Uncertainties Have A Meaning: Information Entropy As A Quality Measure For 3-D Geological Models

J. Florian Wellmann, Klaus Regenauer-lieb, 2012

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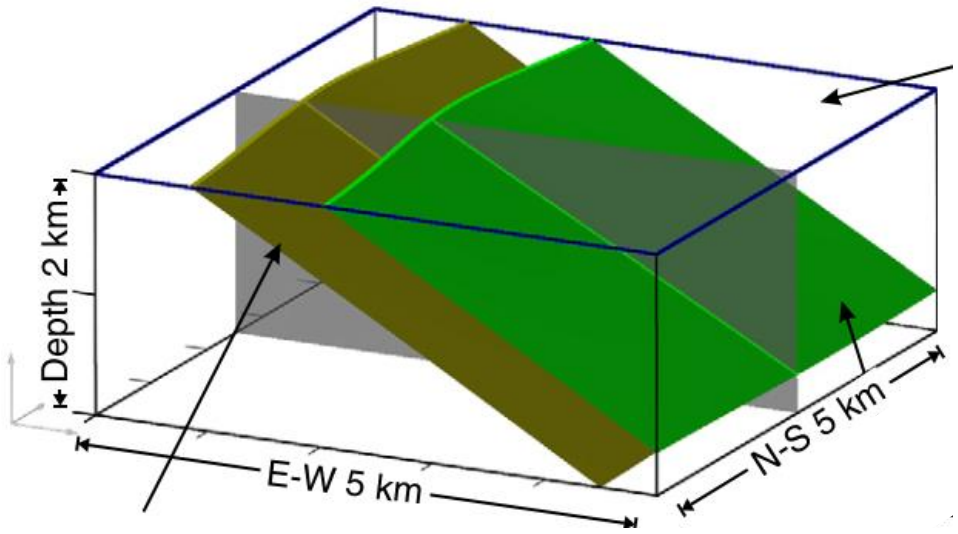

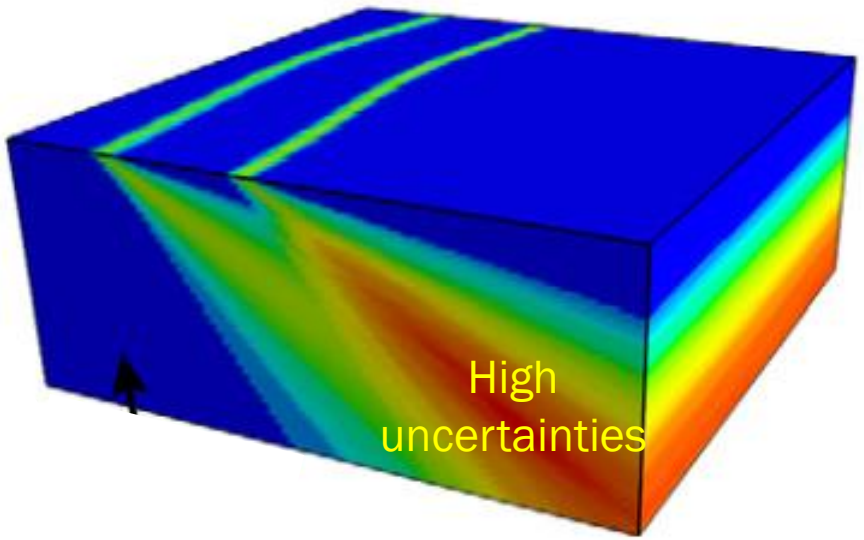

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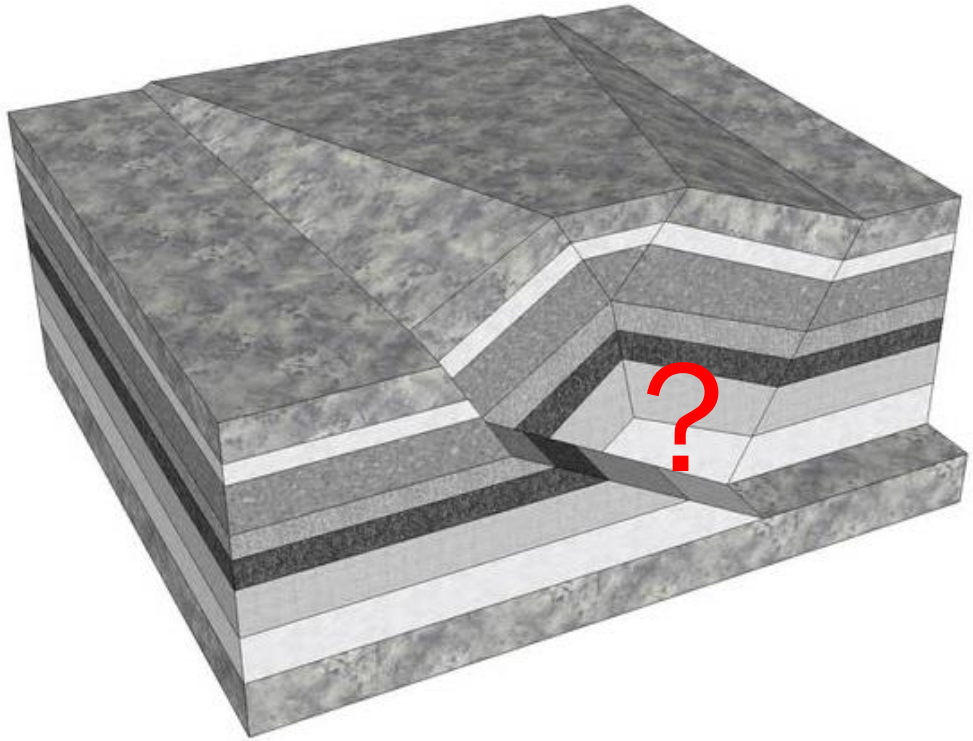
Introduction

- Analyzing, visualizing and communicating uncertainties are important issues as geological models can never be fully determined.



How precise is the position of the boundary and how to describe the uncertainty of it?

