Danmarks Meteorologiske Institut

Uncertainty of Atmospheric Dispersion Prediction

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[7]*Swedish Radiation Safety Authority (SSM)*

Uncertainties

In the early phase of a nuclear accident with potential off-site consequences, prediction of the atmospheric dispersion of radionuclides is of utmost importance.

However, two origins of potentially large uncertainty exist:

- meteorological data
- source term

Nordic Nuclear Safety Research (NKS) projects

MUD: Meteorological Uncertainty of atmospheric Dispersion model results (2012-2013)

FAUNA: Fukushima Accident – UNcertainty of Atmospheric dispersion modelling (2014-2015)

MESO: MEteorological uncertainty of ShOrt-range dispersion (2016)

AVESOME: Added Value of uncertainty Estimates of SOurce term and Meteorology (2017-2018)

SLIM: Source Localization by Inverse Methods (ongoing, 2019-2020)

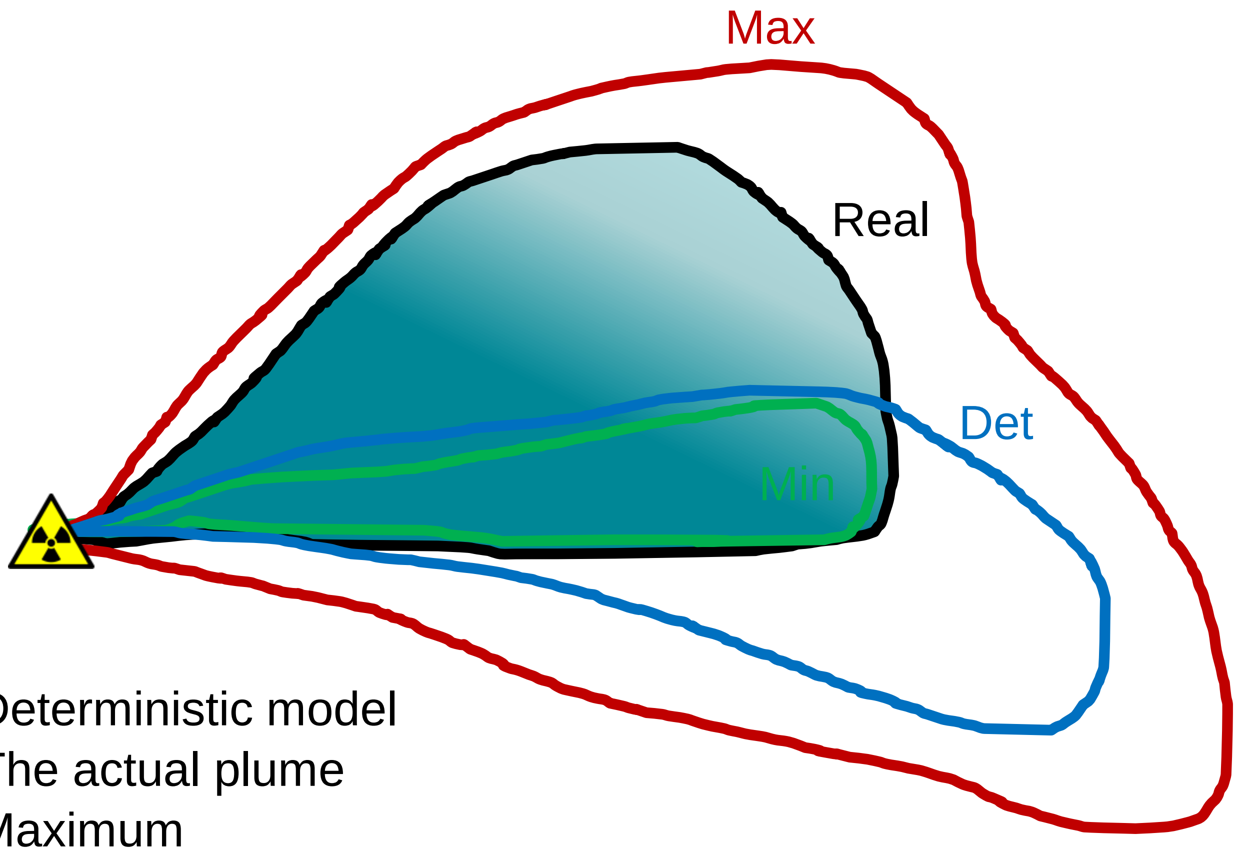
Reports available from www.nks.org

Uncertainties

In AVESOME, we have developed a methodology for quantitative estimation of the variation of atmospheric dispersion model prediction resulting from both sources of uncertainty.

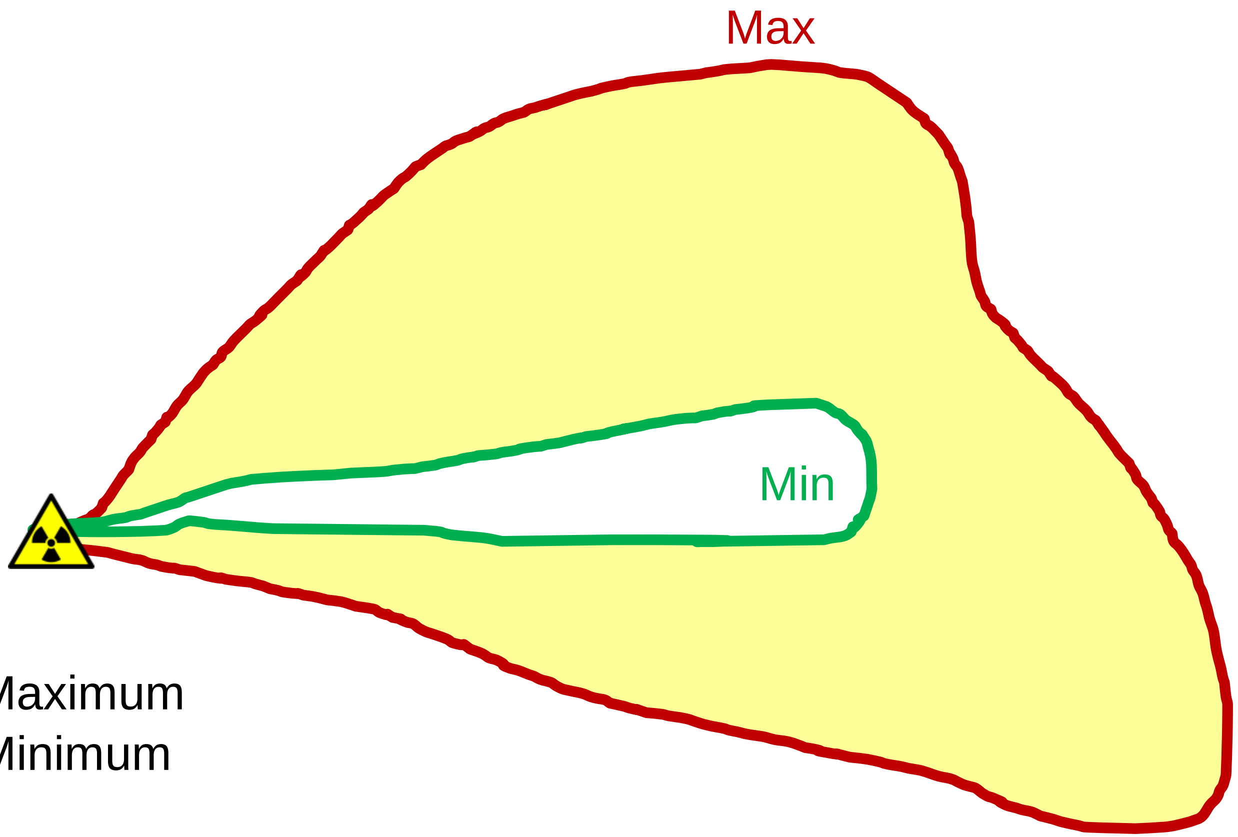
Suited for real-time assessments in DSSs by using supercomputing facilities at national meteorological services.

