Laboratory for Atmospheric and Space Physics
University of Colorado **Boulder**

2021-09-17 Whole Heliosphere and Planetary Interactions Workshop

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The Origins of Long-Term Variability in Martian Upper Atmospheric Densities

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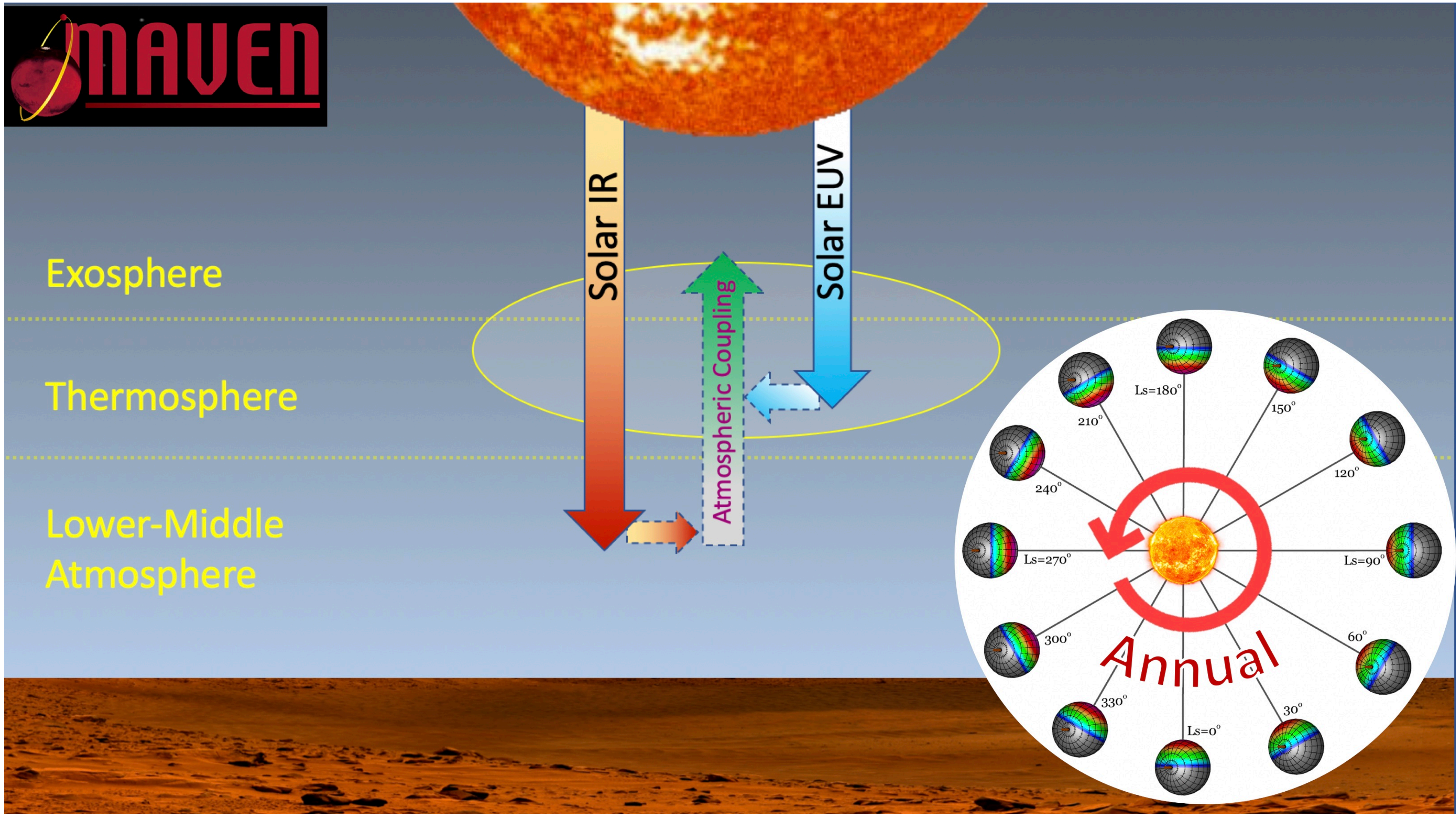
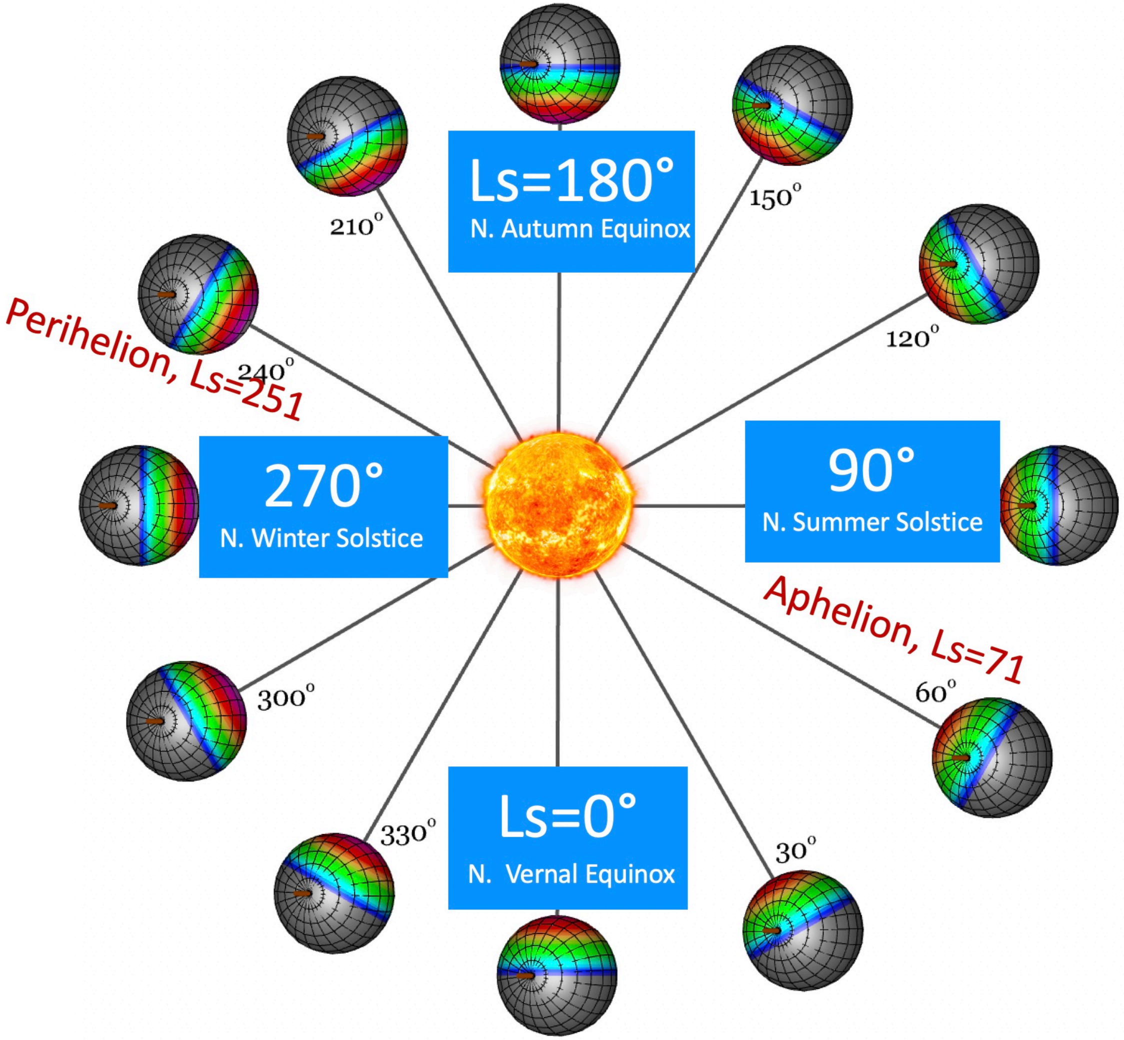
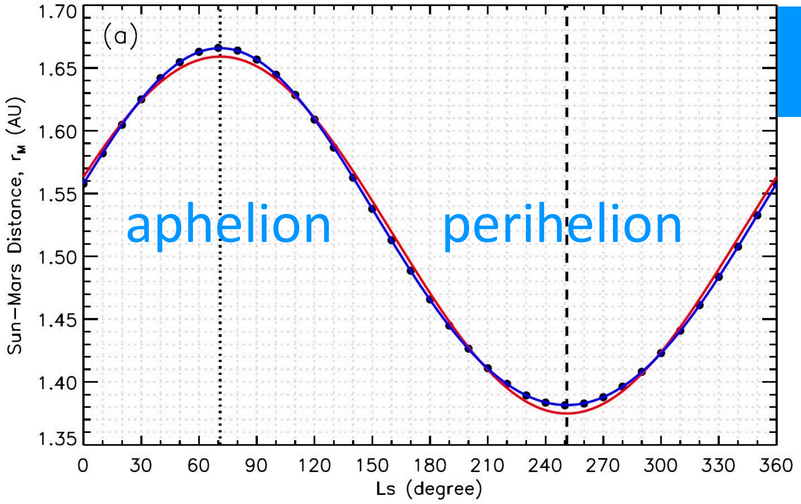


Annual variation of solar irradiance (IR & EUV) at Mars.

