Identifying infill targets using 4D seismic constrained digital LTRO

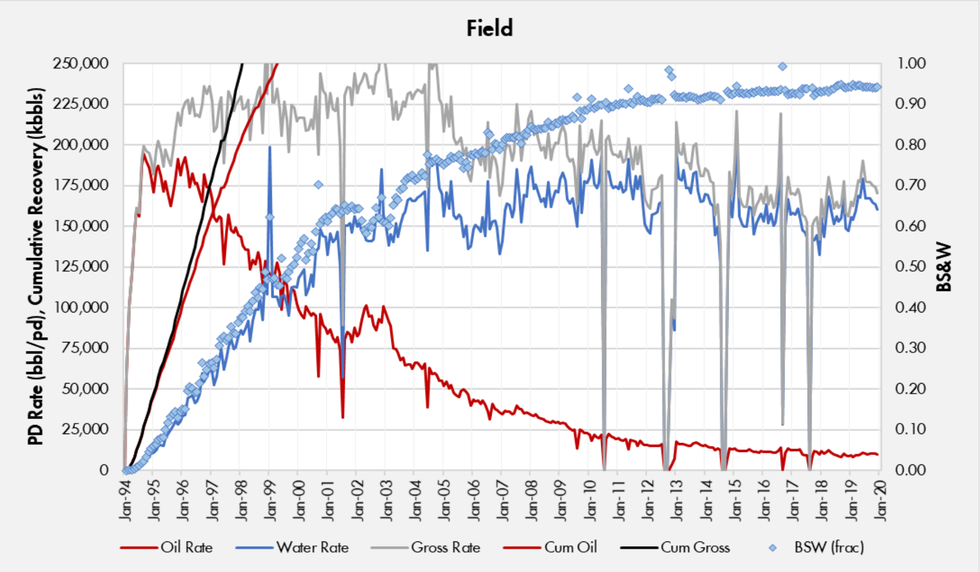
DEVEX, September 2020

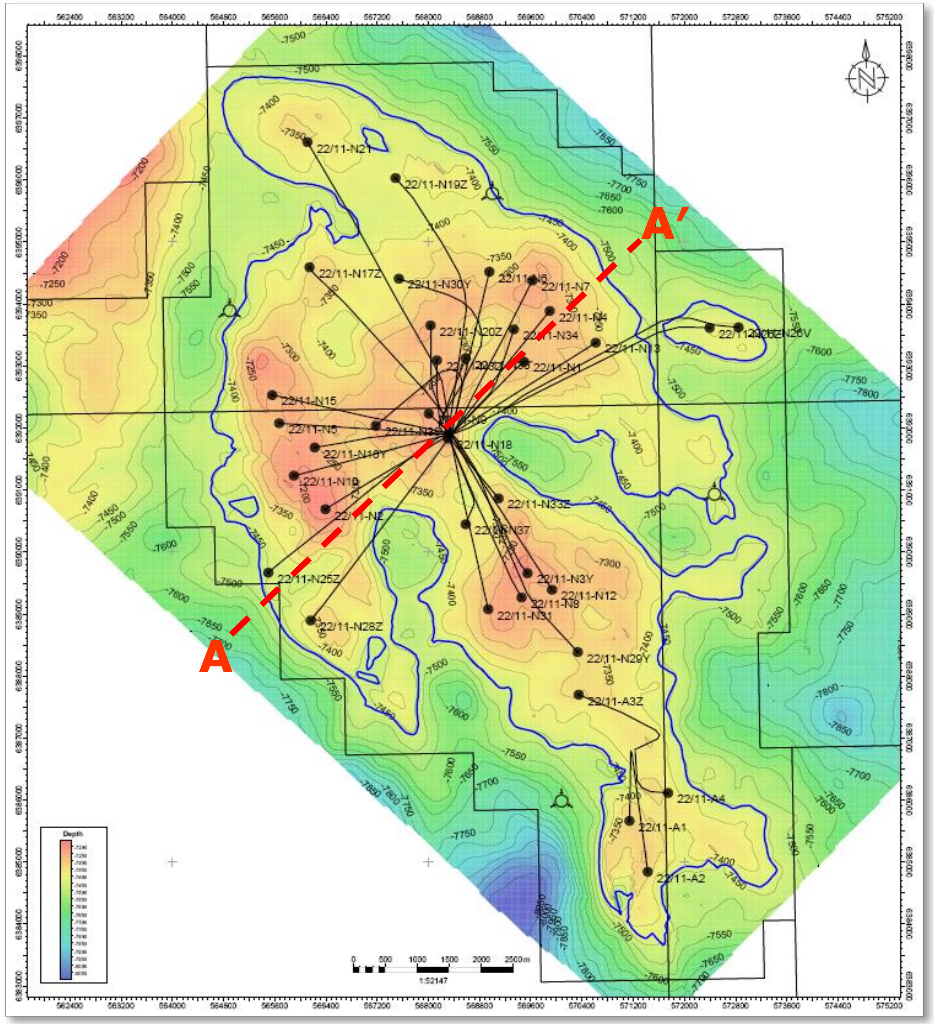
Sadegh Taheri, Laurent Alessio, Babak Moradi, Jon Brain, James Churchill, Katy Jeffrey, Scott Liebnitz, Ryan Singlehurst-Ward

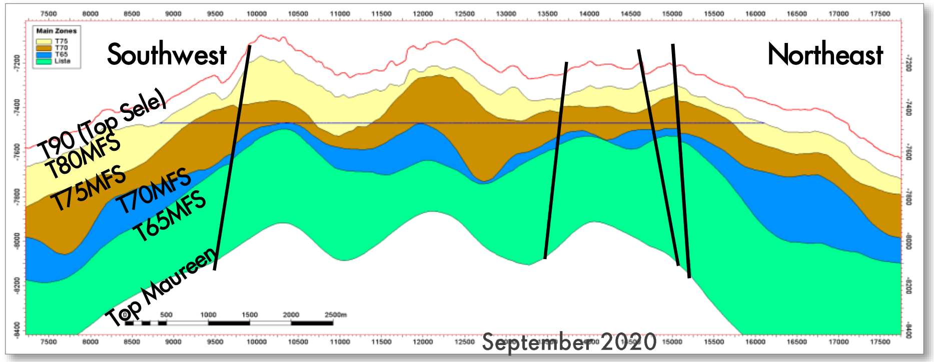
Nelson Field Overview

- Field History and Development
  - Platform
  - Q_{oil} : 10 kbbl/d , Q_{gross} 180 kbbl/d
- Dimensions:
  - 28 platform producers (21 active)
  - 4 subsea producers (2 active)
  - 4 injectors all suspended

- Geology
  - Forties Montrose high Sandstone turbidite
  - T70 & T75 oil bearing sands, OOWC @ 7470 ft tvss
  - Highly developed channel sands and poorly developed overbank deposits
- Reservoir:
  - Pi 3200 psi, Pb 1600 psi, current pressure 2000-2400 psi
  - Strong aquifer from North & South





