Sensitivity analysis of radionuclides atmospheric dispersion

following the Fukushima accident

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Inria informatics mathematics

Context

- Polyphemus/Polair3D, is a radionuclides dispersion model used by the French Institute for radioprotection and nuclear safety (IRSN) under the name LdX
  - for emergency response in case of a nuclear accident,
  - and assessment of its sanitary and environmental impact.

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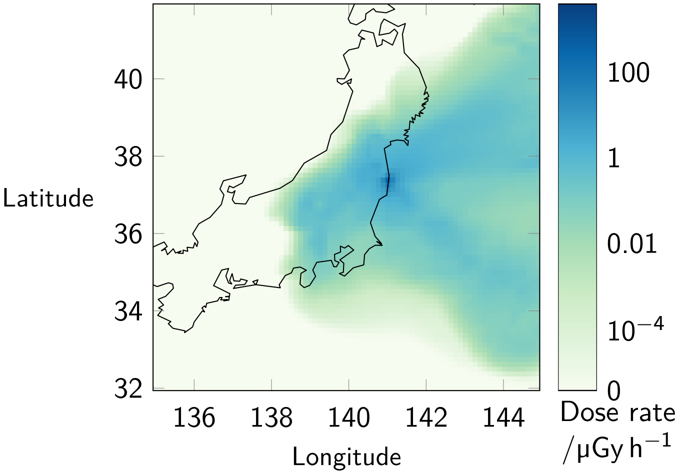
First step

Which uncertain model inputs mostly affect the output uncertainty?

Maximum of gamma dose rate from the deposit



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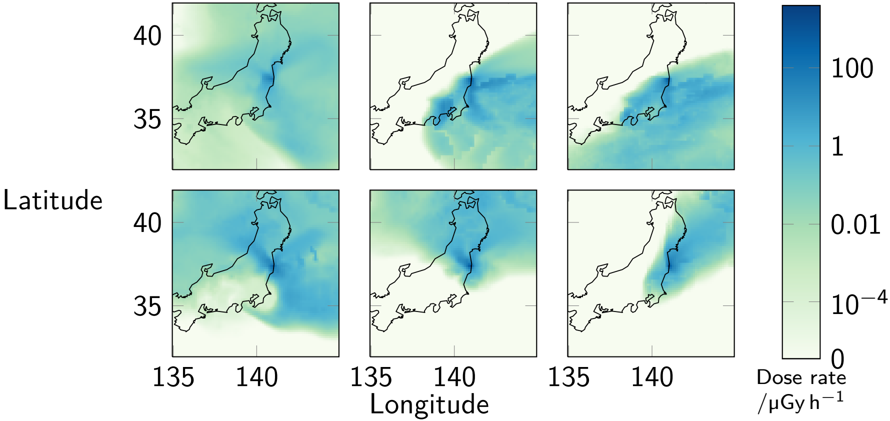

Uncertain model inputs

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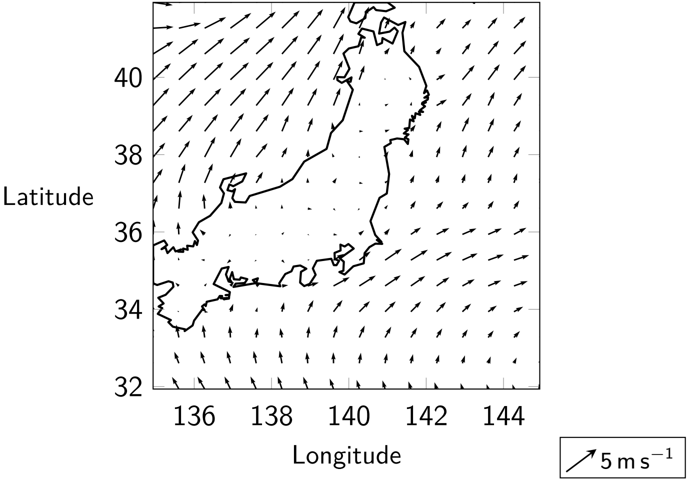
- Meteorological input data
  - Wind
  - Rain
- Source term
  - One time series for each species

