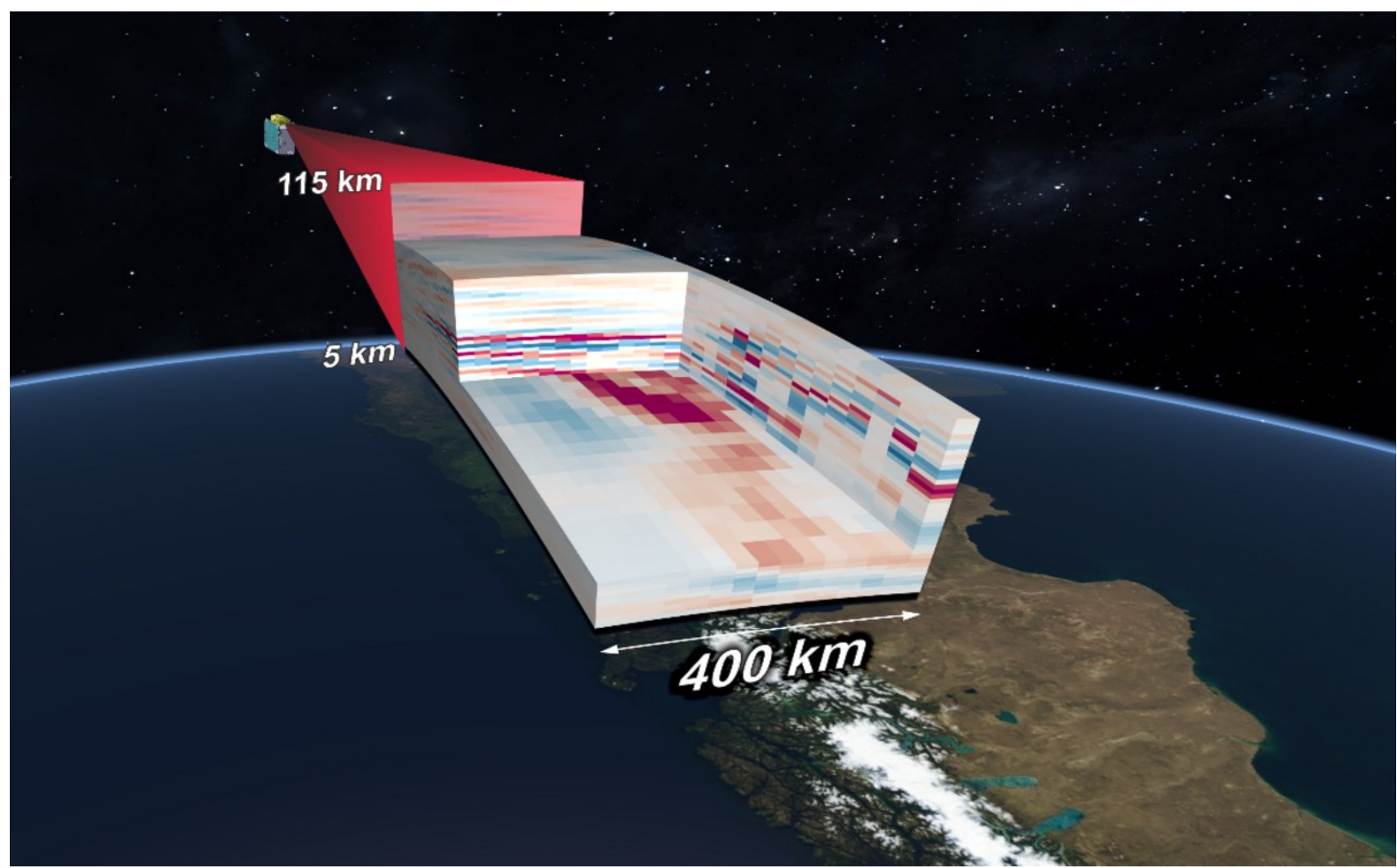


Fig 1. The Changing Atmosphere Infrared Tomography explorer (CAIRT) was proposed for ESA's Earth Explorer 11 to perform high resolution trace gas measurement necessary to diagnose AoA trends. CAIRT was foreseen to achieve a precision of 0.5 years on the AoA, a requirement to assess long-term trends.

agreement. The analysis is repeated three times by driving the model with the meteorological reanalyses MERRA-2, ERA-5, and JRA-3Q, respectively, to check if CAIRT precision would be sufficient to evaluate meteorological reanalyses.

