Determination of the eddy diffusion profile in the mesosphere using SOIR/VEx observations

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Venus Express

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Introduction: Eddy coefficient

- Eddy diffusion coefficient K_{zz} is used to parameterize the efficiency of vertical transport in planetary atmospheres
  - It models in an approximate way vertical mixing of constituents due to dissipative, non-linear, or unsteady motions

- No reliable models exist to calculate K_{zz} in a planetary atmosphere
  → K_{zz} must be determined through comparison with observations

- K_{zz} is essential in planetary atmospheres modelling studies, especially photochemical models

- K_{zz} was determined in the mesosphere and thermosphere by comparison with Pioneer Venus CO_2, He, and N_2 measurements by the mass spectrometer of the Large Probe (von Zahn et al., 1980)

$$K_{zz_{vZ}} = 1.4 \times 10^{13} \cdot {n_a}^{-\frac{1}{2}}$$

Introduction: Our study

- In this study, we use CO_2 & CO measurements by SOIR/Venus Express
  - CO is produced by CO_2 photodissociation
  - Most of CO is recombining below 80 km, especially OH + CO (Yung and DeMore, 1982)

- We also revisit the CO_2 and He observations from Pioneer Venus (von Zahn et al., 1980)

- We use a 1D-photochemical/diffusion model to constrain K_{zz}
  - from 80 to 130 km using SOIR data only
  - from 80 to 200 km combining SOIR and Pioneer Venus data

- We compare the resulting K_{zz} profile with previously used profiles

Introduction: SOIR/Venus Express

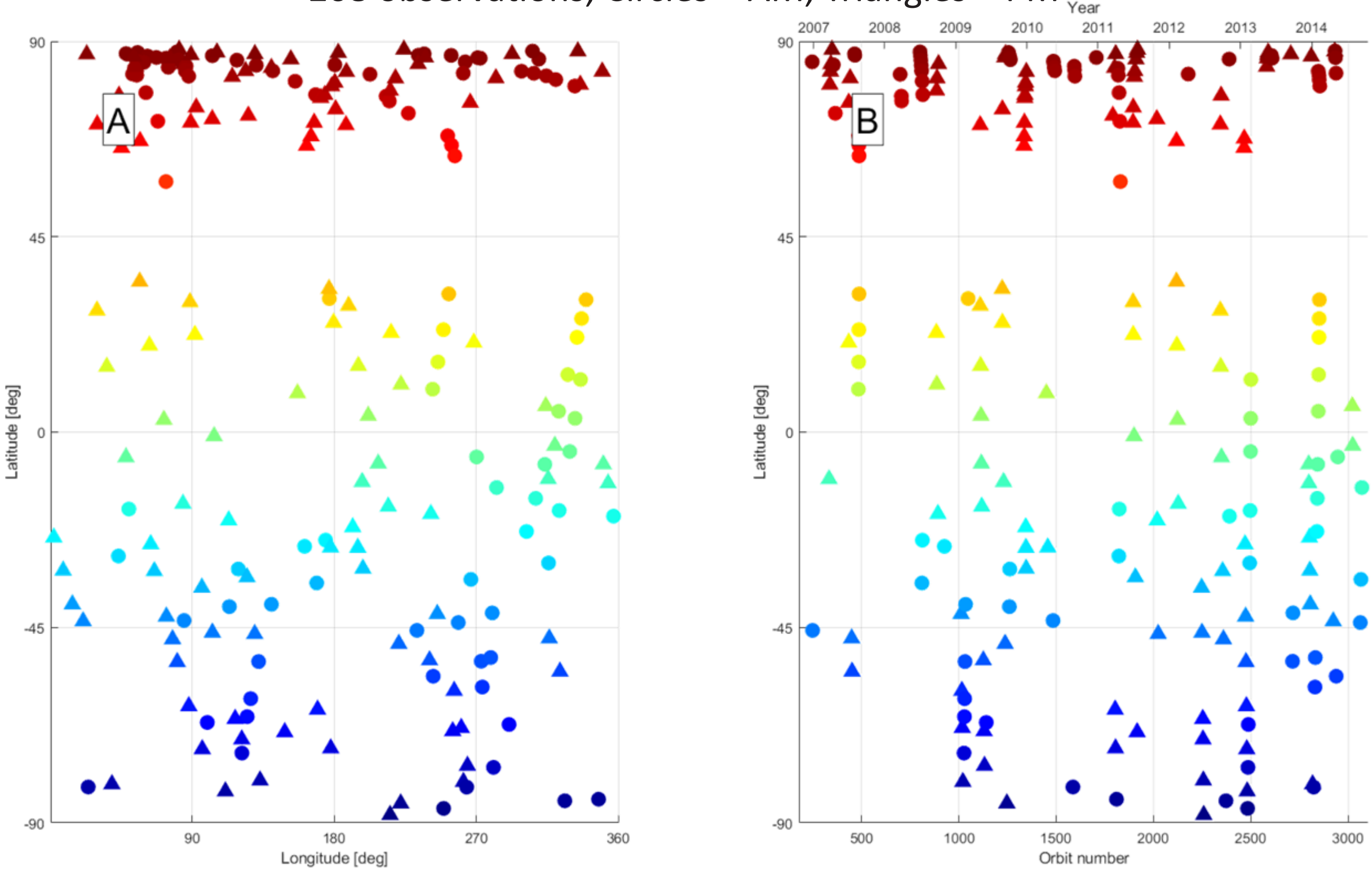
- SOIR was an infrared spectrometer on board Venus Express
  - Echelle grating spectrometer, very high orders (101 to 194)
  - Sensitive in the 2.2 - 4.4 µm (2200 - 4400 cm^{-1})
  - Spectral sampling (0.06 – 0.12 cm^{-1})
  - Spectral resolution (0.11 – 0.21 cm^{-1})

