Methods for Numerically Efficient Estimation of Seismic Risk for Distributed Systems

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Introduction

- The PEER gas-pipeline risk study computes the seismic risk using the PEER Framing Equation

$$P(DV) = \int_{IM} \int_{EDP} \int_{DM} P(DV|DM) f_{DM}(EDP) f_{EDP}(IM) Rate(IM) dDM\, dEDP\, dIM$$

  - Intensity Measure (IM) - Spectral Acc
  - Engineering Design Parameter (EDP) - Permanent ground displacement
  - Damage Measure (DM) - Pipe Strain
  - Decision Variable (DV) - Pipe Break or Leak

Calculation Speed Issues

- Spatially distributed gas pipeline system:
    - For the evaluation of the pipeline system during a single earthquake, realizations of the spatial distribution of the IM are also needed to capture the spatial correlation of the ground motion
- Combining this large set of realizations of the IM with the integrals over EDP and DM for each site leads to long computational times.
    - Including epistemic uncertainty in each model further increases the run times.
- To reduce the run times:
    - Use polynomial chaos (PC) to model the effect of spatial correlation of the IM and epistemic uncertainty in the model inputs (median models)
    - Approximate the EDP, DM, and DV models with linear forms with analytical solutions to the integrals.
- With these approximations, the run times for system risk are reduced by over a factor of 1,000.

Computing the PEER Risk Integral

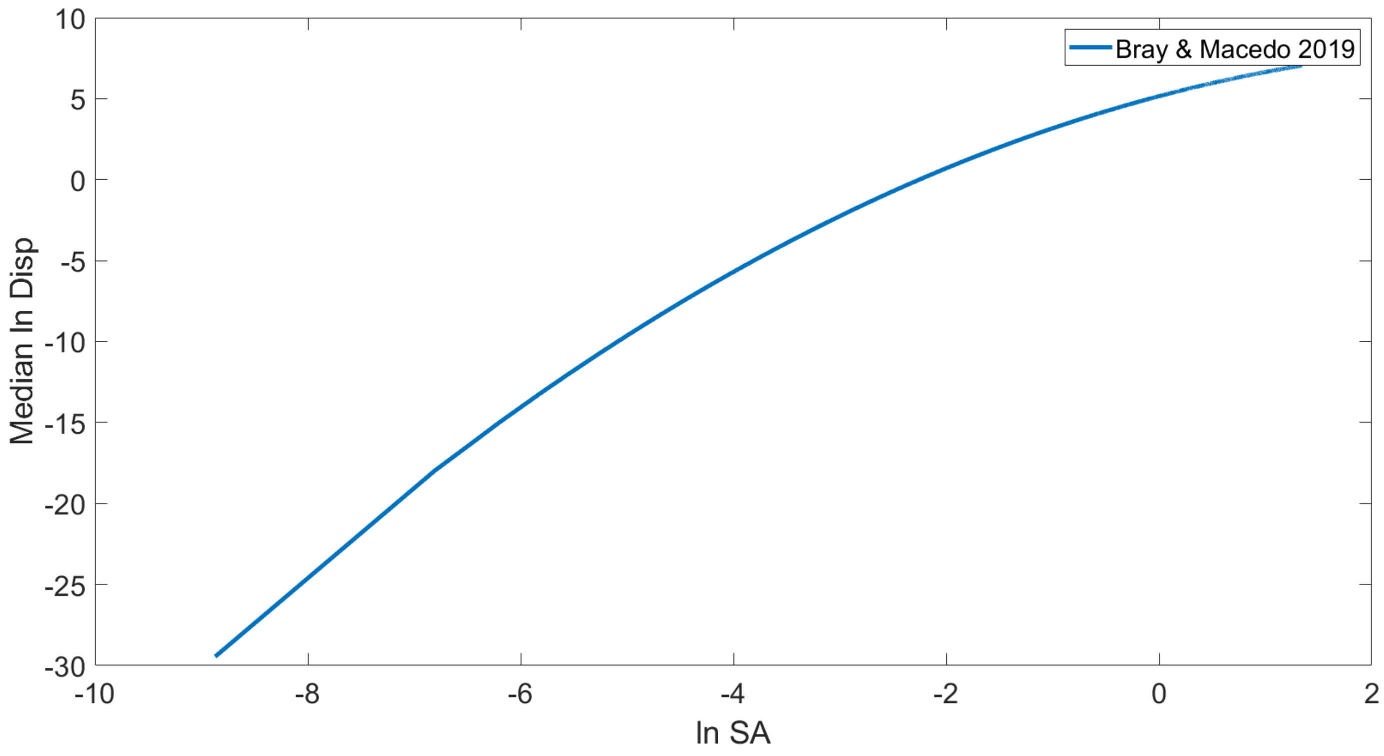
- <u>For a Single Model</u>

  (no epistemic uncertainty)
  - Common approach
    - Numerical integration
  - OpenSRA approach
    - Use approximations to EDP, DM, DV models to allow analytical calculation of the PEER integral
    - Loss of accuracy in total risk is small

