Isotope Ratios in the Upper Atmosphere Observed by NGIMS

Shane W. Stone,[1] Geronimo L. Villanueva,[1] Roger V. Yelle,[2] Mehdi Benna,[1] Meredith K. Elrod,[1] Paul R. Mahaffy[1]

[1]NASA Goddard Space Flight Center
[2]Lunar and Planetary Laboratory, University of Arizona

Introduction

- The processes responsible for atmospheric escape to space enrich the atmosphere in the heavier isotopes of an element, because the lighter isotopes escape at a faster rate. This is true for two reasons:
  - Less energy is required for a lighter isotope to escape.
  - The upper atmosphere, from which escape occurs, is enriched in the lighter isotopes due to diffusive separation.

- NGIMS measures the abundances of neutral and ionic species in the upper atmosphere, and many of their isotopologues.

- We use NGIMS data to investigate the upper atmospheric C and O isotope ratios in CO_2, including their vertical and horizontal variation. These ratios and their variation are important for understanding the population of escaping atoms.

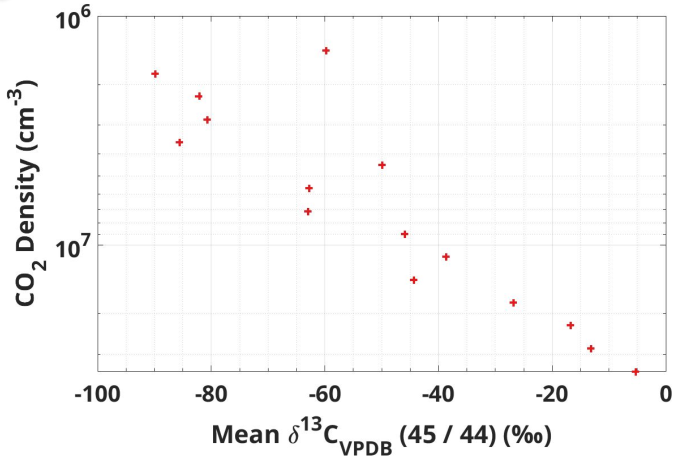
Introduction

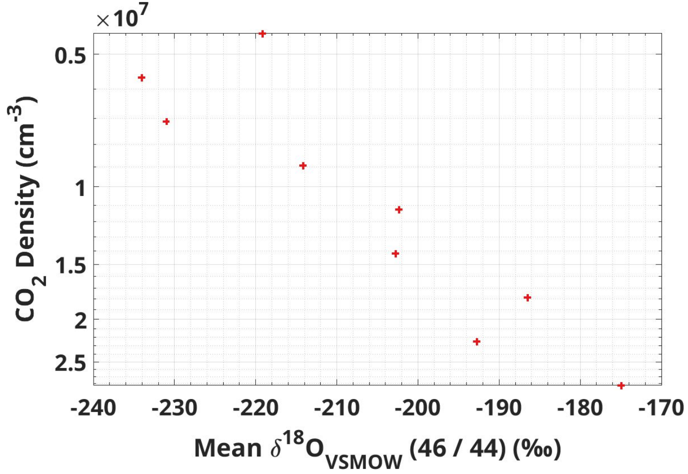
- To obtain an isotope ratio from the NGIMS data, we simply take the ratio of two m/z channels.

- We can then calculate a δ value relative to a standard, e.g. Vienna Pee Dee Belemnite or Standard Mean Ocean Water:

$$\delta^{13}\mathrm{C} = \left[\frac{\left(\frac{^{13}\mathrm{C}}{^{12}\mathrm{C}}\right)_{\mathrm{sample}}}{\left(\frac{^{13}\mathrm{C}}{^{12}\mathrm{C}}\right)_{\mathrm{standard}}} - 1 \right] \times 1000\,‰$$

- Mean profiles are produced from bins of sequential orbits.





