General Comments

This manuscript presents a comprehensive synergistic satellite observation framework for monitoring volcanic SO_2 emissions by integrating geostationary hyperspectral infrared observations from FY-4B/GIIRS and GEMS with polar-orbiting satellite observations from HIRAS, CrIS, IASI, TROPOMI, and MLS. Using the June 2024 eruption of Mt. Kanlaon in the Philippines as a case study, the authors demonstrate the potential of combining high-temporal-resolution geostationary observations with highly sensitive low-Earth-orbit (LEO) measurements to characterize the three-dimensional evolution and atmospheric lifetime of volcanic SO_2 plumes.

The manuscript is generally well structured, and the multi-sensor comparisons provide an interesting perspective on the complementary capabilities of geostationary and polar-orbiting observations. However, several aspects related to retrieval uncertainty characterization, validation strategy, and interpretation of the results require further clarification and improvement before the conclusions can be fully supported.

Therefore, I recommend **major revision** before the manuscript can be considered for publication.

Major Comments

1. The uncertainty characterization of the GIIRS SO_2 retrieval requires further improvement

The retrieval algorithm is based on an optimal estimation framework, in which unresolved atmospheric effects are incorporated into the measurement error covariance matrix S_ε. Although this approach is theoretically reasonable, the current construction of $S_\varepsilon$appears to rely mainly on SO_2-free background scenes.

However, volcanic plume environments differ substantially from background atmospheric conditions, particularly due to:

(1) enhanced water vapor variability;

(2) volcanic ash loading;

(3) cloud contamination;

(4) complex thermal and radiative conditions.

Therefore, the assumption that background residual statistics can fully represent uncertainties under volcanic plume conditions may not always be valid.

The authors should clarify:

(1) How representative are the selected SO_2-free regions for actual volcanic plume environments?

(2) Does S_ε vary with atmospheric conditions, observation geometry, or surface characteristics?

(3) What are the potential impacts of systematic biases that cannot be adequately represented by the covariance matrix?

A sensitivity analysis under different atmospheric conditions would significantly strengthen the uncertainty assessment.

2. The influence of limited GIIRS spectral coverage on SO_2 sensitivity should be discussed more quantitatively

The manuscript demonstrates that GIIRS can successfully detect high-concentration SO_2 plumes but has limited sensitivity to weak signals. Simulation experiments indicate that GIIRS generally underestimates SO_2 total columns, particularly under low-concentration conditions.

However, the manuscript should provide a more quantitative discussion regarding:

(1) the minimum detectable SO_2 column under realistic atmospheric conditions;

(2) the dependence of detection capability on plume altitude;

(3) the effects of surface temperature and atmospheric water vapor.

The reported theoretical detection limit (~3 DU under ideal conditions) may represent an optimistic lower bound. The authors should clarify how this threshold changes when realistic cloud effects, aerosol impacts, and forward-model uncertainties are considered.

3. The impacts of clouds and volcanic ash require more explicit consideration

The manuscript acknowledges that cloud and volcanic ash effects are not explicitly treated in the retrieval framework. However, these effects are particularly important for infrared SO_2 retrievals because volcanic eruptions usually generate SO_2, volcanic ash, and clouds simultaneously.

The authors should discuss:

(1) Whether pixels affected by volcanic ash or clouds were excluded during retrieval;

(2) How thin clouds influence the retrieved SO_2 total columns;

(3) Whether ash-related radiative effects could potentially be misinterpreted as SO_2

signals.

The current retrieval framework may underestimate uncertainties under realistic eruption conditions.

4. The general applicability of the proposed framework should be discussed more carefully

The manuscript suggests that the proposed framework can be directly applied to global volcanic monitoring using future geostationary hyperspectral missions.

This is an important and valuable perspective. However, the current evaluation is based on only a single volcanic eruption case.

The authors should further discuss the applicability of this framework under different conditions, including:

(1) tropical versus high-latitude volcanoes;

(2) explosive versus effusive eruptions;

(3) low-SO_2 versus high-SO_2 emission events;

(4) different surface and atmospheric backgrounds.

Additional case studies would significantly improve the robustness and general applicability of the proposed framework.

Minor Comments

1. The term **"theoretical detection limit"** should be clearly distinguished from an operational detection threshold.

2. The manuscript should provide more details regarding the configuration of the radiative transfer model, including: spectral resolution; spectroscopic database; assumptions regarding surface emissivity.

3. Some statements regarding the "global applicability" of the framework should be moderated unless additional validation cases are provided.

Overall Recommendation

Major Revision

This manuscript provides a valuable contribution by demonstrating the potential of geostationary hyperspectral infrared observations for high-frequency volcanic SO_2

monitoring. The proposed multi-platform synergistic observation framework is promising and scientifically relevant.

However, before the robustness and general applicability of the framework can be fully established, several uncertainties associated with retrieval assumptions, plume-height constraints, detection sensitivity, and multi-sensor comparisons need to be further addressed.