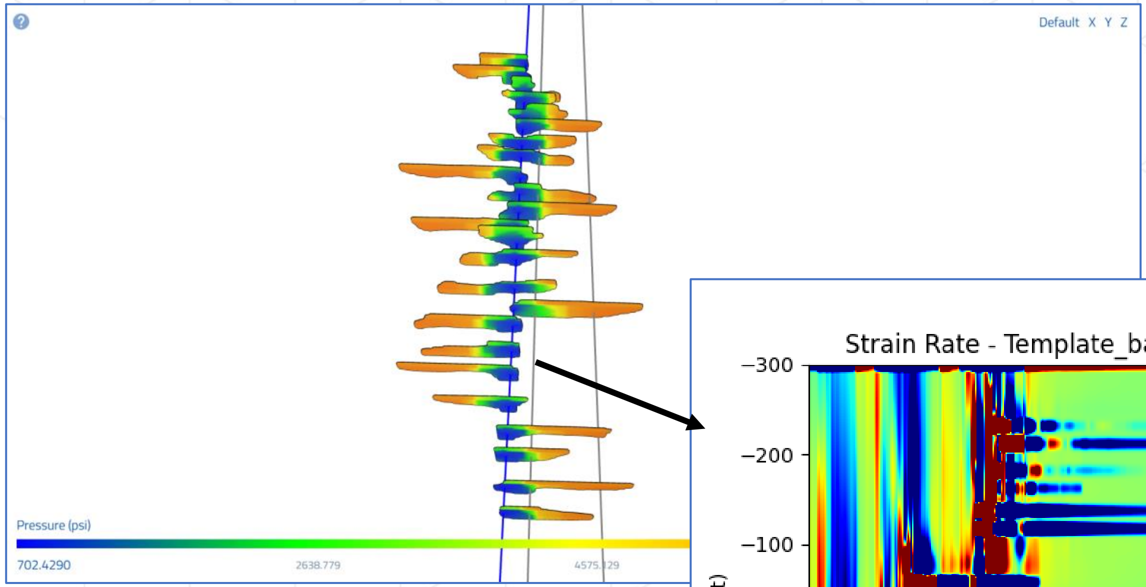
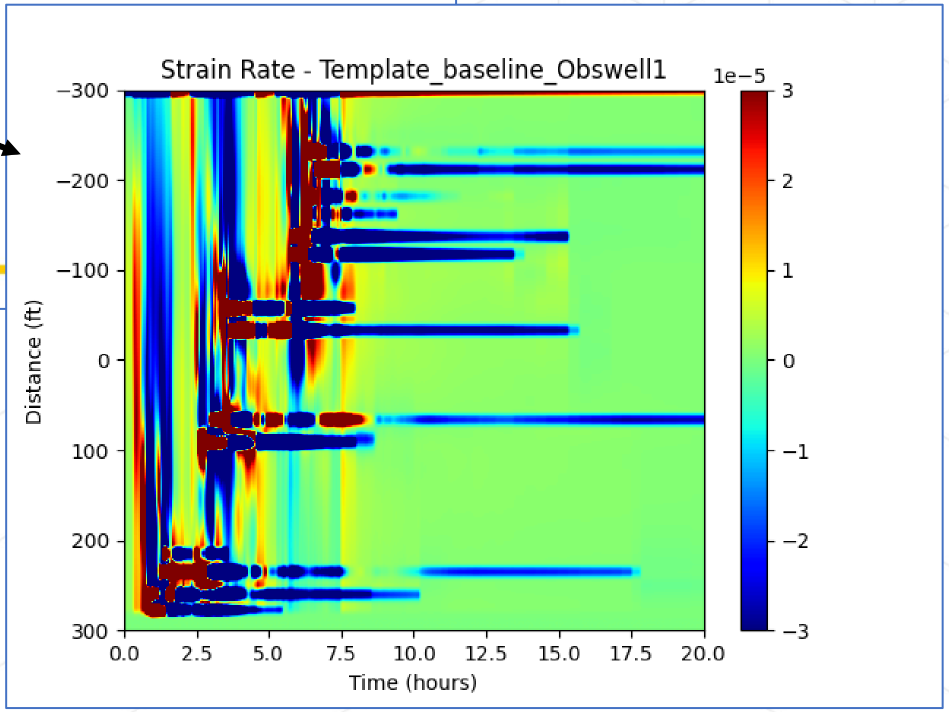


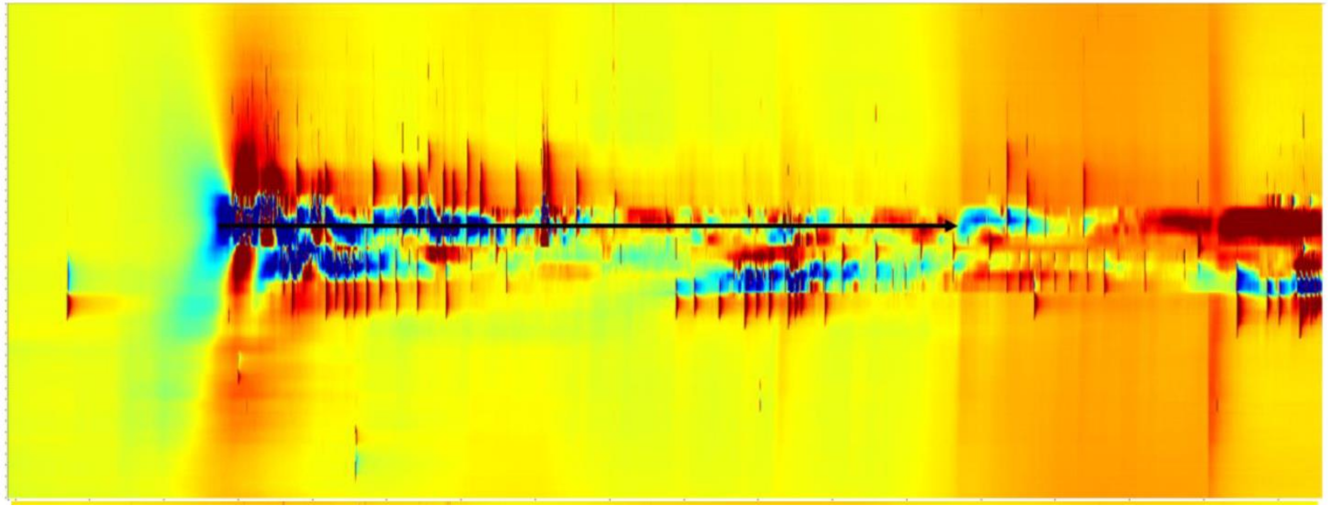


Stress Observation Points and Planes

Modeling Fiber Diagnostics

Agenda

1. Stress calculations in ResFrac
2. Stress Observation Plane Setup & Visualization
3. Fiber Diagnostics Setup & Visualization
4. Fiber Diagnostics Motifs



SPE-204172-MS

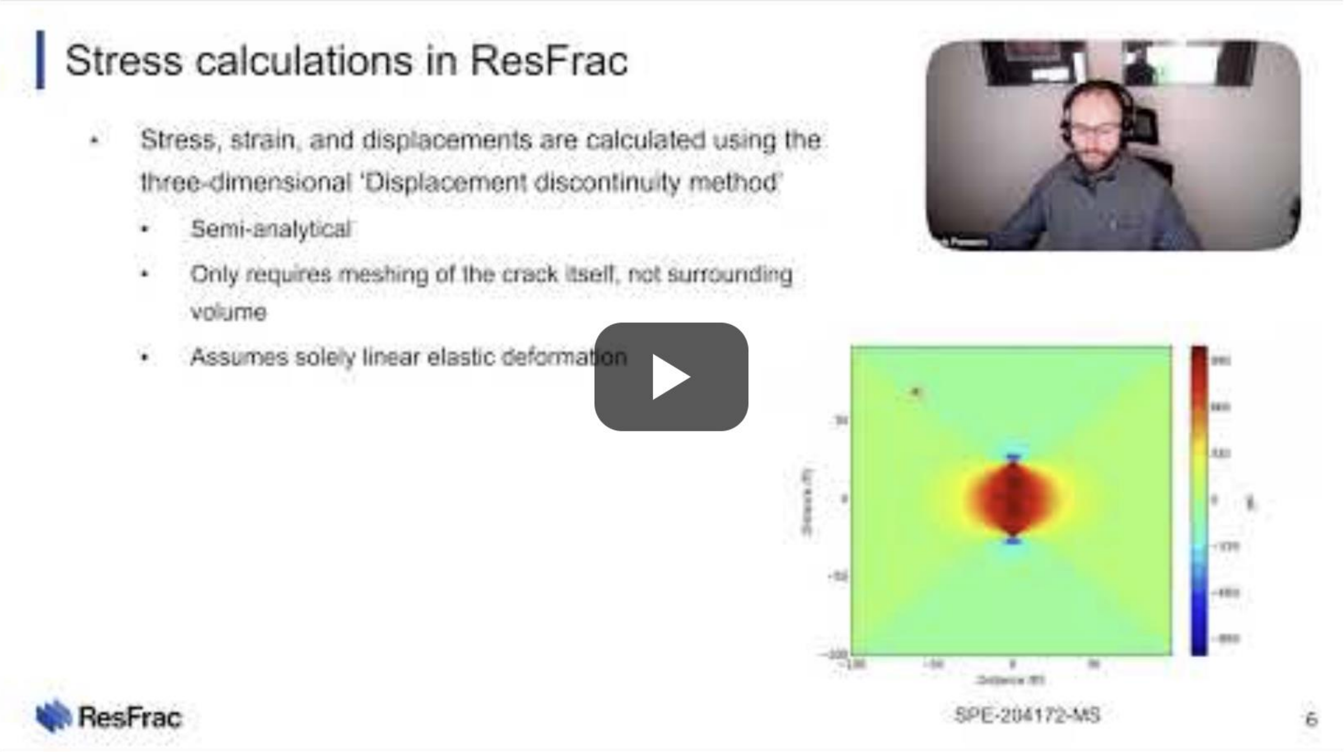
Office Hours

This presentation is also reviewed in the following office hours:

https://www.resfrac.com/library/office-hours/using-python-to-post-process-simulations-and-create-fiber-optic-style-waterfall-strain-plots

Using Python to post-process simulations and create fiber-optic-style waterfall strain plots

