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Etude de l'efficacité du krigeage bayésien pour l'assainissement/démantèlement de sites nucléaires

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Purpose and context:

Radiological characterization is a significant challenge encountered by the nuclear industry when decommissioning and dismantling nuclear infrastructures. Its main goal is to evaluate the quantity and spatial distribution of radioactive contaminations. Recently, statistical tools such as geostatistics have been used to evaluate soil contaminations [2]. The unique context of radiological characterization generates small data sets, and exacerbates estimation problems, such as uncertainties in parameters estimation. Bayesian Kriging allows to take into account estimation uncertainties and predicts more reasonable prediction variances. **Our goal is to evaluate the effectiveness of Bayesian Kriging relative to common geostatistical tools.**

Notations

Z	Random field.	$E[Z] = \mu$	Trend parameter.
x_i	Coordinates of point i .	$Var[Z] = \sigma^2 \Sigma$	Covariance matrix and scale parameter.
x_0	Unobserved point to predict.	$\theta' = (\mu, \sigma^2, \phi)$	Parameters of the model.
$\widehat{z}(x_i)$	Prediction at point x_i without $z(x_i)$.	$k = (Cov(Z(x_0), Z(x_i)))_i$	Covariance vector between prediction target and observed values.
s_{-i}^2	Prediction variance at point x_i without $z(x_i)$.	α	Confidence level related to its confidence interval (CI).

Hypothesis:

- Gaussian process.
- Second order stationarity.
- Isotropic character.

Bayesian kriging equations [3]:

$$E[Z(x_0)|z] = \int_{\Theta} (\mu + k' \Sigma^{-1} (z - \mu)) p_{\theta}(\theta|z) d\theta$$

