Validation of Simulations for Applications in Ground Motion Prediction

Jonathan P. Stewart

UCLA Samueli Engineering

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Collaborators

Sanaz Rezaeian and Nico Luco: USGS, Boulder, CO

Christine A. Goulet: USGS, Pasadena, CA

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Advancements in Physics-Based Simulations - Research Paper

EARTHQUAKE SPECTRA

Findings from a decade of ground motion simulation validation research and a path forward

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Sanaz Rezaeian[1], Jonathan P Stewart, M.EERI[2], Nicolas Luco, M.EERI[1], and Christine A Goulet, M.EERI[3]

Abstract

Simulated ground motions have the potential to advance seismic hazard assessments and structural response analyses, particularly for conditions with limited recorded ground motions such as large magnitude earthquakes at short source-to-site distances. However, rigorous validation of simulated ground motions is needed for hazard analysts, practicing engineers, or regulatory bodies to be confident in their use. A decade ago, validation exercises were mainly limited to comparisons of simulated-to-observed waveforms and median values of spectral accelerations for selected earthquakes. The Southern California Earthquake Center (SCEC) Ground Motion Simulation Validation (GMSV) group was formed to increase coordination between simulation modelers and research engineers with the aim of devising and applying more effective methods for simulation validation. Here, we summarize what has been learned in over a decade of GMSV activities, principally reflecting the views of the SCEC research community but also extending our findings and suggestions for a path forward to broader United States and worldwide simulation validation efforts. We categorize different validation methods according to their approach and the metrics considered. Two general approaches are to compare validation metrics from simulations to those from historical records or to those from semi-empirical models. Validation metrics are categorized into ground motion characteristics and structural responses. We discuss example validation studies that have been impactful in the past decade and suggest future research directions. Key lessons learned are that validation is application-specific, our outreach and dissemination need improvement, and much validation-related research remains unexplored.

[1]Research Civil Engineer, Denver Federal Center, U.S. Geological Survey, Denver, CO, USA
[2]Civil & Environmental Engineering Department, University of California, Los Angeles, CA, USA
[3]Southern California Earthquake Center, University of Southern California, Los Angeles, CA, USA

Corresponding author:
Sanaz Rezaeian, Research Civil Engineer, Denver Federal Center, U.S. Geological Survey, P.O. Box 25046, MS 966, Denver, CO 80225, USA.
Email: srezaeian@usgs.gov

