FORCE 4D - 30 years of 4D seismic on the Norwegian Continental Shelf
Final Agenda

DAY 1 Wednesday 28.11.2018

Time	Topic	Presenter
08:15	Registration and coffee	
08:45	Welcome	Olav Barkved (Petoro)
	Session I: Past, present, and future of 4D	**Chairs: Sirikarn & Olav**
09:00	**Tutorial I:** Past, Present and Future of 4D seismic (technology + application)	Martin Landrø (NTNU)
09:45	**P.1** Nearly 30 years of 4D seismic on the Ekofisk Field	Per Gunnar Folstad (ConocoPhillips)
10:10	**P.2** 4D seismic data on the Heidrun Field	Sissel Grude (Equinor)
10:35	Coffee break & Networking	
	Session II: Past, present, and future of 4D (Continued)	**Chairs: Nirina & Cedric**
11:00	**P.3** Halfdan 4D Workflow and Results Leading to Increased Recovery	Monica Calvert (Total)
11:25	**P.4** 4D seismic for late life field development: Example from Balder and Ringhorne fields	Alexandre Bertrand (Point Resources)
11:50	**P.5** Gjøa Field 4D signal in the water zone and it's possible interpretation	Iti Aggarwal (Neptune Energy)
12:15	Lunch & Networking	
	Session III: Strategies and methods	**Chairs: Olav & Sirikarn**
13:00	**P.6** The value of a long-term approach to time-lapse seismic processing	Patrick Smith (WesternGeco)
13:25	**P.7** 4D broadband case study at the Bøyla field, North Sea	Ross Milne (AkerBP)
13:50	Coffee break & Networking	
	Session IIII: Integration and reservoir model update	**Chairs: Cedric & Nirina**
14:20	**P.8** History Matching Production and 4D Seismic Data in the Norne Field	Rolf Lorenzen (NORCE)
14:45	**P.9** Predicting pressure and fluid saturation changes using 4D seismic attributes, production data and simulation model	Carlos Pacheco (ConocoPhillips)
15:10	**P.10** Integration of 4D into reservoir models	Trine Alsos (Equinor)
15:35	Coffee break & Networking	
	Break Out / Discussion / Demo Sessions	
16:00	**Theme 1:** Value of 4D / Business Case	Facilitator: Mona Andersen (Equinor)
	Theme 2: Data Sharing	Facilitator: Mark Thompson (Equinor)
18:00	Dinner at the NPD	

DAY 2 Thursday 29.11.2018

Time	Topic	Presenter
08:15	Coffee break & Networking	
08:45	Introduction to Day 2	Cedric Fayemendy (Equinor)
09:00	SEG SEAM time-lapse project	Josef Paffenholz
	Session V: Timeshift & Geomechanics	**Chairs: Sirikarn & Cedric**
09:15	**Tutorial II:** Use of timeshift from 4D seismic analysis	Colin MacBeth (ETLP, Heriot Watt)
10:00	**P.11** 4D and Geomechanics: A Geomechanics View	Tron Kristiansen (Aker BP)
10:25	**P.12** Geomechanical-induced 4D time shifts	Thomas Røste (Equinor)
10:50	Coffee break & Networking	
	Session VI: Tools and technology	**Chairs: Nirina & Olav**
11:10	**P.13** A comparison of dynamic time and spatial correlation methods in time-lapse seismology	Brian Russell (CGG/HRS)
11:35	**P.14** 4D Data – A Question of Time	Brian Lynch (DGI)
12:00	**P.15** 4D seismic simulation using 3D convolution and point-spread functions	Lars Zuehlsdorff (NORSAR)
12:25	Lunch	
	Session VII: Future of 4D deployment	**Chairs: Cedric & Sirikarn**
13:10	**P.16** 4D Seismic driving value in the Knarr field.	Erick Alvarez (Shell)
13:35	**P.17** Grane PRM: What can be seen and how can it be used?	Rigmor Elde (Equinor)
14:00	**P.18** Sharing the learnings of 15 years of LoFS at Valhall field	Nirina Haller (Aker BP)
14:25	Coffee break & Networking	
14:45	**P.19** Reservoir monitoring in EQN, history and way forward	Mark Thompson (Equinor)
	Discussion	
15:10	**Theme 3**: Impact of digital Transformation on 4D technology	Facilitator: Colin MacBeth (ETLP, Heriot Watt)
15:40	**Closing Comments and Feedback**	
15:55	Adjourn	

Organizing Commitee:
Olav Barkved (Petoro)
Cedric Fayemendy (Equinor)
Nirina Haller (AkerBP)
Sirikarn Narongsirkul (ConocoPhillips)
Ellen M. Skartveit (NPD)

Abstract 4D talk

Tutorial I: Past, Present and Future of 4D seismic

Martin Landroe

A short history of 4D seismic on the Norwegian Continental Shelf will be given. Early observations regarding repeatability and noise sources that is critical for 4D acquisition leading to the ultimate permanent systems that have been installed at several North Sea fields today are discussed. Key developments in 4D analysis and interpretation techniques, and how various geophysical data can be used and combined to improve the overall understanding and reveal minor details will be covered in the talk. At the end I will discuss future possibilities and why this technology will continue to improve and be a crucial decision tool for reservoir management and monitoring of CO_2 storage.

Title: Nearly 30 years of 4D seismic on the Ekofisk Field

Per Gunnar Folstad: ConocoPhillips

Sirikarn Narongsirikul, Bjarne Lyngnes, Arild Gundersen, Carlos Pacheco, Ruben Thomassen, Reidar Midtun, Marie Skadberg: ConocoPhillips

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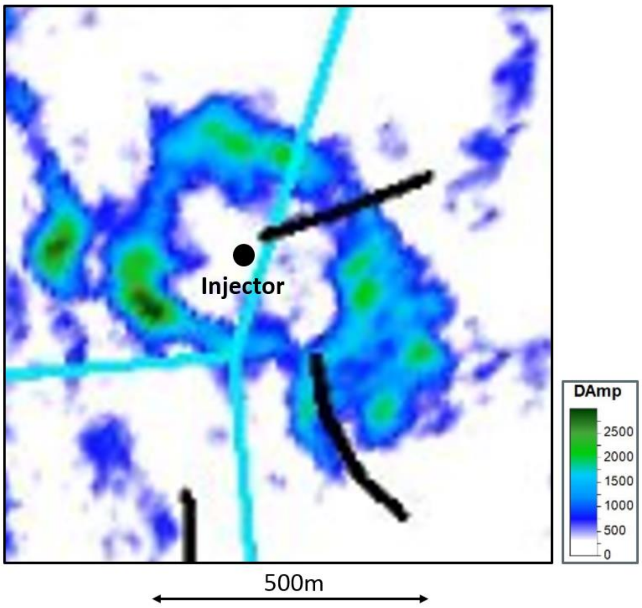
In 1989, the first 3D seismic survey was acquired over the Ekofisk field. About the same time, large scale waterflooding of the field was initiated, making this first 3D survey also serve as a base 4D seismic survey for monitoring of the waterflood. The first monitor survey was acquired over the field in 1999, showing large 4D effects caused by water injection and oil depletion, most significantly as overburden time shifts, but also time and amplitude changes across the reservoir units. Since then, three more monitor surveys were acquired in 2003, 2006 and 2008 before a decision was made to install a permanent reservoir monitoring (PRM) system in 2010. To date, 14 PRM surveys have been acquired, with a 15th survey scheduled for Q3 2018.

