IRSN
INSTITUT
DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

Enhancing nuclear safety

Comparison of ensembles of atmospheric dispersion simulations

Lessons learnt from the CONFIDENCE project about uncertainty quantification

confidence
Coping with uncertainty for improved modelling and decision making in nuclear emergencies

CONFIDENCE is part of the CONCERT project. This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 662287

MEMBER OF
ETSON EUROPEAN TECHNICAL SAFETY ORGANISATIONS NETWORK

19th HARMO conference

4 June 2019

Special CONFIDENCE session

I. KORSAKISSOK, WP1 members

Spyros Andronopoulos, Poul Astrup, Peter Bedwell, Karine Chevalier-Jabet, Hans De Vries, Gertie Geertsema, Florian Gering, Thomas Hamburger, Heiko Klein, Susan Leadbetter, Anne Mathieu, Tamas Pazmandi, Raphaël Périllat, Csilla Rudas, Andrey Sogachev, Peter Szanto, Jasper Tomas, Chris Twenhöfel, Joseph Wellings

IRSN/FRM-414 ind 3

Context

In case of an accidental release of radionuclides

- Atmospheric dispersion models are used to *forecast* the health and environmental impact
- A tool for decision making: countermeasures (evacuation, sheltering, stable iodine intake)
- A tool to reconstruct the contamination events combining simulation and measurements

Results are subject to many uncertainties

- It can include ***stochastic uncertainties*** (i.e physical randomness), ***epistemological uncertainties*** (lack of scientific knowledge), ambiguities (ill-defined meaning), value uncertainties (when the required endpoint is ill-defined), *judgemental uncertainties* (e.g. setting of parameter values in codes), computational uncertainties (i.e. inaccurate calculations), *modelling errors* (i.e. however good the model is, it will not fit the real world perfectly)
- We should also address ***social and ethical uncertainties***, in the analysis of risk and in decision making

The CONFIDENCE project

- COping with uNcertainties For Improved modelling and DEcision making in Nuclear emergenCiEs
- The CONFIDENCE Project will perform research focussed on uncertainties in the area of emergency management and long-term rehabilitation. It concentrates on the early and transition phases of an emergency, but considers also longer-term decisions made during these phases.
- Duration 3 years: 1.1.2017 – 31.12.2019
- 31 partners from 17 European countries
- Budget: 6.201.026 €, request to EC: 3.252.487 €
- Part of CONCERT
- 7 work packages (WPs)
  - WP1: uncertainties in the pre and early release phase (atmospheric dispersion simulations)
  - WP2, WP3: data assimilation, measurements, radioecological models
  - WP4, WP5: stakeholders, transition phase to long-term recovery
  - WP6: visualization and decision-making
  - WP7: education and training

WP1: uncertainties in atmospheric dispersion simulations

1.1 Analyzing and ranking sources of uncertainties (Lead: IRSN)

1. Using ensemble data for meteorological uncertainties (Lead: UK MetOffice)
2. Using meteorological measurements to reduce uncertainties (Lead: EEAE)
3. Uncertainties related to source term (Lead: IRSN)
4. Uncertainties related to models (Lead: PHE)

1.2 Uncertainty propagation and analysis (Lead: IRSN)

1. Simulation and comparisons to observations for the Fukushima case
2. Simulation for the synthetic European case studies

1.3 Emergency response and dose assessment

1. Food chain uncertainty propagation (Lead: BfS)
2. Recommendations and operational methodology in an emergency context (Lead: PHE)

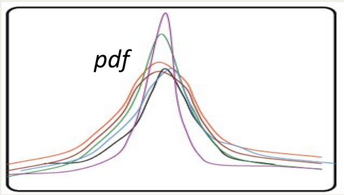
DONE 2017

DONE 2018 / IN PROGRESS

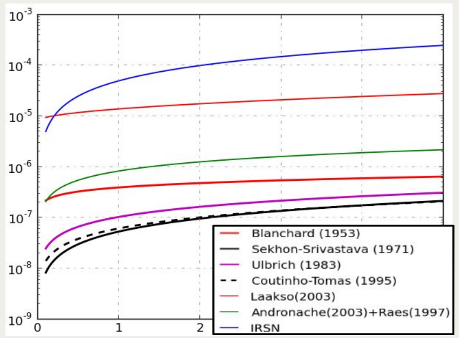
IN PROGRESS 2019

How to quantify the uncertainty of data?

Model parameters



↗ Experts' judgment, literature review



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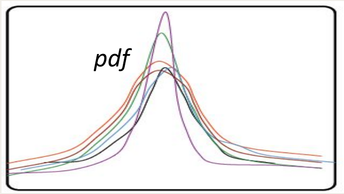
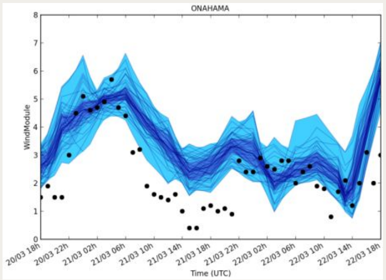
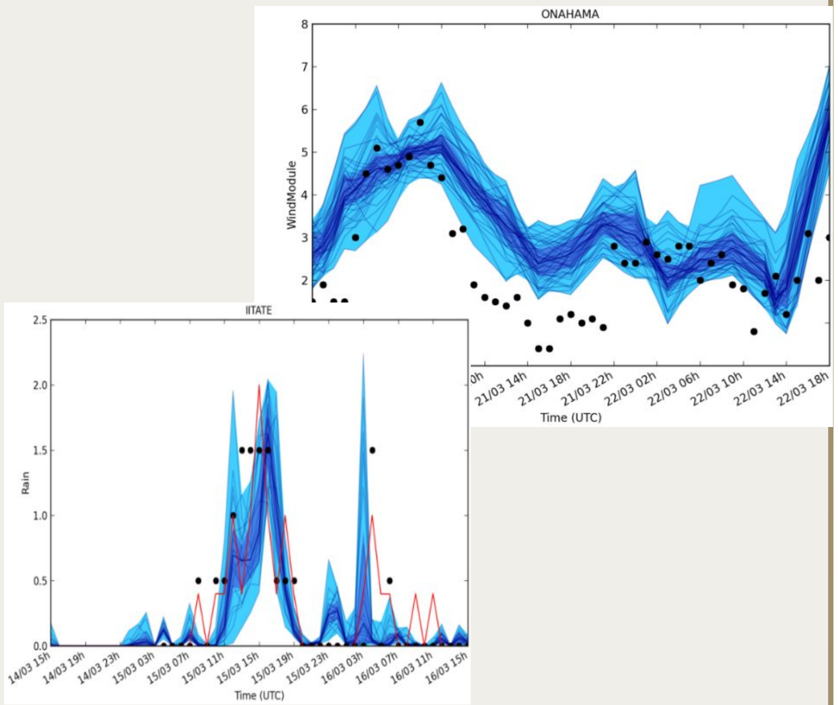