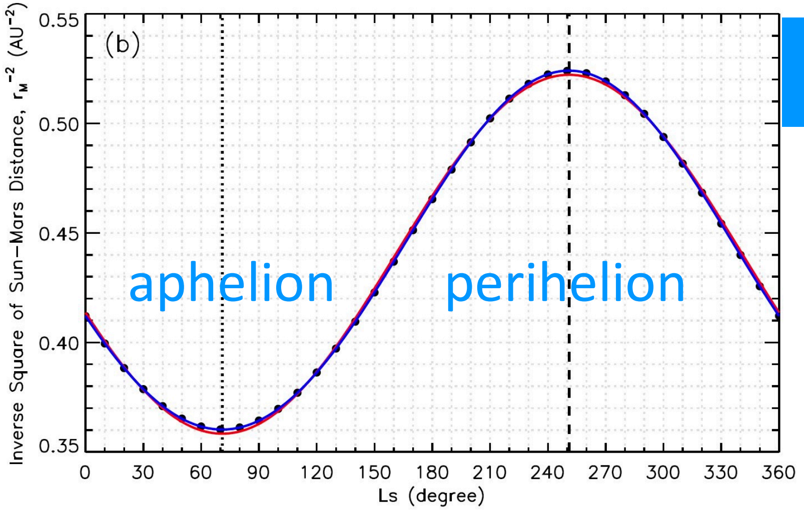


Sun-Mars Distance, r



r(Ls)

Inverse Square of Sun-Mars Distance



$r^{-2}(Ls)$

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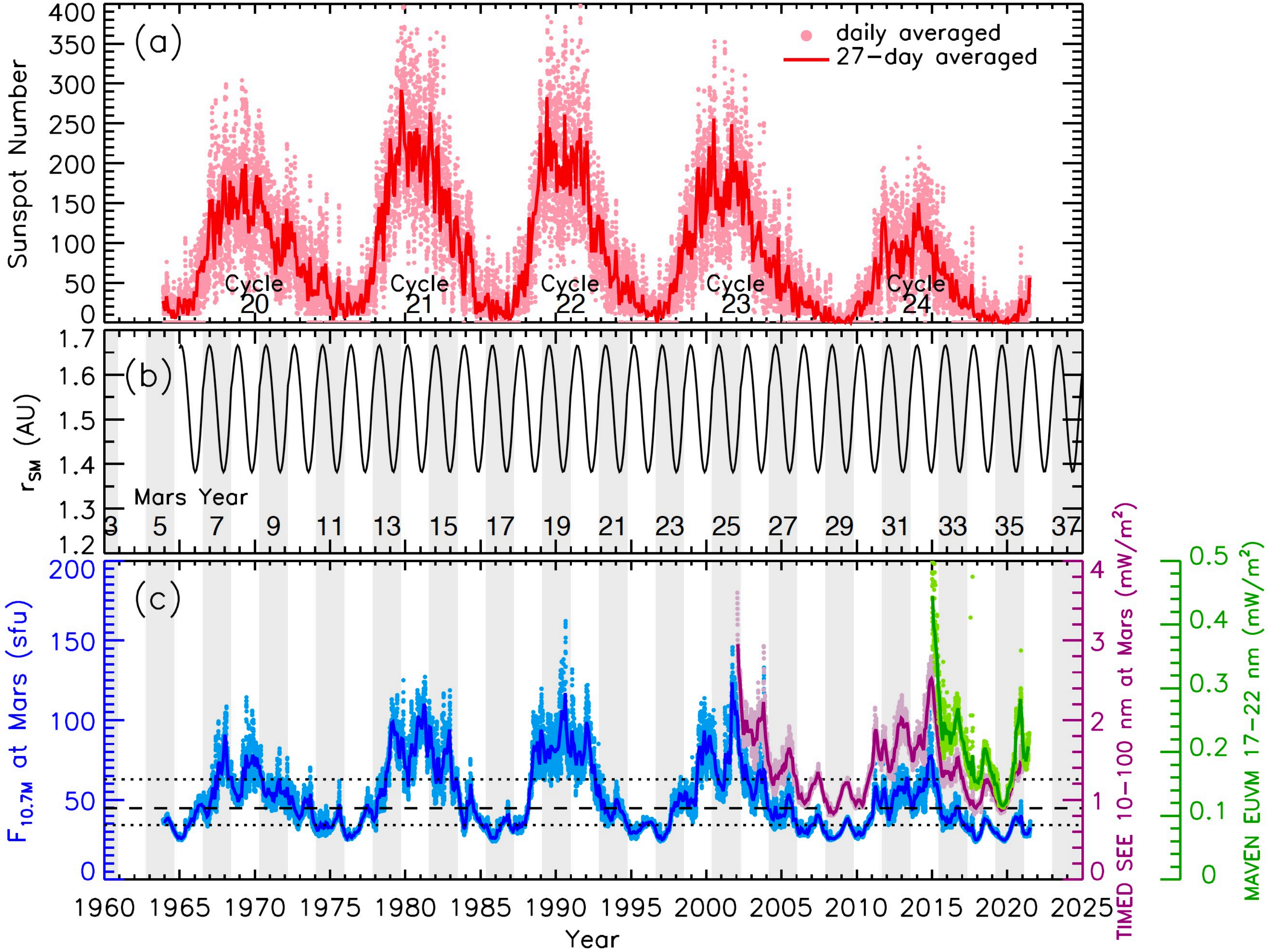
Solar EUV is subject to an additional 11-year solar cycle variation.

sunspot number

Sun-Mars distance

solar EUV at Mars
(3 proxies)



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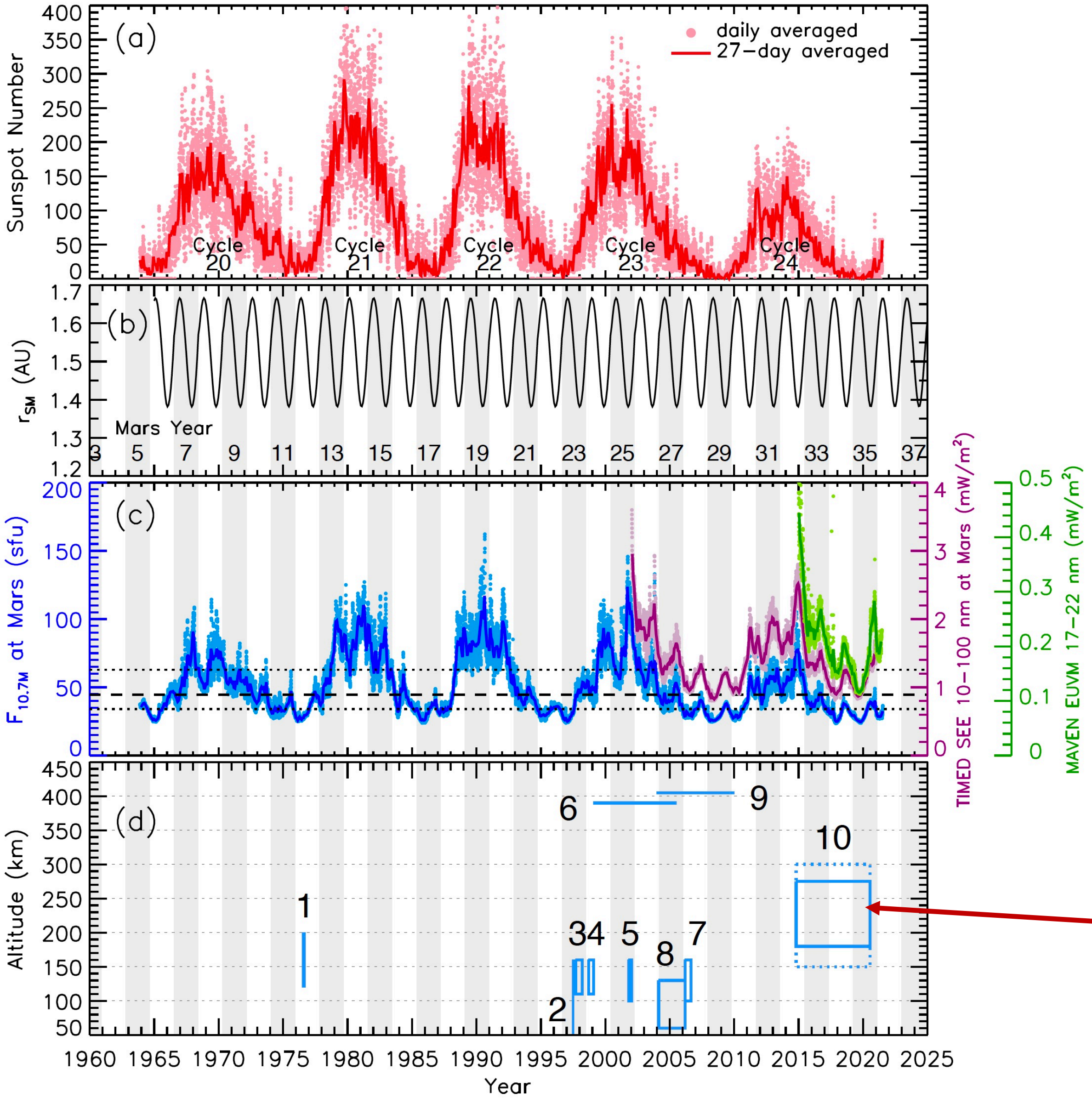
Little is known about the long-term variation of the Martian upper atmosphere.

sunspot number

Sun-Mars distance

solar EUV at Mars
(3 proxies)

upper atmospheric
observations
(altitude & time)



this study

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SZA-dependence of atmospheric densities as seen from a global model.