- SOIR/VEx performed solar occultations
  - Terminator (6AM and 6PM), all latitudes are covered

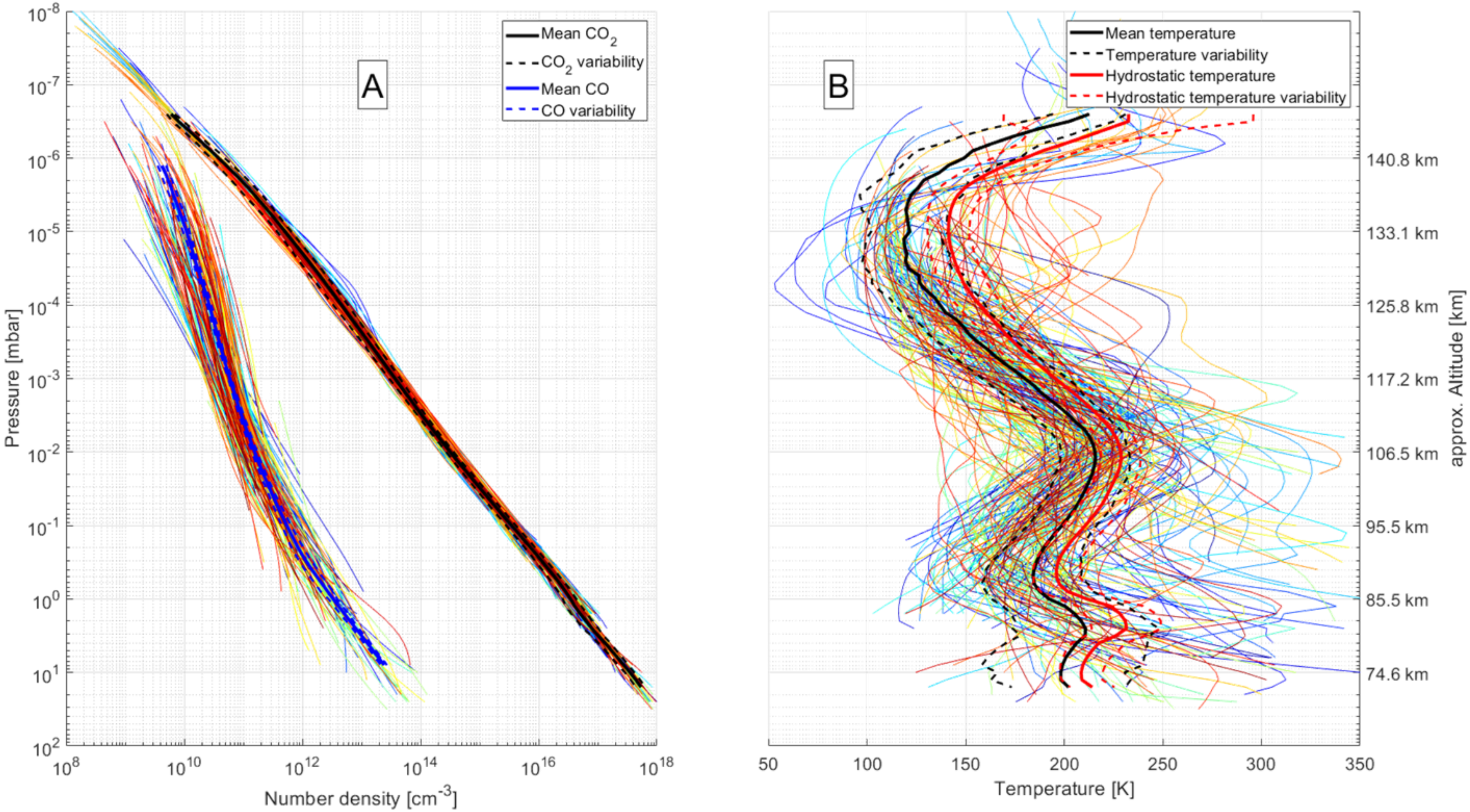
- Four spectral regions measured simultaneously
  - SOIR detected **CO_2**, **CO**, H_2O/HDO, HCl, HF, SO_2 and aerosols

