

Composition and Chemistry of the Neutral Atmosphere of Venus

E. Marcq¹, F. Mills², C. Parkinson³, B. Sandor⁴, A. C. Vandaele⁵

¹: LATMOS, Université de Versailles St-Quentin-en-Yvelines

²: ANU, Canberra

³: Univ. of Michigan

⁴: SWRI, Boulder, CO

⁵: BIRA/IASB, Brussels

European Planetary Science Congress 2014, Cascaís
Session TP3, 2014-09-11



1 Introduction

- Emphasizing variabilities

2 Vertical Profiles

Below the clouds CO, OCS, H₂O

Above the clouds CO, HF, HCl, H₂O, HDO, SO₂

3 Horizontal variability

Latitudinal CO, OCS, SO₂, H₂O

Local time CO, SO₂, SO

4 Temporal variability

Above the clouds SO₂, SO

Below the clouds H₂O? HDO?

5 New detections / Upper limits

Upper mesosphere ClO, H₂SO₄

Cloud layer NO, OCS

Lower troposphere H₂S

6 Open Questions

- Chemistry within cloud region
- Isotopic ratios (long-term evolution)
- Interactions with surface
- Which laboratory studies needed?



1 Introduction

- Emphasizing variabilities

2 Vertical Profiles

Below the clouds **CO**, OCS, H₂O

Above the clouds CO, HF, HCl, H₂O, HDO, SO₂

3 Horizontal variability

Latitudinal **CO**, OCS, SO₂, H₂O

Local time CO, SO₂, SO

4 Temporal variability

Above the clouds SO₂, SO

Below the clouds H₂O? HDO?

5 New detections / Upper limits

Upper mesosphere ClO, H₂SO₄

Cloud layer NO, OCS

Lower troposphere H₂S

6 Open Questions

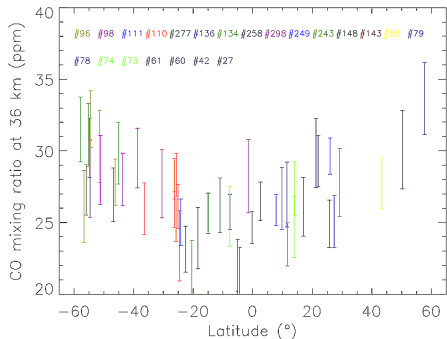
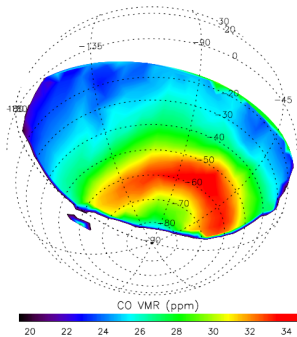
- Chemistry within cloud region
- Isotopic ratios (long-term evolution)
- Interactions with surface
- Which laboratory studies needed?



VIRTIS

Tsang et al. (2008) Maximum near 60°S between 25 – 40 km

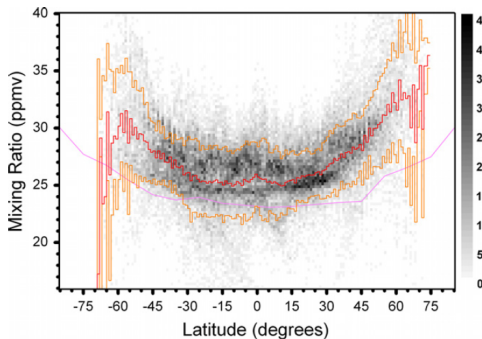
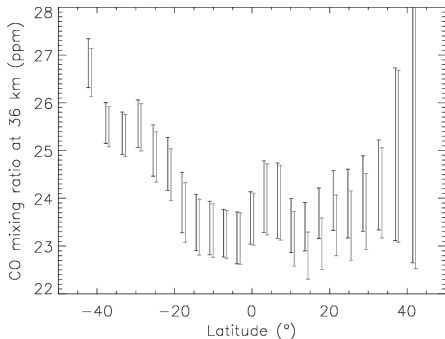
Marcq et al. (2008) From 31 ± 2 to 25 ± 2 ppmv



