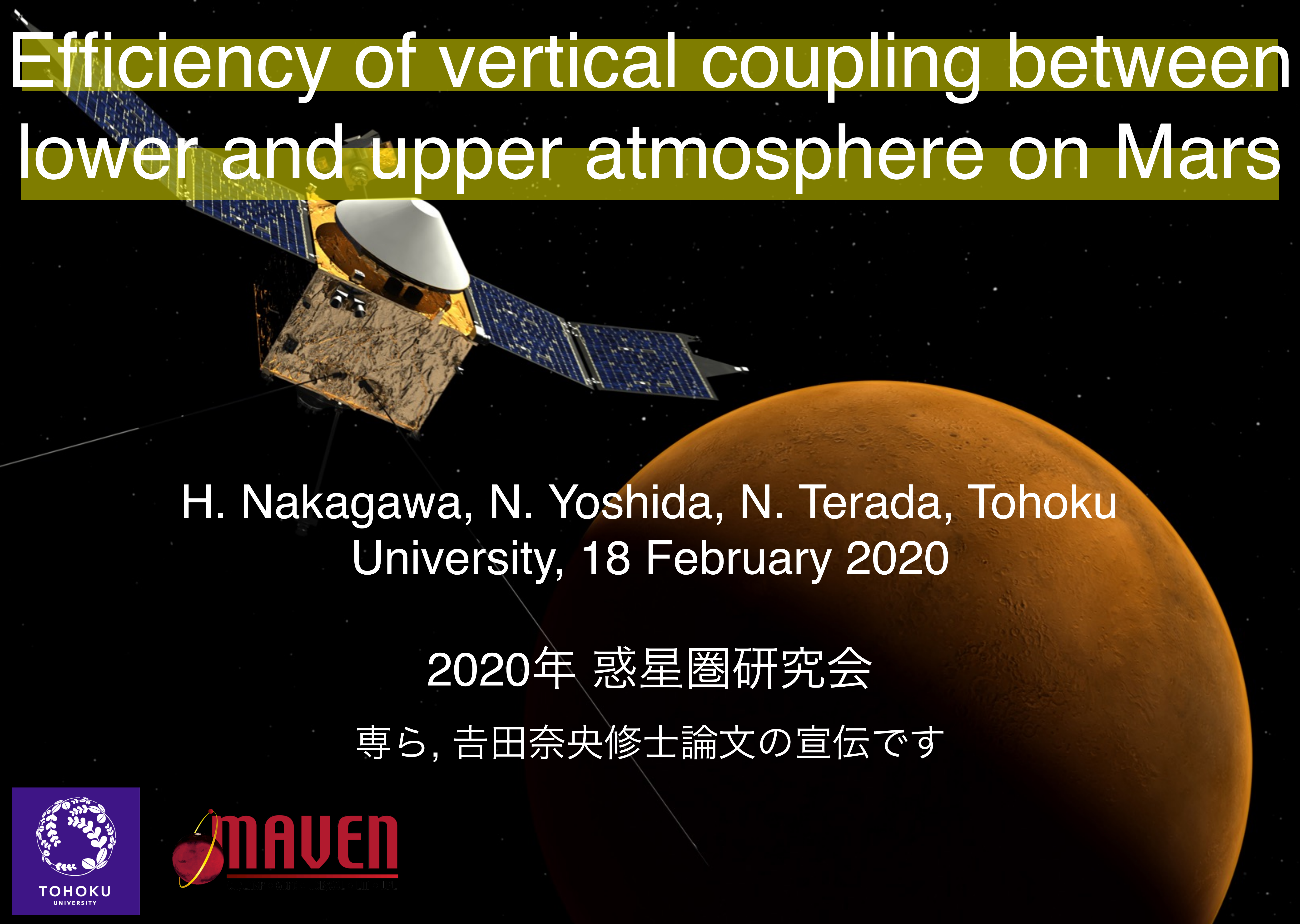
Efficiency of vertical coupling between lower and upper atmosphere on Mars

H. Nakagawa[1], N. Yoshida[1], and N. Terada[1]

[1]Graduate school of Science, Department of Geophysics, Tohoku University

In this study, we investigate the vertical coupling especially of the atmospheric composition between thermosphere, exosphere, and ionosphere, by comprehensive remote-sensing and in-situ observations by Mars Atmosphere and Volatile EvolutioN (MAVEN). N_2/CO_2 at 140 km significantly varies in the range of 0.02 and 0.20 and clearly exhibits seasonal and latitudinal dependences. Seasonal dependence shows a sinusoidal trend that is largest (~0.063 on average) near aphelion and smallest (~0.031 on average) near perihelion. This variation is mainly caused by larger variation of CO_2 density. Latitudinal dependence of N_2/CO_2 appears in northern summer and increase toward the southern winter hemisphere by a factor of two. Our study suggests that the variations of the homopause altitude are most likely the cause of N_2/CO_2 variation at 140 km. Inferred dayside homopause altitudes are in the range of 60 to ~140 km and this fact agrees with Slipski et al. (2018). CO_2 densities at the inferred homopause altitude vary in the range of 10^{10} to ~10^{12} (cm^{-3}), which suggests that eddy diffusion coefficient at the homopause altitude substantially changes by two orders. The homopause altitude would vary not only by inflation and contraction of the lower atmosphere but also by changes in eddy diffusions via turbulence activities. At 200 km, the variation of CO_2^+ density resembles that of CO_2 density. The observed sinusoidal trend of CO_2^+ density suggests that ionospheric density is relatively controlled by the seasonal effect of the neutral upper atmosphere than the effect of solar EUV flux. In contrast, N+ density shows the opposite trend to CO_2^+ density, which could be explained by the fact that the photochemical loss of N+ is caused by the reaction with CO_2. The closer relationship between the neutral upper atmosphere and ionosphere is also confirmed below 250 km. The mixing ratio of CO_2^+/O_2^+ can vary along the season in the range of ~0.017 to ~0.097, by a factor of ~6 around 370 km altitude. CO_2^+ escape rate can change by up to a factor of 6 due to the ionospheric composition. However, additional mechanism to change CO_2^+/O_2^+ might exist to explain the reported ratio of heavy ion escape rates, which may be caused by external forces from above.



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H. Nakagawa, N. Yoshida, N. Terada, Tohoku University, 18 February 2020

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Unexpected high-altitude water

- Active, rapid vertical coupling on Mars than previously thought.

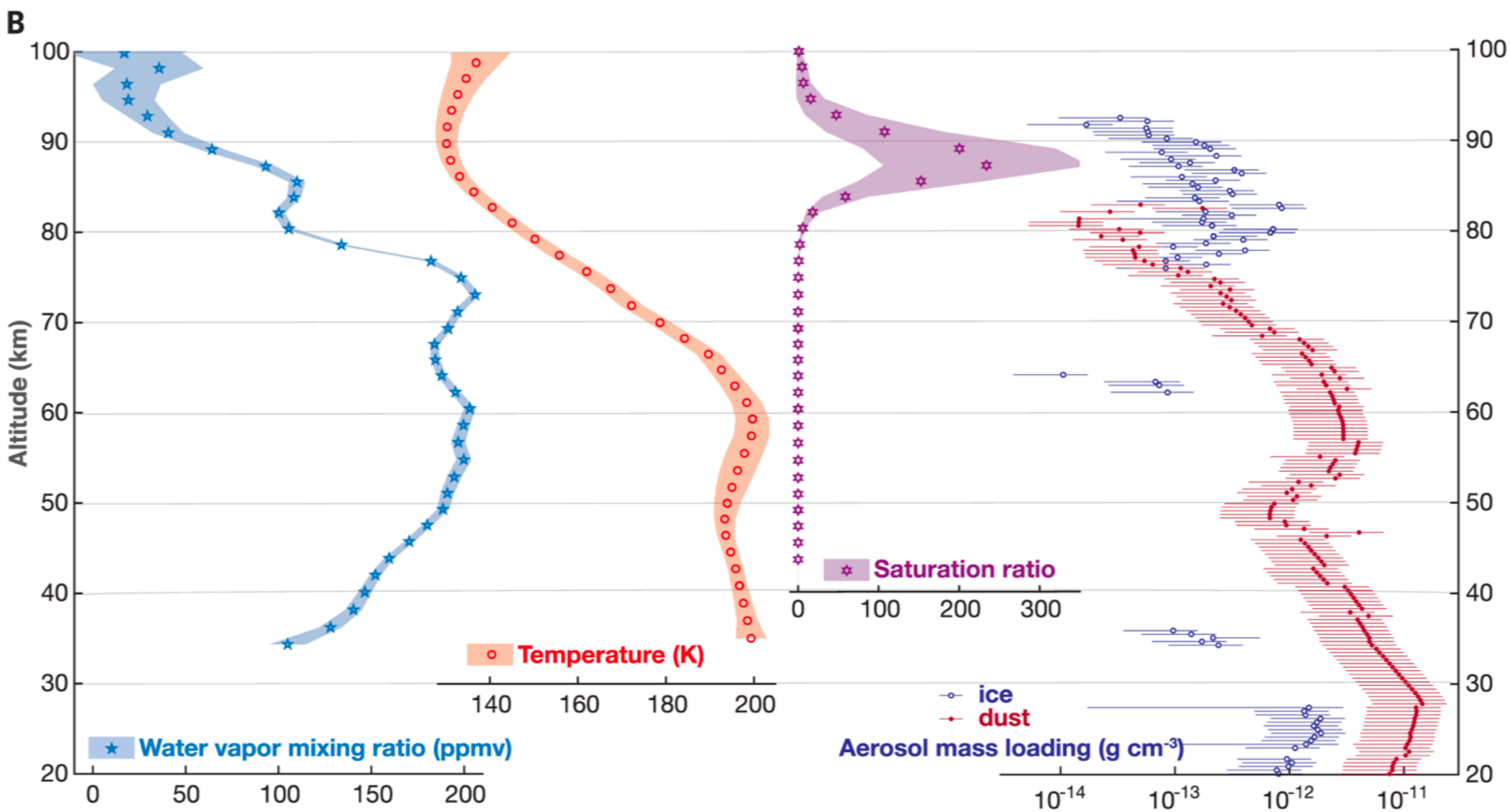


Fig. (Fedorova+20)

Effective transport via circulation

- The global dust storm absorbs sunlight, which intensifies the circulation.