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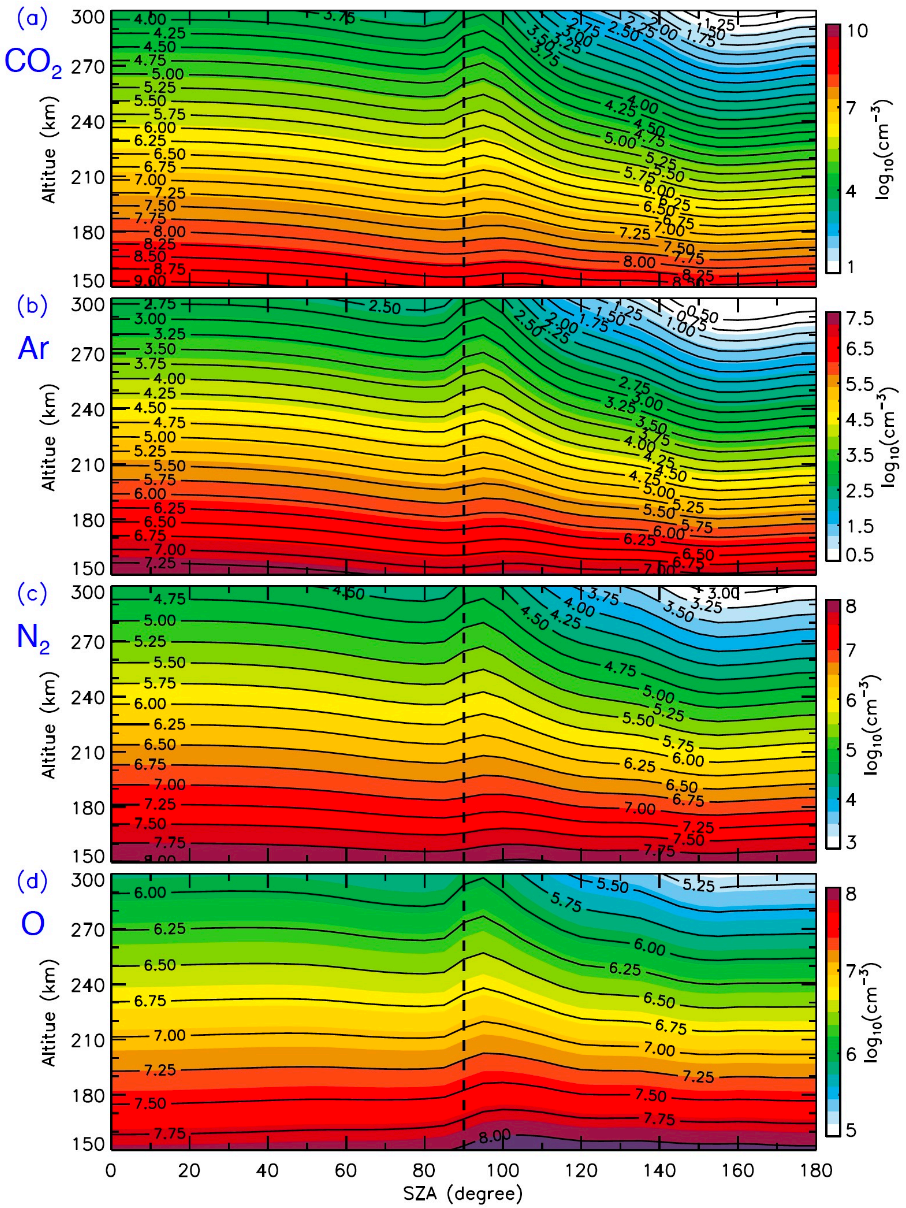
CO_2

Ar

N_2

O



(The MGITM model results for a quiet case are retrieved from *Fang et al*. [2019].)

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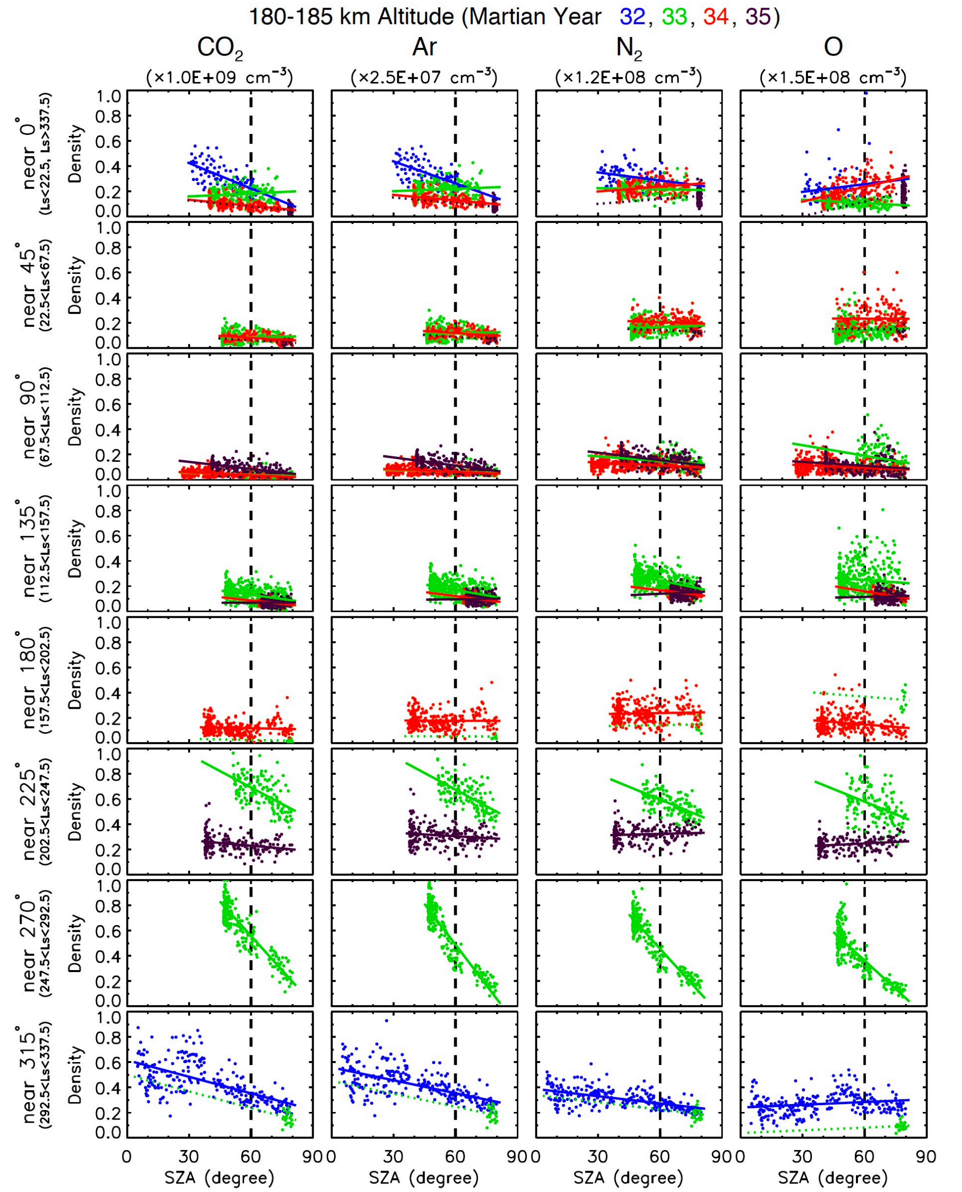
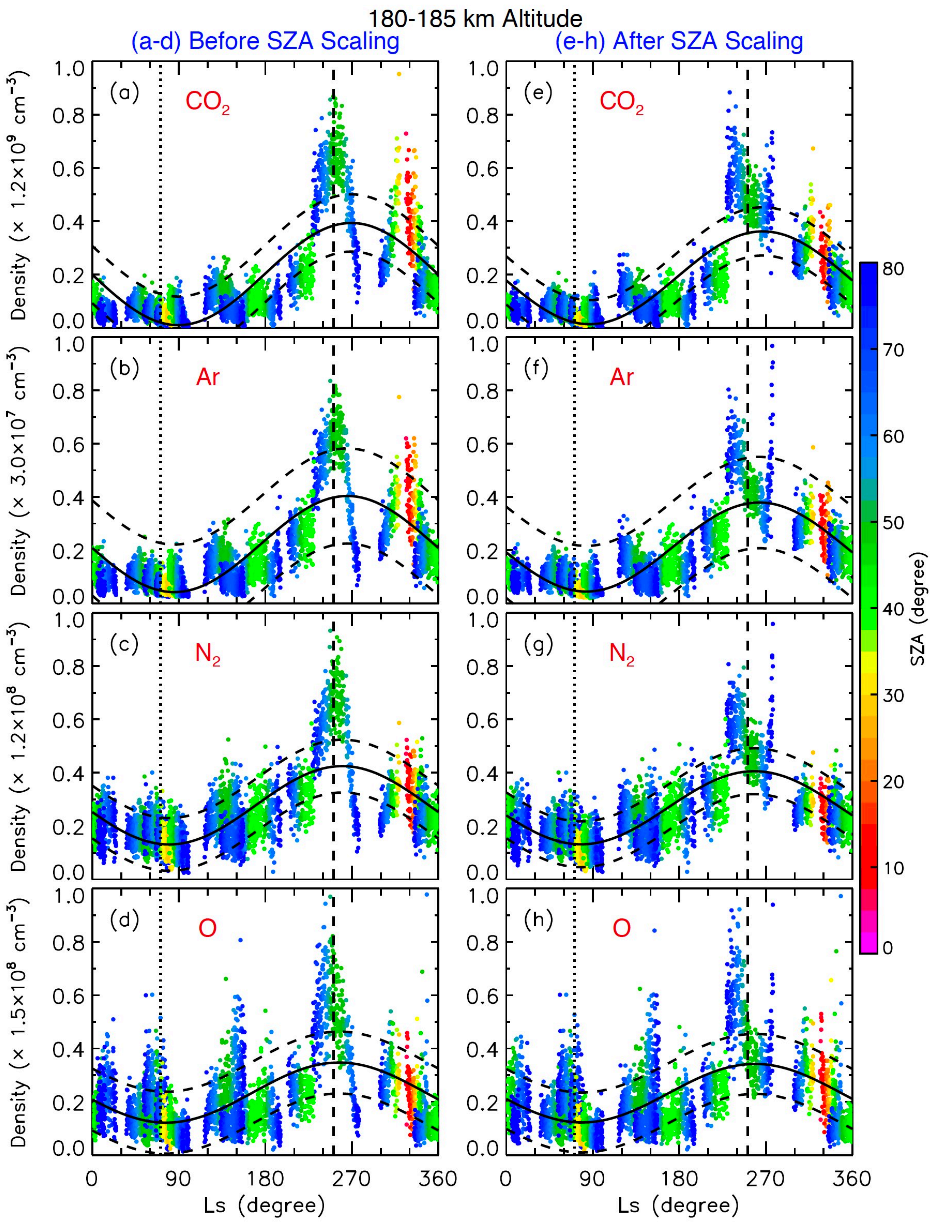
Data processing: density scaling with SZA (dayside to 60°)