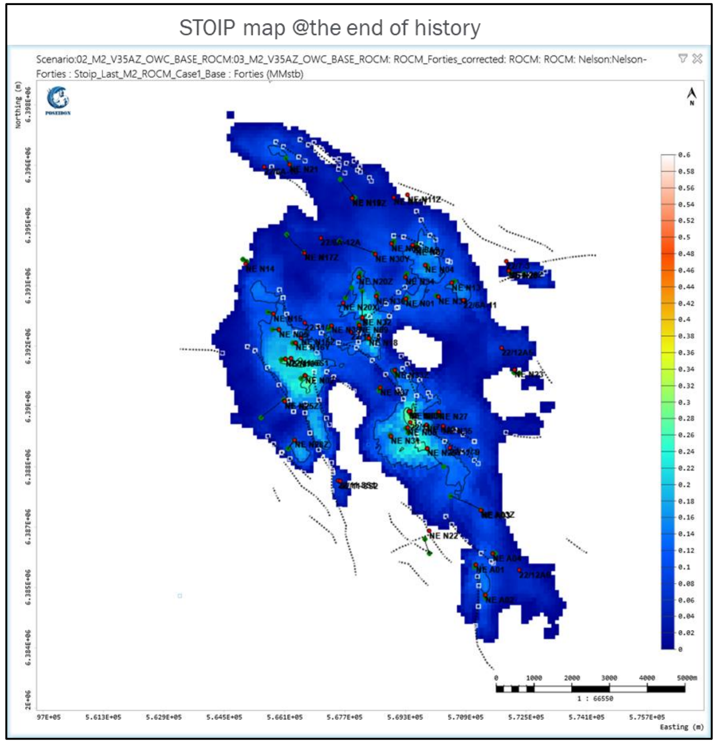


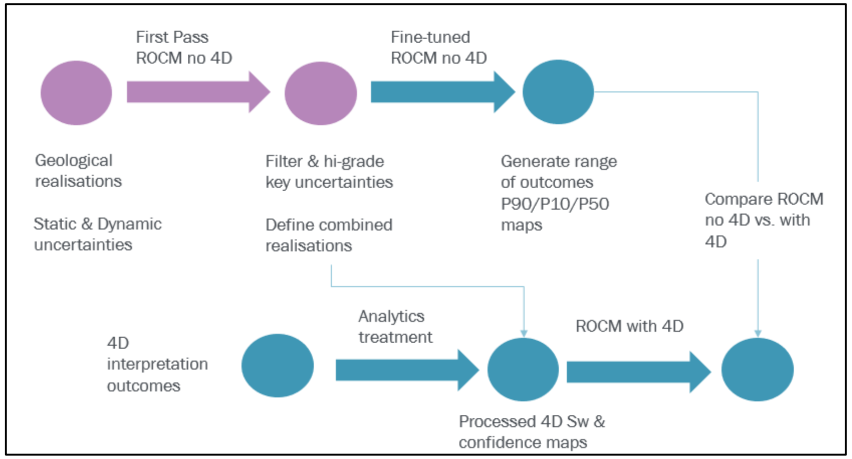
Computer-assisted LTRO (Locate The Remaining Oil)

- POSEIDON tests the initial hydrocarbon distribution, initial contacts, total volumes in place as well as permeability and reservoir quality trends to determine whether certain realisations are more likely to yield an eventual history-match match under a reservoir simulation workflow.

- The Poseidon LTRO workflow integrates the practices of classical LTRO workflows employed within Shell (incorporating all available production and surveillance data, integrating production allocation and geological knowns & uncertainties within the analysis), within a computer-assisted environment integrated with modern analytics, 4D and machine learning methods.

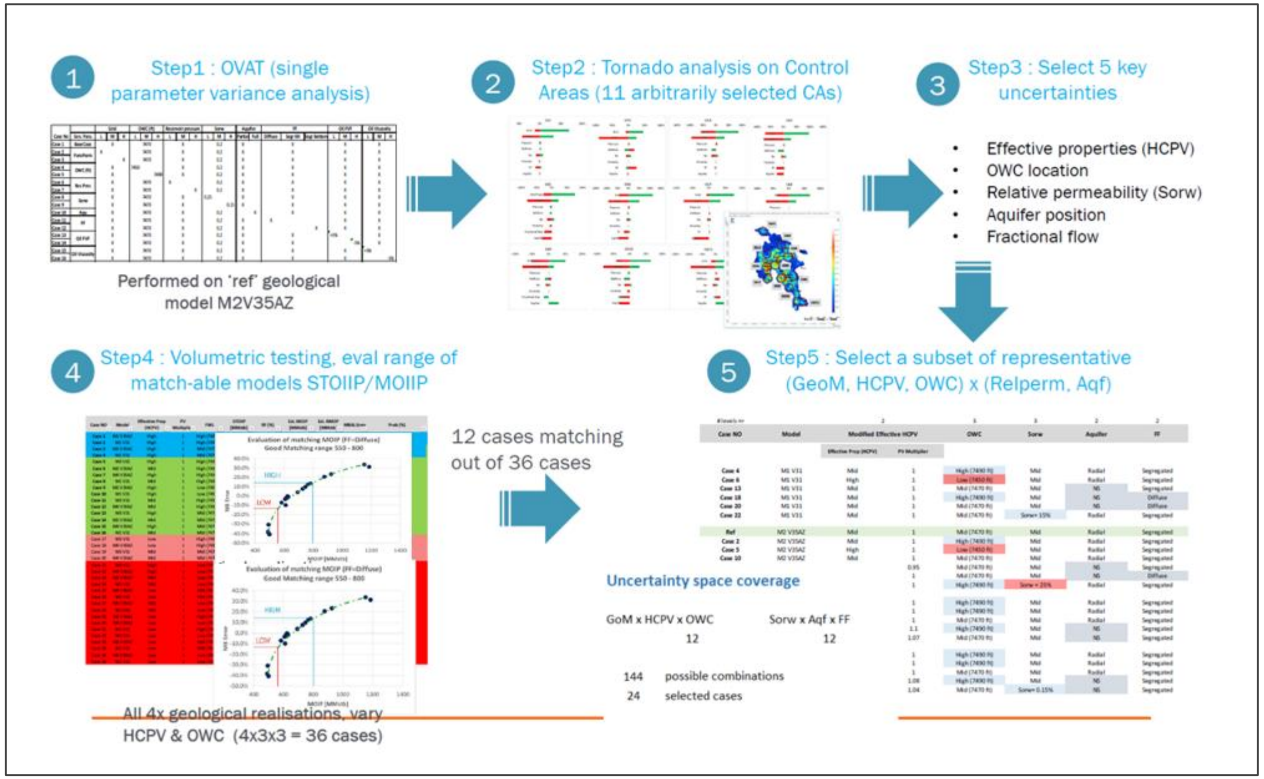
- Deliverables for the POSEIDON service include the following:
  - Identification of potential in-fill well locations
  - Quantification of the impact of geological uncertainties
  - Reservoir mapping:
    - Sweep efficiency quantification and visualisation
    - Fluid saturation maps vs. time



