P43K-3891 Nocturnal Mixed Layers and Water Ice Clouds on Mars

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Abstract

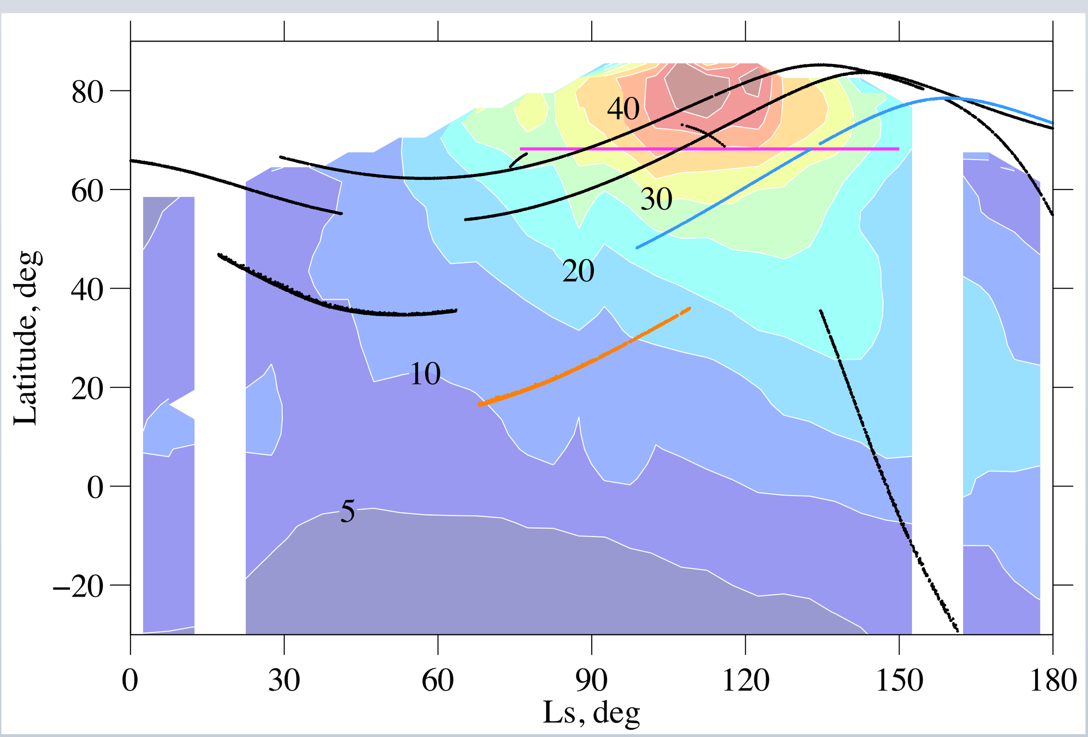
We are using Mars Global Surveyor (MGS) radio occultation (RO) data (Hinson et al., 1999) to investigate the nighttime structure and dynamics in the lower atmosphere of Mars. High-resolution temperature profiles retrieved from the RO data contain unique information about nocturnal mixed layers (NMLs) – detached layers of neutral stability that form at night in response to radiative cooling by a water-ice cloud layer (Hinson et al., 2014; Spiga et al., 2017). Basic properties of the NMLs and constraints on their seasonal evolution can be obtained through analysis the RO profiles.