Input : meteo



➚ Using meteorological forecast ensembles



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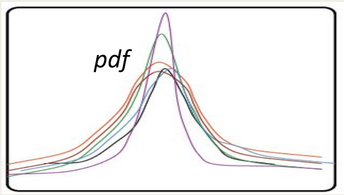
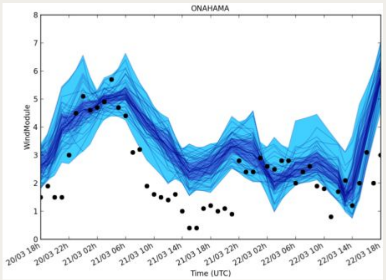
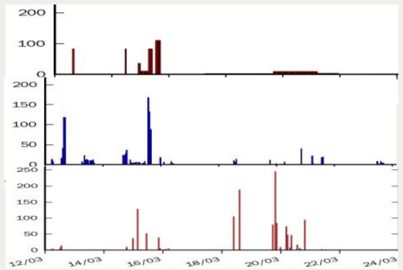


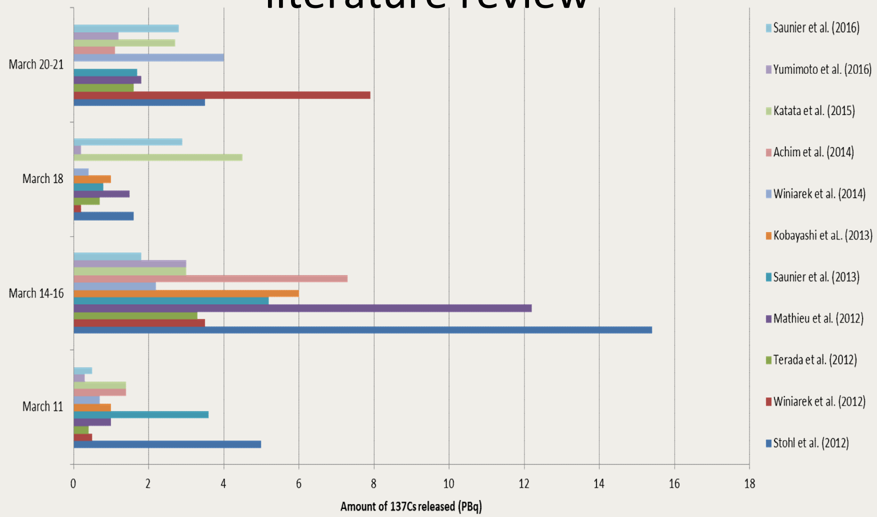
Input : meteo



Input: source term

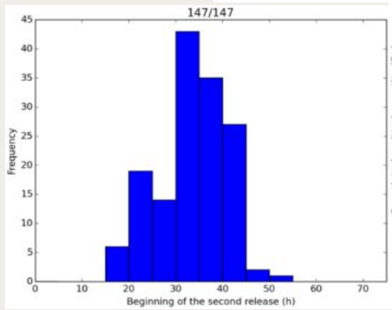


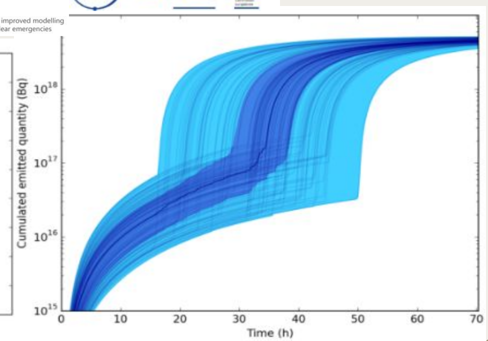
- Past-accident analysis (Fukushima) literature review



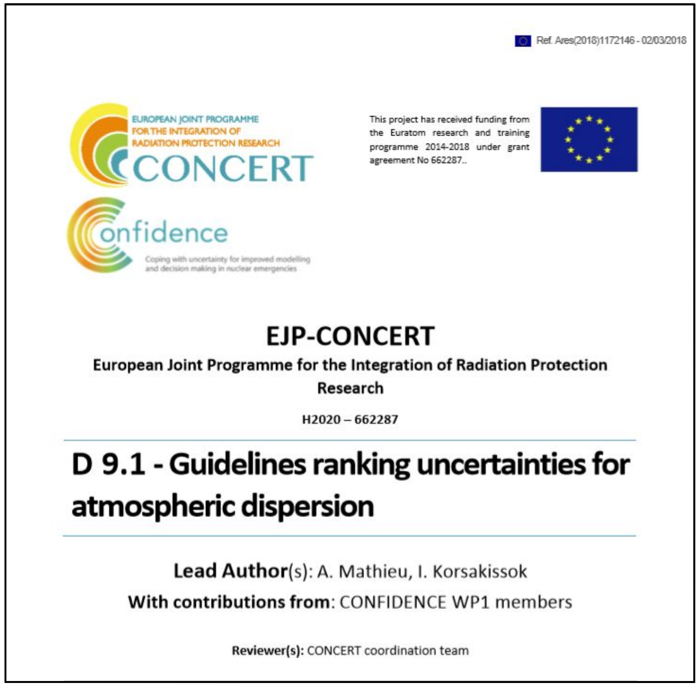
- Emergency : May rely on experts' judgment / ensemble of ST

European projects Confidence FASTNET





Further on input uncertainties…



Ref. Ares(2018)1172146 - 02/03/2018

EUROPEAN JOINT PROGRAMME FOR THE INTEGRATION OF RADIATION PROTECTION RESEARCH CONCERT

confidence – Coping with uncertainty for improved modelling and decision making in nuclear emergencies

This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 662287.

EJP-CONCERT

European Joint Programme for the Integration of Radiation Protection Research

H2020 – 662287

D 9.1 - Guidelines ranking uncertainties for atmospheric dispersion

Lead Author(s): A. Mathieu, I. Korsakissok

With contributions from: CONFIDENCE WP1 members

Reviewer(s): CONCERT coordination team

Deliverable D9.1

D 9.1.1 - Using Ensemble Meteorological Forecasts to Represent Meteorological Uncertainty in Dispersion Models

Lead Author: Susan J. Leadbetter
With contributions from: S. Andronopoulos, P. Bedwell, G. Geertsema, A. R. Jones, I. Korsakissok, J. Tomas, H. de Vries
Reviewer(s): WP1 members

D 9.1.2 - Using meteorological measurements to reduce uncertainty

Lead Author: S. Andronopoulos
With contributions from: G. Geertsema, H. Klein, H. de Vries
Reviewer(s): P. Bedwell, S. Leadbetter, J. Tomas

D 9.1.3 - Guidelines describing source term uncertainties

Lead Author: A. Mathieu, I. Korsakissok, R. Périllat, K. Chevalier-Jabet
With contributions from: F. Stephani, S. Fougerolle, V. Créach, E. Cogez, P. Bedwell
Reviewer(s): WP1 members

D 9.1.4 - Guidelines detailing the range and distribution of atmospheric dispersion model input parameter uncertainties

Lead Author: P. Bedwell and J. Wellings
With contributions from: S. Leadbetter, J. Tomas, S. Andronopoulos, I. Korsakissok, R. Périllat, A. Mathieu, G. Geertsema, H. Klein, H. de Vries, T. Hamburger, T. Pázmándi, C. Rudas, A. Sogachev, P. Szántó
Reviewer(s): WP1 members

