Increased physics, model validation, and explicit uncertainties

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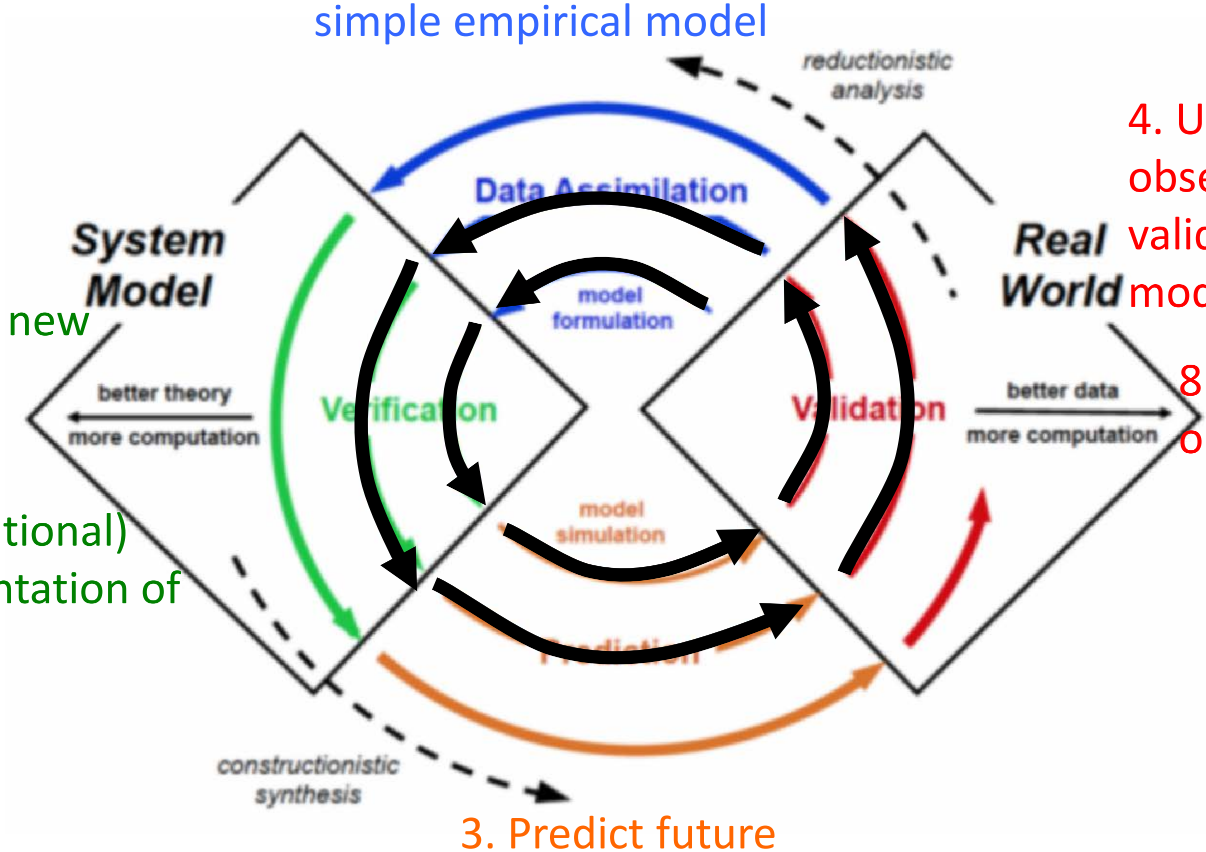
Inference spiral of science

