PROPOSED MODEL FOR ESTIMATION OF ATMOSPHERIC DUST AND CLOUD MASS LOADING ON MARS. A. Bhattacharya[1] , S. Jitarwal[2] , J. P. Pabari[2] and V. Sheel[2], [1]Sardar Vallabhbhai National Institute of Technology Surat-395007, INDIA. Email: ananyo0806@gmail.com, [2]Physical Research Laboratory, Ahmedabad, INDIA

Introduction: Radio occultation based studies of planetary atmospheres of Venus and Mars have provided information related to physical structure of the neutral atmosphere and ionosphere. Important parameters like pressure, temperature, neutral density, electron density are retrieved from the propagation of electromagnetic waves through the planetary atmospheres and its consequent attenuation, refraction and doppler shift.

Characterization of atmospheric dust properties is a problem of fundamental importance to Martian science [1]. The understanding of atmospheric transport of dust, and cloud formation processes are key to advancing accurate prediction of weather events.

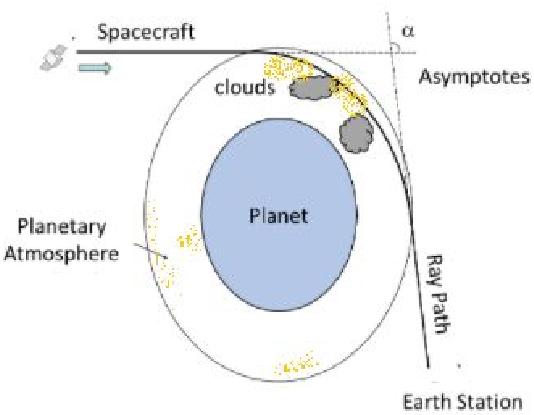

Figure 1. Radio occultation through planetary atmosphere. The ray passes through atmospheric dust (orange) and clouds (grey) undergoing signal attenuation.

Martian atmosphere attenuation budget: The attenuation of electromagnetic waves in S, X, Ka-band has been reported earlier. Main sources of attenuation are ionospheric scintillations, atmospheric dust, water ice clouds and aerosol particles. Other sources include refractive defocussing, antenna mispointing and free space losses. An estimation of losses for different sources and links have been provided. Unlike Venus, the Martian atmospheric gases do not show appreciable absorption in the radio occultation (In private communication with Dr. Paul G. Steffes) and their contribution to signal attenuation is negligible in accordance with Ho et al. (1966) [2].

Table 1: List of all attenuation factors and their magnitudes in S, X, Ka band from [3]

Type of loss	S band	X band	Ka band
Free space loss	260 dB	270 dB	280 dB
Clouds	0 dB	0.05 dB	0.1 dB
Gases	0 dB	0 dB	0 dB
Dust*	0.3 dB	1 dB	3 dB

*Worst case scenario of dust activity

It is observed that atmospheric dust forms the largest component of atmospheric attenuation and is appreciably larger than the other sources. The absorption is significant in the Ka-band.

Mass loading retrieval: The retrieval method for mass loading is similar to the method used for estimating sulphuric acid cloud mass. The residual power loss due to atmospheric attenuation is calculated by subtracting free space loss, refractive defocusing loss and antenna mispointing errors. Refractive index is retrieved using geometric ray shortest distance and bending angle (Eq. 1) [4]. Further, the residual signal loss is converted into total absorptivity using the product of refractive index and an inverse Abel transform of residual loss (Eq. 2). From Table 1, it is inferred that attenuation due to clouds and dust are significant only in X and Ka band (Eq. 4 and 5) [4,5]. We equate total absorptivity to the sum of losses due to cloud and dust driven attenuation.

$$ln(n(r_0)) = \frac{1}{\pi}\int_{a(r_0)}^{\infty} \frac{\delta(a)\,da}{\sqrt{a^2 - a(r_0)^2}} \quad (1)$$

$$\alpha(r_0) = -\frac{n(r_0)}{\pi a(r_0)} \cdot \frac{d}{da}\int_{a(r_0)}^{\infty} \frac{\tau(a)\,a\,da}{\sqrt{a^2 - a(r_0)^2}} \quad (2)$$

$$\alpha_d(\lambda) = 1.029 * 10^6 \frac{\varepsilon''_d}{\lambda((\varepsilon'_d + 2)^2 + \varepsilon''^2_d)} N_T r_m^3 \quad (3)$$

