

SGSIM_LVA: Gaussian Simulation with Locally Varying Angles

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Introduction

The commonly accepted GSLIB program for sequential Gaussian simulation, `sgsim`, permits consideration of a variogram model with a globally specified variogram orientation and search parameters. This is consistent with the strong stationarity assumptions inherent to the simulation algorithm; however, in some instances, the user may wish to refine the orientation of the spatial continuity measure. This program addresses the use of locally varying angles in the specification of the variogram.

Consider a field wherein the principle direction of the variogram model may vary locally (see Figure 1). As simulation begins and a location is visited, the variogram model will be modified to reflect this change in orientation. There is no change to the variogram model structures, types, or range; only a change in the orientation is proposed.

This short note describes the methodology in which these varying orientations are considered in the simulation. A new program is developed to specifically handle locally varying angles, `sgsim_lva`, and the parameters associated to this option are discussed. Numerous 2D and 3D examples are used to test the algorithm and to illustrate its application.

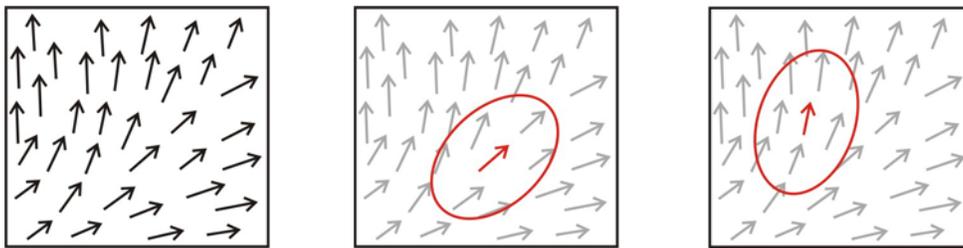


Figure 1: Schematic illustration of locally varying azimuth angles (left) and the impact of a changing azimuth to the variogram model anisotropy directions (middle and right).

Methodology

The user must specify a model of locally varying angles that may include both azimuth and dip angles. All angles must be specified in degrees, and the size (and resolution) of the model must be consistent with the required simulation model. Once the local angles are read into the program, the following steps are taken:

1. Partition angle(s) distribution into the user-specified classes. For each location, the corresponding azimuth and dip angle class is identified.
2. Calculate the average angle within a class and set it as the angle for that class.
3. For each combination of the azimuth and dip classes
 - a. A rotation matrix is calculated and stored in a large 5D matrix called lvrotmat.
 - b. The corresponding covariance lookup table is calculated and stored in a large 5D matrix called lvcovtab.
4. As simulation proceeds and all the nearby data are searched, the relevant rotation matrix and covariance table are used in the kriging subroutine.

Changes to the Parameter File

Minimal change to the original sgsim parameter file was required; only three additional lines were added to the end of the original parameter file:

```

1  17                -locally varying angles (0=no, 1=yes), ncutoffs
   ./data/lvadata.dat      - file with locally varying angles model
4   5                - column for locally varying azimuth, dip

```

The parameters required for each line are described below:

- **ilva, nqt** – a flag to indicate whether locally varying angles will be used, and the number of thresholds required to partition the azimuth and dip angles into quantile classes (for a total of nqt+1 classes).
- **lvaf1** – the file name with the locally varying angles model. This must be at the same grid resolution as the required simulation model, so there must be nx*ny*nz values. It should contain both the locally varying azimuth and dip data.
- **icolazm, icoldip** – column numbers associated to azimuth and dip information from lvaf1.

Applications

A number of examples were constructed to test the performance and efficiency of the proposed algorithm.

Example 1: 2D data with locally varying azimuth angles generated stochastically.

A 2D petroleum data set consisting of 62 wells covering an extent of 10000m x 10000m was considered in this initial example (see top left map in Figure 2). Porosity is used for this simulation.

A stochastic model of azimuth angles was constructed with the intent of having approximately 45° prevalent in the western portion of the field and approximately 135° in the eastern portion of the field. Conditioning data was created to ensure that a stochastic model of azimuth angles would honour this image of an azimuth field. A very long range variogram orienting in the 50° direction was used to construct this angle simulation; this variogram model was chosen arbitrarily. The map of local azimuth angles that will be used as input to the sgsim_lva program may be a little

difficult to see (top right figure in Figure 2); the most important information lies in the actual colour scale of each location.