Introduction

Validation

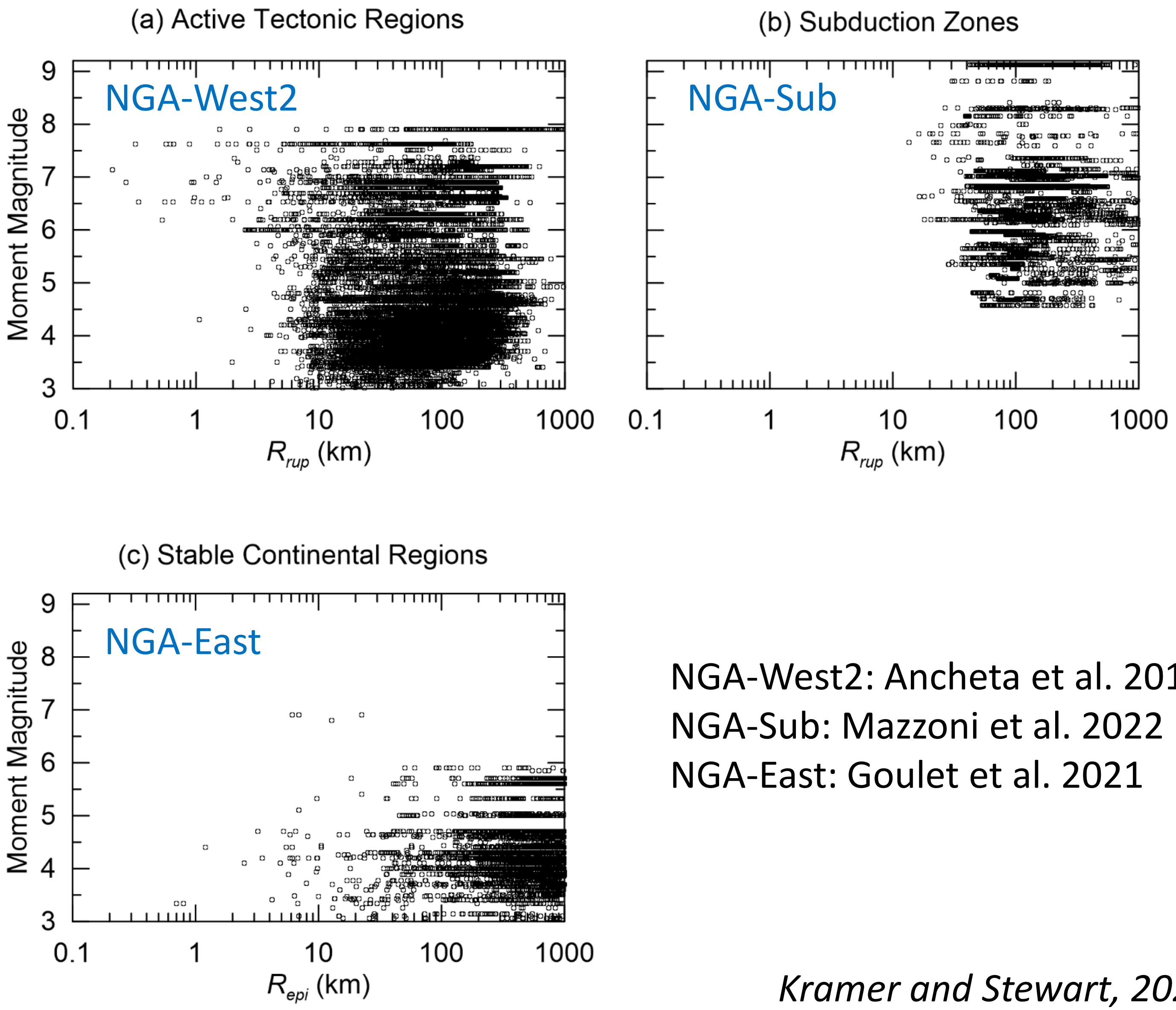
- Comparison of analysis predictions to data
- Aim is assessment of whether the analysis method captures key features of data

Introduction

Validation

Need for simulations

- Fill data gaps



NGA-West2: Ancheta et al. 2014
NGA-Sub: Mazzoni et al. 2022
NGA-East: Goulet et al. 2021

