Title

Zonal wind acceleration in the Martian mesosphere during global dust storm 2018 observed by IR heterodyne spectroscopy

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Abstract

Recent observations have revealed unexpectedly high abundance of water in the middle atmosphere (1.0 ~ 0.1 Pa), which should affect the atmospheric escape of water to space [Maltagliati et al.,2013]. Heavens et al. [2018] also found that the water vapor abundances in the middle atmosphere are further enhanced during the global dust storm (GDS). However, the detailed picture of the middle atmosphere during GDS is not yet addressed.

On June 2018, the GDS occurred on Mars. It is also suggested that the dust particles were lifted to about 80 km [Fedorova et al.,2020], and equinoctial Hadley circulation reinforced by GDS transported the water vapor to 100 km [Aoki et al.,2019].

In order to understand the mesospheric response during the dust storm, we have performed the direct measurement of mesospheric zonal winds and temperature from June to September 2018 by ground-based infrared heterodyne spectroscopy. The observed CO_2 non-local thermodynamic-equilibrium (non-LTE) emission lines at 10 micron are contributed from the mesosphere, peaking at ~ 80 km (~ 0.15 Pa) altitude [Lopez et al., 2011]. The kinetic temperature was derived from doppler width of emission and zonal wind velocity was directly derived from line-of-sight doppler shift of emission core.

Our result suggests that there is not clear difference of the observed kinetic temperature from June to September. Simultaneous observation by MAVEN/IUVS shows a good agreement with this study. On the other hand, zonal wind velocity derived from our observations during the GDS suggest the strong retrograde winds from June to September compared with the measurements of the mesospheric winds during clear sky [Moreno et al., 2009; Sonnabend et al., 2012].

We discuss the mechanism to accelerate the zonal wind during the GDS by comparing with simulations by the Martian general circulation model (MGCM)[Medvedev et al.,2013]. MGCM suggested stronger retrograde winds around 0.1 Pa during MY25 GDS than clear sky at the equator. It agrees with this study. By considering Transformed Eulerian Mean formulation, it is possible that intensified meridional advection from Southern Hemisphere to Northern Hemisphere due to GDS enhanced equational retrograde winds.

[P06] Zonal Wind Acceleration in the Martian Mesosphere during the Global Dust Storm 2018 Observed by Ground-Based IR Heterodyne Spectroscopy

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1 Introduction

- In the Martian atmosphere, the suspended dust absorbs incoming sunlight and contributes localized atmospheric heating.
- It is suggested that global dust storm (GDS) effectively transports water vapor from the near-surface to mesosphere *[Heavens et al.,2018]* and increases the escape rate of atmospheric hydrogen to space.

The Martian mesosphere(30-80 km) remains the least explored region with a highly variable nature that deserves extensive measurements.

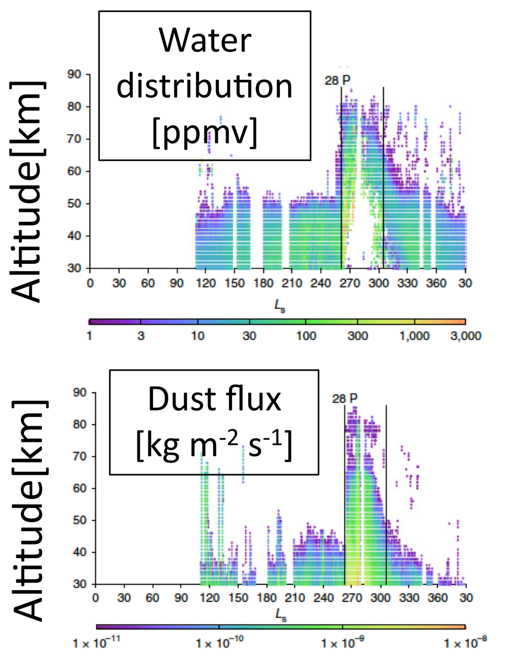


Fig 1. Vertical distribution of total water content and fast dust flux versus the season(solar longitude : Ls) obtained by MEX*[Heavens et al.,2018]*

- From June to August 2018, a strong GDS occurred on Mars.

