SAVE-2

Simulator Analysis and Validation Engine

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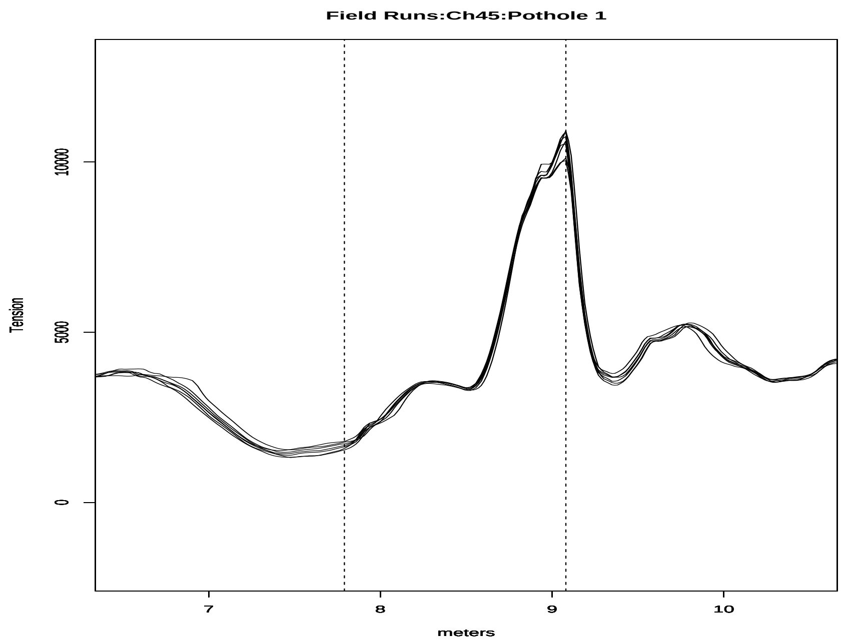
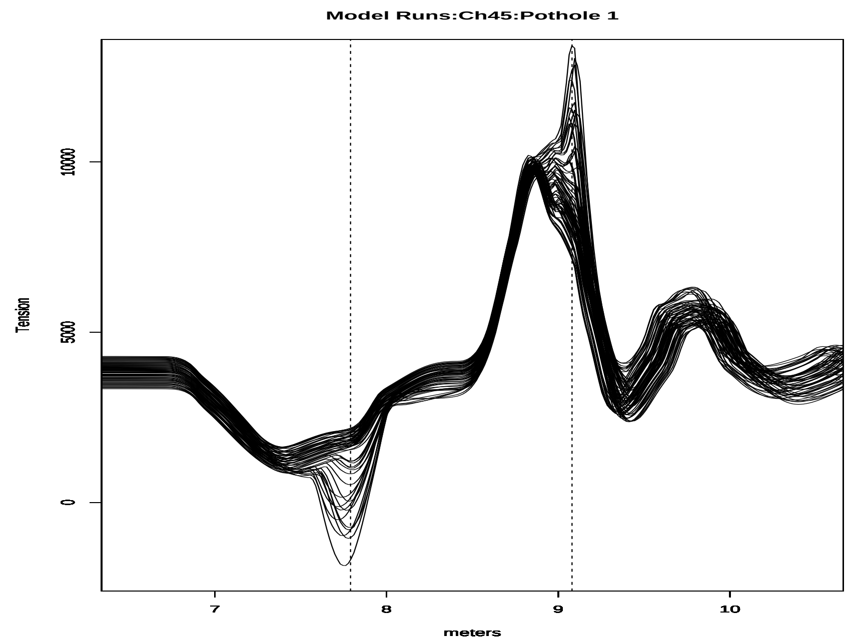
Motivation example

