IRSN
INSTITUT
DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

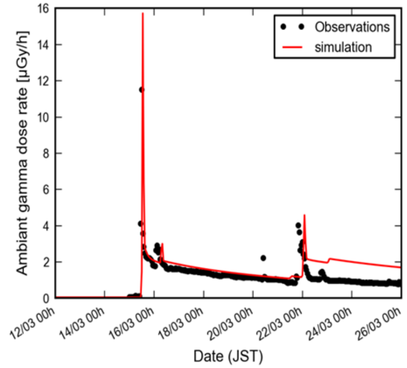
Faire avancer la sûreté nucléaire

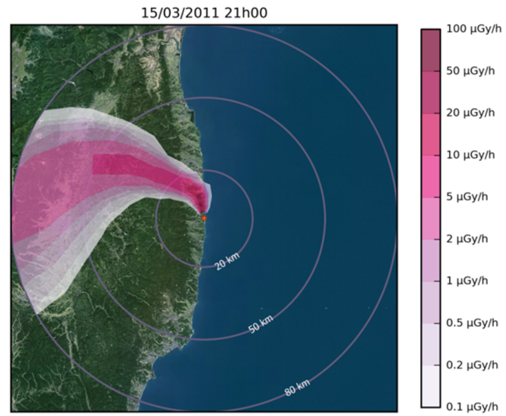
THE FUKUSHIMA DAIICHI POWER PLANT ACCIDENT: A CASE STUDY FOR MODEL EVALUATION AND SENSITIVITY SIMULATIONS AT LOCAL SCALE

I.Korsakissok, A. Mathieu, D.Didier

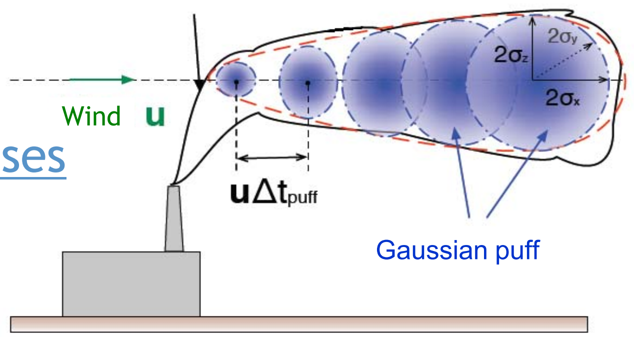
HARMO 15 – 06/05/2013

- Atmospheric dispersion and event analysis
- Comparison to measurements
- Sensitivity analysis
- Conclusions and Perspectives





Gaussian puff model pX



IRSN's operational model, used for emergency purposes

Local scale (< 100 km)

3D meteorological data, varying in time

Radioactive decay: Comprehensive mechanism, decay products

Dry and wet deposition

Dry deposition : *constant velocity* v_d

(0.2 cm/s for particles, 0.7 cm/s for molecular iodine, 0.05 cm/s over water)

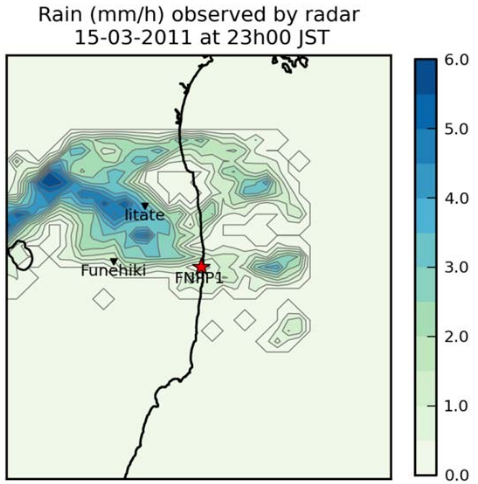
Wet deposition : $\Lambda_s = \Lambda_0\, p_o$ *with* p_o *the rain*

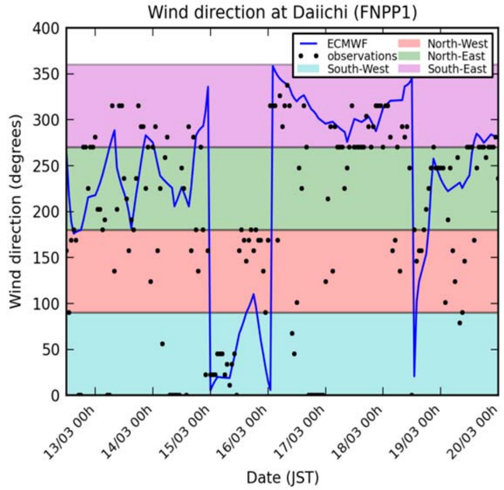
(default: $\Lambda_0 = 5.10^{-5}$ h/mm/s)

Dose rate computation

Meteorological fields

- ECMWF forecast, 0.125° , 3 hours
- Daiichi wind observations, 10 minutes
- Rain radar observations, 10 minutes

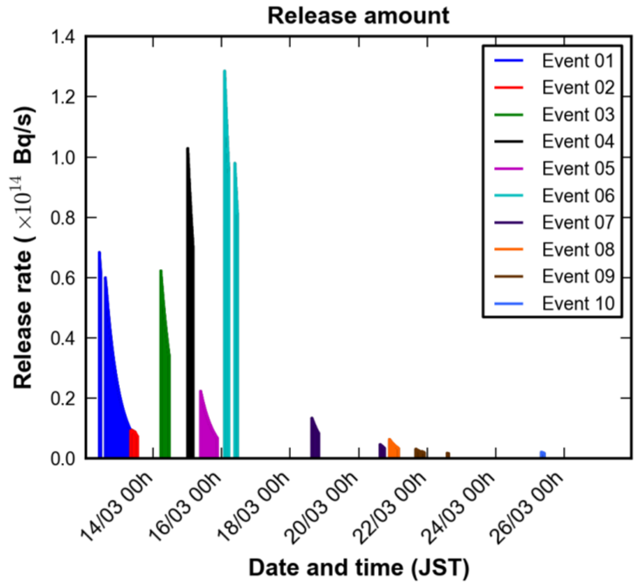




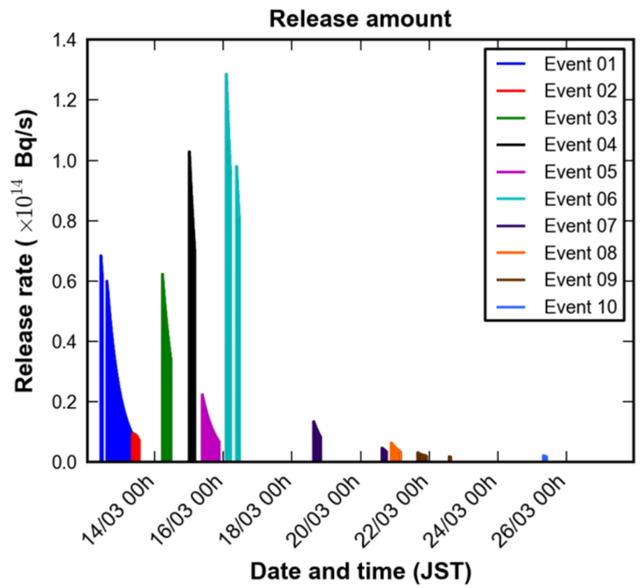
Atmospheric release, IRSN's estimation

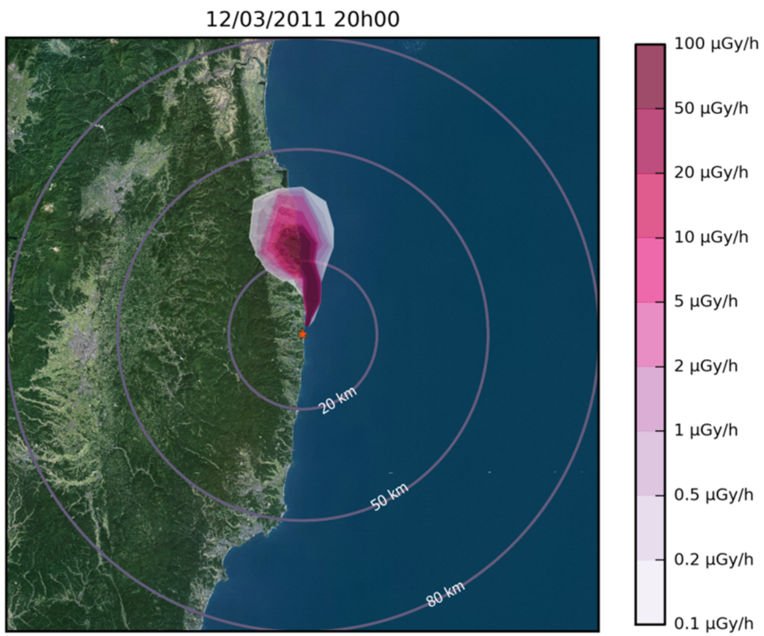
(Mathieu et al, 2012, Elements)

