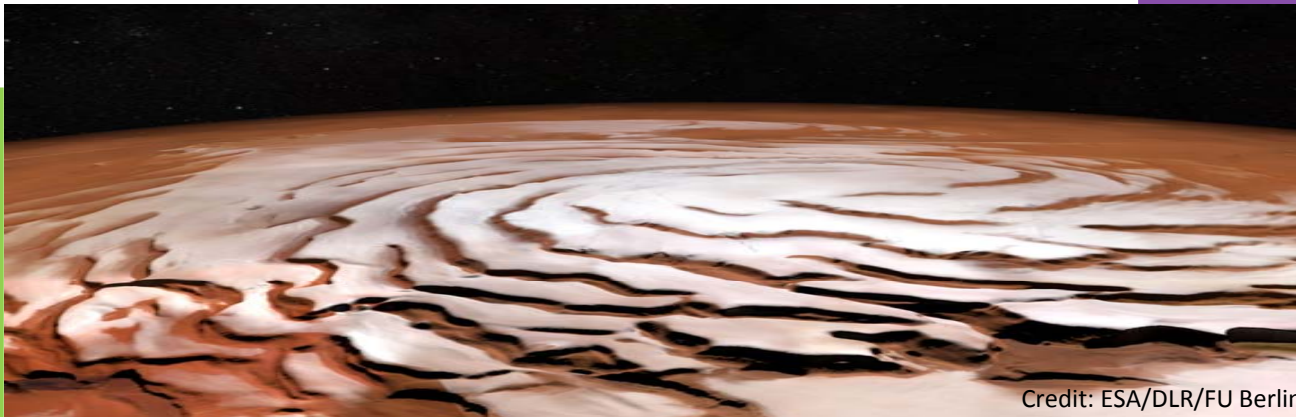




UNIVERSITY OF
LEICESTER

Radio and Space
Plasma Physics
group (RSPP)

Spatial, seasonal and solar cycle variations of the Martian total electron content (TEC): Is the TEC a good tracer for atmospheric cycles?