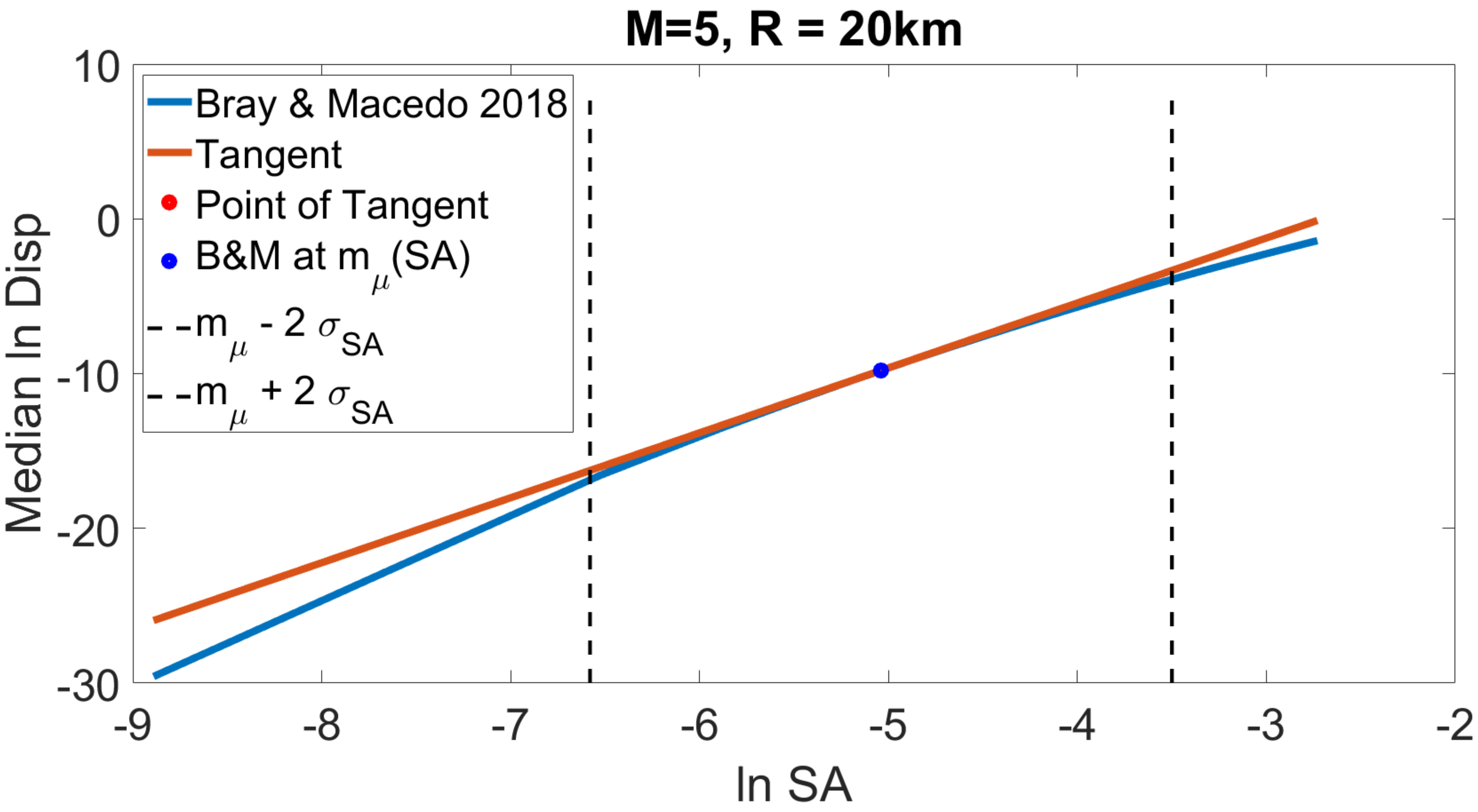
- <u>Epistemic Uncertainties</u>
  - Ground-motion models
  - EDP(IM) model
  - DM(EDP) model
  - DV(DM) model
- Common approaches
  - Logic trees with 3 branches per node for EDP, DM, DV and 15 branches for GMM (ergodic)
    - 405 total branches
- OpenSRA Approach
  - Use polynomial chaos to approximate the epistemic uncertainty in the input models
  - Epistemic fractiles are more accurate than using sparse logic trees (3 branches)

