ESTIMATION OF FAULT CONNECTIVITY USING AN EDGE-DETECTING ATTRIBUTE AS PROXY FOR HYDRAULIC CONDUCTIVITY – PROGRAM fault_connectivity

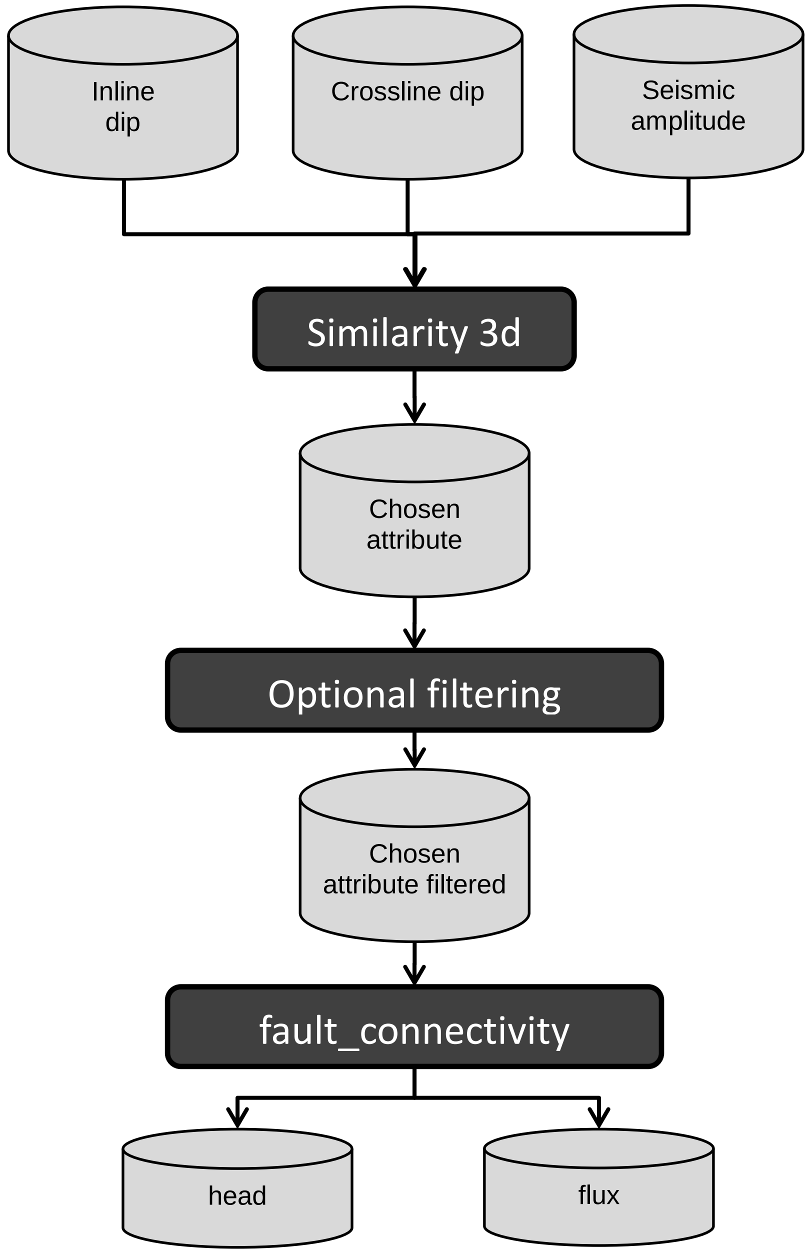
Contents

Overview

This programs assumes that the 3D volumetric result of an edge detecting attribute such as coherence is directly proportional to the hydraulic conductivity of the investigated region. Then the program uses the attribute as a proxy of conductivity to simulate the steady-state flow between two horizons. Mapping the flux between two horizons (or two time/depth slices) is sufficient to highlight the faults that connect both horizons (or time/depth slices). The disjoint faults will be suppressed showing a weaker flow response.

Computation Flow Chart

To compute the fault connectivity attributes, the inline and crossline dip components of the seismic amplitude data need to be computed first, via the program, **dip3d**. The second step is to generate the edge detecting attribute through **similarity3d**. The chosen attribute can be filtered through **fault_enhancement** and can also be submitted to **skeletonize3d**. Finally, **fault_connectivity** program will perform the potential and flow computations on the input hydraulic conductivity proxy, and outputs the potential hydraulic head and flow estimations. The user can also provide horizons as input to limit the computations.



