Preparing for X/Ka Band radio occultations of Venus with VERITAS and EnVision: Retrieving Sulfur Species Abundances

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Abstract

The recently selected VERITAS and EnVision missions will fly with X and Ka Band telecommunications channels, permitting dual band radio occultations of the Venus atmosphere. While signal absorption measurements during S and X Band radio occultations of Venus in the past have been used to retrieve vertical abundances of H_2SO_4 vapor as a function of latitude, Ka Band links have yet to be employed to sound the neutral atmosphere. Laboratory measurements and propagation models of the Venus atmosphere suggest that H_2SO_4 cloud aerosols/vapor and SO_2 absorb radio signals differently between X and Ka bands, permitting inversion of their abundance profiles down to the attenuation limit near 45 km. Such measurements would be of great value to the study of Venus atmospheric chemistry and dynamics. While the bulk abundance of SO_2 at the cloud base has been inferred from microwave/infrared radiometry and from X Band occultations, Ka Band measurements could be used to derive vertically resolved profiles at the deepest altitudes yet, spanning a region where the abundance of SO_2 changes by several orders of magnitude. Vertical profiles of lower cloud bulk density could also be achieved at higher resolution than any prior remote measurements. This presentation will discuss approaches to retrieving H_2SO_4 vapor/aerosol, and SO_2 abundances using dual X/Ka Band radio occultations of the Venus neutral atmosphere. H_2SO_4 vapor can be retrieved with very high accuracy, surpassing that of prior single frequency occultations. Due to the relatively low (high) X (Ka) Band opacity of both SO_2 and H_2SO_4 aerosols, retrievals of these species from dual band occultations are highly degenerate. To improve accuracy, we find that it is necessary to incorporate the results of chemical and dynamical modeling as prior information. At lower latitudes and in regions of high abundance, preliminary results suggest retrievals of SO_2 profiles can be accomplished within 15-20% uncertainty. This error increases at higher latitudes, where models of cloud bulk density span a wider range of predictions. We compare the effects of various assumptions on the accuracy of the resulting retrievals, and discuss prospects for coupling a chemical/dynamics model to the retrieval process.

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Background

Future missions to Venus will be the first to conduct simultaneous X (8.3 GHz) and Ka (32 GHz) band radio occultations, providing a proof-of-concept simultaneous retrieval of sulfur species unattainable before.

How accurately can we quantify the abundances of H_2SO_4 and SO_2 in the cloud-level atmosphere?

We explore this question with a novel data-driven retrieval approach.

