Isotope Ratios in the Martian Upper Atmosphere Measured by MAVEN NGIMS

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Introduction

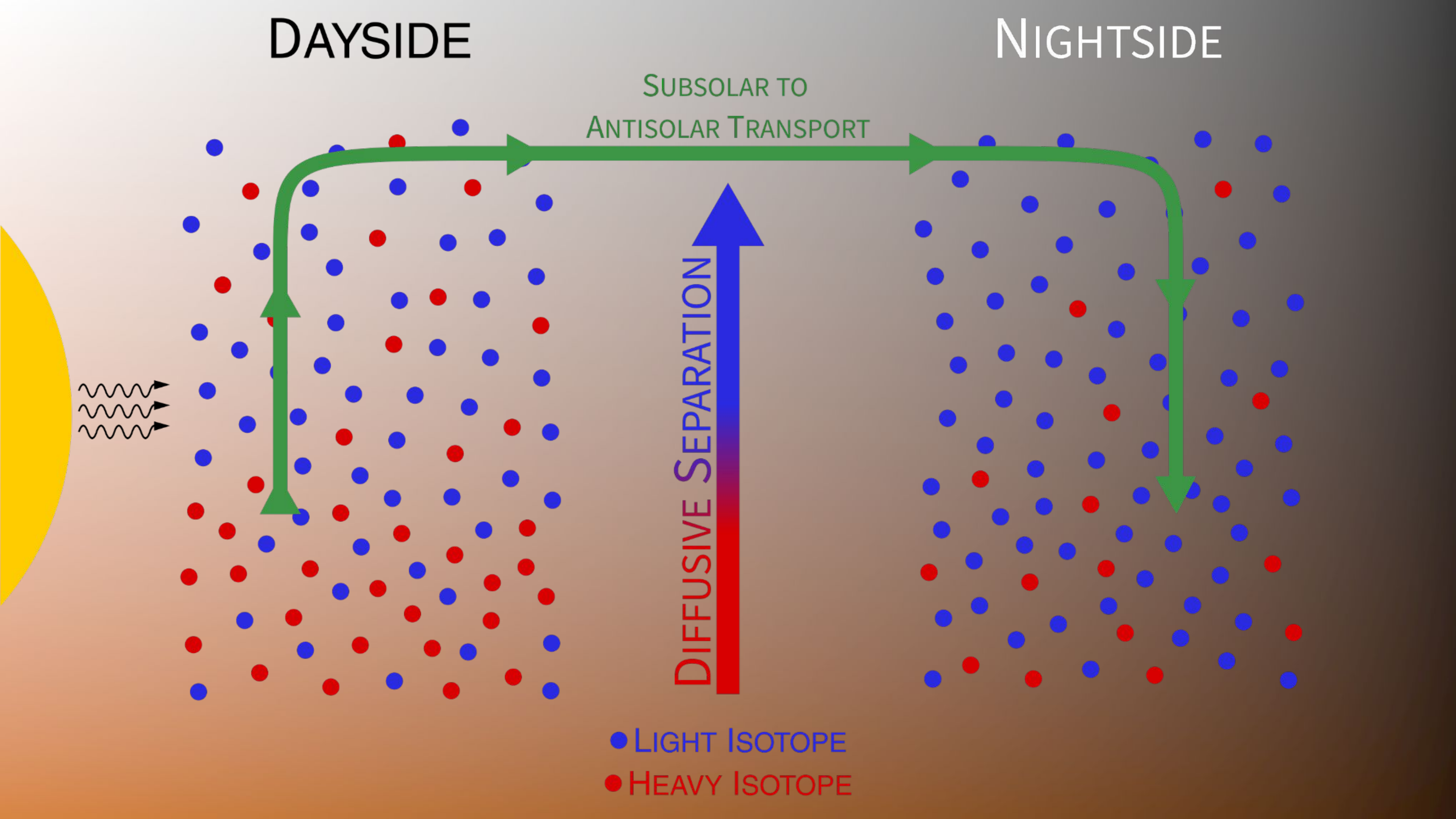
- The processes responsible for atmospheric escape to space enrich the atmosphere in the heavier isotopes of an element, because the lighter isotopes escape at a faster rate. This is true for two reasons:

  — 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.

- The mass spectrometer on MAVEN, called NGIMS, measures the abundances of neutral and ionic species, and their isotopologues.

