UNRAVELING THE EMPLACEMENT HISTORY OF SHIELD FIELDS USING TWO STATISTICAL METHODS.
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Introduction: Shield fields, which are clusters of small shield volcanoes, are the most numerically abundant volcanic feature on Venus. Individual shield volcanoes range from <2 to 20 km in diameter and << 1 km in height, and over 10^6 edificies in ~10^3 clusters have been recognized [e.g., 1, 2]. In terrestrial settings, the non-random orientation of small volcanic constructs within a grouping of such features have been used to infer crustal stress-strain relationships [3, 4]. These methods work from the central assumption that magma tends to ascend preferentially along fractures and zones of pre-existing weakness, resulting in concentrations of edificies in linear arrays that are generally oriented perpendicular to the principal stress direction (σ_1). Building on this assumption, our goal in this project is to use any detected preferred orientations in shield fields to determine which set(s) of fractures in the surrounding terrain are most consistent with the inferred crustal stress-strain conditions at the time of emplacement, thus better constraining the relative stratigraphy of a given shield field. Given the divergent stratigraphic interpretations of Venus, such an approach might provide a set of reference markers to better interpret the geologic evolution of the planet.

Previously, we have reported on an intial software package to detect cluster anisotrophy [5] and prelimary results [6]. Here, we expand on our prior work and report a second algorithm that has been incorporated into the software. A companion abstract [7] will detail application of the software; the methodology is given below.

Numerical methods: As a starting point, we have implemented the two-point azimuth method for detecting anisotrophy in point-like features [8]. In this method, for a given set of N points, there are $N(N-1)/2$ lines that connect each point with all of the others. The azimuths of these connecting lines are tabulated, and the resulting histogram is tested against a series of Monte Carlo models that randomly places an equivalent number of points within the same bounding polygon. Running a set of Monte Carlo models helps insure that any overall field shape anisotropy does not overide the alignments of individual structures.

A complicating factor with this approach is that volcanic fields may be emplaced over an extended period of time under non-uniform stress-strain conditions. If one was able to obtain age dates for individual constructs, one could disentangle various stages of evolution, but in the absence of such measurements, other methods must be employed. One method is to subject the distribution to a cluster analysis in order to subdivide the population into distinct sub-groups, groups which are then analyzed separately [e.g., 9]. But such a method is obviously very sensitive to the algorithms used to define clusters. An alternative method is to use the two-point azimuth method but limit the distance between which azimuths are considered. Cebria *et al.* [10] tested a method whereby they considered only azimuths corresponding to to distances (d) $d \leq |\bar{x} - 1\sigma|/3$, i.e., those distances for which the frequency has a maximum value of less than one standard deviation (σ) from the mean ($\bar{x}$). This method was recently employed in a study of small martian volcanic constructs [11].

MATLAB software: We have implemented both of these models in a separate graphical user interfaces (GUIs) built using MATLAB (MATrix LABoratory) software. In each, the user ingests a pre-prepared text file that is a 2-column listing of the center latitude and longitude of each volcanic construct. The software has been updated so that the user can designate the planetary body of interest (currently Earth, Venus, or Mars). As before, the main body of the GUI consists of three panels (**Figure 1c-d**). In the left-most panel, the distribution of point features (e.g., shields) can be visually confirmed in a *x-y* scatter plot. The middle panel displays a raw, uncorrected histogram of orientation measurements. In the right-most panel, the user specifies the number of Monte Carlo runs to randomly place an equivalent number of shields within the boundaries defined by the edge edifices. Upon execution, a "normalized" histogram is produced from the Monte Carlo results whereby each histogram cell is set equal to the expected value times the observed value divided by the mean value in the Monte Carlo runs.

To determine if a given normalized histogram value is statistically significant to the 95% significance level, the Student's t distribution is used to determine the 95th percentile critical threshold value. Histogram values that exceed the critical threshold value are deemed statistically significant.

Sample results: As a test of the software functionality, we ran both components of MATLAB code using a randomly generated dataset data points from Cebriá *et al.* [10]. This test data set corresponds to a random distribution of 296 points in an area similar to the Michoacán-Guanajuato volcanic field in central Mexico.

Figure 1a gives an x-y scatterplot of these points; **Figure 1b** gives a frequency histogram of distances between points (both figures are from [10]). **Figure 1c** is a screenshot of the MATLAB GUI using the Cebria *et al.* [10] method showing results for the same data given in **Fig. 1a-b**. As expected, no preferred orientations in the normalized histogram given in right-most panel of **Fig. 1c** exceed the critical threshold value, indicating there is no evidence for a strong preferred orientation (consistent with a randomized field). In **Figure 1d,** the same data is run with the standard two-point azimuth method [8]. Here, the raw histogram (middle panel) reveals a broad mode centered at ±90°, an orientation consistent with the E-W elongation of the overall field shape. The Monte Carlo model (**Fig. 1d** right panel), however, indicates that this broad mode does not exceed the significance threshold (i.e., it is an artifact of the field shape).