D 9.1.5 - Guidelines for ranking uncertainties in atmospheric dispersion

Lead Author: J. Wellings and P. Bedwell
With contributions from: S. Leadbetter, J. Tomas, S. Andronopoulos, I. Korsakissok, R. Périllat, A. Mathieu, G. Geertsema, H. de Vries, H. Klein, T. Hamburger, F. Gering, T. Pázmándi, P. Szanto, C. Rudas, A. Sogachev, N. Davis, C. Twenhöfel
Reviewer(s): WP1 members

http://www.concert-h2020.eu/en/Publications

REM Case study

Radiological Ensemble Modelling

Radionuclide	Xe-133	I-131	I-132	Te-132	Cs-134	Cs-136	Cs-137	Ba-137m
Activity(Bq)	3.51E18	2.25E16	2.84E16	1.37E16	2.69E15	6.37E14	2.06E15	2.78E14

Short release scenario

- Location: Borssele
- Duration 4 hours
- 8 radionuclides, no kinetics
- Uncertainties in the pre-release phase

- Release time +/- 6 hours
- Release height 50m +/- 50m
- Released quantity X [1/3, 3]

Meteorological scenario

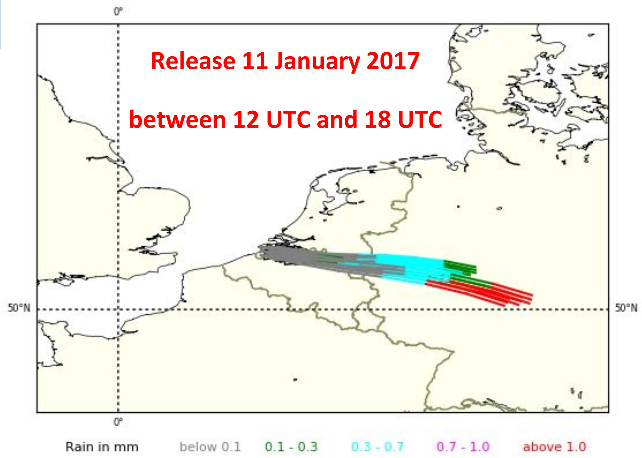
- Ensemble (KNMI), 10 members, 2,5 km resolution
- 72-hours forecast, 1-hour time step
- 11-13 January 2017

Scenario 1: "easy case"

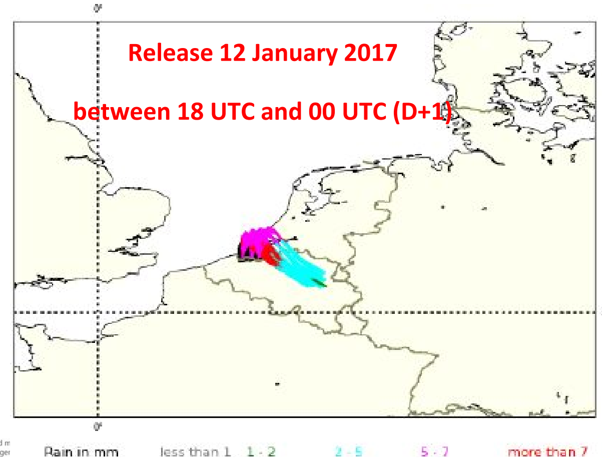
- Release at 12 UTC on January 11, 2017
- established wind direction – small variability
- patchy rain

Scenario 2: "warm front passage"

- Release at 21 UTC on January 12, 2017
- Wind direction is turning – high variability
- High rain



Indicative plume trajectories based on analysed weather between 10m and 500m, and associated rain (cumulated on one hour).



WP1 REM Case study

Participant	Number of simulations	Source perturbations		
		Release height	Release time	Released quantity
IRSN	100 (Monte Carlo) 150	[0, 100m] uniform [0m, 50m, 100m]	[-6h, 6h] uniform T0 + [-6h, -3h, 0h, +3h, +6h]	[1/3, 3] uniform [x1/3, x1, x3]*
BfS	150	[0m, 50m, 100m]	T0 + [-6h, -3h, 0h, +3h, +6h]	[x1/3, x1, x3]*
MetOffice/ PHE	90	[50m]	T0 + [-6h, 0h, +6h]	[x1/3, x1, x3]
EEAE	50	[50m]	T0 + [-6h, -3h, 0h, +3h, +6h]	[x1/3, x1, x3]*
MTA EK	150 Borssele 1 90 Borssele 2	[0m, 50m, 100m]	T0 + [-6h, -3h, 0h, +3h, +6h] T0 + [-6h, 0h, +6h]	[x1/3, x1, x3]*
RIVM	650	[0m, 25m, 50m, 75m, 100m]	[-6h, +6h] with a time step of 1 hour (13 steps)	[x1/3, x1, x3]*
DTU	10 Borssele 1 50 Borssele 2	[50m]	T0 + [-6h, -3h, 0h, +3h, +6h]	[x1/3, x1, x3]*

*Perturbation applied a posteriori on the results

Endpoints

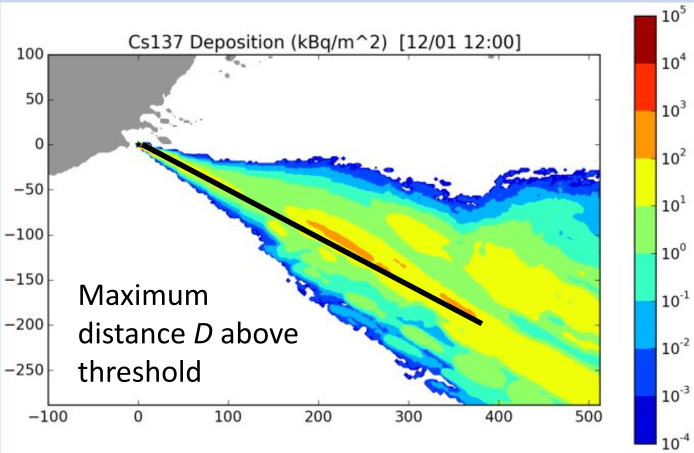
Endpoints: consequences computed at T0+24h

- Ground deposition of ^{137}Cs and ^{131}I
  - ➢ Post-Chernobyl reference level: 37 kBq/m^2 for ^{137}Cs
  - ➢ Other levels: 10 kBq/m^2 for ^{137}Cs, ^{131}I
- Effective dose and inhalation thyroid dose for 1-year old child – 10, 50, 100 mSv

How to use ensemble results?

Deterministic: *one* simulation

^{137}Cs deposition, threshold 37 kBq/m^2

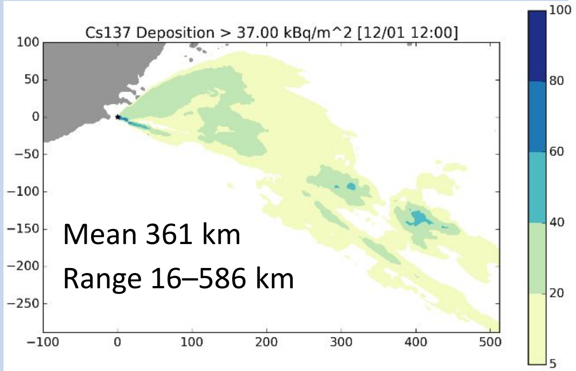


Probabilistic: ^{137}Cs ground deposition for *N* simulations

- ✓ *N* maps of deposition: “postage stamp”
- ✓ Median (or 25th, 75th percentile…) of the *N* deposition maps

