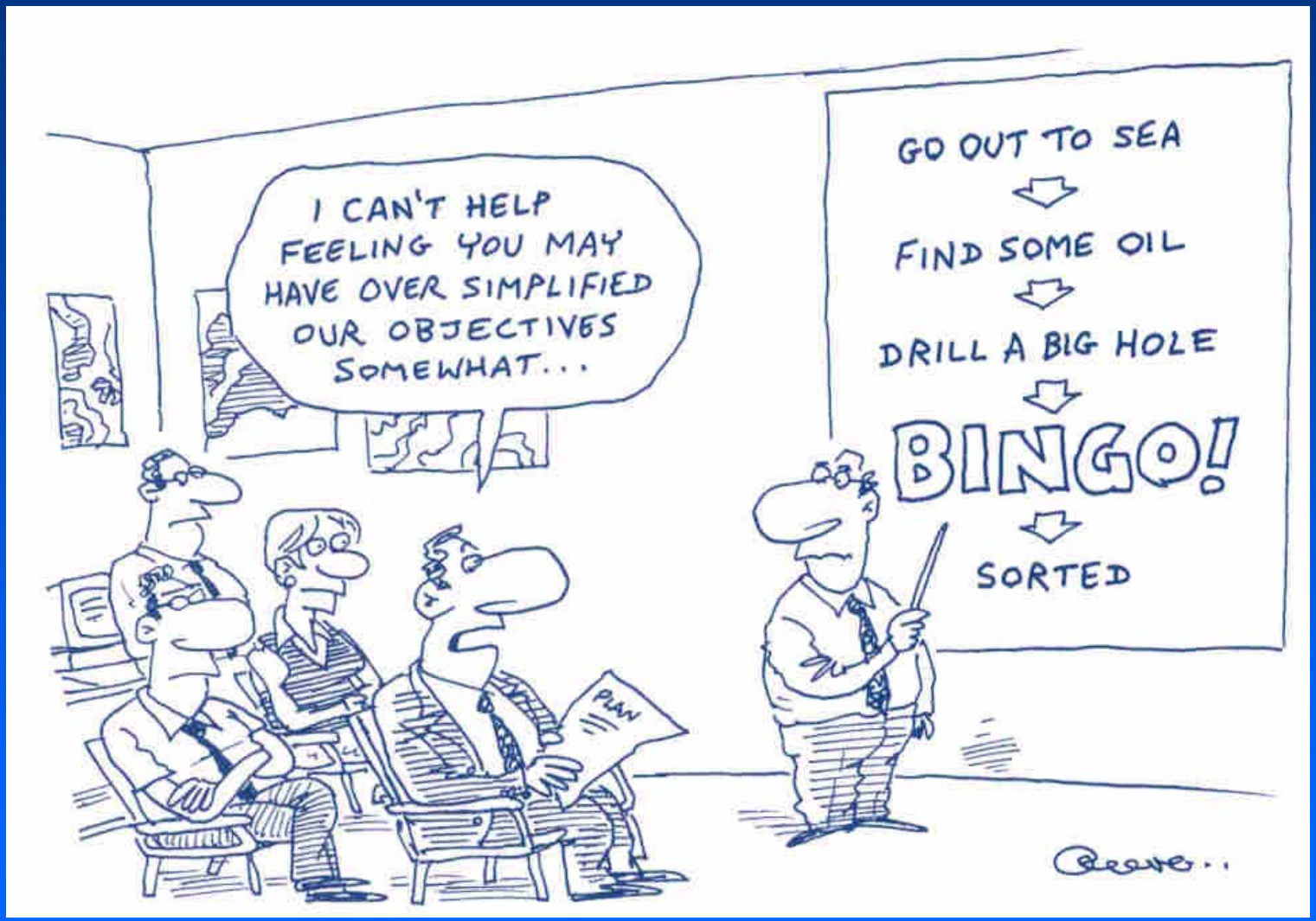
# Risk and Uncertainty in Reservoir Modelling

Mike Christie
Heriot-Watt University

# Outline

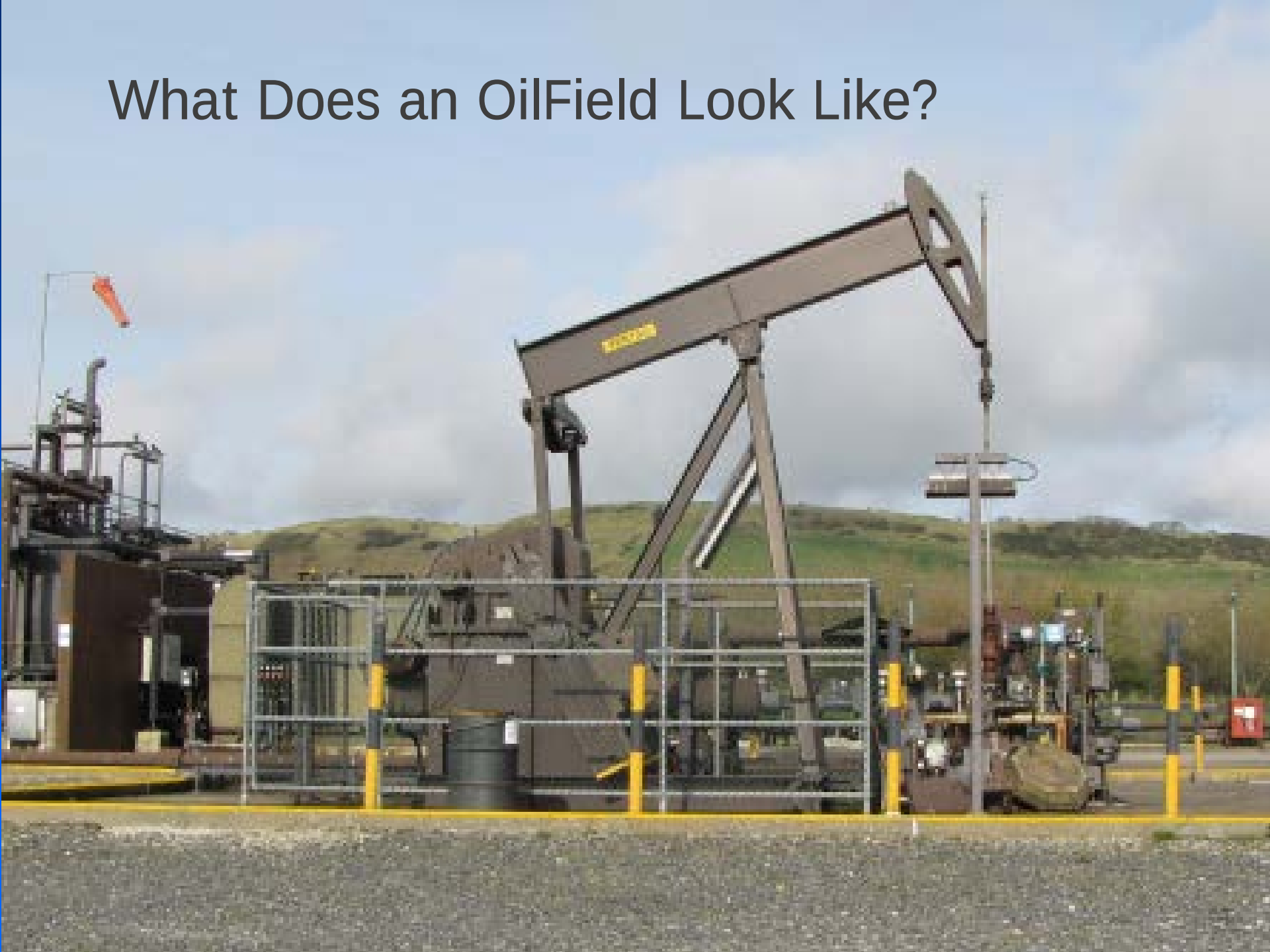
- Oil Fields
  - What are they, what do they look like?
- Mathematics of Reservoir Simulation
  - Equations, getting it right
- Uncertainty in Reservoir Modelling
  - Where does it come from?
- Examples
  - Need for advanced computational techniques

