Well & Reservoir Management for Complex Floods

Focus on Fiber-optics & 4D Seismic in Deepwater

Seminário sobre Aumento do Fator de Recuperação no Brasil
ANP, Rio de Janeiro
March 23-24, 2017

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Tópico 4: "Aumento de Fatores de Recuperação – Desafios e Lições Aprendidas em outras técnicas"

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Reserves: Our use of the term "reserves" in this presentation means SEC proved oil and gas reserves.

Resources: Our use of the term "resources" in this presentation includes quantities of oil and gas not yet classified as SEC proved oil and gas reserves. Resources are consistent with the Society of Petroleum Engineers 2P and 2C definitions.

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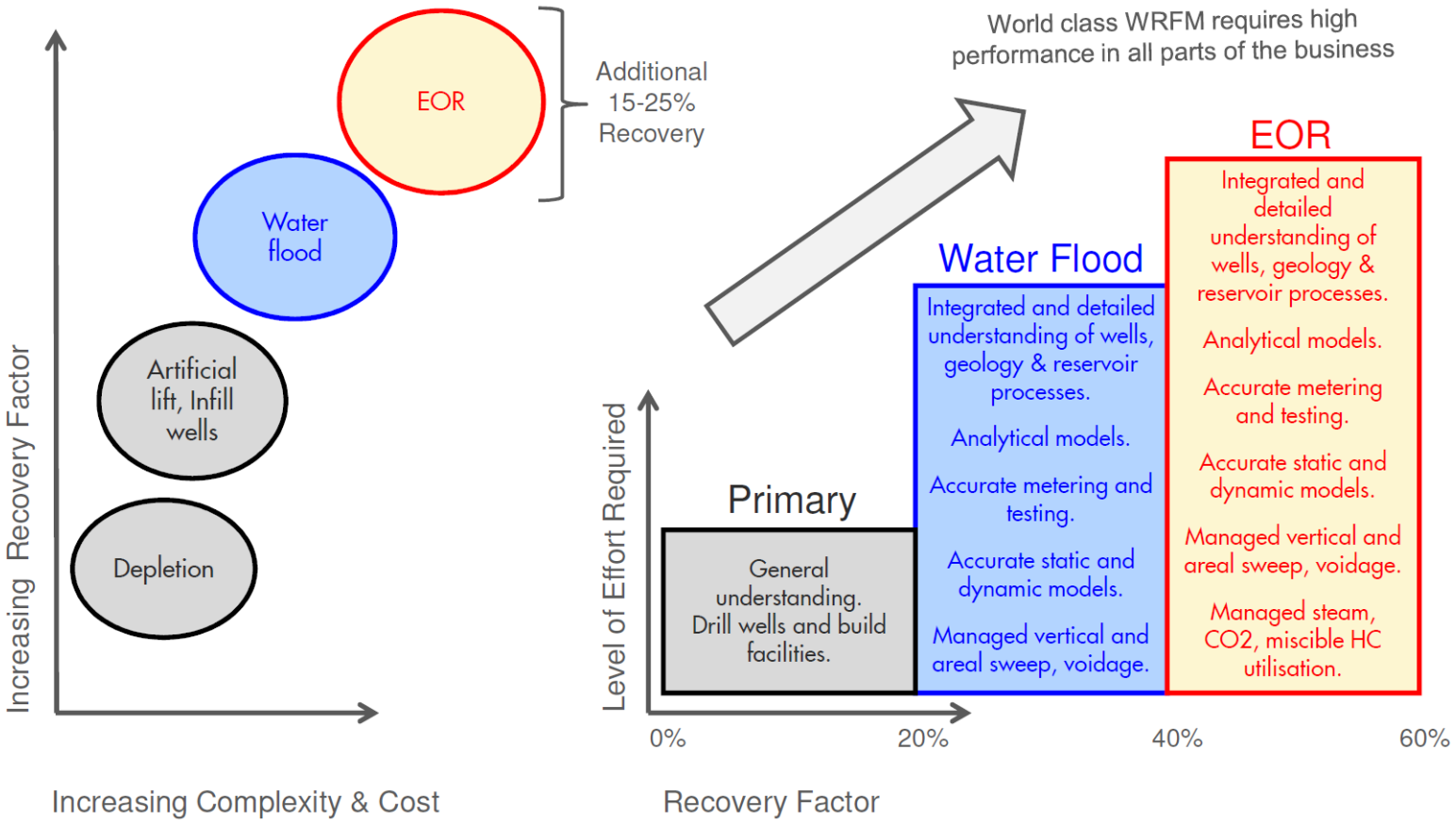
Well & Reservoir Management is Essential for Optimized Recovery



- Complex IOR/EOR projects risk not meeting NPV or production targets
- Well & Reservoir Management (WRM) reduces such risks
- New technologies, including fiber optics and 4D seismic are essential enablers for cost-effective WRM