Operational value of uncertainty estimates



Det: Deterministic model
Real: The actual plume
Max: Maximum
Min: Minimum

Operational value of uncertainty estimates



Max: Maximum
Min: Minimum

Risk zone estimation
Optimization of resources

By taking uncertainties into account, the risk of making decisions based on an inappropriate prediction is reduced

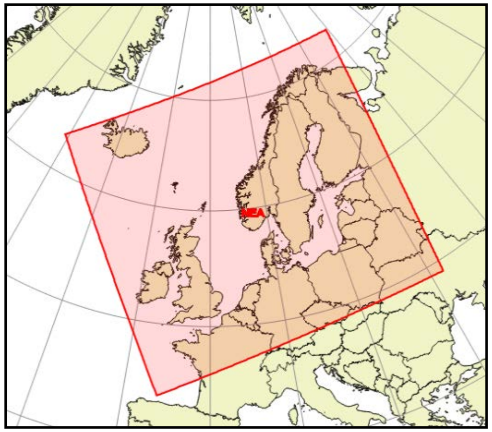
Meteorological uncertainties

Quantify inherent uncertainties in numerical weather prediction (NWP) models from

- Initial conditions (meteorological observations)
- Lateral boundary conditions (outer model)
- Model physics (parameterization of subgrid scale processes)

At DMI, ensemble of 25 members

- Harmonie model
- Updated each three hours
- 54 h forecast
- Horizontal resolution 0.022°
- 65 vertical levels



Meteorological ensemble members are equally likely and span the space of possible representations of reality.

Corresponding ensembles of atmospheric dispersion can be computed from which e.g. uncertainties of predicted radionuclide concentration and deposition patterns can be derived, cf. NKS-B projects MUD and MESO.

Source-term uncertainties

The source term consists of information about the nuclides included in a release and the activity per nuclide. It also describes the height of the release, the duration of the release phases, and the thermal effect of the release.

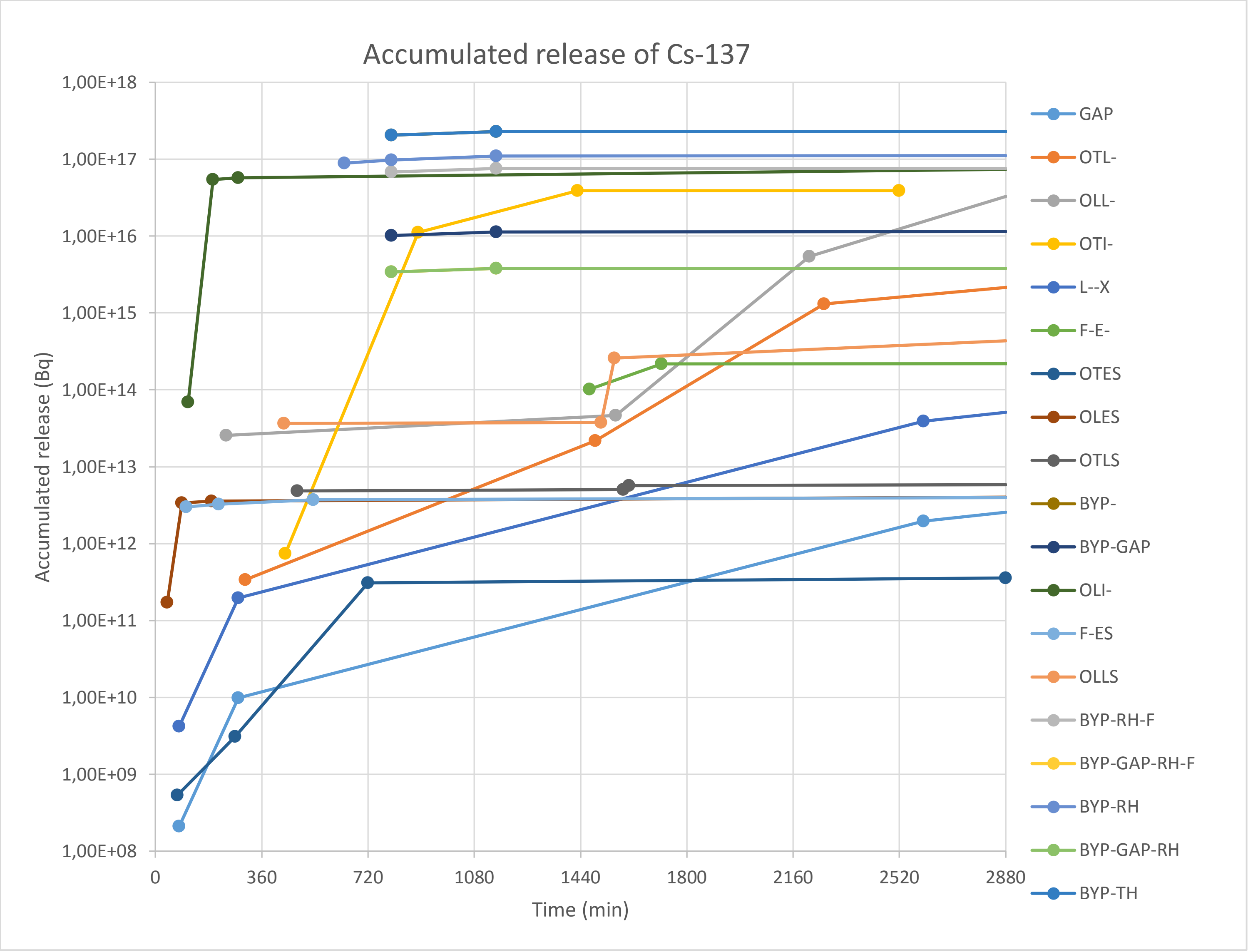
Provision of source terms is not trivial and should be accompanied by an estimate of the inherent uncertainties, i.e. to provide an ensemble of source terms linked to possible release scenarios as well as a-priori probabilities of the members.

Generic BWR source-term ensemble

A 19-member source-term ensemble has been provided by Lloyd's Register Consulting. It consists of a set of early-phase BWR source terms and corresponding weights derived by RASTEP from PSA level 2.