# Developing Oil Fields

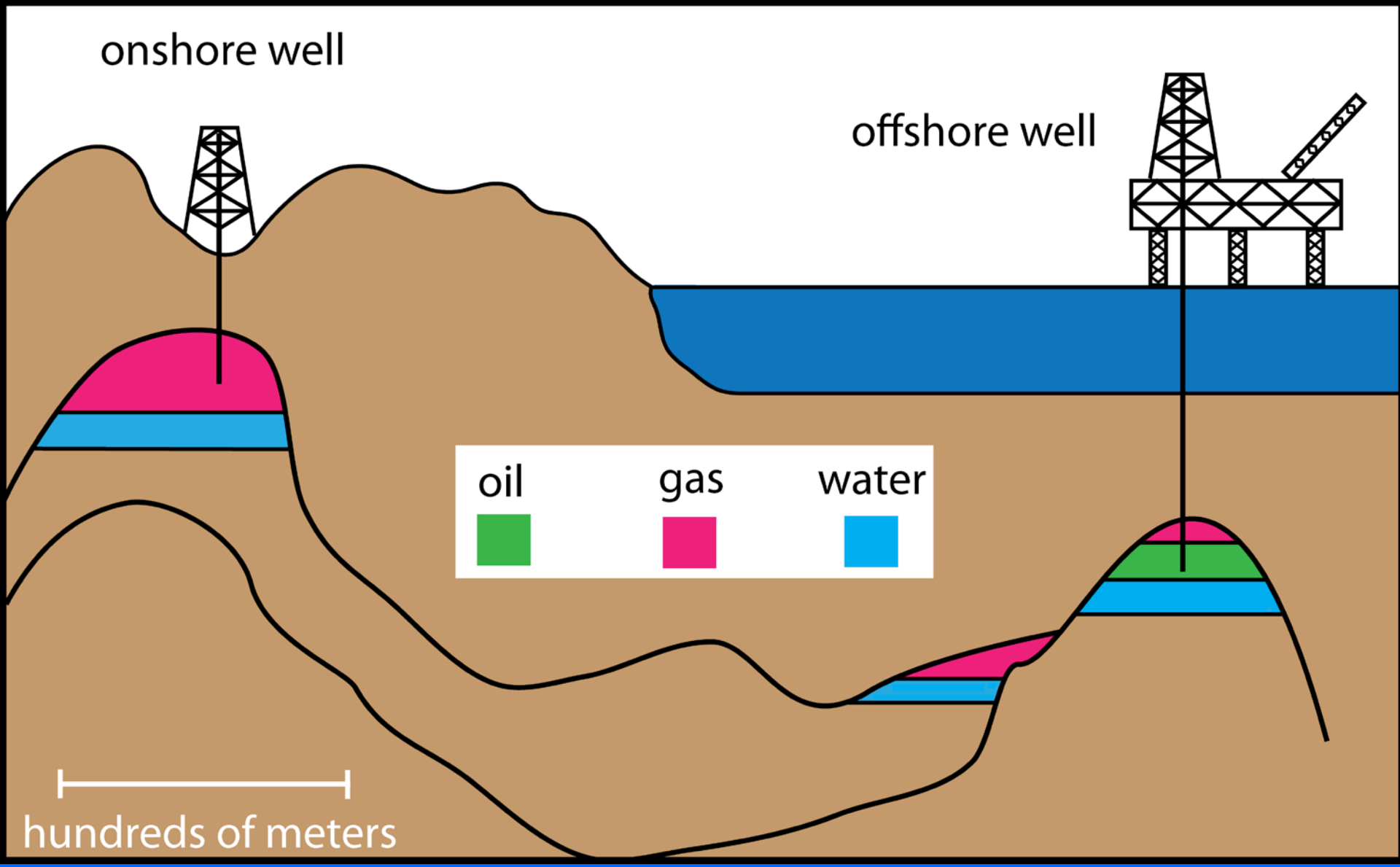


# Oil Fields

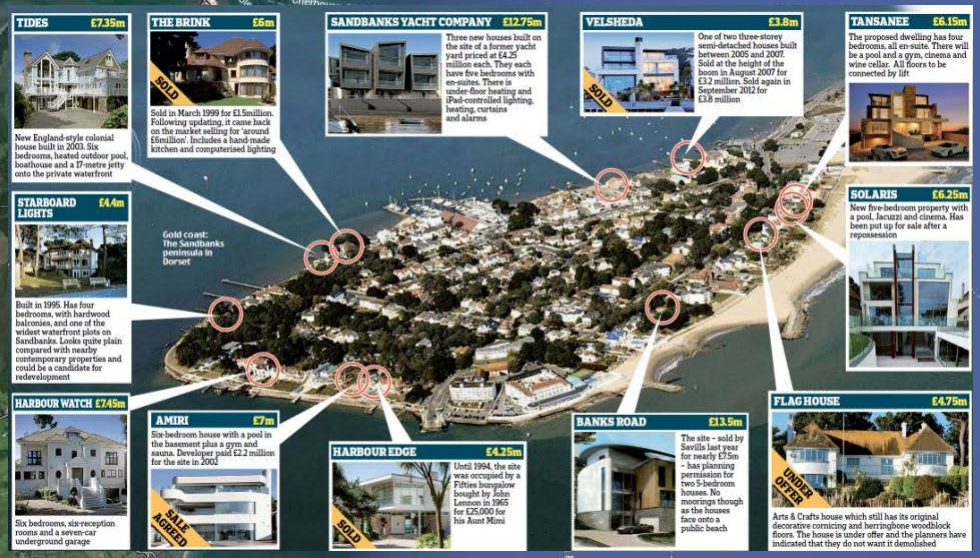
# What Does an OilField Look Like?