For a given threshold *t*

- ✓ *N* maximum distances D_i above *t*
- ✓ Map of probability of exceeding *t*

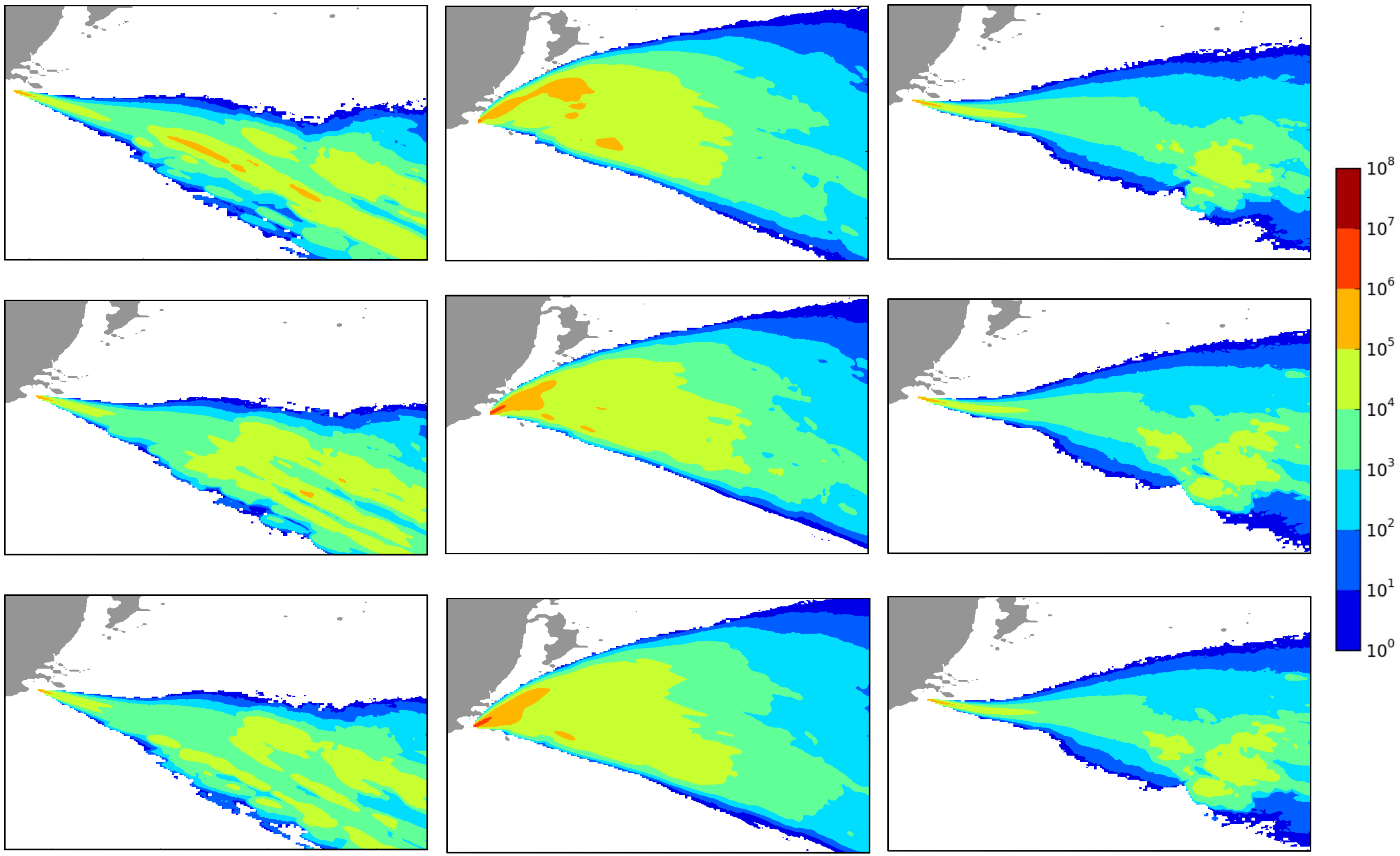


Scenario 1: "postage stamp"

^{137}Cs deposition (kBq/m^2)
at T0+24h - UK MetOffice

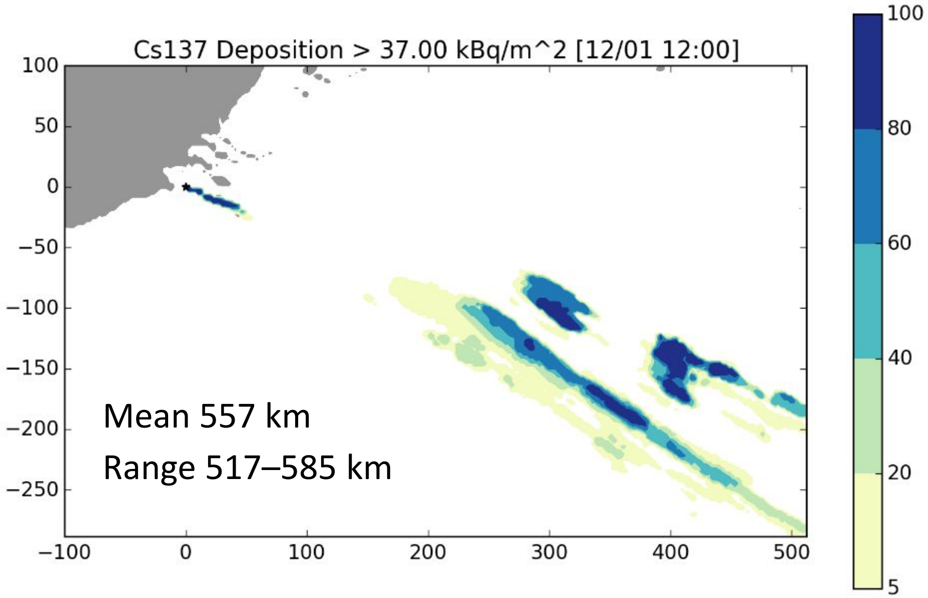
T0 = 12:00 UTC | T0 = 06:00 UTC | T0 = 18:00 UTC

Different meteorological fields

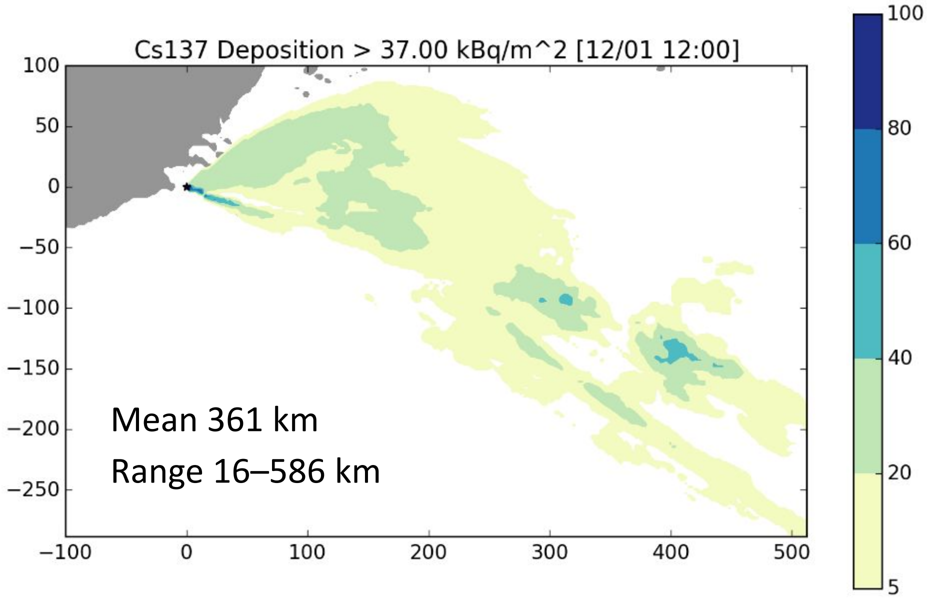


Scenario 1: probability maps

- Maps of probability of threshold exceedance
- For a threshold of 37 kBq/m² for the ^{137}Cs deposition
- Example of UK MetOffice (NAME model)