4D seismic from Ekofisk (from both the early streamer surveys and the PRM system) are being used daily; from overburden well path optimization and containment assurance to reservoir waterfront mapping, seismic PLTs and well target identifications. This paper will review how utilization of 4D seismic at Ekofisk has developed significantly from the first monitor survey in 1999 to how the data is being used today.



4D waterfront mapping 2010-2018

Title: 4D seismic data on the Heidrun Field

Sissel Grude Haug: Equinor

Jon Lippard: Equinor

Katharina Svee Halland: Equinor

Heidrun Breiset Ulsund: Equinor

Daniel Fischer: Equinor

Hanna Blekastad: Equinor

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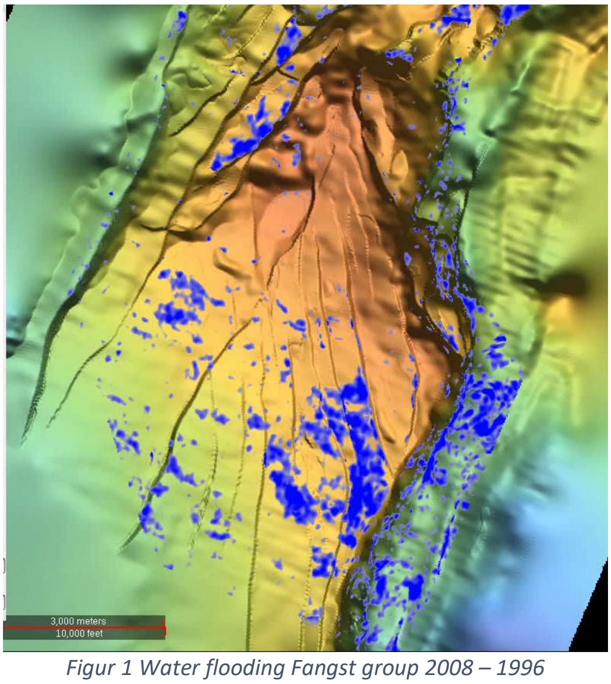
A Short Introduction

The use of 4D seismic data has been a successful tool for monitoring reservoir changes on the Heidrun field. Heidrun has a long seismic 4D history with base surveys acquired in 1986 and 1991. Since 1991, 7 monitor surveys have been acquired with the most recent one in 2018.

The purpose of this presentation is to summarize the 4D history on the Heidrun field including improvements in acquisition and processing. Case studies will be shown to illustrate the high value the 4D seismic data has when placing wells on the Heidrun field.



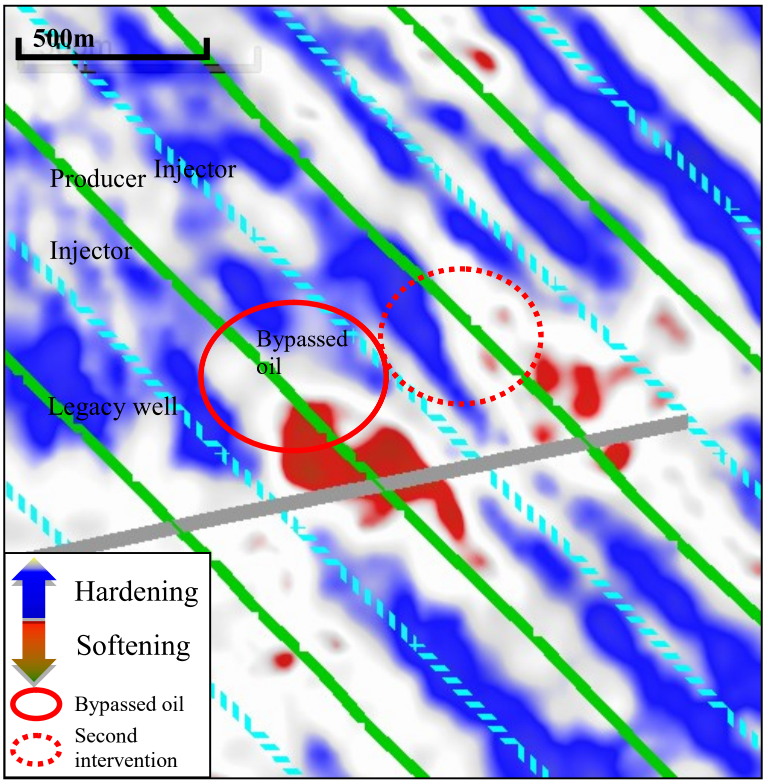
Figur 1 Water flooding Fangst group 2008 – 1996

P.3 Halfdan 4D Workflow and Results Leading to Increased Recovery

Monica Anne Calvert: Total
Andrew Robert Hoover: Total
Luke Vagg: Shell, formerly Maersk Oil
Kiam Chai Ooi: Saudi Aramco, formerly Total
Katja Katrin Hirsch: Total

Abstract

Repeated time lapse seismic surveys have been acquired over the Halfdan oil field located in the Danish North Sea leading to increased recovery in the field. The primary and secondary reservoirs are the Cretaceous & Tertiary Tor and Ekofisk chalk Formations, respectively, and the oil field is developed with a line drive waterflood. The 4D acoustic impedance change is dominated by increased water saturation around injecting wells and gas breakout around producers when the reservoir pressure drops below bubble point. In a few cases, pressure responses can also be seen along the producers and injectors. The 4D project methodology includes interpreting and integrating the inverted time strain and acoustic impedance change from the fast track, intermediate and final datasets allowing for optimization of the processing flow. Detailed analyses of the seismic, well and production data revealed several correlations between porosity, faults and the 4D response and led to numerous well intervention opportunities. In one example, an additional 730bbl/day was added after the 4D highlighted a bypassed oil zone behind a closed production zone, leading to a similar intervention in a neighbouring well. The 4D project methodology and examples from the 2012 4D will be presented here.



P.4: 4D Seismic for late life field development – Example from Balder and Ringhorne fields

Alexandre Bertrand, Tor Veggeland, Ståle Høgden, Rune Musum (Point Resources)

In 2017, Point Resources took over owner- and operatorship of the Balder and Ringhorne fields from ExxonMobil. A plan was established to maximize the area potential by extensive infill drilling, provision of additional processing capacity and field life extension.

Ringhorne Phase III development will start in 2019 with 3 workovers and 6 new wells. Balder Future Project will consist in Jotun FPSO relocation and life extension to maximize capacity, as well as Balder & Ringhorne Phase IV drilling campaigns with 16 and 5 new wells respectively. With these, production in the Balder area is projected to last until 2045.

Through the production life of Balder & Ringhorne, 4D seismic has been used extensively: in 2006, 2009 and 2012 monitor surveys were acquired to support Ringhorne Phase II and Balder Phase III drilling through target maturation and optimization.

In 2018, a new monitor survey was acquired, consisting of a 1000-OBN patch deployed with ROV under the Balder FPSO and a towed streamer survey covering the Balder, Ringhorne and Ringhorne East fields. Fast track processing has been initiated to support the first drilling targets.

This presentation will present value adding examples of 4D usage from previous development phases and give examples from the 2018 operations.