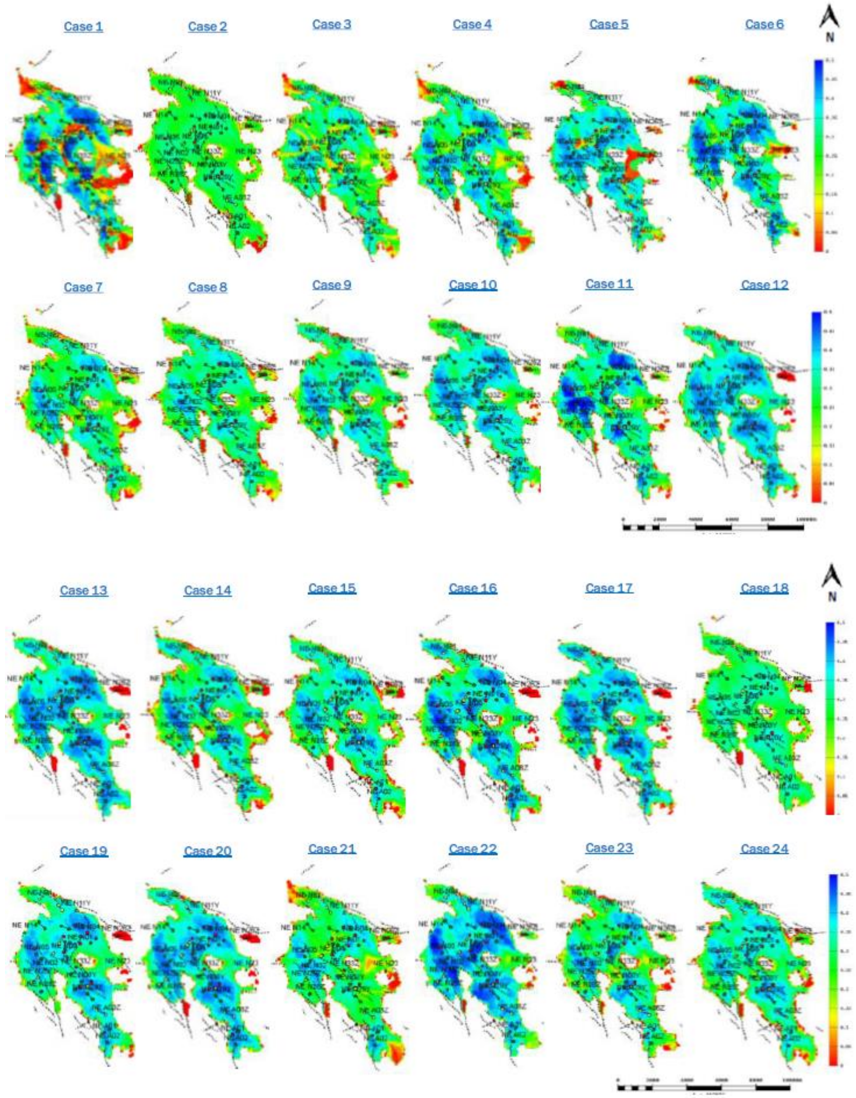


Realisation selection for ROCM, Non-4D

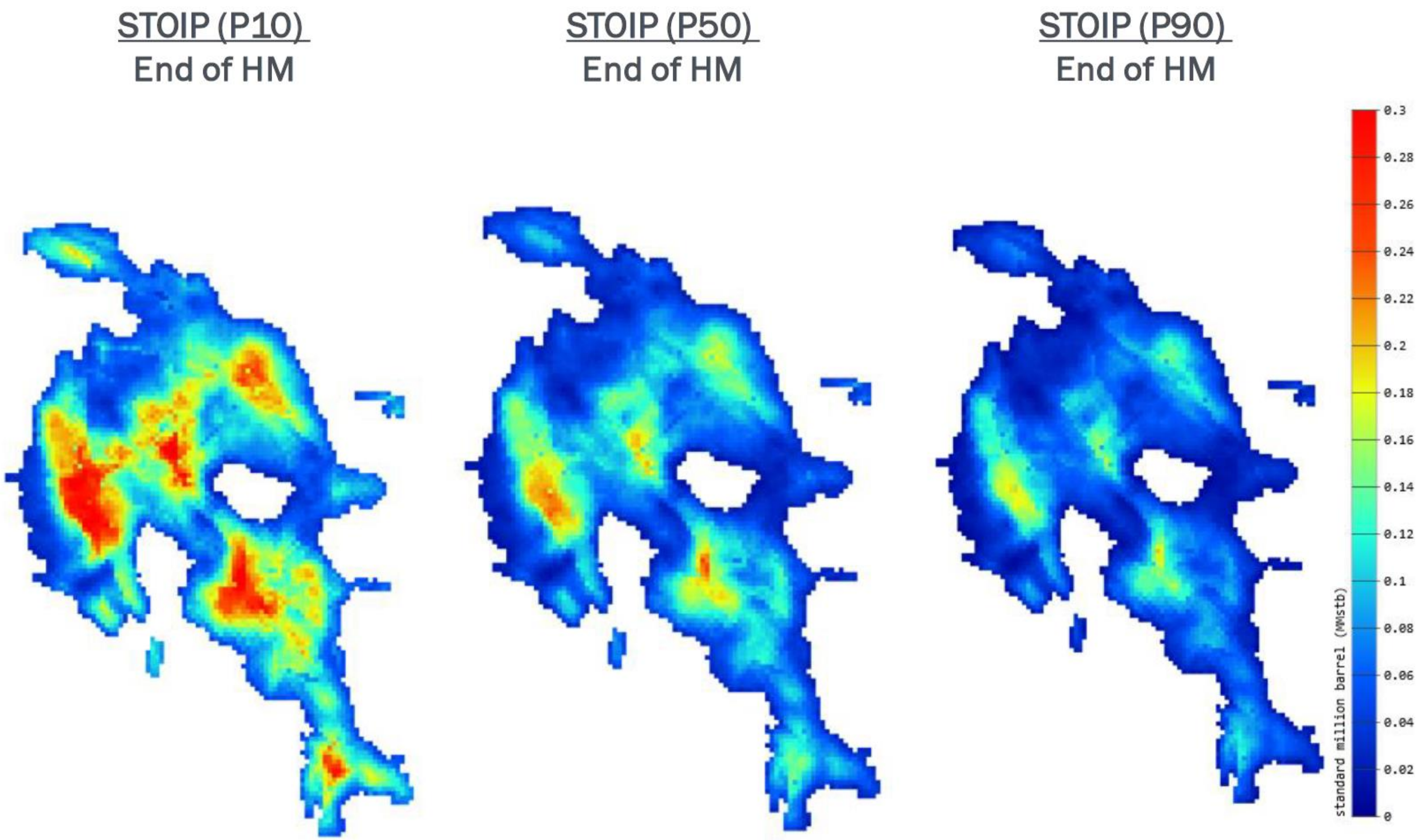
- Uncertainty workflow to establish a manageable number of cases for Remaining Oil Conformance Mapping (ROCM). ROCM equates to LTRO.
    - Run One Variable At a Time (OVAT)
    - Establish key variable from uncertainty tornados
    - Choose variable subset for volumetric testing; 5 selected in this case
    - Screen cases based on MBAL and STOIIP
    - Select a subset of representative variables to capture the uncertainty space and run ROCM. In this example 12 cases were selected from a possible combination of 144