Example EDP(IM) Model

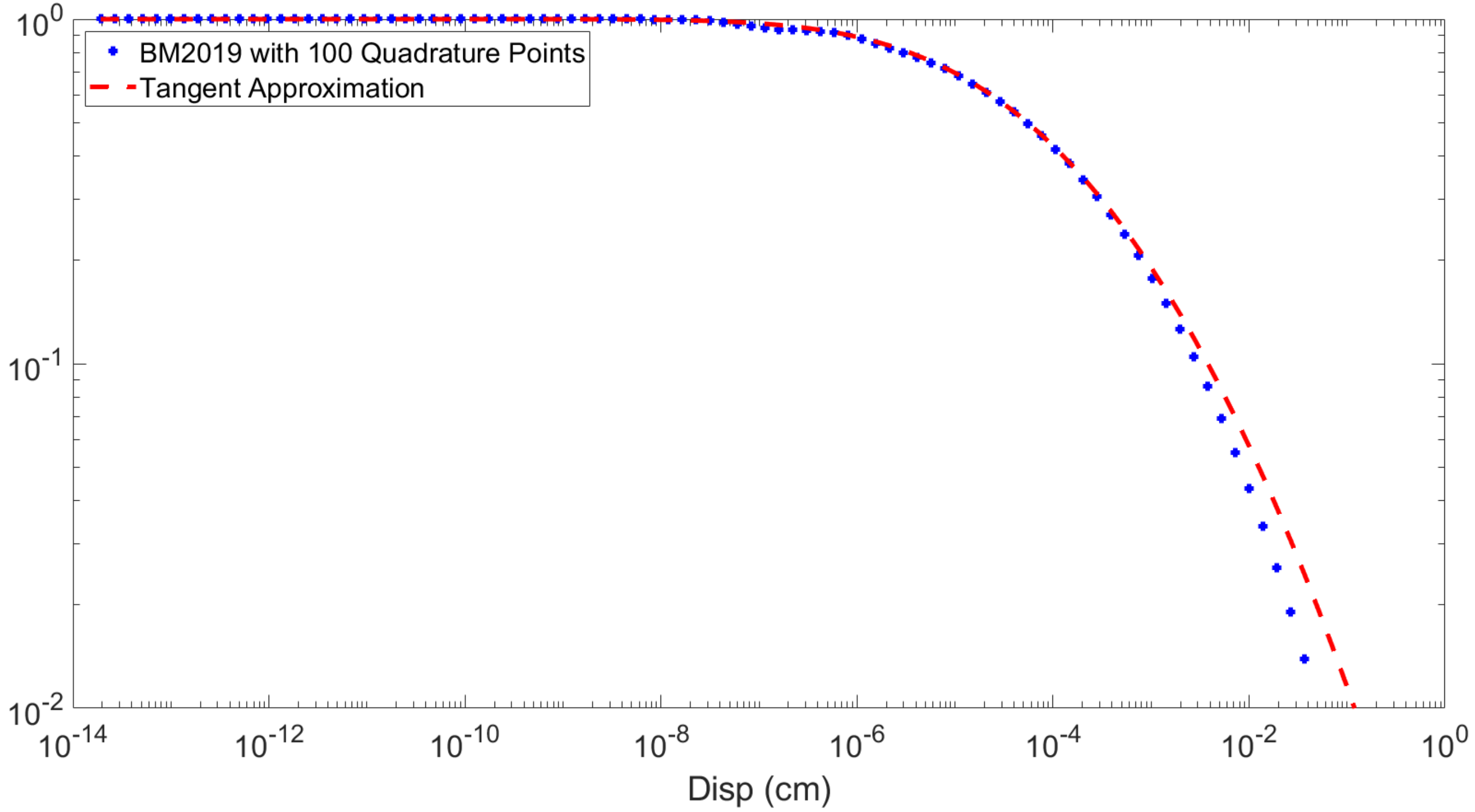
- Permanent Displacement as a function of Spectral Acceleration
  - Bray and Macedo (2019) model has curvature



