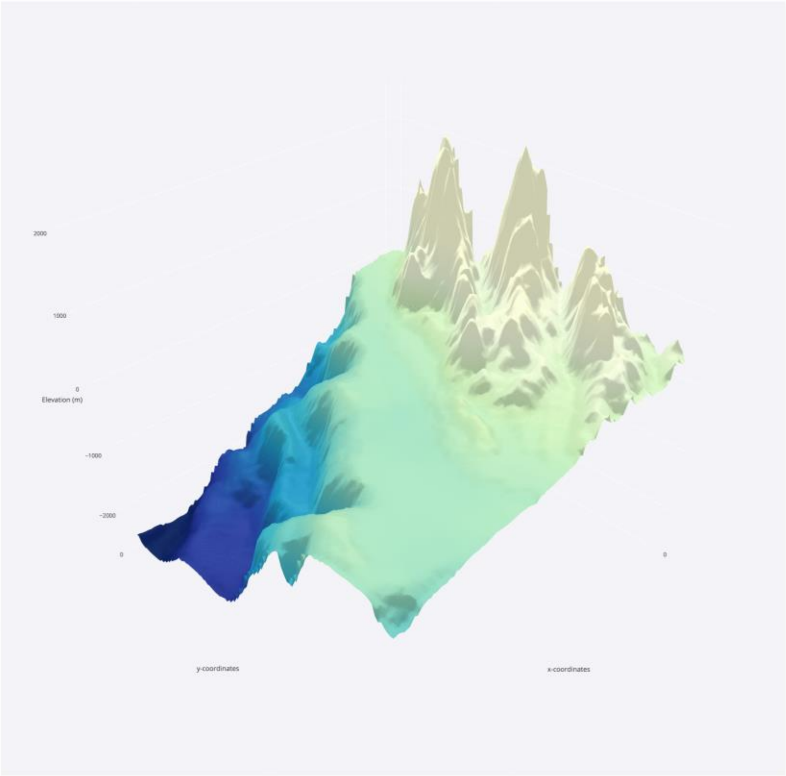
BayesLands: Distributed parallel tempering for uncertainty quantification in basin and landscape evolution via Badlands

Rohitash Chandra

1. EarthByte Research Group, School of Geosciences

2. Centre for Translational Data Science



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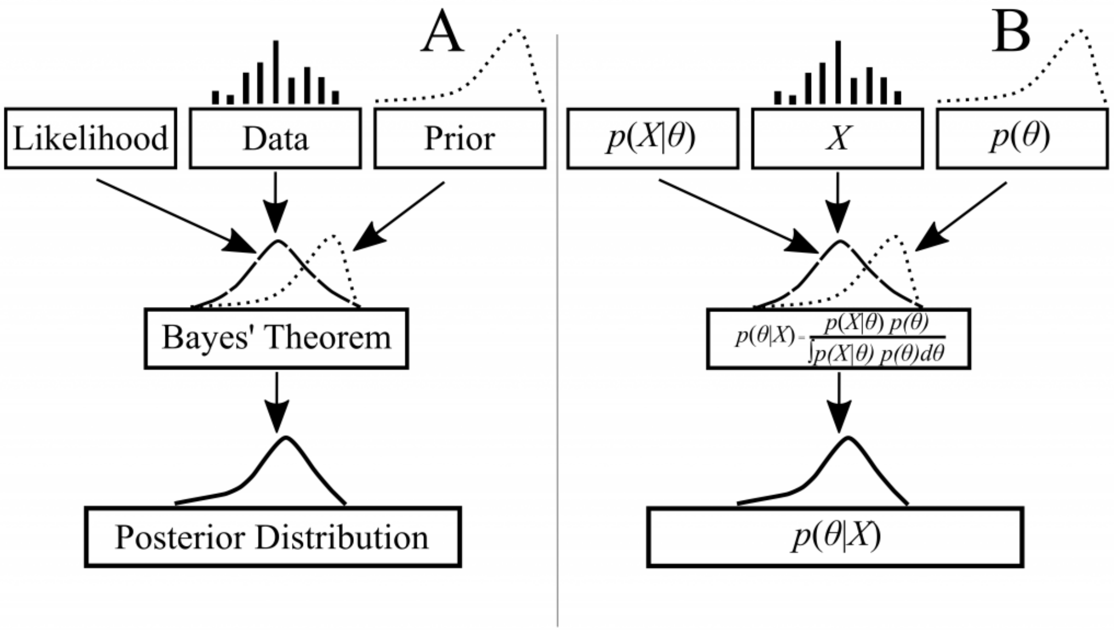
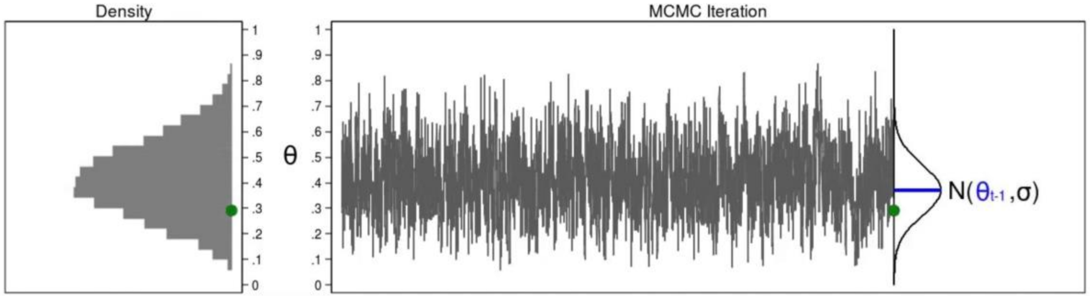
Bayesian Inference and Inversion

- Bayesian inference provides a principled approach towards uncertainty quantification of free parameters in geophysical forward models.
- The use of MCMC methods (that implement Bayesian inference) in the geosciences have been well established, with applications spanning from modelling geochronological ages, inferring sea-level and sediment supply from the stratigraphic record, and inferring groundwater contamination sources.



Markov Chain Monte Carlo sampling methods (MCMC) implement Bayesian inference that sample from a probability distribution. This is based on constructing a Markov chain after a number of steps that has the desired distribution as its equilibrium distribution.