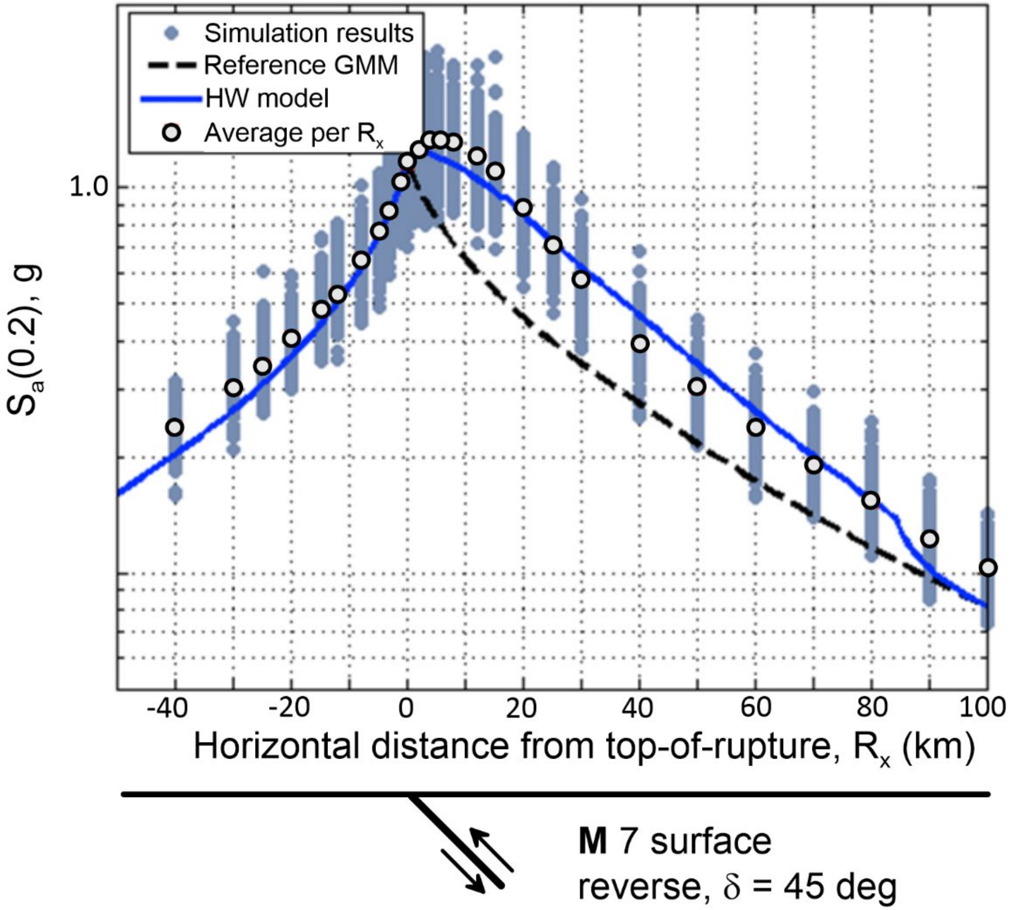
Kramer and Stewart, 2025

Introduction

Validation

Need for simulations

- Fill data gaps
- Assess impacts of particular conditions for ground motion modeling



