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A new stability test for high-resolution palaeomagnetic data

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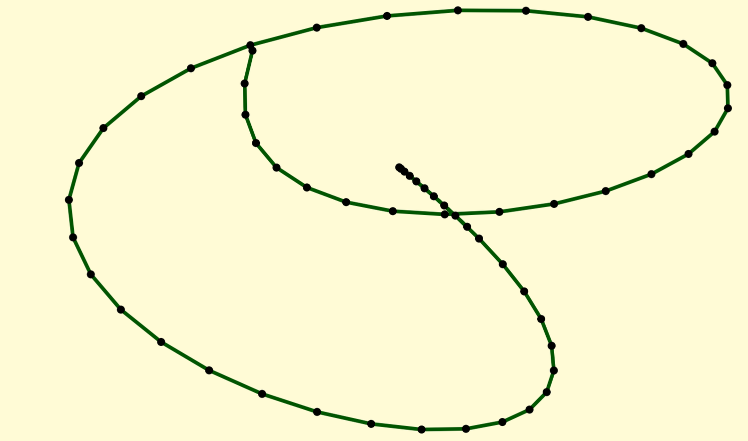
Introduction

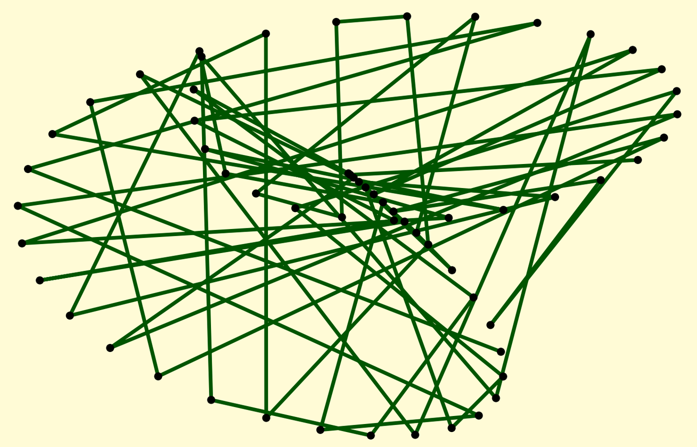
Assessing the reliability of palaeomagnetic directions is a long-standing problem. One popular technique is the use of field tests of palaeomagnetic stability (e.g. Graham, 1949), which analyse the palaeomagnetic directions themselves in the context of their position in the section or core. Perhaps the best known is the reversals test, which determines whether the mean direction computed from the normal-polarity sites is antiparallel to the mean direction for the reversed-polarity sites. Only a small number of stability tests have been devised, and none are universally applicable. We describe a new addition to this arsenal.

The continuity test

Our proposed stability test, the **continuity test**, is aimed at high-resolution studies sampled at sub-kiloyear intervals, and attempts to detect *continuity* in a record of palaeomagnetic directions. Mechanisms which produce spurious magnetization (e.g. heating, lightning, and diagenesis) are unlikely to produce a continuously varying sequence of directions. Thus, a sequence of directions which displays continuous variation is likely to represent a genuine palaeomagnetic record.

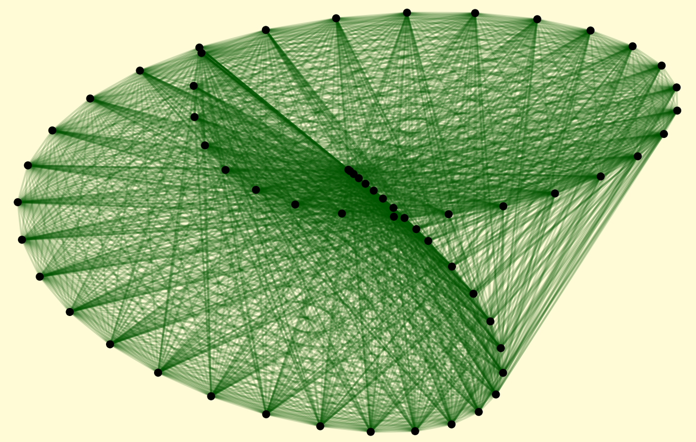


A set of points ordered along a continuous curve. It can be seen that they follow a gently arcing path similar to a secular variation curve.



The same points, connected in a random order. The 'path-like' property is not evident here.

With a finite number of data points, it is impossible to characterize a curve as 'continuous' in the strict mathematical sense. However, we can attempt to formalize the observed difference between 'path-like' behaviour and 'random' behaviour as seen in the figures above.



