Which Scenario Should We Design For? Insights from House Elevation for the Multiple PDF Problem

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HOUSE ELEVATION

Households elevate their homes to manage flood risks, but regulations and guidance are silent on key questions [1, 2].

- Q1 How to adapt guidance to building characteristics or household preferences?
- Q2 How does nonstationary hazard change guidance?
- Q3 Which model of nonstationary hazard to use?

(a) Selinsgrove, PA (b) Houston, TX (c) Plaquemines Parish, LA (d) Dare County, NC

Figure 1: (a) JDG, (b) Google Maps, (c) Mitch Epstein / New York Times (d) Rob Nichols / PSU.

These challenges also affect other adaptation plans and engineering designs (fig. 10).

CASE STUDY: NORFOLK, VA

We model a *hypothetical* house in Norfolk, VA, where sea level rise drives nonstationary future flood hazard, following the approach of ref. [1].

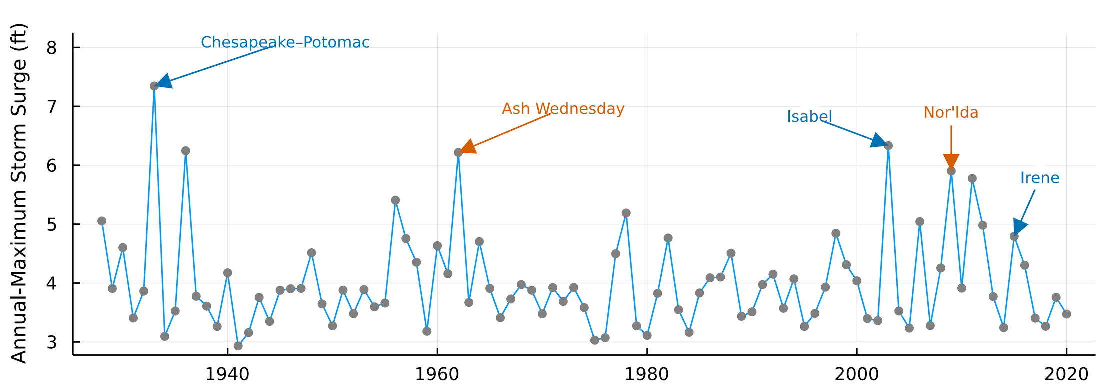

Figure 2: Time series of annual maximum storm surges (after subtracting mean sea level) at Sewells Point, VA. Purple (orange) arrows denote notable tropical cyclones (nor'easters).

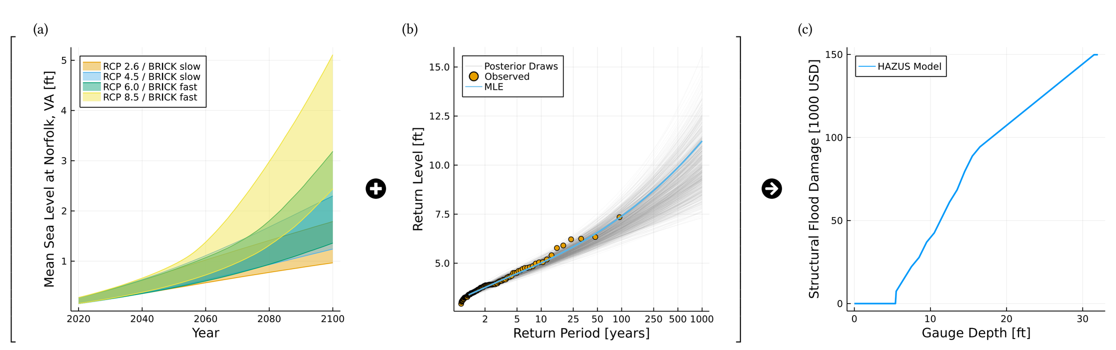

Figure 3: Neglecting hydrodynamics, we add sea level rise (a) to a Bayesian GEV model of storm surge (b) to get flood hazard. The convolution of hazard and fragility (c) yields an assessment of damages and tradeoffs (fig. 6).

ONE SIZE DOES NOT FIT ALL!