10 simulations (meteorology only)

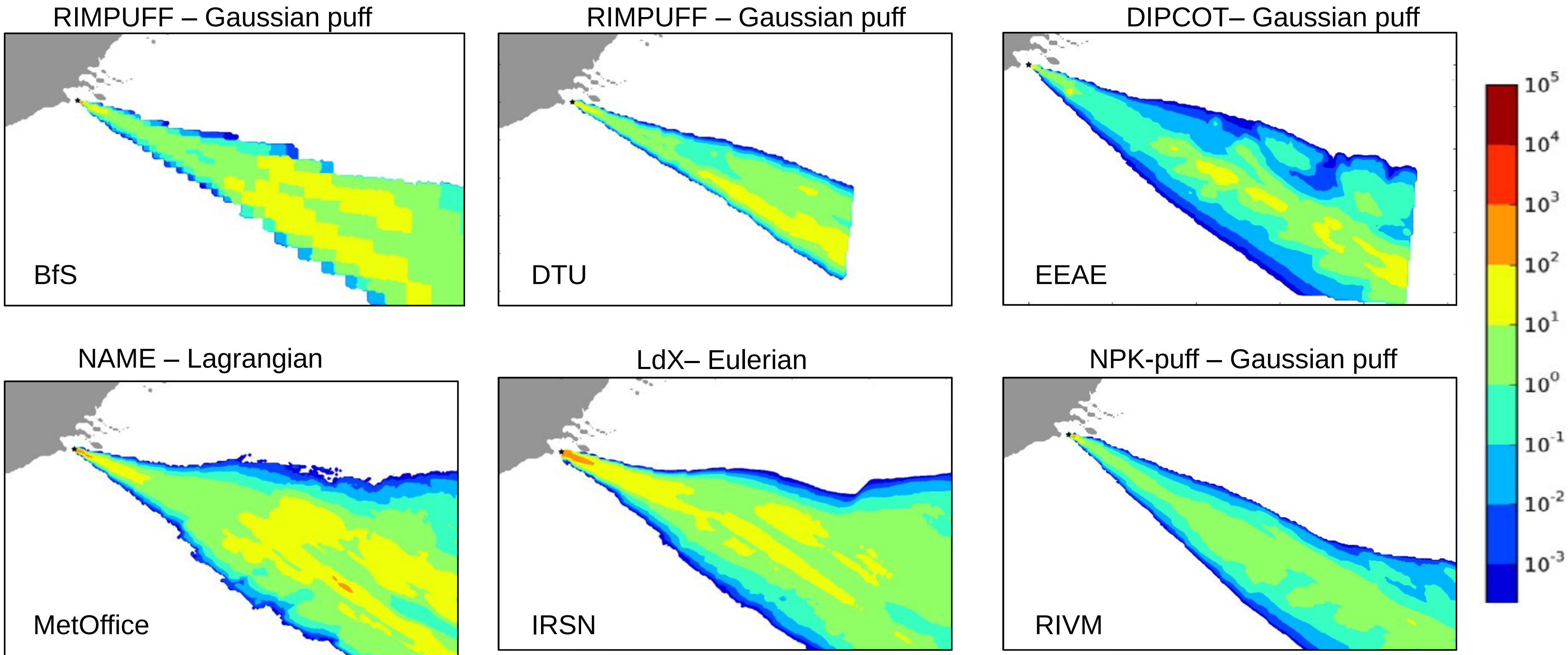


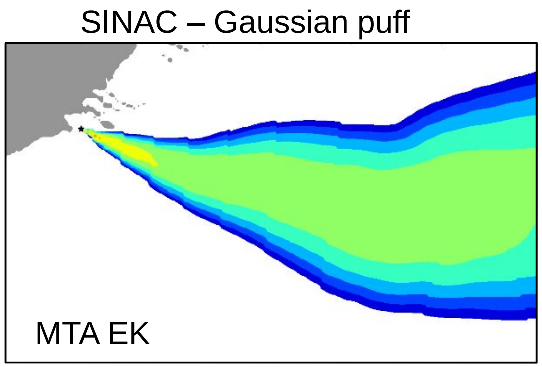
90 simulations (meteorology + source term)

With source perturbations

- ↗ **Maximum distance of threshold exceedance is lower**
- ↗ **Surface covered by low probabilities is larger**

Scenario 1: median of ^{137}Cs deposition (kBq/m²)





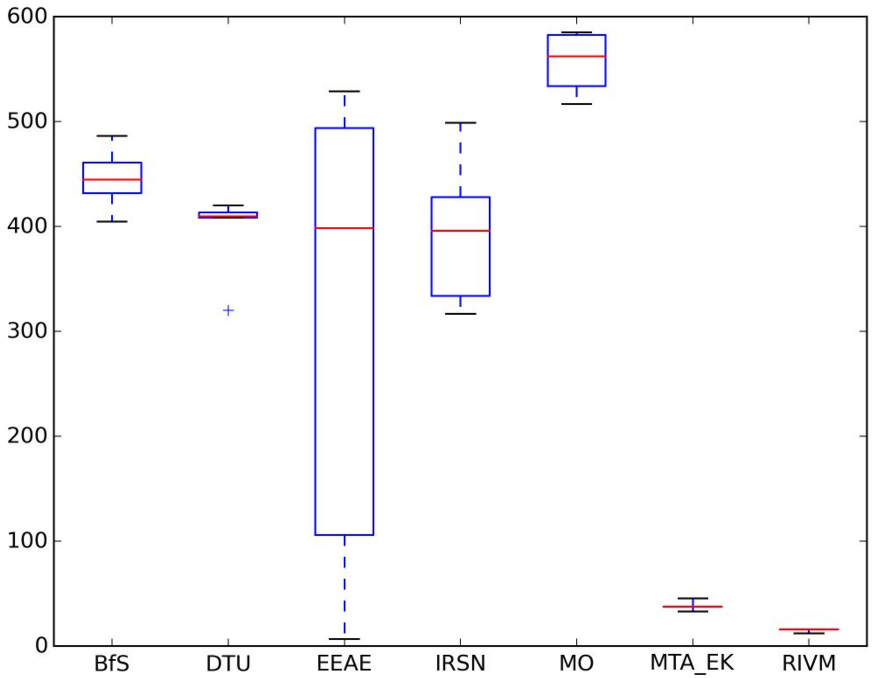
10 simulations (meteorology only)

Differences may come from:

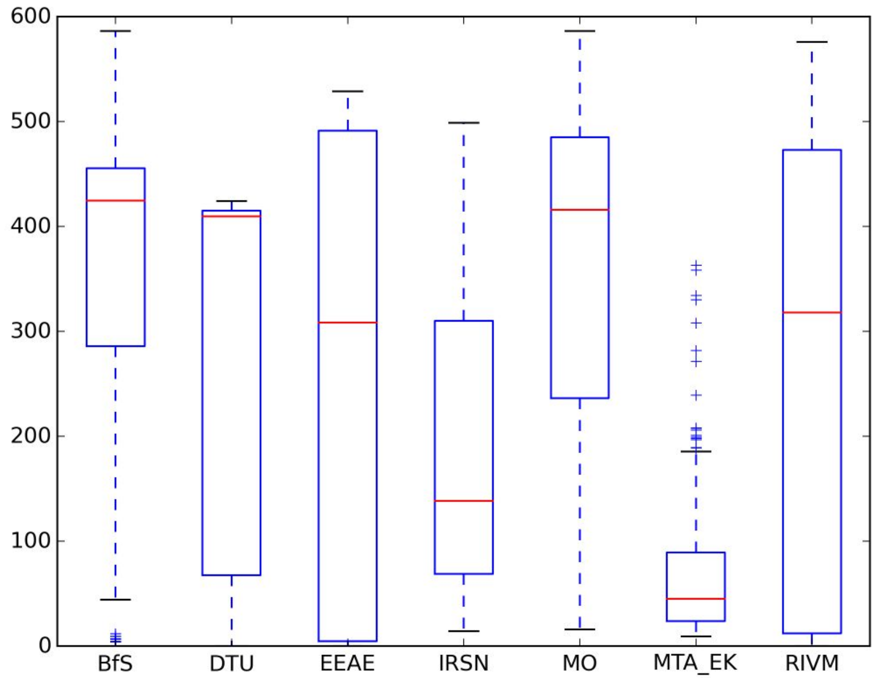
- ✓ Type of models (Gaussian, Eulerian, Lagrangian)
- ✓ Different wet deposition schemes
- ✓ Diffusion coefficients
- ✓ Modelling domain, interpolation…

Scenario 1: box plots

- Maximum distance from the source (km)
- For a threshold of 37 kBq/m² for the ^{137}Cs deposition



10 simulations (meteorology only)



10-650 simulations (meteorology + source term)

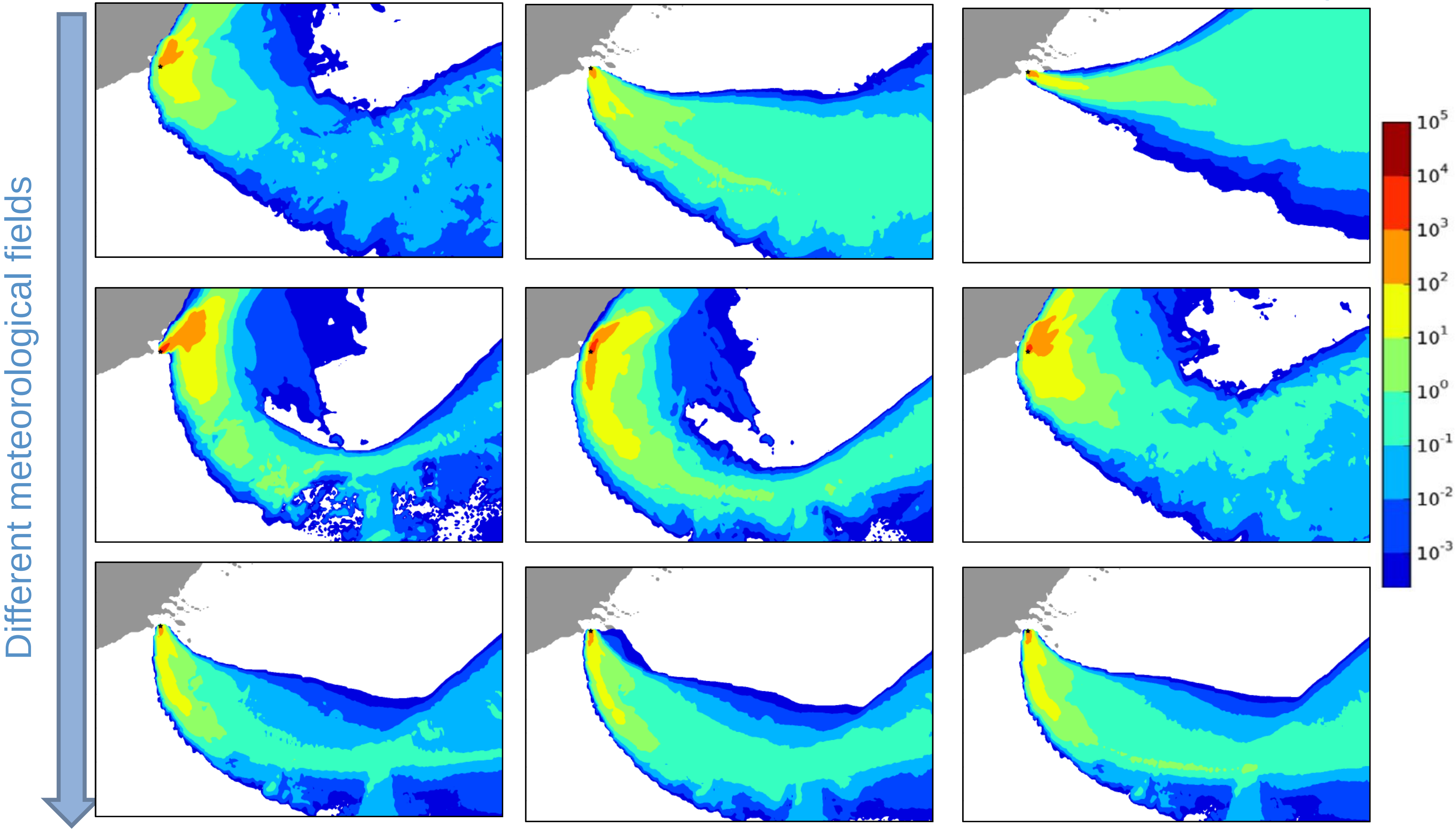
- **Larger variability (boxes' size) with ST perturbations**
- **Inter-model variability not totally encompassed by the range of variation**

Scenario 2: “postage stamp”