Node State	Customised Source Term	Building	Mode
early_failure_spray	OTES	Containment ST2	Transient early/spray
early_failure_no_spray	OTI	Containment ST2	Transient early/no spray
late_failure_spray	OTLS	Containment ST2	Transient late/spray
late_failure_no_spray	OTL	Containment ST2	Transient late/no spray
containment_vent_362_spray	F-ES	Containment ST2	Transient 362 venting/spray
containment_vent_362_no_spray	F-E	Containment ST2	Transient 362 venting/no spray
loca_early_failure_spray	OLES	Containment ST2	LOCA early/spray
loca_early_failure_no_spray	OLI	Containment ST2	LOCA early/no spray
loca_late_failure_spray	OLLS	Containment ST2	LOCA late/spray
loca_late_failure_no_spray	OLL	Containment ST2	LOCA late/no spray
loca_containment_vent_362_spray	F-ES	Containment ST2	LOCA 362 venting/spray
loca_containment_vent_362_no_spray	F-E	Containment ST2	LOCA 362 venting/no spray
loca_gap	GAP	Containment ST1	LOCA gap release (no bypass)
diffuse_leakage	L-X	Containment ST2	Diffuse leakage
melt_bypass_filtered	BYP-RH-F	Reactor Hall	Melt bypass (filtered)
melt_bypass_unfiltered	BYP-RH	Reactor Hall	Melt bypass (unfiltered)
gap_bypass_filtered	BYP-GAP-RH-F	Reactor Hall	Gap bypass (filtered)
melt_TB_overP	BYP-TH	Turbine Hall	Melt bypass
gap_TB_overP	BYP-GAP	Turbine Hall	Gap bypass

Generic BWR source-term ensemble



Generic BWR source-term ensemble

At the early phase of a serious nuclear accident with hardly any knowledge on the source term, the differences between the ensemble members are very large.

Later, when additional information on the plant status is received, the source-term ensemble will become more focused; in the end probably converge to a well-defined source term or a few.

Updated dispersion calculations are required when new information on the source term is received, and when new meteorological data are available (each three hours).

Probably, the entire ensemble is too large to be of practical value. Instead, one may use a scenario-based approach grouping the ensemble members, e.g. mitigation, no-mitigation, containment breach, by-pass scenarios etc.

Combination of a meteorological and a source-term ensemble

Source Term (ST) ensemble of M members combined with an NWP model ensemble of N members.

The overall statistical ensemble consists of $N \times M$ members.

	NWP-1	NWP-2	…	NWP-N
ST-1				
ST-2				
…				
ST-M				

In our case, $25 \times 19 = 475$ dispersion model calculations, which requires efficient calculation on a supercomputer.

Weighted ensemble statistics

Consider an ensemble $e_i, i = 1, \ldots, N$, of e.g. concentration, $e_i = c_i(\boldsymbol{r}, t)$ for a given radionuclide where t denotes time and $\boldsymbol{r}$ location.

With corresponding relative weights,w_i, we can define normalized weight factors ($\sum_i f_i = 1$),

$$f_i = \frac{w_i}{\sum_{j=1,\ldots N} w_j}$$

In case of equal weighting, we have $f_i = {}^1/_N$.

Ensemble average:

$$c_{\text{avg}}(\boldsymbol{r}, t) = \sum_{i=1,\ldots,N} f_i \, c_i(\boldsymbol{r}, t)$$

Weighted ensemble statistics

Probability for exceeding a threshold value c_t:

$$P_\mathrm{t} = \sum_{i=1,\ldots,N} f_i \, \vartheta(e_i > c_\mathrm{t})$$

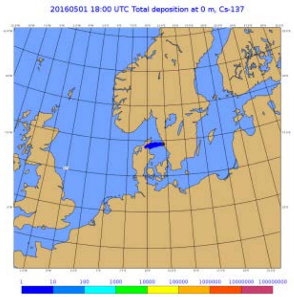
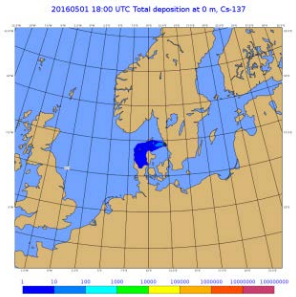
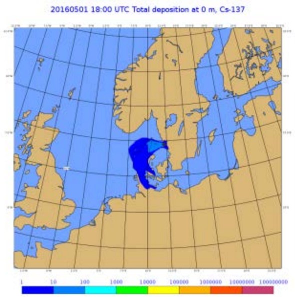
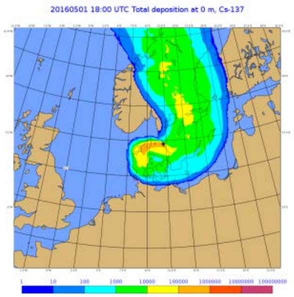
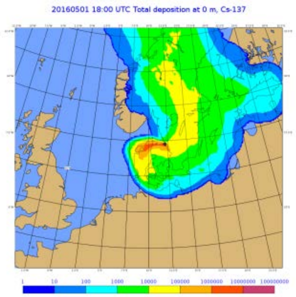
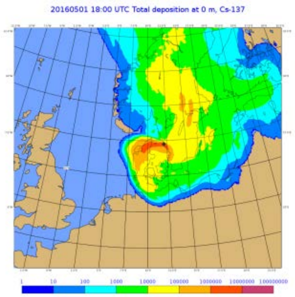
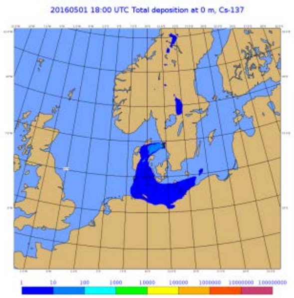
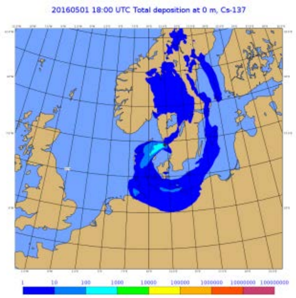
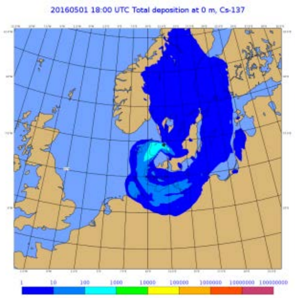
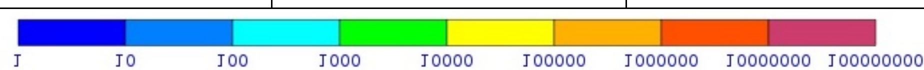
where ϑ denotes the Heaviside step function.