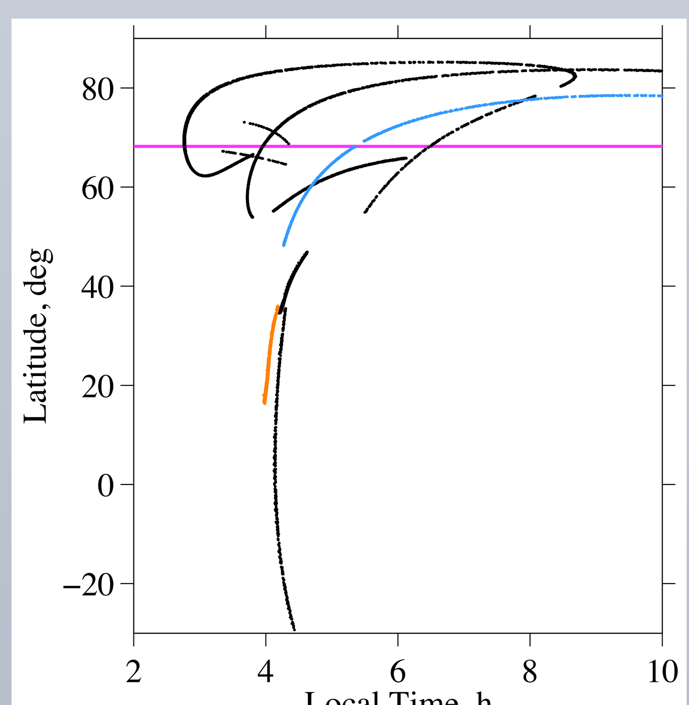
We have examined ~2500 RO profiles in a latitude band centered on the Phoenix landing site (234°E, 68°N), where nighttime water-ice clouds were observed by the LIDAR instrument (Whiteway et al., 2009). Many NMLs were present in early summer of MY27 at ~5 h local time, primarily at 220-320°E, 60-70°N. Their altitude is consistent with the detached cloud layer observed by the Phoenix LIDAR at the same season and local time in MY29. The NMLs confirm that radiative cooling by the Phoenix cloud is sufficient to trigger convective instability, as predicted by a Large-Eddy Simulation (Spiga et al., 2017).

We have also analyzed ~1200 low-latitude RO profiles from Ls = 70-100° of MY28 and Ls = 135-160° of MY24. Tropical NMLs are largely confined to regions of elevated terrain. At 4 h local time, the top of the NMLs is below the peaks of both Olympus Mons and Arsia Mons. The NMLs appear in the same regions where nighttime clouds were observed by the MGS Mars Orbiter Laser Altimeter (MOLA) (Wilson et al., 2007; Neumann et al., 2014).

Two numerical models will be used to interpret the RO results: the FV3 Mars Global Circulation Model at NASA/Ames (Wilson et al., 2017) and Large-Eddy Simulations at the Laboratoire de Météorologie Dynamique (LMD). Goals of the modeling effort include: to identify the processes that control the formation of nocturnal water ice clouds; to understand the spatial distribution of the clouds and their evolution with time of day and season; and to assess the impact of NMLs on the nighttime weather and water transport in the lowest scale height above the surface.

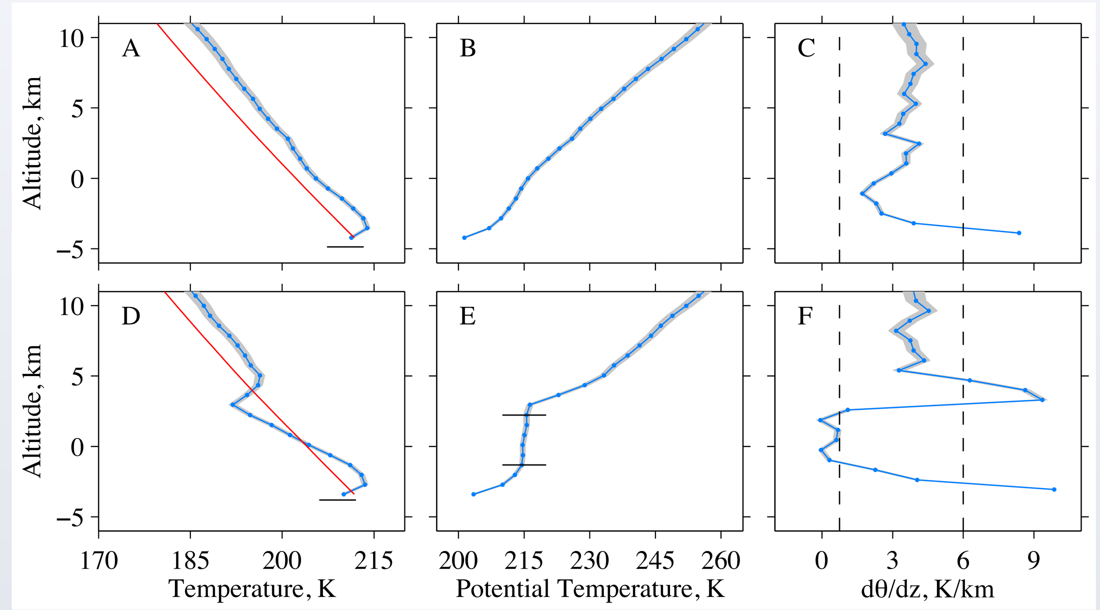
This work is made possible by support from the NASA Mars Data Analysis Program and LMD.