# Oil Reservoir

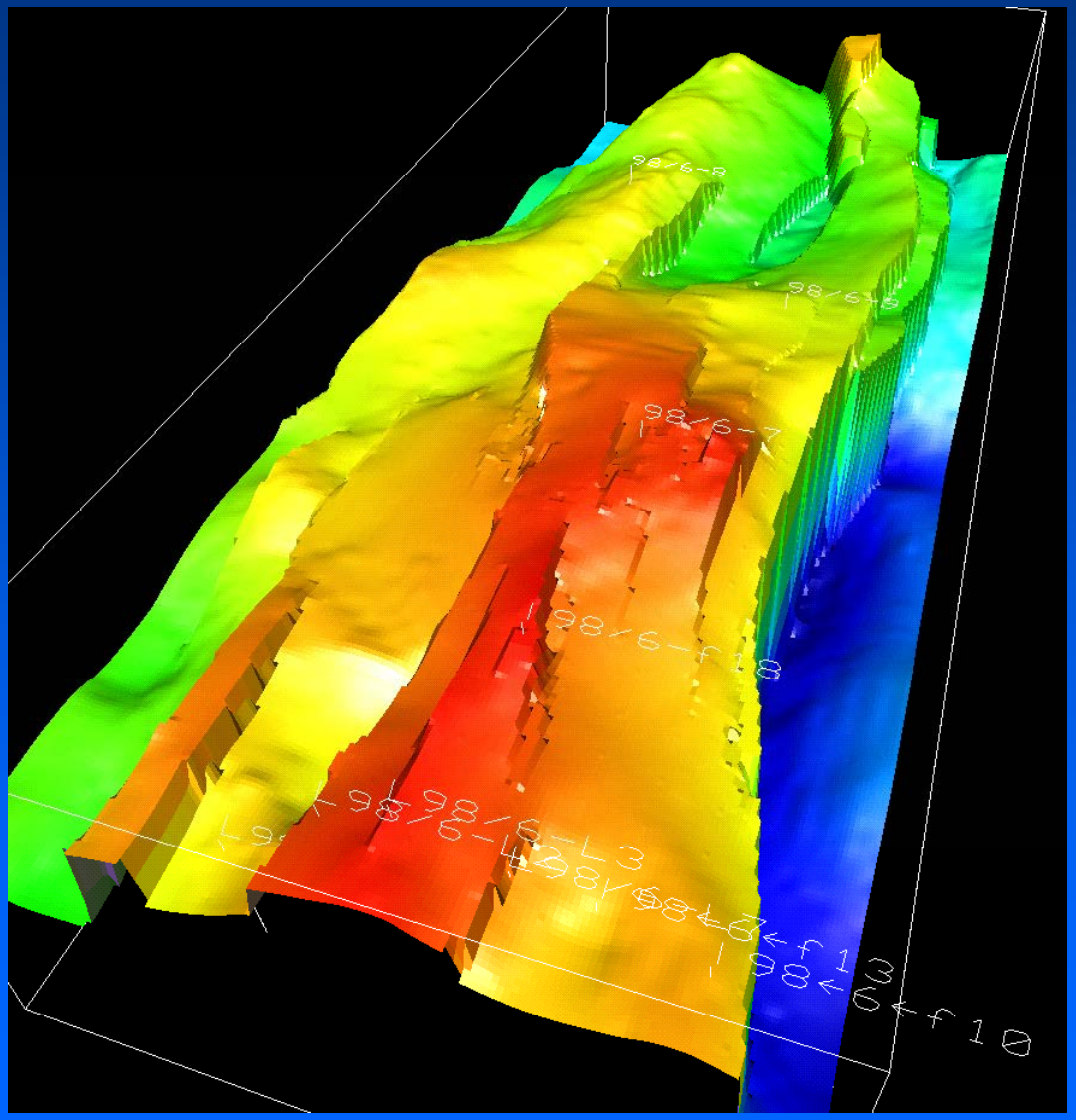


# Wytch Farm Oil Field

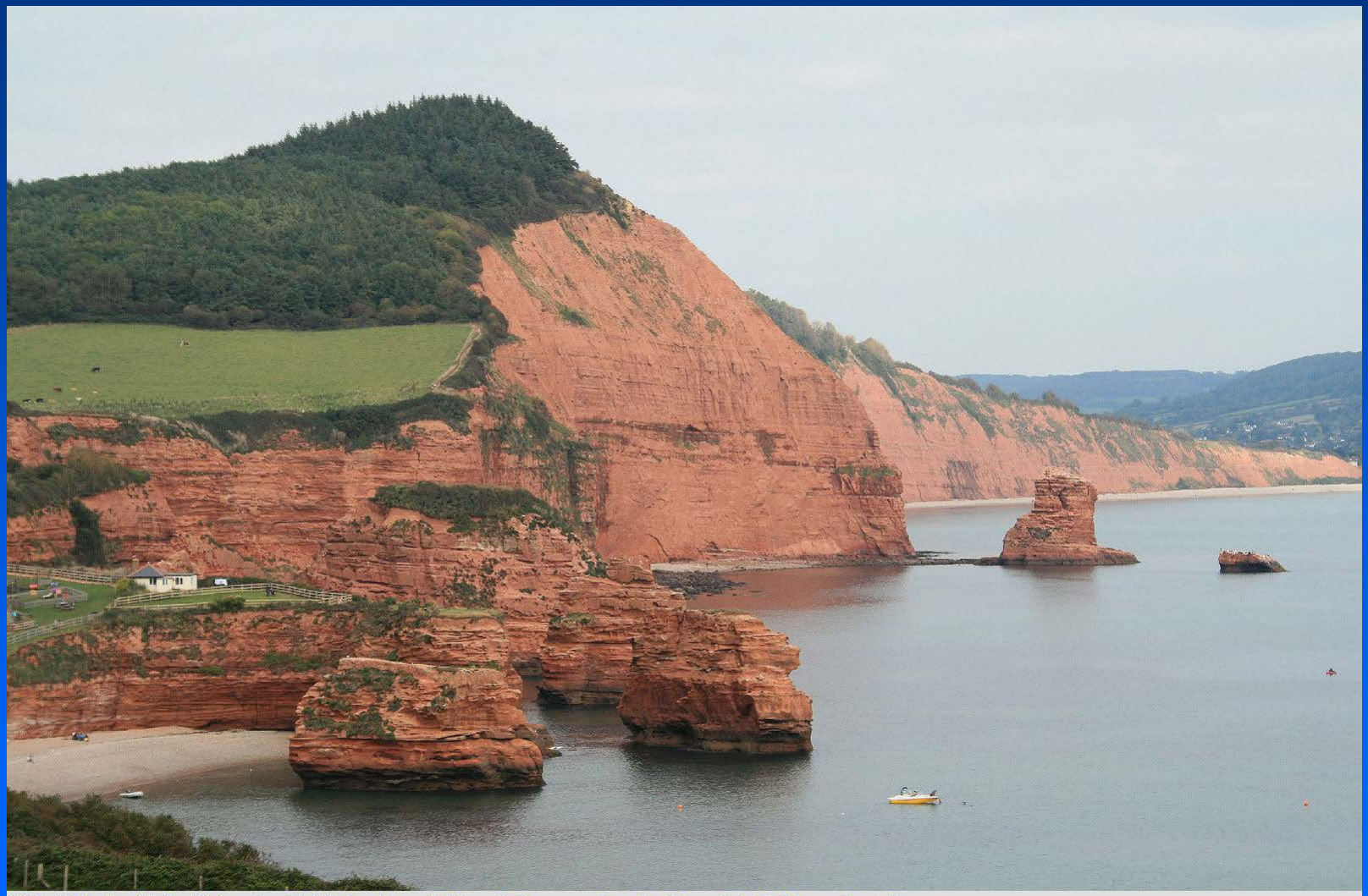


# Wytch Farm from the Sea

# The Wytch Farm Reservoir



# Wytch Farm Geology

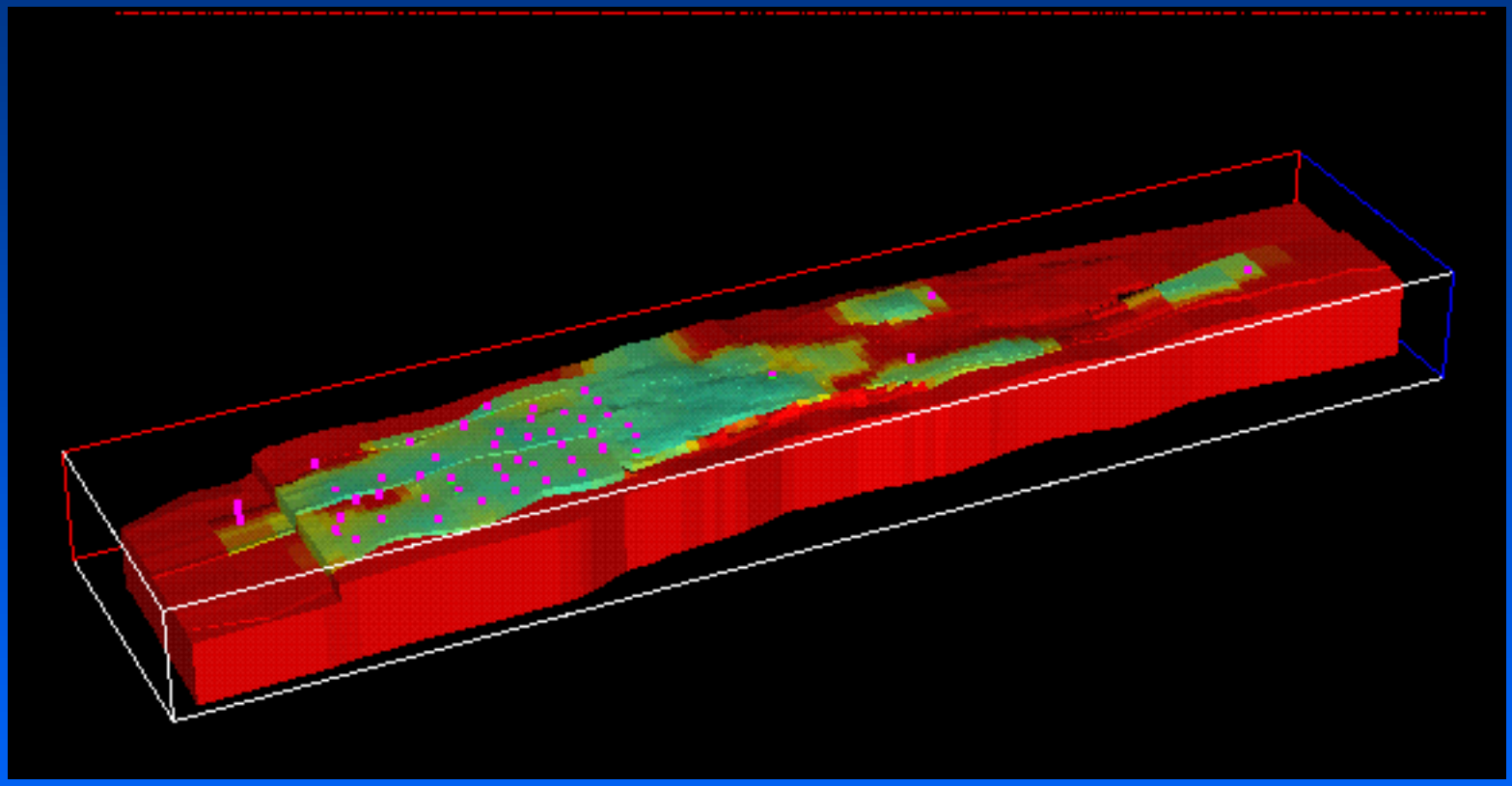


Cliffs of Triassic red beds at Ladram Bay, High Peak and towards Sidmouth, Devon, seen from Smallstones Point, looking northeast. The sequence is of the Otter Sandstone Formation (Ladram Bay cliffs and the various stacks), part of the Sherwood Sandstone Group, and the finer-grained Mercia Mudstone (upper part of the High Peak cliff). Sidmouth is at the right margin of the photograph. Photo: 26th September 2009, about 3 pm, ebbing tide.

# Close up of Sherwood Sandstone Outcrop

Cross-stratified Otter Sandstone Formation, Sherwood Sandstone Group, Trias, in the centre of Ladram Bay, near Sidmouth. The cross stratification is of fluvial origin in a semi-arid to arid environment and is probably, at least in part of flash-flood origin. The scale is a one metre rule.
Photograph: 26th September 2009. Ian West (c) 2009.

# Wytch Farm Reservoir Model



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# Mathematics of Flow in Porous Media

- Conservation of Mass
- Conservation of Momentum
  - replaced by Darcy's law

$$\mathbf{v} = -\frac{k(\mathbf{x})}{\mu}\nabla p$$

- Conservation of Energy
  - most processes isothermal
- Equation of State

# Equations governing flow

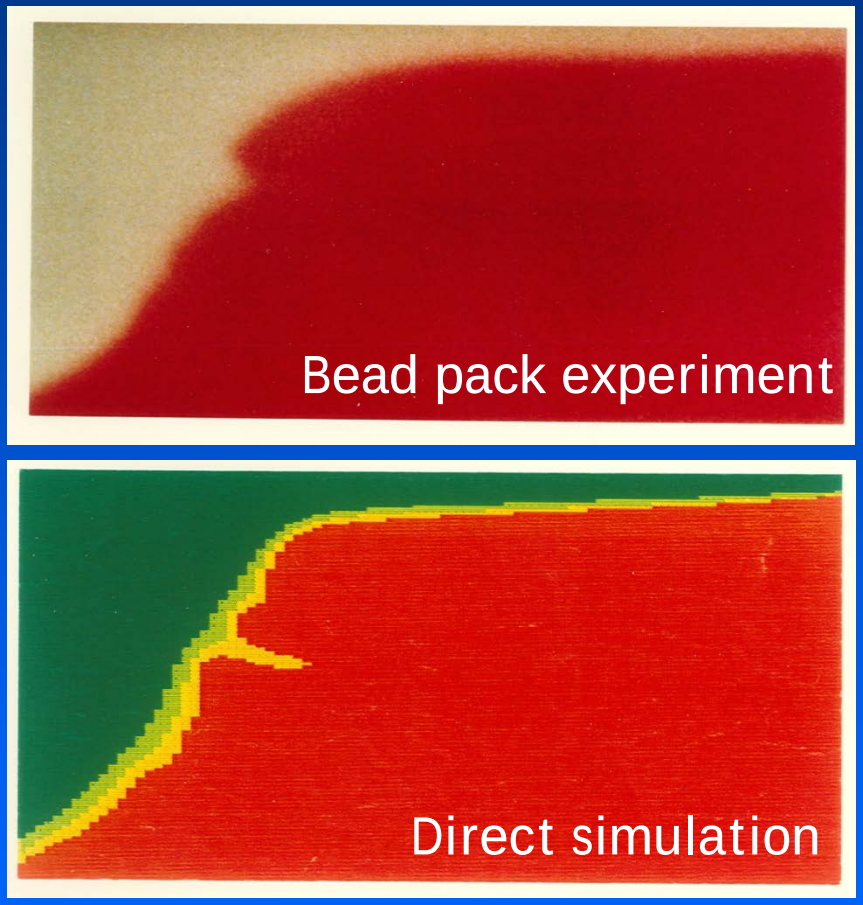
- Parabolic equation for pressure

$$c\frac{\partial p}{\partial t} = \nabla.\left( k(\mathbf{x})\left( \frac{k_{ro}(S)}{\mu_o} + \frac{k_{rw}(S)}{\mu_w} \right)\nabla p \right)$$

- Hyperbolic equation for saturation

$$\phi(\mathbf{x})\frac{\partial\left(\rho_o x_i S_o + \rho_g y_i S_g\right)}{\partial t} + \nabla.\left(\rho_o x_i \mathbf{v}_o + \rho_g y_i \mathbf{v}_g\right) = 0$$

# Low Rate Bead Pack Experiment



# CT Scanned Rock Slab Experiment

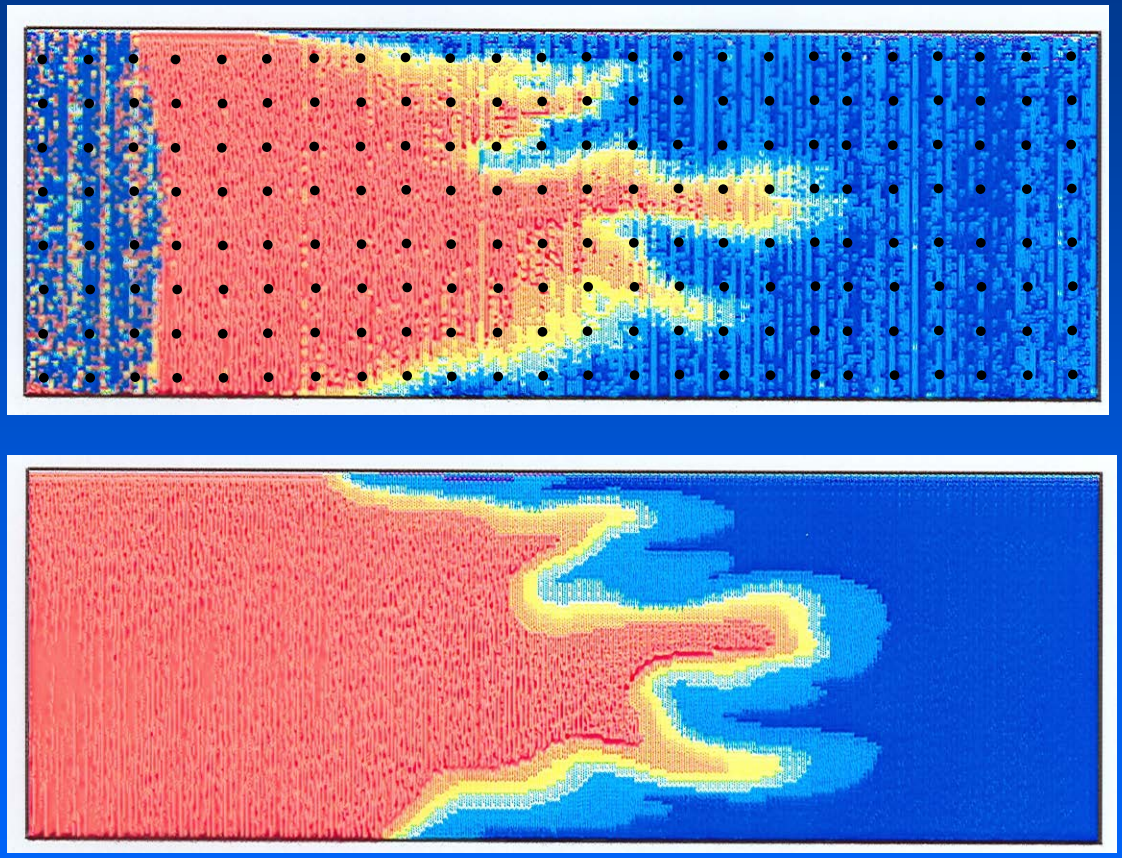


Image from Davies, Muggeridge, Jones, “Miscible Displacements in a Heterogeneous Rock: Detailed Measurements and Accurate Predictive Simulation” SPE 22615 (1991)