↓

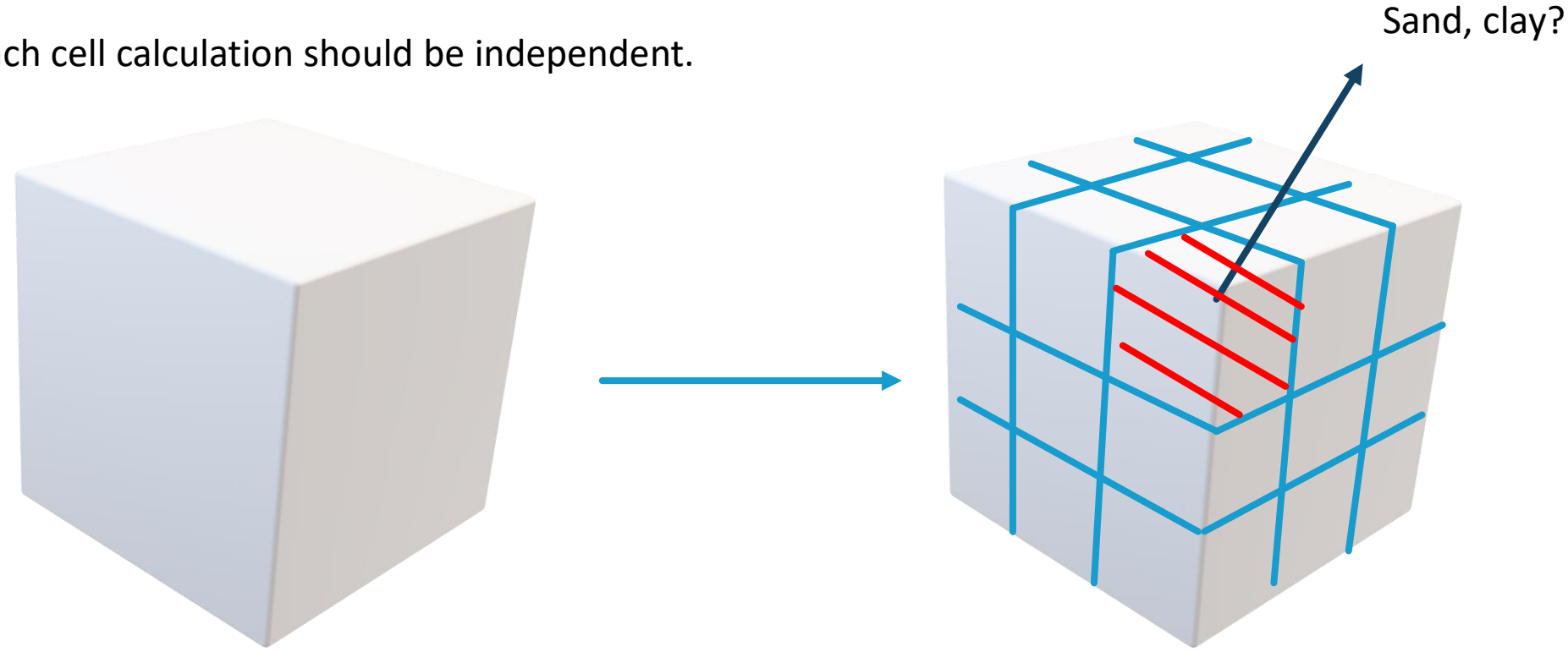
Propose a method to quantify the quality of a geological model.

↓

Visualize uncertainties and make decision that how to further improve the geological model.

Methodology: Visualizing uncertainty

- Subdivide the whole model space into regular raster with equal cell sizes.
  1. For each cell, if there is only one possible outcome(materials), probability (p_i) = 1
  2. The value(entropy) is maximal when n possible materials are equally likely.
  3. Higher n possible materials, higher values(entropy).
  4. Each cell calculation should be independent.

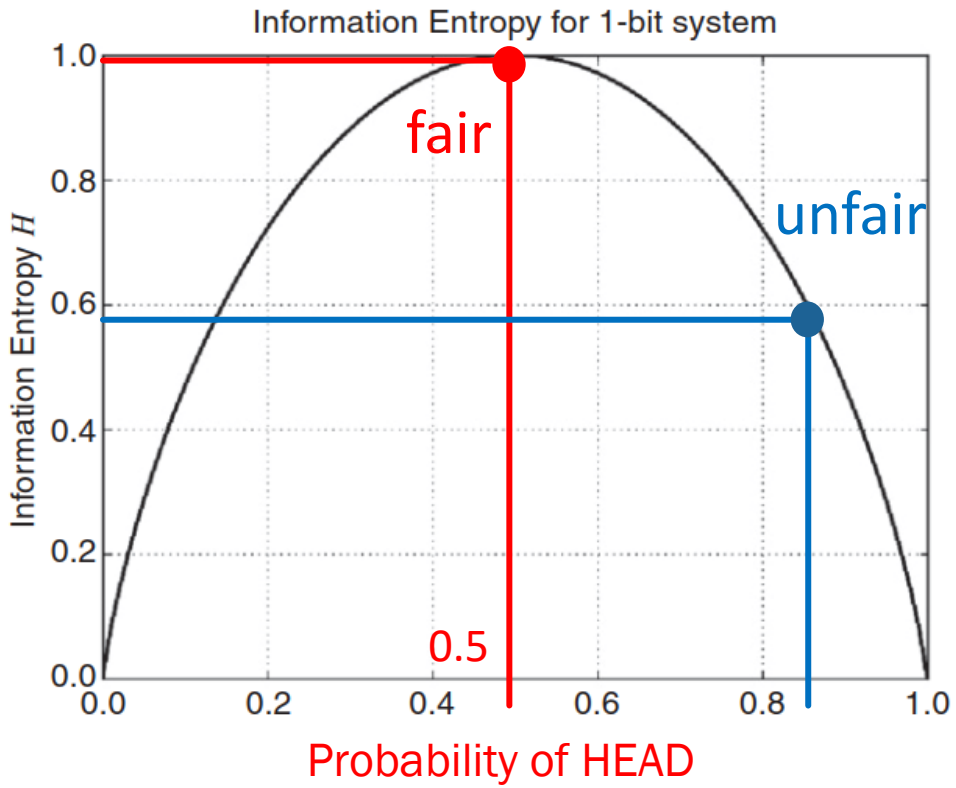


Methodology: Information Entropy—two possible outcomes

$$H = -\sum_{i}^{N} p_i \log p_i$$

(Shannon, 1948)

