

Reviewer Comments

eguphere-2025-63

Guerrieri et al., A Novel Simplified Ground-Based TIR System for Volcanic Plume Geometry, SO₂ Columnar Abundance, and Flux Retrievals

This manuscript is comprehensive and well-written. My concerns are focused on the theoretical basis of the calibration and retrieval routines, as discussed below. I recommend that the manuscript be revised to address these concerns.

I am not familiar with the transmission spectra of chalcogenide glasses, but I do know that chalcogenide glasses contain sulfide compounds. Are the authors certain that the glass transmission spectra do not contain features that overlap with the SO₂ spectra?

Conceptually, the VIRSO2 camera detects SO₂ absorption as differences between the narrow band (NB) and broad band (BB) images of plumes. Implicit in this approach are the assumptions that (1) the BB measurements are not affected by the presence of SO₂, and (2) there are no differences between BB and NB measurements for a clear-sky optical path. As to the first assumption, we see from Fig. 1c that the BB spectral response covers the SO₂ absorption feature at 8.7 μm. The plumes are evident in every image of BB temperatures presented by the authors, indicating that the presence of SO₂ had increased the optical depth of the plumes, relative to clear-sky paths. I do recognize that the presence of steam, ash, and other particulates will also increase the optical depth of a plume, but the authors are focused on SO₂.

The impact of the SO₂ absorption on BB radiance depends on gas concentration and the scene temperature, as the peak radiance can be coincident with the maximum gas absorption. SO₂ is transparent at wavelengths > 9.5 μm, and an alternate design for the BB camera would include a filter to block radiance at wavelengths < 9.5 μm. Admittedly, this design option would introduce a new filter to the calibration procedure.

Regarding the second assumption, the MODTRAN simulations of BB and NB radiance at 226 K shown in Fig. 8b demonstrate that the BB and NB do not agree for clear-sky paths. The authors attribute this difference to the transmission (and temperature) of the NB filter, but (presumably) the MODTRAN simulations were based on the normalized spectral response (Fig. 1c) rather than the transmission of 0.80 cited in the text. An alternate explanation for the differences between the NB and BB radiance is that the NB spectral response excluded the peak radiance for a sky temperature of 226 K whereas the BB spectral response included the peak radiance.

Fig. 8b shows that the corrected NB brightness temperatures (T'_{NB}) are ~45 K warmer than the MODTRAN NB simulations. This large disagreement raises concerns about the ghost

image correction. The current approach is to calculate a correction factor based on the mean value of the black target image (Lines 230-235), but a correction factor based on the background values of the black target image (i.e., outside of ghost image) might be more appropriate.

Additional comments about the determination of sky temperature (T_s), based on Equation 15. To calculate the atm transmission (τ_o) and, in particular, path radiance (L_o) MODTRAN needs a profile of atm temperatures. As discussed in Lines 271-274, NCEP profiles were used, with the top of the atmosphere (TOA) temperature set to 0 K. How, then, can τ_o and L_o be used to determine T_s with the TOA temperature of 0 K “baked in” to the MODTRAN simulations?

The authors make the enigmatic statement that the NB clear sky temperatures (T_{NB}) are 5-10 K lower than the BB temperatures (Line 337), but do not show the T_{NB} temperatures in Figs. 8a or b. I can infer that the comparison refers to the T_{NB} temperatures, which have been “corrected” for the ghost image and temperature/transmission of the 8.7 μm filter, but a reader shouldn’t have to make such inferences. If the authors are referring to the T_{NB} temperatures, then they should show these temperatures explicitly.

The BB Temperature Difference image (DT_{BB}) shown in Fig. 10a provides further example that the BB measurements are sensitive to the presence of SO_2 . The authors state that DT_{BB} and the corresponding NB Difference image (DT_{NB}) are the foundations of the SO_2 retrieval scheme (Line 365) but do not explain why both inputs are necessary. MODTRAN simulations of both BB and NB are performed (Lines 386-387), but to what end? Are there two independent sets of SO_2 estimates, based on DT_{BB} and DT_{NB} , that are compared to make a “composite” estimate? The sky and ground references temperatures for T_{NB} are based on T_{BB} (Eq. 18 and 19), but this formulation does not explain the use of both DT_{BB} and DT_{NB} in the retrieval procedure.

The discussion of viewing geometry and MODTRAN inputs, illustrated in Fig. 11, is a bit confusing. Why are such corrections for wind direction (Eqs. 22 and 23) necessary, when the authors have already corrected for impact of wind direction on “pixel heights” (Eqs. 9 – 12; Fig. 6). What is different about these two sets of corrections?

Returning to Fig. 11, do the authors know the “horizontal thickness,” or HT, of the plume? This knowledge would require observations of the plume from the side opposite the camera. Do the authors assign an HT canonically? The HT, together with camera inclination (θ) and horizontal distance from plume (D_0), defines the length of the optical path through a plume. However, θ and D_0 are measured at the camera and derived from topo maps.

With HT, θ , and D_0 known (or defined canonically), the authors define a “MODTRAN plume” for each line-of-sight (or pixel in the focal plane) and derive estimates of the vertical column density (VCD) of SO_2 . However, the MODTRAN plumes are segments of the actual plume and, as far as I can tell, the RT modeling does not account for upwelling radiance

from the plume beneath the segment in question nor downwelling radiance from the plume above the segment. The camera images suggest that the optical depth of the plumes was significant and, therefore, I suspect that the up- and downwelling radiance was significant.

The comparison of VIRSO2 and TROPOMI-based SO₂ estimates (Section 6) needs to be scrutinized. The results are described as comparable (e.g., Line 477), but Fig. 14b indicates that the VIRSO2-based estimates were consistently 2X higher than the TROPOMI estimates. The minor overlap between the results is achieved when the errors (which are reported to exceed ±50% for both instruments) are incorporated into the figure.

The VIRSO2 images (BB or NB) indicate that the plumes are warmer than the clear-sky temperatures. In other words, the plumes are the sources, or emitters, of the observed radiance. This emission requires that the optical depth of the plume is high enough to minimize the transmission of radiance through the plumes. As the optical depth decreases, due primarily to the dispersion of plumes from their source vents, the plume transmission increases (relative to emission) and the plumes become difficult to detect against the clear-sky background.

Conceptually, the TROPOMI detection of SO₂ is based on the absorption of back-scattered UV radiance passing through the plumes. Once again, if the optical depth of a plume is too high then the plume becomes the source (through back-scattering) of the radiance. Given the strength of SO₂ absorption in the UV, relative to the TIR (Lines 467-469), the plumes detected by VIRSO2 are almost certainly opaque to UV radiance and TROPOMI is measuring back-scattering from the tops of the plumes.

Putting aside my concerns about the derivation of T_{NB}", my interpretation of Fig. 14b is based on the effects of optical depth. The TROPOMI measurements did not sample the interiors of the UV-opaque plumes and, as a result, the VCD were under-estimated. The VIRSO2 measurements did sample the interiors of the plumes, and the resulting estimates of VCD were higher than the TROPOMI estimates. Given the significant role of optical depth, it is hard to think of a scenario where the direct comparison of VIRSO2 and TROPOMI estimates is possible.

As noted above, the plumes were the sources of the TIR radiance and, because the radiance did not pass through the entire plume, it is likely that the VIRSO2 procedure under-estimated VCD.