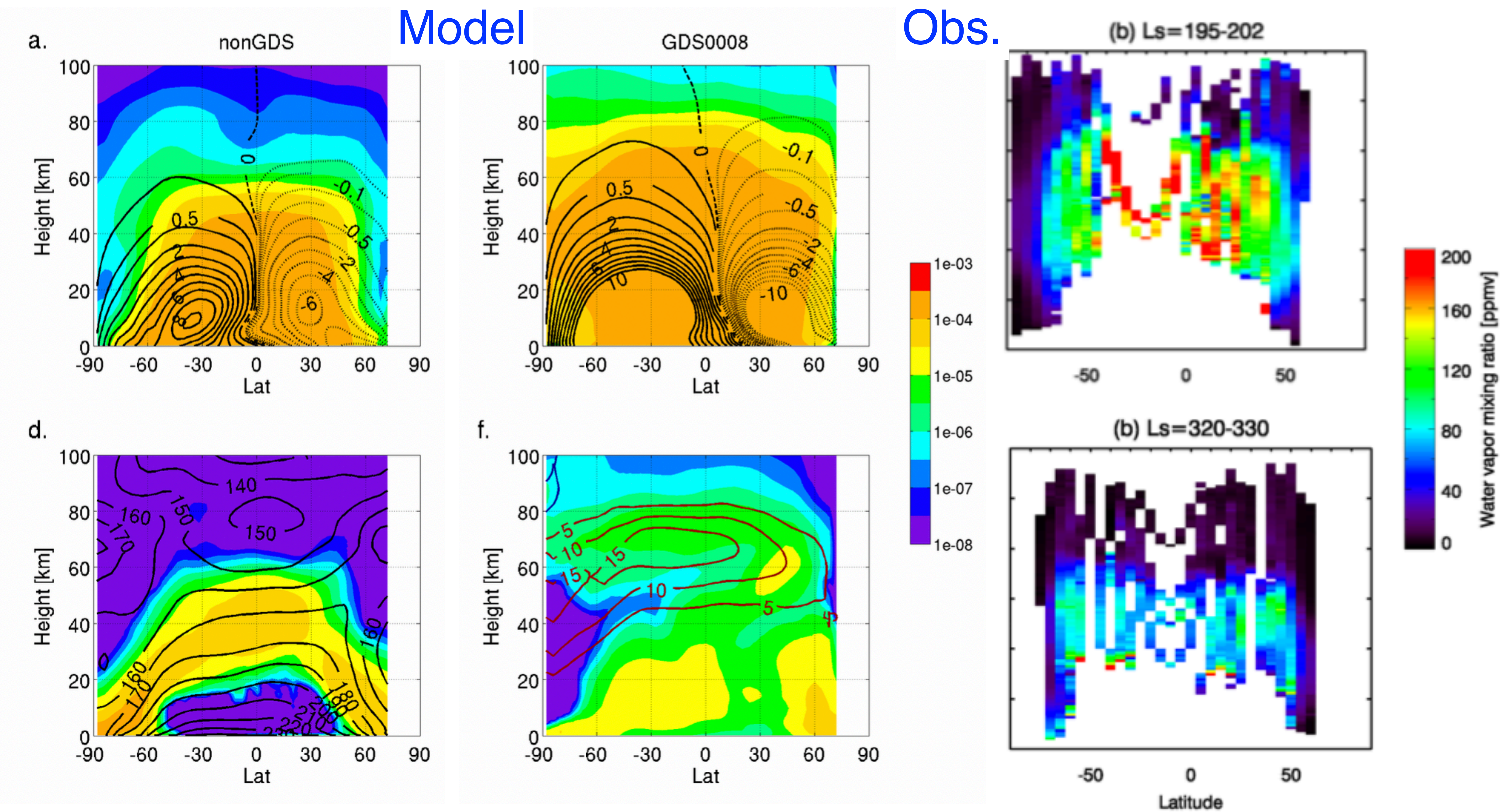
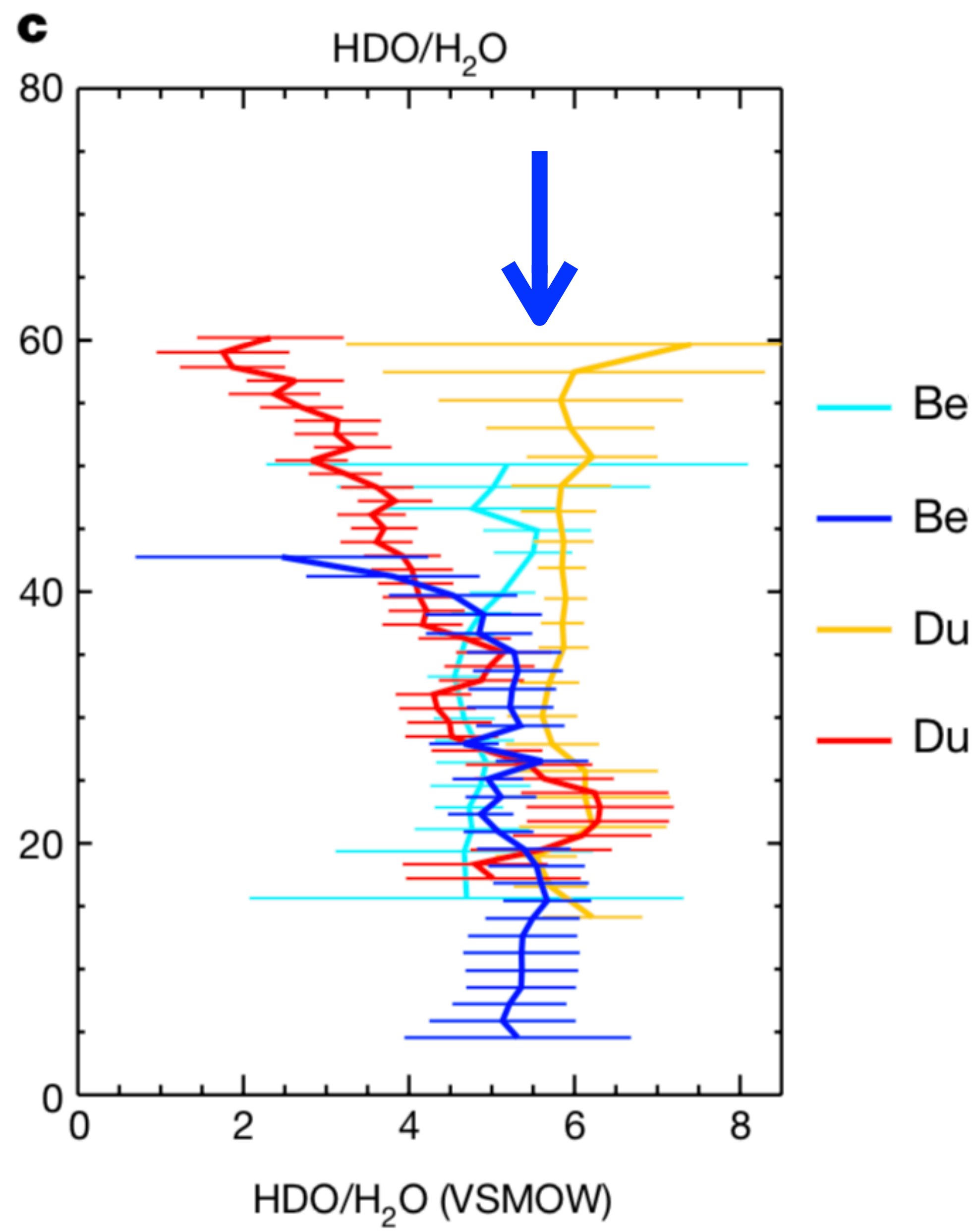


Fig. (Aoki+20; Neary+19)

