Reply to RC2

We thank the reviewer for his/her thoughtful and constructive comments that help improve the quality of our manuscript. We have incorporated the reviewer's suggestions in the revised manuscript. Our point-to-point response to the reviewer's comments are shown below.

Anonymous Referee #2:

Major Comments:

1. To examine the effect of sea-ice and clouds on the model response to stratospheric ozone recovery two simulations are performed, the control and one with no sea-ice and clouds that are invisible to radiation (NCNSI). While it may not substantially change the results of the analysis it seems that one would like to make incremental changes to isolate the effects of clouds and of sea-ice. For example, a set of with invisible clouds and a set with no sea-ice or perhaps with sea-ice invisible to radiation.

Response: We thank the reviewer for this good suggestion.

Following the reviewer's suggestion, to isolate the effects of clouds and of sea-ice, two sets of experiments are conducted. In the first set, we set all the cloud fractions to zero in radiative heating rate and flux calculations and thus suppress the radiative effects of clouds. In the other set of integrations, we set the freezing temperature to -180 degree centigrade so that there is effectively no sea ice in the simulation. These two sets of experiments are denoted as "No Cloud (NC)" and "No Sea-Ice (NSI)" respectively in the following.

As in the other experiments documented in the paper, in order to examine the impact of SOR on surface temperature, two 100-year integrations, prescribed with identical concentrations of well-mixed greenhouse gases (CO2, CH4, N2O, etc.) but different stratospheric ozone concentrations, are conducted in both the NC and the NSI experiments. We assess the SOR impacts by contrasting the means of appropriate variables in the last 85 years of two 100-year simulations (the difference between two equilibrium states).

As shown by Figure R1, the surface temperature response to SOR is 0.18 K in the NC experiment (Figure R1 a), which is similar to that in the NCNSI experiment. The SOR warms not only the stratosphere but also the troposphere (Figure R1 b). We also find non-significant sea ice depletion in both hemispheres, which is opposite to that in the Standard experiment (Figure R1 c). So if there were no clouds, the sea ice only makes a small effect on the stratospheric ozone forcing.

The NSI experiment confirmed the above finding. If there were no sea ice but still clouds, a near-zero global surface warming (about 0.03 K) is resulted (Figure R2 a). The warming in the troposphere in the NSI experiment is also reduced compared to the NC and NCNSI experiments (Figure R2 b). We can also see the reduction of high clouds in the UTLS, which is consistent with that in the Standard experiment (Figure R2 c).

Hence, in summary, as we have concluded, the clouds have more important impacts on the modification of stratospheric ozone forcing than the sea ice. We have added the new experiment results in the relevant texts (lines 10-14 in page 9).

2. As noted in the Introduction work by McLandress et al, 2012 suggests that stratospheric ozone recovery my lead to surface cooling. Would it be possible to generalize and support the results found with CAM3 and comments made in the text by analyzing historical CMIP5 simulations that only vary ozone? For example, the list of models in Table 2 of Sigmond and Fyfe, 2013.

Response: We thank the reviewer for this suggestion. Following the suggestion, we have analyzed the CMIP5 experiments. Five CMIP5 models, CCSM4, CESM1-CAM5, FGOALS-g2, GISS-E2-H, and GISS-E2-R, have ozone-only historical experiments, which, however, does not isolate the effects of stratospheric ozone depletion (http://cmip-pcmdi.llnl.gov/cmip5/docs/historical_Misc_forcing.pdf). We calculated, using RRTMG, the instantaneous forcing of ozone change from 1960 to 2000 to be negative: -0.20 W m^{-2}, although most models (except GISS-E2-R) show weak global warming (Figure R3). The global- and annual-mean sea ice and cloud changes are shown in Figures R4 and R5 respectively, both of which show statistically significant (stippled) responses, such as high level cloud increase and Antarctic sea ice reduction, to ozone forcing, although the pattern, magnitude and even sign of the changes are of noticeable inter-model differeces. Given that the forcing presccribed in the experiment is not exclusively stratospheric ozone change, these results do not lead to conclusive assessment. We have acknowledged in the revised manuscript that it takes further research to elucidate whether and how SOR leads to global warming or cooling in reality.