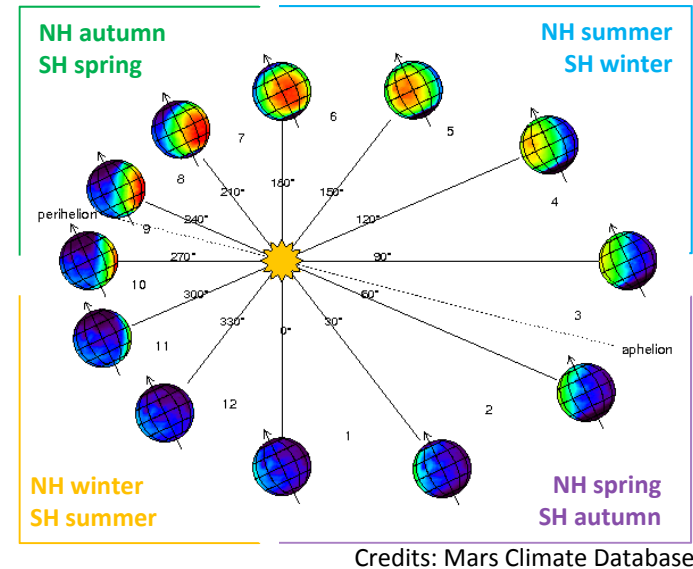


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Context

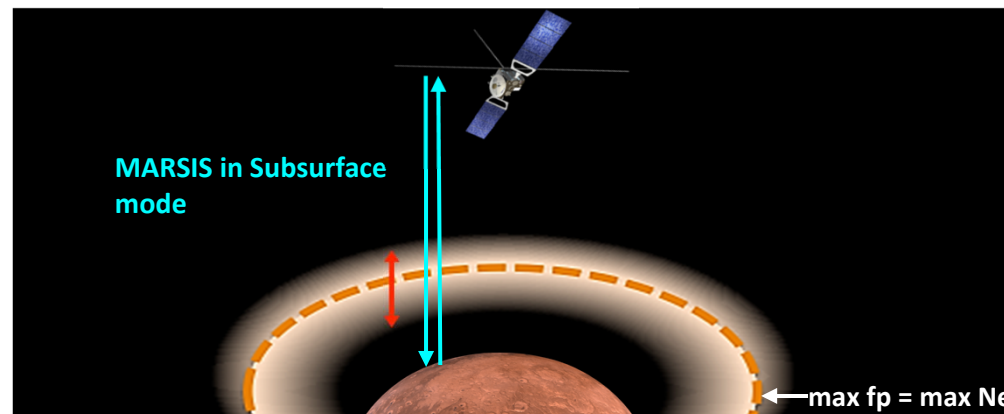
- Despite the large progress made in the last decade, the long-term relationship of the Martian ionosphere and thermosphere is not well-known.
- I.E. How the atmosphere-ionosphere system reacts to external and internal forcing processes, e.g., space weather, magnetic fields, gravity waves, or atmospheric cycles among many others?



- In this study, we go one step further in order to assess whether the ionospheric Total Electron Content (TEC) is a useful tracer for the Martian thermosphere, and eventually, whether the TEC can be used as a diagnostic parameter of the coupling between the lower and upper atmosphere.
- Contrarily to other planets, the heliocentric distance (Mars-Sun) is an important factor for the atmosphere behaviour. We use the Solar Longitude (Ls) as a proxy for the Martian year.

MARSIS – Mars Express radar: TEC

- TEC is the Total Electron Content of the full atmosphere. It is normally defined as:
$$TEC = \int_{h_0}^{h_f} Ne dh$$
- When MARSIS works in the Subsurface mode, TEC is retrieved from the phase delay in the carrier signals, which is directly caused by the ionization in the ionosphere.
 - Only data with Solar Zenith Angles $> 75^\circ$
 - Most of the data come from the dusk hemisphere
 - More than 10 years of data are used. Data from 2005-2015, MY27-32.

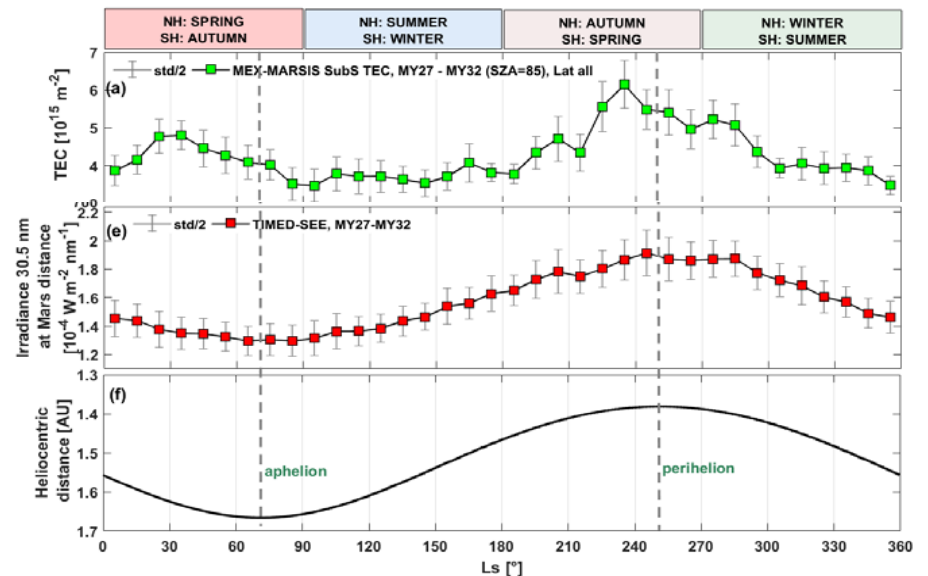


TEC annual variation

As well-known, the ionosphere is formed by the ionization of the thermosphere by solar radiation (EUV and soft X-rays), therefore, it is supposed that the TEC have to follow the irradiance profile.

