GLOBAL MAP OF SURFACE WINDS ON MARS FROM BARCHAN DUNE MIGRATION DIRECTIONS AND HORN ASYMMETRY USING A CONVOLUTIONAL NEURAL NETWORK. L. Rubanenko¹, S Pérez-López¹, L.K. Fenton³, R.C. Ewing¹ and M.G.A Lapôtre¹, ¹Stanford University, Stanford, CA, USA (liorr@stanford.edu). ²Carl Sagan Center, SETI, Mountain View, CA, USA. ³Texas A&M, College Station, TX, USA.

Introduction: Barchan dunes are widespread across the arid surface of Mars. The distinct crescentic morphology of barchans can be characterized by a wide set of parameters, which in turn constitute proxies for the environmental conditions in which the dunes form and evolve. For this reason, barchan morphology is often used to infer the surface conditions on Mars, where meteorological data is scarce [e.g., 1,2,3]. For example, since barchan dunes form and migrate under mostly unimodal winds, their migration direction – inferred from the orientation of their slipface – coincides in many cases with the prevailing wind direction. When a secondary wind component is present, barchans may become asymmetric and their horns may elongate [2]. Consequently, combining observations of slipface orientation and horn asymmetry can provide insight into the time-integrated evolution of dunes and shed light onto wind regimes, seasonality, and possibly, climate change.

Here, we analyze the morphologies of over a million barchan dunes on Mars previously outlined by a convolutional neural network run on images obtained by the Mars Reconnaissance Orbiter Context Camera (MRO CTX). We compile a map of global migration directions of barchan dunes on Mars derived from the orientations of the slipfaces. By spatially correlating horn asymmetry with topography and dune wavelength and sand-flux predictions from a global climate model, we investigate causes for dune asymmetry to isolate regions suspected to be influenced by wind seasonality or a different past climate.

Methods: To map barchan dunes globally on Mars, we employ Mask R-CNN, a state-of-the-art convolutional neural network (CNN) that excels at outlining objects in images [5,6]. The CNN was trained on 1,008 images obtained from the Mars Reconnaissance Orbiter Context Camera (MRO CTX) global mosaic [7], located using the global dune field catalog [8,9]. When used to detect dunes, the CNN reviewed 137,111 images – 55,674 of which were found to contain at least one instance of a barchan dune. To increase the robustness of our results, we filtered the dataset by only selecting objects whose outlines are characteristic of barchan dunes (for more information, see [1]). Additionally, since our model erroneously identified many sublimation-related features as barchan dunes near the south pole, we elected to focus on latitudes -70°N to 90°N in this work. Next, we measure the morphometrics of each dune detected by the CNN by identifying six reference points along its outline: the slipface center, the horns’ apexes, the tail, and the dune sides (Figure 1). The slipface center was identified as the deepest convexity defect along the dune contour. Horn apexes were mapped as the two intersection points between the dune contour and its convex hull closest to the slipface center. The tail of the dune was set as the point furthest away from the slipface along the dunes stoss. Finally, the sides of the dunes were detected as the two extreme points along the dune contour in the direction perpendicular to a vector drawn between the tail and the slipface center. The migration direction of symmetric dunes (horns ratio < 2) is set as the bisector vector of the horns, and the migration direction of asymmetric dunes (horns ratio > 2) is set as the vector emerging from the dune tail to the dune slipface (Figure 1). For each CTX image, we assign a migration direction by averaging the migration directions of all dunes in the image, weighted by the outline detection confidence (output of the neural network) and the slipface detection confidence (estimated from the convexity defect depth of the dune).
Results: We map the global migration directions of barchan dunes on Mars—a proxy for present-day and recent prevailing surface wind directions—by binning the migration directions within each CTX image in bins of 10° between -70°N and 70°N and 2° poleward of 70°N, to emphasize details in the densely populated northern polar erg (Figure 2). We find that dune migration vectors follow consistent directions over up to thousands of kilometers, especially at mid-latitudes (±45°N), where the recorded winds are mainly westerly, and near the equator, where the recorded winds are mainly northerly (Figure 2a). In the north (Figure 2b), we find vector streaks display two opposing migration directions: above latitude 75°N, dunes migrate primarily to the west, while below latitude 75°N, dunes migrate primarily to the east. Finally, we find that topography induces perturbations in the average migration direction: bins that contain more dune-harbor ing impact craters also show larger scatter in the migration direction of dune fields (Figure 3). Even in many lightly cratered bins, non-topographic effects such as seasonality may still induce scatter in dune migration directions.

Discussion: The strong autocorrelation between the migration directions along wind-flow lines, which sometimes extends for thousands of kilometers, indicates that dune migration on Mars is largely controlled by the planet’s global circulation. Additionally, the wind-flow lines mapped both in the polar region (Figure 2a) and in low latitudes (Figure 2b) generally follow the wind stress directions computed by global circulation models [10], providing critical input into models’ abilities to predict weather and climate on Mars. The divergent wind directions we identify in the northern polar region, which agree with those that were previously measured manually by [11], could be a consequence of topographic winds emerging from the polar ice cap, which locally reverse the winds formed by Mars’ circumpolar circulation [12,13]. Bins that contain many dune-harbor ing impact craters show larger scatter in the migration direction of dunes (Figure 3), underlining the role of craters in inducing local winds. However, we also find that when averaged together, the migration direction of intra-crater dunes does not significantly deviate from that of the global wind-flow lines, demonstrating that the global circulation of Mars overall dominates over these local perturbations—consistent with previous local observations (by e.g. [8]).