Figures:

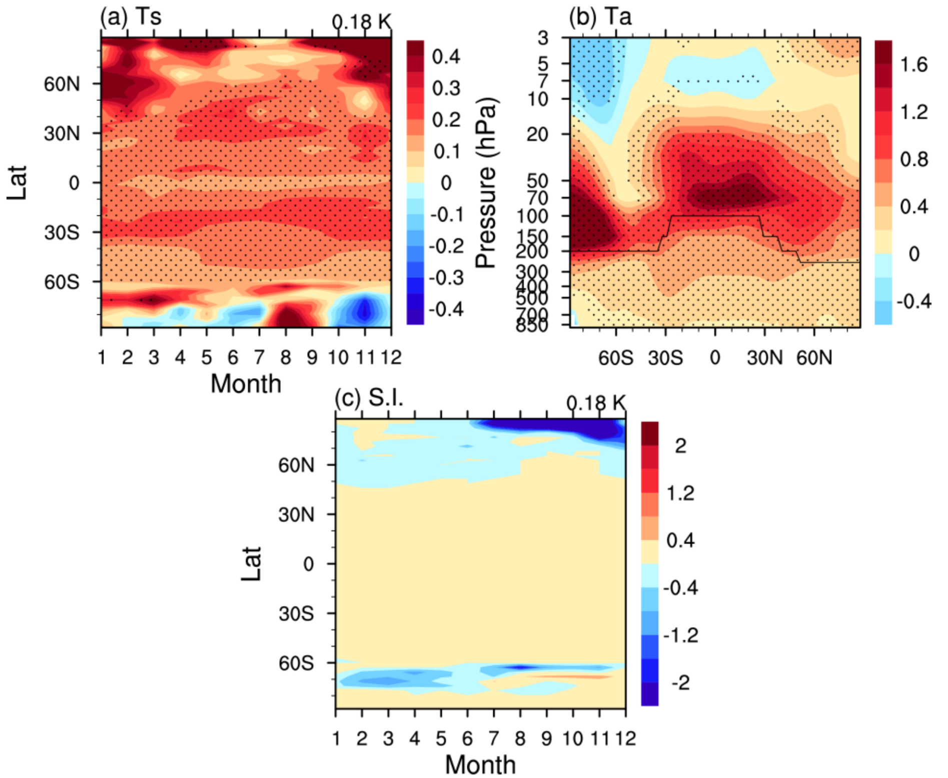

Figure R1. Responses to SOR of (a) zonal mean surface temperature, (b) annual- and zonal-mean air temperature, (c) zonal mean sea-ice fraction in the NC experiment.

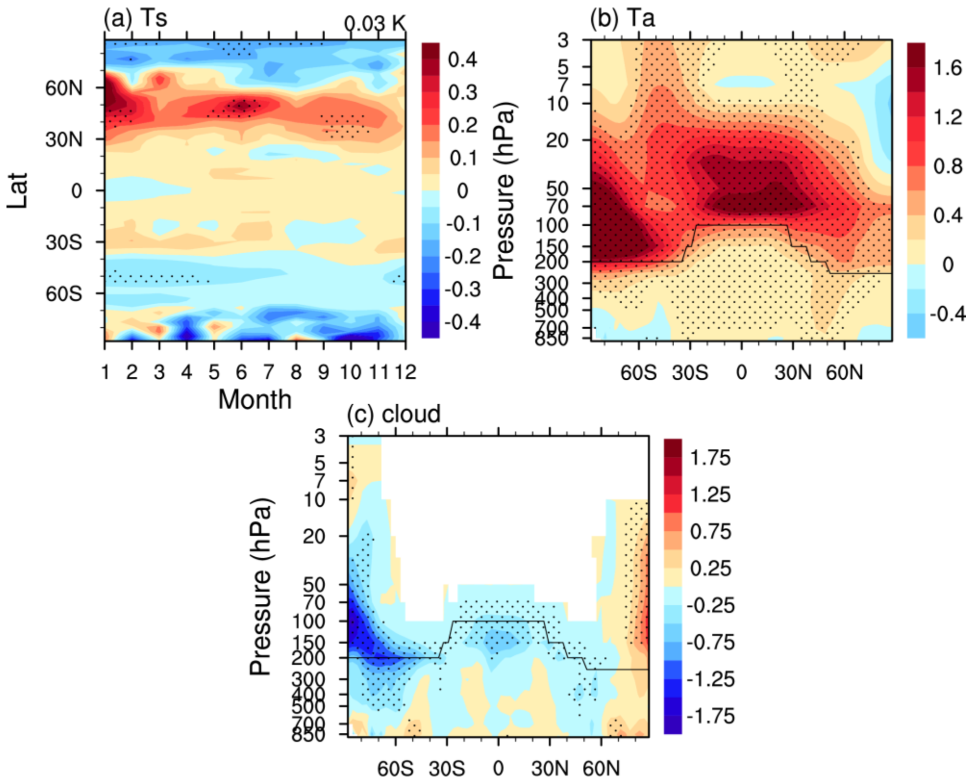

Figure R2. Responses to SOR of (a) zonal mean surface temperature, (b) annual- and zonal-mean air temperature, (c) annual- and zonal-mean cloud fraction in the NSI experiment.

