Geostatistical interpolation and simulation of geologic properties in consideration of regional deformation

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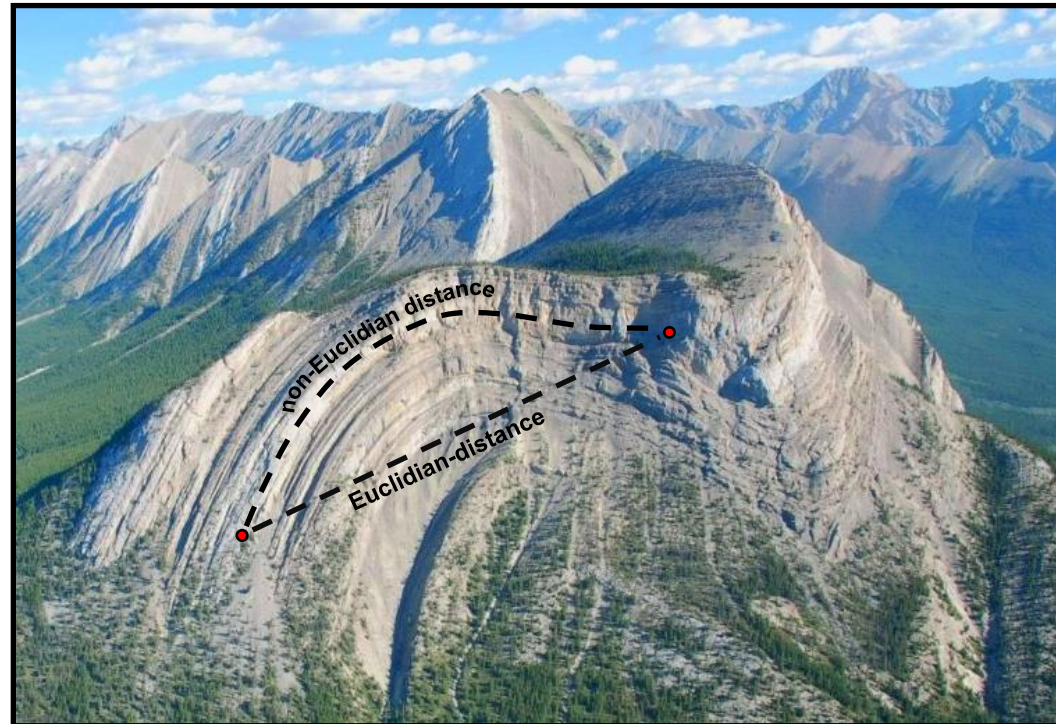[2]Aachen Institute for Advanced Study in Computational Engineering Science, RWTH Aachen, Germany
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Question: In domains featuring structural deformation, which distance should we use to model spatially correlated properties?
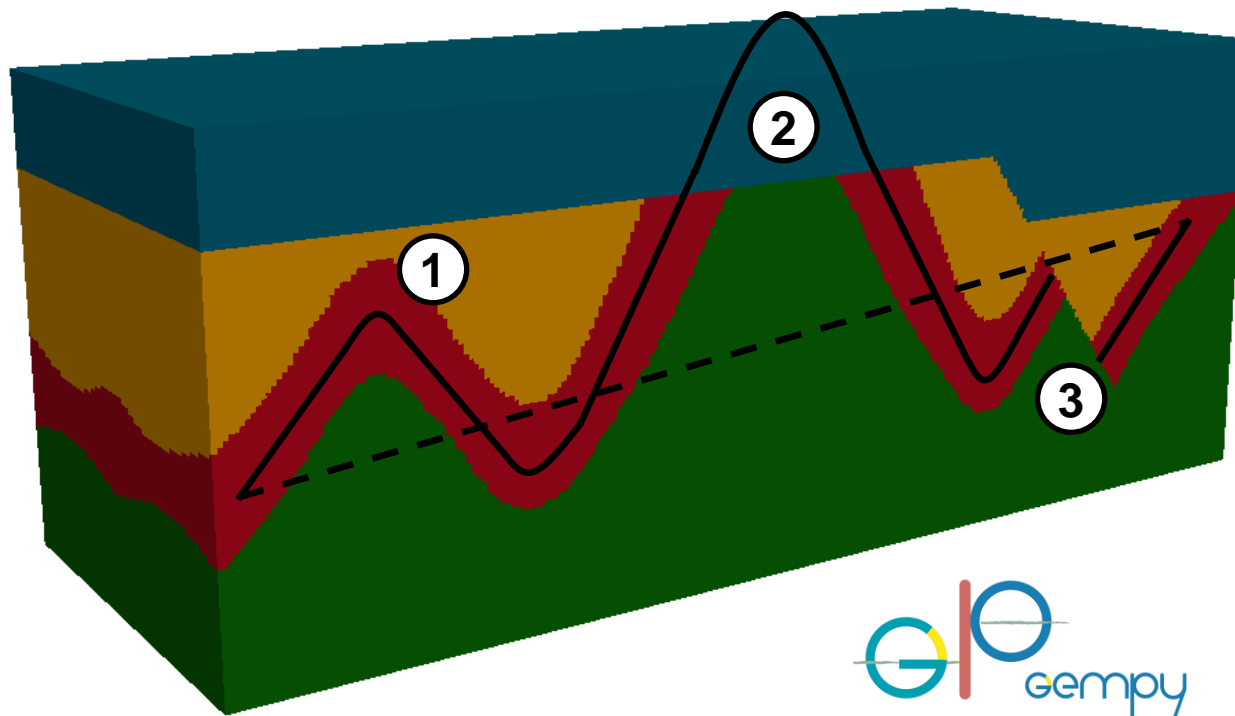