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



DAYSIDE
NIGHTSIDE
SUBSOLAR TO
ANTISOLAR TRANSPORT
DIFFUSIVE SEPARATION
LIGHT ISOTOPE
HEAVY ISOTOPE

Introduction

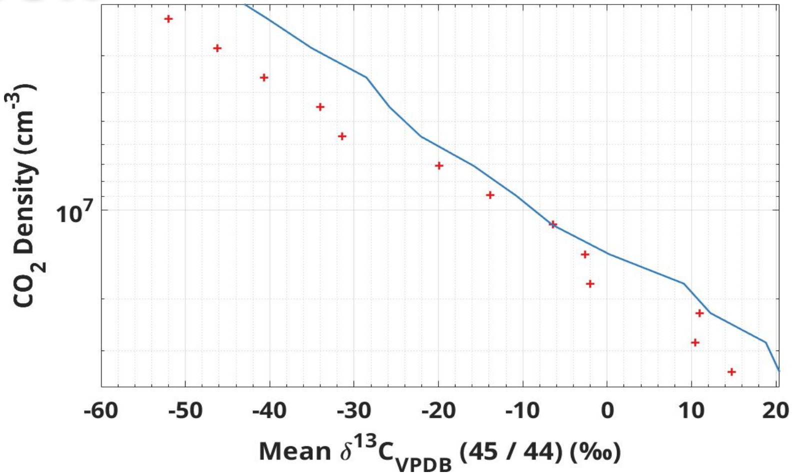
- To obtain an isotope ratio from the NGIMS data, we simply take the ratio of two m/z channels.

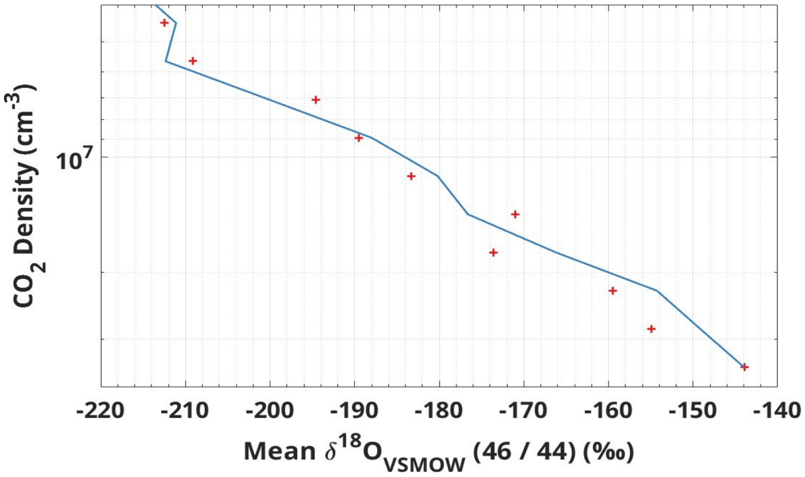
- We can then calculate a δ value relative to a standard, e.g. Vienna Pee Dee Belemnite or Standard Mean Ocean Water:

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

- Mean profiles are produced from bins of sequential orbits to give longitudinal averages.

- CO_2 density is used as the vertical coordinate because it is a convenient proxy for total atmospheric density or pressure that is directly measured by NGIMS.