Ground based

Marcq et al. (2005,2006) SpeX/IRTF, $R \sim 2000$

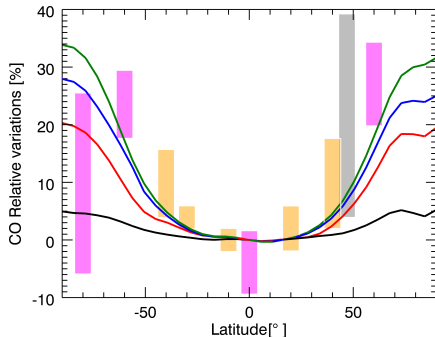
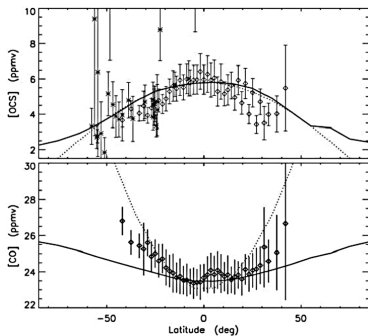
Cotton et al. (2012) AAT/IRIS2, $R \sim 2400$



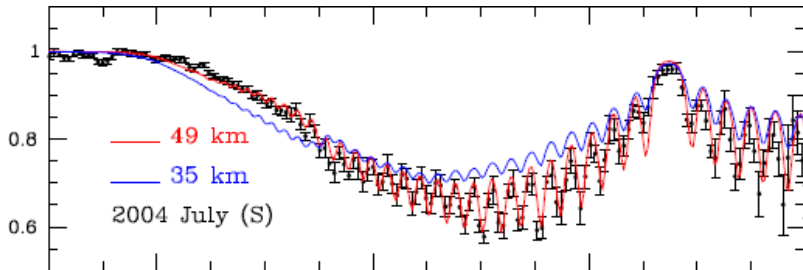
2D (Yung et al., 2009) $\text{OCS} + \text{X} \rightarrow \text{CO} + \text{Y}$ ($3 \cdot 10^{-8} \text{ s}^{-1}$ at 30 km)

3D passive (Marcq&Lebonnois, 2013) $10^8 \text{ s} \leq \tau_{\text{CO}} \leq 5 \cdot 10^8 \text{ s}$

- **Interpretation** CO transported down from mesosphere in polar collar by Hadley-cell like circulation

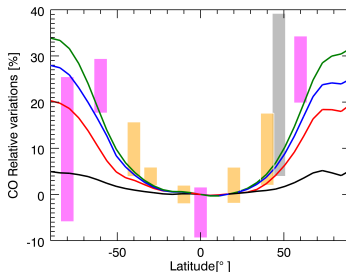
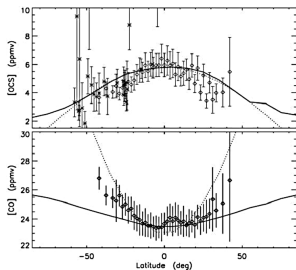


Cotton et al. (2012) Improved fit if CO variations occur near 40 – 50 km



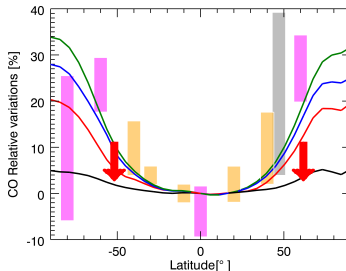
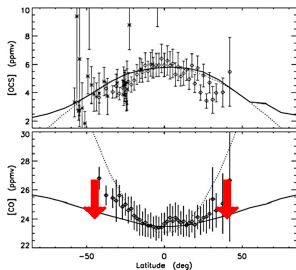
Cotton et al. (2012) Improved fit if CO variations occur near 40 – 50 km