- Tailoring guidance to specific building characteristics can improve outcomes
- Elevating to "BFE plus a foot" is not always optimal [1, 2]
- Both over- and under-building can be costly [3, 4]

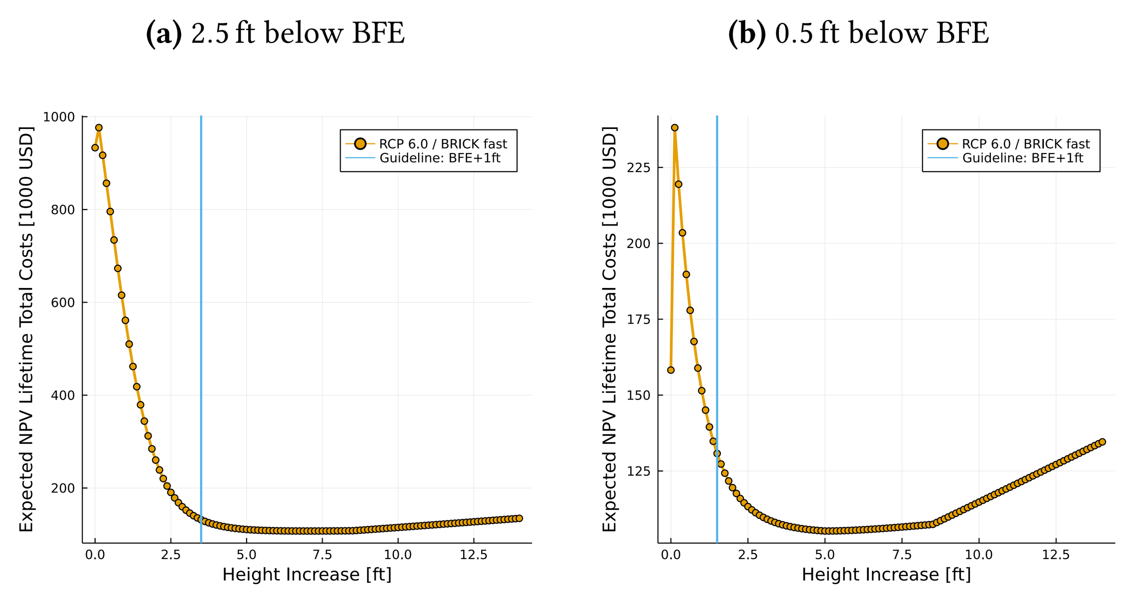

Figure 4: Tradeoffs between construction cost and expected NPV lifetime costs for houses initially situated (a) 2.5 ft below the base flood elevation (BFE) (under representative concentration pathway (RCP) 6.0 with fast BRICK [5] dynamics). Note unequal *y*-axis scales.

THE MULTIPLE PDF PROBLEM

Uncertainties from multiple model structures (*e.g.*, ice sheet dynamics) and/or scenarios (*e.g.*, emissions pathways) create multiple estimates of time-varing hazard, *i.e.*, the ***Multiple PDF Problem***. Including additional models [6–8] *would compound this challenge.*

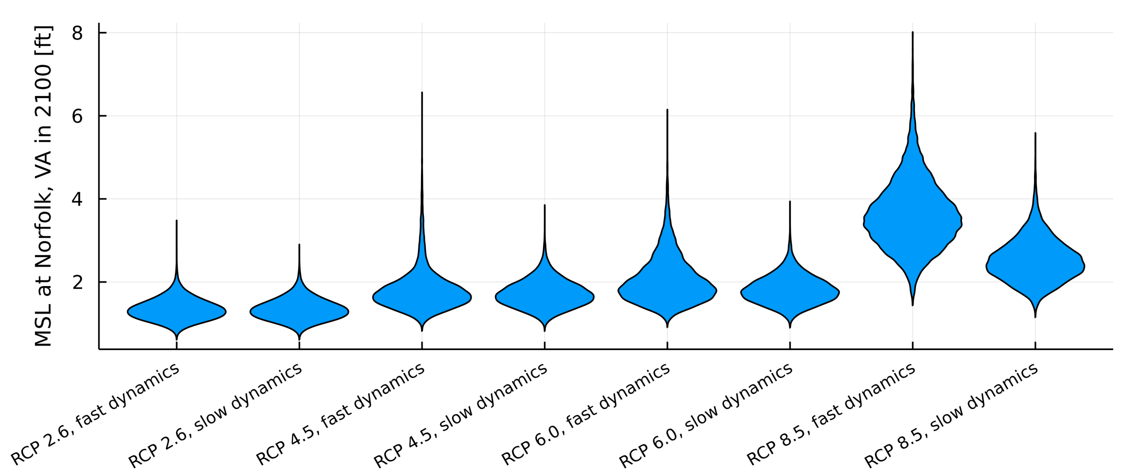

Figure 5: Sea level rise projections use the BRICK model [5, 8]. We consider *eight time-dependent PDFs of sea level rise*: four RCP scenarios × two parameterizations of ice sheet processes.