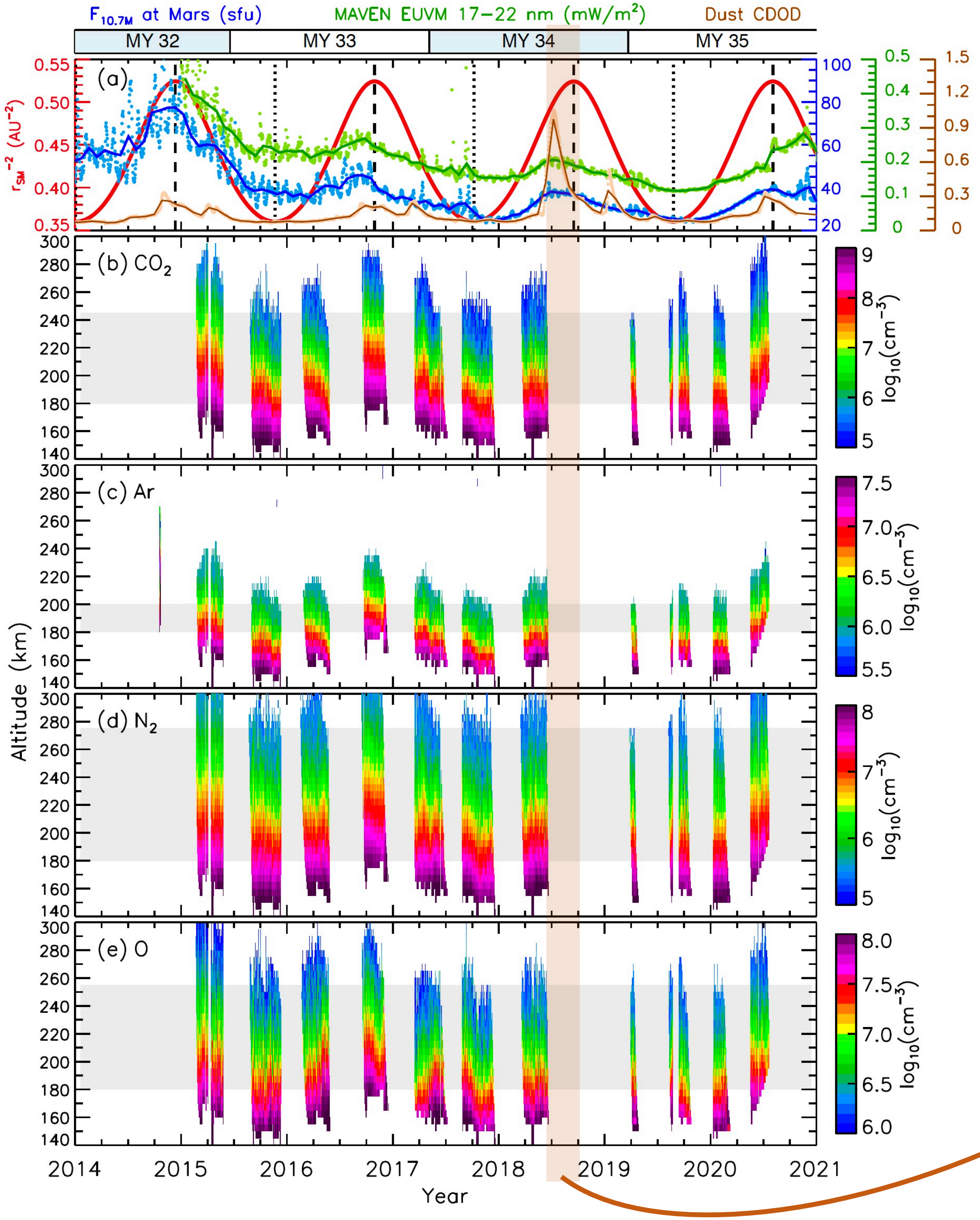
Overview

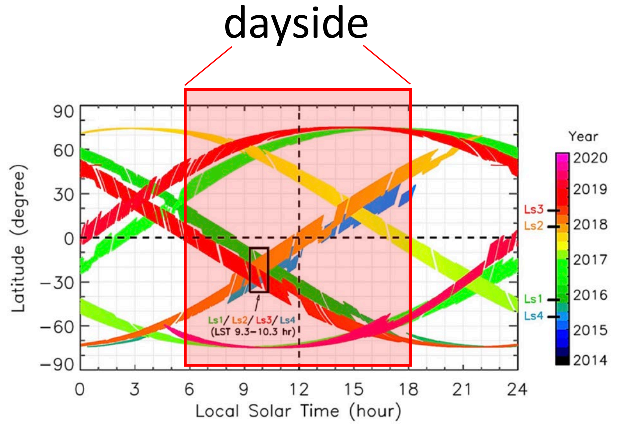
CO_2

Ar

N_2

O





precession of MAVEN periapsis

[*Fang et al.*, 2021]

Unfortunately, high dust activity is not covered by MAVEN dayside observations.