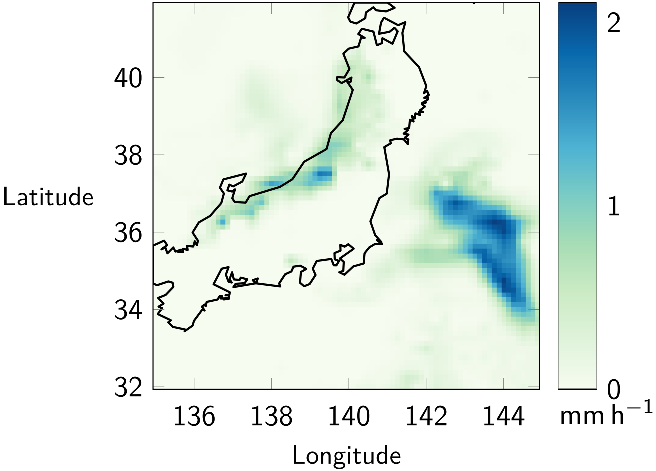
} High dimension

Wind



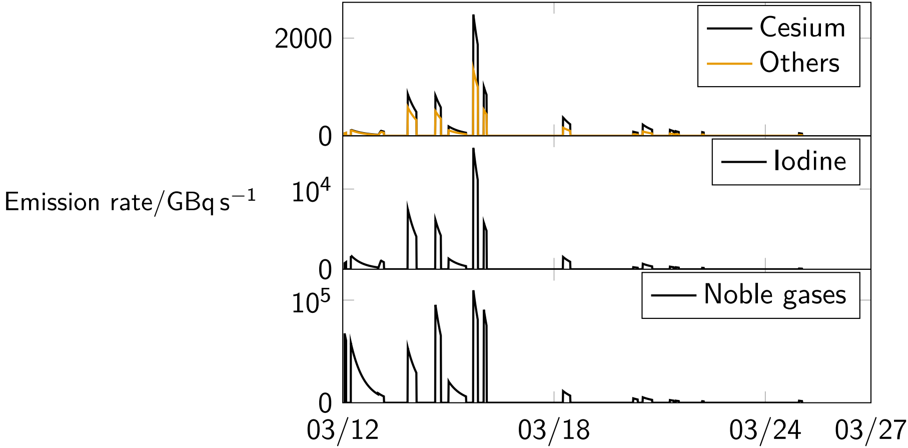
- Because of complex structures, a uniform additive perturbation was used.

Rain



- Here, a uniform multiplicative perturbation was used.

Source term



- Species are parted into 4 families.
- Perturbations: emission factor, altitude and time shift

Choice of a sensitivity analysis method

- Criteria:
  - One simulation $\approx$ 20 h CPU time
  - 19 input variables
  - Interactions and non-linearity were expected

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  - 19 input variables
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Morris' screening method

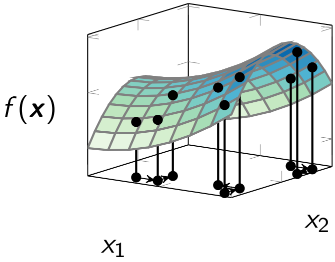
- Computationally cheap
- Classify the inputs into
  1. non-influential;
  2. linearly influential;
  3. non-linearly influential or interacting.

Morris' screening method

- Elementary effects are computed by perturbing each input variable in turn, one at a time.

- Elementary effect:

$$d^{(i)} = \frac{y(\boldsymbol{x}_{\neg i}, x_i + \delta) - y(\boldsymbol{x}_{\neg i}, x_i)}{\delta}$$



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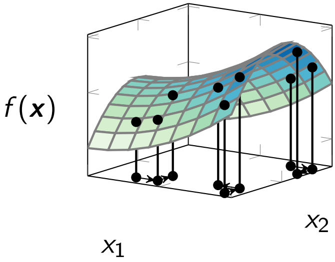

- Starting points are randomised in order to sample the distribution of elementary effects.
- The moments of this distribution are used as sensitivity measures.