Sw change from ROCM results at 2018 (end history), all 24 cases Non-4D

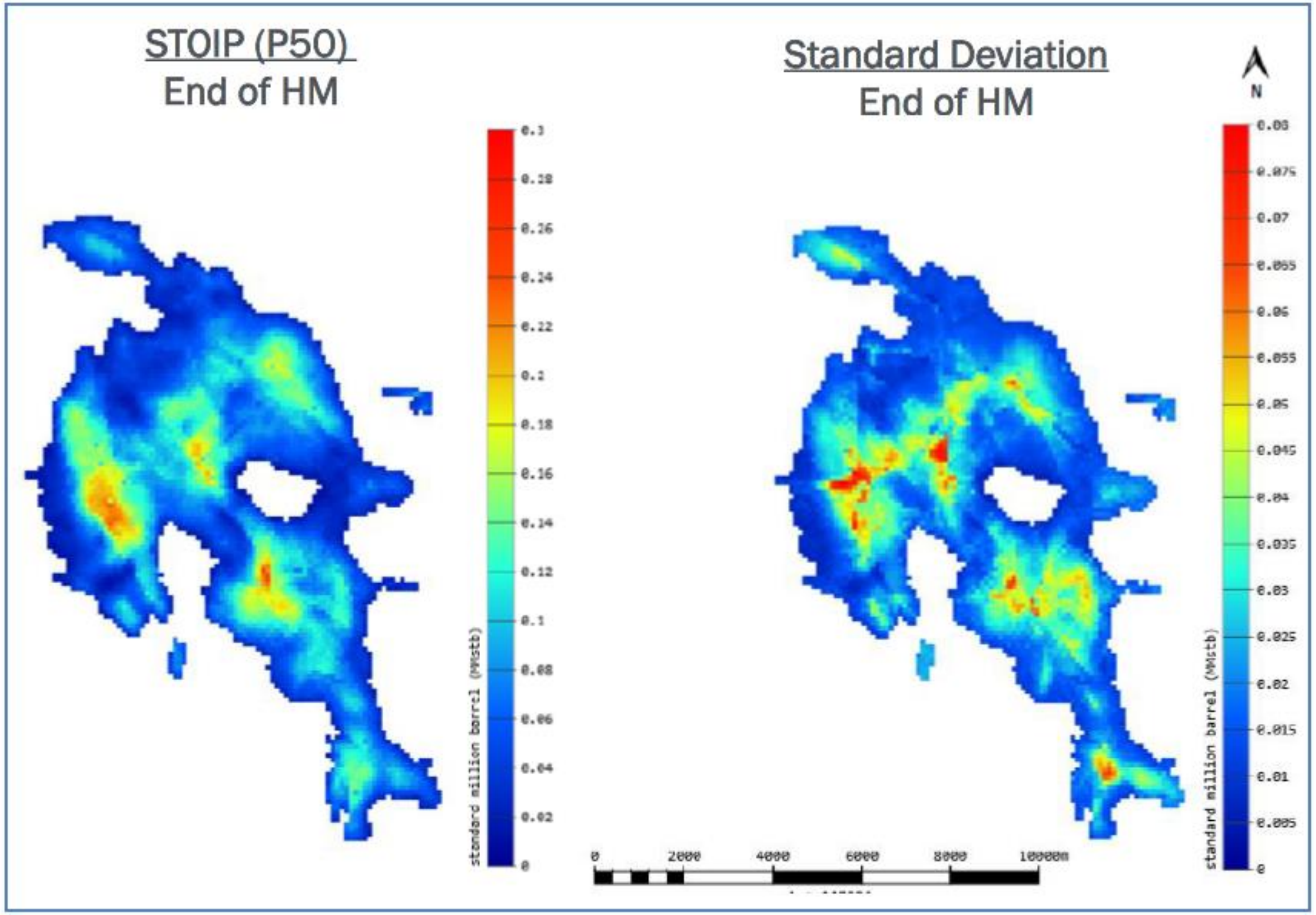


Standard oil in place at the end of HM [MMstb], Non-4D



All calculations have been done for corresponding cells of each case.

P50 STOIP and Standard Deviation of STOIP at end of HM, Non-4D



Non-4D LTRO Summary

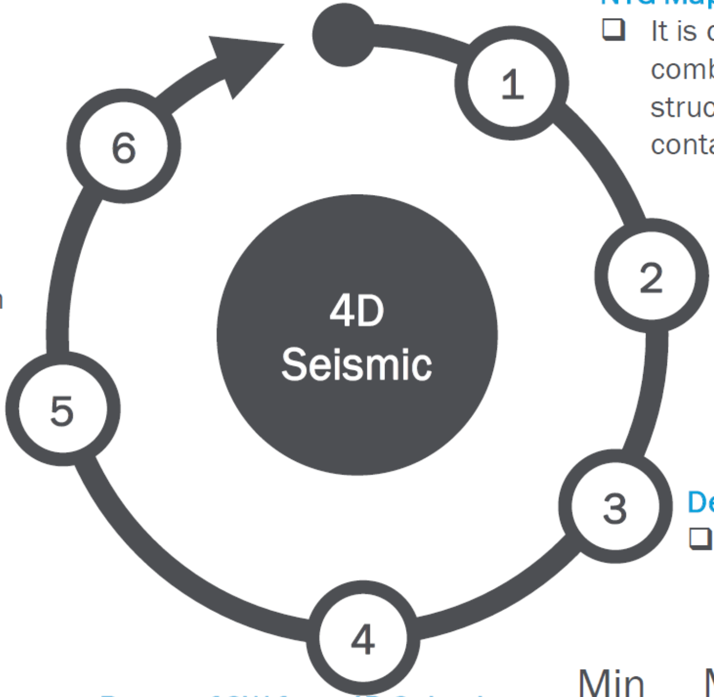
- Potential geological realisations and uncertainties have been assessed in terms of impact on ROCM MatBal match quality
- OVAT sensitivities have been conducted successfully to screen the important subsurface parameters participating in ROCM process or Effective Grid properties (HCPV as combination of Saturation and Porosity)
  - OWC location
  - Relative permeability (Sorw)
  - Aquifer position
  - Fractional flow (moderate but consistent impact)

- Grid model realisations have been tested against reasonable MatBal / MOIP match

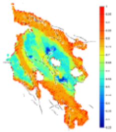
- Statistical MOIP P90/50/10 maps and StdDev map are constructed for the target identification and quantification process.
  - 14 areas have been selected as preliminary potential infills to be rectified prior to prediction.

Overall approach for inclusion of 4D seismic into ROCM

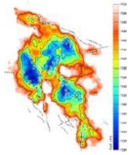
POSEIDON



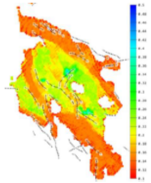
NTG Map
- ❑ It is different for each combination of grid structure, model and contact.



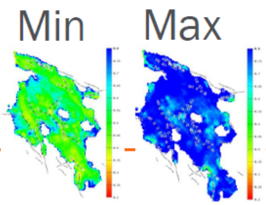
Correction of TVD Seismic
- ❑ Correct TVD seismic to ensure TVD from 4D is located between top of the structure and OOWC



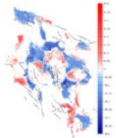
Delta Sw detectable
- ❑ Calculate the delta Sw detectable based on NTG of each case



Range of SW from 4D Seismic
- ❑ Calculate Min and Max of Sw based on TVD seismic and delta Sw detectable



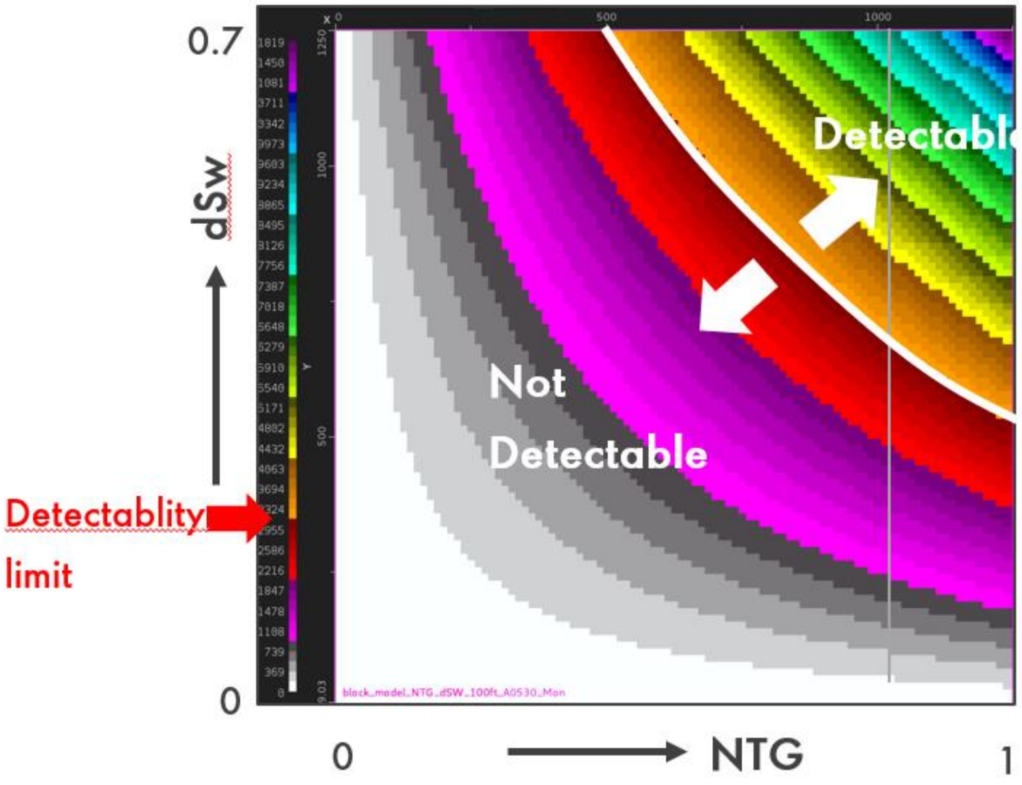
ROCM vs 4D
- ❑ Comparison of Sw from ROCM versus the range of Sw calculated from 4D Seismic



