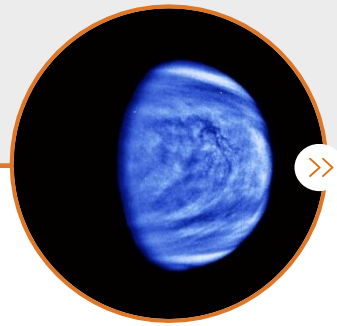
Composition of the Venusian atmosphere

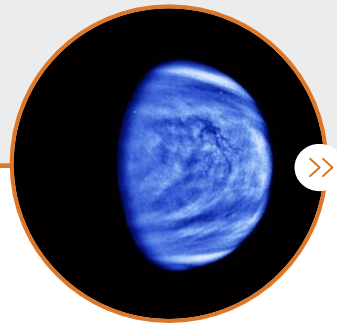
Ann C. Vandaele

BIRA-IASB, Brussels, Belgium



- What we know of the composition of the atmosphere
  - Neutral atmosphere
  - Clouds structure & composition
  - Based on previous observations from space, from Earth

- What is missing, what we do not understand

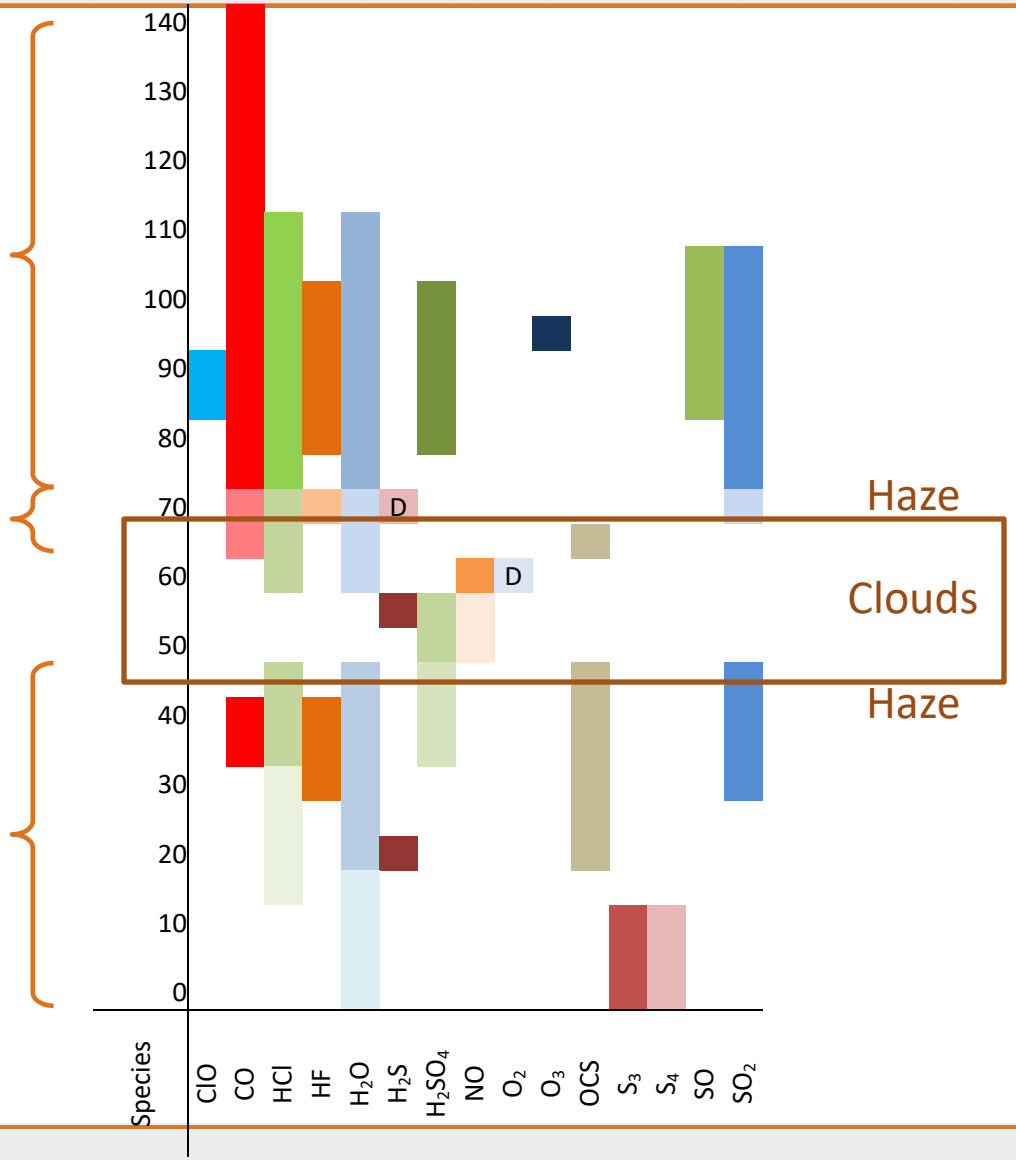


What we know

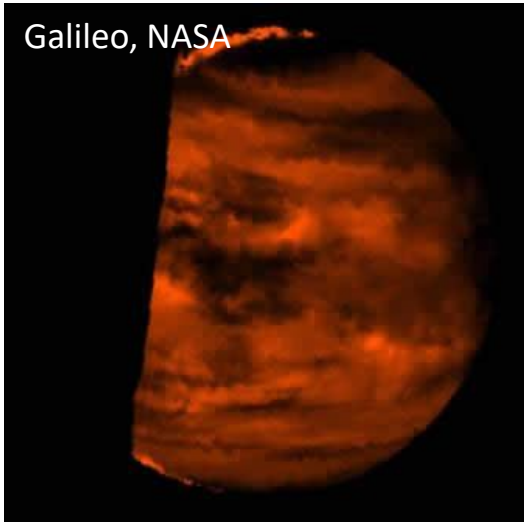
Vertical information
(solar/stellar occultations,
GB sub-mm)

Top of the clouds
(GB & space nadir; IR, UV)

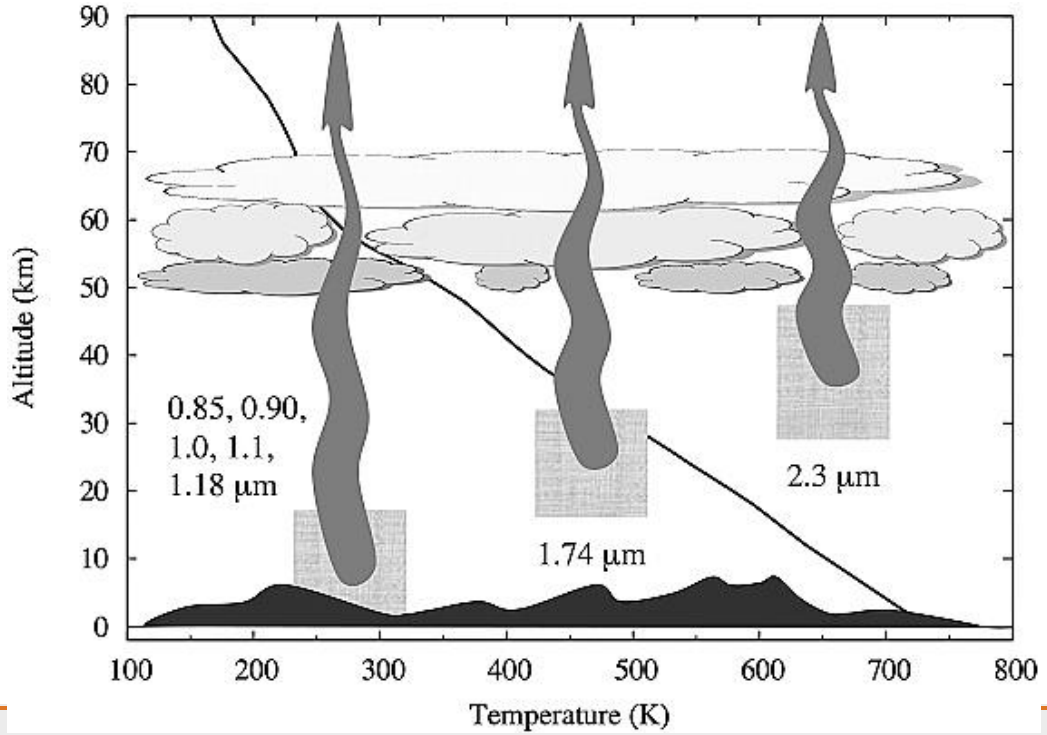
Below the clouds
(GB & Space, IR)