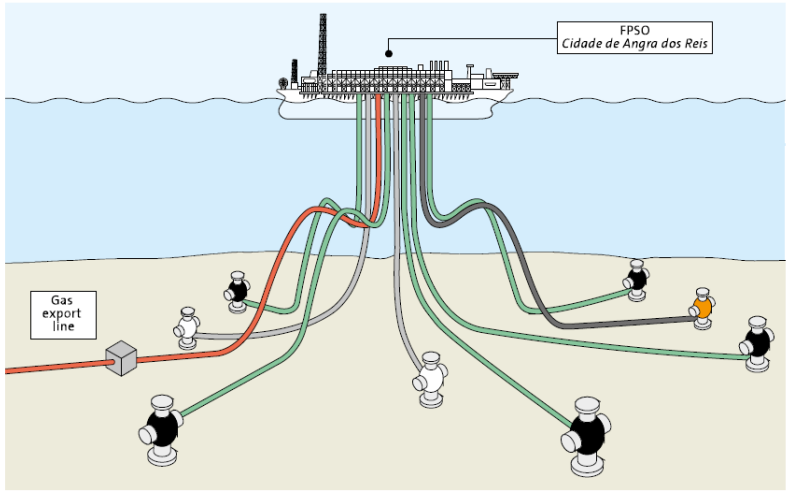
WRM Challenges in Brazil Pre-Salt

- Large reserves in prolific carbonate reservoirs
- Fast-paced developments using FPSOs

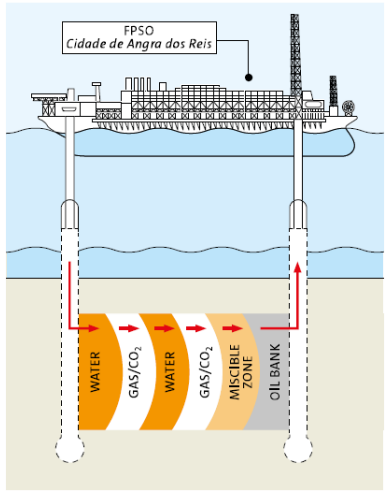
- Complex recovery mechanisms (IOR/EOR)
  - Water & Gas injection
  - Water-Alternating-Gas (WAG)
  - High-perm layers, risk of gas cycling

- **On-demand monitoring needed**
  - Optimize injection schemes
  - Optimize development well locations
  - Respond to unexpected behaviors