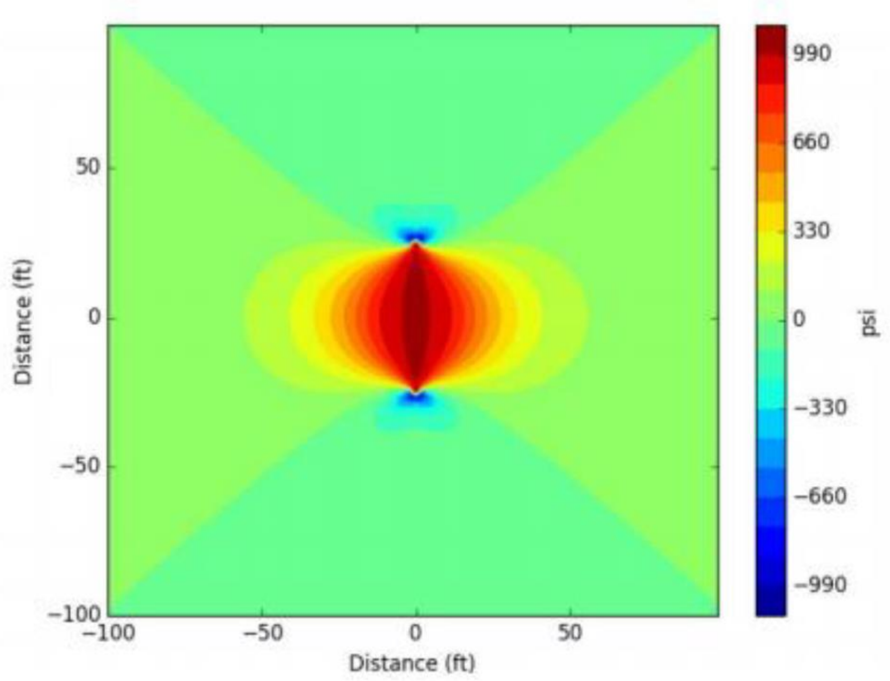
December 23, 2025



Stress calculations in ResFrac

Stress calculations in ResFrac

- Stress, strain, and displacements are calculated using the three-dimensional ‘Displacement discontinuity method’
  - Semi-analytical
  - Only requires meshing of the crack itself, not surrounding volume
  - Assumes solely linear elastic deformation



Fibre-optic strain monitoring (DAS/DTS)

- Primarily deployed through permanent or wireline mechanisms
  - Permanent – cemented and clamped on the outside of the casing
  - Wireline – either pumped or tractored down inside the casing of an uncompleted wellbore
- 3 distinct phases:
  - 1) Strain front created by tension ahead of crack tip
  - 2) Frac hit response controlled by number of frac hits, interaction between fracs, and noise due to water/proppant transport
  - 3) Mechanical closure of open fracture

Field Data Example

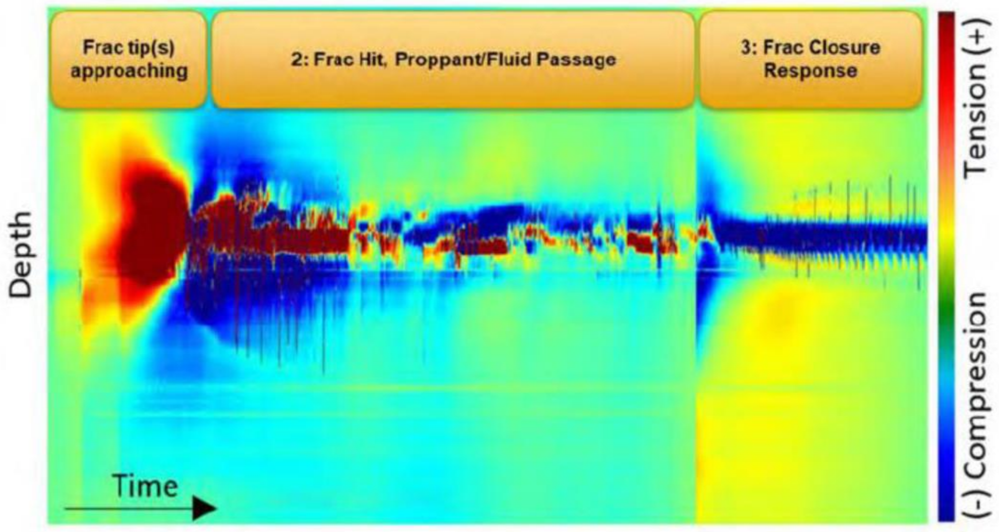


Figure 1—Tension and compression response of the fibre caused by a hydraulic fracture

Fibre-optic strain monitoring (DAS/DTS)

Field Data Example

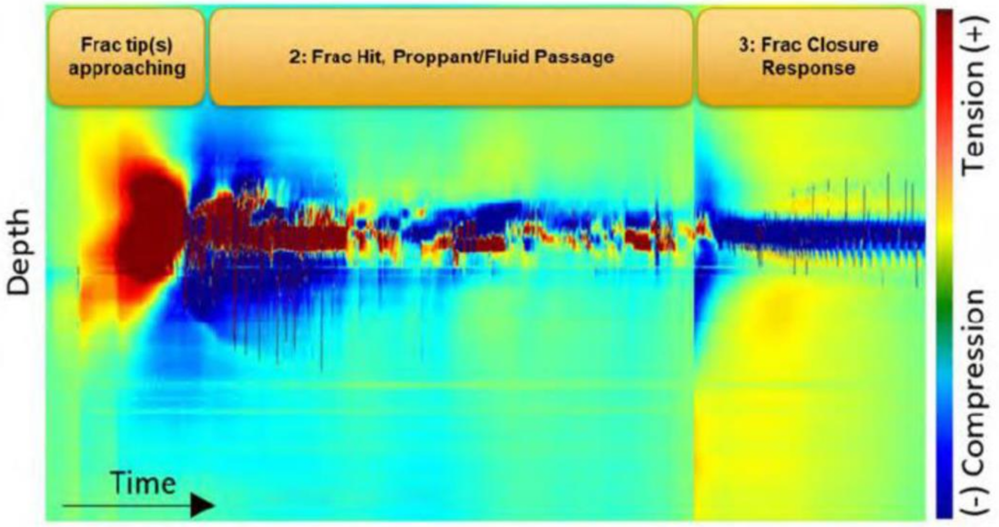
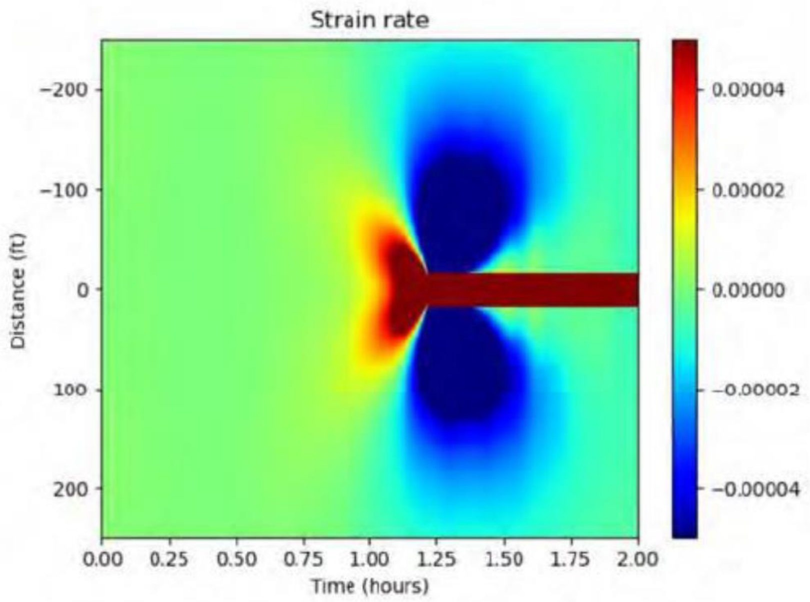


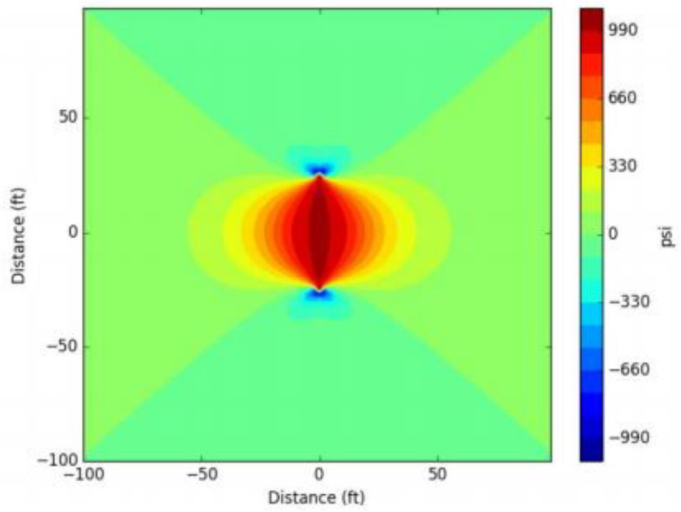
Figure 1—Tension and compression response of the fibre caused by a hydraulic fracture

Simple ResFrac Output



Finite strain vs Infinitesimal strain

- In the field, strain is calculated by taking differences in displacements between two points separated by the ‘gauge length’ then dividing by this length.
- As ‘gauge length’ approaches zero, this is the same as the ‘infinitesimal strain,’ but this is generally different from what is recorded.
- *The tensional region seen in fiber is an artifact of how strain is measured and is not the ‘true’ infinitesimal stress/strain on either side of the rock.*