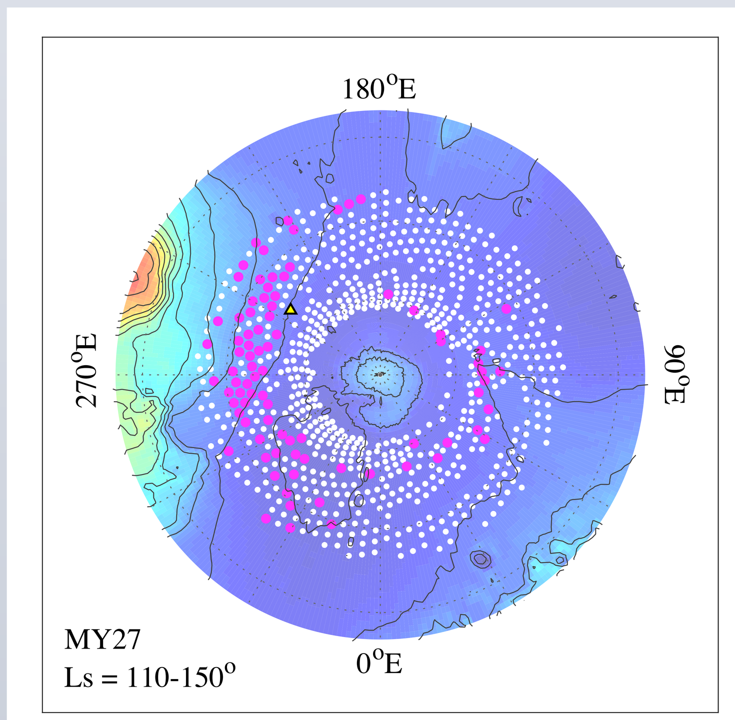


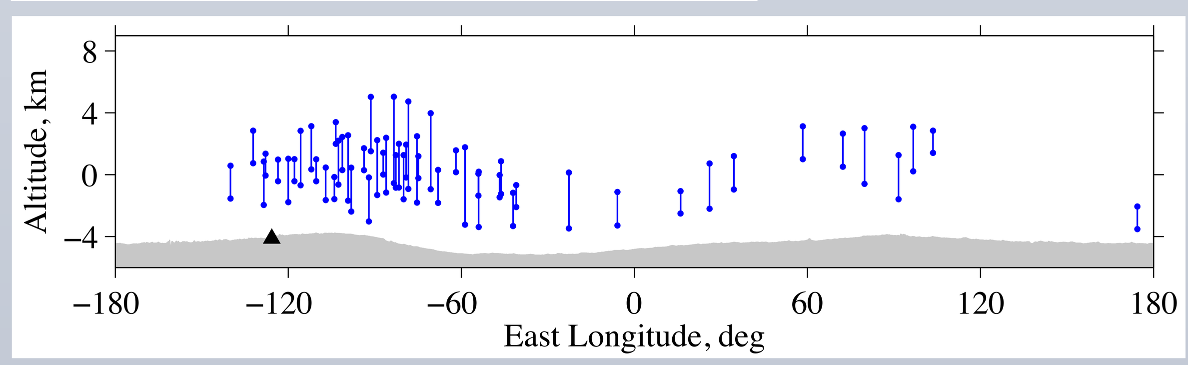
(Above) RO coverage in latitude and season (MY24-28) superimposed on a map of the zonally averaged water vapor column abundance (pr-microns) from the MGS Thermal Emission Spectrometer (Smith, 2004). Colors denote RO measurements from (blue) MY27 and (orange) MY28. The Phoenix LIDAR observed the atmosphere at Ls = 76-151° of MY29 (Whiteway et al., 2009) as shown by the pink line. **(Left)** Coverage in local time.