Below the clouds



- Need to look through the clouds
  - Infrared
  - Only during the night
  - Only through 'Atmospheric transparent windows'



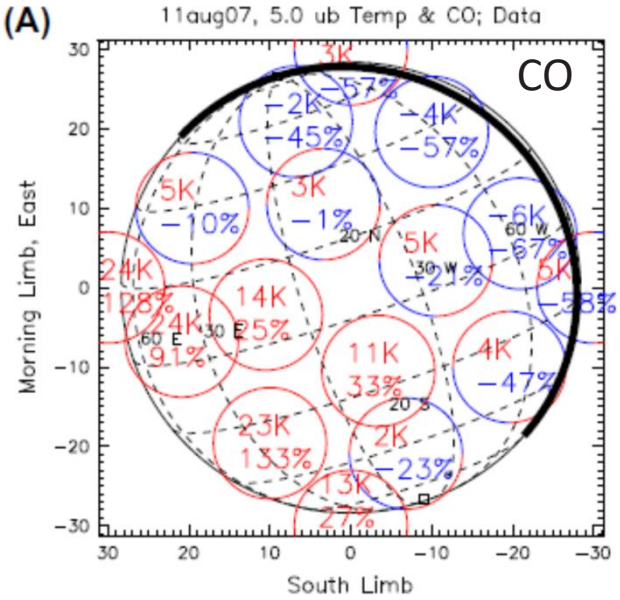
(Bézard and De Bergh, JGR 2007)

➔ Limited number of species
➔ Limited vertical information
➔ Sparse information close to the surface
➔ Need temperature profiles

Above the clouds

- Observations
  - **Solar/stellar occultation, limb**: high vertical resolution, high sensitivity, different species can be detected, but at terminator (solar) or night side (stellar)
  - **sub-mm GB**: vertical information from absorption line profile, 70-100 km; require a temperature contrast between sounded altitude and deeper layers; Day-Night
  - **GB & space nadir, UV & IR dayside**: ~top of the clouds, depending on the wavelength; short-term spatial and temporal variations

- High variability
  - In time and space on short-term/scale
  - On long-term



Clancy et al (2012)

Encrenaz et al (2020)

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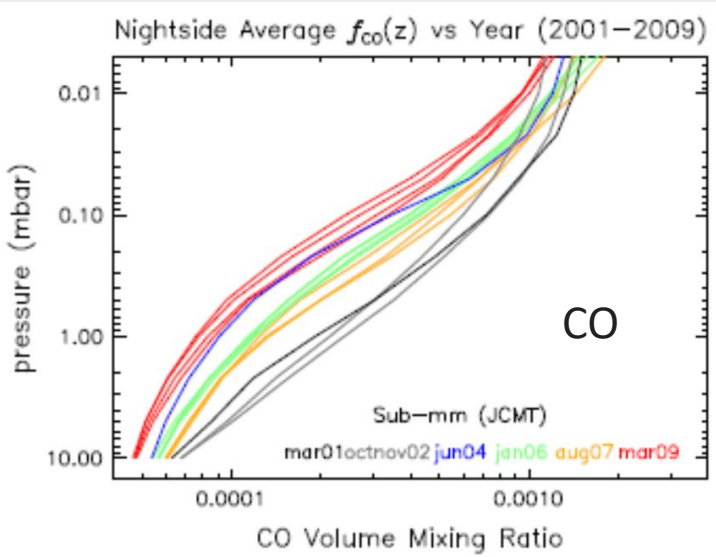
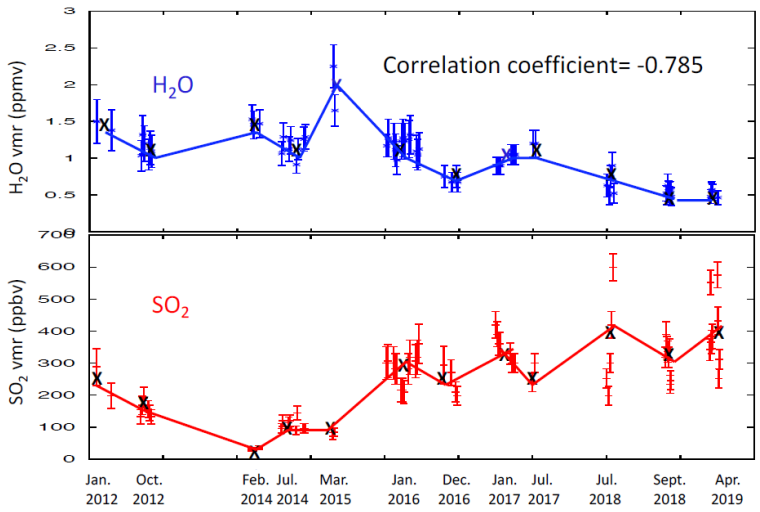