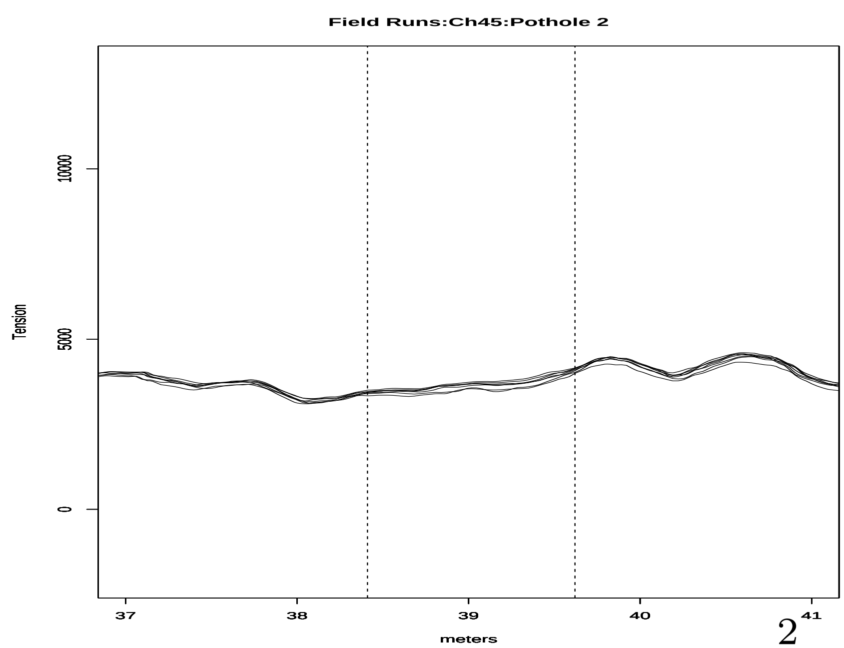
Experiment: Consider a vehicle being driven over a road with two major potholes.

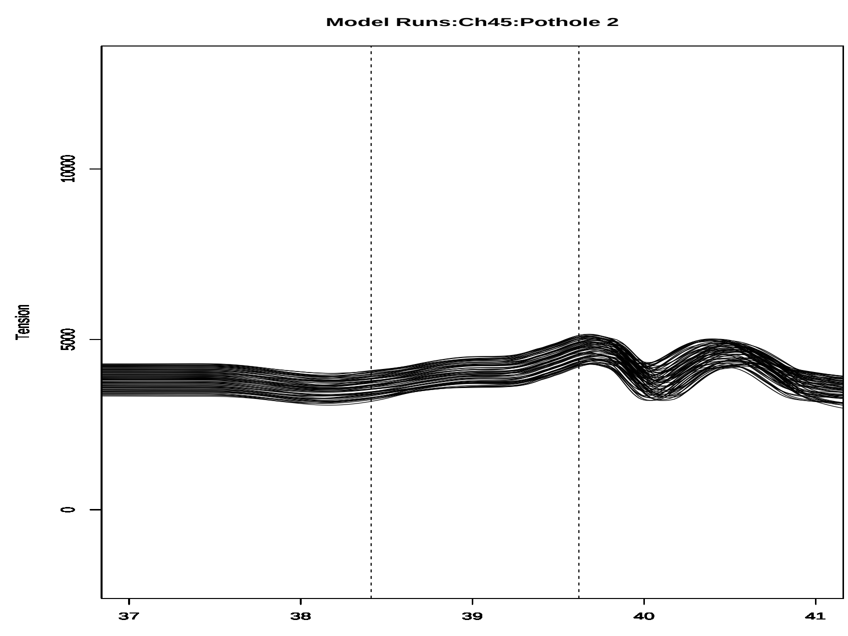
Data:

- Field: Time-history curves of the resulting forces in the tested vehicle,
- Computer model: Time curves obtained when running the model at different **design points**.


