Evidence for SO_2 Long-term variability at Venus' cloud top

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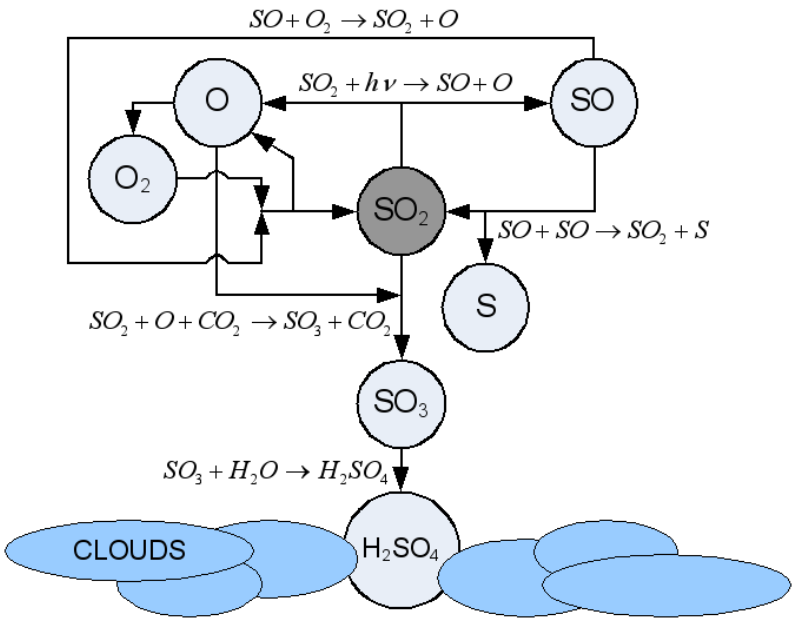
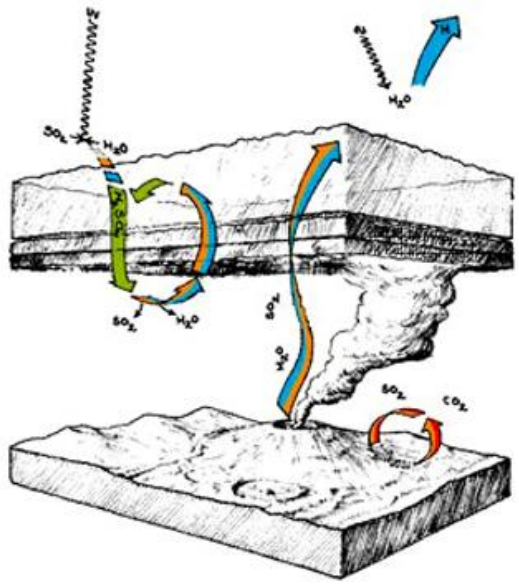
Why looking at SO_2 ?

- SO_2 linked to:
  - Geological activity Long-term ($\sim 10^7$ yr) source for SO_2 assumed to be volcanic outgassing.
  - Cloud formation (and energy deposition) SO_2 is a precursor species to H_2SO_4 through photo-oxidization
  - General circulation Short-term source for SO_2 above the clouds located in lower atmosphere (150 ppmv).





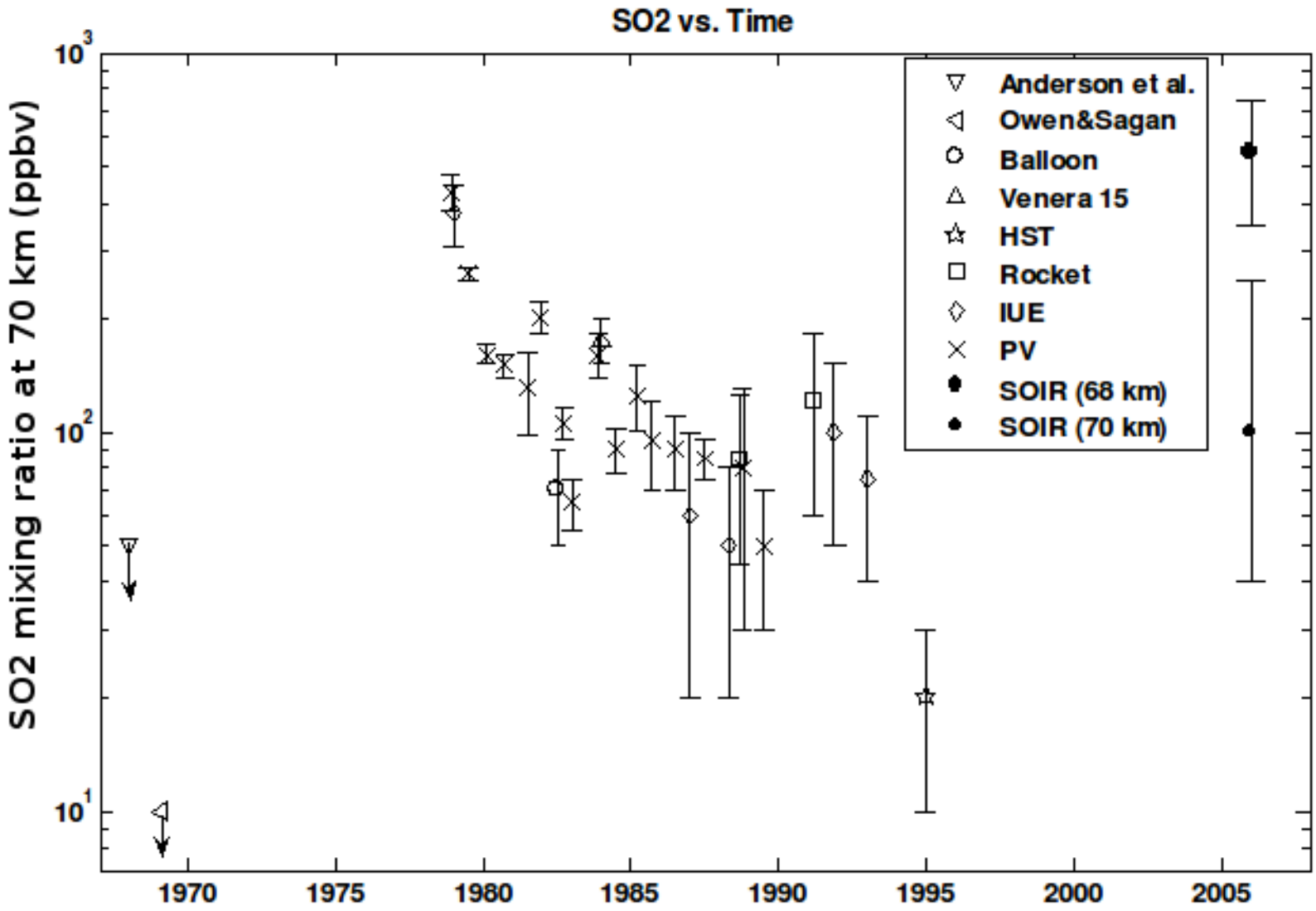
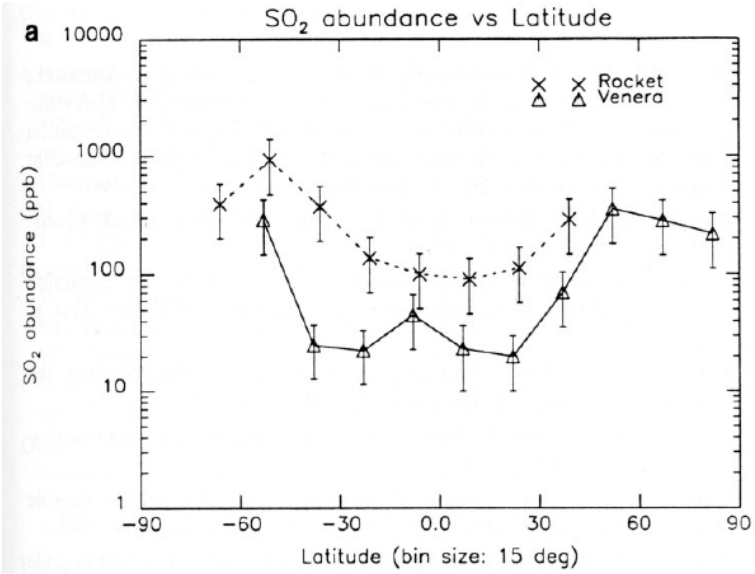