Iti Aggarwal

Neptune Energy

P.5: Gjøa Field 4D signal in the water zone and it's possible interpretation

Across the Gjøa Field (situated in Northern North Sea), the first 4D survey was acquired after 10 years of production. Of the production related 4D signals observed, softening below the oil-water contact (OWC) is very interesting. Similar 4D signals have been observed on neighboring fields, often described as being associated with a paleo-contact supported by well observations. However, for the Gjøa Field no paleo-contact or transition zone has been observed in any of the wells at the depth of the observed 4D signal.

Attributes like quadrature difference and time-shift show possible gas out of solution effects due to pressure drop. There are presently two interpretations to explain this; first is the presence of miscible gas in the aquifer (fizzy water) resulting from solution gas out of the oil zone (and possibly from any residual/irreducible oil below the OWC), second is continued/on-going hydrocarbon migration from of a very prolific source-kitchen immediately adjacent to the Gjøa Field.

P.6: The value of a long-term approach to time-lapse seismic processing

Patrick Smith; WesternGeco

The time-lapse seismic method is a well-established reservoir surveillance technique, and many hydrocarbon-producing fields are covered by multiple vintages of time-lapse seismic data acquired at regular intervals. Standard practice is to process the newly acquired survey in parallel with reprocessing of the data from previous surveys. But, as the number of vintages increases, significant resources are required for this reprocessing, and to re-analyze the resulting data. This processing may take 4-6 months to perform, during which time reservoir decisions may need to be made without input from the newly acquired data. “Fast-track” products can help, but may be of dubious reliability and will occupy yet more resources.

A long-term approach can address these issues. We have developed time-lapse seismic processing workflows that enable a new monitor survey to be processed independently of the previous ones, whilst still maintaining consistency and quality. The newly acquired dataset is simply added to the existing time-lapse seismic database, minimizing processing turnaround and eliminating the need to perform additional processing and interpretation of the older surveys. Reprocessing to improve data quality is performed, when necessary, in the intervals between completion of the most recent survey and acquisition of the next.

The approach is typically initiated after one or more monitor surveys have been acquired, processed and analyzed. Parallel processing of the existing datasets is performed in the normal way, but the components of the flow that involve simultaneous analysis of multiple vintages are modified so that they output reference datasets to which each individual survey can be matched. These reference datasets are then archived for use in processing subsequent surveys.

Computing hardware and software evolves significantly over the 10 years or so that a long-term project may be active. This is handled by regression testing. Example input and output seismic datasets from each step of the processing flow are archived in the initial phase of the project. Prior to acquisition of a new monitor survey, these are compared with equivalent datasets created using the current configuration. Any discrepancies can be addressed before acquisition starts. Rigorous documentation ensures smooth execution of the new survey.

The long-term approach is applicable to all acquisition types, and has been used on a number of fields. Final processed data from a new marine streamer monitor survey is usually delivered 4 to 8 weeks after acquisition completion. This, together with the reduced resource requirements, adds significant value relative to standard practices.

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28-29 November 2018, NPD Stavanger Norway

P.7

Title: a 4D broadband case study at the Bøyla field, North Sea

Julien Oukili[1], Ross Milne[2], Darryl Anderson[1], Kent Andorsen[2], [1]PGS, [2]AkerBP

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Summary

We present a case study of broadband 4D seismic acquisition and processing from the Bøyla field, North Sea, where the interpretation of the targets has previously benefited from broadband seismic solutions for 3D high-resolution imaging. Both the base survey and the monitor survey were acquired with multi-component towed-streamer solutions and the data were fully deghosted at the early stages of the processing. We focus in particular on the added value from the extended bandwidth through interpretation. The examples include seismic data from the early stages of processing, final images and attributes. Conventional 4D processing and interpretation traditionally exclude very low frequencies as they tend to be too noisy, although it is expected to be more repeatable than higher frequencies. In this case, we observe signal down to approximately 2Hz with a distinct 4D response which proves to be important for the correct assessment of the 4D effects and delineations. Besides the common benefits that broadband solutions brought to 3D exploration, we illustrate its unrevealed potential for 4D reservoir monitoring.

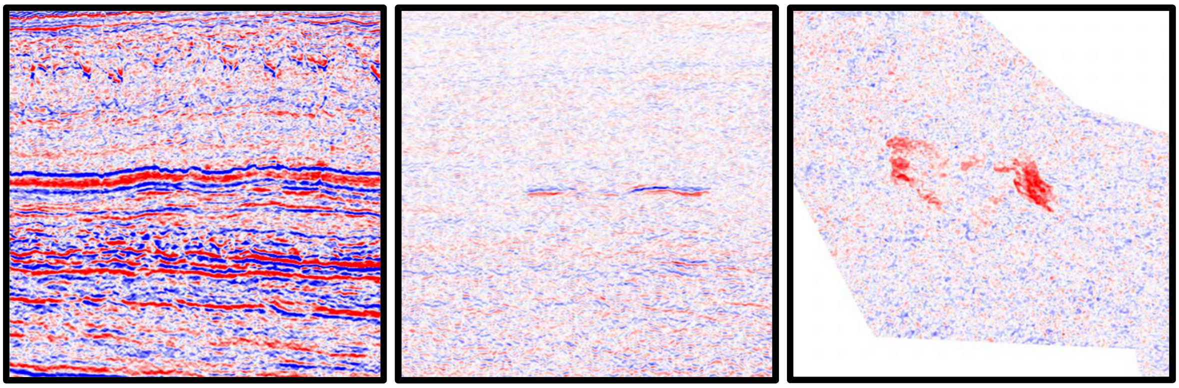

Figure 1. Vertical time section of the monitor survey (left), 4D difference (middle) and time slice through the reservoir (right).

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30 years of 4D seismic on the Norwegian Continental Shelf
28-29 November 2018, NPD Stavanger Norway

History Matching Production and 4D Seismic Data in the Norne Field

Rolf J. Lorentzen: IRIS

Tuhin Bhakta: IRIS / The National IOR Centre

Dario Grana: University of Wyoming

Xiaodong Luo: IRIS / The National IOR Centre

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Summary

Ensemble based assisted history matching using production and seismic data is challenging due to the size and complexity of seismic datasets. One severe problem is that posterior parameter uncertainty is usually underestimated due to the limited number of models in the ensemble compared to the dimension of the data. In this talk we present promising approaches for mitigating this problem.

The presented methodology utilizes a sparse representation of the seismic data, using methods originally developed for image denoising. The approach can be applied to seismic data or inverted seismic attributes obtained from geophysical inverse methods. The seismic response from the forward model is computed using a petroelastic model, that depends on several petrophysical parameters, including lithology, porosity, and saturation.

The workflow is successfully implemented and demonstrated for the Norne field using production data and several vintages of 4D seismic data, released by Equinor. The results show that through this method we can successfully reduce the data mismatch for both production data and acoustic impedance. In addition to better production forecasts, the updated models can be used to simulate reservoir flow more accurately and provide useful information when planning infill wells or EOR strategies.