Distance between the two red points in this folded domain can either be measured along a straight line (Euclidian) or following the geometry of the deormation (Non-Euclidian). (Phtoto: Alberta Geological Survey)

Answer: It obviously depends on when and how the spatial distribution of the property of interest developed. Traditionally Euclidian distances are used but accounting for deformation is useful in many cases.

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Distances in deformed geologic domains

Simple theoretical model created with GemPy:

Structural features:

① **Folding**
The Non-Euclidian distance metric should follow the geometry of the folding.

② **Unconformity**
The distance metric should take eroded parts of the domain into account.

③ **Faulting**
Fault offset should not be considered in the distance metric to represent an unfaulted state of the domain.

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Steps for calculating the Non-Euclidian distance:

Step 1: Reference plane
Create a reference plane (triangular mesh) parallel to top and bottom border fo domain based on the structure of 3D implicit geologic models created with *GemPy* (de la Varga et al., 2019), using the *potential field method* (Lajaunie et al., 1997).

Step 2: Projection perpendicular to geometry
All grid points of the model are projected onto this central reference plane and the normal distance to the plane is calculated for each point.

Step 3: Distance parallel to geometry
Using an algorithm from the field of computer graphics called the *heat method* (Crane et al., 2013), the distance between all vertices of the reference plane is calculated.