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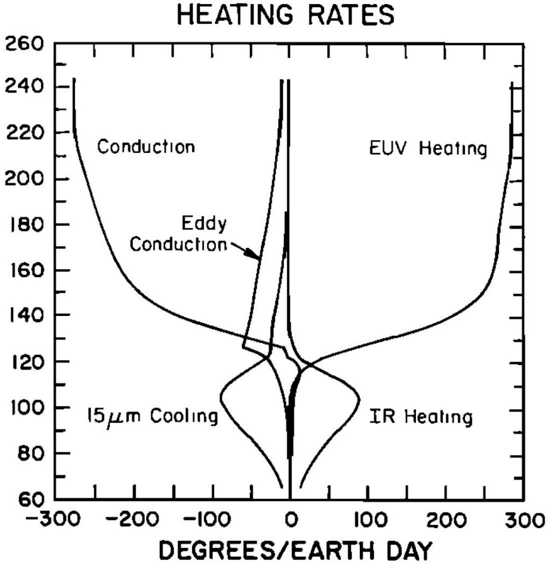
Multiple linear regression to 27-day averaged densities:

$$n = n_0 + n_1 r_{SM}^{-2} + n_2 F_{10.7M}$$

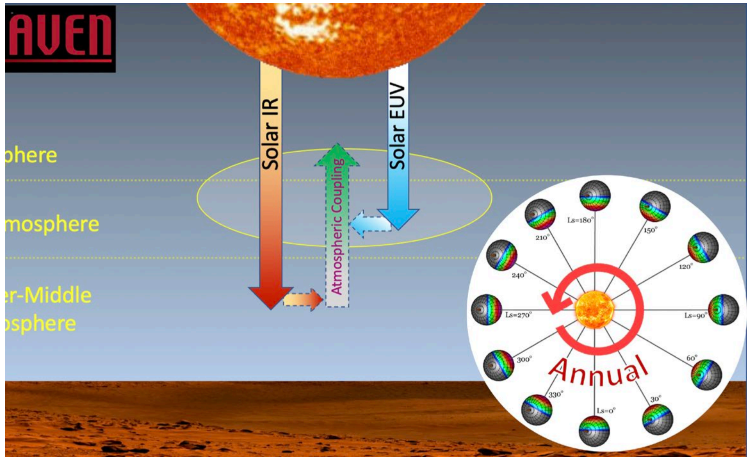
orbital effect

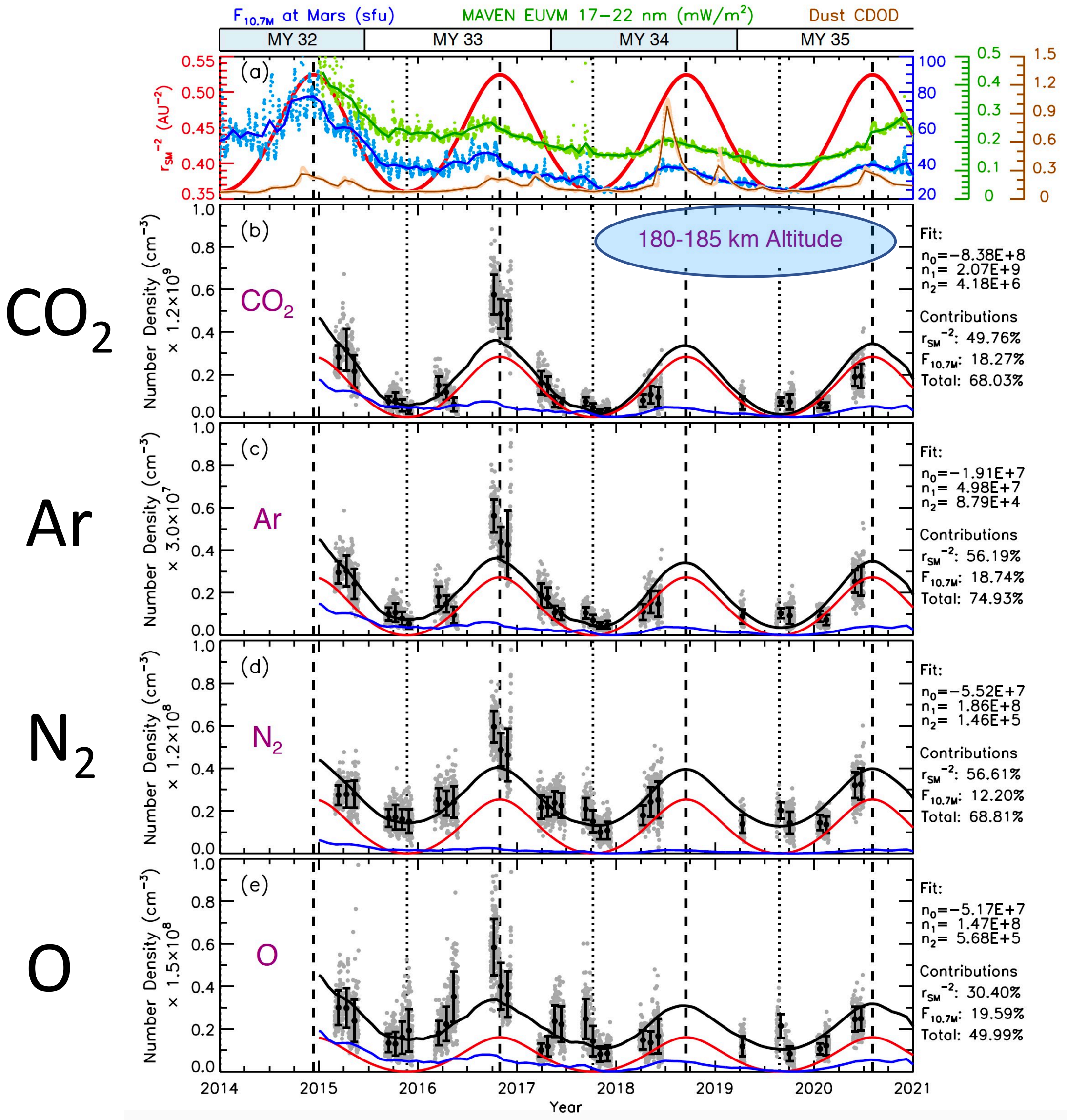
solar EUV effect

Solar IR at Mars	Solar EUV at Mars
Indirect effect	direct effect
upward coupling from the middle atmosphere	local heating



[*Bougher and Dickinson*, 1988]





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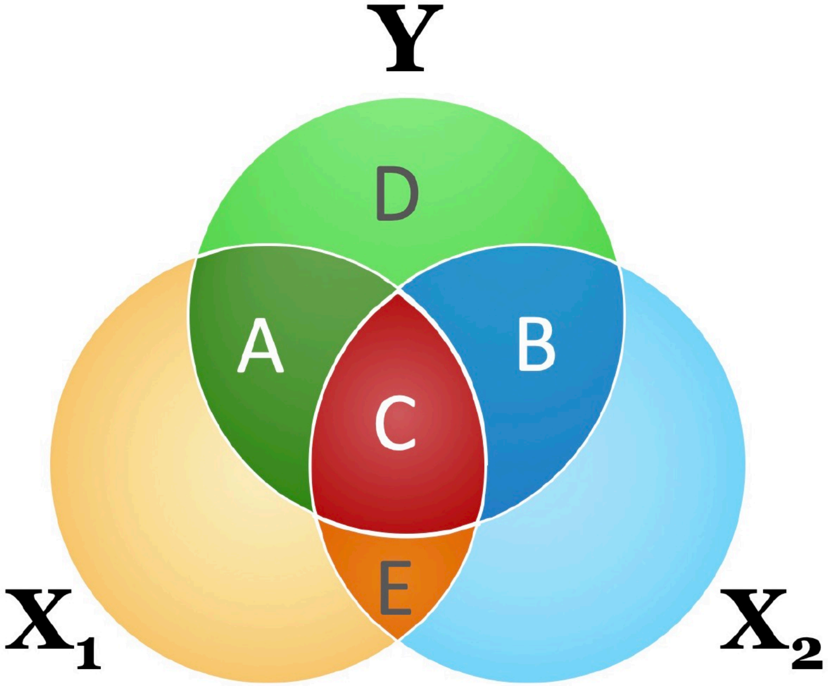
“Dominance Analysis”: determination of relative importance



Squared zero-order correlation between X_1 and Y:

$r_1^2 = A+C$

Squared zero-order correlation between X_2 and Y:

$r_2^2 = B+C$

Coefficient of determination (squared multiple correlation coefficient):

$R^2 = A+B+C$

Contribution of X_1 to variance in Y:

$(r_1^2 + (R^2 - r_2^2))/2 = A + \frac{1}{2} C$

Contribution of X_2 to variance in Y:

$(r_2^2 + (R^2 - r_1^2))/2 = B + \frac{1}{2} C$

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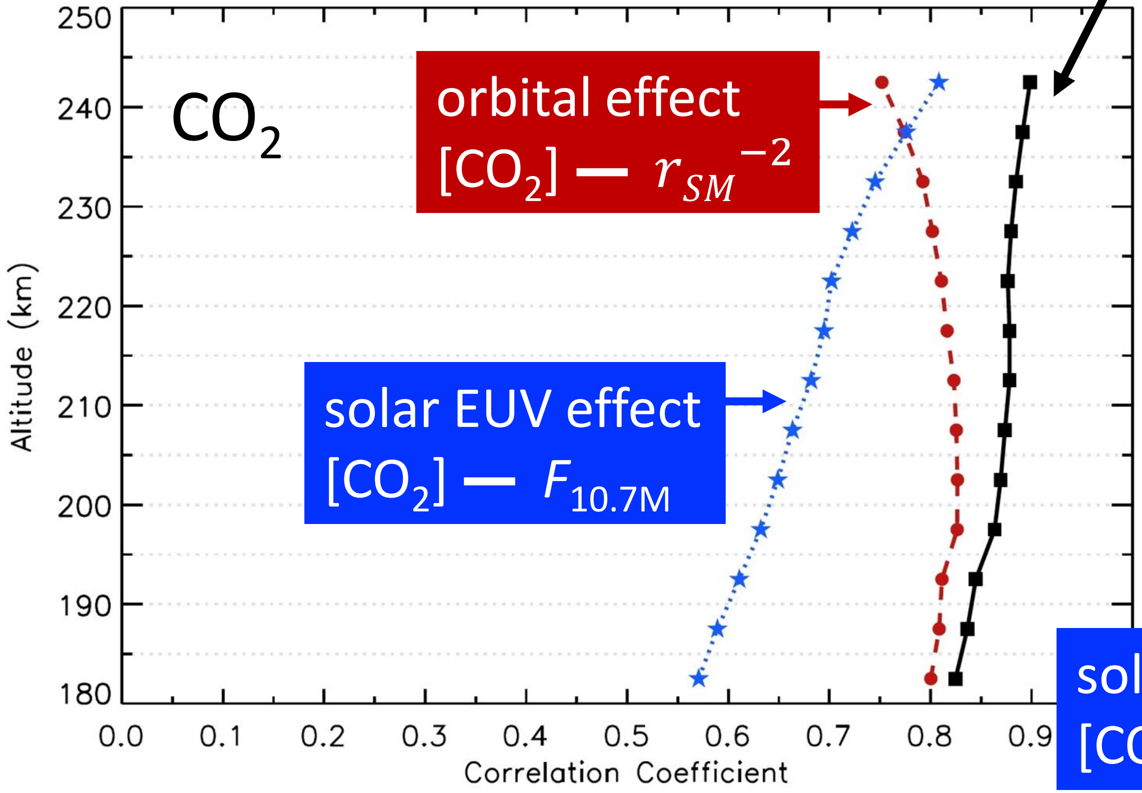
Multiple linear regression: $n = n_0 + n_1 r_{SM}^{-2} + n_2 F_{10.7M}$

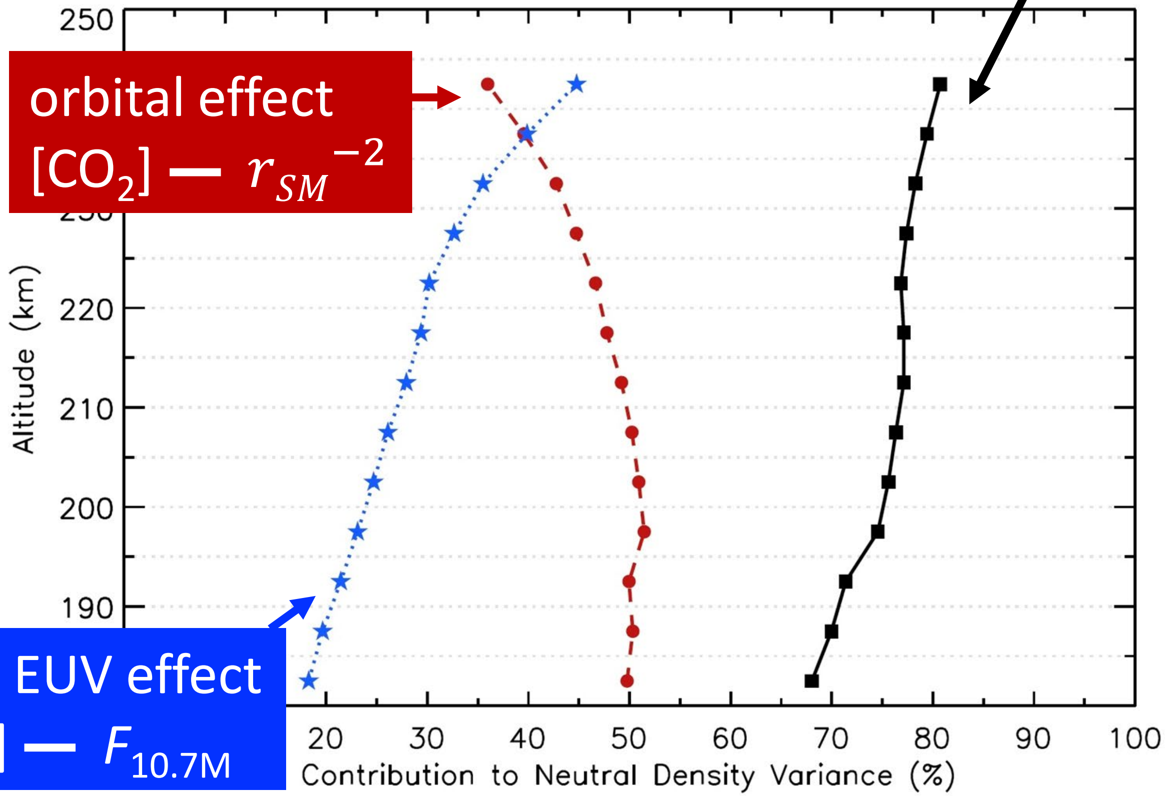
Multiple correlation coefficient, R
$[CO_2]$ — r_{SM}^{-2} & $F_{10.7M}$

coefficient of determination, R^2
$[CO_2]$ — r_{SM}^{-2} & $F_{10.7M}$



orbital effect
$[CO_2]$ — r_{SM}^{-2}

solar EUV effect
$[CO_2]$ — $F_{10.7M}$



orbital effect
$[CO_2]$ — r_{SM}^{-2}

solar EUV effect
$[CO_2]$ — $F_{10.7M}$

correlation coefficients

relative importance

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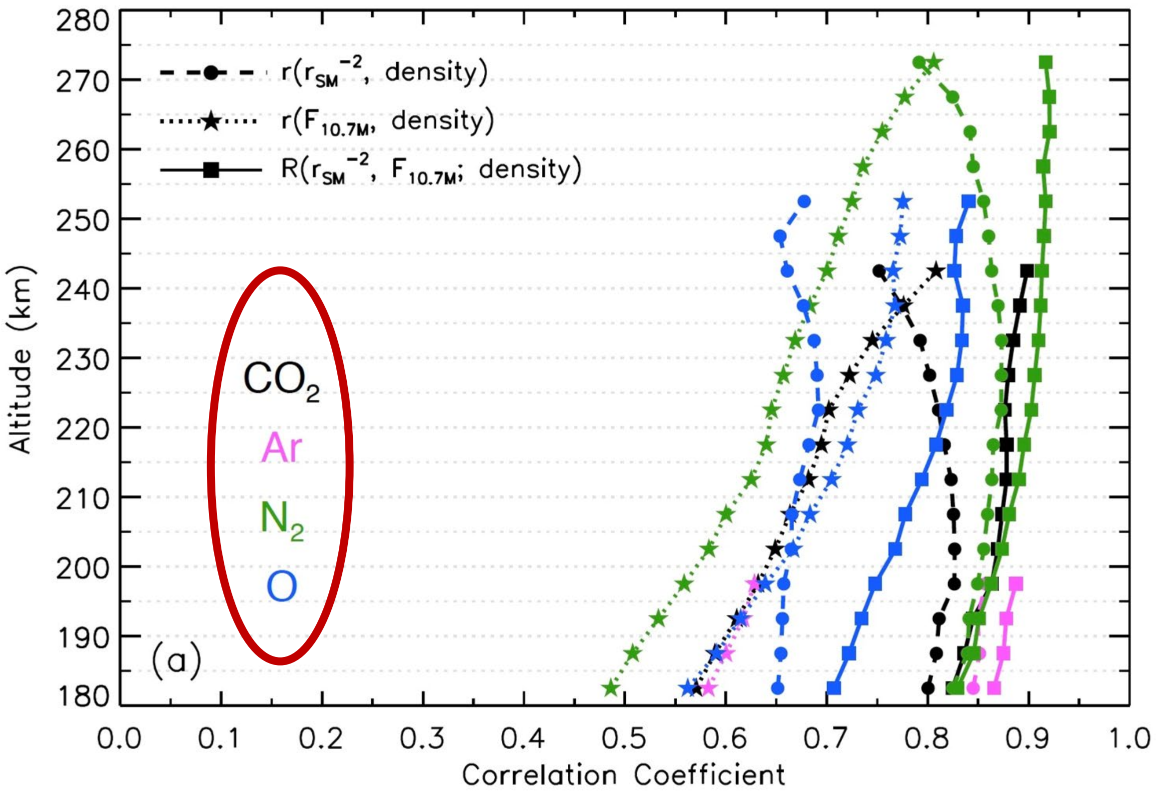
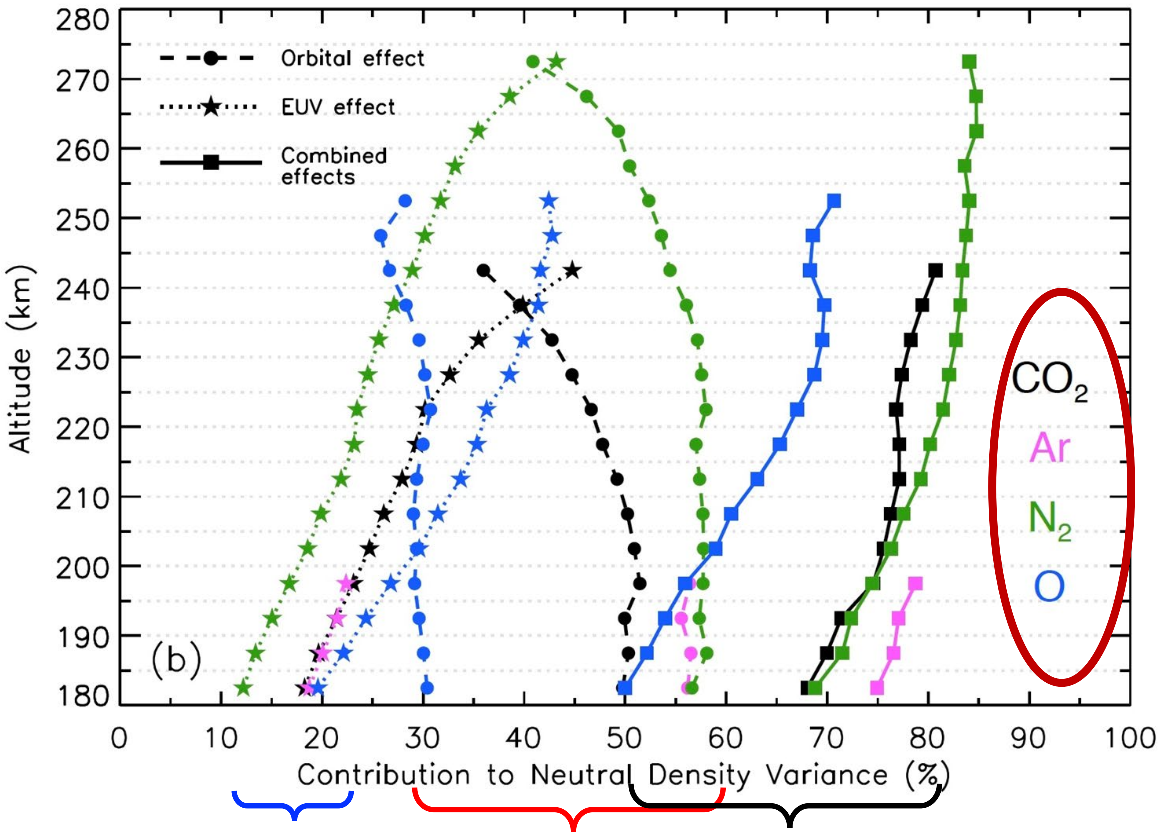
Multiple linear regression: $n = n_0 + n_1 {r_{SM}}^{-2} + n_2 \mathrm{F}_{10.7M}$