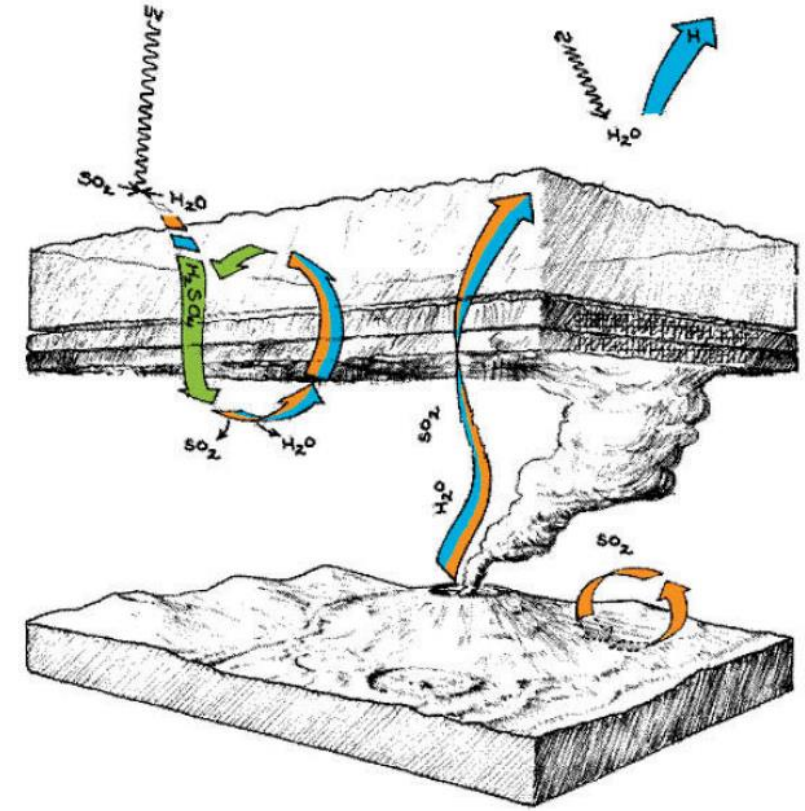
Clancy et al (2012)

