CHEMISTRY AND MODELING OF LOWER ATMOSPHERE OF MARS

A THESIS

Submitted for the Award of Ph.D. Degree of

PACIFIC ACADEMY OF HIGHER EDUCATION AND RESEARCH UNIVERSITY

By

SHAH SIDDHI YOGESHKUMAR

Under the Supervision of

Prof. S. A. HAIDER **Dr. RAKSHIT AMETA**

DEPARTMENT OF CHEMISTRY
FACULTY OF SCIENCE

PACIFIC ACADEMY OF HIGHER EDUCATION AND RESEARCH UNIVERSITY
UDAIPUR

Dedicated to my

Family

DEPARTMENT OF CHEMISTRY

PAHER UNIVERSITY, UDAIPUR

Prof. S. A. HAIDER
Senior Professor

CERTIFICATE

It gives me immense pleasure in certifying that the thesis entitled **"CHEMISTRY AND MODELING OF THE LOWER ATMOSPHERE OF MARS"** submitted by **SHAH SIDDHI YOGESHKUMAR** is based on the research work carried out under my guidance. She has completed the following requirements as per Ph.D. regulations of the University.

(i) Course work as per University rules.

(ii) Residential requirements of the University.

(iii) Regularly submitted Half Yearly Progress Report.

(iv) Published/accepted minimum of two research paper in a refereed research journal.

I recommend the submission of thesis.

Date:

(Prof. S. A. HAIDER)
Ph.D Supervisor
Faculty of Science,
PAHER University
Udaipur

Senior Professor
Physical Research Laboratory
Ahmedabad

DEPARTMENT OF CHEMISTRY

PAHER UNIVERSITY, UDAIPUR

Dr. RAKSHIT AMETA
Associate Professor

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Date:

(Dr. RAKSHIT AMETA)
Co-Supervisor

DECLARATION

I, **SHAH SIDDHI YOGESHKUMAR** D/o **Shri YOGESHKUMAR SHAH** resident of Ahmedabad, Gujarat (India) hereby declare that the research work incorporated in the present thesis entitled **" CHEMISTRY AND MODELING OF THE LOWER ATMOSPHERE OF MARS"** is my own work and is original. This work (in part or in full) has not been submitted to any University for the award of a Degree or a Diploma. I have properly acknowledged the material collected from secondary sources, wherever required. I solely own the responsibility for the originality of the entire content.

Date: **(SHAH SIDDHI YOGESHKUMAR)**
Place: Udaipur Research Scholar

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Place: Udaipur Research Scholar

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I am lifelong grateful to my beloved parents, **SHRI YOGESHKUMAR SHAH** and **SMT. VISHAKHABEN SHAH**, who worked hard to educate me. Their hard work inspired me to do hard in my studies. I ever express my immense sense of gratitude to them for their love, care, encouragement and support right from my birth. I will be deeply beholden to them. It is my pleasant duty to recall with gratitude the everlasting affection, encouragement and all support which I have been receiving from my sister. I also dedicate this thesis to my lovely sister **RIDDHI PARIKH** for her constant motivation and love. I also gathered courage from the warm wishes coming from my lovely and cute nieces, **JIYA** and **JUHI**. I am thankful to my jiju **NAINESH PARIKH** for his encouragement. I am also thankful to all my cousins and family members for their love and support. I thank the God for giving me such supportive and lovable family.

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(SHAH SIDDHI YOGESHKUMAR)

PREFACE

The understanding of the complex behavior of the atmosphere and ionosphere of various planets requires a balanced effort in theoretical modeling, experiments and analysis of the observations. The ability to combine observations with numerical models is critical in predicting atmospheric phenomena. Theoretical models based on fundamental principles in conjunction with data from recent satellites are important to improve our understanding of the physical, chemical and dynamical processes in the atmosphere. Given such importance, modeling of planetary atmospheres has been a major thrust area in India. To help in strengthening this area of research, we have developed various models to study the complex behavior of Martian atmosphere/ionosphere and dust storms. The Martian ionosphere can be divided into D, E, and F region. The Mars ionospheric F- region is formed by EUV radiation with wavelength 90 – 1026 Å at altitude ~125-135 km. Mars ionospheric E-region is produced by X-ray radiation with wavelength of 10-90 Å at altitude ~100-112 km. At night the E-region of Mars disappear because of absence of the primary source of ionization. Most of the radio occultation experiments used radio frequency wave to infer the ionosphere of Mars. The lower ionosphere is made of D region. The D peak of electron density occurs at altitude range from 25 to 35 km. In D layer electron density is less than the positive ion density from which the existence of negative ions can be inferred. The primary sources of ionization of D region are galactic cosmic rays.