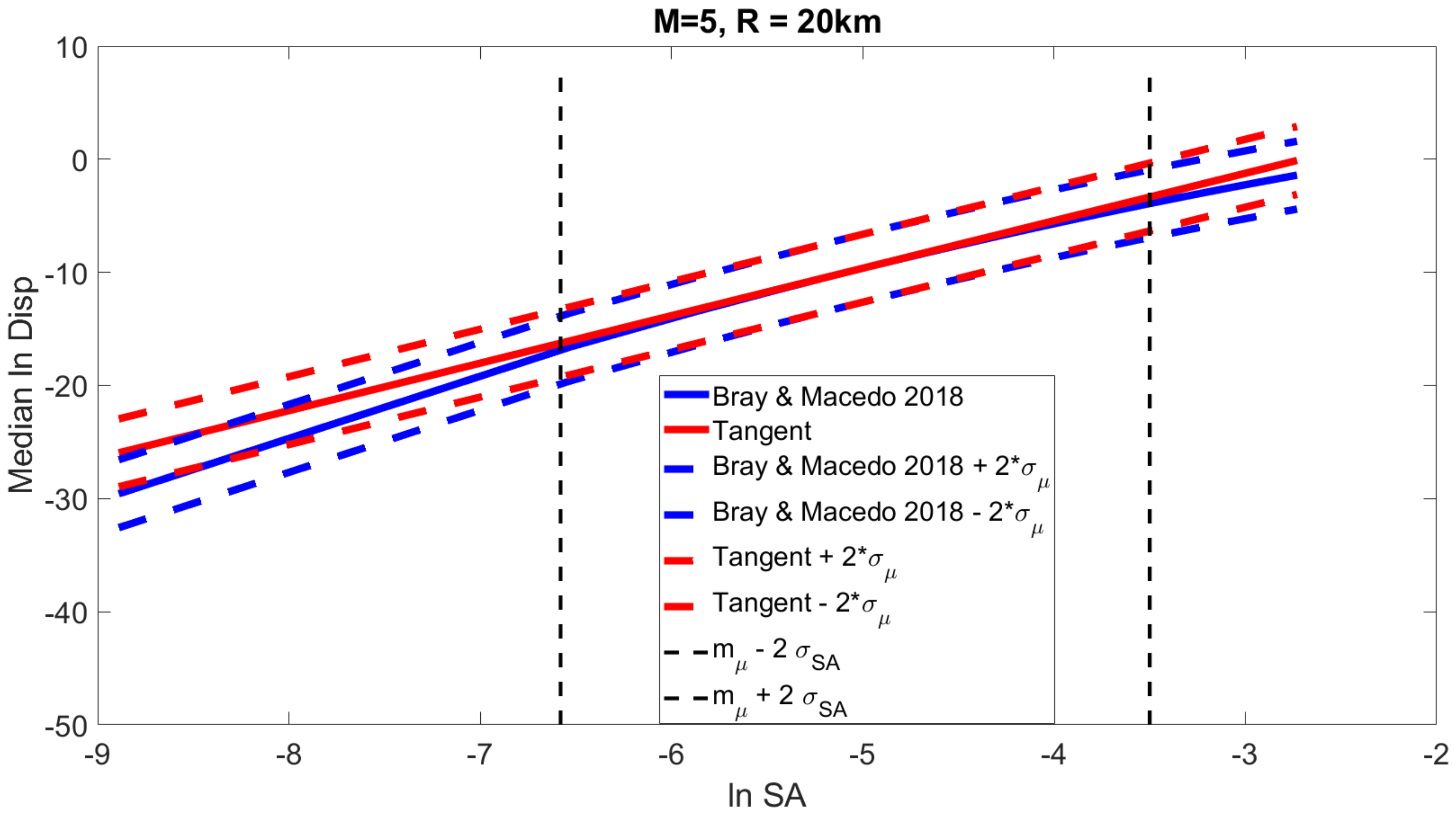
Approximate EDP(IM) Median with Linear Scaling



Accuracy of P(EDP>z) using the Tangent Approximation for Median EDP(IM)