correlation coefficients

relative importance





solar EUV effect orbital effect combined effects

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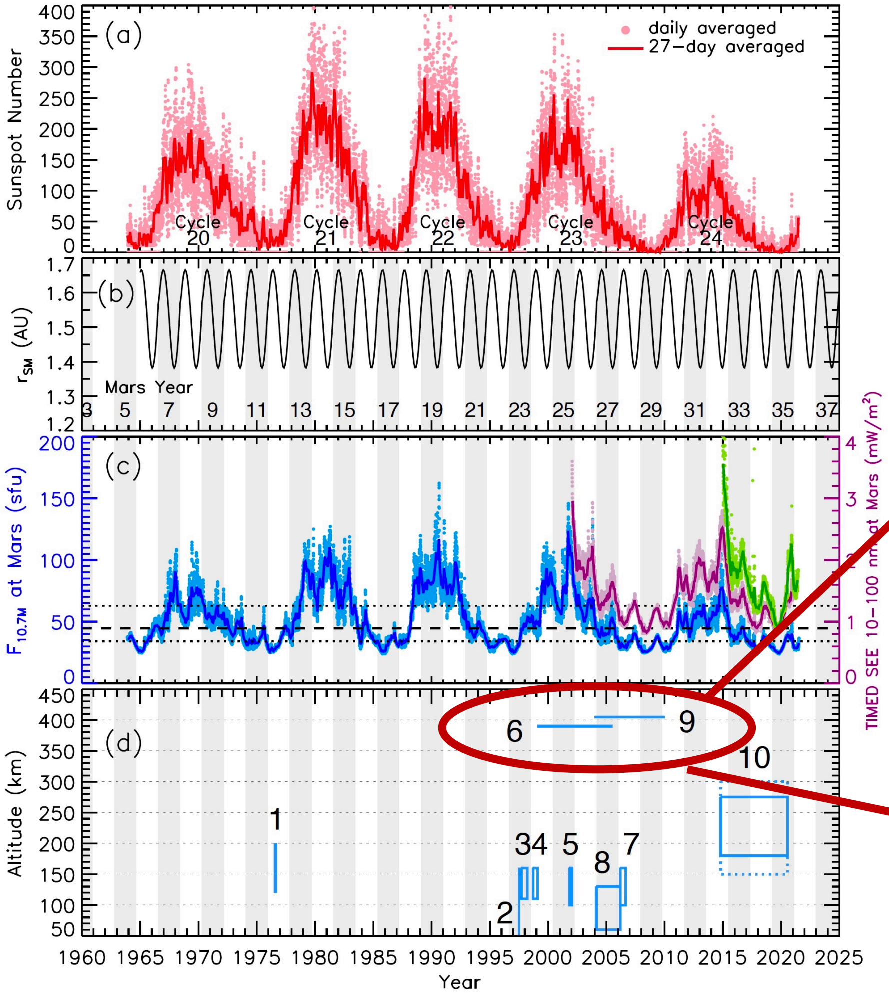
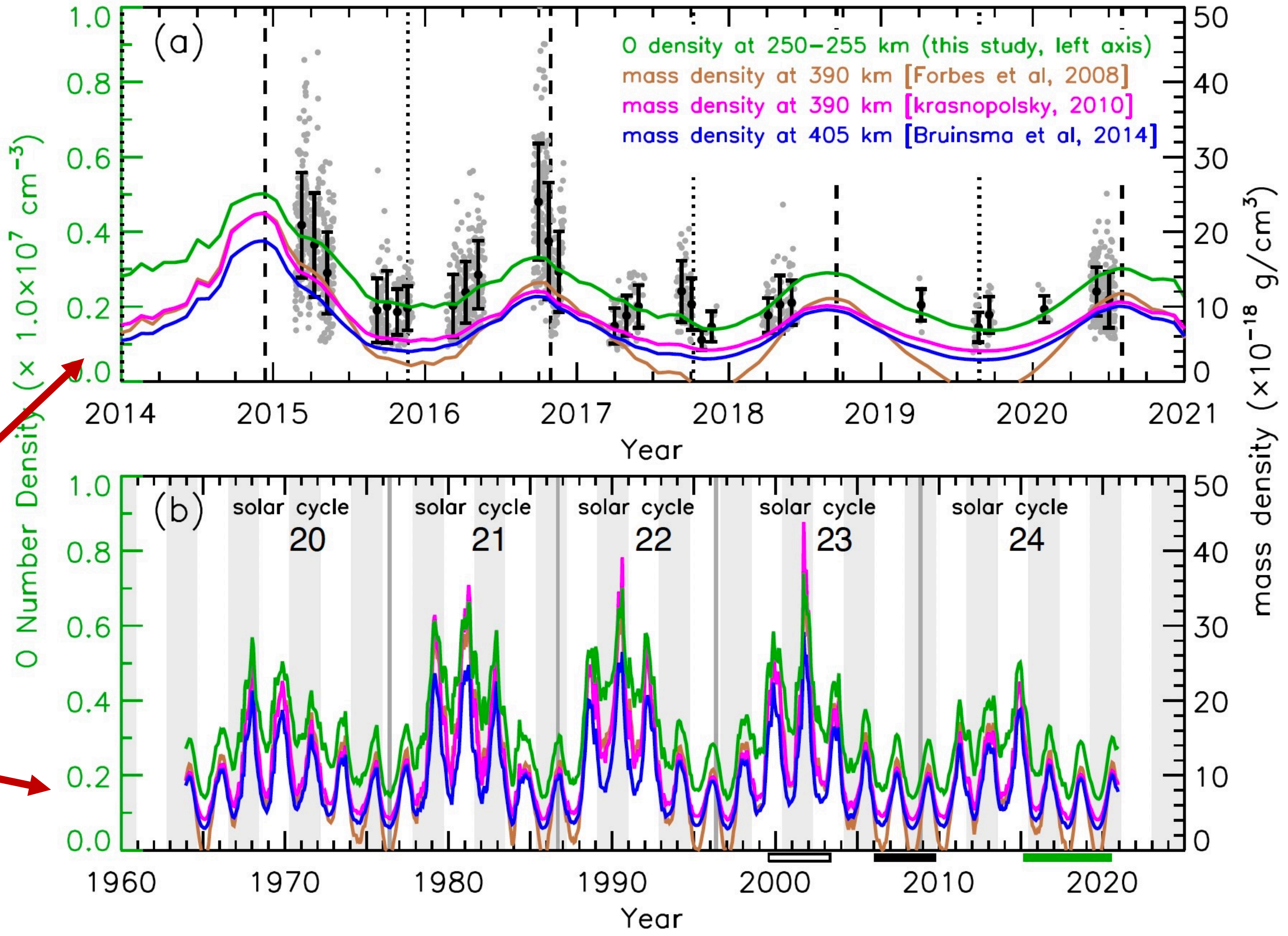
Comparison with previous long-term studies near 400 km