Fraction HDO/H_2O to D/H

- Isotopologue by MAVEN,TGO
- Fractionation factor of water



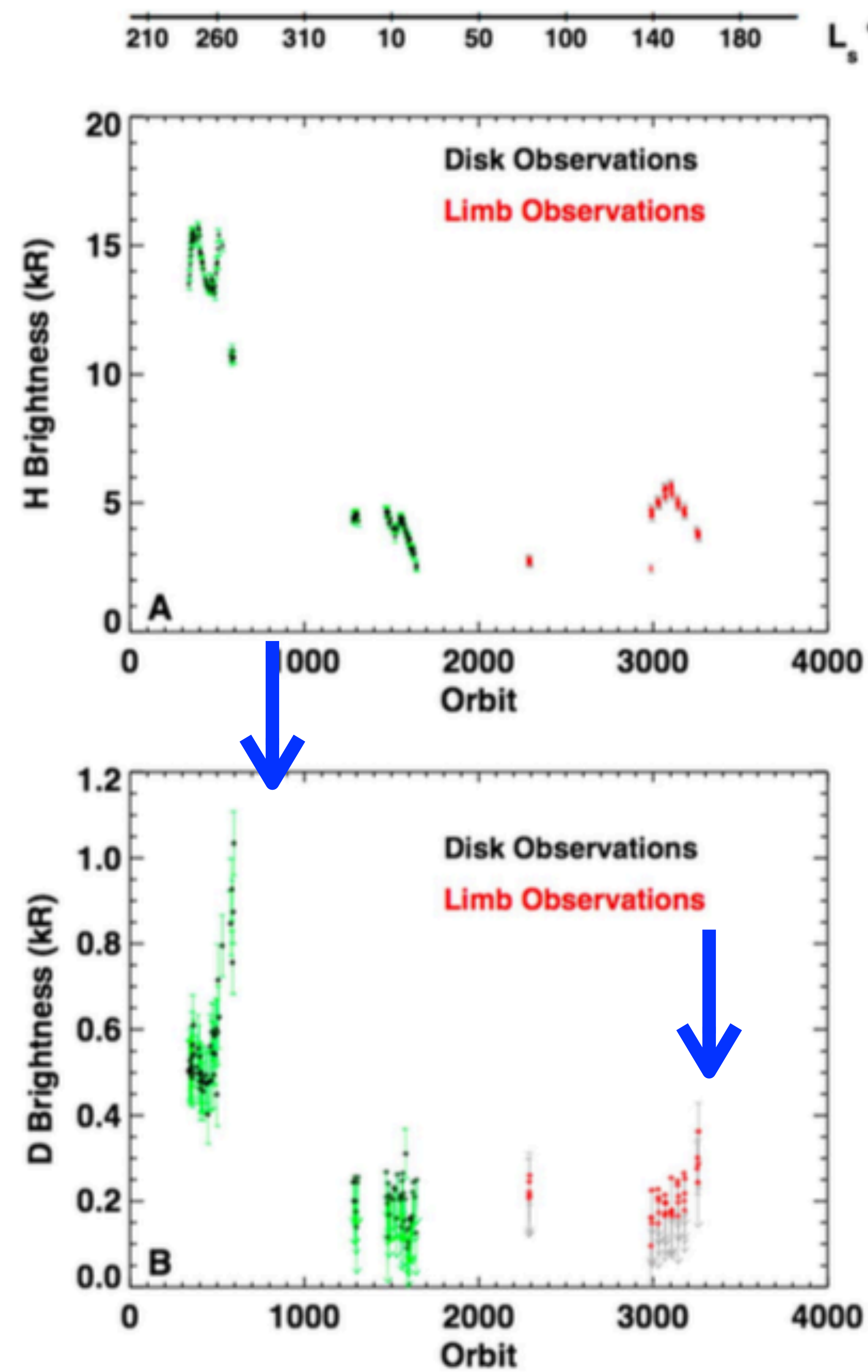


Fig. (Vandaele+19; Clarke+2017)

The effect on the reserver?

- The downward flow is historically considered via direct SW-interaction. The effect on the atmospheric reserver to space?

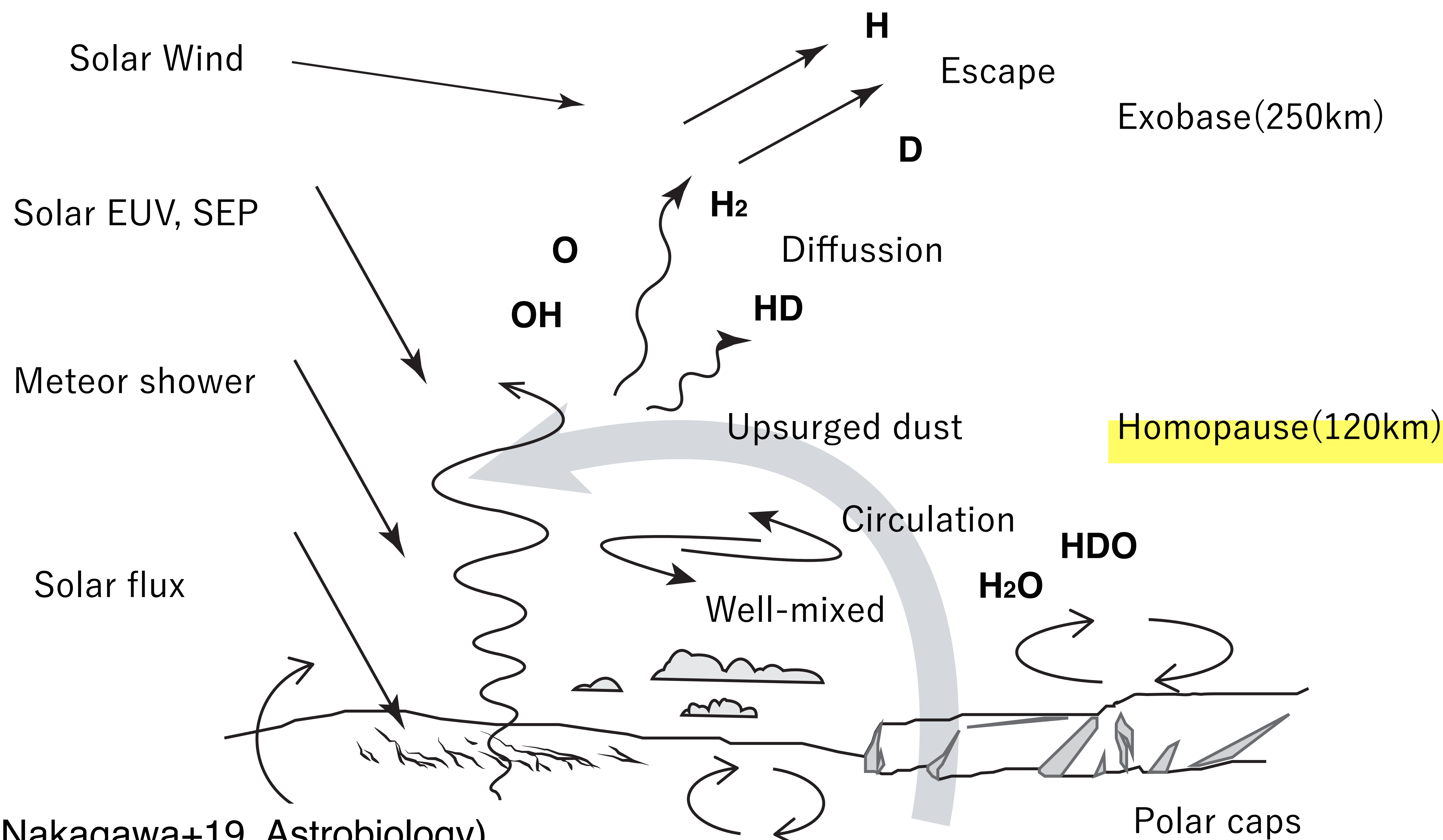


Fig. (Nakagawa+19, Astrobiology)

Observation setup MAVEN

- We investigate the effect of lower atmosphere on the escape.
- IUVS stellar occultation at 20-130 km, IUVS limb remote sensing at 140 km, NGIMS in-situ at 150-400 km.