- Total quantity consistent with NISA estimation
- 73 radioisotopes emitted
- 91% of the released activity comes from noble gases,
- 6% from iodine, < 1% from cesium



Number	Event	Main plume travel direction	Source height
1	Unit 1 - hydrogen explosion	North, then east	diluted on 100m
2	Unit 3 - venting	East (Pacific Ocean)	120m
3	Unit 3 - hydrogen explosion	East (Pacific Ocean)	diluted on 300m
4	Unit 2 - venting	South	120m
5	Unit 2 - breach on the wet-well	West, north-west, south	20m
6	Units 2 and 3 pressure decrease	South	20m
7	-	North	120m
8	-	South	120m
9	Units 2 and 3 (white and grey smokes)	South-west	50m
10	-	West	120m





- **Event 1: 12 March 10h JST (venting) and 15h0 JST (explosion)**

Number	Event	Main plume travel direction	Source height
1	Unit 1 - venting and hydrogen explosion	North, then east	diluted on 100m
2	Unit 3 - venting	East (Pacific Ocean)	120m
3	Unit 3 - hydrogen explosion	East (Pacific Ocean)	diluted on 300m
4	Unit 2 - venting	South	120m
5	Unit 2 - breach on the wet-well	West, north-west, south	20m
6	Units 2 and 3 pressure decrease	South	20m
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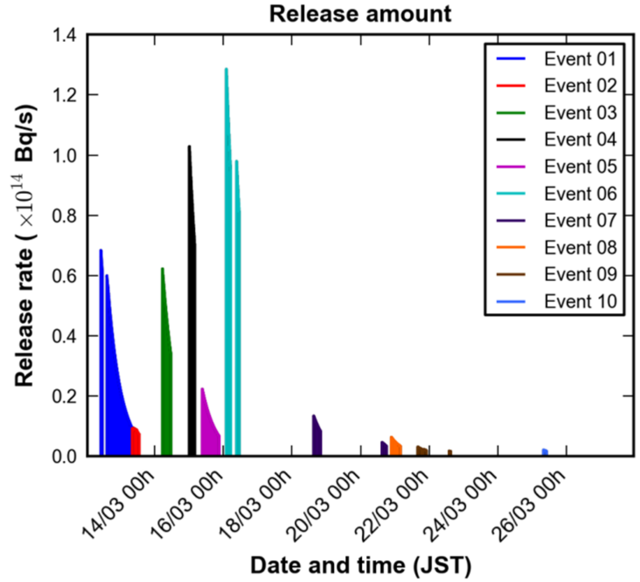

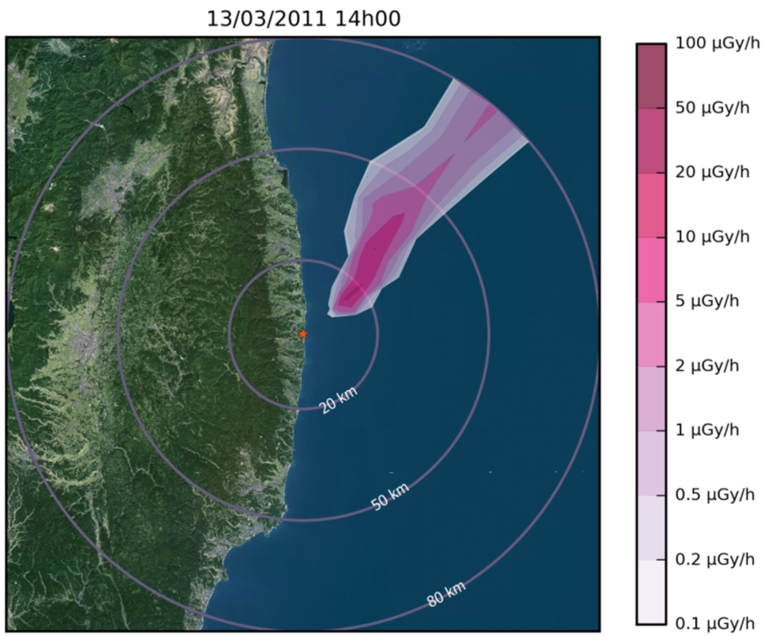

- **Event 2: 13 March 08h JST (venting)**
- **Event 3: 14 March 11h JST (explosion)**

Number	Event	Main plume travel direction	Source height
1	Unit 1 - hydrogen explosion	North, then east	diluted on 100m
2	Unit 3 - venting	East (Pacific Ocean)	120m
3	Unit 3 - hydrogen explosion	East (Pacific Ocean)	diluted on 300m
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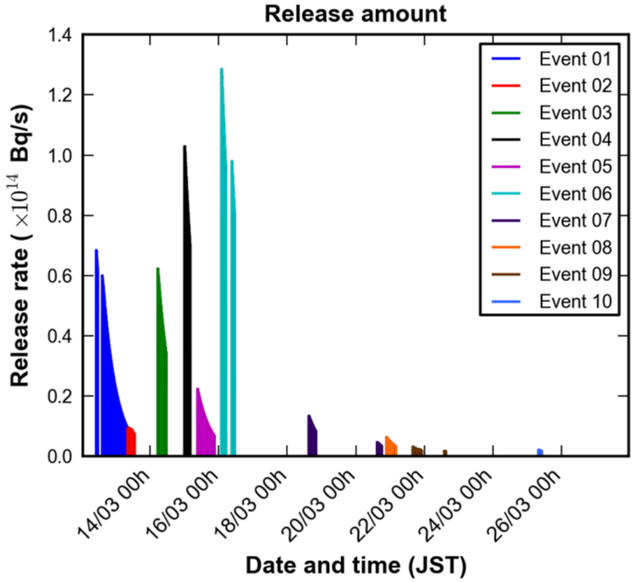
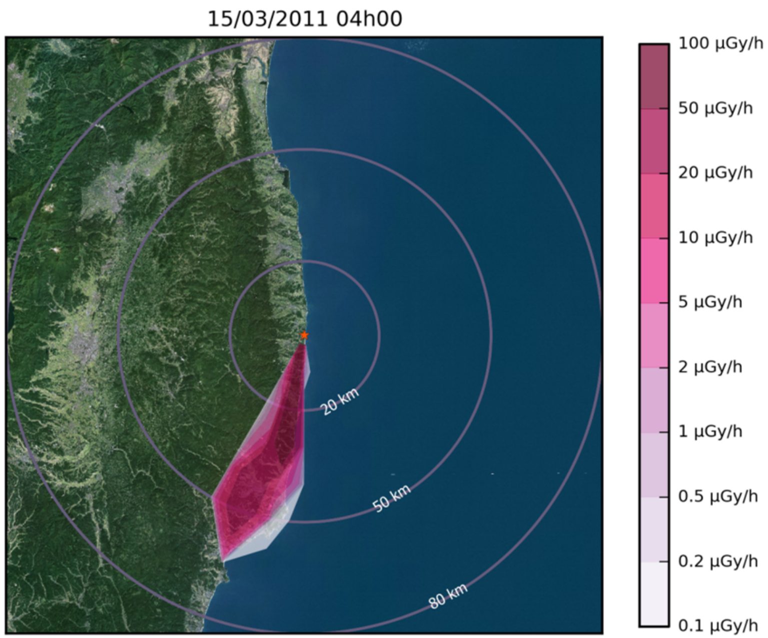