Long-term anticorrelation of the of H_2O and SO_2 variations

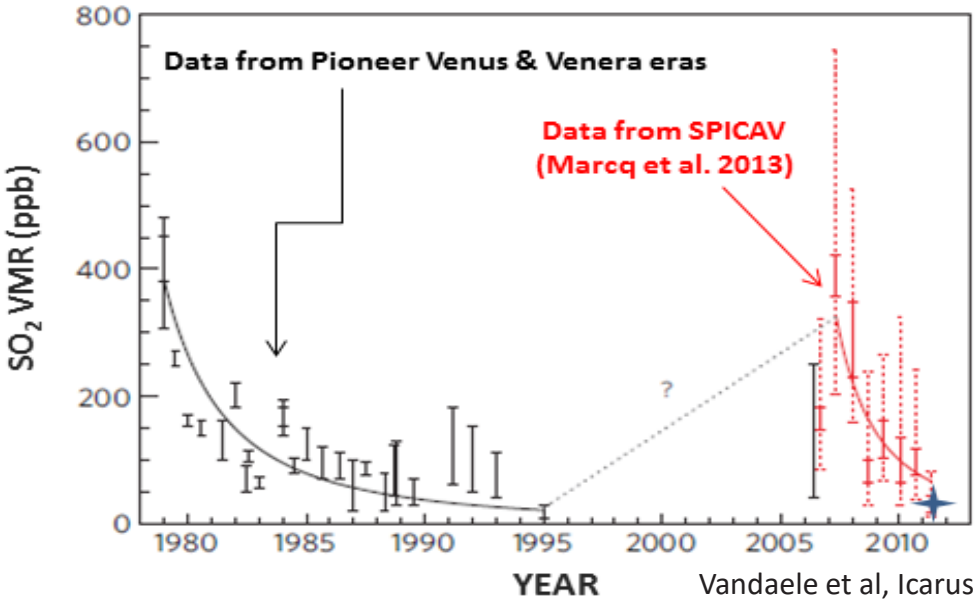


Encrenaz et al (2020)

Example: mesospheric SO_2



Courtesy of David Grinspoon and Carter Emmart

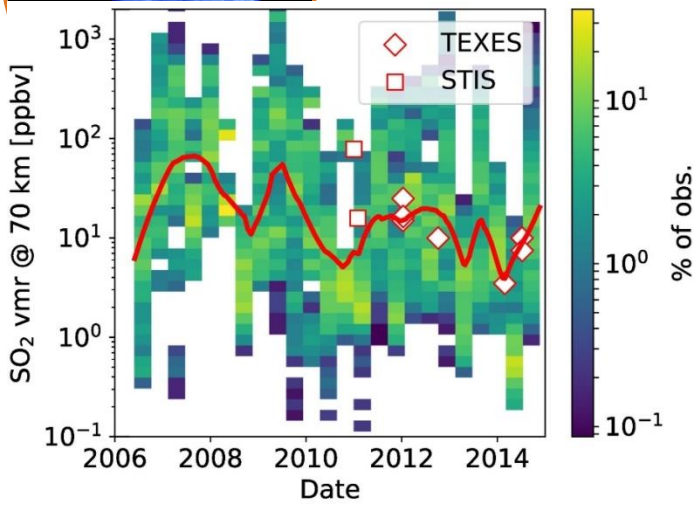


Vandaele et al, Icarus (2017)

Venus Express found episodic injection of SO_2 into the mesosphere

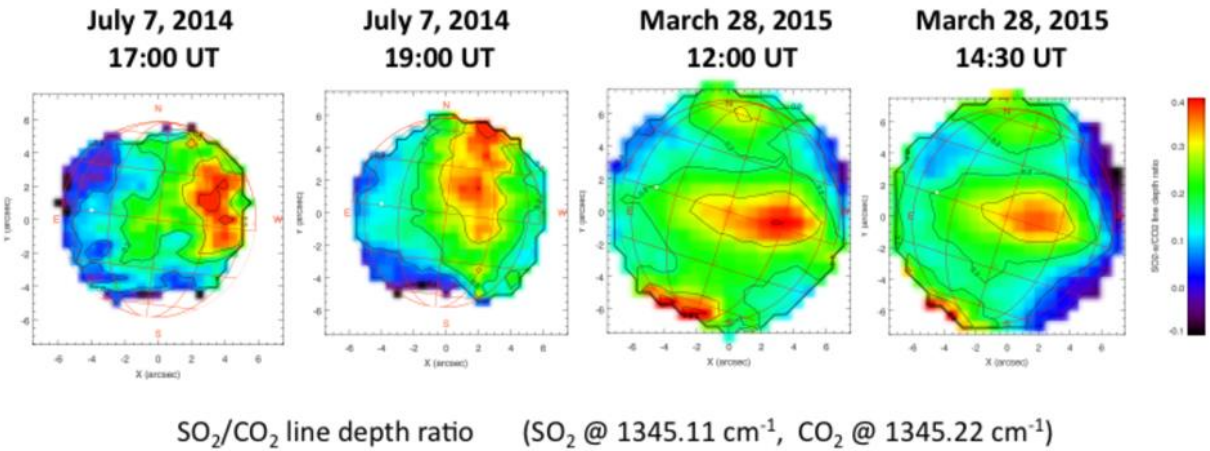
- Is this an connected to volcanic activity ?
  (like Pinatubo)
- Or is it dynamical variability ?
  (like El Niño / La Niña)

