The Ion-Neutral Structure of the Lower Atmosphere of Mars

A Thesis

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DECLARATION

I, **Ashimananda Modak**, S/o Mr. Gurucharan Modak, resident of Room No-B005, PRL Navarangpura Hostel, Ahmedabad – 380009, hereby declare that the research work incorporated in the present thesis entitled "**The Ion-Neutral Structure 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.

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I recommend the submission of thesis.

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Dedicated to my Family

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Abstract

The atmosphere of Mars is mostly CO_2 and other species such as O_3, O, HO, HO_2, H_2O and CO are found in trace amounts but are important in the photochemistry and stability of the CO_2 dominated atmosphere. The orbital properties of Mars and variations in exposure to solar influx lead to seasonal and latitudinal variations of the short lived trace gases, which is not well studied in the literature. Systematic global observations have recently become available for O_3, but are lacking for the other species. We study the spatio-temporal variability of these species based on available observations, and a photochemistry coupled global general circulation model (GCM) for Mars. The GCM simulated seasonal distribution of temperature, N_2, Ar, CO, H_2O, O_3 agree well with inferences from observations wherever available. We retrieve two years (MY 27 and MY 28) of total columnar O_3 from raw spectral data provided by the SPICAM instrument onboard the Mars Express, using a forward radiative transfer model. The seasonal variability is studied in tropical, mid and high latitudes and is compared with the GCM simulations. The high latitudes exhibit the largest seasonal variations in O_3, with a winter high and a summer low and comparison with GCM results is good in general. We have studied the correlation of ozone with dust, retrieved simultaneously from SPICAM observations. In southern tropical latitudes, the columnar ozone is seen to increase during a global dust storm year (MY 28) compared to the ozone column values during a year without global dust storm (MY 27), though the water vapour column between these years remains unchanged. This indicates towards the radiative impact of dust on ozone and its retrieval. We also study the effect of transport on columnar amount of ozone through ozone-carbon monoxide correlation as CO is considered a tracer of dynamics. The dynamical contribution to the ozone column is found to be significant during winter over the southern polar region. In this thesis, we have also studied in detail, the important source and sink processes of odd oxygen (O_3 and O) and their contributions in different locations and seasons. The odd oxygen species are short lived and hence generally taken

in photochemical equilibrium in model calculations. However our study shows that these species do not always remain in photochemical equilibrium. The equilibrium exists only below 30 km, which may extend to 45 km depending on the hygropause level. Thus we have used the effect of water vapour on the loss rates of odd oxygen ($O+O_3$) to classify different photochemical regimes.

Along with these neutral species, Martian lower atmosphere also contains positive and negative ions. Earlier studies using the PRL ion-dust model have shown that the lower ionosphere of Mars is dominated by hydrated ions such as $H_3O^+(H_2O)_2$ and $H_3O^+(H_2O)_3$, $CO_3^-H_2O$, $CO_3^-(H_2O)_2$, and $NO_2^-H_2O$. Dust in the Martian ionosphere acts as a loss agent for the positive and negative ions, while the trace neutral species discussed above are sources for these ions through ion-neutral chemistry. We have investigated the structure of the lower ionosphere of Mars for seasons Ls = 0^o – 90^o, Ls = 90^o – 180^o, Ls = 180^o – 270^o and Ls = 270^o – 360^o over the equatorial, mid-latitude and polar regions for MY 27. The study shows that over polar region the D-layer can disappear due to lack in water vapour even in minimum dust loading scenarios. Thus the ion densities of the major positive and negative ions are strongly dependent on the available water vapour. In the mid and low latitude regions, the ion densities depend on the competing effect of the dust and water vapour.

Keywords: Martian lower atmosphere, atmospheric trace gases, Martian lower ionosphere, Mars GCM, SPICAM, ozone, water vapour, dust in Martian atmosphere, Seasonal variability of ions, hygropause,.

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List of Abbreviations

AU: Astronomical Unit.

CRISM: Compact Reconnaissance Imaging Spectrometer for Mars.

ESA: European Space Agency.

GCM: General Circulation Model.

GCR: Galactic Cosmic Rays.

GFDL-GCM: Geophysical Fluid Dynamic Laboratory GCM.

IRTF: Infrared Telescope Facility.

LMD: Laboratoire de Météorologie Dynamique.

MARCI: the MARs Colour Imager.

MaRS: Mars express orbiter Radio Science experiment.

MARSIS: Mars Advanced Radar for Subsurface and Ionosphere Sounding.

MAWD: Mars Atmospheric Water Detection.

MCD: Mars Climate Database.

MEX: Mars Express.

MGS: Mars Global Surveyor.

MRO: Mars Reconnaissance Orbiter.

MTGCM: Mars Thermospheric GCM.

MAVEN: Mars Atmosphere and Volatile EvolutioN.

NASA: National Aeronautics and Space Administration.

PFS: Planetary Fourier Spectrometer.

PRL: Physical Research Laboratory.

ROSE: Radio Occultation Science Experiment.

RPA: Retarding Potential Analyzer.

SPICAM: SPectroscopy for the Investigation of the Characteristics of the Atmosphere of Mars.

TES: Thermal Emission Spectra.

THEMIS: THermal EMission Imaging System.

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List of Publications/Proceedings

Refereed Journal Publications

1. Retrieval of Martian ozone and dust from SPICAM spectrometer for MY27-MY28 Ashimananda Modak, Varun Sheel and Franck Montmessin (2019), *Journal of Earth Science System* (Accepted on January 14, 2019).

Presentations at conferences

1. Title: Competitive Chemical Processes in Mars' Atmosphere. Brain Storming Session on Vision & Explorations for Planetary Sciences in Decades 2020-2060, Physical Research Laboratory, Ahmedabad, INDIA, 8^{th} -10^{th} November 2017.

2. Loss Mechanism of odd Oxygen in the Photochemistry of Martian Atmosphere. 20^{th} National Science Symposium, 29-31 Jan, 2019, Pune.

Publication attached with the thesis

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