Reply to RC1

Point-by-Point reply

1. **Line 192: add ‘of’ after ‘instead’**

   Done.

   ```plaintext
   with SF₅ source regions being located primarily in the northern hemisphere (Rigby et al., 2010).
   We performed a Monte-Carlo simulation in order to test if T₄ can be considered to be constant over time for each entry region. Firstly, for each entry region we calculated weighted means and standard deviations for each year (instead of for the
   ```

2. **Table 2 could go in the supplement.**

   Done, thanks. We applied small changes to the manuscript accordingly:

   ```plaintext
   create 10000 time series for each entry region. Thirdly, we applied a linear fit to each of the 10000 time series and calculated the mean and the standard deviation of the slope for each entry region. The resulting mean slopes, standard deviations and the ratio of mean slope and standard deviation are listed in Table S1 in the supplementary information Table2. For NH-exTR:
   ```

   ![Table 2](image)

   We updated the supplementary information accordingly:
3. **Line 246: ‘datasets were processed in three steps.’**

Done.

4. **Line 250: I don’t see this age correction formula in the Leedham Elvidge et al. paper. How was this derived?**

We took the correction function that is shown in Fig. 4 of the Leedham Elvidge et al. paper. There, linear fits for different subsets of their data are given in the legend. We took the top one, named “All (no tropical)”. We refer to this Fig. 4 in the revised version of our manuscript:

\[
\Gamma_{corr} = 0.85 \times \Gamma - 0.02 \text{ years}
\]

5. **Lines 313, 385, 390, 420: ‘extend’ should be ‘extent’.**

Done.
Reply to RC2

Point-by-point reply

6. **Minor Comment 1, Line 86:** It is not clear to me why $G(x,t')$ in equation (2) does not depend on the source region $x_i$. That is, $G$ should also be conditionally dependent on $x_i$, such that $G(x,t')$ should be rewritten as $G(x,t'|x_i)$. The authors here have assumed that the transport operators propagating tracer concentrations for all regions $i$ are the same, but I can envision several cases where this would not be true. For example, air propagating into the stratosphere at high latitudes will have no clear path into the stratosphere, as opposed to air straddling the midlatitude tropopause, where isentropic surfaces provide a clear pathway for stratosphere-troposphere exchange. The authors need to provide their rationale here.

Thank you for your constructive comment. In case of an ideal inert linear evolving tracer the differences across individual $G(x,t'|x_i)$ have no influence on calculating the mean age. In contrast, in the quadratic tracer case the mean age cannot be calculated without knowledge of $\Gamma(x|x_i)$. However, if the quadratic term of the tracer mixing ratio time series is sufficiently low, then the concept of $G(x,t'|x_i)$ can be neglected by using the Ansatz expressed in Eq. (2). We concluded that within the scope of this study, which focuses on relatively young mean ages derived from SF$_6$, we can neglect the influence of differences between different $G(x,t'|x_i)$.

We revised the Appendix A in the updated version of the manuscript to clarify our approach:

---

**Appendix A: Calculating mean age in the LMS considering multiple entry regions and an ideal tracer**

In case of an ideal inert linear evolving tracer, the tropical ground time series as a function of transit time $t'$ is given by

$$x(x_{\text{ground}}, t') = a - bt'.$$

(A1)

The negative sign points out, that looking at increasing transit times means looking backwards in time.

Assuming a constant time shift $t_{ei}$ for each entry region $i$, the tracer time series at $x_i$ is

$$x(x_i, t') = a - b \ast (t' - t_{ei}).$$

(A2)

Considering individual transit time distributions $G_i(x, t')$ for each origin fraction $f_i(x)$, the stratospheric mixing ratio $\chi(x)$ of a suitable age tracer at an arbitrary location $x$ in the stratosphere is

$$\chi(x) = \sum_{i=1}^{n} f_i(x) \ast \int_0^{\infty} G_i(x, t') dt'$$

(A3)

Hence, by inserting Eq. (A2) into Eq. (A3), the stratospheric mixing ratio can be expressed as

$$\begin{align*}
\chi(x) &= \sum_{i=1}^{n} f_i(x) \ast \int_0^{\infty} (a - bt' + bt_{ei}) + G_i(x, t') dt' \\
&= \sum_{i=1}^{n} f_i(x) \ast (a + bt_{ei}) - \int_0^{\infty} f_i(x) \ast b \ast \int_0^{\infty} t' + G_i(x, t') dt' \\
&= \int_0^{\infty} \sum_{i=1}^{n} \left[ f_i(x) \ast (a - b(t' - t_{ei})) \right] + G(x, t') dt'.
\end{align*}$$

(A4)

461
The mean age \( \Gamma \) is the first moment of the age spectrum, given by
\[
\Gamma(x) = \int_0^\infty t' \cdot G(x,t') dt'.
\] (A5)