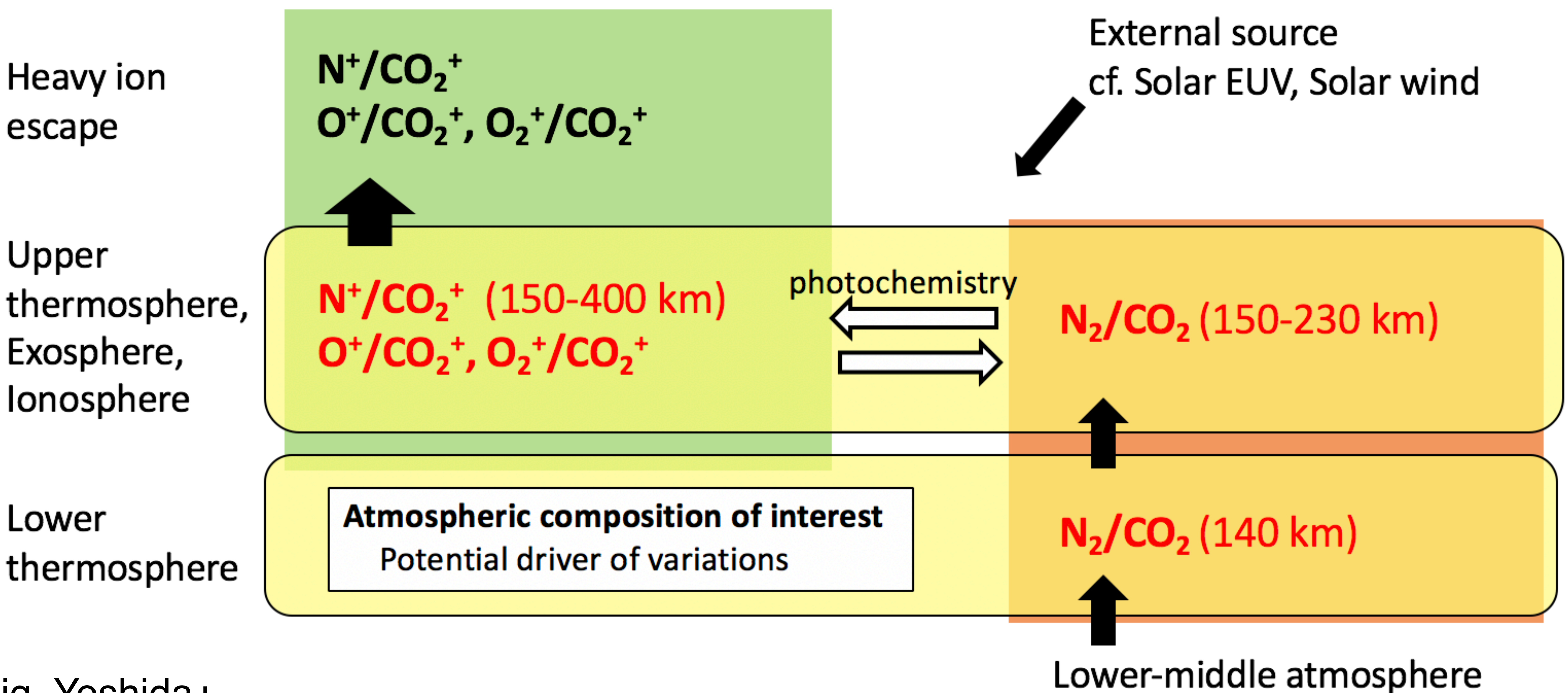


Fig. Yoshida+

Seasonally breathing

- Rising and falling largely in response to behavior at lower altitudes.

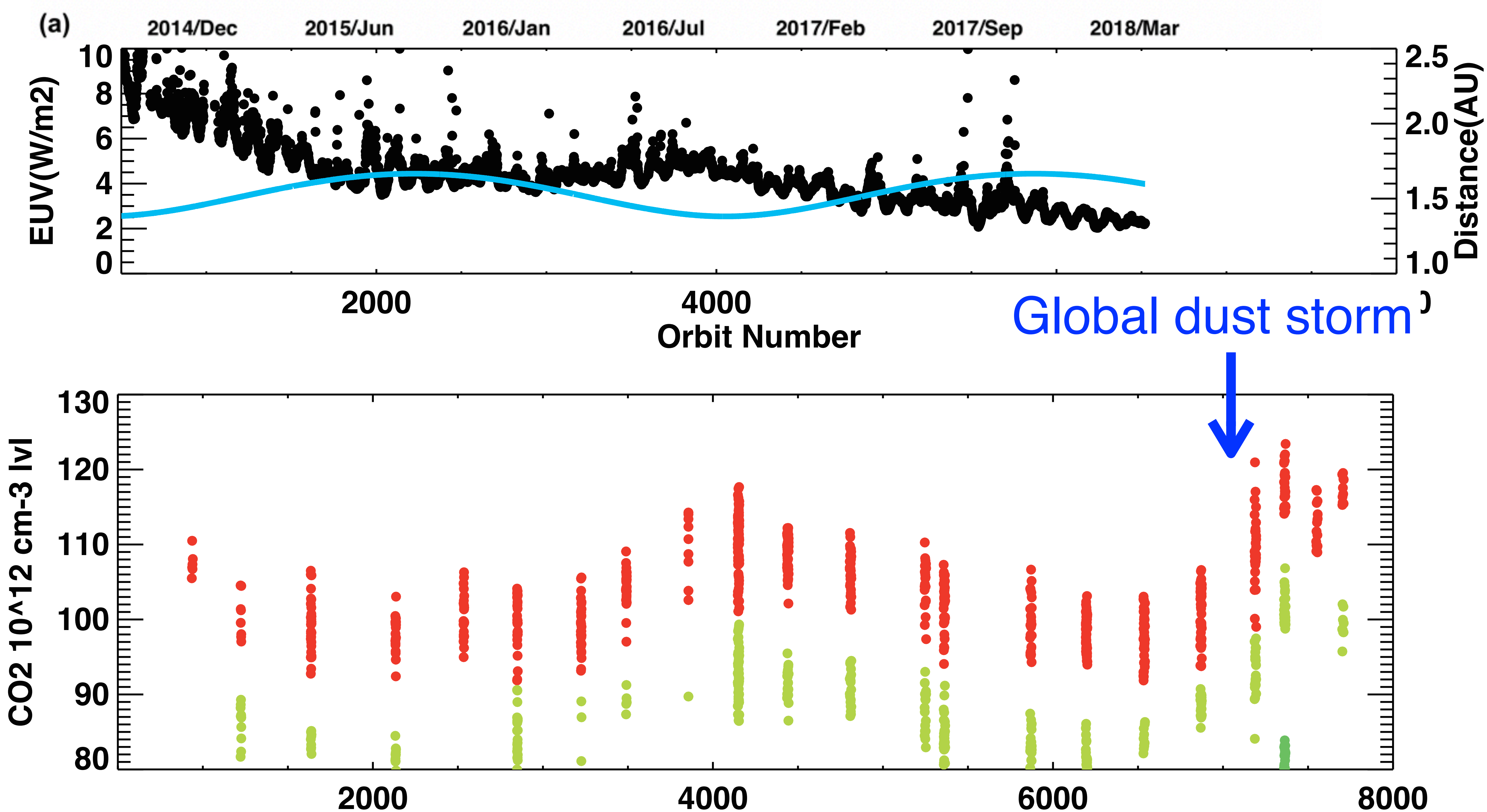


Fig. Variation of the altitudes of pressure level of 10^{12} cm^{-3} by IUVS stellar occultation.

Compositional variation N_2/CO_2

- Seasonal variation of CO_2 and N_2 densities at 140 km by IUVS-limb.

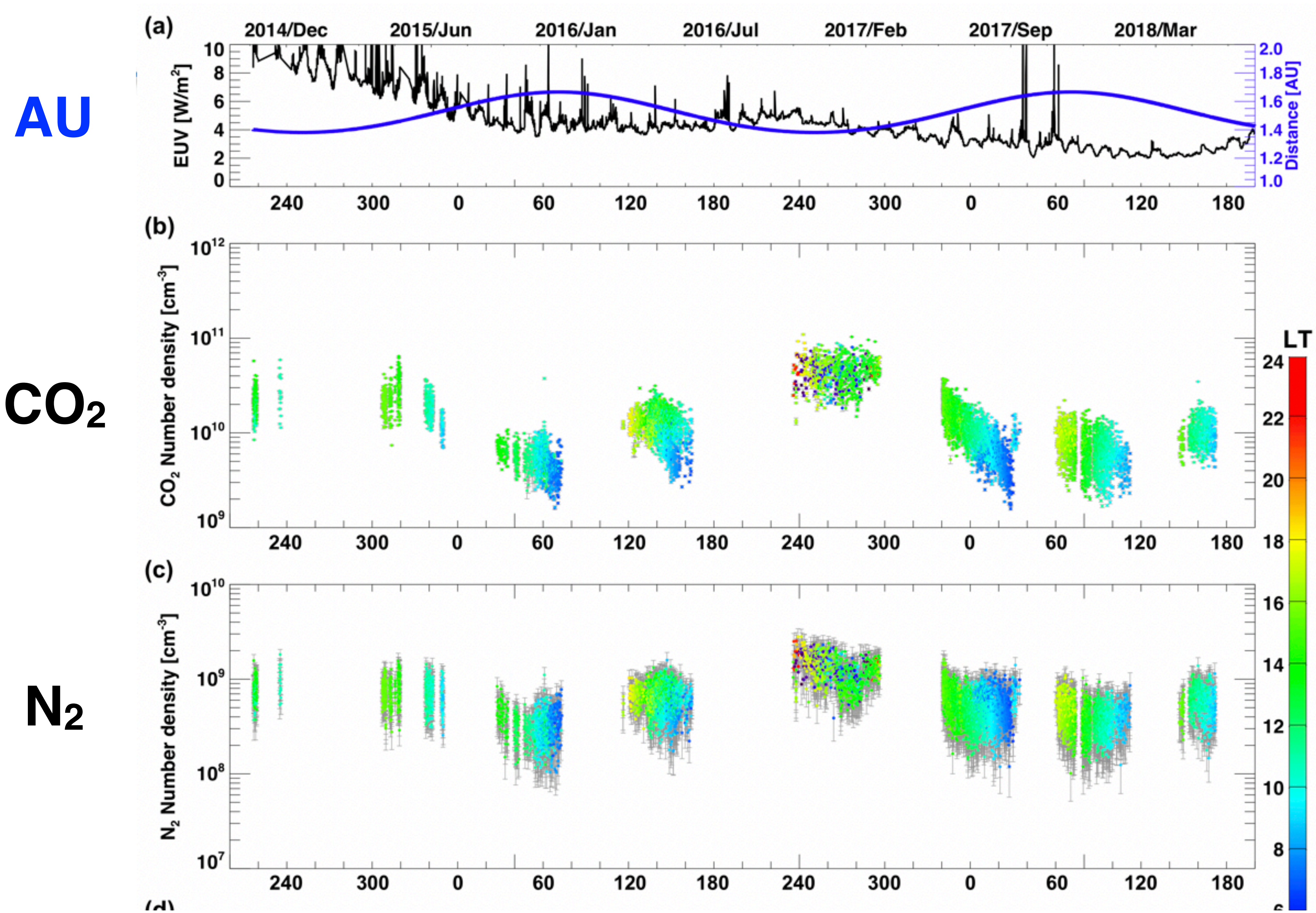


Fig. (Yoshida+submitted)

N_2/CO_2 substantially varies 0.02-0.20

- The result is interpreted as the homopause variation in 80-140 km.

