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Supplementary information

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A dry Venusian interior constrained by atmospheric chemistry

In the format provided by the authors and unedited

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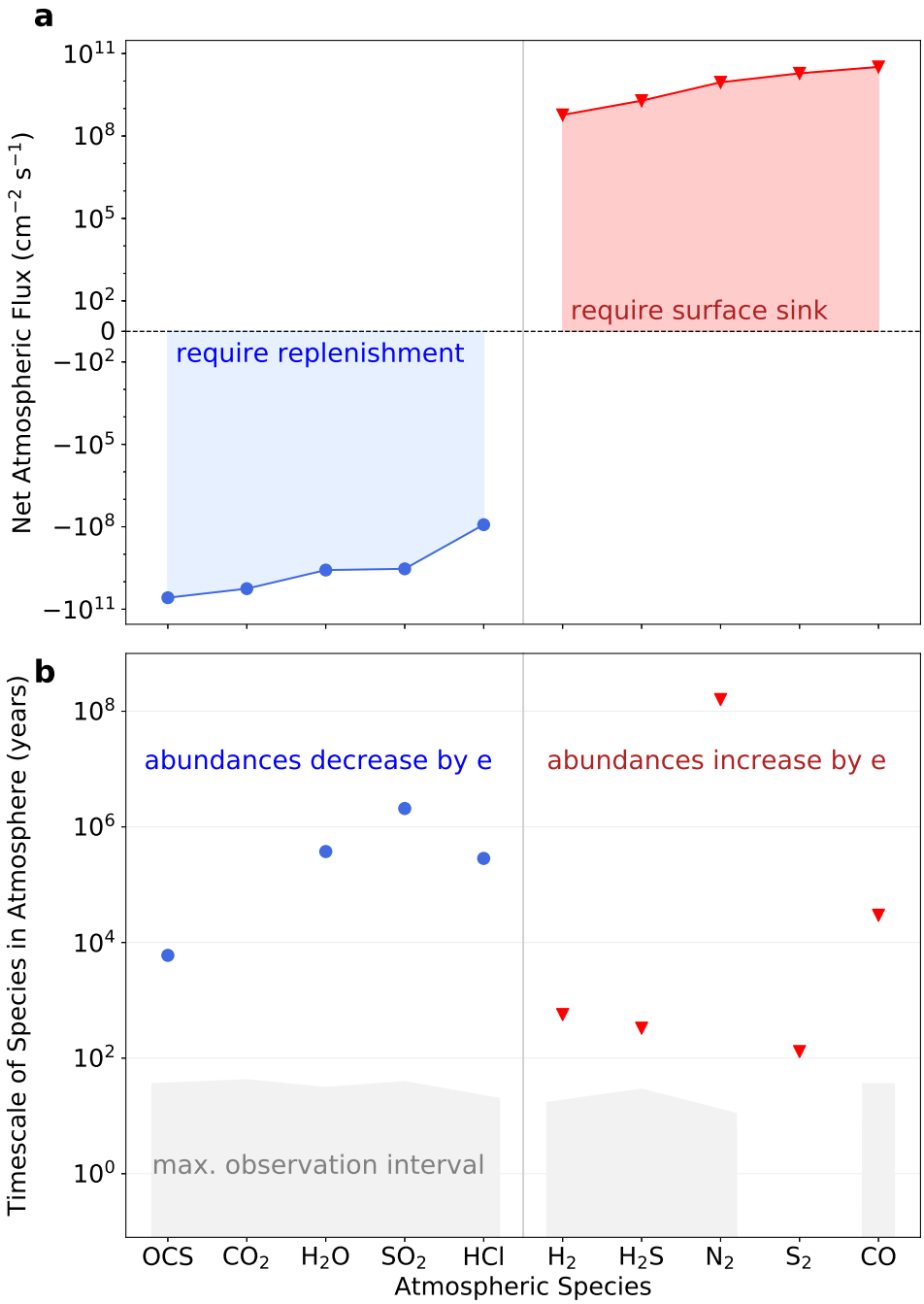


Supplementary Figure 1: Dominant destructive and produced fluxes of species in Venus's atmosphere. a, Calculated net atmospheric flux for the 6 species with the highest rates of destruction (blue line) and production (red line). Species undergoing atmospheric destruction necessitate an equivalent flux for replenishment to maintain atmospheric steady-state (blue shaded region), while species undergoing atmospheric production require a surface sink (red shaded region). **b,** Timescales for species in the atmosphere, determined by the duration it would take for the abundance of the species undergoing destruction to decrease by a factor of e (blue circles), and for the species undergoing production to increase their abundances by a factor of e (red downward pointing triangles). The baseline of lower limits of stability of species in the atmosphere, determined by the largest time interval across observational measurement (grey shaded area). Data sources[2, 3, 4, 5, 6]