Sampling via MCMC (Example)



Step 1: $r(\theta_{new}, \theta_{t\text{-}1}) = \dfrac{\text{Posterior}(\theta_{new})}{\text{Posterior}(\theta_{t\text{-}1})} = \dfrac{\text{Beta}(1,1,0.290) \times \text{Binomial}(10,4,0.290)}{\text{Beta}(1,1,0.371) \times \text{Binomial}(10,4,0.371)} = 0.773$

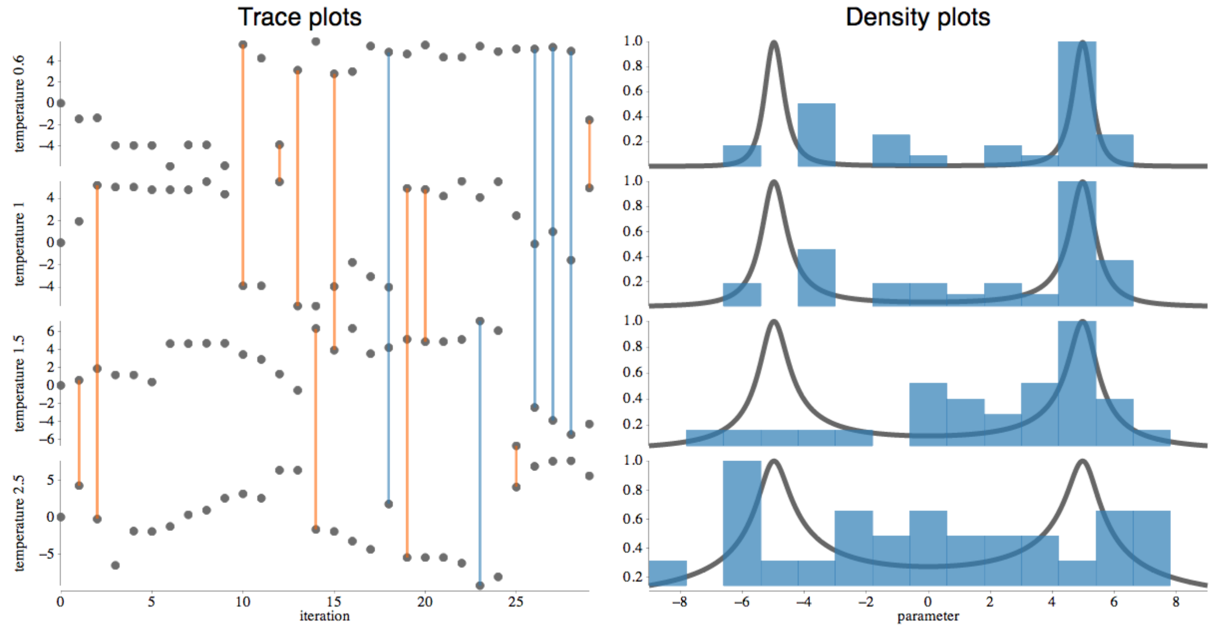
Step 2: Acceptance probability $\alpha(\theta_{new}, \theta_{t\text{-}1}) = \min\{r(\theta_{new}, \theta_{t\text{-}1}), 1\} = \min\{0.773, 1\} = 0.773$

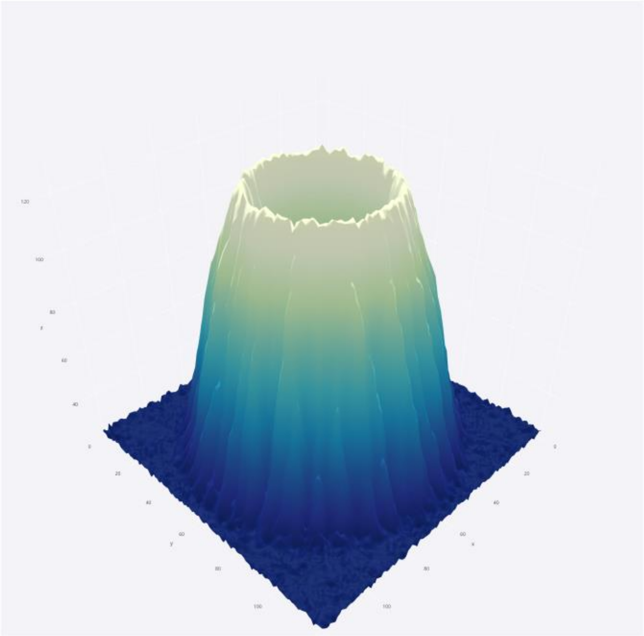
Step 3: Draw $u \sim \text{Uniform}(0,1) = 0.420$

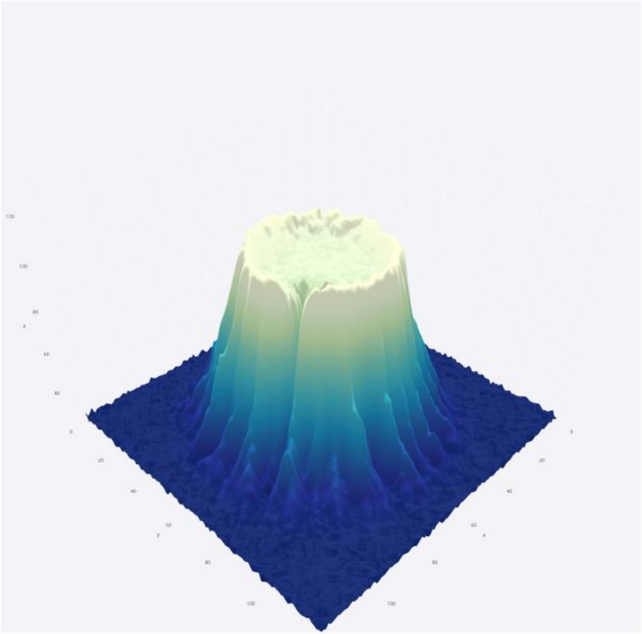
Step 4: If $u < \alpha(\theta_{new}, \theta_{t\text{-}1}) \rightarrow$ If $0.420 < 0.773$ Then $\theta_t = \theta_{new} = 0.290$