N_2/CO_2

Homopause

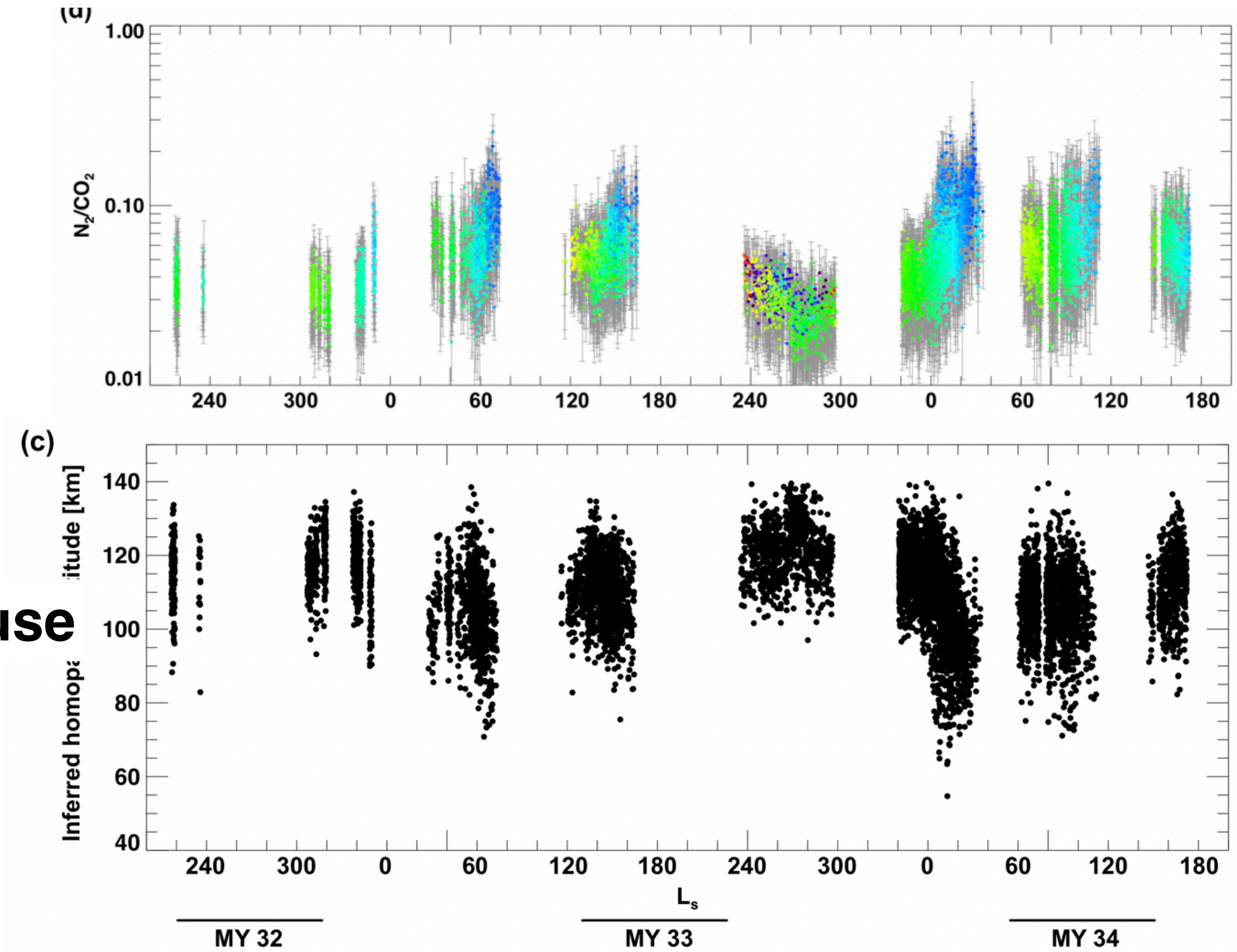


Fig. (Yoshida+submitted)

Eddy diffusion coef. varies 2.0 to 10^4

- Eddy diffusion coefficient (*K*) = Molecular diffusion coefficient (*D*)
- *K* is determined by $D = 1.2 \times 10^{20}/n$ [m^2/s] (Leovy, 1982)

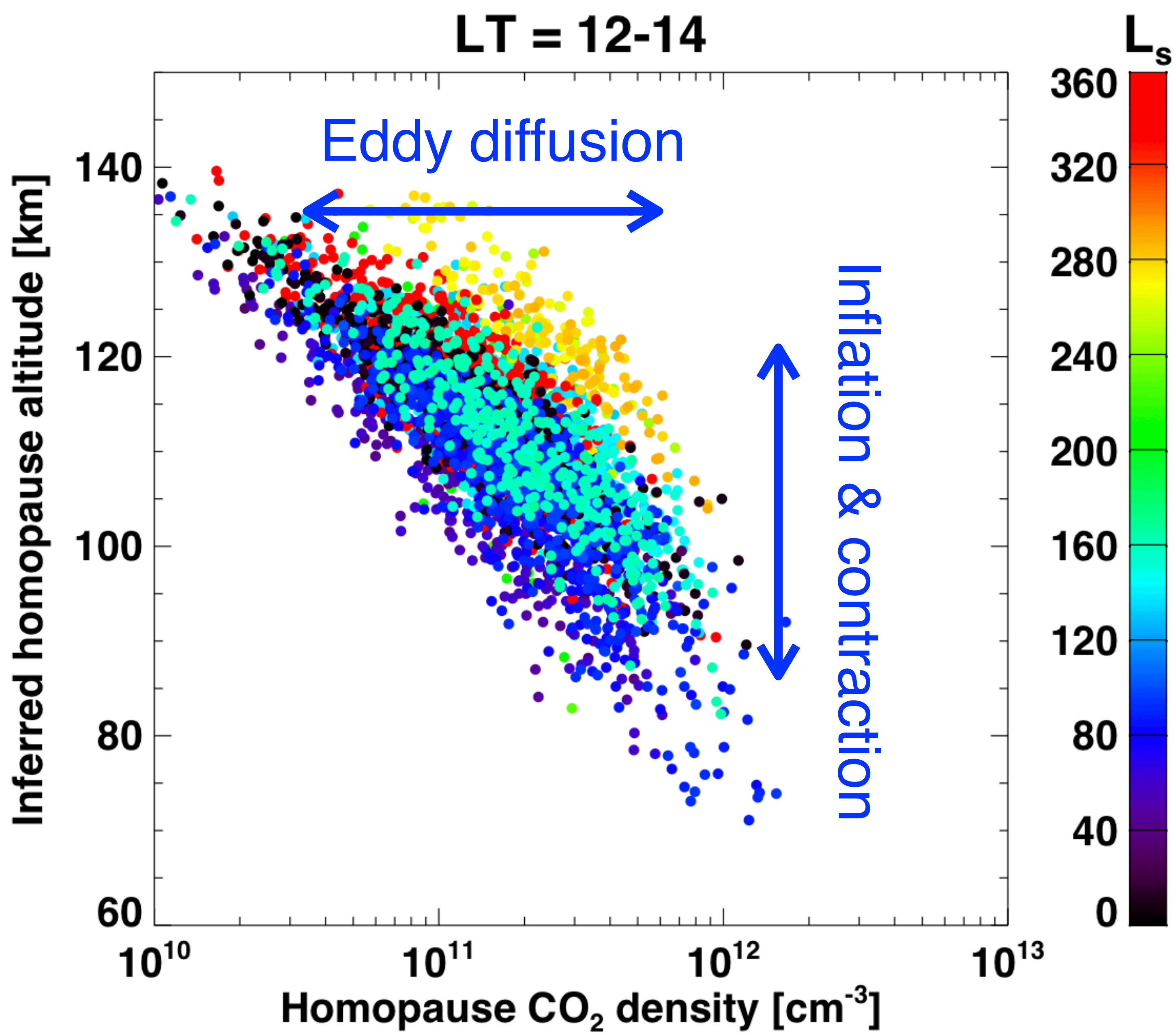


Fig. (Yoshida+submitted)

Ionospheric composition at 200 km

- Exosphere/Ionosphere largely correlate with change in thermosphere.