Measurements at High Latitudes

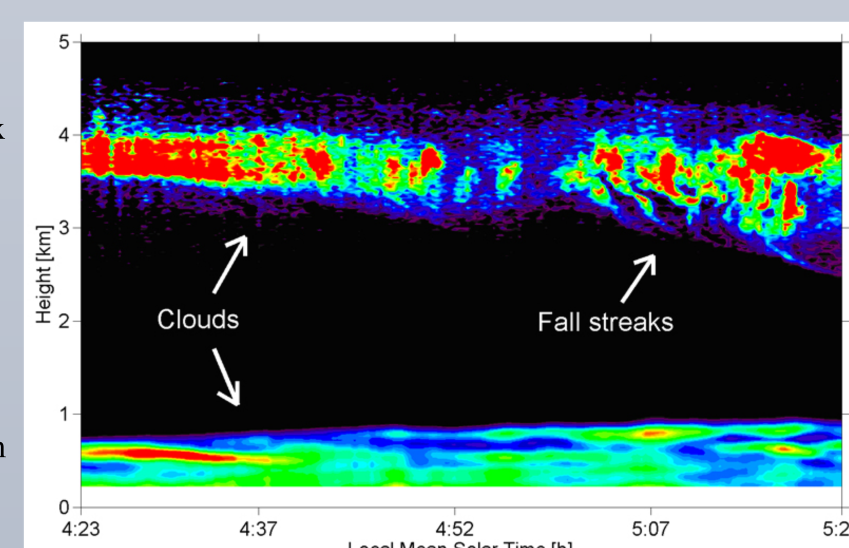


(A) Temperature T, **(B)** potential temperature θ, and **(C)** dθ/dz for an ordinary RO profile. Gray shading shows the 1-sigma uncertainties. **(D, E, F)** RO profile that contains a NML; its upper and lower boundaries are marked by horizontal lines in (E). Both observations are at the same latitude (65°N), local time (5.1 h), and season (Ls = 128°, MY27). The longitudes are (A-C) 357°E and (D-F) 271°E. The red line is a model for the saturation temperature of water vapor (35 pr-microns with a scale height of 3 km). Our working definition of a NML is a layer where dθ/dz < 0.75 K/km with an overlying inversion where dθ/dz > 6 K/km, as indicated by dashed lines in (C) and (F).