Field Runs:Ch45:Pothole 1
Tension
10000
5000
0
7
8
9
10
meters


Model Runs:Ch45:Pothole 1
Tension
10000
5000
0
7
8
9
10
meters


Field Runs:Ch45:Pothole 2
Tension
10000
5000
0
37
38
39
40
41
meters


Model Runs:Ch45:Pothole 2
Tension
10000
5000
0
37
38
39
40
41
meters

Example of input parameters

Parameter	Type (label)	Uncertainty
Damping 1 *(force dissipation)*	Calibration (u_1)	15%
Damping 2 *(force dissipation)*	Calibration (u_2)	15%
Bushing Stiffness (Voided)	Unmeasured (x_1)	15%
Bushing Stiffness (Non-Voided)	Unmeasured (x_2)	10%
Ride Height	Measured	10%
Front rebound travel until Contact	Unmeasured (x_3)	5%
Front rebound bumper stiffness	Unmeasured (x_4)	8%
Rear Spring Stiffness	Measured	10%
Sprung Mass	Unmeasured (x_5)	5%
Unsprung Mass	Unmeasured (x_6)	12%
Body Pitch Inertia	Unmeasured (x_7)	12%

Questions

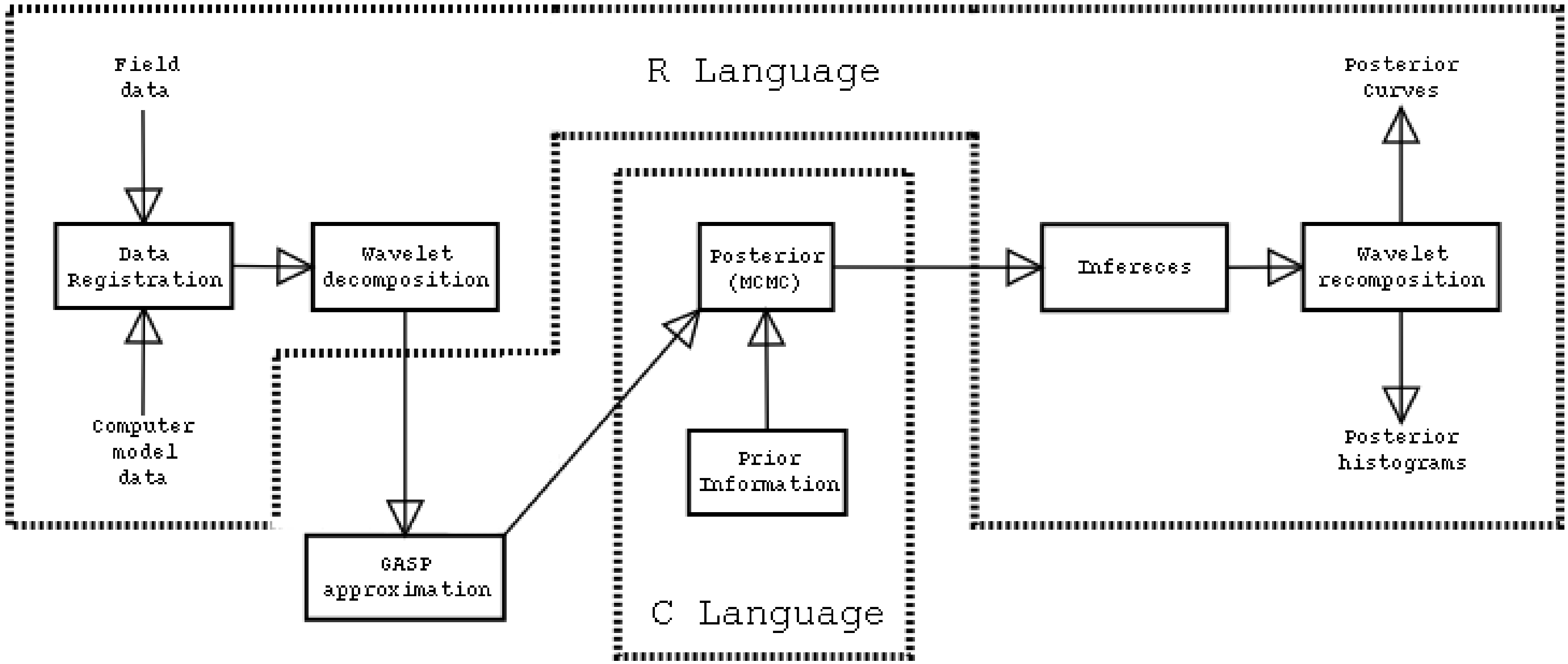
- Is a particular computer model correct?, $\longrightarrow$ Wrong question
- We ask: Does it provide predictions that are accurate enough for the intended use(s), including both bias and uncertainty?.
- $P\,(|\text{prediction - truth}| < \delta) > \alpha$?
  δ = tolerable difference
  α = assurance/confidence,
- Can the field experiment be reduced/extrapolated?