The Solar flare response is a key problem in the planetary ionosphere. The solar flares are sudden increases in solar radiation associated with sunspots. The occurrence of solar flares directly depends on sunspot number which in turn depends on solar activity.

The sunspot number increases as the sun progresses in its activity during 11-years solar cycle. The solar flares are broadly classified as X, M, C and B-classes according to their X-ray brightness in the wavelength range 1 to 70 Å. The GOES, which operate in geostationary orbit above the earth track the solar flares reaching the earth by measuring the X-ray, flux at shorter wavelengths (0.5-3 Å and 1-8 Å) because these shorter wavelength X-ray fluxes are more sensitive to the solar flares. Among various Mars' missions, the MGS was the only mission, which measured a large number of electron density profiles (5600) in the ionosphere of Mars during solar maximum conditions so far. It observed the responses of about 32 solar flare events in the electron density profiles of Martian ionosphere. Therefore, the electron density data of MGS is very useful to understand the implications of solar flares on Mars. We have also carried out modelling of D and E region ionosphere of Mars due to impact of soft X-rays, hard X-rays and GCR radiations during solar flare and non-flare conditions. We have reported hard X-rays as a new source of ionization, which also produced D region ionosphere of Mars. We have studied response of all 32 Solar flare in the E region ionosphere of Mars. The effect of ozone, dust, and Schuman resonance frequencies in D region ionosphere of Mars are also studied. In absence of measurements, our model results will provide a benchmark values that may help to guide the design of future atmospheric/ionospheric payloads of Mars.

In the present thesis, we have described eight chapters. In chapter 1, we have introduced Martian atmosphere and ionosphere. In the second chapter, we have described three theoretical models, (1) Energy loss method, (2) Analytical yield spectrum, and (3) Continuity equation. In the third chapter, we have studied effect of solar flares in D region ionosphere of Mars.

In the fourth chapter, we have discussed the response to solar X-ray flares in the E region ionosphere of Mars. In the fifth chapter, we have studied seasonal variability of the ozone in lower ionosphere of Mars. In the sixth chapter, we have described the electrical conductivity and SR frequencies in the lower ionosphere of Mars. In the seventh Chapter, we have discussed the summary and conclusions on the work carried out in the present investigation. Finally, in eighth Chapter, we described the future work.

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Contents

List of Figures

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PUBLICATIONS

Effect of Dust Storm and GCR Impact on the Production Rate of O_3^+ in MY 28 and MY 29: Modeling and SPICAM Observation

S. A. Haider[1], Y. S. Siddhi[1,2], J. Masoom[1,2], S. Bougher[3]

[1]Planetary Sciences Division, Physical research Laboratory, Ahmedabad, India

[2]Research Scholar, Faculty of Science, Pacific Academy of Higher Education of ResearchUniversity, Udaipur, India

[3]Climate and Space Sciences and Engineering, University of Michigan, Ann Arbor, USA

ABSTRACT

We have developed a seasonally dependent energy loss model to calculate the zonally averaged production rates of O_3^+ due to impact of galactic cosmic rays in the dayside troposphere of Mars between solar longitudes (Ls) ~0° and 360° at low latitudes (2°N, 2°S, 25°N, and 25°S), mid-latitudes (45°N and 45°S), and high latitudes (70°N and 70°S) in the Martian Year (MY) 28 and MY 29. We also represent the seasonal variability of zonally averaged ozone column density obtained from Mars Climate Database (MCD; Millour et al., 2014, https://hal.archives-ouvertes.fr/hal-01139592) during the daytime. These results are compared with the daytime observations of column ozone made by Spectroscopy for the Investigation of the Characteristics of the Atmosphere of Mars onboard Mars Express (MEX). At mid-to-high latitudes ozone column density is maximum in northern winter and minimum in southern summer. At low-to-middle latitudes (2°N–S, 25°N–S, and 45°N–S), the production rates of O_3^+ represent a broad peak between altitudes 26 and 45 km in both hemispheres. The peak production rates are increasing up to Ls = 47.5° and then stabilized at about 2.5×10^{-8} cm^{-3}/s. At Ls ≥ 47.5° the peak production rate of O_3^+ starts decreasing until it disappeared after Ls = 127.5°. A major dust storm occurred in MY 28 at Ls~280° in southern latitudes (~25°–35°S). During the dust storm period, dust opacity, ozone column density, and O_3^+ production rate on the surface of Mars were increased by a factor of ~3.