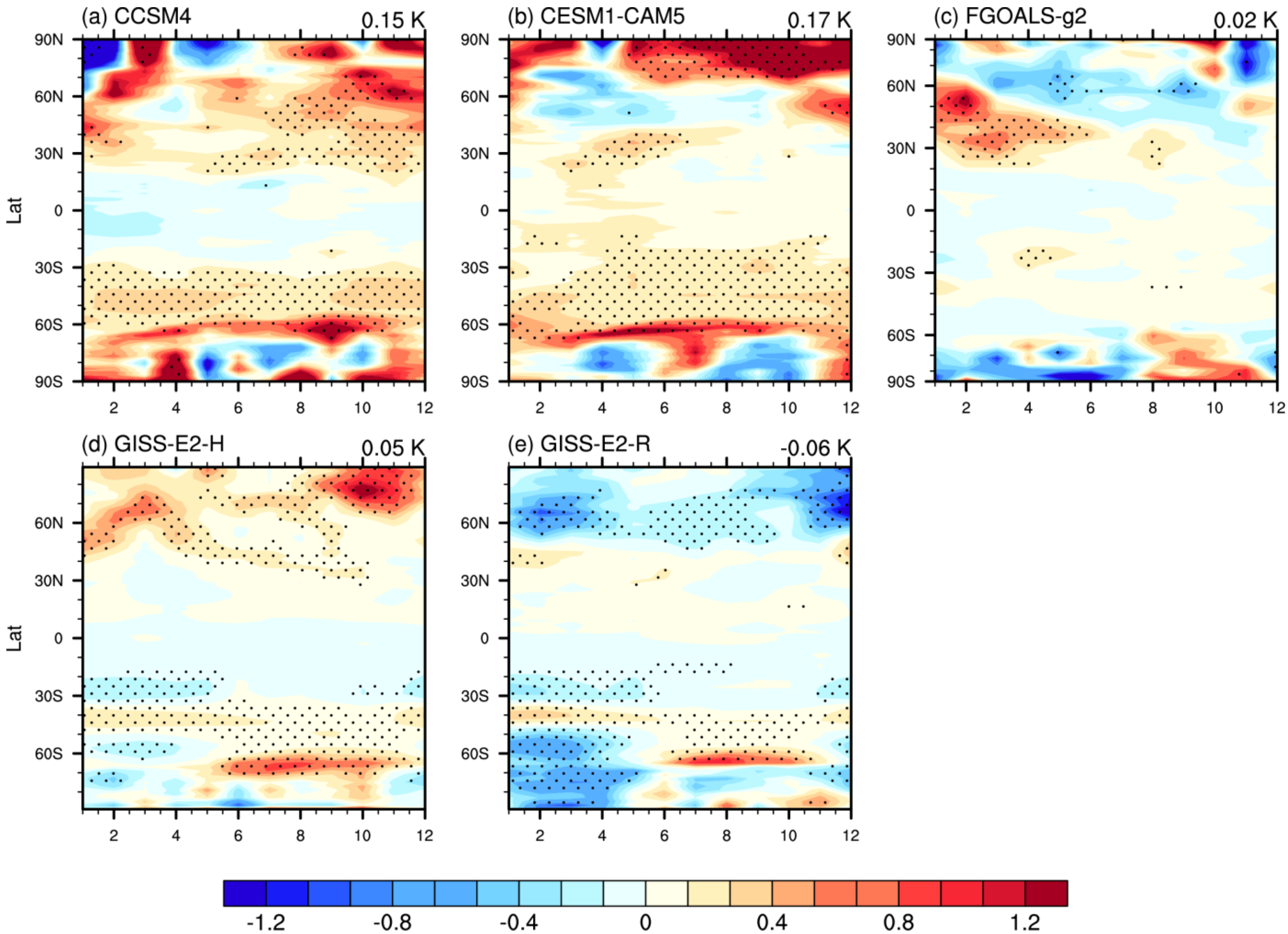

Figure R3. Zonal-mean surface temperature trends from 1960 to 2000 for historicMisc ozone only runs from (a) CCSM4, (b) CESM1-CAM5, (c) FGOALS-g2, (d) GISS-E2-H, and (e) GISS-E2-R, unit: K/40 yrs.