SAVE-2 provides answers

Steps of the analysis

- Inputs,
- Data registration and Wavelet Decomposition,
- Response Surface Approximation,
- Bayesian Analysis
- Outputs and plots.

SAVE-2



R Language
Field data
Data Registration
Computer model data
Wavelet decomposition
GASP approximation
Posterior (MCMC)
Prior Information
C Language
Infereces
Wavelet recomposition
Posterior Curves
Posterior histograms

Data Registration

Field and model-run curves should occur at the same "locations".

Steps

1. Convert time-histories to distance-histories,
2. Compute the average of model runs as *reference curve*,
3. Align curves to match the peaks of both major potholes.
4. Wavelet representation of the curves

Representation of the data in the analysis

The m computer model and f field response curves are represented as

$$y^M(\boldsymbol{z}_j; d) = \sum_{i=1}^{\mathcal{W}} w_i^M(\boldsymbol{z}_j)\psi_i(d), \qquad j = 1, \ldots, m$$

$$y_r^F(\boldsymbol{x}^*; d) = \sum_{i=1}^{\mathcal{W}} w_{ir}^F(\boldsymbol{x}^*)\psi_i(d), \qquad r = 1, \ldots, f.$$

where $w_i^M(\boldsymbol{z}_j)$ and $w_{ir}^F(\boldsymbol{x}^*)$ are the wavelet coefficients and

$\boldsymbol{x} = (x_1, \ldots, x_7)$ key vehicle characteristics

$\boldsymbol{u} = (u_1, u_2)$ unknown computer model calibration parameters

$\boldsymbol{z} = (\boldsymbol{x}, \boldsymbol{u})$

Bayesian analysis

We use a Bayesian Gaussian Spatial Process approximation to each of the model wavelet coefficient function $w_i^M(\boldsymbol{z})$. Its posterior, given GASP parameters and model-run data, at a new input $\boldsymbol{z}$ is

$$N\left(w_i^M(\boldsymbol{z})|\widehat{\mu}_i(\boldsymbol{z}), \widehat{V}_i(\boldsymbol{z})\right)$$

For the i^{th} wavelet coefficient

$$\begin{aligned} w_i^R(\boldsymbol{x}^*) &= w_i^M(\boldsymbol{x}^*, u^*) + b_i(\boldsymbol{x}^*) \\ w_{ir}^F(\boldsymbol{x}^*) &= w_i^R(\boldsymbol{x}^*) + \varepsilon_{ir} \qquad\qquad r = 1, \ldots, f. \end{aligned}$$

where $(\boldsymbol{x}^*, \boldsymbol{u}^*)$ are the "true" but unknown parameters.

Posterior distribution

- Given the observed data $D = \{\bar{w}_i^F, S_i^2, \widehat{\mu}_i(\cdot), \widehat{V}(\cdot) : \ i \in \mathcal{W}\}$.

