Using Downhole Temperature Sensing Technology to Diagnose Well Performance

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Outline of the Presentation

- Introduction: Concept of Intelligent Wells
- Basics of Distributed Temperature Sensors (DTS)
- Interpretation Measurements: Theoretical Approach
- Applications of DTS
  - Flow profiling
  - Gas Lift
  - Reservoir characterization
  - Acid stimulation
  - Hydraulic fracture diagnosis

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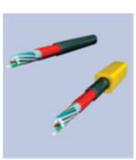
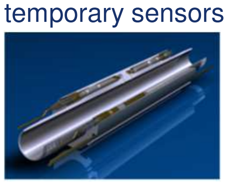
Concept of Intelligent Technology

Downhole measurements by permanent or temporary sensors





data

Interpret measurements to flow conditions

flow profile

control strategies

Downhole control device to regulate flow for optimization

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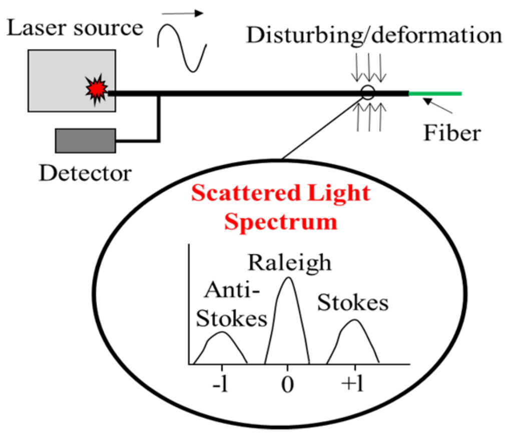
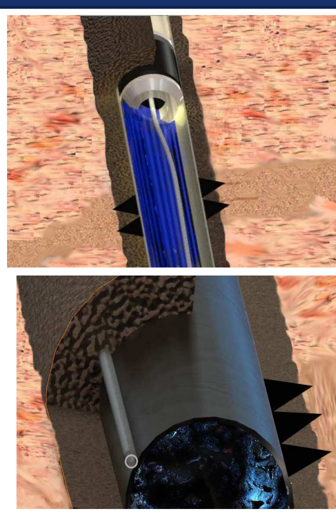
Basics of Fiber Optic Sensor System

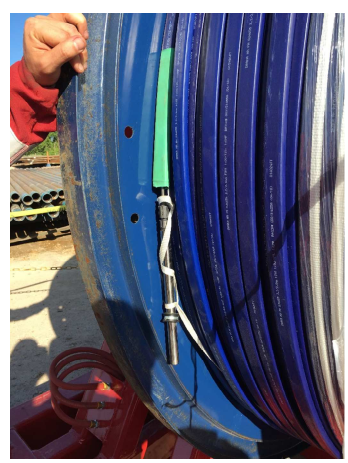


- Based on laser light backscatter
- Anti-stoke Raman band is sensitive to temperature (DTS)
- Rayleigh scatter has the same frequency as source (DAS)