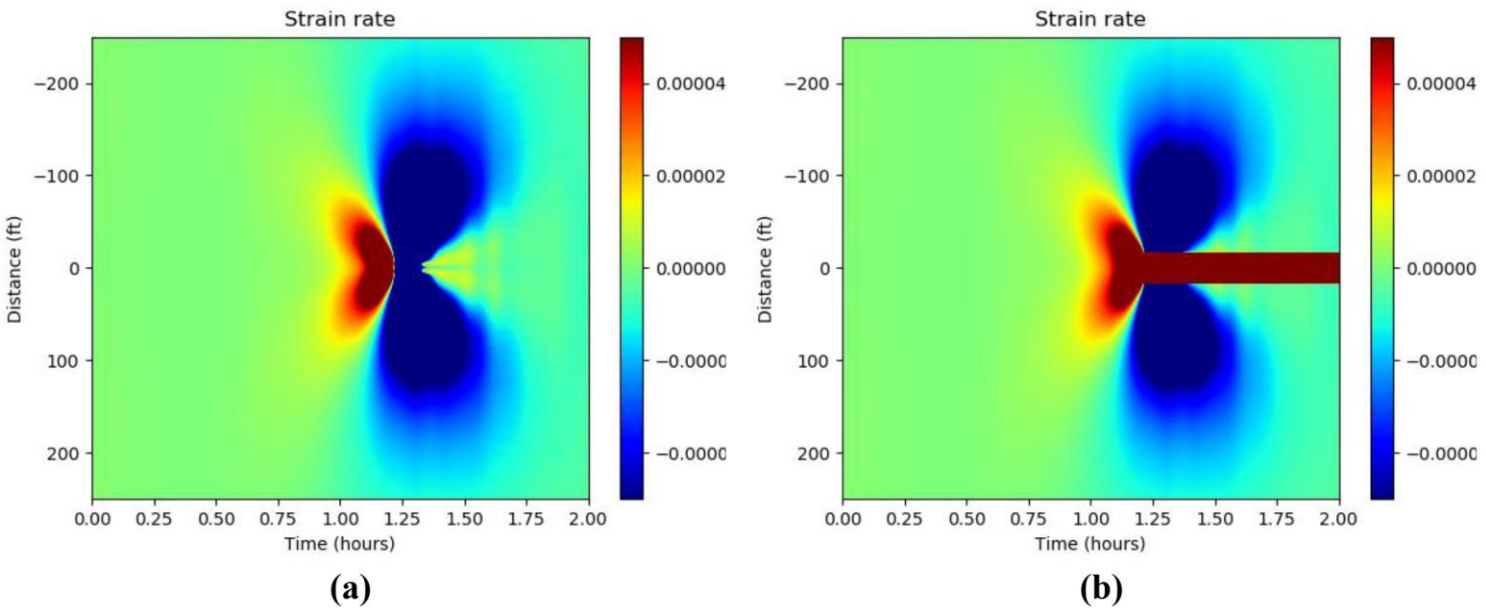


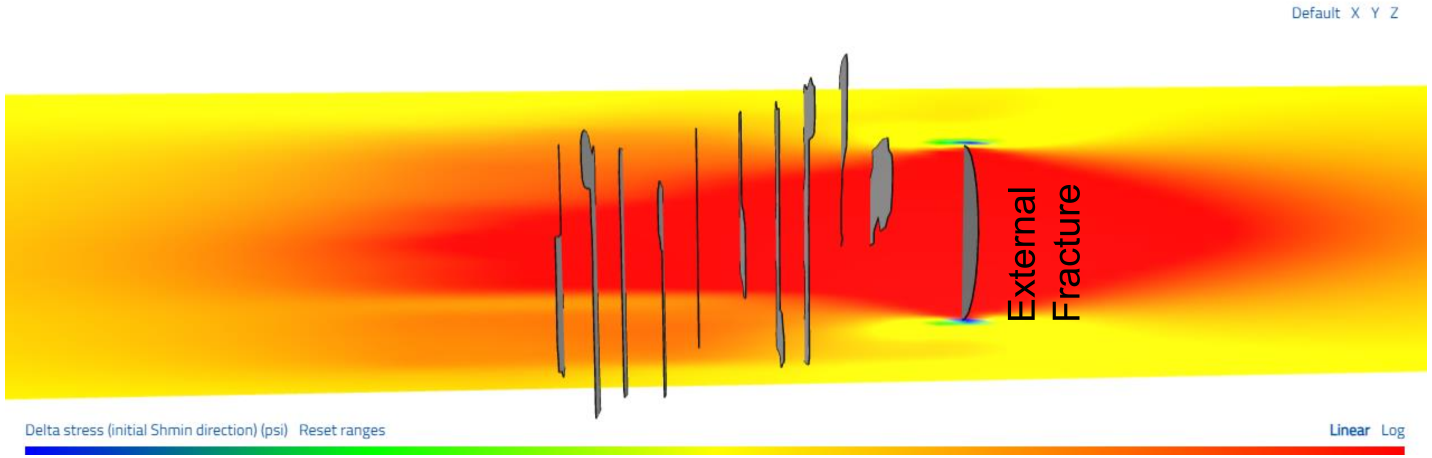
Figure 3 – Strain rate calculated from (a) true strain (b) displacement (fibre approach)

Stress Observation Planes

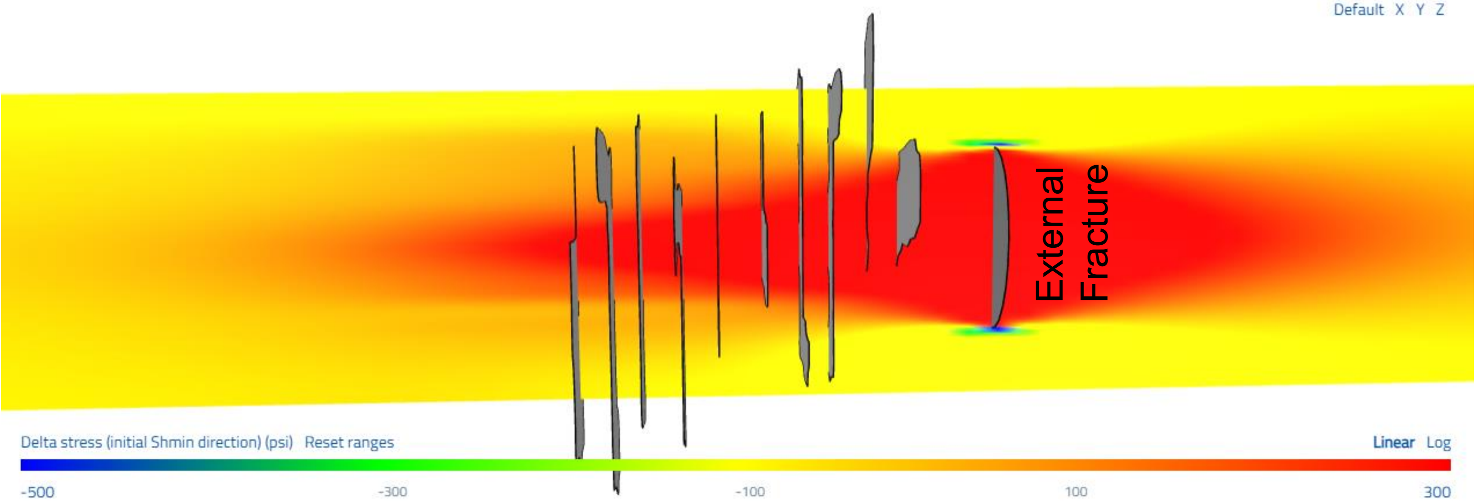
Setup & Visualization

Stress Observation Planes – How to Input

We can use stress observation planes to monitor the amount of stress shadowing around the fractures. This is most often used to 'tune' the pressure of an external fracture to create the correct stress state for the next stage.



Immediately after frac, the fractures are still open and are causing greater stress shadowing.



As the fractures close, the stress shadowing is reduced.

Stress Observation Planes – Output Options

Output Options

Stress observation planes can be created in the x, y and z directions. You can specify as many planes as you think you might need. If you specify too many (a lot) you may actually run out of memory in the simulator and cause the simulation to terminate.

STRESS OBSERVATION POINTS AND PLANES

	nx	ny	nz	minx [ft]	maxx [ft]	miny [ft]	maxy [ft]	minz [ft]	maxz [ft]
1	100	100	1	-1100	900	-1000	1000	9750	9750

New Row Resize Table

Specifies the granularity, or number of elements, of the plane. Since this plane is going to cut across the z axis, the number of elements in the z direction is 1 i.e., flat. The x and y axis of the plane will have 100x100 elements.

Every plane is referenced to the center of the matrix region, found in the meshing options tab.

CENTER OF MATRIX REGION [FT]

Matrix center in x direction [ft]	Matrix center in y direction [ft]	Matrix center in z direction [ft]
-100	0	9465

For instance, the matrix center in the x direction is -100’. The plane is specified from -1100’ to 900’, so a 2000’ long plane centered around x matrix center.

The min and max z values are the same since the plane is flat in this direction.

ResFrac

Observation Planes

Output Options Tab

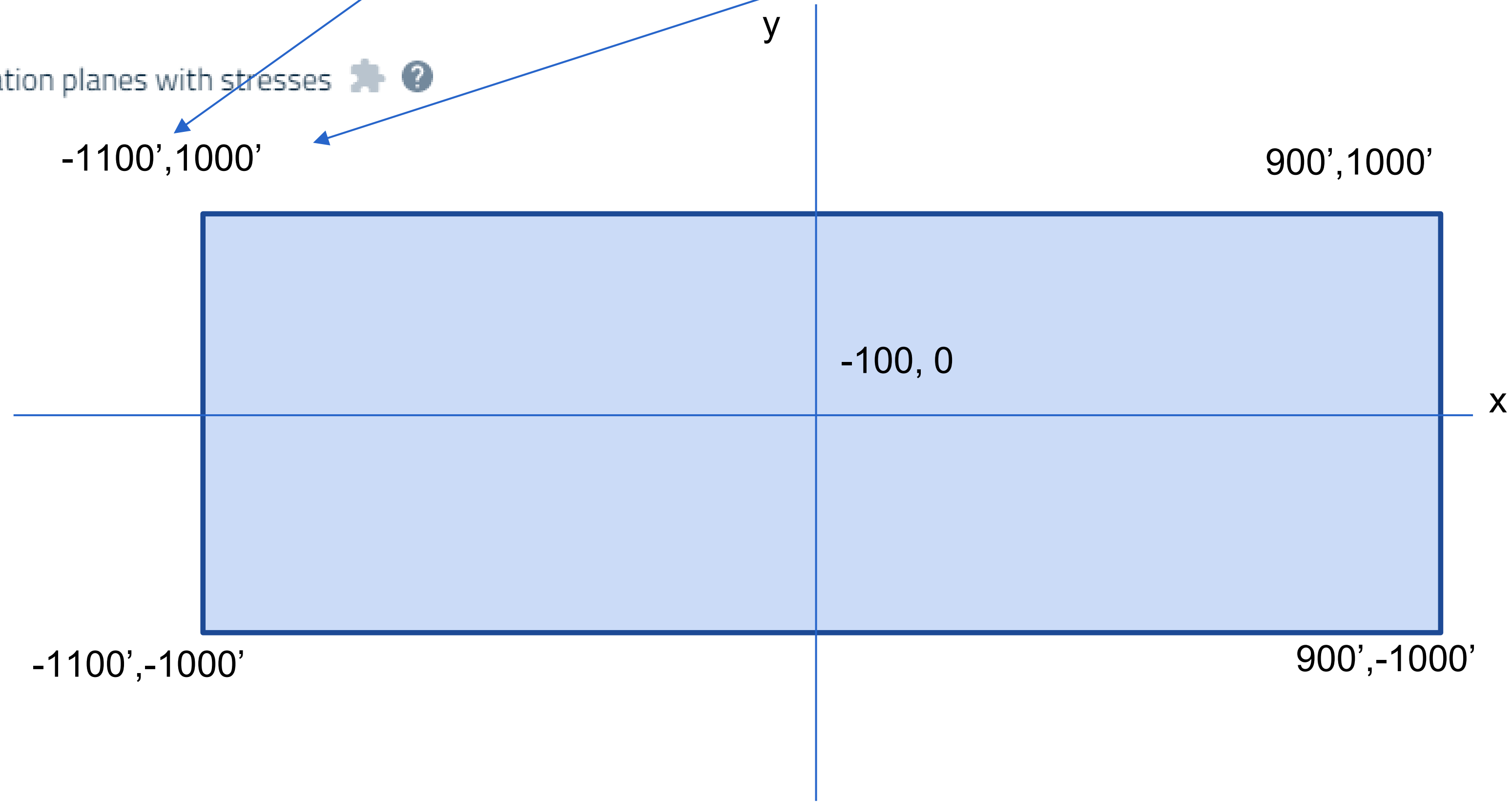
STRESS OBSERVATION POINTS AND PLANES

	nx	ny	nz	minx [ft]	maxx [ft]	miny [ft]	maxy [ft]	minz [ft]	maxz [ft]
1	100	100	1	-1100	900	-1000	1000	9750	9750

Specifies how many segments the plane is divided up.

