LIDAR FOR MARS ATMOSPHERIC STUDIES ON 2007 SCOUT MISSION "PHOENIX"

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ABSTRACT

The Canadian Space Agency is providing MET, a group of meteorological instruments, for the NASA 2007 Scout Mission, Phoenix. MET will provide data for characterizing Mars' present climate and weather processes at the landing site. The lidar provides data on the location, structure, and optical properties of clouds, fogs, and dust plumes within the Martian Planetary Boundary Layer. The lidar is based on a Nd:YAG laser operating at 100 Hz with a pulse energy of 1 mJ. The system incorporates a pan-tilt steering capability and is able to probe the Martian atmosphere out to ranges of about 20 km.

1. INTRODUCTION

Phoenix is focussed on the Mars program's central theme to "follow the water" under the scientific direction of the Principal Investigator, Peter Smith, of the Lunar and Planetary Laboratory, University of Arizona, Tucson. The Phoenix lander targets the northern plains between 65 and 75N and is scheduled to reach the surface in June 2008 and to operate for up to 150 sols during the northern summer [1].

In recent measurements by the Mars orbiter, Odyssey, it has been observed that large amounts of water ice are inferred from the combined results of the Gamma Ray Spectrometer (GRS) and the High Energy Neutron Detector (HEND) in the circumpolar regions [2], [3]. Modeling the gamma ray and neutron fluxes has shown that high concentrations of ice are to be found within 50 cm of the surface. The key functional requirement of Phoenix is to deliver samples of surface and subsurface soil and of ice to the Thermal Evolved Gas Analyzer (TEGA) for differential scanning calorimetry and mass spectroscopic analysis; and to the Mars Environmental Compatibility Assessment (MECA) for microscopic and electrochemical analysis.

A robotic arm will excavate a trench to allow analysis of the geology and chemistry of samples retrieved from the regolith and the sub-surface icy layer. Samples will come from a trench up to one meter deep and a neutron spectrometer will link Phoenix and Odyssey results. Imaging systems will document the morphology of the trench walls.

Atmospheric measurements will provide information on the present-day environment, including horizontal and vertical transport of water vapor during the polar summer. Past climates will be studied from the records left in the soil layers. A mass spectrometer sensitive to minute quantities of organic molecules will enable an assessment of the habitability of the icy layer for past and present microbial life.

The mandate to "follow the water" necessarily includes better characterization of the Martian atmosphere as part of improved understanding of the Martian hydrologic cycle. To that end, the Canadian Space Agency is providing the meteorological (MET) atmospheric instrumentation. The MET instrumentation includes temperature and pressure sensors as well as a lidar. The lidar is mounted upon a pan-tilt unit, permitting measurement in both the vertical and horizontal directions. The lidar is expected to make the first lidar soundings ever of the Martian atmosphere from the planet's surface.

The instrument Co-Investigator and leader of the MET science team is Allan Carswell of Optech and York University. MDRobotics is the Prime Contractor for the MET instrumentation with lidar development being led by Optech personnel. The science team activities are centered at York University with members from several other academic institutions.

2. LIDAR CAPABILITIES ON MARS

The structure and evolution of the Martian planetary boundary layer (PBL) is key to obtaining an understanding of the surface-atmosphere interactions, particularly the exchange of volatiles. The lidar has the capability of probing the Martian atmosphere at ranges out to many kilometers from the lander site. The data obtained over this extended atmospheric region will significantly expand the atmospheric information obtained by the in-situ MET sensors and the other Phoenix instruments located on the lander near the surface. The lidar will provide quantitative information on the structure and depth of the Martian boundary layer, the location, structure and optical properties of clouds, fogs and dust within the boundary layer as well as some information on the spatial and temporal changes in the boundary layer.

Information on the formation and movement of clouds, fogs and dust plumes will enhance the ability to model and understand the key atmospheric processes. The MET lidar will provide additional information on the spatial and temporal optical properties of the atmosphere over an extended spatial region. This will include valuable new information on diurnal and seasonal changes, particularly with respect to location and opacity of cloud and fog layers that form and dissipate at various altitudes during the day.

The high spatial and temporal resolution of the lidar measurements will enable the detection and measurement of small variations in the structure of the Martian atmosphere. In particular, when viewing in a quasi-horizontal direction the lidar has the capability to measure the location and extent of dust devils, a ubiquitous and poorly understood component of the Martian atmosphere [4]. Pointing upward, the lidar will profile the vertical structure of the atmosphere. Although the Martian atmosphere is generally quite dusty there is the possibility that at higher altitudes there could be regions with little dust content. If this is the case, lidar measurements of the Rayleigh scattering from the molecular atmosphere would provide the ability to measure atmospheric temperatures in these regions [5].