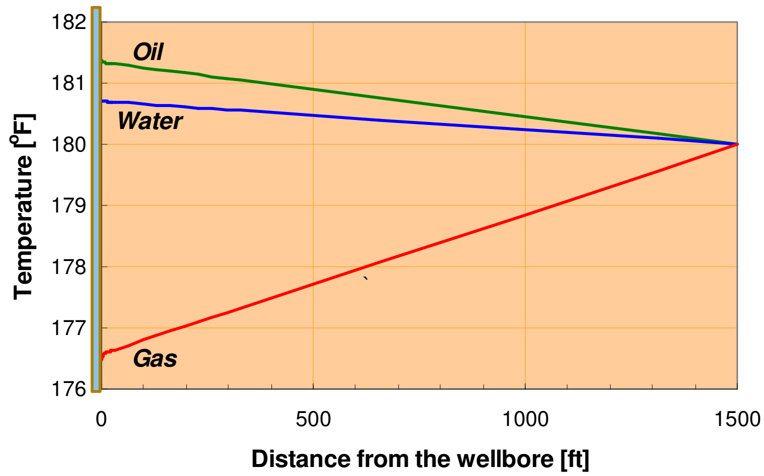
Deployment of DTS Cable



Sierra, et al. SPE 116182



Temperature Behavior of Fluids



Temperature of fluids changes when flow through porous medium

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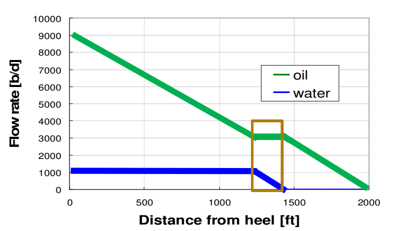
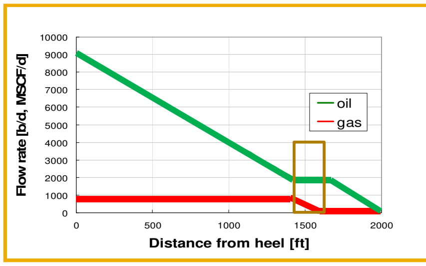
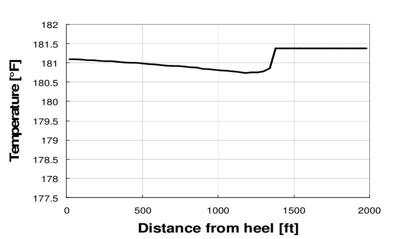
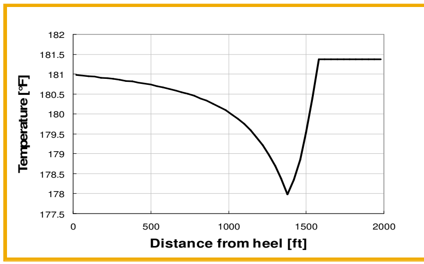
Inflow Temperature Signatures









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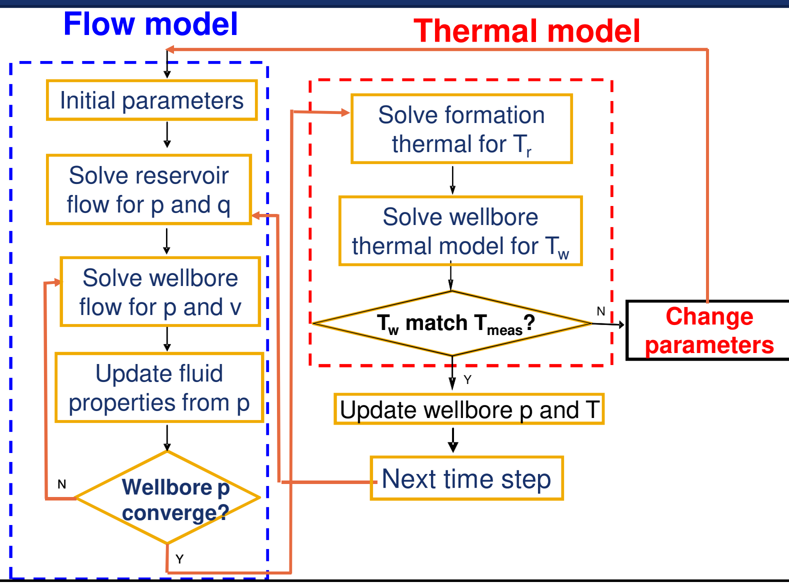
Interpret Temperature for Flow Conditions



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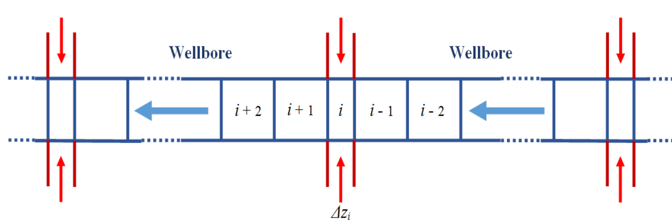
Wellbore Model

Energy balance equation (Yoshioka, et al., 2005)

$$\frac{1}{v}\frac{\partial T}{\partial t} - \frac{\beta T}{\rho v \hat{C}_p}\frac{\partial p}{\partial t} = \frac{2\gamma}{R}\frac{\rho_I v_I}{\rho v}(T_I - T) + \frac{2(1-\gamma)}{R\rho v \hat{C}_p}U_T\left(T_I|_{r=r_w} - T\right) - \frac{\partial T}{\partial z} + K_{JT}\frac{\partial p}{\partial z} - \frac{g\sin\theta}{\hat{C}_p} = 0$$

accumulation **convection** **conduction** **Joule-Thomas/geothermal**



- Can be used for all applications
- Well structure dependent

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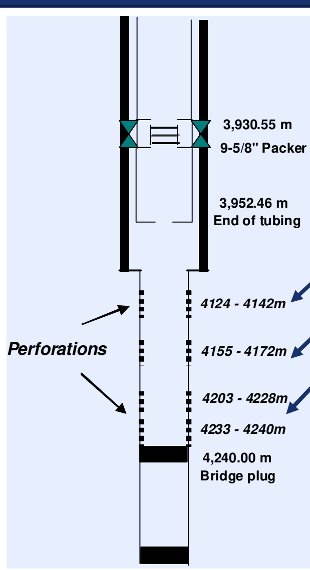
Reservoir Models: Field-Application Based