- **Consequence** $\text{OCS} + \text{X} \rightarrow \text{CO} + \text{Y}$ loss rate near 10^7 s and $\tau_{\text{CO}} \sim 10^7 \text{ s}$

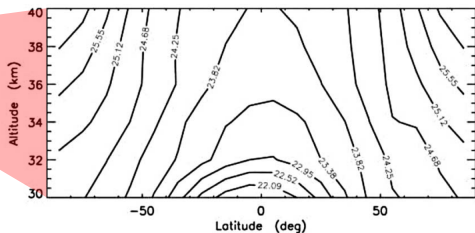
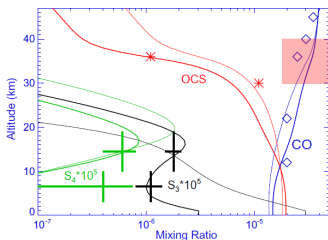


Cotton et al. (2012) Improved fit if CO variations occur near 40 – 50 km

- **Consequence** $\text{OCS} + \text{X} \rightarrow \text{CO} + \text{Y}$ loss rate near 10^7 s and $\tau_{\text{CO}} \sim 10^7 \text{ s}$



- CO (& OCS) latitudinal distributions **qualitatively consistent with Hadley cell-like circulation** extending up into lower mesosphere
 - CO & OCS vertical gradients near equator consistent with net:
 $\text{OCS} + \text{X} \rightarrow \text{CO} + \text{Y}$
 - $\text{OCS} + ? + \text{aerosol} \rightarrow \text{CO} + ? + \text{aerosol}$
 - $\text{S} + \text{OCS} \rightarrow \text{CO} + \text{S}_2$
 - $\text{SO}_3 + 2 \text{OCS} \rightarrow \text{CO}_2 + \text{CO} + \text{SO}_2 + \text{S}_2$
- All at least somewhat speculative!**
- CO & OCS high latitude vertical gradients may **not** be consistent!



1 Introduction

- Emphasizing variabilities

2 Vertical Profiles

Below the clouds CO, OCS, H₂O

Above the clouds CO, HF, HCl, H₂O, HDO, SO₂

3 Horizontal variability

Latitudinal CO, OCS, SO₂, H₂O

Local time CO, SO₂, SO

4 Temporal variability

Above the clouds SO₂, SO

Below the clouds H₂O? HDO?

5 New detections / Upper limits

Upper mesosphere ClO, H₂SO₄

Cloud layer NO

Lower troposphere H₂S

6 Open Questions

- Chemistry within cloud region
- Isotopic ratios (long-term evolution)
- Interactions with surface
- Which laboratory studies needed?



1 Introduction

- Emphasizing variabilities

2 Vertical Profiles

Below the clouds CO, OCS, H₂O

Above the clouds CO, HF, HCl, H₂O, HDO, SO₂

3 Horizontal variability

Latitudinal CO, OCS, SO₂, H₂O

Local time CO, SO₂, SO

4 Temporal variability

Above the clouds SO₂, SO

Below the clouds H₂O? HDO?

5 New detections / Upper limits

Upper mesosphere ClO, H₂SO₄

Cloud layer NO

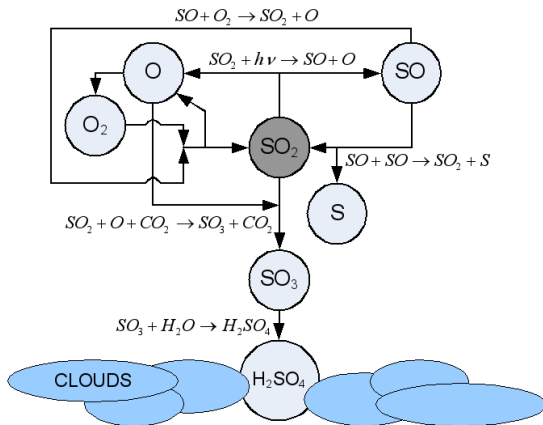
Lower troposphere H₂S

6 Open Questions

- Chemistry within cloud region
- Isotopic ratios (long-term evolution)
- Interactions with surface
- Which laboratory studies needed?