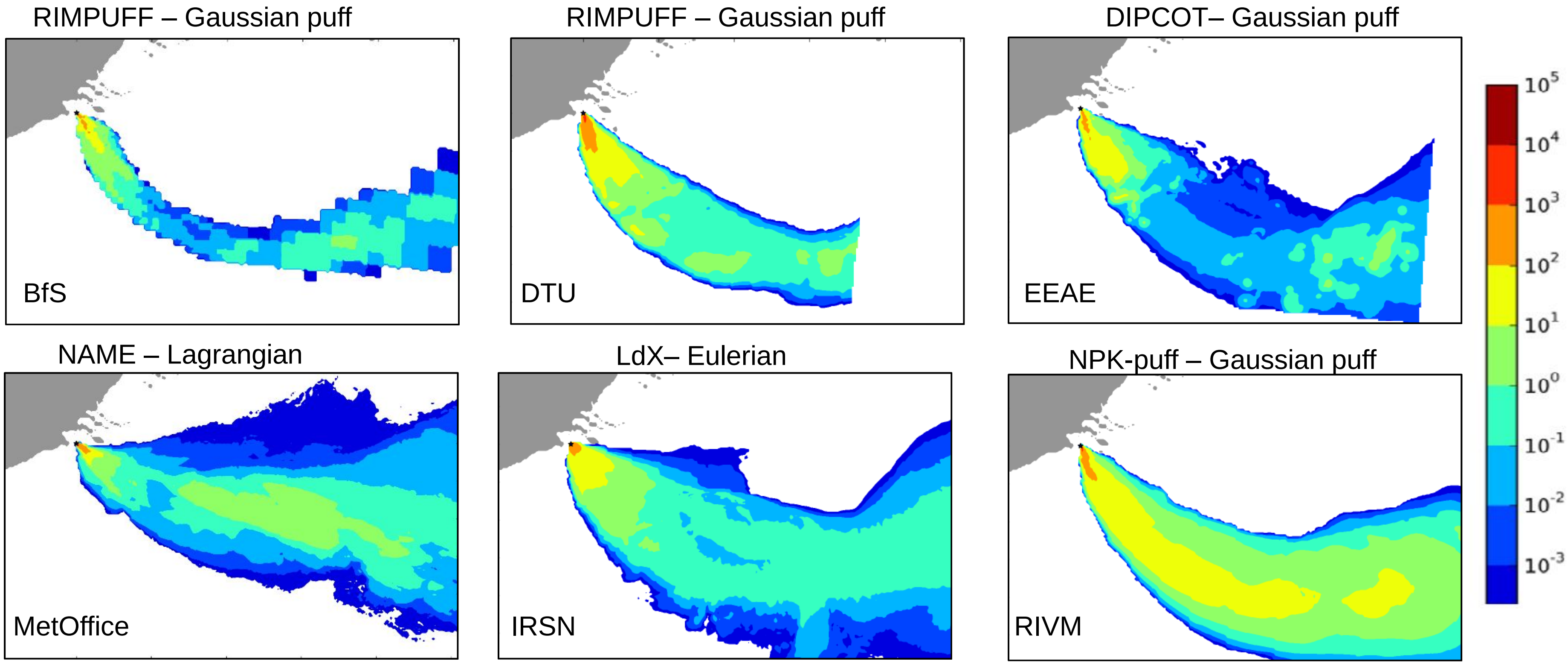
^{137}Cs deposition (kBq/m^2)

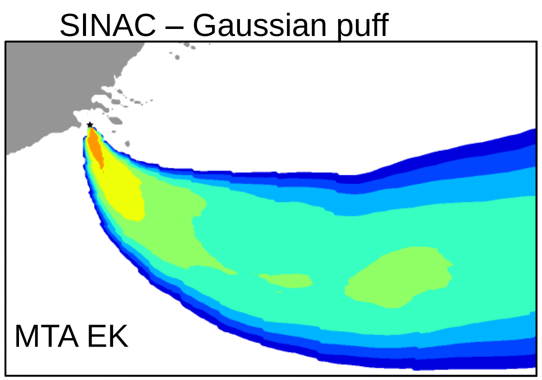
at T0+24h - IRSN

T0 = 15:00 UTC | T0 = 21:00 UTC | T0 = 03:00 UTC Day+1



Scenario 2: median of ^{137}Cs deposition (kBq/m^2)



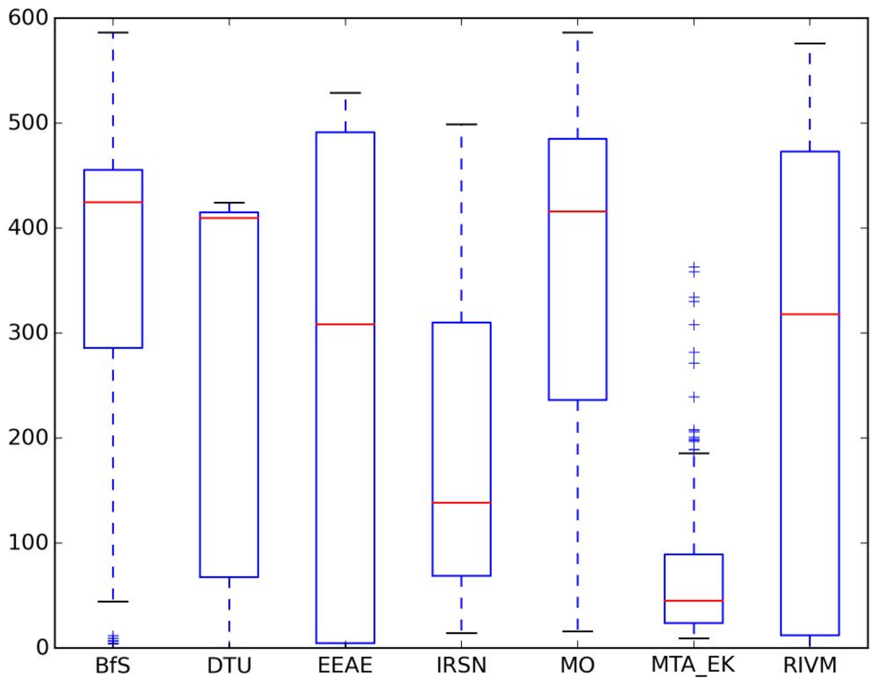


Differences may come from:

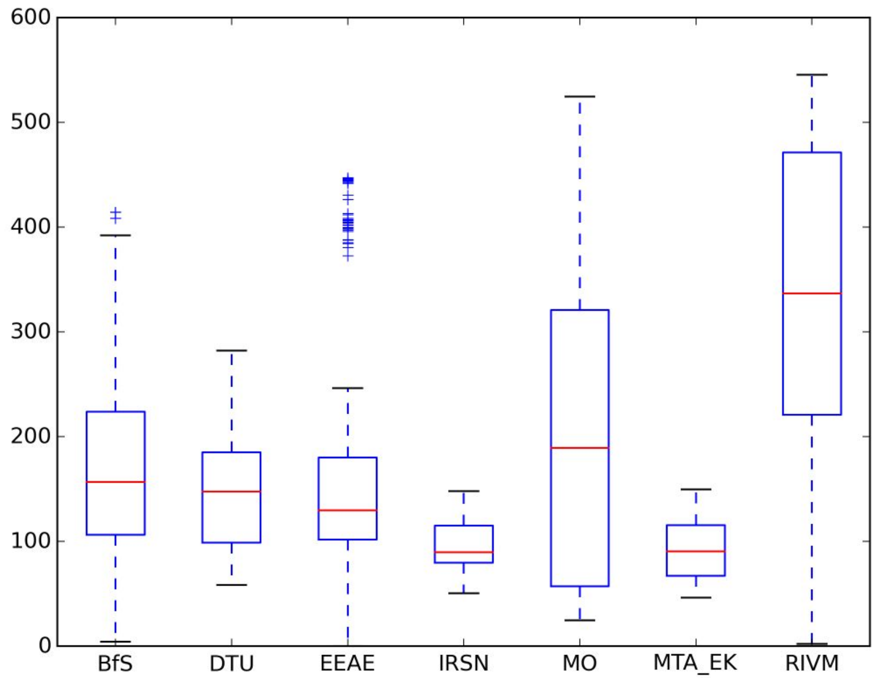
- ✓ Type of models (Gaussian, Eulerian, Lagrangian)
- ✓ Different wet deposition schemes
- ✓ Diffusion coefficients
- ✓ Modelling domain, interpolation…

Scenario 2: box plots

- Maximum distance from the source (km)
- For a threshold of 37 kBq/m² for the ^{137}Cs deposition



