CH_4 and HDO/H_2O distributions on Mars observed by SUBARU/IRCS

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Abstract

We present distributions of D/H ratio in water vapor at the northern spring by ground-based observations. Although it is suggested that Mars has a drastic water cycle with sublimation-condensation process, previous observations of water vapor could not discriminate between the sublimation-condensation process and the atmospheric dynamics. Monitoring of D/H ratio in water vapor is a powerful tool to distinguish the processes because the lighter H_2O vapor preferentially sublimate whereas the heavier HDO vapor preferentially condense due to the difference in their vapor pressures. Previous observations by the IRTF/CSHELL found that the HDO/H_2O ratio varied between about 2 to 8 (relatively to Standard Mean Ocean Water (SMOW)) depending on location and local time at the northern spring (Villanueva et al., 2008; Novak et al., 2011). However, they could not perform simultaneous observations of H_2O and HDO due to the narrow spectral coverage of the CSHELL. The SUBARU/IRCS can observe H_2O and HDO features simultaneously owing to the wide spectral coverage. We investigated D/H ratio in water vapor depending on latitude and longitude using the IRCS. The observations were performed during the northern spring in the Mars Year 31 (Ls=52.4° and Ls=52.9°). The retrieved values of H_2O/HDO ratio are generally consistent with the previous reports. The latitudinal distribution of HDO/H_2O ratio exhibits maximum at sub-solar latitudes (~20 N). This gradient has an agreement with the previous result reported by Novak et al. (2011), and suggests that rich condensation of HDO vapor at high latitude and equatorial region. Meanwhile, the longitudinal distributions of HDO and H_2O abundances show the local enhancement over Arabia (~330W). However, the HDO/H_2O ratio is not appeared clear variation over the region. It suggests that the local enhancement is controlled by atmospheric dynamics. In addition, we performed similar observation during the northern summer (Ls=96.2°). From the preliminary analysis of the measurement, we find enhancement of HDO abundances around the north polar cap for the first time.

Introduction : Is Mars water-rich planet ?

* Recent observations suggest rich water at the polar caps and underground.

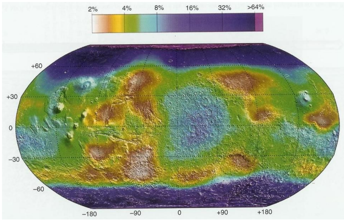
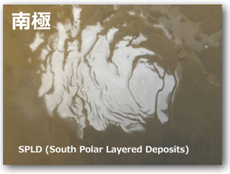


図 4 : Odyssey 搭載 GRS の中性子分光観測による火星地表面の H_2O 分布。実際に観測されるのは水素による中性子吸収であるため、Water Equivalent Hydrogen と呼ばれる量（おおむね水の分布を示すと考えられている）である。±60° より極側で多量の水がある他、赤道付近にも 8%程度の水を有する領域が見られる。これらが大気と平衡状態にあるのか、あるいは変遷する途中の姿を見ているのかは明らかになっていない。(NASA/MO-GRS/Los Alamos National Laboratory)

(火星気象オービター提案書より抜粋)



Introduction : Water cycle on Mars

* Recent observations show the water cycle in the atmosphere.

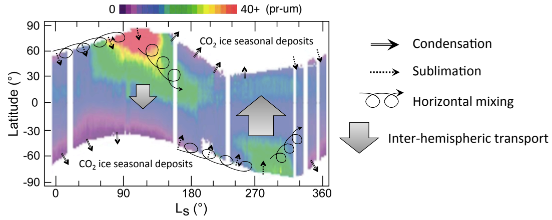


Fig. Seasonal cycle of water vapor (Appere et al., 2012)

Motivation : With HDO/H2O observations, sublimation-condensation process in water (including surface-atmosphere interaction) is investigated

$$\alpha = \frac{(D/H)_{ice}}{(D/H)_{vap}} = 1.43 \quad @\ 200K$$

(Montmessin et al., 2005)

(The saturated vapor pressure of HDO is less than that of H2O).