5. New observations indicate model deficiencies, improve model theory

1. Initial observational data, simple empirical model



4. Use new observations to validate current model

6. Re-verify new model

8. Use (more) new observations ....

2. Verify (computational) Implementation of model

3. Predict future

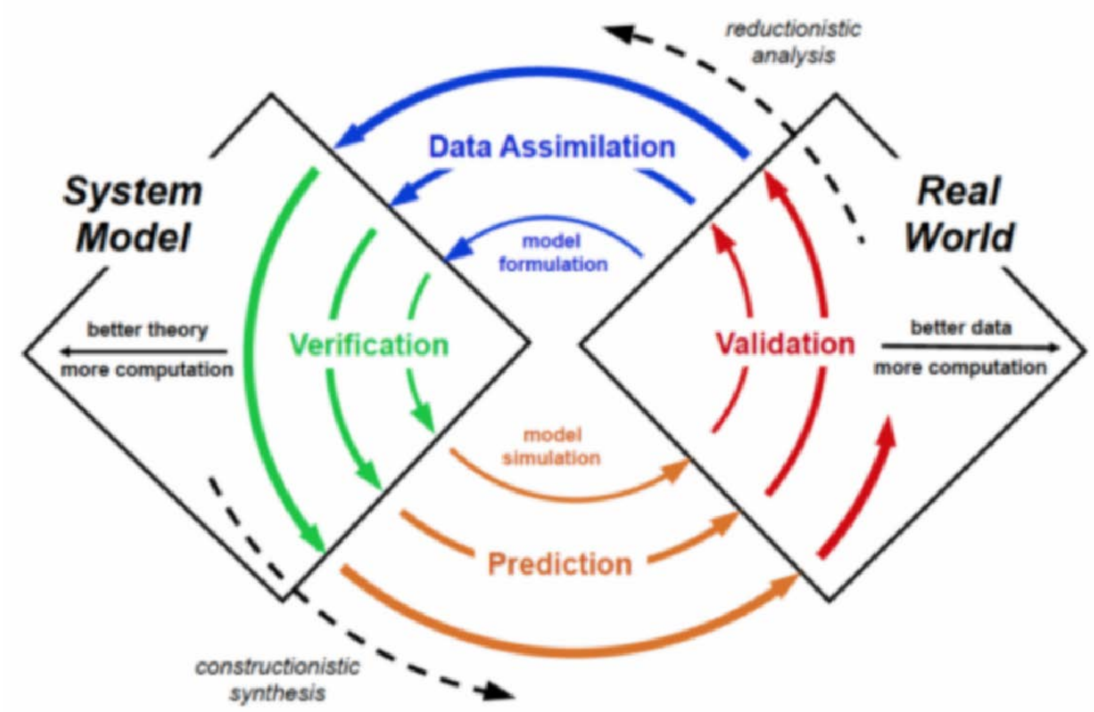
7. Predict (more) future situations

Inference spiral of science

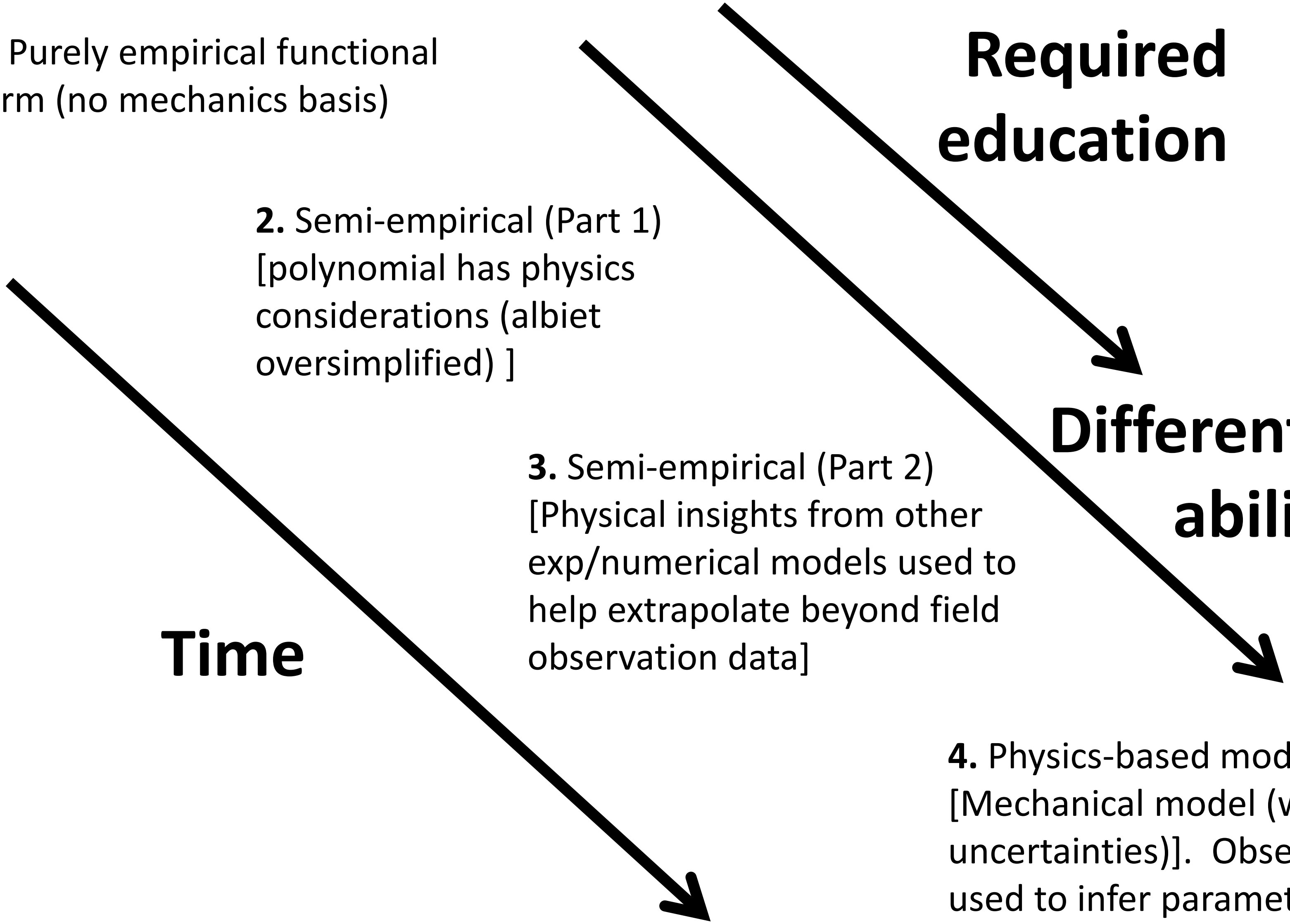
How to prevent diminishing returns?

