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Evaluating the precision of age of air derived from trace gas satellite observations

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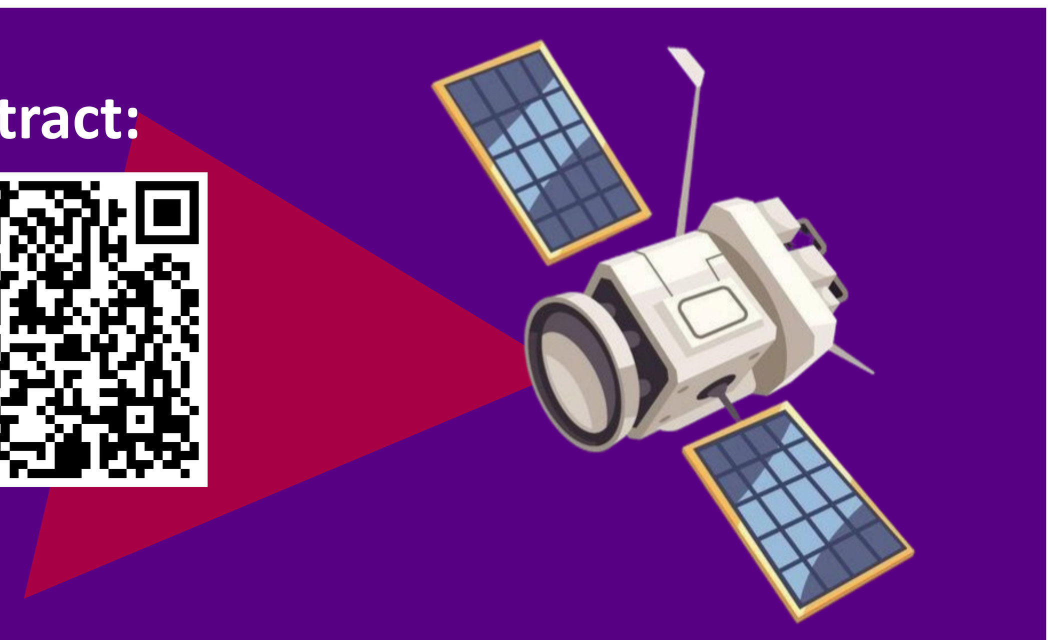
Abstract:



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.

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 agreement. The analysis is repeated three times by driving the model with the meteorological reanalyses MERRA2, ERA5, and JRA-3Q, respectively, to check if CAIRT precision would be sufficient to evaluate meteorological reanalyses.