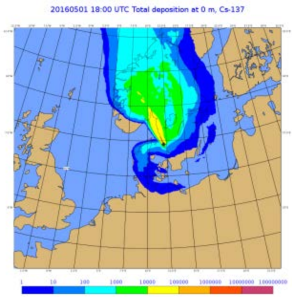
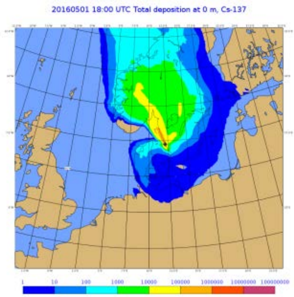
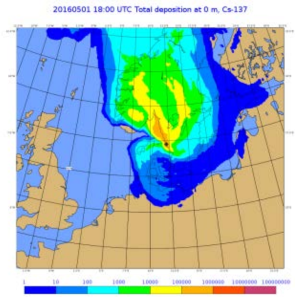
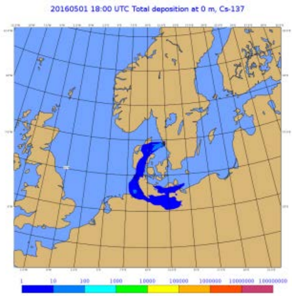
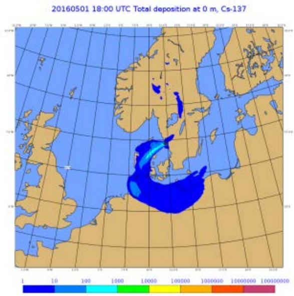
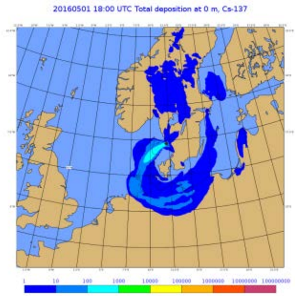
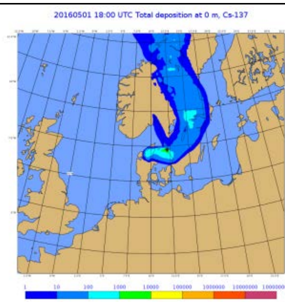
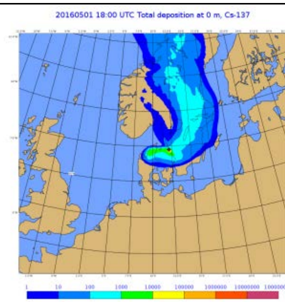
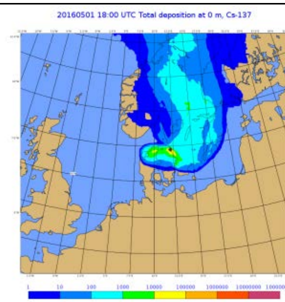
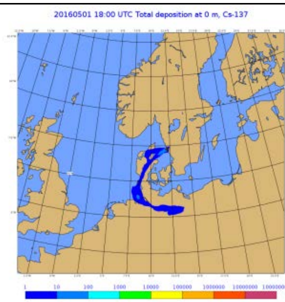
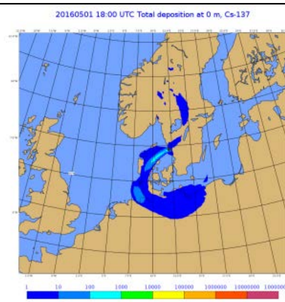
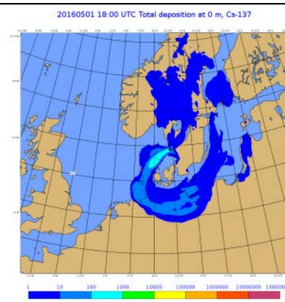
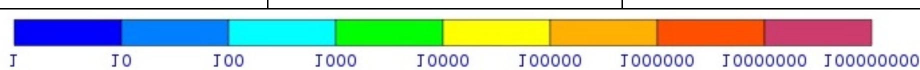
Another possibility is to calculate weighted quantiles, e.g. the 5th, 50th and 95th percentiles of the ensemble distribution.

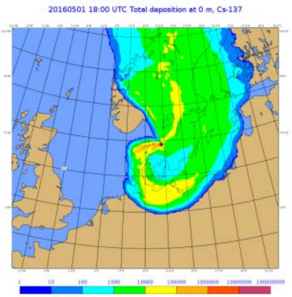
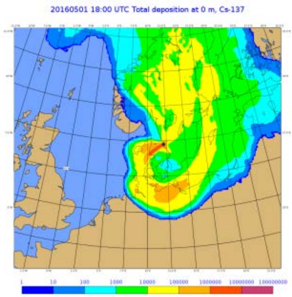
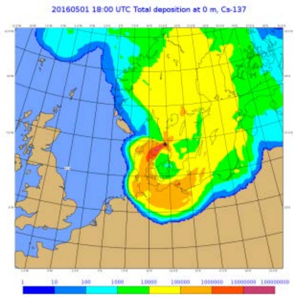
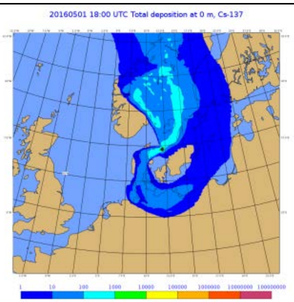
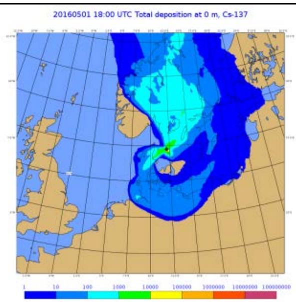
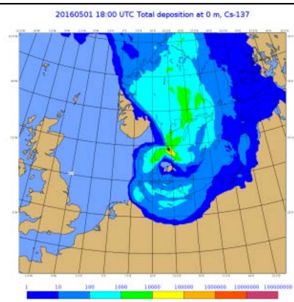
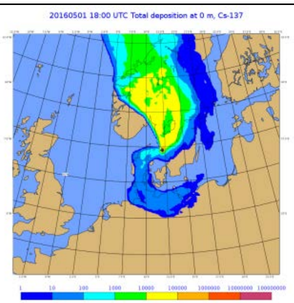
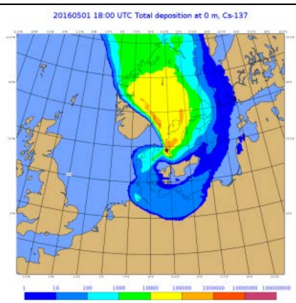
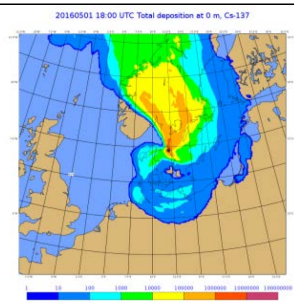
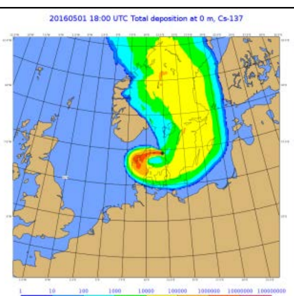
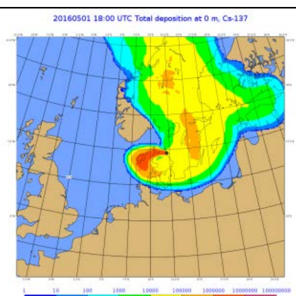
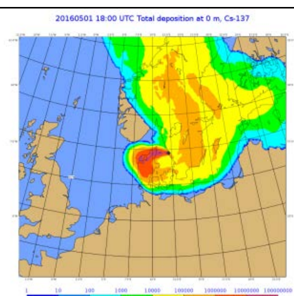
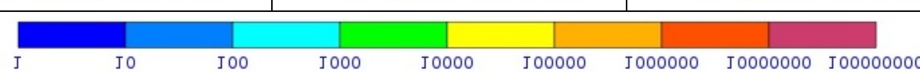
Note that unlikely severe cases are suppressed.