  $\pi(\boldsymbol{w}^{M*}, \boldsymbol{b}, \boldsymbol{z}^*, \boldsymbol{\theta} \mid D) = \pi(\boldsymbol{w}^{M*} \mid \boldsymbol{b}, \boldsymbol{z}^*, \boldsymbol{\theta}, D) \cdot \pi(\boldsymbol{b} \mid \boldsymbol{z}^*, \boldsymbol{\theta}, D) \cdot \pi(\boldsymbol{z}^*, \boldsymbol{\theta} \mid D)$

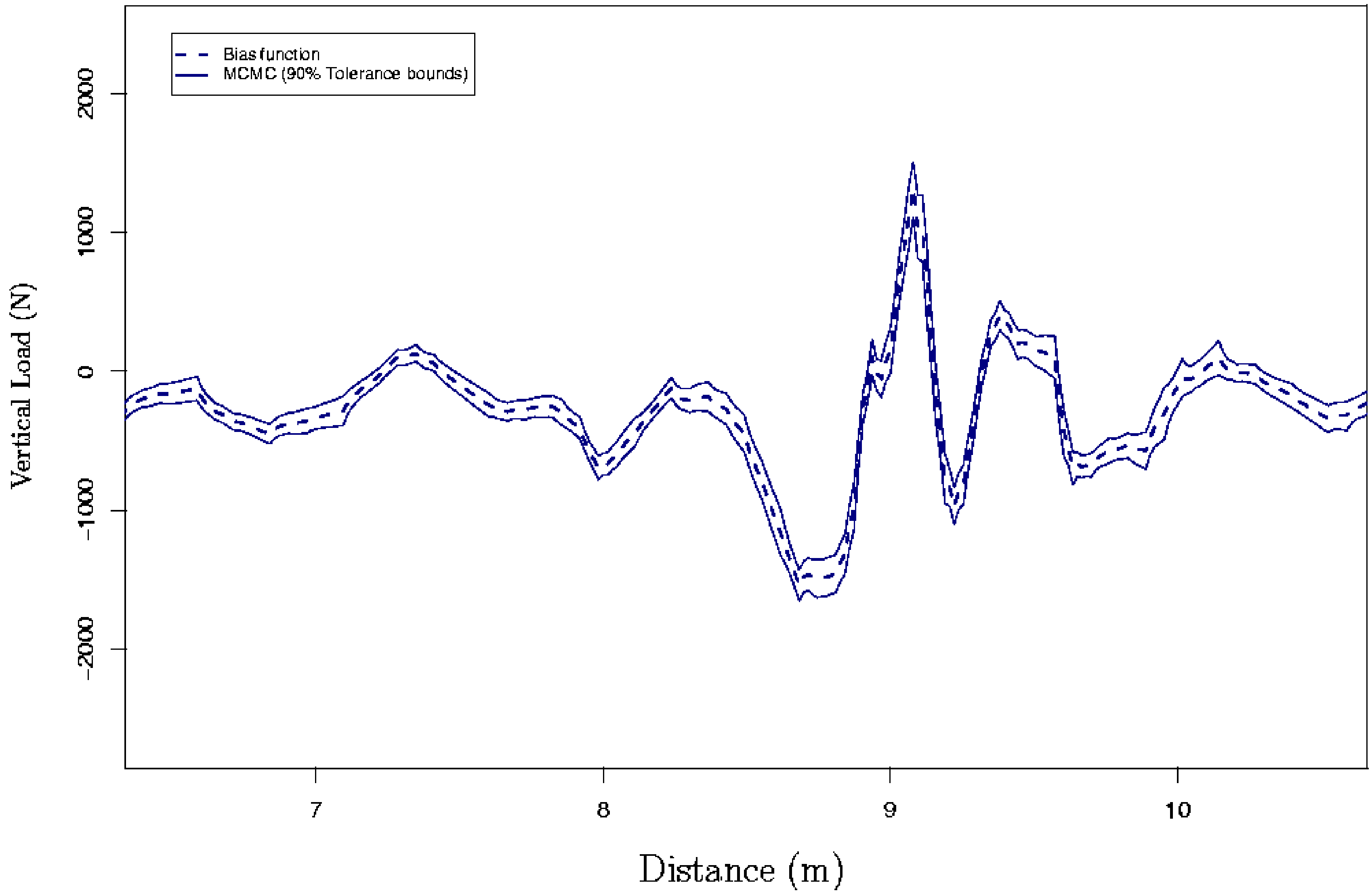
  $\boldsymbol{\theta} = (\boldsymbol{\sigma}^2, \boldsymbol{\tau}^2)$ are the variances of the errors.