Example: mesospheric SO_2



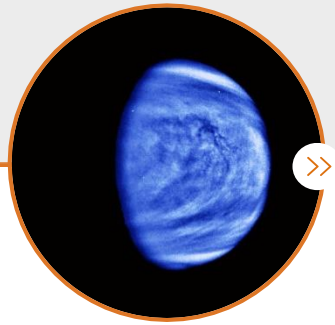
Marcq et al, Icarus (2020)

- Mesospheric SO_2 is highly variable – spatially and temporally.
- Local mesospheric SO_2 enrichment = enhanced upwelling of tropospheric air.
- *What causes these upwellings?*

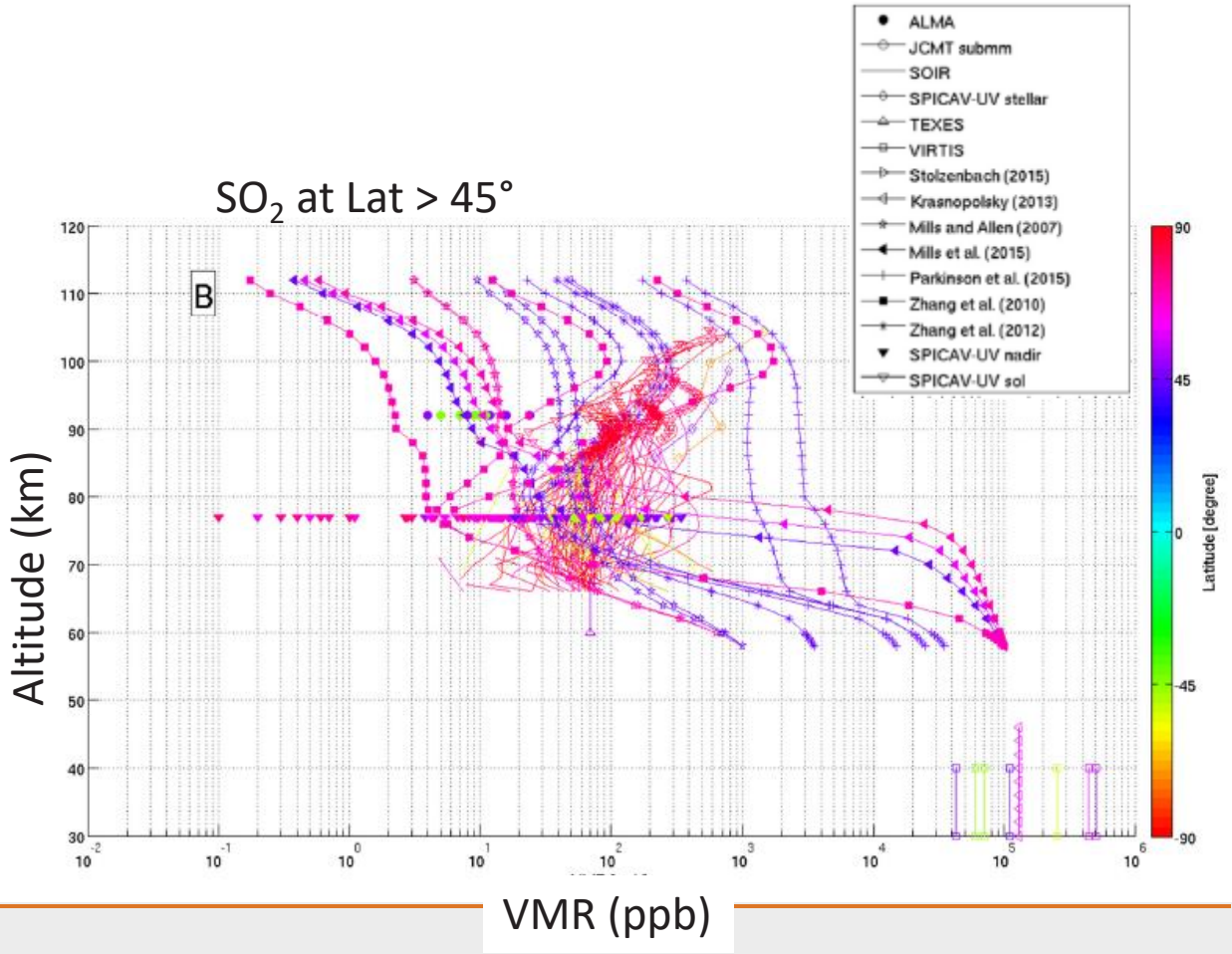


Encrenaz et al (2013)