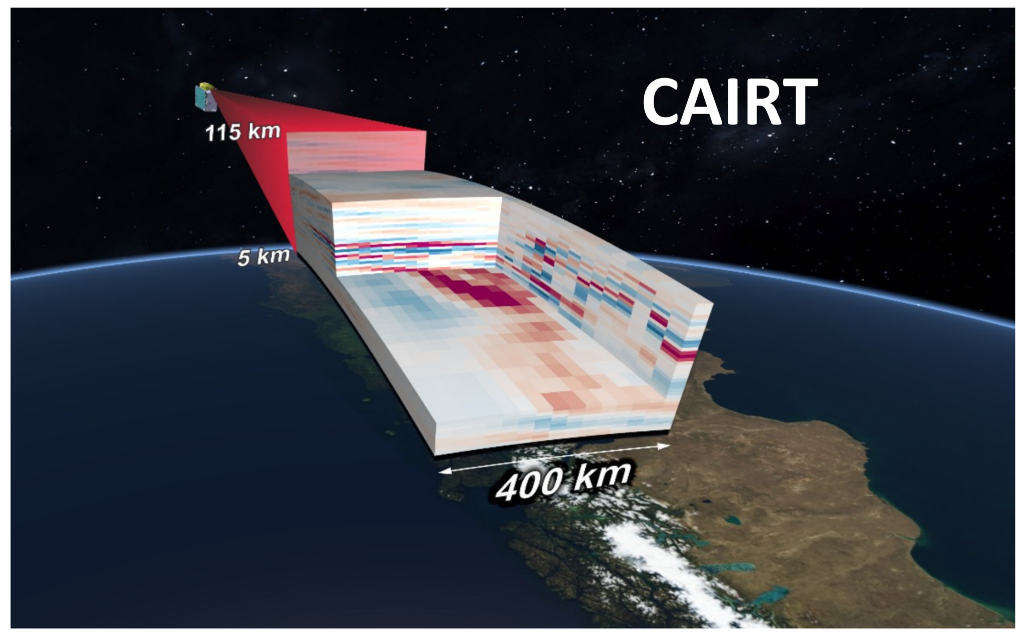


Fig 1. The Changing Atmosphere Infrared Tomography explorer (CAIRT) was proposed for ESA's Earth Explorer 11 to perform high resolution trace gas measurement necessary to diagnose AoA trends. CAIRT was foreseen to achieve a precision of 0.5 years on the AoA, a requirement to assess long-term trends.

Uncertainties related to input

The AoA computation relies on several assumptions. First of all, a tropospheric reference timeseries is chosen compute the time elapsed since emission at the surface. Figure 2 shows how at 25 km the zonal mean SF_6 AoA can shift almost 0.5 years depending on the choice of reference curve. The offset is relatively constant in the atmosphere. The fact that SF_6 is destroyed by electrons in the mesosphere results in unphysical aging of the air. A correction for this reaction has been proposed by Garny et al. (2024), which relies on an exponential function fitted to model data. A choice thus has to be made of which model to use to compute the fit parameters. Figure 3 shows the difference in zonal mean SF_6 AoA when correcting with parameters obtained from the EMAC model (ECHAM/MESSy Atmospheric Chemistry, a global atmosphere-chemistry model) or parameters obtained from the BASCOE model. The sink correction hence results in an additional uncertainty on the AoA.

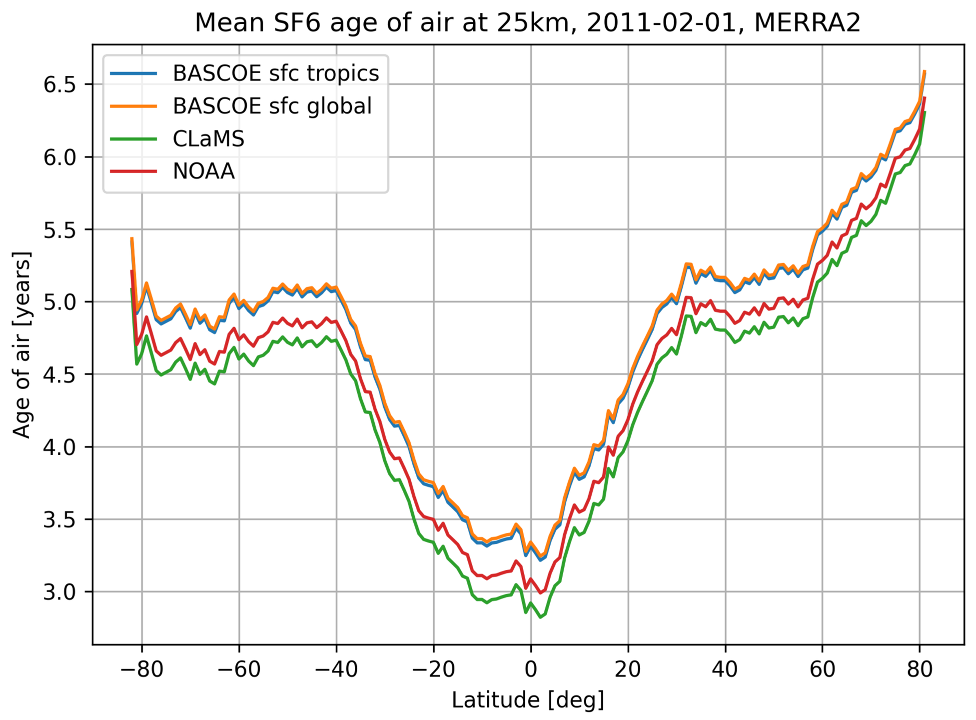


Fig. 2. Zonal mean SF6 AoA differences at 25 km computed using different tropospheric reference time series.