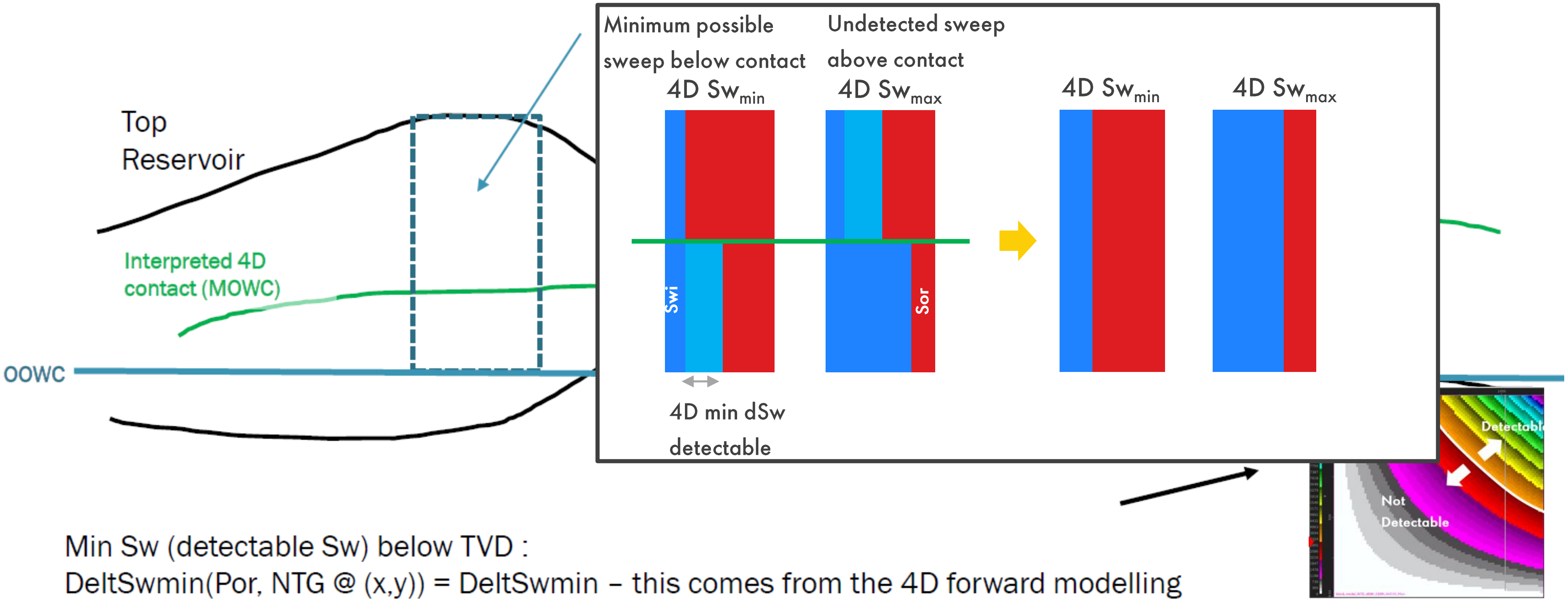
4D-Constrained ROCM maps
- ❑ Re-run ROCM cases that are out of Sw 4D band to improve the results

Build & Validate Models

- The integration with 4D seismic data significantly reduces resource density uncertainty. A key part of this project was the development of a Nelson-specific Sw detectability function. The function recognises that a detectable moved OWC is dependent on Sw change, porosity and N/G. It is not as simple as above the moved OWC being upswept and below the moved OWC being swept.
- 4D response is a function of Porosity and NTG, and what is tracked by the 'top MOWC' is the minimum detectable change in saturation.
- The higher the NTG, the lower the delta Sw required for the 4D signal to be detected.
- Combining ROCMs based on MBAL and fractional flow with 4D seismic interpretations excludes resource density patterns that do not conform to both approaches and therefore reducing resource uncertainty.



Calculate Min and Max Sw Maps



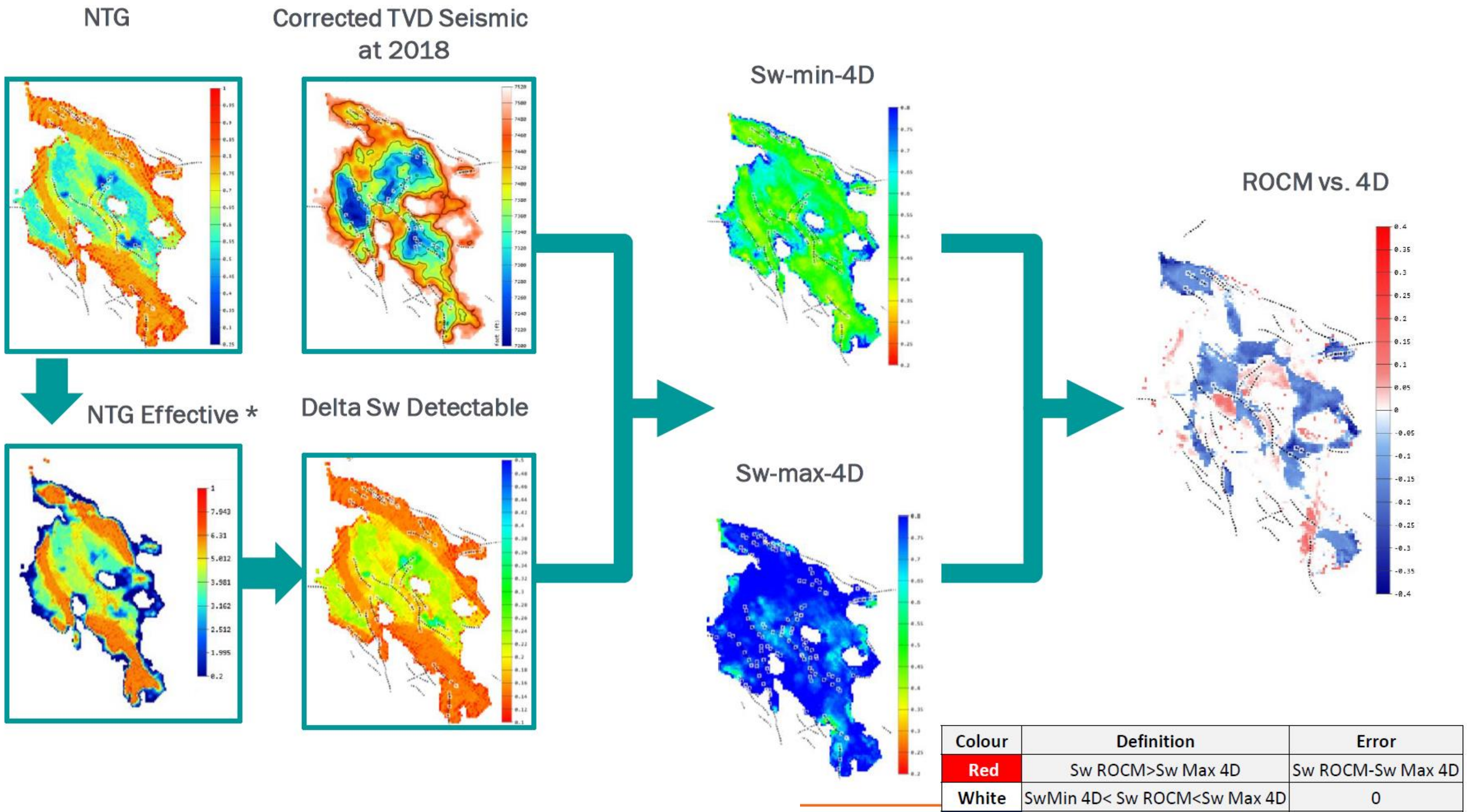
Min Sw (detectable Sw) below TVD :
DeltSwmin(Por, NTG @ (x,y)) = DeltSwmin – this comes from the 4D forward modelling