3. THE LIDAR SYSTEM

Developing a lidar system for operation on Mars presents a number of very challenging design considerations. Foremost among these are the stringent limitations on size, mass and power consumption. To address these challenges the science team undertook an evaluation of the measurement capabilities that could realistically be incorporated in the Phoenix lidar. This involved examining the many well-demonstrated terrestrial capabilities of lidars and undertaking to balance the value of the science to be derived with the complexity and risk associated with operation on Mars.

As a result of these considerations a prioritized set of science goals and mission requirements was developed for the lidar measurements. These include:

1) 3D location and extent of clouds, fogs and dust devils.
2) 3D distribution of scatterers (dust, ice crystals)
3) Ice/Dust discrimination via polarization
4) wind velocity (tracking inhomogeneities)
5) surface topography
6) high altitude temperature (Rayleigh scattering)
7) particle size information (multi-wavelength lidar)

In this list the priorities were set first by the science value of the measurement and subsequently by the difficulty of implementation on Mars. DIAL measurements were not included in the considerations because of the inherent additional complexities of these systems.

Items 1) and 2) on the list can be accomplished with a relatively simple elastic backscatter lidar utilizing a single wavelength transmitter and receiver. Item 3) necessitates the incorporation of polarization optics and a second detector channel. The tracking of inhomogeneities (Item 4) places additional demands on the spatial and temporal resolution of the system and increases the needed capacity of the data handling system. To optimize the measurement of surface topography (Item 5), precise information on the lidar pointing resolution and stability is required. For high altitude Rayleigh temperature measurements (Item 6) visible wavelength emission and PMT detection is clearly indicated along with extended signal integration times. Finally for particle sizing measurements (Item 7) multi-wavelength lidar operation would be needed.

Based on these considerations the specifications for a baseline single wavelength lidar have been established as indicated in Table 1.

Table 1. Baseline lidar

Transmitter: Nd:YAG @ 1064 nm
Pulses: 10 nsec, 100Hz, 1 millijoule
Beam divergence: 1 milliradian
Receiver: 10 cm diameter
Receiver FOV: 4 milliradian
Detector: Si:APD
Wallplug efficiency; >4%
Pan-tilt capability: 360° horizontal, 105° vertical (zenith to -15°)

A Nd:YAG diode-pumped laser with passive Q-switching for the laser source and has already demonstrated successful performance in other space-borne lidar systems. A NIR enhanced Si:APD for the detector offers the advantages of being compact and with operation at relatively low voltage. A single aspheric lens receiver configuration is currently included in the baseline system.

The lidar will be positioned with the transmitted laser beam and the collinear viewing field-of-view directed upward from the deck of the lander. The lidar unit will incorporate a pan-tilt capability such that when in operation, the beam pointing direction can be varied over a wide angular range to enable the lidar beam to probe a large region of the atmosphere around the lander. The lidar pointing capability also allows for a downward pointing angle of –15 degrees to provide for full atmospheric coverage with lander surface tilts of up to 15 degrees and to enable surface reflection and topographic measurements. In addition the lidar will have a downward pointing parking mode so that the exit optics are protected from ambient atmospheric dust when not in operation.

4. MODELLED LIDAR PERFORMANCE

Extensive modeling of the lidar performance has been undertaken. Although there are some data on the Martian atmosphere, quantitative information on the optical characteristics needed for detailed lidar performance analysis is quite limited. This is particularly true for the clouds and dust conditions on Mars.

When the lidar operates in zenith-looking mode the vertical distribution of scatterers, characterizing the planetary boundary layer will be measured. Lidar retrieval of the terrestrial boundary layer height is based on detecting the negative gradient in the lidar backscatter signal associated with the decrease in aerosol backscatter, which is typically found in the transition zone from the mixed layer to the overlying free troposphere. The extent to which this boundary layer discontinuity will exist on Mars is still to be determined, in view of the predominant suspension of very fine dust particles throughout the Martian atmosphere.

Examples of the projected signal-to-noise performance of the baseline lidar are shown in Figures 1 to 4. These figures present the variation of the signal-to-noise ratio (SNR) versus range, while various parameters are changed. SNR = 5 is shown for a typical indication of the maximum detectable range with appropriate accuracy.

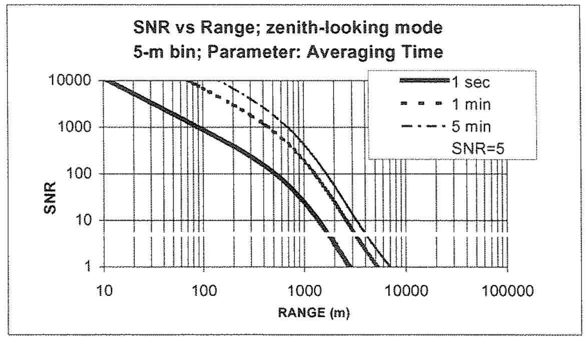

Fig. 1 SNR vs. Range, Zenith Looking Mode, Parameter: Averaging Time

Fig. 1 shows the expected lidar performance in zenith-looking mode for measuring the vertical distribution of scatterers, with the parameter averaging time (number of shots) for typical dust conditions with the total optical depth of 0.3. Figure 2 shows the expected lidar performance in the zenith-looking mode for the same dust conditions measuring the vertical distribution of scatterers, with the parameter bin size (range resolution). Fig. 3 shows the expected lidar performance in zenith-looking mode for the vertical distribution of scatterers, with the parameter dust optical depth.

