**INTERPRETING AIRFLOW DYNAMICS FROM RIPPLE PATTERNS AND MIGRATION RATES ON MARS.**
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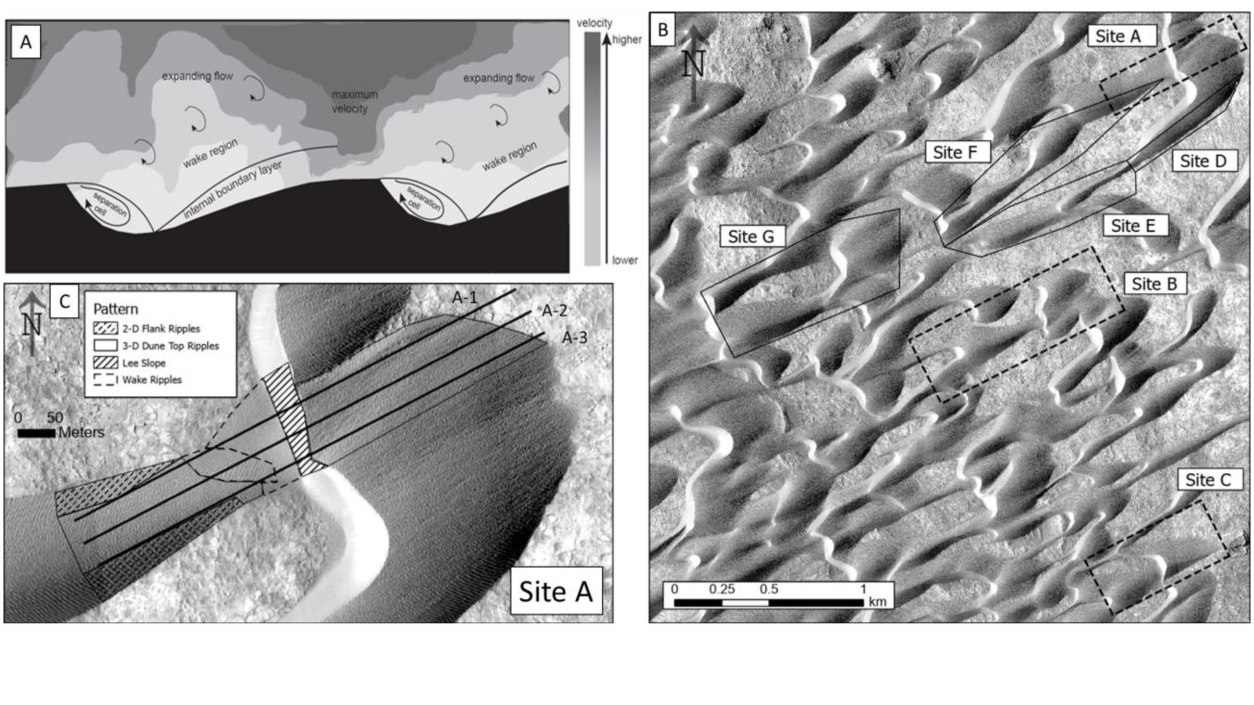
**Introduction:** Large ripples form striking patterns on the slopes of martian sand dunes. The ripples vary in orientation, wavelength, plan-view morphology, and rates of migration and variations in the ripple patterns are recognized to signal the effects of the regional and local winds and feedbacks between winds and dune topography [1]–[3]. Using high-resolution imagery on Mars, it is possible to detect ripple motion via repeat imagery and calculate ripple displacement magnitudes, which in turn can be used to infer how airflow on Mars moves over dunes and through a dune field.

Airflow over dunes is a well described phenomenon on Earth that affects the transport of sediment over a dune and through a dune field (Fig. 1). Wind flows are compressed as they feel the topography of the dune stoss slope and accelerate to the dune crest [4]. Flow separation and flow decompression occurs as flows move past the sharp break in slope at the dune brink. A recirculation cell forms in the dune wake marked in its downwind extent by a reattachment point and returns flow toward the dune lee at a distance related to the dune shape and height [5]. Downwind of the flow reattachment point, an internal boundary layer develops and grows as flow recovers to the overlying flow. This idealized dune-modified flow scenario varies with wind flows from different directions, with different intensities, and with dune shape [5]. Additionally, dune-modified flows are increasingly recognized to play an influencing role in dune interactions in which an upwind dune approaches and may collide with a downwind dune [6].

On Earth, empirical measurements of the effects of dune topography on airflow requires monumenting dunes with extensive field instrumentation [5], sophisticated laboratory visualization methods [6], or computational fluid dynamic modeling [7]. No direct measurements of dune modified airflow have yet been made on Mars. However, owing to the size of the ripples on the dunes on Mars, a rich signal of airflow over dunes, between dune interactions, and through a dune field exists. Using repeat HiRISE images, we examine the ripple patterns and the displacement of these ripples to interpret airflow dynamics around dunes in the dune field at Nili Patera, Mars.