How to run

Fault_connectivity program is located under the *Image Processing Attributes* -> **fault_connectivity** of the main **aaspi_util** window (Figure 1). The user needs to specify the input edge detecting attribute data, unique project name, and suffix (Figure 2). The *Primary parameters* are *Maximum number of iterations*, *Percent iteration change that signifies convergence*, *iteration weight*, *Head value condition (top)*, *Head value condition (bottom)*, *Conversion, Pseudo sand-shale conductivity* and the check-box *Input is inversely proportional to conductivity*. The second tab shows options for the Horizon parameters (discussed under **Define the operation window** section). Under the *Parallelization parameters* tab, the user can specify mpi-related parameters, such as the number of processors (Figure 3). Click the "*Execute fault_connectivity*" button, on the right lower corner, to run the program. The potential head volume has “head_” prefix, and the flux result file name has “flux_” prefix.

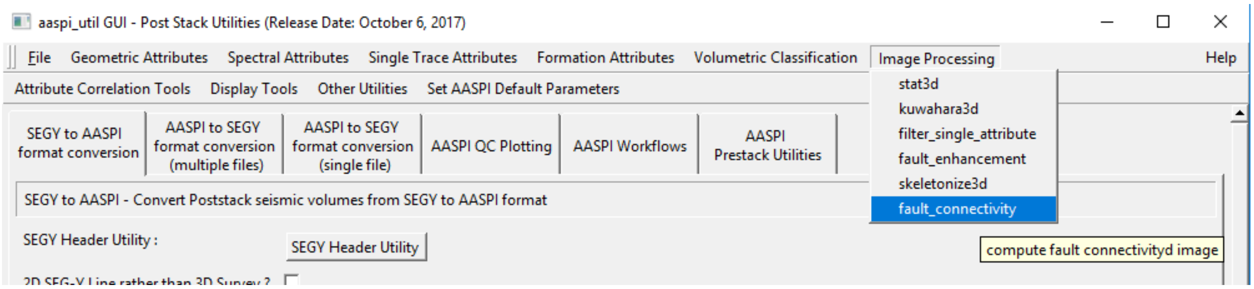


Figure 1. The **fault_connectivity** program is under *Image Processing* dropdown of the **aaspi_util** window.