At x, y, the 4D signal provides a range of possible Sw average for the reservoir, as per the following formula:

Max Sw = [(Top – TVD_Contact)*(Swi+DeltSwmin) + (TVD_Contact – Cell Bottom)* (1-Sorw)] / (Top-Bottom)

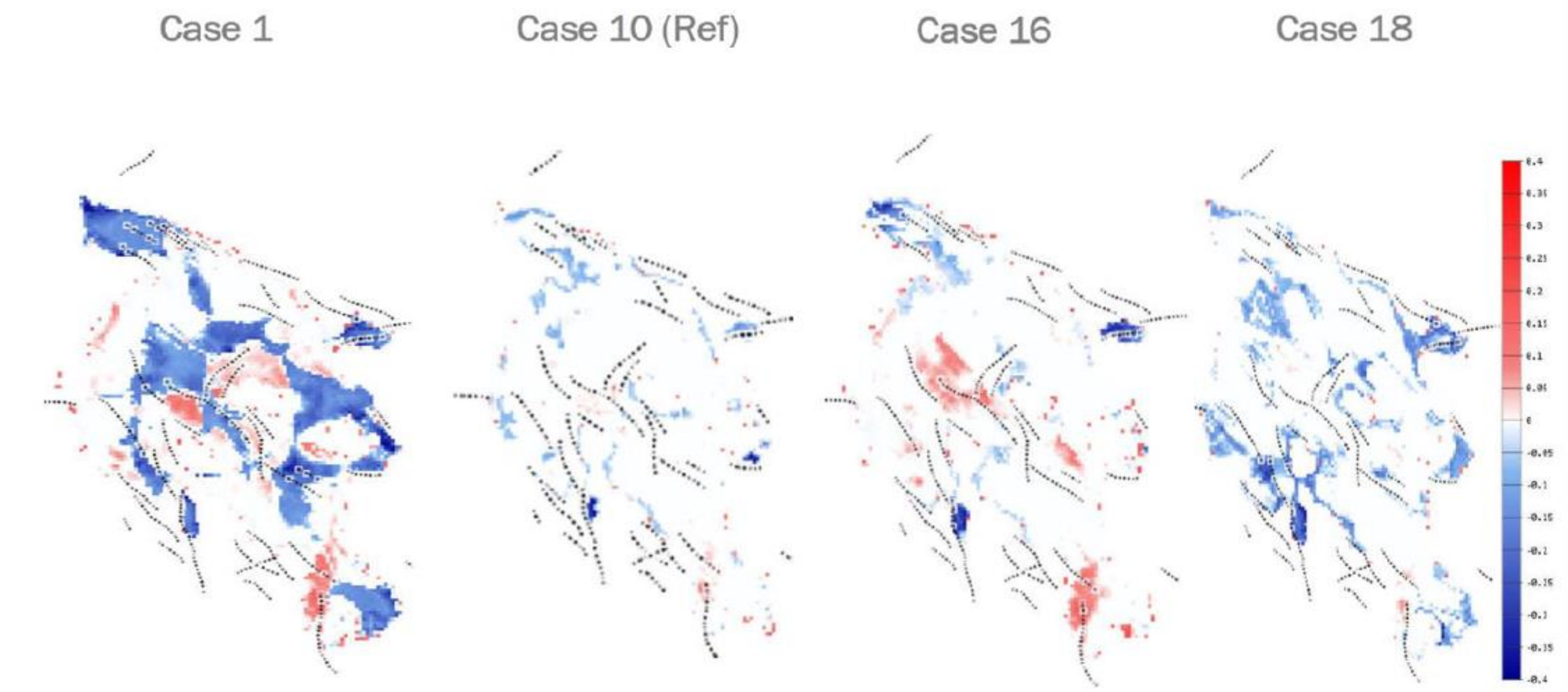
Min Sw = [(Top – TVD_Contact)*Swi + (TVD_Contact – Cell Bottom)* (Swi+DeltSwmin)] / (Top-Bottom)

Example workflow



Colour	Definition	Error
Red	Sw ROCM>Sw Max 4D	Sw ROCM-Sw Max 4D
White	SwMin 4D< Sw ROCM<Sw Max 4D	0
Blue	SwMin 4D>Sw ROCM	Sw ROCM-SwMin 4D

ROMC vs. 4D Seismic



Colour	Definition	Error	Remark(s)
Red	Sw ROCM>Sw Max 4D	Sw ROCM-Sw Max 4D	Too much water encroachment compared to seismic info
White	SwMin 4D< Sw ROCM<Sw Max 4D	0	Match with seismic info
Blue	SwMin 4D>Sw ROCM	Sw ROCM-SwMin 4D	Less water encroachment compared to seismic info