Introduction : HDO/H2O GCM simulation

* A GCM simulation suggests that HDO/H2O ratios rage between 2 to 5 due to condensation

Modeling the annual cycle of HDO in the Martian atmosphere

F. Montmessin[1] — *JGR* **110**, (2005)
NASA Ames Research Center, Moffett Field, California, USA
T. Fouchet
LESIA, Observatoire de Paris, Paris, France
F. Forget
Laboratoire de Météorologie Dynamique, Institut Pierre Simon Laplace, Paris, France

(1st HDO/H2O simulation with GCM)
(other not-included process :**Regolith adsorption**)

tion of ozone on Mars by *Lefèvre et al.* [2004]). It includes the major processes affecting water vapor in the Martian atmosphere (except regolith adsorption); e.g. transport by winds, exchanges with the surface, atmospheric condensation and sublimation as well as sedimentation of icy particles. Water can either sublime (if ice is present on the

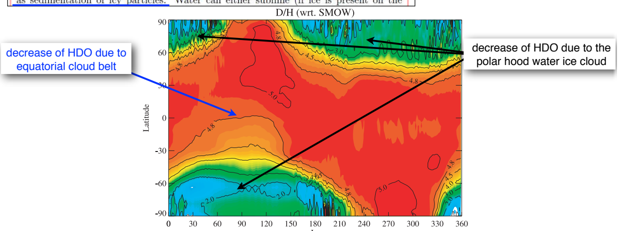


Fig. Latitudinal and seasonal distribution of the zonally averaged abundances of the D/H ratio in the vapor phase (Montmessin et al., 2005)

Introduction : HDO/H2O Observations

✓ Previous reports of HDO/H2O distribution is very limited (Only 1 paper in literature):

- Owen et al. (1980) : $(HDO/H_2O)_{Mars}$ = (6±3)xVSMOW [global-mean]
- Krasnopolsky et al. (1997) : $(HDO/H_2O)_{Mars}$ = (5.5±2)xVSMOW [global-mean]
- **Villanueva et al. (2008) : Significant Local-time dependence**
- **Novak et al. (2011) : Significant Latitudinal distribution**

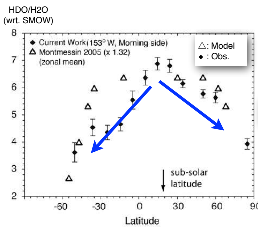


Fig. Latitudinal distribution of HDO/H2O observed by IRTF/CHESLL at Ls=50 (Novak et al., 2011).

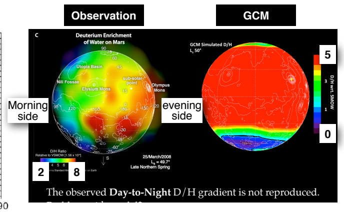


Fig. Map of HDO/H2O observed by IRTF/CHESLL at Ls=50 (Villanueva et al., 2008).

Further investigation of HDO/H2O is indispensable

Key questions

Goal : Understanding of sublimation-condensation process in water (including surface-atmosphere interaction)

- **Latitudinal distribution of HDO/H2O at different season ?**
- **Longitudinal distribution of HDO/H2O ?**
- **Local-time dependence of HDO/H2O ?**

Remote-sensing by high-resolution NIR spectrometer from space-craft is the best way to investigate those. However, there are no such instruments. **NOMAD/TGO will be able to do that (It will be able to obtain 3-D HDO/H2O map by Nadir & Solar-occultation observation mode).** Ground-based observation with high-resolution NIR spectrometer is only way at the moment. We investigated HDO/H2O on Mars using SUBARU/IRCS. It can obtain longitudinal or latitudinal distribution over the planet at the same time.

