Response to Anonymous Referee #3

I would like to begin by thanking the reviewer for the time they've taken to read and constructively comment on the manuscript titled 'An adaptation of the CO_2 slicing technique for the Infrared Atmospheric Sounding Interferometer to obtain the height of tropospheric volcanic ash clouds' (amt-2018-447). We believe that these comments have helped to improve the content and clarity of the manuscript and we hope that you agree.

Below are responses to the comments made. The reviewer's comments are coloured in blue and are in bold font. Our responses are offset from these and in black. Text in italics are relevant passages from the revised text.

Specific Comments:

In the description of simulated ash spectra (section 4.1, page 6, lines 6-7), are specified the AOD, Effective Radius and Cloud Heights ranges used, but no reference about the ash type considered, that is the aerosol optical properties (extinction and absorption coefficient, asymmetry parameter, etc . . .) used in simulation. Which ash type was used? Andesite? Obsidian? Pumice? Other?

> An additional line has been included:
>
> *'The refractive index used in this study is from measurements made of ash from the Eyjafjallajökull eruption (Peters, 2010): the main eruption considering in this study. In the future different refractive indices could be used such as those in Prata et al. (2019).'*

Why you use different AOD and Effective Radius ranges for channel selection (section 4.1) and simulation results (section 4.2)? AOD=5-15 and Ref=5-10 micron for channel selection, AOD=0.5-15 and Ref=1-10 micron for simulation results. Can you explain better?

> **Following here the answer to the same question posed by referee #1:**
>
> In this study we have used a range simulated ash spectra. For the channel selection we use ash spectra representative of optically thick volcanic ash clouds (AODS: 5-15, ER: 5-10). We then test this on a wider range of ash properties which represent thinner plumes before applying the technique to real ash scenes. We have expanded the first paragraph in section 4.1 to indicate why we chose these ranges and to emphasise that it is then tested on a wider range of properties including those more representative of thinner ash clouds:
>
> *'IASI has over 300 channels which fall within the CO_2 absorption band, and so, to ensure computational efficiency an appropriate subset of these channels must be selected. To do this the CO_2 slicing technique was first applied to 384 simulated ash spectra. These are `ideal' test cases which do not include other aerosols or aqueous cloud. These spectra include six different atmospheres: high latitude, mid-latitude day and night, tropical daytime and polar summer and winter (including atmospheric profiles created for MIPAS; Remedios et al., 2007). The spectra were modelled using the refractive indices of samples of volcanic ash from the Eyjafjallajökull eruption in 2010 (Peter, 2010): the main eruption considered in this study. In the future different refractive indices could be used such as those in Prata et al. (2019). A range*

of ash properties were explored: cloud heights between 200 and 900 hPa (going slightly above the tropopause), ash effective radius between 5 and 10 µm, and ash optical depths between 5 and 15 (referenced at 550 nm). Typically, the effective radius is less than 8 µm for very fine ash (such as in a distal plume) and between 8 and 64 µm for fine ash (Marzano et al. 2018). The range of ash optical depths is highly variable. Ventress et al. (2016) and Balis et al. (2016) recorded ash optical depths of less than 1.2 from dispersed plumes from Eyjafjallajökull in 2010; however much higher values can be expected closer to the volcano or following large explosive eruptions. The effective radius and AOD explored here for the channel selection is in the upper range and above what might be expected: values which may only be true close to the volcanic vent. The spectrum of an optically thin plume is more difficult to differentiate from a clear spectrum commonly leading to the signal ($I_{obs}(\nu)$-$I_{clr}(\nu)$) to be within the instrument noise and subsequently will result in no retrieval. A decision was made to select the channels used using idealised optically thick cases, which may only be true close to the vent, for which the plume should be evident in the majority of the CO_2 channels. The selected channels are tested on a wider range of AODs and effective radius in section 4.2 including smaller values that are more representative of a disperse plume.'

I think it would be very interesting to evaluate the heights obtained from CO_2 slicing as a function of AOD, Ref and cloud top pressures. In fig. 6 (g-i) are shown the frequency for which the CO_2 slicing was unable to return a height value. I suggest to insert 3 similar panel to show the frequency for which the CO_2 slicing returns a good value (for example a value that differ from the truth max +/- 500 meters or +/- 1 km). In this way we could better understand in which conditions the CO_2 slicing is applicable and reliable.

As suggested, three additional panels were added to figure 6 which is shown below. These show the frequency of cases where the difference between the simulated and retrieved values are less than 0.5 km. These plots demonstrate that the CO_2 slicing technique performs slightly less well for cases with smaller ash optical depths and effective radius. It also supports the previous observation that the CO_2 slicing technique does not perform as well at the pressure extremes tested.

We have included the updated plot in the manuscript and added a few lines in section 4.2:

'[about failed aods and er] …. This observation is supported by figure 6j-k which shows the number of cases where the difference between the simulated and retrieved pressure is less than 0.5 km: which is slightly lower for a smaller effective radius and ash optical depth.'

'[about failed extreme pressures] …. The majority of failed cases are shown to be at the pressure extremes, Fig. 6i. Similarly, Fig. 6l indicates that there are fewer cases where the pressure difference between the simulated and retrieved pressures are less than 0.5 km at these pressures.'