- The outputs of the MCMC are

$$\left\{(\boldsymbol{w}^{M*})^h, (\boldsymbol{b})^h, (\boldsymbol{x}^*)^h, (\boldsymbol{u}^*)^h, (\boldsymbol{\theta})^h\right\}_{h=1}^{N}$$

- From these we reconstruct the bias curves

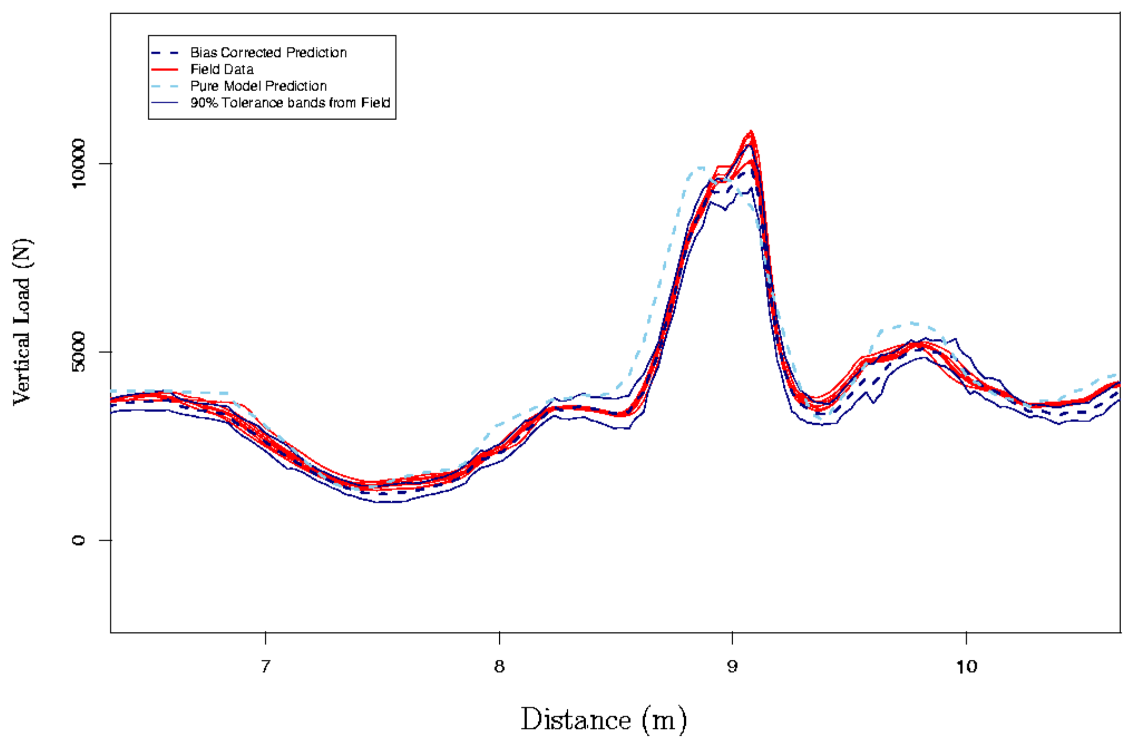
$$b^{(h)}(d) = \sum_{i=1}^{\mathcal{W}} b_i^{(h)} \psi_i(d)$$



Bias function
MCMC (90% Tolerance bounds)
Vertical Load (N)
2000
1000
0
-1000
-2000
7
8
9
10
Distance (m)