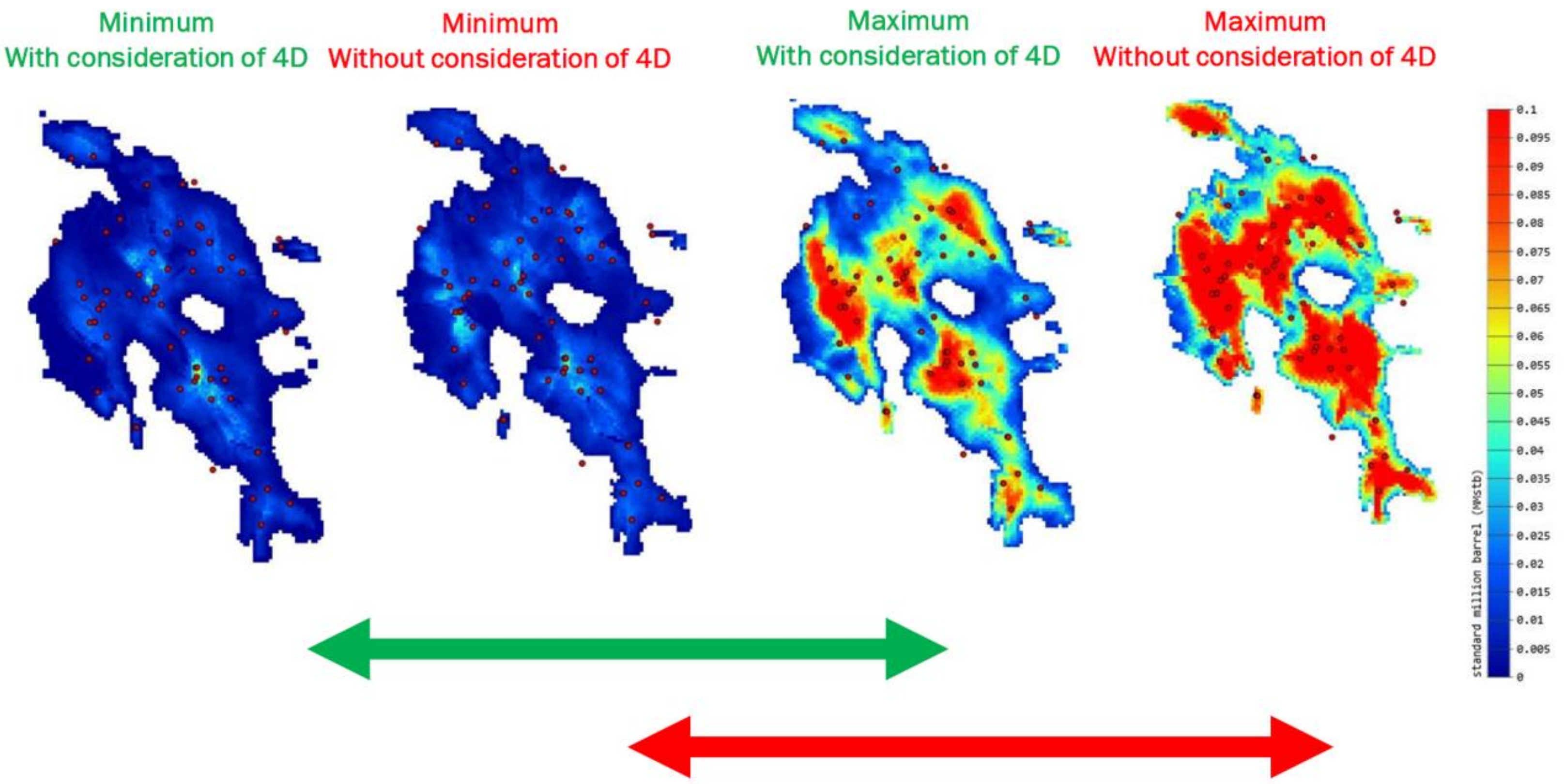
4D constraining of ROCM

CASE	MBAL & SW ERROR	4D CONFORMANCE
1	🔴	🟢
2	🔴	🟢
3	🔴	🟢
4	🔴	🟢
5	🔴	🟢
6	🔴	🟢
7	🟢	🟢
8	🟢	🟢
9	🟢	🟢
10	🟢	🟢
11	🟢	🟢
12	🟢	🟢

CASE	MBAL & SW ERROR	4D CONFORMANCE
13	🟢	🟢
14	🟢	🟢
15	🟢	🟢
16	🟢	🟢
17	🔴	🟢
18	🟢	🟢
19	🟢	🟢
20	🟢	🟢
21	🔴	🟢
22	🔴	🟢
23	🟢	🟢
24	🟢	🟢

Material balance green<5% red>5%

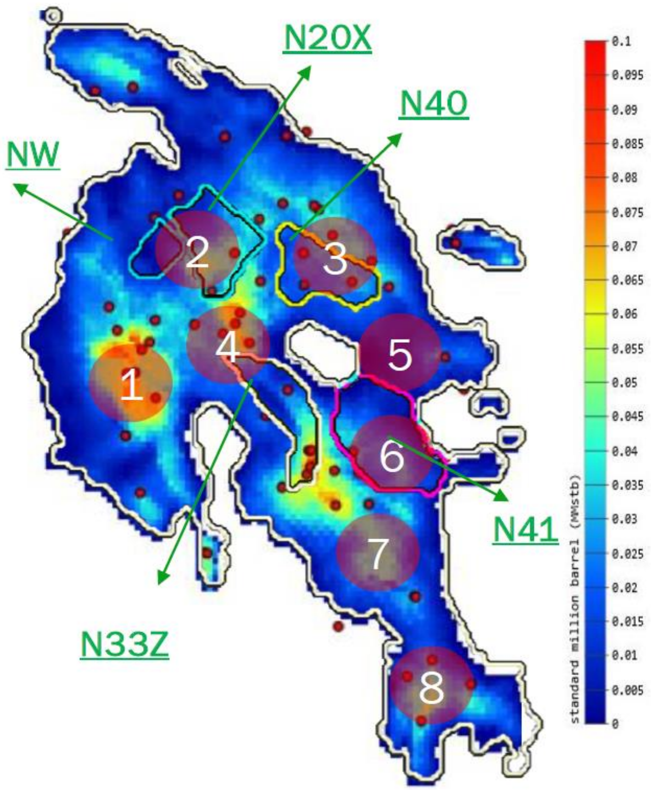
Movable oil in place at 2019 (End HM)



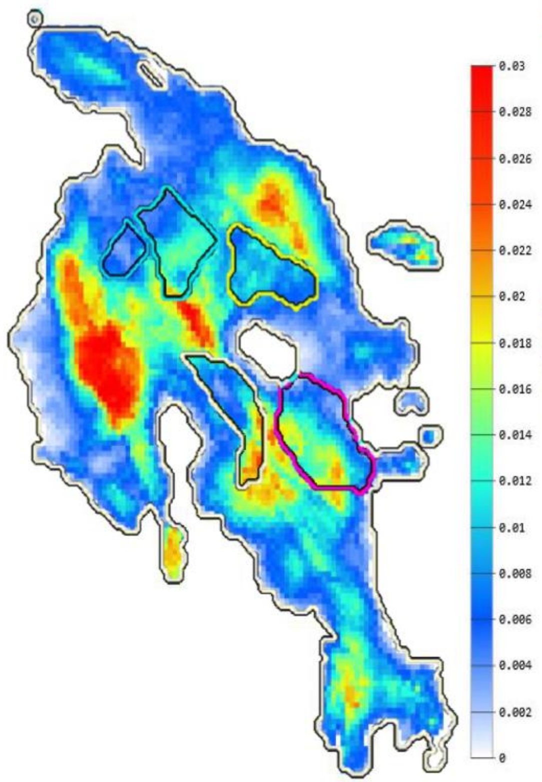
The remaining MOIP range at 2019 (end HM) associated with the 15 matching 4DCon ROCM realisations are compared to that of the 24 non-4D ROCM realisations.

Movable oil in place and targets at 2019

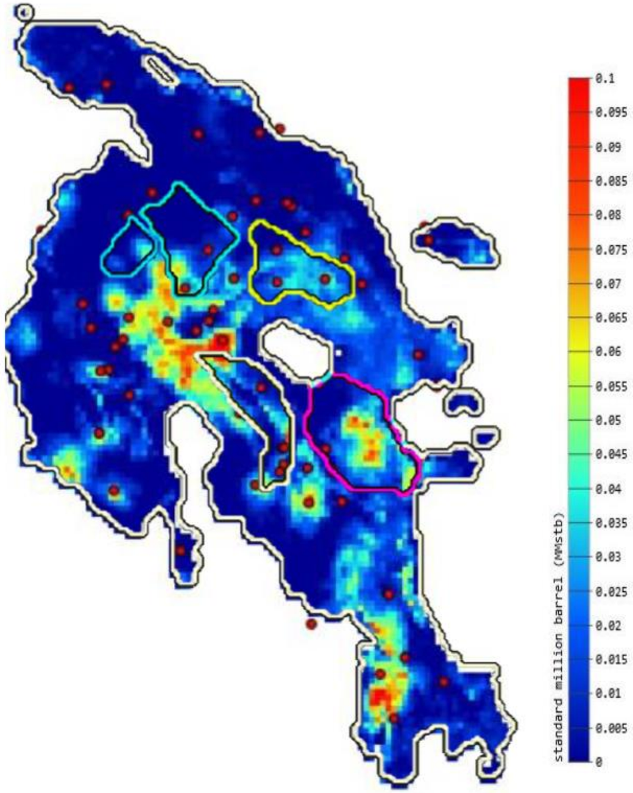
MOIP P50 [MMstb]
With 4D constraint
@ End of HM (2019)



