OBSERVATIONS OF MARS ATMOSPHERIC DUST AND CLOUDS WITH THE LIDAR INSTRUMENT ON THE PHOENIX MISSION

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Introduction:

The Phoenix spacecraft [1] landed on the Artic region of Mars on 25 May 2008 and operated through the summer for five months [2]. Throughout this period the LIDAR instrument [3] observed atmospheric dust and water ice clouds up to a height of 20 km by measuring the backscatter of laser radiation that was transmitted upward from the lander [4]. A summary of the findings from this experiment will be presented.

Measurements:

Figure 1 shows the basic LIDAR measurement and analysis product for the study of dust in the atmosphere of Mars. The backscatter of pulsed laser light is detected to a height of about 20 km. Analog detection is used for heights below 10 km and photon counting is used up to 20 km. The height distribution of detected backscatter signal on mission sol 48 ($L_s = 98.57^o$) is shown in Fig 1a. The amount of scattering material in the atmosphere is proportional to the extinction coefficient. This is the fractional decrease in laser pulse energy per unit length as it propagates through the atmosphere. The extinction coefficient can also be considered as the effective cross sectional area of particulates per unit volume. This was derived from the LIDAR signal using the method of Fernald [5] with a constraint applied such that the extinction integrated in the vertical matches the total optical depth as measured by the Phoenix Surface Stereo Imager (SSI). Figure 1b shows the profile of extinction coefficient derived from the measurements in Fig 1a.

The profile measured on sol 48 (Fig. 1) is typical for moderate dust loading with no clouds. There is a layer of enhanced dust loading that is distributed approximately evenly to a height of 4 km above the ground. This is due to the lifting of dust from the surface and the vertical mixing by convection and turbulence during daytime within the Planetary Boundary Layer (PBL). The vertical distribution of dust provides an indication of the depth of the PBL, which was variable between 4 km and 6km.

Figure 2 shows a comparison of LIDAR measurements on Mars and the Australian Desert. Each of these measurements corresponded to the maximum observed dust loading during campaign period. During the Pheonix mission the atmospheric dust loading reached a peak around summer solstice (sol 30) and then generally decreased. The Australian profile was obtained during wind storm conditions with a LIDAR system that was equivalent to the instrument on Phoenix [6]. There is notable similarity within the boundary layers on Mars and Earth, but there is much less dust loading above the boundary layer on Earth.

Figure 3 shows a contour of the extinction coefficient profile derived from the LIDAR measurements over the entire mission. The atmospheric dust loading was greatest around summer solstice at the start of the mission and then declined through the summer. During the second half of the mission, starting 50 sols after summer solstice ($L_s = 117^o$), the LIDAR detected a regular pattern of cloud formation each night within the planetary boundary layer.

Figure 4 shows the LIDAR cloud measurements plotted with respect to the time of sol. A shallow surface based cloud formed at around midnight (Mars local solar time) and a second cloud layer formed after 1 am at heights between 3 and 6 km. For each sol in late summer the water ice clouds remained throughout the night and then dissipated when the atmosphere warmed sufficiently during daytime [7]. As the summer progressed toward autumn, the clouds persisted longer into the morning hours and extended further toward the ground. Clouds were not detected in the afternoon or evening.

A contour plot of LIDAR backscatter coefficient from sol 99 is shown in Fig. 5. The enhanced backscatter at 3 – 4 km and below 1 km indicates the outline and internal structure of the clouds that drifted above the Phoenix landing site. These clouds formed at an estimated temperature of -65^o C, consistent with water ice crystals [4]. The pattern of vertical streaks at the base of the 3 – 4 km cloud after 05:00 is consistent with ice crystals precipitating from the cloud, and eventually sublimating in the dry air below the cloud. Later in the mission the precipitation streaks were observed to reach the ground.