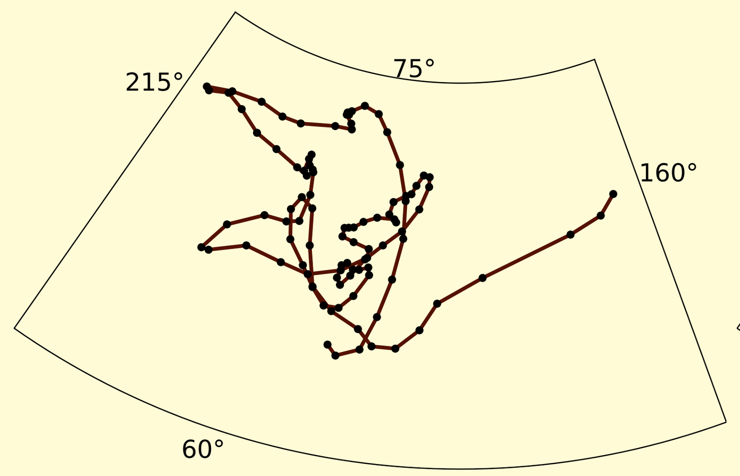
Every possible point-to-point connection.

Along a path, the average point-to-point distance tends to be shorter than for arbitrarily ordered points. The continuity test calculates the average angular distance between consecutive measurements, and compares it with the average angular distance between *all* pairs of measurements. While it is possible that the mean adjacent-point distance will be lower than the overall mean distance purely by chance, this possibility can be reduced by subsetting the data, as described in the results sections.

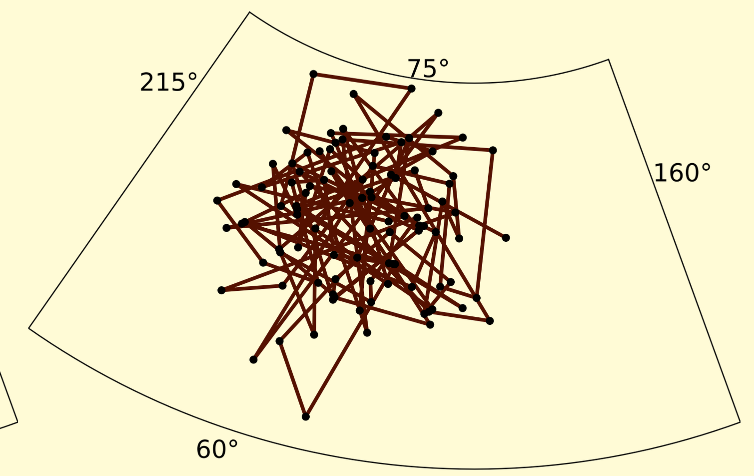
Results on modelled data

We applied the continuity test to two sets of modelled data. The first was generated using the CALS10k.1b model (Korte et al., 2011) for an arbitrary point on the Earth's surface, to represent an idealized set of palaeomagnetic measurements. We generated 10 kyr of data, sampled at 100 yr intervals to give 100 data points.

To simulate data with non-palaeosecular variation we generated a corresponding set of random data. These data were drawn from a Fisher distribution with a mean direction and κ value calculated from the CALS10k data. This distribution was intended to represent spurious variation caused by bioturbation, diagenesis, sample alignment errors, machine noise, and other random factors.