Figure: from Esposito et al. (1997)

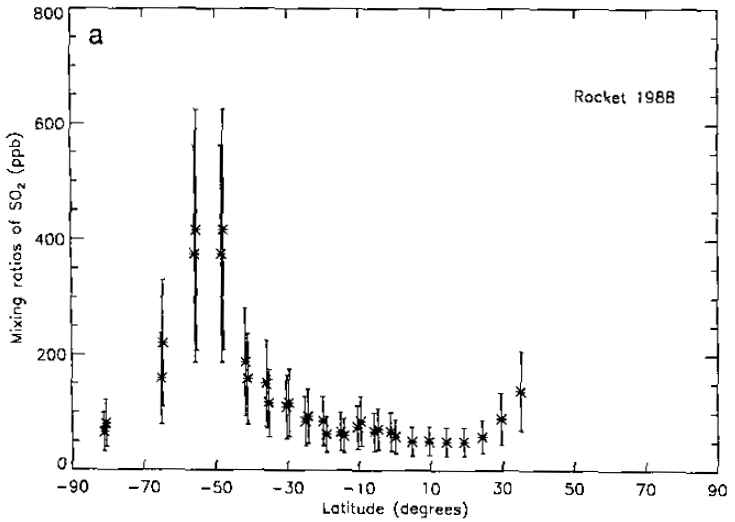
- Venera 15

  1993 Zasova et al., IFS: **Equator to pole increasing gradient** (by a factor of ~ 10 at high latitudes ($> 30°$))



- Rocket

  1994 Na et al., UV: similar trend. Explained by faster photo-dissociation rate at lower latitudes (lower SZA).



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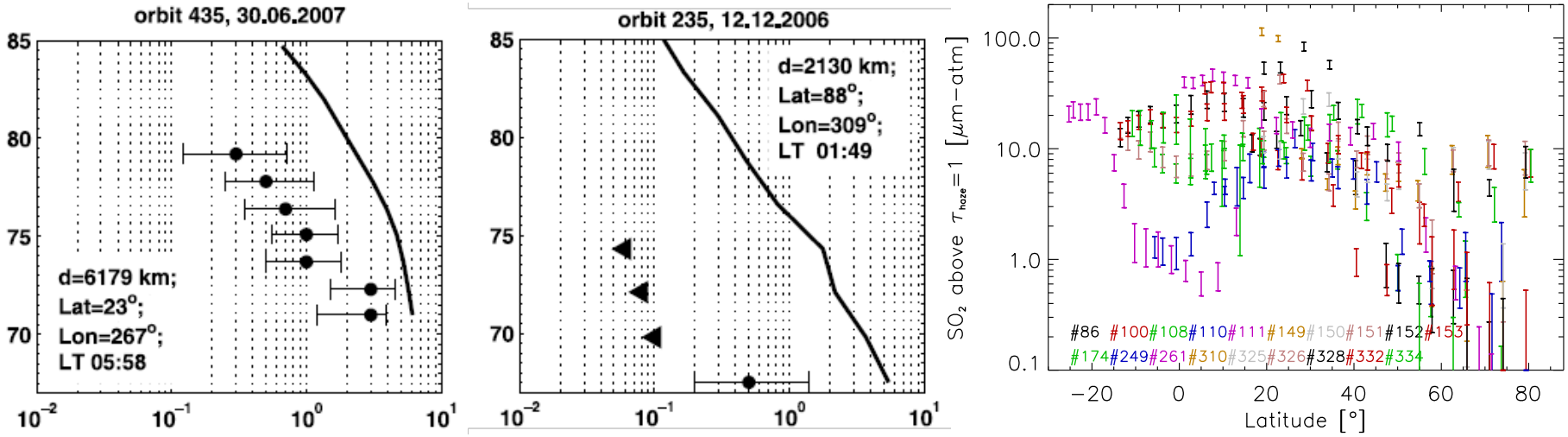
- High levels of SO_2
  - 2008 Belyaev et al., SOIR: $\sim$ **1 ppmv** at cloud top (low latitudes), scale height between 3 km and 1 km.
  - 2010 Marcq et al., SPICAV-UV: similar abundances.
- Latitudinal variations
  - Both studies found the latitudinal gradient reversed compared to the 1980s.



- SPICAV-UV
  - $170 - 320$ nm, 1.5 nm spectral resolution
  - FOV : $0.24° \times 0.94°$ with slit, spatial resolution $0.7'$
  - **Nadir** mode (**Any** emission angle)
  - **Dayside** (SZA $< 89°$)

- About 200 selected orbits
  - From orbit #23 to #2100
  - Science cases
    - Mostly pericenter and off-pericenter.
    - Latitudinal scans (preferred) or spot-pointing.

- Model
  - Same as **Marcq et al. (Icarus, 2011)**
  - σ(SO) needs to be improved!
- Fitting
  - First guess using a multilinear interpolation on lookup tables.
  - Final estimate by running the Fortran model inside the IDL Levenberg-Marquardt routine to retrieve N_{SO_2} (SO_2 column density above $\tau_{haze} = 1$).
  - Translation into mixing ratio q_{SO_2} at 72km dependent on τ_{haze} profile.