Instruments: SUBARU / IRCS

* IRCS has been designed to deliver diffraction limited images from 2 to 5 µm, as well as providing spectroscopy with grisms and a cross-dispersed echelle. The camera can also be used as a slit viewer for the echelle spe

HDO/H2O analysis
We use **H2O line at 3035 cm-1** and **HDO line at 2677 cm-1** because these lines are **enough strong**, **not saturated**, and **does not have any contaminations: the other terrestrial lines (O3, N2O, CH4, and H2O isotopes etc), Martian CO2 lines, and solar lines.**

coverage	x 5 bands	
Spectral resolution	~20,000	~40,000
Slit	0.14”x6.69”	0.47”x30”
Pixel Scale	0.06”	0.2”

(1) 2.94-3.01 µm telluric H2O lines
(2) 3.10-3.18 µm telluric H2O lines
(5) 3.72-3.81 µm telluric HDO lines Martian CO2 isotope lines

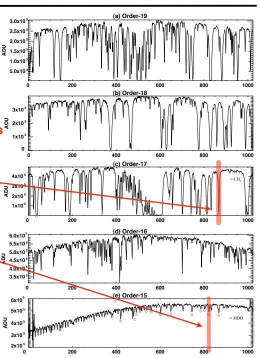


Fig. An example of measured spectrum by IRCS (5-min integration).

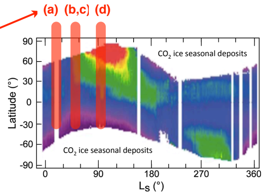
Owing to the wide spectral coverage, we could performed absolute simultaneous observations of multiple CH_4, H_2O, HDO, and CO_2 lines.

2011-2012 Observing campaign by SUBARU/IRCS

Table. Summary of SUBARU/IRCS observation during 2011-2012 periods

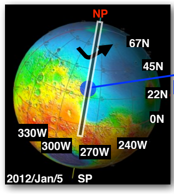
Date	(a) 2011/12/1 4:00-5:30 (1h) (b) 2012/1/4 1:00-6:00 (5h) (c) 2012/1/5 1:00-6:00 (5h) (d) 2012/4/12 20:00-2:30 (4h) [(d)Joint observation with PFS]
Ls	(a) 37° (b,c) 52° (d) 96°
Slit position	(a,c,d) N-S direction (b) E-W direction
Target	CH4, HDO, H2O, CO2 isotope

✓ We observed Mars using IRCS (a near-infrared echelle spectrometer) on 4 nights during 2011-2012 periods. The observations aim to investigation of HDO/H2O, CO2 isotopes, and CH4 distributions.



Points of our observations
- ✓ First simultaneous observation between H2O, HDO, CH4 and CO2 isotopes
- ✓ Investigation of HDO/H2O latitudinal distribution at different seasons
- ✓ Investigation of HDO/H2O local-time dependence
- ✓ First investigation of HDO/H2O ratio at local summer (during sublimation of the northern polar cap).
- ✓ Detail observation of the potential CH4 source areas.
- ✓ Simultaneous observation between SUBARU and PFS.

Observations and Method of analysis



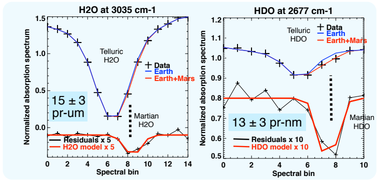


Fig . An example of fitting to the spectra taken by IRCS in HDO and H2O spectral ranges at latitude 35 degrees north.

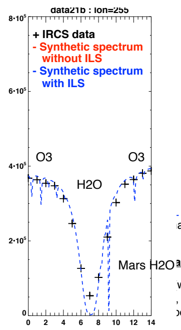
Average/binning : For HDO/H2O analysis, the all data are 5 minutes integration and 10-pixel binning (which is corresponding to observing seeing).

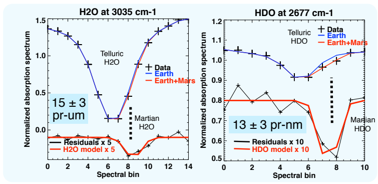
Separation between telluric and Martian contributions & determination of column density :

* In order to detect tiny Martian line (which is shifted due to doppler-shift), we should separate between Martian and Terrestrial contributions. For that, we developed **a RT model** for each line (± 0.5 cm-1 from line center), and derive the best-fitted one with Levenberg-Marquardt algorithm.