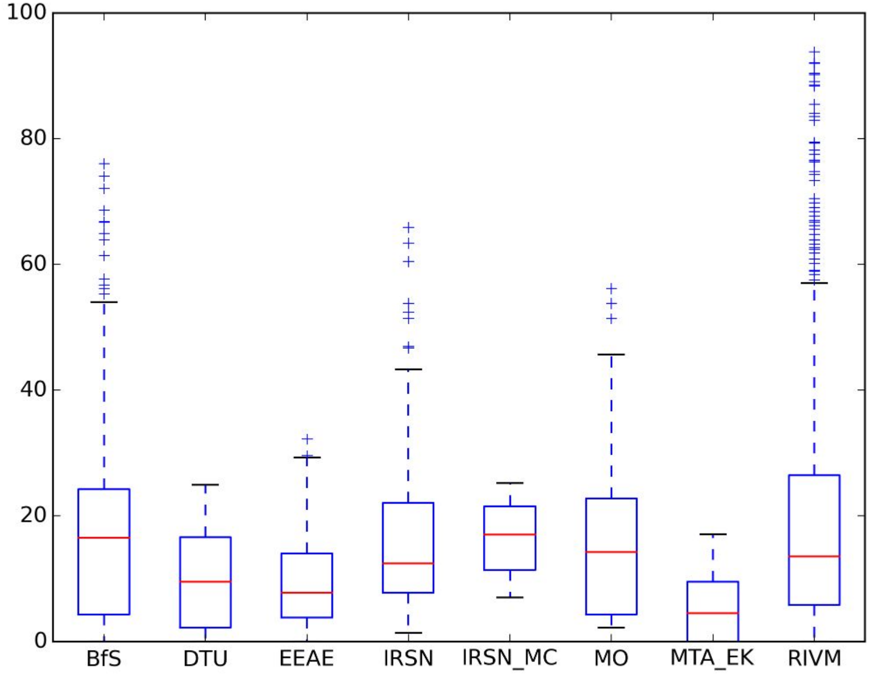
Scenario 1



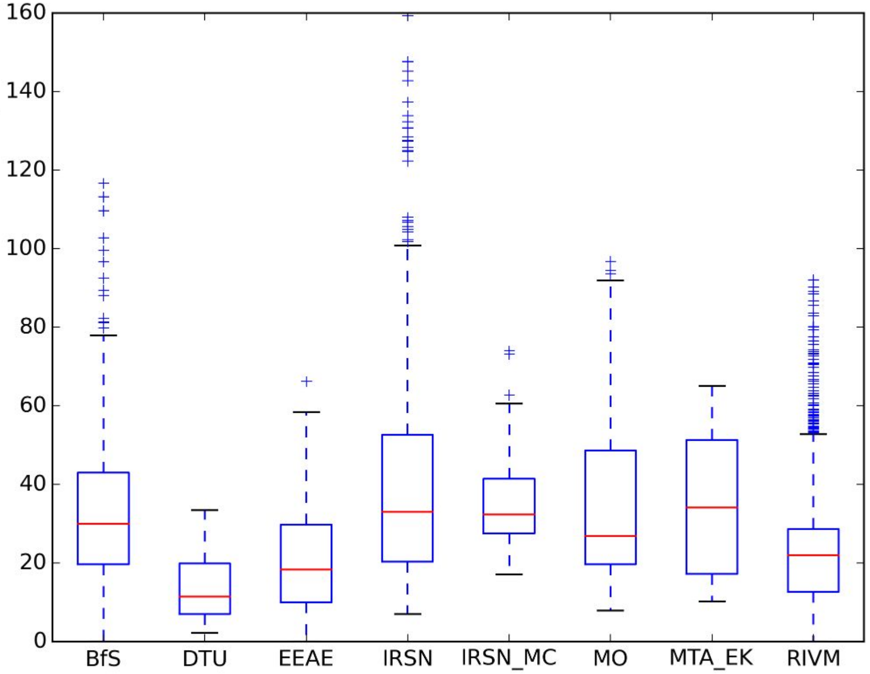
Scenario 2

Scenario 2: box plots

- Maximum distance from the source (km)
- Thresholds on the effective and inhalation thyroid doses



10 mSv - Effective dose



50 mSv - Inhalation thyroid dose

- **Good agreement between the uncertainty estimations and median values**
- **A few outliers in some ensembles give much larger distances**

Conclusions

Influence of source perturbations

- Importance of taking into account source perturbations
- Larger ensembles' spread
- **More perturbations induce lower distance above a given threshold**

Inter-model variability

- Less important when overall uncertainties are larger
- Some models or configurations may be more appropriate to the case
- Part of this variability may be taken into account
- **An uncertainty assessment with only one model will always be partial**

Uncertainty assessment

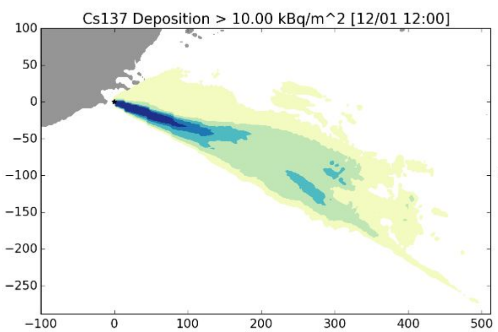
- Lower threshold induces higher distances / probability
- Surface above threshold (instead of distance) limits the effect of outliers
- **Importance of choosing correctly the threshold and percentile**

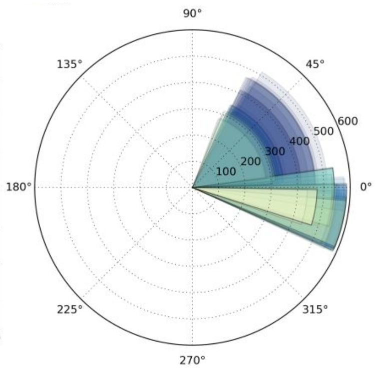
Uncertainties in an emergency context

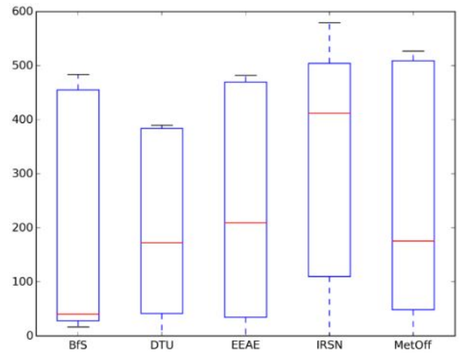
- Our knowledge of uncertainties will always be partial…
  - Deep uncertainties, lack of information
  - Have to tackle the main sources of uncertainties!
  - Avoid false confidence in probabilistic results…

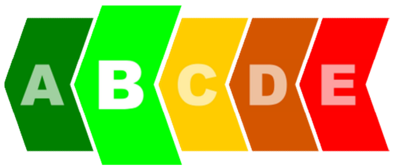
- Computational time: how many members are needed to correctly represent uncertainties? How to reduce computational time?
  - Reducing the number of members: clustering techniques, adaptive sampling
  - Model reduction: emulators, model assumptions
  - Adaptation to the endpoint: domain size and resolution…

➚ **How to include uncertainties in output products for decision makers?**









Next steps…

Case studies in progress

- Fukushima and Western Norway ongoing (not synchronised between participants)

Other tasks in the remaining year

- Food chain uncertainty propagation
- Recommendations and operational methodology in an emergency context

Dissemination

- Dissemination workshop (December 2019, Slovak Republic) → https://www.eu-neris.net/

Thank you for your attention!