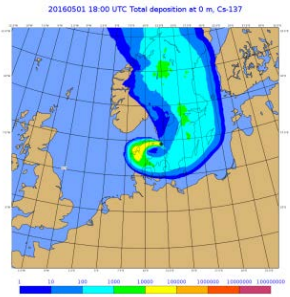
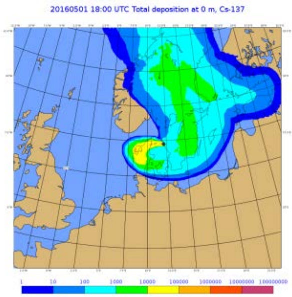
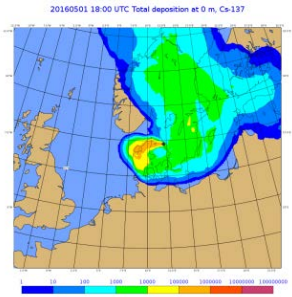
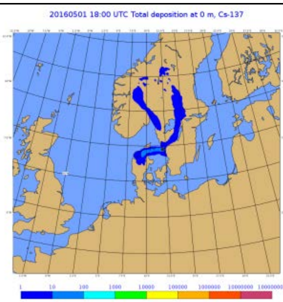
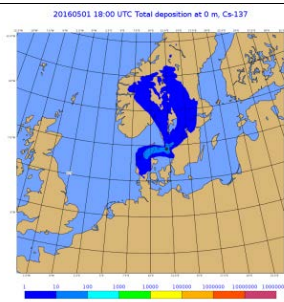
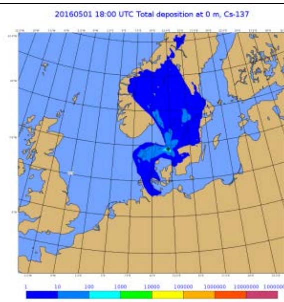
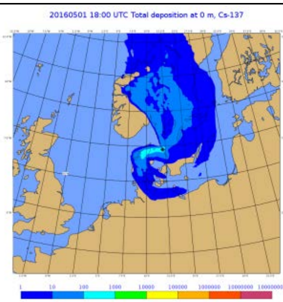
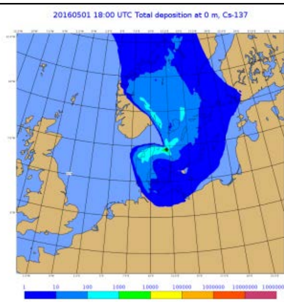
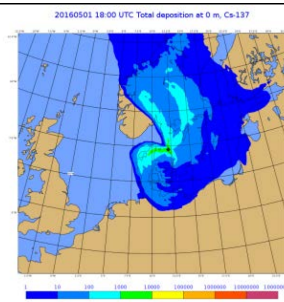
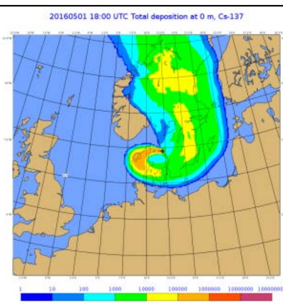
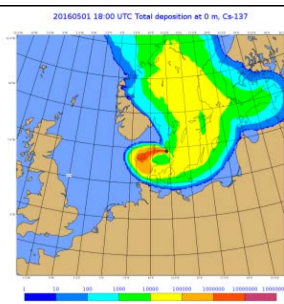
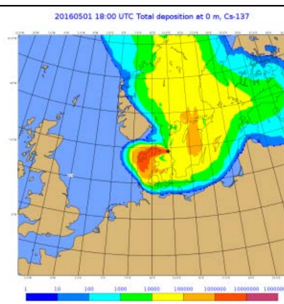
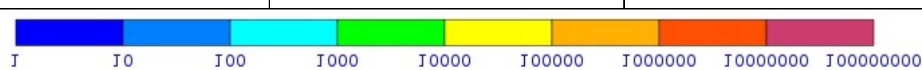
Release from Ringhals NPP

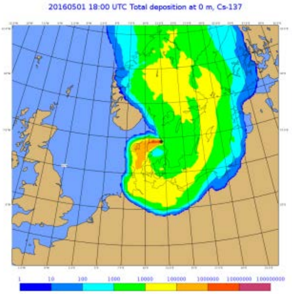
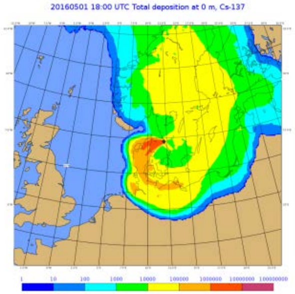
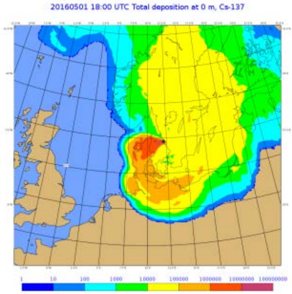
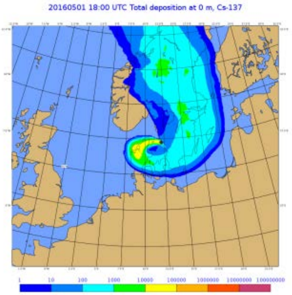
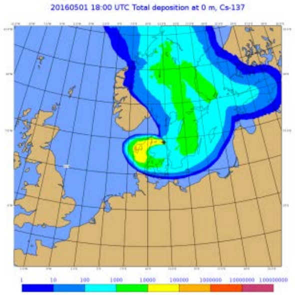
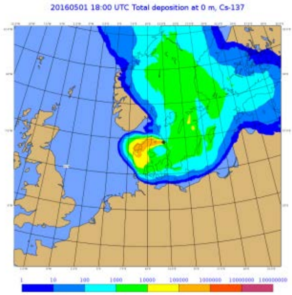
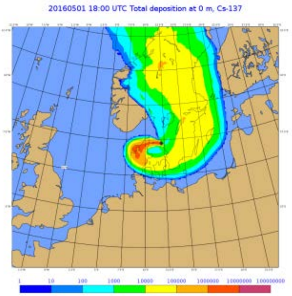
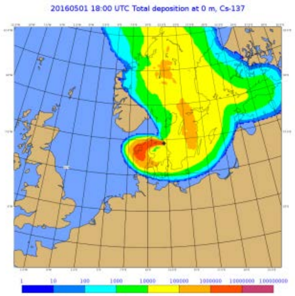
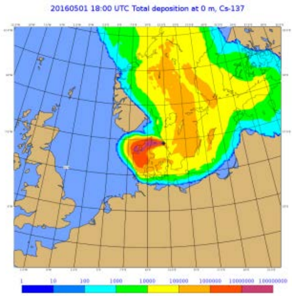
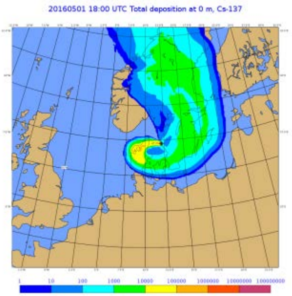
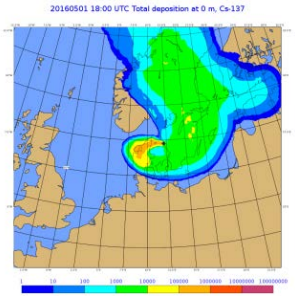
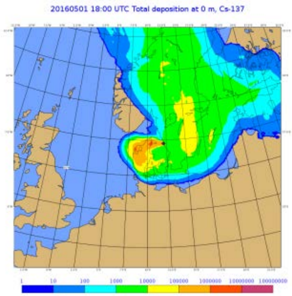
Percentiles of accumulated deposition (Bq/m^2) of Cs-137 for the 19 individual source terms of the generic BWR source-term ensemble. Release start (SCRAM) at 2016-04-27 12:00 UTC.