P: probabilities
N: possible outcomes(how many kinds of material may appear)
H: information entropy



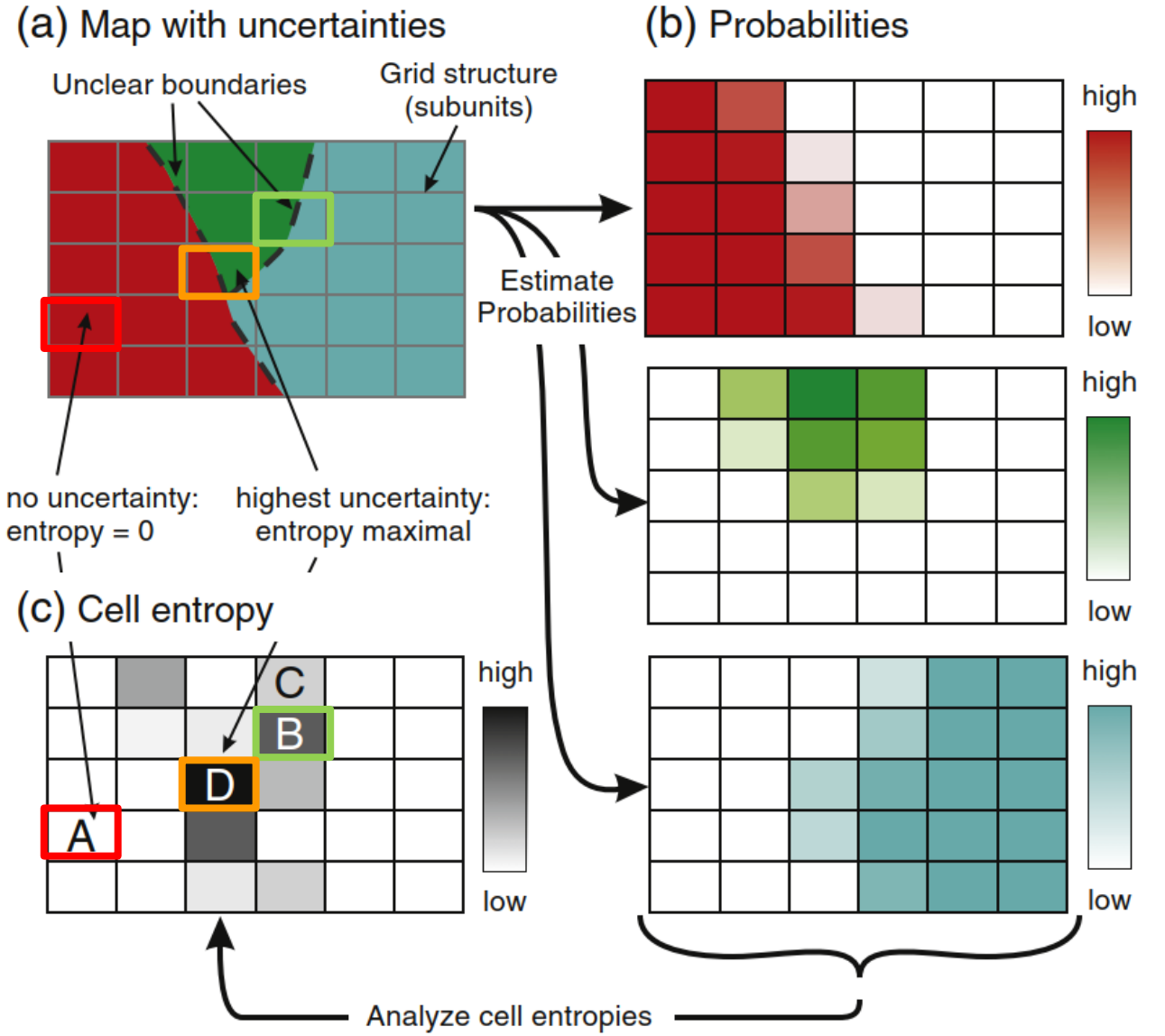
- If the coin is fair

→ head and number is equal → entropy(H) is highest.

- If the coin is unfair

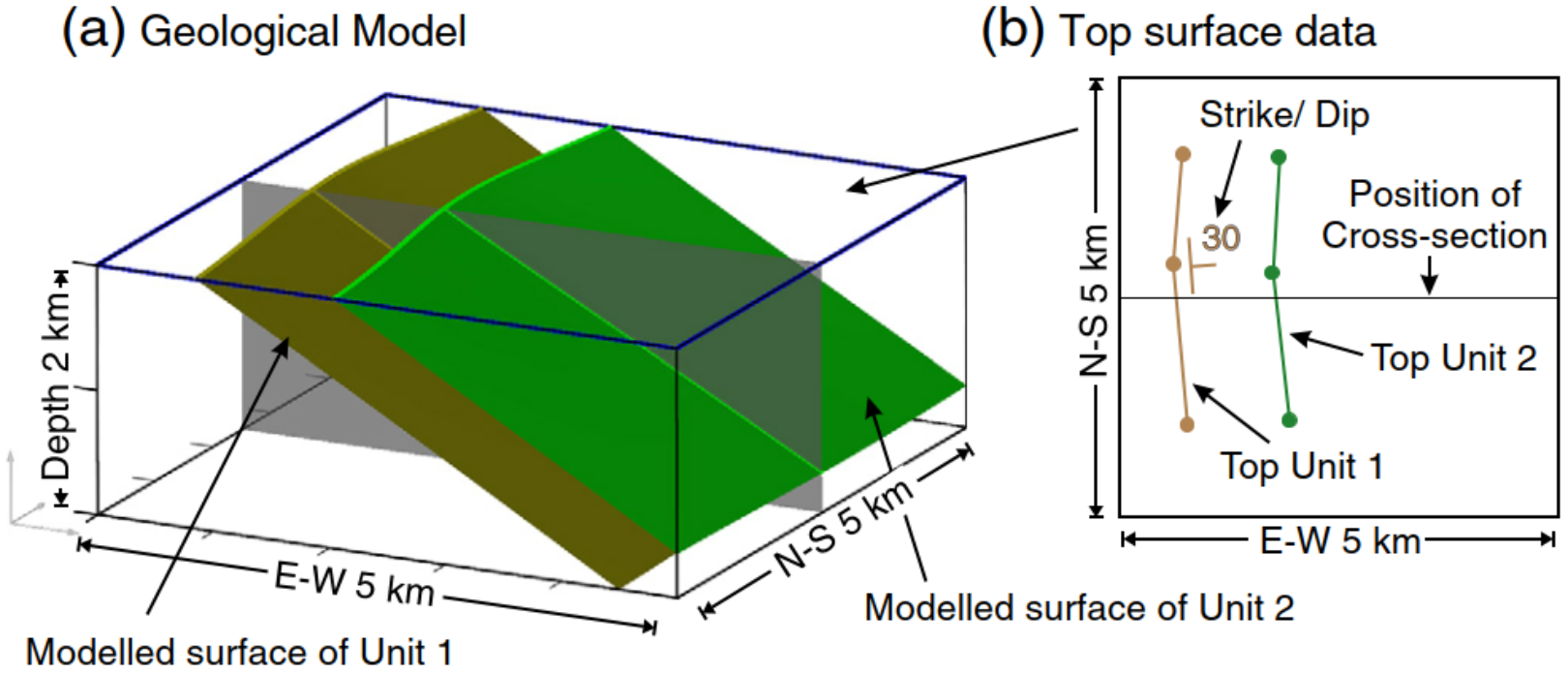
→ the entropy(H) is lower.