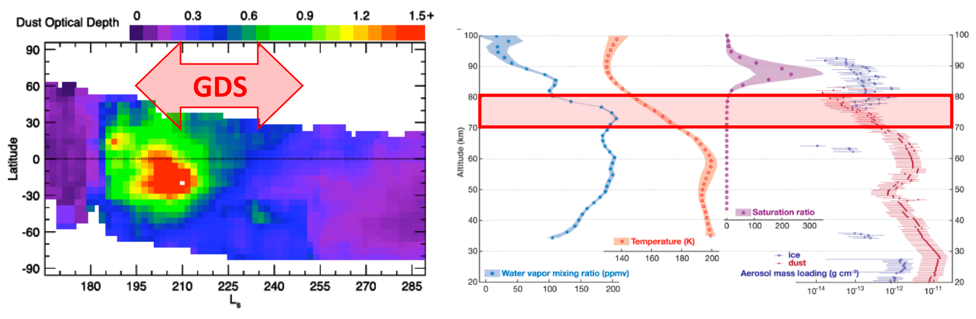


Fig.2 (left)Detail of THEMIS retrieved dust optical depth at the surface around 2018 GDS*[Smith et al.,2019]* (right) Retrieved profiles of the H_2O mixing ratio, temperature, and saturation ratio derived from Exo Mars/ACS (Ls=197.8 / 47.27° N / LT 17:27) *[Fedorova et al.,2020]*

- GDS occurred after Ls=195° , peak dust opacity was around Ls=205° and it lasted by Ls=250° *[Smith et al.,2019]*
- It was suggested that dust lifted up to 80 km *[Fedorova et al.,2020]* , and equinoctial Hadley circulation reinforced by GDS transported water vapor to ～100km*[Aoki et al.,2019]* .

Purpose

We report a direct observation of a zonal wind velocity and temperature during the 2018 GDS around 80 km on Mars in order to understand the mesospheric response during GDS.

2 Observation

targeted line : non-LTE CO_2 emission of 10 μm band
instrument : Mid-Infrared LAser Heterodyne Instrument (MILAHI) onboard 0.6 m telescope at Mt.Haleakala.
The field of view : 4”. (Fig 3. yellow circle)
Frequency resolution : 10^7 (~1[MHz] for CO_2 spectrum at 10 μm)*[Nakagawa et al.,2016]*

Table.1 Observation parameters

month/day (2018)	Ls	angular diameter	
Jun/21-27	197-201	19.1” - 20.1”	GDS
Aug/29-31	239-241	21.4” - 21.0”	
Sep/01-06	242-245	20.8” - 20.0”	
Ost/01-10	260-266	15.8 ”- 14.5”	
Nov/09-20	285-291	11.1” - 10.7”	

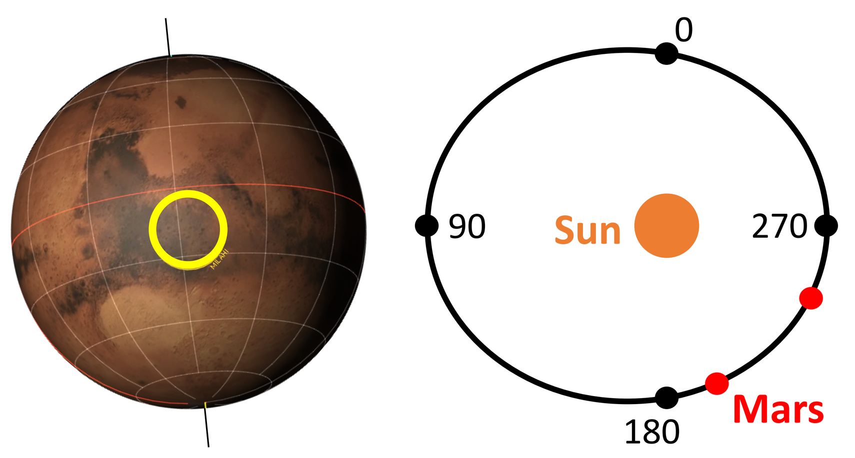


Fig 3. (left)Field of view of the telescope for Mars (right) Solar longitude(Ls)