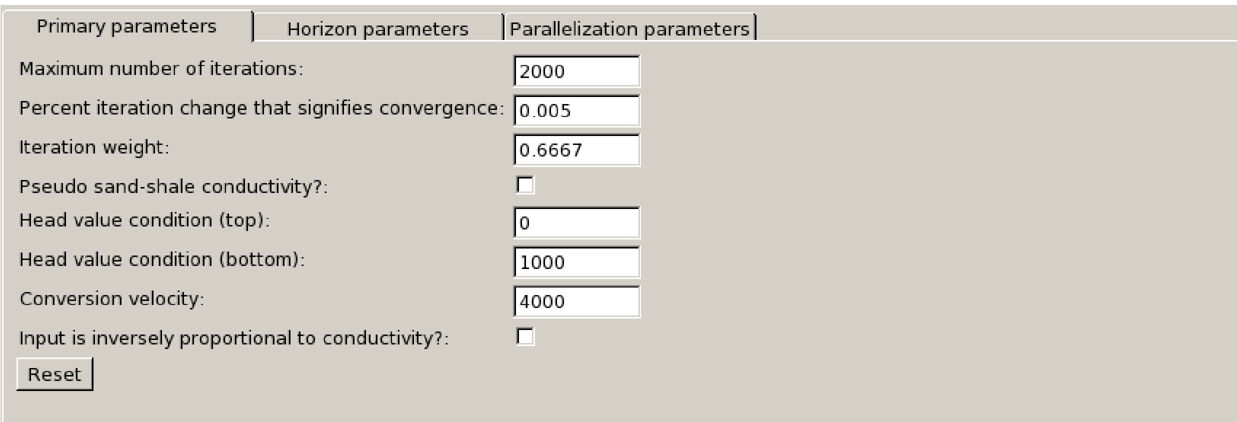


Figure 2**.** Main windows of the **fault_connectivity** program. Browse for input file (edge detecting attribute / hydraulic conductivity proxy), and specify unique project name and suffix*. Maximum number of iterations*, *Percent iteration change that signifies convergence*, *iteration weight*, *Head value condition (top)*, *Head value condition (bottom)* and *Conversion velocity* are completed with average values that were used during development testing. The user can choose to change if appropriate. *Pseudo sand-shale conductivity* linearly converts the input to range from 0.01 to 1000 (useful when data might have negative or zero values*). Input is inversely proportional to conductivity* is an option for the program to assume low values of the input attribute to be proportional to high values of hydraulic conductivity and vice-versa (a fault has low values compared with the background in **outer_product_similarity** but the same fault has high values of **fault_probability**).

The *Maximum number of iterations and Percent iteration change that signifies convergence* are the parameters with higher impact on processing cost and significance of the results and are sensitive to input data. A higher number of iterations will yield a better image, but will take longer. The opposite can be said to the *Percent iteration change that signifies convergence* – a high number indicates that a rough approximation is good enough and the program will stop iterating sooner. The iteration weight is set to 2/3, a number traditionally optimal for the weighted Jacobi method used in the **fault_connectivity** program. With noisy data as an input, the solution might diverge, and setting this value to 1.0 will require more iterations to approximate the solution, (making the whole process slower) but may (or may not) solve the divergence.

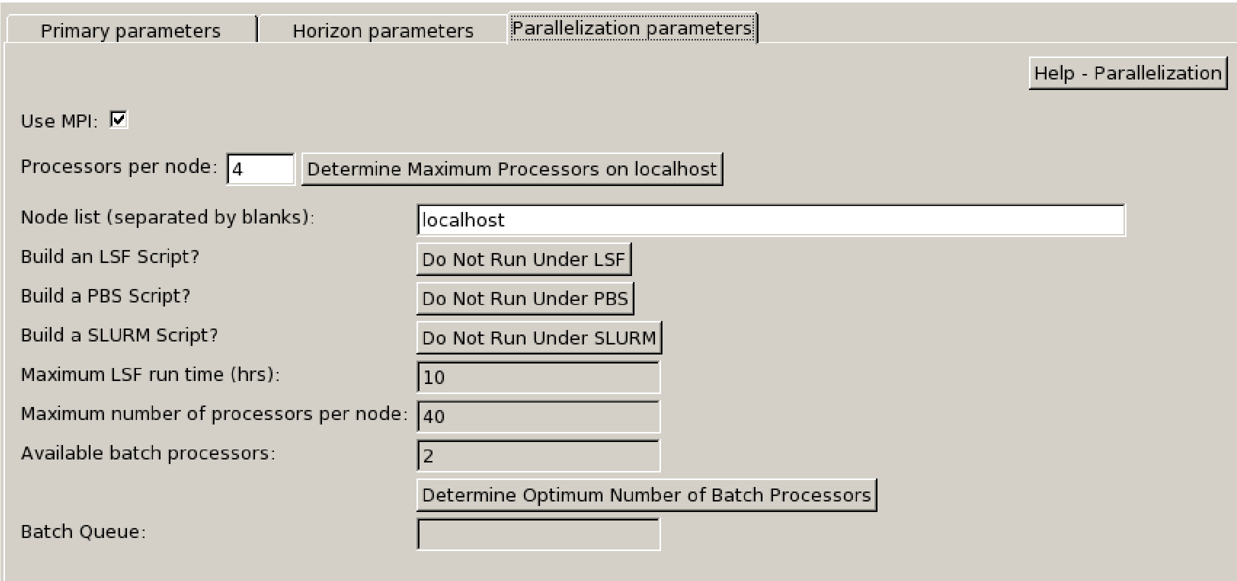


Figure 3. *Parallelization parameters* tab: specifies the number of processors used for parallel processing.

Define the operation window

The user has the option to use either a constant time/depth window or a window defined by top and bottom horizons. The functionalities in defining the operation window are discussed below.