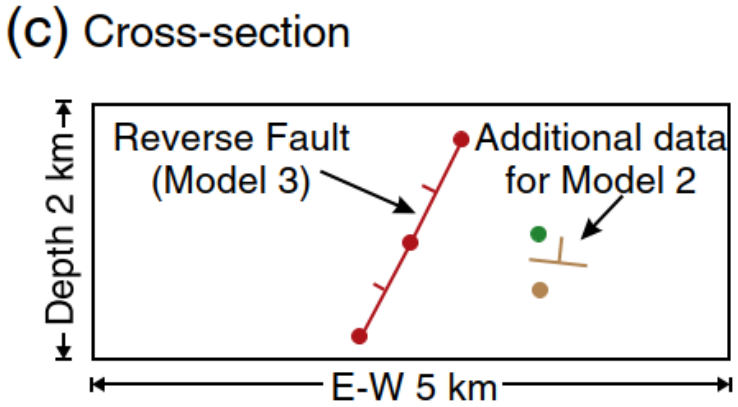
Methodology: Information Entropy—in a spatial context

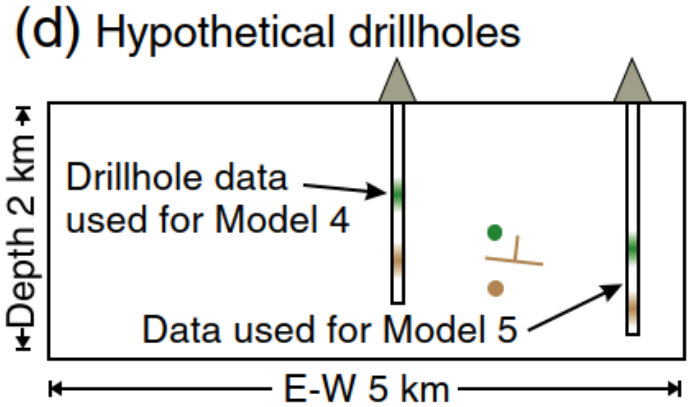


- Entropy = 0 where one member has the p = 1 and others are 0. e.g. cell A
- Two members are equally probable, entropy becomes higher. e.g. cell B
- Three members are equally probable, entropy becomes highest. e.g. cell D