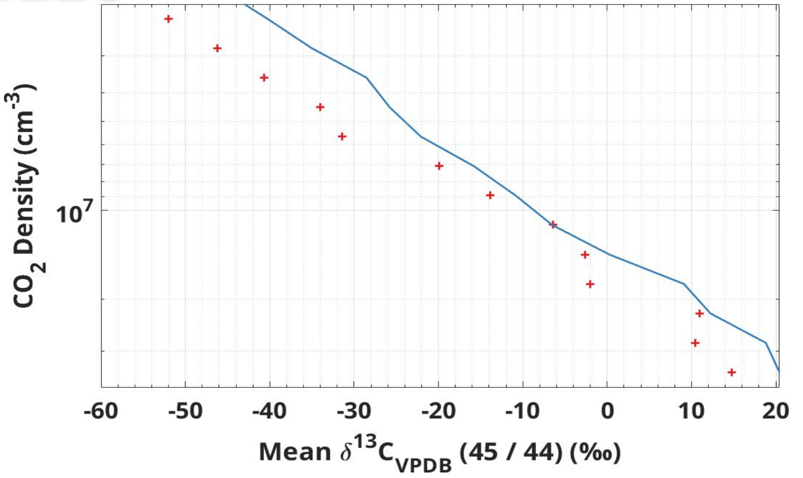
Mean Profiles

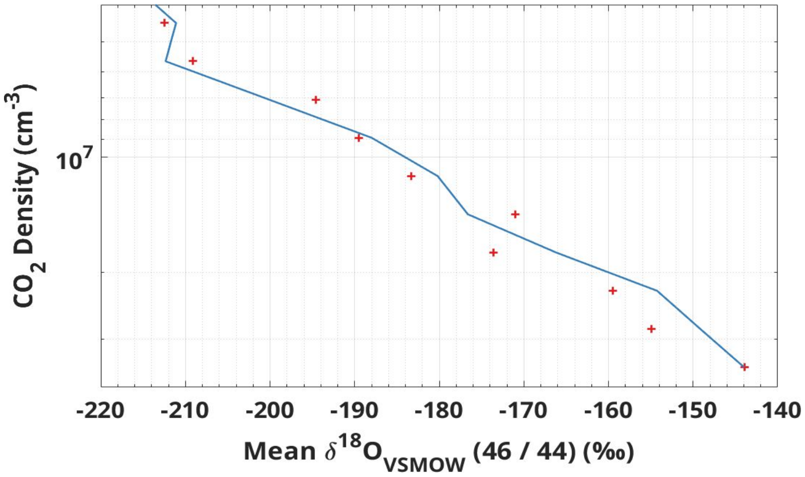
- Shown here are:
  - **$\delta^{13}C_{VPDB}$ in CO_2** from m/z channels

    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 ($^{16}O^{12}C^{16}O$)

  at L_S ~ 235° (MY 33), 3–5 p.m. local time.
- In blue is the slope and magnitude of the isotope ratio we would expect given the masses of the two species and the density of the lighter isotopologue.



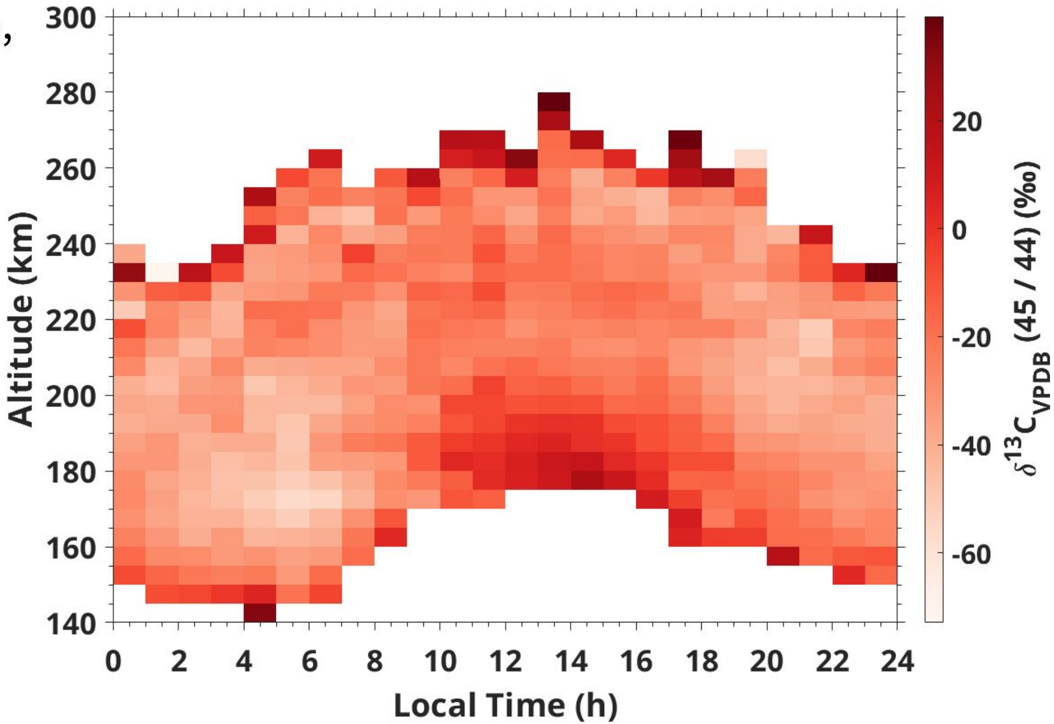


Local Time Variation

- We also bin these isotope ratios on variables like Martian local time, latitude, and season, as we have for the neutral species (Stone et al. 2022, *JGR: Planets*).

- Here, data from the entire mission is binned on altitude and local time.