Figure 1. Data-driven algorithm flowchart

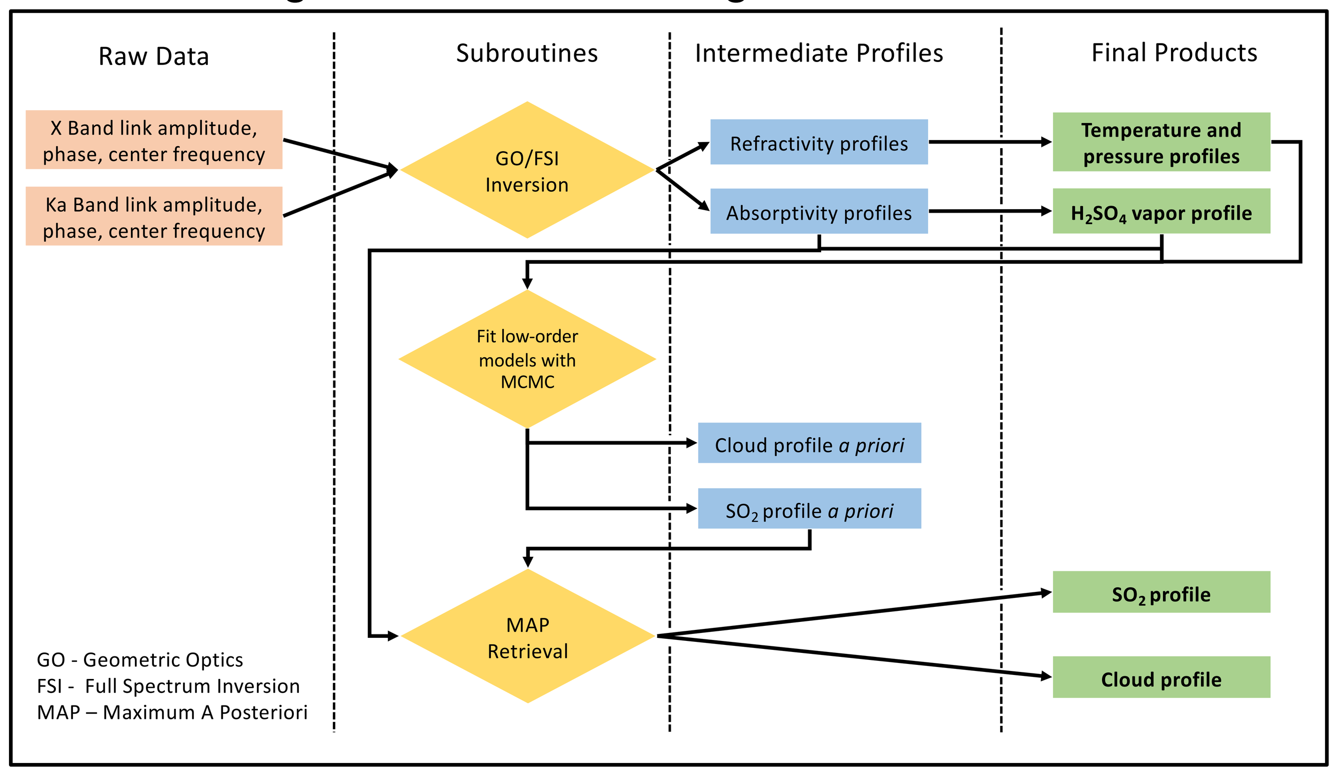
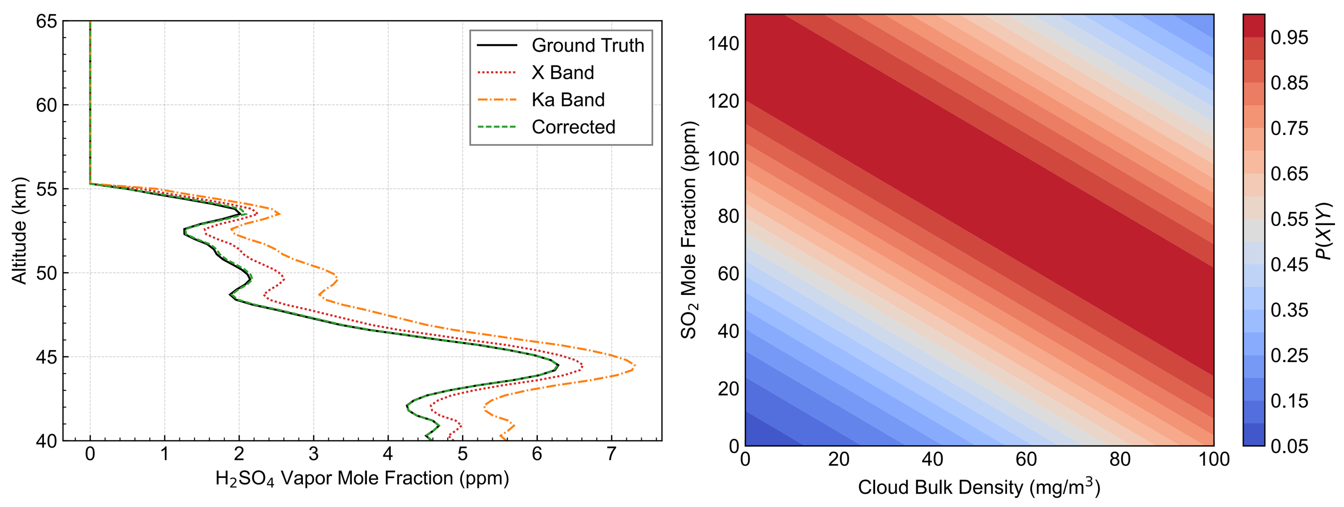