- Set up the physical model based on the problems
- Applications:
  - Vertical well flow profiling
  - Gas lift well monitoring
  - Reservoir characterization in horizontal wells
  - Acid stimulation evaluation
  - Hydraulic fracture diagnosis

Application: Identify Water Entry



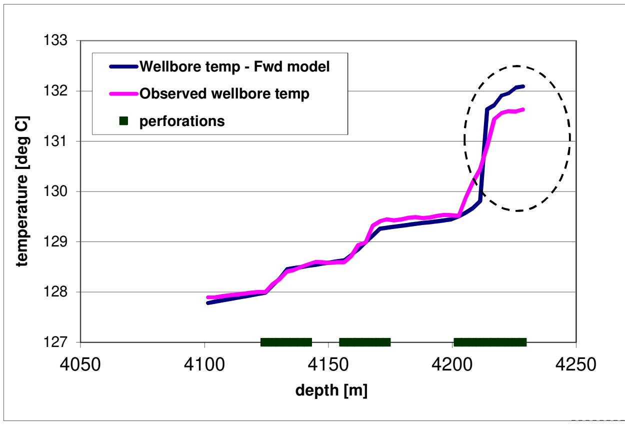
- **Inclined gas well (~30^{o} deviation through payzone)**
- **Permeability: 1.4 – 682 md**
- **Completion skin factor**

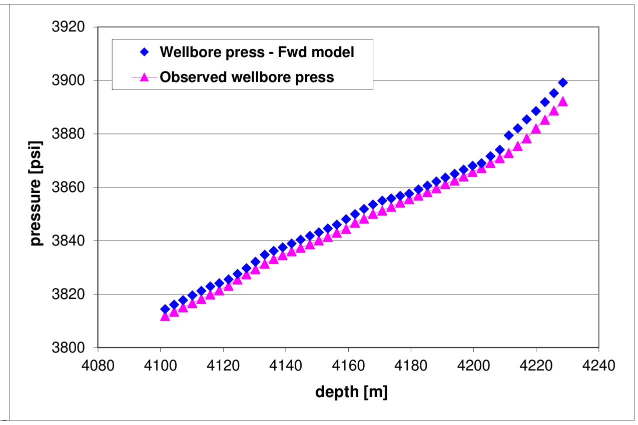
Zone 1: -0.9
Zone 2: -0.8
Zone 3 and 4: -1.0

- **Gas production: 100 MMCF/day**
- **Water production: 1000's bbl/day**
- **Question: which zone produces water?**

(SPE 115753, Achinivu, et al., 2008)

Matching T and P with Permeability as Parameter





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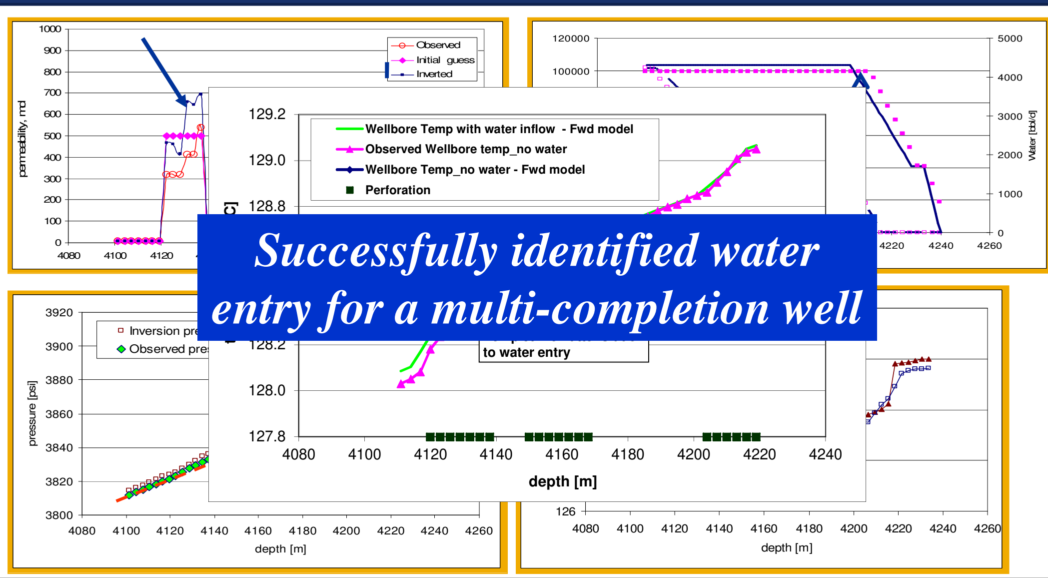
Inversion of Water Entry in Gas Well