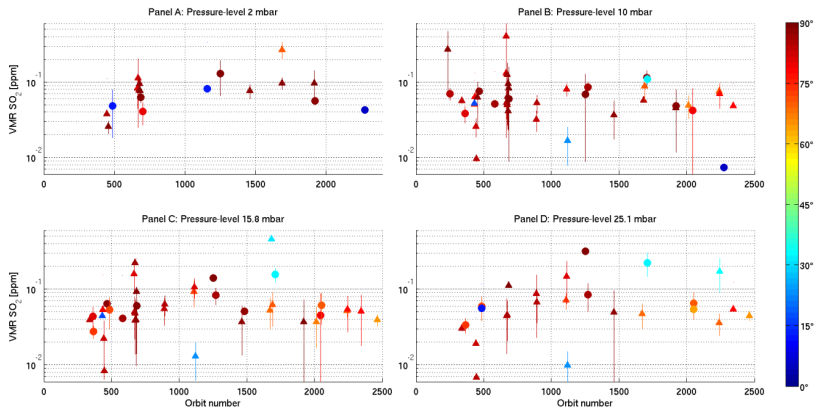
- Successful modeling by Yung & DeMore (1982) of SO₂ observations near cloud top
 - O from CO₂ photolysis primarily consumed by CO
 - Recombination and oxidation of SO₂ to H₂SO₄



