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Supplementary material

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Appendix 1.   Assessment of correlations between GIS-based, gridded climatic data and elevation in the *Nothofagus* treeline zone across New Zealand.

Appendix 2. A description of the hierarchical data structure and scale-dependent regression analyses using random effects coefficients.

Appendix 3. Pearson's correlations among random effects coefficients for the eight abiotic factors at each of the five spatial scales.

Appendix 4 – Moran's I correlograms, used to assess the presence of spatial autocorrelation in the residuals of the top-ranked multiple linear regression models at each of the five scales.

Appendix 1. Assessment of correlations between three GIS-based, gridded climatic variables and elevation in the *Nothofagus* treeline zone across New Zealand.

As the response variable used in our analyses was treeline elevation, it was necessary to avoid using available climatic data in our analyses that were possibly highly correlated with elevation due to the way they were derived. We initially considered two spatial climatic datasets for use in our analyses: extreme wind days and water balance ratio. The spline interpolation procedures used to generate these datasets from long-term weather station records included elevation-related adjustments(Leathwick et al. 2002a) to account for changing climatic processes with increasing elevation. The inclusion of elevation as a covariate in the interpolation procedures therefore aims to locally adjust the broad spatial estimates derived from the weather station data alone.

We assessed the degree to which these two datasets were correlated with elevation in the general zone of transition from forest to alpine vegetation, between 500m and 1500m above sea level. We did this by randomly generating 1000 points in the GIS within this transition zone in areas where *Nothofagus* treelines occur across New Zealand. At these points, we extracted elevation from a 25m resolution digital elevation model, and values for the two climatic variables. The extreme wind days dataset was at a 500m resolution and was obtained from the New Zealand National Institute for Water and Atmosphere (Wratt et al. 2006)and the water balance ratio dataset was at a 100m resolution and was available as part of the Land Environments of New Zealand database (Leathwick et al. 2002b).

Extreme wind days and water balance ratio were only weakly correlated with elevation within the *Nothofagus* treeline forest-alpine transition zone (Figures A1 a and b).