- Shown here are:
  - **$\delta^{13}C_{VPDB}$ in CO_2** from m/z channels

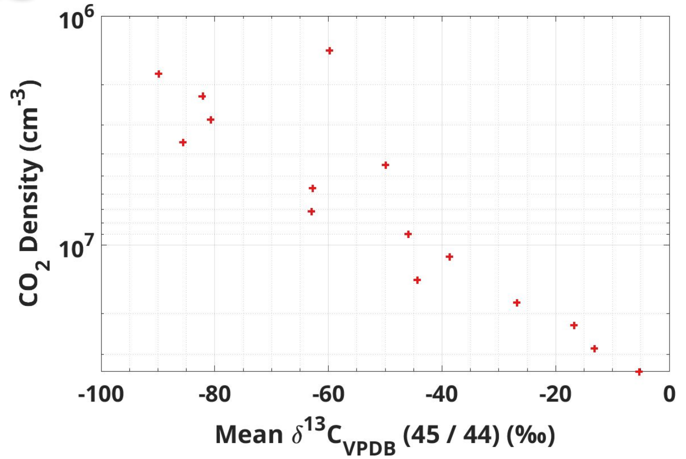
    45 ($^{13}C^{16}O_2$) and 44 ($^{12}C^{16}O_2$)

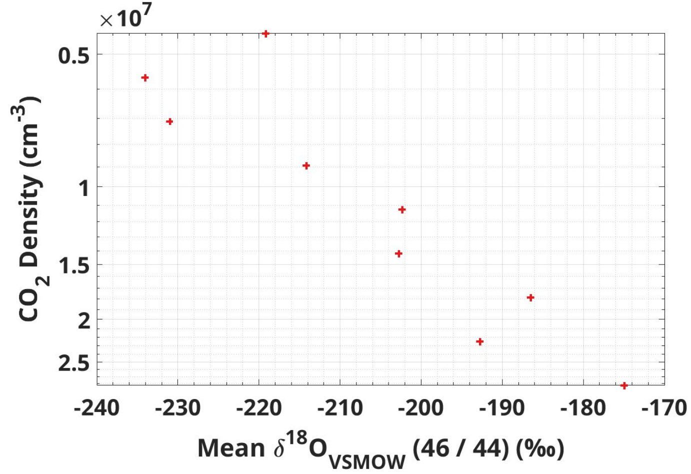
  - **$\delta^{18}O_{VSMOW}$ in CO_2** from m/z channels

    46 ($^{18}O^{12}C^{16}O$) and 44 ($^{16}O^{12}C^{16}O$)

- In the upper atmosphere, isotope ratios decrease with height due to diffusive separation.
  - Lighter species have a larger scale height.