2. Simulated satellite AoA

The following figures show CAIRT AoA computed with the method of Voet et al. (2025), using a tropospheric reference equal to the lower boundary of BASCOE in the tropics, and a sink correction derived from the BASCOE simulations. Figure 2 A-C show the difference of the clock tracer AoA and the satellite AoA on the orbit tracks at 25 km. Figure 2 D shows a time series of the zonal mean CAIRT AoA on top of the clock tracer in the Northern mid-latitudes at 25 km. The retrieval error on the AoA is generally smaller than the differences between the reanalyses.

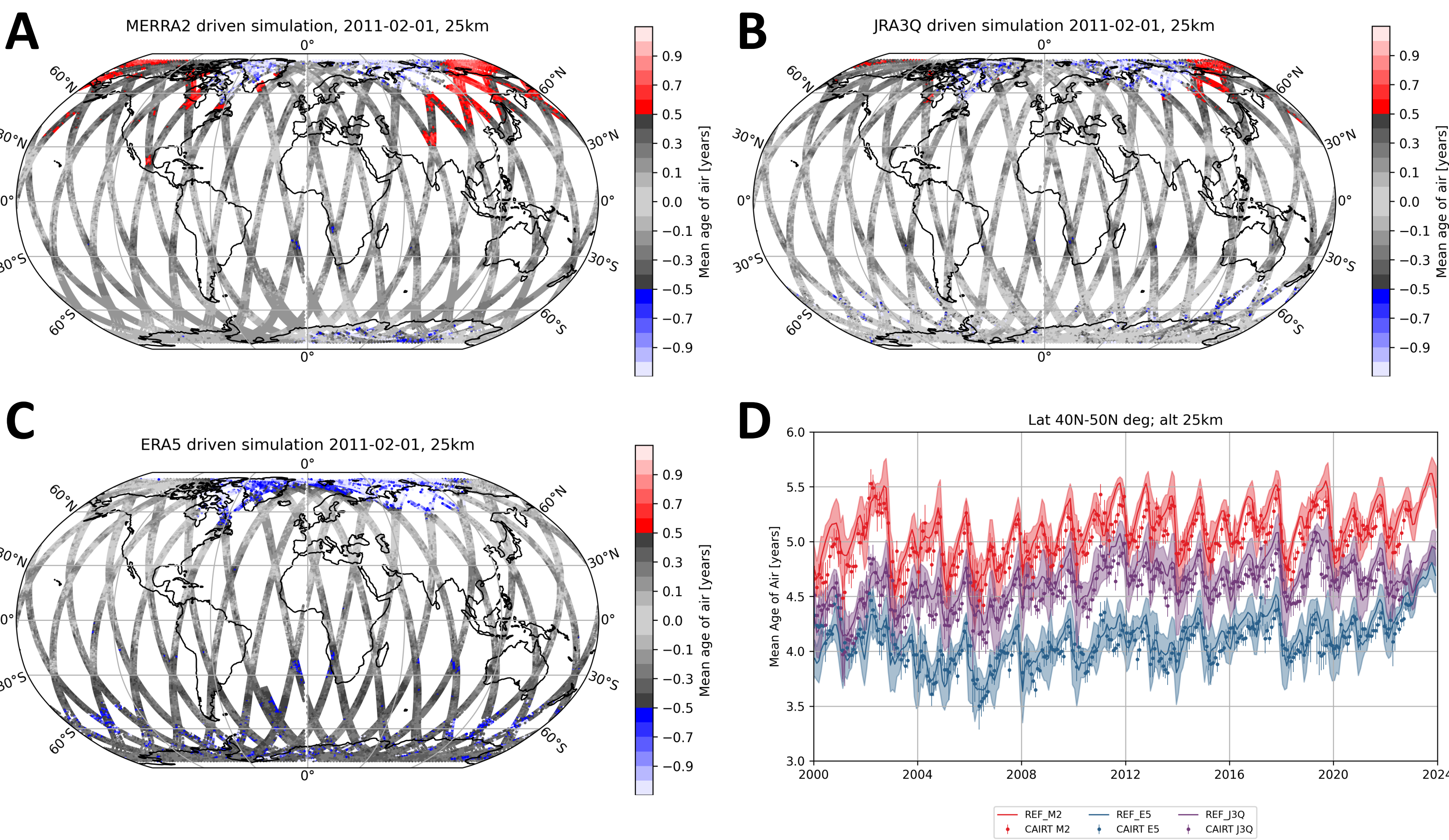


Fig. 2. A, B, C: Difference between simulated daily averaged CAIRT AoA at 25 km on 2011-02-01, derived from different driving reanalysis data sets, and the clock tracer AoA from a simulation driven by the same reanalyses. D: Daily zonal mean CAIRT AoA at 25 km in the Northern mid-latitudes on the 15th of every month, 2000-2023, compared with clock tracer AoA from BASCOE, driven by MERRA2, JRA-3Q and ERA5. The shaded areas are the 1 σ monthly variability. The error bars on the CAIRT AoA represent the total uncertainty of the daily average.

3. Sources of bias due to AoA computation

The AoA computation relies on several assumptions.

1. Tropospheric reference

A tropospheric reference time series is used to compute the time elapsed since emission at the surface. At 25 km, the choice of reference shifts zonal mean multi-tracer AoA by up to 0.4 years (Fig. 3). The offset is relatively constant throughout the atmosphere and similar for all three reanalyses (only MERRA-2 shown here).

