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High-definition wellbore trajectory – drilling, completion and production considerations

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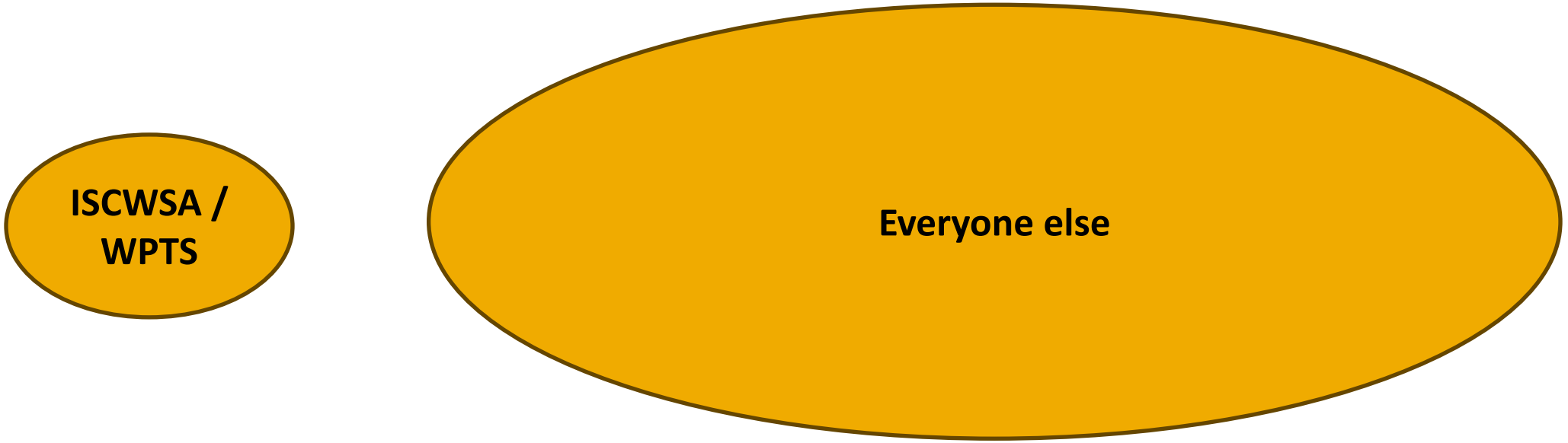
2025-26 Distinguished Lecturer

Agenda

- Wellbore Surveying – Background and motivation
- Dogleg Severity (DLS) and High-density data
- Applications
  - ESPs
  - Rod pumps
  - Running casing
  - Cementing
  - Wellbore placement
- Conclusions

Background

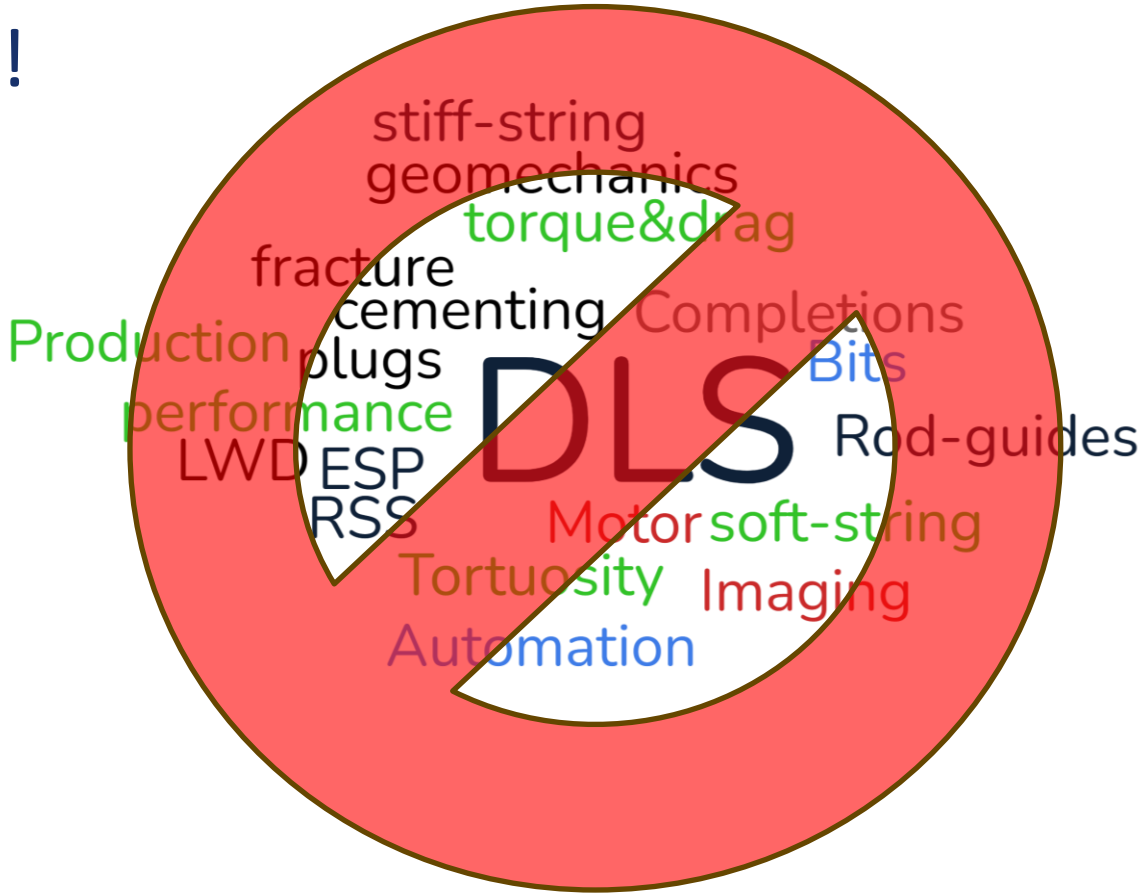
- Knowing the trajectory of the well is an essential part of direction drilling.
- Wellbore positioning uncertainty – two main levels of understanding



Industry Steering Committee on Wellbore Surveying Accuracy
Wellbore Positioning Technical Section (of SPE)

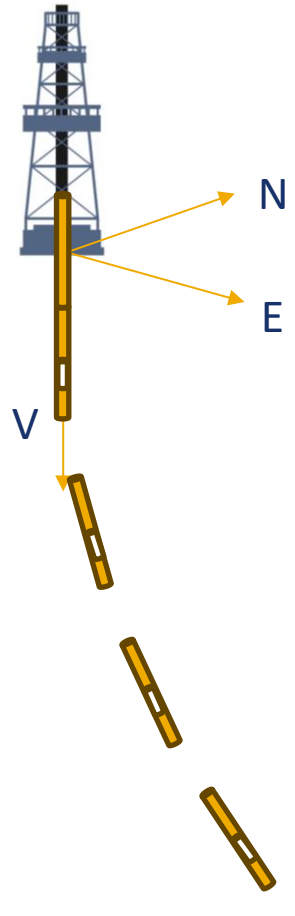
Motivation

- Dogleg severity (DLS) and 100-ft survey data are use everywhere!



Wellbore Surveying

- Nowadays, almost all wells are drilled and surveyed using some form of measurement-while-drilling, MWD.



Survey #	MD	Inclination	Azimuth	Vertical	North	East
1	0	0	0	0	0	0
2	94	0.54	60.64	94	0.22	0.39
3	188	2.03	266.25	187.98	0.33	-0.89
4	282	4.06	263.69	281.84	-0.15	-5.86
5	376	5.76	264.84	375.5	-0.94	-13.86
6	470	8.69	263.12	468.74	-2.21	-25.62

