COMPARATIVE POINT PATTTERN ANALYSIS OF HYPERBOREAE UNDAE, MARS, AND THE RUB' AL KHALI SAND SEA, EARTH. M. A. Bishop[1,2], [1]Planetary Science Institute, 1700 East Fort Lowell Road, Tucson, AZ 85719, USA, [2]School of Natural and Built Environments, University of South Australia, Adelaide, SA 5095, Australia (bishop@psi.edu)

Introduction: The geographic signature of dune distribution and self-organization as measured by the *R*-statistic offers a viewpoint on the geography of crescentic eolian systems and proposes an index from which to determine the degree of self-organization across a variety of spatial scales. Fields of simple dunes (dome, barchan, barchan-seif) are comparatively less regular in distribution than are those fields, or part thereof, that consist of compound (barchanoid) morphologies whose patterns are more highly regular [1]. This analog study examines and compares the geography of crescentic dune patterns for the Martian north polar erg, Hyperboreae Undae, and the Rub' al Khali sand sea of the Arabian Peninsula, Earth.

Methods: Data points representing the point of maximum crest-line curvature for both barchan and barchanoid crescentic dunes were derived by on-screen ('heads-up') digitization using the software ArcView 3.3 and ArcGIS 9.2. Nine georeferenced and sinusoidal projected narrow angle Mars Orbiter Camera (MOC NA) images produced some 2800 data points for Hyperboreae Undae. Similarly, 3400 data points projected to WGS 84 UTM Zone 39N were derived from a 3-sec (90 m) SRTM (Shuttle Radar Topography Mission) DEM tile for the Rub' al Khali dunes.

Synopsis of statistical calculations: Commonplace in the analysis of point pattern is nearest neighbour analysis (NNA). The nearest neighbour distance for an event in a point pattern, is the distance from that event to the nearest event, also in the point pattern. NNA calculates the dimensionless statistic *R*, which is the ratio of the observed average distance between nearest neighbors of a point distribution (r_o) and the expected average distance (r_e) between nearest neighbors as determined by a theoretical pattern; the Poisson probability distribution. For each point, the shortest distance among all neighbors becomes the nearest distance which is then averaged using all points. In its simplest form the nearest neighbor statistic, *R*, compares the observed, r_o, with the expected, r_e, (random) nearest neighbor distances and identifies whether points are random ($R \cong 1$), completely clustered ($R = 0.0$, in which all points lie on top of each other) or dispersed ($R = 2.00$ in which points distribute in a square lattice, or $R = 2.149$, which is the theoretical value for the most dispersed pattern, being that of a triangular lattice). 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; although recent work by Baloga et al., [2] has shown that according to sample size, the range for statistical significance may require adjustment.

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, higher-ordered neighbor (H-ON) analysis (2nd, 3rd, 4th …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. Higher-order neighbor statistics reach beyond the local scale represented by the nearest neighbor measure, by offering greater insight into patterns over a more regional perspective.

Results and Discussion: H-ON statistics have shown that the patterns for fields of crescentic dunes within Hyperboreae Undae are one of statistically significant dispersion (Figure 1).

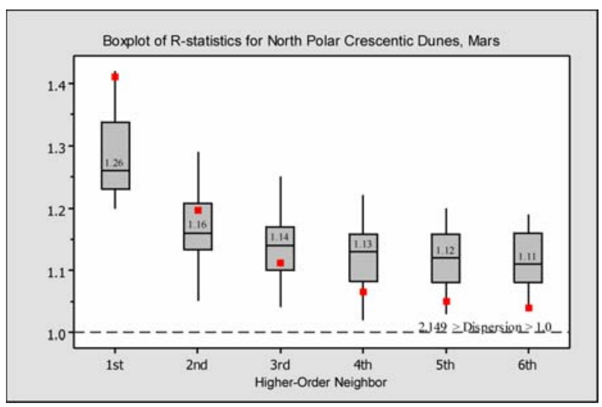

Figure 1. A boxplot of the distribution of the *R*-statistic for the ordered neighbors of crescentic dunes. Each boxplot represents a synopsis of the range of *R*-values determined for Hyperboreae Undae. The plots show: (a) that all *R*-statistics fall within the statistical field of dispersion (b) numerical median values (c) the absence of outliers (d) positive (right) skew of the data for the 1st, 2nd, 3rd, and 6th higher-order neighbors which indicates fewer data points having values above the median (e) a slightly negative skewed distribution for the 4th higher-order neighbor which shows more data demonstrating a greater degree of dispersion (f) a near-normal distribution of data points for the 5th higher-order neighbor. Comparatively, box symbols (red) show *R*-indices

from a sample of the Rub' al Khali barchanoid dunes for a single areal extent of 15,595 square km; *n* = 2,428 points (Table 1).