Figure 2: (Right) Dual X/Ka band occultations of Venus will achieve equivalent or greater accuracy in retrieved H_2SO_4 vapor abundance compared to prior S and X band occultations [1]. (Left) Retrieval of H_2SO_4 aerosol bulk density and SO_2 mole fraction, however, is non-unique, as illustrated by the likelihood distribution for retrieval at a single altitude.

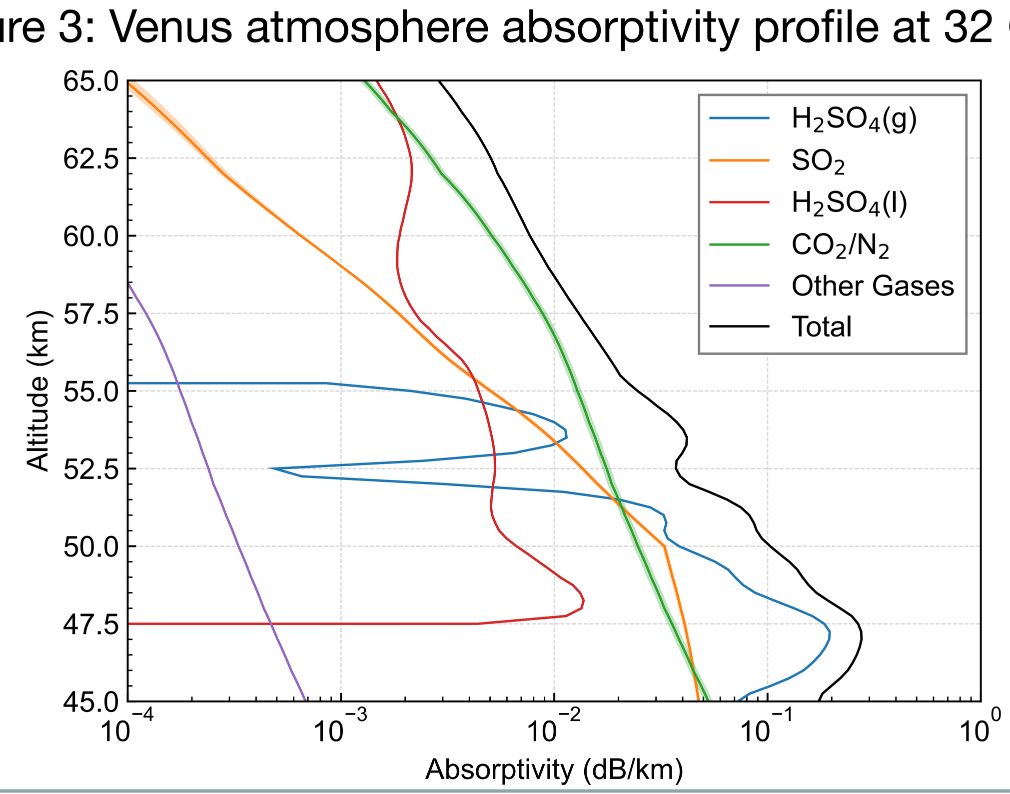


Model Uncertainty

Uncertainties in absorption model parameters for H_2SO_4 and SO_2 have been determined by assessing the likelihood of occurrence against laboratory measurements under simulated Venus conditions [2].

$$p(a|\mathbf{x}) \propto c * \prod_{i=1}^{n} p(x_i|a, \sigma_i)$$

Figure 3: Venus atmosphere absorptivity profile at 32 GHz



Simulated Retrievals

Figure 4: The results of chemistry/transport models and prior atmospheric measurements, representing an ensemble of vertical distributions of sulfur species abundances, were used to simulate retrievals of H_2SO_4 and SO_2.