Long-term variability

Mahieux et al. VEx/SOIR occultations

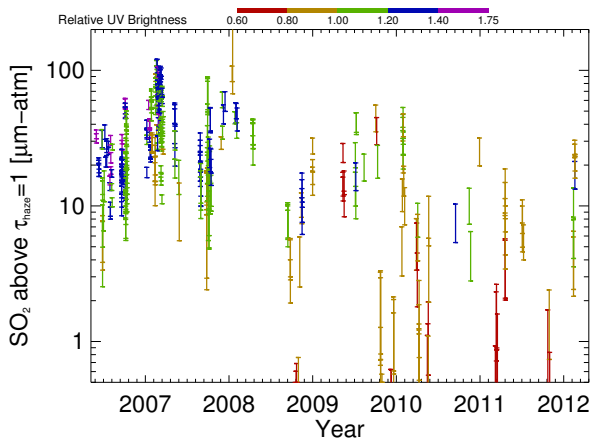
Marcq et al. (2013) VEx/SPICAV-UV nadir



Long-term variability

Mahieux et al. VEx/SOIR occultations

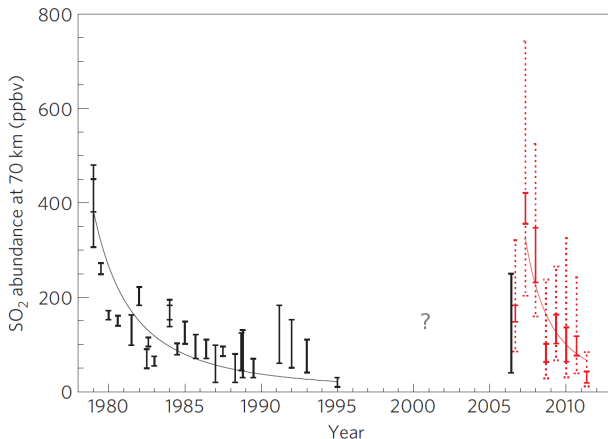
Marcq et al. (2013) VEx/SPICAV-UV nadir



Long-term variability

Mahieux et al. VEx/SOIR occultations

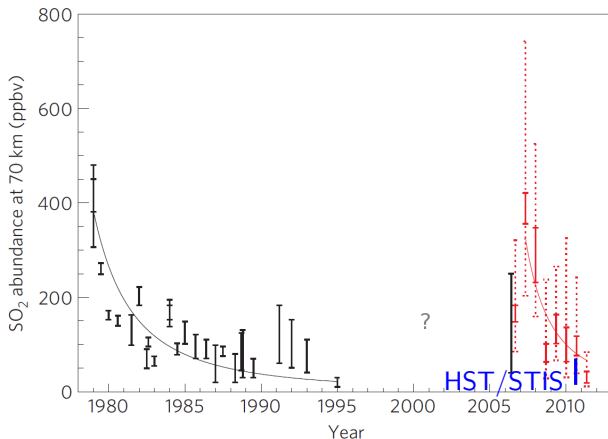
Marcq et al. (2013) VEx/SPICAV-UV nadir



Long-term variability

Mahieux et al. VEx/SOIR occultations

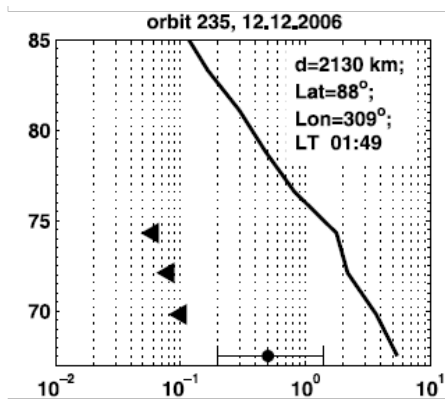
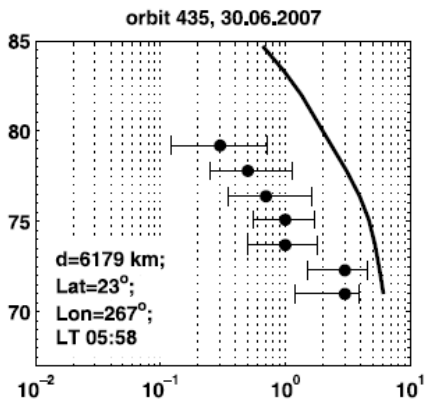
Marcq et al. (2013) VEx/SPICAV-UV nadir



Latitudinal variations

Belyaev et al. (2008) Decreasing with increasing latitude

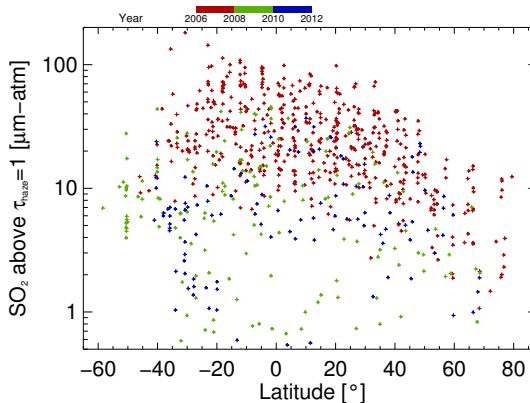
Marcq et al. (2011,2013) Similar trend whenever SO₂ abundant



Latitudinal variations

Belyaev et al. (2008) Decreasing with increasing latitude

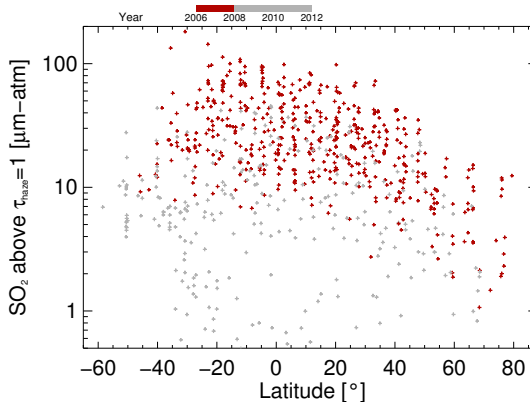
Marcq et al. (2011,2013) Similar trend whenever SO₂ abundant