- This does not happen between $L_s \sim [20,60]$
- The same effect is observed at all latitudes and solar cycle phases

We evaluate the effect of the neutral atmosphere on the ionosphere.

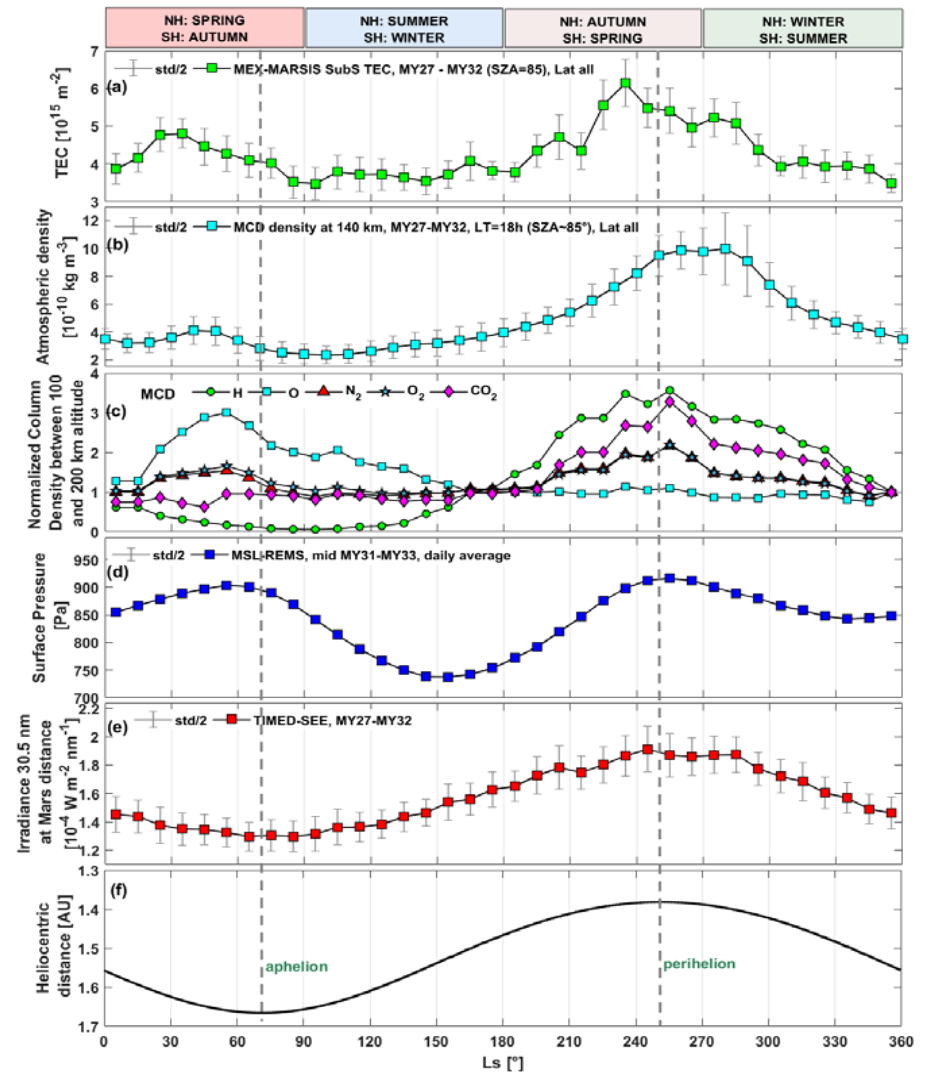


TEC annual variation

In principle, the ionosphere is formed by the ionization of the thermosphere by solar radiation (EUV and soft X-rays), therefore, it is supposed that the TEC have to follow the irradiance profile.