Methodology: Geological modeling and uncertainty simulation







- Model 1---

Visualize uncertainties

- Model 2---

Reduction of uncertainties

- Model 3---

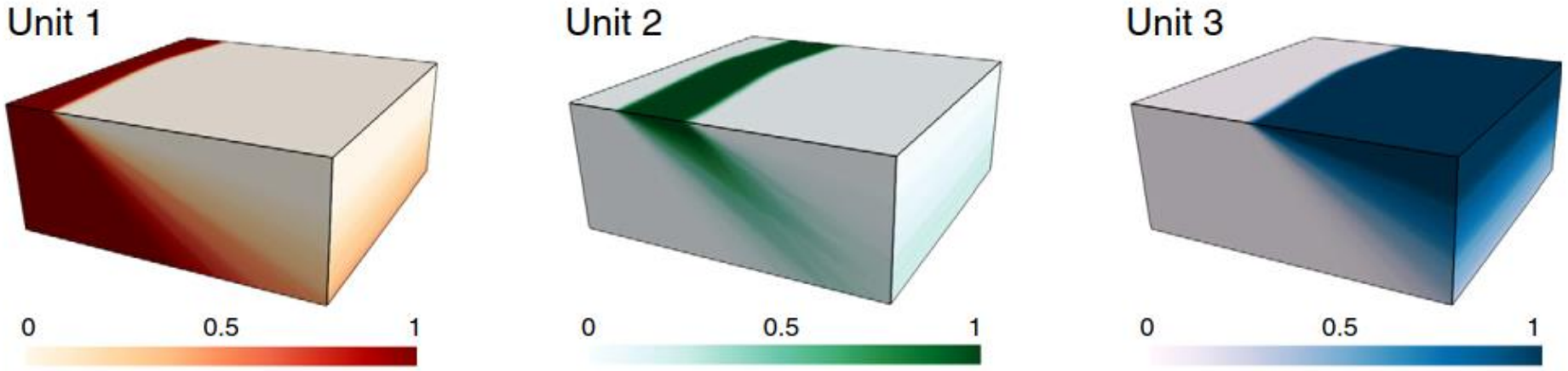
Results of a geological hypothesis test

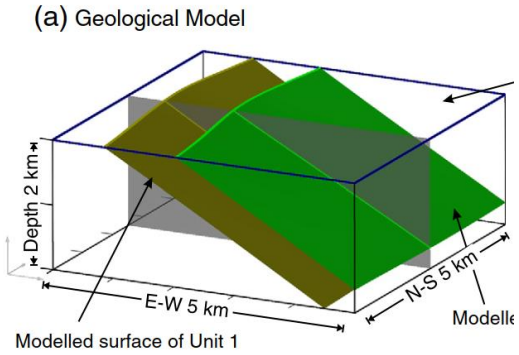
- Model 4 & 5---

Testing the effect of additional drillhole data

Result: Model 1, visualization of model uncertainties

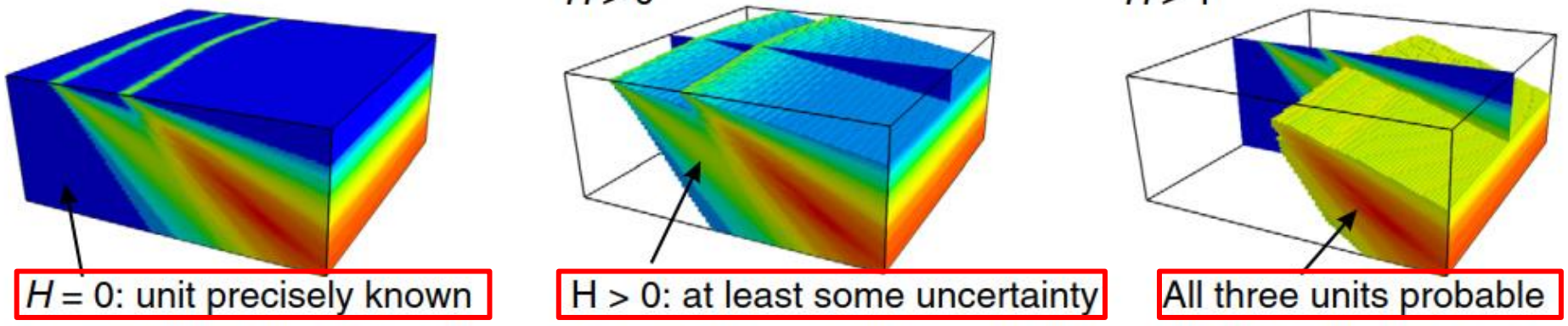
(a) Unit probabilities



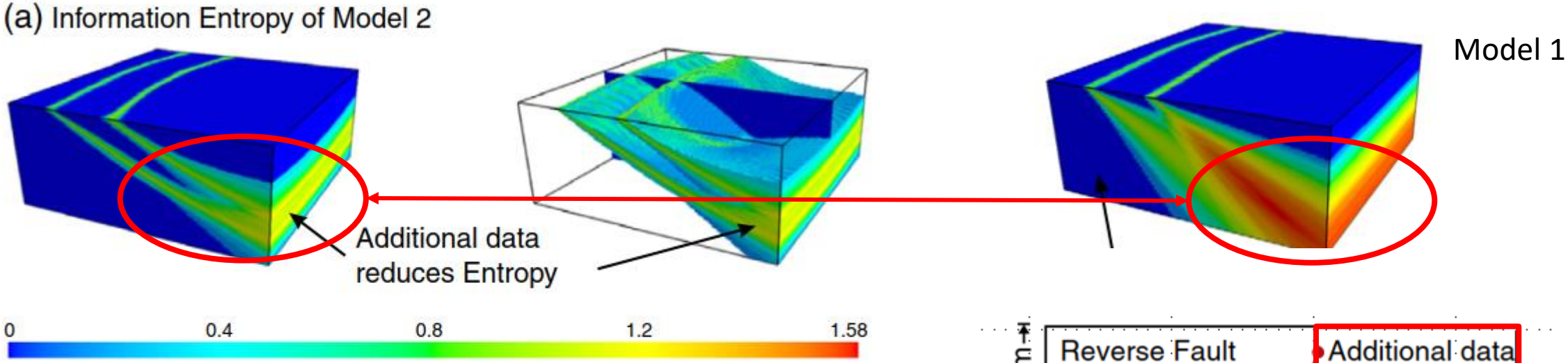


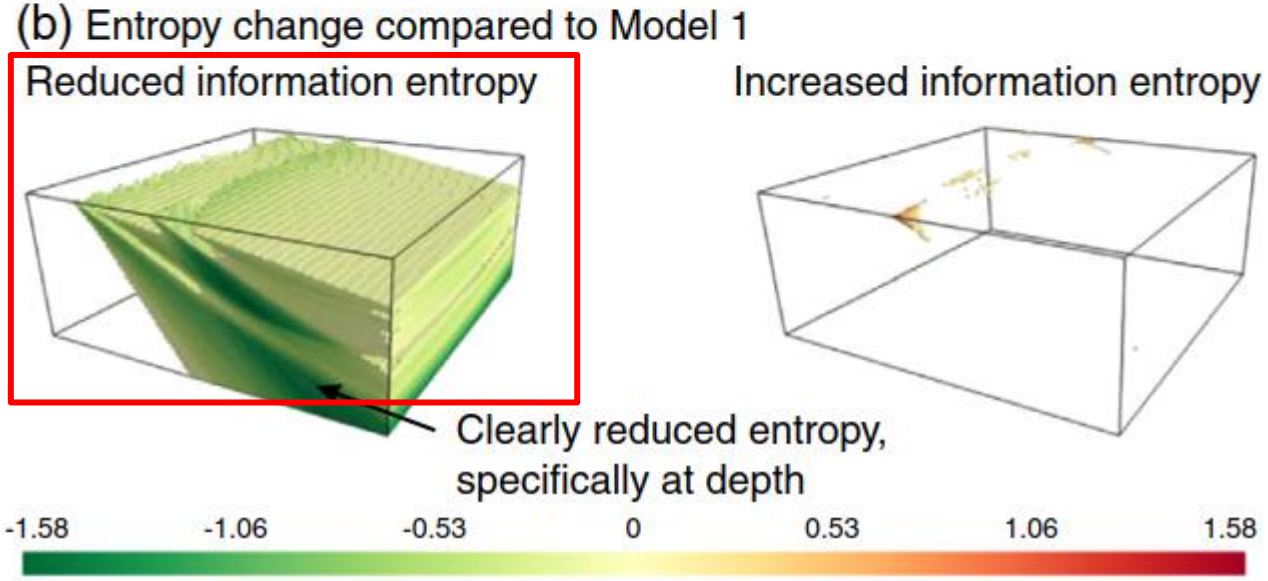
50 possible realizations

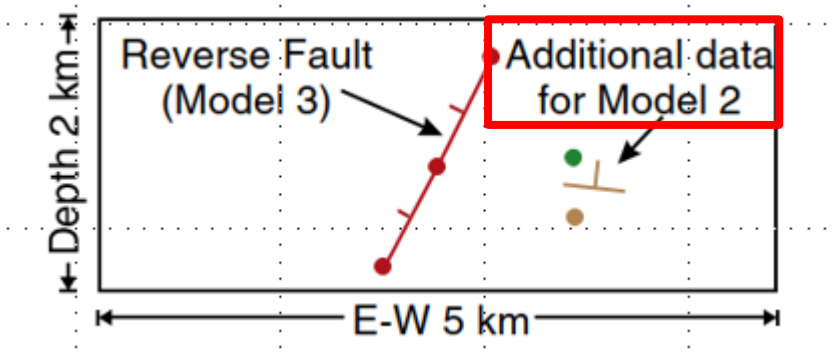
(b) Information entropy (H)