Source Term	10th percentile	50th percentile	90th percentile	A priori prob.
OTES				0.0271%
OTI				0.0074%
OTLS				0.0775%
				

Source Term	10^{th} percentile	50^{th} percentile	90^{th} percentile	A priori prob.
OTL				0.0127%
F-ES				8.9338%
F-E				6.8910%
OLES				0.0521%
				

Source Term	10th percentile	50th percentile	90th percentile	A priori prob.
OLI				0.4911%
OLLS				0.0077%
OLL				0.0001%
BYP				0.0423%
				

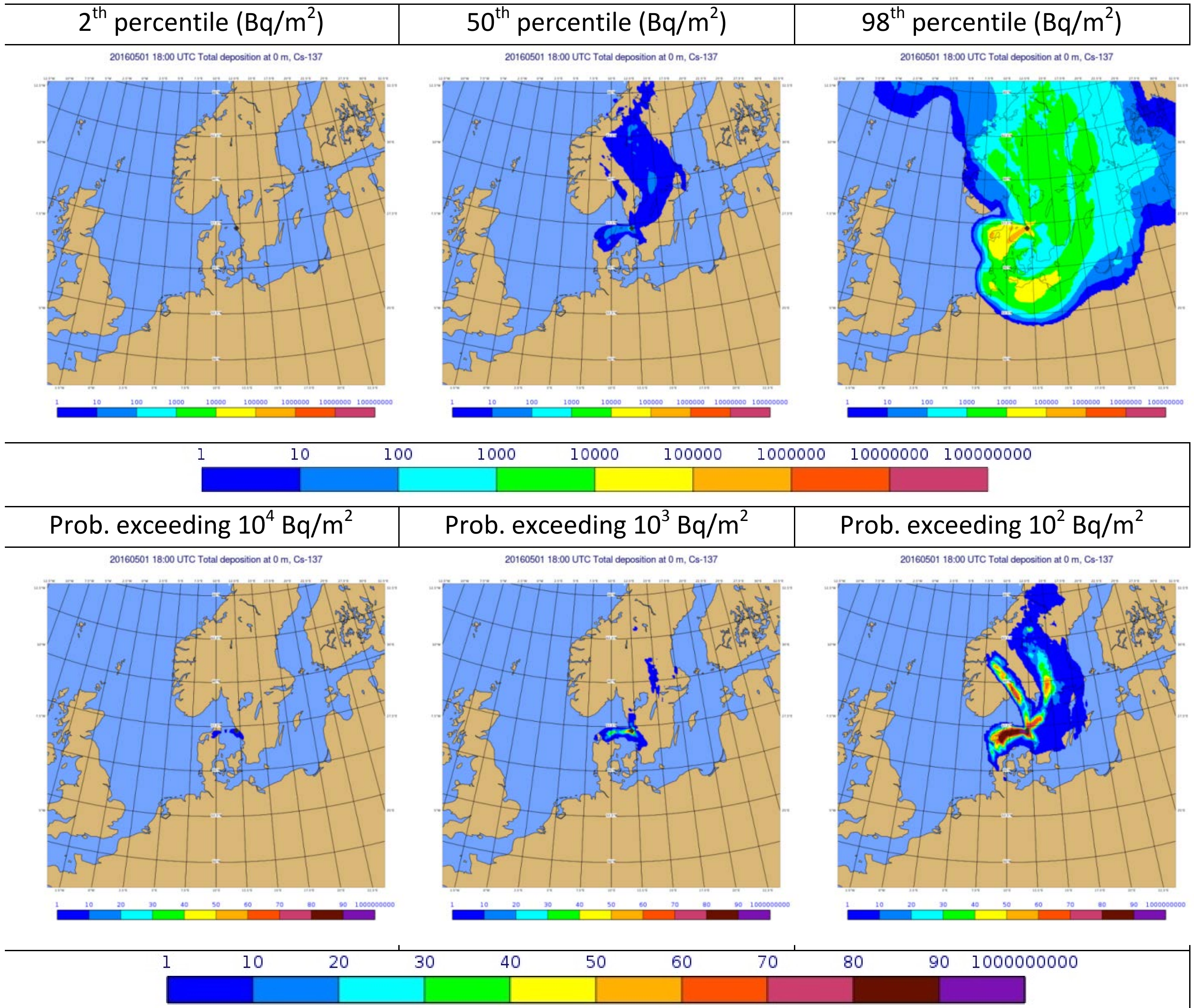
Source Term	10th percentile	50th percentile	90th percentile	A priori prob.
BYP-GAP-RH				0.0463%
GAP				1.8334%
L-X				81.4042%
BYP-RH-F				0.0000%
				

Source Term	10th percentile	50th percentile	90th percentile	A priori prob.
BYP-RH				0.0463%
BYP-GAP-RH-F				0.0000%
BYP-TH				0.0423%
BYP-GAP				0.0847%
	 1 10 100 1000 10000 100000 1000000 10000000 100000000			

EOF

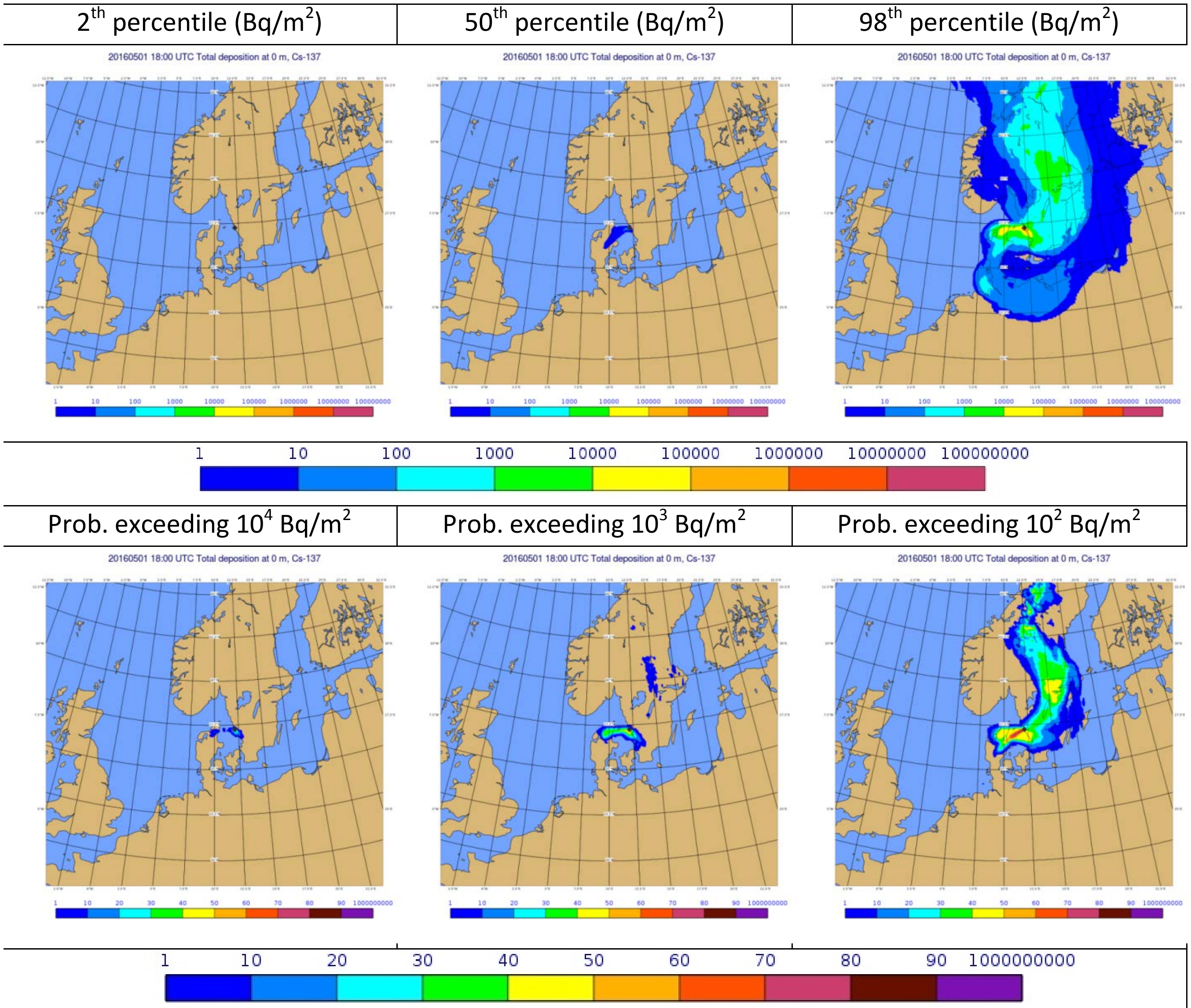
Entire ensemble (19 source terms)