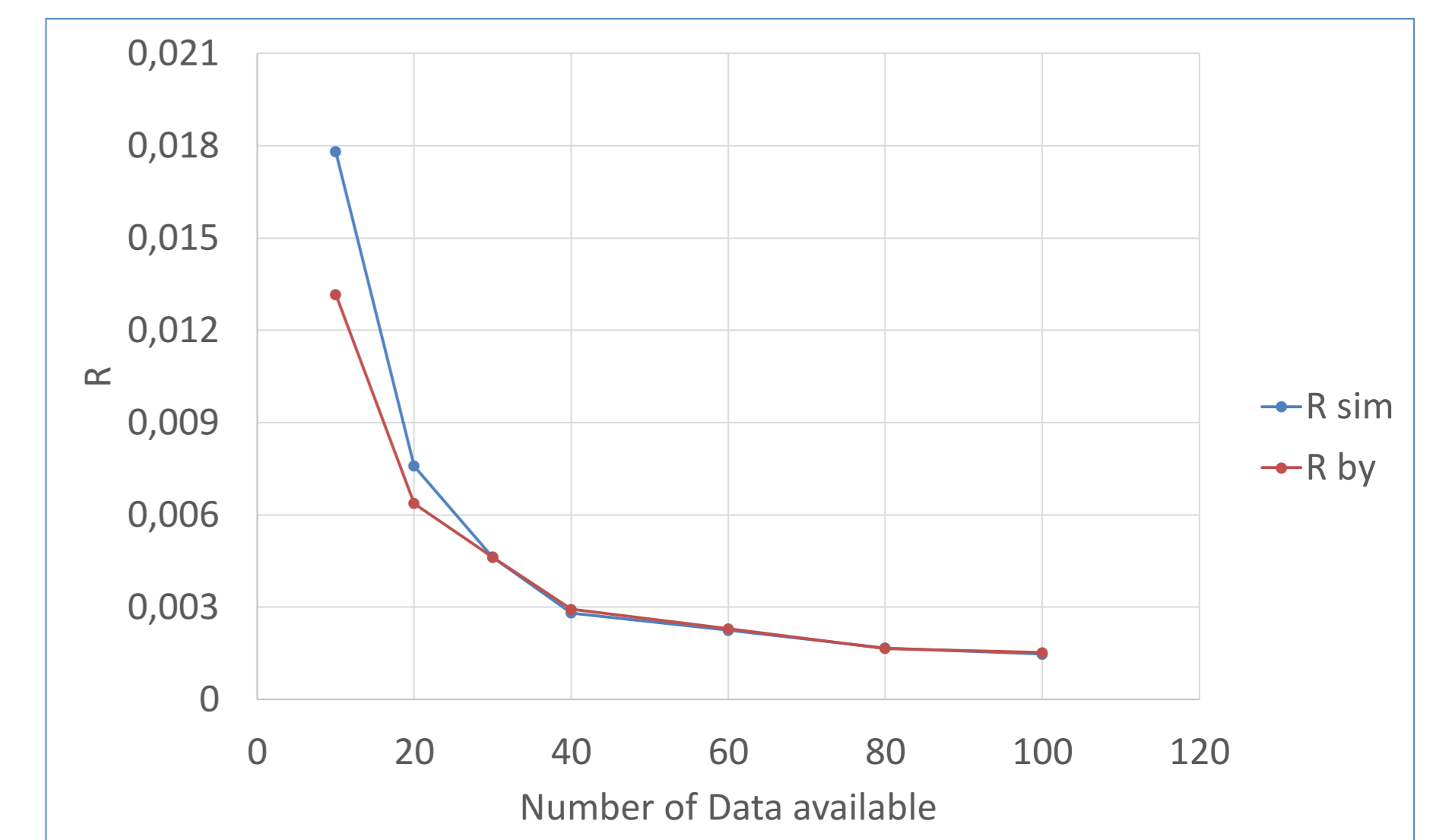
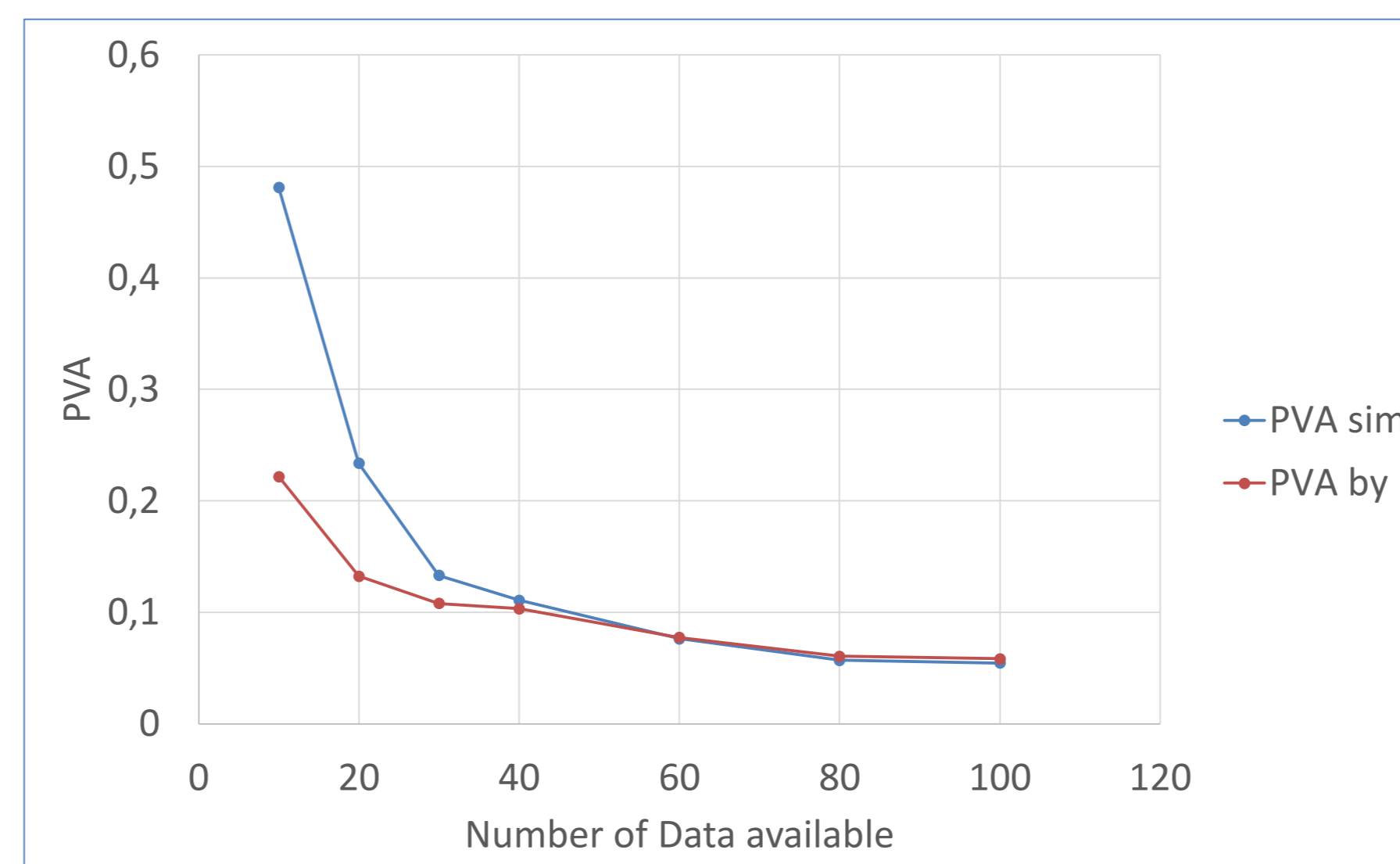