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1. Zarekarizi, M. et al. *Nature Communications.* doi:10.1038/s41467-020-19188-9. 2. Xian, S. et al. *Journal of Hydrology.* doi:10.1016/j.jhydrol.2017.02.057. 3. Ansar, A. et al. (2019). 4. Doss-Gollin, J. et al. *Earth's Future.* doi:10.1029/2019ef001154. 5. Wong, T. E. et al. *Geoscientific Model Development.* doi:10.5194/gmd-10-2741-2017. 6. Kopp, R. E. et al. *Earth's Future.* doi:10.1002/2017ef000663. 7. DeConto, R. M. et al. *Nature.* doi:10.1038/nature17145. 8. Ruckert, K. L. et al. *Scientific Reports.* doi:supp. 9. Schneider, S. H. *Nature.* doi:10.1038/35075167. 10. Schneider, S. H. *Climatic Change.* doi:http://dx.doi.org/10.1023/A:1014276210717. 11. Wong, T. E. *Advances in Statistical Climatology, Meteorology and Oceanography.* doi:10.5194/ascmo-4-53-2018. 12. Yao, Y. et al. *Bayesian Analysis.* doi:10.1214/17-ba1091. 13. Gelman, A. et al. (2020). 14. Gelman, A. et al. *British Journal of Mathematical and Statistical Psychology.* doi:10.1111/j.2044-8317.2011.02037.x. 15. Quinn, J. D. et al. *Earth's Future.* doi:10.1029/2020ef001650. 16. Hausfather, Z. et al. *Nature.* doi:10.1038/d41586-020-00177-3.

IT MATTERS WHICH PDF YOU CHOOSE!

Any optimal strategy or Pareto frontier is conditional upon an (explicit or implicit) model of future outcomes.

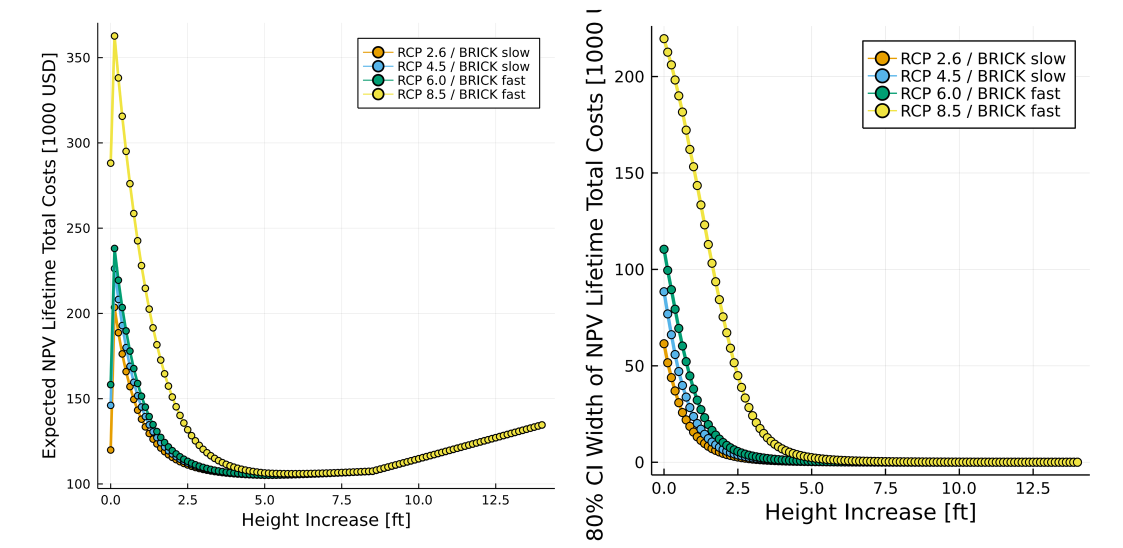

Figure 6: Tradeoffs between (L) construction cost and expected lifetime costs or (R) construction cost and the uncertainty of future lifetime costs depend on the PDF selected.