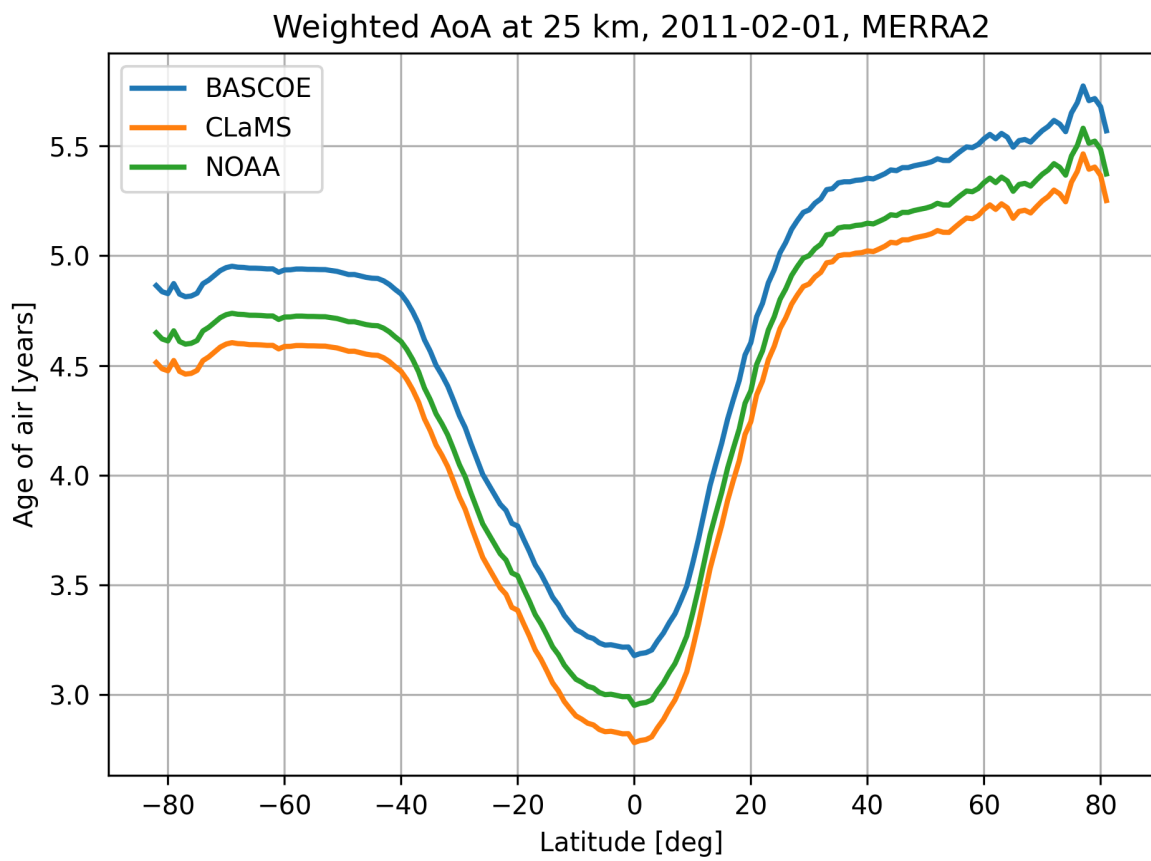


Fig. 3. Zonal mean multi-tracer AoA differences at 25 km computed using different tropospheric reference time series.

2. Mesospheric sink correction

Mesospheric destruction of SF_6 causes an unphysical ageing of the air. The correction of Garny et al. (2024b) relies on an exponential fit to model data and therefore depends on the model used to derive it. Figure 4 compares corrections based on EMAC and BASCOE, showing that this choice introduces an additional uncertainty in AoA which is latitude dependent.