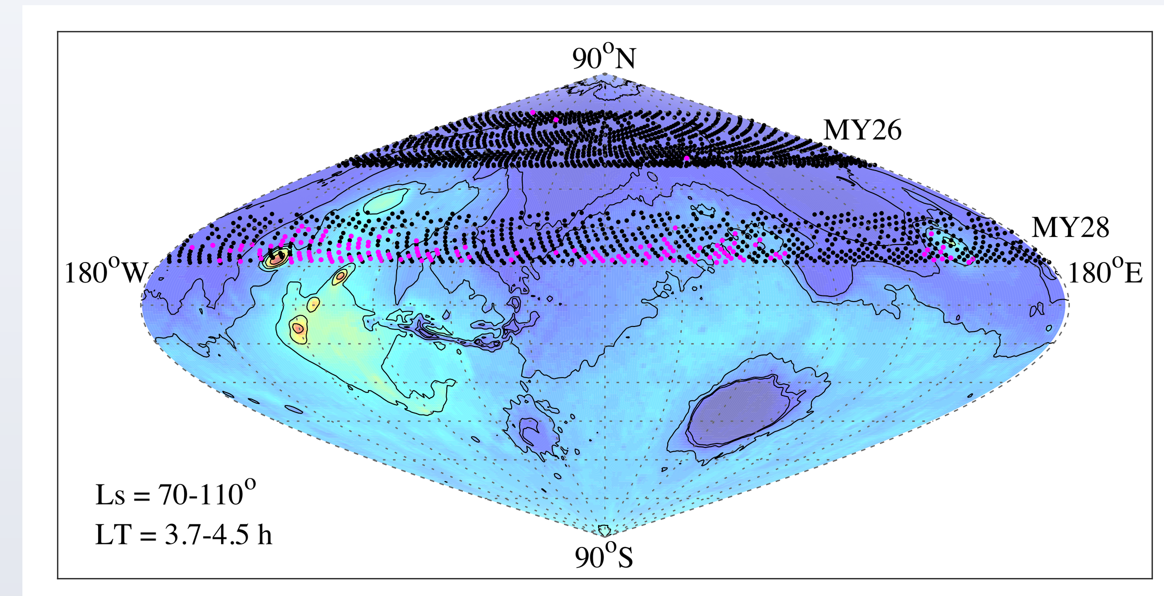


(Left) Map of NMLs at high northern latitudes in summer. Among this set of profiles, 86 contain a NML (pink dots) and 647 do not (white dots). The local time drifted from 4.4 h at 54°N to 7.4 h at 77°N. NMLs are common near the Phoenix landing site (triangle) and sporadic elsewhere. **(Below)** Longitude-height distribution of NMLs at 60-75°N. The local time is ~5 h. The average depth of the mixed layer is 2.6 km. Gray shading shows the surface at 68°N; the Phoenix landing site is marked by a triangle.