- **Event 4: 15 March 00h JST (venting)**



Number	Event	Main plume travel direction	Source height
1	Unit 1 - hydrogen explosion	North, then east	diluted on 100m
2	Unit 3 - venting	East (Pacific Ocean)	120m
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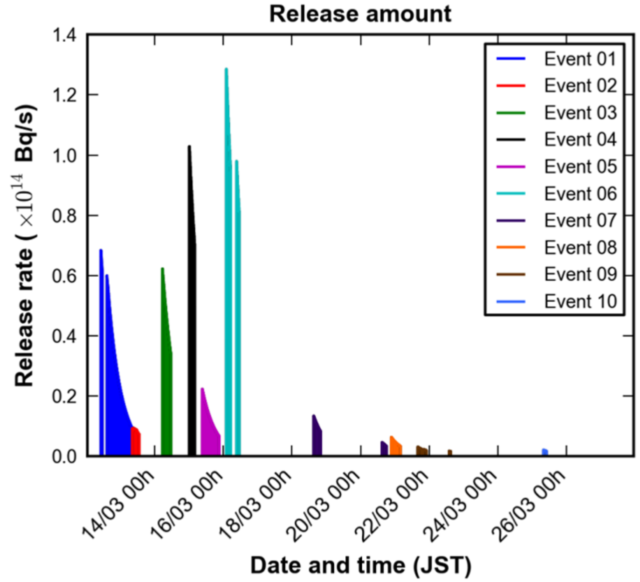

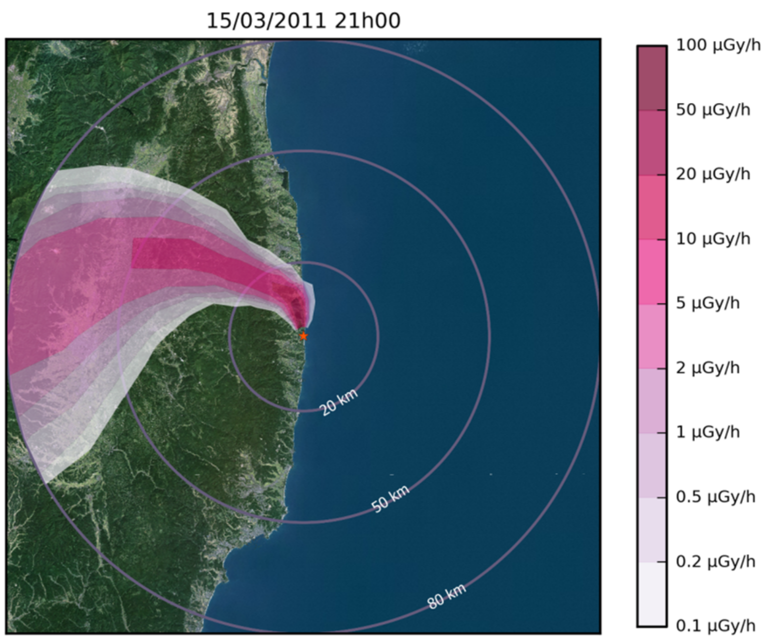

- **Event 5: 15 March 09h JST to 21h JST**
- **Wet deposition**

Number	Event	Main plume travel direction	Source height
1	Unit 1 - hydrogen explosion	North, then east	diluted on 100m
2	Unit 3 - venting	East (Pacific Ocean)	120m
3	Unit 3 - hydrogen explosion	East (Pacific Ocean)	diluted on 300m
4	Unit 2 - venting	South	120m
5	Unit 2 - breach on the wet-well	West, north-west, south	20m
6	Units 2 and 3 pressure decrease	South	20m
7	-	North	120m
8	-	South	120m
9	Units 2 and 3 (white and grey smokes)	South-west	50m
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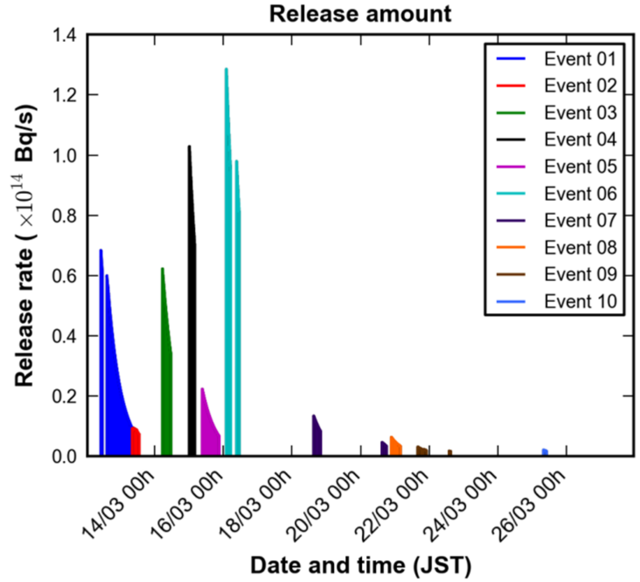