Discussion:

The Phoenix LIDAR measurements of atmospheric dust indicate that the planetary boundary layer (PBL) on Mars is well mixed up to a height of 4 km by the daytime turbulence and convection during summer above the northern polar region. The Phoenix LIDAR also observed that water ice clouds form within the PBL each night in late summer and that ice crystals precipitate toward the surface. The Phoenix LIDAR observations have demonstrated that water ice crystals grow large enough to precipitate significant distances through the atmosphere of Mars. In the early morning hours the clouds formed at ground level and at heights around 4 km since these were the coldest parts of the PBL. The cloud was capped at the top of the PBL because daytime turbulent mixing does not transport moisture above that height. The overall process was that water ice was transported downward by precipitation at night, it sublimated as the atmosphere warmed in the morning, and then the vapor was mixed back up through the PBL by turbulence and convection during the daytime. The clouds and precipitation act to confine water within the PBL.

References:

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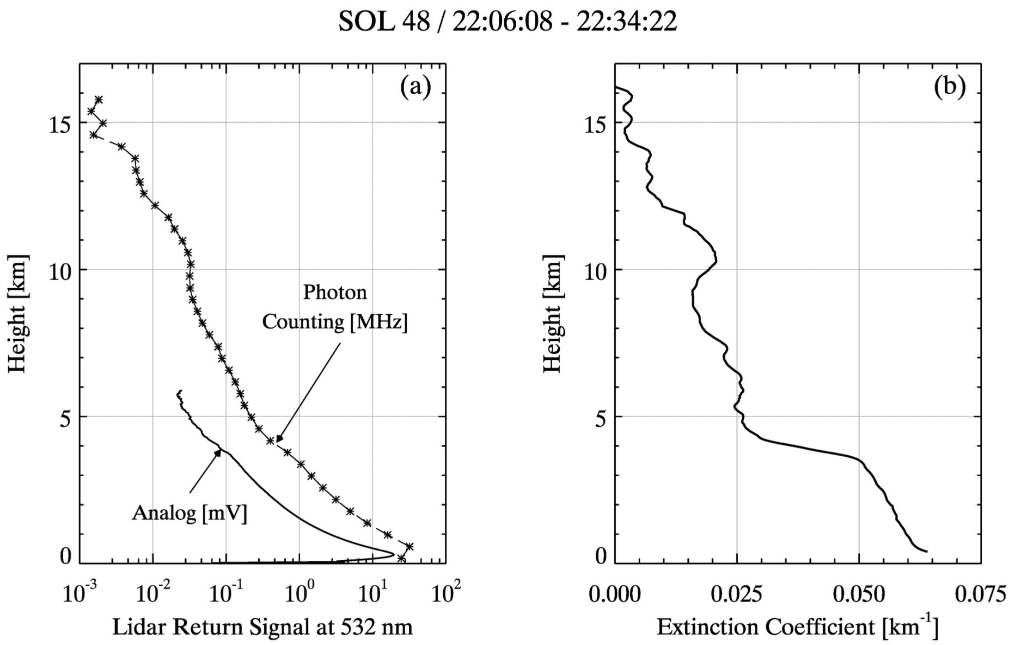

Figure 1. Phoenix LIDAR backscatter signal on mission sol 48 (a) and the derived extinction coefficient (b). There is greater atmospheric dust loading at heights below 4 km due to lifting from the surface and mixing within the Planetary Boundary Layer.

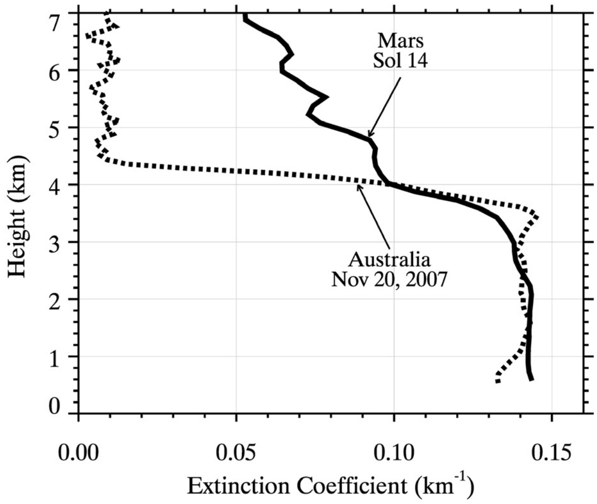

Figure 2. Profiles of extinction coefficient derived from the Phoenix Mars LIDAR measurements on mission sol 14. A profile measured above the Australian desert in windstorm conditions with an equivalent lidar system on 20 November 2007 (dashed) is shown for comparison.