Latitudinal variations

Belyaev et al. (2008) Decreasing with increasing latitude

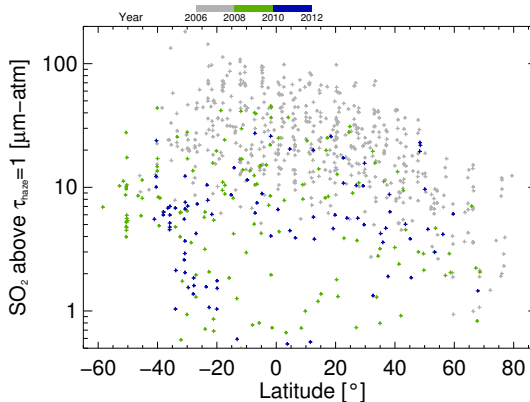
Marcq et al. (2011,2013) Similar trend whenever SO₂ abundant



Latitudinal variations

Belyaev et al. (2008) Decreasing with increasing latitude

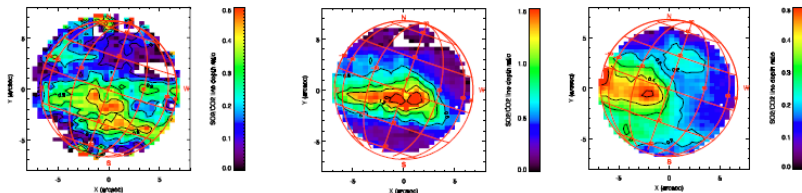
Marcq et al. (2011,2013) Similar trend whenever SO₂ abundant



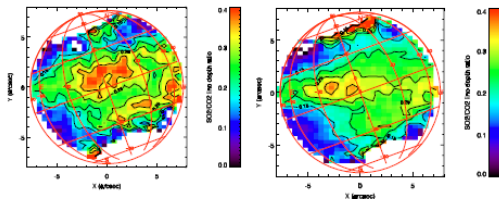
Short scale variability

Encrenaz et al. SO₂/CO₂ maps @ 7 μm (cloud top level)

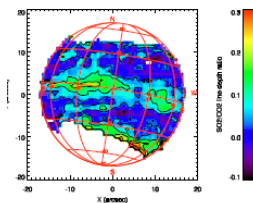
10, 11 & 12 January 2012 - Timescale: 1 day



4 October 2012 - Timescale: 2 hours

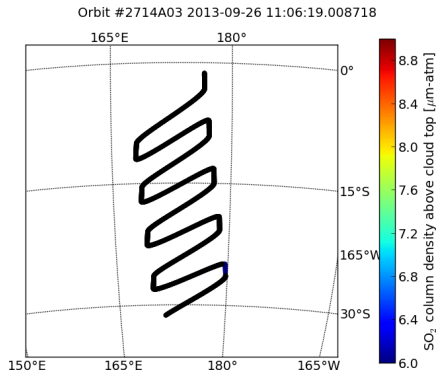
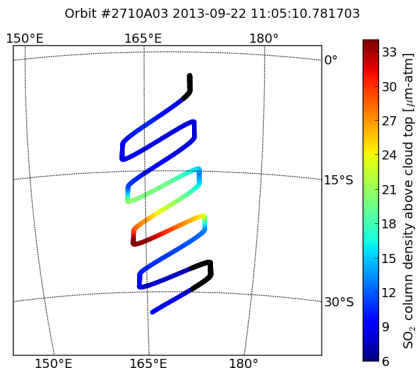