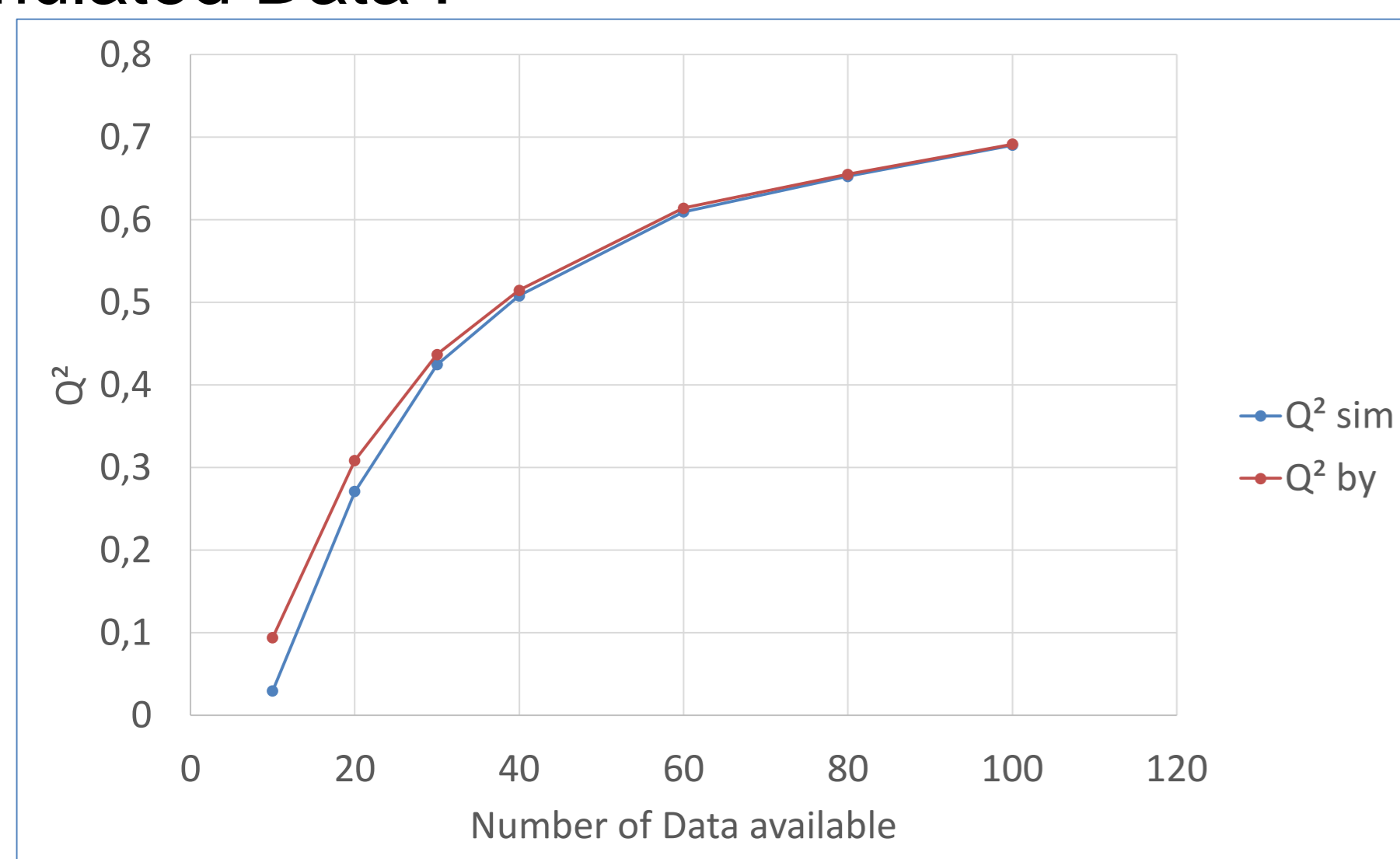
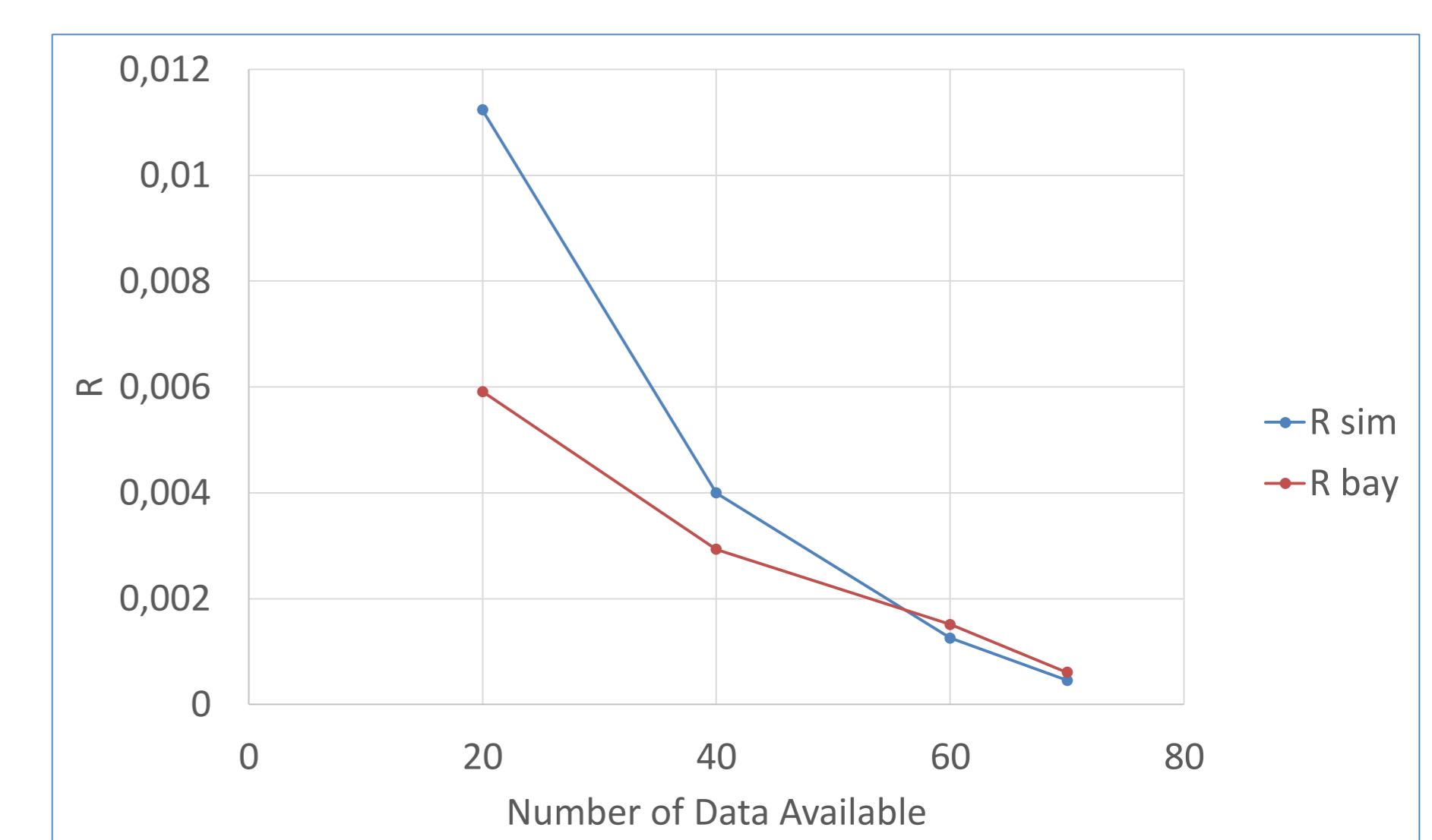