Modified from Donahue and Abrahamson, 2014

Introduction

Validation

Need for simulations

Simulation methods

- Physics-based stochastic

Introduction

Validation

Need for simulations

Simulation methods

- Physics-based stochastic
- Deterministic and hybrid methods

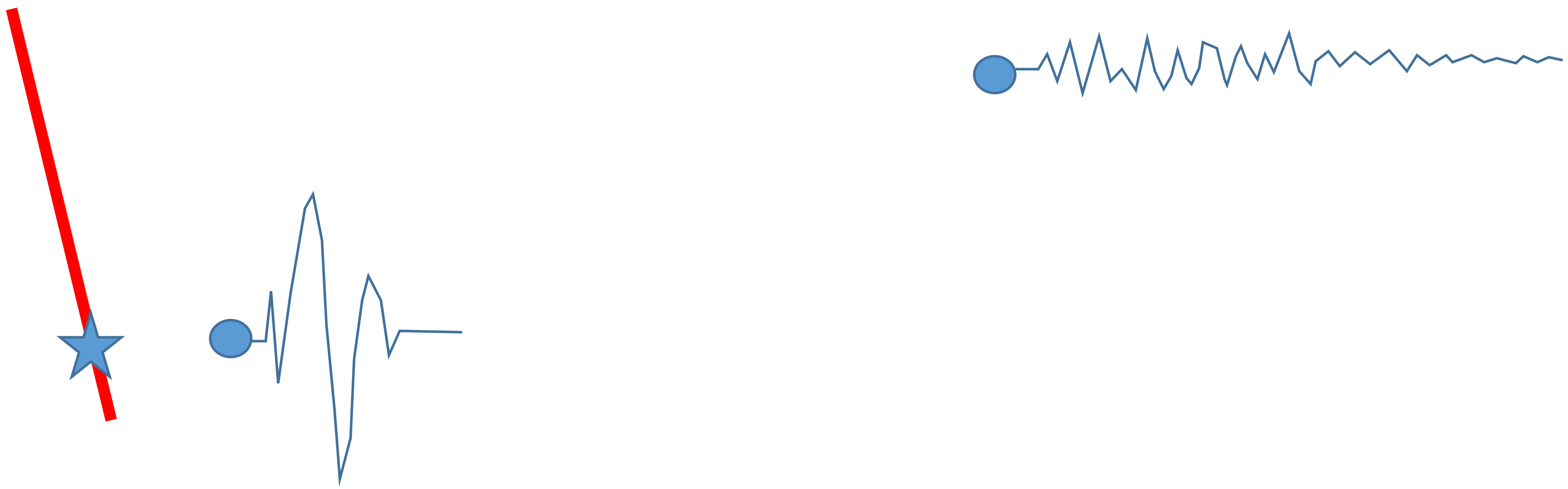
Present focus

Validation for ground motion prediction

Ground motion scaling

- Refers to how ground motion changes in response to changes in a parameter

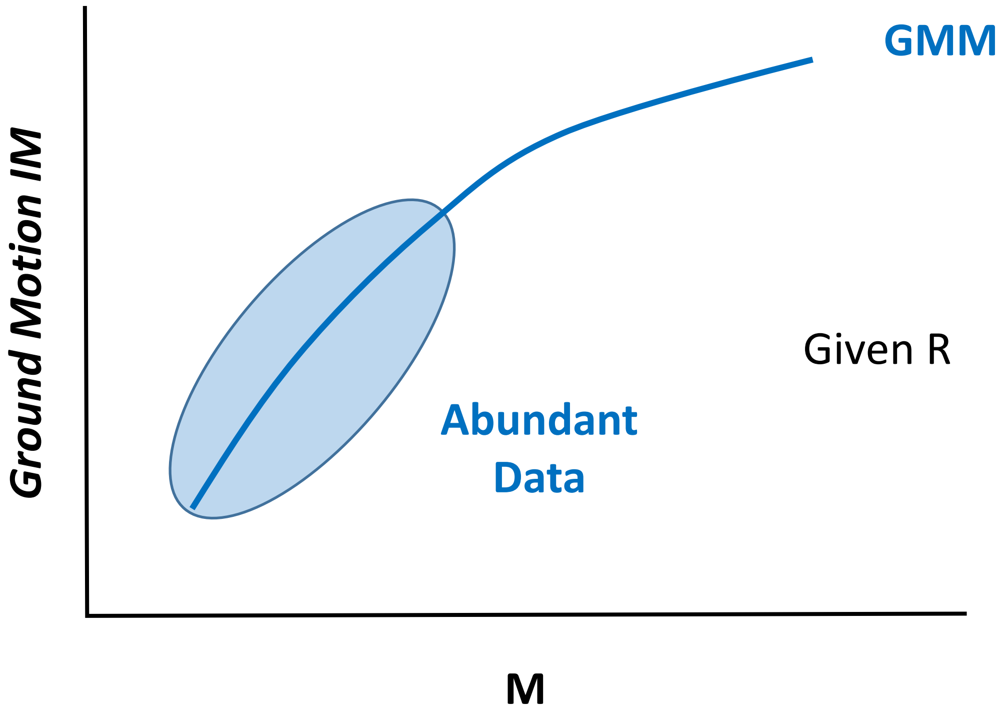
e.g., distance-scaling



Validation for ground motion prediction

Ground motion scaling

- Refers to how ground motion changes in response to changes in a parameter
- Critical component of GMMs