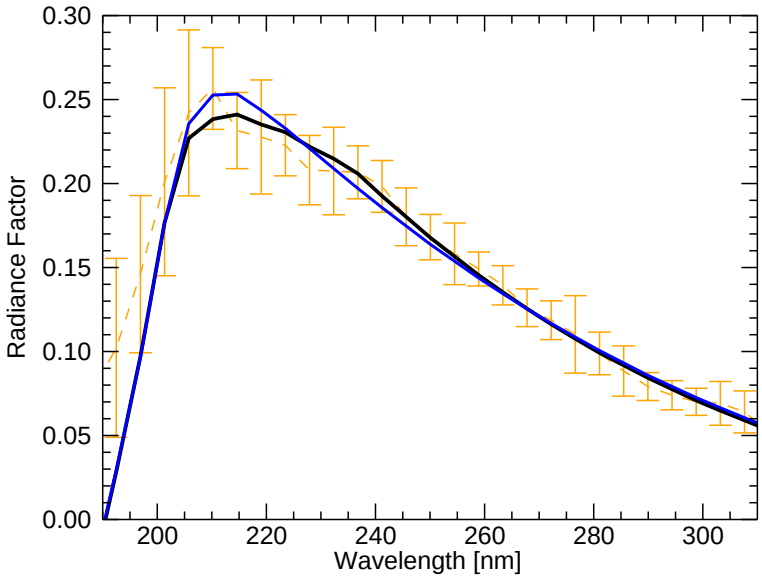


Figure: Fit with $2 \pm 1\,\mu$m-atm of SO_2 (#1338)

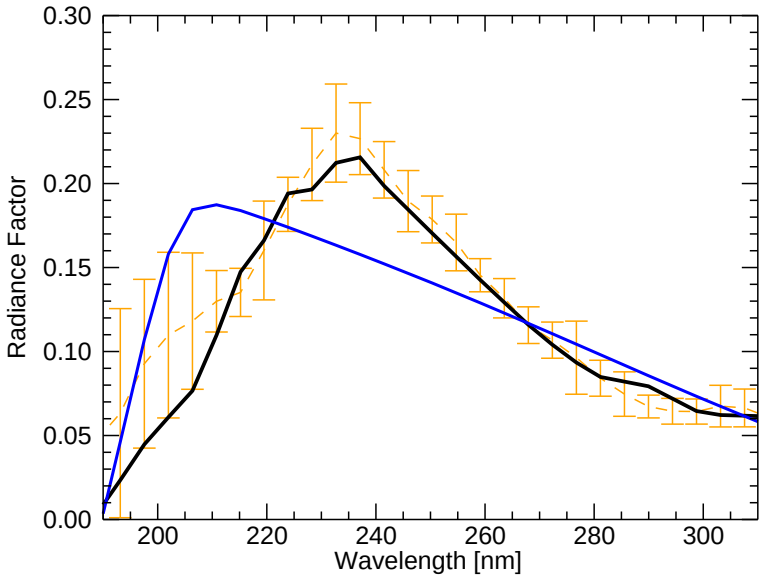


Figure: Fit with $63 \pm 5\,\mu$m-atm of SO_2 (#595)

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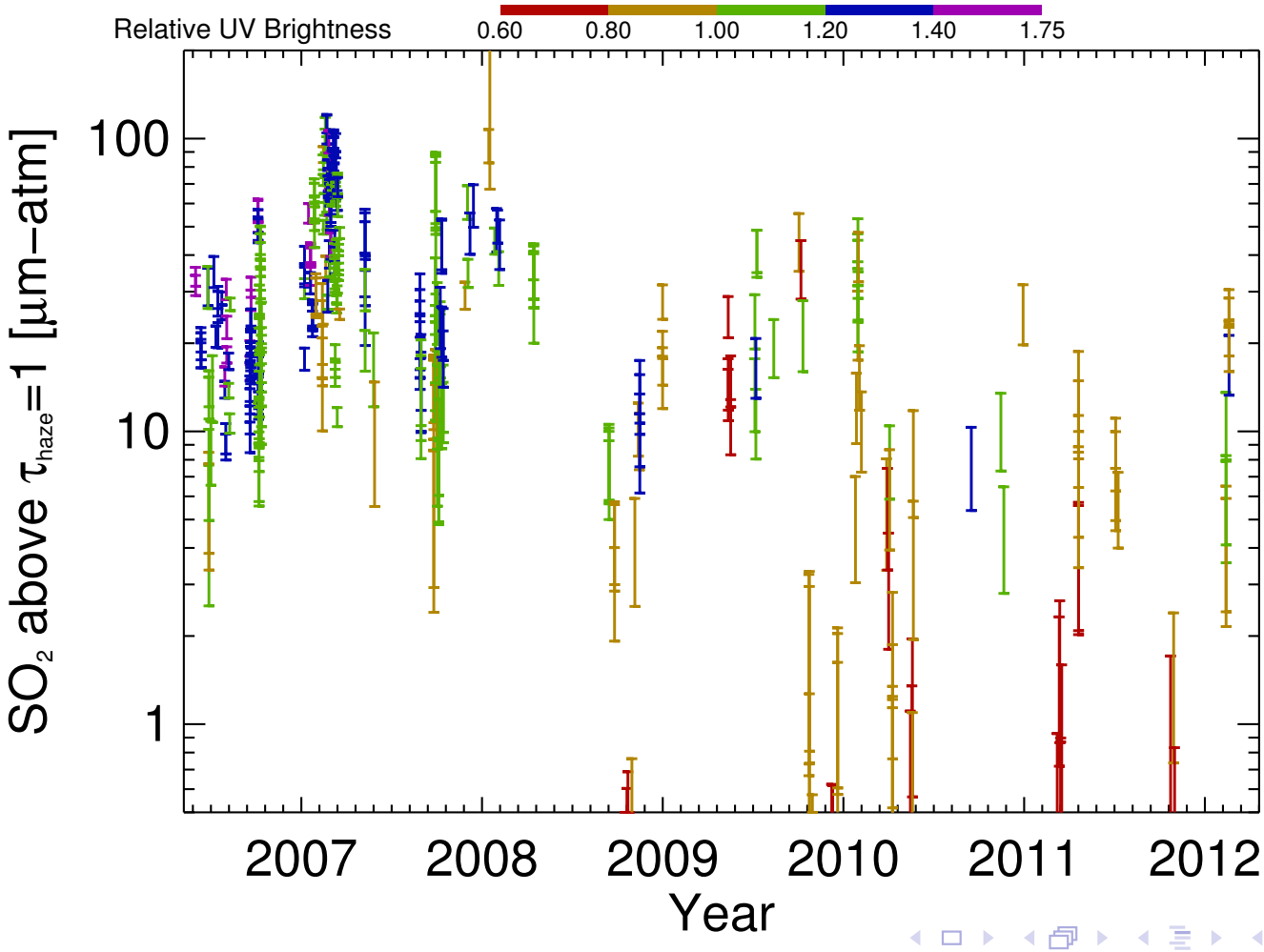
Secular evolution of SO_2

- Strong variability on timescales larger than a week.
- Decrease by a 5 to 10 factor between 2007 and 2012.



- **Decrease very similar to the 1980's**
- $\sim$ 30 Earth year periodicity ?
  - Data coverage too sparse and too short to be conclusive.