Weights assigned to PDFs or simulations, **including implicit uniform weights**, should be communicated transparently to facilitate critique and improvement

SYNTHESIZING PDFS FOR DECISION RELEVANCE

While comparing results across many PDFs is a valuable exploratory exercise (see, *e.g.*, fig. 6), providing end users (*e.g.*, households practicing engineers, and planning departments of local governments) with many PDFs may lead to confusion, inconsistency, and potentially liability (see refs. [9, 10]).

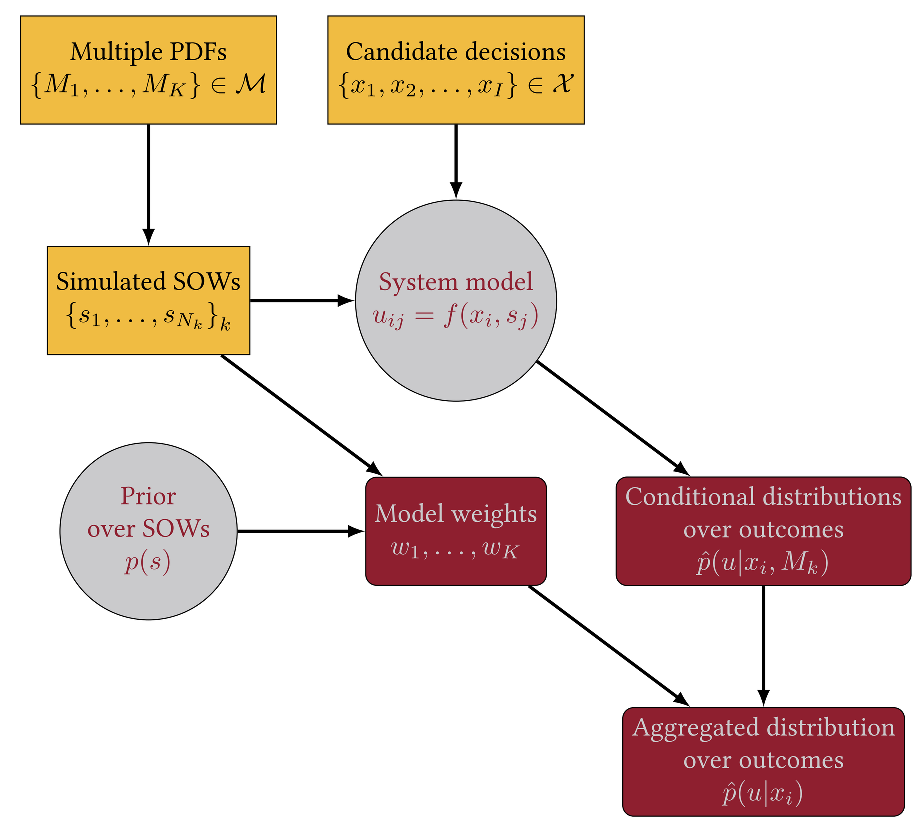

Figure 7: "Prior Model Averaging" framework.

Our approach to synthesizing PDFs is designed for the common case of assessing decisions using simulations (SOWs) from each of K PDFs. A system model (f) quantifies the performance (u) of a decision (x) under a single SOW (s). To synthesize, we weight PDFs using an approach based on Bayesian Model Averaging [11, 12].