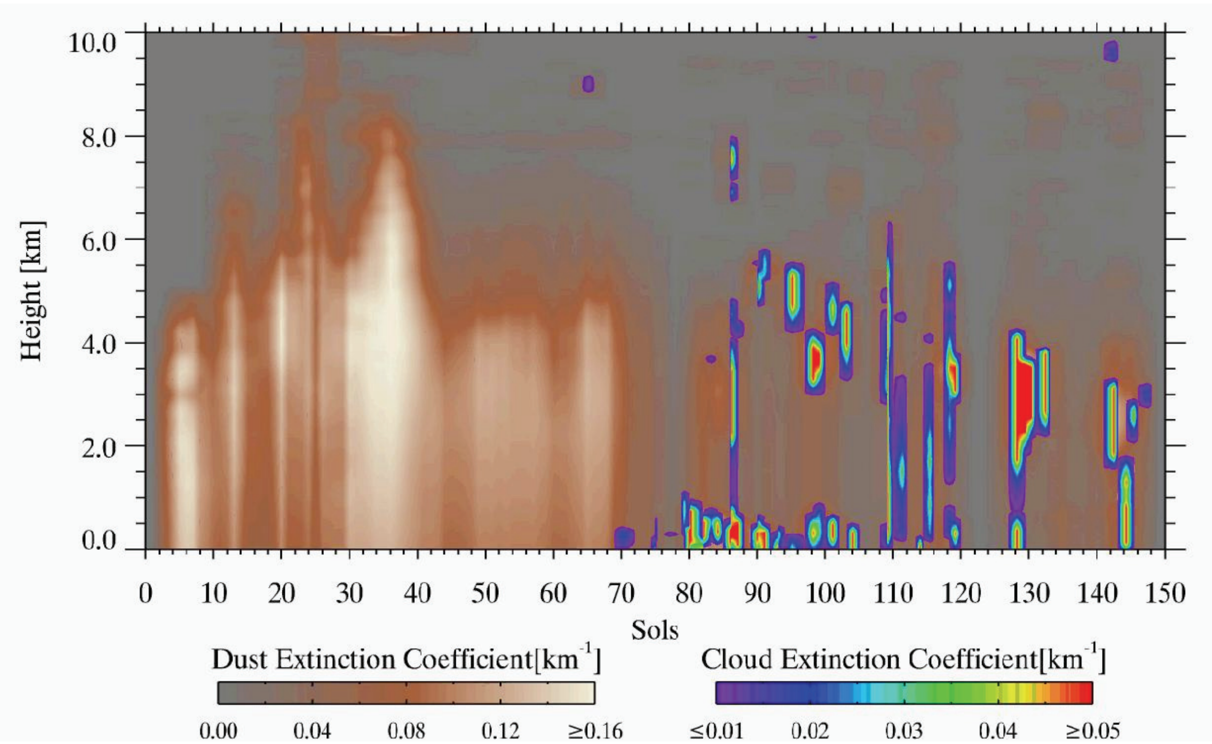

Figure 3. Contour plot of extinction coefficient derived from the Phoenix LIDAR measurements over the entire mission. The grey-brown-white colour scale is used for dust and the blue-green-red scale is used where clouds were detected. Gaps in the cloud contours over more than one day were due to a lack of nighttime measurements (e.g. sols 135-140).