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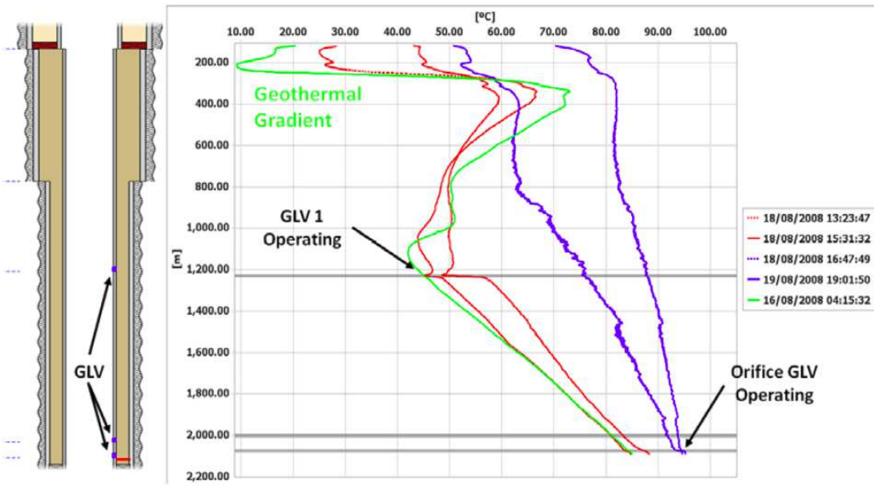
Application: Gas Lift Performance Monitoring



- Offshore UK well (SPE 150197, Castello, et al., 2012)

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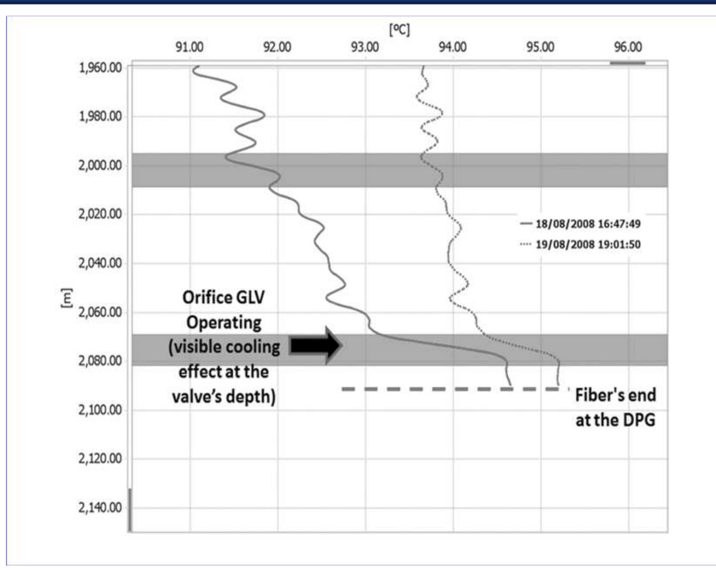
Gas Lift Performance Monitoring



- During production, DTS is monitoring operating valve performance
- Temperature change by Joule-Thomson is about 1° C at stable production
- Simple and quantitative application

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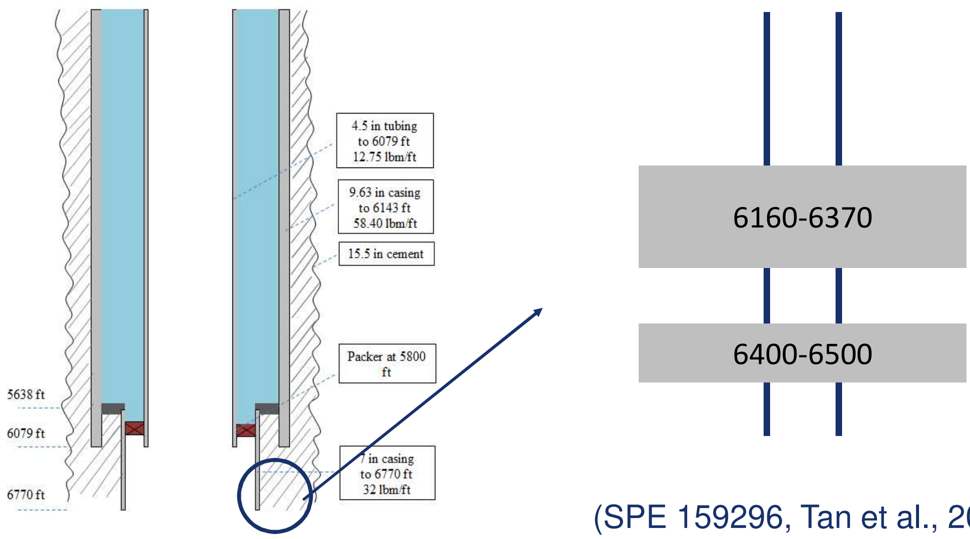
Application: Matrix Acidizing Diagnosis