Otherwise $\theta_t = \theta_{t\text{-}1} = 0.371$

Parallel tempering MCMC



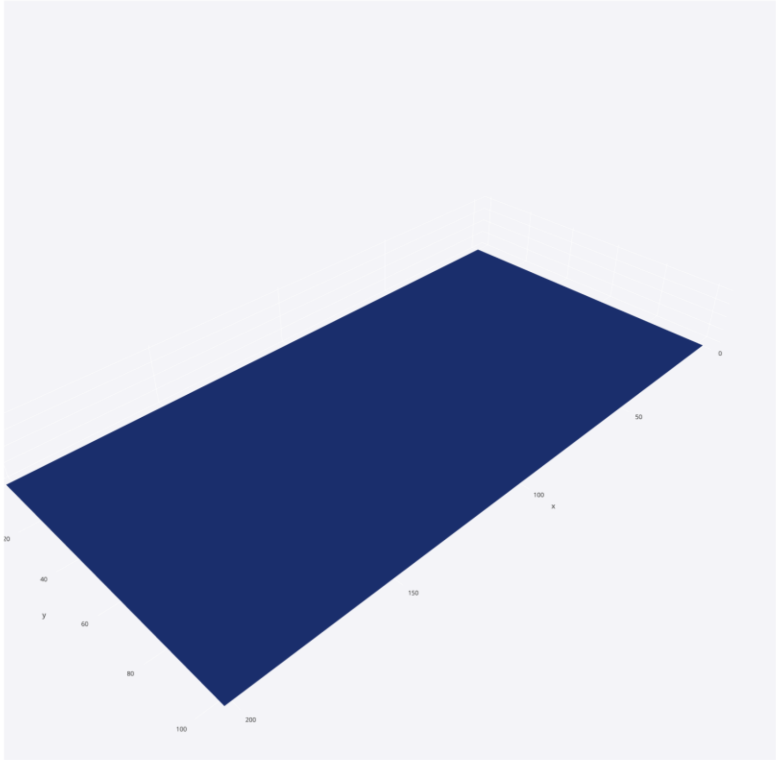




Region: 1.4 km by 1.4 km. Evolution time: 50 thousand years

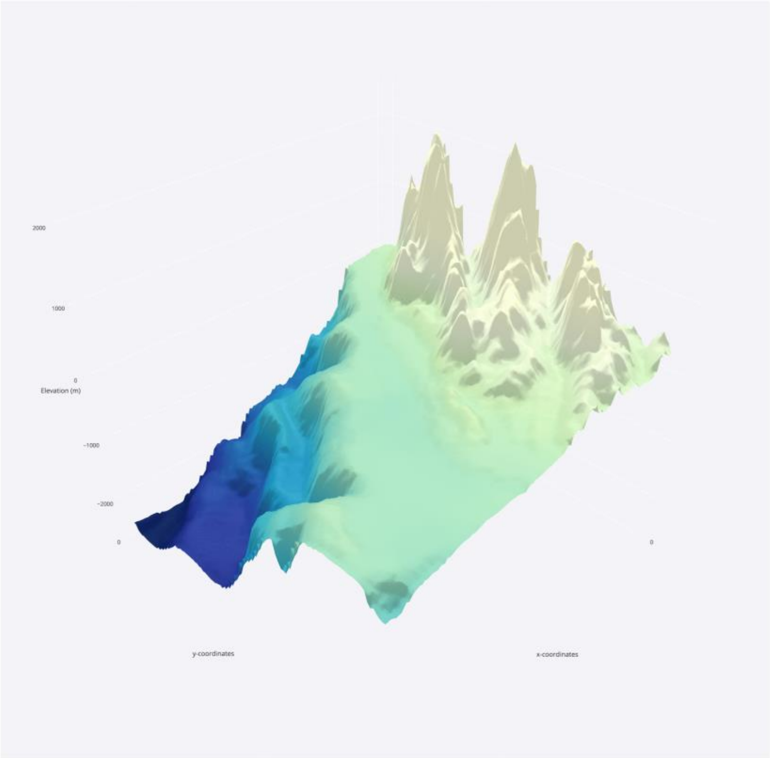
Crater problem

Badlands: Basin and landscape evolution model
Synthetic Mountain Problem



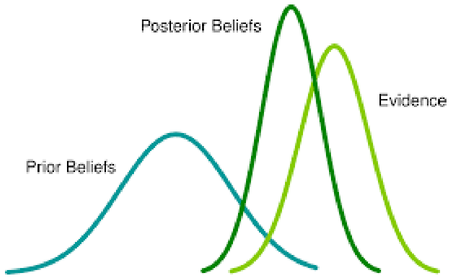
Evolution time: 10 million years

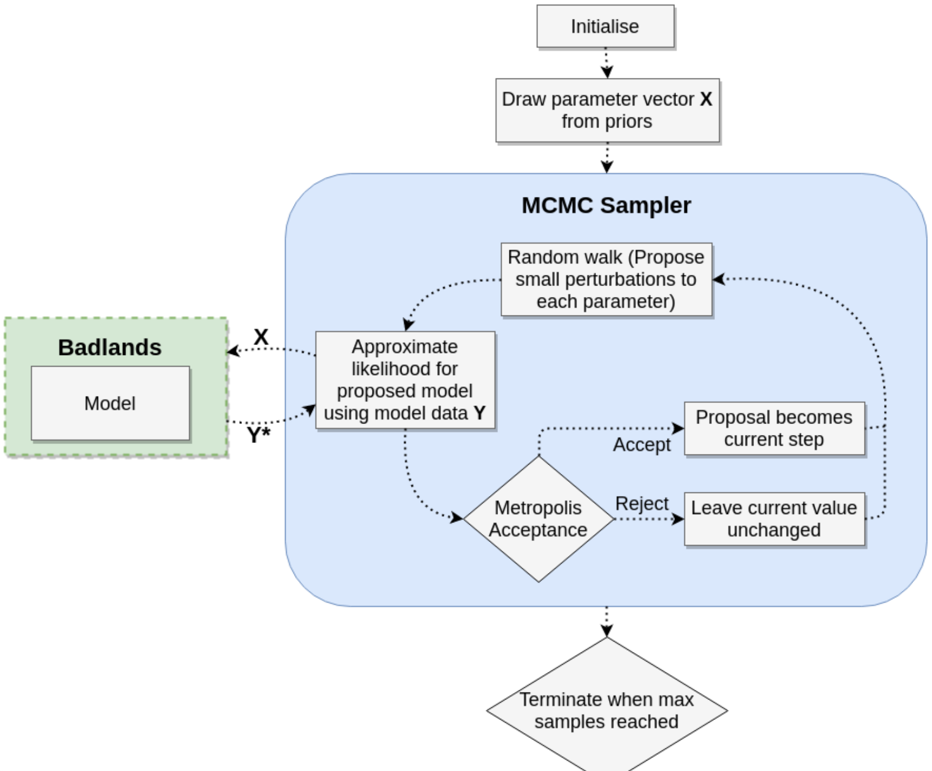
Continental Margin Problem: South Island New Zealand



Region: 136km by 123km
Evolution time: 1 million years
Resolution: 1km

BayesLands is a framework for model parameter estimation and uncertainity quantification in Badlands

