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Interactive comment on "Delayed Recovery of mid-latitude lower stratospheric Halogen Loading" *by* Andreas Engel et al.

Anonymous Referee #2

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This paper describes a reformulation of the EESC metric that attempts to account for the difference in stratospheric mass transport through photochemical loss regions vs. transport outside of the loss regions. The result is a relatively older mean age used to calculate EESC and thus a delay in future mid-latitude lower stratospheric EESC values to 1980 levels of roughly one decade.

Unfortunately, the paper has a number of fundamental flaws that make it unsuitable for publication. The major issues include (1) the absence of path height dependence in the fractional release and modified age distributions, (2) the assumption of constant stratospheric dynamics and photochemistry over nearly a century for the results to be valid, (3) the relatively minor role of EESC in future mid-latitude ozone depletion compared to N2O and (4) the absence of many relevant references and discussion of

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previous work.

Main comments:

1. The authors mention in Section 2 that chemical loss is not uniform throughout the stratosphere and argue that on average the longer a fluid element remains in the stratosphere the larger the integrated chemical loss will be. This is not the case. The highly nonlinear loss dependence on altitude and latitude make the path an air parcel has taken much more important than the time an air parcel has resided in the stratosphere. Hall (2000) described the concept of maximum path height and the relationship between the path height and age distribution. Hall showed quite clearly that the mass fraction of an air parcel that has passed above some height, such as the height above which photochemical loss is rapid, is determined by the transport due to mass continuity and not the circulation, including mixing, that determines age distributions. Thus, the age distribution is only weakly linked to stratospheric photochemical destruction of any trace gas. This means that it is the circulation due to mass continuity that is most relevant in the estimation of EESC.

The circulation due to mass continuity is essentially the residual circulation and it has been shown, such as by Birner and Bonisch (2011) that the transit time due to the residual circulation is at most 3.5 years in the polar regions where the air parcels reached a minimum pressure of less than 0.1 hPa, well into the mesosphere, before descent into the polar vortices. This also implies that transit times throughout the mesosphere are actually less than 3.5 years. Mixing of air horizontally acts to increase the age of the stratosphere nearly everywhere (e.g. Garny et al., 2014) but not necessarily the maximum path height of a parcel and thus it's photochemical loss. The mixing is what drives the old tail in the age distribution and this mixing is not directly correlated with changes in path height.

The more appropriate time scale for photochemical loss is the mean arrival time at the location(s) where each trace gas is rapidly destroyed. Once an air parcel passes through a region of rapid photochemical loss for a particular tracer the first time then all of that tracer is destroyed (converted into chlorine and bromine in this case) and it doesn't matter what happens to the air parcel from then on as far as the fractional release. Subsequent aging has no further effect on the release of chlorine or bromine. The mean arrival times at the region of rapid photochemical destruction for each trace gas will be dependent on the stratospheric transport each year and will be variable.

2. The assumption of constant stratospheric dynamics and photochemistry from the late 20th century to the late 21st century is certainly not a good one. What is the sensitivity of the results to the predicted changes in the stratospheric circulation?

3. N2O is only mentioned briefly in the conclusions but mid-latitude ozone depletion in the late 21st century will be due primarily to N2O concentrations (Ravishankara et al., 2009, Portmann et al., 2012, Butler et al., 2016). The variability and uncertainty in the N2O concentrations will be much more of a factor in the return of mid-latitude ozone to 1980 levels than the small variability in the decline of EESC.

4. All of the above references are relevant to this study and none of them were included. The study of Waugh et al. (2007) is also highly relevant since they explore and discuss the age vs. path sensitivity of inorganic chlorine in the stratosphere.

A further point, what is special about recovery to 1980 levels? As was discussed in Newman et al. (2007) the year chosen to be the initial year causes large variability in the recovery time due to the steep slope of EESC around 1980 and the gradual slope in the late 21st century.

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