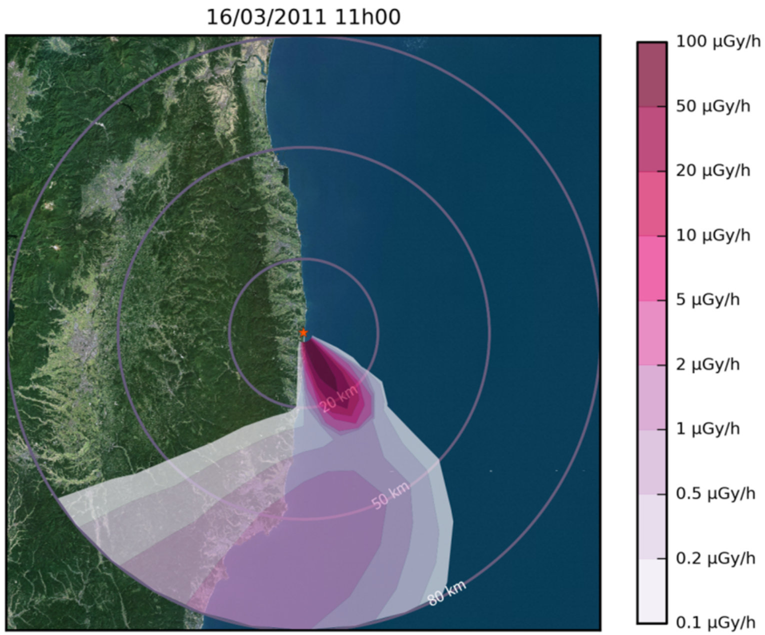

- **Event 6: 16 March 01h and 10h JST**
- **Certainly overestimated**

Number	Event	Main plume travel direction	Source height
1	Unit 1 - hydrogen explosion	North, then east	diluted on 100m
2	Unit 3 - venting	East (Pacific Ocean)	120m
3	Unit 3 - hydrogen explosion	East (Pacific Ocean)	diluted on 300m
4	Unit 2 - venting	South	120m
5	Unit 2 - breach on the wet-well	West, north-west, south	20m
6	Units 2 and 3 pressure decrease	South	20m
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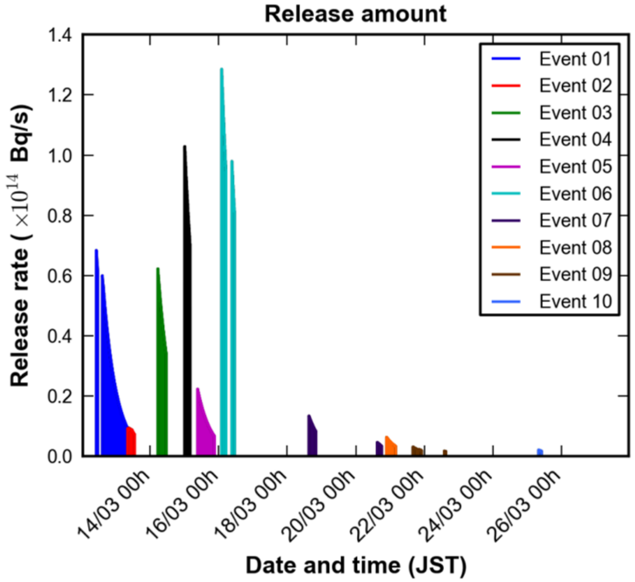
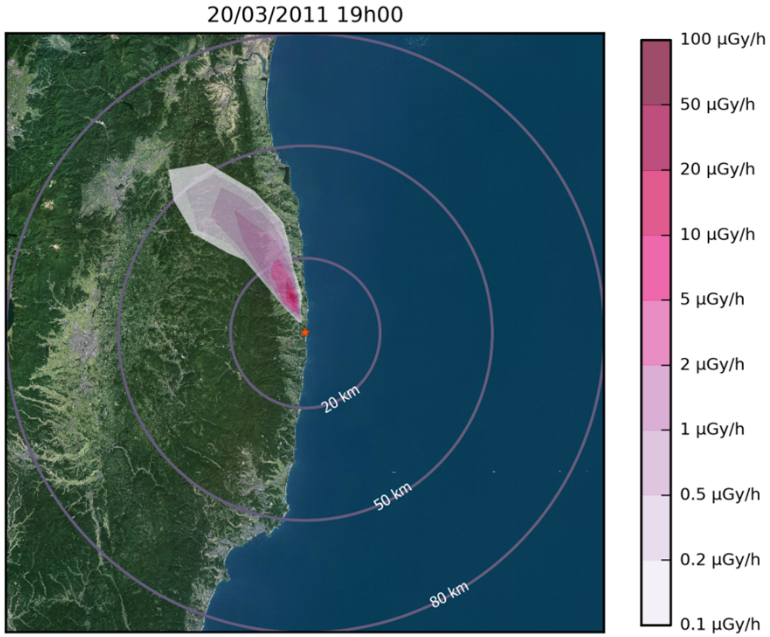
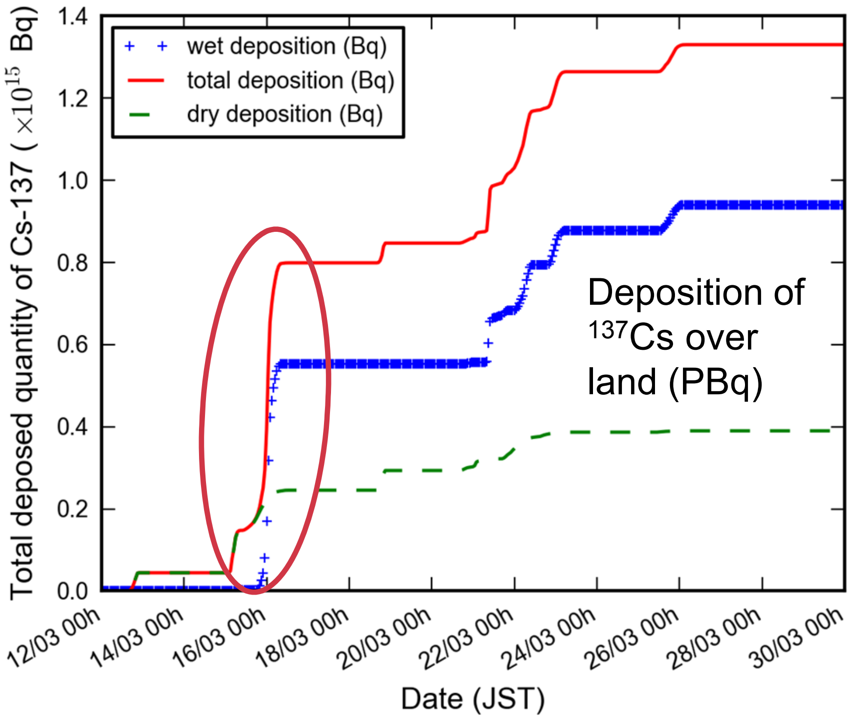
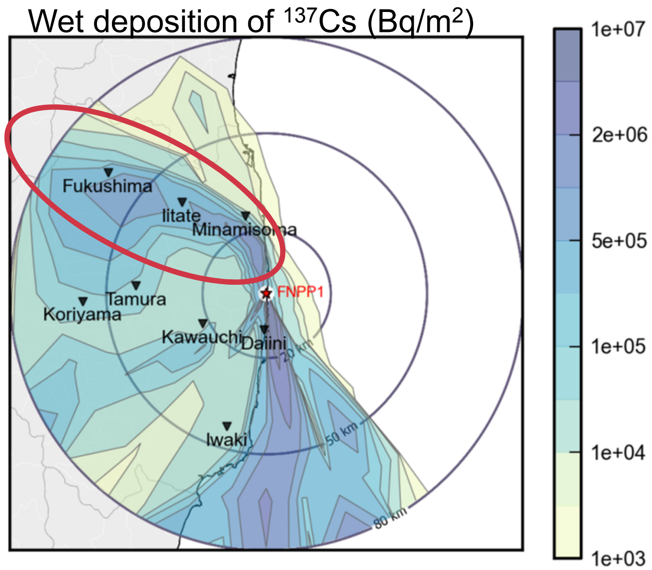




- **Events 7-10: smaller releases**
- **Wet deposition on 21-22 March**

Assessment of the contamination of the Japanese land at local scale





Wet deposition in
the NW
(Event 5 – March 15)

- Wet deposition: 2/3 of total deposition
- Wet deposition in the north-west
- Dry deposition mostly along the coast

But… how does this compare to measurements ?

Gamma dose rate measurements

- 8 monitoring stations within 60 km of FNPP1
- Good temporal resolution (10 minutes), with a few missing data
- Drawbacks: spatial coverage too scarce, no detail on plume composition

Deposition measurements

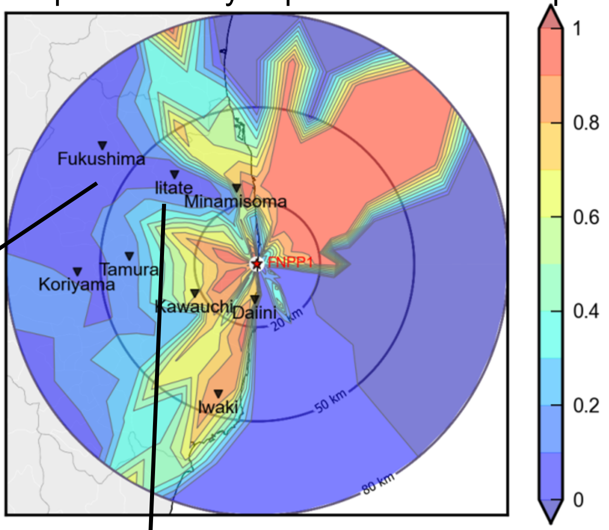
- Ground measurements of deposition
- Very good spatial coverage, but less information in “hot” areas
- Drawbacks: integrated in time, no information on plume passage, noble gases, short-lived radionuclides