Similarly, pattern regularity (dispersion) is also characteristic of the mega-barchanoids of the Rub' al Khali (Empty Quarter) sand sea of the Arabian Peninsula (Figure 2). Spatial statistics for the prevailing northernmost dune field demonstrates close agreement with the geographic indices of compound crescentic (barchanoid) dunes of Hyperboreae Undae (Table 1).

Ordered Neighbor	*R-statistic*	Z_R	*Pattern*
1st	1.41	39.0531	Dispersed
2nd	1.20	26.4533	Dispersed
3rd	1.11	18.4745	Dispersed
4th	1.07	12.6199	Dispersed
5th	1.05	10.0091	Dispersed
6th	1.04	9.97432	Dispersed

Table 1. Ordered neighbor statistics for mega-barchanoid dunes, Rub' al Khali erg (Area of dune sample = 15,595 square km; *n* = 2,428 points, 3-sec SRTM data)

For an area of 15,595 square km and 2,428 data points, the nearest neighbor shows the highest degree of dispersion, *R* = 1.41, with successively lesser but highly significant patterns of regularity for all higher orders (Table 1; Figure 1). Several smaller intra-field comparisons were made for which the *R*-indices of the NN ranged between 1.39-1.47; results that characterize local variations in distribution.

Overall, both ergs demonstrate that the regularity of pattern is greatest for the 1st- and 2nd-order distances followed by a distribution that migrates towards randomness with each successive order. Dispersion or a spatial semblance of uniformity characterizes the geography of these sand seas. Furthermore, spatial homogeneity and its apparent relationship to morphology is a process that typifies the crescentic dunes of both the Hyperboreae Undae and Rub' al Khali sand seas. The repetitious compound morphology and substantial areal extent for the dunes of the Empty Quarter implies that a relationship exists between form and the degree of pattern uniformity. Such occurrences are found also for sequences of barchanoid morphology within Hyperboreae Undae. In both instances this implies that the evolution of crescentic dunes into compound fields identifies with the process of long term self-organization (and maturity) of the eolian system. Where domes, barchans, barchan-seif and short barchanoid 'chains' occur, the degree of self-organization is less than for those regions comprising compound forms. Therefore, it is plausible that spatial statistical indices may indicate a relative scale from which dune field maturity can be ascertained across a variety of scales. These results parallel the views of Wilkins and Ford [2] who suggest that eolian systems reflect, within different spatial regions of the field, the sum of changes that result in the spatially variable states of dune field organization.

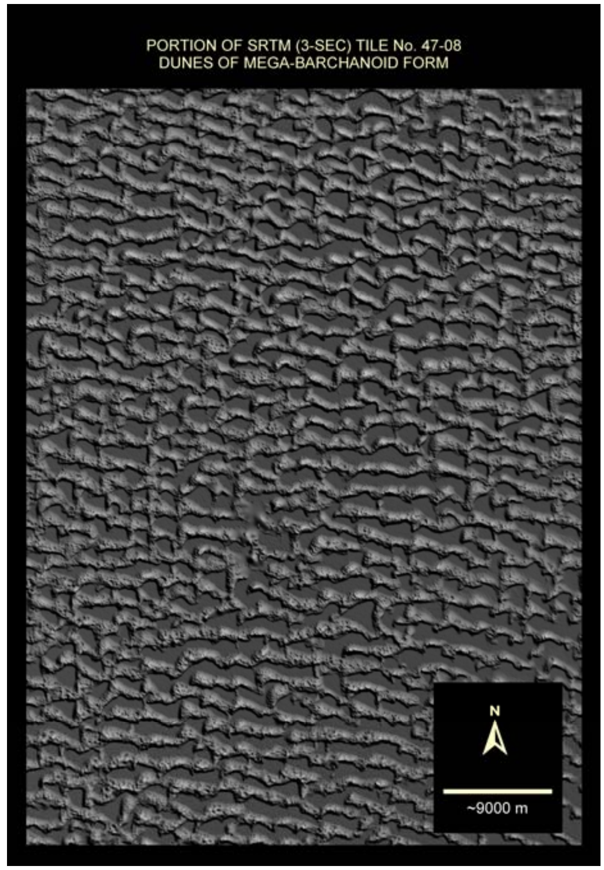

Figure 2. Radar part-image (image center ~54.183ºE, 22.278ºN) of the Rub' al Khali mega-barchanoids.

Summary: Ordered neighbor analysis of point patterns has shown that dune geography for high-latitude dune fields on Mars and the terrestrial erg Rub' al Khali is not a random process, but one that identifies with a geomorphic system that has evolved towards a pattern of uniformity and self-organization across a variety of spatial scales.

References: [1] Bishop M.A. (2007) *Icarus 191,* 151-157. [2] Baloga, S.M. et al., (2007) *Journal of Geophysical Research 112*, E03002. [3] Wilkins D.E. and Ford R.L. (2007) *Geomorphology 83,* 48-57.