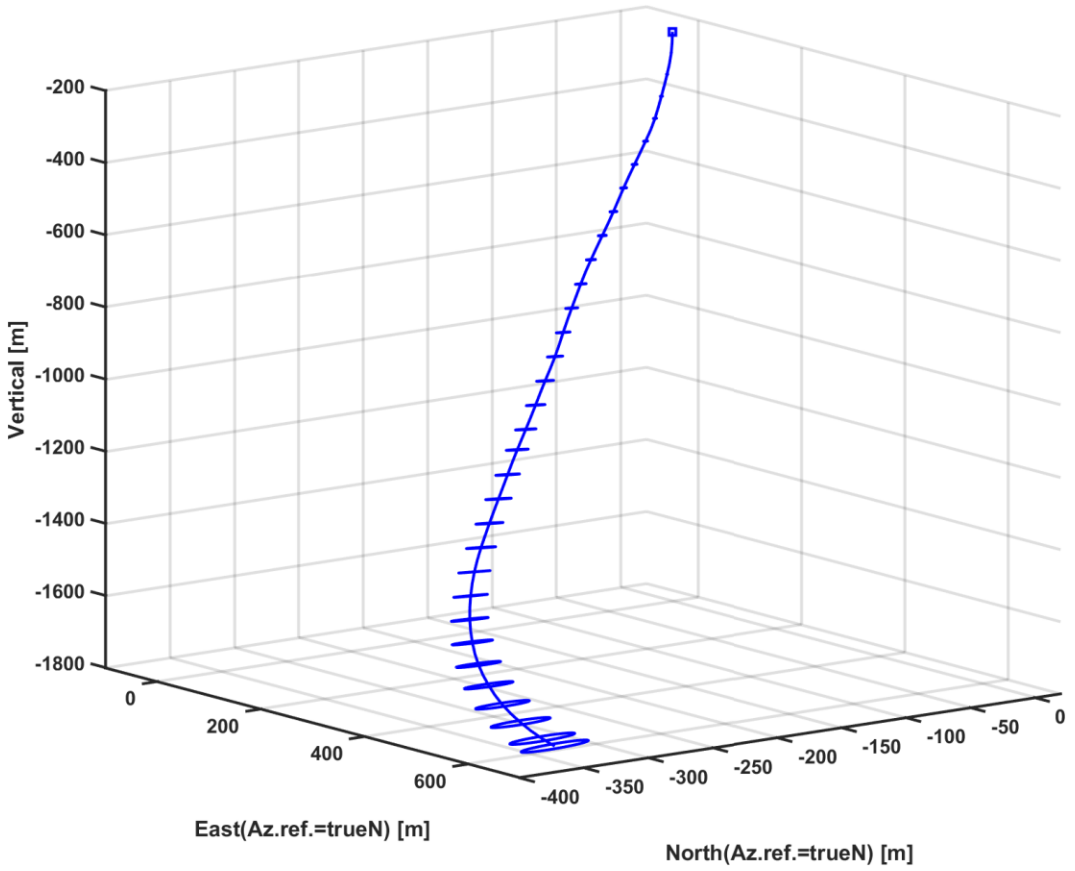
Minimum curvature

Wellbore Surveying

1. Modern survey instruments measure fields (physical phenomenon):
   i. Gravity Field
   ii. Earth Magnetic Field
   iii. Earth Rotational Rate

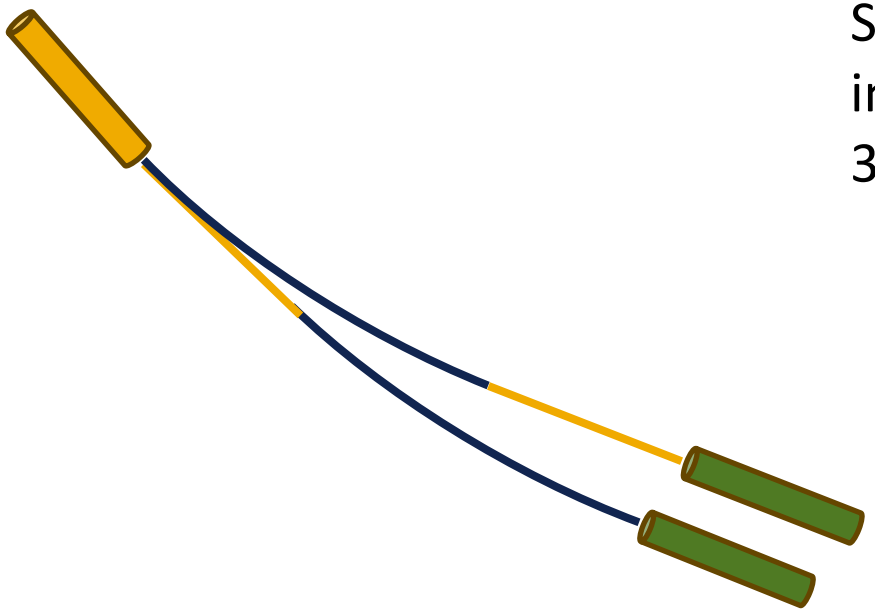
   – These quantities are converted to orientation angles: Inclination, Azimuth and Toolface

   – Errors in the field measurements are propagated in a complex way into orientations and positions



Wellbore Surveying

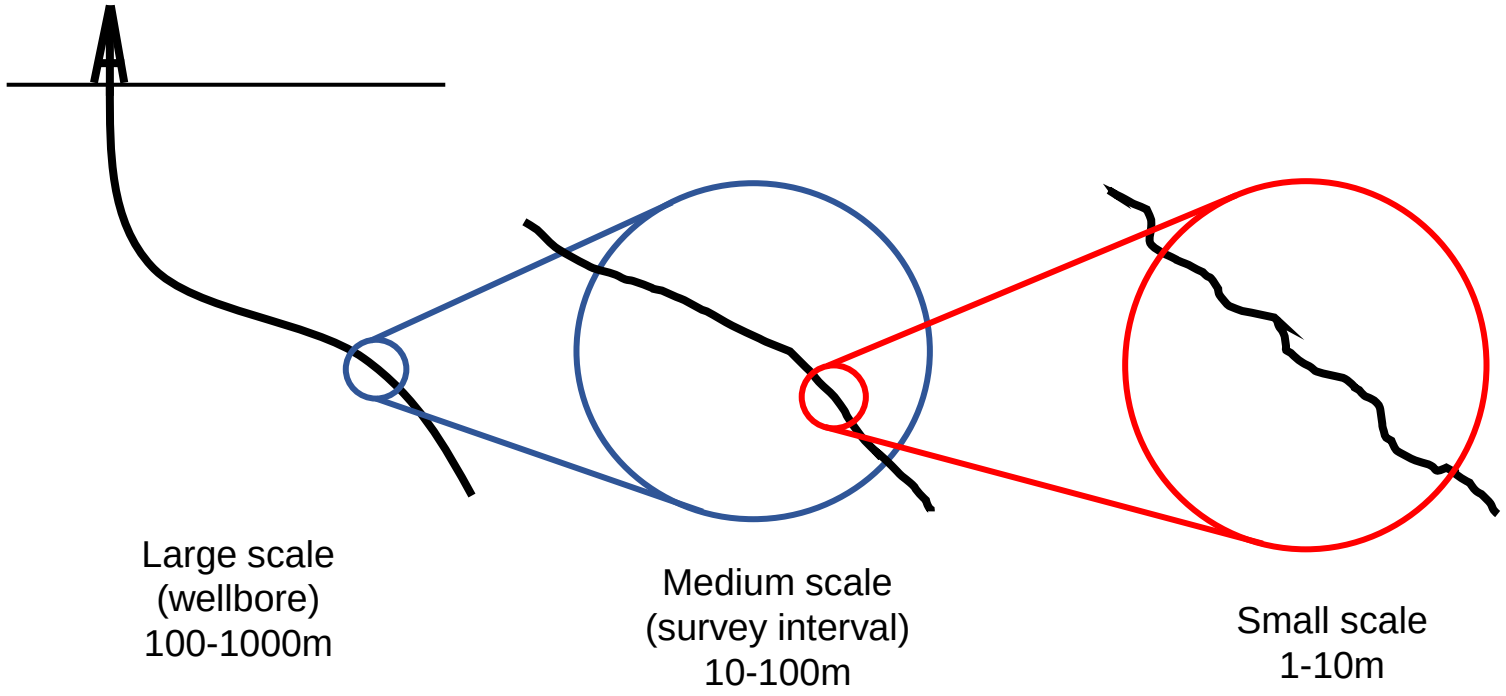
2. The orientation angles and the minimum curvature (assumption) are used to compute the position of the instrument in three dimensions: North, East and Vertical