In case of \( G(x,t') \), Eq. (A5) translates into the mean age of air originating from source region \( i \) \( \Gamma_i(x) \)
\[
\Gamma_i(x) = \int_0^\infty t' \cdot G_i(x,t') dt'.
\] (A6)

Inserting Eq. (A6) into Eq. (A4) yields:
\[
\chi(x) = \sum_{i=1}^{N} \left[ f_i(x) \left[ (a + \beta t_{air}) - \sum_{i=1}^{N} \left[ f_i(x) \cdot \beta \cdot \Gamma_i(x) \right] \right] \right].
\] (A7)

Since the sum of all origin fractions equals 1, Eq. (A7) can also be written as
\[
\chi(x) = a + \sum_{i=1}^{N} \left[ f_i(x) \cdot \beta \cdot t_{air} \right] - b \cdot \sum_{i=1}^{N} \left[ f_i(x) \cdot \beta \cdot \Gamma_i(x) \right].
\] (A8)

The mean age \( \Gamma(x) \) equals the sum of individual \( \Gamma_i(x) \), weighted by their respective origin fraction \( f_i(x) \);
\[
\Gamma(x) = \sum_{i=1}^{N} f_i(x) \cdot \Gamma_i(x).
\] (A9)

By inserting Eq. (A9) into Eq. (A8), we can thus reduce the number of unknown parameters:
\[
\chi(x) = a + \sum_{i=1}^{N} \left[ f_i(x) \cdot \beta \cdot t_{air} \right] - b \cdot \Gamma(x).
\] (A10)

\[
\chi(x) = \int_0^\infty \left[ a - \beta t' + b + \sum_{i=1}^{N} \left( f_i(x) \cdot t_{air} \right) \right] \cdot G(x,t') dt'.
\] (A4)

which is equivalent to
\[
\chi(x) = a + b + \sum_{i=1}^{N} \left( f_i(x) \cdot t_{air} \right) - b \cdot \int_0^\infty t' \cdot G(x,t') dt'.
\] (A5)

Then the mean age \( \Gamma \) is the first moment of the age spectrum, given by
\[
\Gamma(x) = \int_0^\infty t' \cdot G(x,t') dt'.
\] (A6)

Inserting Eq. (A6) into Eq. (A5) yields:
\[
\chi(x) = a + b + \sum_{i=1}^{N} \left( f_i(x) \cdot t_{air} \right) - b \cdot \Gamma(x).
\] (A7)

Equation (A10) can be solved for \( \Gamma \), which yields
\[
\Gamma(x) = \frac{\chi(x)}{b} + \frac{\sum_{i=1}^{N} \left( f_i(x) \cdot t_{air} \right)}{b^2}.
\] (A9)

7. **Minor Comment 2, Section 2.2.2**: I am curious about the calculation of \( t_{xi} \). The procedure outlined in steps (i)-(iii) essentially sounds like a description of how to calculate the SF6-age, which previous studies have used to calculate the tropospheric mean age (albeit using an SF6 surface boundary condition that only averages stations over northern midlatitudes). The details of the regions considered may be slightly different, but the procedure is basically the same. So why not reference this literature? In particular, the authors should review these studies:


- **Orbe, Clara, Darryn W. Waugh, Stephen Montzka, Edward J. Dlugokencky, Susan Strahan, Stephen D. Steenrod, Sarah Strode et al.** "Tropospheric Age of Air: Influence
Thank you for your constructive comment. We referenced the proposed literature in the updated version of the manuscript:

8. Technical Comments: Line 83: The concept of “origin fraction” referred to here certainly precedes the Hauck et al. (2020) study and the authors should properly reference the literature. For example, see these studies:


Thank you for pointing that out. We referenced the proposed studies in the updated version of our manuscript:

8. Technical Comments: Line 83: The concept of “origin fraction” referred to here certainly precedes the Hauck et al. (2020) study and the authors should properly reference the literature. For example, see these studies:


Thank you for pointing that out. We referenced the proposed studies in the updated version of our manuscript:

χ(x1, r') by calculating a weighted mixing ratio time series. The relative importance of individual source regions can be described by so-called origin fractions (e.g. Orbe et al., 2013, 2015). We use the origin fractions f',(x') as by Hauck et al. (2020) as weights for each χ(x1). f',(x') is the fraction of air at x', that entered the stratosphere through x1. By

Reply to RC3

Point-by-Point reply

1. Line 25. ... isentrope, and approximates

Done.

2. Line 39. ... made contact with

Done.
3. **Line 48. making fewer assumptions compared to deriving age spectra.**

Done.

4. **Line 51. ... measurements, an infinite lifetime is commonly assumed.**

Done.

5. **Line 308. Our findings indicate that... (no comma needed after ‘indicate’)**

Done.

6. **Lines 313, 385, 390, 420: ‘extend’ should be ‘extent’**.

Done.