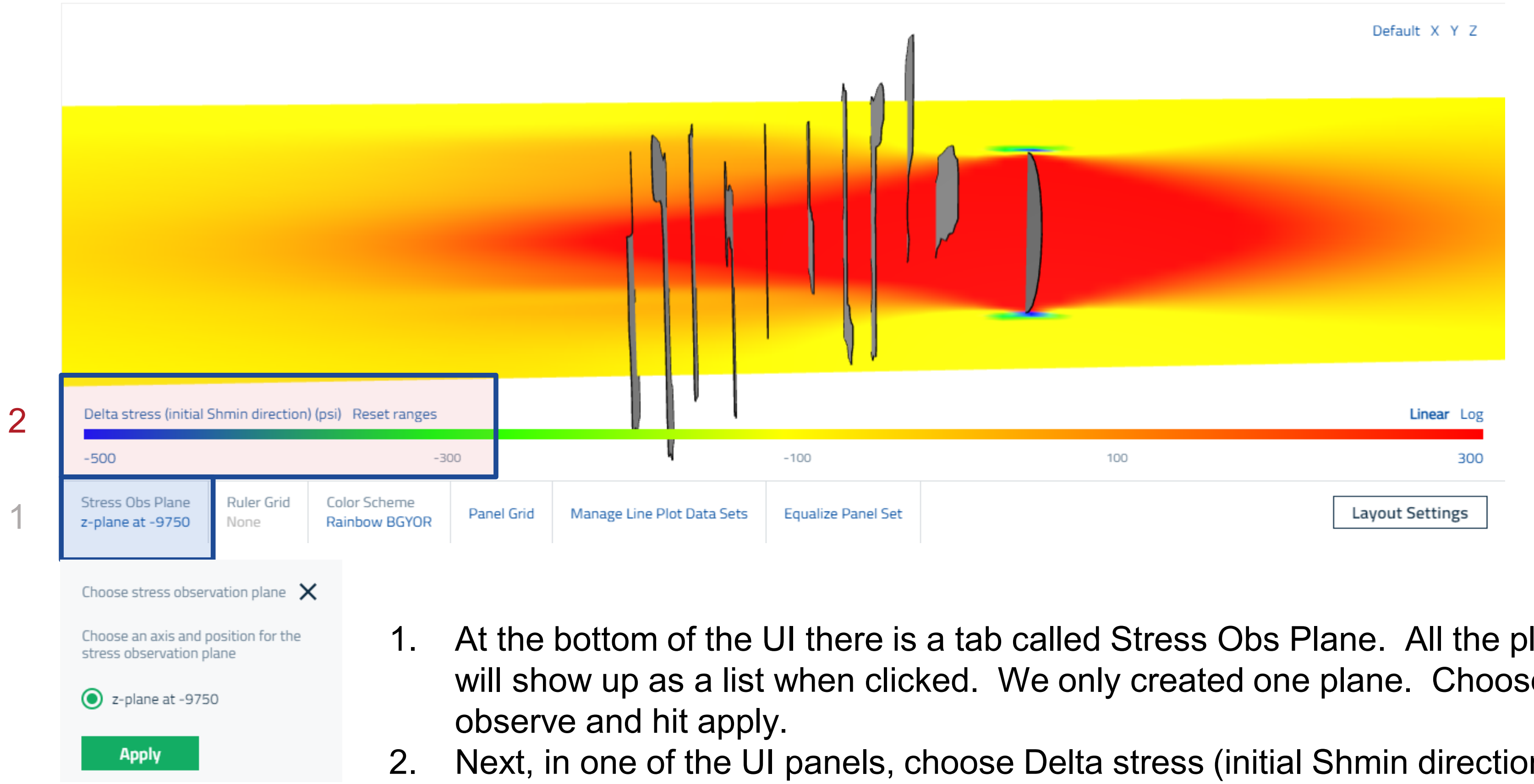
Specifies the coordinates of the corners of the cube. Since this a z plane the thickness is the same depth.

☑ Rotate stress observation planes with stresses



ResFrac

Stress Observation Planes – Viewing the Plane in the UI



1. At the bottom of the UI there is a tab called Stress Obs Plane. All the planes previously created will show up as a list when clicked. We only created one plane. Choose the plane you wish to observe and hit apply.
2. Next, in one of the UI panels, choose Delta stress (initial Shmin direction) or Delta stress (initial Shmax direction). This will display the plane chosen previously.

Stress Observation Points at Well MD

If using stress/strain/displacement reporting with the intent to simulate a fiber response along a well, it may be convenient to specify your ‘stations’ directly along a well’s trajectory.

With this setup option, the code will output ‘stress tensor’ stress/strain/displacement values in the direction aligned with the well orientation at each location, rather than outputting only the stress tensor values alonged with the principal stress direction.

STRESS OBS POINTS AT WELL MD

	Well name	Measured depth [ft]
1		

New Row Resize Table

Stress Observation Planes - Options

Only sxx stress in obs points (checked): In order to create smaller files and save memory, toggling this will only outputs the stresses in this direction, which happens to be the most oft used direction.

Output obs point strains: If specifying specific stress observation points (either in the ‘Stress observation points and planes’ table or the ‘Stress obs points at well MD’ table) then the corresponding strain is outputted as well.

Output displacements to tracking file: If specifying specific stress observation points, then displacements for these points are outputted. This is similar to how DSS fiber is outputted.

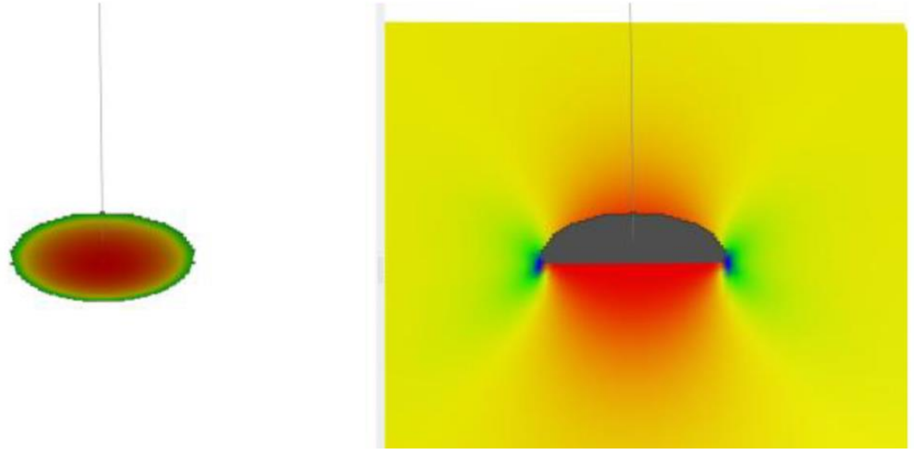
Extra stress observation plane outputting: Allows extra file outputting to visualize the obs point strains and displacement in the 3D UI. Otherwise, they are just output to the sim_track file.

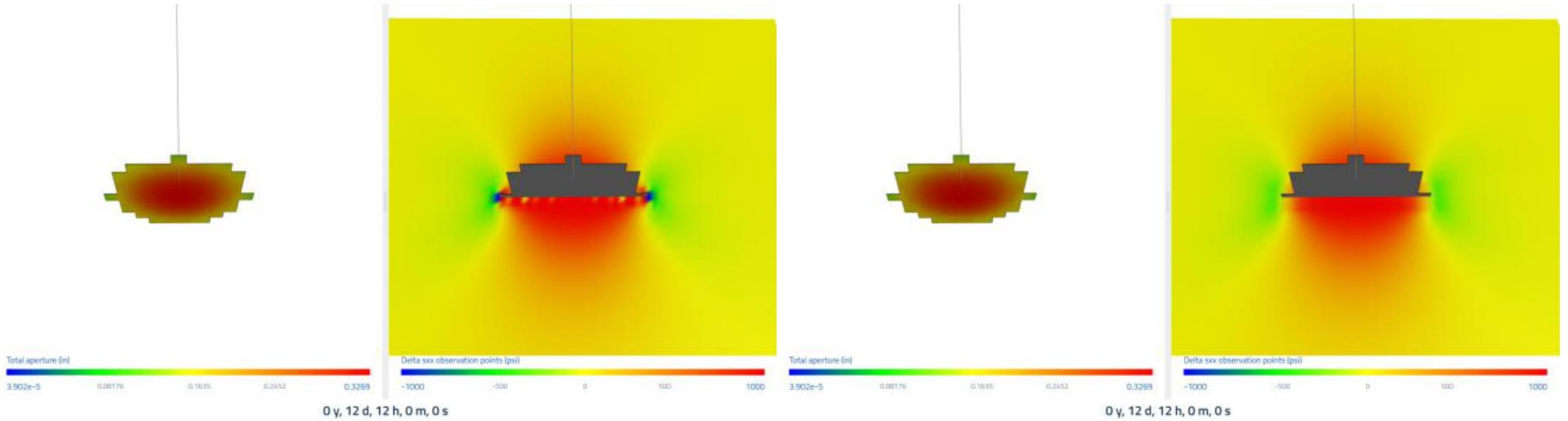
Rotate stress observation planes with stresses (checked): Rotates the plane in the direction of Shmax. Note that this rotation occurs *after* establishing the dimensions of the plane in the table. In other words, the coordinates are set *before* rotation.