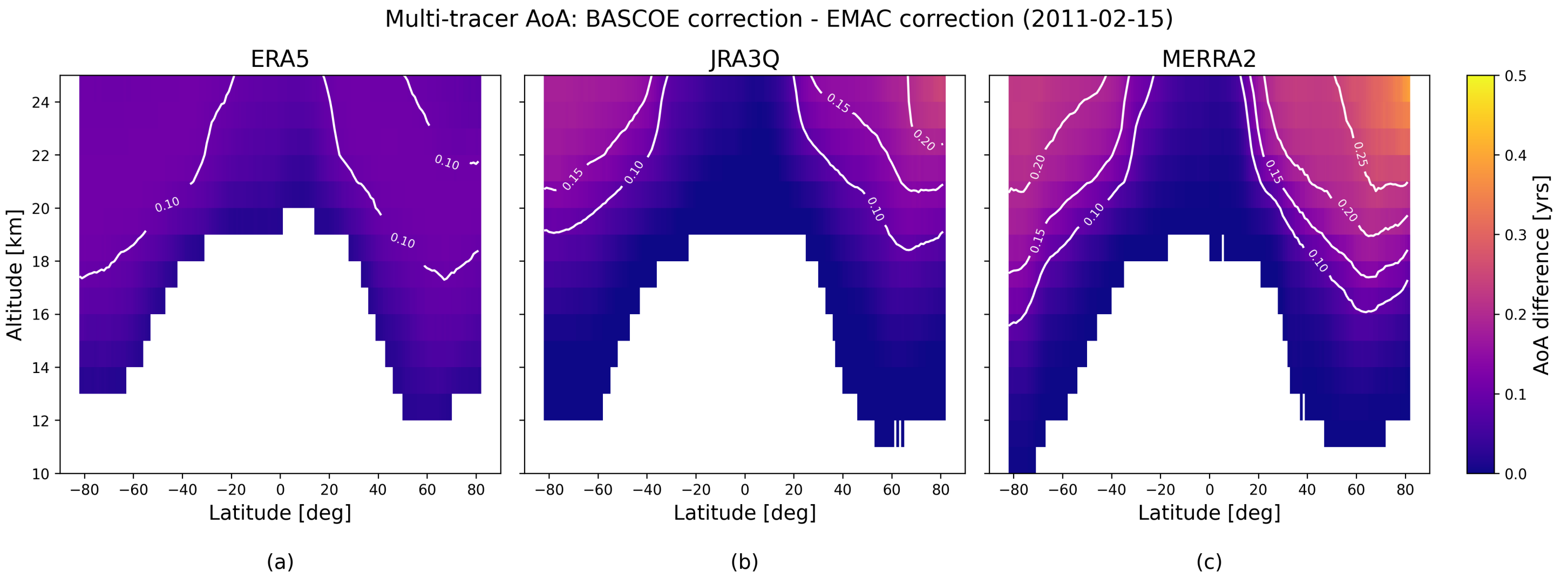


Fig. 4. Zonal mean SF_6 AoA differences computed using a sink correction from EMAC and sink corrections derived from BASCOE simulations.

3. Ratio of moments (ROM)

The ROM defines the width of the inverse Gaussian age spectrum used in the AoA computation. ROM fields were estimated from a single January 1980 tracer pulse in BASCOE and compared with ROM field derived from the CLaMS model. Satellite AoA varies only minimally between different ROM fields (Fig. 5).

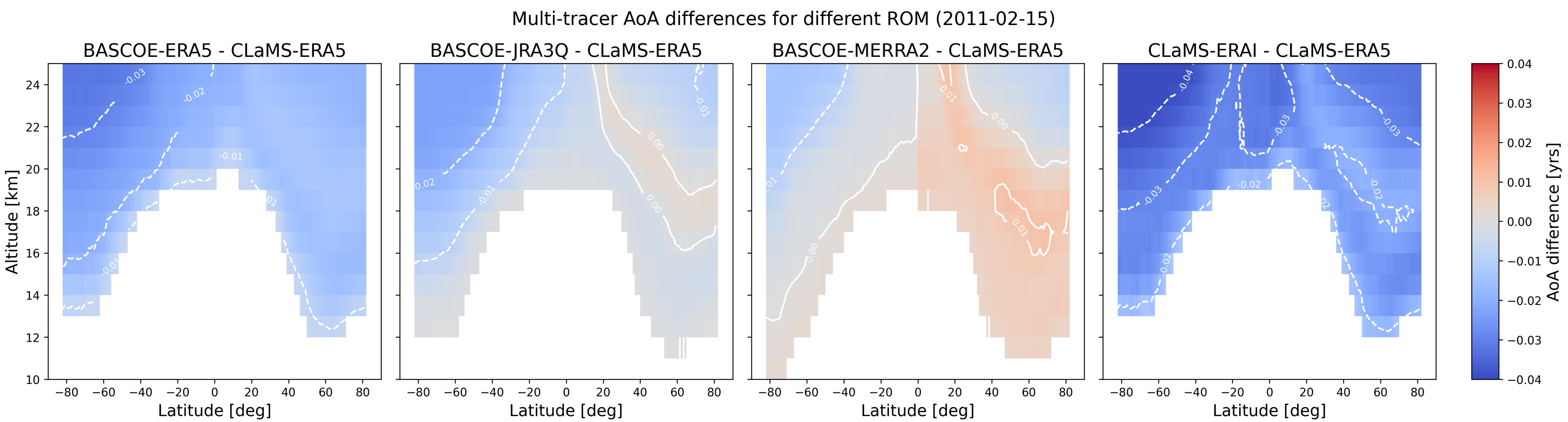


Fig. 5. Zonal mean multi-tracer AoA differences computed using different ROM fields.

4. Conclusions

- CAIRT multi-tracer AoA achieves retrieval errors < 0.5 years at 25 km over most of the globe, generally smaller than the spread between reanalyses.
- The AoA computation can lead to biases of up to 0.4 years due to the choice of tropospheric reference and 0.25 years due to the choice of sink correction.
- Multi-tracer AoA is robust to the choice of ROM.

References

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