As a preliminary test, the following small grid was considered for simulation:

$$\begin{aligned} nx, xmn, xsiz &= 400, 12.5, 25.0 \\ ny, ymn, ysiz &= 400, 12.5, 25.0 \end{aligned}$$

Using this grid, conditioning data and an arbitrarily chosen variogram model for porosity (with the principle direction oriented in the 40° azimuth direction), the original sgsim program was compared against the modified sgsim_lva program. The bottom maps in Figure 2 show the result of the two simulations. There is a clear difference in the two simulated realizations. The direction of continuity in the sgsim model is globally oriented in the 40° direction as expected. The locally varying angles as defined by the azimuth map is reflected in the modified simulation algorithm, in particular, the 135° principle direction evident in the eastern portion of the field is clearly honoured.

In terms of computational efficiency, the original sgsim ran in 3.5s while the sgsim_lva program was completed in 17s. The time difference between the two programs can be attributed to the construction of the large covariance look-up table in the steps preceding the actual simulation.

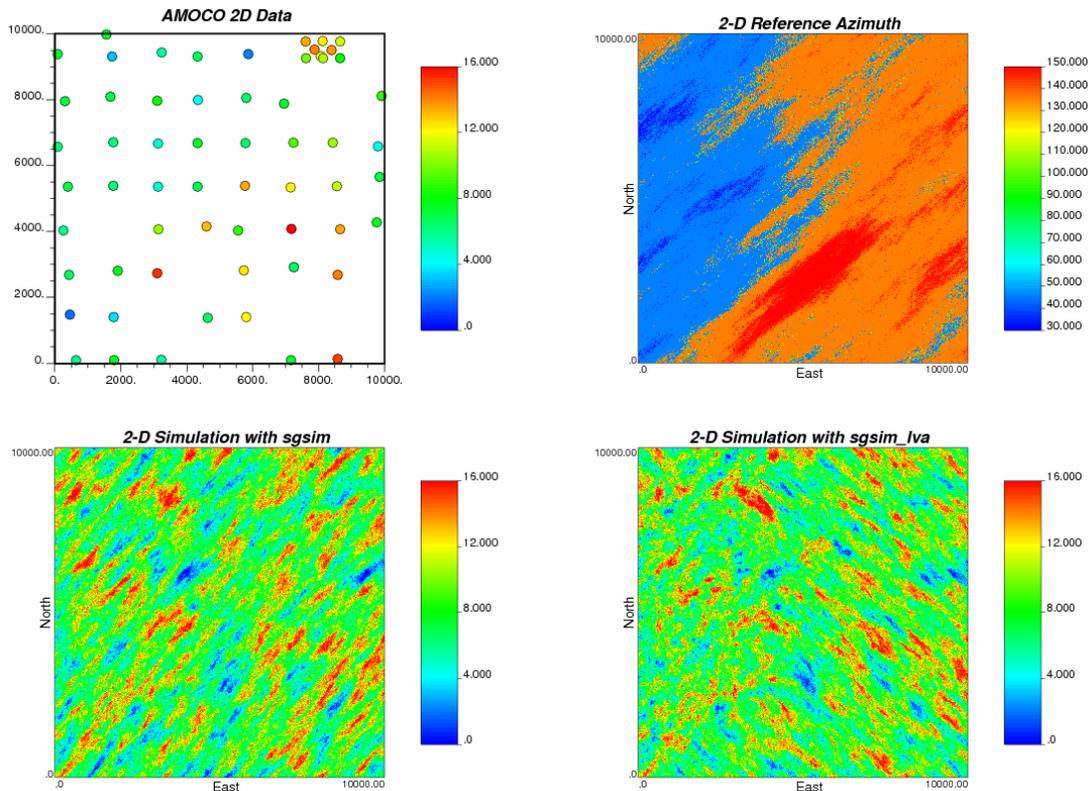


Figure 2: Amoco data set (top left) used to illustrate impact of locally varying angles (top right) on simulation results: conventional sgsim (bottom left) and sgsim with locally varying angles (bottom right).