SOIR CO_2 and CO coverage

208 observations, Circles = AM, Triangles = PM



SOIR CO_2 and CO dataset



1D-photochemical/diffusion model (1)

- Continuity equation for species i

$$\frac{\partial n_i(z,t)}{\partial t} = P_i(z,t) - \frac{\partial \Phi_i(z,t)}{\partial z}$$

  – where $P_i(z,t)$ is the production and $\Phi_i(z,t)$ is the vertical flux
- Minor species diffusion approximation

$$\begin{aligned}\Phi_i(z,t) = \quad & -D_i(\mathrm{z}) \cdot \left(\frac{\partial \mathrm{n}_i(z,t)}{\partial z} + \mathrm{n}_i(z,t) \cdot \left(\frac{1}{H_i(z)} + \frac{1+\alpha_i}{T(z)} \cdot \frac{\partial T(z)}{\partial z} \right) \right) \\ & -K_{zz}(\mathrm{z}) \cdot \left(\frac{\partial \mathrm{n}_i(z,t)}{\partial z} + \mathrm{n}_i(z,t) \cdot \left(\frac{1}{H_a(z)} + \frac{1}{T(z)} \cdot \frac{\partial T(z)}{\partial z} \right) \right)\end{aligned}$$

  – where $D_i(z)$ is the molecular diffusion, $H_i(z)$ is the species i scale height and $H_a(z)$ is the atmosphere scale height
- Molecular diffusion coefficients

$$D_i(\mathrm{z}) = \frac{1}{k_B} \cdot \left(\sum_{j \neq i} \frac{n_i(z)}{b_{ij}(z)} \right)^{-1} \text{ with } b_{ij} = A_{ij} \cdot T^{s_{ij}-1}, A_{ij} \text{ and } s_{ij} \text{ tabulated}$$