N^+ shows opposite which may due to its loss process via

$N^+ + CO_2 \rightarrow N + CO_2^+$

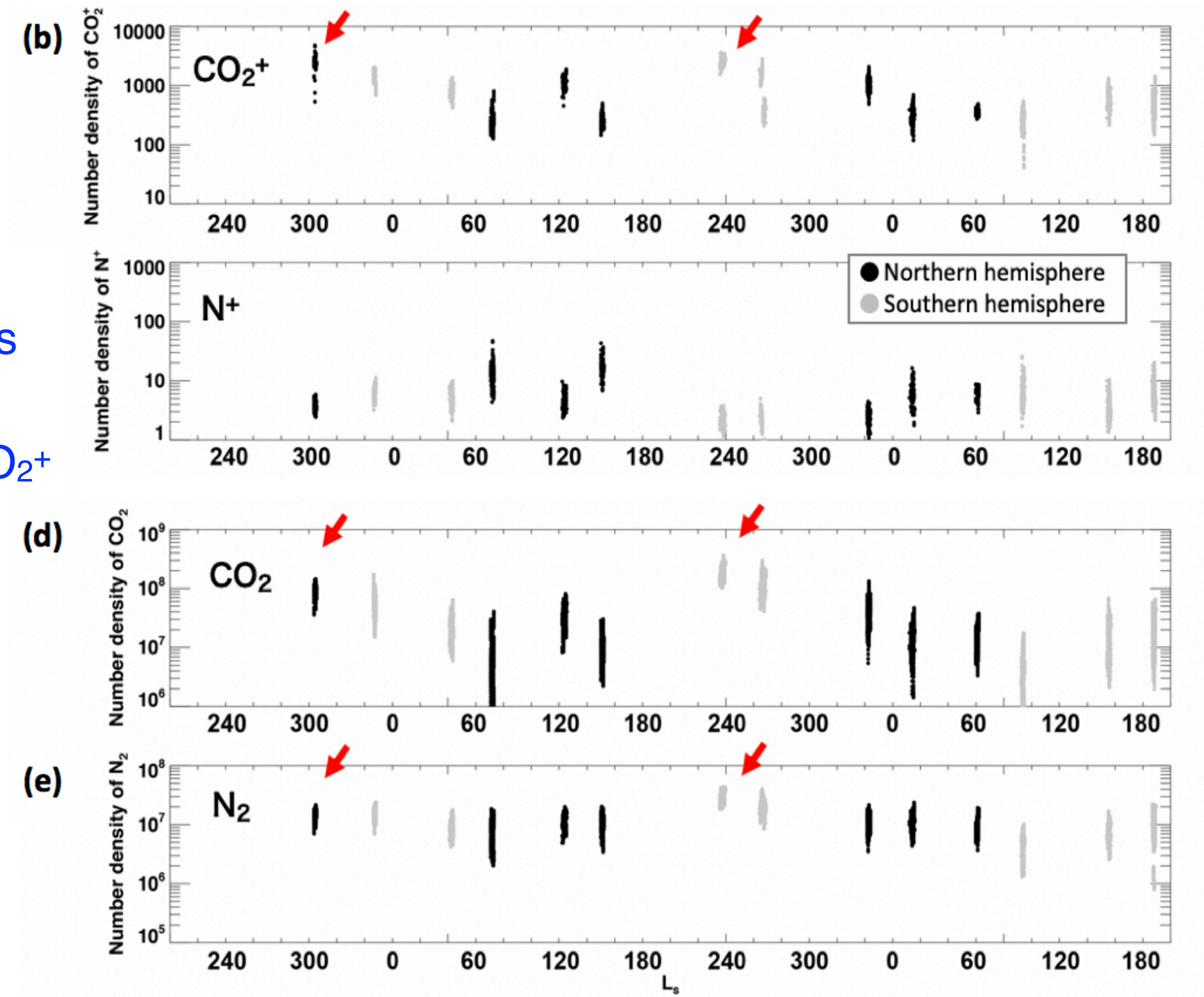


Fig. (Yoshida+prep.)

Effect on the escaping species

- Seasonal variation of the atmospheric reserver CO_2^+ to space.
- CO_2^+/O_2^+ can vary in 0.017 and 0.097. Less variation in O^+/O_2^+.

cf. MEX,MAVEN ion escape

$O_2^+ : O^+ : CO_2^+ =$

1.00 : 1.11 : 0.22 (Carlsson+06)

1.00 : 1.52 : 0.25 (Lundin+09)

1.00 : 0.38 : 0.04 (Inui+18)

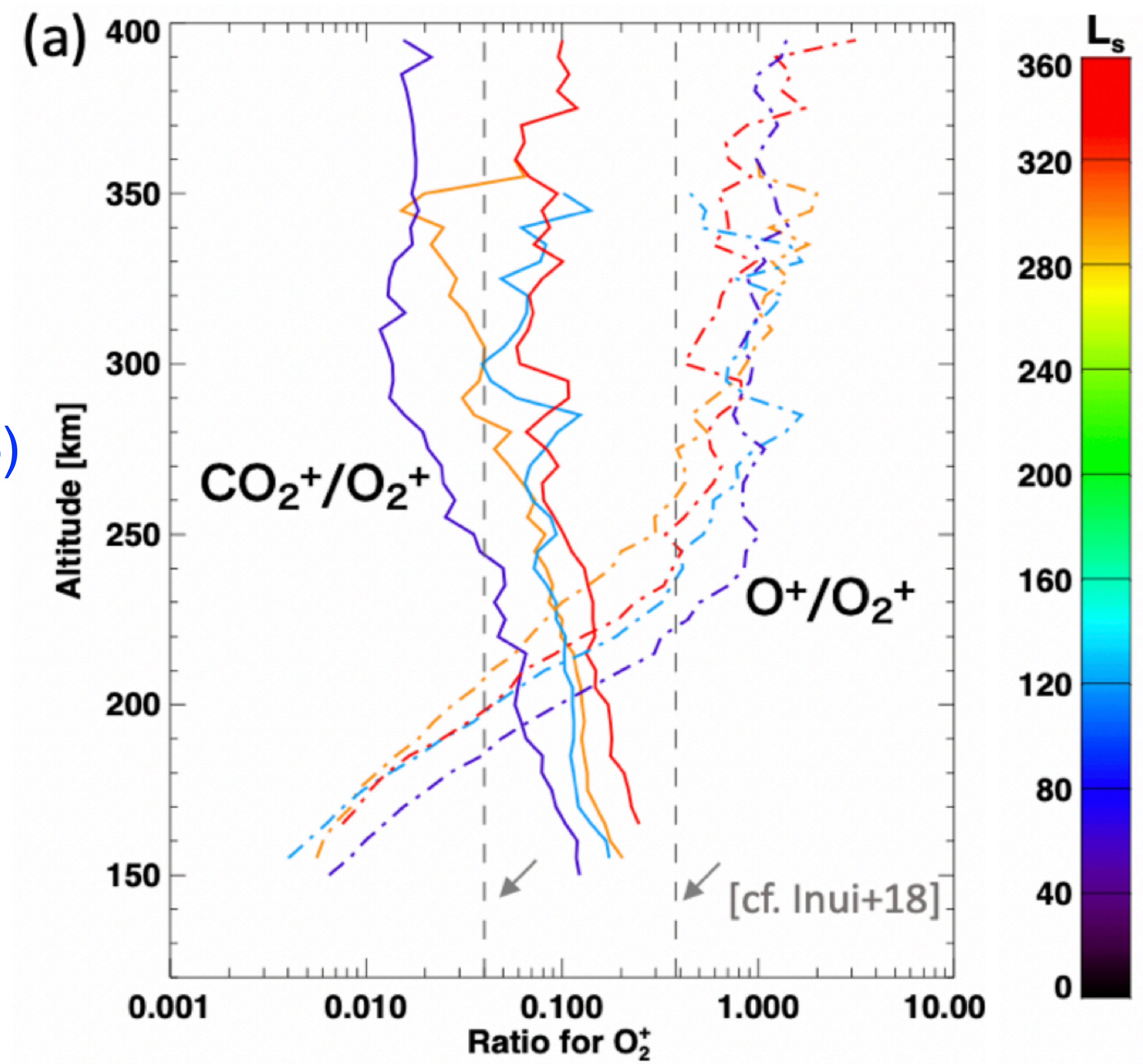


Fig. (Yoshida+prep.)

SW-interaction from above, of course

- Increase of slopes at photo-dynamical region, by three-times large.
- IMF interaction (Najib+11)? Magnetosonic wave (Fowler+18)?
- Relative importance of both from below and from above to discuss