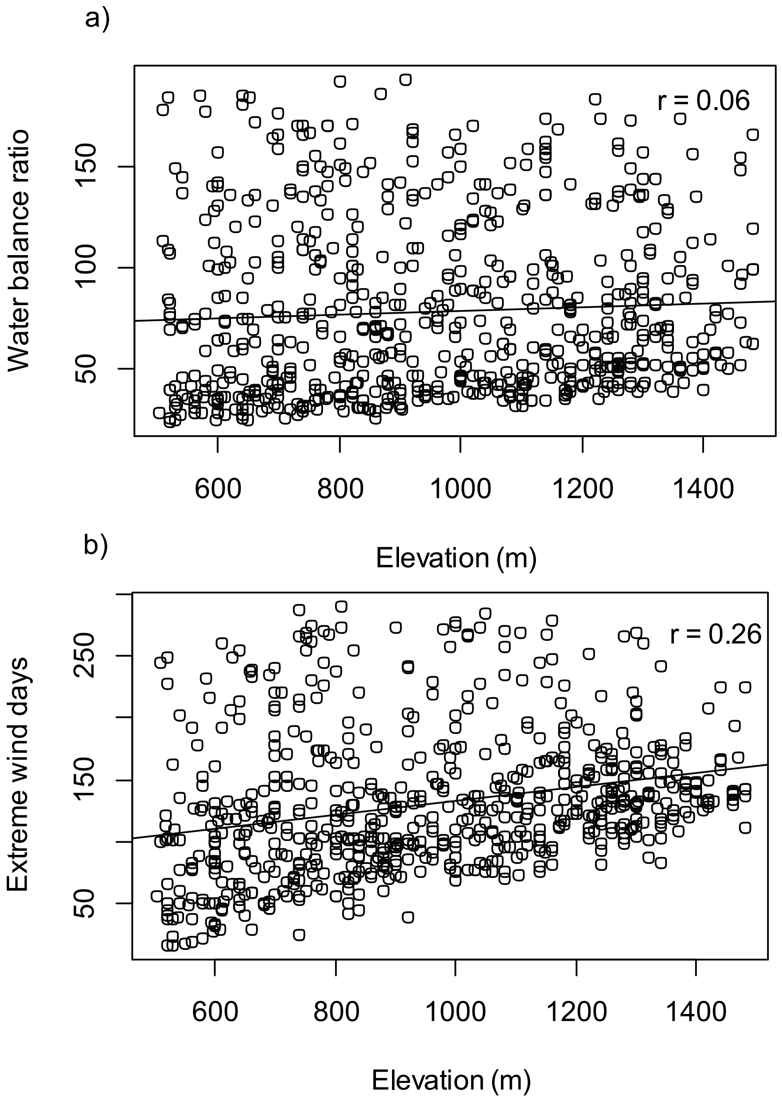


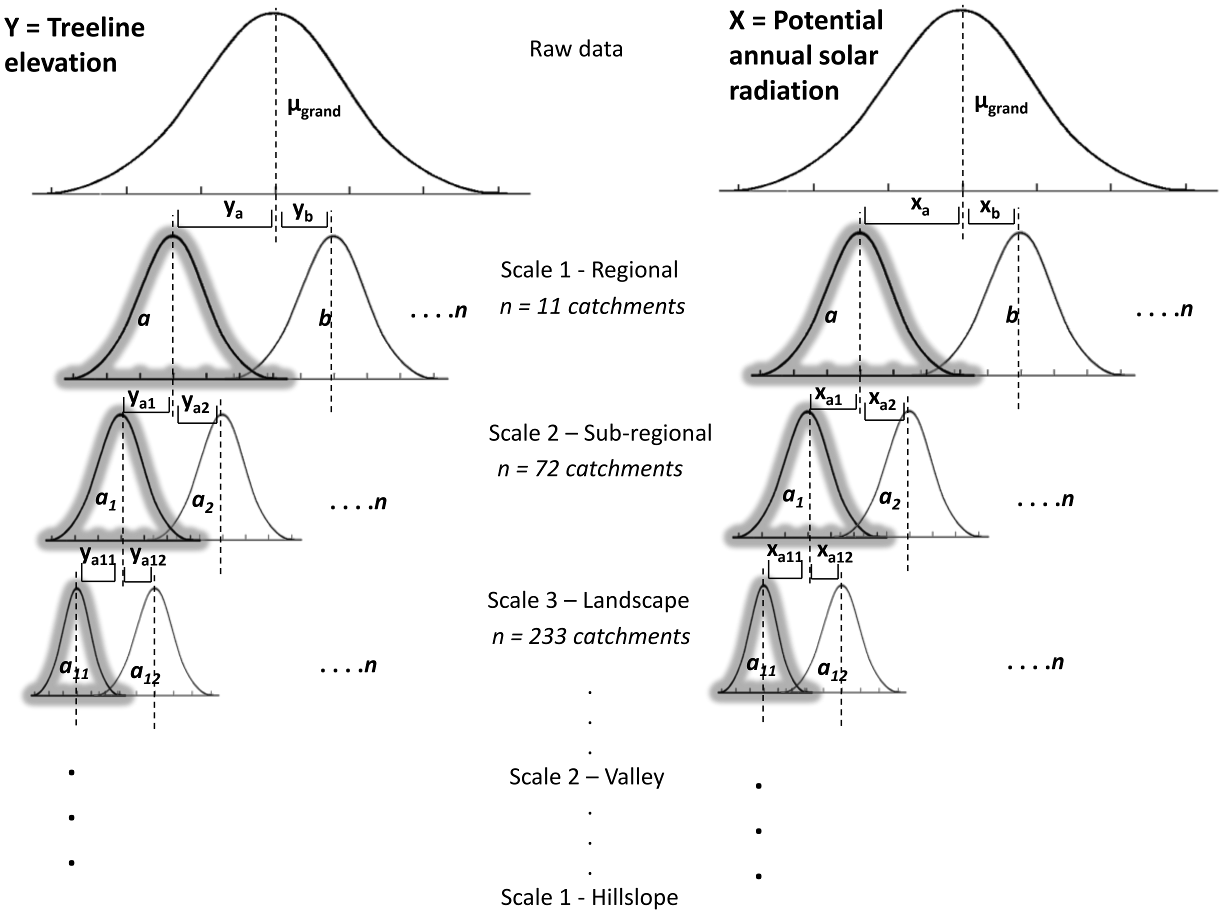
Figure A1. Scatterplots showing trends between two climatic variables and elevation extracted at 1000 random points within the *Nothofagus* treeline forest-to-alpine transition zone (500 – 1500m elevation) across New Zealand.