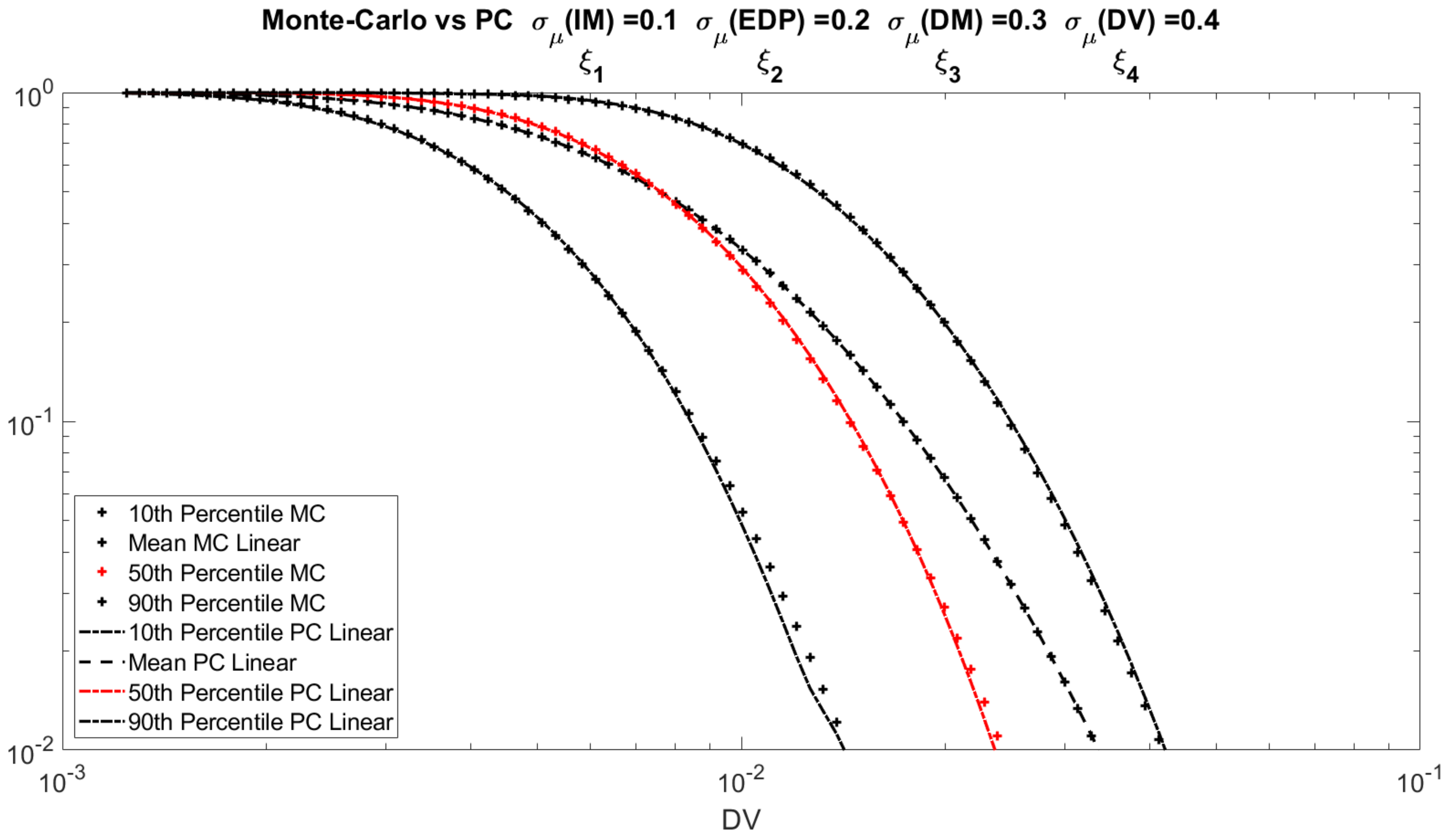
Epistemic Uncertainty in Median EDP(IM) Model



