Solid Earth Discuss.,
https://doi.org/10.5194/se-2020-83-RC1, 2020
© Author(s) 2020. This work is distributed under
the Creative Commons Attribution 4.0 License.

Solid Earth
Discussions

Interactive comment on "On a new robust workflow for the statistical and spatial analysis of fracture data collected with scanlines (or the importance of stationarity)" *by* Andrea Bistacchi et al.

rodrigo Correa (Referee)

rodrigo.correa@utexas.edu

Received and published: 17 July 2020

Comments to author: Manuscript number: se-2020-83 Title: On a new robust workflow for the statistical and spatial analysis of fracture data collected with scanlines (or the importance of stationarity)

To Bistacchi and others,

Overview

Printer-friendly version

Discussion paper

The paper presents a workflow to analyze the spatial organization of fractures in scanlines. The main distinguishing contribution of this paper is the use of stationarity as a prerequisite to calculate statistics. The proposed workflow is composed of two stages. The first stage is based on non-parametric analysis mostly based on cross-plots of rank-ordered position and spacings, to detect trends or patterns. If trends are recognized in the first stage, authors propose a normalization or division of scanline into sub-sets, to obtain stationary statistical properties. The second stage is based on a parametric analysis to define the most appropriate distribution to represent each stationary part of the scanline. The paper is a valuable contribution. They present a useful workflow to assess spatial organization of fractures. The discussion about stationarity in fracture networks is also an important concept, especially for statistical modeling and extrapolation purposes. I enjoyed the reading. The paper is well-written and I could understand the objectives, discussion and results. However, I do have minor revisions that I believe will help to improve comprehension of the readers and increase impact of the publication.

General Comments

1. You should add in your introduction more references related to the subject of spatial organization of fractures. Many important publications touching on this topic were not cited (e.g. Laubach et al 2018, Sanderson and Peacock 2019, Hanke et al 2018). The Journal of Structural Geology has a volume dedicated to this subject (Volume 108) and has plenty of relevant references that were not cited. You should compile some of these recent references in your introduction and expose how your method improves the analysis of spatial organization of fractures among what is already published.

2. Fractal distributions are only discussed in line 59, although they are commonly found in fracture systems. There is also no explanation of why power-laws were not included in the parametric tests. As fractal fracture networks have no characteristic size, I doubt that stationarity can be reached when analyzing these systems with your method. You should include a discussion about why you did not use power-laws in the parametric

CC BY

distribution and if the stationarity-based workflow would work in fractal networks too.

3. The segmentation of the scanline in “sub-sets” is excellent to separate stationary parts of your data. However, it may affect reliability of this workflow to identify spatial organization of clusters, since each domain is going to be analyzed separately. The advantage of methods that do not separate data into sub-sets, such as NCC, is the possibility to identify patterns in a variety of scales. Invariably if a segmentation is done, less information about the spatial organization will be available to be analyzed.

Specific comments

Line 24 – Twiss and Moores, 2006 is not really a reference for traditional fractured formation analysis, it is a general structural geology book. You should add here more examples of fracture analysis literature. A traditional one, to start, and that you should add here, is Pollard and Aydin 1988 that also talks about advancements in the topic along the last century.

Line 43 - You should add here some more references related to the topic of spatial organization of fractures.

Line 55 – Two other references may be worthy to include here. Hooker and Katz 2015 assessed the impact of syn-kinematic cementation on the spatial organization. Cladouhos and Marret 1996 assessed the evolution of fault systems through linkage and interaction during growth.

Line 58:59 – Clustering is also thought to be caused by difference in subcritical crack indexes. Suggest to include Olson’s publications in the references and discussion. (e.g. Olson 2004).

Line 61 – What is the scale of Large-scale trends? Please specify.

Line 92 – Another advantage of NCC is that is analyses non-neighbor fracture spacings, making it possible to calculate, for example, cluster spacing and width in the same analysis.

CC BY

Line 94 – You should explain in more detail what the term “cluster barycentres” mean.

Line 103 – I do not think that stationarity is prerequisite to detect a meaningful statistic. Stationarity should be a prerequisite to extrapolate statistics on a spatial domain (e.g. for geostatistical modeling of spatially distributed variables). Indeed, most used geostatistical algorithms demand stationary parameters as input (e.g. Sequential Gaussian Simulation; Sequential indicator simulation). However, if extrapolation/modeling is not the objective of the statistical analysis, the values are providing reliable information of the sampled scanline, and could be used for other objectives such as comparison between sites (which scanline has the biggest intensity? or which scanline has the biggest CV?). The term “meaningful statistic” is present along the text in many places. I suggest you provide a wider context and explain such impactful statement.