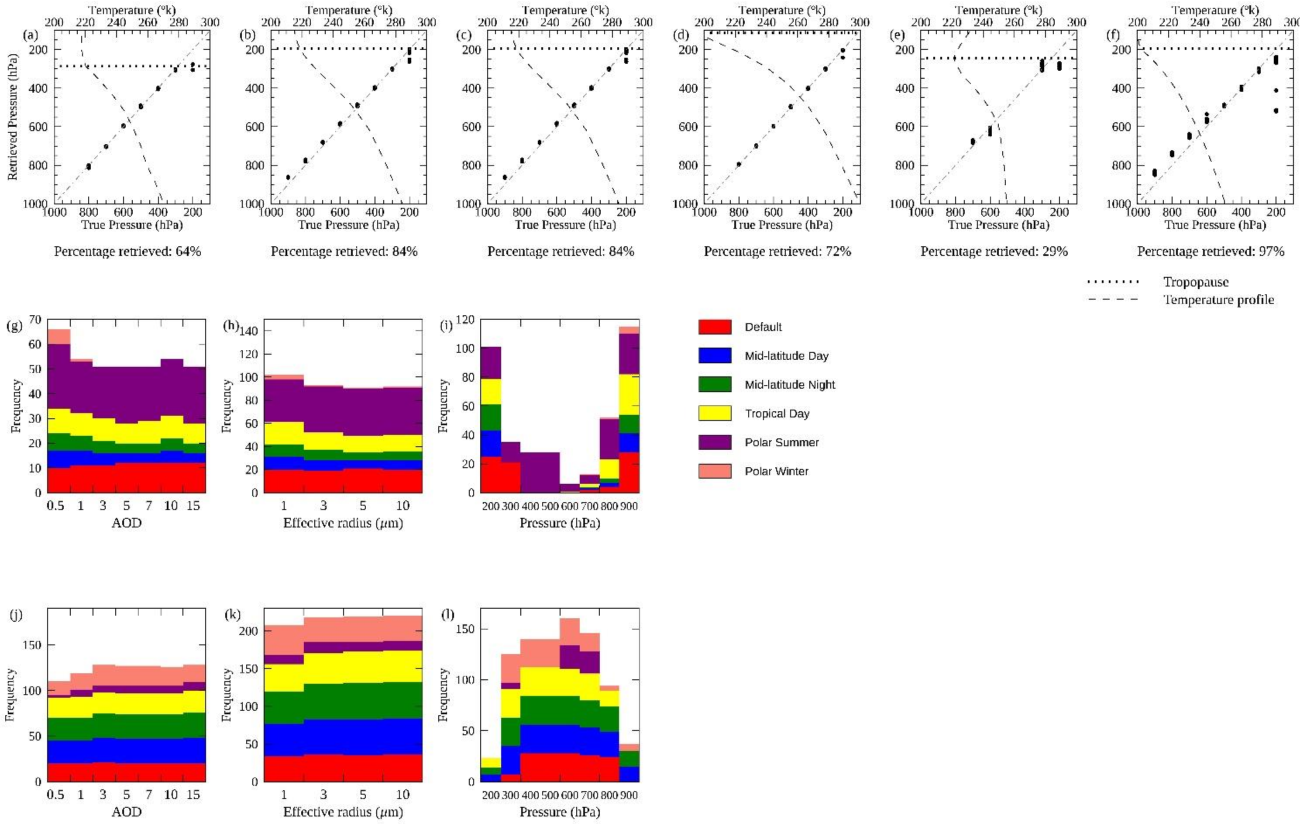

Figure 6 caption: Final CO_2 slicing pressure results for RTTOV simulated ash spectra (a total of 224 spectra per atmosphere). Panels (a)-(f) show the true (simulated) pressure plotted against the CO_2 slicing retrieved value for the six different atmospheres. (a) RTTOV default atmosphere (high latitude), (b) Mid-latitude day, (c) Mid-latitude night, (d) Tropical day, (e) Polar summer (f) Polar winter. In this case, the simulated spectra include the following ash properties: ash optical depth ranging between 0.5 and 15, ash effective radius ranging between 1 and 10 μm and pressure values between 200 and 900 hPa. Below each plot is a value indicating the percentage of successful retrievals (where a height value can be obtained and all quality control conditions have been met). (g) The frequency of ash optical depths for which the CO_2 slicing technique was unable to return a height value. (h) Same as (g) for the effective radius. (i) Same as (g) for the ash cloud pressure. (j) The frequency of ash optical depths for which the difference between the simulation and CO_2 slicing height is less than 0.5 km. (k) The same as (j) for effective radius. (l) The same as (j) for ash cloud pressure. Related statistics can be seen in table 4. The equivalent plot, where the values which have not met the quality control conditions has been included in the appendix, figure A7.

Technical Comments

Page 4, line 1: transmittance is not radiance, so it can't be "emitted" . . .. I suggest to replace the sentence with: "the atmospheric transmittance at channel v of the layer between the pressure level p and the instrument (top of atmosphere)".

Done

Page 5, line 3: "with" instead of "which" ?

We've changed which to that. The line now reads: *'The effect of surface emissivity is expected to be minimal as channels within the* CO_2 *absorption band have weighting functions that peak above the surface, as shown in Fig. 1d.'*

Page 10, line 6: here you said "4 days" for Grímsvötn eruptions, while in fig. 7 the days are only 3 (20110521 PM, 20110522 AM, 20110522 PM, 20110523 AM).

Corrected.

Figure 2: the y-label is "Pressure (mbar)" not "Altitude (km)".

Updated to hPa.

Figure 3: the x-label of the last two lines is missing ("CO_2 Wavenumber (cm-1)").

This has been corrected.

Figure 4: the same as above.

This has been corrected.