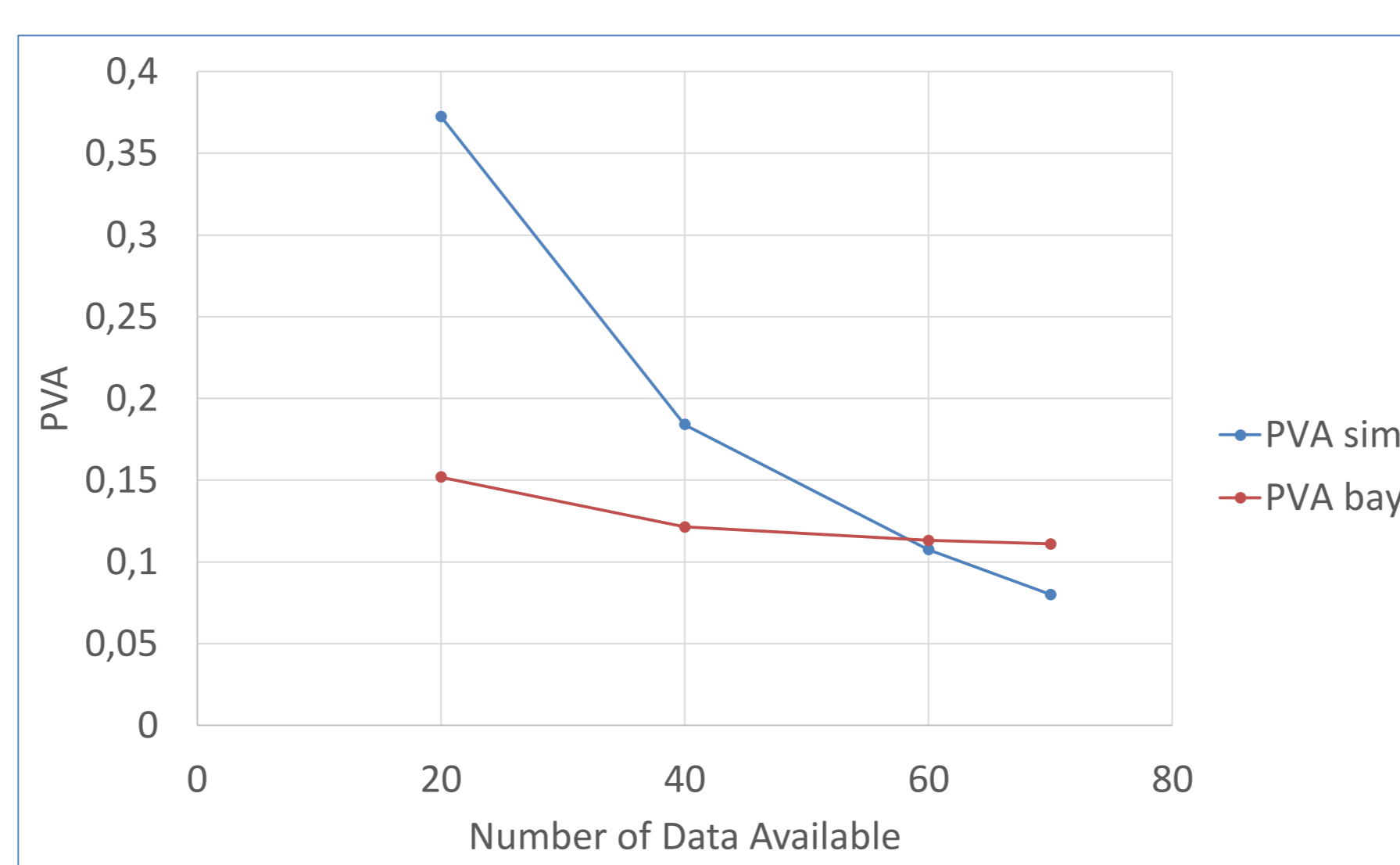
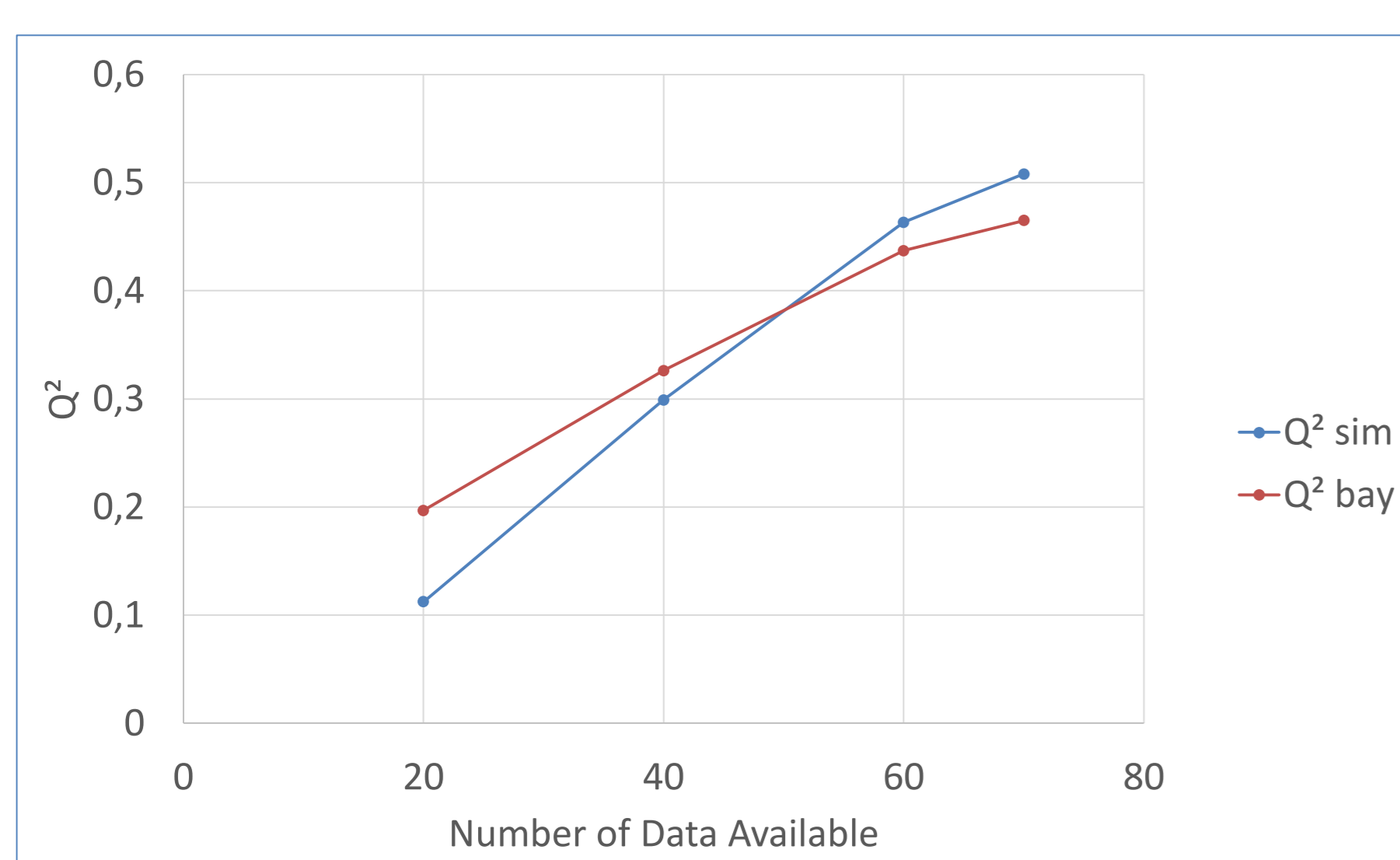
$$Var[Z(x_0)|z] = \int_{\Theta} \sigma^2 (1 - k' \Sigma^{-1} k) p_{\theta}(\theta|z) d\theta + \int_{\Theta} ((\mu + k' \Sigma^{-1} (z - \mu)) - E[Z(x_0)|z])^2 p_{\theta}(\theta|z) d\theta$$