Same azimuths and inclinations – different 3D positions

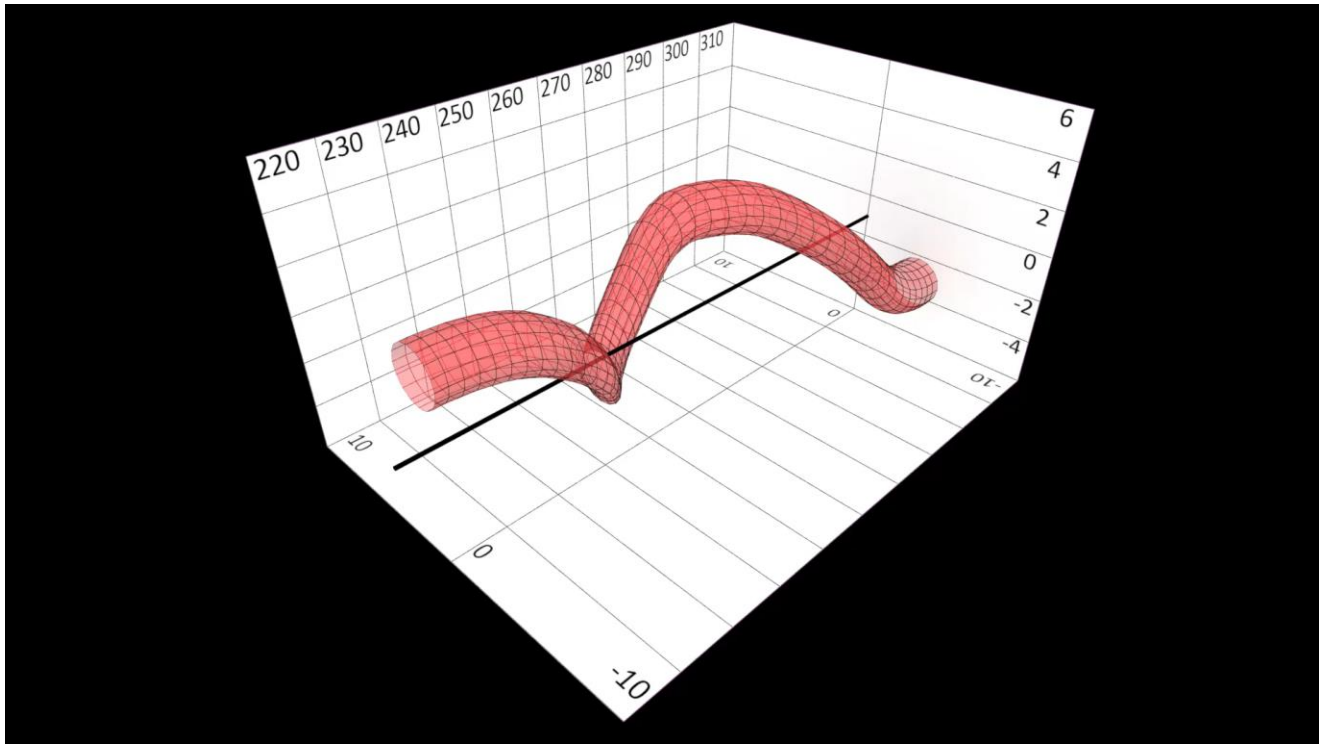
Wellbore Surveying

3. The trajectory is not smooth



Wellbore Surveying

4. The survey instruments only show information on what they measure
   I. MWD in open-hole typically does not show the tortuosity of the casing
   II. Casing surveys typically do not show the tortuosity of the open-hole or production tubing



- $4^{1/2''}$ production tubing
- $7''$ casing
- $9^{5/8''}$ casing

Dogleg Severity

Dogleg Severity is a measure of the change in inclination and azimuth of a borehole, usually expressed in degrees/100 ft.

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$$DLS = cos^{-1}\left[cos(I_2 - I_1) - sin(I_1)sin(I_2)\left(1 - cos(A_2 - A_1)\right)\right]/\Delta MD$$

Where:

DLS = dogleg severity in degrees/l00 ft

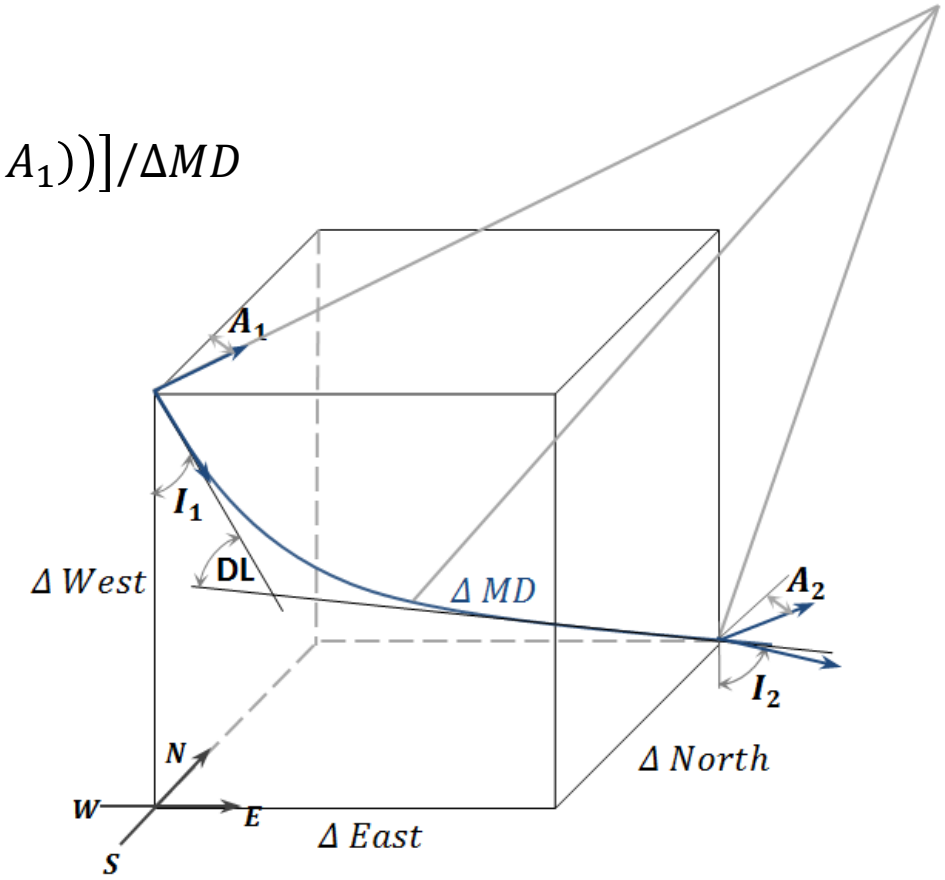
MD = Measured Depth between survey points in ft

I1 = Inclination (angle) at upper survey in degrees

I2 = Inclination (angle) at lower in degrees

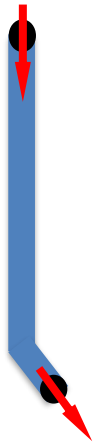
A1= Azimuth direction at upper survey

A2 = Azimuth direction at lower survey

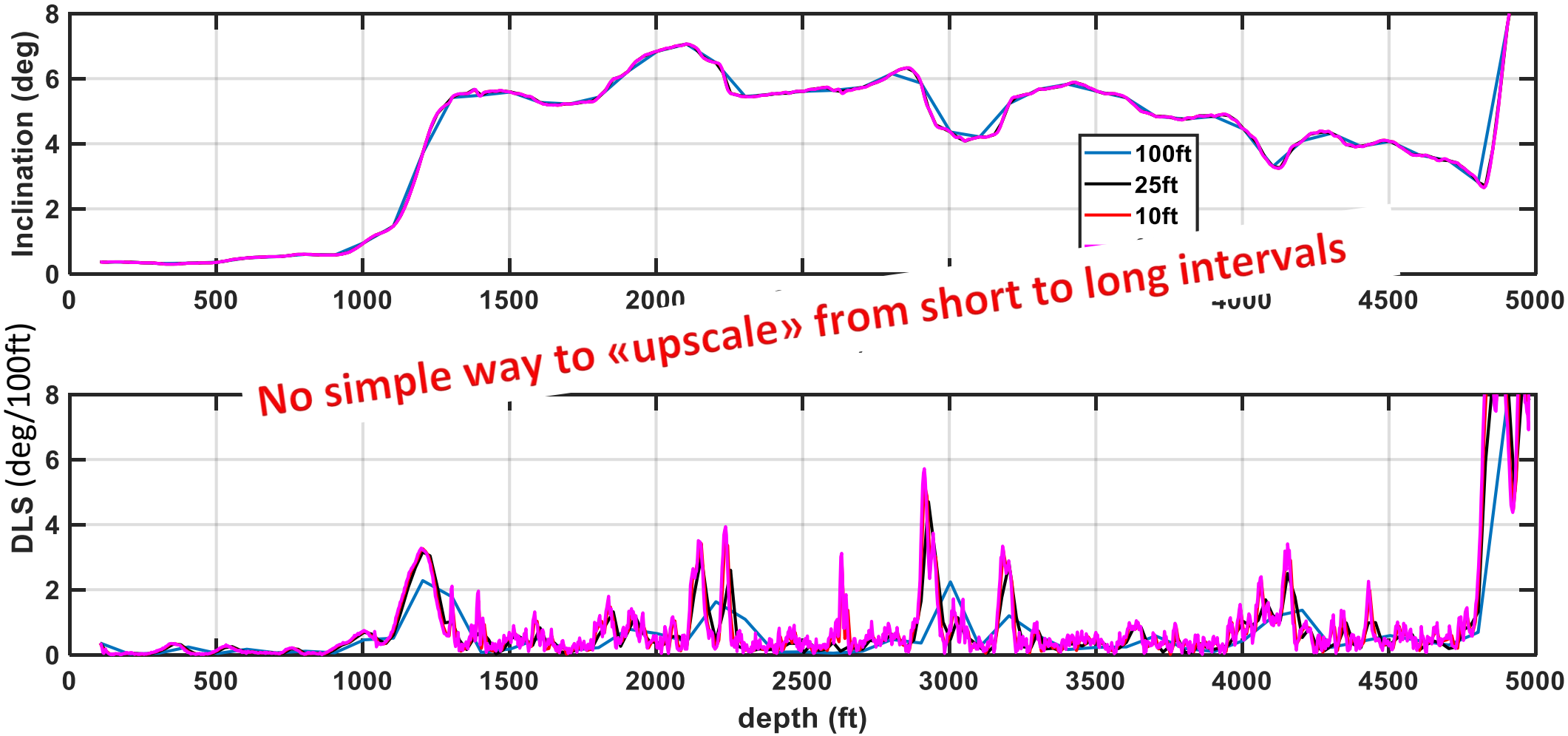


Dogleg Severity

It is based on only two survey points

				
• Low DLS • Low Tortuosity				

Dogleg Severity and high-density data



High-density data & DLS

- Drilling or post-drilling surveys at 100 ft. intervals, and derived DLS based on that data, may not adequately describe the deviation and trajectory of the wellbore
- High density survey data provides more information to help understand the wellbore trajectory and quantify the wellbore tortuosity
- The source of the survey, tubular and survey tool, cannot be ignored