Example 2: 2D data with four quadrants of constant azimuth directions.

This second example is similar to the first in that the same conditioning data are used; however, two primary modifications are made. Firstly, the local azimuth field is simplified into four quadrants with 30° azimuth in the SE corner, 120° azimuth in the SW corner, 90° azimuth in the NE quadrant and 0° azimuth in the NW quadrant. The purpose of this change was to simplify the identification of the directions of continuity in the simulated realization; this is achieved by reducing the noise seen in the stochastic angle model. Secondly, a finer 10m x 10m grid is considered resulting in 1000 x 1000 blocks in X and Y, giving a total of 1 million cells. This will test the programs efficiency for larger grids. Further a larger variogram range of 2000m was also chosen in both the minimum and maximum principle direction for the specified model, and correspondingly applied to the search radius.

Figure 3 shows the results of the simulation with directional arrows corresponding to the local principle direction. The bottom right map clearly shows that the local angles are reproduced in the simulation. The time to execute the simulation increased from 32.754s for sgsim to 50.205s for sgsim_lva. The increase in time from the previous example can be attributed to a number of factors: larger number of grid blocks, longer variogram range, and longer search radius. The latter two factors contribute to a longer time to generate the large covariance lookup table that is indexed by the azimuth and dip classes.

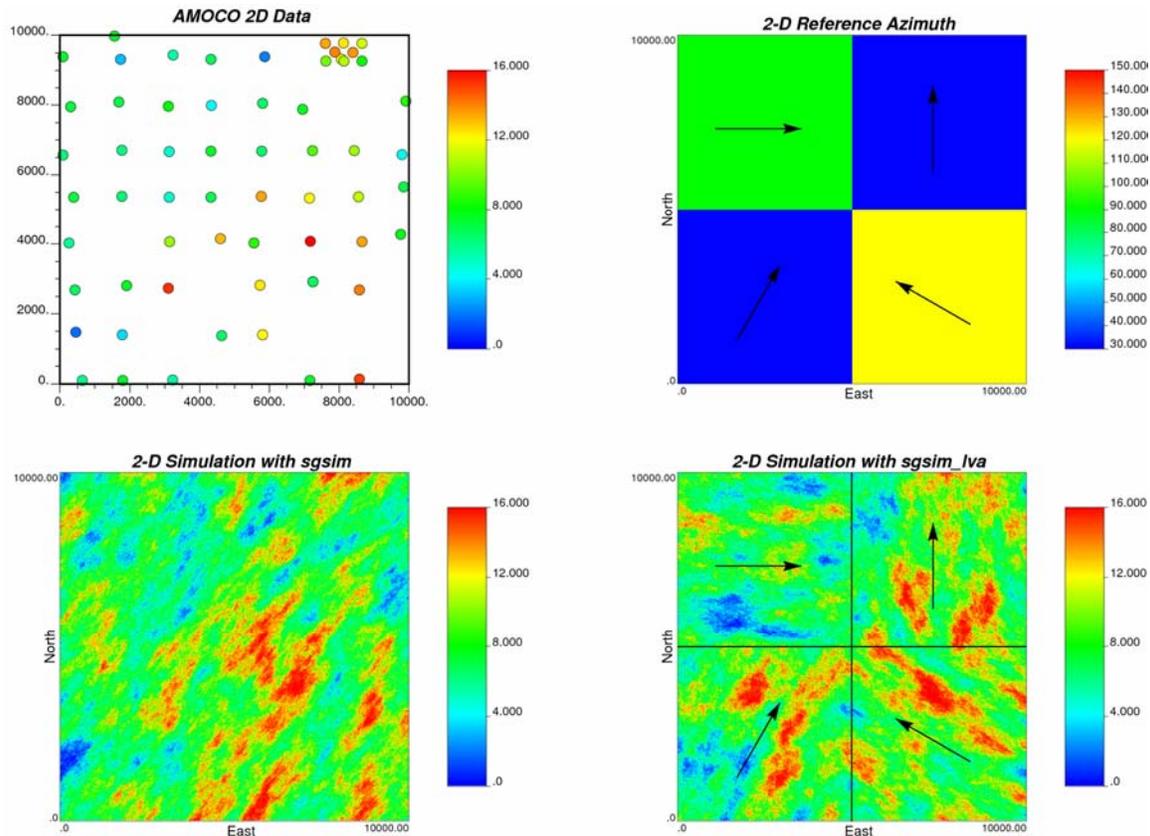


Figure 3: Amoco example with a discrete locally varying azimuth map (top left): conventional sgsim (bottom left) and sgsim with locally varying angles (bottom right). On the right hand

maps, arrows representing the principle direction of continuity are superimposed for comparison with the simulation.