* The model considers terrestrial H2O, HDO, and O3 lines, Martian H2O and HDO lines, solar lines, and the instrumental line shape (ILS) of IRCS. The Lorenz width is considered as line-width for terrestrial molecules, while the doppler width is considered as line-width for martian molecules. The gaussian function is assumed as the instrumental line shape of IRCS. The solar spectrum is obtained from ACE-FTS observation (Hase et al., 2010). The continuum is assumed to be liner function in the narrow spectral range. The free parameters are line center position, column density of terrestrial H2O, Martian H2O, the factor of continuum (ax+b), and width of ILS.

Observations and Method of analysis





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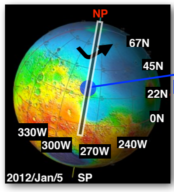

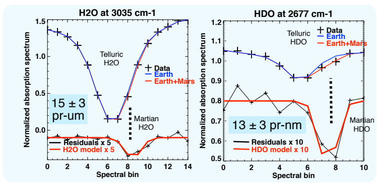

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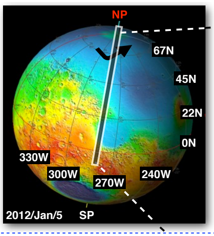
Latitudinal distribution at Ls = 52° (LT = 13-15)



- The H2O amounts have a good agreement with the values derived from Mars Climate Database (GCM).
- **The values of HDO/H2O ratios are maximum at middle latitudes (20-40° N). The distribution would be explained by condensation in the atmosphere.**
- The mean value of HDO/H2O is 3.3 ± 1.0. It is slightly smaller than the values by previous reports (→ future work : Update of RT model).

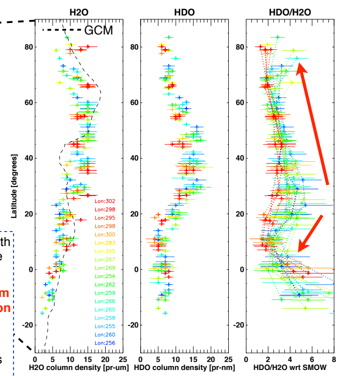
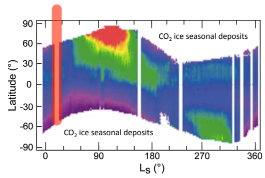


Fig . Latitudinal distributions of H2O, HDO, and HDO/H2O wrt SMOW observed by IRCS. Differences in colors show the observing longitudes. The values in HDO/H2O are the averaged over the longitudes and error bars show their standard deviations

Latitudinal distribution at Ls = 37°



- Since it was high-humidity during observations on 12/1 and 4/12, Martian H2O amounts could be derived by SUBARU. Here, I use MCD model for HDO/H2O analysis.
- **The values of HDO/H2O ratios are maximum at middle latitudes (20-40° N) and around 10° S.** The distribution would be explained by condensation in the atmosphere.

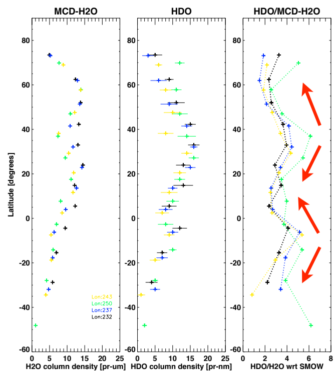
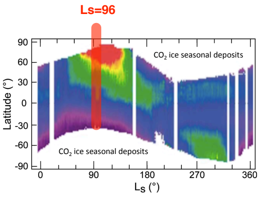


Fig . Latitudinal distributions of H2O derived from GCM, and HDO, and HDO/H2O wrt SMOW by IRCS at Ls = 37°.

Latitudinal distribution at Ls = 96°



✓ **We detect HDO sublimation of the northern polar cap for the first time.**

✓ The H2O/HDO ratio is increased from low latitudes to high latitudes. The mean value of H2O/HDO ratio is quite small. It is suggested that the quantity of H2O sublimation has an annual-variation (Montmessin et al., 2012, MEX-SWT). Retrieval of H2O amounts will be performed using MEX/PFS data during the same period.