3 Method

～non-LTE emission～
- Molecule: CO_2
- Wavelength: 10 μm band
- Altitude: 70-80 km *[Lopez et al.,2011]*

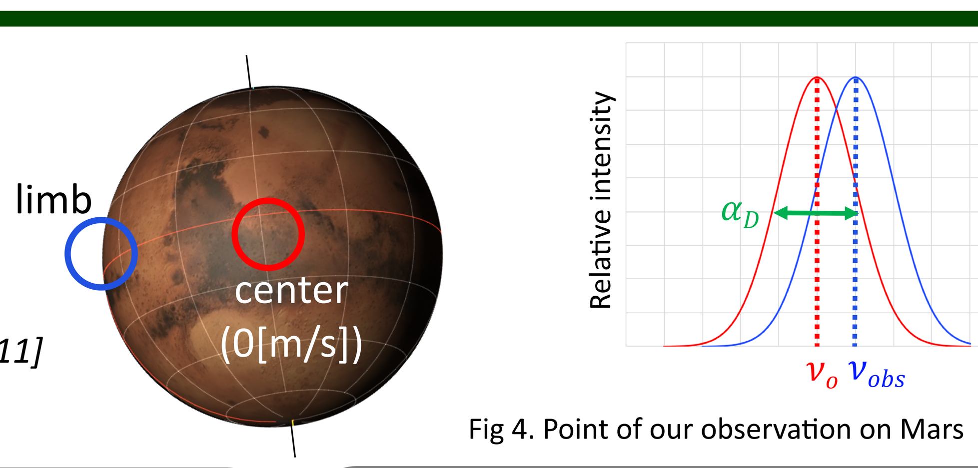


Fig 4. Point of our observation on Mars

➢ Doppler effect of light(wind velocity)

$$\nu_{obs} = \nu_o \frac{\sqrt{1-(\frac{V}{c})^2}}{1-(\frac{V}{c})}$$

V : wind velocity
c : velocity of light

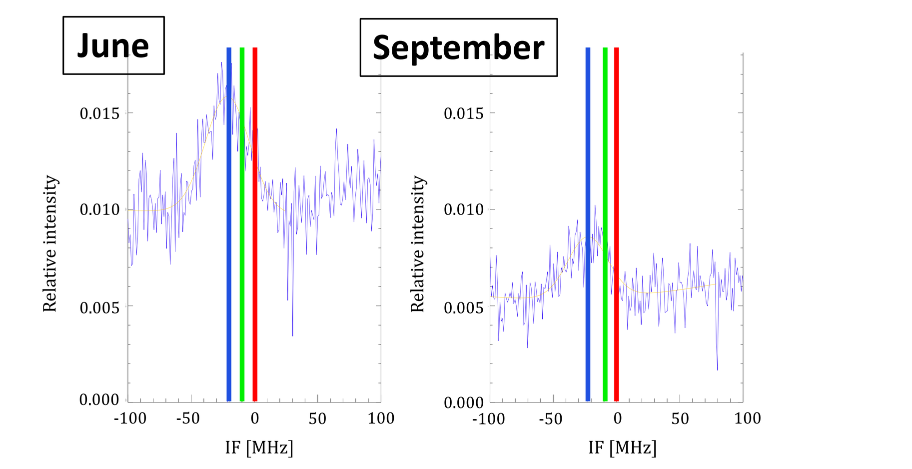
➢ Doppler width(temperature)

$$\alpha_D = 2\nu_o\left(\frac{2k_BT_{kin}}{mc^2}\right)^{\frac{1}{2}}$$

T_{kin} : kinetic temperature
m : molecular mass
k_B : Boltzmann constant
α_D : Doppler width

4 Result

— : center spectral core — : limb spectral core
— : previous study (retrograde 100 m/s)