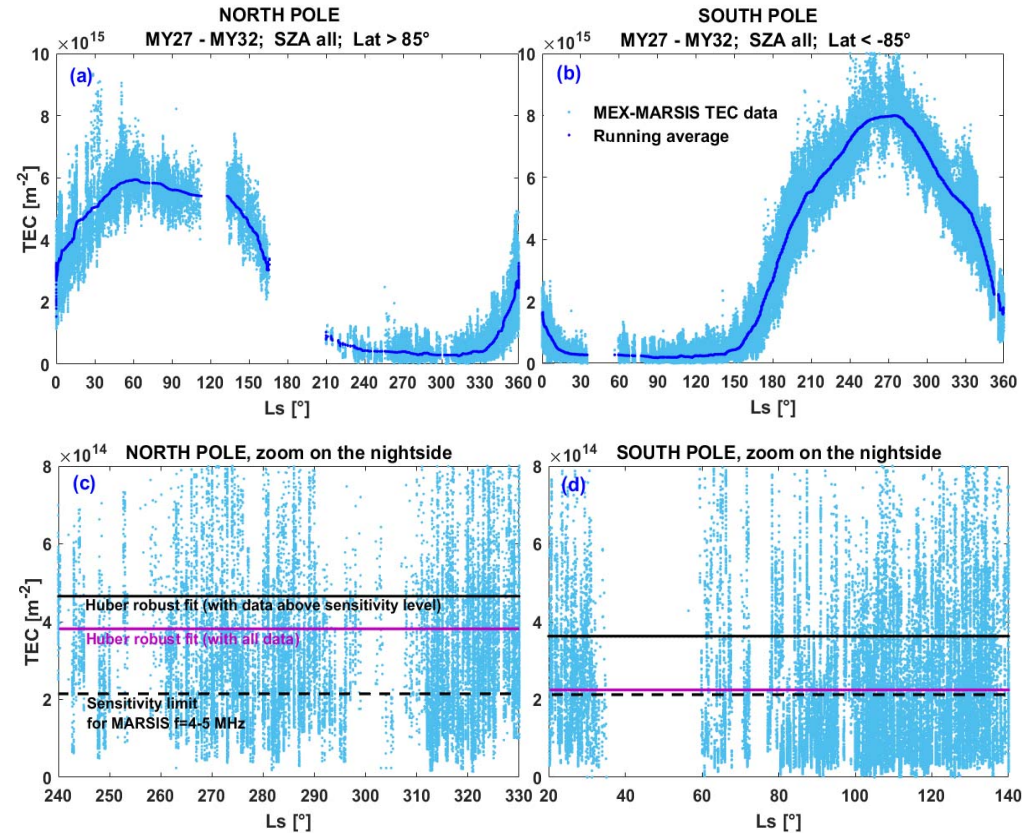
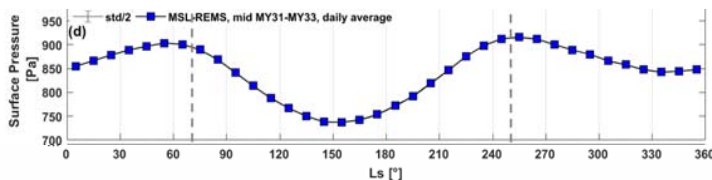
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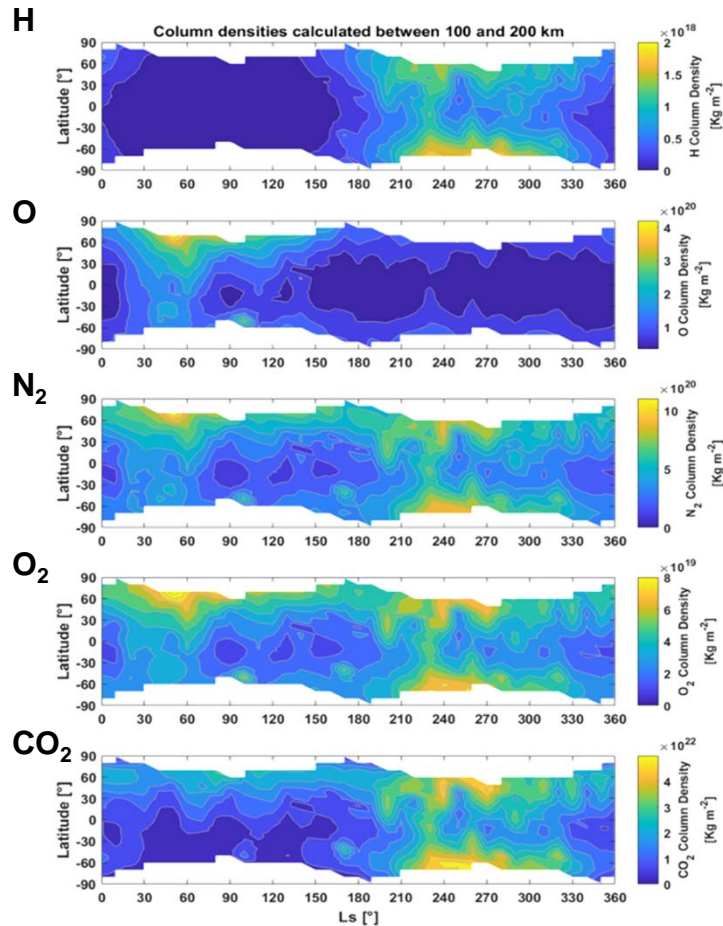