Stress calculations in ResFrac – BEM Adjustment

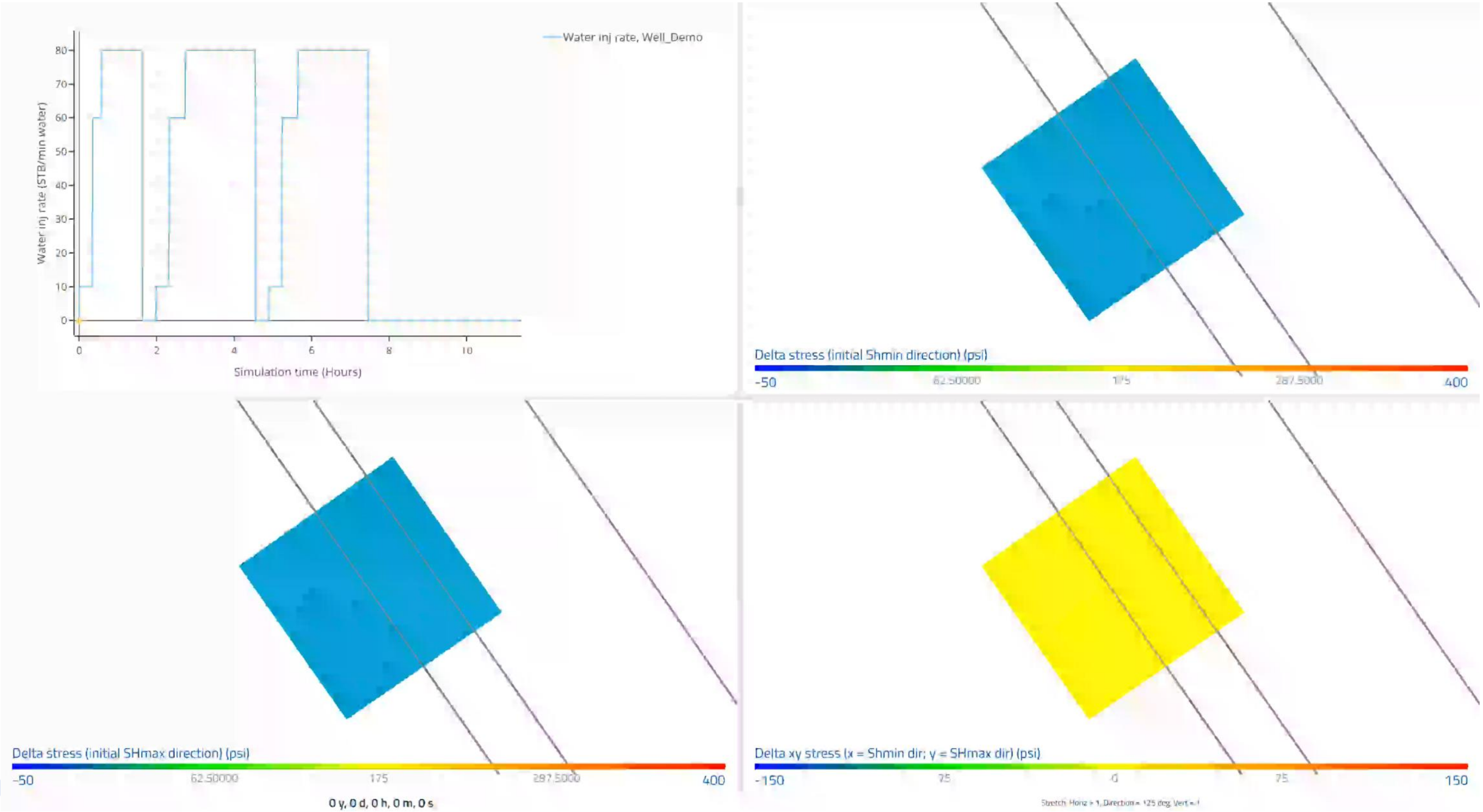
- With the boundary element method, numerical artifacts can cause inaccurate very close to a matrix element (infinite stress).
- BEM adjustment used in calculating stress shadow moves the ‘observation point’ outward perpendicular to the crack.

☑ Do not apply BEM proximity adjustment to individual observation points





Example:


Water inj rate, Well_Demo
Water inj rate (STB/min water)
80
70
60
50
40
30
20
10
0
0
2
4
6
8
10
Simulation time (Hours)
Delta stress (initial Shmin direction) (psi)
-50
62.50000
175
287.5000
400
Delta stress (initial SHmax direction) (psi)
-50
62.50000
175
287.5000
400
0 y, 0 d, 0 h, 0 m, 0 s
Delta xy stress (x = Shmin dir; y = SHmax dir) (psi)
-150
75
0
75
150

Fiber Diagnostics

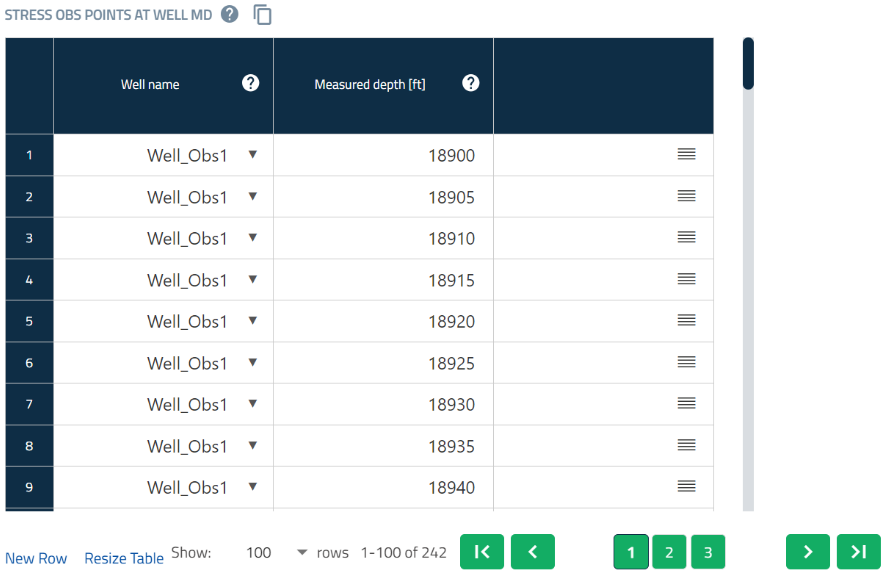
Setup & Visualization

Simulation Setup

To setup a simulation to create a waterfall plot from the outputs, you will need to create ‘Stress observation points’ to represent the location of the fiber. This can be done in the ‘Stress observation points and planes’ table or the ‘Stress obs points at well MD’ table on the ‘Output Options’ panel in the builder.

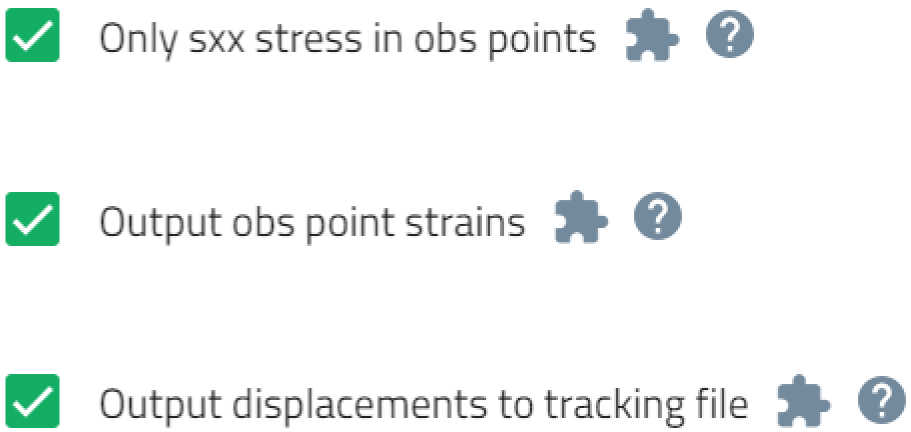
Requirements:

- Points should be in a line, though multiple different lines can be included to represent different fiber wells.
- Points should be spaced equidistantly.
- ‘Output obs point strains’ and/or ‘Output displacements to tracking file’ should be checked depending on plotting preference. (See next slide)


STRESS OBS POINTS AT WELL MD

	Well name	Measured depth [ft]	
1	Well_Obs1	18900	
2	Well_Obs1	18905	
3	Well_Obs1	18910	
4	Well_Obs1	18915	
5	Well_Obs1	18920	
6	Well_Obs1	18925	
7	Well_Obs1	18930	
8	Well_Obs1	18935	
9	Well_Obs1	18940	

New Row Resize Table Show: 100 rows 1-100 of 242 1 2 3



Using the python script to create waterfall plots

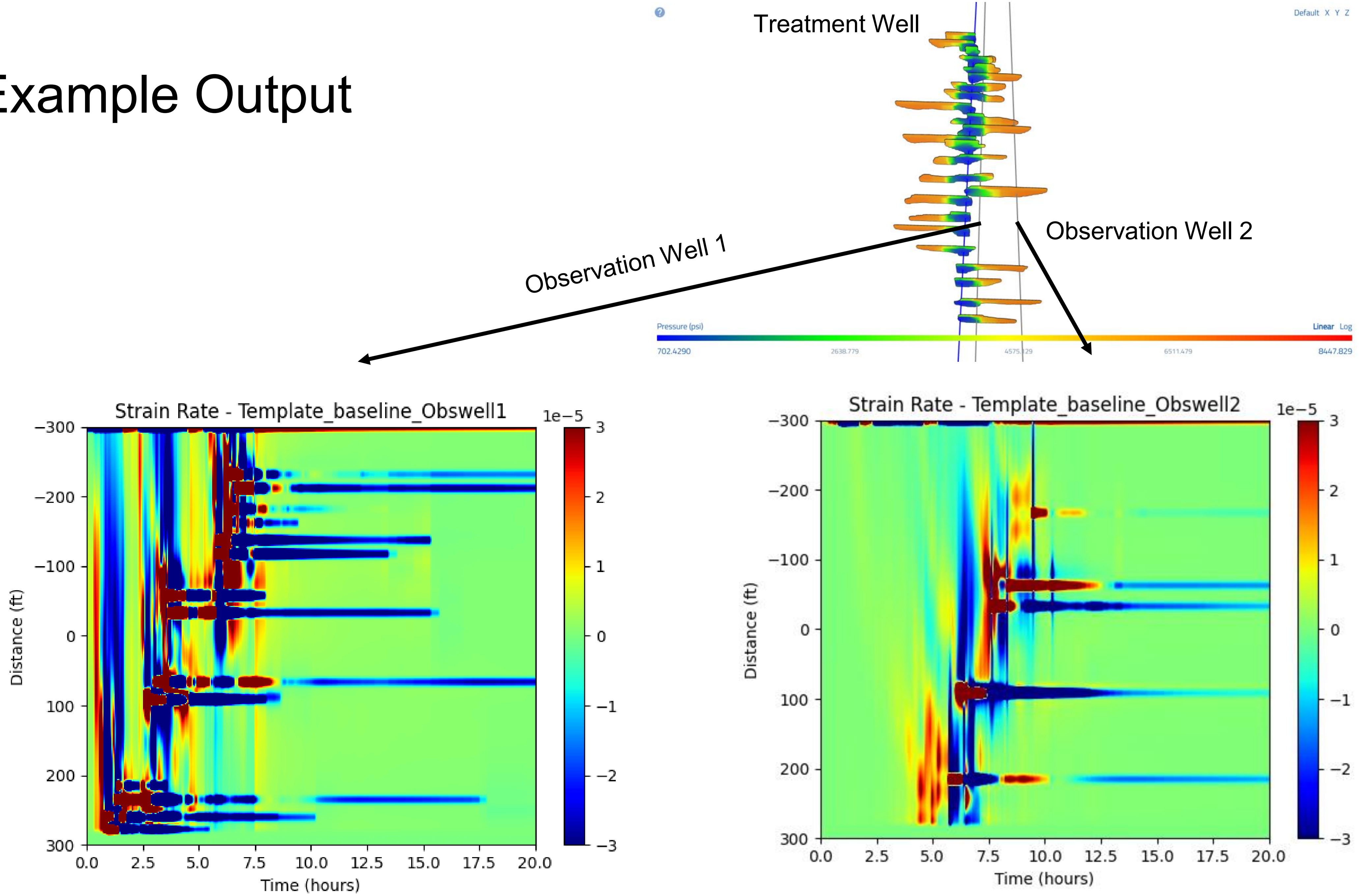
If you would like to use our python script to create fiber waterfall plots, please reach out to support@resfrac.com and we would be happy to provide it to you!