Step 4: Combination
Step 2 and step 3 result in two distance portions for each grid point, one vertical to the reference plane (direction of sedimentation) and one parallel to the reference plane, following the deformation of the layer. Combining these distance leads to the total Non-Euclidian distance between two grid points in the model.
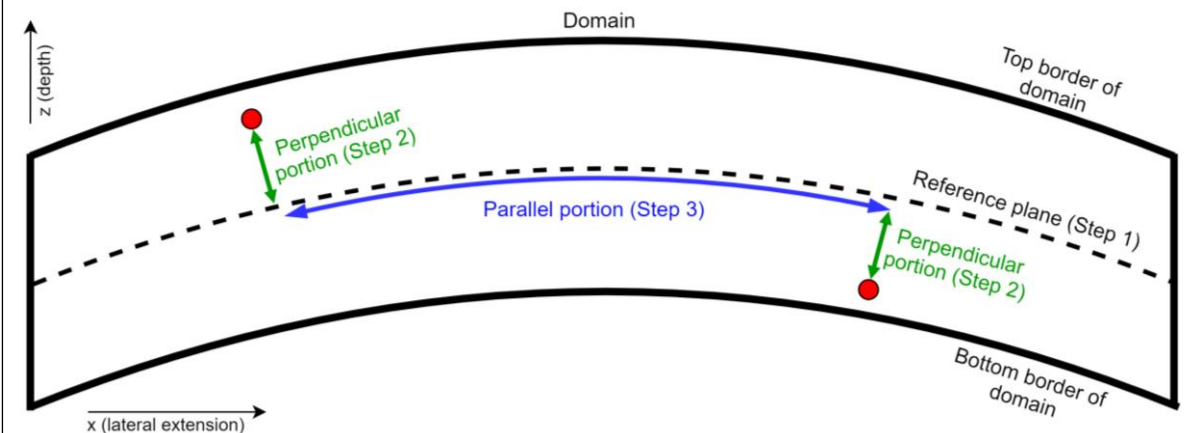
Unconformities:
Eroded parts of the domain are automatically included, as the scalar field in GemPy and thus the reference plane are modeled through eroded areas.
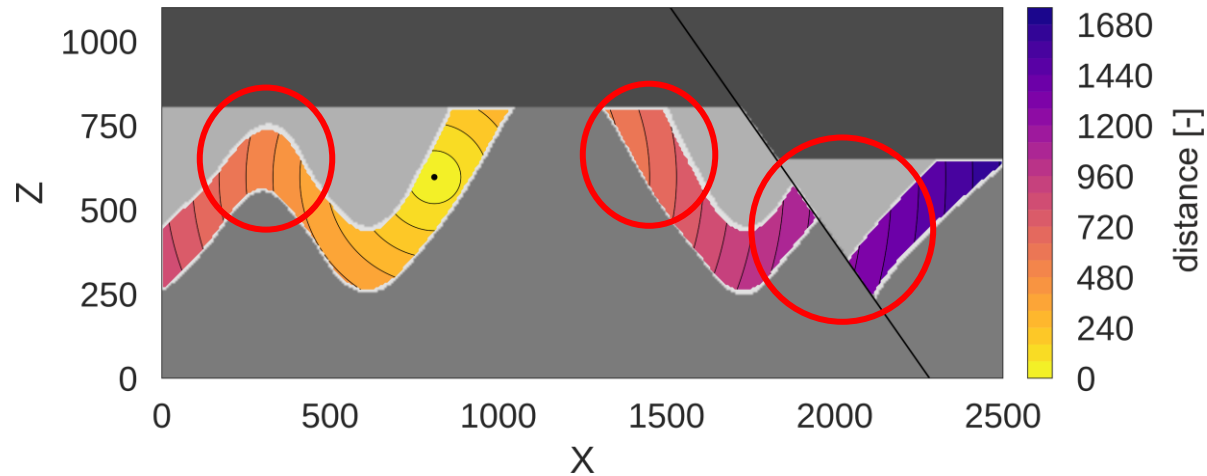
Faults:
As of now, the algorithm requires to manual input of a constant fault offset. This offset is substracted from the total distance between points located in different fault blocks.

Sketch visualizing the steps of the Non-Euclidian distance algorithm in a somplified 2-D case.
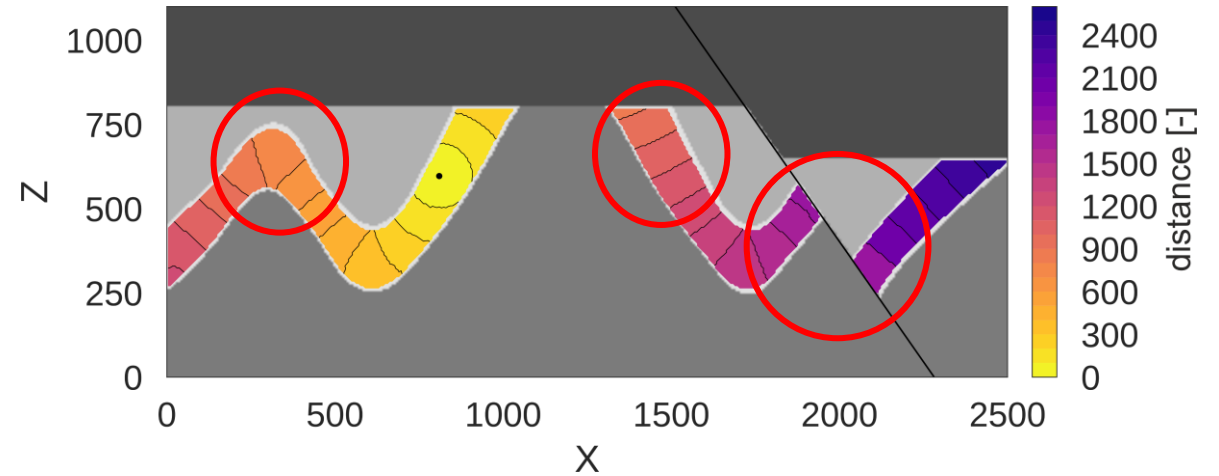
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Euclidian distance field