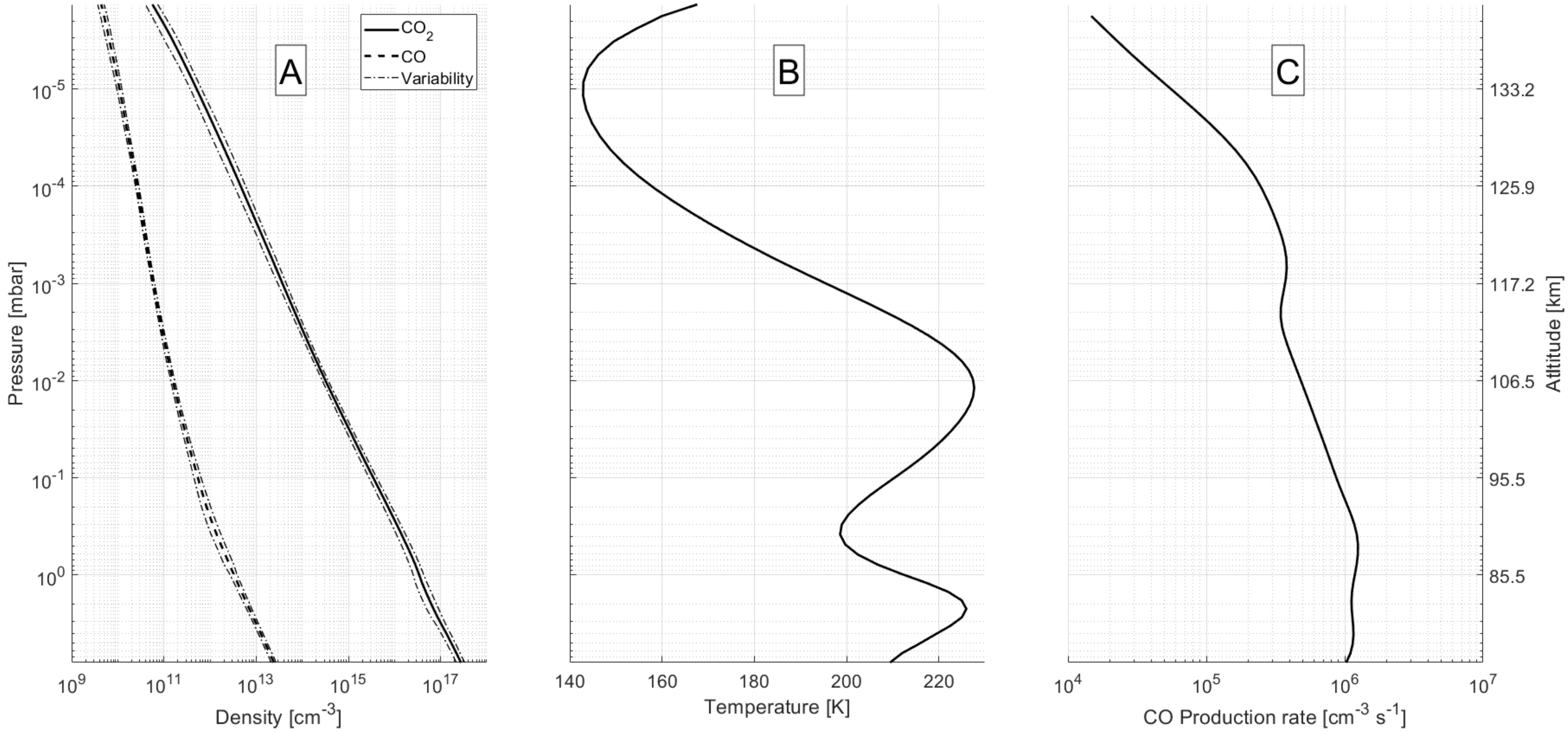
1D-photochemical/diffusion model (2)

- Four photodissociation reactions

$$CO_2 + h\nu \rightarrow CO + O$$
$$CO_2 + h\nu \rightarrow CO + O(P)$$
$$CO_2 + h\nu \rightarrow CO + O(1s)$$
$$CO_2 + h\nu \rightarrow CO(P) + O$$

  - Assuming recombination occurs outside of the simulated altitude range
- Other species are present in the studied altitude range, such as N_2, He, O and various ions
  - Not included in the simulation, weakly impact the optical depth and molecular diffusion
- Temperature in hydrostatic equilibrium with CO_2, kept constant
- Lower boundary conditions: fixed number densities
- Time step of 10^4 s
- Model run until steady state is reached