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# Uncertainty in Reservoir Description

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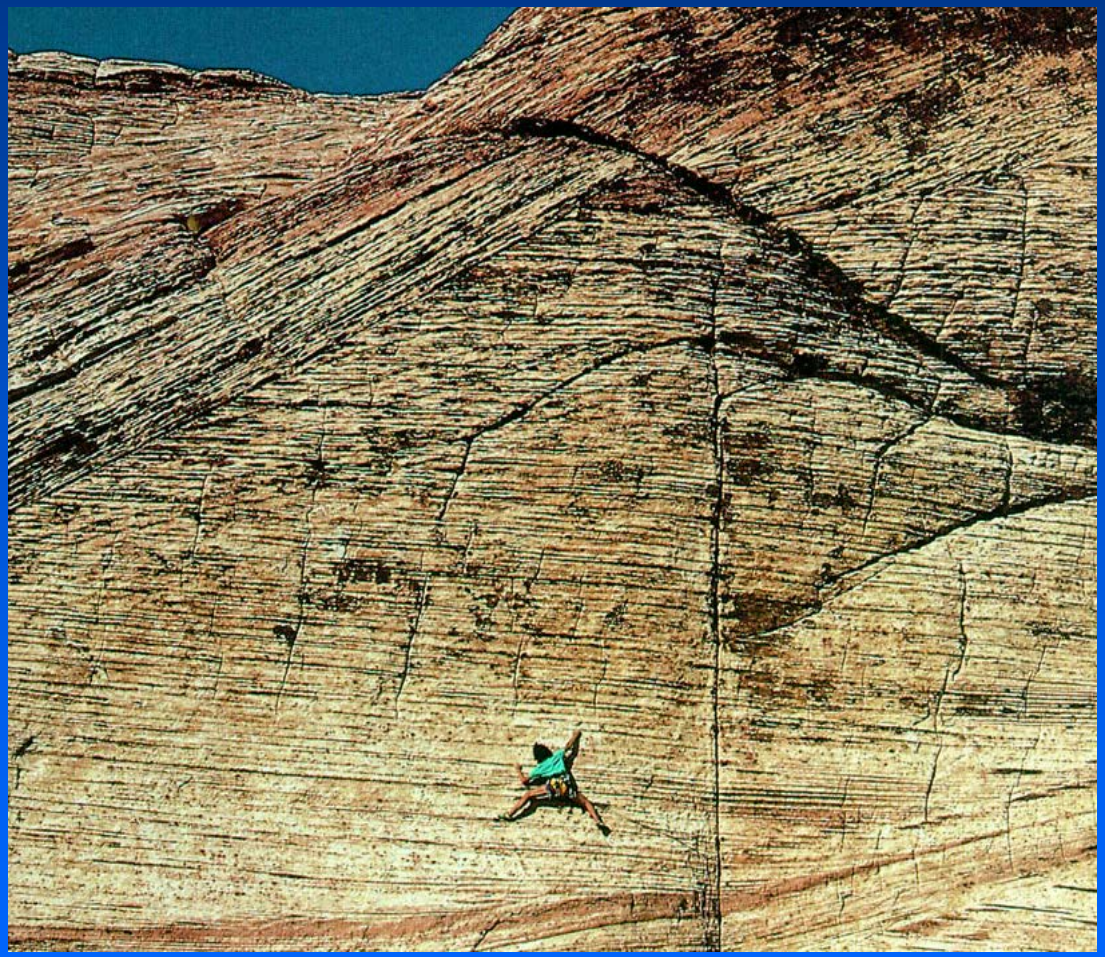
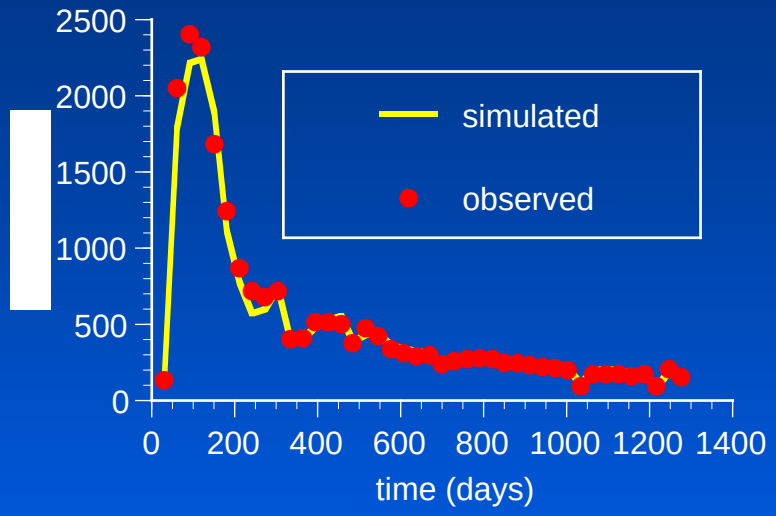
# Data Collection