Link between troposphere and above the clouds SO_2

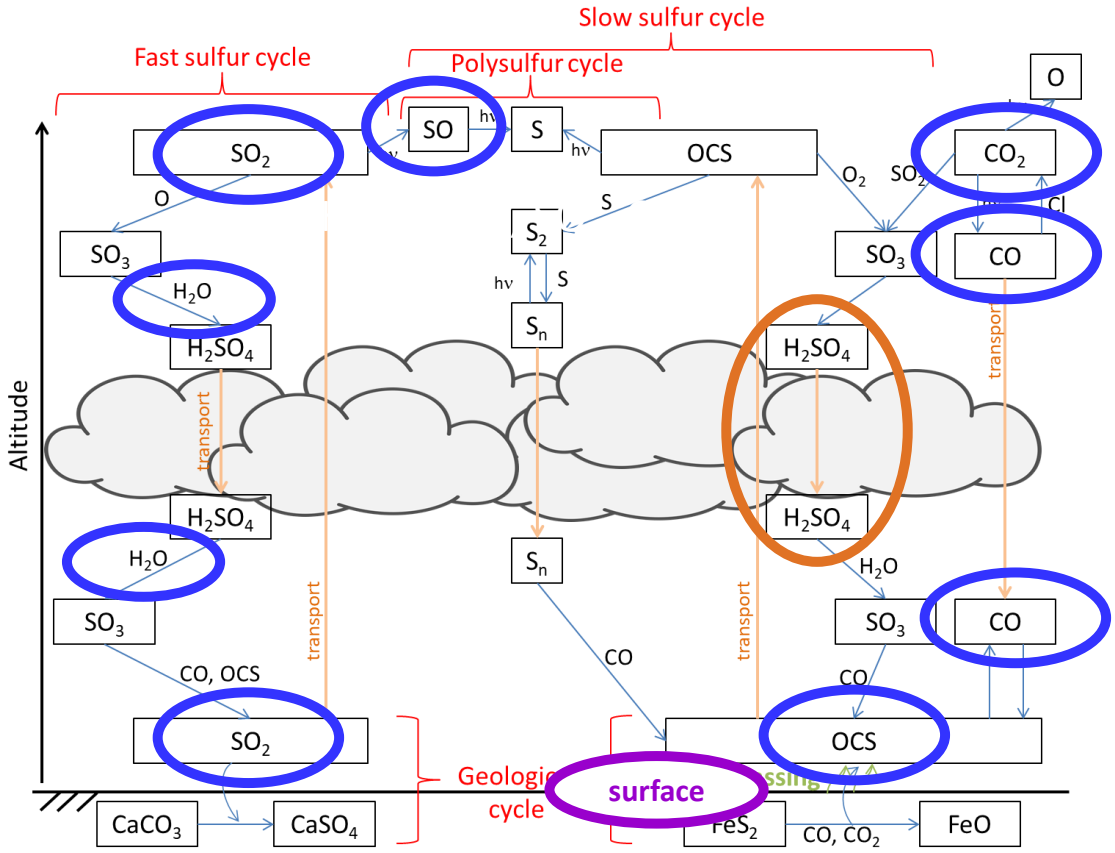


- Decrease of 3 orders of magnitude between 30-40 km and top of the clouds
- Models cannot reproduce the strong gradient through the clouds