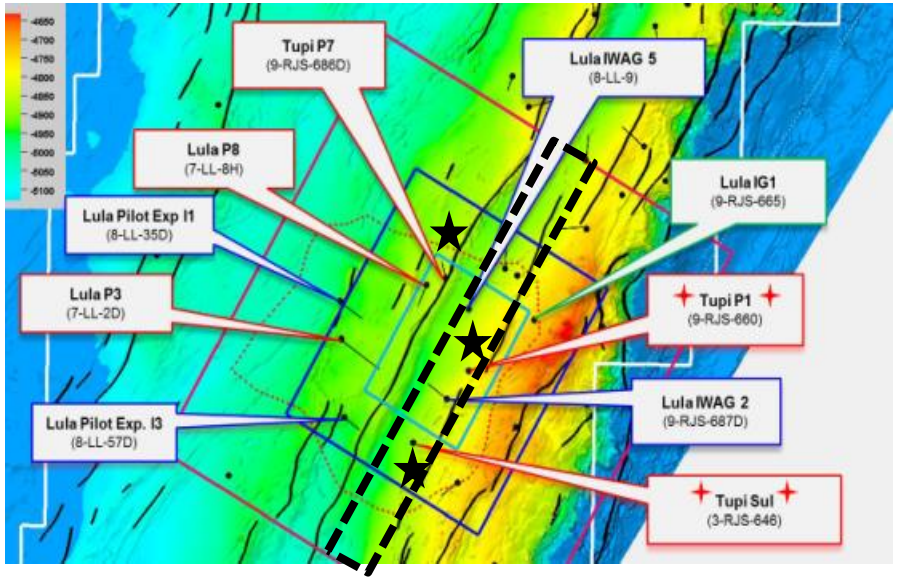
SUBSEA SCHEMATIC



WAG SCHEMATIC

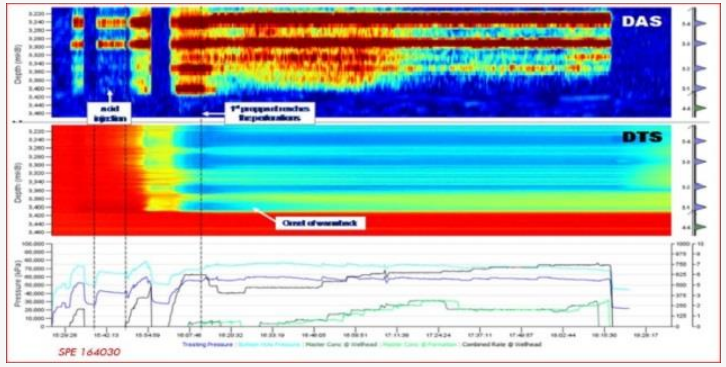


● Production wells ● Gas injector wells ○ WAG injector wells

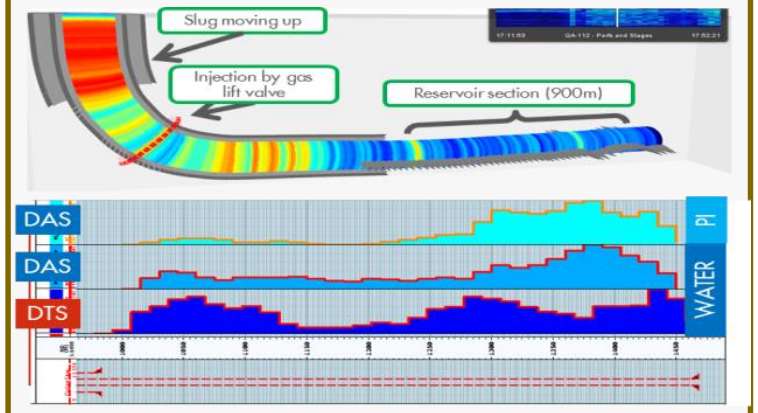


Benefits of Distributed Fiber Optic Sensing for In-Well Monitoring

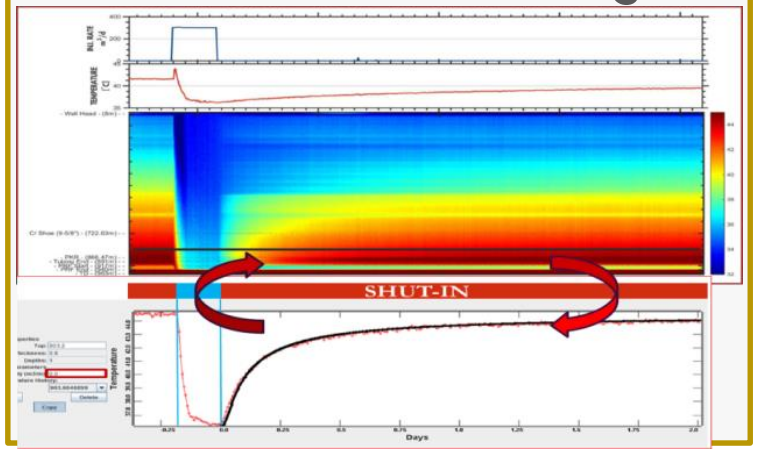
DTS+DAS Hydrofrac



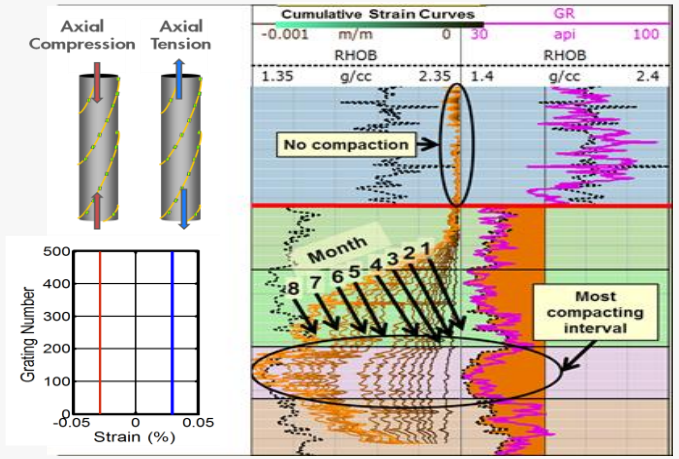
DAS+DTS Flow Profiling



DTS Warm back Profiling



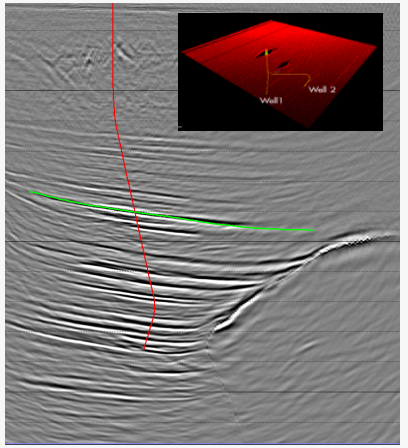
DSS Reservoir Compaction

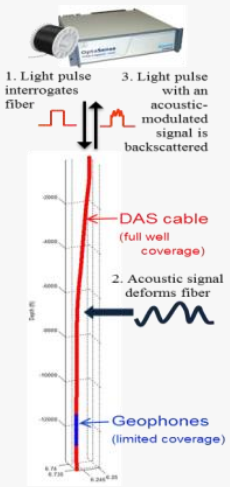


Fiber Optic Sensing Applications

- Production and Injection Flow
- Warm back Injector profiling
- Reservoir compaction
- Hydro frac monitoring
- Vertical Seismic Profiling (VSP)
- **Not ready for subsea wells**