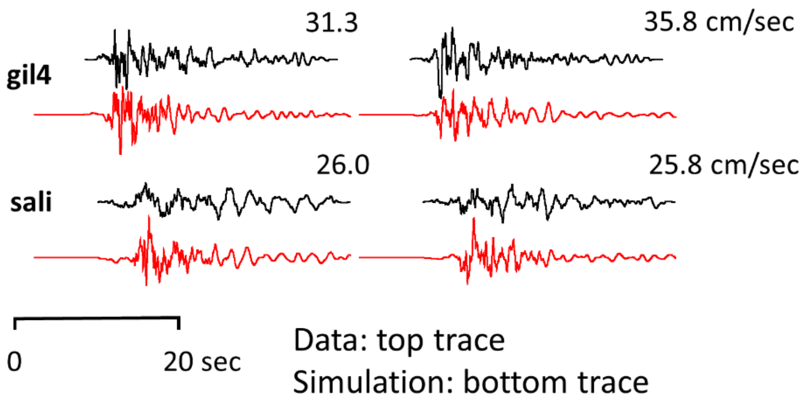


Validation for ground motion prediction

Ground motion scaling

Validation methods

- Waveform comparisons to data



Modified from Graves and Pitarka, 2010

<u>Issues:</u>

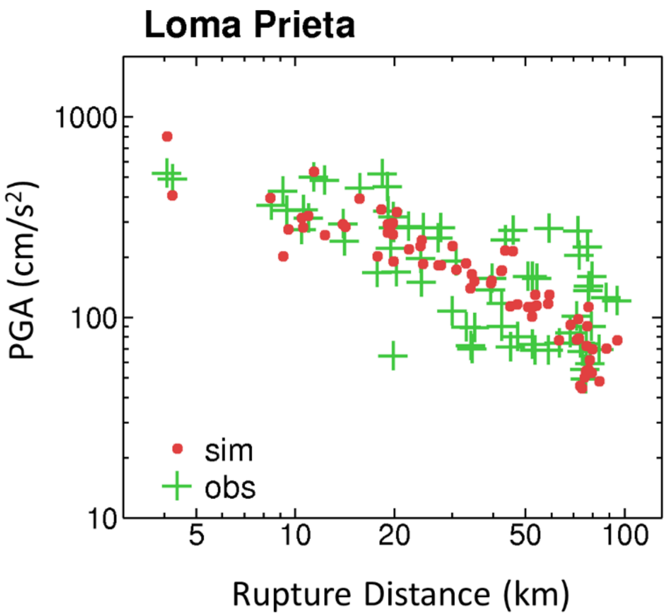
1) Potential for circularity
2) High-frequency components of ground motion may not be considered
3) Difficult to assess scaling

Validation for ground motion prediction

Ground motion scaling

Validation methods

- Waveform comparisons to data
- Ground motion IM comparisons to recordings



Modified from Graves and Pitarka, 2010

<u>Issues:</u>

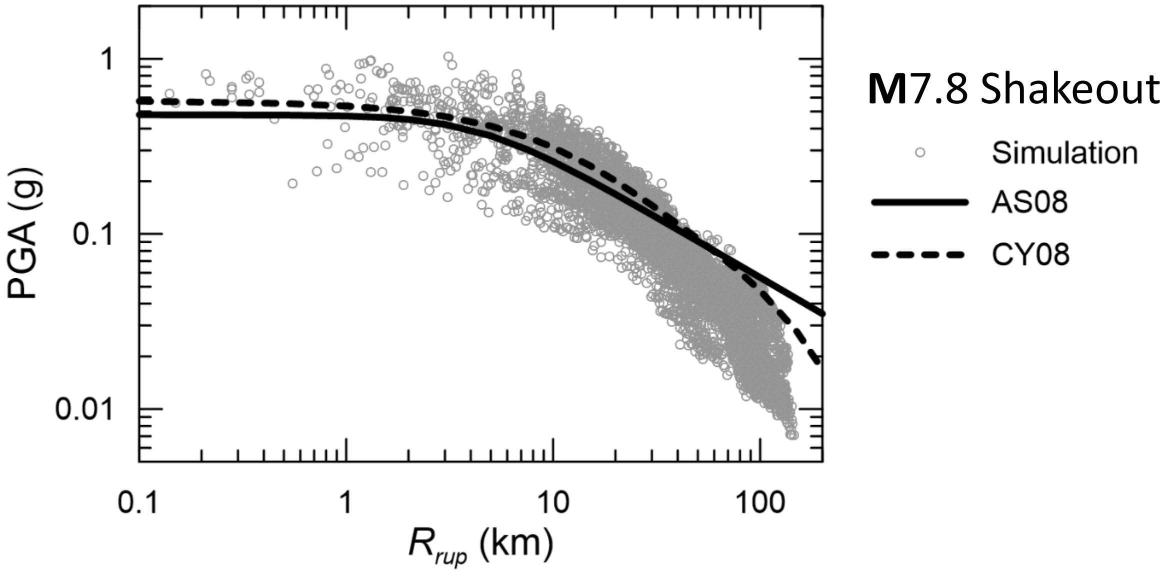
1) Data limitations
2) Potential for circularity

