Scientific challenges for lidar-based dust and ice cloud characterization on Mars

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INTRODUCTION

Dust is the background aerosol in Mars, permanently distributed along all the planet, and hence the principal driver of the Martian climate. **Ice clouds** observed in Mars are composed of H_2O and CO_2 ice particles, which form at rather different altitudes and over diverse seasons and regions. In addition, they can potentially interact with dust particles (nucleation issues). The scientific goals of the **MiLi project** (*'Miniaturized Lidar for MARS Advanced Atmospheric Research'*) are addressed to the **characterization** of those both Martian aerosols **in vertical resolution**. These studies will represent a key factor to investigate their climatic implications on Mars.

MARTIAN AEROSOLS: Vertical impact in the atmosphere

Mars vs. Earth atmosphere

Averaged values (w.r.t. Earth)	Mars	Earth
Distance to Sun (km)	227 940 000 (1.5)	149 600 000 (1)
Orbital inclination (º)	25 (1.09)	23 (1)
Eccentricity	0.093 (5.8)	0.016 (1)
Translational period (terrestrial days)	686.9 (1.9)	365.2 (1)
Rotational period (terrestrial hours)	24.6 (1.03)	23.9 (1)
Diameter (km)	6 786 (0.53)	12 756 (1)
Mass (kg)	0.11	1
Surface gravity (m s^{-2})	3.7 (0.38)	9.8 (1)
Surface pressure (mbar)	6 (0.006)	1013 (1)
Surface temperature (K)	220 (0.74)	298 (1)
Scale height (km)	10-12	1-2
Tropopause height (km)	35-40	10-15
ABLH (km)	10 (5-10)	1-2
Atmospheric gases (predominant)	CO_2 (95%)	N_2 (78%) + O_2 (21%) + other minor gases (O_3, …)
Aerosol types (predominant)	**Dust** **Water ice clouds** CO_2 ice clouds	**Dust**, smoke (i.e. biomass burning), marine, pollution, volcanic ash **Water ice clouds**

Dust: Impact on temperature

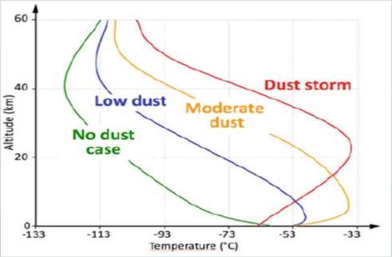

Figure 1. *Temperature profiles for different dust loads [Forget, 2008].*

Water ice clouds: Distribution and opacity

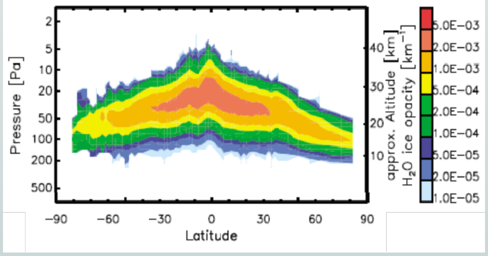

Figure 2. *Simulated water ice opacities (namely cloud extinction coefficients) from radiance/noise modelling [Kleinbohl et al., 2009].*

Vertical characterization: Lidar observations on Mars

MiLi system [2β + 1δ]

Elastic backscatter lidar with three channels: two orthogonal components of polarization in the backscattered light at one wavelength (532 nm), and the total backscattered signal at a second wavelength (905 nm).

Optical properties (inversion methods applied):

- **Particle backscatter coefficient (β) at 532 nm and 905 nm (2β)**
- **Volume linear depolarization ratio (δ) at 532 nm (1δ)**

The aim is to develop **a terrestrial version of the future lidar on Mars - the MiLi system -,** which represents an extended performance of the first lidar on Mars, the Phoenix mission, by incorporating, in particular, depolarization capabilities.

Scientific objectives

Dust

- ✓ First estimation of the depolarization ratio (δ).
- ✓ Earth-based mass concentration estimation.
- ✓ Daily, seasonal and year-to-year DOD variability.
- ✓ Height-resolved versus column-integrated optical properties.
- ✓ Dust transport: impact of dust scavenging on the vertical distribution, and ascent of dust layers due to radiative heating.
- ✓ Vertical estimate of the particle size, and assessment of the bi-modal (fine and coarse) dust contributions.
- ✓ Dust-induced radiative effect.

Water ice clouds

- ✓ First estimation of the depolarization ratio (δ).
- ✓ Vertical layering, and maximal altitude.
- ✓ Daily, seasonal and year-to-year variability of cloud occurrence, and opacity (cloud optical depth, COD).
- ✓ Dust-cloud interactions: cloud formation (INP detection).
- ✓ Transport of water to the upper atmosphere.
- ✓ Ice cloud-induced radiative effect.

MiLi challenges

The primary scientific MiLi challenges for **Mars atmospheric exploration** are three-fold: 1) detection of **high-altitude dust and ice cloud layers** (> 30 km height; plausible dust-cloud interactions); 2) for the first time, estimation of the **depolarization ratio of the Martian dust and ice clouds**; and 3) **discrimination between dust and clouds** (related to lidar-derived depolarization).

Earth-based representative atmospheric scenarios are simulated by considering the presence of dust and ice clouds on Mars, being discussed in terms of expected lidar signals.