Percentiles of deposition of Cs-137 and probabilities for exceeding threshold values.



Mitigation ensemble (6 source terms)

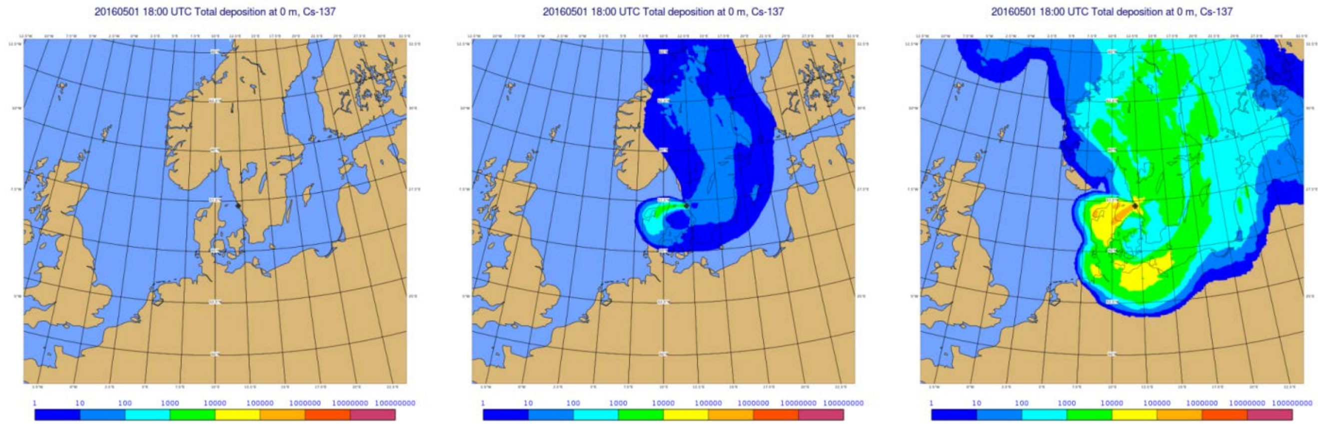
Percentiles of deposition of Cs-137 and probabilities for exceeding threshold values.



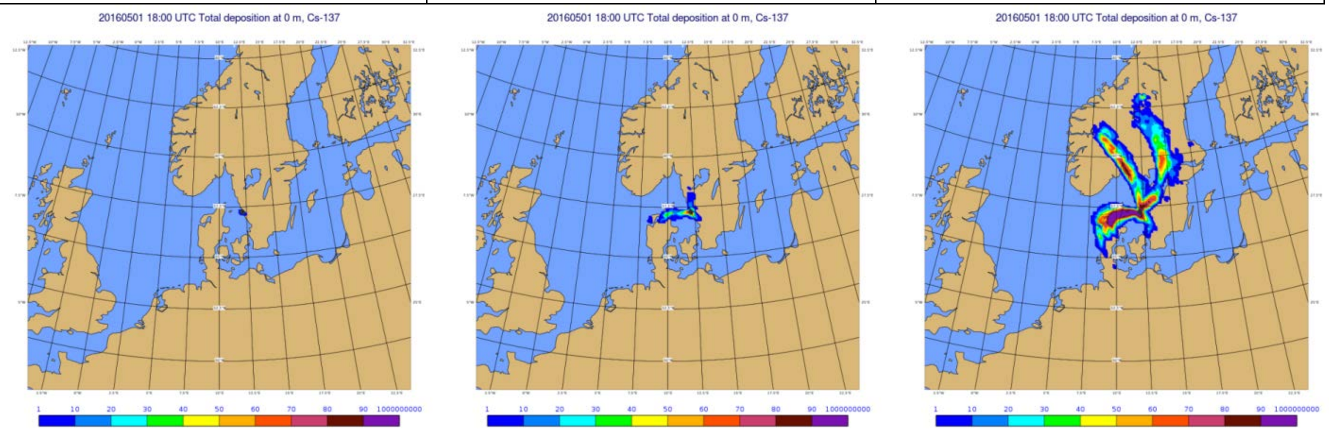
No-mitigation ensemble (13 source terms)

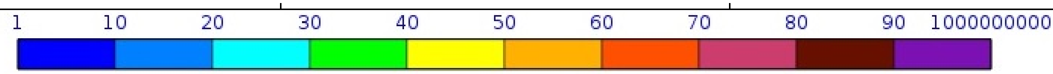
Percentiles of deposition of Cs-137 and probabilities for exceeding threshold values.

2^{th} percentile (Bq/m^2)	50^{th} percentile (Bq/m^2)	98^{th} percentile (Bq/m^2)