Exponential increase in field observational data [more Eqs(?), better reconniassance(?)]

1. Improved model formulations (more physics) that allow greater utilization of observations and better assimilation of field, laboratory, and numerical modelling
2. More robust validation (how well do current models actually perform in a 'blind' prospective sense)
3. Understanding uncertainties as a means to identify fruitful areas to concentrate effort (and as a by-product provide predictions with explicit uncertainty estimates)



Modelling progression



Required education

Differentiation ability

Time

1. Purely empirical functional form (no mechanics basis)

2. Semi-empirical (Part 1) [polynomial has physics considerations (albiet oversimplified)]

3. Semi-empirical (Part 2) [Physical insights from other exp/numerical models used to help extrapolate beyond field observation data]

4. Physics-based model [Mechanical model (w spatial uncertainties)]. Observations used to infer parameters and constitutive relations

Physics-based modelling

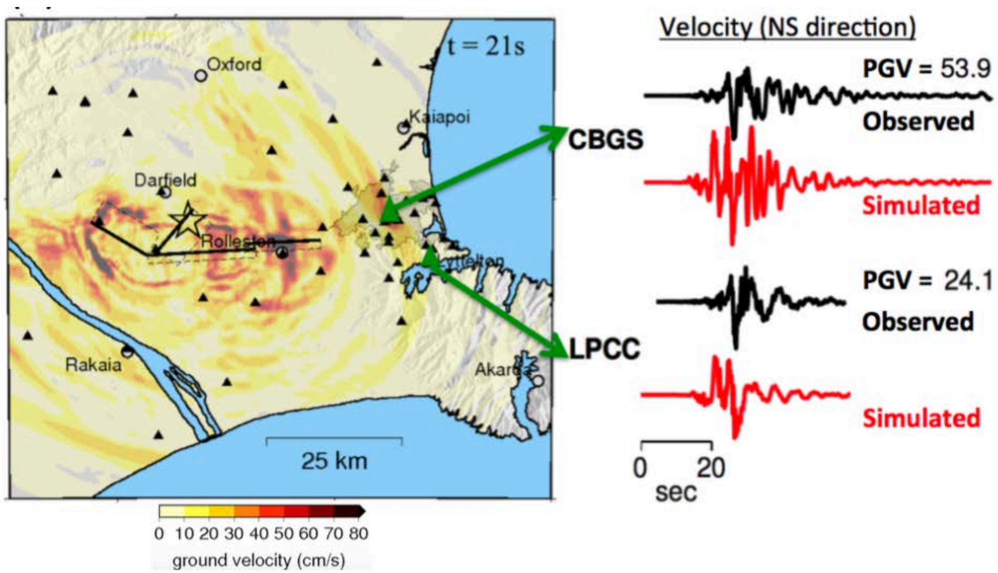
- Empirical liquefaction-induced impact models are tied directly to factor of safety approach used for triggering analyses