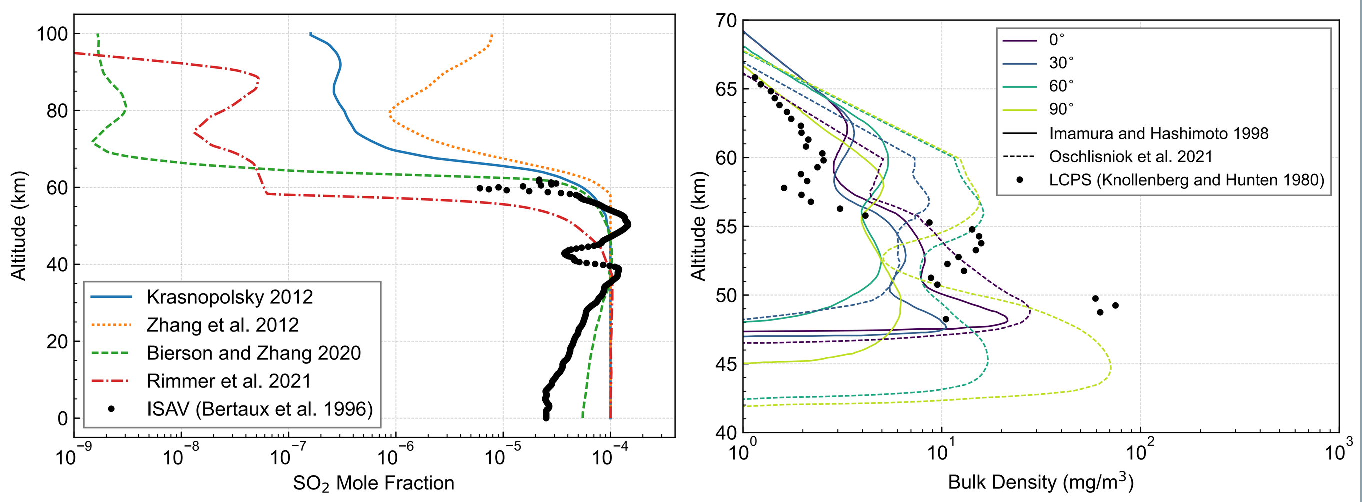


Table 1: Model atmospheres used to test retrievals

Set Number	H_2SO_4 vapor	H_2SO_4 aerosol	SO_2
1	VEX VeRa, 18°	Imamura and Hashimoto, 0°	Krasnopolsky
2	VEX VeRa, 45°	Imamura and Hashimoto., 30°	Bierson and Zhang 2020
3	VEX VeRa, 80°	Oschlisniok et al., 60°	Rimmer et al.
4	VEX VeRa, 85°	Oschlisniok et al., 90°	Bertaux et al., ISAV-1

Figure 5: Low-dimension models for SO_2 and cloud abundances

SO_2

- x_0: Base abundance
- h_0: Depletion altitude
- s_0: Depletion scale height

Cloud

- b_0: cloud base
- b_1: 1st layer boundary
- b_2: 2nd layer boundary
- b_3: cloud top
- m_0: Layer 1 bulk density
- m_1: Layer 2 bulk density
- m_2: Layer 3 bulk density