Euclidian distance field within domain of interest. Structural features of the domain do not affect the distance field. Maximum distance from central point of the distance field to right corner of the domain is around 1700 distance untis. .
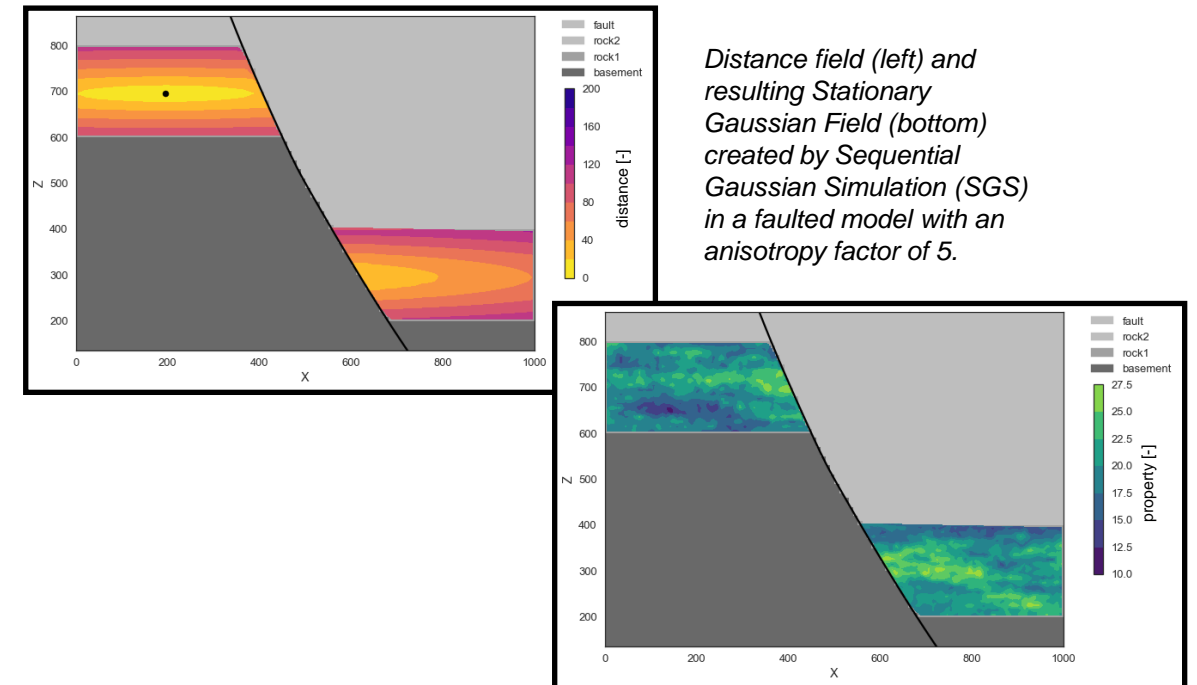
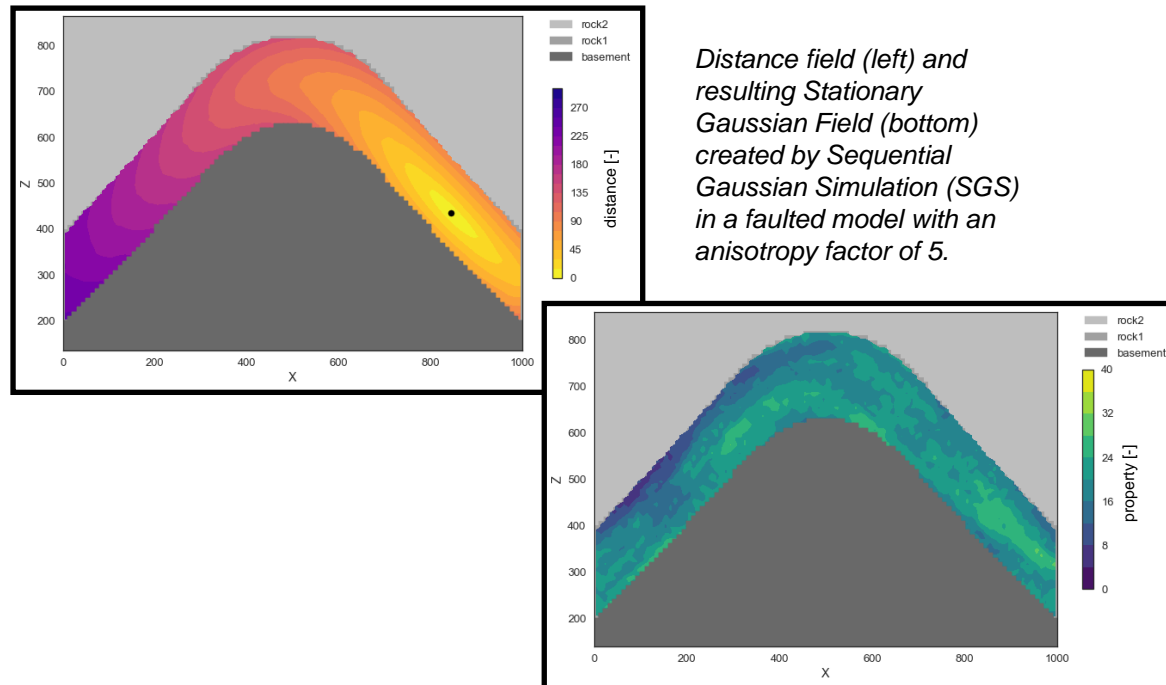## Non-Euclidian distance field