Seismic hazard loading

$$CSR_{Mw7.5,\sigma'_v} = 0.65 \frac{\sigma_v}{\sigma'_v} \frac{PGA}{g} \frac{r_d(M_w)}{MSF(M_w)}$$

$$\rightarrow CSR = \mathcal{F}(PGA, M_w)$$

- Inputs: Ground motion simulation methods are now able to provide seismic hazard directly in the form of acceleration time series
  - How to utilize this within empirical liquefaction impact models? (simply PGA and Mw?)
  - [e.g. we know that Mw alone is a poor proxy for number of cycles (being also a function of distance and deep basin conditions)]
  - Using a(t) directly?



Physics-based modelling

QuakeCoRE
NZ Centre for Earthquake Resilience

Soil element constitutive behaviour

- Modelled directly (.... although we need more test data under complex/realistic loading conditions)

Modelling system (layer) interactions

- Demand: How dynamic and constitutive response of soil elements modifies the transmitted ground motion to other soil elements in the system
- Capacity: Void redistribution and geometric nonlinearities

Physics-based modelling

Pros:
-Governing mechanics
-Develop an understanding of the problem
-'Extrapolation' to cases of interest is physically based
-A clear framework in which field, laboratory and numerical observations and insights can be integrated

-Simulations represent actual sensitivity of reality (?)

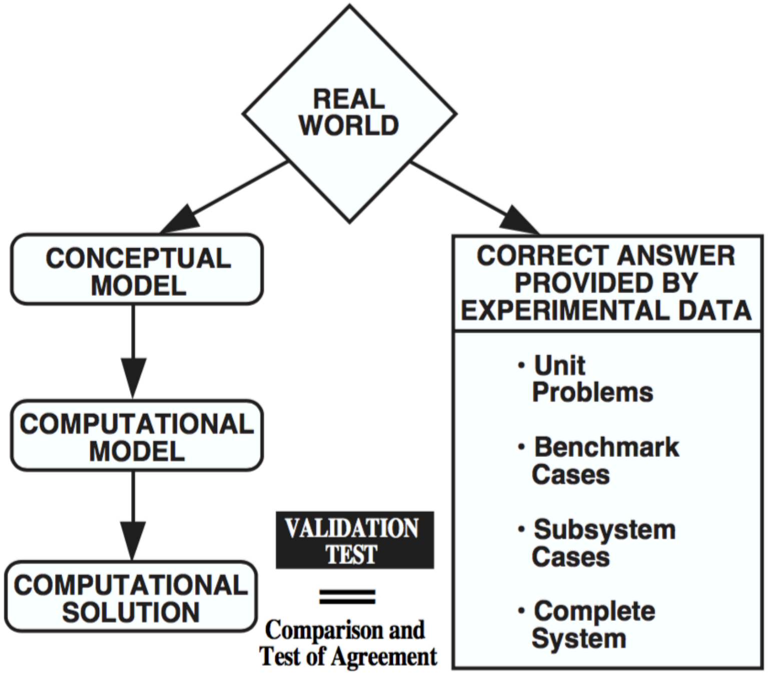
Hinderances:
-Methods to determine parameters often not well defined
-Simulations too sensitive to inputs
-Only the person who developed the model(s) can use it
-Validation is often biased because analyst is model developer