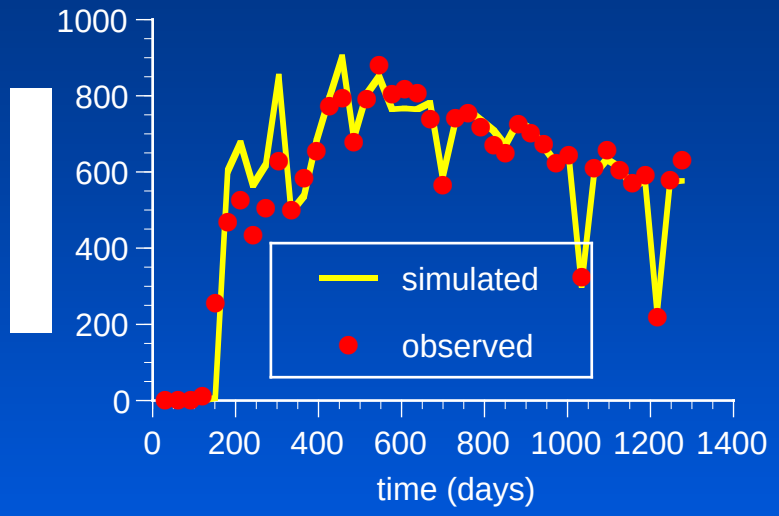


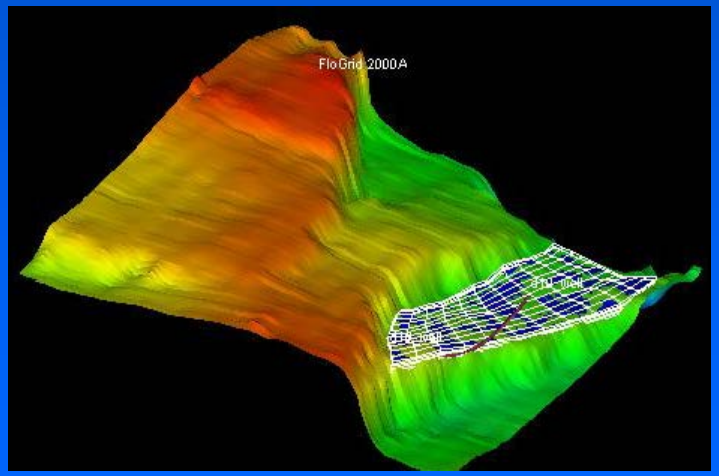
$$\phi(\mathbf{x}) = ?$$

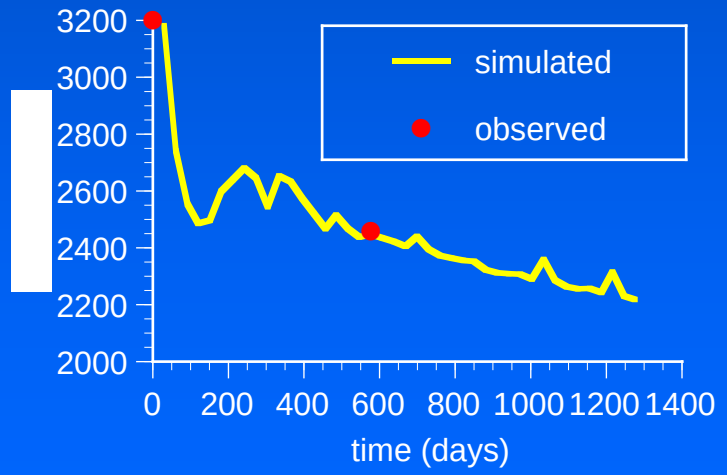
$$k(\mathbf{x}) = ?$$

# Model Calibration: Teal South

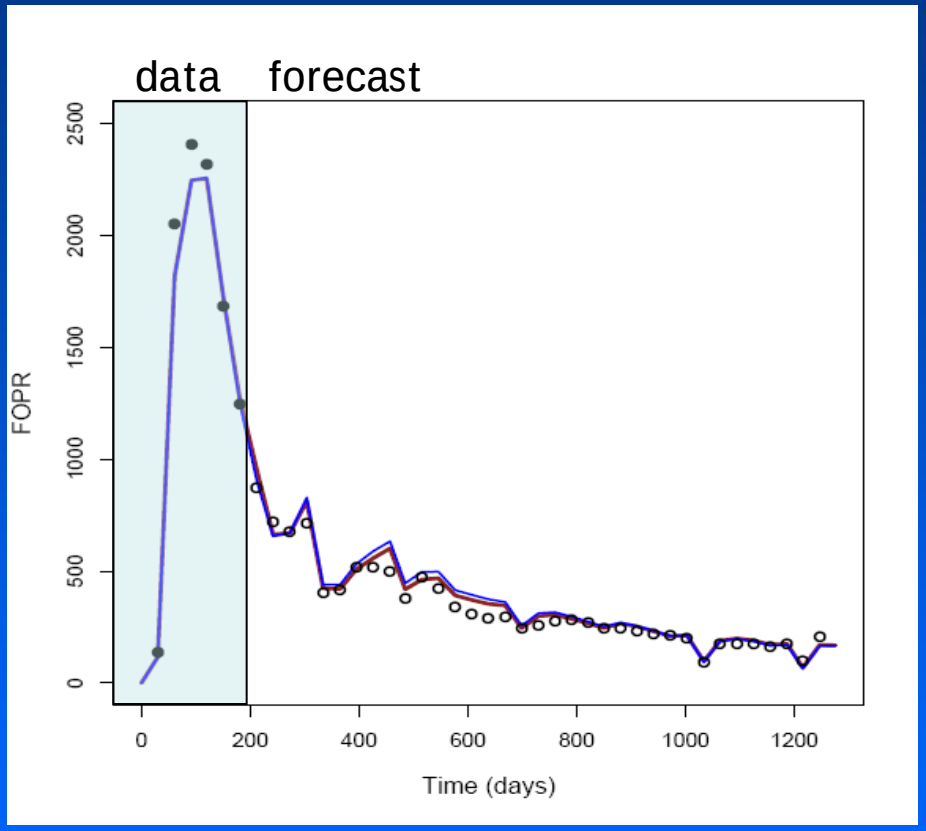


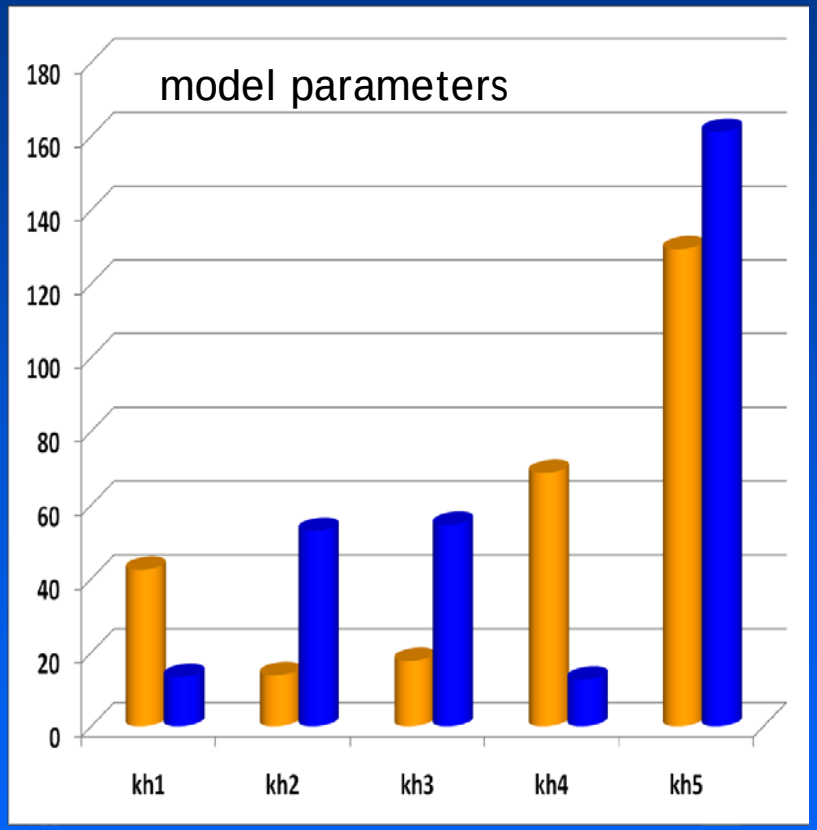



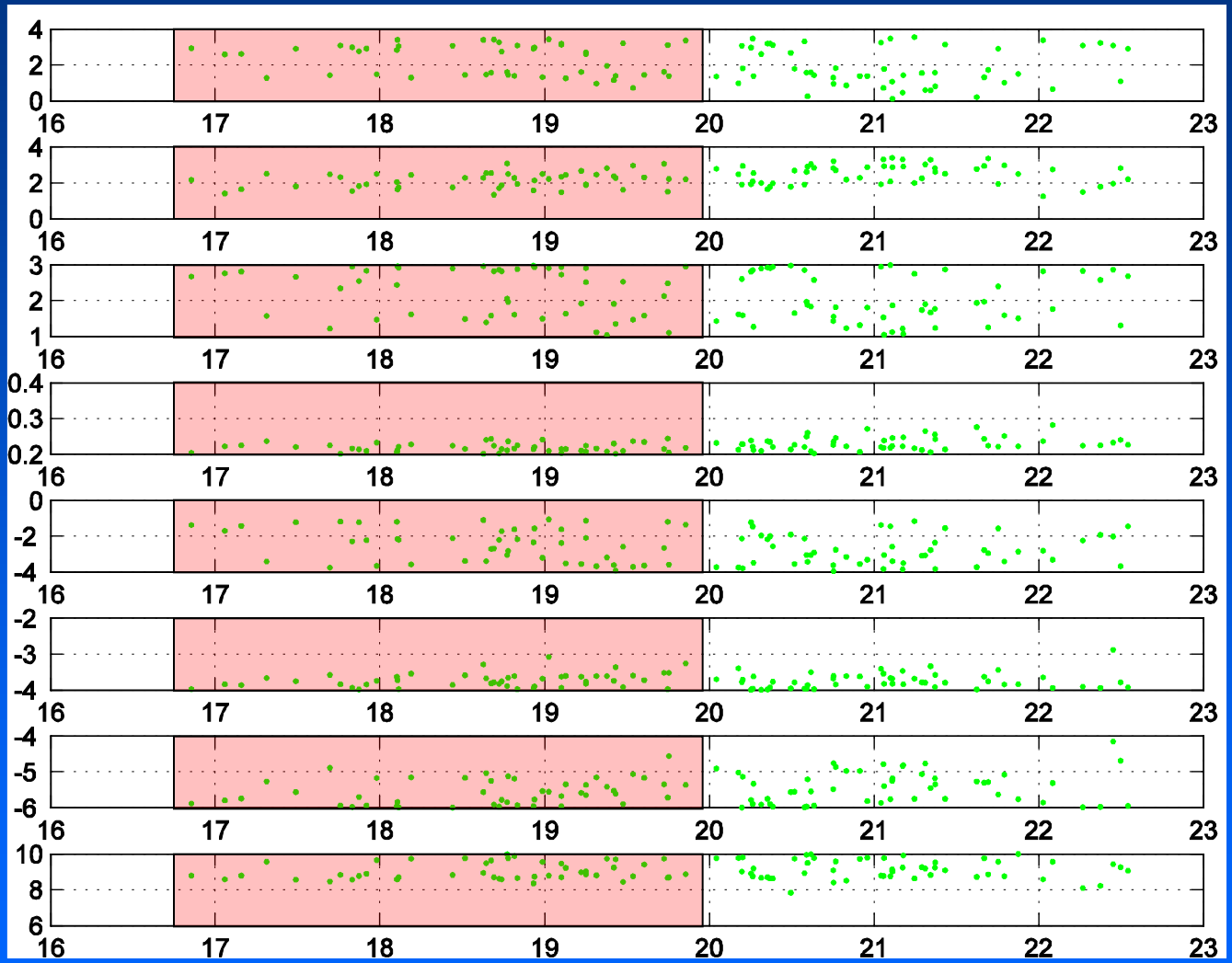



# Calibrated Models are Non-Unique



# Range of Possible Values for Unknown Parameters




$\log(kh_1)$

$\log(kh_2)$

boundary

porosity

$\log(kv/kh_1)$

$\log(kv/kh_1)$