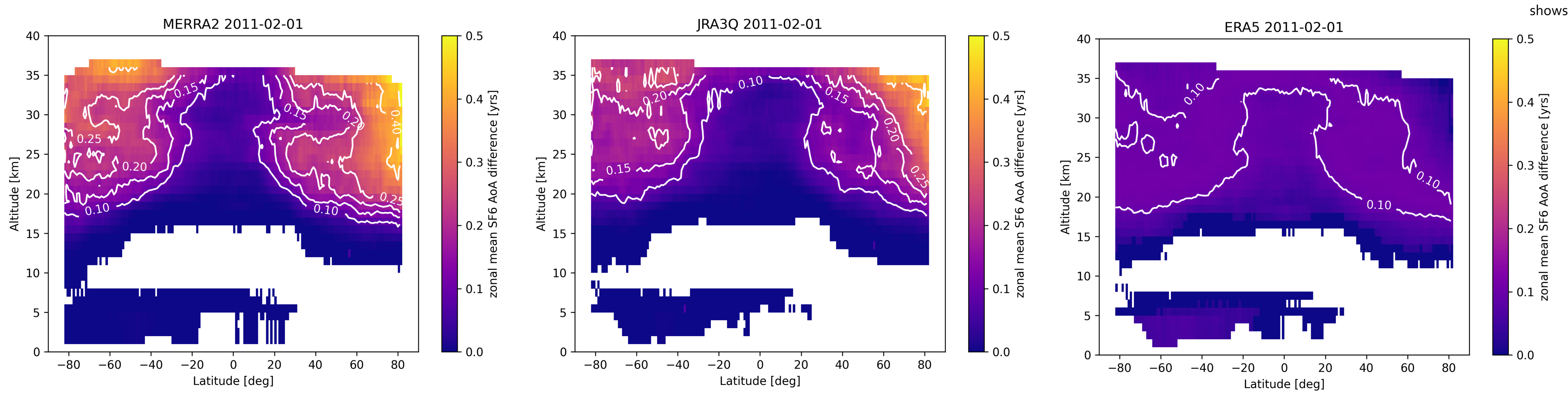


Fig. 3. Difference of zonal mean SF6 AoA computed with sink correction parameters derived from BASCOE and parameters derived from EMAC.

Simulated satellite AoA

The following figures show CAIRT AoA computed with the method of Voet et al. (2025) in an ideal model world, i.e. using a tropospheric reference equal to the lower boundary conditions of BASCOE in the tropics, and a sink correction derived from the BASCOE simulations. Figure 4 shows time series of the clock tracer AoA and the simulated CAIRT AoA for two latitude bands. Figure 5 shows the difference of the clock tracer AoA and the satellite AoA on the orbit tracks.