(SPE 159296, Tan et al., 2012)

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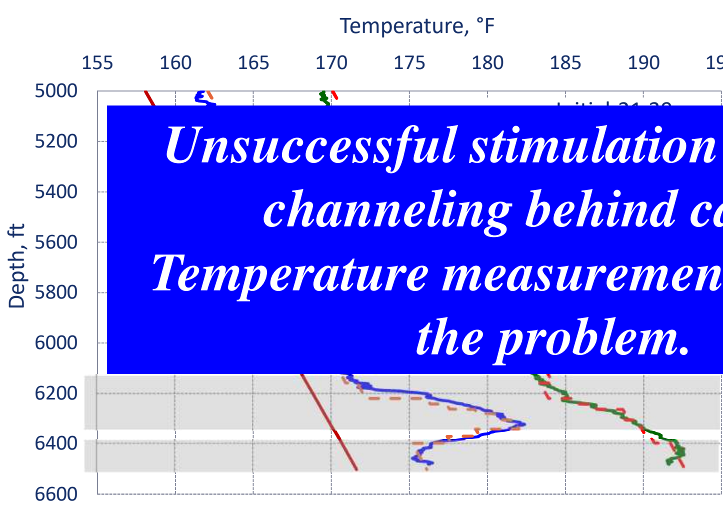
Temperature Analysis



Unsuccessful stimulation caused by channeling behind casing. Temperature measurement identified the problem.

n Inversion	
	percentage
	26%
	48%
	9%
6400-6500 ft	**17%**

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Application: Reservoir Characterization

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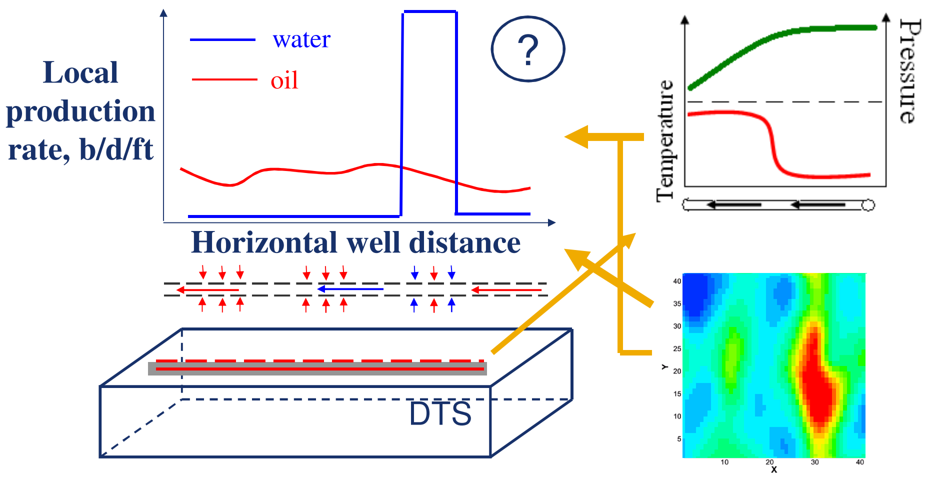

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Conventional History Matching of Watercut

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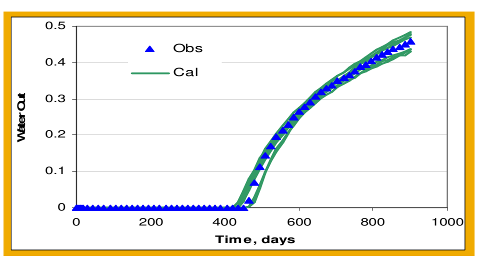