➚ **Both kinds of measurements have to be used**

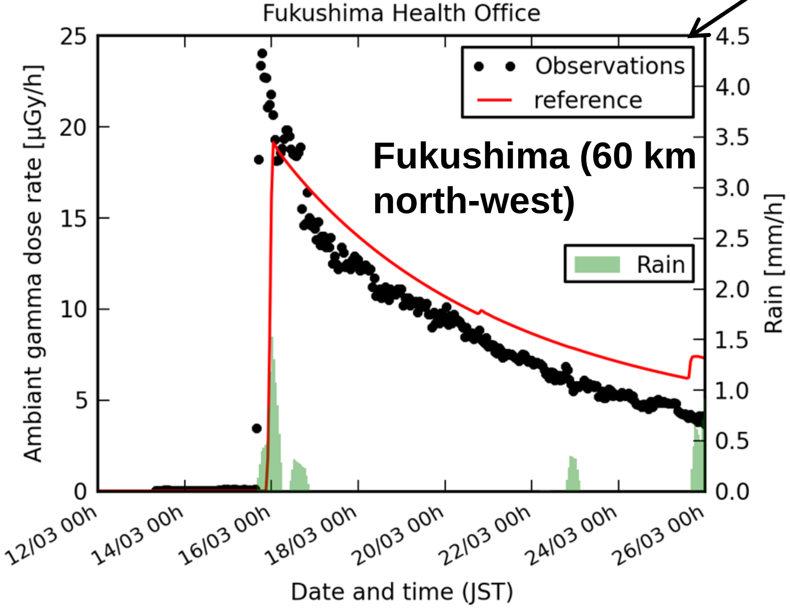
➚ **Can a model be good both on gamma dose rate and deposition ?**

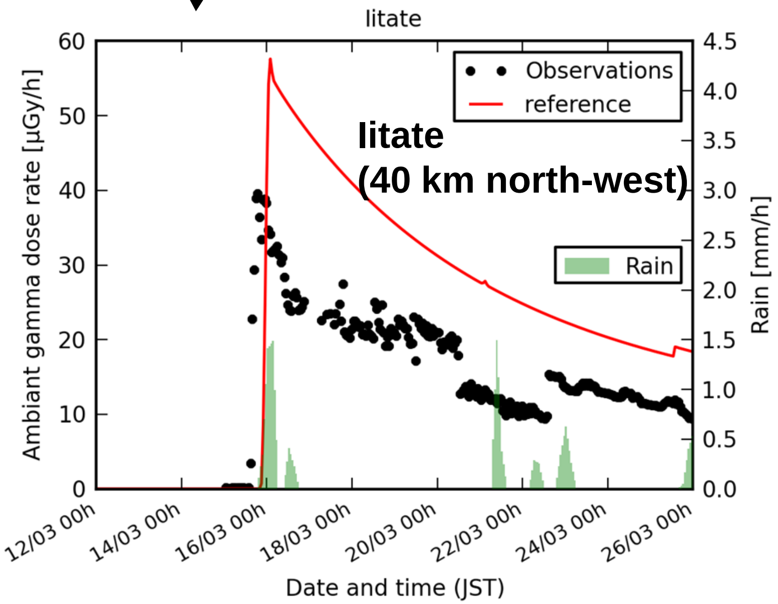
Comparison to gamma dose rate monitoring stations

Proportion of dry deposition on total deposition of ^{137}Cs



- **(1) north-west stations**
  - Wet deposition (95% of the peak dose rate)
  - 6-hour delay on the plume arrival time
  - Simulation within a factor 2 of the observations

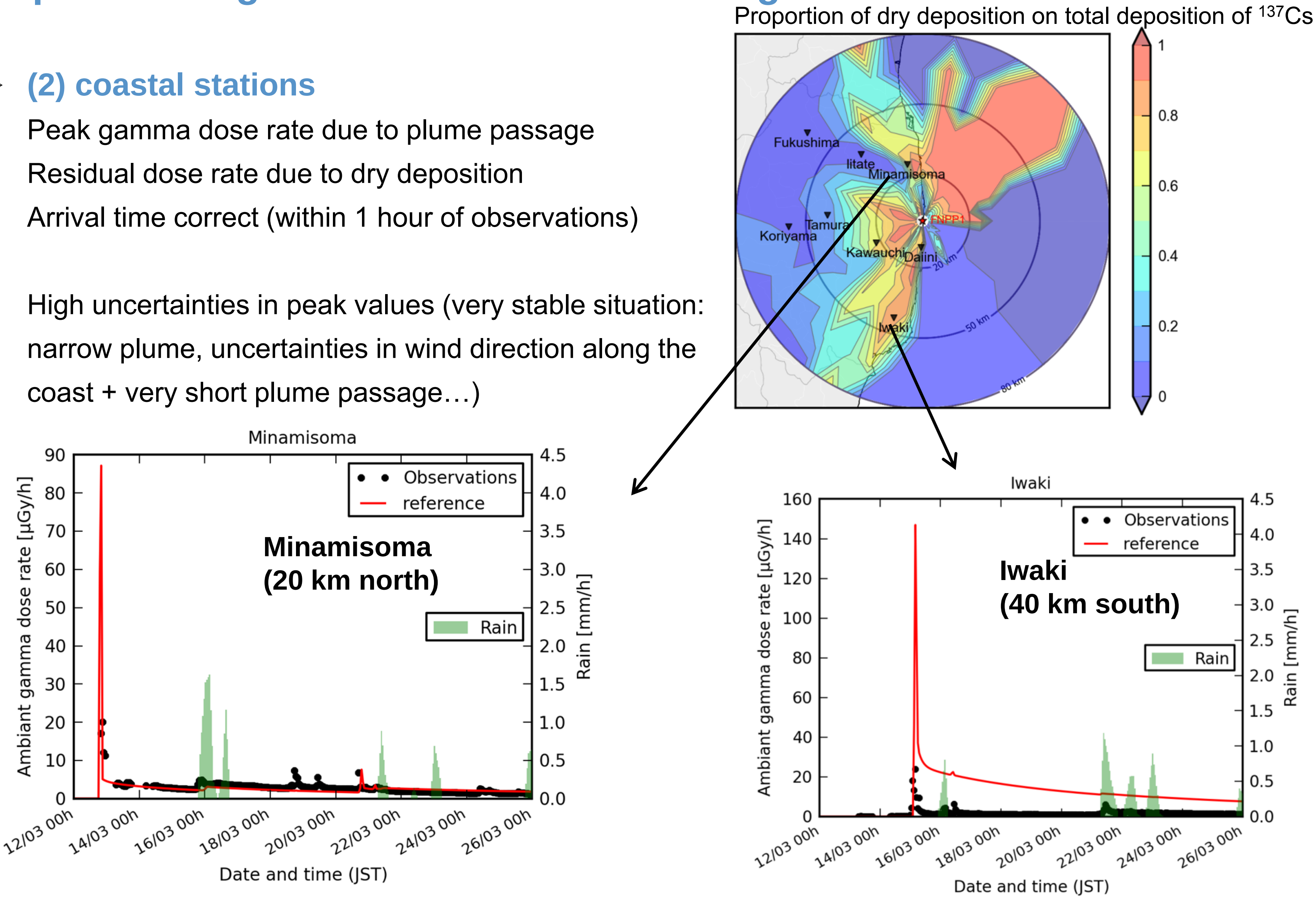




Comparison to gamma dose rate monitoring stations

- **(2) coastal stations**
- Peak gamma dose rate due to plume passage
- Residual dose rate due to dry deposition
- Arrival time correct (within 1 hour of observations)