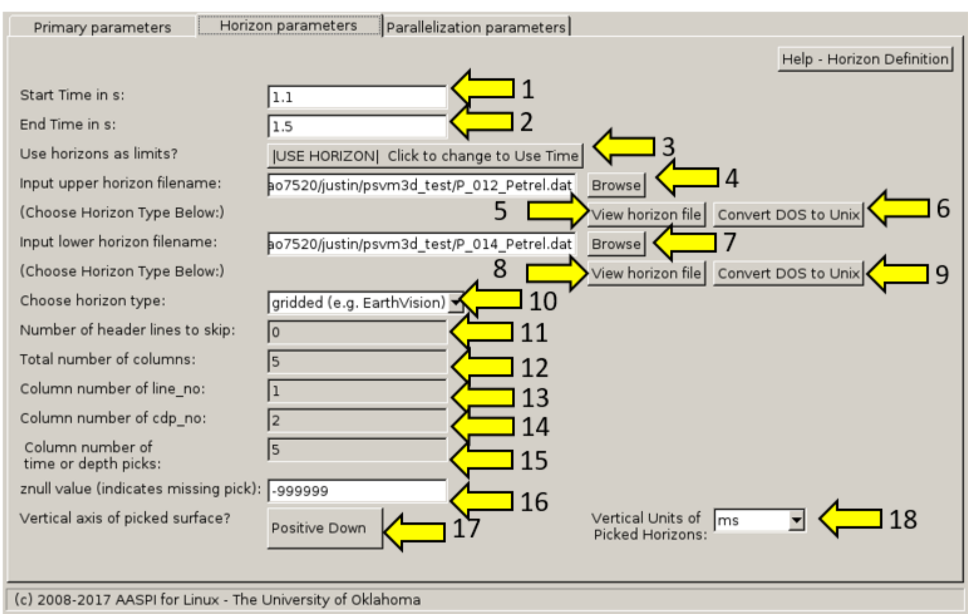


Figure 4**.** Horizon parameters tab: specify horizon or time/depth windows.

Horizon definition

The horizon definition panel will look the same for almost all AASPI GUIs:

1. Start time (upper boundary) of the analysis window.
2. End time (lower boundary of the analysis window.
3. Toggle that allows one to do the analysis between the top and bottom time slices described in 1 and 2 above, or alternatively between two imported horizons. If *USE HORIZON* is selected, all horizon related options will be enabled. If the horizons extend beyond the window limits defined in 1 and 2, the analysis window will be clipped.
4. Browse button to select the name of the upper (shallower) horizon.
5. Button that displays the horizon contents (see Figure 1).
6. Button to convert horizons from Windows to Linux format. If the files are generated from Windows based software (e.g. Petrel), they will have the annoying carriage return (^M) at the end of each line (Shown in Figure 1). Use these two buttons to delete those carriage returns. Note: This function depends on your Linux environment. If you do not have the program **dos2unix** it may not work. In these situations, the files may have been automatically converted to Linux and thus be properly read in.
7. Browse button to select the name of the lower (deeper) horizon.
8. Button that displays the horizon contents (see Figure 1).
9. Button to convert horizons from Windows to Linux format. (see 6 above).
10. Toggle that selects the horizon format. Currently *gridded* (e.g. EarthVision in Petrel) and *interpolated* (ASCII free format, e.g. SeisX) formats are supported. The gridded horizon are nodes of B-splines used in mapping and have no direct correlation to the seismic data survey. For example, gridded horizons may be computed simply from well tops. The x and y locations are aligned along north and east axes. In contrast, interpolated horizons are defined by *line_no, cdp_no (crossline_no)* and *time* triplets for each trace location. Examples of both formats are shown in Figure 1. If *interpolated* is selected, the user needs to manually define each column in the file.
11. Number of header lines to skip in the *interpolated* horizon files.
12. Total number of columns in the *interpolated* horizon files.
13. Enter the column number containing the *line_no (inline_no)* of the interpolated data triplet.
14. Enter the column number containing the *cdp_no (crossline_no)* of the interpolated data triplet.
15. Enter the column number containing the *time* or *depth* value of the interpolated data triplet.
16. *Znull* value (indicate missing picks) in the horizon files.
17. Toggle to choose between *Positive Down* and *Negative Down* for the horizon files (e.g. Petrel uses *Negative Down*).
18. Choose the vertical units used to define the horizon files (either *s*, ms, *kft, ft, km,* or *m*).