KEY MESSAGE

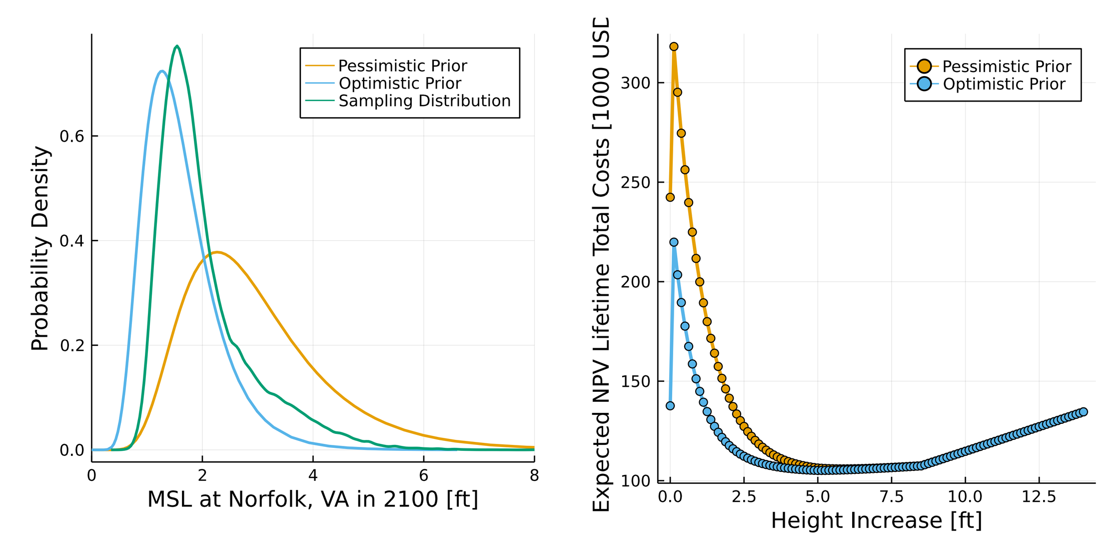

Figure 8: The prior model averaging approach (fig. 7), uses a probability distribution representing subjective belief to average insights across each PDF available. Alternative priors can provide robustness checks.

- Natural extensions to Bayesian updating
- Belief $p(s)$ can't be "right" [13, 14] or "neutral" [15]
- Instead, we can ask **what assumptions are different priors consistent with?**

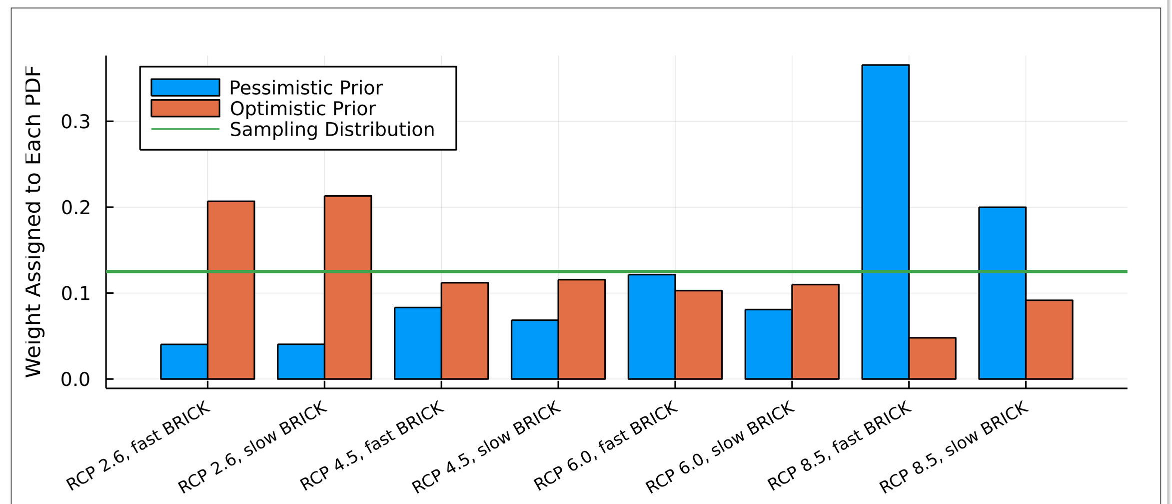

Figure 9: The weights assigned to each PDF (from fig. 5) under each prior considered.

"Pessimistic" ("Optimistic") prior heavily weights RCP 8.5 (2.6), which is unlikely given current policies [16].

LOOKING AHEAD

This didactic example illustrates a need for better synthesis and communication of deep uncertainties for decision making. **LET'S COLLABORATE ON:**

- More complex models to capture more relevant metrics
- Better models of nonstationary hazards
- Interacting, sequential decisions

(a) Stormwater (b) Bridge Clearance

Figure 10: House elevation is just one of many design problems where nonstationary hazards, subject to scenario nd model structure uncertainties, drive outcomes. (a) JDG (b) D. Howard / Wikipedia.

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