Result: Model 2, uncertainty reduction with additional data

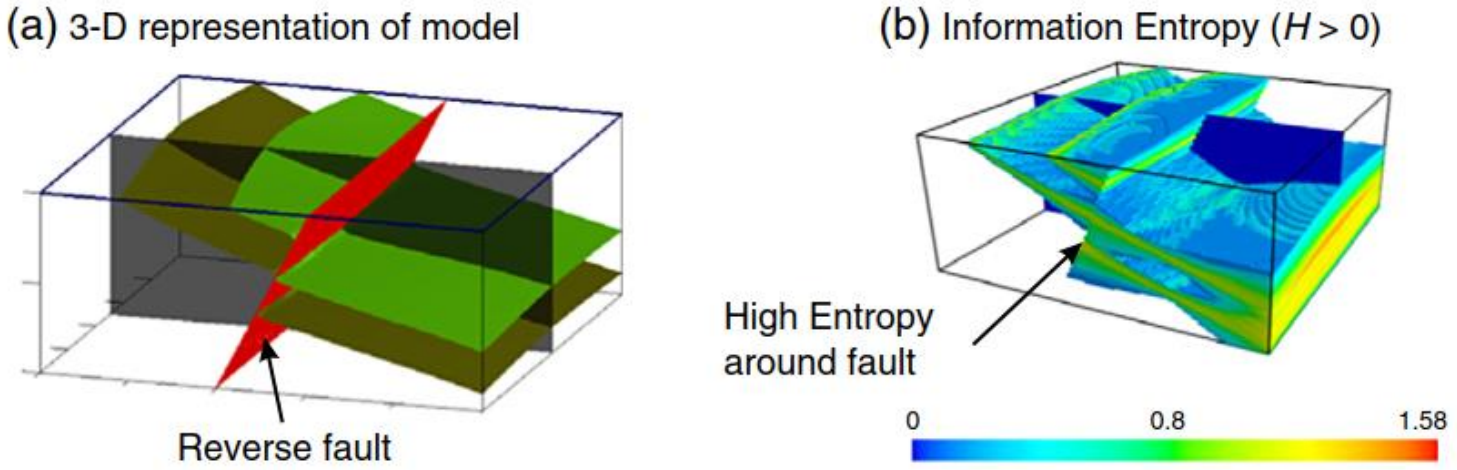


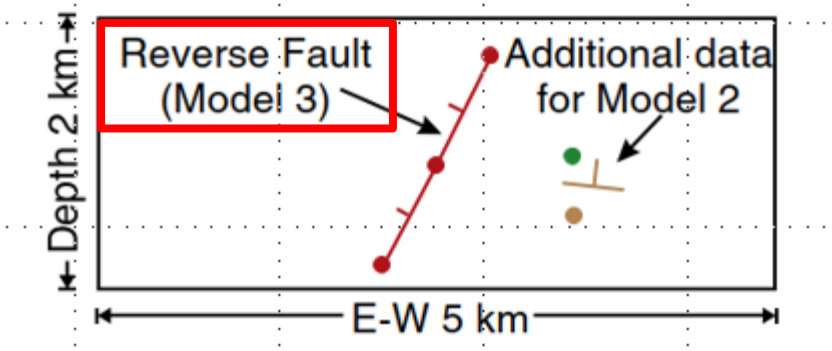


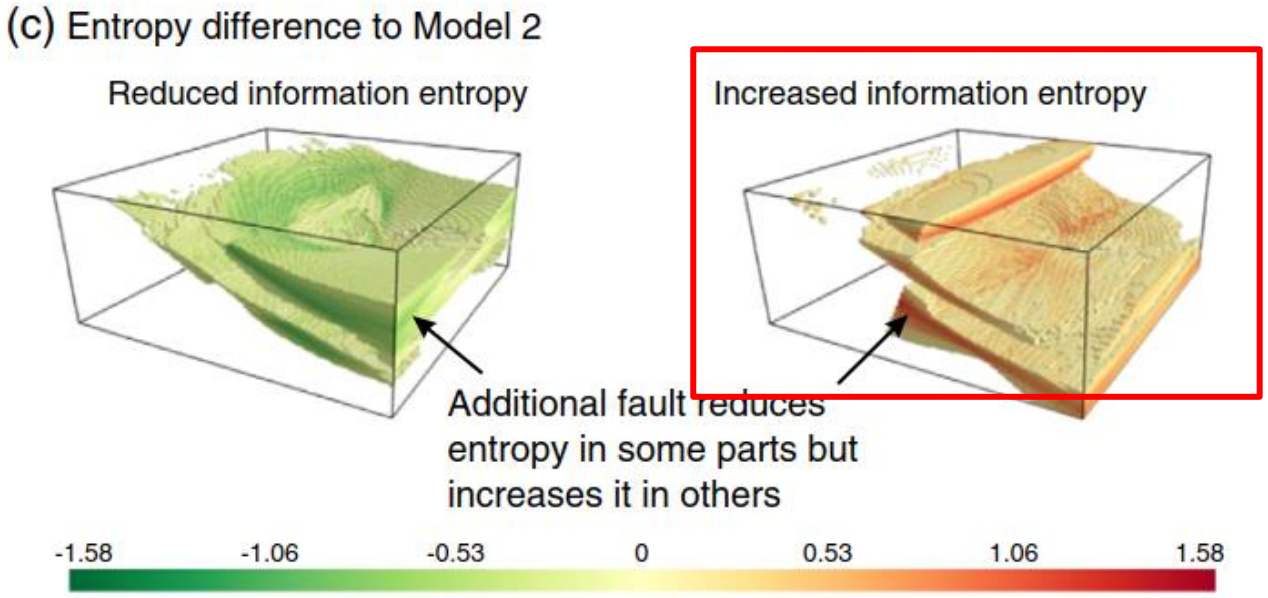


- Adding additional data at large uncertainty part reduce the entropy.