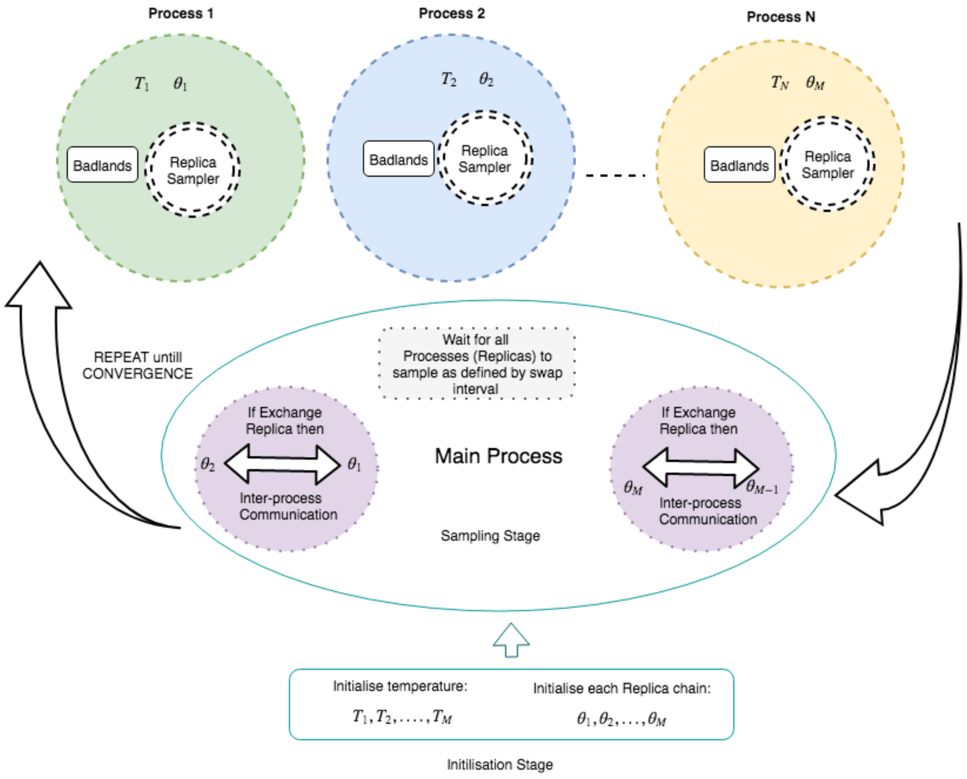




Parallel Tempering BayesLands

Features high performance Computing implementation

Each replica (process) features a separate core

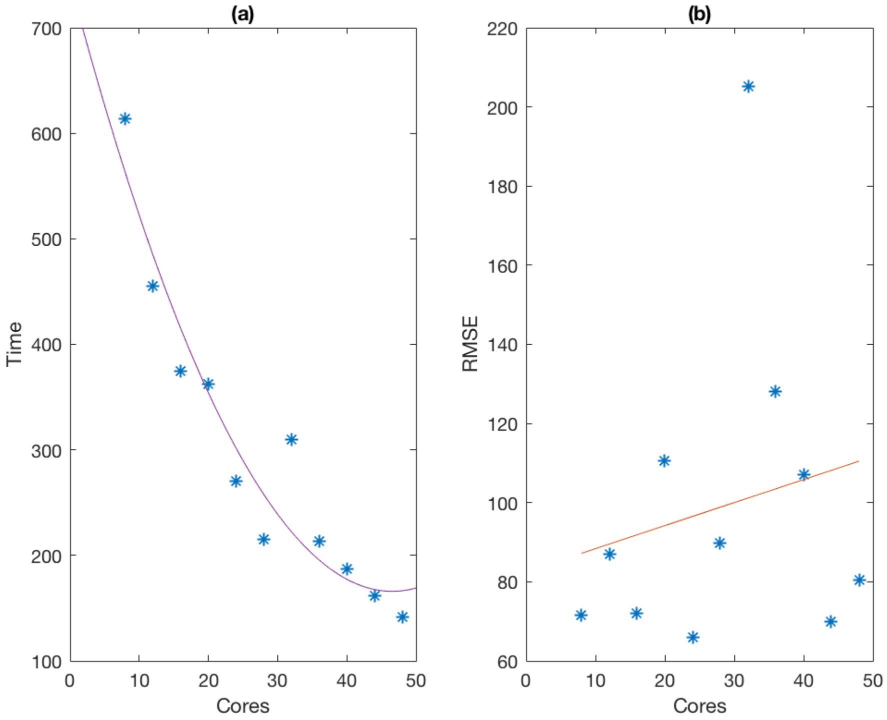


Experiments and results

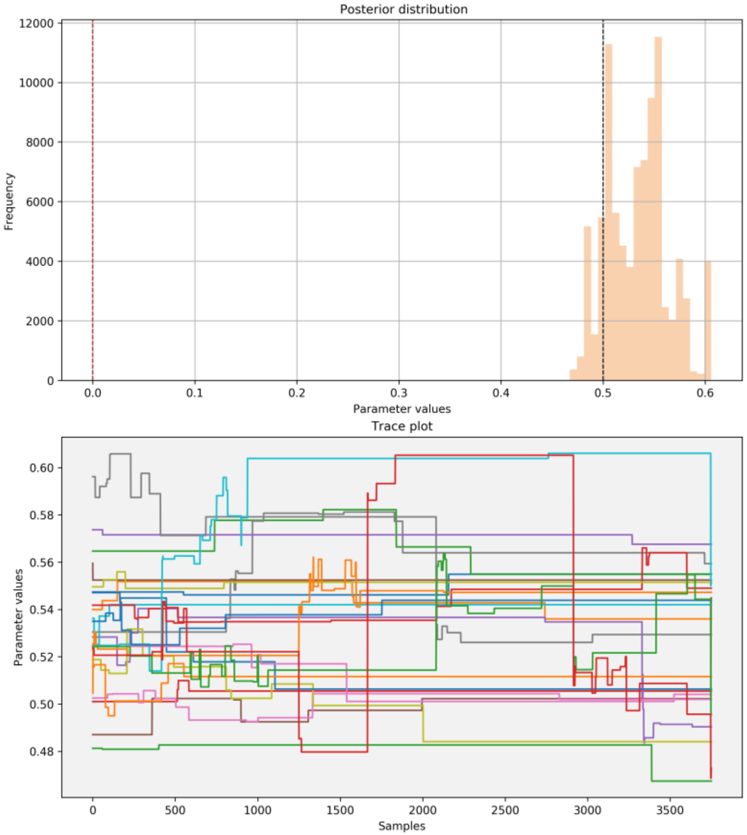
Evaluate effect of number of replica (cores) on accuracy of simulation (prediction) of topography and sediments

Visualize accuracy of predictions with uncertainty

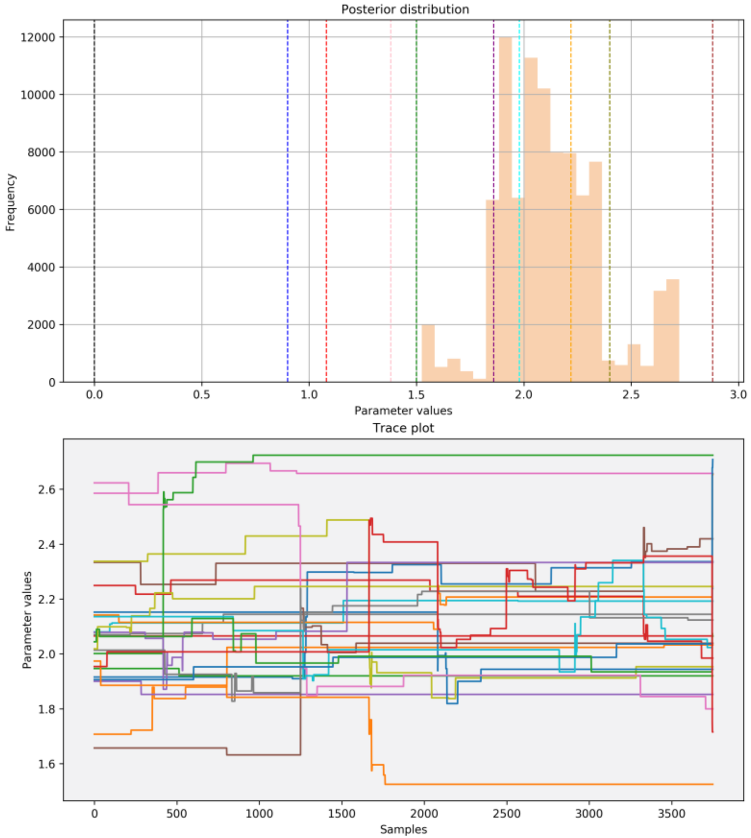
Number of replica (core) vs Time and Accuracy (RMSE)