Example 3: 3D unconditional simulation with locally varying azimuth and dip

All previous examples were two dimensional and consequently have only considered the case of locally varying azimuths. This example was constructed to test the impact of varying both the azimuth and the dip angles. A simple octant model was constructed for both the 3D locally varying angles model at a resolution of 100 x 100 x 100 blocks in the X, Y and Z directions, for a total of 1 million cells. Figure 4 shows several slices through the 3D model generated by `sgsim_lva`. Figure 5 shows 2D images of the azimuth, dip and simulated model in the XY, XZ and YZ planes.

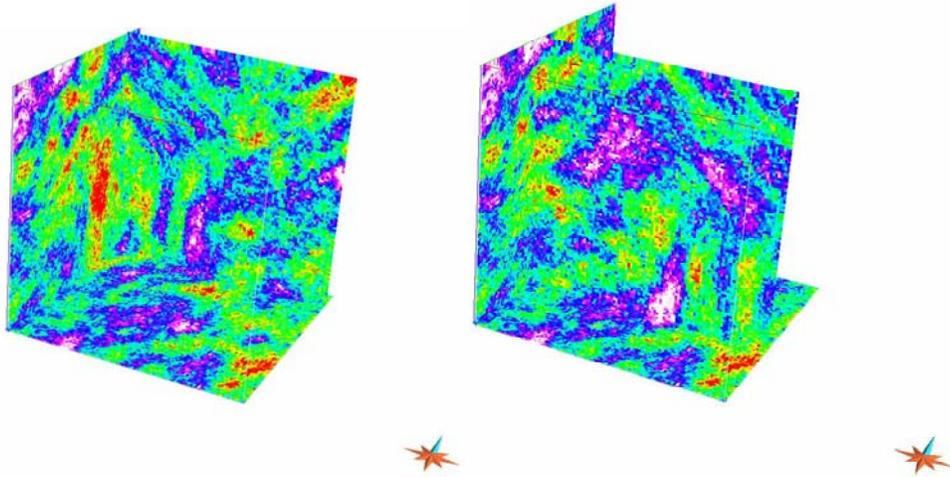


Figure 4: Visualization of the 3D simulated realization using `sgsim_lva` with locally varying azimuth and dip angles.

The computational effort for this case was reasonable; while the original `sgsim` required 52.961s to execute, the `sgsim_lva` program required 4min 40.718s to complete the simulation.

Discussion

There is great flexibility offered through the partitioning of the angle distributions. It permits the user to refine the class partitions, and this refinement is constrained only by the amount of free memory available on their individual computers. In cases where fewer partitions are required, only those with any locations in the class are used. This occurs in situations like the discrete angle models constructed for Examples 2 and 3 in the previous section.

Despiking of the local angles may be required; this is implemented in the current program. Again, this is particularly relevant in instances where the angle(s) distribution is discrete, as in Examples 2 and 3 above. In the case where the angle models are generated stochastically (conditional to some key locations) or the angle distributions are more continuous, then despiking should not be an issue.

One idea may be to permit the user to partition the distribution based on user-defined intervals in units of the angles range (specified in degrees). This would avoid too much smoothing of angles due to averaging within a class, especially if too few classes are specified.

This modified version of the conventional Gaussian simulation algorithm considered only a change in the variogram orientation; no change to the search ellipsoid is proposed. As such, the user should use sufficiently large search ranges and permit the kriging weights to be determined through the refined variogram model.

A model size of 6.25 million cells was also generated using the `sgsim_lva` program for the 2D Amoco data set. The modified program (`sgsim_lva`) required 5m31s, while the original `sgsim` program ran within 3m28s with the same parameters. The primary limitation appears to be the size of the covariance table, not necessarily the size of the simulation model. The larger the covariance lookup table (>1million elements), the more memory is required and the program may terminate during the array allocation phase.