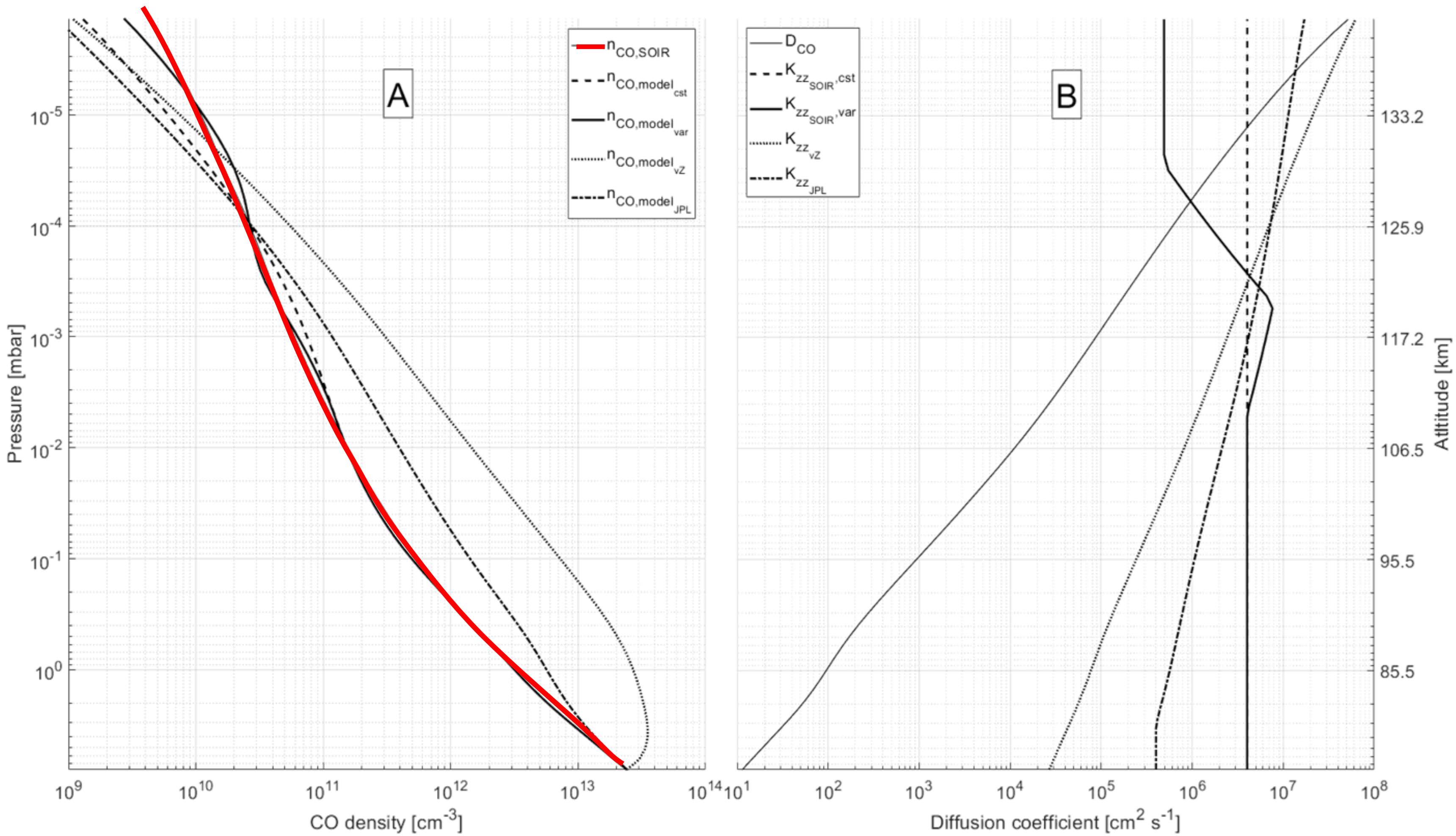
Eddy diffusion fit: SOIR only (1)