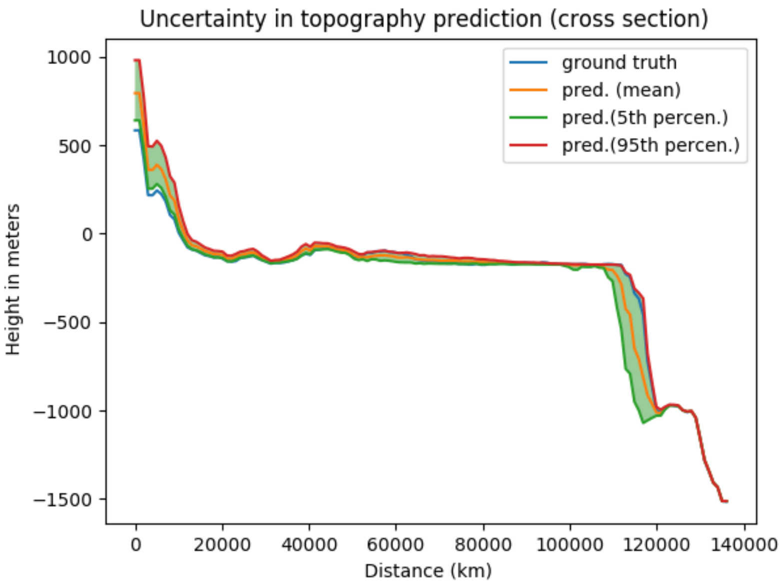
Posterior distributions

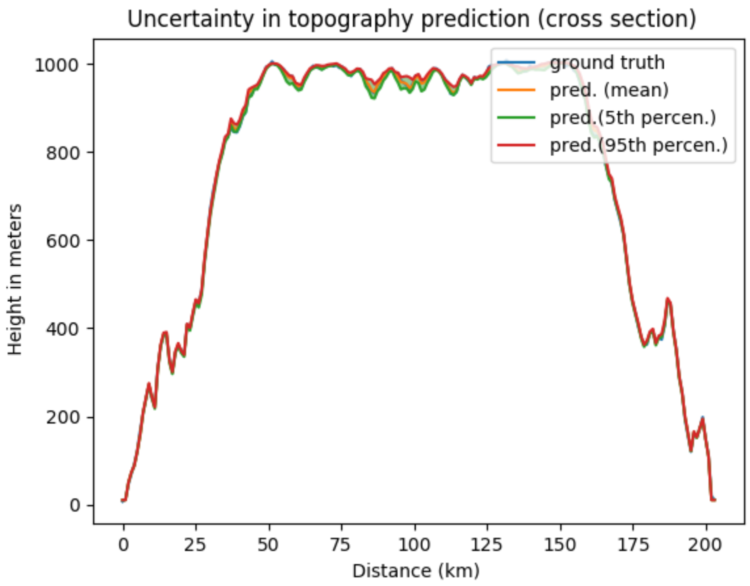


Aerial diffusion



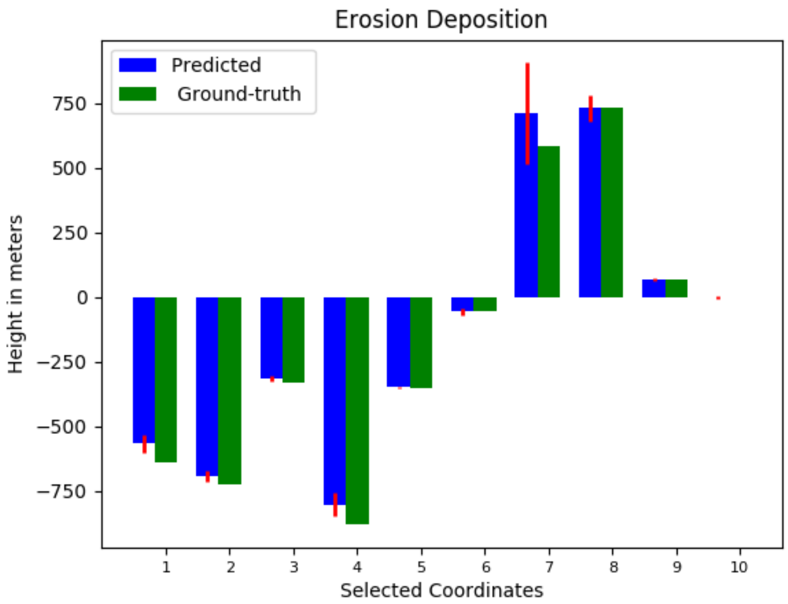
Precipitation



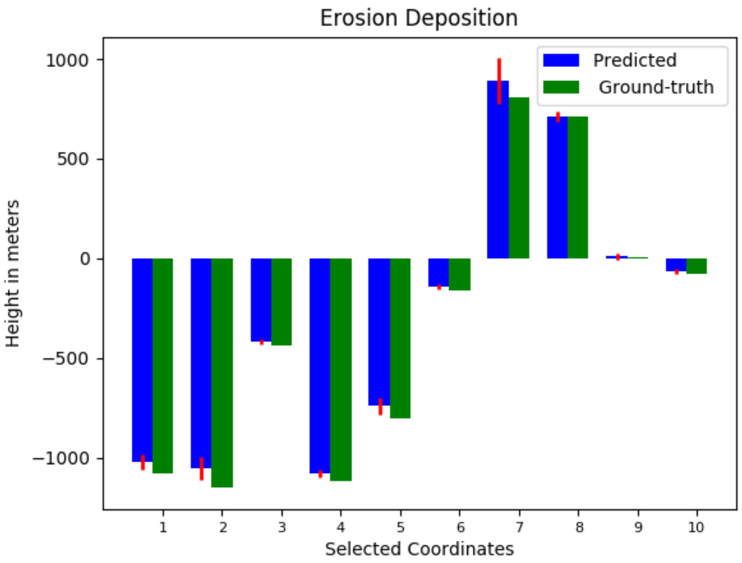


Cross-section: prediction and uncertainty

Erosion-deposition prediction accuracy