1. Provide a name for the dataset.
2. Specify the location of the relevant sim_track file that contains the data.
3. Specify a distance along which the waterfall plot will be made.
4. Select start and end times for the plot.
5. Specify the first and last stress observation points to be included. *These are equivalent to the row numbers in the stress observation point tables.*
6. Select the attribute to be plotted, most often ‘Strain’.
   - TrueStrain – Plots the ‘infinitesimal’ strain rate at each location. Must have ‘Output obs point strains’ checked in output options.
   - Strain – Plots the strain rate calculated from displacement between stations (stress observation points). Must have ‘Output displacements to tracking file’ check in output options.
7. Specify the setup option
   - ‘Explicit’ if stress observation points are set up with the ‘Stress observation points and planes’ table
   - ‘MD’ if stress observation points are set up with the ‘Stress obs points at well MD’ table
8. Provide a name for the plots.

Using the python script to create waterfall plots

```
name = "Template_baseline_Obswell1"
filename = "C:\ResFracProAdmin\data\projects\Collateral Dev\workflows\Fiber Match\simulations\Base_ObsWells_NoBEM_v3\Results\sim_track_Base_ObsWells_NoBEM_v3.cs
if True:
    datin = Dataset(name, filename)
    datin.df = pd.read_csv(datin.filename, delimiter=',', header=[1, 2], skiprows=[3])
    datin.fulldatain = datin.df.values
    datin.distance = 600  # ft
    datin.mintime = 0  # hrs
    datin.maxtime = 20  # hrs
    datin.firstpoint = 1    # Row number of the first stress observation point along the observation line (one indexed)
    datin.lastpoint = 121   # Row number of the last stress observation point along the observation line (one indexed)
    datin.attribute = "Strain"  # Options: Stress, Stress w/ prothermo, Displacement, True strain, True strain w/ porothermo, Strain
    datin.setupoption = 'MD'    # Options: MD, Explicit (Use MD is assigning well the Well & MD option; Use explicit if setting up explicit x,y,z locations)
    datin.plotname = "Template_baseline_Obswell1"
    datlist.append(datin)
```

Example Output



Fiber Diagnostics Motifs

High Fidelity Fibre-Optic Observations and Resultant Fracture Modeling in Support of Planarity

Mojtaba Shahri; Andrew Tucker; Craig Rice; Zach Lathrop; Dave Ratcliff; Mark McClure; Garrett Fowler

Paper presented at the SPE Hydraulic Fracturing Technology Conference and Exhibition, Virtual, May 2021.
Paper Number: SPE-204172-MS
https://doi.org/10.2118/204172-MS
Published: April 27 2021

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Abstract

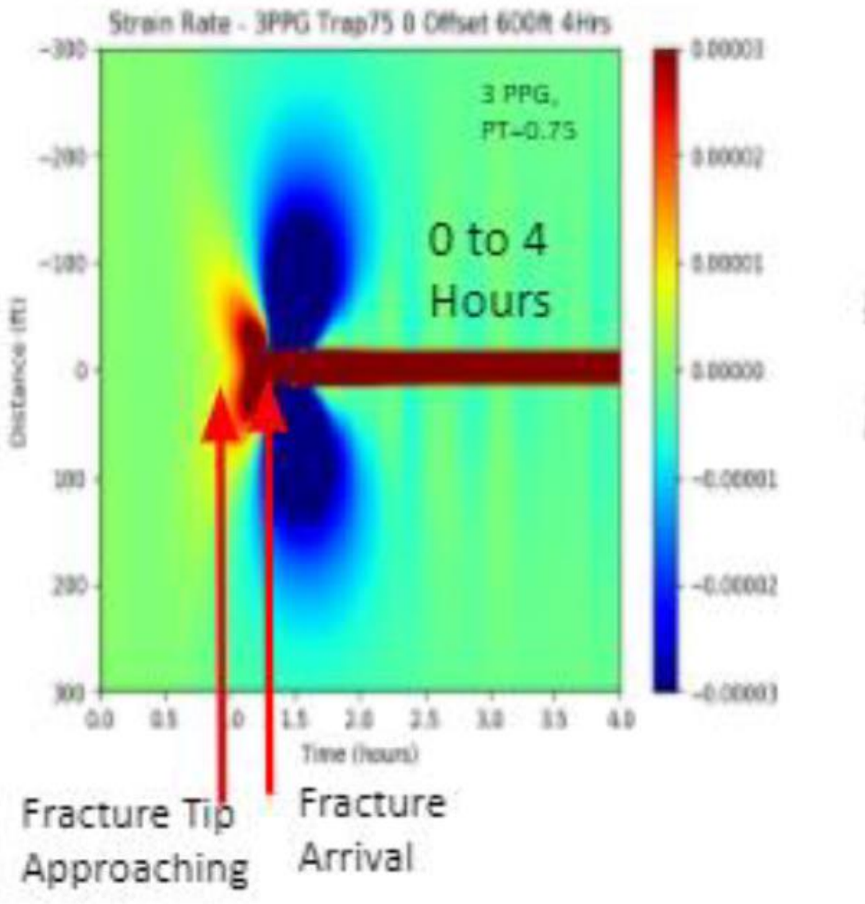
In the last decade, we have observed major advancements in different modeling techniques for hydraulic fracturing propagation. Direct monitoring techniques such as fibre-optics can be used to calibrate these models and significantly enhance our understanding of subsurface processes.

In this study, we present field monitoring observations indicating consistently oriented, planar fractures in an offset-well at different landing zones in the Permian basin. Frac hit counts, location, and timing statistics can be compiled from the data using offset wells at different distances and depths. The statistics can be used to calibrate a detailed three-dimensional fully coupled hydraulic fracturing and reservoir simulator. In addition to these high-level observations, detailed fibre signatures such as strain response during frac arrival to the monitoring well, post shut-in frac propagation and frac speed degradation with length can be modeled using the simulator for further calibration purposes.

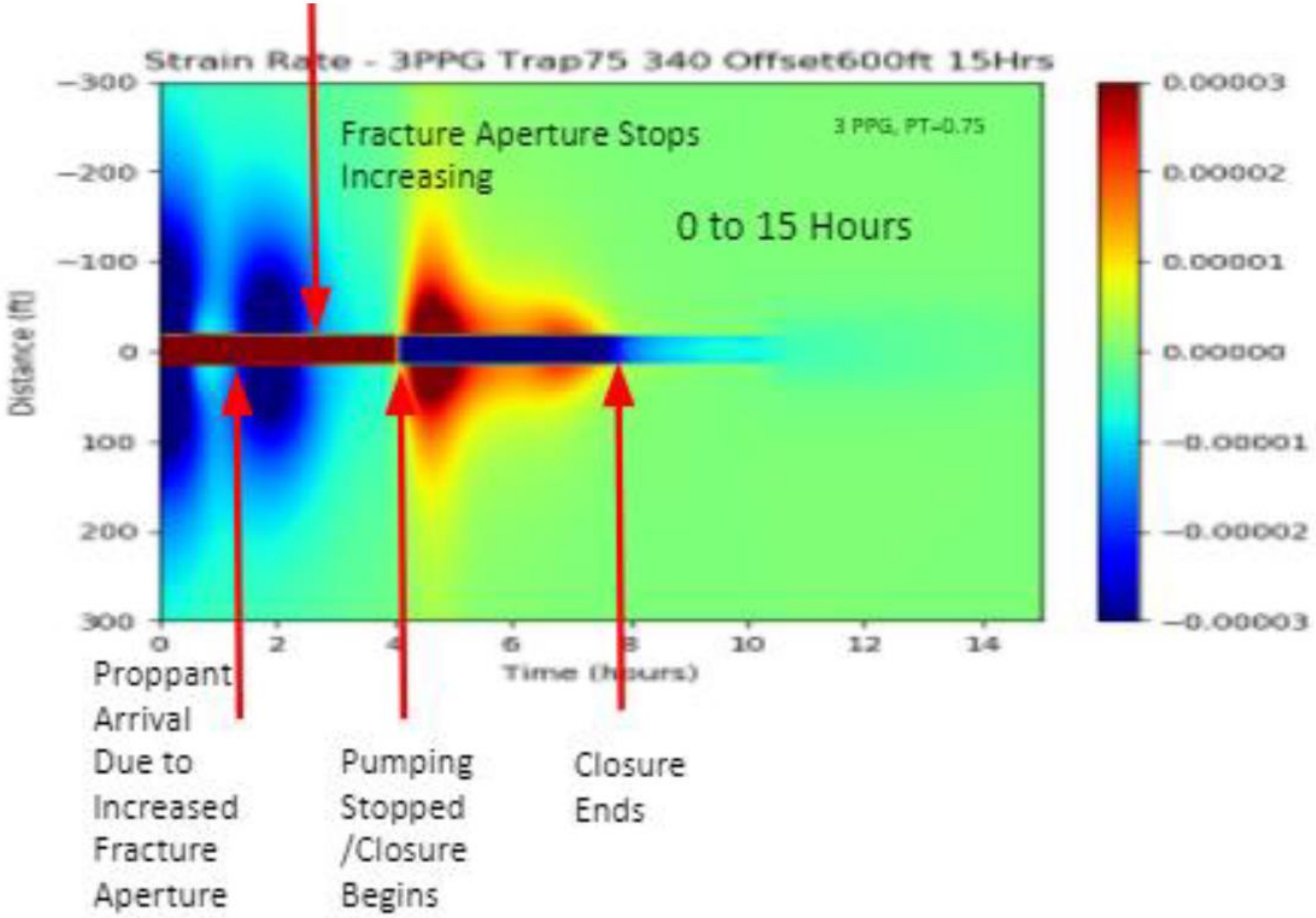
Application to frac modeling calibration is presented through different case studies. The simulator was used to directly generate the 'waterfall plot' output from the fibre-optic under a variety of scenarios. The history match to the large, detailed synthetic fibre dataset provided exceptional model calibration, enabling a detailed description of the fracture geometry, and a high-confidence estimation of key model parameters. The detailed synthetic fibre data generated by the simulator were remarkably consistent with the actual data. This indicates a good consistency with classical analytical fracture mechanics predictions and further confirm the interpretation of planar fracture propagation.

This study shows how careful integration of offset-well fibre-optic measurements can provide detailed characterization of fracture geometry, growth rate, and physics. The result is a detailed picture of hydraulic fracture propagation in the Midland Basin. The comparison of the waterfall plot simulations and data indicate that hydraulic fractures can, in fact, be very well modeled as nearly-linear cracks (the 'planar fracture modeling' approach).