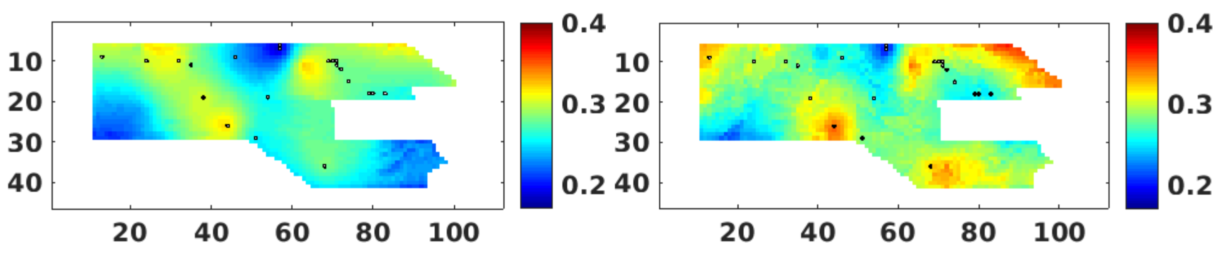

Figure 1: Mean porosity in top layer. *Left:* Before history matching, *Right:* After history matching.

Predicting pressure and fluid saturation changes using 4D seismic attributes, production data and simulation model

Carlos Pacheco: ConocoPhillips

Sirikarn Narongsirikul, Reidar Midtun: ConocoPhillips

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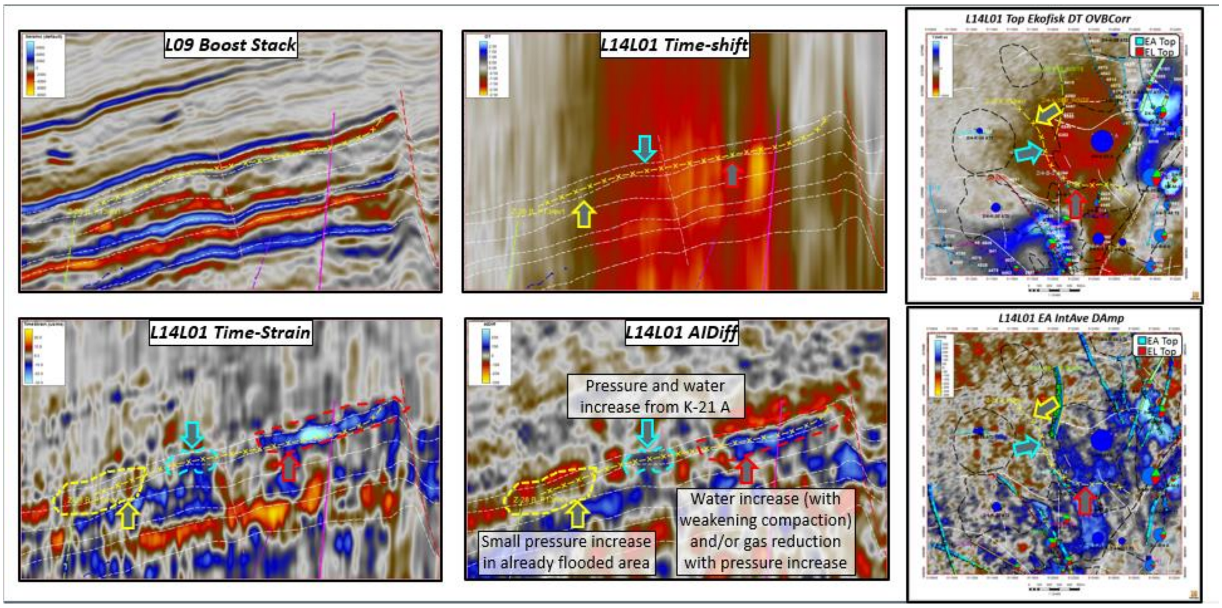
Optimizing the location of infill wells in a mature field such as Ekofisk with a long history of production and a hectic drilling schedule requires a fast and integrated solution that incorporates all available data in an efficient manner. In addition to finding locations with remaining oil in between the many producers and injectors, it is of paramount importance to drilling safety and well performance to characterize the pore pressure behavior on the target area and more specifically along the proposed well paths.

In the Ekofisk chalk field, there are multiple sources of data and models available to characterize pressures and fluid saturations in the reservoir. Traditionally, pressure and water saturation logs from recently drilled wells in addition to produced fluid rates and borehole pressures in the producer and injector wells are used in history matching to generate a deterministic flow model which characterizes the dynamic behavior of pressures and saturations. More recently, seismic 4D attributes have increasingly been incorporated as additional data to be assimilated in the history matching process and in the estimation of the dynamic behavior of the reservoir properties. In this paper I describe a methodology or framework to efficiently integrate all the relevant data regarding flow model properties, well activities, production data and observed 4D attributes to estimate the pressure and fluid saturation changes from the reference history matched model at a reference date to a target date given by the last available seismic survey.

The methodology presented in this paper is based on a non-linear and constrained rock physics model 4D inversion that uses estimated seismic elastic properties and a reference history matched flow model. This methodology is a shortcut to doing full seismic assisted history matching in the sense that it quickly calculates deviations between the elastic properties predicted from the model and the observed elastic seismic attributes generating alternative pressure and fluid saturation profiles along the planned well paths without explicitly using production and injection data. The method then finds an alternative solution in reservoir property changes that better explain the observed seismic attributes and honors constraints given by surrounding well activities. The workflow and results will be illustrated with a recently planned producer well.



Seismic 4D Attributes along planned well path which are input to 4D RPM inversion.

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28-29 November 2018, NPD Stavanger Norway

Integration of 4D seismic into reservoir models

Trine Alsos: Equinor ASA

Marius Heide: Equinor ASA

Bård Osdal: Equinor ASA

Bjørn Tore Samuelsen: Equinor ASA

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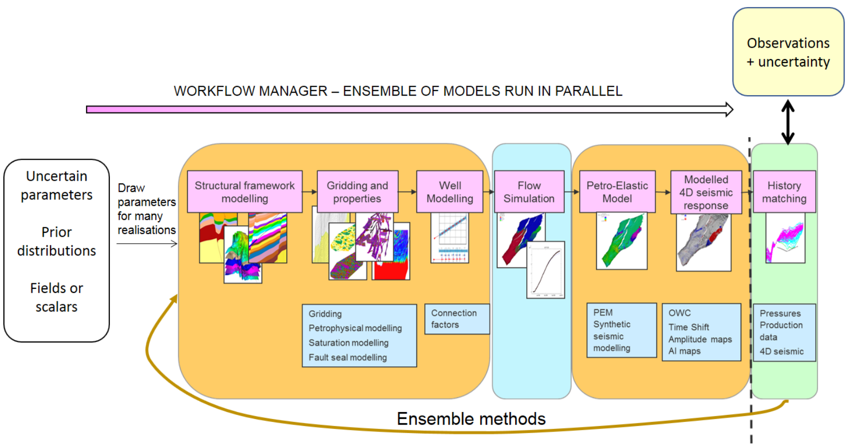
A Short Introduction

Reservoir management, infill well planning and production forecasting is often at least partly based on a flow simulation model. For more reliable predictions, the model should be updated using the information gained from all observations, including time-lapse seismic, when available. Often updates have been done using "manual history matching" by testing the response from single changes to the model, such as opening or closing faults, modifying sand distributions or changing permeabilities in an area. Although assisted history matching methods have been available, they have been challenging to use for 4D seismic data, partly due to the amount of observations in a time-lapse seismic dataset.