- **How easy is to get high-density data? and**
- **If DLS is not sufficient to characterize the trajectory, what is?**

High-density data

- Post-drilling
  - Continuous gyro – 1990's
  - RSS trajectory control systems 2000's
- Real-time while drilling
  - Single-axis continuous inclination azimuth – 2000's
  - RSS trajectory control systems 2010's
  - Six-axis continuous inclination and azimuth – 2020's

Database (based on 25K ft well)

- MD, Inc and Azi every 100 ft

4KB

- MD, Inc and Azi every 1 ft

314KB

- 10-sec standard definition (480p) TikTok video

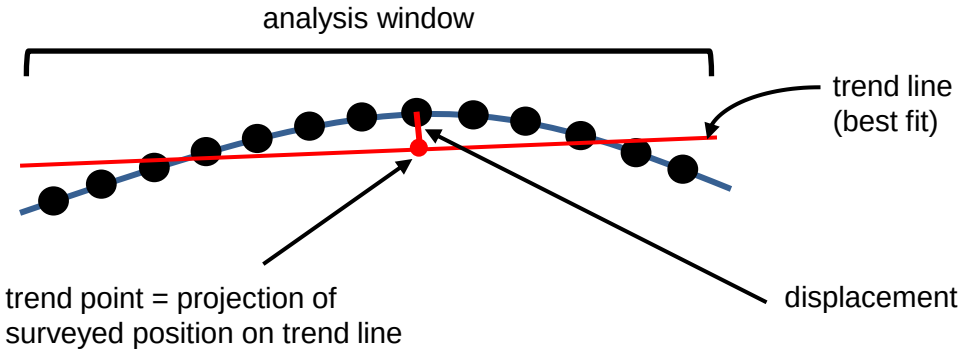
3MB

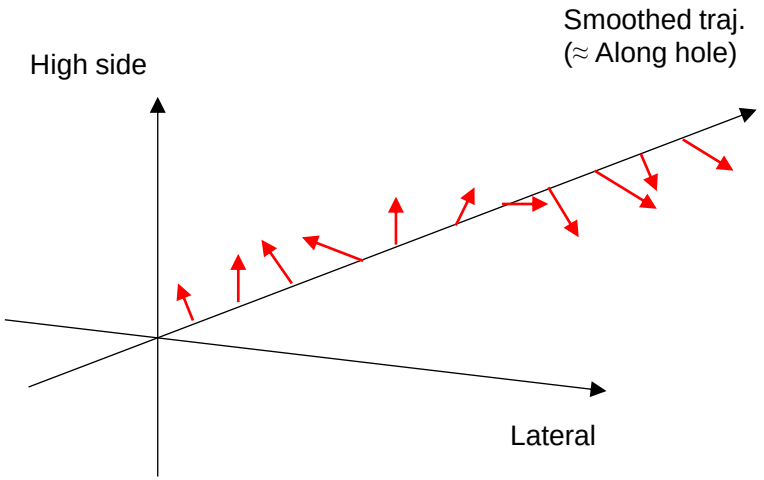
- 1000 ft LWD run

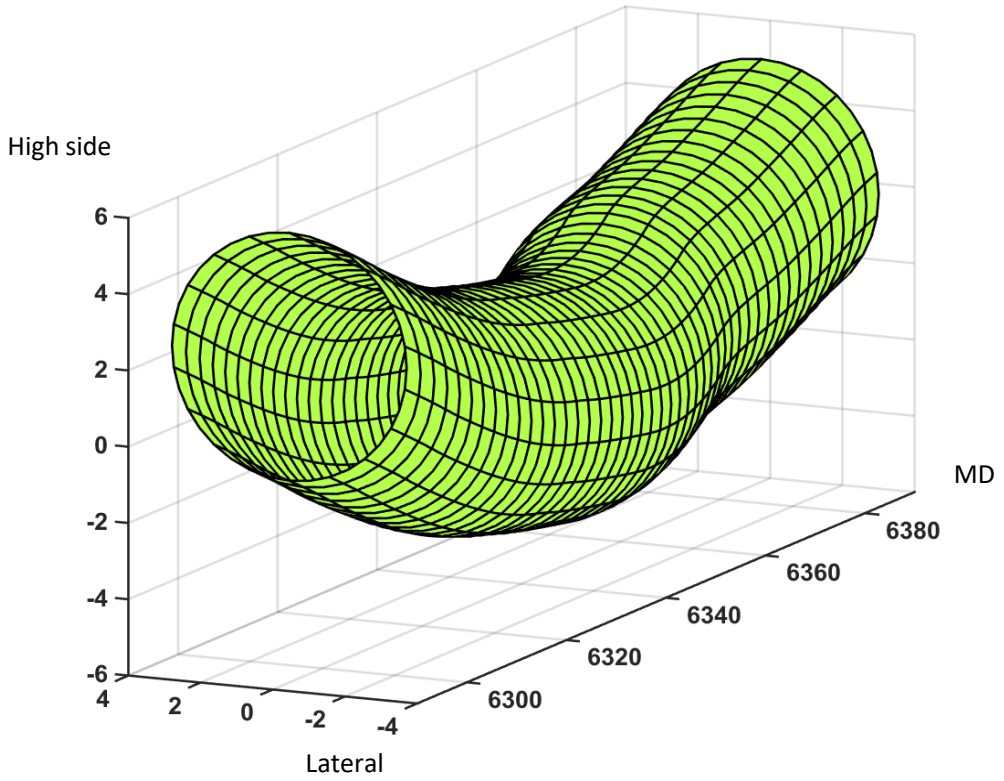
~1GB

Electrical Submersible Pumps (ESP) placement

- 1 ~ 3 ft high density data, converted to 3D position coordinates, allows a more details analysis than DLS