Better documentation

Robust validation

Validation

- Unit problems (e.g. lab element tests) -> Complete system



REAL WORLD

CONCEPTUAL MODEL

COMPUTATIONAL MODEL

COMPUTATIONAL SOLUTION

VALIDATION TEST

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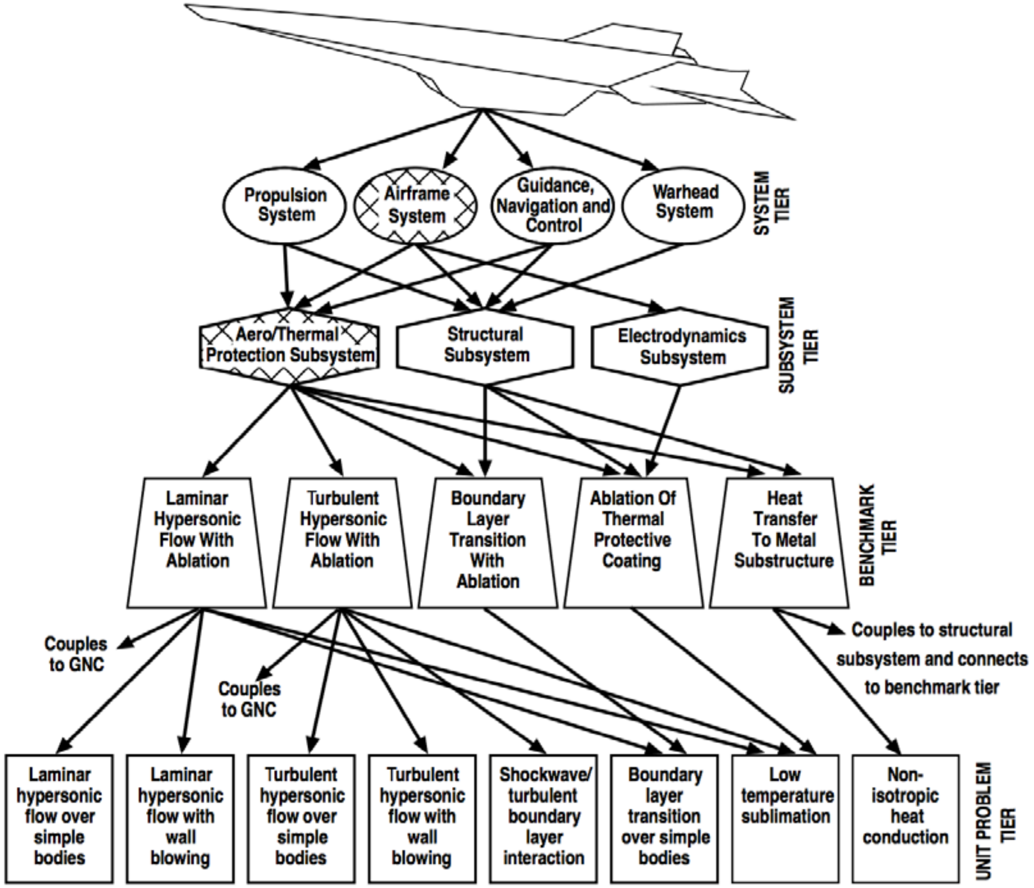
Comparison and Test of Agreement

CORRECT ANSWER PROVIDED BY EXPERIMENTAL DATA

- Unit Problems
- Benchmark Cases
- Subsystem Cases
- Complete System



SYSTEM TIER

Propulsion System

Airframe System

Guidance, Navigation and Control

Warhead System

SUBSYSTEM TIER

Aero/Thermal Protection Subsystem

Structural Subsystem

Electrodynamics Subsystem

BENCHMARK TIER

Laminar Hypersonic Flow With Ablation

Turbulent Hypersonic Flow With Ablation

Boundary Layer Transition With Ablation

Ablation Of Thermal Protective Coating

Heat Transfer To Metal Substructure

Couples to GNC

Couples to GNC

Couples to structural subsystem and connects to benchmark tier

UNIT PROBLEM TIER

Laminar hypersonic flow over simple bodies

Laminar hypersonic flow with wall blowing

Turbulent hypersonic flow over simple bodies

Turbulent hypersonic flow with wall blowing

Shockwave/ turbulent boundary layer interaction

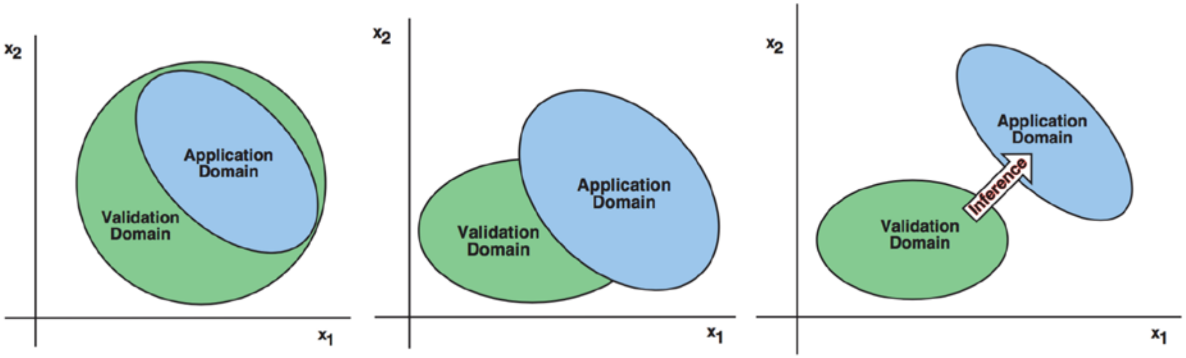
Boundary layer transition over simple bodies

