General comments

In this paper, the authors apply the optimal estimation ORAC algorithm to retrieve the macro- and microphysical properties of the 2019 Raikoke volcanic ash clouds using geostationary thermal infrared imagery. ORAC is a well-established algorithm with several recent publications describing the method and its validation, mostly in meteorological clouds. The application of a flexible and, importantly, open-source code to volcanic ash retrievals is a welcome addition to the literature. The authors highlight the potential advantages of their approach: formal error estimates, handling of multilayer situations, improved effective radius estimation by inclusion of an additional IR channel, and better treatment of ambiguities in height retrieval.

The paper is well-written and easy to follow, the figures are of good quality. My main criticism is that the improvement in height retrievals seems a bit overstated. Plume height is the only parameter the authors attempt to validate in the current study against lidar and geometric height estimates. The presented comparison, however, indicates that ORAC has limited skill in retrieving stratospheric plume heights, at least in the current case characterized by a nearly isothermal lower stratosphere. Nevertheless, I recommend the manuscript for publication after minor revisions. Below is a list of questions and suggestions the authors might want to consider for improvement.

Specific comments

- Lines 143-144: Can you explain, in a sentence or two, the main differences between the ORAC cloud and aerosol FM that made you choose the cloud model for volcanic ash?
- Line 190: You assume spherical particles, although volcanic ash clouds often contain non-spherical particles. For example, the MISR Active Aerosol Plume-Height project (V. Flower, R. Kahn, J. Limbacher / NASA GSFC) retrieved aerosol properties for a low-altitude part of the Raikoke plume on 23 June 2019 from multiangle observations, which indicate a high fraction (>0.6) of non-spherical particles.

  Is ORAC able to handle non-spherical particles in general? Can you speculate about the retrieval errors caused by assuming spherical particles for non-spherical ones?

  The MISR results are available at https://appliedsciences.nasa.gov/our-impact/news/misr-plume-heights-and-aerosol-characteristics-2019-raikoke-eruption, although the linked Powerpoint file seems corrupted at the moment.
- Lines 285-286 and Eq. 10: The definition of ash mass loading is indeed the same as that of cloud liquid water path (LWP) and assumes no vertical variation in cloud/ash particle size. For marine stratocumulus clouds, however, effective radius often increases linearly from cloud base to top. Because the effective radius derived from VIS-NIR bispectral observations is representative of the cloud top, the assumed vertical homogeneity results in an overestimated LWP. For such boundary layer clouds, an ‘adiabatic’ model has been proposed, which leads to a proportionality factor of 10/9 instead of 4/3 in Eq. 10. This adiabatic correction reduces the VIS-NIR LWP by 17%, which agrees better with microwave LWP estimates for marine Sc.

Your estimate of the Raikoke ash cloud geometric thickness is 1.04±0.56 km, which is larger than the ~300 m typical thickness of marine Sc. Thus, vertical variations in ash particle effective radius can also introduce biases in ash mass loading when vertical homogeneity is assumed.

Can you comment on which part of the ash cloud (top, middle, bottom) your IR-based effective radius estimates are representative of? Do you expect vertical variations in effective radius—perhaps a decrease from base to top, in contrast to marine Sc—and how would these bias your ash mass load estimates?

- Line 344: "***there is no information on particle size for opaque plumes***". Perhaps you could note this limitation earlier, when describing the method in section 3.
- Lines 359-360: You state that "***The ORAC heights are, however, an improvement to simply matching a brightness temperature to a NWP profile***…"; but, you don't demonstrate this. Could you perhaps plot the height or height range derived by matching the minimum plume BT within the black circle in Fig. 3a to the ERA5 profile?
- Lines 360-362: How big are the differences in the 5 cost values? Are these differences significant?
- Lines 389-391: You suggest that the increase in effective radius is due to a retrieval artefact at large satellite view zenith angle (VZA). Cloud drop effective radius retrieved by the plane-parallel VIS-NIR bispectral method has been found to increase at large VZA due to 3D effects (shadowing, illumination) affecting the VIS reflectances (Maddux et al., 2010, 10.1175/2010JTECHA1432.1; Grosvenor and Wood, 2014, 10.5194/acpd-14-303-2014; Horvath et al. 2014, 10.1002/2013JD021355).

  How does VZA affect your IR measurements that could explain this retrieval artefact? Is it differential limb cooling in the various channels due to increased absorption by CO_2 and/or water vapor? Can you explain it by the topology (shape of constant effective radius curves) of the ORAC look-up tables plotted in Fig. 10?
- Lines 459-460: You state that there is generally good agreement between the ORAC and validation heights. However, Fig. 7 suggests that the agreement between ORAC and GOES-17 is better in the troposphere, while the skill of ORAC in the stratosphere seems limited. GOES-17 indicates heights between 10-16km, while ORAC retrieves near constant heights around 12-13km. You state elsewhere that the IR measurements had little influence on the retrieved stratospheric heights, which were close to the chosen a priori near 12km. Perhaps a more nuanced statement on the height comparison is needed here.
- Lines 479-482: Purely as a suggestion for future study, I recommend analysing ORAC retrievals for the 2021 La Soufriere eruptions, where the tropical temperature profile shows a sharp inversion at the tropopause and distinct temperature increase in the stratosphere. ORAC stratospheric height retrievals might have better skill in a tropical case than in the current mid-latitude case characterized by an isothermal lower stratosphere. CALIOP and GOES-17 height estimates are available for La Soufriere too.
- Lines 529-534: Bruckert et al. (2022, 10.5194/acp-22-3535-2022) in the same special issue also show that resolving the individual phases of the 2019 Raikoke eruptions

improves the total ash burden forecast and reduces ash mass overestimation, compared to using continuous and constant eruption source parameters.

Technical corrections

- Line 49: “in satellite-based**,** ash cloud retrieval” -> remove the comma
- Line 173: “interpola**R**ted” -> “interpolated”
- Line 183: Is λ the wavelength?
- Line 258: “problem of **a** multiple solutions” -> remove “a”
- Line 265: “a tropospheric**,** a priori ash layer pressure” -> remove the comma
- Line 268: “which is a typical **of** value for ash” -> remove “of”
- Line 417: “side-view**,** times-series” -> remove the comma
- Line 449: “were ~0.3–0.7 km according to” -> “…were ~0.3–0.7 km **thick**…”
- Line 455: “would **be** fall below” -> remove “be” or “fall”
- Line 501: “**their** is very little” -> “there”
- Fig. 8a: I presume, the black line is the CALIOP ground track with green indicating the section plotted in panel c.
- Line 504: “for a cloud layer**s**” -> “layer”
- Line 602: “converts to a **different** in absolute” -> “difference”