Supplementary Text 1: Additional atmospheric production and destruction in the Venusian atmosphere

Other than the key species used to constrain the Venusian volcanic gas chemistry, we calculate other species being atmospherically destroyed in the atmosphere. While not essential for our work, we briefly note the primary reaction pathways dominating over the atmospheric column, beyond OCS, CO_2, H_2O and indirectly SO_2 and CO, reviewed in Subsection Photochemical losses.

HCl is primarily destroyed through the offset in the reaction rates of

$$\mathbf{HCl} + \mathrm{HS} \rightarrow \mathbf{H_2S} + \mathrm{Cl}, \tag{1}$$

$$\mathbf{H_2S} + \mathrm{Cl} \rightarrow \mathbf{HCl} + \mathrm{HS}. \tag{2}$$

in the cloud layer at 45–65 km from the surface.

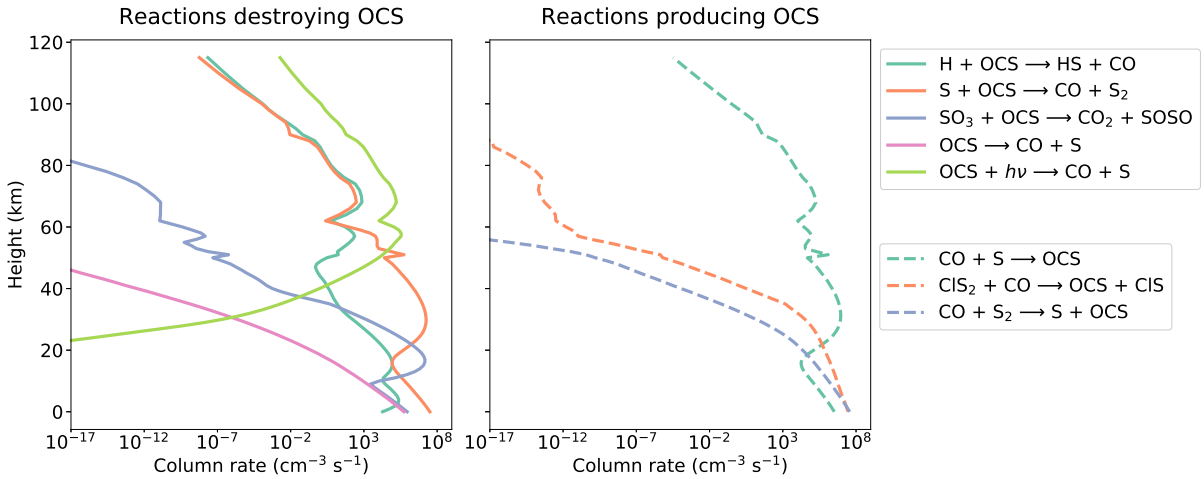
As we are interested in understanding the climate history of Venus, which is intimately tied to the evolution of its water and carbon inventory, we do not look further at nitrogen species in the current work.

Through thermochemical and photochemical processes, some atmospheric species are also being produced in surplus, as shown in Supplementary Figure 1 (top figure, red line). For example, the high rates of destruction of OCS, CO_2, and H_2O, are equivalent to high rates of production of CO, S_2 and H_2S and following elemental abundance conservation (Equations 1–8). These species necessitate a sink to sustain steady-state, through processes not considered in the chemical-kinetic network. These processes can encompass weathering sinks and atmospheric escape, and their analysis is outside the scope of this work.