Polar ionosphere

- The Martian TEC at the Poles only responds to solar irradiance changes and neutral atmospheric variations
- However, the heliocentric distance is an important factor to be considered as there is a notable irradiance variation when each pole is illuminated.
- **NIGHTSIDE:** TEC of the North pole is **1.3** times larger.
- This is consistent with a **1.9** higher column density during the Northern winter than during the Southern winter: $N_e \sim \sqrt{N} \sim \sqrt{1.9} \sim 1.3$



Ionosphere-thermosphere simulation



The simulation was performed for **SZA=85°**, **local time 18h**, and keeping the **solar flux constant** for the entire simulation.

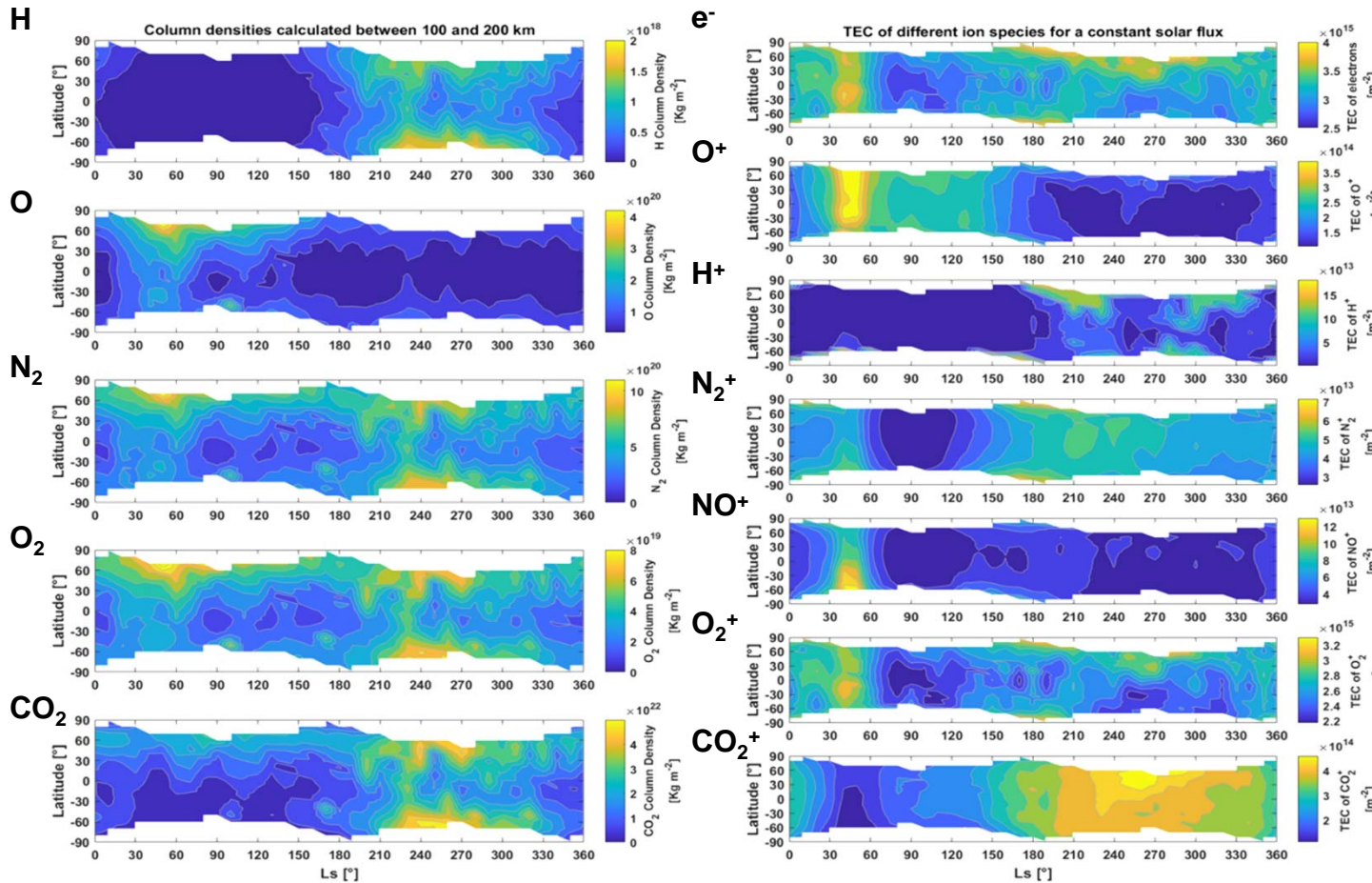
Ionospheric Model:

The numerical/physical **model IPIM** (Marchaudon and Brelly, 2015)

Neutral atmosphere:

The Global Circulation Model (**GCM**)- Laboratoire de Meteorologie Dynamique (**LMD**) (e.g. Montmessin et al., 2017).

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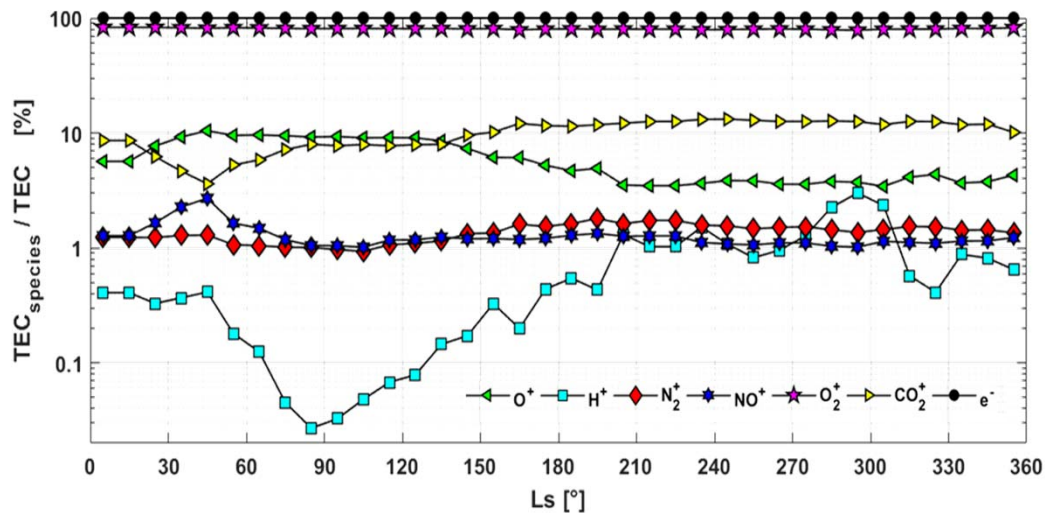
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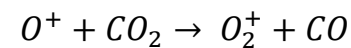
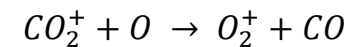
TEC contribution of each ion specie