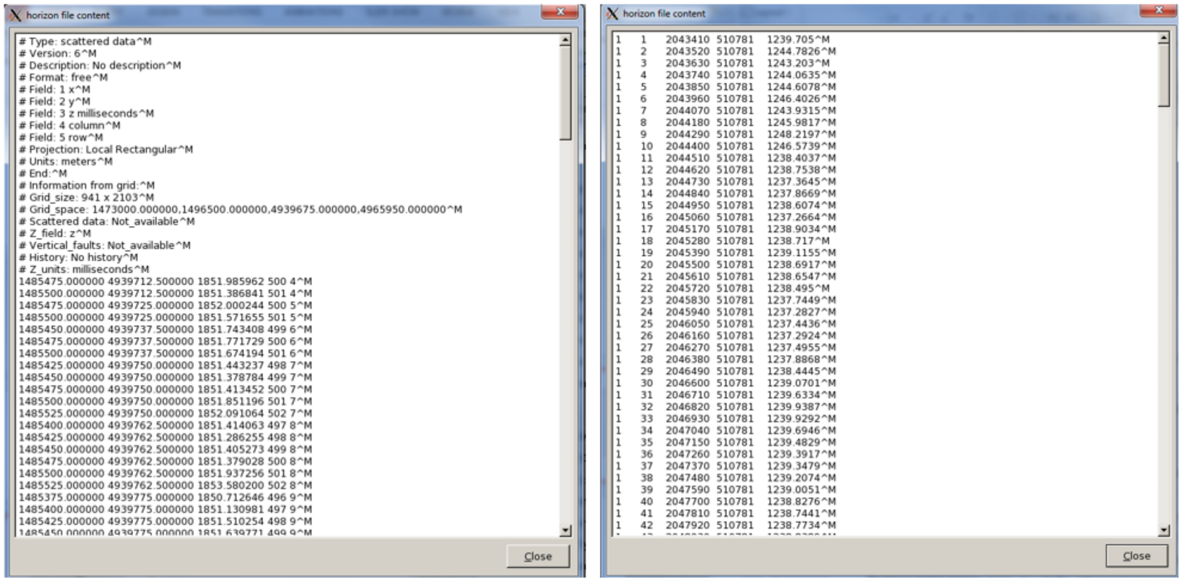


Figure 5. (left) A gridded horizon file (EarthVision format). (right) An interpolated horizon file with five columns (ASCII free format).

Mathematical Background

The program uses a finite-difference scheme to solve the steady-state three-dimensional saturated flow equation (1) assuming that the hydraulic conductivity is proportional to misalignment of the seismic reflectors (or inversely proportional to the seismic coherence attribute).

$$\frac{\partial}{\partial x}\left(K_x \frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_y \frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_z \frac{\partial h}{\partial z}\right)=0 \qquad (1),$$

where K_x, K_y, and K_z are the conductivities of the media in the *x*, *y*, and *z* coordinate directions (LT^{-1});
h is the hydraulic head, a combination of potential energy due to elevation, and pressure energy (expressed in L units)
The flow between two adjacent voxels using the finite difference notation is giving by equation 2.

$$Q_{i+0.5,j,k} = KX_{i+0.5,j,k}\Delta z * \Delta y \frac{h_{i+1,j,k} - h_{i,j,k}}{\Delta x} \qquad (2),$$

where $Q_{i+0.5,j,k}$ is the volumetric flow rate through the face between voxels *i,j,k* and *i+1,j,k* (with units L^3T^{-1});
$KX_{i+0.5,j,k}$ is the hydraulic conductivity along the row between nodes voxels *i,j,k* and *i+1,j,k* (with units LT^{-1});
$\Delta x, \Delta y, \Delta z$ are the distance between nodes in the *x*, *y*, and *z* coordinate directions. These equations are arranged to for a linear system that is iteratively solved using the weighted Jacobi method. More details in Pires de Lima (2017).

Example: Syneresis and polygonal faulting (New Zealand)

The Great South Basin (GSB) is a highly faulted New Zealand Basin and which also shows the presence of syneresis. Morley et al. (2017) describes the syneresis as exhibiting a honeycomb-shaped morphology, with the structures approximately 200 m in diameter. The proxy for hydraulic conductivity input (Figure 6) was computed by applying a directional Laplacian of a

Gaussian (dLoG) filter (Machado et al., 2016) to an outer product similarity volume (Pires de Lima and Marfurt, 2017). This volume was then used as input to the **fault_connectivity** program.