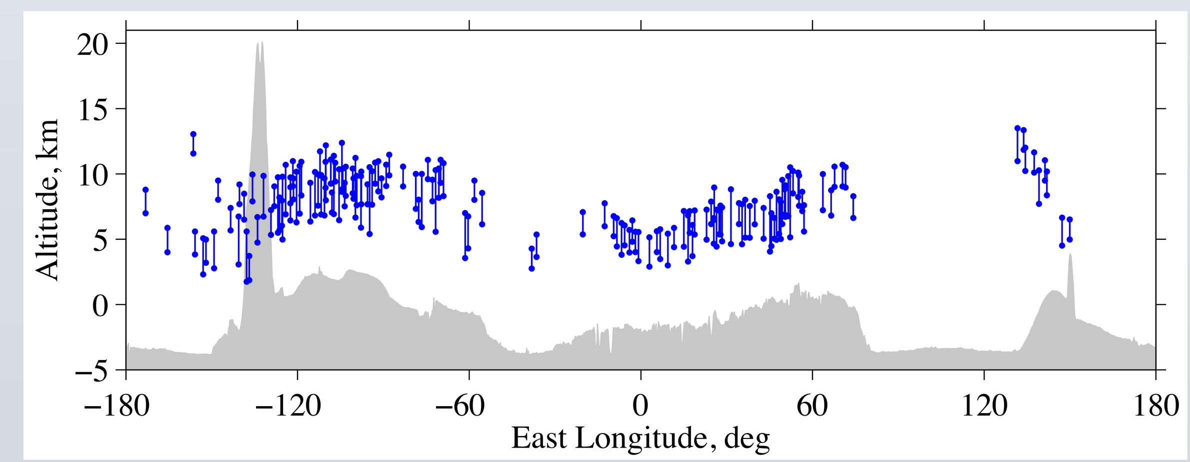


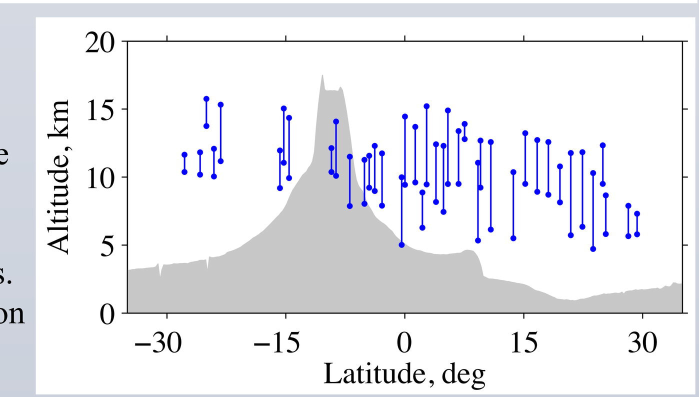
(Right) Ground fog and a detached cloud layer observed by the Phoenix LIDAR at Ls = 122° of MY29 (Daerden et al., 2010). The RO profiles confirm that radiative cooling by the detached cloud layer is sufficient to trigger convective instability and formation of a NML, as predicted by Spiga et al. (2017).

Measurements at Low Latitudes

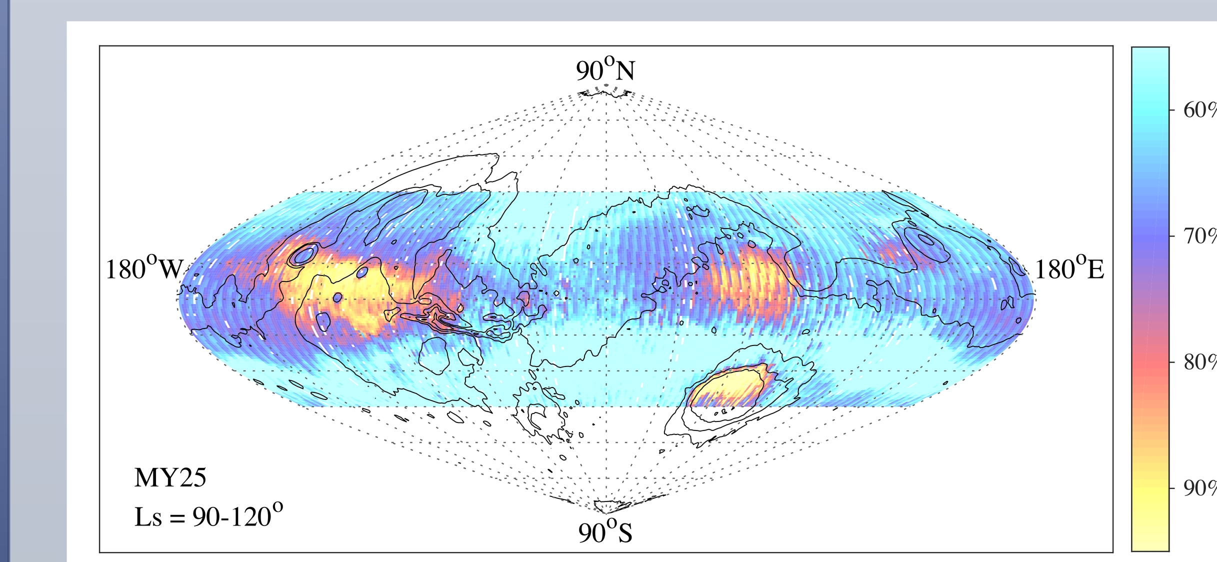


(Above) RO results from MY26 & 28 at a local time of ~4 h. Dots mark the locations of measurements and colors indicate the presence (pink) or absence (black) of a NML. At this season (Ls = 70-100°), NMLs are common at low latitudes (18%) and rare at high latitudes (0.3%). Tropical NMLs appear in three regions: (1) the Tharsis plateau, (2) Arabia Terra & Syrtis Major, and (3) southwest of Elysium Mons.