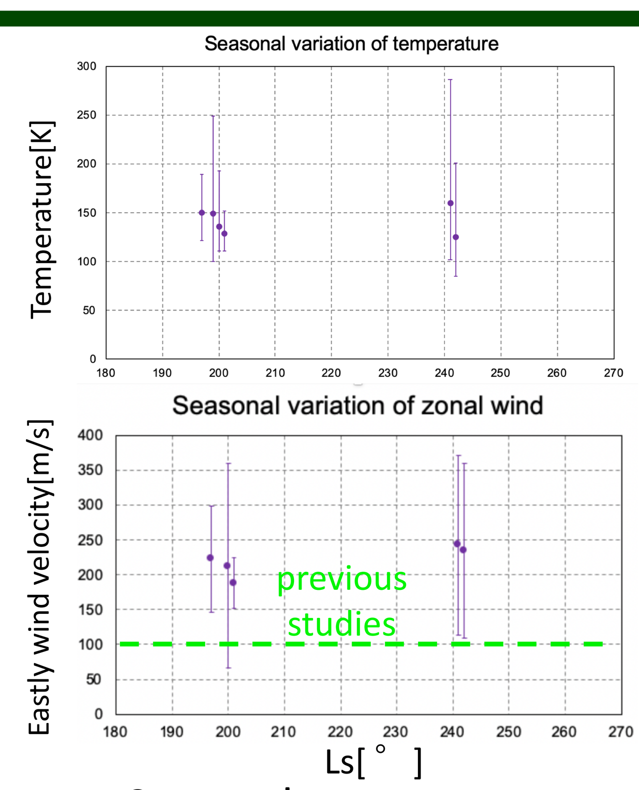


Fig 5. (left)Doppler shifted of CO_2 non-LTE emission on June and September (right)Seasonal variation of zonal wind and temperature

- There is not clear difference of temperature from June to September.
- Stronger retrograde wind during GDS than previous study during clear sky.

5 Simultaneous observation

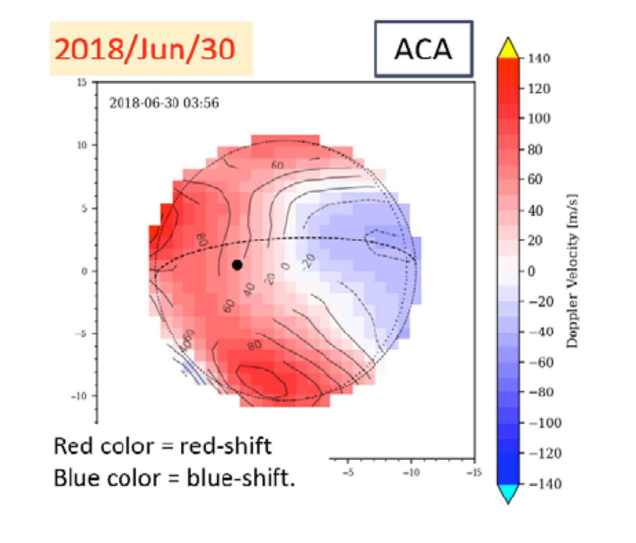


Fig.6 Doppler shift map obtained from ALMA ACA 12CO(2-1) observation *[Aoki et al., in prep].*