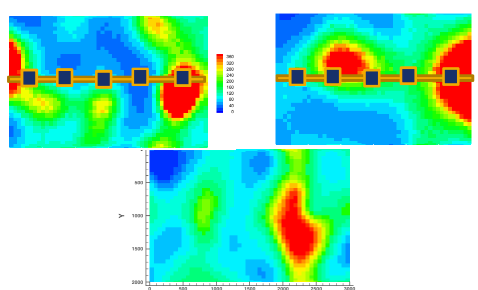

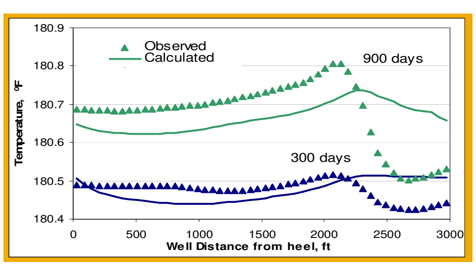

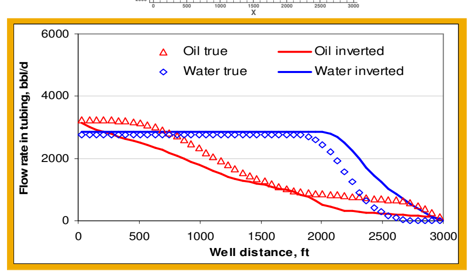

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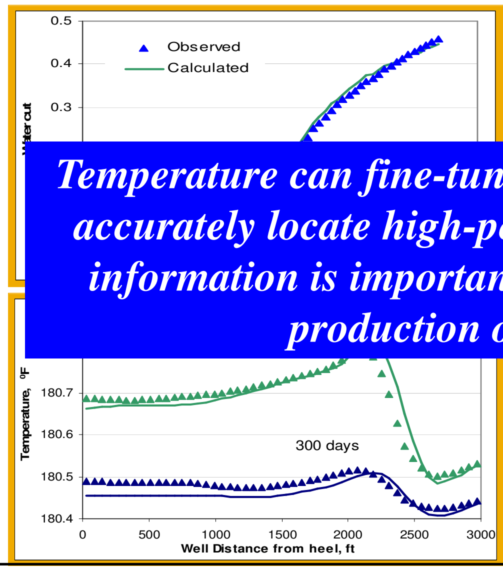
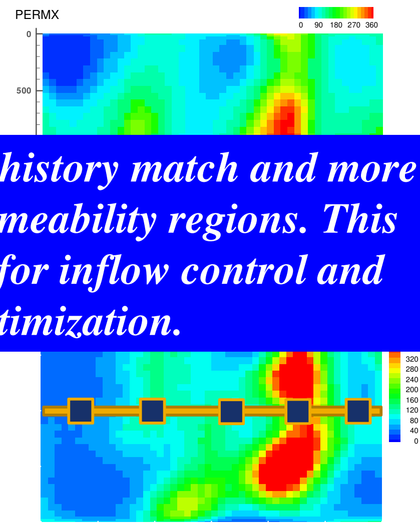
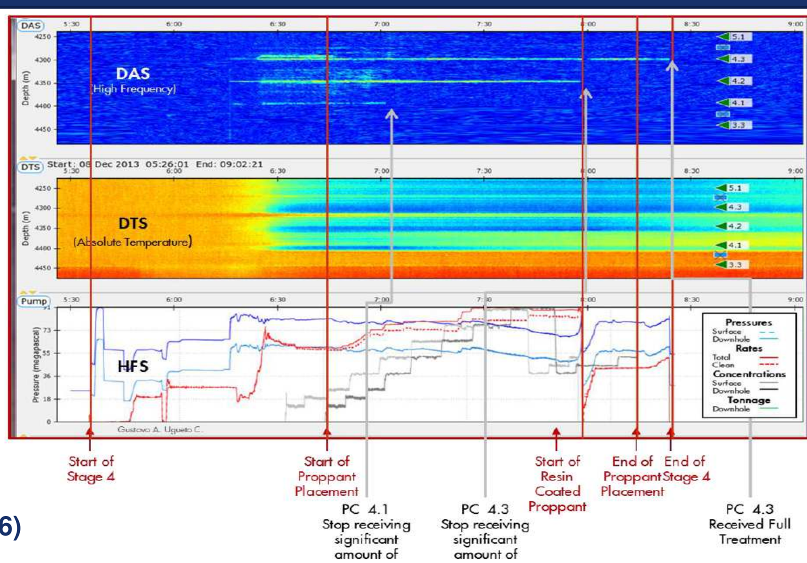
Integrated Approach – Matching Data