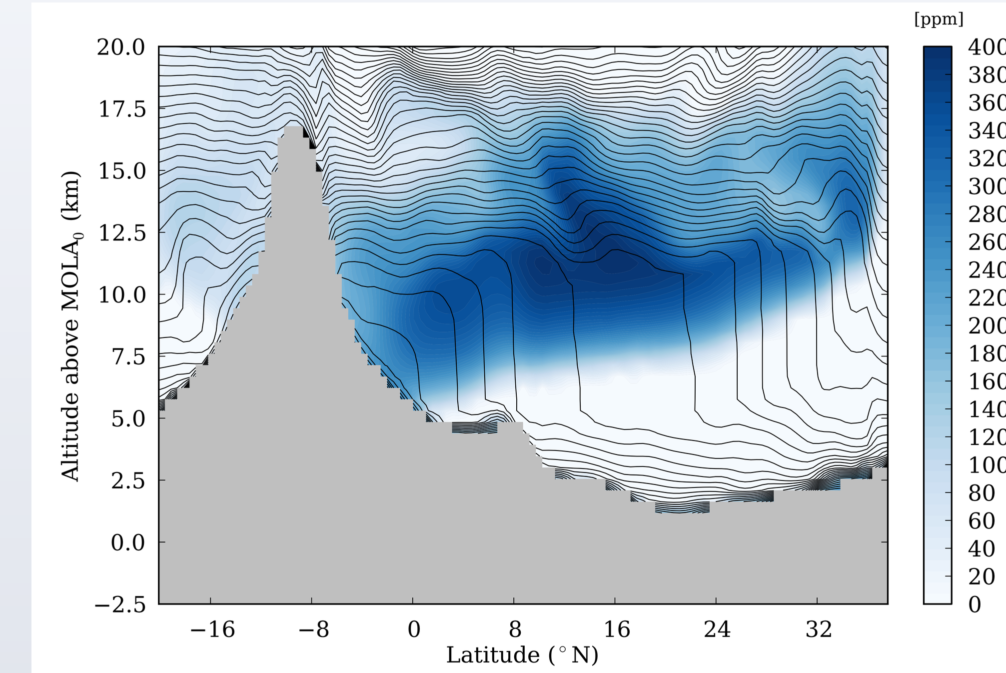


(Above) Longitude-height cross section of NMLs at 15-30°N near summer solstice (Ls = 70-100° of MY28). The average pressure at the top of the NML is 250 Pa. Gray shading shows the surface at 19°N, through the peak of Olympus Mons. **(Right)** Latitude-height cross section of NMLs at 215-265°E in summer (Ls = 135-160° of MY24). Gray shading shows the surface at 240°E, through the peak of Arsia Mons. The NMLs are below the peaks of the volcanoes at the local time of these observations (~4 h).

