Reply to Report #1

We thank the reviewer for the comments and we are sorry if we have not fully addressed some of the points raised in the review of the previous version. We collected below the new minor comments of the reviewer (in bold), to which we replied in detail (our replies in italics).

1. The change of drag coefficient from $C_D = 1$ to $C_D = 0.1$ in this revision now produces better predictions of the upstream spread. It is notable how the change in methodology (from fitting effective radius to fitting upwind spread) leads to a factor of ten change in the inferred value for C_D. Given this, caution is clearly needed when fitting parameters based on 'single point' measurements. Consequently, and as noted in the previous review, it would be valuable to see how the cross-wind spreading predicted by the model compares to that of the eruption, by plotting the GOES-13 observations of the extent of the cloud on the right hand plots of figure 7.

Figure 7 was already full of information, so we modified Figure 8 adding a comparison with GOES-13 observations. For the 1st phase, we plotted the satellite observation at the end of the phase, i.e. approximately 1.5 hours after the onset. For the second phase, which lasted approximately 2 hours, GOES-13 observation were available only 1.5 hours and 2.5 hours after the beginning of the phase. For this reason, also for the second phase the comparison between satellite observations and model results has been done 1.5 hours after the onset of the phase, and not at the of the emission. With the introduction of the new panels in Figure 8, also the main text has been modified:

> *"For these reasons, and because in the following of the paper we are mostly interested in quantifying the upwind spreading of the umbrella cloud, we use the value $C_D = 0.1$ as reference value. For this value of the drag coefficient, simulated umbrella cloud thicknesses 1.5 hours after the onset of each phase are compared in Fig. 8 with cloud top IR brightness temperatures as retrieved by NOAA GOES-13 geostationary satellite. First of all, it is important to remark that the images on the left have been cropped from a larger satellite image, and have not been reprojected in the same UTM projection zone used for the right panels (WGS 84/UTM zone 18S), so the two areas represented in the left and right panels do not correspond. In addition, as already stated, model simulations use a constant wind (in time and space), extracted at the vent coordinates and at the neutral buoyancy level, and thus downwind spreading can differ substantially from the real one. In any case, a qualitative comparison shows that the cross-wind spreading of the two phases of the eruption matches well that predicted by the model. In addition, we observe from the contour plots in the right panels that the larger volumetric flow rate injected at the neutral buoyancy level for the second phase resulted in a thicker cloud, with a total height of column and umbrella of*

approximately 15.5 km and 17.5 km above sea level for the first and second phase, respectively. Also these values compare well with those reported in Van Eaton et al. (2016)."

2. The expression (48) for the upwind spreading is improved and simplified in this revision, but there is still no statement of the range of parameters (windspeeds, plume fluxes, etc.) over which this expression is valid. In my view this is crucially important, to avoid unintentional misuse of this expression by researchers in the future.

The reviewer is correct and now we added the following text at the end of the paragraph after expression (48):

"It is important to remark that the fitting parameters we obtained are valid for the range of tropopause wind speeds (35-80 ms^{-1}) and mass flow rates ($10^6 - 10^8$ kgs^{-1}) investigated in this analysis, and that extrapolations outside these ranges should be avoided."

3. line 660: what precisely is d_{down} (from line 655 this is the downwind distance of the centreline from the vent, but is the centreline position measured at the NBL)?

As suggested by the reviewer, we modified the text before Eq. (48) to better explain what d_{down} is:

"Also in this case there is a power law dependence of the upwind spreading d_{up} on the two input variables and, if we denote with h and d_{down} the NBL height and the downwind distance of the centerline from the vent (measured at the NBL), respectively, we can write:"