Anonymous Referee #1

We would like to thank the reviewer for the time and the useful comments that helped to clarify important aspects of the model results.

General Comment: This paper examines the Antarctic ozone depletion between 1960 and 1980 in both observations and 17 Chemistry Climate Models (CCMs) based on the REF-B1 scenario from CCMVal2. These models derive an anthropogenic depletion from 1960-1989 between 26.4% and 49.8% of the total period (1960-2000). Observations over the same period suggest a higher depletion of 56%. The paper is clearly written, concise, and adds to the scientific understanding of what the return date choice for "full recovery" implies. I recommend this paper be published after minor revisions (see below).

Specific comments.

Page 3 lines 3-4 All the models certainly do show a 1960-1980 depletion (26.4-49.8%), with approximately six model showing values less than 35%. For these 17 models there was large effort to understand how well these models represented transport, dynamics, and chemistry (i.e., the SPARC Report on the Evaluation of Chemistry-Climate Models, 2010). That is, the range in models is not just due to different dynamical variability. It would be interesting to highlight the models that did better in these process oriented diagnostics in Table 2. This was the approach used in Chapter 2 of the 2010 WMO assessment.

The Discussion and Conclusion section now includes a detailed discussion of the results obtained with respect to the outcome of the SPARC CCMVal evaluation of their photochemistry, transport and UTLS characteristics and the discussion in Chapter 2 of WMO (2010). It turned out that two of the three highest ranked CCMs in SPARC CCMVal (CMAM and WACCM) indeed reproduce the observed total decline between 1960 and 2000 and the relative decline between 1960 and 1980 very well. This has now been highlighted in the text. We included the following paragraph:

"The observed decrease in total column ozone between 1960 and 2000 was reproduced - within its uncertainty range - by 7 models (CMAM, LMDZrepro, UMSLIMCAT, UMUKCA-METO, UMUKCA-UCAM, WACCM and ULAQ). Two of these CCMs (CMAM, WACCM) obtained the highest ranking in an evaluation of their photochemistry and transport characteristics performed within the SPARC CCMVal activity [SPARC CCMVal, 2010] and discussed in Chapter 2 of the 2010 WMO ozone assessment [WMO, 2011], providing confidence in the robustness of their results. 4 CCMs (AMTRAC3, CNRM-ACM, GEOSCCM, MRI) simulated a stronger ozone decline, and 6 CCMs (CAM3.5, CCSRNIES, EMAC, EMAC-FUB, NIWA-SOCOL, SOCOL) underestimated the observed ozone decline. This divergent model behaviour may be due to the representation of polar ozone chemistry in the models, their dynamical and transport characteristics, or to a combination of both. Based on the detailed evaluation performed as part of the SPARC CCMVal activity [SPARC CCMVal, 2010], we found in our study that the CCMs that represent the observations well, generally (with one exception) show a good potential for chlorine activation and (all) a good representation of chemical ozone depletion in Antarctic spring. CCMs with a stronger ozone loss than observed (cf. Table 2) partly tend to a slight overestimation of chemical ozone depletion (AMTRAC3, GEOSCCM). For some CCMs with weaker ozone decline between 1960 and 2000 a consistent underestimation of chemical ozone depletion was found (CCSRNIES, EMAC, CAM3.5). Thus, the deviations of some CCMs from the observed ozone decline can partly be explained by deficiencies in their polar ozone chemistry. However, in addition, models that underestimate the observed ozone decline were found to suffer from either a too fast transport of air into the Antarctic polar vortex (SOCOL, NIWA-SOCOL) or a too weak insolation of the polar vortex from mid-latitudes in the lower stratosphere (CAM3.5, CCSRNIES, EMAC, SOCOL, NIWA-SOCOL). Both

effects lead to lower ESC concentrations by the end of the 20th century in these models (cf. Fig. 1), and as a result an underestimation of the observed polar ozone decline due to ESC. Consistent negative Antarctic ozone changes were diagnosed in the CCMs prior to 1980 as a result of chemical depletion by ESC. This pre-1980 halogen-induced Antarctic ozone depletion amounts to values between 26.4 ± 3.4 and 49.8 ± 6.2 % of the simulated ozone depletion between 1960 and 2000. Hence the CCM simulations are consistent with the observational estimate of a significant EESC induced ozone decline in 1960-1980, albeit nearly all CCMs underestimate the observed decline of 56.4 ± 6.8 %, derived from the NIWA combined total column ozone data base. However, note that the two CCMs, ranked highest in the SPARC CCMVal evaluation of their photochemistry and transport characteristics, CMAM and WACCM, [SPARCCCMVal, 2010] nearly agree with the observed decline between 1960 and 1980 within its uncertainty range."

You suggest the the temperature trend in the 1960-1980 period was different in observations relative to most models (Figure 5). Are there any other issues with the models that could explain the lower depletion in this period? E.g., the CCMs used in this study also did not include additional very-short lived bromine (VSL) species. This addition 5-7 pptv of inorganic bromine should contribute to the underestimate the total loss in the 1960-1980 period. It will be interesting if you (not for this paper) redo this analysis for the CCMI models that include this additional VSL bromine source.