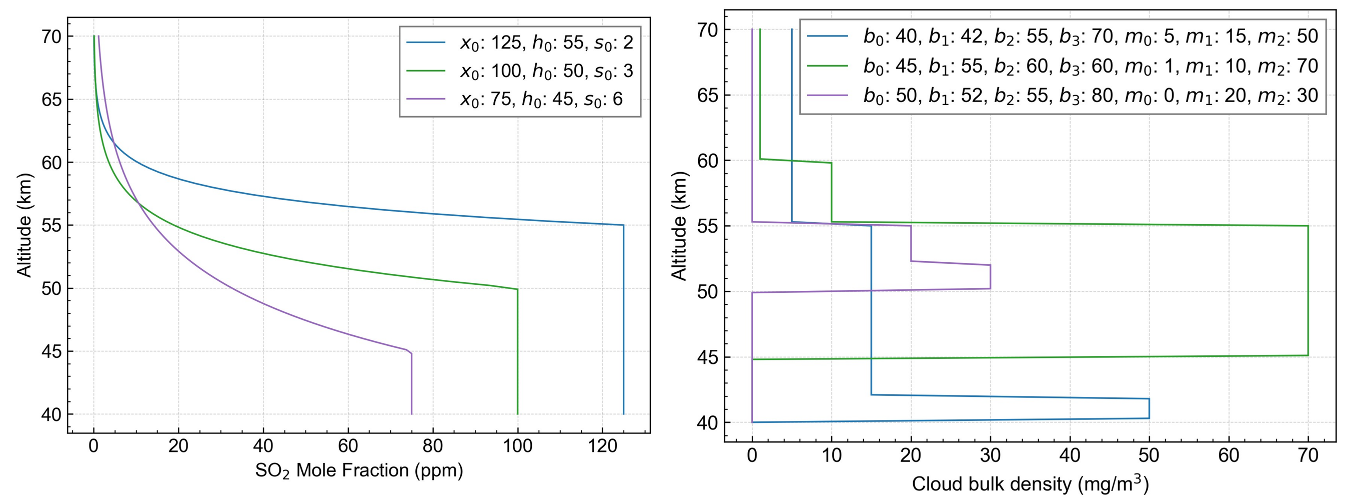
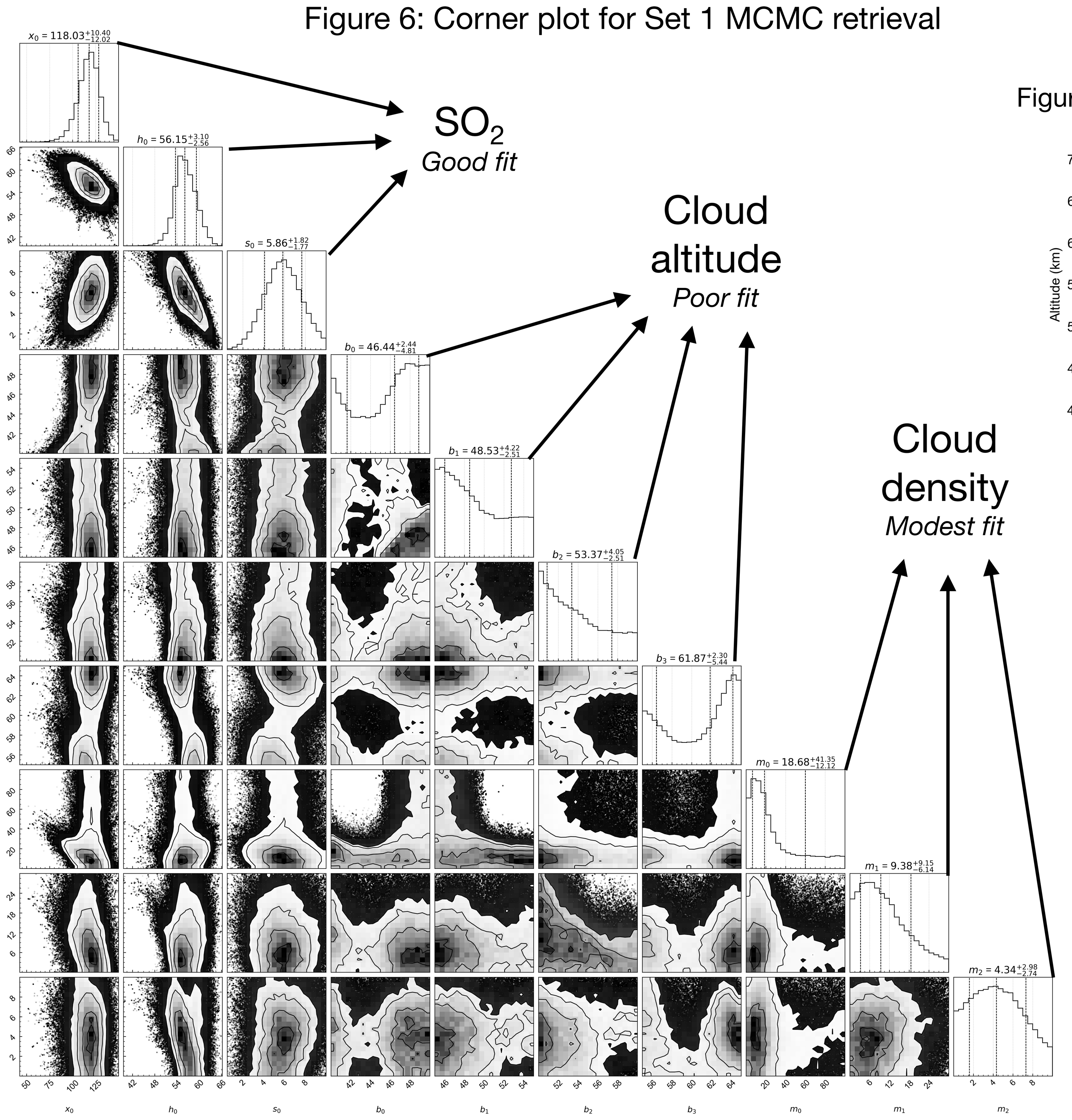