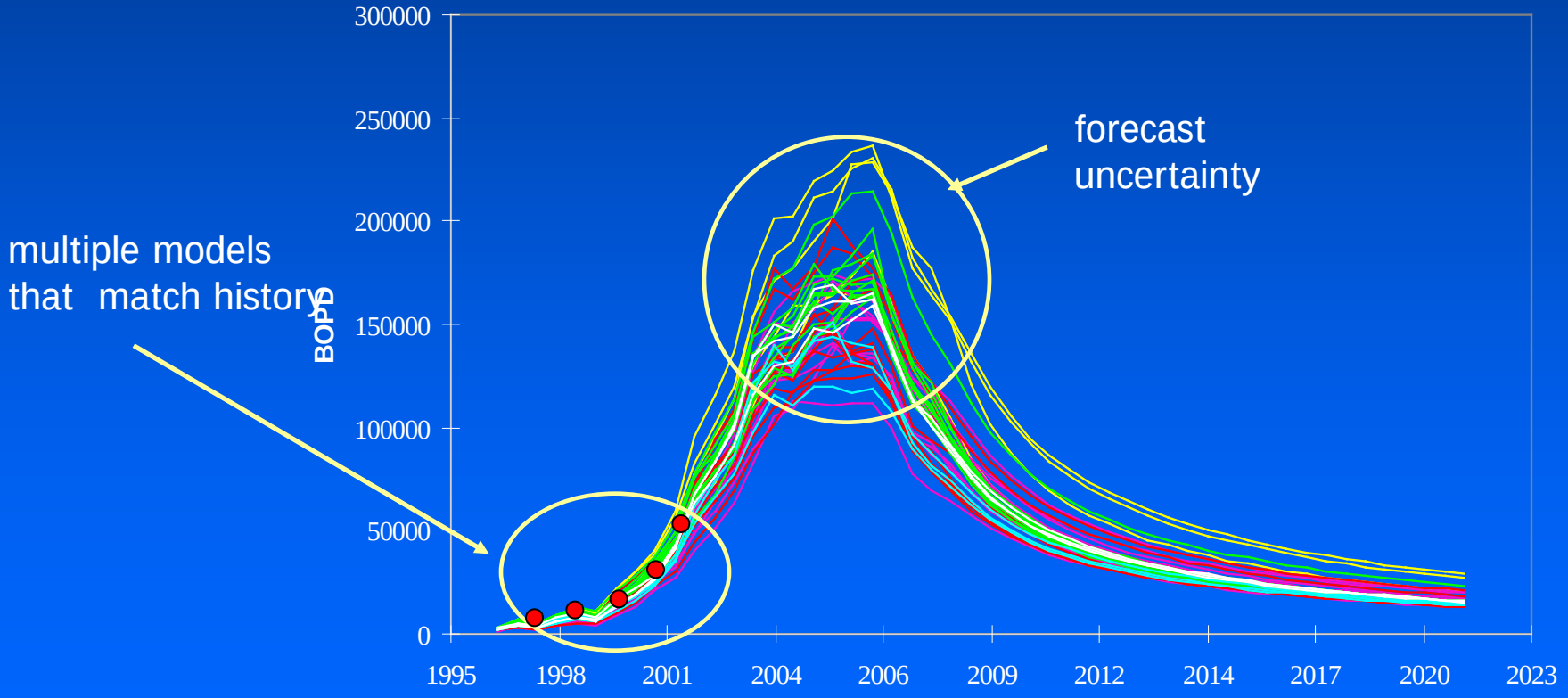
$\log(c_r)$

aquifer strength

# Uncertainty Quantification

Generate multiple models that agree with known data

Use models to predict future behaviour



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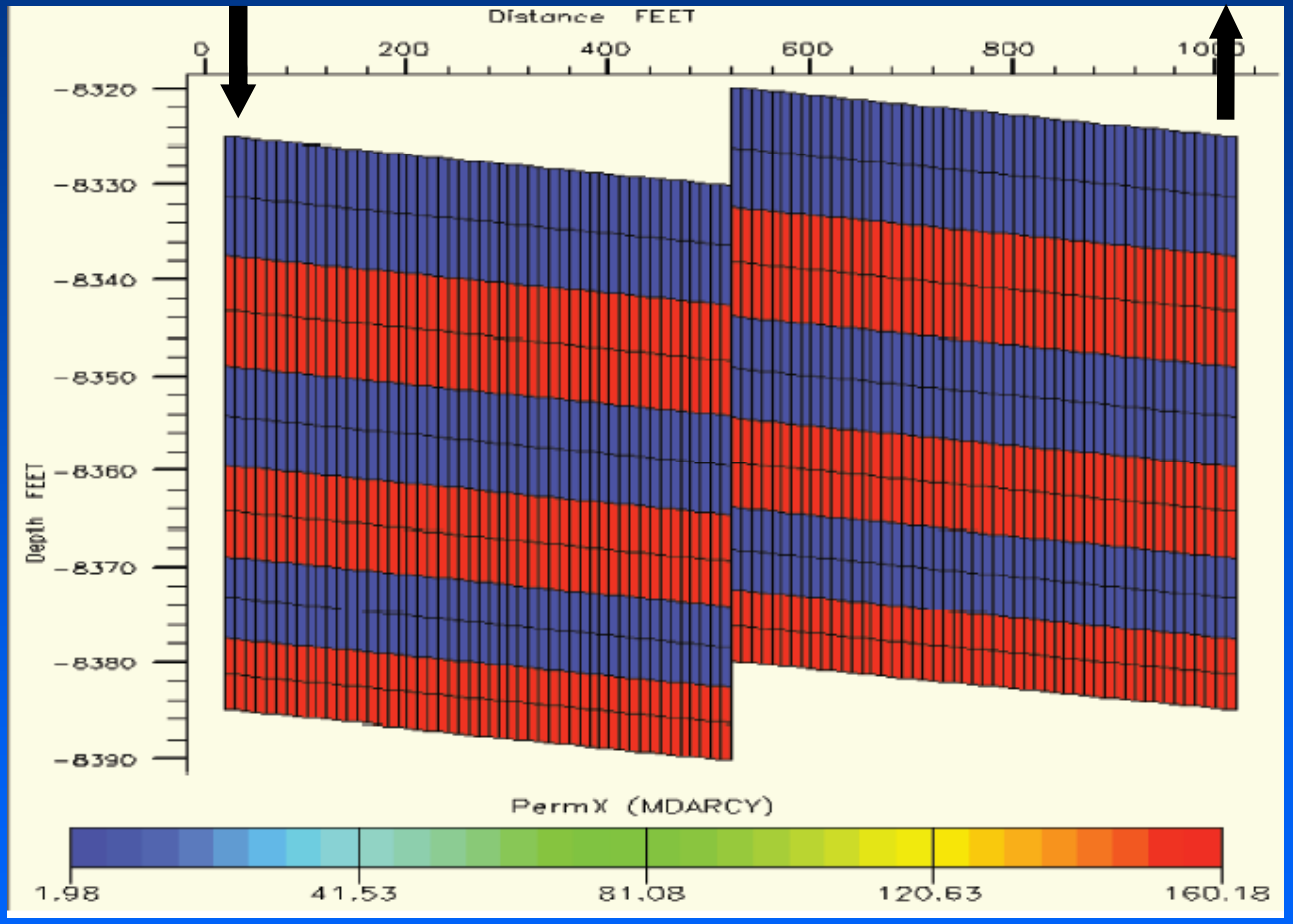
# What kind of problems?

- History matching
  - Generate multiple models consistent with data
- Forecasting
  - Predicting likely production (including range)
- Optimisation
  - Decision making, under uncertainty