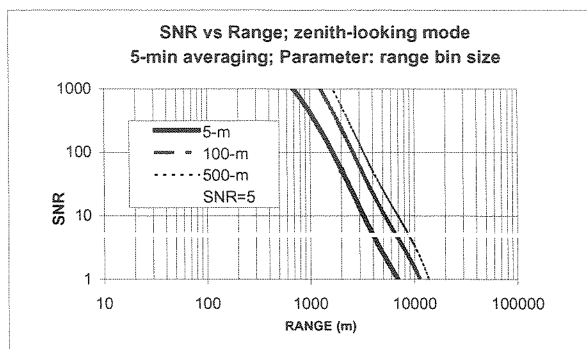

Figure 2: SNR vs. Range, Zenith Looking Mode, Parameter: Range Bin Size

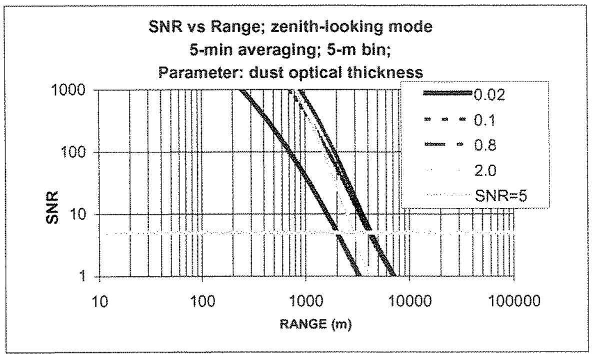

Fig. 3: SNR vs. Range, Zenith Looking Mode, Parameter: Dust Loading

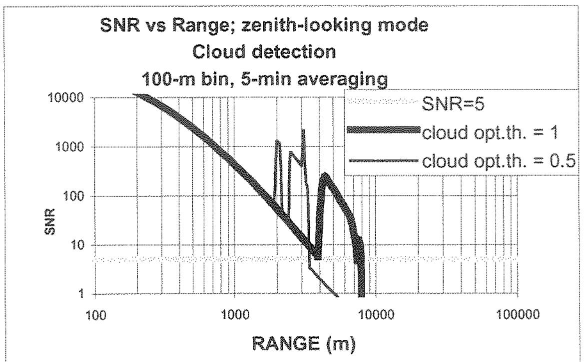

Fig. 4. SNR vs. Range, Zenith Looking Mode, Cloud Detection.

Fig. 4 shows the expected lidar performance in zenith-looking mode for cloud detection, with the background dust optical thickness of 0.1. The cloud optical thickness values are indicated in the figure legend.
The lidar retrieval of cloud location is based on backscatter signal associated with the sharp increase in aerosol backscatter, which is typical for most types of clouds [6]. To date, there is no published data on the backscatter and extinction coefficients of Martian clouds of any type. However the recent report of the MOLA cloud measurement analysis [7] suggests that backscatter and extinction coefficients might be quantified for 1064 nm in the near future for the clouds detected by MOLA.

Utilizing the pan-tilt capability the lidar will also be used to undertake some quasi-horizontal measurements to study dust devils and thermal plumes in the atmosphere. In this horizontal mode sequential stepped scans will be made about selected viewing directions that will be specified to provide clear fields of view between the other structures on the lander deck surface. These horizontal lidar measurements, using dust as the tracer, will provide some information on the structure of the surface wind field and the behavior of turbulent eddies and convective dust plumes near the Martian surface.

5. SUMMARY

The MET lidar will add significant new information on the atmosphere of Mars. Measurement modes and schedule can be changed as desired during the mission to optimize the value of the measurements and to address atmospheric properties of particular interest. Joint measurements of the Phoenix lidar and the Phoenix Surface Stereo Imager (SSI) camera will provide enhanced 3-D imagery of atmospheric conditions. Specifically, the lidar measurements will target:

- Martian planetary boundary layer vertical profile, structure and evolution and the boundary layer height.
- 3D cloud, dust and dust devil distribution and variation.
- Limited information on the atmospheric winds and turbulence structure.
- Temperature profile (in dust-free regions).
- Potential gravity wave information (from vertical temperature and dust profiles).

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