



# Understanding the atmospheric chemistry of Venus from the surface to 110 km

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## Abstract

Venus is a natural laboratory to test our understanding of atmospheric sulfur chemistry. Previous chemical models of Venusian atmosphere have focused on either the lower or middle atmosphere. In this work we perform the first thorough analysis of an atmospheric chemistry model that extends from the surface to 110 km. We find that flux of species through the cloud deck (~40 km-70 km) can have a significant effect on the vertical profiles.

## 1. Introduction

Venus's atmosphere can be broadly divided into a lower and middle atmosphere that are separated by the clouds. Previous chemical modeling efforts have focused on understanding these parts of the atmosphere independent of one another. In this work we perform the first analysis of atmospheric chemistry from the surface to 112 km.

Venus Express and ground based observations have revealed stark differences in these regions. The lower atmosphere has observed abundances of SO<sub>2</sub> (~ 200 ppm), OCS (~ 10 ppm), and CO (~ 10 ppm). Many previous studies have tried to understand the chemical pathways between these species but as of yet their is no consensus [1, 2, 3].

In the middle atmosphere there are abundant observations of SO<sub>2</sub> which is highly depleted relative to the lower atmosphere and is highly temporally variable. In the middle atmosphere SO<sub>2</sub> also increases in mixing ratio with altitude, the so-called "SO<sub>2</sub> inversion" [4].

## 2. Our Model

In this we extend the model of [5] to the surface of Venus. We have added the lower atmosphere reactions from [2]. All chemical reactions were also checked for

updates from the JPL kinetic chemistry database [6]. We tested multiple eddy diffusivity profiles including those from [2, 5, 7].

## 3. Results

### 3.1. SO<sub>2</sub>

The SO<sub>2</sub> system was of particular interest for this work because of the wealth of observations. Previous lower and middle atmosphere models use boundary conditions that are inconsistent with one another. Lower atmosphere models consistently predicted SO<sub>2</sub> concentrations in the cloud level in excess of 100 ppm while middle atmosphere models (which begin in the clouds) would apply a lower boundary condition of < 10 ppm (See Table 1).

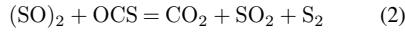
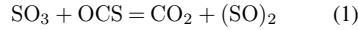
Table 1: Mixing ratio of SO<sub>2</sub> and the boundary of different lower and middle atmosphere models. Note that the model of Yung et al. [3] which uses a higher SO<sub>2</sub> concentration also produced an SO<sub>2</sub> profile inconsistent with observations.

Reference	Model Domain	SO <sub>2</sub> (ppm)
Krasnopolsky [2]	0-47 km	130
Krasnopolsky [7]	47-112 km	9.7
Zhang et al. [5]	58-112 km	3.5
Yung et al. [3]	58-112 km	130

When coupling the lower and middle atmosphere we find the in the lower atmosphere SO<sub>2</sub> readily diffuses into the middle atmosphere. This leads to mixing ratios far in excess of the observations. This is due to the fact that SO<sub>2</sub> has an extremely long chemical lifetime in the lower atmosphere. SO<sub>2</sub> is also produced at the base of the cloud layer as H<sub>2</sub>SO<sub>4</sub> from the clouds is thermally decomposed. All this suggests that there is some unknown sink of SO<sub>2</sub> in the cloud region or that SO<sub>2</sub> is inhibited from passing through the cloud region. Separating these possibilities will the focus of future work.

### 3.2. CO and OCS

In the lower atmosphere most models have focused on the relationship between CO and OCS. This is in part motivated by the observations that at the base of the clouds the OCS mixing ratio decreases rapidly while CO increases [8].  $\text{SO}_3$  has been suggested as to play a role in this conversion because this part of the lower atmosphere is uniquely high in  $\text{SO}_3$  from the thermal decomposition of  $\text{H}_2\text{SO}_4$ . Krasnopolsky and Pollack [1] proposed the pathway



This pathway relies on  $(\text{SO})_2$ . Previous lower atmosphere models however did not include  $(\text{SO})_2 \rightleftharpoons \text{SO}$  equilibrium reactions. We find that when including this reaction, reaction 2 is effectively halted. From this we suggest that either OCS and CO are not chemically linked and are responding to independent forcing or a different mechanism is responsible. Future laboratory work could help identify chemical pathways between  $\text{SO}_3$ , OCS, and CO.

### 4. Conclusions

This work is a first attempt to understand the chemical interactions between the lower and middle atmosphere of Venus. We find that some previously proposed chemical pathways break down when a more complete chemistry is included and new challenges arise. Going forward we will investigate the role the clouds themselves play in these chemical processes.

### Acknowledgements

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### References

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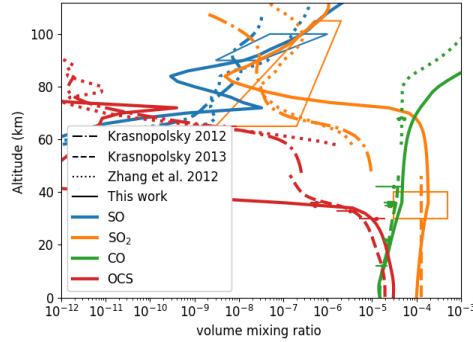


Figure 1: Comparison of our model results to previous models. Observed abundances are shown as points with error bars and boxed regions (which include variability and measurement errors). Because we cannot tune boundary conditions in the cloud layer our model does not match the observations as well as previous more focused models.

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