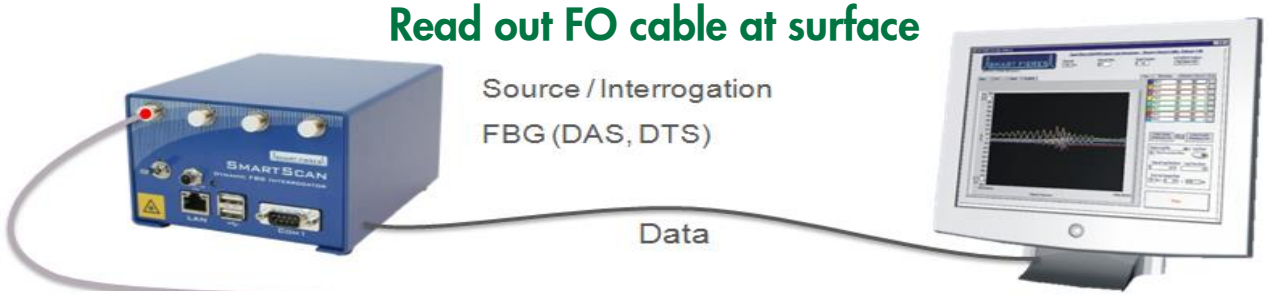
DAS VSP

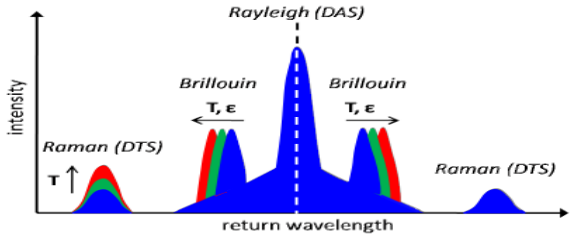


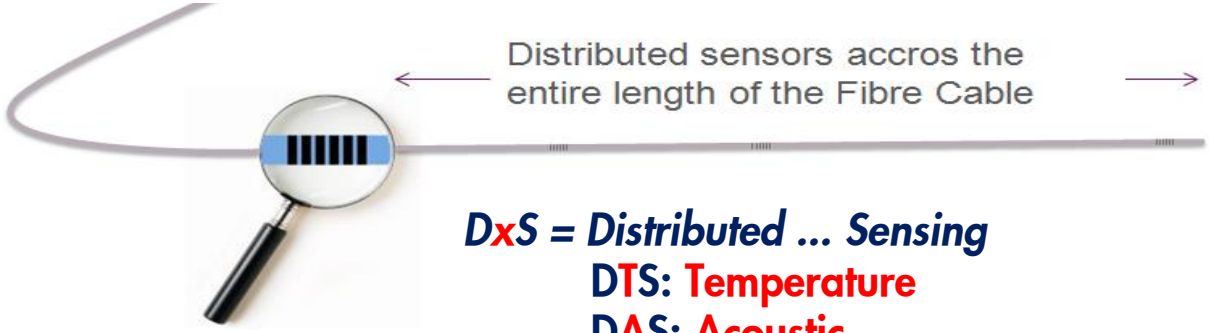


Distributed Fiber Optic Sensing – Cable Installation

Read out FO cable at surface





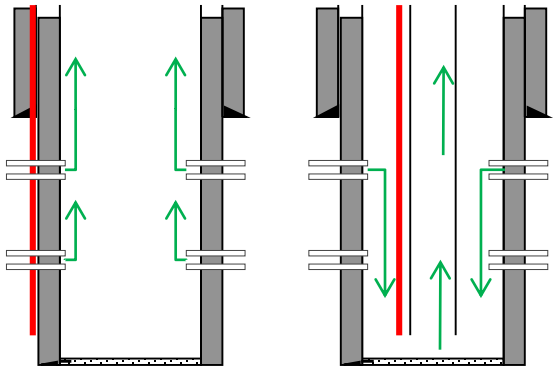


DxS = Distributed ... Sensing

DTS: Temperature
DAS: Acoustic
DPS: Pressure
DSS: Strain
DCS: Chemical

"anything that deforms the fibre"

FO-cable *permanently* installed



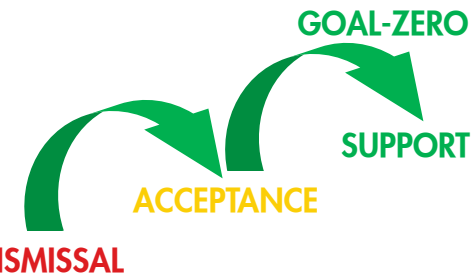
FO-cable cemented behind casing or strapped to tubing

Installation Notes

- For Gas Lift or VSP fiber down to packer is sufficient
- For deepwater wells fiber is strapped to tubing
- For DVA wells fiber may be run as wireline
- Installation in subsea wells needs industry pull

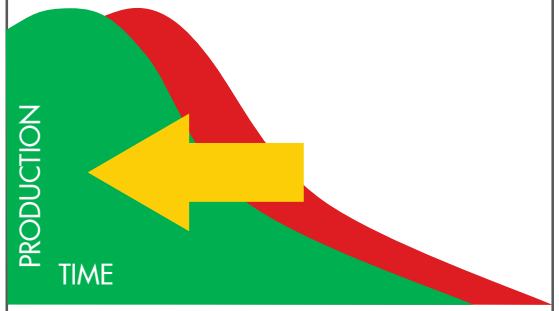
Benefits from 4D Seismic for Areal Monitoring

MAINTAIN LTO, REPUTATION, HSSE



Monitoring injection, disposal, CCS, blow-out, OOZI. Drill safely into partially depleted reservoirs.