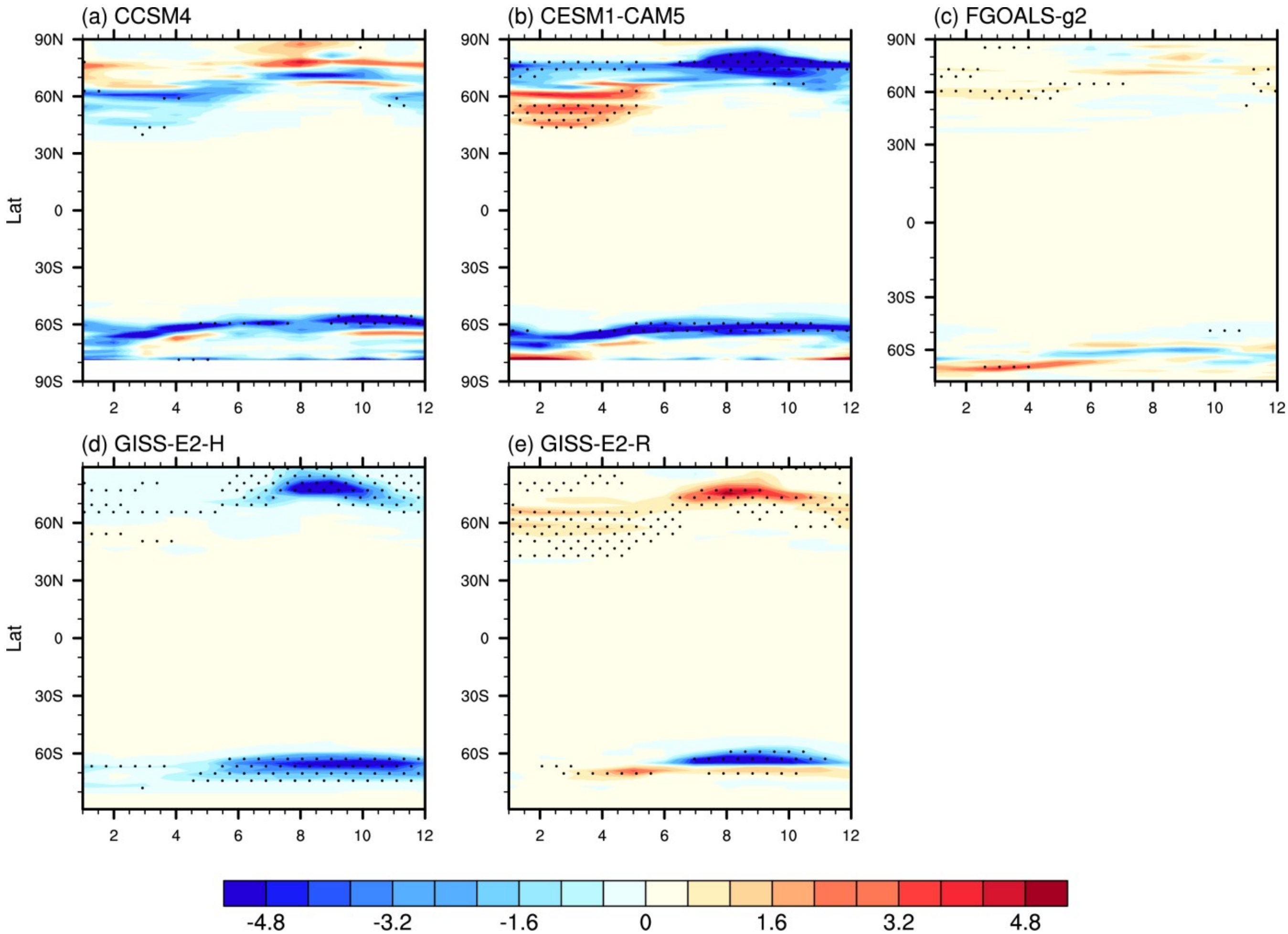

Figure R4. Zonal-mean trends of sea ice fraction from 1960 to 2000 for historicMisc ozone only runs from (a) CCSM4, (b) CESM1-CAM5, (c) FGOALS-g2, (d) GISS-E2-H, and (e) GISS-E2-R, unit: %.

