Interpreting Wind Directions from Sand Dune Morphologies in the Northern Mid-Latitudes of Mars

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GEOL394

Introduction (A)

- Few in-situ measurements of winds exist for the martian surface (only procured from several landers and rovers)
- Sand dunes are useful for atmospheric and geological inquires as they sit at the boundary between the two fields.
- Of the 7 types of sand dunes identified in the Mars Global Digital Dune Database [1], 5 were seen in this study and are shown in Figure 1.
- Experiments have shown that sand dunes respond to wind directions through 2 main modes of transport:
  1) Bedform Instability Mode [2, 3]
  2) Fingering Mode [4,5]
- Max Gross Bedform Normal Transport (MGBNT) and it's inverse (IMGBNT) are principles of the Bedform Instability Mode that provide a mathematical relationship between dune morphologies and wind directions [6,7]

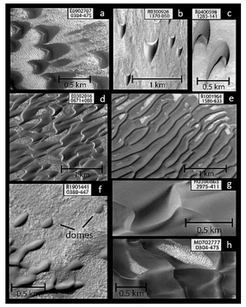

Figure 1: *Examples of martian dunes adapted from Figure 2 in Hayward et al. (2007). (a-c) barchan dunes, (d) barchanoid dunes, (e) transverse dunes, (f) dome dunes, and (g-h) star dunes.*

Hypotheses

H_0: Wind directions in the MLR interpreted from dune crest orientation data obtained from remote sensing images are not significantly different from prevailing wind directions generated from the Ames General Circulation Model for Mars.

Scientific Working: Wind directions interpolated from dune crest orientation data obtained from remote sensing images are significantly different from prevailing wind directions generated from the Ames General Circulation Model and may represent mean and storm directions

Location of Study (B)

Criteria for Study Site Selection

- Dune fields in the Northern Mid-Latitude Region (MLR), defined as 30°-65° N
- "Clustered" dune fields (i.e. high spatial density in a small region)
- Good CTX coverage of the dune field (i.e. at least 1 clear image included ~70-100% coverage of the dune field)
- Good HiRISE coverage (i.e. at least 1 clear image included ~70-100% coverage of the dune field, if possible)
- Simple topography (i.e. no complicated surface features; flat surrounding area)
- Common geologic unit in host environment (if possible)

Selected Region (TR4)

- 640,600 km² in Chryse Planitia
- Lower portion of N. Mid-Latitudes (34°-45° N)

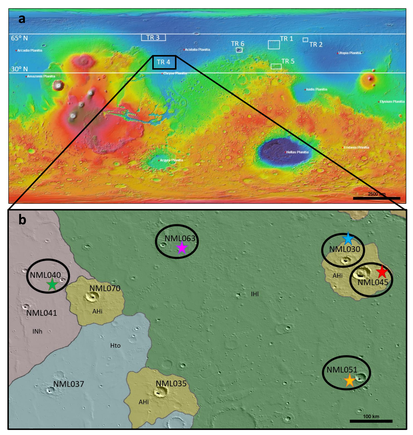

Figure 2: *a) A colorized MOLA elevation map shows the MLR bounded with horizontal white lines and 6 Target Regions (TRs). b) A cutout of Target Region 4 (TR4) with a basemap of the USGS geologic map of Mars (Tanaka et al. 2014). Black ovals indicate locations of dune fields and accompanying IDs (i.e. NML0XX) and colored stars correspond to results in box D.*

Methods (C)

Below is a simplified method for 1) inferring wind directions from orbital observations of sand dunes, 2) extracting wind directions from the NASA Ames General Circulation Model (GCM) for Mars, 3) evaluating similarities in mean wind directions from the inferred and modeled winds using a statistical analysis.

Inferred Wind Directions (7 Steps)

(1. Identify dune field → shown in Box B *Location of Study*)
2. Identify image coverage (HiRISE and CTX) at selected dune fields
3. *Map dune crestlines (Type I and II)

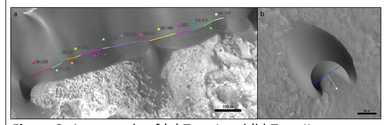

Figure 3: *An example of (a) Type I and (b) Type II measurements.*

4. *Color crestlines

Figure 4: *2 rules (a-b) were created for dividing crestlines into groups.*

5. Determine crestline groups for IMGBNT calculations (checking dune modes)
6. IMGBNT calculations with program
   - pro_gbnt_rev.pro
7. *Interpreting IMGBNT results

Modeled Wind Directions (2 Steps)

1. Run 2 programs in IDL
   - rd_ncdf_case.pro
   - ustar_sandflux.pro
2. Extract data for statistical analysis

Statistical Analysis (4 Steps)

1. Determine mean values
2. Calculate standard deviations
3. Independent, 2 sample t-test to compare mean wind directions

$$t = \frac{X_A - X_B}{\sqrt{\frac{S_A{}^2}{n_A} + \frac{S_B{}^2}{n_B}}}$$

4. Accept or reject null hypothesis
   - 2 tailed test
   - P = 0.2 → t_{crit} = 1.282

t-test Assumptions

- *Data are normally distributed*
- *Each sample was taken at random*
- *Variance between samples is the same*