References

Leathwick, J. R. et al. 2002a. Climate Surfaces for New Zealand. - Landcare Research, Lincoln, New Zealand.

Leathwick, J. et al. 2002b. Land environments of New Zealand: a technical guide. - New Zealand Ministry for the Environment.

Wratt, D. S. et al. 2006. Climate for crops: integrating climate data with information about soils and crop requirements to reduce risks in agricultural decision-making. - Meteorological Applications 315: 305–315.



Appendix 2. A description of the hierarchical data structure and regression analyses using random effects coefficients.

Figure A2. A conceptual diagram to illustrate the hierarchical structure of the data and the analyses used in the study. Details are provided below.

Hierarchical structuring of the data and random effects coefficients

Figure A2 first of all illustrates how data for treeline elevation (on the left) and the abiotic variables (potential annual solar radiation shown as an example on the right) used in our analysis are hierarchically structured based on nested river catchments. The bell curves represent conceptually the distribution of data extracted at treeline sample points, spaced at 500m intervals along treelines, within different catchments (spatial units) at different scales. The distribution at the top is for the full dataset (eg. 53,912 data points at treeline). At each scale, the data are partitioned by catchments, which are treated as random effects. At scale 1, for example, the datasets as a whole are partitioned into 11 regional-scale catchments. At scale 2, the data are partitioned into 75 sub-regional-scale catchments, each of which are nested within one of the 11 catchments at scale 1. This structure is repeated across the five scales used in the analysis.

Using the hierarchical structure described above, data for each variable (treeline elevation and each of the eight abiotic explanatory variables) were initially modelled using an intercept-only, hierarchical linear model (ie. random intercept mixed effects model). These models simply represent how the random intercepts produced by the model for each spatial unit (catchment) at each scale deviate from the random intercept of the catchment at the scale above, within which they are nested. These random intercept deviations are termed "random effects coefficients". For example, in Figure A2, y_a and y_b are the random effects coefficients that describe the deviation of the treeline elevation intercepts for catchments *a* and *b* at the regional scale (Scale 1) away from the overall mean treeline elevation across all of the data (μ). In this case, the intercept for catchment *a* is lower (ie the random effect coefficient y_a is negative) than the overall treeline elevation mean, while the intercept for catchment b is higher (the random effect coefficient y_b is positive). Similarly, intercepts for treeline elevations within catchments at Scale 2 deviate away from the intercepts for the Scale 1 catchments within which they are nested. For example, the random effects coefficient y_{a1} shows a negative deviation of the treeline elevation intercept for catchment a_1 (which is nested within catchment *a*) away from the catchment *a* intercept. Thus, the random effects coefficients at each scale represent the variability in the data for a given variable (eg. treeline elevation, potential annual solar radiation, etc.) at that scale, independent of the other scales.

Regression analyses at each scale

The main aim of our study was to determine to what extent treeline elevation variation was associated with variation in the eight abiotic explanatory variables at the five scales of interest. We achieved this by regressing the random effects coefficients for treeline elevation at each scale (as the response variable) against the random effects coefficients for the eight abiotic variables. For example (referring to Figure A2 above), a vector notation representation of a simple regression between treeline elevation and potential annual solar radiation at Scale 1 would be achieved as:

$$\begin{bmatrix} y_a \\ y_b \\ \cdot \\ \cdot \\ y_n \end{bmatrix} = \begin{bmatrix} 1 & x_a \\ 1 & x_b \\ \cdot & \cdot \\ \cdot & \cdot \\ 1 & x_n \end{bmatrix} \begin{bmatrix} ß_0 \\ ß_1 \end{bmatrix} + \begin{bmatrix} \varepsilon_a \\ \varepsilon_b \\ \cdot \\ \cdot \\ \varepsilon_n \end{bmatrix}$$

where y_i are random effects coefficients for treeline elevation at Scale 1, x_i are random effects coefficients for a given abiotic factor (solar radiation, water balance ratio etc.) at Scale 1, and β_0 and β_1 are the intercept and slope parameters of the regression model. The regression error, $\varepsilon_i \sim^{\text{iid}} N(0,\sigma^2)$.