where n is refractive index, a is perpendicular distance of geometric ray from centre of the planet, δ is bending angle, τ is residual loss due to atmospheric absorption, α is total absorptivity, α_d is attenuation due to dust at altitude r_0, λ is wavelength of the EM wave, N_T is total number density of dust, r_m is mean radius of dust particle and ε'_d, ε''_d are dielectric constants of dust. Eq. (3) can be rewritten as:

$$\alpha_d(\lambda) = 1.029 * 10^6 \frac{\varepsilon''_d}{\lambda((\varepsilon'_d+2)^2 + \varepsilon''^2_d)} \frac{3M_d}{4\pi\rho_d} \quad (4)$$

$$\alpha_c(\lambda) = \frac{1.8\pi M_c}{\lambda\rho_c} \frac{\varepsilon''_c}{((\varepsilon'_c+2)^2 + \varepsilon''^2_c)} \quad (5)$$

Here M_d is dust mass loading, ρ_d is density of dust particle, α_c is attenuation due to dust at altitude r_0, M_c is cloud mass loading, ρ_c is the density of cloud particles and ε'_c, ε''_c are effective dielectric constants of cloud particles.

For single frequency radio occultation in Ka band, we neglect the contribution of cloud attenuation.

$$\alpha(r_0)_{Ka} = \alpha_d(\lambda_{Ka}) \quad (6)$$

For dual frequency radio occultation in X and Ka band, we compute the contributions of dust and cloud to obtain the product of total number density of particles and cube of mean radius. Multiplication of retrieved parameters with average density gives the mass loading of cloud and dust in the Martian atmosphere. Dielectric properties of cloud condensation nuclei and water ice can be obtained using appropriate mixing models [6, 7].

$$\alpha(r_0)_{Ka} = \alpha_d(\lambda_{Ka}) + \alpha_c(\lambda_{Ka}) \quad (7)$$

$$\alpha(r_0)_X = \alpha_d(\lambda_X) + \alpha_c(\lambda_X) \quad (8)$$

Table 2: List of input variables and output variables for the retrieval models

Model	Input	Output
Single link: Ka band	$\delta, \tau, \lambda, \varepsilon'_d, \varepsilon''_d, \rho_d$	M_d
Double link: X and Ka band	$\delta, \tau, \lambda, \varepsilon'_d, \varepsilon''_d, \rho_d, \varepsilon'_c, \varepsilon''_c, \rho_c$	M_d, M_c

Expected Outcomes and Applications: It is expected that one can obtain dust and cloud mass loading profiles in the atmosphere of Mars using the proposed retrieval method. Radio science experiment surveys the Martian atmosphere till the surface region. Therefore, the technique provides an opportunity to retrieve dust mass loading profile using an orbiter borne instrument. Both Orbiter to Earth (O2E) and Orbiter to Orbiter (O2O) radio occultation experiments in single and dual frequency can provide data for estimating mass loading profiles.

Future directions: With new advancements in small satellite technology and design of constellation network, a real time weather or atmospheric survey network consisting of dual frequency radio occultation can be useful to study variations in dust activity in lower atmosphere and provide a global coverage of atmospheric dust and clouds. Mass loading profiles can provide new input for atmospheric radiative transfer models, global and regional climate models that can be useful to predict dust activity using data assimilation.

Intense dust storms can pose a challenge to human and robotic exploration of Mars. Therefore, the method of radio occultation and dust retrieval technique can be useful in design of long-term missions including planning of EDL events [1].

Future Mars orbiter missions with Ka-band frequency or dual frequency (i.e., X and Ka-band) radio occultation can test the method and obtain large volumes of datasets for constraining the mass of water ice clouds and atmospheric dust.

References: [1] Forget F. and Montabone L. (2017) *47th ICES,* 175. [2] Ho W. et al. (1966) *JGR, 71,* 5091-5108. [3] Ho C. et al. (2002) *DECANSO* [4] Oschlisniok J. et al. (2012) *Icarus, 221,* 940-948. [5] Cimino J. (1982) *Icarus, 51,* 334-357. [6] Wang Z. and Zhang P. (2004), *J. Quant. Spectr. & Rad. Trans., 83,* 423-433. [7] Haberle R. M. et al. (2017), *Cambridge University Press, Ch 5.*