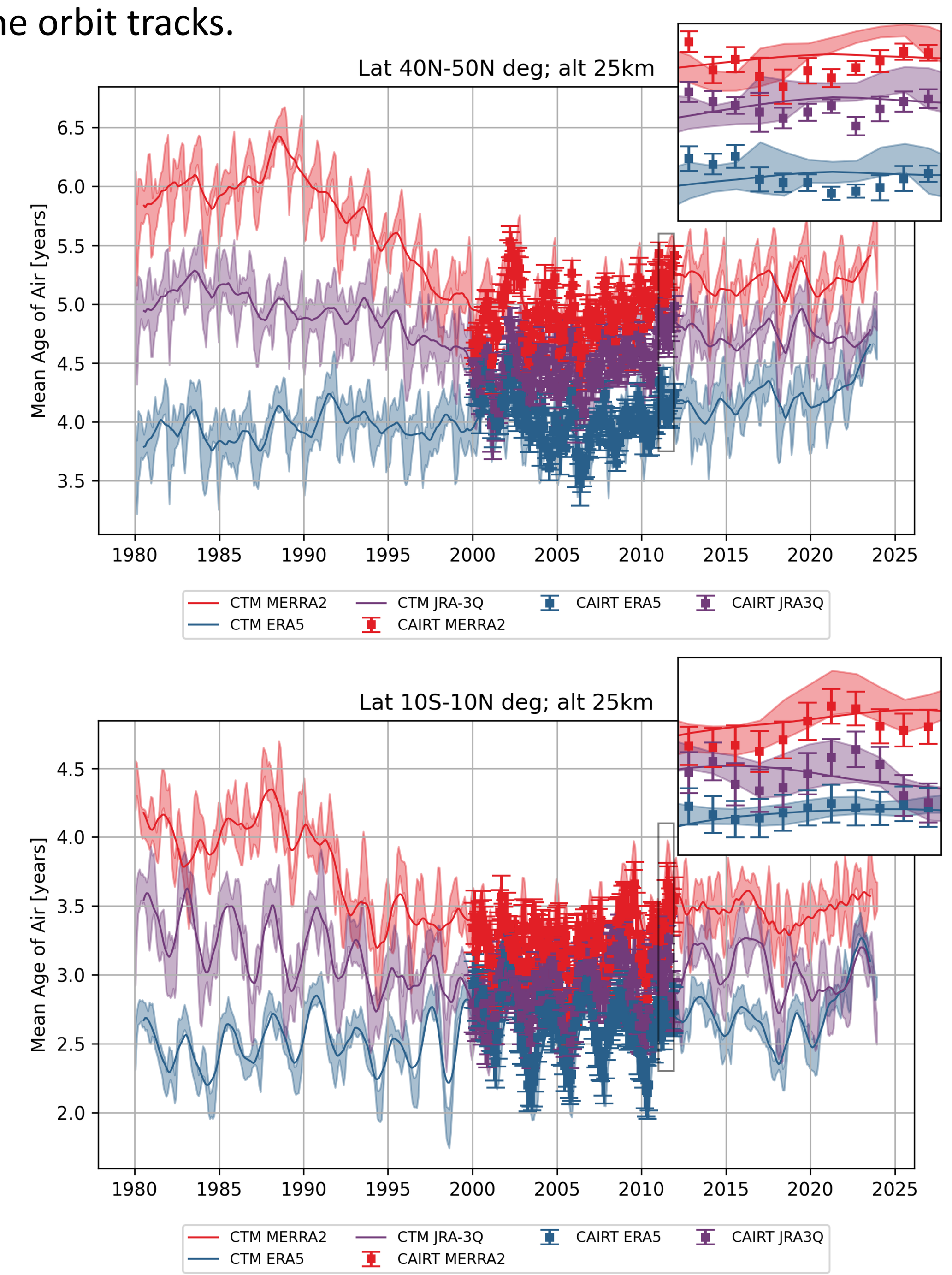


Fig. 4. Daily zonal mean CAIRT AoA at 25 km in the Northern mid-latitudes on the 15th of every month, 2000-2011, compared with clock tracer AoA from BASCOE, driven by MERRA2, JRA-3Q and ERA5. The solid lines are a 12-month rolling average of monthly zonal mean clock tracer AoA. The shaded areas are the 1σ monthly variability. The error bars on the CAIRT AoA represent the total uncertainty of the daily average. The inset shows a zoom on the year 2011.