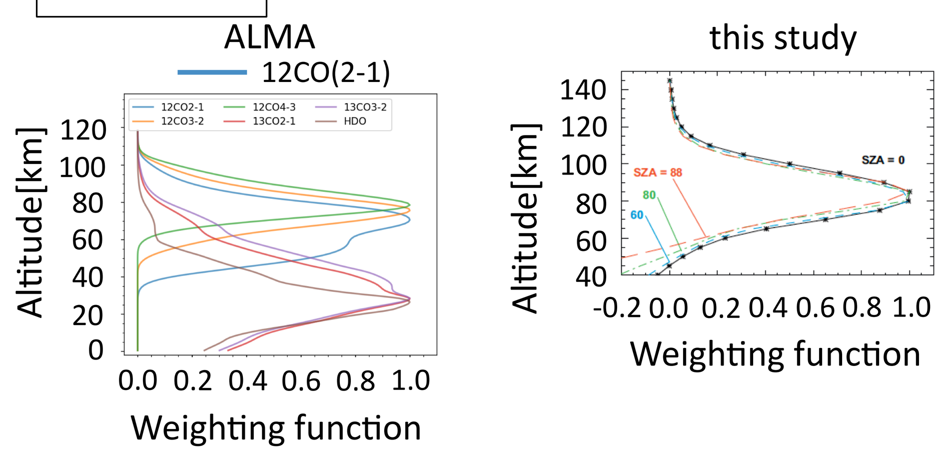
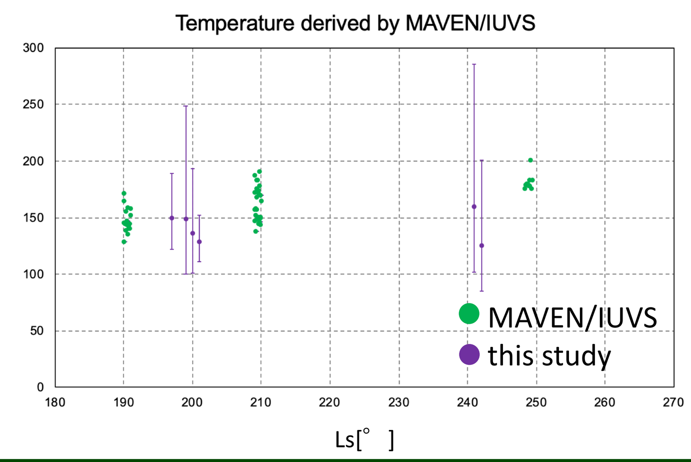


Fig.7 Weighting function of (left)ALMA (right)this study*[Lopez et al., 2011]*

- ALMA also detected retrograde wind at equator.
- It suggested smaller value than our result due to wide altitudinal sensitivity of ALMA observation.

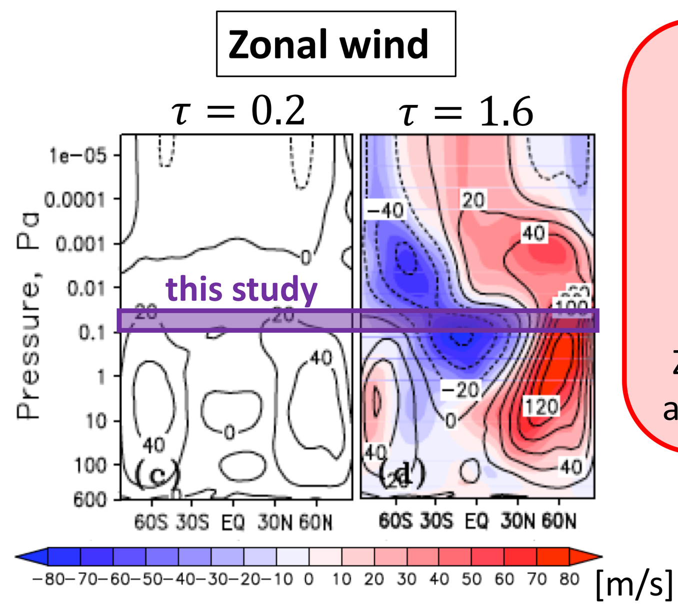


Temperature

- Simultaneous observation by MAVEN/IUVS at 70-90 km shows a good agreement with this study from June to September.

Fig.8 Seasonal variation of temperature derived by MAVEN/IUVS averaged 30° S-30° N and 70-90 [km] altitude

6 Discussion



Transformed **E**ulerian **M**ean formulation *[Andrews et al., 1987]*

$$\frac{\partial \bar{u}}{\partial t} = \bar{v}^*\left[f - \frac{\frac{\partial}{\partial\phi}(\bar{u}\cos\phi)}{a\cos\phi}\right] - \overline{w}^*\frac{\partial u}{\partial z} + \frac{\nabla\cdot F}{\rho_0 a\cos\phi} + \bar{X}$$