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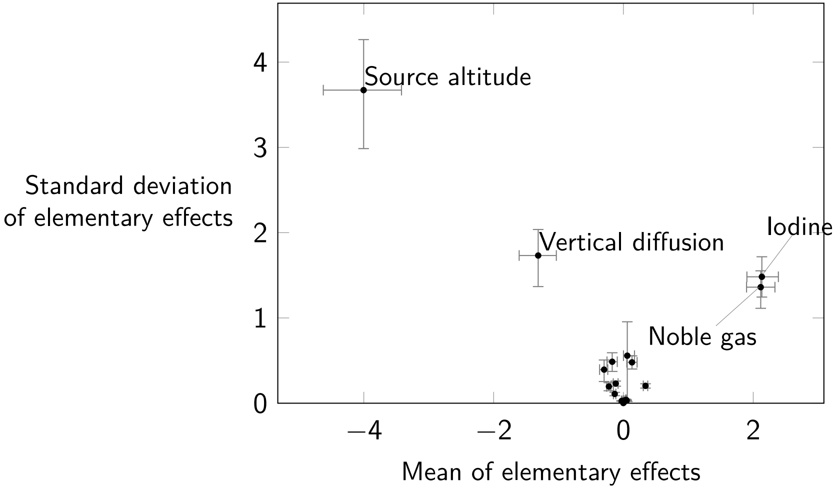
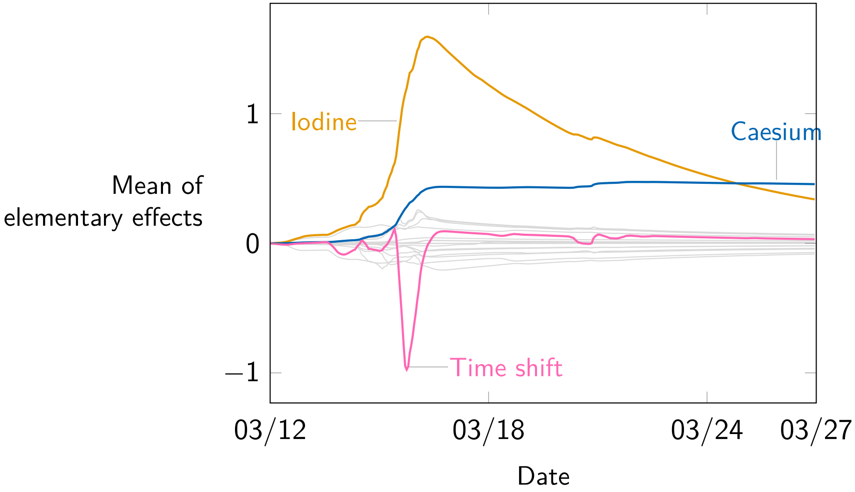
2. Thresholding
   - Elementary effects are replaced by a shape mismatch criterion.
3. Involving observation
   - Classical statistical scores (factor 2, root mean square error)
   - Temporal comparison of simulated and observed signals (peak time match)

Spatio-temporal average of atmospheric dose rate



Spatial average of deposit dose rate



Screening

Input	Atmosphere (aggregated)	Deposit (aggregated)	Shape	Scores	Peaks time
Scavenging coeff.	−	+	=	+	+
Horiz. diffusion	−−	−−	+	=	+
Vertical diffusion	+	=	+	+	+
Winds	=	+	++	++	++
Rain	−	+	=	+	+
Clouds	−−	−−	−	−	−
Factor for Iodine	++	++	++	++	+
Caesium	=	+	+	+	+
Noble gases	++	−−	−−	−−	+
Other species	−	−	−	−	−
Time shift	++	++	++	+	++
Source altitude	++	+	+	+	+

Paper under review

Title:

*"Screening sensitivity analysis
of a radionuclides atmospheric dispersion model
applied to the Fukushima disaster"*

Submitted to *Atmospheric Environment*.

Next step

- Calibration of the inputs probability distributions using observations
  - This requires very large simulation samples
- Emulation of the model by a Gaussian process
  - First results are promising

Thank you.

Design of experiment

Variable	Lower bound	Upper bound	Symbol
Below cloud factor/$\mathrm{h\,s^{-1}\,m^{-1}}$	0.05	0.5	a_b
Below cloud exponent	0.6	1	b_b
In-cloud factor/$\mathrm{h\,s^{-1}\,m^{-1}}$	0.05	0.5	a_i
In-cloud exponent	0.6	1	b_i
Precipitation$^{(\times)}$	0.5	2	p
Clouds base height$^{(\times)}$	0.67	2	C_h
Clouds thickness$^{(\times)}$	0.5	2	C_t
Dry deposition velocity/$\mathrm{mm\,s^{-1}}$	0.5	5	v_d
Zonal diffusion/$10^4\,\mathrm{m^2\,s^{-1}}$	0	1.5	K_u
Meridional diffusion/$10^4\,\mathrm{m^2\,s^{-1}}$	0	1.5	K_v
Vertical diffusion$^{(\times)}$	0.33	3	K_z
Zonal wind$^{(+)}$/$\mathrm{m\,s^{-1}}$			w_u
$z \in [0\,\mathrm{m}, 40\,\mathrm{m}[$	-3	3	
$\vdots$	$\vdots$	$\vdots$	
$z \in [2600\,\mathrm{m}, 3400\,\mathrm{m}[$	-6.7	6.7	
Meridional wind$^{(+)}$/$\mathrm{m\,s^{-1}}$			w_v
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$\vdots$	$\vdots$	$\vdots$	
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Emission of Caesium family$^{(\times)}$	0.33	3	E_{Cs}
Emission of Iodine family$^{(\times)}$	0.33	3	E_I
Emission of noble gases$^{(\times)}$	0.33	3	E_g
Emission of other species$^{(\times)}$	0.33	3	E_o
Emission delay$^{(+)}$/h	-6	6	Δt
Source elevation/m	[0,40[	[280,400[	z