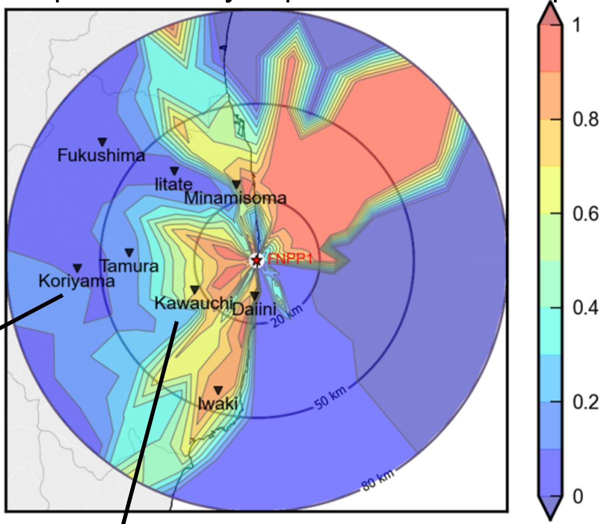
- High uncertainties in peak values (very stable situation: narrow plume, uncertainties in wind direction along the coast + very short plume passage…)

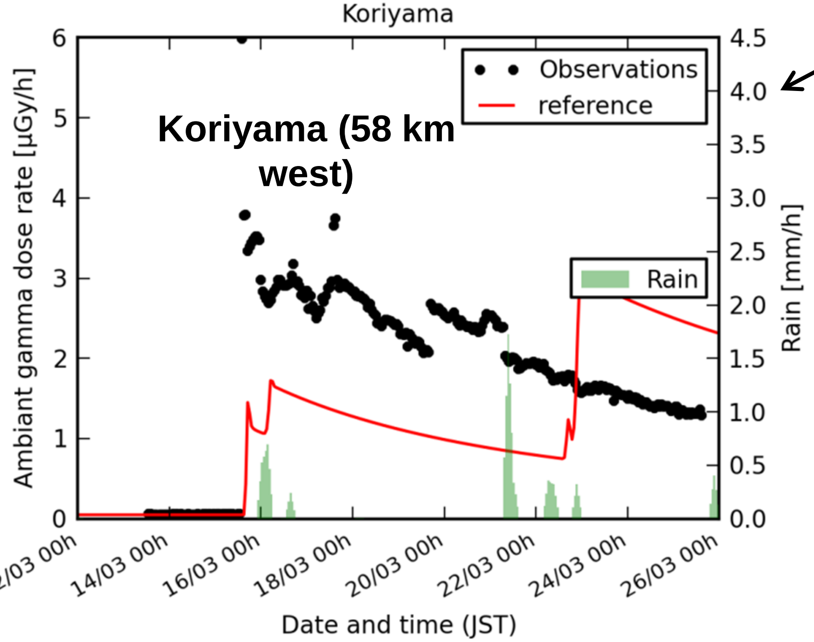


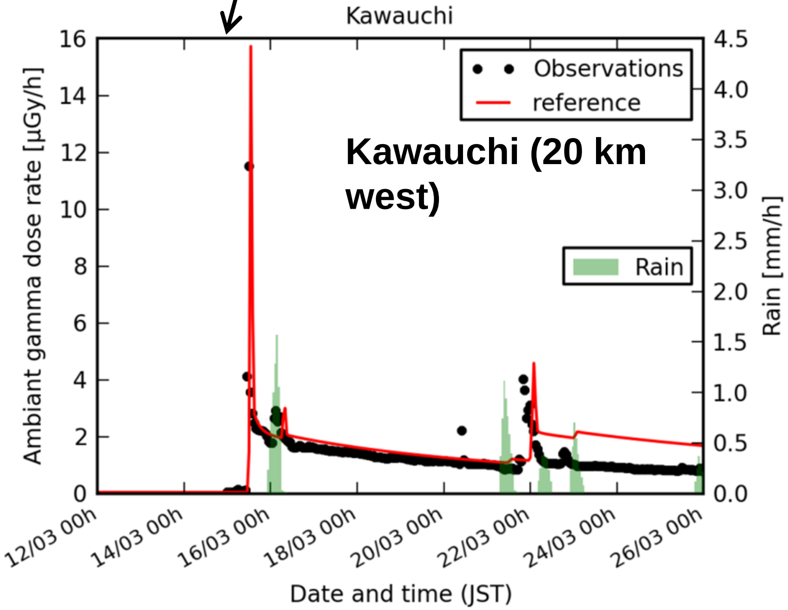
Comparison to gamma dose rate monitoring stations

- **(3) inland stations**
  - Several peaks due to various events
  - Dry and wet deposition
  - Arrival time correct (within 3 hours for Koriyama)
  - Simulation within a factor 2 or 3 of the observations
  - Very good agreement at Kawauchi

Proportion of dry deposition on total deposition of ^{137}Cs

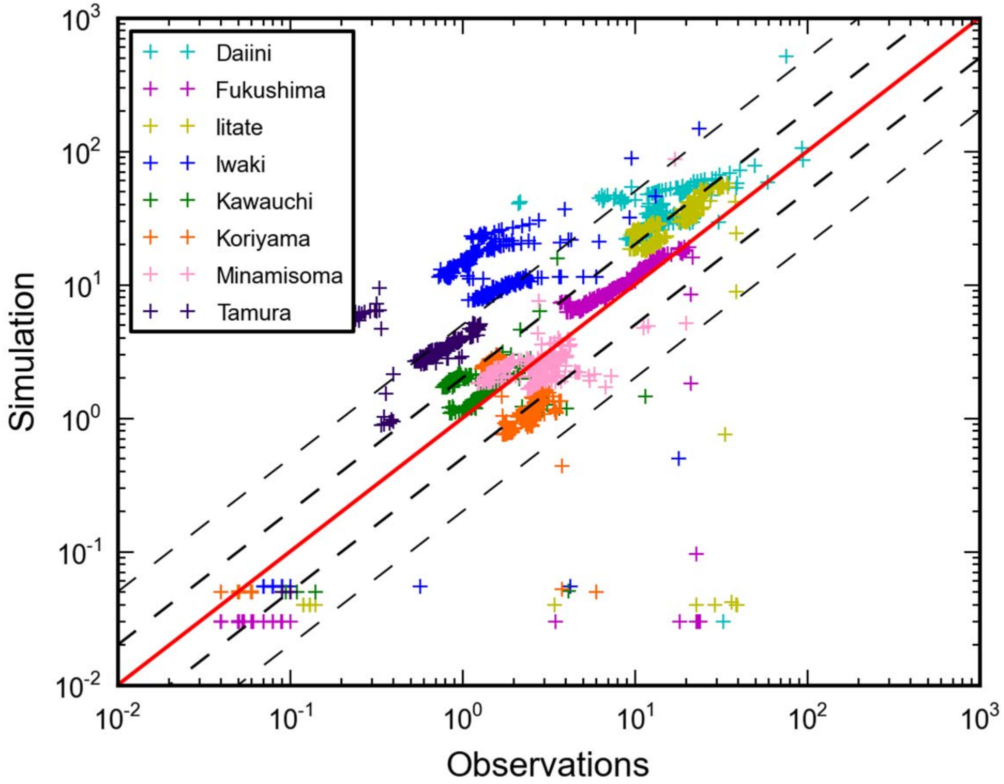






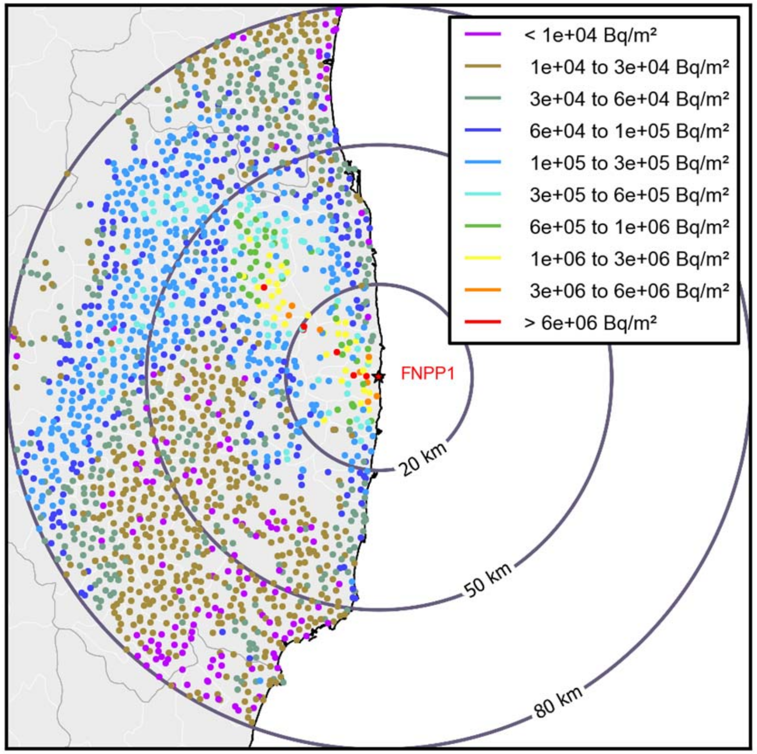
Comparison to gamma dose rate monitoring stations