If the relationship between the random coefficients for treeline elevation and those for potential annual solar radiation at Scale 1 were positive, this would indicate that treeline elevation and potential annual solar radiation both deviate from their overall grand intercepts in a positive way across the catchments at Scale 1, thus suggesting that higher treeline elevations are correlated with higher potential annual solar radiation values at Scale 1. This type of regression was repeated at all other scales to look at scale-dependent relationships between treeline elevation and the eight different abiotic variables. Multiple regression models were constructed in a similar way, with random effects coefficients for multiple abiotic variables regressed against those for treeline elevation. Thus, the regression analyses at each scale are accounting for how variation in treeline elevation is associated with variation in abiotic variables, independent of the other scales.

Appendix 3. Pearson's correlations among random effects coefficients for the eight abiotic variables at each of the five spatial scales.

Scale 1 – Regional

	Potential annual solar rad.	Mountain mass index	Compound topographic index	Water balance ratio	Extreme wind days	Soil nutrients	Soil moisture holding capacity	Earthquake intensity
Potential annual solar rad.	1	-0.233	-0.664	-0.574	-0.155	-0.522	-0.281	-0.593
Mountain mass index	-0.233	1	0.547	-0.292	-0.459	-0.324	0.493	-0.298
Compound topographic index	-0.664	0.547	1	0.247	-0.054	-0.004	0.577	0.188
Water balance ratio	-0.574	-0.292	0.247	1	0.206	0.298	-0.306	0.754
Extreme wind days	-0.155	-0.459	-0.054	0.206	1	0.449	-0.135	0.029
Soil nutrients	-0.522	-0.324	-0.004	0.298	0.449	1	-0.036	0.529
Soil moisture holding capacity	-0.281	0.493	0.577	-0.306	-0.135	-0.036	1	-0.248
Earthquake intensity	-0.593	-0.298	0.188	0.754	0.029	0.529	-0.248	1

*At the regional scale, CTI and Earthquake intensity were omitted as explanatory from multiple regression analyses due to relatively strong collinearity with other variables.

Scale 2 – Sub-regional

	Potential annual solar rad.	Mountain mass index	Compound topographic index	Water balance ratio	Extreme wind days	Soil nutrients	Soil moisture holding capacity	Earthquake intensity
Potential annual solar rad.	1	-0.219	0.116	-0.368	0.266	-0.021	0.197	-0.395
Mountain mass index	-0.219	1	-0.036	0.064	-0.218	-0.007	<.001	0.116
Compound topographic index	0.116	-0.036	1	-0.394	-0.027	0.026	0.121	-0.24
Water balance ratio	-0.368	0.064	-0.394	1	0.02	0.177	-0.055	0.545
Extreme wind days	0.266	-0.218	-0.027	0.02	1	0.223	-0.047	0.031
Soil nutrients	-0.021	-0.007	0.026	0.177	0.223	1	0.352	0.318
Soil moisture holding capacity	0.197	<.001	0.121	-0.055	-0.047	0.352	1	-0.108
Earthquake intensity	-0.395	0.116	-0.24	0.545	0.031	0.318	-0.108	1

Scale 3 – Landscape

	Potential annual solar rad.	Mountain mass index	Compound topographic index	Water balance ratio	Extreme wind days	Soil nutrients	Soil moisture holding capacity	Earthquake intensity
Potential annual solar rad.	1	-0.202	0.093	-0.17	0.137	-0.139	0.008	-0.134
Mountain mass index	-0.202	1	0.135	-0.001	-0.125	0.023	0.027	0.06

Compound topographic index	0.093	0.135	1	-0.32	-0.14	0.033	0.192	-0.149
Water balance ratio	-0.17	-0.001	-0.32	1	0.14	0.191	0.03	-0.516
Extreme wind days	0.137	-0.125	-0.14	0.14	1	0.133	-0.108	-0.535
Soil nutrients	-0.139	0.023	0.033	0.191	0.133	1	0.485	0.179
Soil moisture holding capacity	0.008	0.027	0.192	-0.108	-0.047	0.485	1	0.031
Earthquake intensity	-0.134	0.06	-0.149	-0.535	0.037	0.179	0.031	1