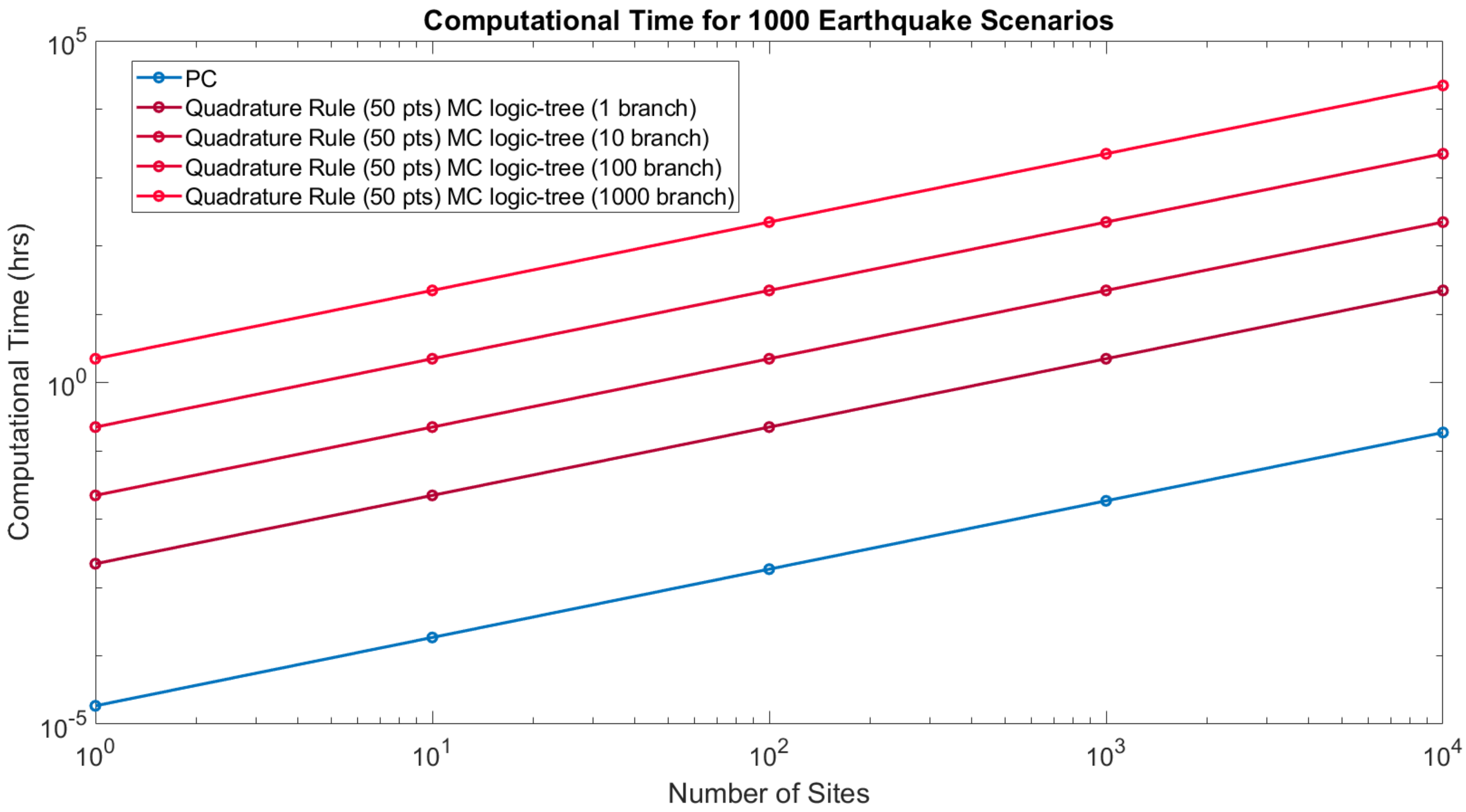
Approximation using PC to Propagate the Epistemic Uncertainty

- Polynomial Chaos
  - Models the change in distribution of the results using a set of basis functions with amplitudes
  - Applied to IM, EDP, DM, and DV
  - Epistemic fractiles are computed through post-processing step with efficient sampling

Accuracy of Epistemic Uncertainty Fractiles



Improved Calculation Times for System Risk to Gas Pipelines Including Epistemic Uncertainties



Summary

- For spatially extended systems, such as natural gas pipelines, direct estimation of the PEER risk integral including epistemic uncertainties can be very slow
- Significant improvements in computational speed can be made using approximations for the shape of the median EDP(IM), DM(EDP), and DV(DM) that result in analytical solutions to the PEER integral with an acceptable reduction in accuracy
- Additionally, improvements in computational speed for addressing epistemic uncertainty in the IM, EDP, DM, and DV can be made using Polynomial Chaos in place of direct sampling of the logic trees
- Overall, the improvement in speed is over a factor of 1,000 compared to numerical integration and sampling of the logic trees, making it practical to compute system risk for gas pipeline using desktop computers (~10 minutes)