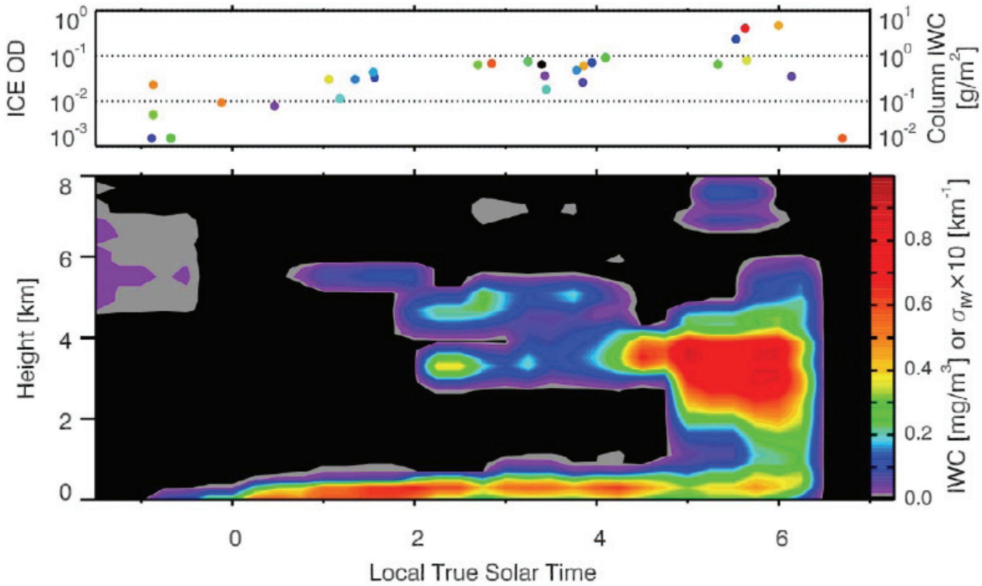

Figure 4. Bottom: Contour of the profiles of extinction coefficient and ice water content (IWC) derived from the Phoenix LIDAR measurements. This includes all the measurements during the mission plotted as a function of time of day. Top: The ice cloud optical depth and column IWC obtained by integrating the shown in the bottom panel.

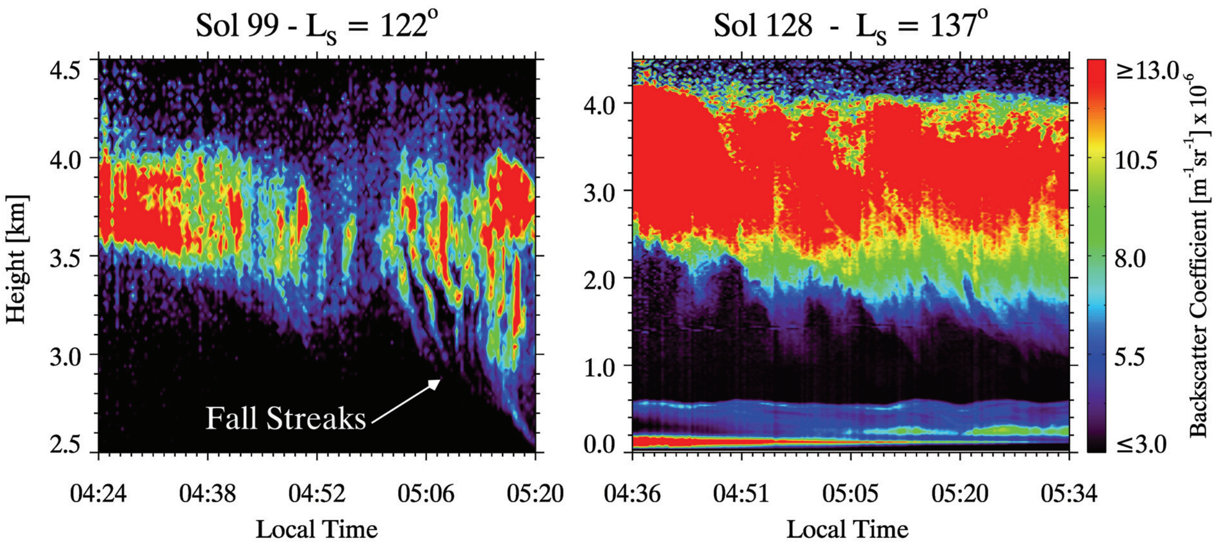

Figure 5. Contour of lidar backscatter coefficient for two case studies with clouds in the planetary boundary layer of Mars