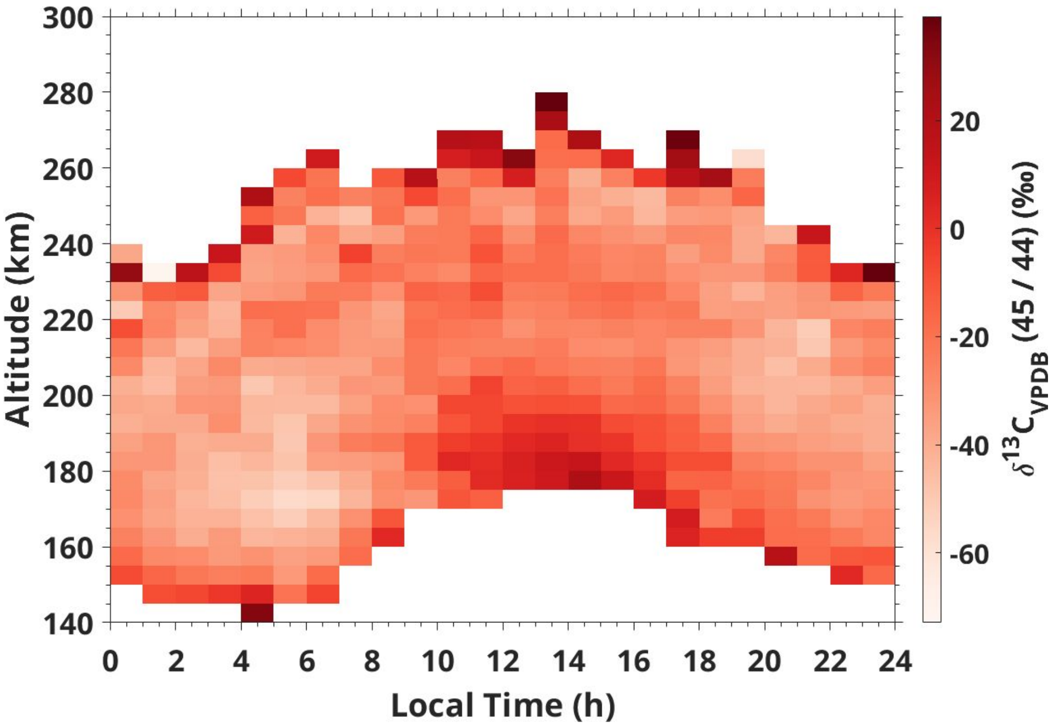
    — Because there is a significant temperature variation between the dayside and the nightside, the expected diurnal variation due to subsolar to antisolar transport is convolved with the contraction of the atmosphere on the nightside.



Local Time Variation

- Due to variation of the temperature, the mixing ratios of the two isotopologues change across a constant altitude surface simply because of the change in scale height of the atmosphere.