Development of integrated modelling workflows and ensemble smoother methods for model update has opened up new possibilities for assisted history matching of reservoir models to time-lapse seismic data, and so far demonstrated good results. As the word "assisted" underlines, this is not an automated process. Running sensitivities and working with the prior ensemble of models constitutes the main part of the work for successful assisted history matching. This is even more valid when 4D seismic is used as observation data. But combining reservoir knowledge, 4D seismic understanding and automated modelling workflows makes it possible to run sensitivities in an efficient manner. Sometimes this is enough for understanding which updates that are needed in the model. In other cases the parameterization is more complex and ensemble smoother algorithms can lead to additional insight about the reservoir.

Through some examples from the Norne field where 4D seismic has been used in model updates since 2001, it is shown how the mix of sensitivities and more automated processes has helped improving the reservoir understanding and models, and that even now after 20 years of production new 4D seismic data can show surprising results.



Integrated modelling improves possibilities for model updates based on time lapse seismic, either by running sensitivities or by using ensemble methods for assisted history matching

SEAM Time Lapse and Life of Field project

Shauna Oppert, Joseph Stefani, Daniel Eakin, Adam Halpert, Chevron
Jorg V. Herwanger, Andy Botrill, Peter Popov, MP Geomechanics
Lijian Tan, Advanced Geophysical Technology
Vincent Artus, Kappa Engineering
Michael Oristaglio, Yale University
Josef Paffenholz, FairfieldGeo, Chair SEAM BoD

How accurately can geophysical remote sensing detect and quantify changes in relatively soft oil and gas reservoirs during production? The SEG Advanced Modeling (SEAM) Corporation undertook a pilot project to study this question by performing a realistic, large-scale simulation of monitoring a deepwater turbidite reservoir.

The goal of SEAM Time Lapse was to create a high-quality synthetic data set containing time-lapse seismic (and other geo-physical) data — as well as the ground-truth reservoir model — to serve as a virtual laboratory to investigate the value of different seismic attributes as monitors of reservoir changes. The data and model can be used to test reservoir management workflows designed to close the loop between reservoir engineering, rock physics, and time-lapse remote sensing, in strategies intended to optimize the economics of reservoirs by increasing or prolonging production. The project aimed at using state-of-the-art technology in digital geologic model building, in reservoir and geomechanical simulations, and in large-scale elastic-wave seismic simulations.

After the successful conclusion of the pilot project which served as a proof of concept, the full scale Life of Field project was started which is currently underway.

Tutorial II: Use of time-shifts from 4D seismic analysis

Colin MacBeth, Professor of Reservoir Geophysics,

Heriot-Watt Institute of Petroleum Engineering, Edinburgh, UK.

I provide historical background to the use of post-stack time-shifts in industry today. Starting from the acknowledgement of 4D as one of the main monitoring methods for improving recovery factors in both the UK and Norwegian continental shelves, I summarise the early days of 4D seismic interpretation based on post-stack and pre-stack amplitudes. This is followed by a discussion on post-stack time-shifts and the earliest possible uses of this attribute on the strongly compacting chalk fields of Valhall and Ekofisk. Details of the benefits for geomechanical assessment for overburden integrity are provided together with further examples from the Shearwater, Snorre, Norne and Ekofisk fields. For this, a key relationship is described that links seismic signatures to the dynamic properties (Figure 1). Time-shift signatures from the Svale, An'Teallach and Cinguvu fields give further examples for the cases of gas injection, gas breakout or water flooding. The overall magnitudes of such time-shifts is compared and contrasted in Figure 2. Finally, the leading edge of time-shift technology is described: offset dependence, re-migration, 4D tomography and 4D FWI. I conclude by remarking that time-shifts are a solid seismic attribute, increasingly popular for application to geomechanics, however many challenges are yet to be surmounted before the full potential can be realised.

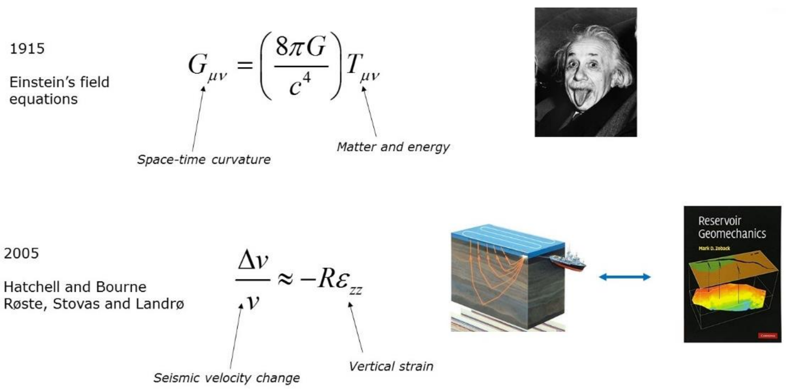


Figure 1 – I show a loose analogy, for illustration purposes, between Einstein's unification of space-time and matter-energy, and the equations used by Hatchell and Røste to link the seismic and geomechanical domains.

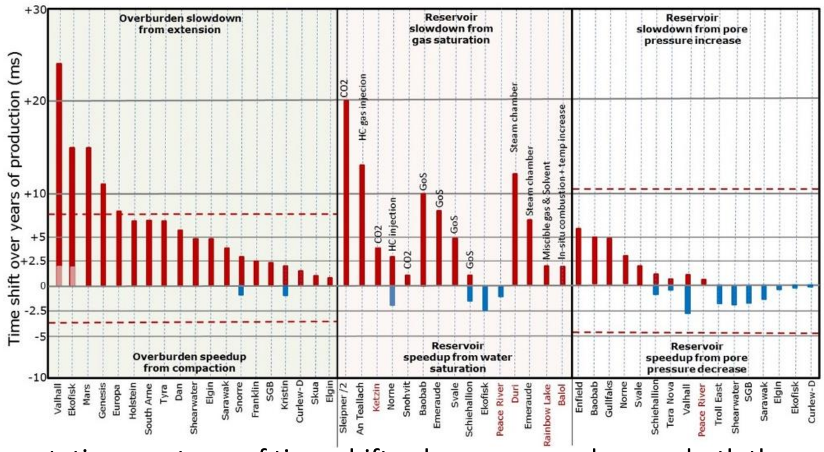


Figure 2 – A representative spectrum of time-shift values measured across both the reservoir and overburden. After MacBeth et al. (2018).

P.11: 4D and Geomechanics: A Geomechanics View

By: Tron G. Kristiansen, Engineering Geology Manager, AkerBP

During some of the early applications of 4D seismic in fields experiencing significant reservoir compaction, like the chalk fields on the NCS, it was observed significant seismic timeshifts associated with the resulting subsidence above the compacting reservoir. These correlations could easily be observed in these fields since these fields typically had geomechanics models in place used to predict seafloor subsidence with time. These findings should be of general interest in the industry since all reservoirs compact to some extent when reservoir pore pressure is reduced in the reservoir during production of oil and gas. Therefore, mapping observed timeshifts and other seismic attributes, versus predicted timeshifts and other seismic attributes to verify subsurface models is only a matter of seismic accuracy and repeatability.

This presentation will share some of the field observations from the early 4D data, which could be explained from geomechanics. In addition to the timeshifts, we will look at compaction around horizontal wells and shear wave splitting in the overburden. We will look at the use of 4D seismic to verify the geomechanics models and their use in reducing infill drilling risk in complex and dynamically changing overburdens. We will see that both shale pore pressure and fracture gradients are changing above a compacting reservoir and that these effects impact the seismic velocities with time.

We will also discuss the important shale rock physics link between seismic observations and geomechanics to use seismic changes in a more quantitative sense, and what the next steps could be in the use of 4D seismic for geomechanics use.