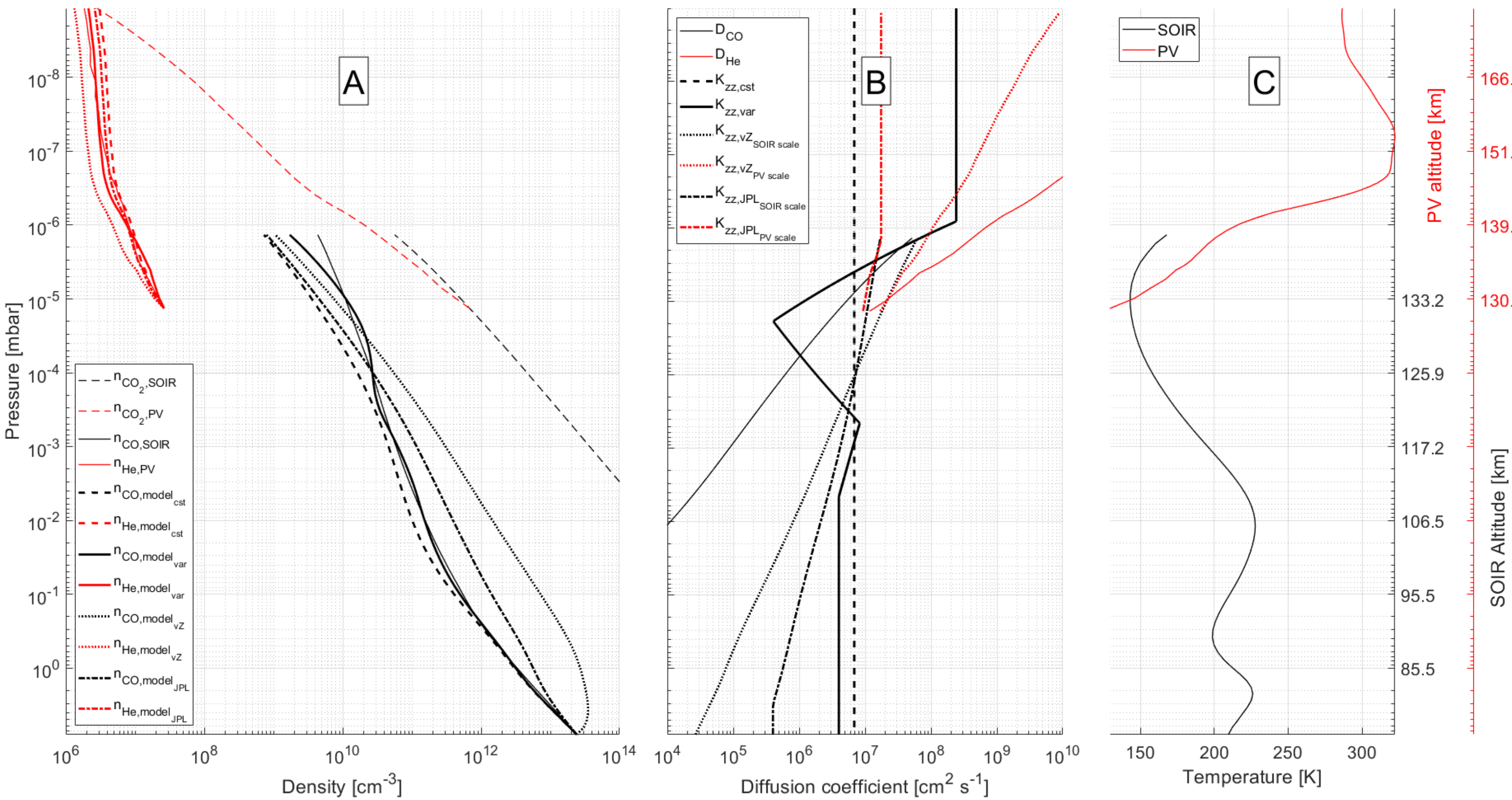
The column CO production rate is equal to 3.8×10^{12} cm^2/s, which is of the same order of magnitude as reported by Yung and DeMore (1982).

Eddy diffusion fit: SOIR only (2)

- Fit of n_{CO} by adjusting K_{zz} using Levenberg-Marquardt algorithm



Eddy diffusion fit: SOIR and PV



Conclusions

- CO_2 and CO database from SOIR and He and CO_2 Pioneer Venus measurements
- We could determine a K_{zz} profile extending from 80 to 200 km
- This profile is different from previous K_{zz} found in the literature
- K_{zz} profile could be use in GCMs and photochemical models
- The homopause altitude is located at
  - 6×10^{-5} mbar or ~126 km for CO
  - 4×10^{-5} mbar or ~128 km for He
- Work will be submitted this week for publication

THANK YOU!
MORE INFO?

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Comparison of the "scale heights"

$$\log\left(\frac{n_{CO}(z)}{n_{CO}(z_0)}\cdot\frac{T(z_0)}{T(z)}\right)=\frac{m_{CO}}{m_{CO_2}}\cdot\log\left(\frac{n_{CO_2}(z)}{n_{CO_2}(z_0)}\cdot\frac{T(z_0)}{T(z)}\right)$$

$$p_\alpha(z)=p_\alpha(z_0)\cdot\exp\left(-\frac{m_\alpha\cdot g}{k_B}\cdot\int_{z_0}^{z}\frac{dz'}{T(z')}\right)$$

$$\log\left(\frac{n_\alpha(z)}{n_\alpha(z_0)}\cdot\frac{T(z_0)}{T(z)}\right)=m_\alpha\cdot\left(\frac{-g}{k_B}\cdot\int_{z_0}^{z}\frac{dz'}{T(z')}\right)$$