- **Overall performance**
- FAC2 : 52% (proportion of values within a factor 2 of the observations)
- FAC5 : 85% (proportion of values within a factor 5 of the observations)
- Correlation: 0.72
- Figure of Merit in Time (FMT): 0.43

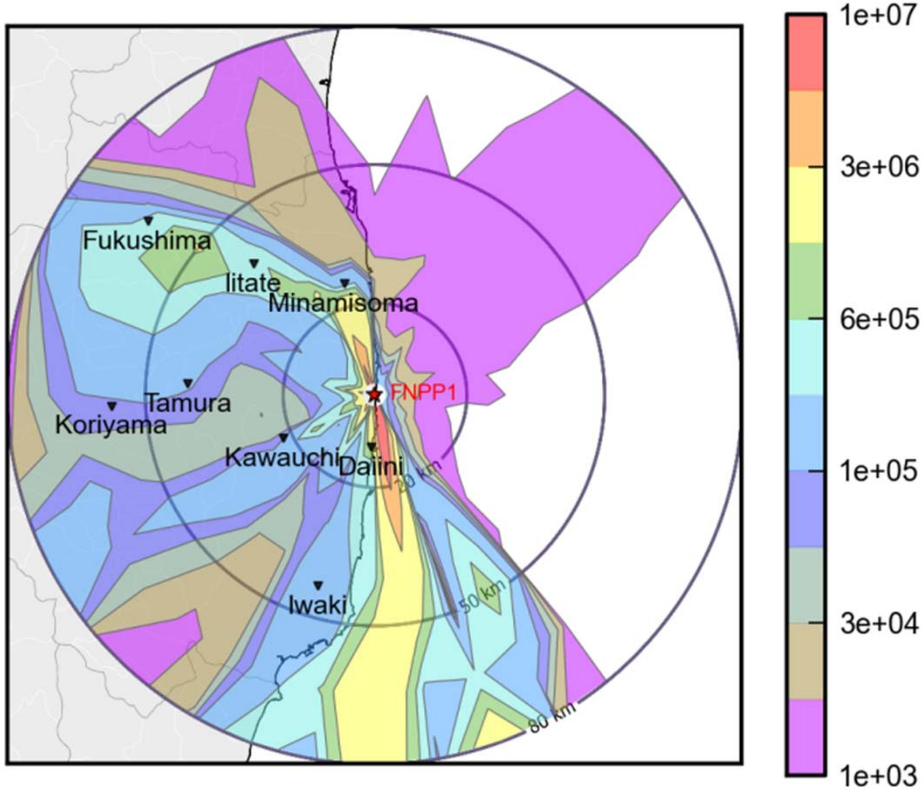


Very good compared to "traditional" models behavior on dispersion experiments

Comparison to MEXT deposition measurements of ^{137}Cs

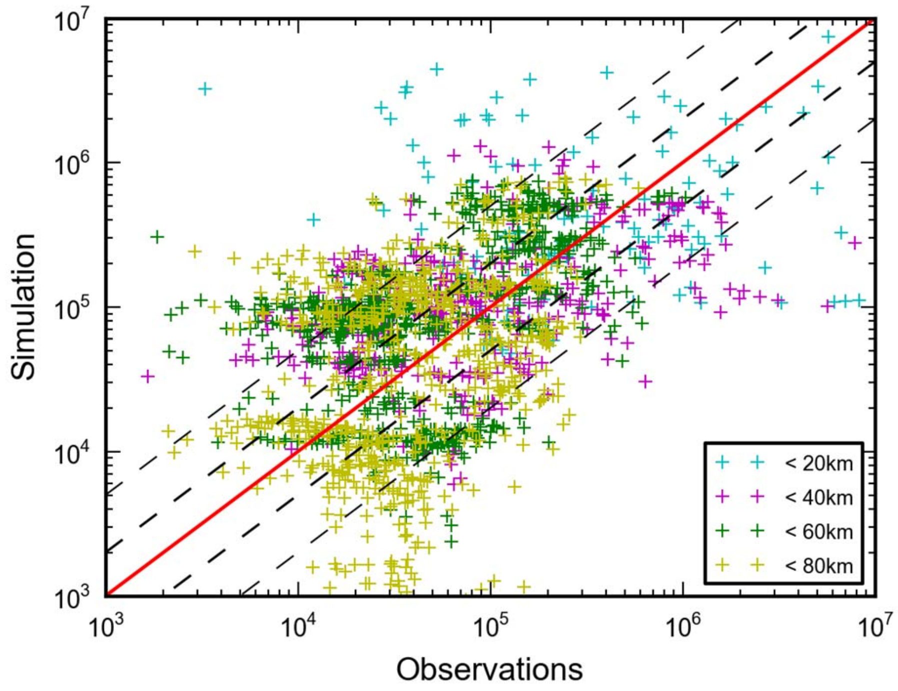


^{137}Cs deposition measurements (Bq/m^2): 1800 points within the simulation domain (80 km)

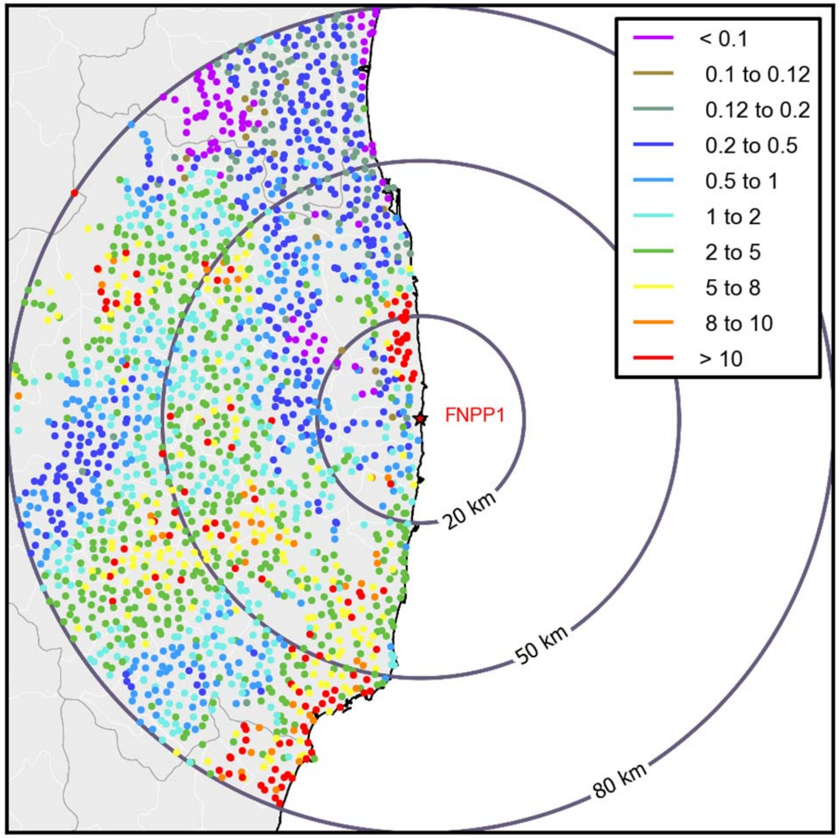


Simulated values of ^{137}Cs (Bq/m^2)

Comparison to MEXT deposition measurements of ^{137}Cs



- **Overall performance**
  - FAC2 : 31%
  - FAC5 : 73%
  - FAC10: 90%



- Map of « bias factor » C_M/C_O
- **Red**: overestimated by a factor 10
- **Purple**: underestimated by a factor 10
- **Blue** and **green**: within a factor 5

Questions…

We know there are huge uncertainties in the input data…

- Release assessment: timing of peaks, quantities (overestimation on March, 16)
- Meteorological data: wind direction (problems on March, 15 and along the coast), rain

But how do they compare to model uncertainties ?