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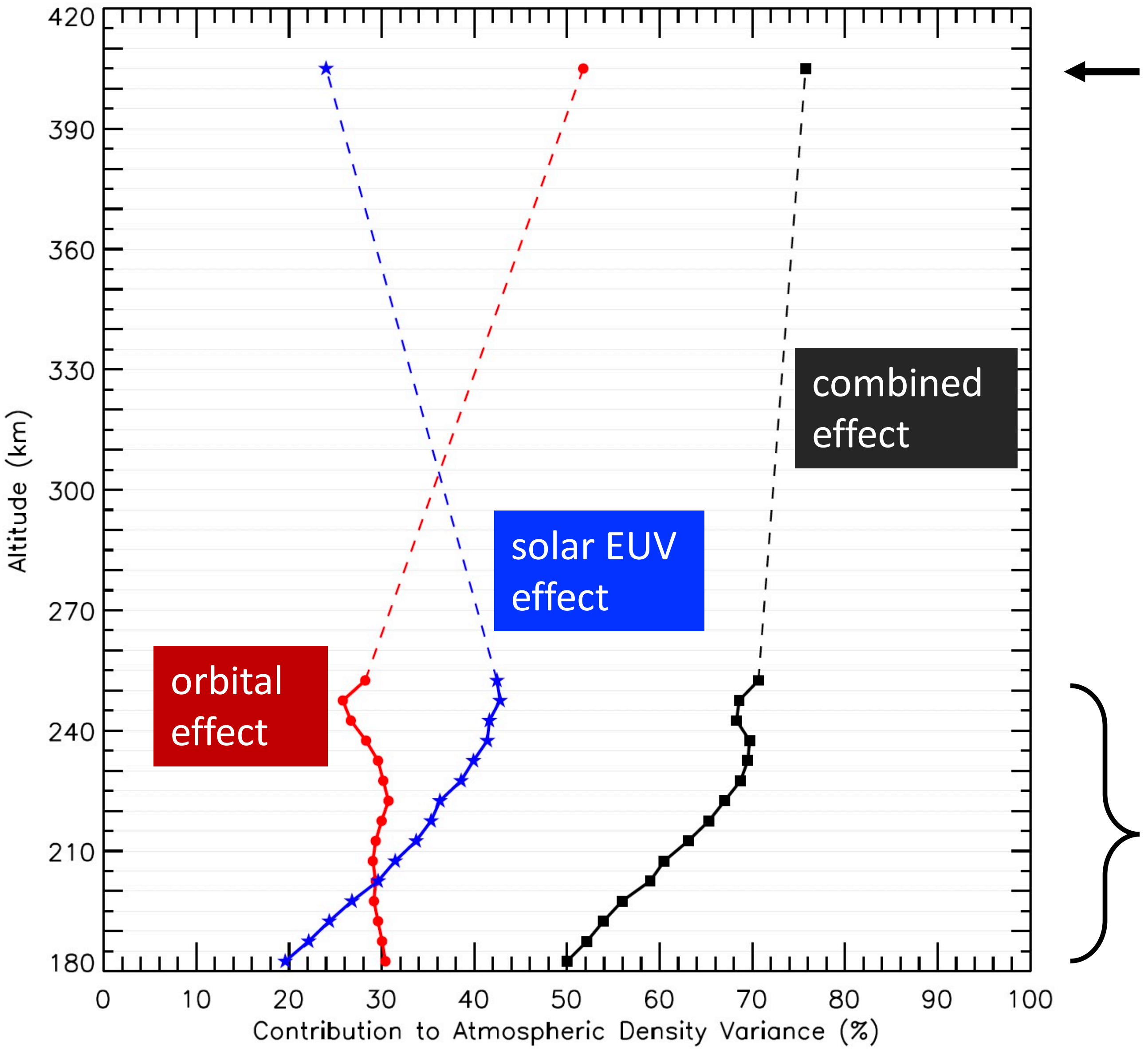
Altitude variation during solar min



derived from MO estimated mass densities

derived from MAVEN measured O densities

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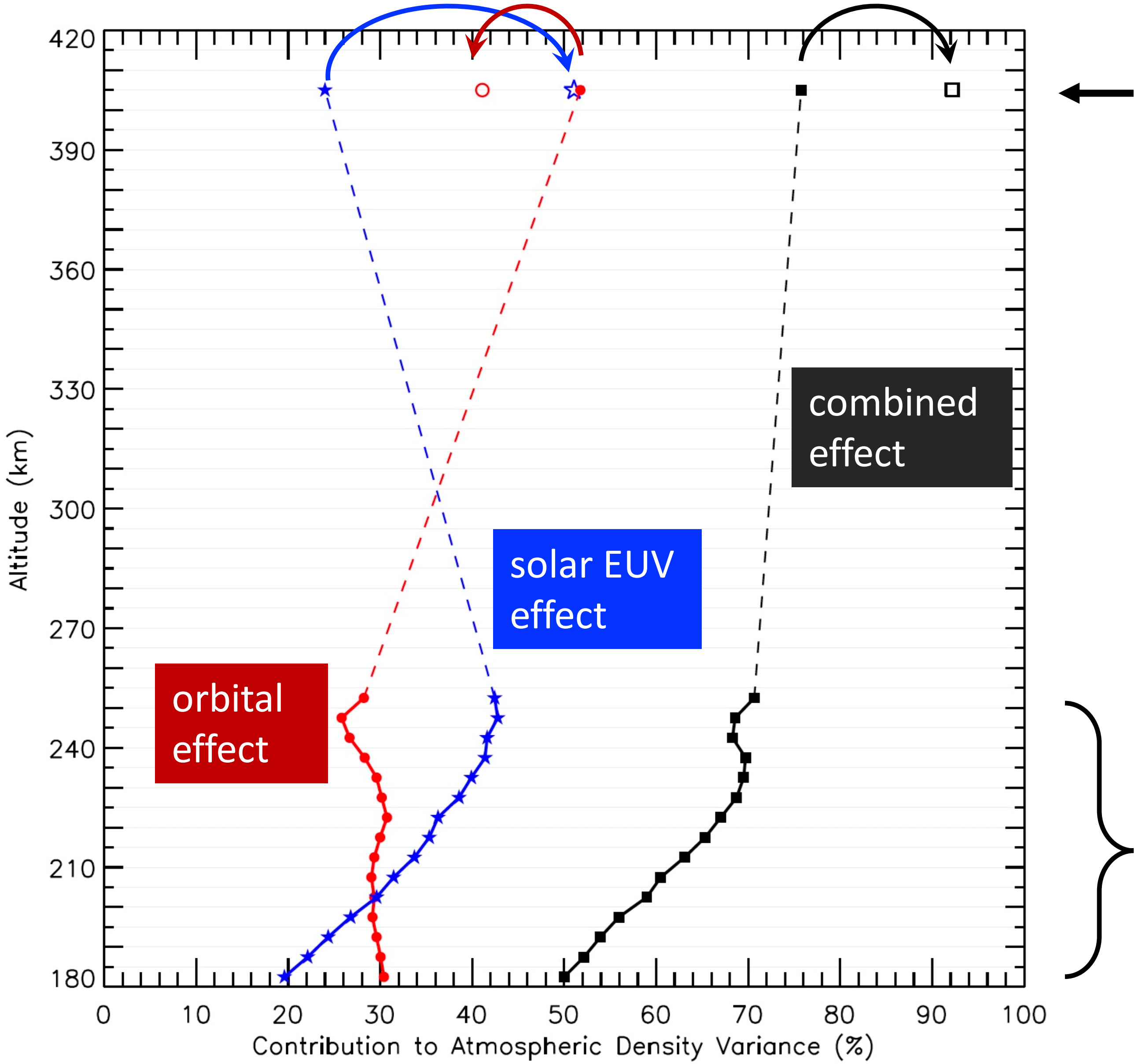
Solar cycle variation: from solar min to solar max



derived from MO estimated mass densities

derived from MAVEN measured O densities

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Summary and Conclusions

- Orbital and solar EUV effects on CO_2, N_2, Ar, and O densities within 180-275 km in the Martian upper atmosphere are quantified for the first time in MAVEN measurements.
- The relative importance of these two effects varies with altitude, indicating the competition in the upper atmosphere between the indirect effect of solar infrared (via the upward coupling from the middle atmosphere) and the direct effect of solar EUV (due to local heating).
- The orbital (solar EUV) effect decreases (increases) with altitude.
- The orbital effect and solar EUV effect are comparable at approximately 240 km, 270 km, and 205 km for CO_2, N_2, and O, respectively.
- The orbital (solar EUV) effect plays a predominant role in affecting density distributions below (above) these transition altitudes.
- Near 400 km, the orbital effect is always a key driver regardless of the solar cycle phase. The role of solar EUV effect changes from secondary to primary from solar min to solar max.

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