Author reply to Anonymous Referee #1

Thank you for reading and considering my revised manuscript carefully. I can see that my interpretation of the analyzed trends in HALOE methane from my Figure 6 and their correspondence with changes in AoA were faulty in several instances, as you pointed out in paragraphs 3 and 4 of your comment. According, I have read (or re-read) and am now making reference to most of the citations that you provided in your comment to me. Based on your suggestion, I rely now on the findings of Ploeger et al. (2015a) instead of Stiller et al. (2012) because of its recent improvements for the analysis of the trends in SF_6 from MIPAS.

Two recent papers have also been helpful to me (i.e., Konopka et al., Hemispheric asymmetries and seasonality of mean age of air in the lower stratosphere: Deep versus shallow branch of the Brewer-Dobson circulation, accepted for publication in JGR, February 2015, 10.1002/2014JD022429; and also Ploeger et al., Quantifying the effects of mixing and residual circulation on trends on stratospheric mean age of air, accepted for publication in GRL, February, 2015, doi:10.1002/2014GL062927). The first paper provides a clear description in its Section 4.2 about the effects of residual circulation versus eddy mixing on the mean AoA, and I have tried to follow their findings when interpreting the trends in HALOE methane in the last three paragraphs of Section 5 of my revised manuscript (I have also attached those three paragraphs to the end of this reply). Furthermore, I now refer to the recent GRL manuscript of Ploeger et al. (2015b) in this revision because they are pertinent to my findings about the HALOE methane trends in the middle stratosphere of the northern hemisphere. I now think that there must have been a change in the AoA characteristics of that region from the decade of the HALOE measurements (1992 to early 2000s) versus the decade of the MIPAS measurements (2002-2012) because their respective trends do not agree. More specifically, the AoA trends in Fig. 2a of Ploeger et al. (GRL, 2015,) for 1990-2013 disagree in the middle stratosphere of the northern hemisphere with the findings in their Fig. 3a for the MIPAS period, 2002-2012. Therefore, I tentatively conclude that if Ploeger et al. had also constructed separate AoA trends for the HALOE period (1992-2005), it would become apparent that there has been a decadal change in AoA since about 1990 for that region of the northern hemisphere.

Attachment (last three paragraphs from Section 5 of revised manuscript);

To put the analyzed trends from CH_4 into context for 1992-2005, they are interpreted as follows. First, for the tropics the small positive trends in Figs. 8 and 9 for the lower stratosphere (50 and 30 hPa) are equivalent to the average trend of 3.0 %/decade for tropospheric methane; no trend in the BDC is indicated in that region. Note, however, that a correction for the estimated trend in the long-term performance of the HALOE CH_4 gas cell would add about 1.9%/decade to the MLR diagnosed trends herein, or somewhat larger than the average tropospheric trend. A positive trend for CH_4 in this region implies a decreasing (or younger) AoA, which is generally consistent with the AoA estimates of Diallo et al. (2012, Fig. 13) and Monge-Sanz et al. (2012, Fig. 3) from their analyzed winds and heating rates for the period of about 1990-2010. Trends in the tropical HALOE CH_4 mixing ratio are increasing from 30 to 5 hPa and imply that AoA is decreasing in that region, too. In other words, the region where the analyzed CH_4 trends are greater than about 4.9 %/decade corresponds to where AoA estimates ought to be decreasing. This finding differs from the AoA trends of Diallo et al. and Monge-Sanz et al., although it is in reasonable agreement with the findings of Ploeger et al. (2015b, Fig. 2) based on their analyses of AoA trends for 1990-2013. An increase in the CH_4 of the mid to upper tropical stratosphere may have occurred in 1992 due to the effects of the Pinatubo aerosols (Considine et al., 2001; Al-Saadi et al., 2001). That initial acceleration of the BDC was likely followed by an extended period of negative CH_4 trends, as reported by Rosenlof (2002) and Nedoluha et al. (1998). Randel et al. (1999) also reported on a rather episodic rebound for the CH_4 of the lower mesosphere in 1997-1998. However, Fig. 10 indicates that the upward extension of CH_4 at the 2-hPa level at that time may have been merely due to interactions with the QBO.

For the middle latitudes the results in Figure 6 indicate likely contributions from the effects of both horizontal transport and mixing. The trends agree broadly with the early findings of Rosenlof (2002) that were based on HALOE CH_4 from just 1992-2001. Positive CH_4 trends in the middle stratosphere may imply a weakening of the subtropical barriers to transport out of the tropics and toward middle latitudes. This assumption agrees with the decreasing AoA reported by Ploeger et al. (2015b, Fig. 2) for the southern hemisphere. However, it is at odds with their findings for the northern hemisphere, where they found a significant increase in AoA for the period 2002-2012. It is tentatively concluded that there was a decadal change in the CH_4 and the AoA trends and in the BDC for the northern middle latitudes for 1992-2005 versus 2002-2012, related to changes for both the mean meridional circulation and the mixing.

For the high latitudes Fig. 6 shows negative CH_4 trends at the northern latitudes near 10 hPa that extend equatorward to 50°N, indicating an exchange of vortex air to lower latitudes. No equivalent net equatorward transport is apparent at 10 hPa in the southern hemisphere. Finally, there are hemispheric differences in the CH_4 trends of Fig. 6 for the lower stratosphere, too. In particular, the positive trends at middle latitudes of the northern hemisphere indicate a net poleward transport of younger, tropical air that is consistent with a decrease in the transit time for the shallow branch of the BDC (Bönisch et al., 2011). At southern high latitudes the polar vortex seems to have remained largely intact at higher altitudes. An accelerated descent of the air poleward of 65˚S may have extended to below the 20-hPa level, bringing older air to the lower stratosphere where it was mixed efficiently with the air at middle latitudes. Thus, the results in Fig. 6 point to distinct differences in the forcing mechanisms and for the shallow versus the deep branches of the BDC within the two hemispheres.

Author response to Anonymous Referee #2

Thank you very much for reviewing my revised manuscript. My replies to your specific comments follow below.

p. 2, lines 3/4: Your recommended change was made.

p. 4, lines 10/11: On p. 4, line 14, I now refer to Section 5 for more details.

p. 5, lines 1 to 8: I agree with your cautionary comments and have adopted the points that you made (see revised p. 5, lines 4-17).

p. 5, line 12: The correct font is used now.

p. 9, line 14: I have added your clarifying sentence on revised p. 9, lines 25/26.

p. 9, line 25: This sentence was modified as shown on revised p. 10, lines 4/7.

Additional paragraphs: Some rather extensive changes were made for the revised manuscript. Three paragraphs were added to the revised manuscript, and they begin at bottom of p. 18 and carry on through the end of Section 5 on p. 20. My reply to the concerns of Referee #1 about my original paragraphs contains more detail about how I arrived at this updated interpretation of findings about my analyzed trends from the HALOE methane. I also attached those three paragraphs at the end of my reply to Referee #1, if you wish to look at them.