26 February 2014



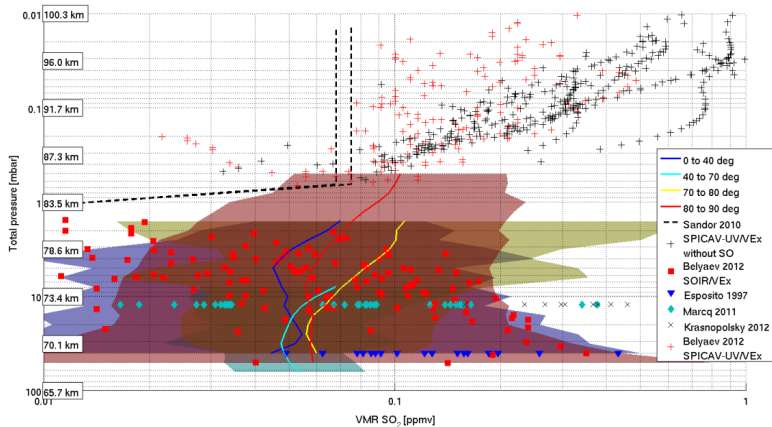
Short scale variability

Marcq et al. Mapping mode of SPICAV-UV. Spatial variability over 10^2 to 10^3 km, temporal variability over ~ 1 day.



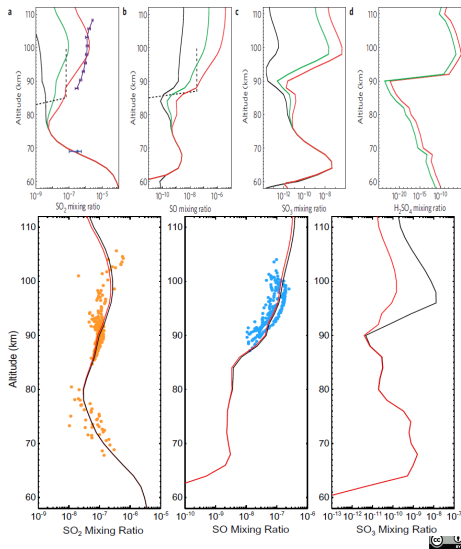
Summary & Vertical profiles

- Two distinct regions
 - 70-80 km Source: lower atmosphere
 - 85-100 km Source: ?



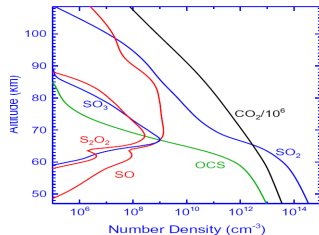
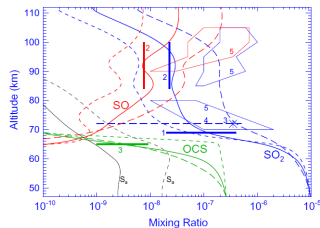
Zhang et al. (2010, 2012)

- Source of upper SO₂ derived from putative H₂SO₄ reservoir
- However, Sandor et al. (2010) derived an upper limit of 3 ppbv for H₂SO₄ at 85 – 100 km
 - Much lower than the ~ 1000 ppb proposed by Zhang et al. (2010)
 - Still lower than near-saturated H₂SO₄ from Zhang et al. (2012)



Krasnopolsky (2012)

- No photolysis of H₂SO₄
 - ⇒ No SO₂ inversion layer
- Formation of H₂SO₄ in a narrow layer near cloud top
 - ⇒ Steep decrease of SO₂ (and H₂O) above the clouds
 - Delivery of SO₂ (and H₂O) through this bottleneck controls chemistry above the clouds
- Strong variability (factor ~ 30 above 70 km) of S-bearing species with:
 - variations of eddy diffusion near 60 km
 - variations of SO₂/H₂O ratio at lower boundary



- No modelled atmospheric source of SO₂ or SO is known above 85 km, but **all observations require one must exist.**
- Observations require a **third sulphur reservoir** to balance the sulphur budget (S_x ?)
- Temporal variations of SO₂, SO, SO₂+SO and SO₂/SO are strong, **however** physical mechanisms driving these variabilities are not yet identified.
- Discrepancies between sub-mm measurements of H₂SO₄ (Sandor et al., 2012) and photochemical models emphasize the importance of **new research in photochemical-dynamical modeling.**

