PILOT STUDY OF HIGHER ORDER NEIGHBOR STATISTICS FOR CRESCENTIC DUNES OF THE MARTIAN NORTH POLAR REGION.

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Introduction: Dune fields are self-organizing and correspond to environmental changes in climate, sediment availability and particle transport [1], [2], [3]. The geographical self-organization of dune fields using spatial statistical techniques have been little explored [4] and may offer significant insight into the evolution of eolian systems, and by proxy, a perspective on climate history. This pilot study reports a summary of simple crescentic dunes (barchans) using ordered neighbour point pattern analysis within a geographical information system (GIS). Such abstract recognition may be useful in landscape interpretation where time coupled with degradation, erosion and burial takes a significant toll on the geometry, relief and identity of landforms, and where landscape is inaccessible as with extra-terrestrial surfaces.

Methodology: First-order NN statistics identify a particular pattern (clustered, random, dispersed) at the local scale, while higher order statistics are capable of discerning spatial patterns at regional or global scales [5]. Such spatial characterization can imply an understanding about underlying geomorphic processes [4]. To test this reasoning on Martian surface features, we undertook a pilot study of crescentic dunes in the North Polar region (Figure 1).

The flexibility inherent in GIS allows simple scripts to be written to perform the required, more complex and time-consuming calculations of spatial analysis. Scripts in the form of GUI-based extensions have been developed by investigators over a number of years and are numerous. The USGS [6] has developed a projection and spheroid extension for ArcView® that allows planetary images to be geo-referenced while numerous extensions for classical and spatial statistical analysis are also widely available.

Point pattern analysis involves the representation of 4-D features as objects with zero dimensionality. For dunes, the representative point for the object was positioned at the apex of the slip face. Failure to rigorously define the area of investigation has historically presented a problem for spatial analysis; commonly known as the Modifiable Areal Unit Problem (or MAUP). To minimize the effects of this problem, a boundary perimeter which enclosed all dunes was constructed. In ArcView®, an extension to automatically apply a "convex hull" is available [7] for this task.

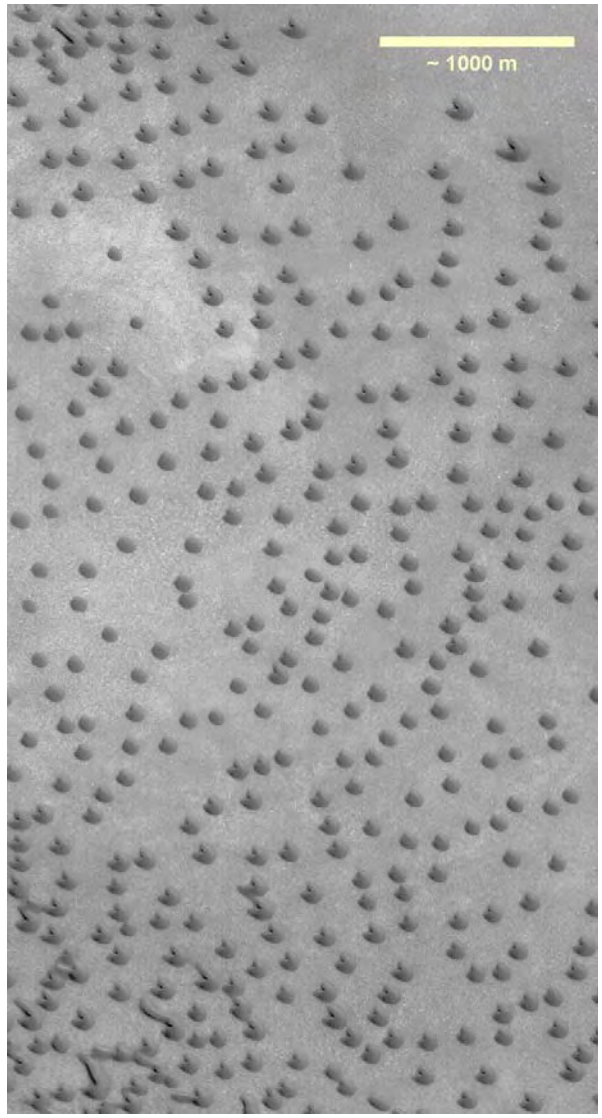

Figure1. Crescentic dunes of the North Polar region, Mars. A portion of MOC image E1010728 centered at 51.31° W 71.48° N.

