Solid Earth Discussions

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Comment on se-2021-45

David Sanderson (Referee)

Referee comment on "Investigating spatial heterogeneity within fracture networks using hierarchical clustering and graph distance metrics" by Rahul Prabhakaran et al., Solid Earth Discuss., https://doi.org/10.5194/se-2021-45-RC2, 2021

This paper is an interesting contribution to an important topic – the analysis spatial variation in fracture networks. The paper introduces some methods, established in other areas but new to this area of earth science. The work is based on some interesting field data, and is both well written and illustrated. I recommend publication, but offer the following comments (see also comments on early sections in annotated pdf).

Section 1,2

The authors provide a concise, clear background to the treatment of fracture networks as graphs (Section 2). The level of explanation is appropriate for the rest of the paper, but I highlight, in an annotated version of the manuscript, a few areas that the authors might want to clarify or omit.

Section 3

The introduction to the field area is similarly clear and concise. There is no mention of a recent paper by Procter and Sanderson (2017) that discusses the spatial variability of fractures in the same geological units, just a few kilometres to the west. This paper not only uses graphs to represent the network, but also provides a statistical evaluation of the between layer and within layer variability of fracture intensity.

Section 4: Methods

Section 4.2 discusses a range of graph measures used in the subsequent hierarchical clustering. There is a lot of technical detail in the definition of these measures, which is difficult to follow but the sources are all clearly stated. What would be most helpful to the reader would be an evaluation of what each measure is contributing in terms of the geometry and topology of the network. For example:

- The "fingerprint measure" clearly defines a block "shape", both in terms of the number of sides and aspect ratio of the overall shape. Given that most block have 4-6 sides, an average aspect ratio would a little less than 2 and I would expect that this parameter

would mainly be reflecting variation in aspect ratio.
- The D-measure is mainly based on the clustering of the node distribution. Given that the divergence and alpha centrality seem to vary little, I would think this measure mainly reflects variation in the node intensity, which seems to be supported by Fig. 14.

It would be good to have a similar evaluation of the other measures. In particular, it is not clear to me how the variation in fracture orientation is captured by these measures. Since the distribution of sets with differing orientation is a major feature of at least two of these regions (Passchier et al 2021), it is surprising that this aspect is omitted from description of the measures and appears to play little role in the clustering..

Section 5: Results

This provides a detailed analysis of three regions and presents the results of the mapping of spatial variability in terms of the HC of the measures used. The results are presented through sets of five similar diagrams for each of the three regions. Some of the material in these diagrams could be transferred to "supplementary material" (e.g. heat maps and dendrograms of the clustering).

It is probably worth comparing the characteristics of each region. From Table 1, the number of fractures/branches/nodes, with similar ranges of fracture intensity (P21) in Figs 9, 14 and 19. The average degrees are also very similar (~3.15) indicating a close approximation to a 3-regular graph (or mesh). Apart from the "fingerprint" of block shape (Fig. 7e), there is no information on the distributions of the other measures used in the clustering.

It seems to me, that Region 2 illustrates the strengths and weaknesses of the methodology, so starting with a complete analysis of this area would make sense. The other two regions could then be treated more concisely, with emphasis on what they contribute to the study.

Section 6: Discussion

In the section on choice of graph metrics, the paragraph from lines 378-386 is key to this paper. An unweighted graph cannot contain information on geometry, since a graph is invariant to change in shape and size. Thus, geometry must be represented through the embedding of the graph in a (geographical) space or by including geometrical measures in the weights. The former allows specification of orientation and length, and measure of the frequency and intensity of elements to unit area. The way this paragraph is written implies that length and orientation could be incorporated but were not in the present study – this is "shooting one's self in the foot".

Conclusions and Abstract

Both these sections are written in a vague way, expressing the aims and aspirations of the study, instead of focusing on the main findings.

David J Sanderson

Procter, A., Sanderson, D.J., 2017. Spatial and layer-controlled variability in fracture networks. Journal of Structural Geology doi.org/10.1016/j.jsg.2017.07.008.

Please also note the supplement to this comment:
https://se.copernicus.org/preprints/se-2021-45/se-2021-45-RC2-supplement.pdf