Fracture Arrival & Crossing



Proppant Arrival & Closure



Sensitivity to Young's Modulous

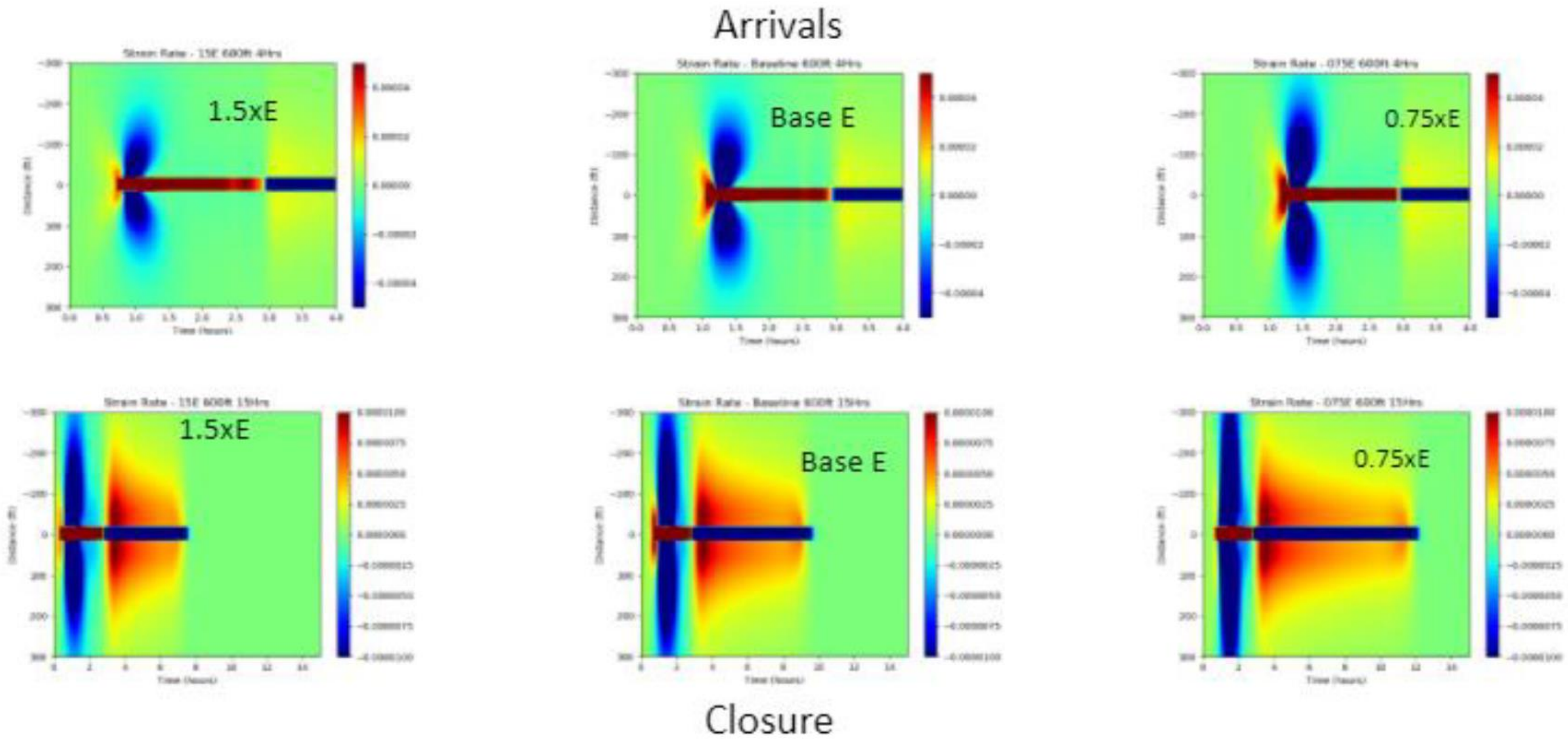


Figure 6 – Fibre response for three different values of Young's modulus

Angle of fracture compared to well

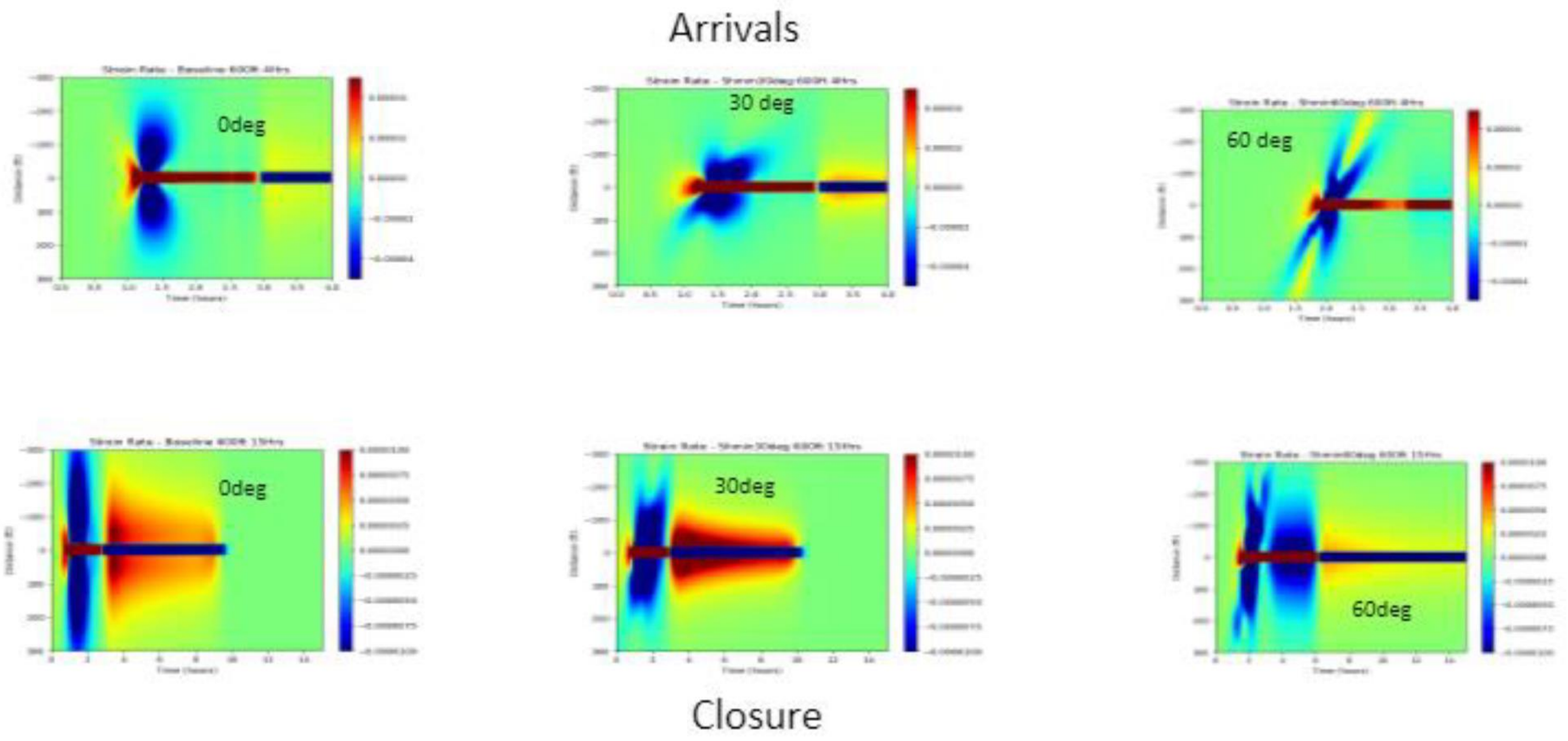


Figure 8 – Fibre response for three different angles of intersection between the fracture and the wellbore

Angle of fracture compared to well

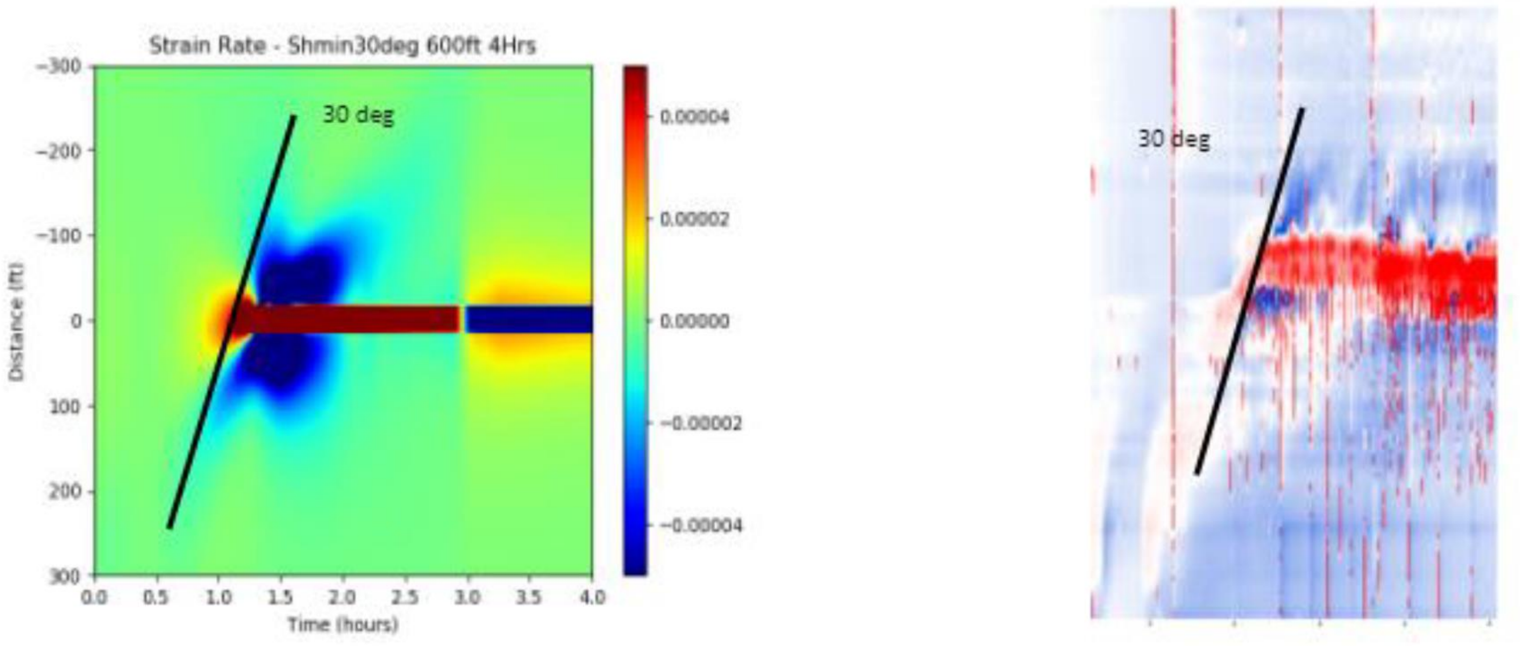


Figure 9 – Synthetic and actual waterfall plot for an intersection at a 30° angle from being perpendicular