Validation for ground motion prediction

Ground motion scaling

Validation methods

- Waveform comparisons to data
- Ground motion IM comparisons to recordings
- **Ground motion IM comparisons to GMMs**



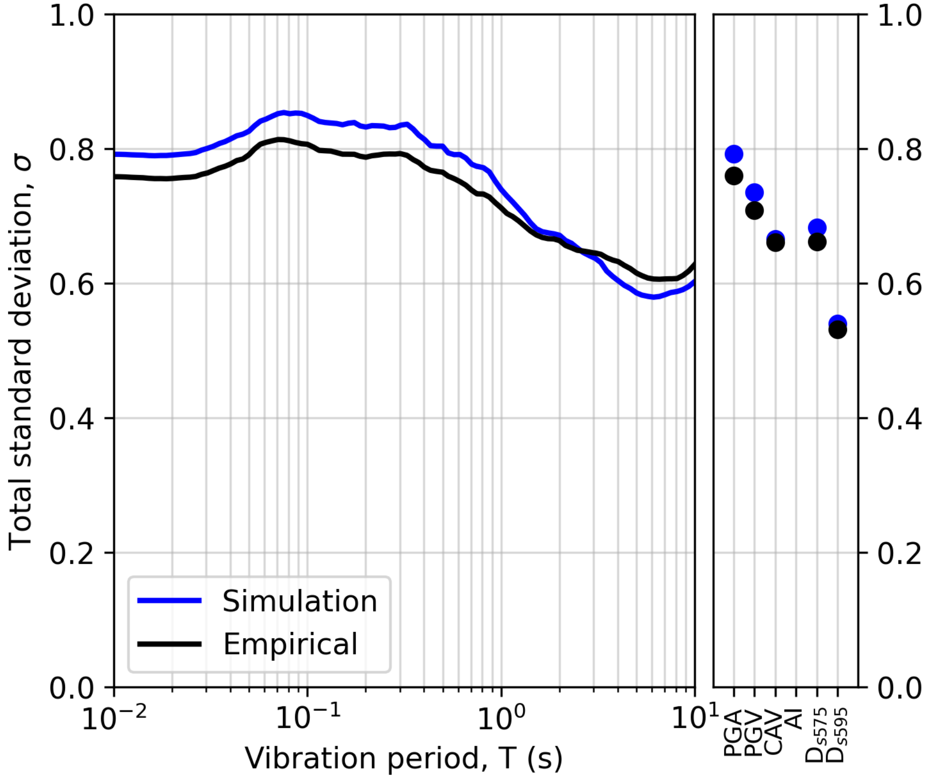
Modified from Star et al., 2011

Validation for ground motion prediction

Ground motion scaling

Validation methods

- Waveform comparisons to data
- Ground motion IM comparisons to recordings
- Ground motion IM comparisons to GMMs



Lee et al., 2022

Issue: GMM limitations beyond data range

Closure

Value of independence in validation research

Ideal sequence:

- Initial validation $\rightarrow$ model improvement $\rightarrow$ updated validation
- Results in improved models and parameter selection protocols

Need for validation continues

- Advancements in simulation methods (3D, dynamic rupture)
- Greatest validation needs: scaling, aleatory (sigma), epistemic

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