**Methodology:** To examine inferred airflow patterns over dunes and through Nili Patera Dune Field several pairs of dunes were chosen for analysis (Fig. 1)

***Figure 1.*** *(A) Models of flow over dunes. (B) HiRISE image of our study area. Sites A-C, outlined in dashed rectangles, are primarily used in investigations of wake flow, and areas outlines in solid polygons are primarily used in investigations of 2-d ripples on dune flanks. (C) Study Site A with ripple patterns mapped and analysis transects marked.*



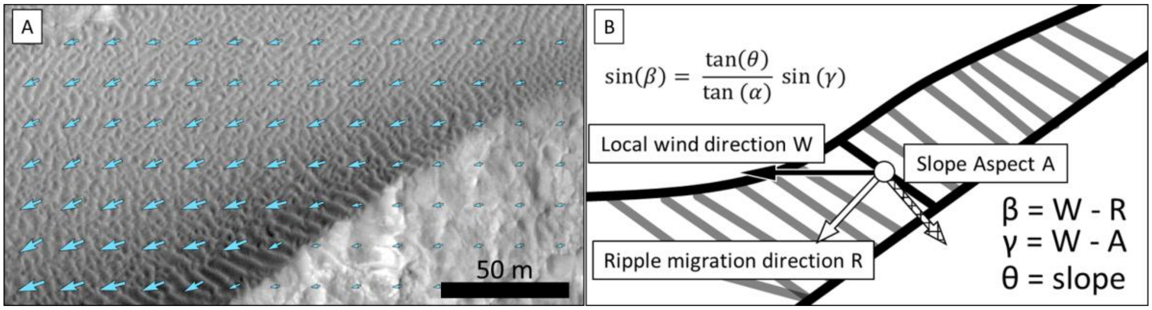



***Figure 2.*** *(A) COSI-Corr results in Site A (Fig. 1) with migration direction indicated by arrows and magnitude indicated by size. (B) Methodology to determine formative wind direction from ripple orientation and topography.*

using the criteria that the leading (upwind) dune had no immediately upwind obstructions and sand coverage was continuous from the stoss of the leading dune to the lee of the trailing (downwind) dune. In these areas, ripple length, orientation, and wavelength were measured in ArcGIS on HiRISE images. Slope and aspect were measured from HiRISE DEMs. Ripple migration rate was determined from repeat HiRISE images and Co-registration of Optically Sensed Images and Correlation (COSI-Corr, Fig. 2). We investigate correlations among elevation, ripple pattern, and ripple migration rates to infer how the ripples were affected by dune-modified airflow. We also use 2-d (straight-crested) ripples on the steep flanks of dunes to infer the regional, formative winds using a relationship between ripple orientation and slope established by Howard [8] and previously used on Mars [2].

**Results:** We find that changes in ripple patterns and migration rates in dune wakes are consistent with length scales of flow reattachment for airflow over dunes measured on Earth at 4-7 dune heights (Fig. 3). Changes of ripple patterns on spurs formed on the dune leeward sides are found to be coincident with changes in ripple migration rates, suggesting that these patterns are reflective of lee-side airflow. Furthermore, the location of these boundaries indicate reattachment lengths between 4 and 7 brink heights for the examined dunes, consistent with terrestrial investigations [5].

Ripples on dune flanks are shown to behave according to terrestrial models for ripple development on steep slopes and compensating for these slope effects allows them to act as indicators of dune-modified and regional wind directions. These were found to be particularly useful indicators of secondary, along-dune flows that develop on slopes sheltered from primary winds.

This detailed assessment of ripple measurement and ripple migration rates advances the use of ripples on martian dunes and sand sheets to infer dune- and field-scale wind dynamics. These measurements also indicate that the low density atmosphere on Mars does not significantly modify the behavior of wind-topography interactions compared to Earth. Such observations provide targets for computational fluid dynamic and large-eddy simulation models seeking to reveal complex airflows across dune fields both on Earth and on Mars.

**References:**[1] N. T. Bridges, et. al, Nature, 2012. [2] J. R. Zimbelman and M. B. Johnson, Aeolian Res., 2017. [3] R. C. Ewing, A. et. al, JGR Planets 2010. [4] K. D. Runyon, et. al, Aeolian Res., 2017. [5] M. C. Baddock, et. al, Earth Surf. Process. Landforms, 2011. [6] N. R. Bristow, et. al, JGR Earth Surf., 2018. [7] W. Anderson and M. Chamecki, Phys. Rev. E 2014. [8] A. D. Howard, Bull. Geol. Soc. Am., 1977.

***Figure 3.*** *Migration rate / H on dune A (Fig. 1). On each transect, the boundary between "wake ripples" and "dune top ripples" (denoted by the color transition) coincides with a kink or flattening of the R/H curve. We take this to be a change in flow consistent with a point of reattachment.*