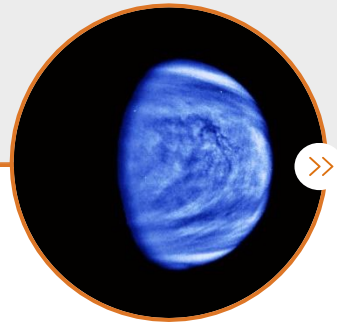


Missing species

- Example – Sulfur cycle
- SO_3, $(SO)_2$, Sn
- Liquid H_2SO_4
- O_2
- Also missing laboratory supporting data



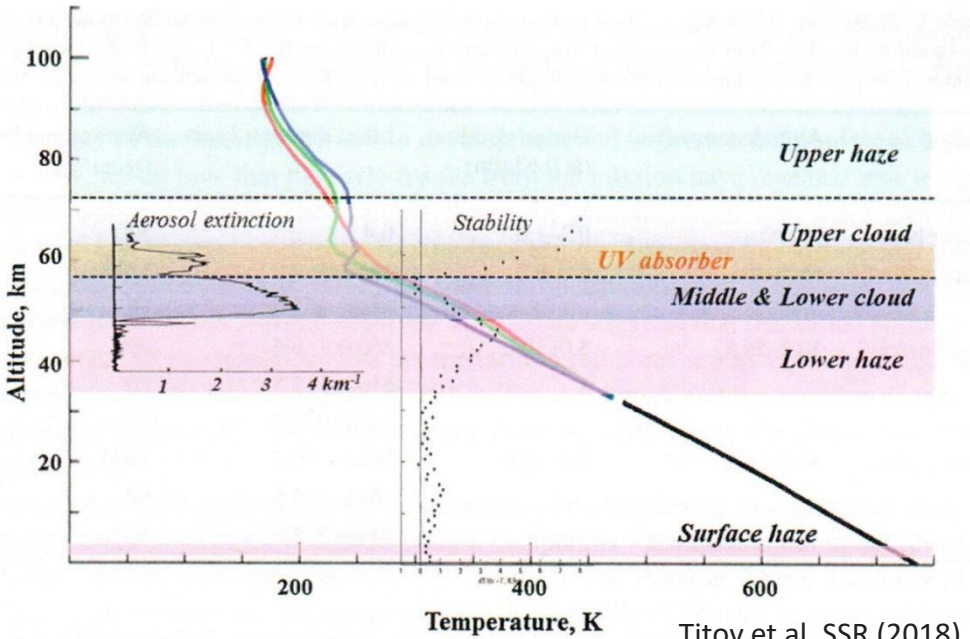
Vandaele et al, ORE (2020)



Clouds

- Impact on the radiative balance – impact on retrieval below the clouds
- Vertical structure - Different 'modes'
- Refractive index compatible with 75-85% H_2SO_4
  - but Glory observations compatible with higher RI
  - Descent probes found traces of P, S, Cl, Fe

  ➔UV absorber in the upper clouds still unidentified
- Structure/composition highly variable wrt latitude, spatial & temporal scales

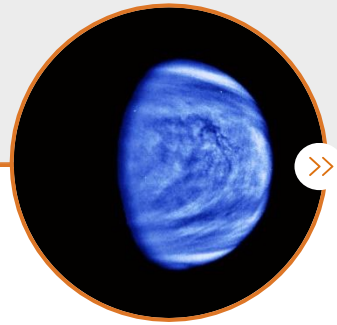


Titov et al, SSR (2018)

➔ Need *in situ* observations of the composition & structure

➔ Long-lived aerial platforms sounding different altitudes, latitudes

➔ High resolution spectra to identify UV absorber



Final words

- Venus surface-atmosphere should be investigated as one system:
  - Need to identify the role of surface's changes, eventually volcanism, in supplying the atmosphere
  - Need to understand the role of dynamics in the variability of trace gases and exchanges between the low atmosphere and that above the clouds
  - Need to better understand the chemistry & composition of the clouds ➔ need also to know the gaseous composition & chemistry below the clouds
  - Below the clouds:
    - we need to characterize the spatiotemporal variability, BUT remote sensing is restricted to the night
    - We need more vertical information, BUT remote sensing restricted to specific IR windows, i.e. altitudes

➔ Need of holistic approach, including different assets/platforms/instruments

➔ in situ observations of the composition & structure within and below the clouds

➔ Orbiter investigation of the surface and atmosphere above the clouds