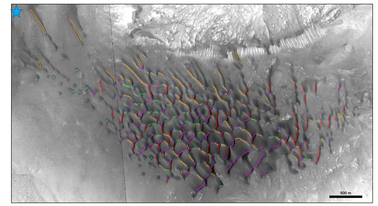

Figure 5: *A composite image showing dune field NML030 from (L) CTX image F20_043611_2229_XN_42N031W and (R) HiRISE image ESP_043611_2230 with colored crestline measurements overlaid.*

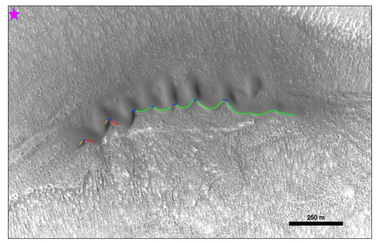

Figure 6: *A view of dune field NML063 from HiRISE image ESP_019124_2240 with colored crestline measurements overlaid.*

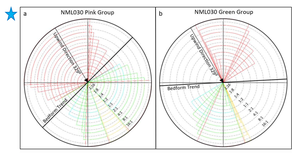

Figure 7: *Results of IMGBNT calculations for (a) pink and (b) green, both Type I groups of crestlines in NML030.*

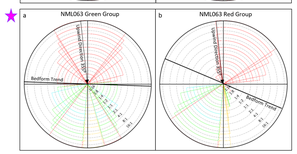

Figure 8: *Results of IMGBNT calculations for (a) green and (b) red, both Type I groups of crestlines in NML063.*

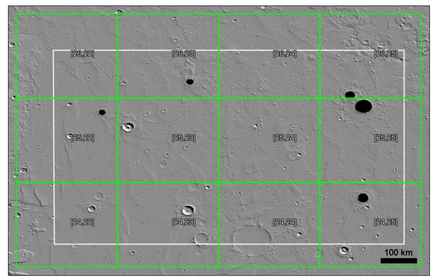

Figure 9: *To locate grid boxes for extracting modeled wind directions a portion of the GCM grid (green boxes) is overlaid on TR4 (white box). Black ovals from (Robbins and Hynek 2012a) indicate the locations of the craters that host TR4's 9 dune fields.*

Results (D)

Similar to Box C *Methods*, results are reported in 3 sections: 1) inferred wind directions, 2) modeled wind directions, and 3) statistical analysis. Note that all winds recorded are in the upwind direction (i.e. direction winds are entering a dune field).

Inferred Wind Directions

- Primary and secondary wind directions are recorded with an estimated transport ratio which can be used as a proxy for wind strength

	Inferred Wind Direction Results				Statistical Analysis Results		
	Dune Field	Primary Wind Direction (deg)	Secondary Wind Direction (deg)	Estimated Transport Ratio	Calculated t Value	t_{crit} Value	Accept Null Hypothesis?
★	NML030	329 ± 14	25 ± 34	4:1	-1.169	1.282	Yes
★	NML063	355 ± 13	22 ± 62	16:1	3.022		No
★	NML040	28 ± 12	314 ± 15	4:1	-42.211		No
★	NML051	331 ± 22	43-55	16:1	-4.378		No
			47-59	8:1			
			53-63	4:1			
★	NML045	313 ± 16	32 ± 12	4:1	-20.763		No

Table 1: *Organized by dune field ID, (r) Inferred wind directions from IMGBNT calculations are reported with (y) results of t-tests for comparison.*

Modeled Wind Directions

- Rose histograms showing the modeled wind directions were created for each GCM grid box that contains a dune field

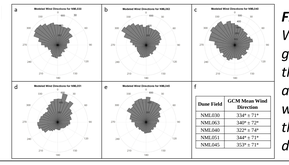

Figure 10: *(a-e) Wind directions generated from the Ames GCM are displayed with (f) showing the mean wind directions.*

Statistical Analysis

- t-tests show the null hypothesis was accepted at dune field NML030 but rejected at 4 other fields (see Table 1)

Discussion (E)

Regional Interpretation

- Dune fields in the eastern portion of TR4 (NML030, NML045, NML051) all contain strings of barchan dunes on the western edges of the dune fields that appear to march southeast
- The eastern dune fields are significantly larger than then those in the west (NML063, NML040) and may provide regional clues to sediment sources local to TR4
- No change was observed in inferred or modeled wind directions due to crater morphology
  - Although the dune morphology in every field was consistent with the interpretation that 2 (or more) wind directions had influenced the crestlines during the most recent period of dune construction

Influence of Statistics

- Sample size differences between inferred and modeled winds
- GCM data may not be normally distributed → inaccurate use of statistical model?

Future Work

- Run new versions of statistical analysis
- Analyze TR4 dune fields with Fingering Mode to compare results with this study

References/ Acknowledgements (F)

[1] Hayward R. K. et al. (2007) *JGR*, 112, E11007. [2] Rubin D. M. and Hunter R. E. (1987) *Science*, 237, 276-278. [3] Rubin D. M. and Ikeda H. (1990) *Sedimentology*, 37, 673-684. [4] Reffet et al. (2010) *Geology*, 38, 491-494. [5] Courrech du Pont et al. (2014) *Geology*, 42, 743-746. [6] Fenton L. K. et al. (2014a) *Icarus*, 230, 5-14. [7] Fenton L. K. et al. (2014b), *Icarus* 230, 47-63. [8] Tanaka et al. (2014) *Planet Space Sci*, 95, 11-24. [9] Robbins S. J. and Hynek B. M. (2012a) *JGR*, 117, E05004.

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