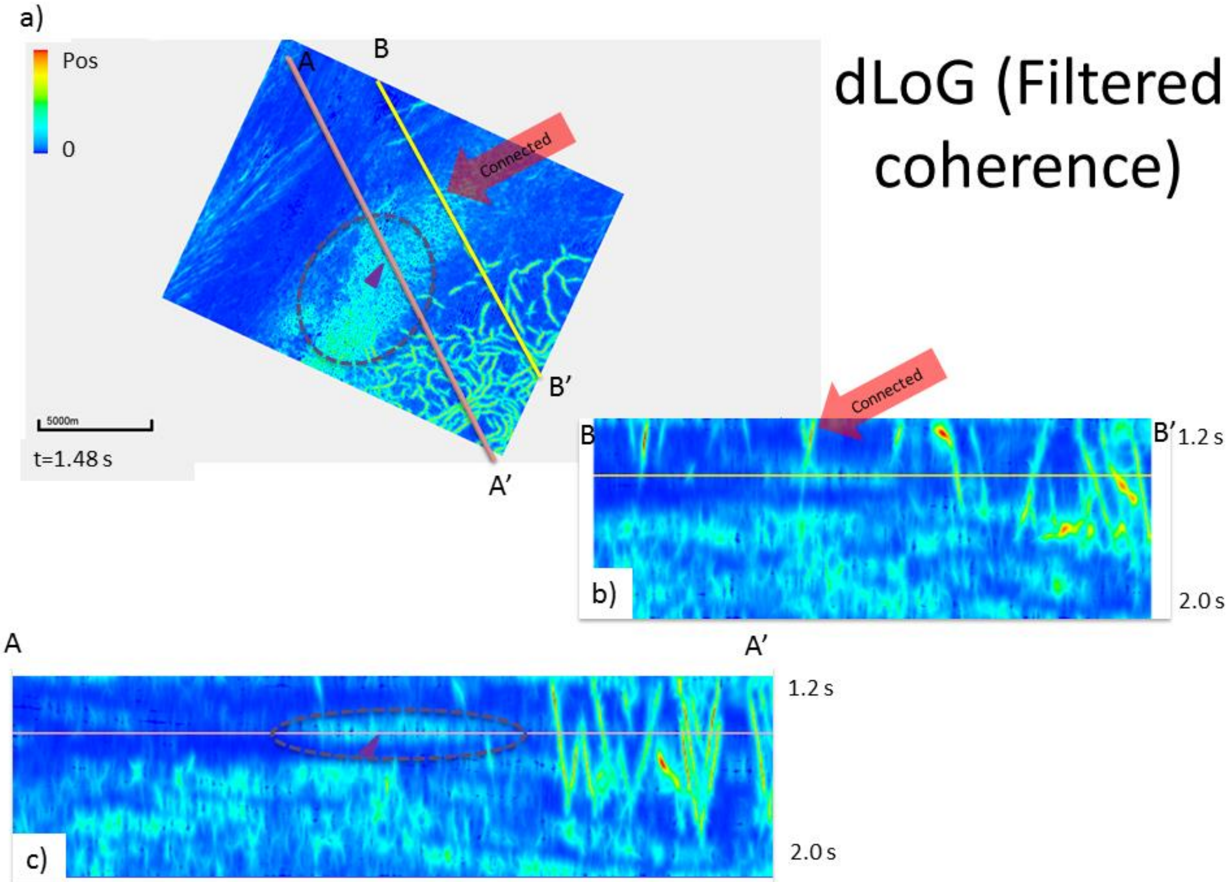


Figure 6. (a) Time-slice and (b,c) cross-section of the dLoG filtered coherence. The purple triangle and purple ellipse point to depth restricted (not connected) syneresis formations. The red arrow points to a fault that extends from top to bottom (connected) of the analyzed volume.