# IC Fault Model

Injector Producer




3 Parameters

$k_{low}$ = [0 .. 50 ] md

$k_{high}$ = [100 .. 200] md

throw = [0 .. 60] ft

Objectives (rates)
obj1 = FOPR
obj2 = FWPR

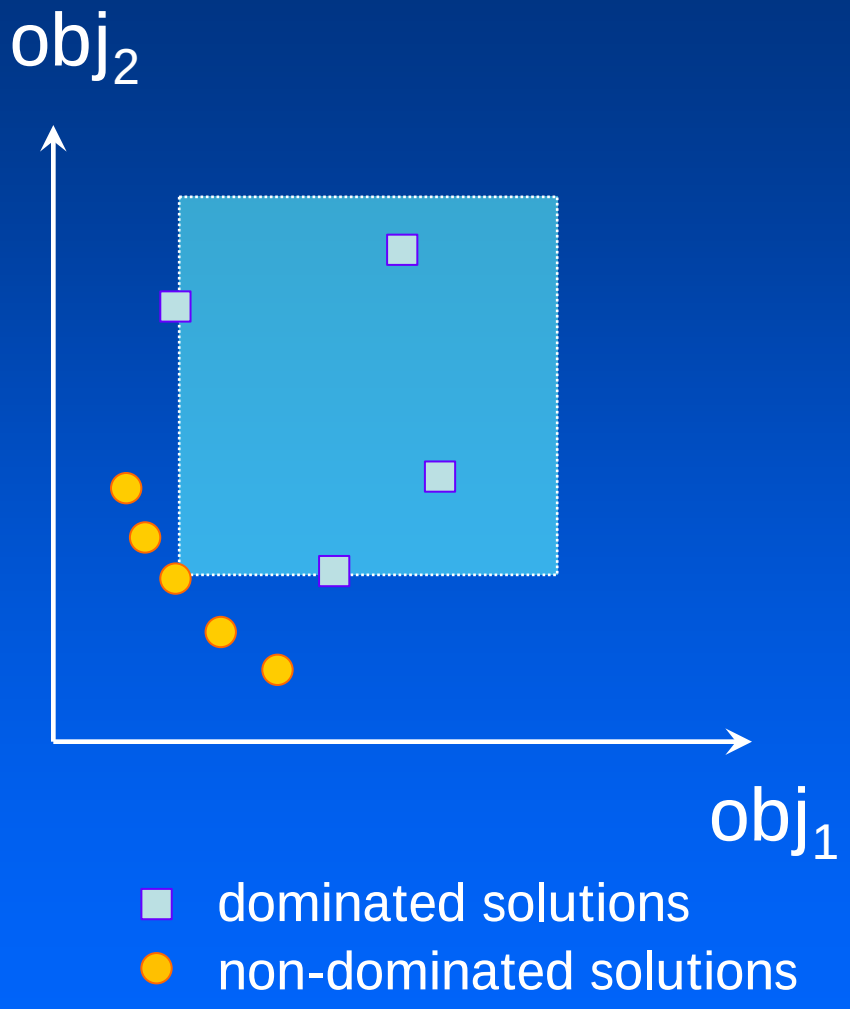
Misfit = obj1 + obj2

Z. Tavassoli, J. N. Carter, and P. R. King, Imperial College, London

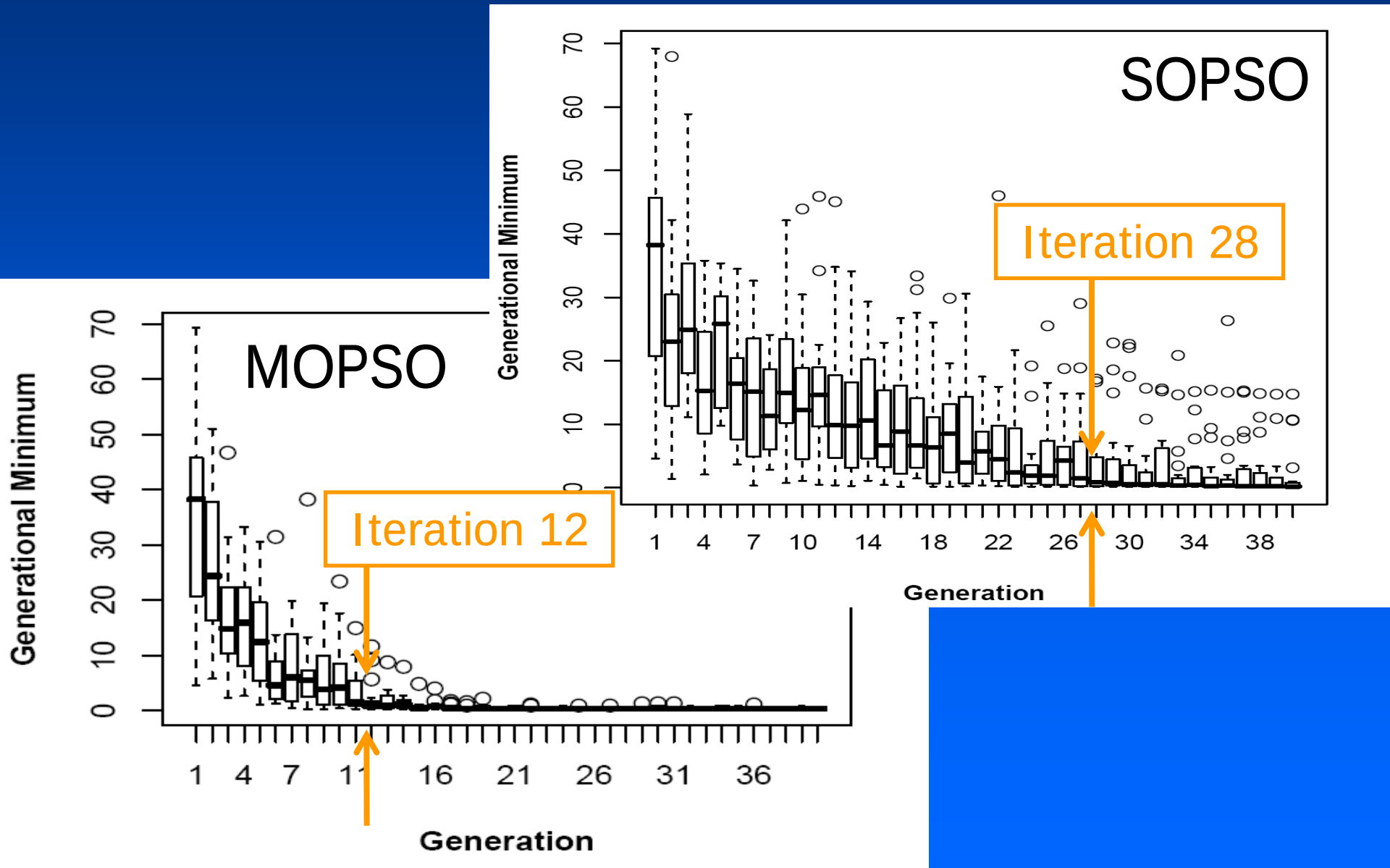
# Multi-Objective PSO: Pareto Dominance

1) A is not worse than B in all objectives

2) A is strictly better than B in at least one objective

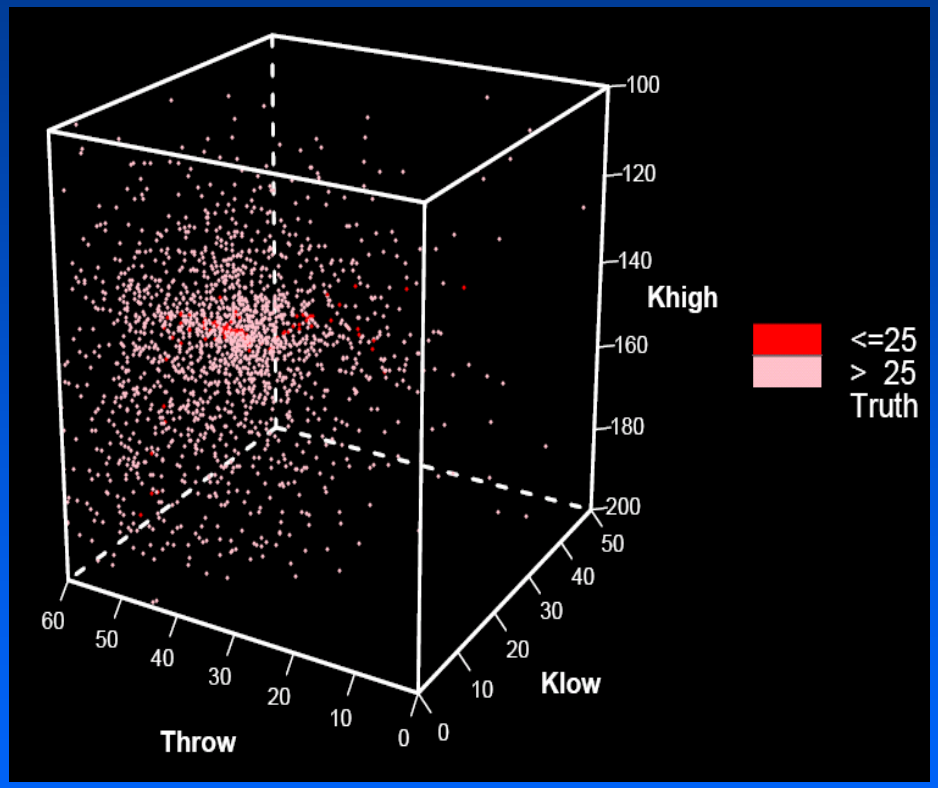


# Convergence Speed – 20 Runs

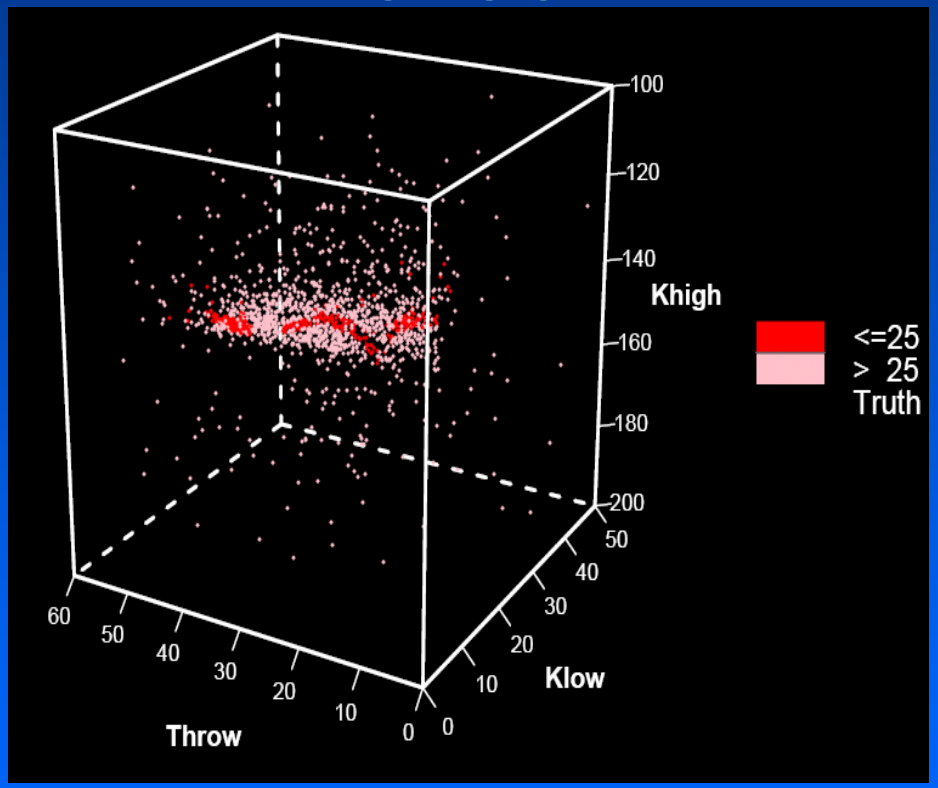


# Diversity of Models

SOPSO

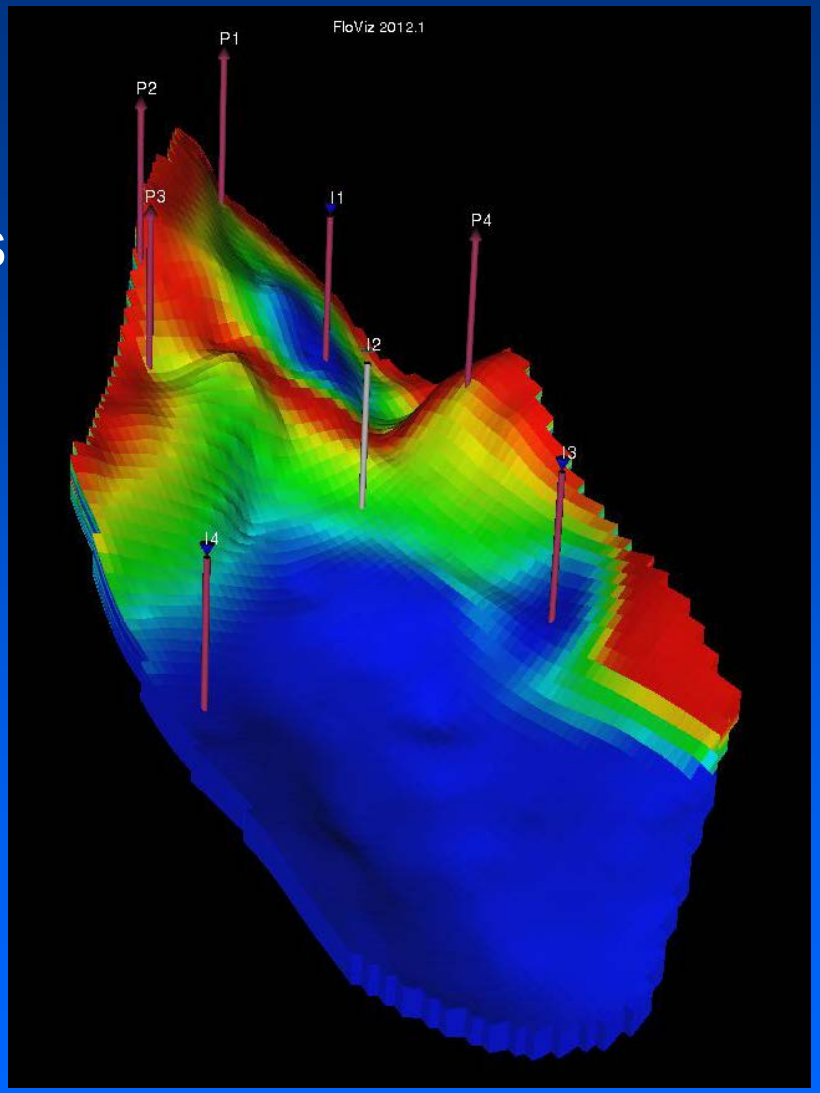



MOPSO



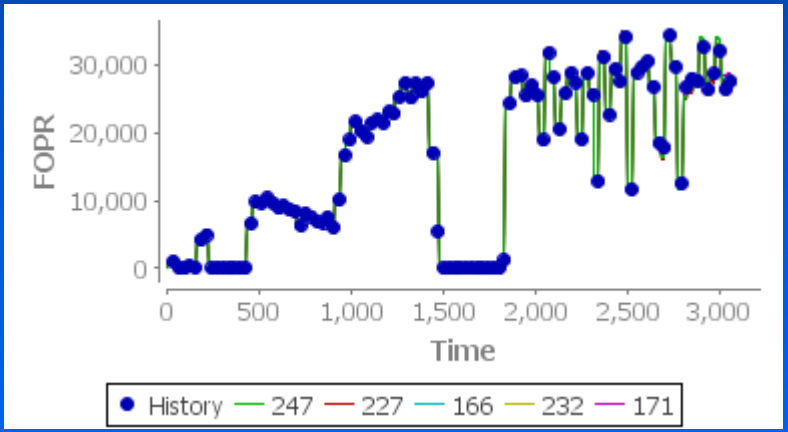
# Optimisation

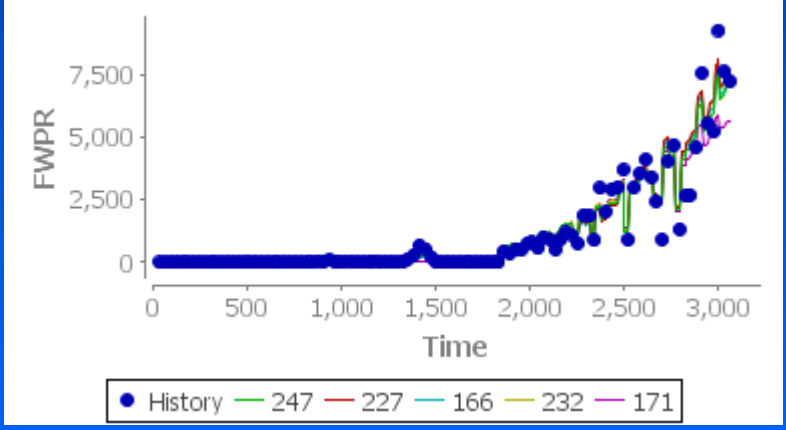
- Scapa field
  - Used for student projects