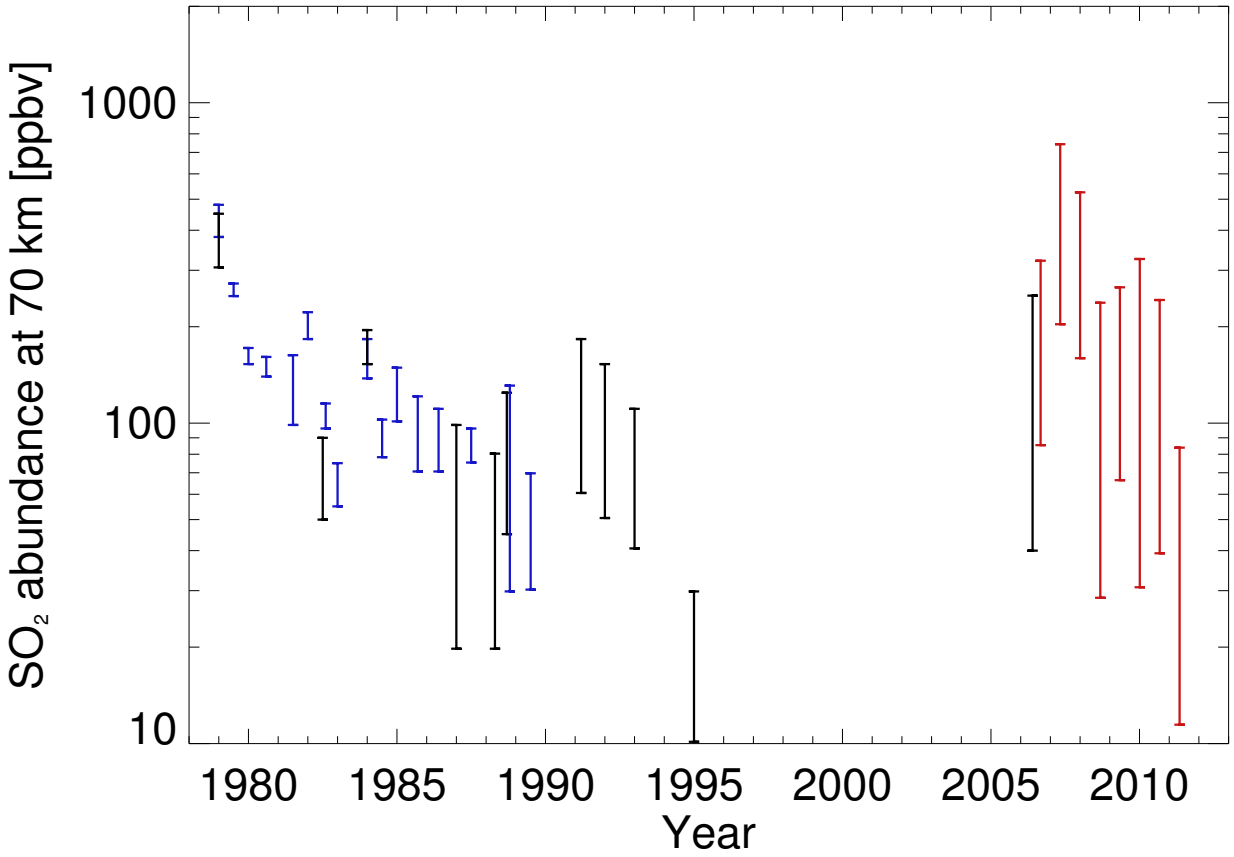
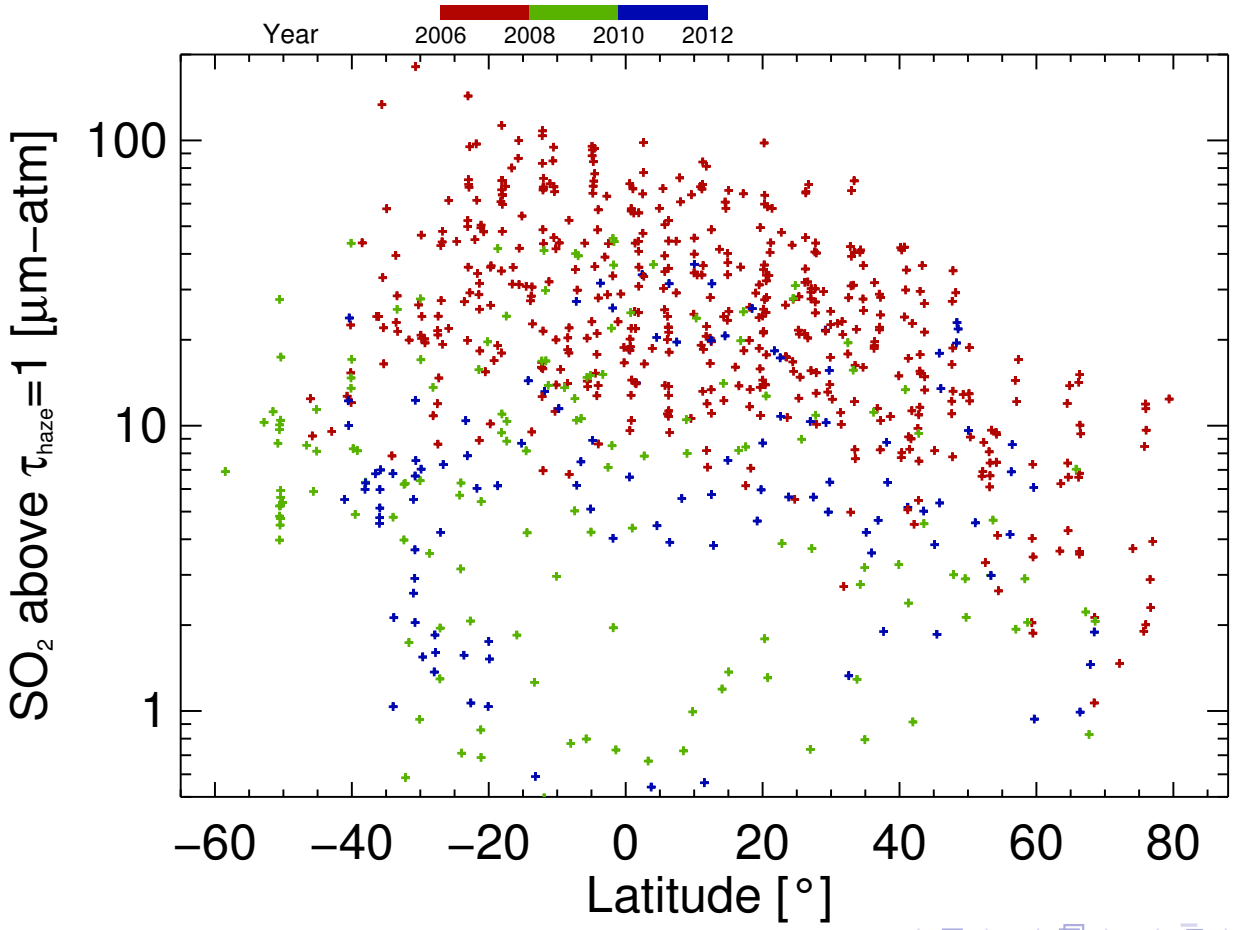


Figure: Secular evolution of SO_2 at cloud top level (UVIS, SPICAV-UV)

N_{SO_2} vs. Latitude

- **Evidence for two regimes**
  - Most of the time: decreasing N_{SO_2} with increasing latitude.
  - At some point after 2009: increasing N_{SO_2} with increasing latitude.