Scale 4 – Valley

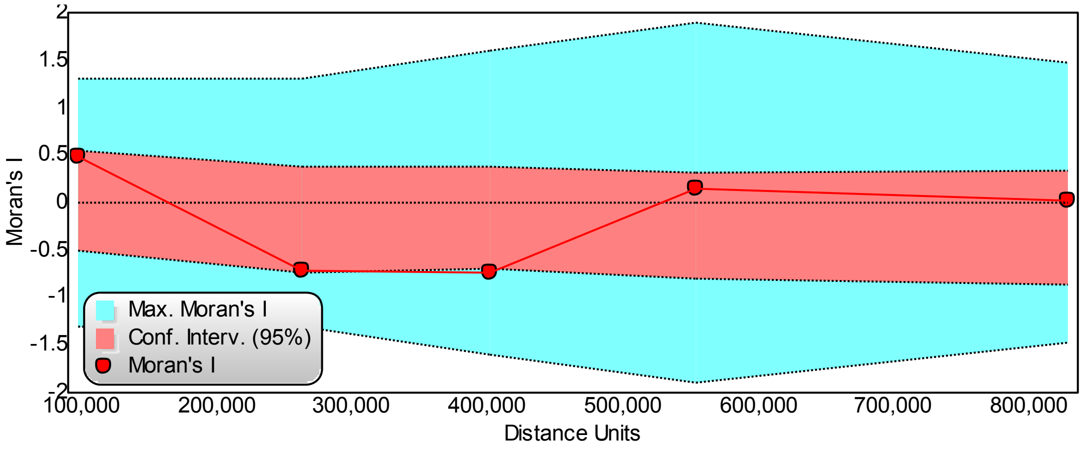
	Potential annual solar rad.	Mountain mass index	Compound topographic index	Water balance ratio	Extreme wind days	Soil nutrients	Soil moisture holding capacity	Earthquake intensity
Potential annual solar rad.	1	-0.068	0.034	-0.115	0.286	0.024	0.013	-0.094
Mountain mass index	-0.068	1	0.007	0.046	0.174	-0.042	-0.032	0.036
Compound topographic index	0.034	0.007	1	-0.103	0.032	0.012	0.074	-0.011
Water balance ratio	-0.115	0.046	-0.103	1	0.136	0.09	-0.102	0.494
Extreme wind days	0.286	0.174	0.032	0.136	1	-0.088	-0.062	<.001
Soil nutrients	0.024	-0.042	0.012	0.09	-0.088	1	0.11	0.165
Soil moisture holding capacity	0.013	-0.032	0.074	-0.102	-0.062	0.11	1	-0.02
Earthquake intensity	-0.094	0.036	-0.011	0.494	<.001	0.165	-0.02	1

Scale 5 – Hillslope

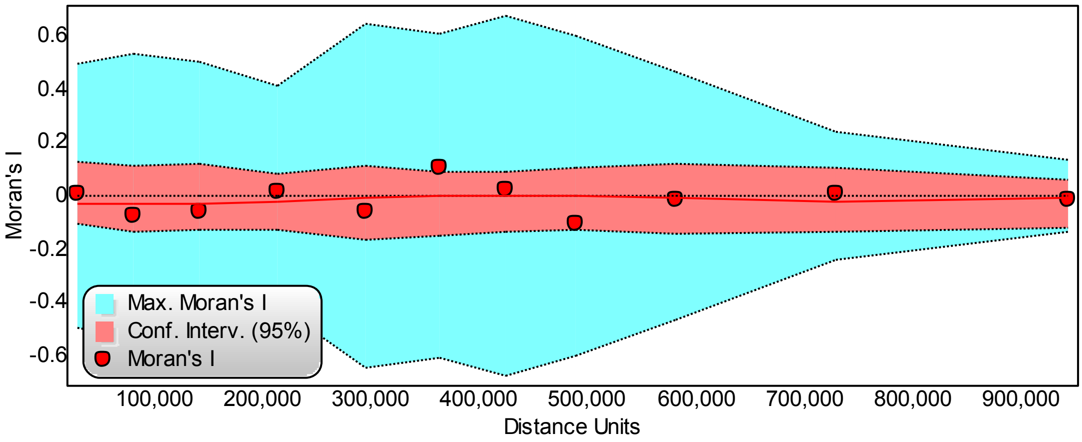
	Potential annual solar rad.	Mountain mass index	Compound topographic index	Water balance ratio	Extreme wind days	Soil nutrients	Soil moisture holding capacity	Earthquake intensity
Potential annual solar rad.	1	0.008	-0.016	0.008	0.459	0.062	-0.058	-0.077
Mountain mass index	0.008	1	0.012	-0.041	0.072	-0.021	-0.005	<.001
Compound topographic index	-0.016	0.012	1	-0.09	0.123	0.019	0.038	0.029
Water balance ratio	0.008	-0.041	-0.09	1	0.222	-0.082	-0.058	-0.022
Extreme wind days	0.459	0.072	0.123	0.222	1	-0.102	-0.086	-0.022
Soil nutrients	0.062	-0.021	0.019	-0.082	-0.102	1	-0.053	0.063
Soil moisture holding capacity	-0.058	-0.005	0.038	-0.058	-0.086	-0.053	1	-0.023
Earthquake intensity	-0.077	<.001	0.029	0.321	-0.022	0.063	-0.023	1