Result: Model 3, geological hypothesis testing

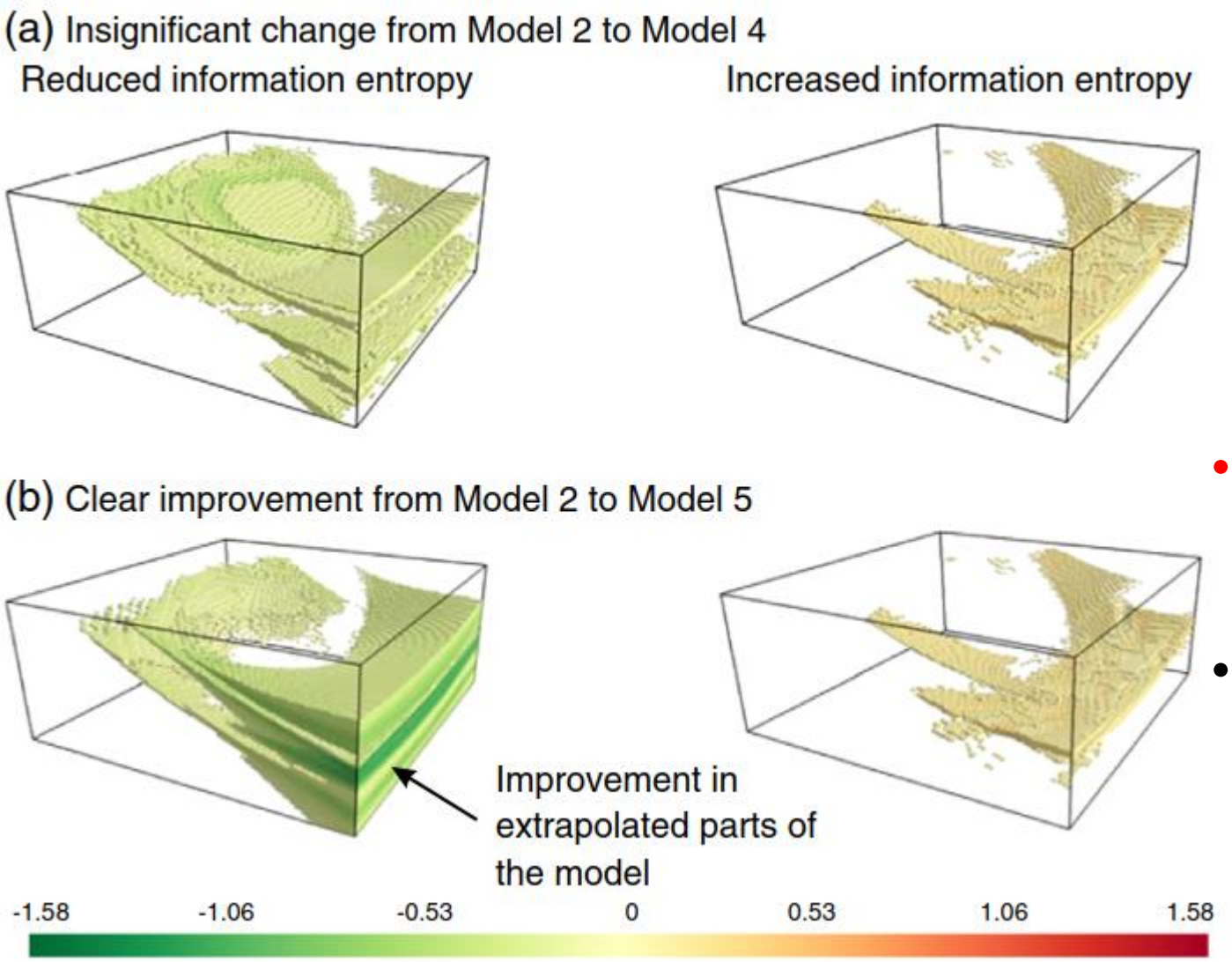


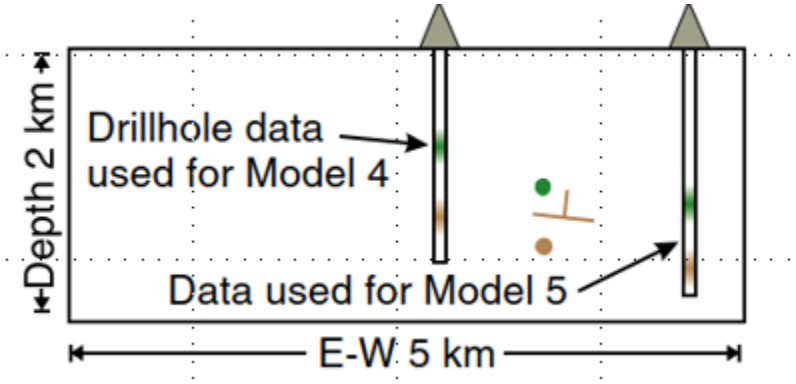




- High entropy around fault which offsetting the geological units.
- The importance of geology desk study shows here.

