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Metamodeling and optimization of probabilistic scores for long-range atmospheric dispersion applied to the Fukushima nuclear disaster

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In case of a nuclear accident that may imply a release of radioactivity into the environment, atmospheric dispersion models are used to infer mitigation actions, and complement field measurements for the assessment of short and long term environmental and human health impacts. These models compute the concentrations of radionuclides in the atmosphere, the deposited quantities on the ground, as well as the gamma dose rates. These results are used to evaluate the risk over the accident region, compute the special intervention areas and make the recommendations to protect the population.

Currently, the simulations of atmospheric dispersion models are subject to large uncertainties because the knowledge on input data and physical parameters is limited. In fact, uncertainties in atmospheric dispersion models can be due to different sources: weather forecasts, emission term, deposition velocities on the ground, scavenging coefficients, turbulent diffusion coefficients, and numerical approximations. A previous global sensitivity analysis of an Eulerian transport model, Polyphemus/Polair3D, relied on Sobol' indices and identified the most influential parameters (Girard et al., 2016). The most important sources of uncertainties were found to be the meteorological variables and the emission term.

The uncertainties are sampled by ensemble of simulations, obtained by perturbing the uncertain input parameters and by randomly sampling from an ensemble of source terms and an ensemble of meteorological forecasts. The perturbations on the inputs may not be properly described and need calibration. This is carried out by optimizing ensemble scores or probabilistic scores, like the variance of the rank histogram or the Continuous Rank Probability Score (CRPS), which make use of observational data to evaluate the performance of an ensemble of simulations.

However, this optimization requires a large number of simulations, so that the computational time is too high with current dispersion models. To circumvent this issue, we built a mathematical approximation of the model, i.e., a metamodel based on dimension reduction (e.g., with principal component analysis) and statistical emulation (e.g., interpolation of training samples with radial basis functions). The metamodel is then used in the ensemble calibration procedure.

Our study implements the approach with a long-range atmospheric dispersion model, ℓdX, applied to the Fukushima nuclear disaster. ℓdX is part of C3X, the IRSN modeling platform used during nuclear emergencies. The ensemble simulations make use of meteorological ensemble forecasts of the European Center for Medium-range Weather Forecast (ECMWF), an ensemble of 6 emission terms and random perturbations on the other inputs. In the evaluation and calibration process, we made use of radiological observations of activity concentration, deposition and dose rate collected in Japan.