Appendix 4. Moran's I correlograms, used to assess the presence of spatial autocorrelation in the residuals of the top-ranked multiple linear regression models at each of the five scales.

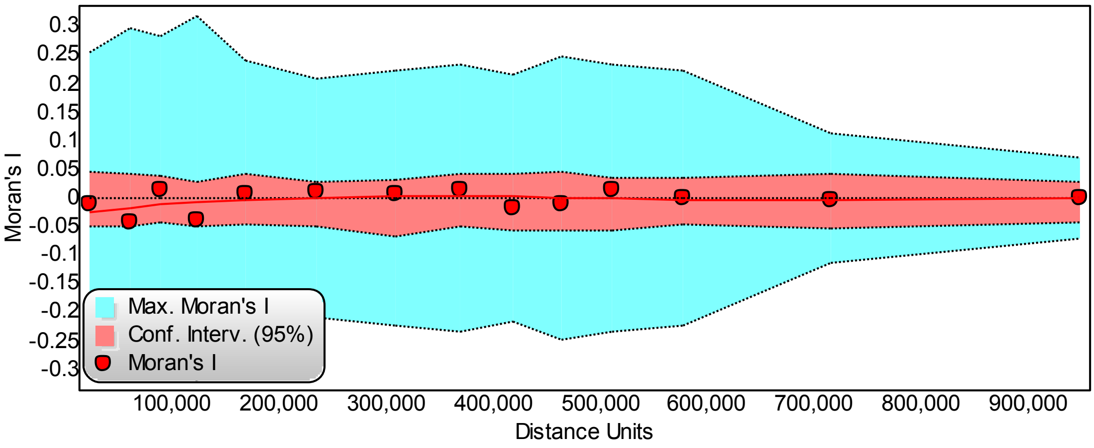
Scale 1 – Regional



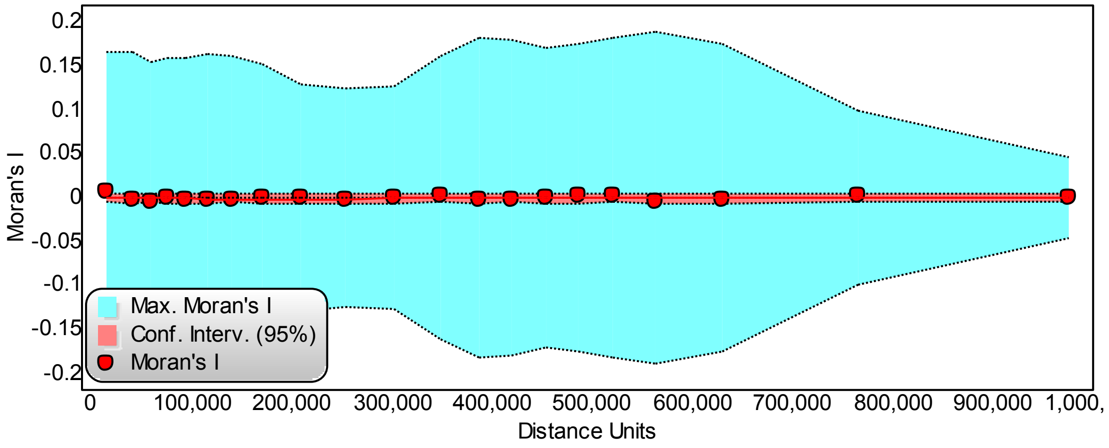
Scale 2 – Sub-regional



Scale 3 – Landscape



Scale 4 – Valley



Scale 5 – Hillslope