Simulations for Earth-based representative MiLi atmospheric scenarios on Mars

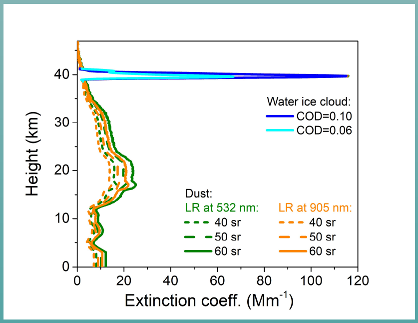

Figure 3. *Extinction coefficient profiles at 532 nm (green) and 905 nm (orange) as obtained for several Earth-based atmospheric scenarios on Mars.*

Real Earth atmospheric scenarios under intense dusty and usual cloudy conditions were extrapolated for Martian dust and ice clouds simulations:

- Dust and cloud properties were obtained at 532 and 905 nm (Angstrom exponent=0.25): their variation in terms of the lidar ratio (LR) for dust: 40 sr, 50 and 60 sr, and the cloud optical depth (COD=0.06 and 0.10), respectively.
- Dust optical depth (DOD) varied from 0.36 to 0.54, keeping similar in both planets, and being then the extinction coefficient lower on Mars.
- Dust occurrence until 7 km height on Earth is 'extended' up to reaching altitudes of 90 km on Mars.
- A detached water ice cloud is 'included' at 40 km height .

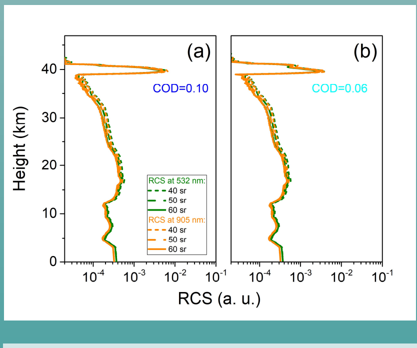

Figure 4. *Range-corrected signal (RCS) at 532 nm (green) and 905 nm (orange) as computed by using the lidar equation from those Earth-based atmospheric scenarios shown in **Fig. 3**: (a) and (b) for a detached water ice cloud with COD= 0.10 and 0.06, respectively.*

Lidar equation (range-corrected signals, RCS):

$$P(r,\lambda)\, r^2 = C\, O(r)\, \beta(r,\lambda)\, exp[-2 \int \alpha(R,\lambda)\, dR]$$

Lidar ratio (sr):

$$LR = \alpha(r,\lambda) / \beta(r,\lambda)$$

$P(r,\lambda)$ is the total lidar backscattered signal

(r: range/height, λ: wavelength: 532 and 905 nm)

$\alpha(r,\lambda)$ is the extinction coefficient [m^{-1}]

$\beta(r,\lambda)$ is the backscatter coefficient [m^{-1} sr^{-1}]

C is the instrumental constant (receiver efficiency, pulse energy, detector area, …) (= 1, assumed)

O(r) is the overlap function (= 1, for simplicity)

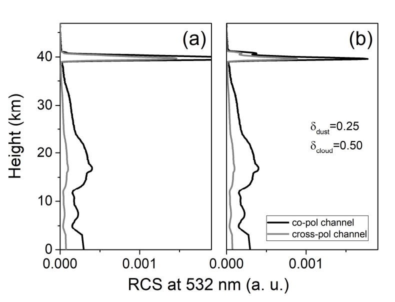

Figure 5. *Both co-pol and cross-pol channels at 532 nm (for instance, Martian scenarios under dusty and cloudy conditions with DOD=0.54 (LR=60 sr) and (a) COD=0.10, and (b) COD=0.06), by assuming (Earth-like) δ values at 532 nm for dust and water ice cloud of 0.25 and 0.50, respectively.*

Volume linear depolarization ratio (definition):

$$\delta = \beta^{\perp} / \beta^{\parallel} \cong P^{\perp} / P^{\parallel}$$

$P^{\parallel}$ is the co-pol signal (parallel to the laser emitted signal)

$P^{\perp}$ is the cross-pol signal (perpendicular to the laser emitted signal)

Each signal channel can be expressed as a function of the total signal P and δ as follows:

$$P^{\parallel} = P \times [1/(1+\delta)]$$

$$P^{\perp} = P \times [\delta/(1+\delta)]$$

FUTURE WORK

- Those **simulation approaches** will be performed **backwards**: from MiLi signals (RCS, δ) to both dust and ice cloud optical properties (e.g. for clouds detected at < 30 km height).
- **Implementation** of the **lidar retrieval procedures** to obtain the aerosol (dust, clouds) optical properties under Martian conditions.
- **Validation activities**: comparison of MiLi observations against those from a reference lidar under Mars-analogue conditions on Earth (field campaign in a dust-influenced environment).

References: Daerden et al., Geophys. Res. Lett., 37, L04203, https://doi.org/10.1029/2009GL041523, 2010; Forget et al., Planet Mars: story of another world. Springer-Praxis books in popular astronomy. Springer, 2008; Kleinböhl et al., J. Geophys. Res., 114, E10006, doi:10.1029/2009JE003358, 2009.

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