Zonal wind acceleration — Meridional advection — Vertical advection — Eddies

Fig.9 Zonal wind velocity predicted from GCM (Ls= 190-200°) Shaded is the difference between τ = 0.2 and MY25 GDS (τ = 1.6) *[Medvedev et al., 2013]*

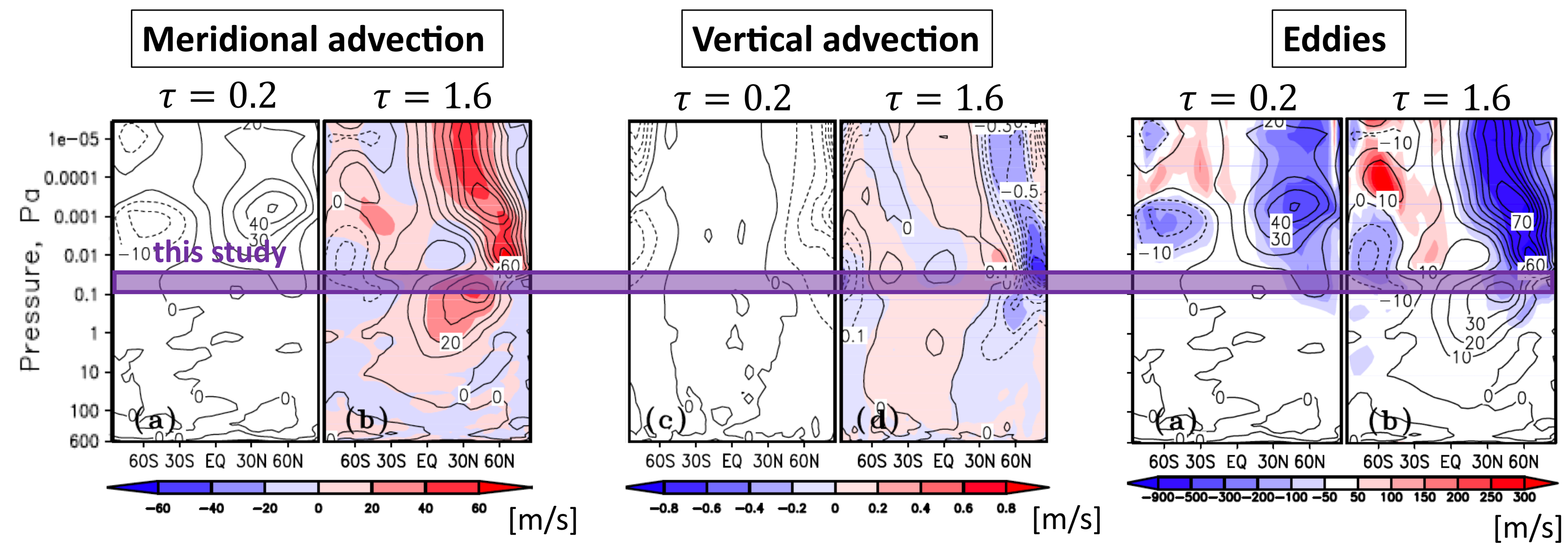


Fig.10 Same as Fig.9, but (left)meridional advection (center)vertical advection (right)eddies*[Medvedev et al., 2013]*

- GCM predicted zonal wind acceleration during GDS by 60 m/s, which could coincide this study.
- Meridional advection from southern hemisphere (summer) to northern hemisphere (winter) was enhanced during GDS.

7 Summary

- Our result suggests retrograde wind at 70-80 km and constant temperature on Mars from June to September . Simultaneous observation by ALMA also detected retrograde wind *[Aoki et al., in prep]* and MAVEN/IUVS shows a good agreement with this study .
- The observed winds are quite stronger than those by the previous studies during clear sky.
- It is confirmed that zonal wind during GDS was accelerated and also meridional advection from southern hemisphere to northern hemisphere was enhanced by GDS*[Medvedev et al., 2013]* .
- Explaining the difference of wind velocity and temperature during the GDS should improve our understanding of dynamics processes in the mesosphere on Mars.

Acknowledgement

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