Line 140:143 – Here you should include a discussion about stationarity in fracture networks with fractal or power-law distributed spacings. These types of network may never reach stationarity because they lack characteristic size.

Line 142 - What is the scale of small-scale? Please specify.

Line 200 – The weblink requires a password, could not access it.

Line 221 – It is confusing how you refer to the tests here. Could you be more specific? Maybe you could refer to it as Position-Spacing test and Spacing-Spacing test. Other option is to define clearly in text what are you calling of first and second tests.

Line 309:310 – Interesting conclusion. I imagine that the polynomial function you choose to model the trend is going to impact the resulting residual, i.e. the normalized scanline. It is not clear to me if your method is sensible to overcome poor trend fitting. Probably for each different trend fit, residuals are going to be different too, and that may ultimately affect the type of distribution you identify in the residual parametric test. Did you assess how the residuals changed for each fit using different order polynomials? This assessment may give you and your readers more confidence in the

Printer-friendly version

Discussion paper

CC BY

proposed workflow. It would show that the log-normal distribution identified here is the fracture system signal and not an artifact from the trend removal.

Line 316 - Is there an explanation of why joint and extensional veins were considered together in your analysis? Do you think they pertain to the same fracture set and are genetically related? I imagine joints have no cement in it, and veins have been cemented. Why would joints not be affected by the cementation phase of the veins, if they are timely related? Your analysis of spatial organization considers both joints and veins together. Therefore, they must be interpreted as genetically related. Otherwise the interpretations in lines 344-349 will not be true. Keep in mind that if you are describing the spatial organization of two different sets together, you should not use that information to think about the fracture genesis or evolution, as they could have developed in very different time with different history.

Line 344:349 - That is a very interesting conclusion. My only concern is on the fact that joints and veins are here being analyzed together. If they pertain to the same set, why does joints not been affected by cementation as the veins were? Maybe they have a different timing. If so, I would recommend doing analysis separately. Cementation can affect the spatial organization of fractures (Hooker and katz, 2015; Hooker et al 2018, Laubach et al 2019). An analysis separating them in two sets (in case it is applicable) may yield a different conclusion.

Line 353 – Why is Poisson distribution not reliable? Please explain.

Line 362 - It can be meaningless. I would add that it can be meaningless to extrapolate statistical behavior in a spatial domain.

Line 375:383 – You should add here a discussion of your workflow applied to power-law distributed (fractal) networks. I believe you should also assess power-law distribution in the parametric tests. If your method is not applicable to fractal fracture networks, you should acknowledge here. If it is applicable, explain why you did not use it in the parametric test, since it is a common distribution observed in fracture networks.

CC BY

Line 386:387 - NCC can identify clusters or periodic behavior even without the normalization by the large-scale trend. It happens because it uses non-neighbor fracture spacings. It may be possible for example to see a periodic behavior in a large scale (10-100m) and a clustered behavior in smaller scales (<1m). If you are using NCC, there is no need to build a stationary data. However, if you use stationary data subsets you will have a partial result, it will not be able to see spatial organization of clusters with respect to each other or spatial organization of large length-scales in the data, because it is segmented.

Technical corrections

Line 291 – blue line color description does not match the figure.

Line 292 – green line color description does not match the figure.

Line 385 – Please rewrite this sentence "...and will help better understanding the development of fracturing...". It does not sound complete.

The papers below are referenced in the text but are not listed in the reference list:

Line 134 – Borradaile, 2003

Line 135 – Caine and Forster, 1999; Mitchel and Faulkner 2009

Line 145 – Wasserman, 2004

Line 266 – Lilliefors, 1967; Lilliefors, 1969

Line 275 – Ogata et al 2017

Line 276 – Bistacchi et al 2015

Line 314 – Korbar, 2009; Mittempergher et al 2019

Line 390 – Dershowitz et al 2003; Elmo and Stead 2010; Bonneau et al 2016

Figure comments

CC BY

Figure 1/Line 69 – Numbers (1)...(8) are not shown in the figure. Add number in the figure for better comprehension of figure captions.

Figure 1/Line 70 – CSF and CSD were not explained in the text before this figure. I suggest to include the full name of those here, or include a brief explanation in the text before you reference this figure.

Figure 1/Line 72 - The abbreviation EDF was not defined anywhere on text. Please define it somewhere before the figure or in the figure caption.

Figure 5a – The CSD graph shows a blue curve without identification.

Good luck,

Interactive comment on Solid Earth Discuss., https://doi.org/10.5194/se-2020-83, 2020.

Printer-friendly version

Discussion paper

CC BY