$$H = kT/mg$$

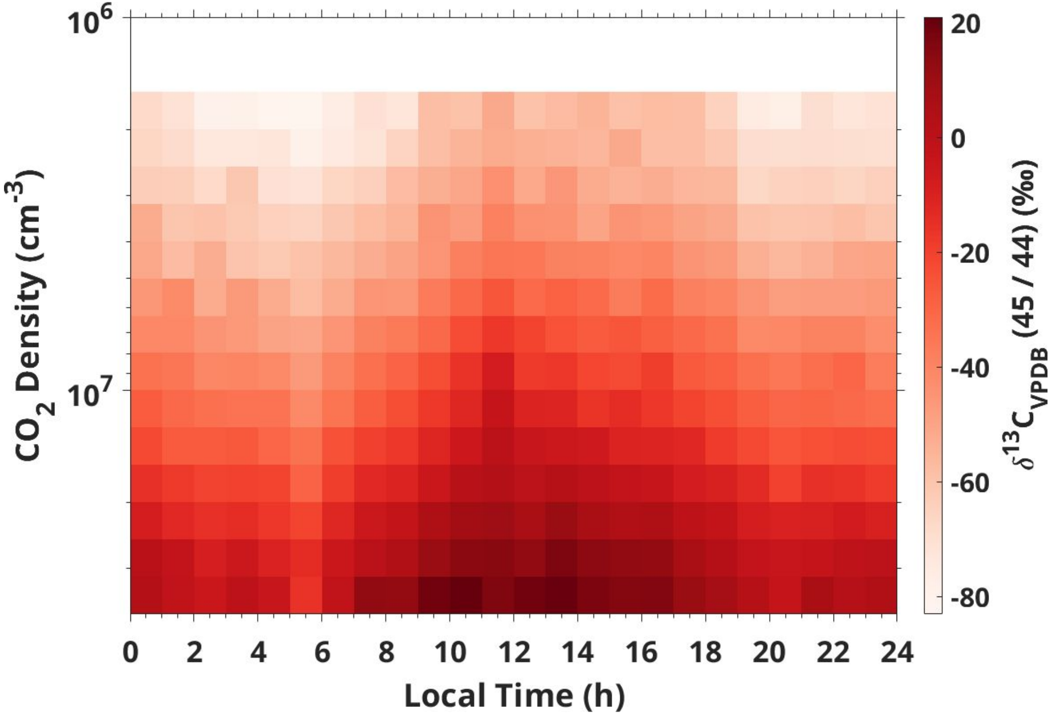


Local Time Variation

- When CO_2 density is used as the vertical coordinate, the effect of this contraction of the atmosphere on the nightside is not present and the diurnal variation due to transport is more clear.

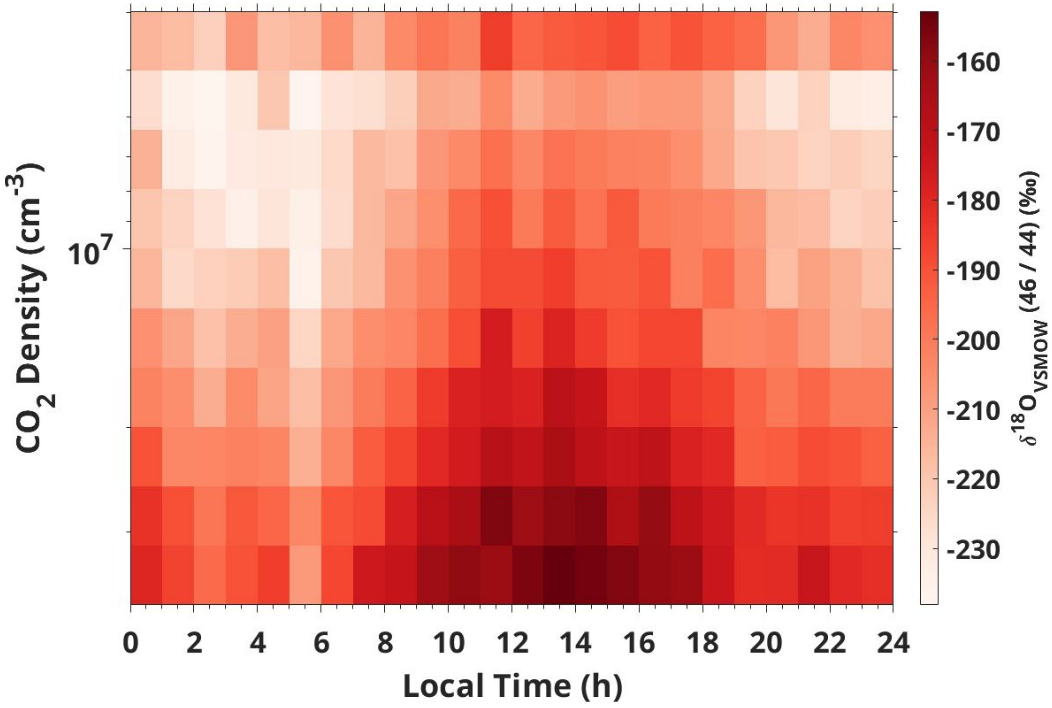
- We find substantial variation of $\delta^{13}C$ in CO_2 over a Martian day.

- This is the most significant trend observed in the variation of the isotope ratios. It is observed across all seasons and latitudes.



Local Time Variation

- A similar diurnal variation is observed for $\delta^{18}O$ in CO_2.
- The diurnal variation of an isotope ratio in the upper atmosphere has important implications for the isotopic composition of the gas which can escape to space.
- In this case, the destruction of CO_2 leads to the formation of O_2^+, then the escape of O *via* dissociative recombination.



Conclusions

- Vertical profiles of isotope ratios in CO_2 have been obtained from the NGIMS data.
- The isotope ratios observed in CO_2 vary substantially with local time.
- Measurement of these ratios their variation in the upper atmosphere 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^+.
- We will explore the variation of the isotope ratios with respect to latitude and season and amid dust storms.
- Further analysis and detailed uncertainty calculations are required.