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Schumann resonance frequency and conductivity in the nighttime ionosphere of Mars: A source for lightning

S. A. Haider[1], Jayesh P. Pabari[1], J. Masoom[1,2] and Siddhi Y. Shah[1,2]

[1]Planetary Science Division, Physical Research Laboratory, Ahmedabad, India

[2]Research Scholar, Faculty of Science, Pacific Academy of Higher Education and Research

University, Udaipur, India

ABSTRACT

We have solved the Maxwellian equations of electromagnetic waves which oscillate within the cavity formed in the lower ionosphere of Mars between 0 and 70 km. The electrical conductivity and Schumann Resonance (SR) frequencies are calculated in the lower ionosphere of Mars, in the presence of a major dust storm that occurred in Martian Year (MY) 25 at low latitude region (25°–35°S). It is found that the atmospheric conductivity reduced by one to two orders of magnitude in the presence of a dust storm. It represents a small dust layer at about 25–30 km altitudes where lightning can occur. We also found that the SR frequencies peak at ~18 km with values 19.9, 34.5 and 48.8 Hz for the modes l = 1, 2 and 3, respectively, in the non-homogeneous medium. Our results indicate that practical or measurable values of SR are dependent on the altitudes.

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Characteristics of solar X-ray flares and their effects on the ionosphere and human exploration to Mars: MGS radio science observations

P. Thirupathaiah[a,1], Siddhi Y. Shah[a,b], S.A. Haider[a,*]

[a]Planetary Sciences Division, Physical Research Laboratory, Ahmedabad, India

[b]Faculty of Science, Pacific Academy of Higher Education and Research University, Udaipur, India

ABSTRACT

Responses of solar X-ray flares were observed in a layer of the Martian ionosphere at altitudes of ~110 km from 32 electron density profiles obtained by radio science experiment onboard Mars Global Surveyor (MGS) during solar cycle 23. Of the 32 profiles recorded during flare periods, 10 were associated with X-class flares, 12 with M class and 10 with C class flares. The flare E-peak densities vary with solar X-ray flux, Solar Zenith Angle (SZA), Solar Longitude (Ls) and latitudes. Ionospheric Electron Content (IEC) and E-peak electron production rates of these flare profiles are estimated in the E region ionosphere. We found a maximum increase of ~200%, ~140% and ~90% in the time series of IEC for X, M and C class flares respectively. The dependence of flare E-peak electron production rate with Ls is fitted by a sinusoidal function. We have also calculated biological doses ~0.1-1.0×10^{-1}, 1-8×10^{-3} and 1-6×10^{-4}Gy for X, M, C class flares respectively to study the human risk for exploration to Mars. Among 10 X-class flares X1 is a strong solar flare that gives highest dose, which is potentially lethal for human risk in Mars' space.

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Presentations in Conference/Symposium

1 Model calculation of production rate of H_2O and O_3 on lower atmosphere of Mars: Seasonal Variability

Siddhi Y. Shah, S. A. Haider

Date: 9-12 February, 2016

Organizer: 19th National Space Science Symposium held at Space Physics Laboratory, Vikram Sarabhai Space Center, Thiruvananthapuram.

2 Effect of Solar flares on ionosphere of Mars

Siddhi Y. Shah, S. A. Haider

Date: 8-10 November, 2017

Organizer: Brain Storming Session on Vision and Explorations for Planetary Sciences in Decades 2020-2060, Physical Research Laboratory, Ahmedabad.

3 Calculated electron density due to impact of hard X-rays in D region ionosphere of Mars: First model result

Siddhi Y. Shah, S. A. Haider

Date: 29-31 January, 2019

Organizer: 20th National Space Science Symposium to be held at Savitribai Phule Pune University, Pune.

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Siddhi Y. S, Haider,S.A., Molina-Cuberos, G. J,Abdu, M.A., Batista, I (2019), A coupled model of the D and E regions of Mars' ionosphere for flare and non-flare electron density profiles: Comparison with Earth's ionosphere, Icarus. (Under review).

Haider, S. A., **Siddhi Y. S**, Masoom, J., Sheel, V., and Kuroda, T (2019), Dust loading on ozone, winds and heating rates in the tropics of southern atmosphere of Mars: Seasonal variability, climatology and SPICAM observations. Q J R MeteorolSoc, (Under review).