Title: Geomechanical-induced 4D seismic time shifts

Thomas Røste (Equinor)

Contact email: thros@equinor.com

Introduction

Production-induced geomechanical stress changes cause velocity changes in the overburden that might be detected as 4D seismic time shifts. The strength of the velocity changes depends on the degree of pressure changes and the elastic properties of the reservoir and overburden layers. Even small velocity changes (less than 1%) might accumulate into detectable seismic time shifts at the top reservoir, since the overburden thickness typically ranges from one to several kilometers.

Recent research shows that geomechanical-induced time shifts are typical in the overburden for many fields, not only chalk or high-pressure, high-temperature reservoirs but also sandstone reservoirs close to hydrostatic pressure (Røste and Ke, 2017). Examples from the Snorre, Heidrun, and Statfjord fields show strong correlation between overburden time shifts, geomechanics, and reservoir pressure changes. Such time shifts can be used to indicate undrained areas and transmissibility across faults, which is useful information for increased oil recovery, well planning, and reservoir model updating.

Figure 1 shows an example with time shifts (97-09) along a vertical profile at the Snorre Field. Note the strong time shifts apparent as a blue “bar”, starting right beneath the seabed, increasing toward the top reservoir (BCU).

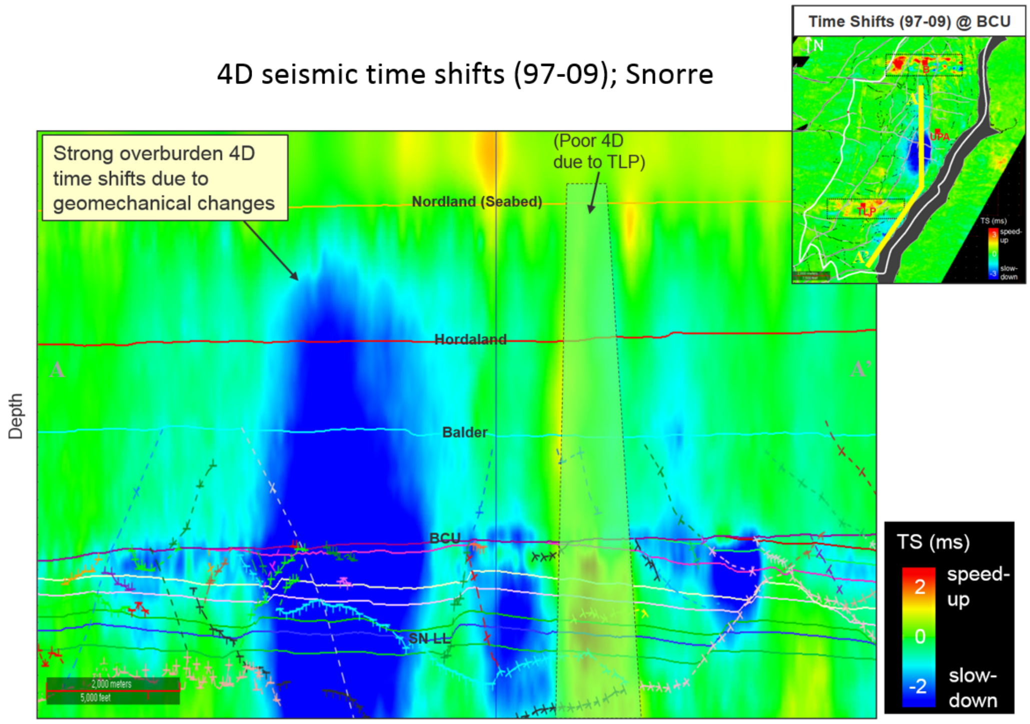


Figure 1: Time shifts (97-09) along a vertical profile A (indicated by yellow solid line on 4D map, top right). Slow-down (blue) in overburden indicates areas where the reservoir is depleting. Area with low repeatability (because of platform shadow) is outlined by black dots.

A comparison of dynamic time and spatial correlation methods in time-lapse seismology

Dr. Brian Russell

Vice President, CGG GeoSoftware

Calgary, Alberta

Abstract

One of the key calibration steps in the time-lapse seismology workflow is the computation of optimal dynamic time and spatial shifts needed to calibrate multiple monitor surveys with a base survey. Most early approaches were done using the cross-correlation technique, which could be implemented dynamically in time using multiple correlation windows and then interpolating the results. This can lead to noisy time-shifts and can be improved by cross-plotting the correlation time shifts versus the equivalent correlation coefficients and applying a filter to keep only those shifts within a user-defined zone.

However, in the last few years several newer techniques have been developed for computing the dynamic shifts, which include:

- The Taylor series expansion method
- Dynamic time warping
- Vector warping using Gaussian correlation

The cross-correlation technique and the first two of the above methods, the Taylor series and dynamic time warping techniques, compute shifts in the vertical time direction only. But the vector warping approach computes shifts in the vertical time direction and both horizontal directions, meaning that it can be used to assess geomechanical changes in the reservoir over time.

In this talk I will summarize each of these methods and show examples of applying the methods to the Gregoire Lake In-Situ Steam Pilot (GLISP) project from Northern Alberta. The GLISP project was an early time-lapse study which monitored the time progression of a steam front in a heavy oil sand play.

P.14: 4D Data – A Question of Time

Brian J. Lynch: Dynamic Graphics
Graham Brew: Dynamic Graphics

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Introduction

Time-lapse seismic is part of a genre of 4D attributes now associated with the Oil and Gas Industry. Of the many 4D data types perhaps time-lapse seismic has arguably provided the greatest impact. 4D data has been proven to provide great insights to the dynamics of the reservoir, but like any valuable commodity it's potentially worth must be extracted. Use of a purpose-built environment is essential in maximizing the return of investment in acquiring the data in the first place. This paper describes the elements that would form such an immersive environment allowing efficient data analysis, rapid data loading and integration of an ever growing list of time variant data types within a common viewing area. Such an environment will provide enormous opportunity for understanding the complexities of the reservoir which can be described not from one data source but as a product of multiple 4D responses. Tools to extract, map and cross reference within such an environment provide the tools to complete the AHM (Assisted History Match) workflow to ensure a continual decrease in the uncertainty surrounding reservoir flow models.