Thank you for pointing at this issue. We have added a discussion on the potential effects of VSLS in the Discussion and Conclusion section. The following text was included:

"Another potential reason for the underestimation of the Antarctic ozone decline before 1980 in most CCMs might be the effect on chemical ozone depletion by short-lived bromine compounds of natural biogenic origin, so-called very short lived substances (VSLS). The effects of VSLS which contribute 20-30 % to the present-day stratospheric bromine content [WMO, 2011] on Antarctic stratospheric ozone were not included in the CCMVal-2 simulations. Braesicke et al. [2013] and Sinnhuber and Meul [2014] showed that taking brominated VSLS in their CCMs into account leads to a significant reduction of Antarctic polar ozone. In a transient REF-B1 simulation using the same FUB-EMAC CCM as included in this study but with prescribed VSLS sources, Sinnhuber and Meul [2014] found a reduction of October mean ozone in the lower Antarctic stratosphere of more than 20 %. However, although constant VSLS emissions were prescribed over the whole simulation period of 1960-2005, the impact of VSLS was stronger in the most recent period after 1980 with enhanced chlorine due to combined bromine-chlorine catalytic ozone loss cycles. Hence, including the VSLS effect leads to an enhancement of the 1960-2000 Antarctic ozone depletion, but reduces the relative change in 1960-1980 compared to the full period. Further insight is expected from the analysis of the new CCMI- simulations that will include the effects of VSLS."

Page 3, equation 1. The authors did a very nice job of explaining the approach of determining the degree of halogen-induced ozone for the 1960-1980 period. Question: the temperature anomaly at 100hPa is used in the regression fit to address dynamical variability. What equation (1) does not address is the sensitivity of the ozone chemistry in the model to absolute biases in temperature. It therefore would be very informative to show the lower polar stratosphere absolution temperature evolution similar to Figure 4. E.g., if two models both show a similar representation of ESC (i.e., consistent transport/dynamics) and a similar absolute temperature trend (new figure), and would happen to have a different temperature trend vs ozone trend sensitivity (Figure 5) – I believe this would highlight issues in the chemistry representation between the two models. Generally, it would be nice to comment on how this technique could be used to evaluate model components.

A new Figure 6 has been added showing the evolution of absolute temperature at 100 hPa where chemical ozone depletion is strongest. The individual CCM temperature curves have not been adjusted to a common basis in 1960, revealing the large spread in absolute temperature between the models. In the Discussion and Conclusion section an additional paragraph discussing the role of temperature for ozone transport and chemistry has been added on P6, L29::

"*Figure 5 shows the evolution of the polar cap mean SON mean temperature at 100 hPa between 1960 and 2000, fitted with piecewise linear trends from 1960 to 1980 and from 1980 to 2000. While the Antarctic lower stratosphere temperature observations showed warming in SON from 1960 to 1980, the CCMs span a wide range of trends, indicating different temperature trend regimes resulting from model dynamical variability differing from what happened in reality. In addition, the absolute temperature values differ between the CCMs by more than 10 K, which directly affects the potential for chemical ozone loss in the models*."

Page 4. The discussion of how the observations are combined are in reasonably detailed. Based on this discussion and use of equation 1 (and 2) this work suggests a decline of 56.4 +-6.8%. Maybe I missed it, but how did you come up with an uncertainty value for this decline (i.e., +-6.8%)?

For both the model data and the observations, the uncertainty values for the regression model fit coefficient were calculated using standard error propagation. The following sentence has been added to the text at the end of Section 2:

"*Uncertainty values of the total column ozone and further derived quantities have been calculated by applying the standard formulae for error propagation to determine the uncertainties on the regression model fit coefficients*."

Also, since the results are for SON mean total ozone polar cap average (e.g., Figure 2) – are you masking the model results for periods that are in the dark with little ozone depletion (e.g., high latitudes in September)? That is, are you treating the model and observations derivation of the 1960-1980 decline in a consistent manner?

We agree that the underestimation of the ozone loss in the models might be related to a sampling bias of the CCMs that include high latitudes with little ozone depletion in their polar cap mean, while the observations are made in sunlight. However, this is only an issue in September. Moreover, the region of the polar cap that is in perpetual darkness is very small (as a fraction of the whole area poleward of 60°S) and shrinks to zero by the end of September. So, this effect should be of the order of a few percent. We included the following sentence in the article:

"*Apart from the chemical and dynamical performance of the models, their underestimation of the ozone loss might be related to a sampling bias of the CCMs that include high latitudes with little ozone depletion in their polar cap mean, while the observations are made in sunlight. However, this bias exists in September only. Moreover, the region of the polar cap that is in perpetual darkness is very small (as a fraction of the whole area poleward of 60°S) and shrinks to zero by the end of September. So, this effect should be of the order of a few percent*."

Figure 2 caption is missing the prime symbol in "c T".

The prime has been added in Figs 2 and 3.