ACCELERATE PRODUCTION



Manage EOR, injectors, production. Improve forecasts and planning.

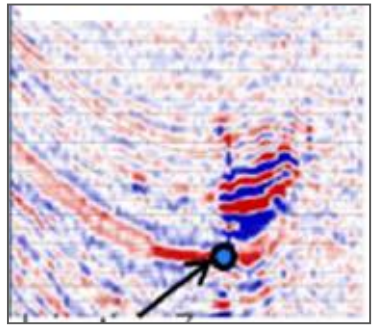
INCREASE ULTIMATE RECOVERY

Identify (un)drained areas, fluid contact, compartmentalization. Optimize new wells.

REDUCE COST

Avoid wrong wells. Optimize well number. Optimize injectant use.

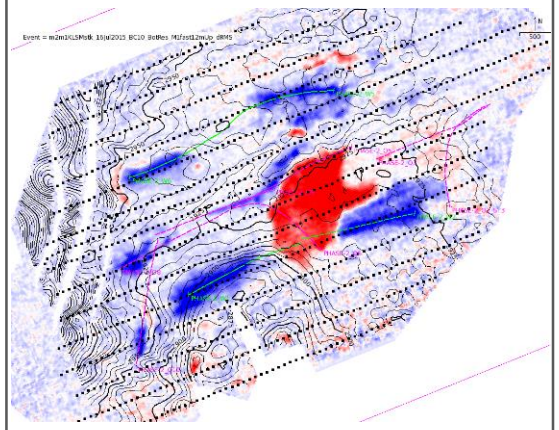
Monitor for out of zone injection



Injection zone

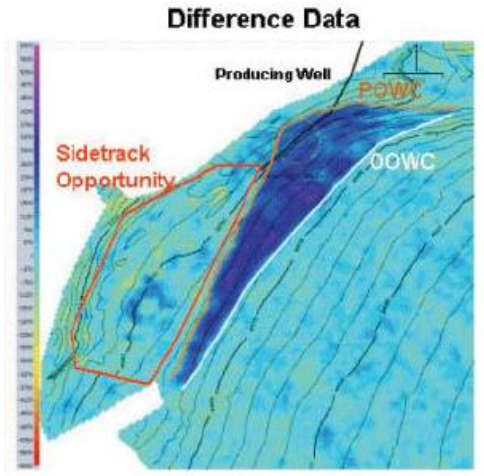
Hatchell et.al., SEG 2013

Optimize injection & offtake rates



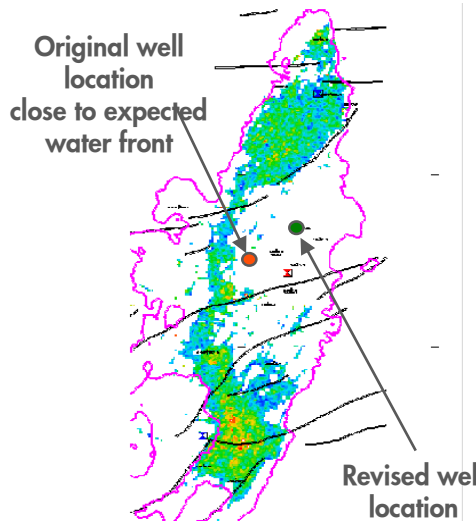
Galarraga et. al., SEG 2015

Identify by-passed oil



Ebaid et.al., TLE 2008

Avoid wrong wells



Koster et. al., SEG 1999

DEVELOPMENT

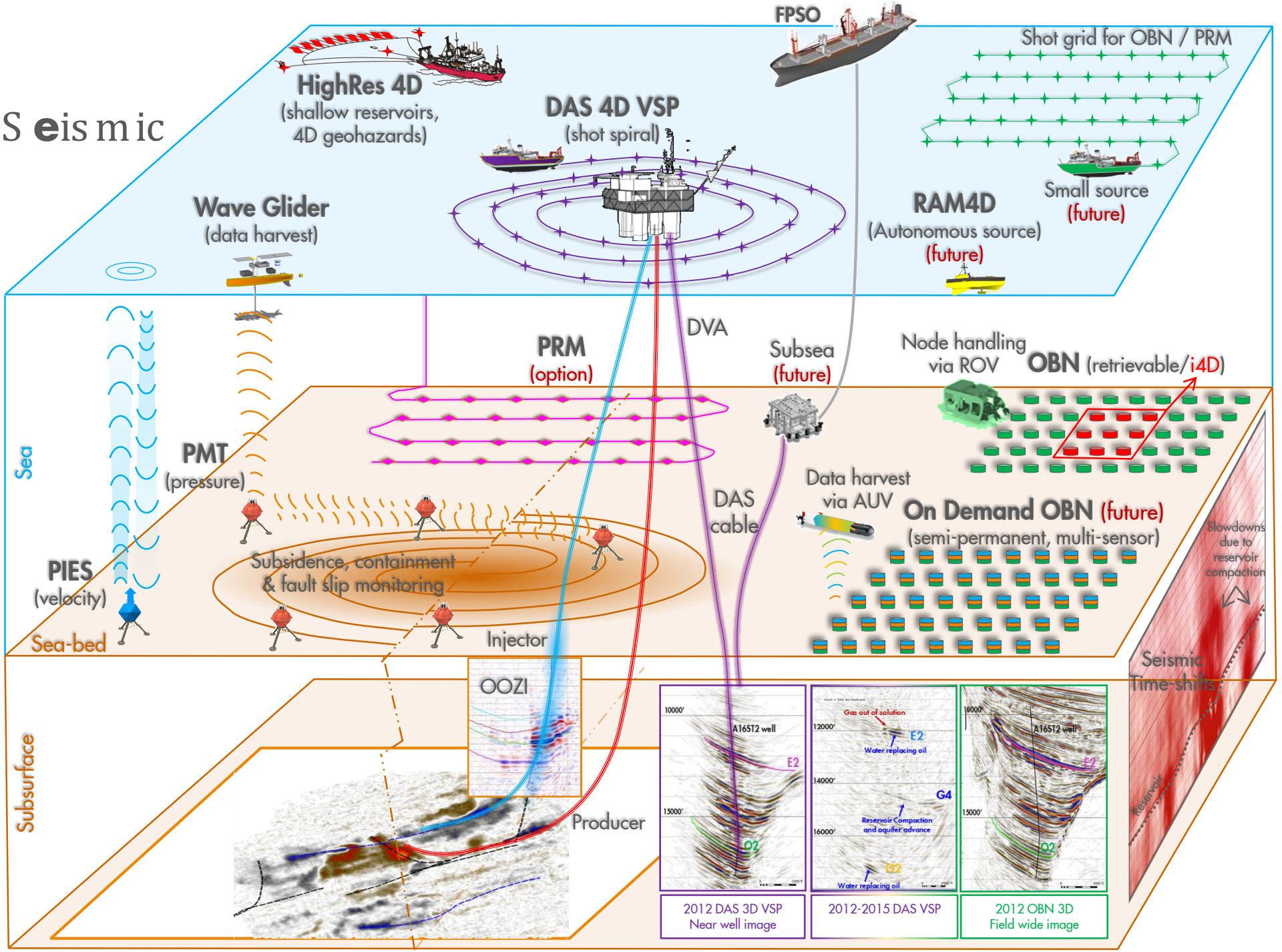
Cost-effective 4D Seismic Technologies

Technologies

