A COMPREHENSIVE STUDY OF CLOUD COVERAGE AND SPIRAL TROUGH MORPHOLOGY ACROSS THE MARTIAN NORTH POLAR LAYERED DEPOSITS. K. A. Lutz\(^1\), R. L. Hawley\(^1\), and M. C. Palucis\(^1\), \(^1\)Department of Earth Sciences, Dartmouth College, Hanover, NH, United States (katherine.a.lutz.gr@dartmouth.edu)

Introduction: The north polar layered deposits (NPLD) of Mars consist of atmospherically deposited layers of dust and water ice [1] preserving Mars’ climate history over the lifetime of the deposits. The thickness and composition of these layers could offer insight into climatic variations in the deposition of ice and dust on Mars [2]. Within the NPLD are large troughs that have been shown to migrate poleward through a combination of lateral ice transport by wind and insolation-driven sublimation (i.e., [3], [4]). This large-scale lateral ice transport on the NPLD will affect apparent deposition rates and layer thicknesses, so understanding trough migration is key to understanding the climate history recorded in the deposits.

The leading model for trough migration is that ice is laterally transported through cyclic step migration driven by katabatic winds, which cause katabatic (or hydraulic) jumps in regions where wind rapidly decelerates [5], combined with ice loss from sublimation (predominantly on the equator-facing trough slopes) [3]. Prior work suggests that trough-parallel clouds serve as a proxy for katabatic jumps and their associated ice transport and spiral trough migration due to katabatic winds [5]. However, the conclusions made by Smith et al. [5] were based on data taken over ~10 years of the Martian cloud record, whereas there are now ~18 years of data. Also, the katabatic wind-driven sublimation and deposition model assumes troughs have asymmetric wall reliefs, with a high-side (sublimation) and a low-side (deposition), but the variability in trough morphology across the entire NPLD is unknown.

Our work expands on the work of Smith et al. [5] by building an updated cloud atlas to understand the location and frequency of cloud coverage on the NPLD. We then test whether there are regional patterns in surface trough morphology, as regions have previously been distinguished across the NPLD based on their surface characteristics and subsurface layering [6]. Lastly, we investigate if troughs with persistent trough-parallel cloud coverage over the last ~20 years are morphologically different (i.e., comparing cross-section shape, wall slopes, relief) than troughs in regions of inactive or no clouds.

Methodology:

NPLD Cloud Analysis. We analyzed 13,857 Thermal Emission Imaging System (THEMIS) visible light spectrometer (VIS) images of the Martian north polar region (northward of 82°) available on Arizona State University’s Mars Image Explorer for Mars years 26–35 [7]. We examined each of these THEMIS VIS images for quality, the presence or absence of clouds, and cloud type (when present).

If clouds were identified they were classified into three broad categories: trough-parallel clouds (similar to the low-altitude clouds with an elongated structure located parallel to the NPLD troughs identified in Smith et al. [5]), wispy clouds, and general cloudiness. When visible, other related cloud features were noted, such as the presence of undulations, or linear cloud structures.

NPLD Trough Geometry. We identified differences between trough morphology across the NPLD using cross-sectional analysis. We extracted 3,192, 35 km long cross-sectional trough profiles, with profiles taken every 5 km down-trough perpendicular to the trough thalweg. We used a HRSC and MOLA Blended 200m DEM (v2) [8] resampled to 1000m/pixel, to reduce noise but retain trough shape information. We calculated various trough metrics for every trough profile. Our trough metrics (Fig. 1) were pole-facing relief (A minus A’), equator-facing relief (B minus B’), relief difference (the difference between A minus A’ and B minus B’), pole-facing slope (average slope between A and C), equator-facing slope (average slope between B and C), width (B’ minus A’), and depth (the average of A minus A’ and B minus B’).

![Figure 1. Examples of trough profiles (location of profiles shown in Fig. 2) with key trough locations marked (blue circles) that were used to calculate our trough geometry metrics. The R1 trough also has a central peak (often referred to as a central promontory [6]) between points A and C. Vertical exaggeration 1/20 for the R1 trough profile and 1/30 for the R7a profile.](image)
Results:

Updated NPLD Cloud Atlas. Our study identified ~800 THEMIS images out of the total ~13,800 that had clouds (Fig. 2, inset). Of those, ~400 were identified as near-surface trough-parallel clouds (black circles, Fig. 2), with ~33% of those being undular trough-parallel clouds. Of the remaining images, ~5% contained linear cloud features, ~16% contained wispy cloud features, and the remainder showed general cloudiness. Cloud coverage across the NPLD is not uniform, both for clouds in general and for trough-parallel clouds. Most clouds were observed to be associated with troughs and either centered around the pole or seen on the outer margins of the deposit. Regions 1 and 3 tend to have the highest number of clouds, including trough-parallel clouds, followed by regions 2, 4 and 5. Regions 6 and 7 (a and b) have few to no clouds. This low frequency of clouds is important to note as region 7a does have a notable number of troughs per area.

Trough Profile Morphology. Our quantification of the shape of NPLD troughs, using trough width, depth, wall slope and relief, from ~3000 profiles, finds that trough shape is variable within a single trough, between neighboring troughs, and between regions, and that trough morphology is overall not statistically different between the regions identified by Smith and Holt [6]. Roughly 88% of the trough cross-sections we investigated showed trough relief asymmetry and trough-parallel clouds were often observed near these asymmetrical troughs (per [5]), but the remaining troughs were symmetric and “v-shaped”.

Linking Cloud Presence with Trough Morphology. To understand how trough-parallel cloud presence or absence linked to our trough morphology metrics, sections of the NPLD were visually identified that had high trough-parallel cloud presence (blue boxes, Fig. 2), low trough-parallel cloud presence but high presence of other cloud types (yellow boxes, Fig. 2), and both low trough-parallel cloud and other cloud type presence (red boxes, Fig. 2). Three 25 km long sections of these three subtypes, consisting of 5 trough profiles each, were selected to compare metrics in these regions and note if they were statistically significantly different from one another, using a Kruskal-Wallis Test followed by a post-hoc Dunn’s Test if the null hypothesis could be rejected. We found statistically significant links (i.e., p-values < 0.05 with 95% confidence) between cloud presence and trough wall relief difference, as there was a significant difference between all three subtypes, but in general, cloud subtype did not have statistically significant trends with trough profile morphology.

Figure 2. A map of the NPLD where THEMIS images with trough-parallel clouds (black circles) and general cloudiness (white circles) were identified in this study. The green lines indicate the location of the R1 and R7a trough profiles displayed in Figure 1.

Conclusions: Our extended cloud atlas, covering ~18 Earth years of THEMIS VIS imagery, finds that trough-parallel cloud timing and location has been consistent for ~2 decades, suggesting regions with clouds are continuously active in terms of modern-day change. This suggests that regions with clouds would have evidence of modern-day change that could potentially be observed with high-resolution orbital data. Our quantification of the shape of NPLD troughs combined with cloud presence suggests that while a net constructional cyclic step model can explain the overall evolution and migration of the NPLD troughs, other processes are also likely at play.

Acknowledgments: This research was conducted at Dartmouth College and supported by a NASA Mars Data Analysis Grant (#80NSSC21K1097), a Dartmouth Scholarly Innovation and Advancement Award, and a National Science Foundation GRFP to K. Lutz (#2236868).