Low temperature sublimation

Non-isotropic heat conduction

Validation

- Unit problems (e.g. lab element tests) -> Complete system
- Recognition of extrapolation inherent in prediction



- Transparency and reproducibility of validation:

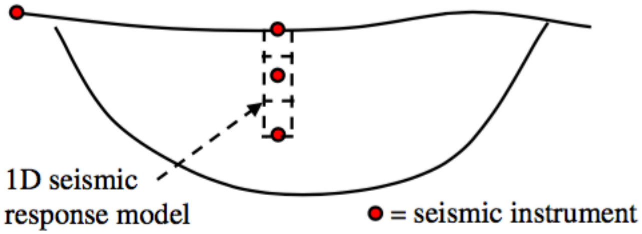
Usually (apparent) validation performed by the same people who are proponents (and often developers) of the numerical tools used

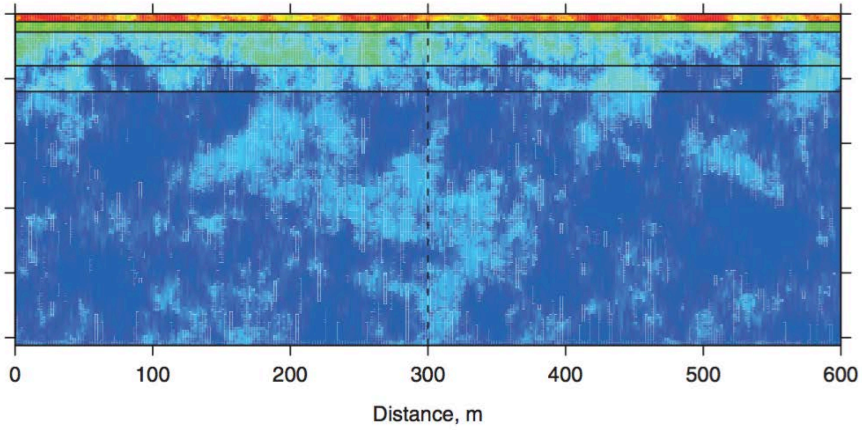
  - Open-source validation datasets (e.g. NGL)
  - Multi-year and multi-investigator validation initiatives (e.g. LEAP)

Uncertainties

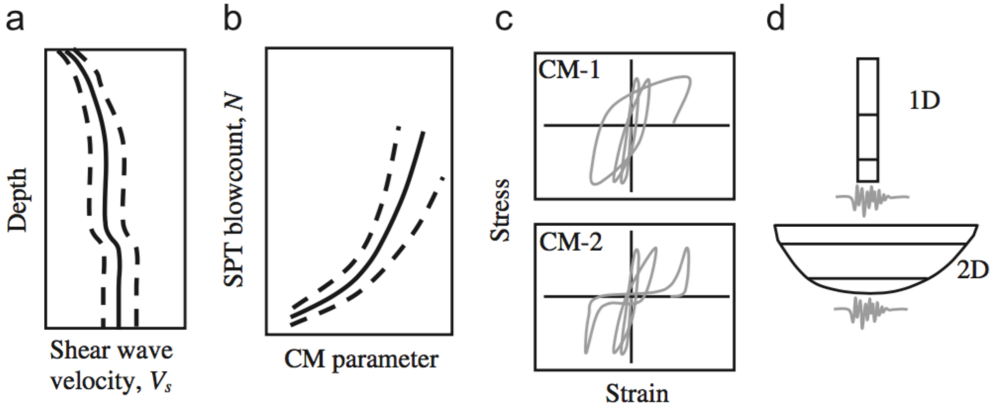
- Explicit consideration of uncertainties lags behind engineering seismology and structural earthquake engineering

- Consideration of uncertainties is critical to:
  - Transparent predictive precision of model
  - Identify principal sensitivities in problem <- places for further research





Site characterization uncertainty



(a) Site characterization; (b) constitutive parameters; (c) constitutive models; (d) model methodology