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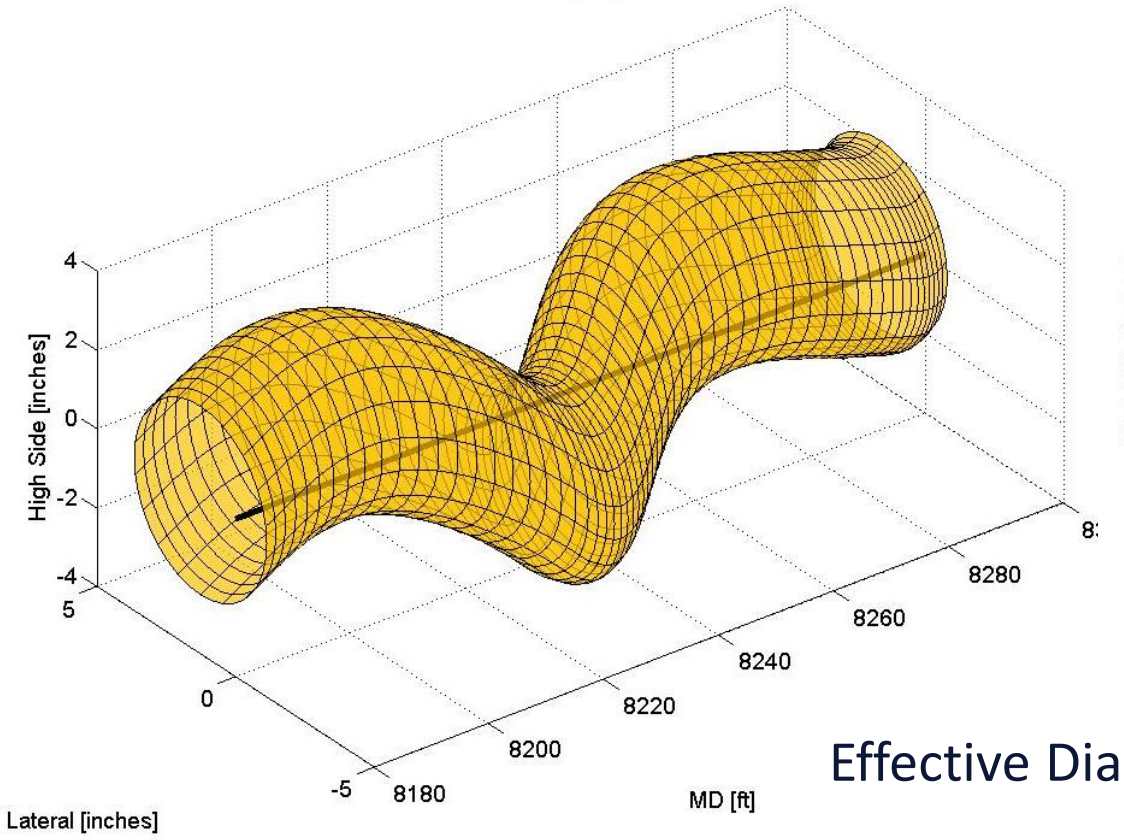
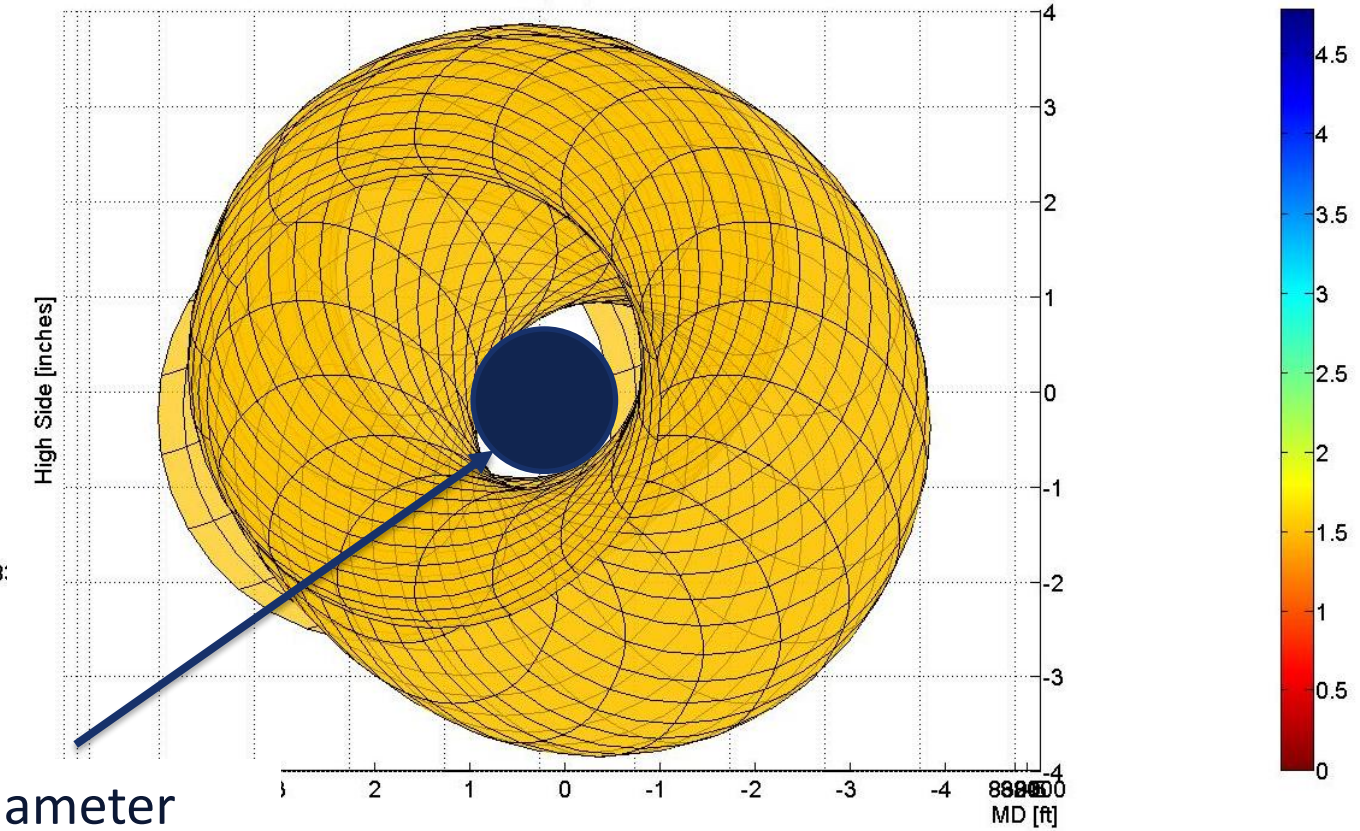
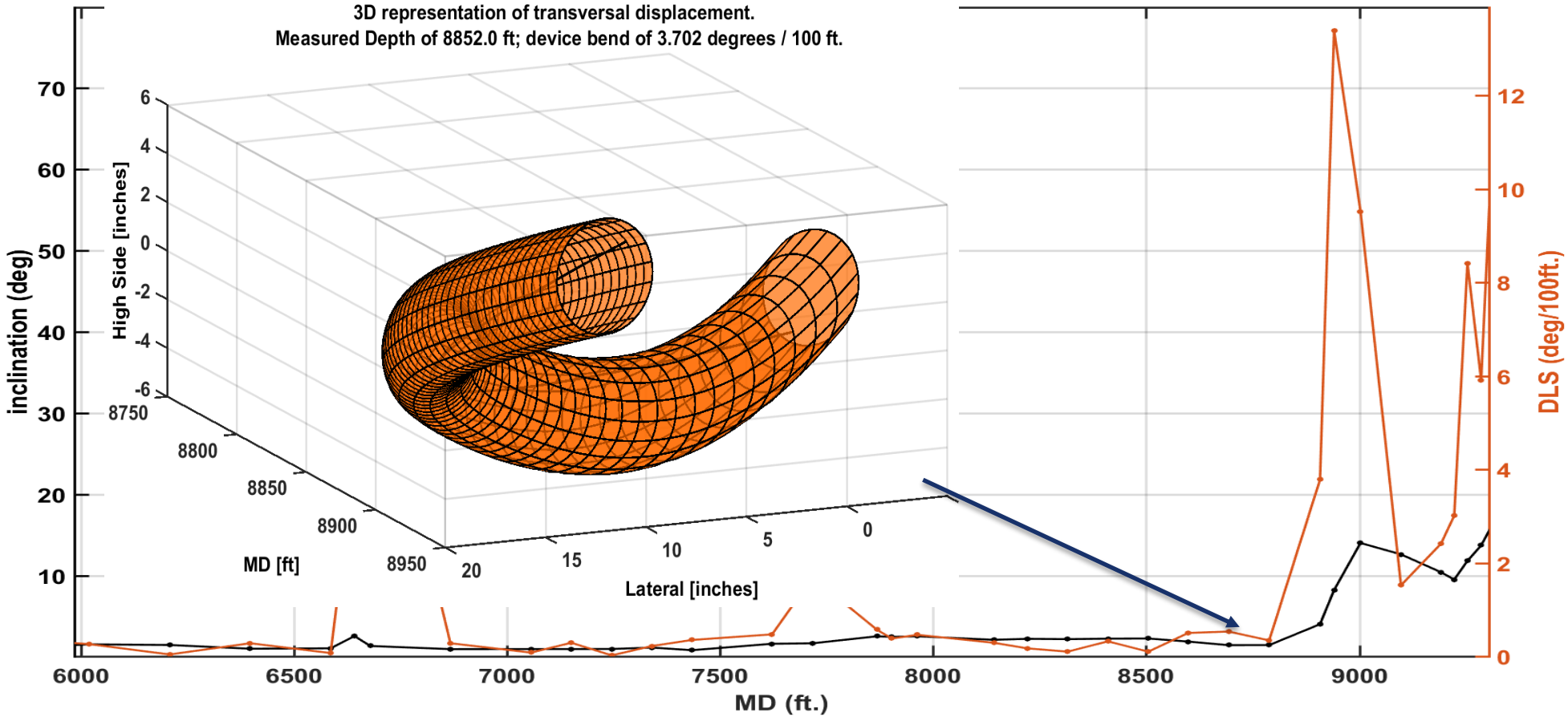