# Field Level History Match

- Match to first 10 years of history
  - Remaining data used to check forecast



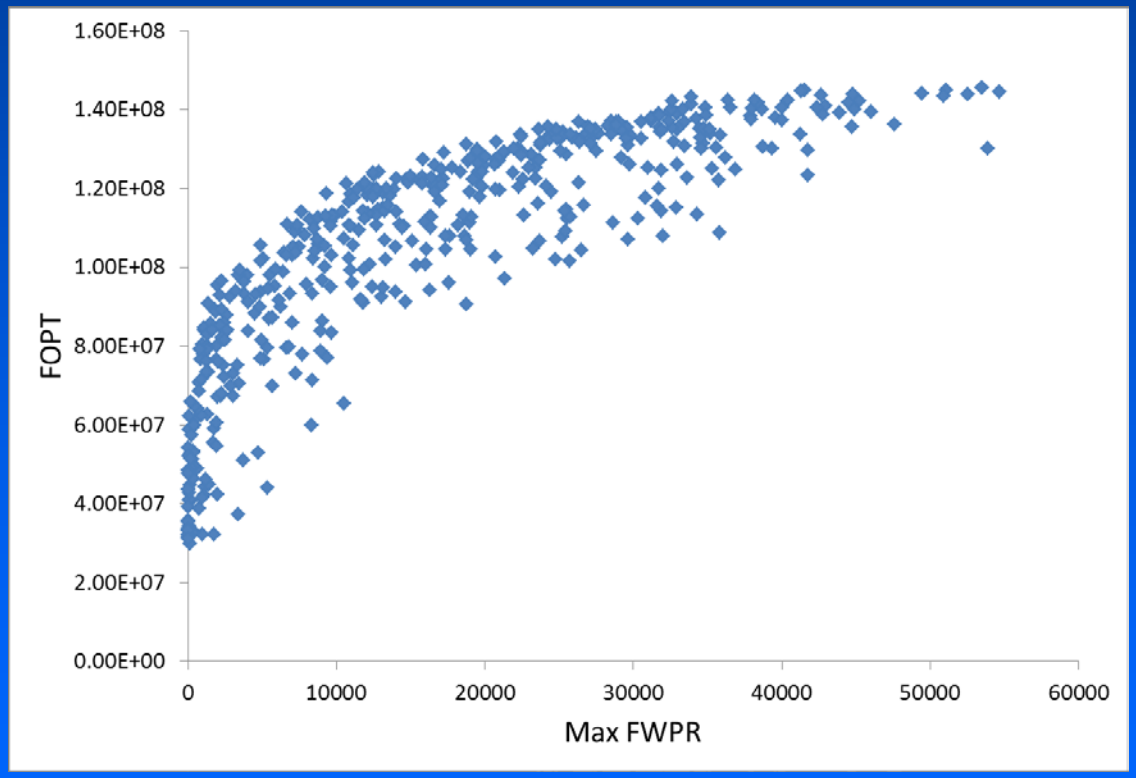



# Optimisation

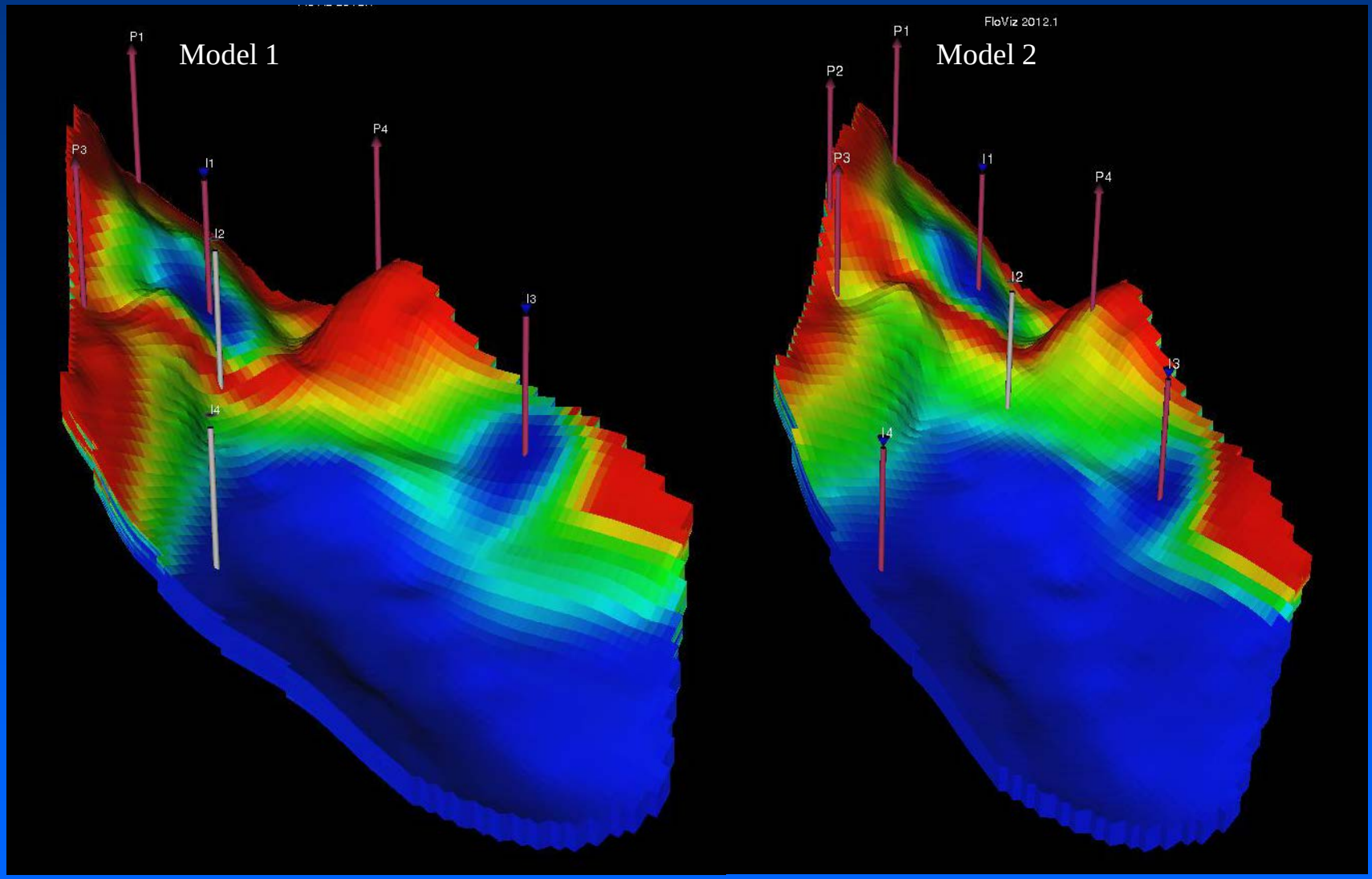
- Multi-Objective
  - Maximise cumulative oil (FOPT)
  - Minimise maximum water rate (FWPR)
- Optimisation variables
  - Well locations (16 variables – i, j for each well)
  - Injection well rates
  - Injection well status (‘open’ vs ‘shut’)

# Optimise Well Locations and Injection Rates

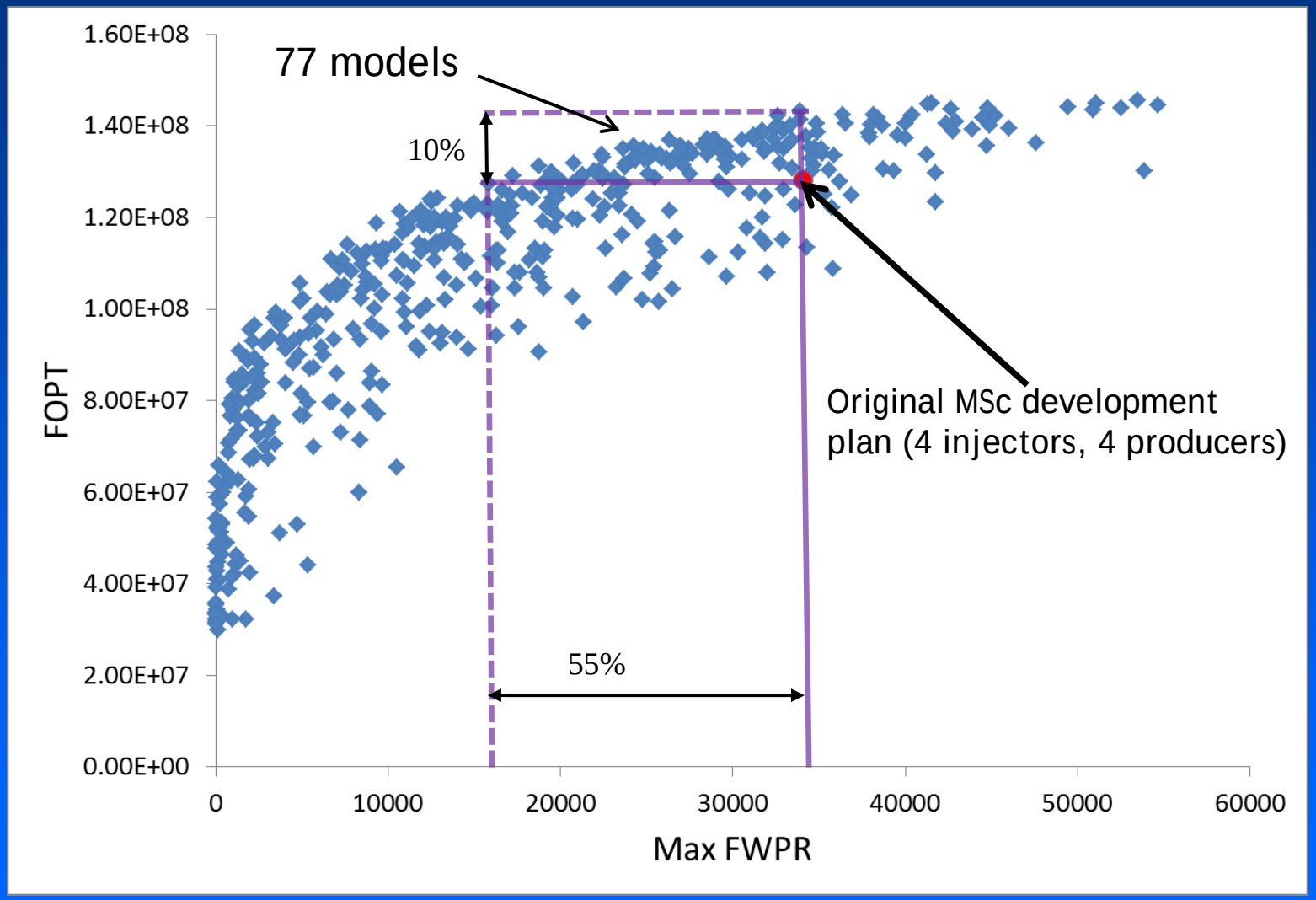
- Vary injection well rates and locations of wells
  - Well rates in [0,15] MBD



# Oil Saturation Comparison



# Comparison with Original MSc Plan



# Where Does EQUIP come in?

- 3 factors
  - Data input is uncertain
  - Models take time to run
  - Decisions are costly
- Need
  - Fast, effective model calibration techniques
  - Combine maths, stats, computer science, engineering