Response to reviewer 1

We thank the reviewer for their comments which have helped to improve and clarify several points in the manuscript. We are pleased that the reviewer found the manuscript to be well written and organised, and we address their comments below. We have included line numbers with respect to the revised marked-up document to accommodate matching changes in the manuscript in response to these comments.

Significant Comments:
Lines 98-99: Are there separate variables for cloud ice and precipitation-size ice (snow and graupel)? If so, please be more specific here.

In the UKCA climate-chemistry model the different aspects of cloud ice, including snow, pristine ice and riming particles, are all considered together as part of one prognostic cloud ice variable. We have added the sentence "The cloud ice variable includes snow, pristine ice and riming particles." (Line 108). Microphysical processes such as melting snow and riming are represented but the prognostic variable provides the bulk response of all these components as cloud ice. The references included in the text in this paragraph provide further details of the microphysical scheme.

Line 171: Are there any biases in this tropospheric ozone product relative to sondes or other satellite observations?

The tropospheric ozone product used in this paper is that of Ziemke et al. (2011). Ziemke et al. (2011) evaluated the MLS/OMI product against ozonesondes and an alternative satellite product which combined SAGE and MLS with ozonesondes to estimate tropospheric ozone. There is no apparent systematic under- or over- estimation across the sonde sites. We have added the following sentences discussing this evaluation: "In an evaluation against ozone sondes with broad coverage across the globe, the MLS/OMI product generally simulated the annual cycle well (Ziemke et al., 2011). The annual mean tropospheric column ozone mixing ratio of the MLS/OMI product was found to have a root mean square error (RMSE) of 5.0 ppbv, and a correlation of 0.83, compared to all sonde measurements. The RMSE was lower and correlation higher (3.18ppbv and 0.94) for sonde locations within the latitude range 25°S to 50°N." (Lines 207-212)

Lines 219-220: The correlation is also not improved with ICEFLUX in the southern extratropics.

The reviewer is correct. This paragraph has been revised to: "Overall, the ICEFLUX approach reduces the errors in the annual cycles of lightning. This scheme improves the correlation between simulated and observed lightning compared to CTH scheme in the northern extratropics and southern tropics. It has a lower correlation in the northern tropics, where both approaches for simulating lightning have difficulties, and in the southern extratropics, where the magnitude of the bias is much reduced upon compared to the CTH approach." (Lines 263-268).

Lines 236-237: It would benefit the paper if these statistics were presented for the latitude bands.

We present an extended version of Table 1 with latitude bands included below. The top section of this table is the original version which remains in the manuscript. The other sections show statistics for other latitudes bands which we have decided not to add to the manuscript. The adjusted RMSE for each region was calculated using the mean bias over the full 60S-60N region. While we agree that it was worth examining these statistics, we feel they do not significantly add to the manuscript. An additional conclusion could be that the adjusted RMSE of the ZERO simulation is lower than that for the CTH and ICEFLUX simulations in northern midlatitudes. However, given the still comparatively large unadjusted RMSE in the region, this does not add sufficient value to merit inclusion of such a large amount of extra data.

Latitude band	Run	r	RMSE (DU)	Mean bias (DU)	adjusted RMSE (DU)
Full 60S-60N	CTH	0.82	5.5	-2.8	4.1
	ICEFLUX	0.84	5.7	-3.2	3.9
	ZERO	0.83	10.7	-7.4	4.6
60N-30N	CTH	0.65	4.0	–	3.6
	ICEFLUX	0.67	3.8	–	3.5
	ZERO	0.69	6.4	–	3.0
30N-Eq	CTH	0.95	3.3	–	3.4
	ICEFLUX	0.96	3.4	–	2.6
	ZERO	0.96	9.2	–	2.7
Eq-30S	CTH	0.90	4.0	–	2.4
	ICEFLUX	0.93	4.9	–	2.2
	ZERO	0.93	12.3	–	5.1
30S-60S	CTH	0.81	8.6	–	6.1
	ICEFLUX	0.81	8.9	–	5.8
	ZERO	0.81	13.5	–	6.3

We realise that we omitted an explicit description of the range of the MLS/OMI product in the manuscript (60S-60N), so we have added a comment to the data description section (Line 198) and the Table 2 caption.