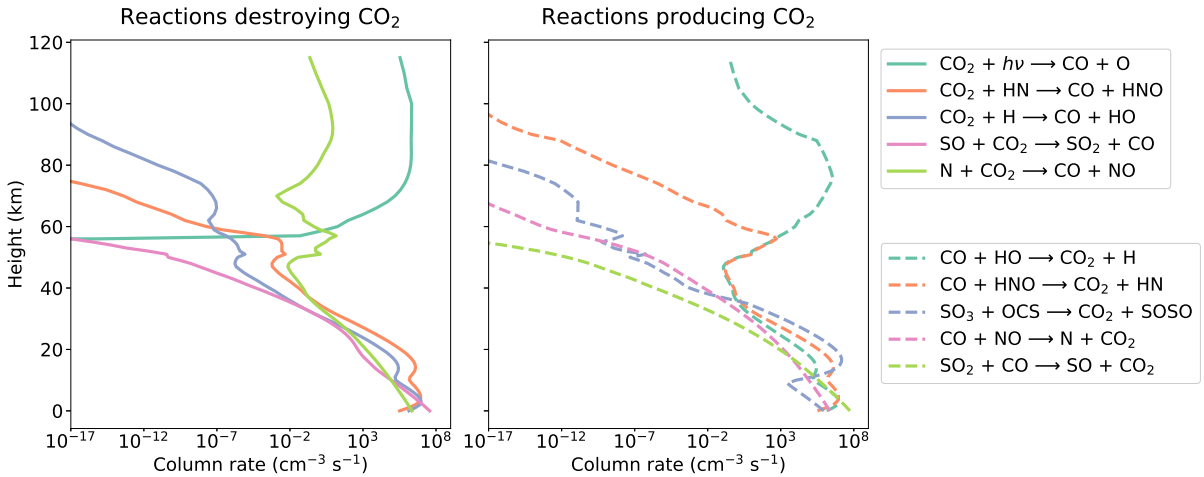
Supplementary Text 2: Reaction rates affecting OCS, CO_2, and H_2O

Individual reaction rates influencing the abundance profiles of OCS, CO_2 and H_2O are calculated at each altitude step. The resulting rates for the most significant reactions producing or consuming these key species are presented in Supplementary Figs. 3–5 as a function of altitude.

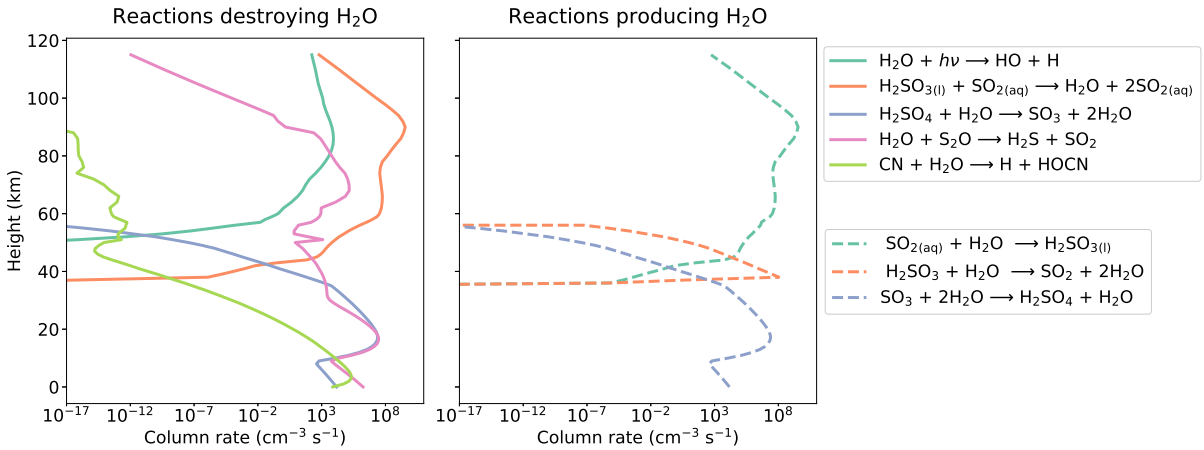
It is important to note that the plotted reaction rates represent the instantaneous rate of each reaction at the final time step for a given altitude. These values essentially capture a "snapshot" of the parcel's chemistry at the last step before the parcel moves, and do not reflect the complete chemical history of the parcel. This is calculated using Eq. 15, where $k(z)$ and n_{X_i} are the rate of the reaction and number density of reactants at the final point in time at which the parcel remains at the given height z. While this analysis effectively identifies the dominant reactions, it does not provide the column-integrated rate at steady state within the Eurlerian frame, which would require integration over time.