- Sensors on sea surface, seabed, boreholes
- Retrievable or permanent

Monitoring Objectives

- Water injection, sweep efficiency
- Out-of-zone injection, geomechanics, subsidence
- **Optimal quality/cost trade-off**



RESULTS

DAS VSP for Low-Cost Water Flood Monitoring in Deepwater

What it is

- Use existing fiber optic cables to generate 4D images around wells
- Advantages: non-intrusive, permanent, low-cost, on-demand
- 4D seismic images to monitor performance of water sweep near injectors/producers frequently and without well intervention

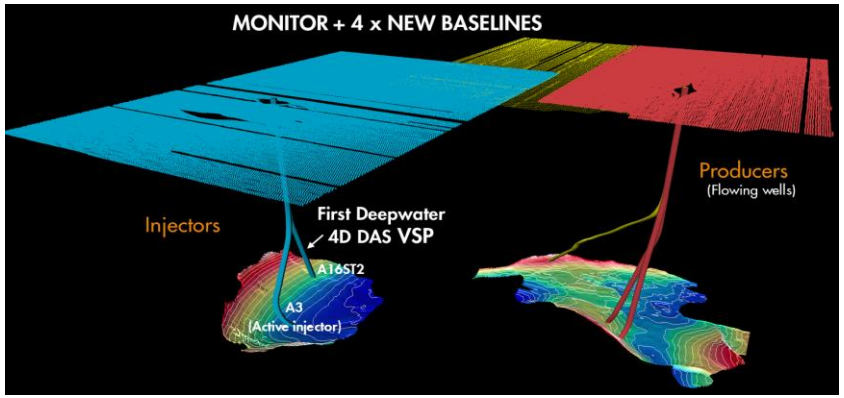
Achieved Milestones

- Surveys in 5 wells at Mars/Ursa show robustness under well conditions (flowing/shut-in), fiber types, and well geometries
- Proof of concept of 4D VSP validated against conventional 4D OBN