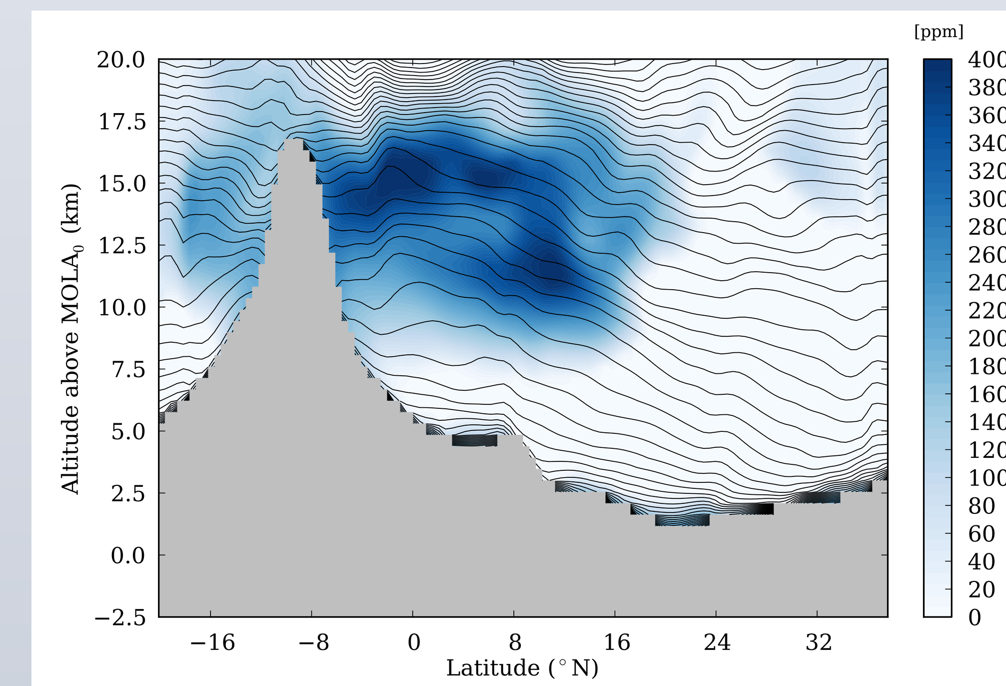


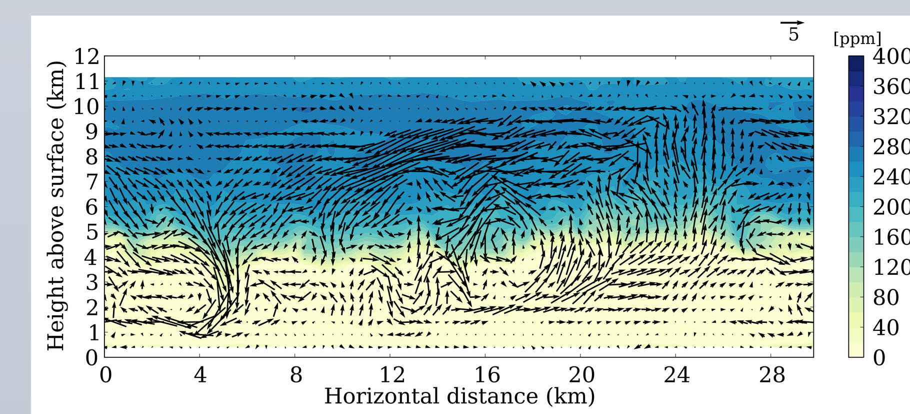
(Above) Measurements by the Mars Orbiter Laser Altimeter (MOLA) of the round-trip reduction in signal intensity caused by nighttime water-ice clouds (Wilson et al., 2007; Neumann et al., 2014). These observations are from early summer of MY25 (Ls = 90-120°) at a local time of 2 h. The clouds are most opaque (yellow) in the same regions where NMLs appear in RO profiles. The peaks of the Tharsis volcanoes and Olympus Mons are visible above the cloud layer.

Numerical Models



Results from a pair of simulations in the Tharsis region at Ls = 120° by the LMD mesoscale model (Spiga et al., 2017). **(Above)** Latitude-height cross sections at 240°E of the water-ice volume mixing ratio (blue shading) and the potential temperature (contours) from a simulation with radiatively active clouds. The local time is 3 h. Cloud radiation generates a deep NML, in good agreement with the RO observations. **(Below)** In a second simulation with passive clouds, the NML is absent.





Water-ice volume mixing ratio (color shading) and convective winds (arrows) from a Large-Eddy Simulation at 240°E, 8°N with radiatively active clouds (Spiga et al., 2017). The local time is 3 h. The LES resolves the convective motion associated with the NML near Arsia Mons. Intense downdrafts (> 5 m/s) produce localized precipitation that resembles the fall streaks, or virga, observed below nighttime cloud layers by the Phoenix LIDAR (Whiteway et al., 2009).

References

Daerden et al., GRL 37, L04203, 2010. **Hinson et al.**, JGR 104, 26,997-27,012, 1999. **Hinson et al.**, Icarus 243, 91-103, 2014. **Smith**, Icarus 167, 148-165, 2004. **Spiga et al.**, Nat. Geosci. 10, 652-657, 2017. **Neumann et al.**, Abstract P51B-3911, AGU Fall Meeting, 2014. **Whiteway et al.**, Science 325, 68-70, 2009. **Wilson et al.**, GRL 34, L02710, 2007. **Wilson et al.**, www-mars.lmd.jussieu.fr/granada2017/abstracts/-wilson_granada2017.pdf, 2017.