Response to Reviewer 1

Reviewer comments are shown in black, author responses in red, and changes to the text are in blue.

1) There is occasional confusion (e.g. line 8 of the abstract) about the role of the changing BDC in this paper. Increasing BDC will of course create more methane flux into the stratosphere but it will not necessarily cause an increase in SWV directly through increased advection because it cools the tropopause cold point. Please make this clear.

We have clarified this throughout the paper. For example:

- Climate models project that increasing surface temperatures will increase the rate of tropical upwelling (Butchart and Scaife, 2001; Butchart et al., 2010). This means that more methane enters the stratosphere, which will further affect SWV (Austin et al., 2007). However, enhanced tropical upwelling will not necessarily lead to increases in SWV as adiabatic expansion of the tropical tropopause layer cools the CPT (Randel et al., 2006; Dhomse et al., 2008).
- Figure 4b shows that the rate of tropical upwelling is projected to increase through the 21st century, as simulated by other CCMs (Butchart et al., 2010; SPARC CCMVal-2, 2010). Stronger tropical upwelling transports more methane from the troposphere into the stratosphere where it undergoes subsequent oxidation to water vapour via Reaction R1 (Austin et al., 2007). Stronger tropical upwelling has also been shown to lead to reduced ozone concentrations in the tropical lower stratosphere (Bekki et al., 2013), resulting in cooling of the CPT and subsequent decreases in SWV (Randel et al., 2006; Dhomse et al., 2008).

2) p2 Line 29 is also unclear about the role of the BDC increase. Is this not simply an increase in methane flux entering the stratosphere. Please reword this sentence for clarity.

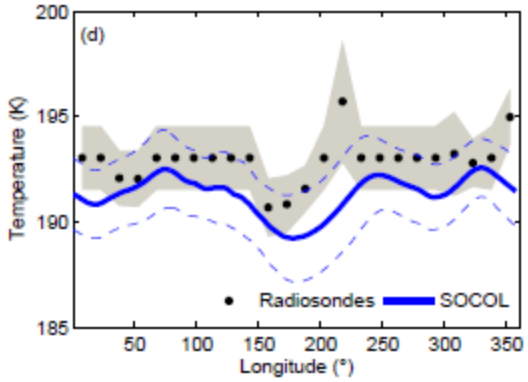
We have done so, as detailed in the first bullet point above.

3) There is a problem with the uncertainty envelopes in Figure 1. The authors show the interannual standard deviations if I understand correctly. However, this is not the uncertainty on the multiannual means plotted in the solid lines. The envelopes should be narrowed by a factor equal to the square root of the number of years included to give the uncertainty in the means.

As noted in the caption of Figure 1, we show the standard deviations rather than the standard error (standard deviation divided by the square root of the number of years). Since we want to show the range of potential uncertainties (as indicated by the standard deviations), we decided to keep the uncertainty envelopes as they are.

4) Line 26 argues that the too moist stratosphere can not be due to the tropopause cold point temperature bias as this is too cold in the model. However, as the authors state elsewhere, the SWV is dependent on the minimum temperature that air parcels experience on their transit - this is more related to the coldest regional temperatures at the tropopause, e.g. in the west pacific. So is the model cold bias everywhere? We need more than the zonal mean here.

We have added a panel to Figure 1 comparing modelled equatorial temperatures with radiosonde measurements (the same dataset that was used in Figure 1a) as a function of longitude. This new plot (below) shows that, although SOCOL agrees with measurements within one standard deviation, mean modelled temperatures are colder than observations and there is no warm bias in the model at the coldest point.



(d) Annual-mean modelled equatorial CPT temperature (90 hPa) compared with radiosonde measurements of the CPT as a function of longitude. The grey shaded areas represent one standard deviation either side of the observations and the dashed blue lines indicate one standard deviation either side of model data.

5) p4 Line 33 argues that the results will not be biased by the incorrect seasonal phasing of water vapour entry into the stratosphere. This may not be quite right as the BDC increases most in winter under climate change. The authors should at least acknowledge this.
We removed this sentence, but did also add that the BDC is strongest in winter in our discussion of Figure 1a:
Modelled temperatures in the tropical lower stratosphere reflect the behaviour of the Brewer-Dobson circulation well; a colder environment is simulated during the boreal cold period when the Brewer-Dobson circulation is stronger.

6) p5 line 15: most or all CC models?
All – we have changed this:
Figure 4b shows that the rate of tropical upwelling is projected to increase through the 21st century, as simulated by other CCMs (Butchart et al., 2010; SPARC CCMVal-2, 2010).

7) p8 Line 22: Joshi et al, GRL, 2006 were the first to point out circulation changes due to stratospheric water vapor.
Thank you – we have included this reference:
Such cooling through the 21st century is also expected to affect circulation patterns in the lower stratosphere and troposphere (Joshi et al., 2006; Maycock et al., 2013).

8) p9 line 3: can the authors give any estimate of the relative size of surface climate warming due to stratospheric water vapor compared to say greenhouse gases?
As we do not have a simulation with only stratospheric water vapour changing, we cannot say anything about the relative influence on surface climate.

9) Figure 4 panel c shows an apparently decreasing trend in cold point temperature variance. This could be important given the non-linearity of saturated water vapor pressure with temperature. Is it due to changing tropospheric variability in ENSO for example? Scaife et al 2003 and Garfinkel et al 2013 discuss the effects of tropospheric variability on SWV which ought to be considered here.

While we are interested in long-term trends in SWV rather than variability, we do know that there is an increased tendency towards ENSO conditions in the RCP 6.0 SSTs we prescribed for our simulations, so this may contribute to the upward trend in SWV. We have noted this:

Increases in the amount of water vapour entering the stratosphere are also linked with El Nino/Southern Oscillation conditions (Scaife et al., 2003), which occur more frequently throughout the 21st century under RCP 6.0.