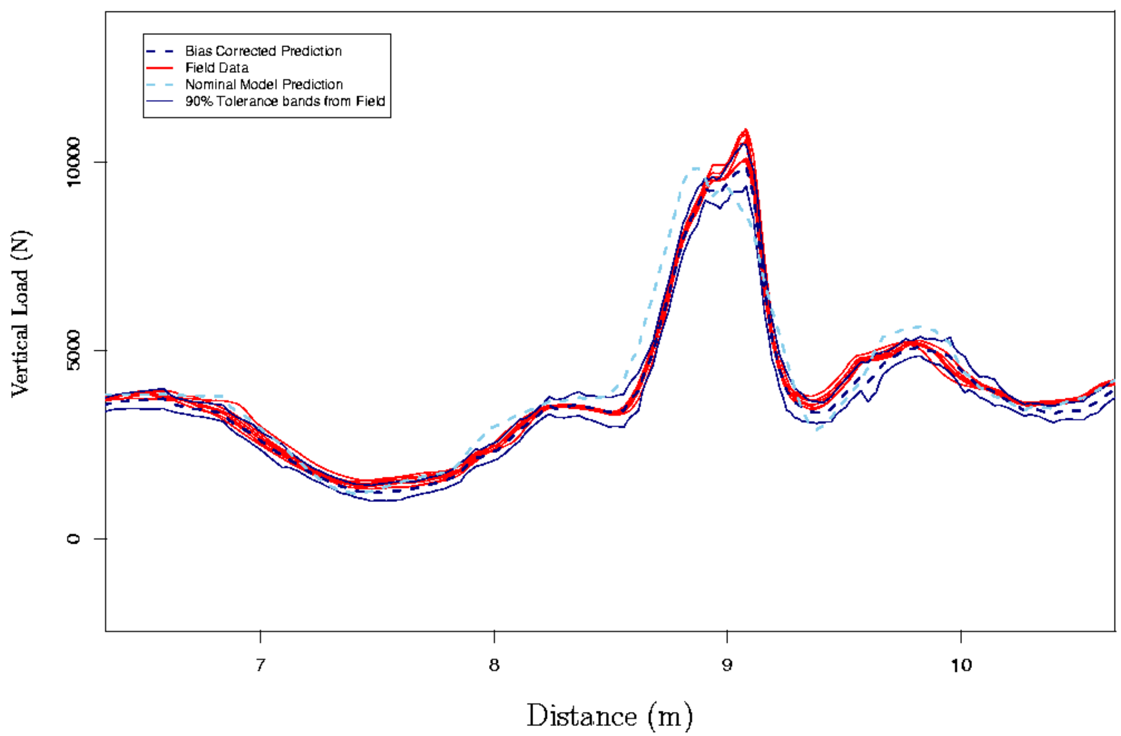
- The posterior sample of *bias-corrected predictions* of reality is

$$(y^R)^{(h)}(d) = \sum_{i=1}^{\mathcal{W}} \left((w_i^{M*})^{(h)} + b_i^{(h)} \right) \psi_i(d), \;\; h = 1, \ldots, N.$$