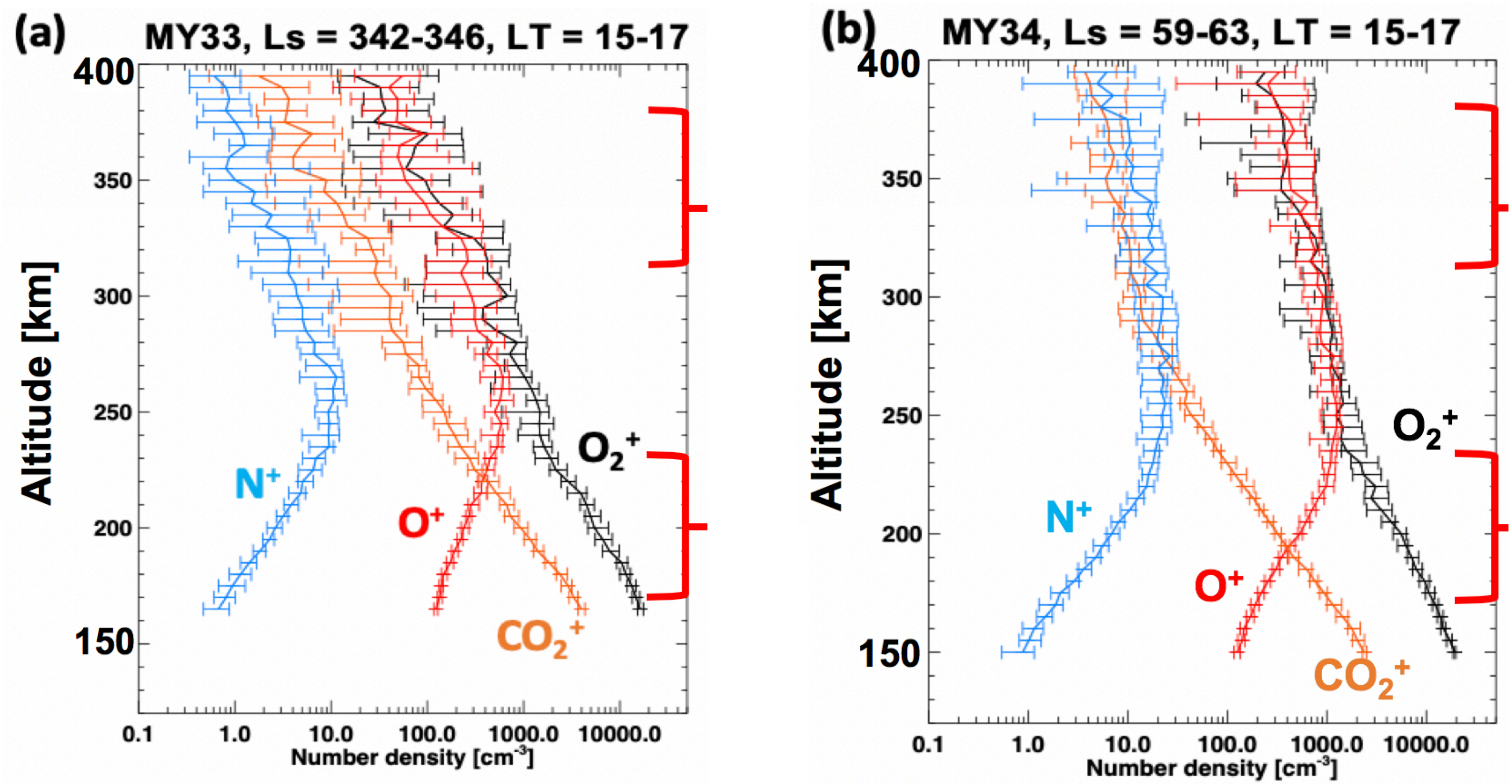
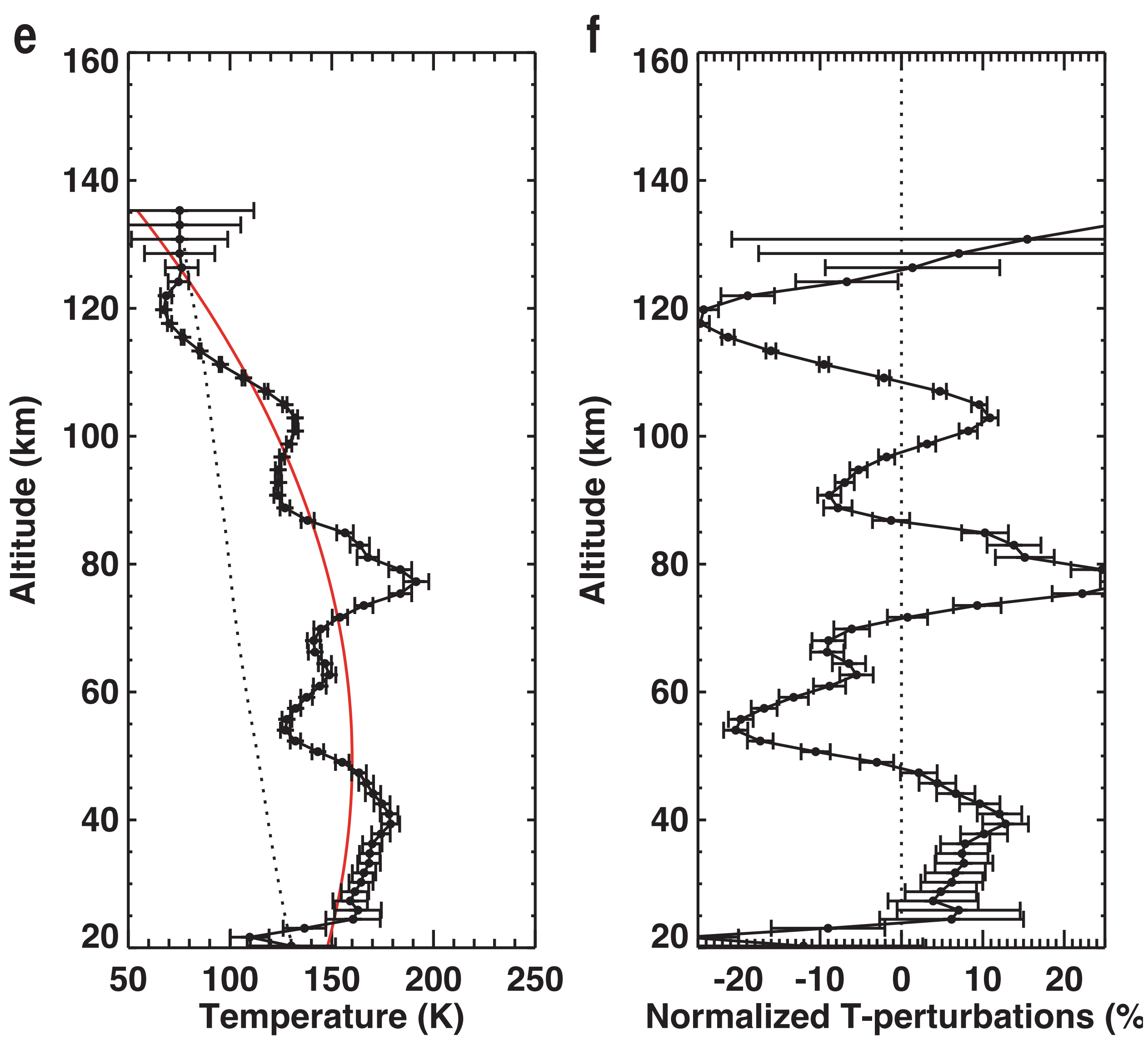


Fig. (Yoshida+prep.)

Ubiquitously existing waves

- Vertical coupling via ubiquitously existing atmospheric waves.
- Upward propagating waves change circulation/thermal structure.
- SZA(LT)-dependence.