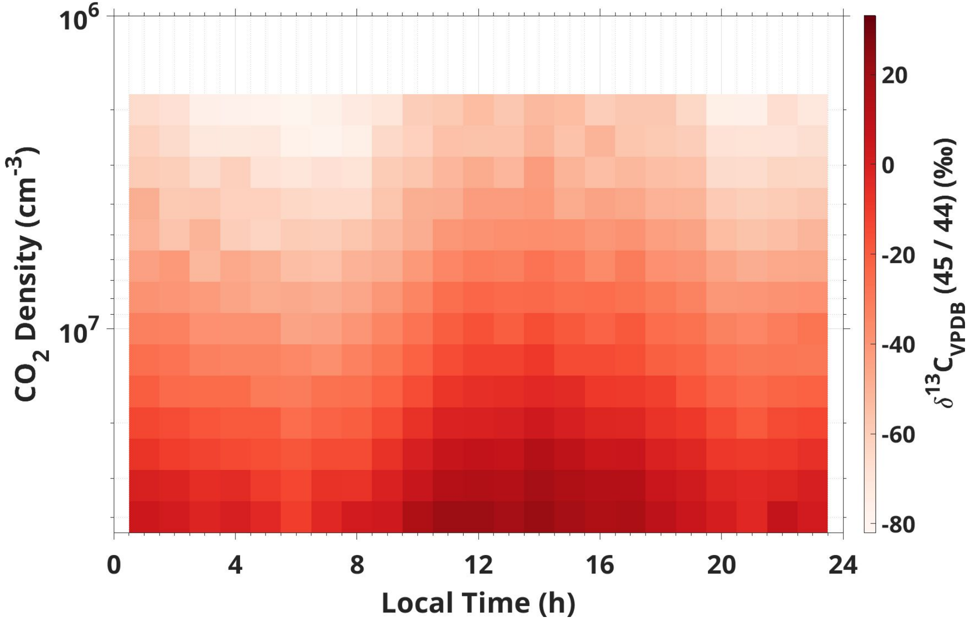
$$H = kT/mg$$





Local Time Variation

- We can also bin these isotope ratios on variables like Martian local time, latitude, and season, just as we have for all the neutral species.
- We find substantial variation of $\delta^{13}C$ in CO_2 over a Martian day.
- This trend follows the temperature: $\delta^{13}C$ is smaller where the temperature is cooler and larger where the temperature is warmer.



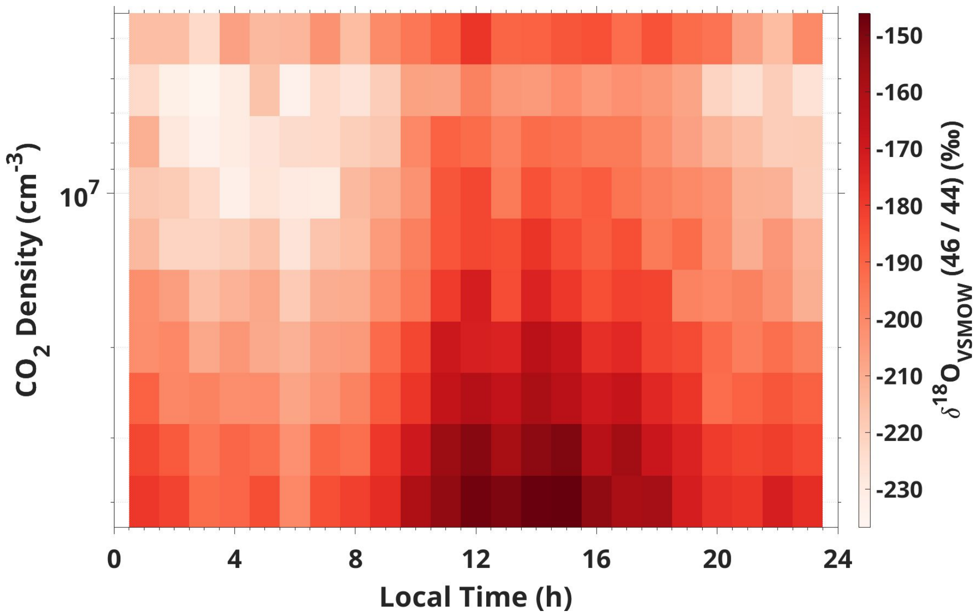
Local Time Variation

- A similar variation is observed for $\delta^{18}O$ in CO_2.

- This trend is due to subsolar to antisolar transport:

  — Heating on the dayside leads to upwelling, transporting upward gas enriched in the heavier isotopologue.

  — Downwelling on the cooler nightside transports downward gas enriched in the lighter isotopologue.



Conclusions

- Vertical profiles of isotope ratios in CO_2 have been calculated from the NGIMS data.
- The isotope ratios in CO_2 vary substantially with local time.
- Calculating these ratios in the upper atmosphere and understanding their variation is important to characterize the population of escaping atoms.
- These measurements are obtained in the NGIMS neutral mode, but we can also look at isotope ratios in the ionosphere.
  - For example, the isotope ratios in O_2^+ may be interesting.
- The isotope ratios measured by NGIMS in the upper atmosphere can be validated to some extent by extrapolating downward until the ratio reaches the lower atmosphere value, which occurs around the homopause.
- Further analysis and uncertainty calculations are required.