Non-Euclidian distance field within domain of interest. Structural features of the domain do affect the distance field. Maximum distance from central point of the distance field to right corner of the domain is around 2400 distance untis. Roughness in isolines results from projection error..

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Anisotropies and Random fields

Traditionally, **anisotropies** in sample data are detected by calculating the variogram cloud and the experimental variogram in different directions, creating a directional variogram that is subsequently used in kriging (e.g. Webster and Oliver, 2007). As the distance computed with the presented algorithm consists of two parts, one perpendicular to the structure of the layer and one parallel, following the layer, a factor can easily be applied to these partial distances.

This *anisotropy factor* can be used **to model anisotropies parallel to the deformation of a domain**. If a modeled property is highly continuous along the horizontal extent of a layer, the distance measure in this direction can be divided by this factor and thus shortened in relation to the perpendicular distance portion. This is especially useful for elongated strataform structures.

Distance field (left) and resulting Stationary Gaussian Field (bottom) created by Sequential Gaussian Simulation (SGS) in a faulted model with an anisotropy factor of 5.

Distance field (left) and resulting Stationary Gaussian Field (bottom) created by Sequential Gaussian Simulation (SGS) in a faulted model with an anisotropy factor of 5.

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Outlook and references

Outlook:

Developing the code:

- Quantify the projection error in the perpendicular part of the distance calculation.
- Automate procedure for handling faults .
- Allow non-constant fault offset.
- Tackle robustness issues regarding the kriging matrices.
- Develop or link to more advanced variogram modeling (Curriero, 2006).
- Full integration into GemPy release version.

Testing and comparing:

- Testing distance metric based on rotating the scalar field.
- Compare results to similar approaches in GeoModeller (Guillen et. al., 2011) or SKUA-GOCAD (Mallet, 2004).
- Tests in real world settings.

References:

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