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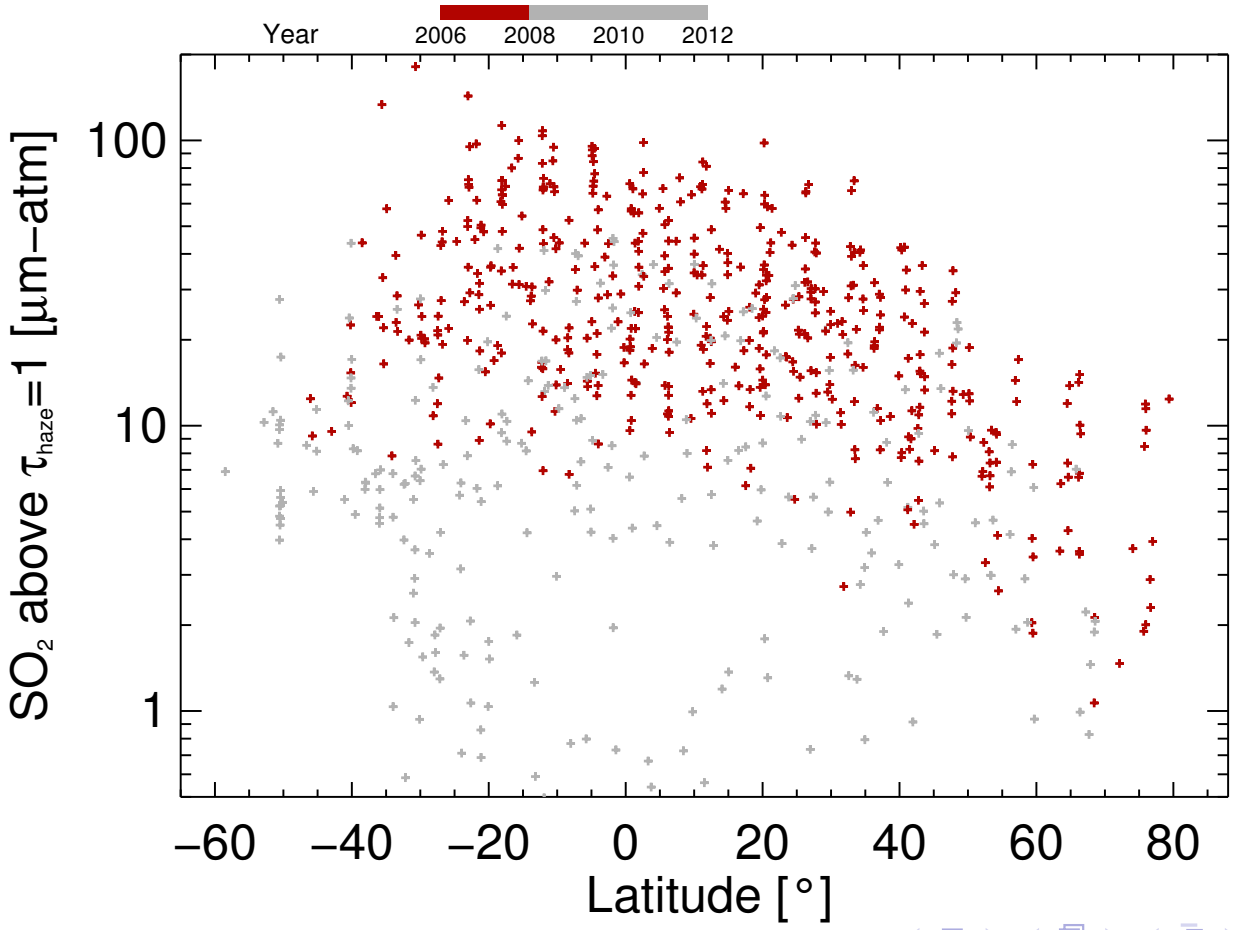