Result: Model 4 & 5, uncertainty reduction with additional data

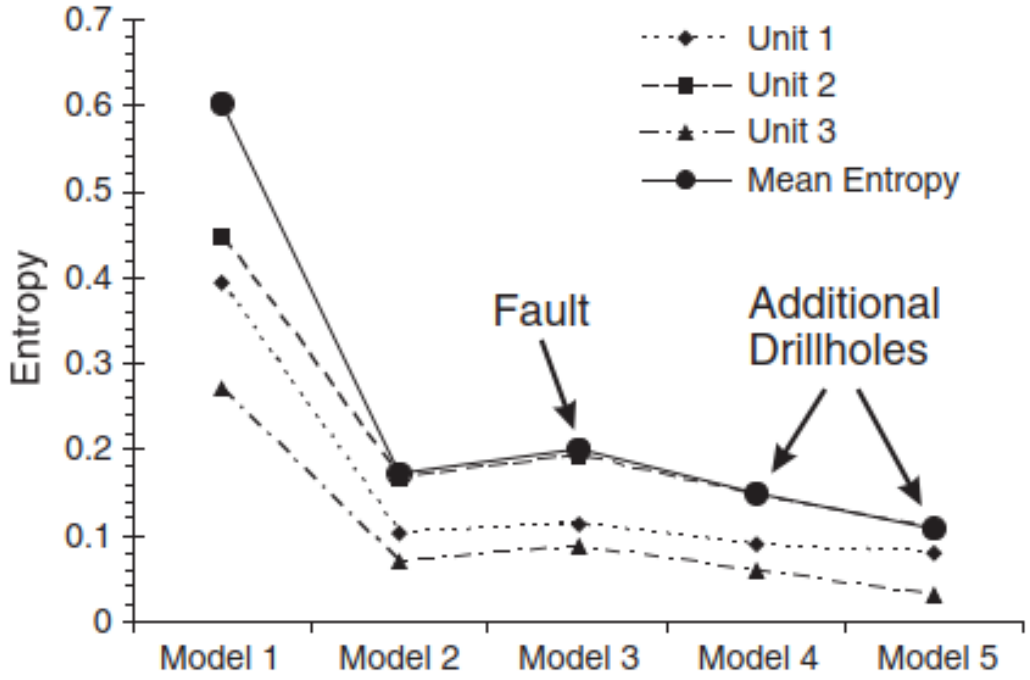


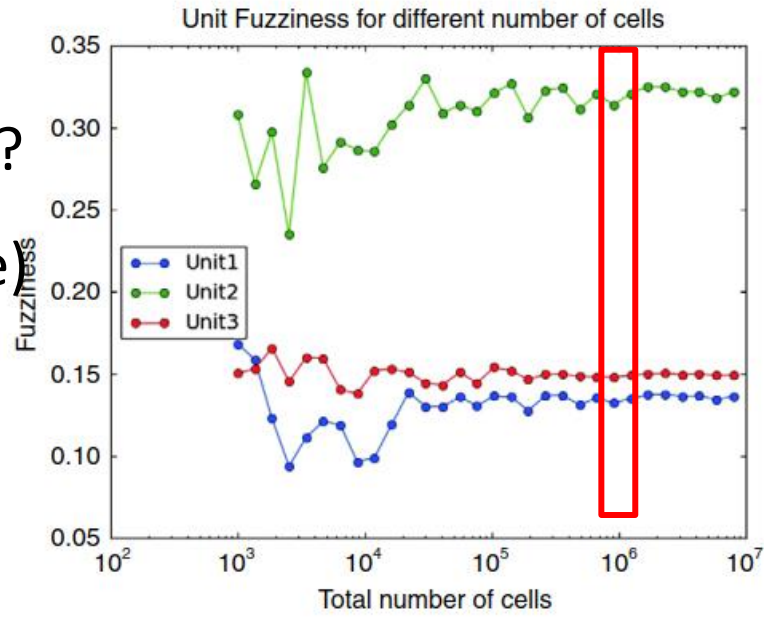


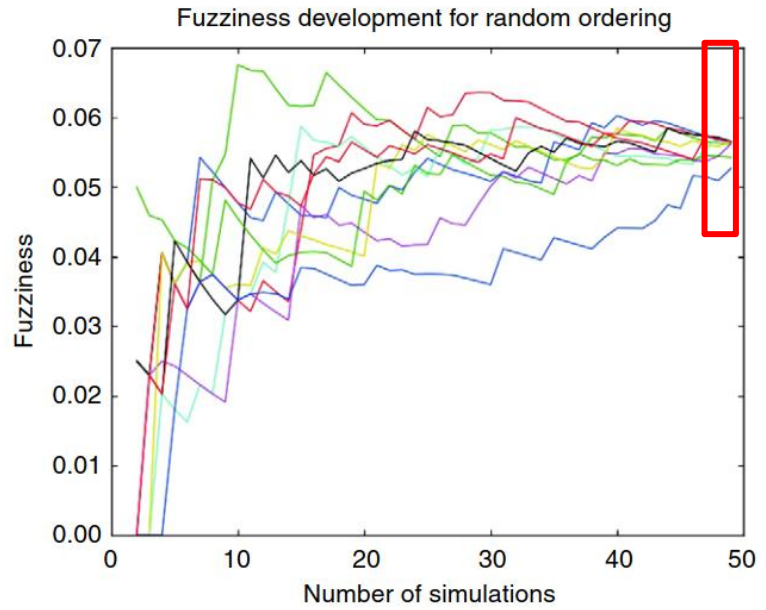
- Where and how the additional data help optimize the geological model.
- Reduction of the entropy helps to make the decision.

Result: comparing models

- How the difference of additional data effect the entropy?
- Fuzziness(which is similar to the concept of entropy here) is used as convergence criteria for simulation.







Conclusion

- Beyond pure uncertainty visualization, the measure can be interpreted in a quantitative way.
- Useful to describe overall uncertainties and focus on high uncertainty part to make further decision.
- Adding more information on right place significantly improve model's quality.