Future work will explore shield fields on Venus using both the whole-field (Lutz) and local-scale (Cebria) methods, and compare and contrast the two.

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Acknowledgements: This work was supported by a NASA Planetary Mission Data Analysis grant to BJT. The authors thank Jose M. Cebriá for graciously providing a copy of his test data.

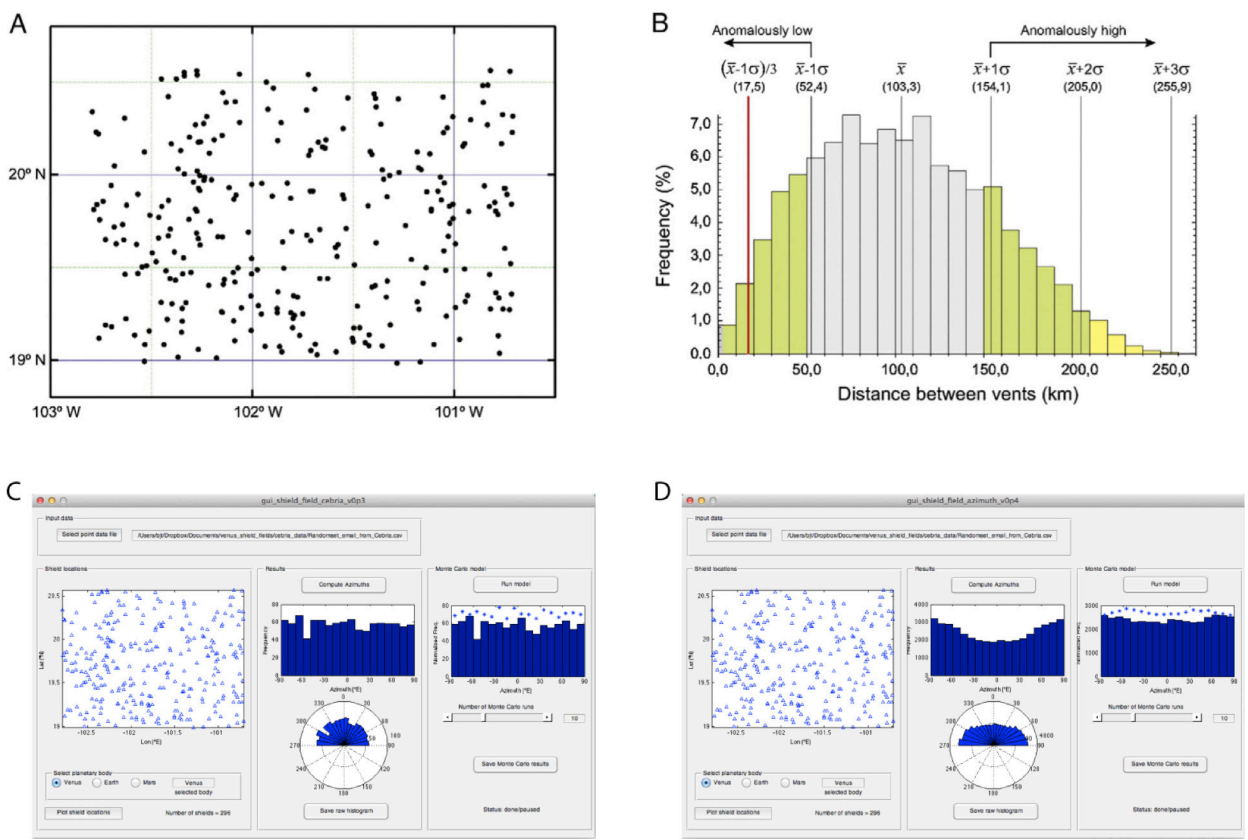

Figure 1. (a) Randomized distribution of 296 points from Cebria *et al.* [10]. **(b)** Frequency histogram (expressed as % of total population) of the lengths of all possible lines interconnect the points in Fig. 1a. **(c)** Snapshot of MATLAB GUI that implements Cebria *et al.* [10] method. Data from Fig. 1a is given in the left panel, the raw histogram and rose plot in the middle panel, and normalized histogram via Monte Carlo model are given in the right-hand panel. None of the histogram bins exceed the critical threshold value (indicated by * symbols). **(d)** Snapshot of MATLAB GUI that implements Lutz [8] method using data from Fig. 1a; left, middle, and right panels are set up the same as described for Fig. 1c.