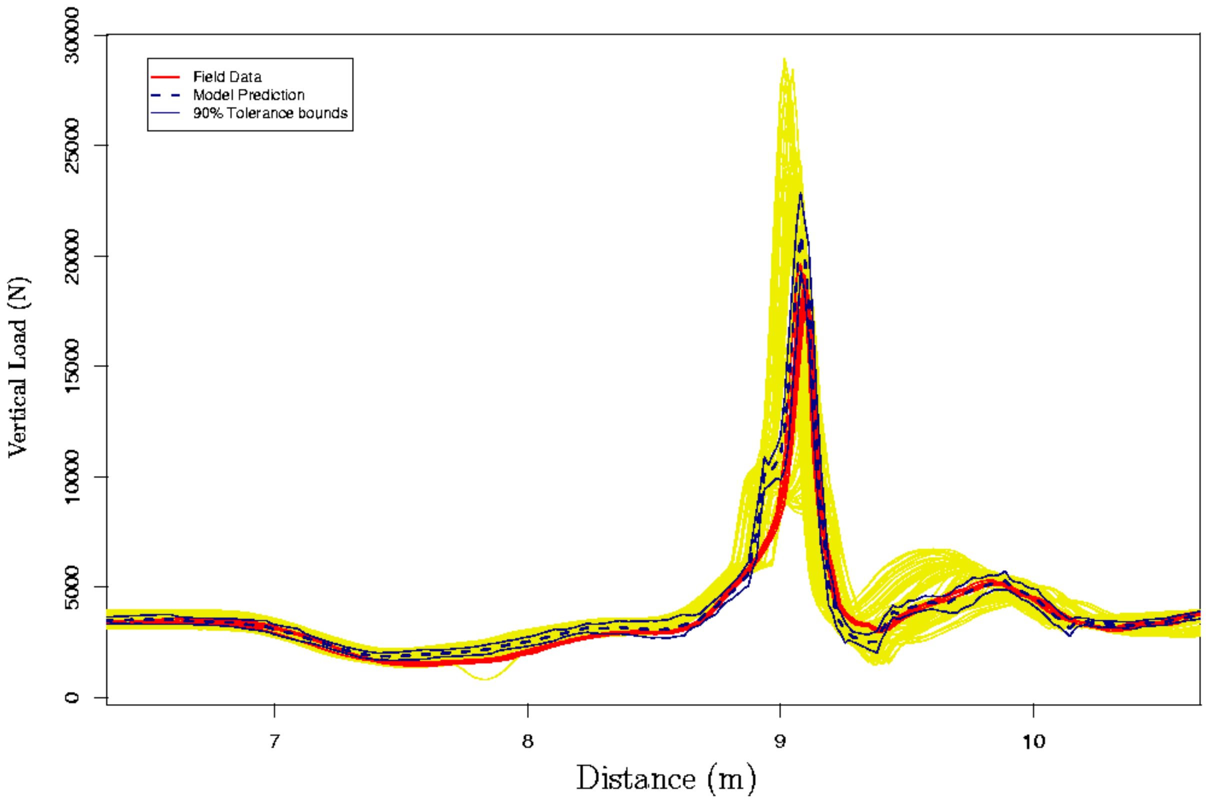


- The posterior sample of *individual (field) bias-corrected prediction* curves is

$$(y^F)^{(h)}(d) = \sum^{\mathcal{W}} \left((w_i^{M*})^{(h)} + b_i^{(h)} + \epsilon_i^{(h)} \right) \psi_i(d), \ \ h = 1, \ldots, N.$$



Extrapolations: under different conditions



Example of an input file

$File: C:/XXX/PX11tk1.ascii

!DATA TYPE: TIME-HISTORY!

!NUMBER OF CHANNELS: 4!

!SAMPLE RATE: 409.6!

!TOTAL NUMBER OF POINTS/CHANNELS: 40960!

$CHANNEL DESCRIPTION FULL SCALE UNITS POLARITY

——- —————————- —————- —————— ——————

1 RFST 41654.980

2 RRTL 51384.940

3 RFDL 33160.090

4 VEHS 130.000 mp

$ Time CH 1 CH 2 CH 3 CH 4

!BEGIN DATA:!

.000000 10.175 -1.569 15.187 .004

System Requirements

- The R statistical software package (version 1.8.1 or higher): available under GNU-GPL terms..
- The wavethresh package (version 2.2-8 or higher) for R: available under GNU-GPL terms.
- The ATLAS (Automatically Tuned Linear Algebra Software) library: available under GNU-GPL terms.
- The GNU Scientific Library: available under GNU-GPL terms.

THANKS!