Line 300: It is not clear how you are defining the tropopause. How are the 380K surface and the 2 PVU surface combined?

We have added a reference and modifed the text to read: “These budget terms are for the troposphere. Here, the tropopause is defined at each model time step using a combined isentropic-dynamical approach based on temperature lapse rate and potential vorticity (Hoerling1993).” (Line 391-395). The reference provides the details and motivation for the tropopause definition used in the UKCA model. It uses a thermal definition equatorward of 13 degrees, and a dynamical definition poleward of 28 degrees. In between there is a smooth transition using weightings of the two definitions. This definition of the tropopause overcomes issues with the individual definitions and produces a tropopause surface which is a continuous function of latitude.

Line 436: I am not sure what is the significance of this Ox production in the first 20 minutes. Isn’t it primarily just the production of NO2 as it comes into equilibrium with NO in the atmosphere after flashes occur? Very little ozone production is going to be produced in 20 minutes.

Following NO emission, the NO is oxidised to bring NO into equilibrium with NO2. This happens principally though the reaction of NO with O3. The Ox production term diagnosed here does not include this reaction flux since the NO2 product is also an Ox species – no Ox is produced or lost from this reaction. Instead the Ox production term is dominated by the oxidation of NO by peroxy radicals. A small proportion of this Ox production in the first 20 minutes will be associated with equilibration, but the remainder reflects equilibrium NOx cycling and consequent O3 production. We have added the following text: "oxidation of NO to NO2 by peroxy radicals." to the Ox budget description in Section 4 (Line 388). The Ox budget diagram (Figure 6) demonstrates, terms through the use of a grey arrows, that reactions converting O3 to NO2 and vice versa are not counted in the Ox budget.

Table 2: What are the percentages? Are they the percentage changes from the CTH scheme? More meaningful might be to show the percentage changes of CTH and ICEFLUX from ZERO.

Good point. The percentage differences shown in Table 2 are with respect to the CTH scheme. We have now added a statement to this effect to the table caption. We choose to show changes with respect to CTH to demonstrate both the small effect of horizontal changes in distribution (the ICEFLUX column) and the large effect of emission changes (the ZERO column). We agree that percentages with respect to ZERO are useful but feel that percentages with respect to CTH make the above point most clearly.

Figure 5: There should be stratospheric influx of NO2 and other NOy species.

We thank the reviewer for highlighting this. The figure referred to is figure 6 in the new manuscript. The stratospheric influx is an inferred quantity which is derived to balance the other budget terms. It is not calculated for each species individually but is a value for the influx of total Ox, though this is dominated by the O3 contribution. We felt that the most accurate way to portray this was by including a stratospheric influx arrow pointing to the Ox label, instead of any individual species. We have added a statement describing the stratospheric influx term in the figure 6 caption.

Minor Comments:

Line 21: comparison of models

Changed to "between". Line 22

Line 183: define ACCMIP

Changed. Line 224

Line 267: .....instead the correlation values between the model and the sonde data (Figure 3) provide a more......

Changed. Line 356

Line 302: ....production and losses when lightning is added (Table 2).

Changed to "when lightning NOx emissions are removed". Line 397

Line 446: The increase is linear up to approximately 0.006 fl km-2 min-1 and then becomes steeper up to o,02 fl km-2 min-1 at which....

We show below Figure 11A plotted with a linear x-axis which highlights the linear features which change at approximately 0.02 fl. km^{-2} 20min^{-1}. We have revised the text to read: "A linear increase in Ox production is apparent up to approximately 0.02 fl. km^{-2} 20min^{-1} at which point the two schemes produce 1 to 1.5 kg km^{-2} 20min^{-1} of Ox. Beyond this point, the Ox production simulated by the ICEFLUX approach increases still linearly but with a shallower gradient." (Lines 568 - 570)