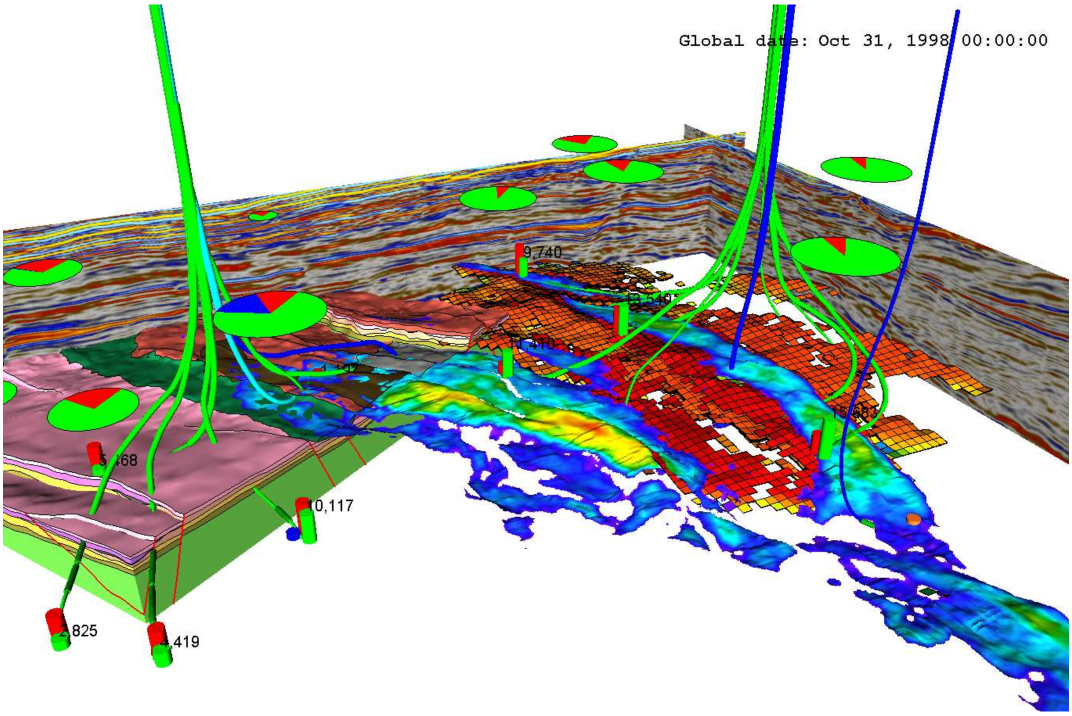

Figure 1: *An example of an integrated environment from CoViz 4D. Combination of different file types ranging from cellular grids, volumes, surfaces, annotation, production towers, wells, 4D attributes. Assigning time stamps to the various dynamic data types allows a controlled sequencing of events*

4D seismic simulation using 3D convolution and point-spread functions

L. Zühlsdorff and T. Kaschwich (NORSAR)

I. Lecomte (University of Bergen and NORSAR)

Most 4D seismic workflows require some kind of seismic forward modelling from dynamic reservoir models that were previously converted into the elastic domain. However, routine application of full wavefield modelling, which is considered as the most complete approach, may not be practical if many different modelling scenarios need to be compared.

Green's functions as generated from ray-based wavefront construction open new ways to very efficient PSDM simulation. They can be generated by ray-tracing in sufficiently smooth background models and for selected target points. These target points are considered as scattering points, i.e., they do not require any reflecting interface. Green's functions are used for generating so-called illumination vectors, each of them representing a valid shot and receiver combination of a given survey. Only interfaces perpendicular to an existing illumination vector can be illuminated by the given survey geometry; thus the combination of all illumination vectors for all shot and receiver pairs provides general information on which target dips and azimuths can potentially be illuminated at the respective target point. Converting illumination vectors into scattering wavenumbers and combining them with the amplitude spectrum of a given wavelet provides a specific 3D filter that integrates both illumination and resolution properties. Strictly speaking, this filter is only valid at the location of the initial scattering point; however, if the background model is combined with a detailed interface-based target model, the filter can be applied to a representative model volume around the scattering point. The idea is to provide a fast-track approach to simulate pre-stack depth migrated seismic images from the layered model without actually doing the migration, but still taking survey, overburden and wavelet into account. The depth domain representation of the filter is a point-spread function, which also provides a direct measure of both lateral and vertical resolution.

Doing this kind of fast-track PSDM simulation cannot fully replace a more detailed and complete "brute force" approach consisting of full wavefield modelling and imaging, however, the 3D filter-based method is extremely fast and flexible and provides a significant improvement if compared to common 1D convolution approaches. Key applications include all modelling approaches that do not necessarily require the full wavefield, e.g., time-lapse feasibility testing as based on existing rock physics and reservoir modelling.

P.16 4D Seismic driving value in the Knarr field.

Presenter: Erick Alvarez

In this presentation we show how 4D seismic has had substantial impact for the Knarr field reservoir management. We also show how improvements on seismic imaging 4D images translate into significant reduction on the ambiguity of 4D signals. 3D and 4D deterministic and probabilistic inversions were used to perform static and dynamic model updates, which are then used to polarise additional infill opportunities, as well as to drive the execution of a PLT campaign with the intention of improving ultimate recovery of the field.

FORCE
30 years of 4D seismic on the Norwegian Continental Shelf
28-29 November 2018, NPD Stavanger Norway

Title: Grane PRM: What can be seen and how can it be used?

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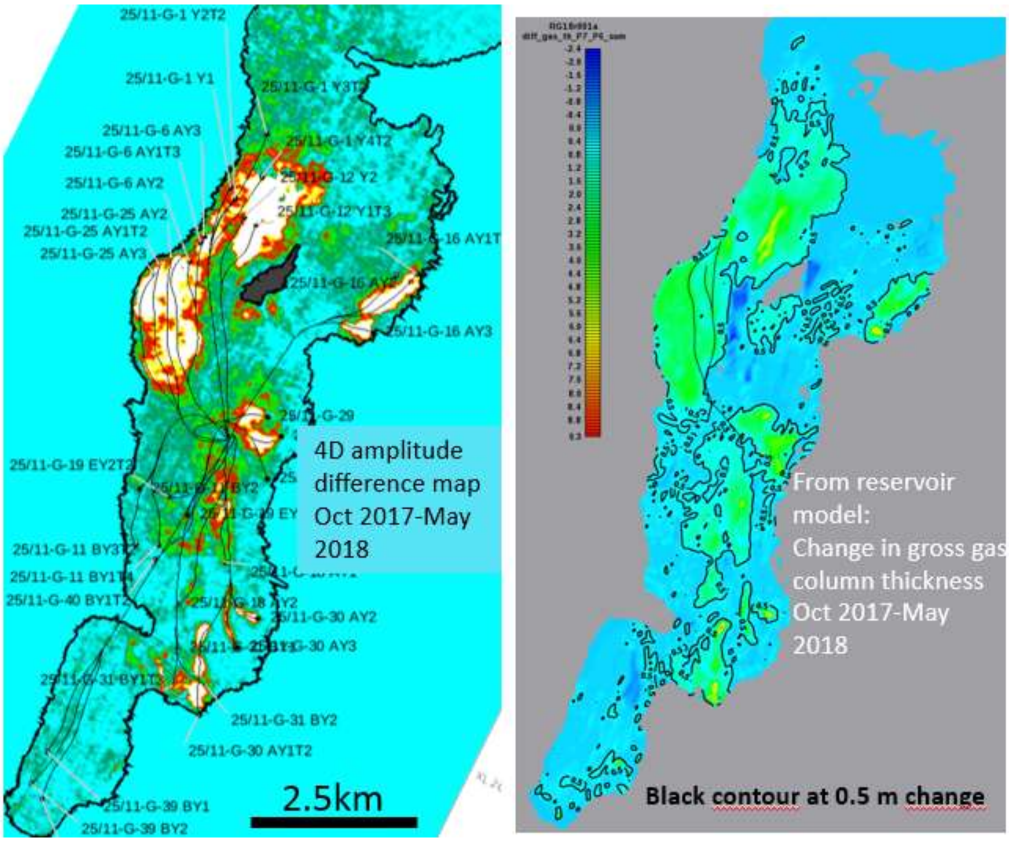
A Short Introduction

From production start in 2003 until 2013 Grane has had a biannual 4D program. Since 2014, 9 PRM surveys have been acquired; two surveys per year. The final processed data are available on the work stations typically 8-10 days after last shot. Frequent acquisitions, high quality data and fast deliverance give a unique possibility to monitor dynamic behavior which would not be possible with a traditional 4D approach.
The first step in the analysis is to generate a seismic PTP (Production Tracking Plot (“PLT”)) for all producers for conclusive identification of fluid dynamics along and around the wells. This procedure can help production engineers on adapting branch control and optimized production. The good compatibility between the simulation model and the PRM observations increase the confidence on simulation model and reservoir predictions. The possible mis-matches however are investigated to be adapted for new release of simulation Model.