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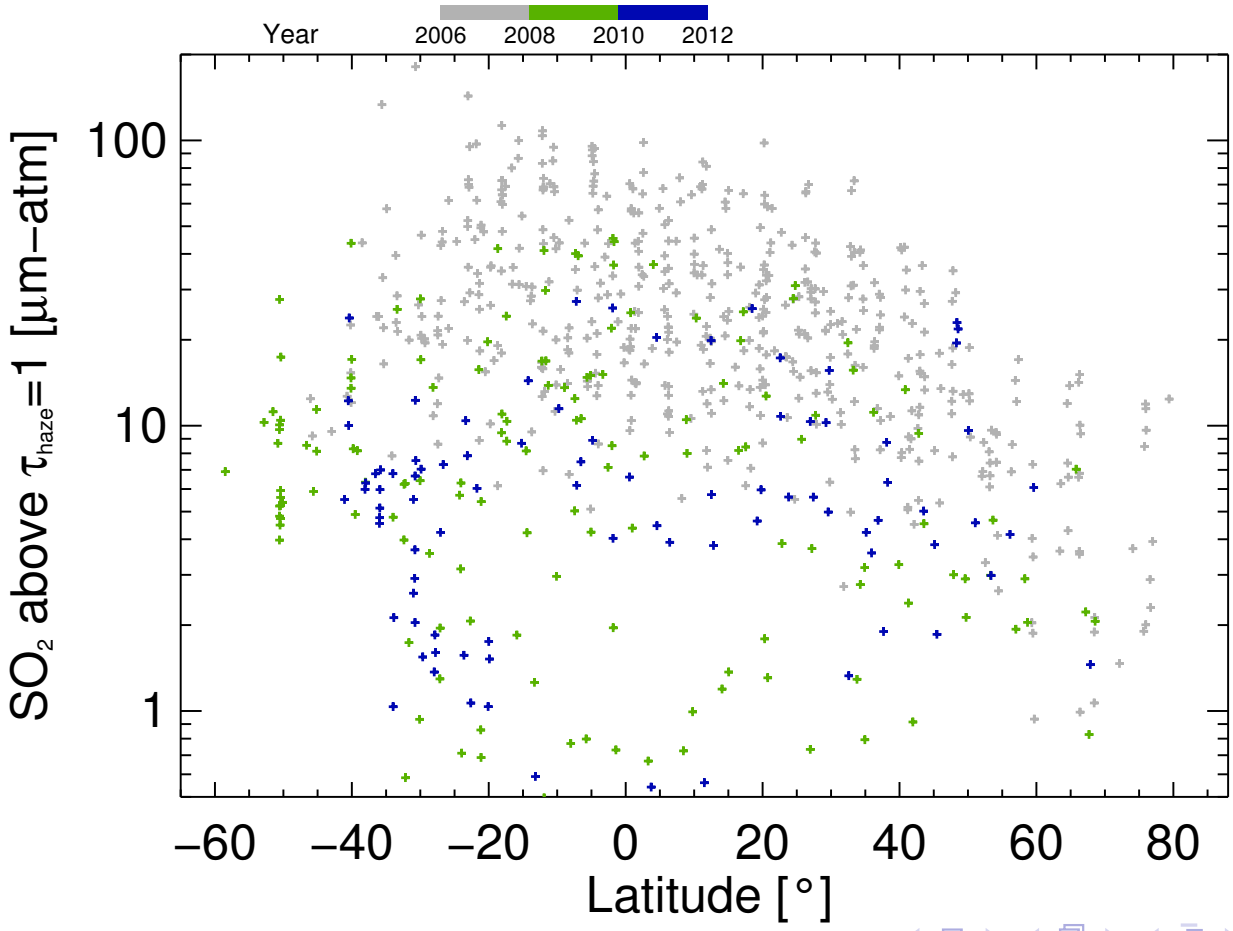
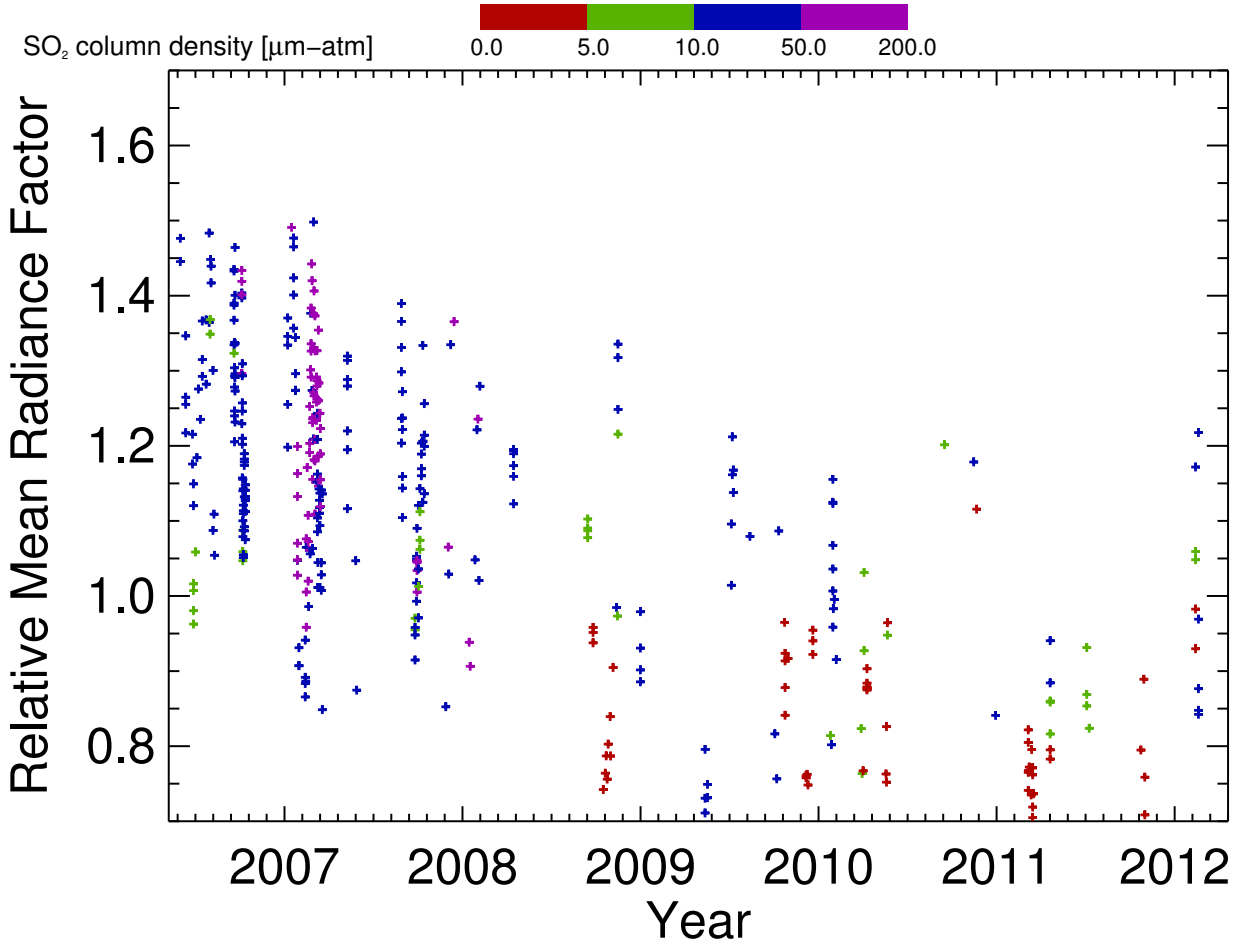


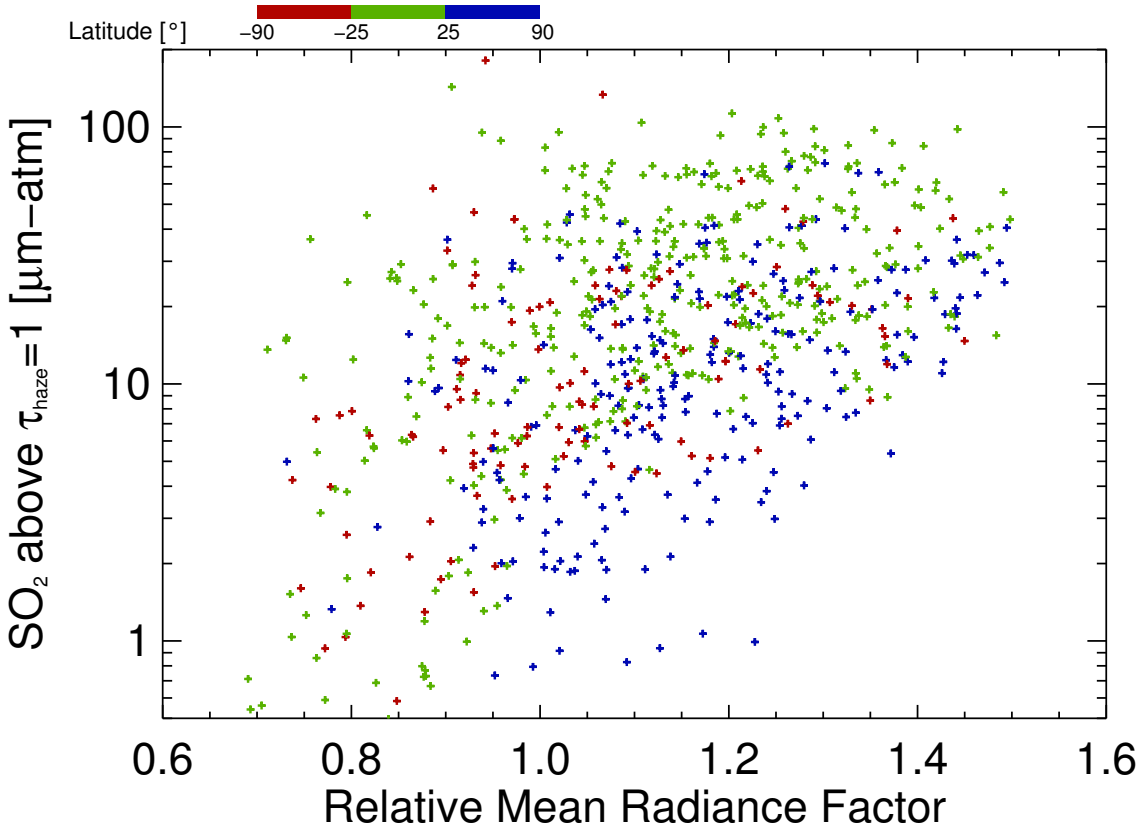
Secular Evolution of mean UV brightness

- **Substantial decrease($\sim -40\,\%$) over 5 years.**
- Concurrent with SO_2 decrease. Causal link?