(The authors acknowledge the use of Mars Orbiter Camera images processed by Malin Space Science Systems that are available at http://www.msss.com/moc_gallery/).

NNA is founded upon the concept of complete spatial randomness through analysis of the *R*-statistic. In its simplest form the nearest neighbor statistic, R, compares the observed, r_o, with the expected, r_e, (random) nearest neighbor distances;

$$R = \frac{r_o}{r_e} \quad (1)$$

and identifies whether points are random ($R \cong 1$), completely clustered ($R = 0.0$) where all points to lie on top of each other, or dispersed, where a value of $R = 2.00$ is a square lattice, or ($R = 2.149$) which is the theoretical value for the most dispersed pattern, being that of a triangular lattice.

The extent to which the observed average distance differs from the expected average distance can be measured using the comparison of their difference with the standard error of the average distances among nearest neighbors. The magnitude of the standard error is indicative of how likely any difference between the observed and the expected pattern is to occur by chance. If the difference is relatively small compared to the standard error, this difference is regarded as not statistically significant, while a large difference relative to the standard error indicates the difference is statistically significant. The standard error of the difference between the observed and expected average distance for the nearest neighbor statistic is;

$$SE_r = 0.26136\sqrt{\frac{A}{n^2}} \quad (2)$$

The key test statistic for evaluating the significance of the difference between an observed and random distribution is based upon the standardized Z score where:

$$Z_R = \frac{r_o - r_e}{SE_r} \quad (3)$$

If $Z_R > 1.96$ or < -1.96 it can be expressed that the difference is statistically significant at $\alpha < 0.05$. Alternatively, if $-1.96 < Z_R < 1.96$ the pattern is not statistically different from a random pattern, regardless of visual appearance.

With an ability to detect patterns, NNA has been extended to accommodate second, third and higher-order neighbor statistics to detect heterogeneous processes at different spatial scales. As with the nearest or first–order neighbor, ordered neighbor analysis (2^{nd}, 3^{rd}, 4^{th} …etc) is based on comparing the observed average distances (spacing) between neighboring points and a known pattern, and evaluates the pattern at different spatial scales. The calculation of higher order statistics and Z-scores follow the expressions outlined above, however, the constants for the expected average distances and the standard errors need to be adjusted.

Results and Discussion: The NN statistics show that the pattern for the barchan dunes is one of statistically significant dispersion (Table 1).

Ordered Neighbor	*R-statistic*	Z_R	Pattern
1^{st}	1.44	16.02	*Dispersed*
2^{nd}	1.20	10.59	*Dispersed*
3^{rd}	1.16	10.34	*Dispersed*
4^{th}	1.14	10.18	*Dispersed*
5^{th}	1.11	9.43	*Dispersed*
6^{th}	1.11	10.15	*Dispersed*

Table 1: Ordered neighbor statistics for 358 crescentic dunes (Area = 13.09 square km)

The nearest neighbor (1^{st}-order neighbor) shows the highest degree of dispersion, $R = 1.44$, with successively lesser but still highly significant patterns of dispersion for all higher orders (Table 1). The observed nearest neighbor is found at a distance of 140 m with each successive order being at 170, 210, 240, 260 and 290 meters, respectively. Dispersion or a spatial semblance of uniformity is characteristic of both the local and regional geography of this dune field. Spatial homogeneity is a process that typifies the barchan dunes of this northern polar dune field.

Summary: These results alone are not able to determine the relationship between spatial patterns and self-organization. The state of geographical maturity (equilibrium) or immaturity (quasi-equilibrium) of dunescapes requires comparative studies with terrestrial dune fields, alongside further analysis of other Martian fields. However, the results presented here do indicate that spatial signatures are capable of extending the understanding of eolian processes across a variety of scales.

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