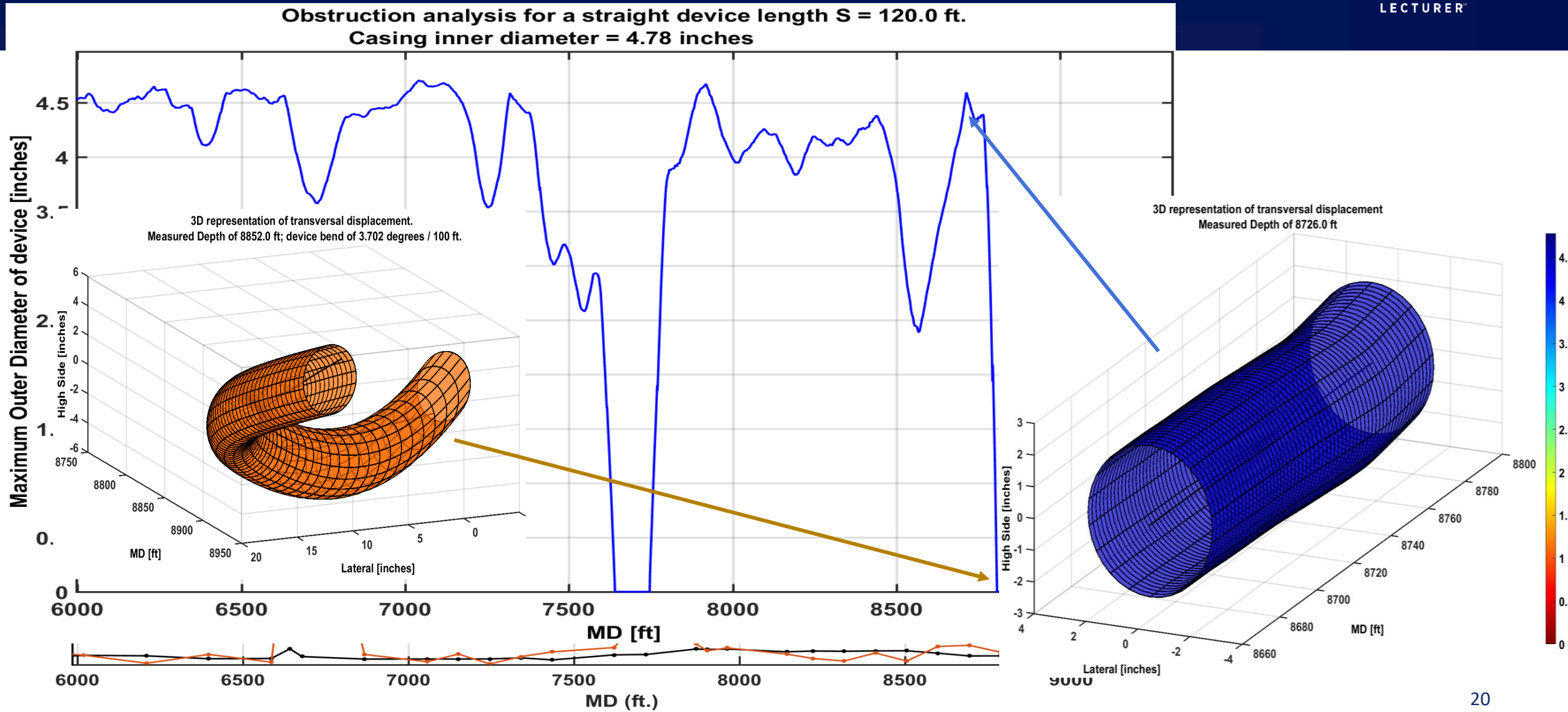
Effective Diameter

ESP placement

- Background: Unconventional well, ESP to be installed for artificial lift; SPE 185140
  - Based on DLS, a 120 ft long ESP was placed at 8792 ft – approx. cost 200K USD

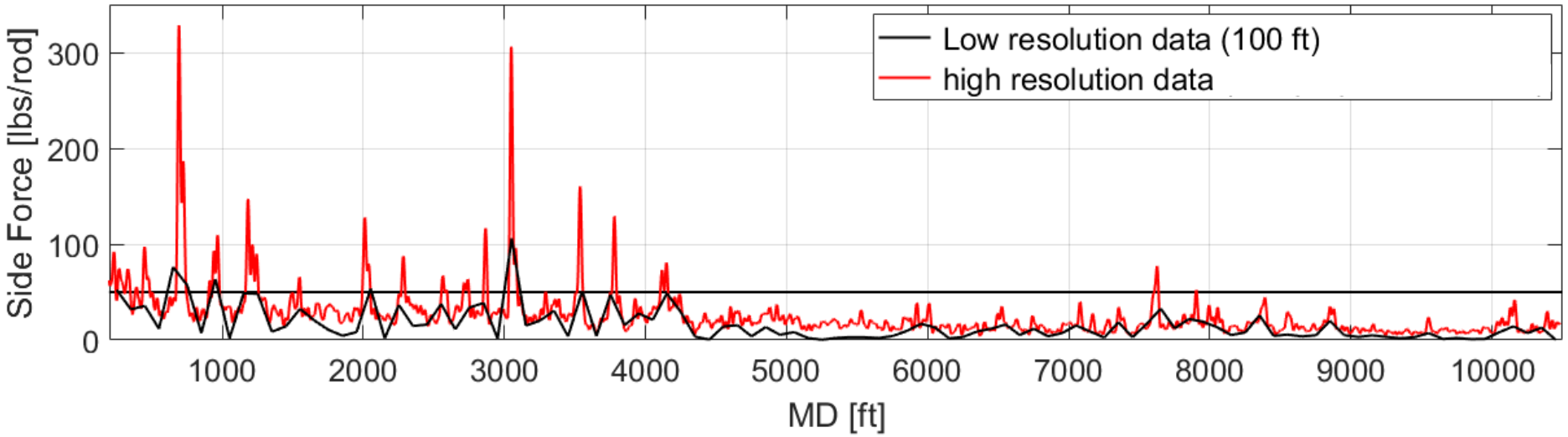


ESP placement



Rod pumps

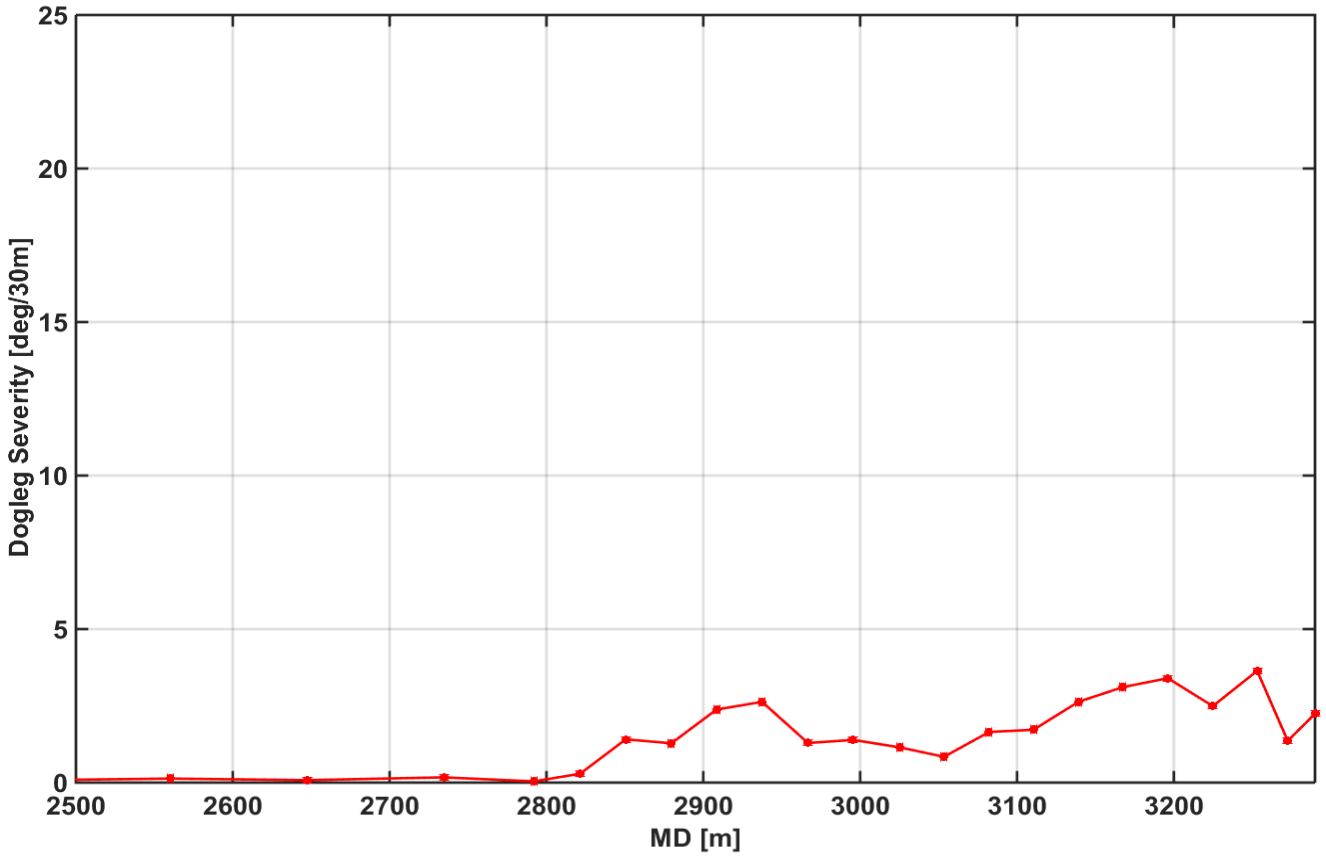
- The main concern is associated tubing and rod erosion → side forces are estimated, and mitigation actions are driven by the magnitude of the force; SPE 190935