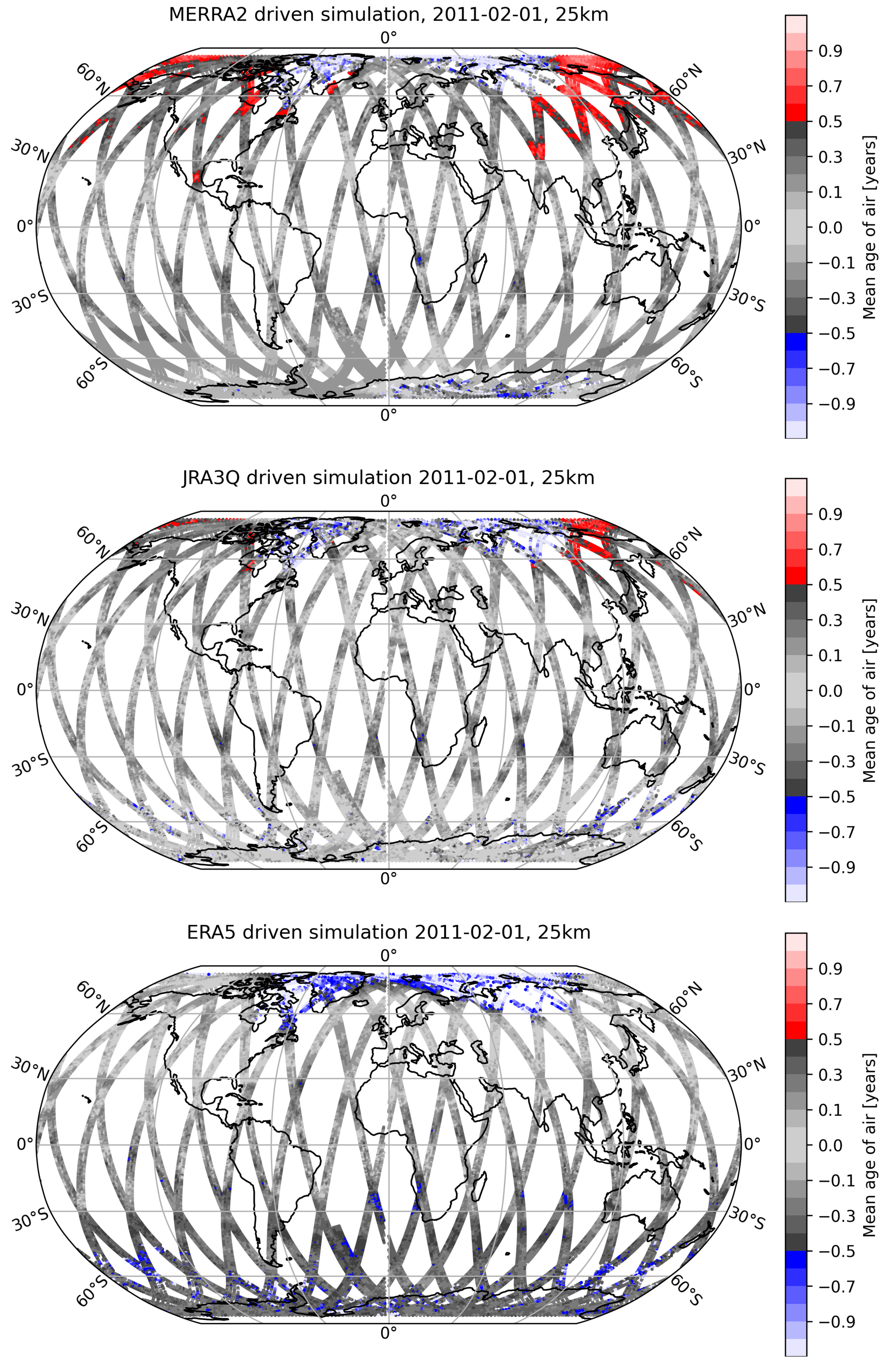


Fig. 5. Difference between simulated daily averaged CAIRT AoA at 25 km on 2011-02-01, derived from different driving reanalysis data sets, and the clock tracer AoA from a simulation driven by the same reanalyses.

Conclusions & next steps

The age of air can be computed from simulated satellite observations with the resolution of the CAIRT satellite concept, with an error bar of 0.5 years over most of the globe. The largest errors are found at the North Pole. Additional uncertainty comes from the choice of tropospheric reference and the sink correction for SF6-based AoA.

A study of the seasonality of the observations is necessary. The time series may allow to determine the observation period required to robustly separate the three reanalyses.

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