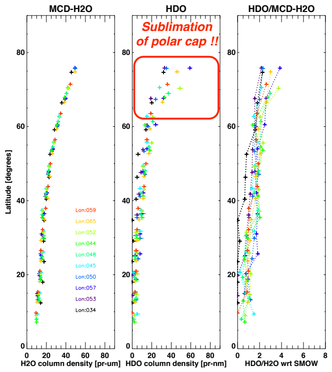
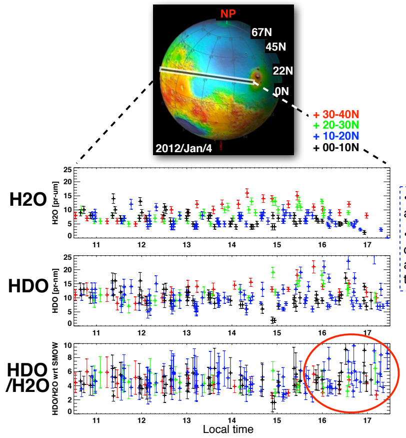
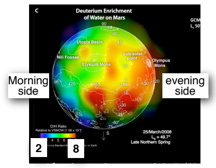


Fig . Latitudinal distributions of H2O derived from GCM, and HDO, and HDO/H2O wrt SMOW by IRCS at Ls = 96°.

Local time dependence at Ls = 52°

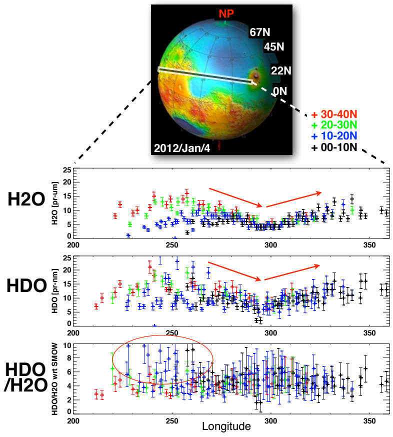


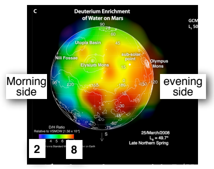


- A clear local-time dependences of H2O and HDO amounts do not appear.
- A strong local-time (or longitudinal) distribution of HDO/H2O ratios appears at 16-18 h. It is basically consistent with the result by Villanueva et al. (2008).

← Fig. Local times distributions of H2O, HDO, and HDO/H2O wrt SMOW at Ls = 52°. Differences in colors show the observing latitudes (Red: 30-40N, Green: 20-30N, Blue:10-20N, and Black:0-10N). The values in HDO/H2O are the averaged over the longitudes and error bars show their standard deviations.

Longitudinal distribution at Ls = 52°





- A clear longitudinal distributions of H2O and HDO amounts appear (Wave-3 structure @270W...? [Future Work]).
- Although it is not distinguished from local-time dependence, a strong longitudinal distribution of HDO/H2O ratios appears around 240 degrees.

← Fig. Longitudinal distributions of H2O, HDO, and HDO/H2O wrt SMOW at Ls = 52°. Differences in colors show the observing latitudes (Red: 30-40N, Green: 20-30N, Blue:10-20N, and Black:0-10N). The values in HDO/H2O are the averaged over the longitudes and error bars show their standard deviations.

Summary

- **Motivation** : Investigation of sublimation-condensation process in water on Mars with HDO/H2O observations. We performed observation of its latitudinal distribution and local time dependence using SUBARU/IRCS.
- **Latitudinal distribution** : Our observations at Ls=52 and Ls=37 show that the values of HDO/H2O ratios decrease from the sub-solar latitude (~20N) to north-pole and low-latitude together with HDO and H2O amounts.It would be basically explained by condensation in the atmosphere.
- **Local-time / Longitudinal distribution :** A strong longitudinal distribution of HDO/H2O ratios appears around 240 degrees or 16-18 h. A clear longitudinal distributions of H2O and HDO amounts appear. The further investigation of the distributions are one of the important future works.