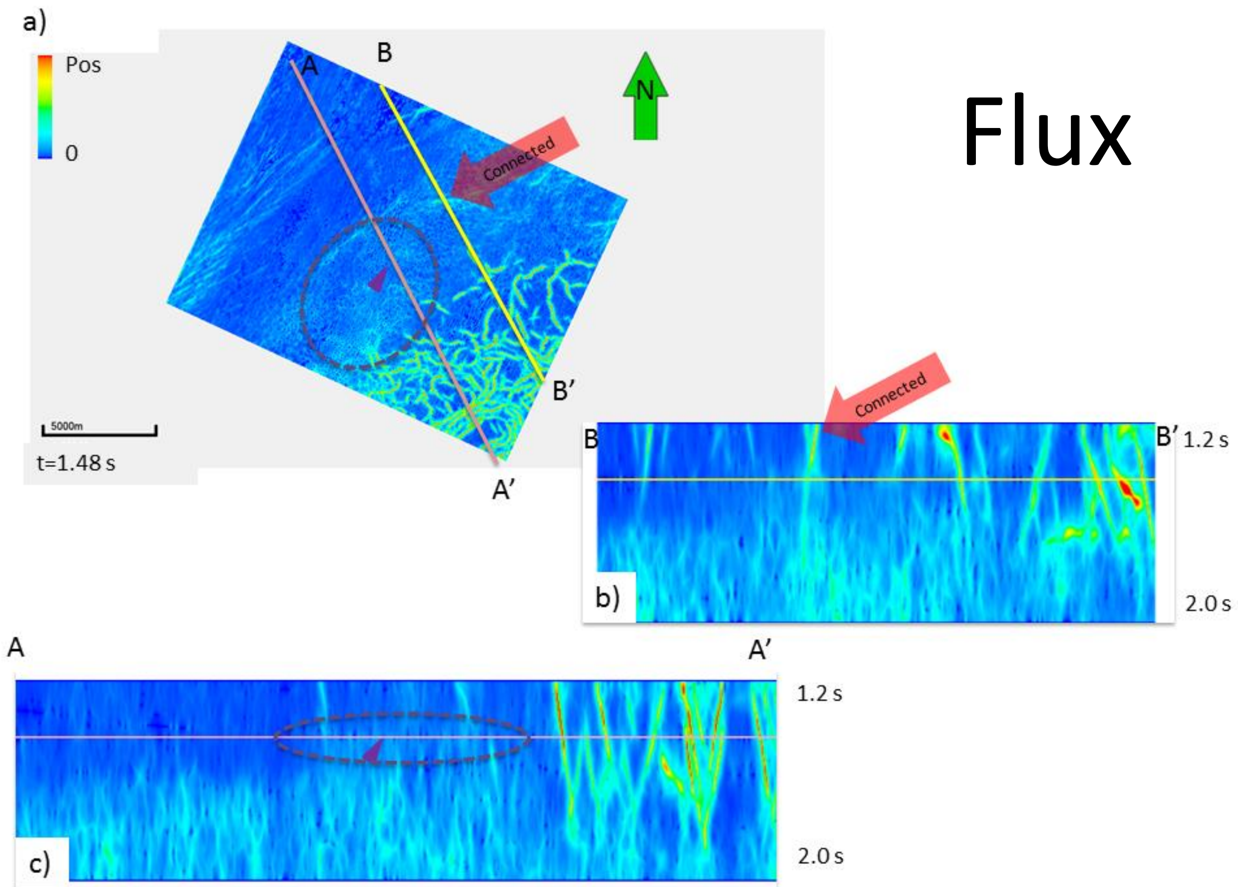


Figure 7. (a) Time-slice and (b,c) cross-section of the computed flow. The purple triangle and purple ellipse point to areas that are not connected from t=1.2 s to t=2.2 s. The red arrow points to connected faults that became more visible on the flow computation results.

References

Morley, C. K., A. Maczak, T. Rungprom, J. Ghosh, J.A. Cartwright, C. Bertonib, N. Panpichityota, 2017, New style of honeycomb structures revealed on 3D seismic data indicate widespread diagenesis offshore Great South Basin, New Zealand: Marine and Petroleum Geology, 86, 140-154.

Pires de Lima, R. A. “Linking image processing and numerical modeling to identify potential geohazards”, Master’s thesis, The University of Oklahoma, 2017, http://hdl.handle.net/11244/51902.

Pires de Lima, R. A. and K. Marfurt, 2017, Quantifying fault connectivity drilling hazards through simple flow computations: SEG Technical Program Expanded Abstracts, https://doi.org/10.1190/segam2017-17786445.1.