ResFrac

Fractures passing above or below

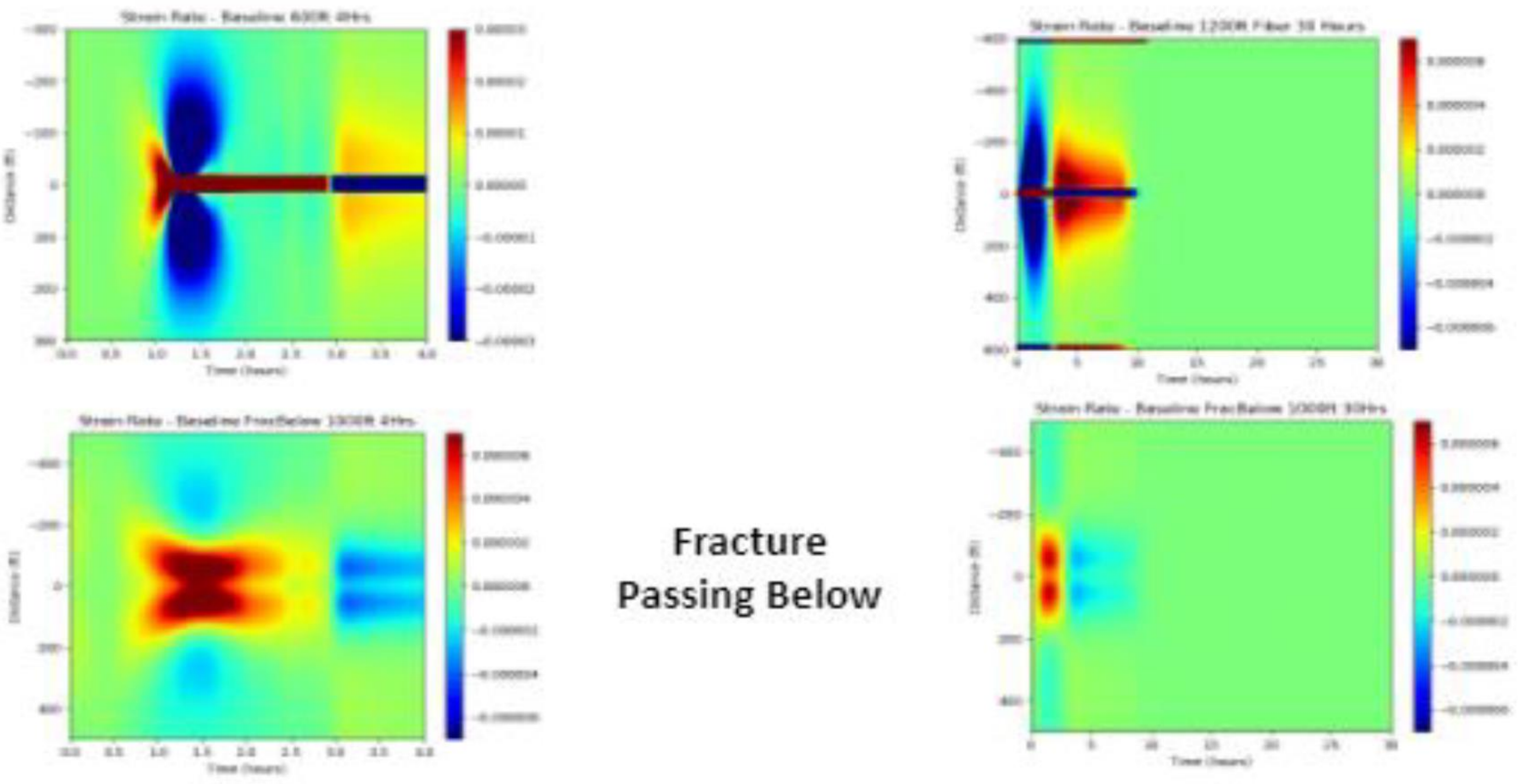


Figure 16 – Signature of a fracture intersecting a monitor well (top) vs. passing below (or above) a monitor well (bottom).

Fractures passing above or below

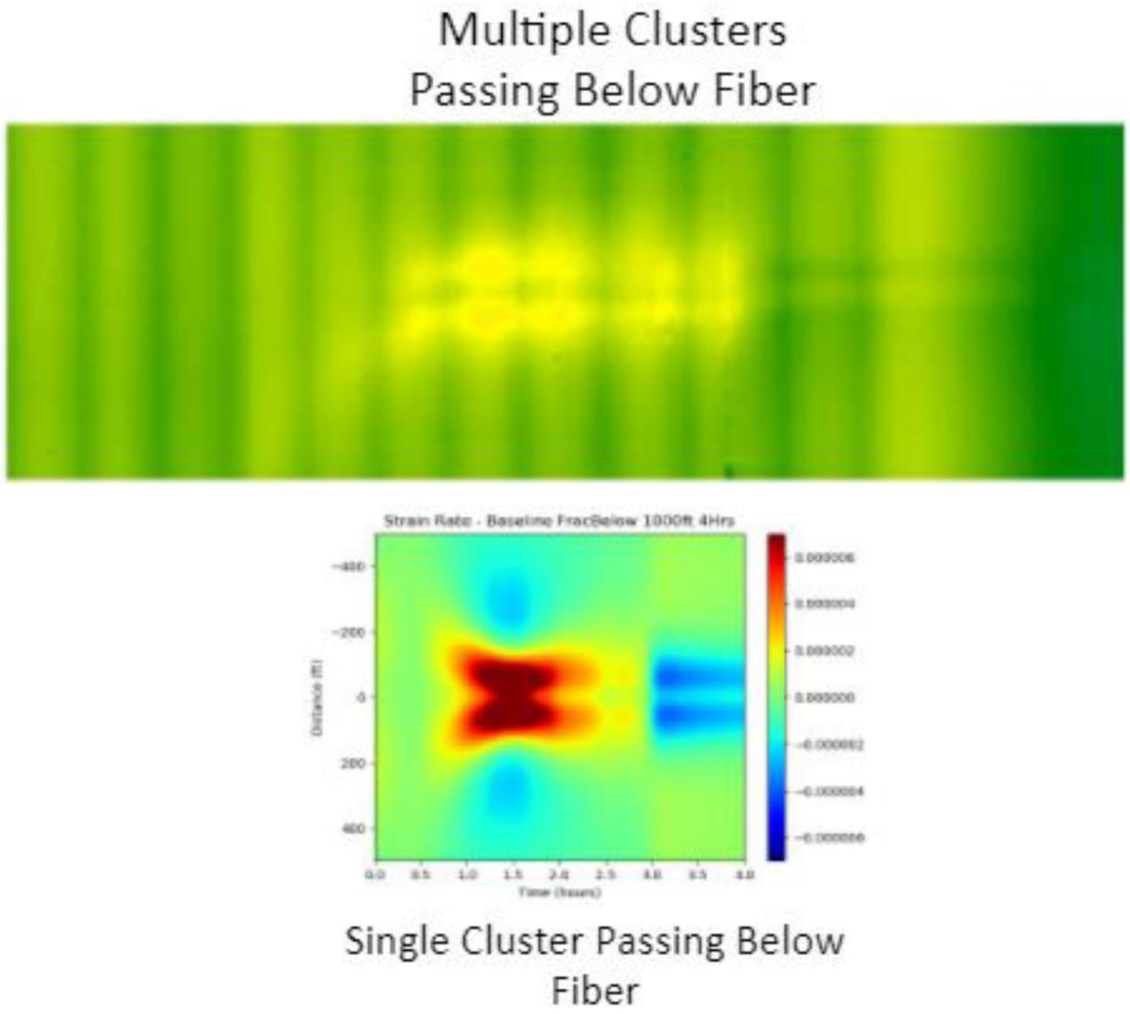


Figure 17 – Actual and synthetic fibre response for a fracture passing below the wellbore

ResFrac

Multiple fractures in a stage

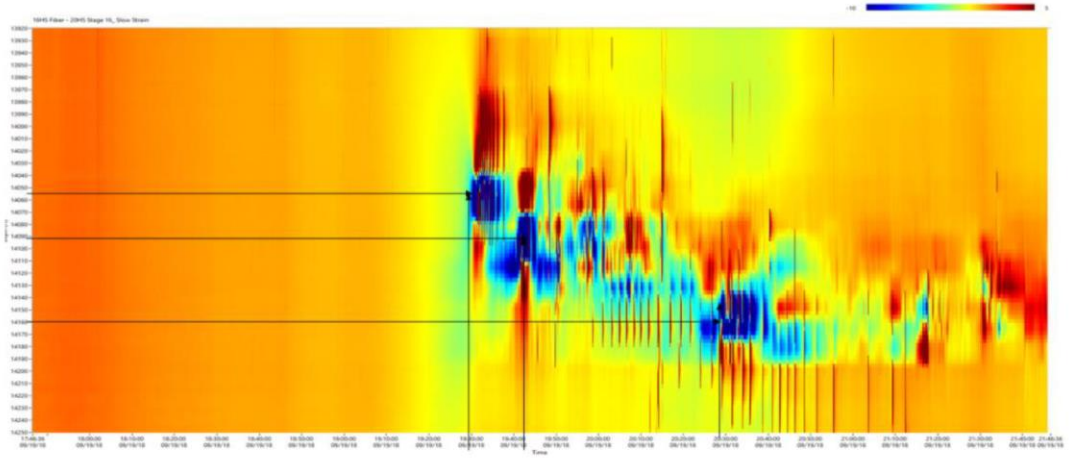


Figure 18 – Multiple fracture hits detected at different point along the fibre. Note that the color scheme is flipped from majority of figures with blue as tension and red as compression here.

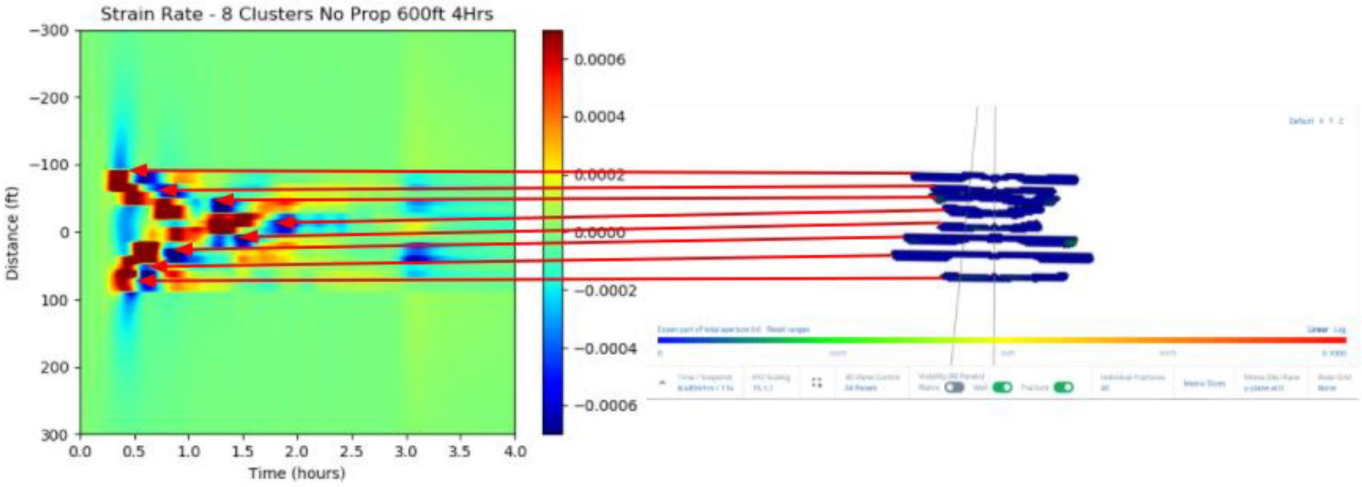


Figure 19 – Simulated multi-cluster frac hits

Thank You!

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cponners@resfrac.com

Last updated Feb 2026