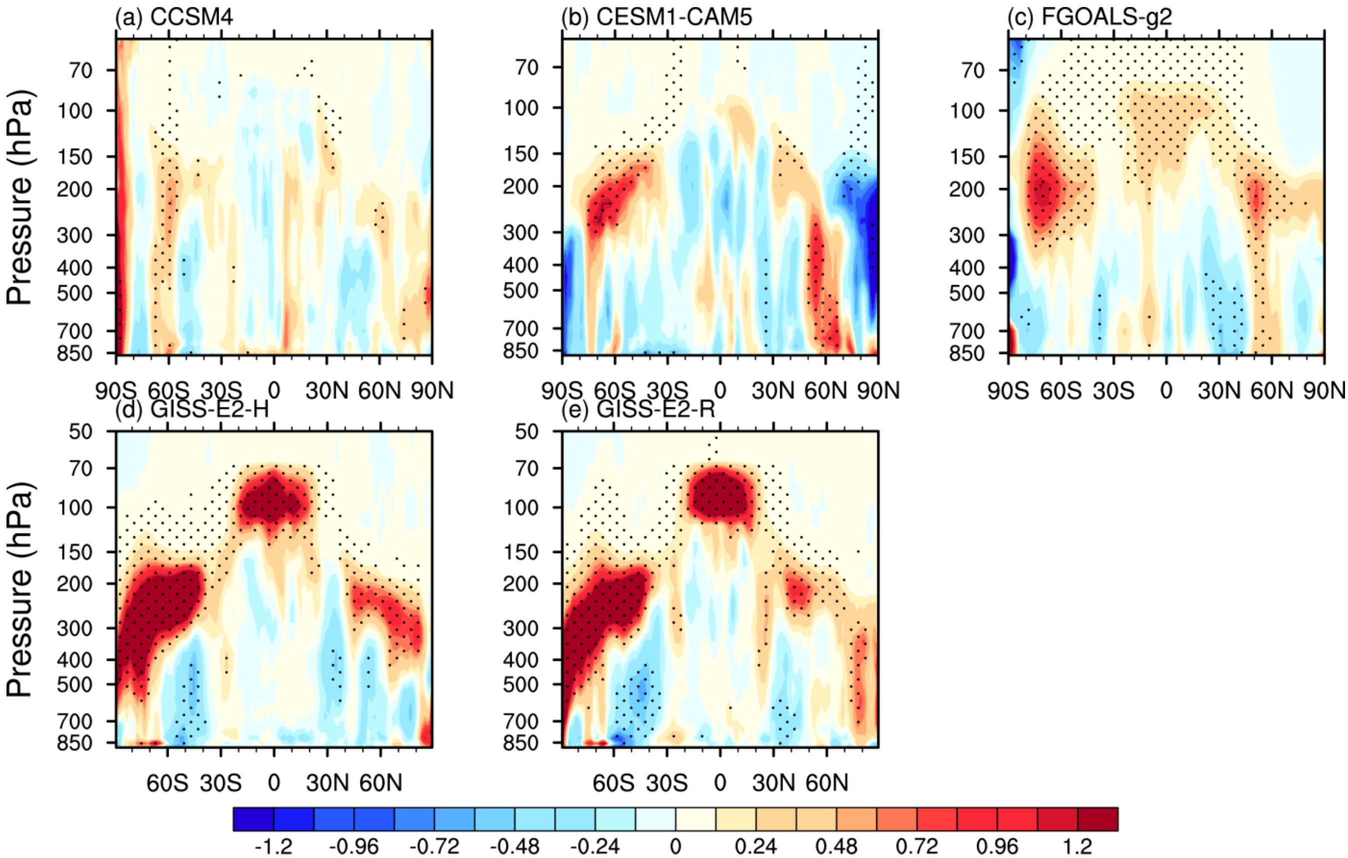

Figure R5. Zonal- and annual-mean cloud fraction trends from 1960 to 2000 for historicMisc ozone only runs from (a) CCSM4, (b) CESM1-CAM5, (c) FGOALS-g2, (d) GISS-E2-H, and (e) GISS-E2-R, unit: %.