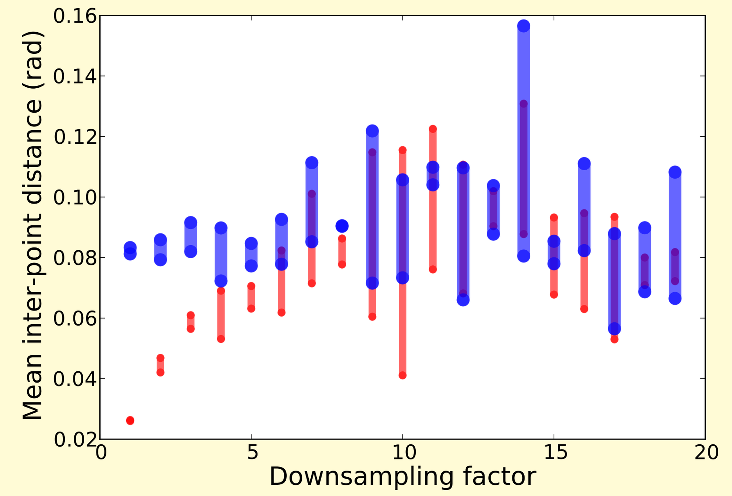


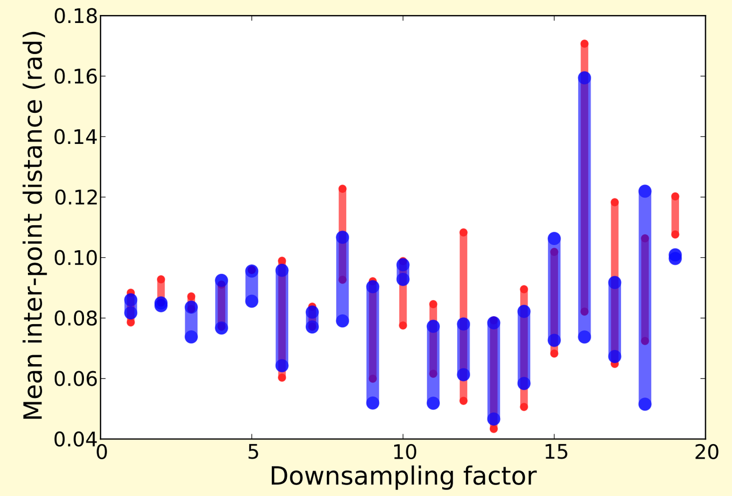
Data generated from the CALS10k model.



Random Fisherian data with the same parameters.

We applied the continuity test to these data sets. To reduce the chance of false positives, we split each dataset into two subsets, each downsampled by a factor of two. (Thus, set 1 contains all the odd-numbered measurements, and set 2 the even-numbered). The continuity test was considered positive only if *both* the mean adjacent-point distances were below *both* the overall mean inter-point distances.

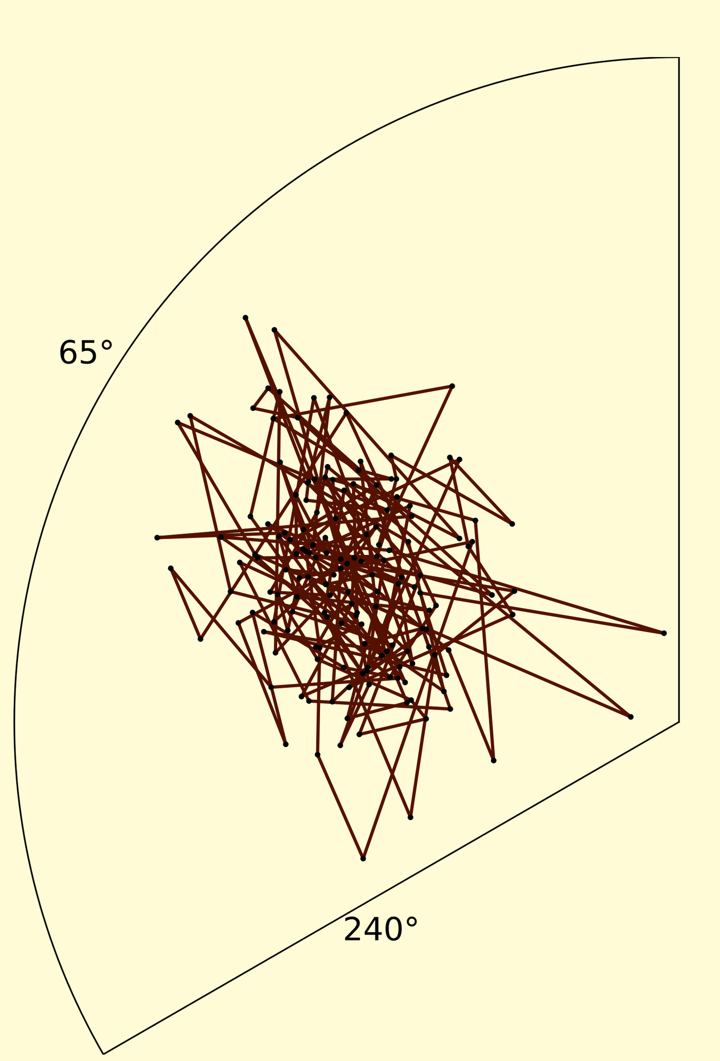




Continuity test results at various downsampling factors for CALS10k (left) and Fisherian (right) data. Spread of all inter-point distances shown by blue line; spread of adjacent inter-point distances shown by narrower red line. The test passes when the red line is entirely below the blue.

To evaluate the test's performance on sparsely sampled data, we applied it both to the original data sets and to downsampled versions of these data. As the figure above shows, the continuity test could distinguish between CALS10k and Fisherian data for downsampling factors of up to five, corresponding to a 500 yr sampling interval.

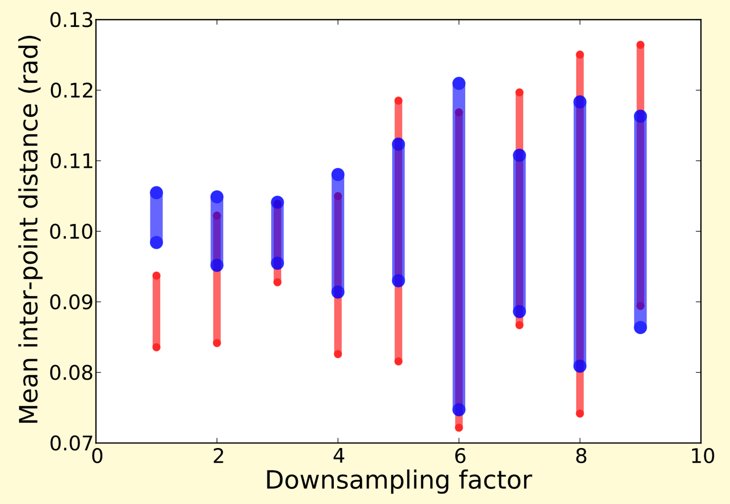
Results on measured data



Directions from ODP core 744A; every fifth point plotted.