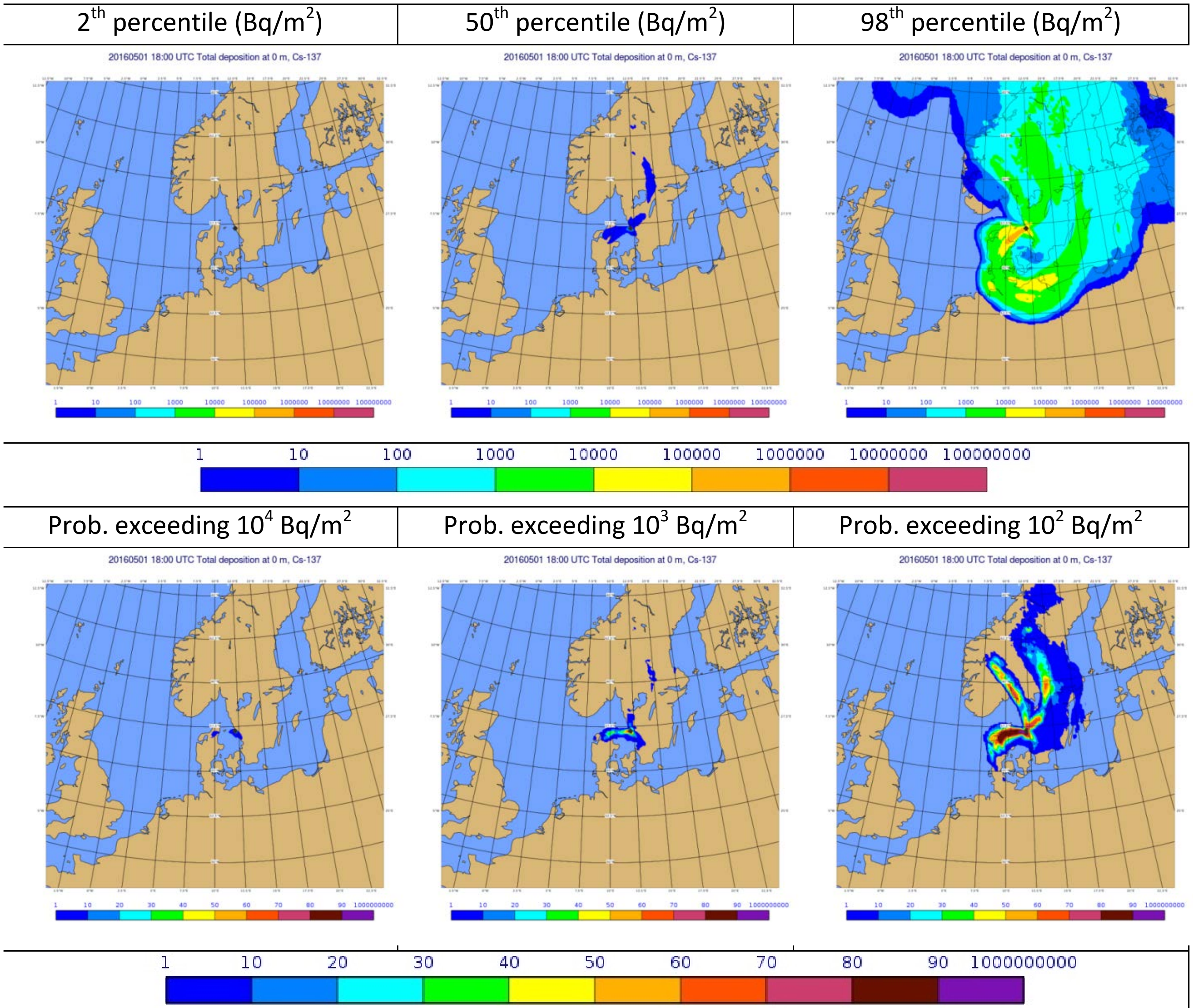
Prob. exceeding 10^4 Bq/m^2	Prob. exceeding 10^3 Bq/m^2	Prob. exceeding 10^2 Bq/m^2





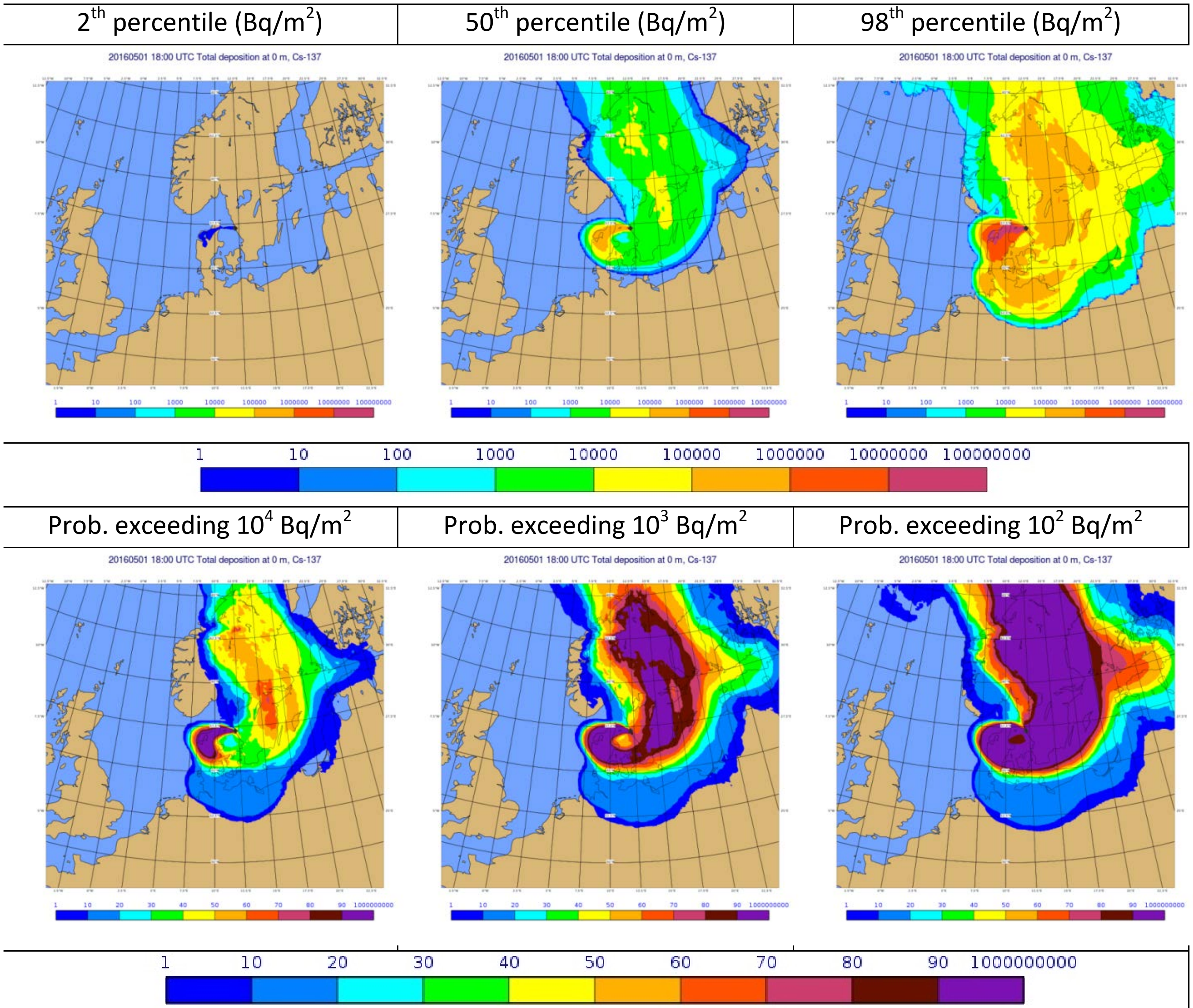
Containment breach **ensemble (12 source terms)**

Percentiles of deposition of Cs-137 and probabilities for exceeding threshold values.



By-pass ensemble (7 source terms)

Percentiles of deposition of Cs-137 and probabilities for exceeding threshold values.



Conclusions and Outlook

By taking into account uncertainties, the risk of making decisions based on an incorrect prediction of the dispersion is reduced.

Use of quantitative uncertainties requires:

- Education/training of emergency response staff
- Careful communication with decision makers

Effects of ***meteorological*** uncertainties on atmospheric dispersion calculations for nuclear emergency management operational at DMI since 2014.

Combined effects of ***source-term*** and ***meteorological*** uncertainties operational at DMI from summer 2019.

Outlook:

- Ensemble modelling: future of numerical weather prediction
- Outcome of the EU FASTNET project is going to be useful
- Further work required on deriving source-term ensembles by using the RASTEP formalism, and exploring their effects on atmospheric dispersion

Reports of MUD, FAUNA, MESO and AVESOME available from www.nks.org