Figure 6: Corner plot for Set 1 MCMC retrieval



MCMC Fits

Figure 7: Markov Chain Monte Carlo draws for each set in Table 1

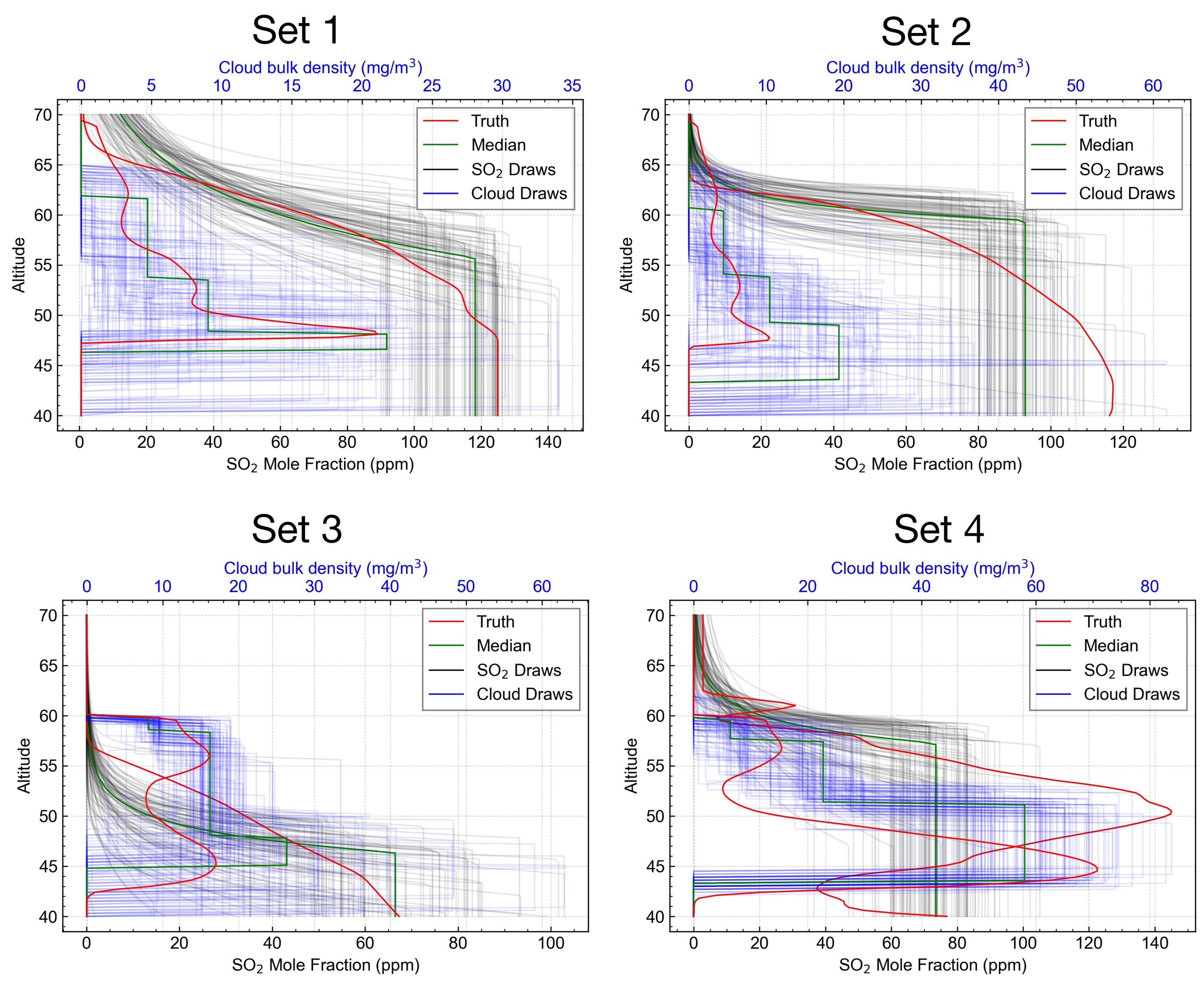


Figure 8: Set 1 Prior covariance matrix including variances from MCMC fits

$$S_{ij} = \sigma_a{}^2 e^{-|i-j|\delta z/h}$$

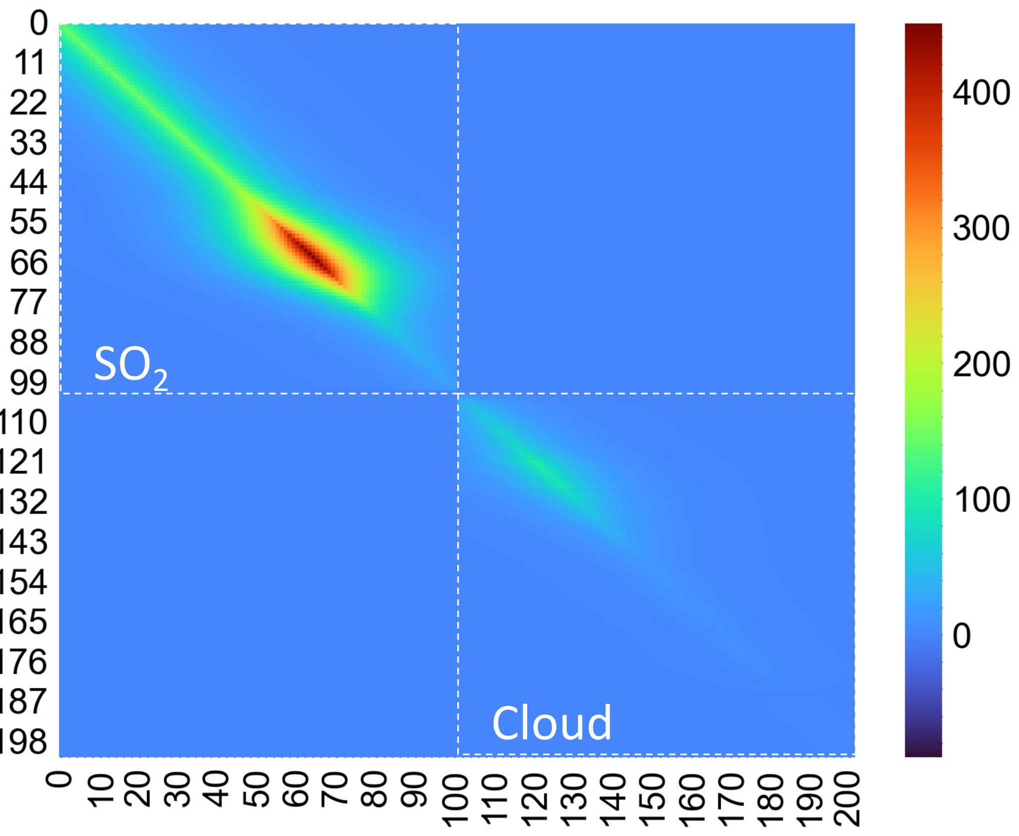
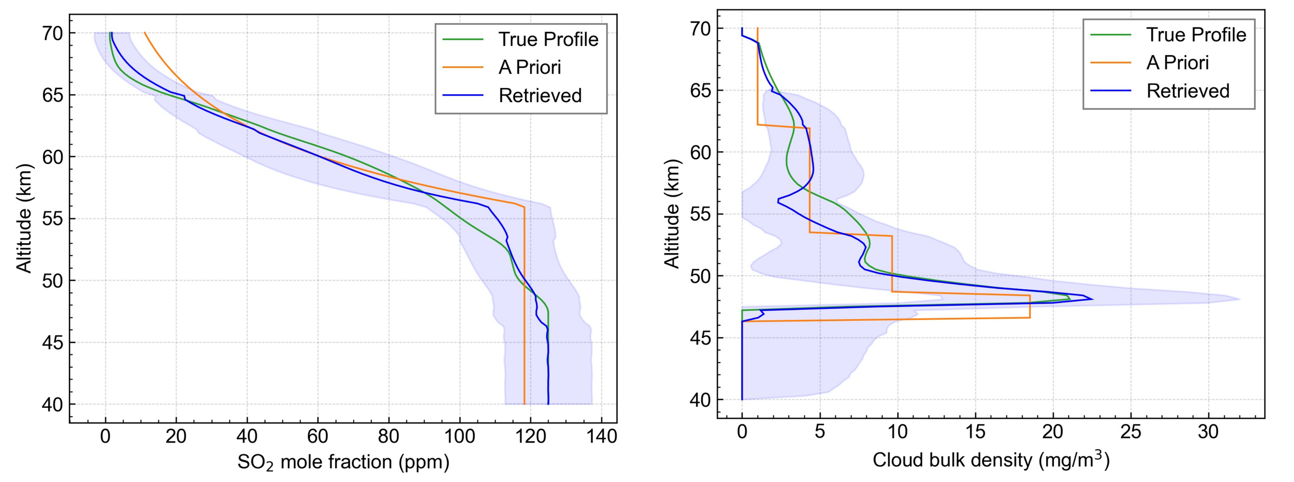


Figure 9: Final retrieval for Set 1 with h=10 for SO_2 and h=0.5 for cloud density



Conclusions

- Simulations suggest that X/Ka band occultations permit determination of SO_2 and H_2SO_4 aerosol vertical profiles, which was not possible on previous missions
- A novel data-driven retrieval algorithm has been demonstrated here, and a model-driven algorithm is also being assessed

References

[1] Oschlisniok, J., et al., *Icarus*, 362, 2020
[2] Akins, A. B., & Steffes, P. G., *Icarus*, 351, 2020
[3] Krasnopolsky, V. A., *Icarus*, 218, 2012
[4] Bierson, C. J., & Zhang, X., *JGR: Planets*, 125(7), 2020
[5] Rimmer, P. B. et al., *PSJ*, 2(4), 2021
[6] Bertaux, J.-L. et al. *JGR: Planets*, 101(E5), 1996
[7] Foreman-Mackey, D. et al., *PASP*, 125(925), 2013