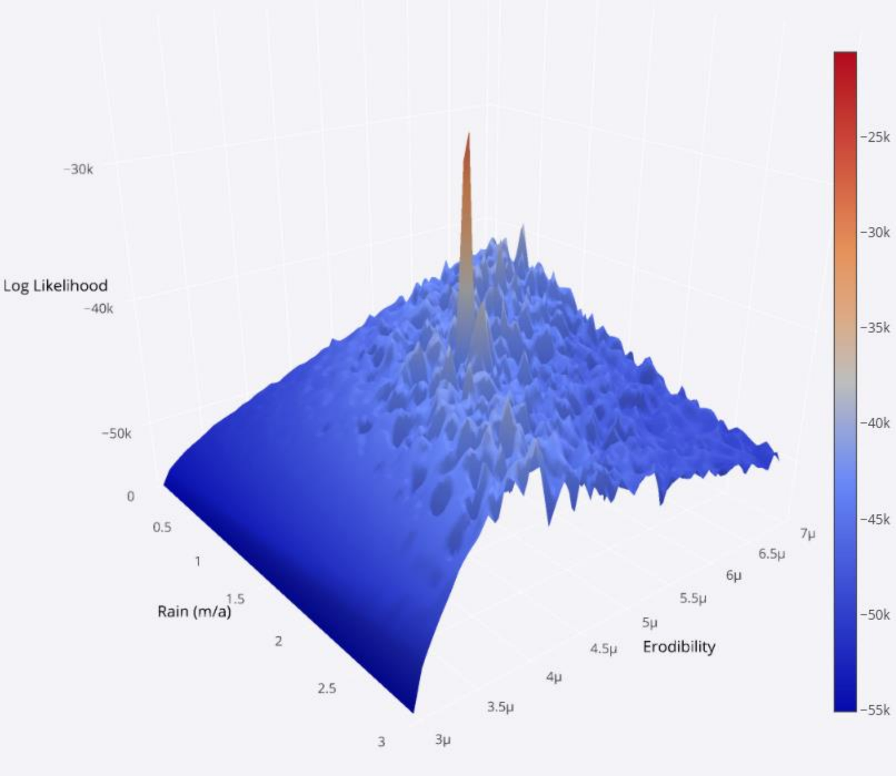


50 % evolution time (0.5 million years)



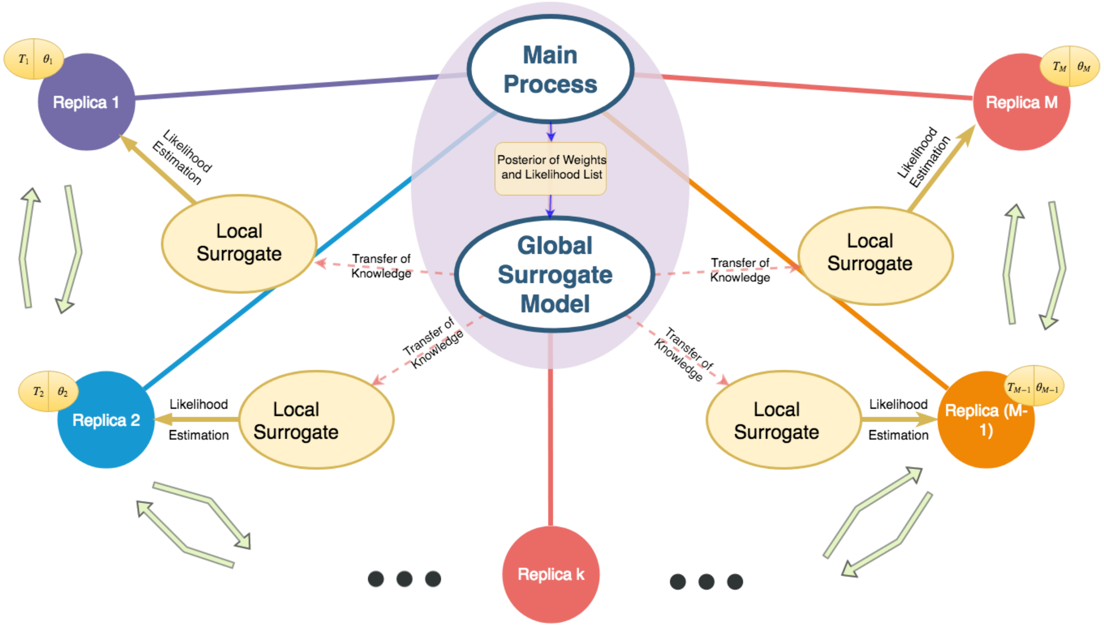
100 % evolution time (1 million years)

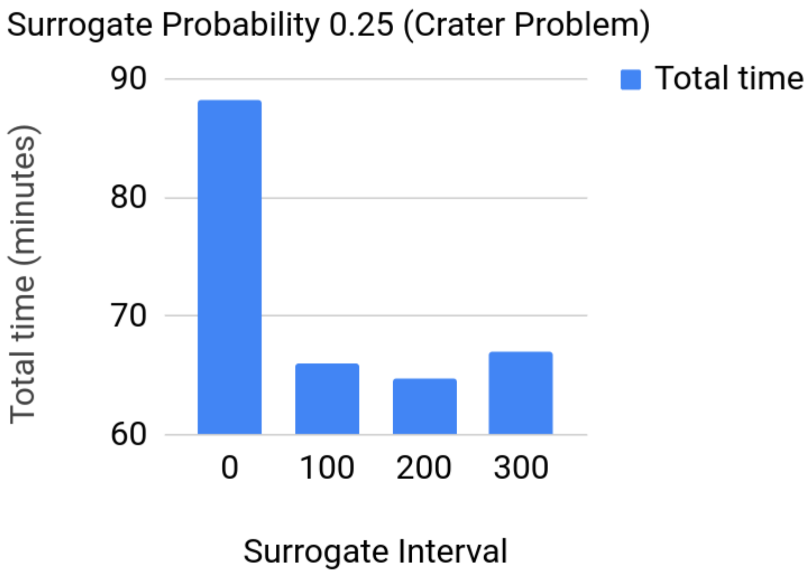
Multi-modality

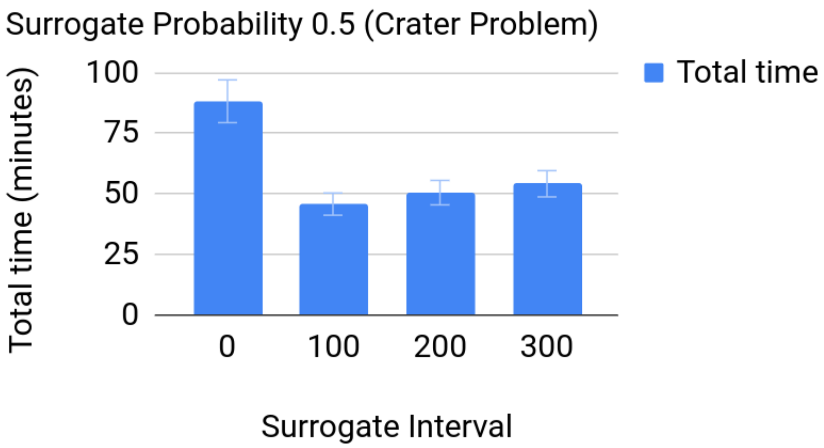


Challenge: computationally expensive problems in geoscience!