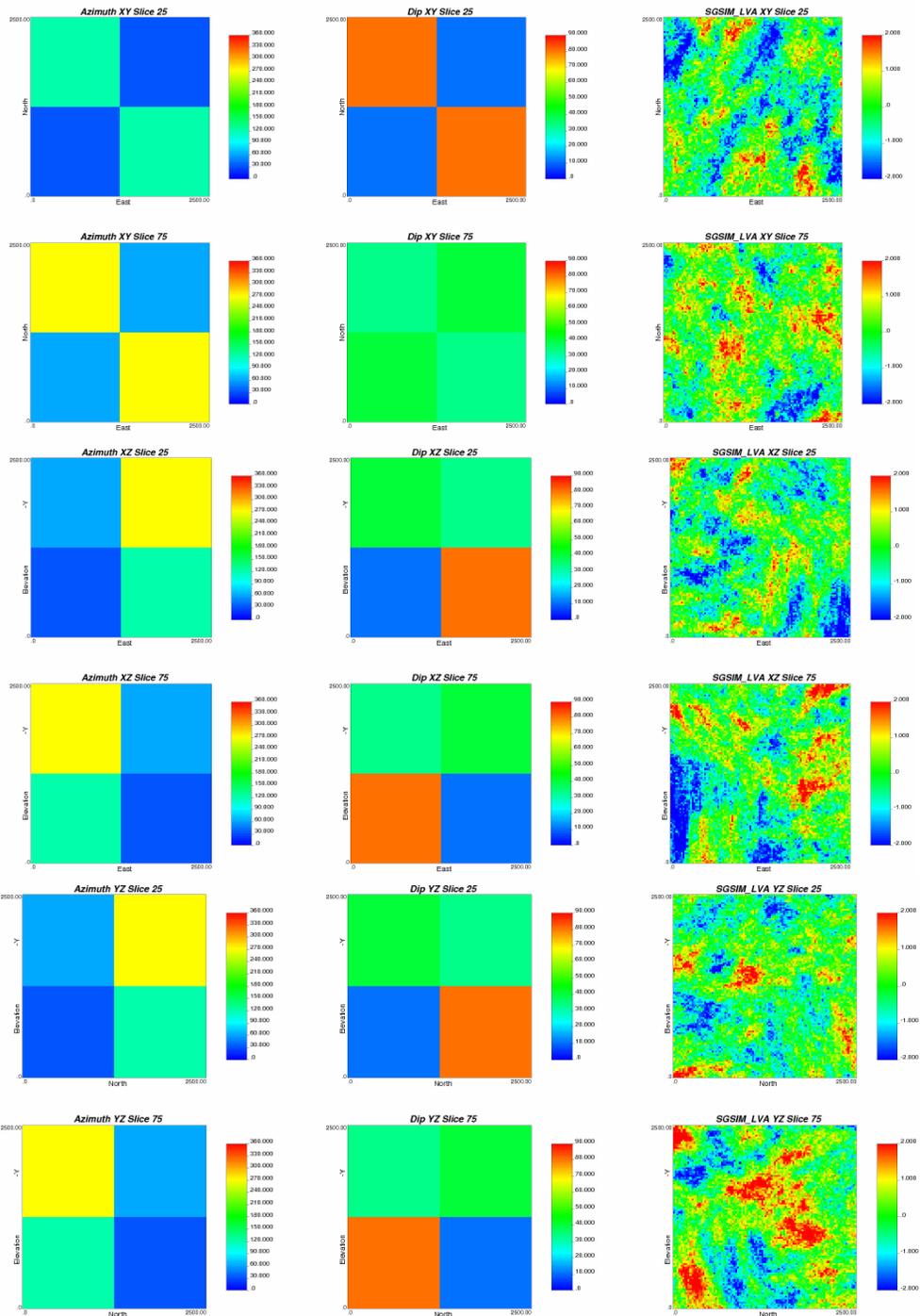


Figure 5: Two slices of the azimuth (left), dip (right) and simulated model (right) in the XY, XZ and YZ planes.