Planetary surface dating from crater size-frequency distribution measurements: spatial randomness and clustering

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To draw conclusions about the impactor population – or about the age of a surface unit – using a crater count, you have to be certain that the crater population corresponds to an exposure to the impact flux in a known way.

In an ideal scenario, each impact produces a single crater, which is retained by the surface until the time of observation. This process produces a random spatial configuration of the craters.

Real surfaces are rarely so well behaved. One must be selective in choosing counting areas which are geologically homogeneous: not only in their formation, but also in their modification history. The quality of the conclusions depends strongly on making an adequate choice of area.

A randomness analysis can be used to verify the homogeneity of a measured population, and conversely to reject counts which are spatially non-random.
Ingredients of a crater age measurement

- Known size-frequency distribution of impacting bodies
- Some estimate of the variation of the impact rate as far back as the oldest observable surfaces
  (a similar system can be devised for a two-population model)

- Impact craters form independently of each other
  - be cautious of secondaries, fragmented impactors

- Accumulating surface retains its crater population
  - Or, more weakly, has a spatially uniform resurfacing history

Violation of either condition yields a non-random population.
What does a non-random population look like?

- Clustered sub-unit near Elysium Mons, Mars
- Two obviously clustered regions, which normally would be excluded from a crater count for dating
- Possible to recognise this clustering with a visual inspection, but more objectively, how can we measure the degree of clustering?
How to measure spatial randomness?

• Split population into bins by diameter – wish to examine clustering only between comparably-sized craters. We use root-2 bin spacing

• Select measure sensitive to clustering; two shown here:
  • Mean 2nd-closest neighbour distance (M2CND)
  • Standard deviation of adjacent area (SDAA)
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- Compare clustering measure to histogram for series of random configurations of same population.

- Assess degree of clustering: SDs above/below mean.
Influence of boundary

- The range of possible values for a clustering measure for random configurations is sensitive to the shape of the counting area boundary.

- In this extreme example – a disjoint counting area – we see a trimodal variation of the mean closest neighbour distance measure.

- In general, differently shaped areas will show different ranges for the expected variation of the clustering measure (e.g. a circular crater floor vs. an elongated lava flow of equivalent area).

- This is the reason to use a numerical approach to the problem.
Example site: Pickering crater, Mars

- 80 km lava-flooded crater with a younger flow entering from NW
- Boundary is unambiguous
- Expect unit and its underlying basement to have well-defined ages
- No obvious modification: expect a ‘clean’ crater count here
- Some larger craters protrude through the flow from the underlying surface (Platz et al. 2010)
Pickering crater: randomness analysis

- Apparent clustering in smallest 88 m bin - measurement effect, cf. resolution fall-off

- ‘Well-behaved’ populations in 120, 180 and 250 m bins

- More separated than random populations in 350, 500 and 710 m bins

- ‘Well-behaved’ again in 2 km bin (1 and 1.4 km bins empty)
Pickering crater: non-random diameter range

- More separated than random populations in 350, 500 and 710 m bins. *Why?*

- Many of the craters located close to unit boundary

- Not obvious from visual inspection

- Likely relates to lesser flow thickness near the boundary: some of these craters belong to the underlying unit

- Exclude these bins from diameter range used to determine age, since this population is non-random
What is random?

- From a random scattering, any configuration is possible, but some are less likely than others.

- What is deemed likely or unlikely is determined by the clustering measure.

- Roughly 2 of 100 random configurations will lie beyond the $2\sigma$ boundary; 1 in 1000 beyond $3\sigma$.

- It’s always possible to construct special configurations which any one measure will not identify.
  - e.g. equidistant points around the edge of a circular unit would defeat the SDAA measure.

- Judgement should be a combination of the analysis result and an examination of the configuration for possible geological influences.
Conclusions

- A randomness analysis provides a deeper understanding of the spatial structure of a measured crater population
- Deviations in randomness measures can highlight the influence of geological modifications of the crater population
- Presentation of a randomness analysis can help others make an objective assessment of the quality of an age measurement
- The technique is of particular relevance to the study of early solar system impactor populations

Randomness analysis software

- Runs in IDL virtual machine, as Craterstats
  - Start from Craterstats utilities menu, or by double-clicking randomness_analysis.sav

- Select an .scc crater-count file produced by CraterTools
  - this file contains the crater locations and the unit boundary polygon as well as the diameters
  - can select more than one file with ctrl-clicks

- Program settings can be changed by editing randomness_analysis/settings.txt inside the craterstats folder
  - clustering measure
  - iterations
  - starting path for file-open operations

Planetary surface dating from crater statistics – PGM Meeting, USGS Flagstaff, 19 June 2012
Randomness analysis software

- Results are placed in a sub-folder where the .scc file resides
  - composite results figure
  - crater map
  - n_sigma plot

- Additionally, a text file containing a table of the n_sigma values is placed together with the .scc file
  - used by Craterstats to recreate the n_sigma plot
Randomness analysis software - task

• Modify the file randomness_analysis/settings.txt to use the m2cnd clustering measure

• Start craterstats, and then the randomness analysis utility

• Select the crater-count sample/Pickering.scc

• Wait for the analysis to finish, then examine the results

• Create a crater-count plot in craterstats, displaying the n_sigma diagram

• Create two fits for the basement age and the resurfacing age using appropriate diameter ranges, taking account of the randomness analysis results