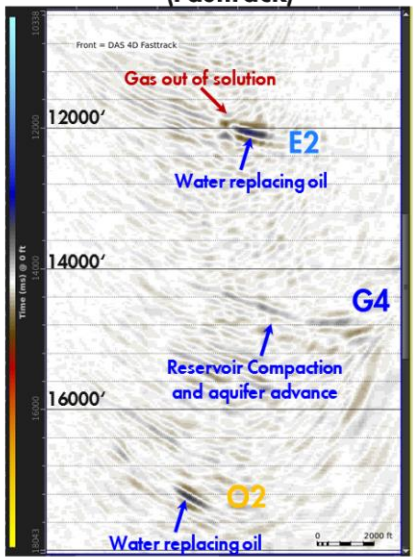
Next steps

- Demonstrate GoM cost target of $1mln per multi-well survey
- Increase area covered by advanced imaging techniques
- Support effort to qualify technology for subsea wells

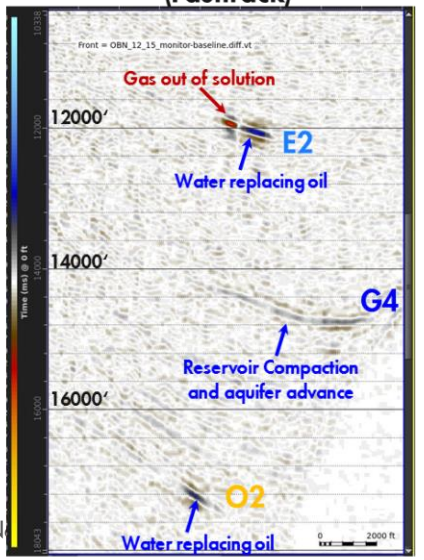
DAS VSP at Mars and Ursa (2015/2016)



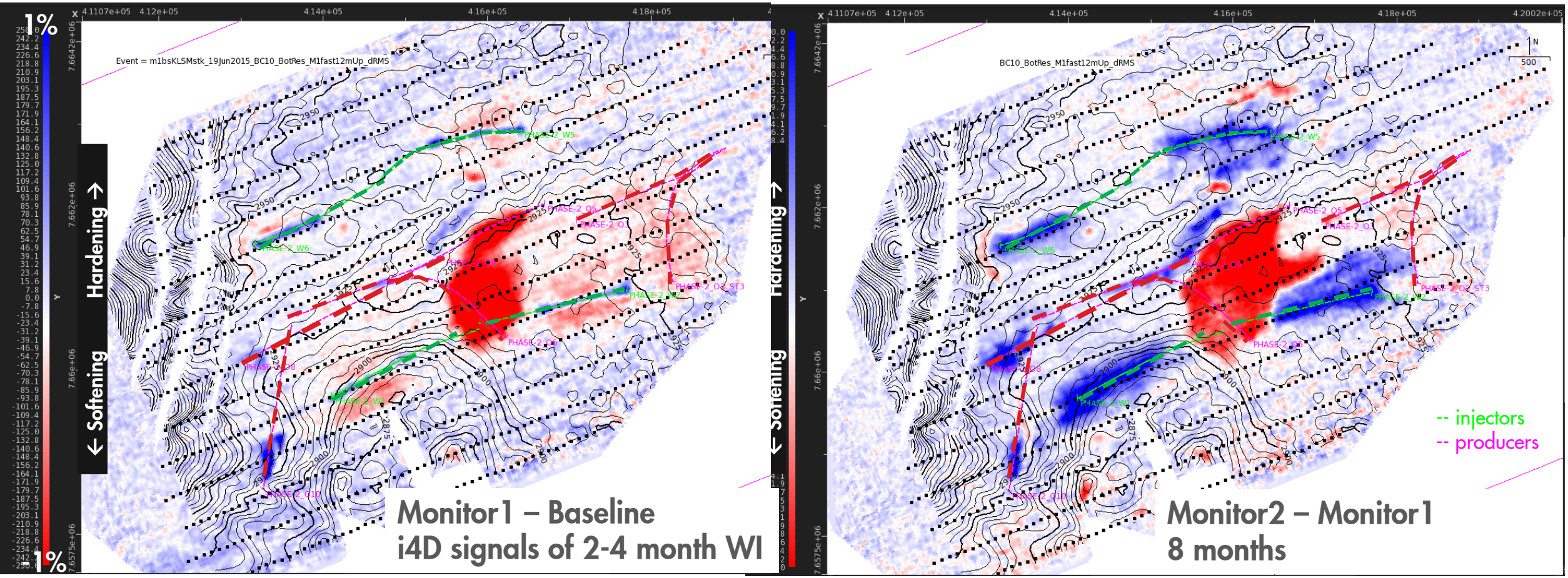
DAS VSP (2012 – 2015) (Fasttrack)



OBN (2012 – 2015) (Fasttrack)