Validation criteria (Cross-Validation) [1]:

- $Q^2 = 1 - \frac{\sum_{i=1}^n (z(x_i) - \widehat{z}(x_i))^2}{\sum_{i=1}^n (z(x_i) - \mu)^2}$
- $\Delta_{\alpha} = \frac{1}{n} \sum_{i=1}^n \phi_i, \phi_i \begin{cases} 1 & \text{if } z(x_i) \in CI \\ 0 & \text{else} \end{cases}$
- $PVA = \left| \log \left(\frac{1}{n} \sum_{i=1}^n \frac{(z(x_i) - \widehat{z}(x_i))^2}{s_{-i}^2} \right) \right|$
- $R = \frac{1}{m} \sum_i^m (\Delta_{\alpha_i} - \alpha_i)^2$

Experiment:

1. Comparison on simulated data sets (Gaussian Process) and a real data set (G3 reactor decommissioning project).
2. Parameters estimated with Maximum Likelihood.
3. Computation of validation criteria values for Bayesian Kriging and Simple Kriging.
4. Variation in the size of the available data set.

Results:**Simulated Data :****Real Data Set :****Conclusions and Future Work:**

- Bayesian Kriging gives more realistic results, despite longer calculation times.
- Extension to nugget effect and anisotropic cases.

References:

- [1] Demay, C., looss, B., Gratiot, L.L., Marrel, A., (pre-print) Model selection based on validation criteria for Gaussian Process regression: applications on the characterization of chemical segregation 17.
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- [3] Kitanidis, P.K., 1986. Parameter Uncertainty in Estimation of Spatial Functions: Bayesian Analysis. Water Resources Research 22, 499–507.