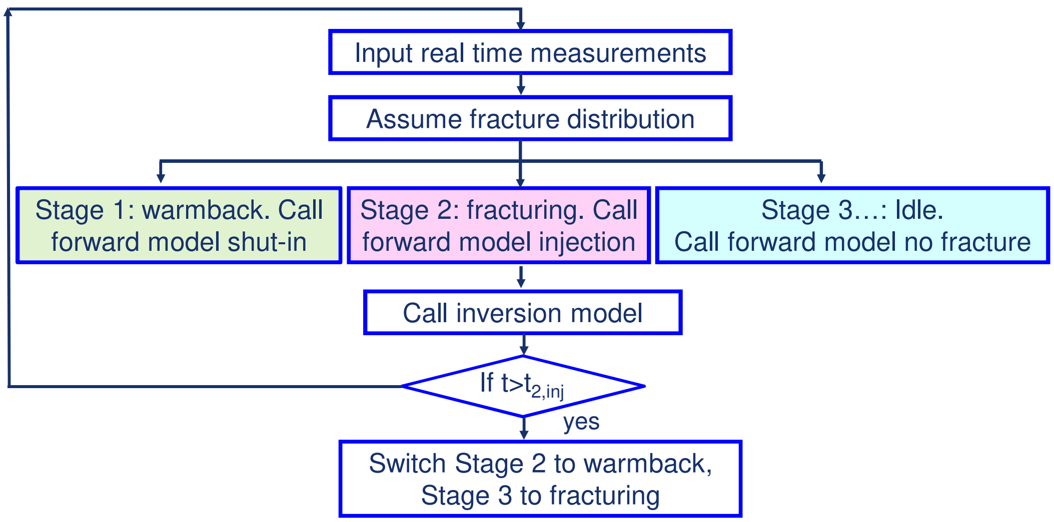
Temperature can fine-tune history match and more accurately locate high-permeability regions. This information is important for inflow control and production optimization.

Application 5: Fractured Well Diagnosis



(Ugueto, 2016)

Workflow for Multistage Fracturing



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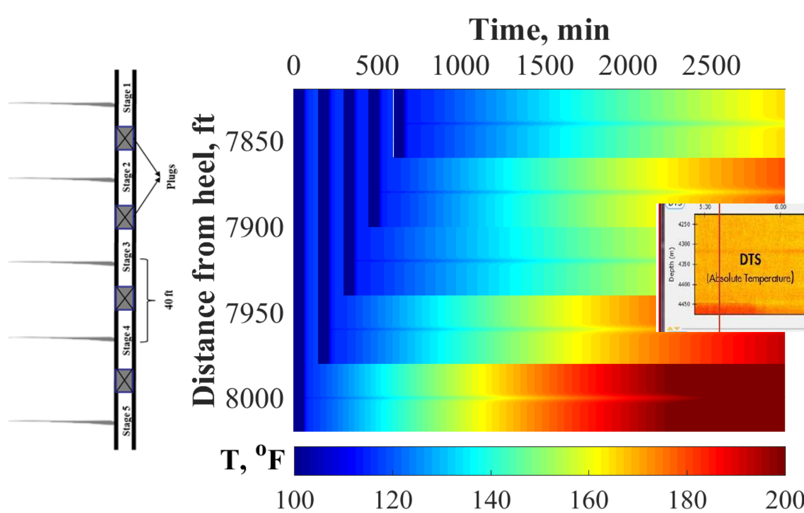
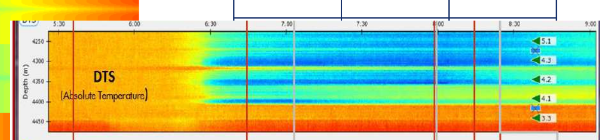
Simulation of Temperature Distribution



stage	q, bpm	x_f, ft
1	5	147
4	8	235
5	10	293



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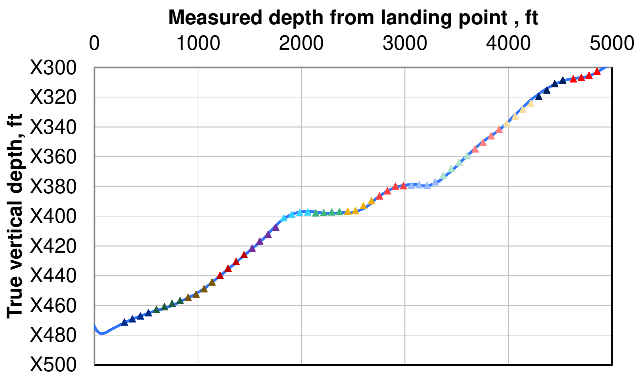
Example: Flow Profile during Production



Formation	
Permeability (nD)	583
Porosity (%)	4.2
Pore pressure (psi)	4630
Reservoir compressibility (1/psi)	1.68E-04
Gas specific gravity	0.56

Fracture/Wellbore	
Fracture spacing (ft)	77
Fracture width (in)	0.24
Fracture porosity (%)	25
Fracture permeability(mD)	1250
Wellbore pressure (psi)	2860

Production Profile	
Gas rate (Mscf/d)	1600
Water rate (STB/d)	160
GOR (Mscf/STB)	9-10

- Eagle Ford gas well
- 15-stages fracturing treatment, 4 cluster per stage (SPE 170874, Cui, et al., 2014)