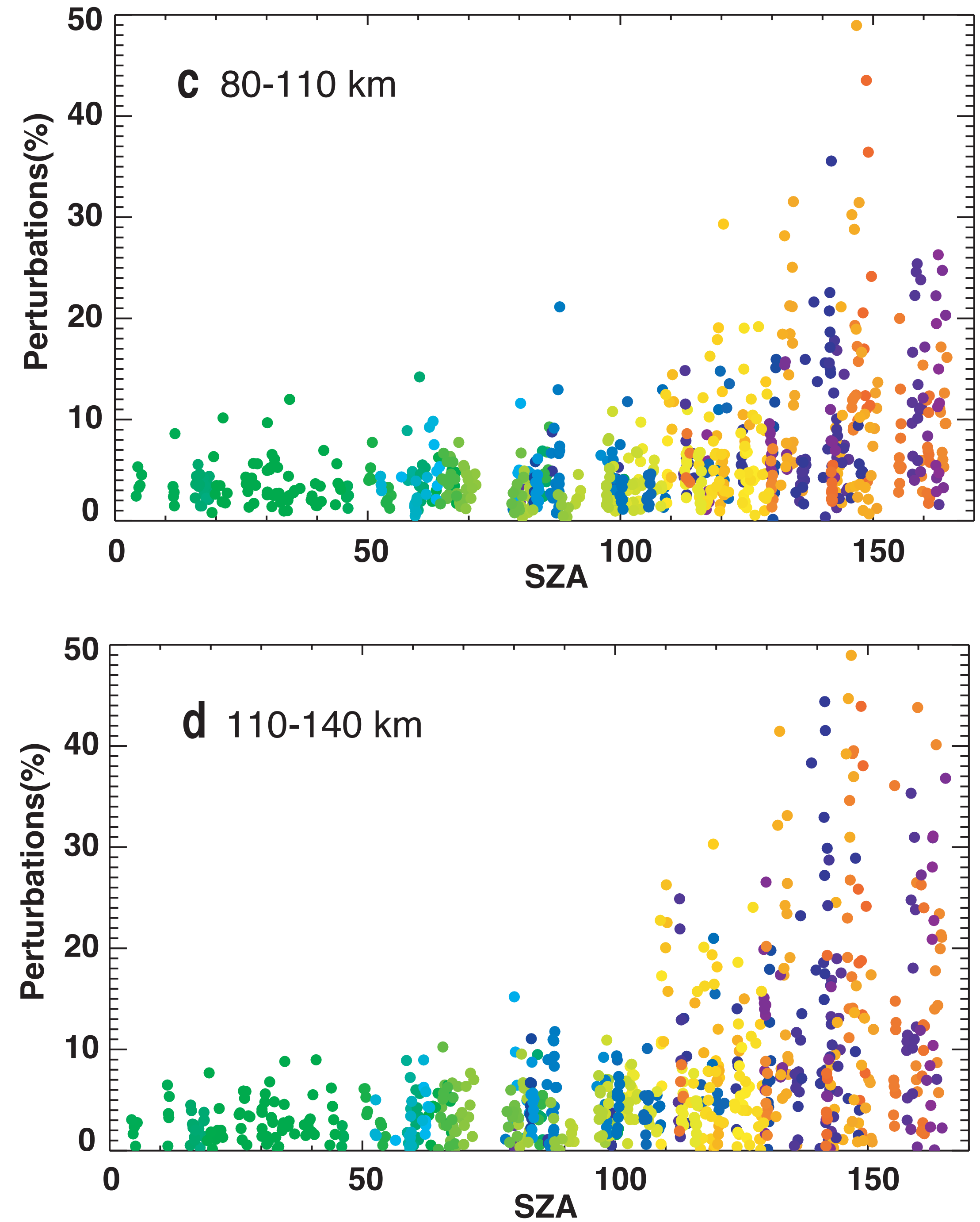
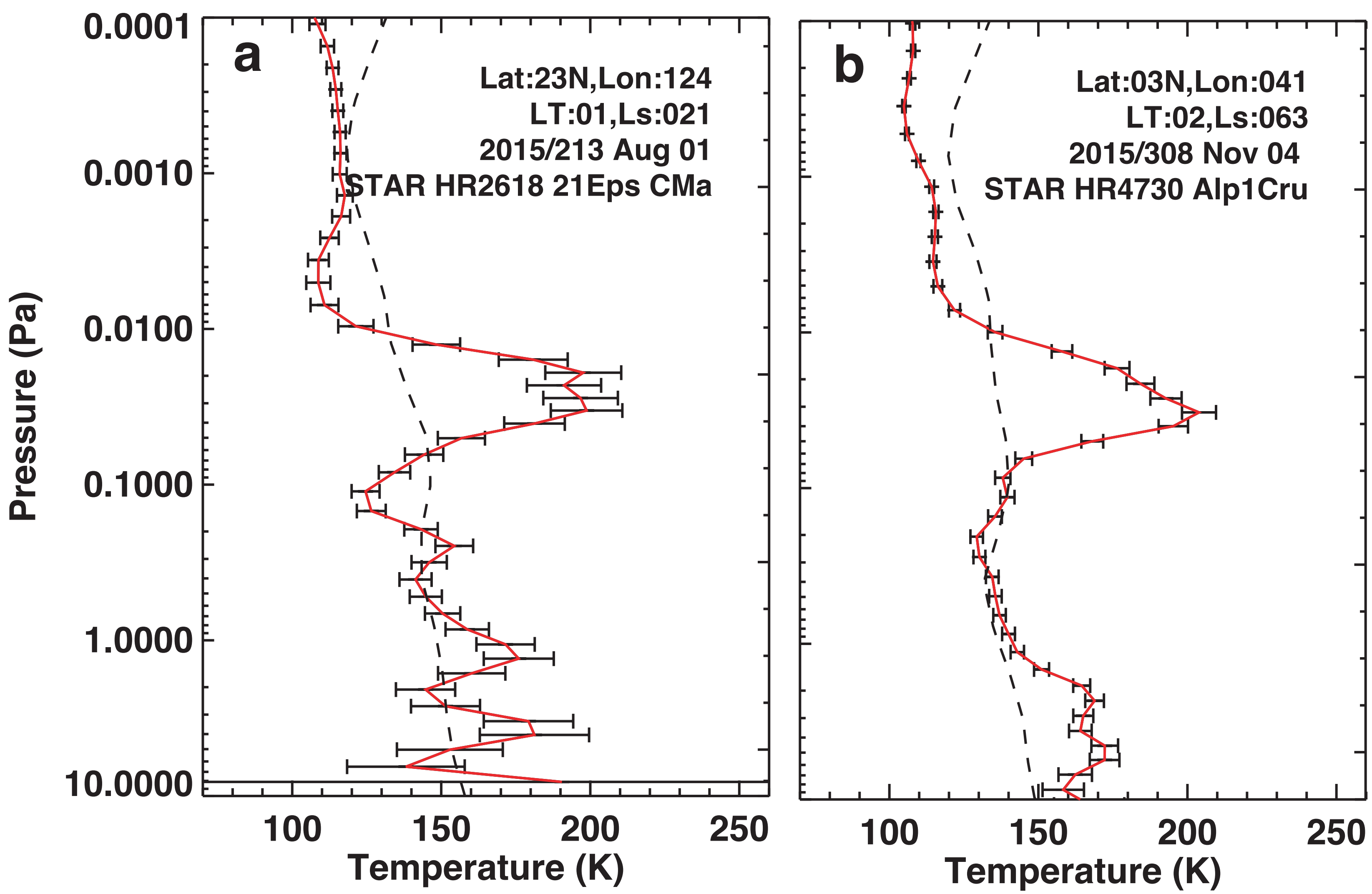


Fig. (Nakagawa+prep.)

Thermal tides lead unexpected structure

- Planetary-scale waves modulate the thermal structure?
- Still poorly understood by current models.



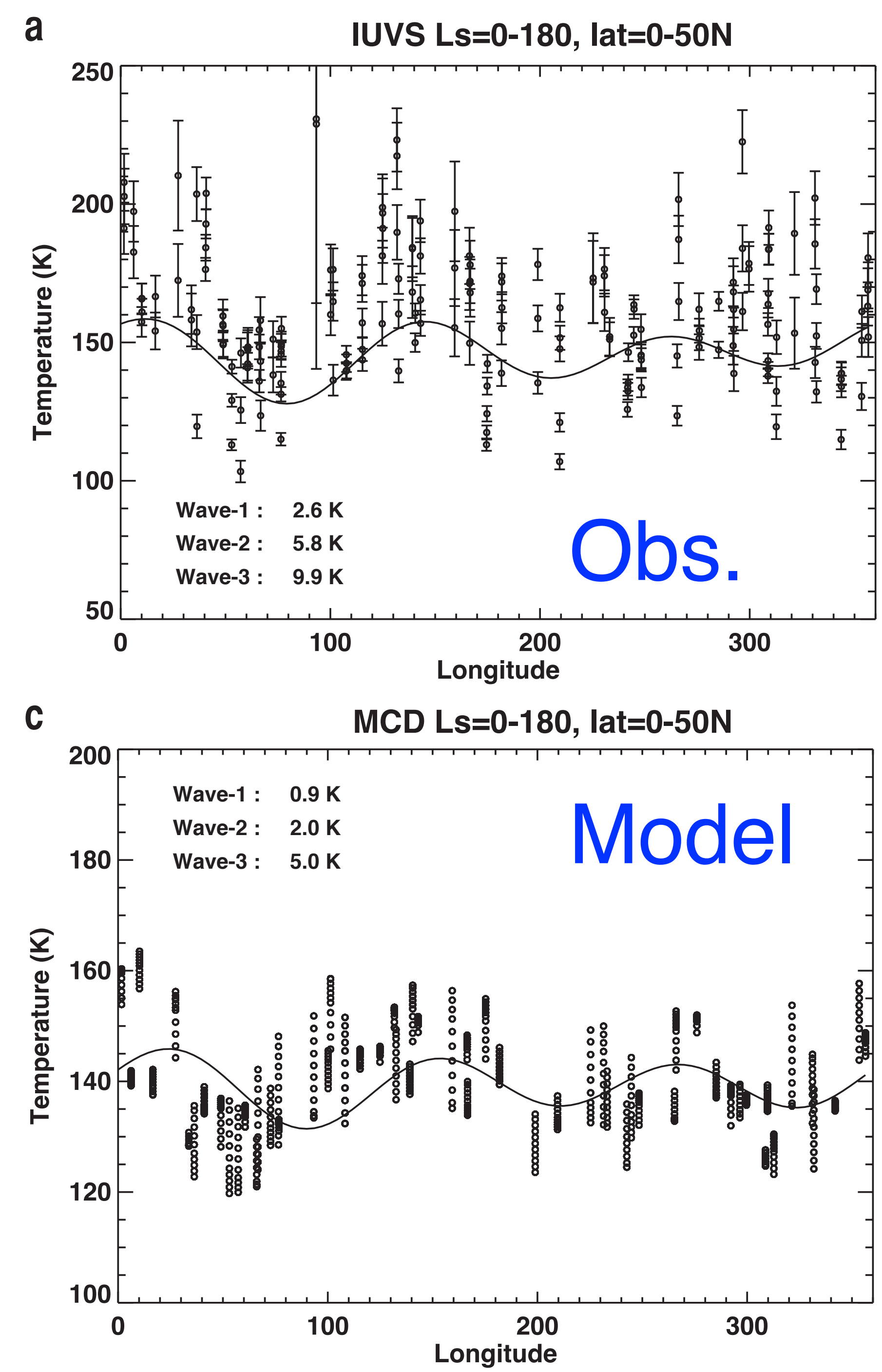


Fig. (Nakagawa+20)

Summary

- The efficiency of vertical coupling between lower and upper atmosphere has been addressed in order to clarify its impact on the atmospheric escape and evolution.
- Can affect on the homopause altitudes, so that upper atmospheric composition. N_2/CO_2 varies in 0.02 to 0.20.
- The eddy diffusion coefficient to vary between 20 and 10^4.
- Ionospheric composition has also seasonal variation. CO_2^+/O_2^+ varies in the factor of six.
- Unexpected thermal structure in the middle atmosphere. Poorly understood by current models.
- The link between lower and upper via waves is under debate.
- Comprehensive observations by MAVEN and TGO will provide further understanding of whole system of the Mars atmosphere.