- Side forces from low and high resolution data differ significantly

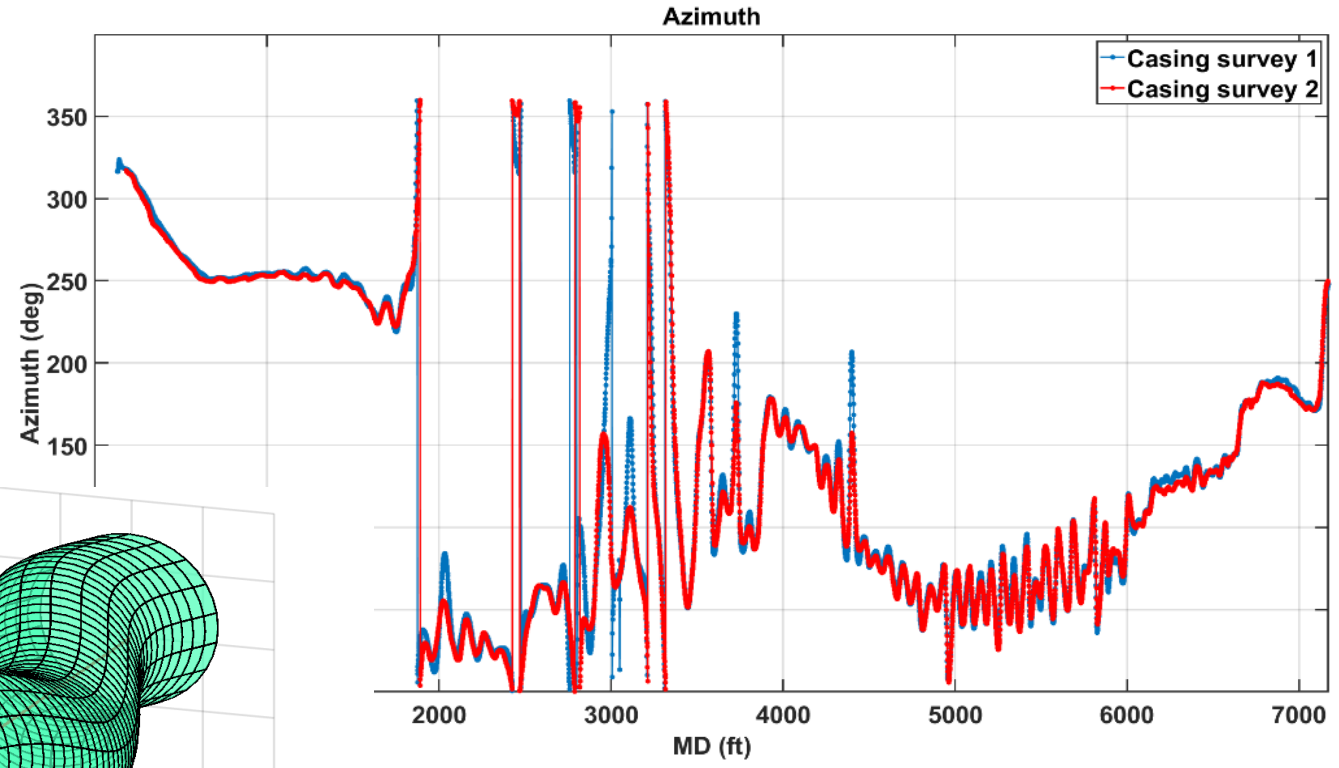
- Low resolution data misses some small-scale bending which results in lower calculated side forces and a recommendation of fewer guides

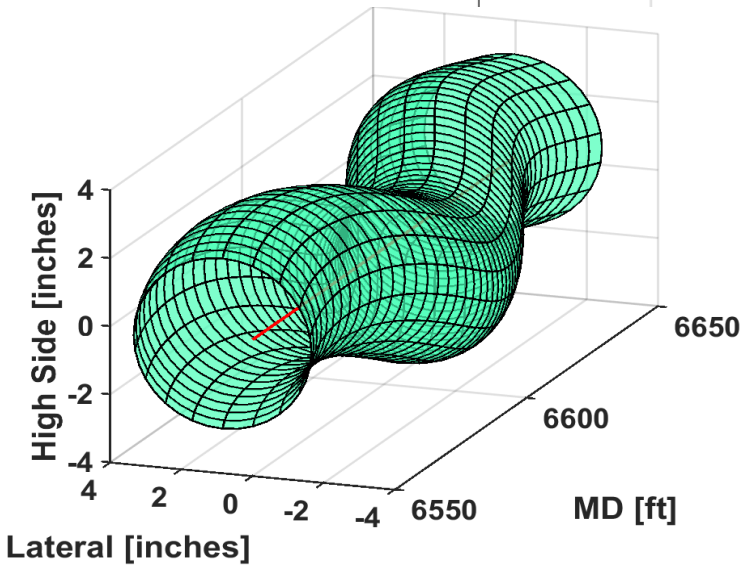
Casing Running



- The 9⅝ in casing hang up at 3,264m and could not go any further.
- High density shows the quality (or lack of) of the well
- Several meters of casing had to be abandoned.
- 6.5M USD cost