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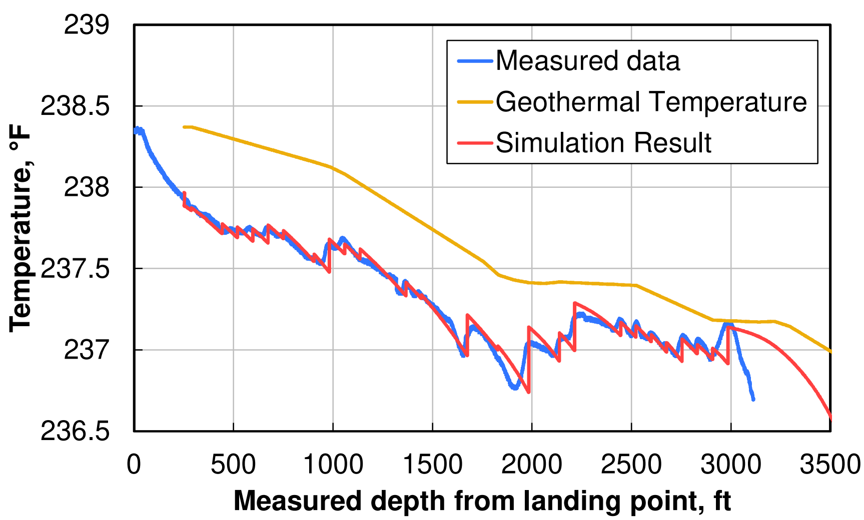
Matched Temperature for Interpretation



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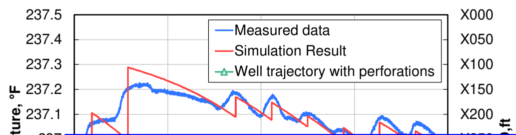
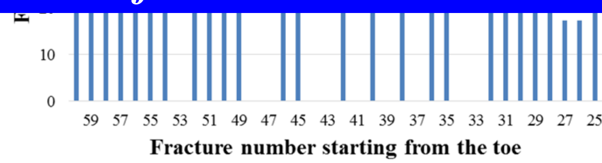
Fracture Distribution Interpretation



Temperature measurements can predict flow distribution for multistage fractured wells. The information can be used for fracture design optimization and flow control.



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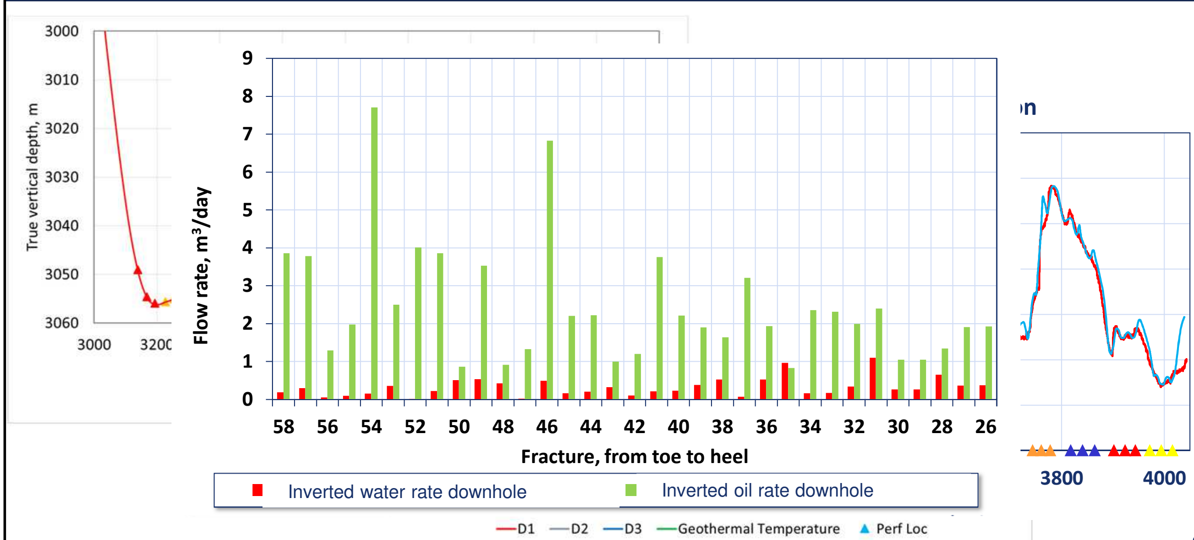
Challenges in Interpretations



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Conclusions

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- Downhole measurements by intelligent completion provide valuable information and is a powerful tool for well operation diagnosis
- The applications are broad, ranging from production, injection to well stimulation (acidizing and fracturing)
- Mathematical models are critical for quantitative interpretation
- Challenges are large data base, data processing, computation speed for field application
- Integrated efforts can promote the technology in oil and gas industry

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