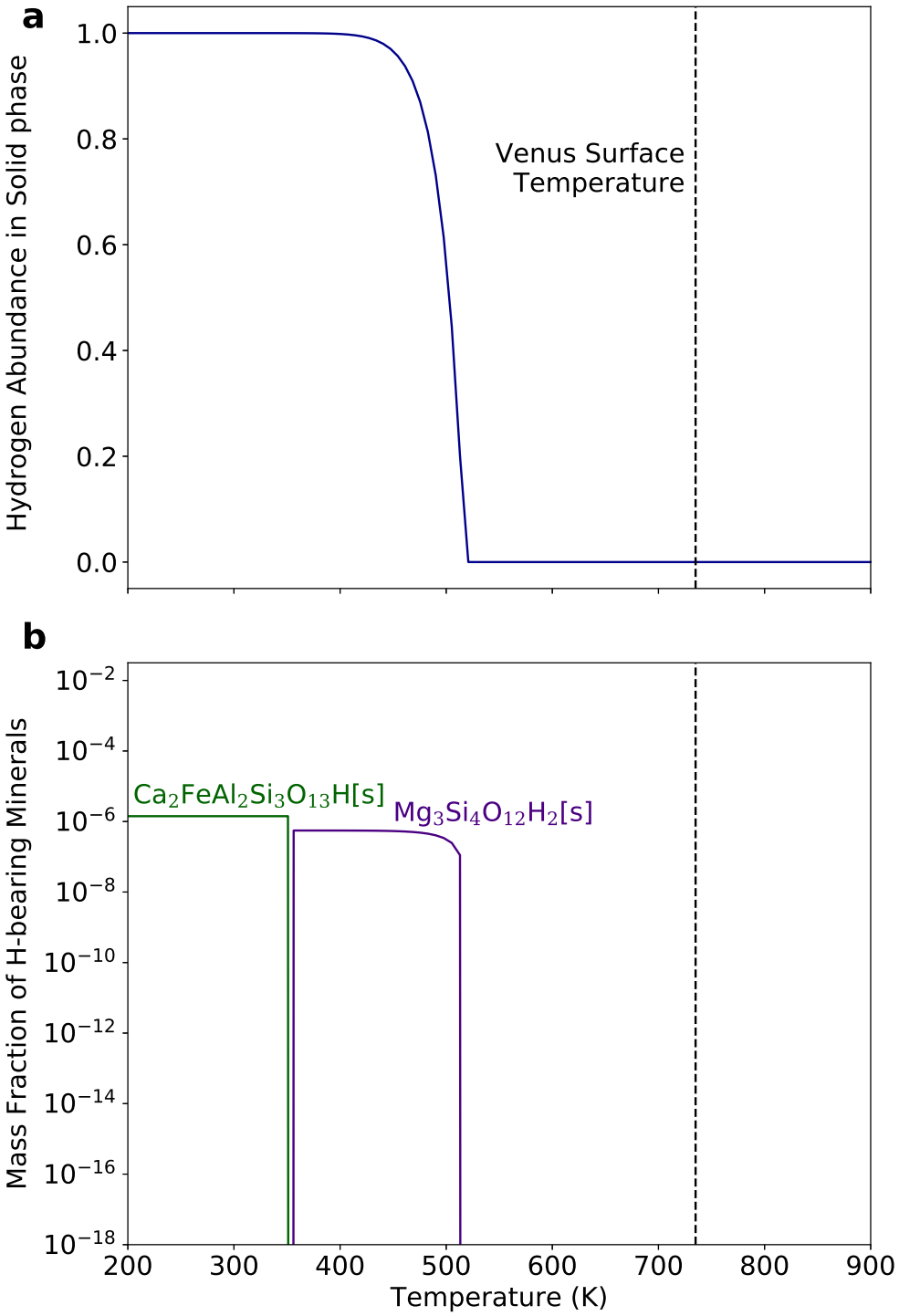
Supplementary Figure 2: Dominant chemical reactions affecting OCS: The dominant chemical reactions producing (left subplot, solid lines) and destroying (right subplot, dashed lines) OCS as a function of altitude. Column rates represent instantaneous values at the final time step for each altitude and do not capture the complete chemical history.



Supplementary Figure 3: Dominant chemical reactions affecting CO_2: The dominant chemical reactions producing (left subplot, solid lines) and destroying (right subplot, dashed lines) CO_2 as a function of altitude. Column rates represent instantaneous values at the final time step for each altitude and do not capture the complete chemical history.



Supplementary Figure 4: Dominant chemical reactions affecting H_2O: The dominant chemical reactions producing (left subplot, solid lines) and destroying (right subplot, dashed lines) H_2O as a function of altitude. Column rates represent instantaneous values at the final time step for each altitude and do not capture the complete chemical history.



Supplementary Figure 5: Hydrogen abundance and mineral composition on the Venusian surface. a, Elemental abundance of hydrogen in the solid phase relative to the total surface-atmosphere hydrogen reservoir, as a function of temperature. Venus's surface temperature is indicated as a reference point (black dashed line). **b,** The mass fraction of hydrogen-bearing minerals at the lower boundary of the Venusian atmosphere, considering chemical and phase equilibrium, plotted as a function of temperature.

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