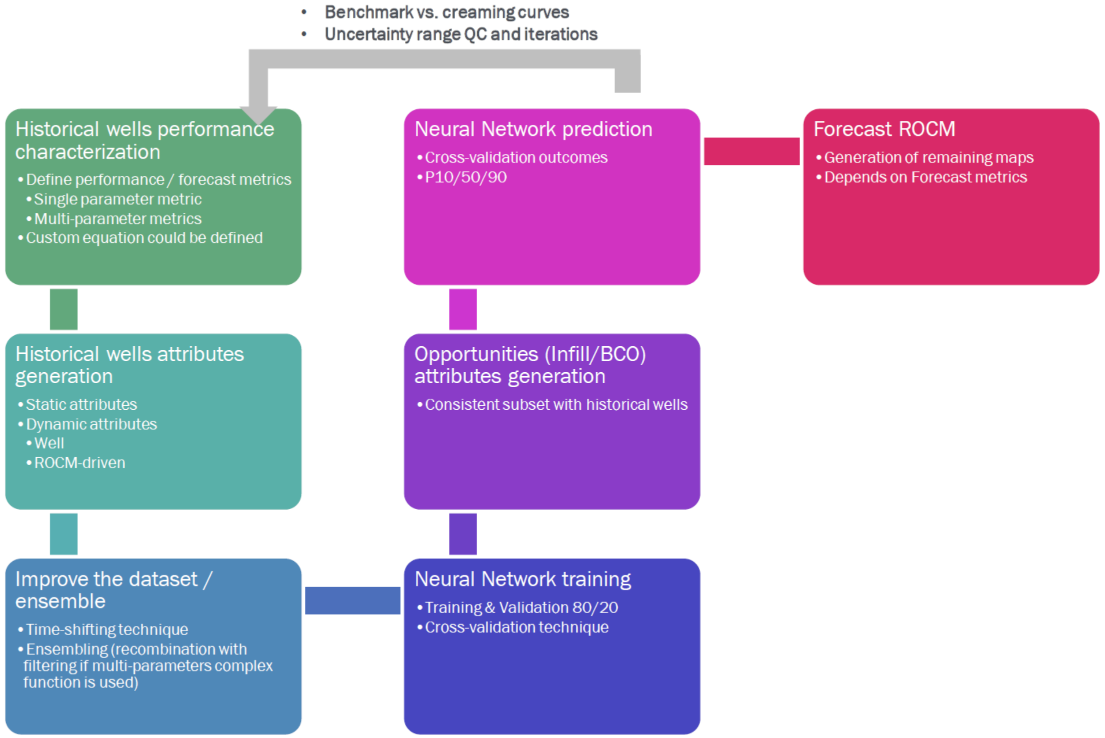
Standard Deviation
MOIP [MMstb] With 4D constraint
@ End of HM (2019)



MOIP Attic [MMstb]
From 4D Seismic 2018

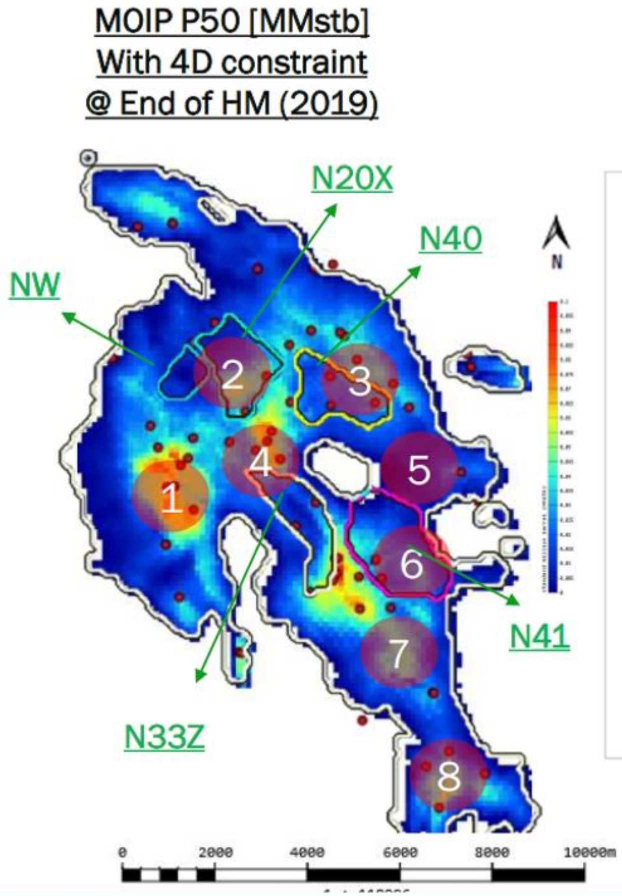


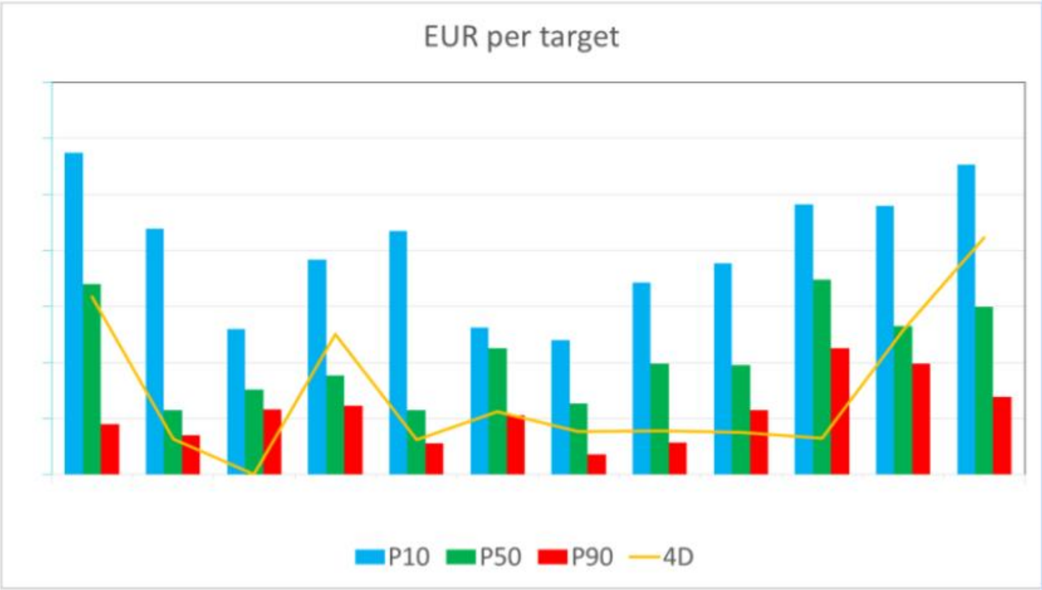
General forecasting workflow



The approach consists of developing and testing a range of predictive models, in order to achieve the ability to produce a range of representative forecasts. These models are developed with alternative machine learning that integrate different ROCM & underlying geological datasets to historical well performance parameters.

EUR Forecast summary





Summary and value for Nelson

- Shell, THREE60 Energy and OGTC developed a new workflow which incorporates data analytics, fractional flow algorithms and 4D seismic data.
- In this project, the reservoir dynamics were evaluated using classical reservoir engineering techniques, inclusive of material balance and sweep efficiency assessment. Thereafter, a structured approach integrating the 4D seismic dataset into the LTRO process was developed.
- 4D seismic constrained LTRO produced a series of Remaining Oil Compliance Maps (ROCM) and generated P90, P50 and P10
    - This allows an independent comparison to '4d attic' deterministic maps
- Innovative workflow improved uncertainty and risk capture within the identification of opportunities.
- Improved workflow for forecasting EUR and production profiles of infill targets using machine learning techniques application
- The 4DConstrained ROCM workflow identified remaining potential within some of higher NTG areas which are predicted to be fully flushed by a 4D Attic approach.

Q&A

Thanks to Nelson field partners: ExxonMobil, Apache, RockRose and PremierOil