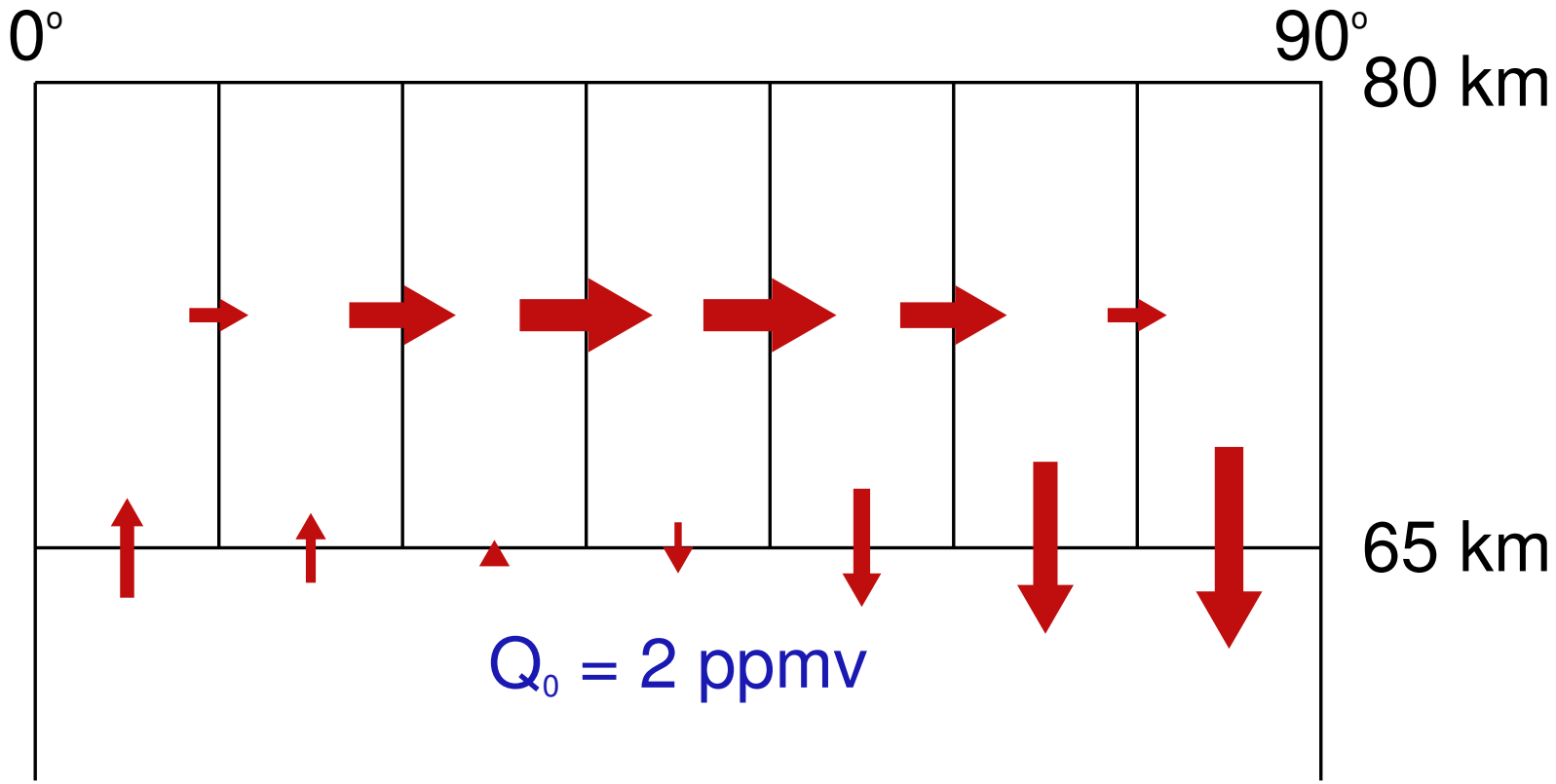


Correlation between N_{SO_2} and UV brightness

- **UV absorber anti-correlated with SO_2 column density in excess of $10\,\mu$m-atm.**
  - Hints at a conversion between SO_2 and UV absorber.
  - **And/Or** a sheltering of SO_2 by overlying UV bright haze



- Simple box model
  - Prescribed meridional circulation, photochemical time, SO_2 abundance in the reservoir.
  - Able to fairly simulate decreasing SO_2 with increasing latitude.



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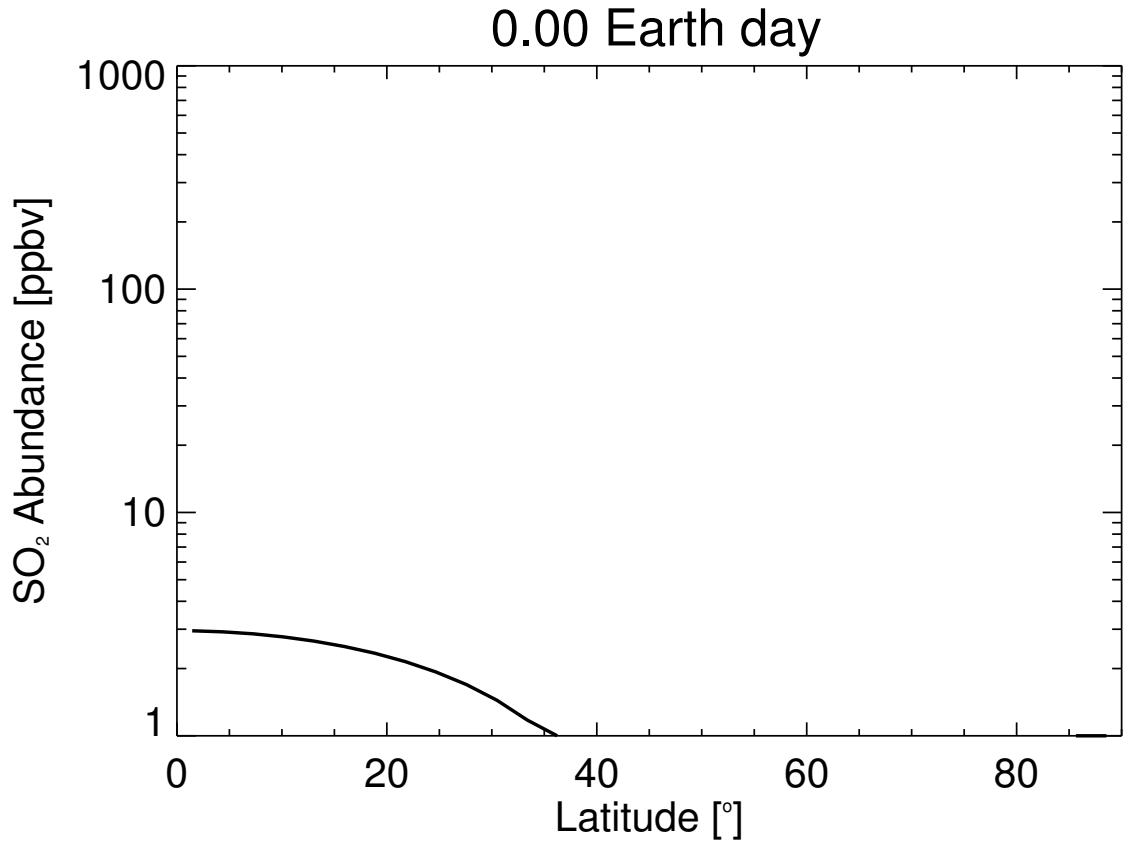