We applied the continuity test to early Oligocene data from ODP core 744A which is already known to constitute a reliable palaeomagnetic record (Roberts et al., 2003). We split the data into five equally spaced subsets, rather than the two subsets used for the model data. This increases the specificity of the test, and more importantly avoids any convolution effects: the core was measured at 1 cm intervals using a magnetometer with a ~4.5 cm response function, so spurious path-like behaviour woud be expected in the raw data. Note that, when the directional data are downsampled to this resolution (as shown at left), it is difficult to detect any path-like characteristics by visual inspection: the data looks similar to the random Fisherian data generated for the model data test.

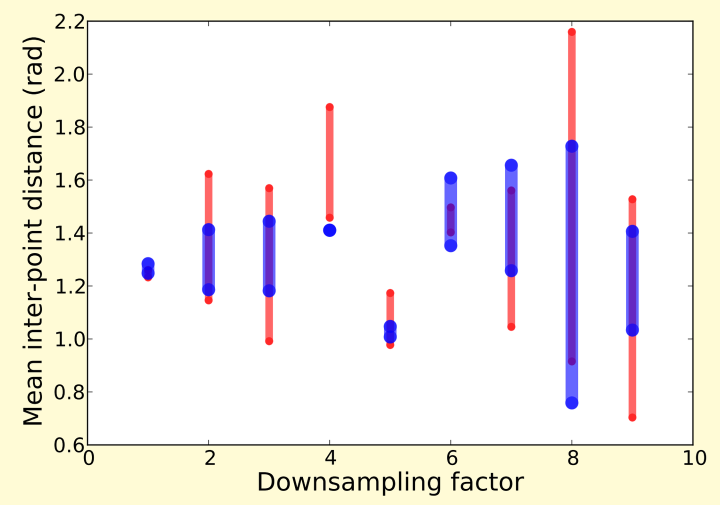
The 744A record passes the 'five-subset' form of the test. In contrast to the model data, the downsampled versions of the record do not pass; this is probably due to the relatively low sedimentation rate in this record (~7.5 m/Myr in the section used for this experiment), and to the larger number of subsets used.



Results of the continuity test on core 744A. The non-resampled record passes the test, although the downsampled versions do not.

We achieved similarly successful results from further tests on continuous core records with higher sedimentation rates. From the results of the 744A test, it seems likely that the sedimentation rates determined for this core are close to the lower limit for the applicability of the continuity test. This limit assumes the necessity of downsampling to 5 cm to avoid convolution effects; it may be possible to extend it by mathematically deconvoluting the data before analysis (see e.g. Jackson et al., 2010).

Results on 'bad' data



To evaluate the test's ability to produce a negative result for unreliable data, we conducted a deliberately flawed analysis of data from a discrete sample study at Fairfield Quarry, New Zealand (Lurcock, 2012). Palaeomagnetic directions were fitted from demagnetization steps heavily affected by thermal alteration. As would be expected, the continuity test gives negative results, both for the raw data and for downsampled data sets.

Conclusions

The continuity test shows promising preliminary results on both modelled and measured data: in the experiments conducted so far, it accurately distinguishes genuine palaeomagnetic variation from spurious remanence.

Like other stability tests, it is not universally applicable: most obviously, it requires sufficiently dense sampling. Our results so far suggest that the sample spacing in the time domain must be below ~1 kyr for the test to be effective. Many continuous-core records fulfil this criterion when measured at 1 cm intervals in a long core magnetometer.

The continuity test is still undergoing evaluation and refinement. The main remaining challenge is to produce quantitative statistical results from the test. At present, it delivers a simple pass/fail result. An informal measure of the result's 'strength' can be obtained by looking at the difference between the subsets on the graph; however, it would be more useful to generate a numerical estimate of the probability that a given data-set is showing 'PSV-like' behaviour, allowing the test result to be associated with a confidence interval. Bootstrap techniques, already successfully applied to the fold test (Fisher & Hall, 1990), show promise in achieving this goal.

Another potential development is the expansion of the test to produce 'windowed' results for a series of sub-sequences within a long core. Rather than a single result, this would provide a running index corresponding to particular parts of a core, allowing more and less reliable parts of a palaeomagnetic record to be distinguished.

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