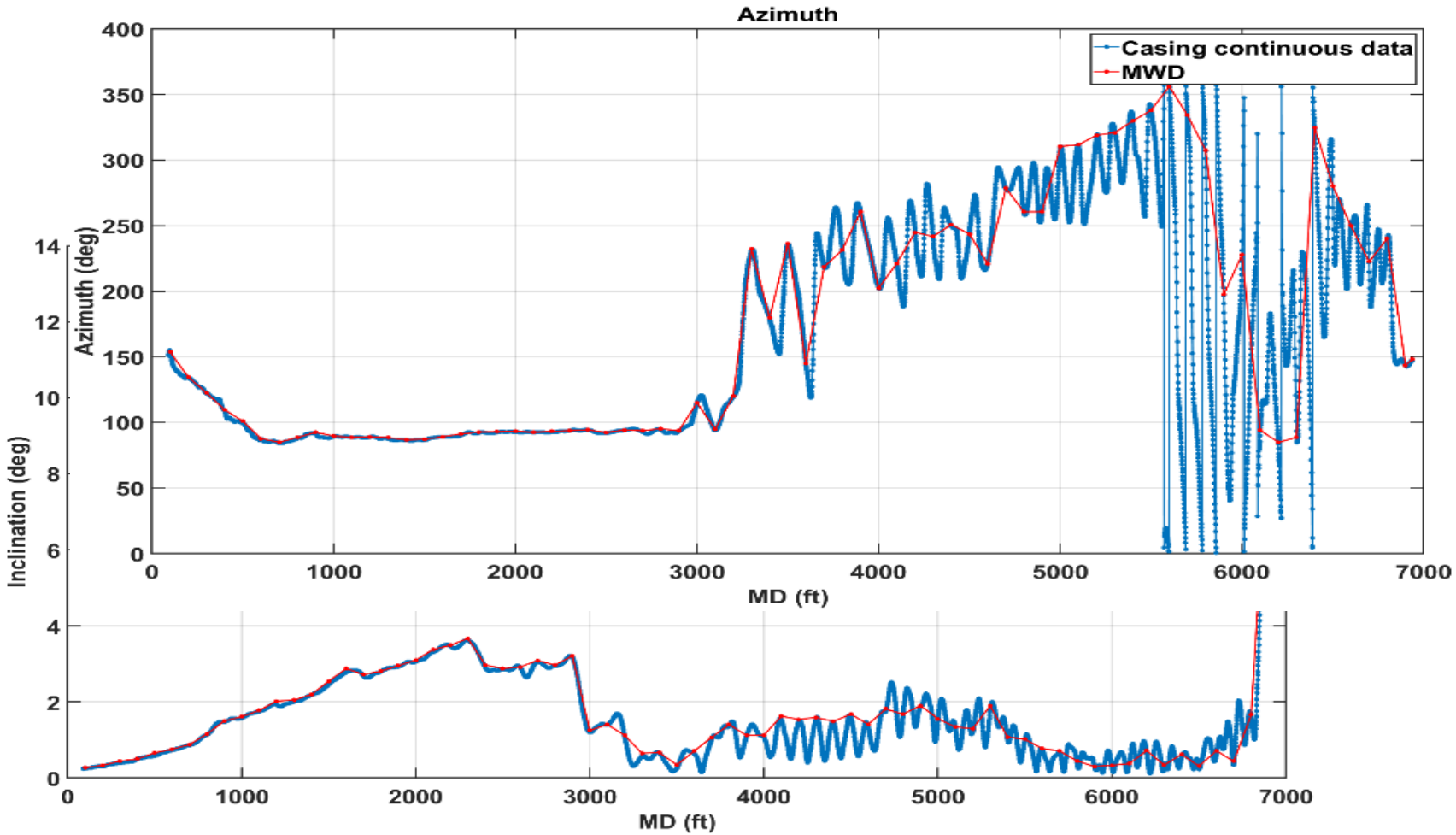
Casing Running





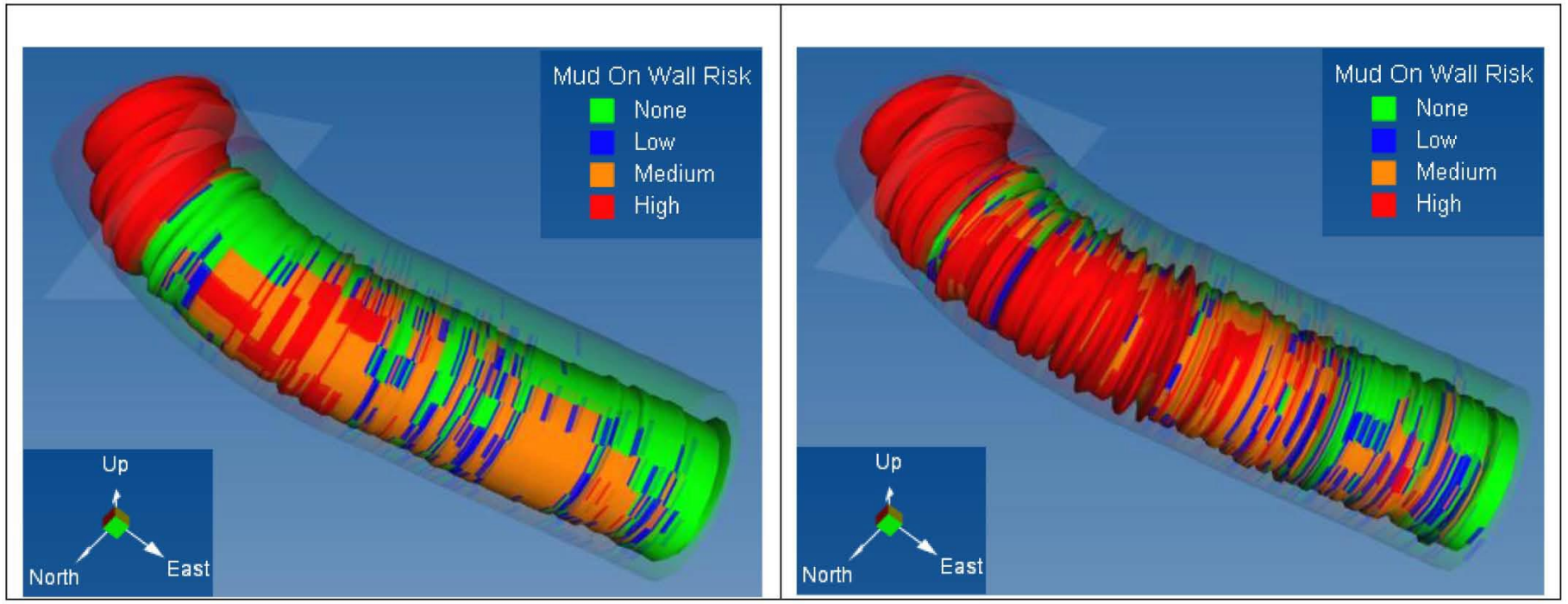
- First high-density casing run shows significant buckling
- The operator wanted to know if pulling the casing in tension will fix the problem
- The casing was pulled 28in (2M lbs) and a second high density survey was run

Casing Running



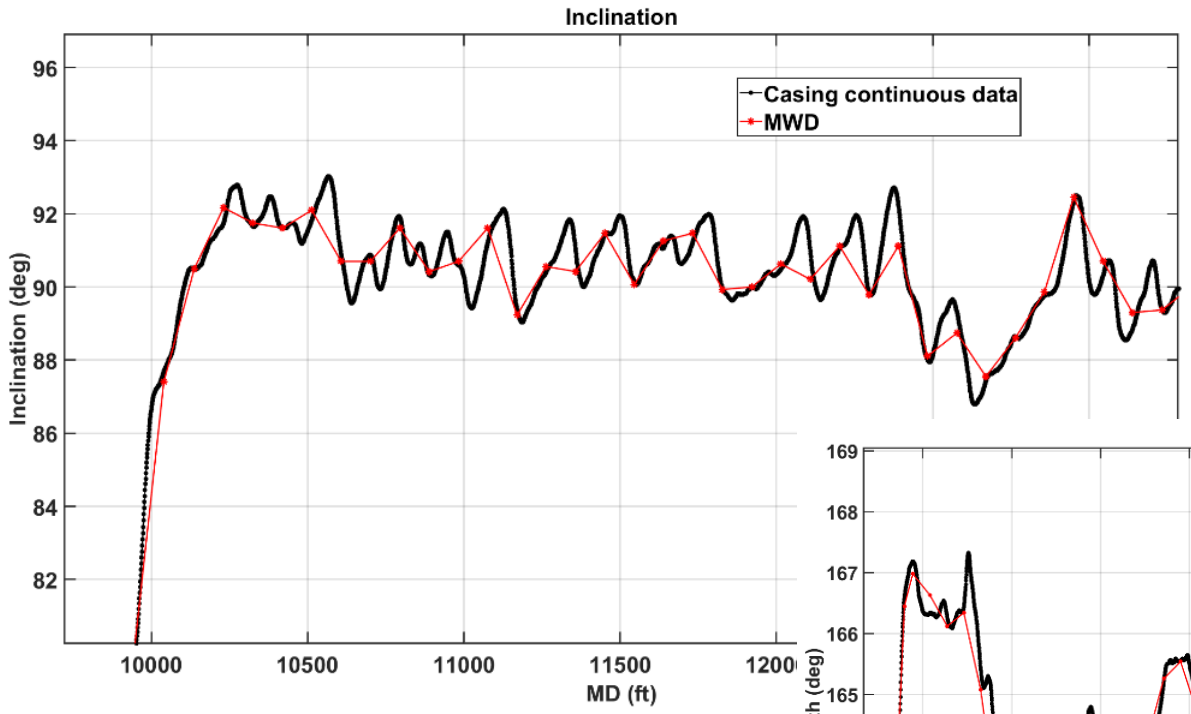
- Issues with completion resulted in running a high-density casing gyro
- Significant helical buckling is seen in inclination and azimuth
- Standard procedure was to push the casing down to section TD
- Drilling of the vertical section and casing running procedures have been updated

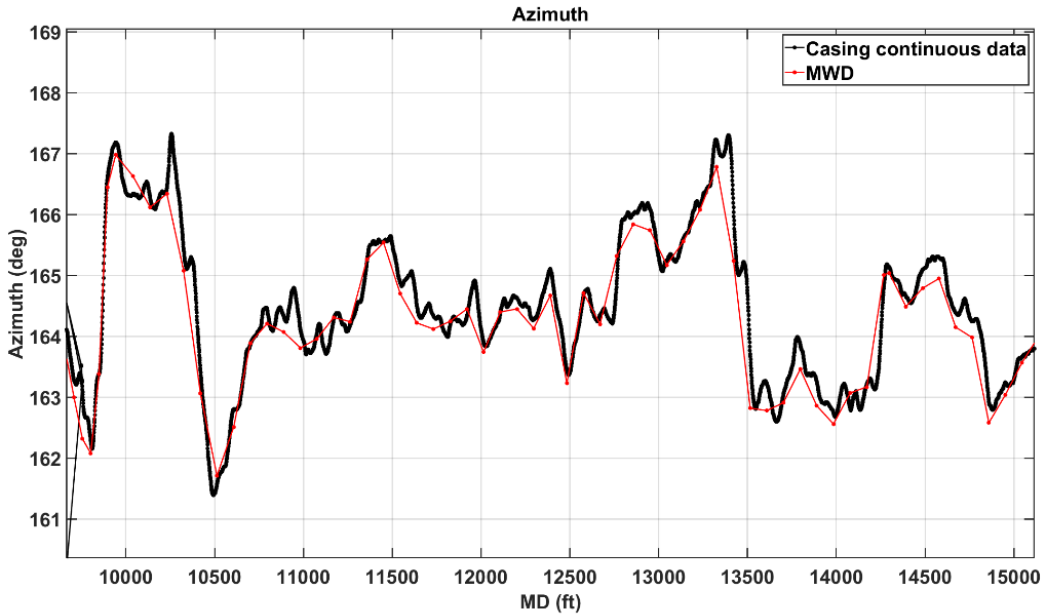
Cementing – mud removal



Mud removal simulation of the same wellbore using static MWD (a) and high resolution MWD (b) – SPE 194101.

Wellbore Placement





- Lateral section of an unconventional well
- TVD difference was 18ft
- Lateral difference was 50ft

Conclusions

High-definition data

- Smoother well paths and reduction in TVD and lateral errors
- Improvements to torque and drag models, mud removal and cementing
- Identification of problematic areas for running casing
- Identification of issues with casing
- Identification of best placement of ESPs
- Allows high fidelity calculation of side forces for rod-guide placement
- Reduction in TVD and lateral errors

more profoundly

The survey data is a key aspect of the lifecycle of the well and the field

- Drilling
- Completion
- Production
- Maintenance
- Enhanced Recovery
- Decommission and Abandonment
- Re-purposing

The survey data is a company asset

Request and use high density survey data – DLS should only be used for planning!

Acknowledgement - Thanks

- SPE DL Committee for opportunity
- My family for the encouragement
- My colleagues for the very valuable feedback
- SLB for supporting this effort

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