Figure: Simulation with $V_{max} = 12\,m/s$, $Q_{65\,km} = 2\,ppm$ and $\tau_0 = 5 \cdot 10^4\,s$ starting from no SO_2 above the clouds

- Simple box model
  - Also able to reproduce (qualitatively) rapid SO_2 decrease along with a suppression of the latitudinal gradient

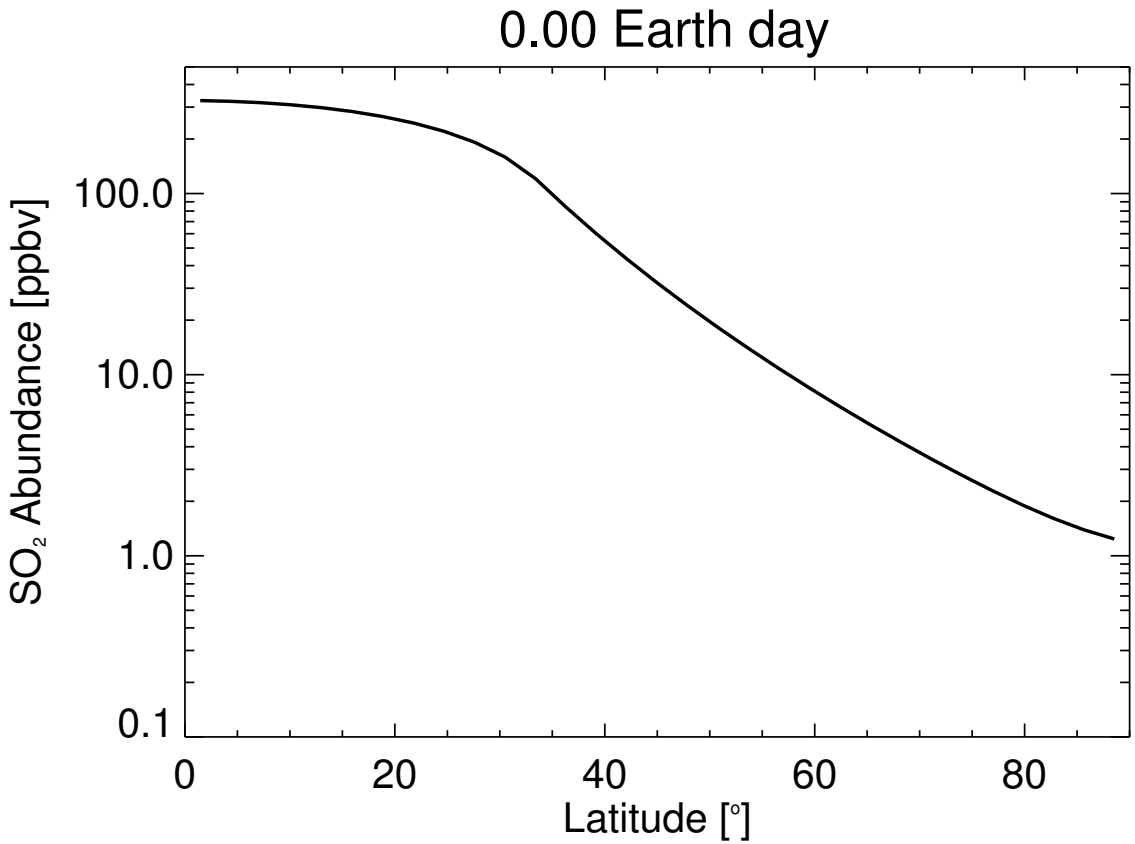

Figure: Simulation with $V_{max} = 0\,m/s$, $Q_{65\,km} = 2\,ppm$ and $\tau_0 = 5 \cdot 10^4\,s$ starting from previous equilibrium

- Long-term
  - **SO_2 at Venus cloud top alternates between rapid increases (seen in early 2007 ?) and slower decreases (lasting at least $5-10$ years).**
  - Evidence for **anti-correlated variations of UV brightness.**
- Short-term
  - **Evidence for two regimes** for SO_2, fast transitions between regimes (several Earth days).

    SO_2-rich: Advection of volatiles more efficient than photo-chemical removal. Usual situation between 2006 and 2008.

    SO_2-poor: Occurs mainly after 2008. Probably caused by a temporary decreases in the general circulation and/or SO_2 mixing ratio within and below the clouds.
  - Changes in the prevalence of both regimes may also cause the long-term (decadal) variations.
- Manuscript being reviewed at *Nature Geoscience*.

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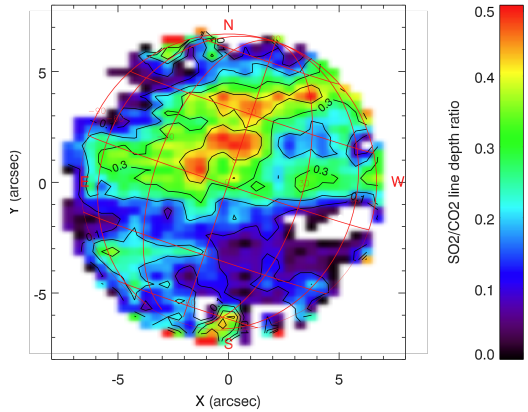
- **How does upper haze variability affect SO_2 retrievals?** VMC and/or VIRTIS-Vis could help.
  - Retrieving UV cloud top height is possible with SPICAV (CO_2 band near 200 nm), but with a low accuracy (76 ± 6 km). No variations found.
- **Challenge to chemical models**: simulating these two regimes.
- **Extend SPICAV data set**, but most usable orbits have been processed between 2006 and 2012...
  - New observation modes ? (mapping)
- **Need for a long-term monitoring of SO_2** (for at least 30 years!)
  - Measurements of other minor species involved in sulphur chemistry also highly welcome (CO, H_2O, HDO).



SO_2/CO_2 maps near 7.4 μm from Encrenaz et al. (2012) for 10-11-12 Jan. 2012