Sharing the learnings of 15 years of LoFS at Valhall field

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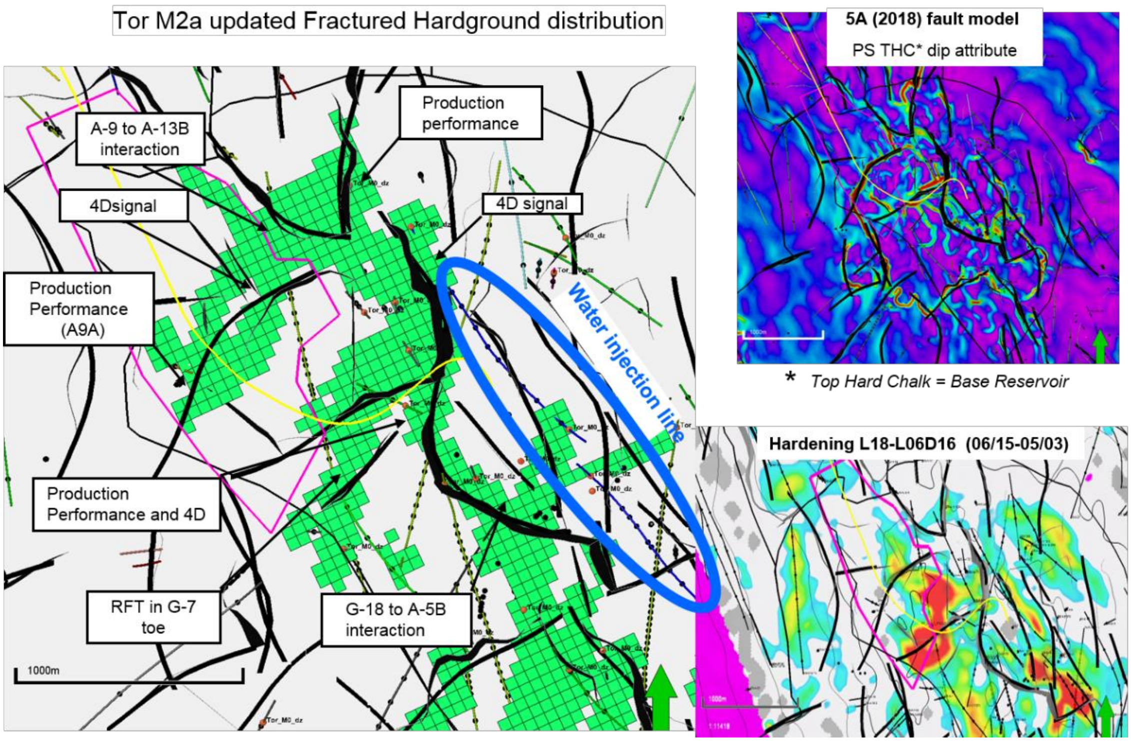
The Valhall chalk field has been a pioneer for seismic technologies for almost two decades. This giant oil field, on production since 1982, has subsequently seen its subsurface revealed by 2D seismic in the 70’s, first 3D seismic in 1992, then 4D seismic with ultimately the installation of a permanent array on the seafloor in 2003. With 19 surveys acquired with the permanent array since 2003, the subsurface team has a very dense imaging of the field activity, hence the name Life Of Field Seismic by similarity with medical imaging monitoring. One imaging challenge is the presence of a gas cloud above the most prolific region of the field; this has led to a well-developed use of converted wave (PS) data, a strong focus on geological understanding and integration of production data. This paper will present the various challenges encountered by the team while utilizing this massive seismic library at a multi-scale level, from a well-focused approach to supporting a full field strategy. The Valhall field is indeed developed with a water injection scheme since 2006 and we will show how 4D seismic has revealed the importance of some geological heterogeneities which are fractured hardgrounds. If there is no doubt that 4D seismic has contributed to our current understanding of the field, there is still a lot to learn to improve our data management approach and streamline our interpretation workflow to support the high-activity pace of the field, in a context of “soft” and uncertain data such as Valhall.



The left side picture illustrates how the distribution of the Fractured Hardground facies (green) was updated in the reservoir model using data integration (RFT, production data, 4D…). The understanding of the fault pattern (top-right figure) and the interpreted 4D hardening signal (bottom-left) were key information to support this update.

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30 years of 4D seismic on the Norwegian Continental Shelf
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4D Seismic to Geophysical Reservoir Monitoring. An Evolution!

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Introduction

Time lapse seismic or 4D seismic, since its first use on a 4D pilot run on the Oseberg field and later full-field study and application on the Gullfaks field has evolved into the business of Geophysical Reservoir Monitoring (GRM), including Permanent Reservoir Monitoring (PRM), such that GRM is now actively used on over 70% of Equinors operating licenses. The widespread use of GRM has seen not only the introduction of a wide range of monitoring technologies but an equally broad range of applications for GRM data. Additionally, the organization has also evolved over time to effectively use GRM information in a broad range use of applications.

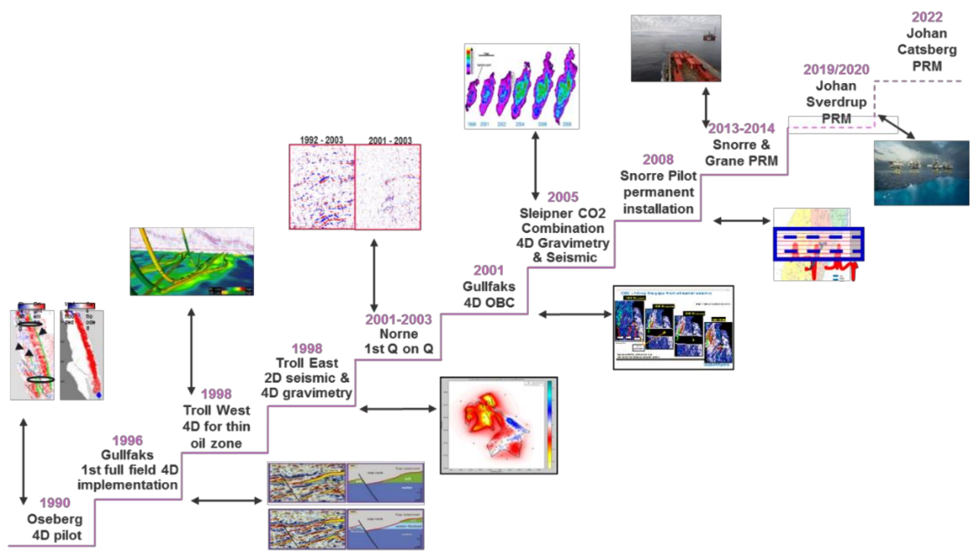

Figure 1 *The evolution from time-lapse seismic to geophysical reservoir monitoring and the use of a broad range of monitoring technologies.*