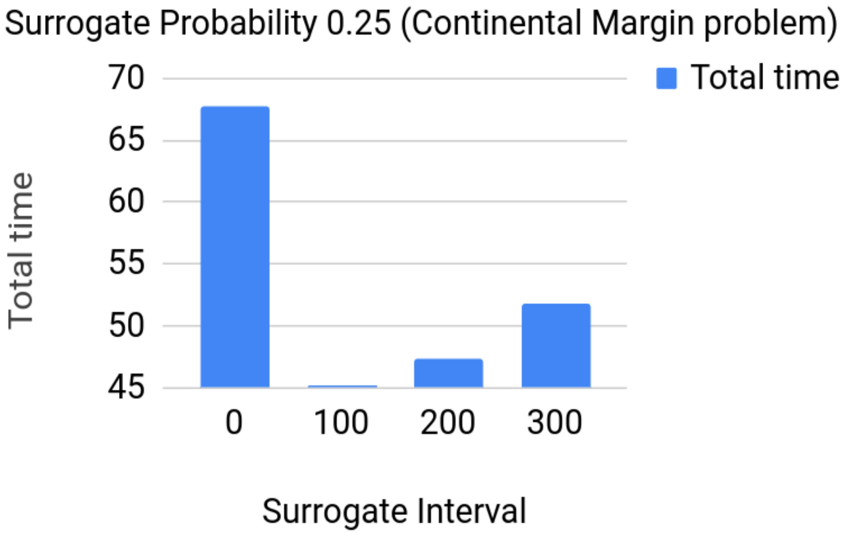
Surrogate-assisted Parallel tempering

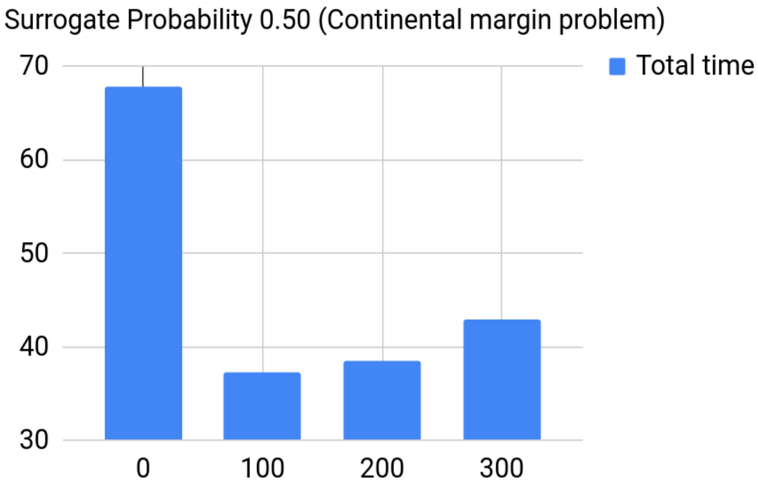




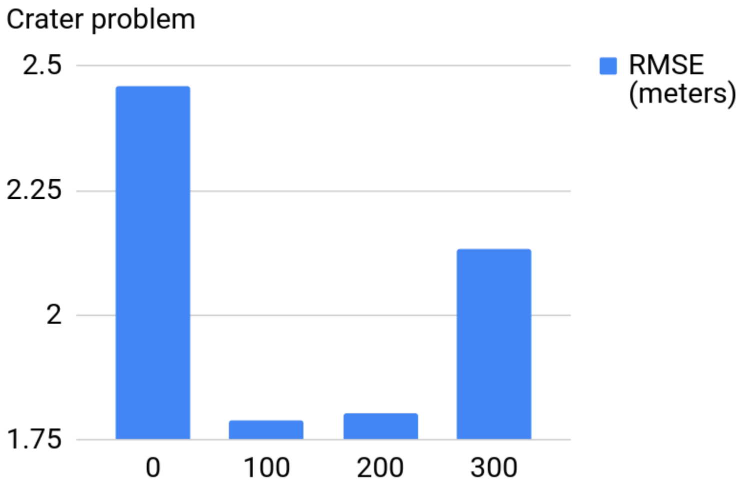


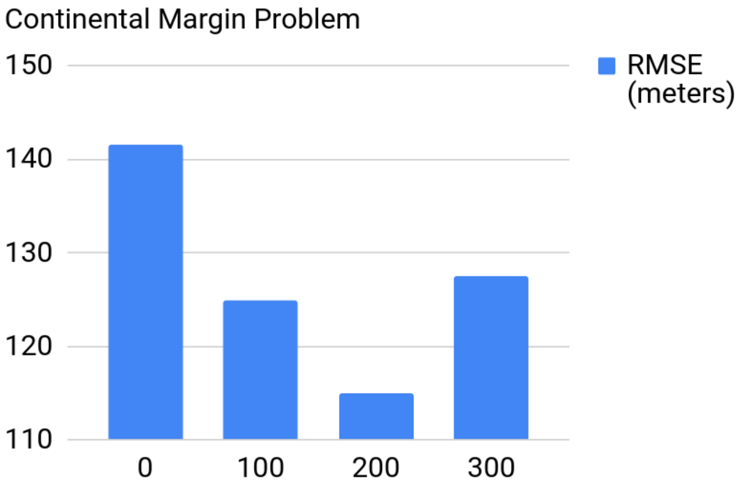
Time saved: Crater problem



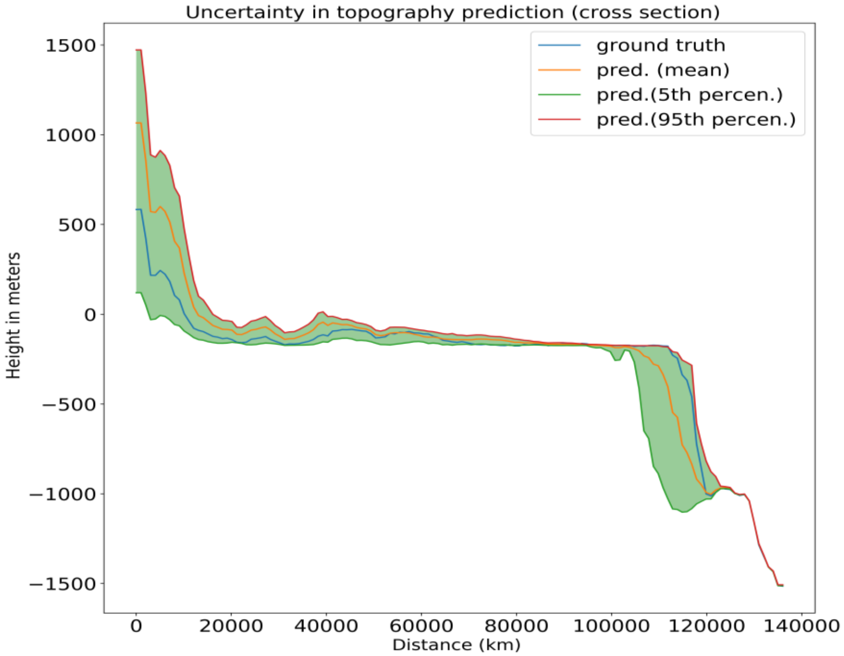


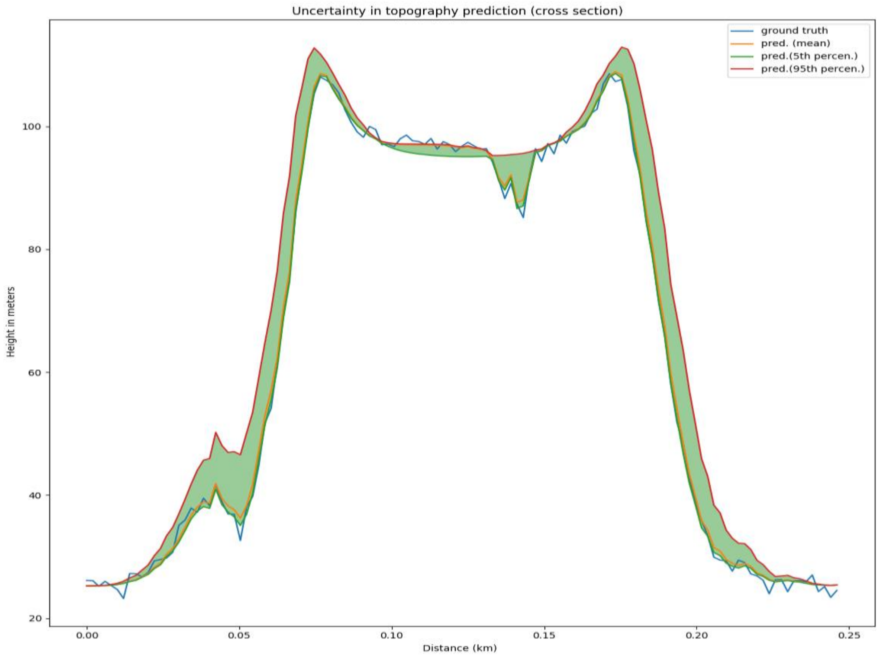
Time saved: Continental Margin problem





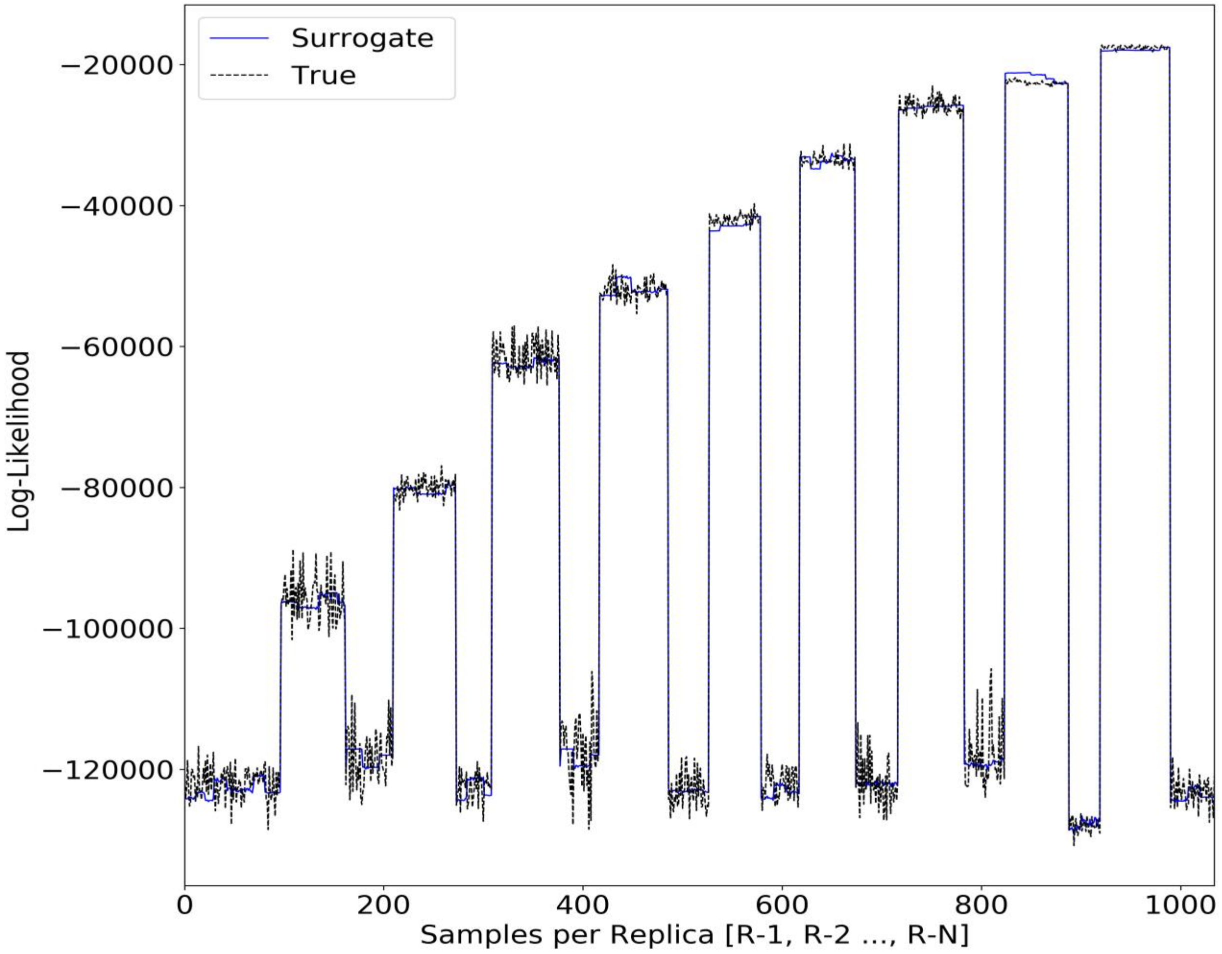
Topography simulation (prediction) accuracy





Cross-section: prediction and uncertainty with Surrogate used

Surrogate Likelihood prediction



Conclusions and future work

- The results show that Parallel Tempering Bayeslands is a promising methodology for parameter estimation and uncertainty quantification.

- Surrogate-assisted Parallel Tempering can be helpful for expensive problems, without losing accuracy.

- In future, it would be helpful to model region-based or time-varying rainfall distributions in Badlands.

- The distributions could be used to generate more information about the effects of climate change in geological timescales.

- Scope for optimisation methods such as evolutionary algorithms for models with hundreds – thousands of parameters
- Can be extended to other geophysical inversion problems.
- Benchmark Geoscience problems for optimisation and Inference.
- Application to continental problems: Australia!
- Fusion of Bayeslands with gPlates
- Application to other problems: Reef Modelling, Underworld, Mineral exploration

Questions welcome

- Acknowledgements

Danial Azam, Nathaniel Butterworth, Tristan Salles, Sally Cripps, and Dietmar Muller

- Technical Reports:

Rohitash Chandra, R. Dietmar Müller, Ratneel Deo, Nathaniel Butterworth, Tristan Salles, Sally Cripps: Multi-core parallel tempering Bayeslands for basin and landscape evolution https://arxiv.org/abs/1806.10939

Rohitash Chandra, Danial Azam, R. Dietmar Müller, Tristan Salles, Sally Cripps: BayesLands: A Bayesian inference approach for parameter uncertainty quantification in Badlands https://arxiv.org/abs/1805.03696

- Resources:

https://www.earthbyte.org/bayeslands-resources/

- Github:

https://github.com/badlands-model/surrogate-pt-Bayeslands

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