The largest contribution to the TEC comes from the O₂⁺ ion, which oscillates between the 77 and 82%

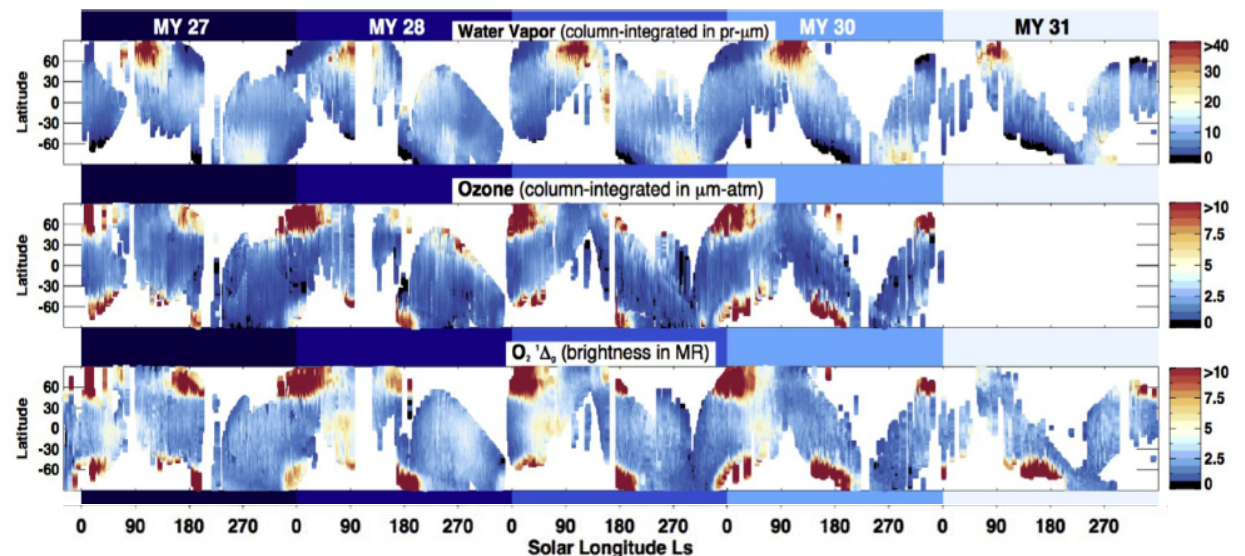
The second largest contribution comes from the O⁺ and CO₂⁺ ions (3-13%), being more important O⁺ during the first part of the year, and CO₂⁺ during the second part of the year.

These two species are a key to produce O₂⁺, and so, the TEC.



Is the TEC a good tracer for atmospheric cycles?

- It looks like it is! 😊
- Mars Express - SPICAM instrument have shown that while the polar cap sublimation is occurring, oxygen species below 50 km have a cyclical annual behaviour that agrees pretty well with our ionospheric observations and modelling (both temporal and location-wise).
- It looks like the double peak in the TEC annual profile is most likely a consequence of the seasonal variability of the thermosphere, produced by changes atmospheric cycles at low altitude.



Adapted from Montmessin et al., 2017

Conclusions

- α We have shown that the TEC parameter can be used as a good proxy for a systematic assessment of the thermosphere-ionosphere coupling.
- β Moreover, the TEC can be also used for monitoring the effects of low atmospheric cycles on the upper atmosphere.
- γ TEC is routinely measured by Mars Express and can be used for thermosphere monitoring (which is not routinely observed).
- δ Paper under review at *JGR Planets*, after minor revisions

Thank you for
your attention!!



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Credit: ESA/DLR/FU Berlin