Permanent Reservoir Monitoring (PRM) at BC-10 O-North

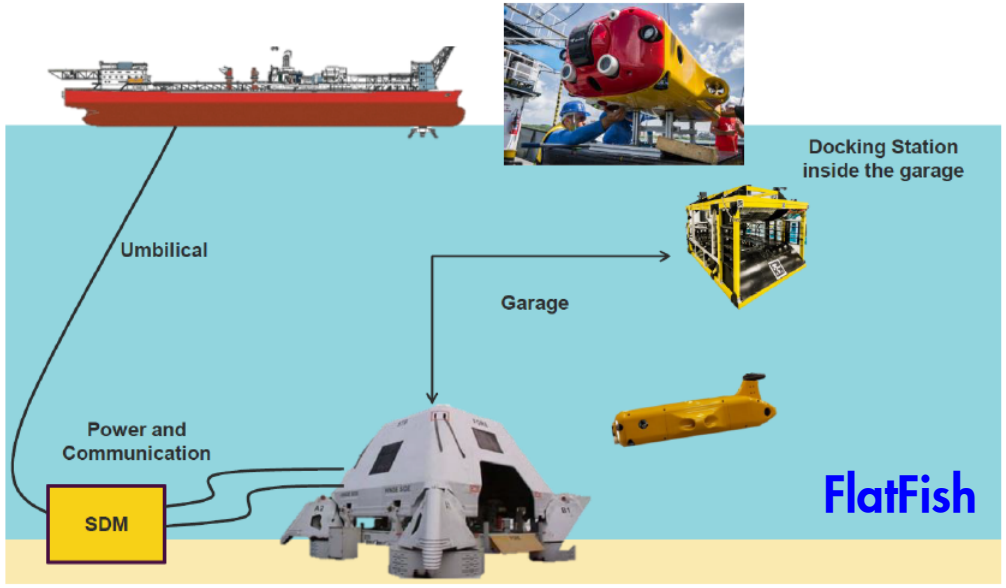


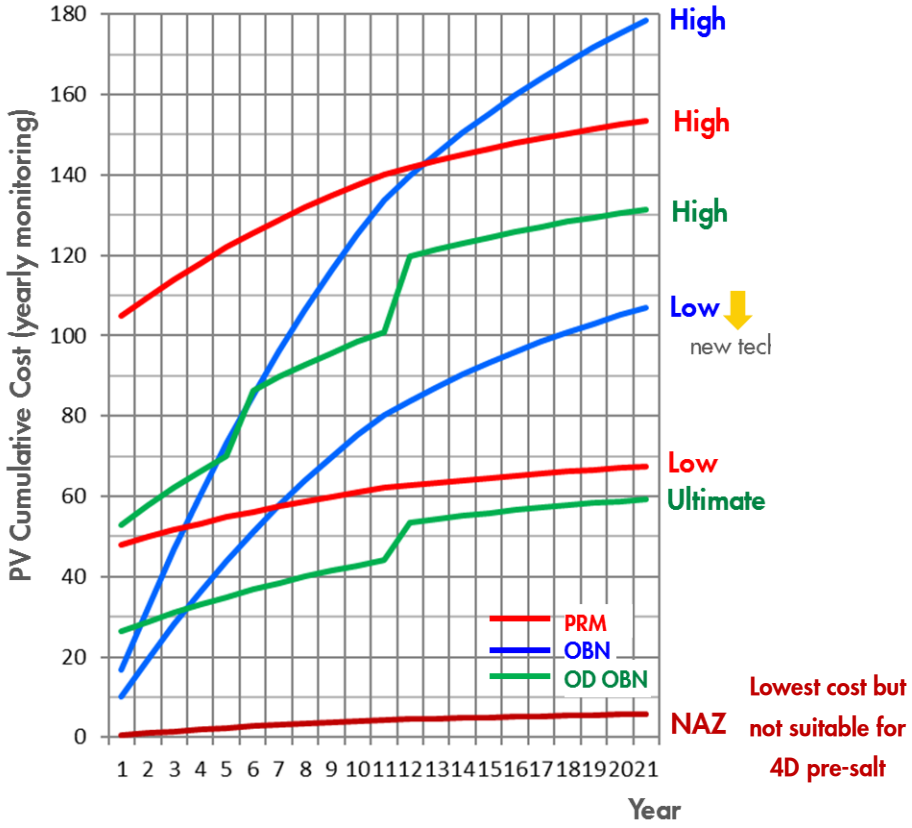
Frequent monitoring impacts WRM → confirms injection in zone, adequate water sweep, allows optimization of injection & offtake rates / reveals detailed reservoir architecture & aquifer support

Galarraga et. al., SEG 2015

The Future – Seismic & Fiber-Optic Surveillance in Brazil Pre-Salt

- Cost-effective On-Demand OBN system
- Data harvesting by AUV (OPEX savings)
- Development / Manufacture / Field Trial
- Subsea fiber-optics: data acquisition & integration
- Levy funded development (proposed)





Ultimate on-demand ocean bottom nodes (OD OBN) for cost-effective reservoir monitoring of pre-salt reservoirs

Lessons Learned – Fiber Optics & 4D Seismic

Near well Monitoring

- One may monitor areas near injectors/producers using DAS VSP
- DAS VSP is very robust against well conditions, geometries, and fiber types
- Fiber optic installations in subsea wells will change the game in deepwater

Full-field Monitoring

- 4D seismic sensitivity improves significantly with permanent sensors
- This is required to monitor small effects between frequent surveys
- Timely 4D seismic can help optimize well operations & reduce risk