- Deposition parameters: deposition velocity, scavenging coefficient
- Dispersion parameters: Gaussian standard deviations, mixing height

- **What are the most sensitive parameters ?**
- **What are the most sensitive results ?**

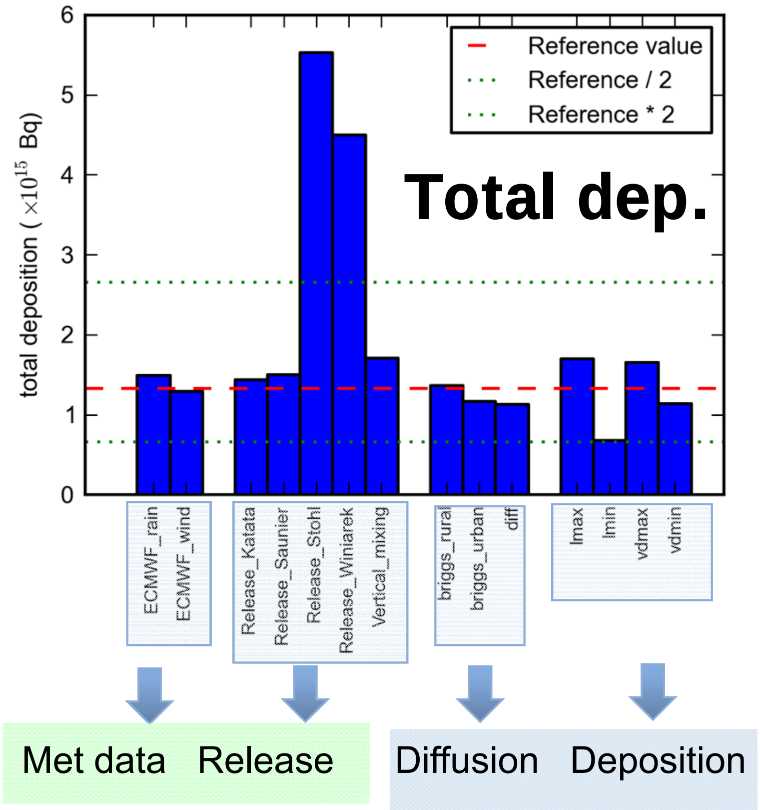
Reference value in **red**, name on figures in *blue*

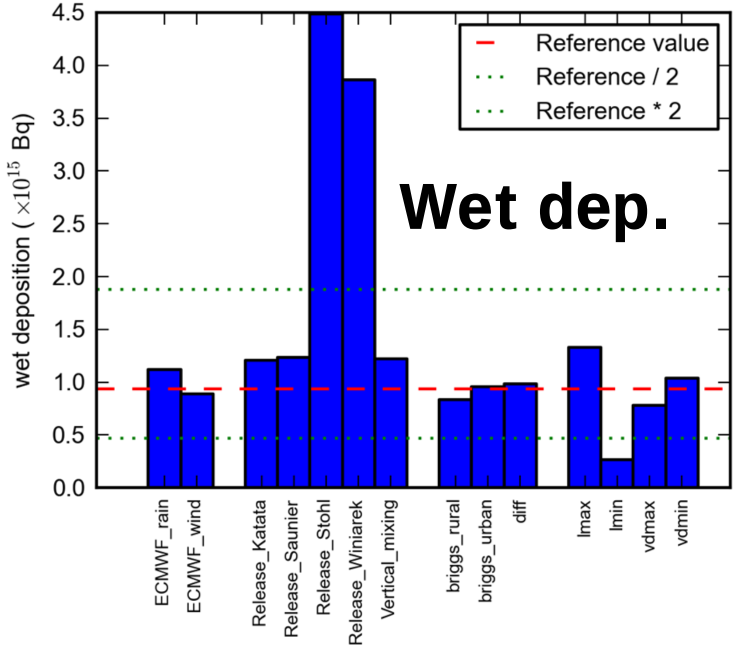
Input parameters

- Release height: time varying, diluted between 20 and 150m (*Vertical mixing*)
- Release: IRSN, Katata et al, 2012 (*Release_Katata*), Stohl et al, 2011 (*Release_Stohl*), Saunier et al, 2013 (*Release_saunier*), Winiarek et al, 2013 (*Release_winiarek*)
- Rain: radar , ECMWF forecast (*ECMWF rain*)
- Wind fields: ECMWF + obs, ECMWF only (*ECMWF wind*)

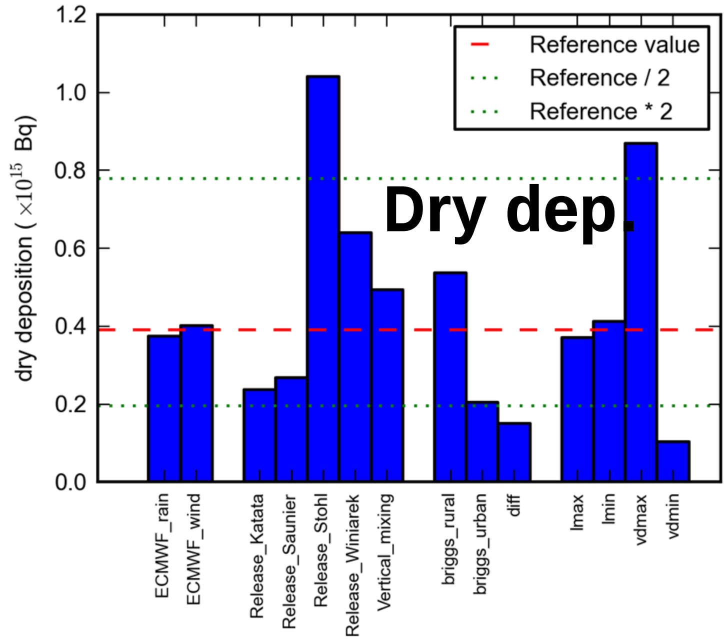
Modeling parameters

- Standard deviations: **Pasquill ,** Briggs rural, Briggs urban, Diffusion constant
- Dry deposition velocity : **2E-3 m/s**, 5E-4 m/s (*vdmin*), 5E-3 m/s (*vdmax*)
- Dry deposition for iodine I_2 : **7E-3 m/s**, 1E-3 m/s, 2E-2 m/s
- Wet deposition (Λ_0): **5E-5**, 1E-5 (*lmin*), 1E-4 h.s-1.mm-1 (*lmax*)

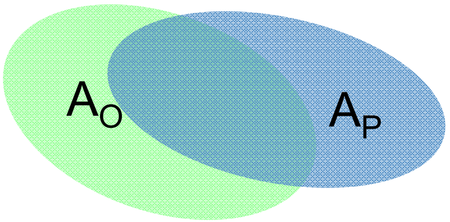




- Within a factor 2, except for some source terms
- Deposition parameters, vertical diffusion (dry dep)
- *Compensation between dry and wet deposition: less deposition (vdmin) means more scavenging*



Spatial coverage for a given threshold: figure of merit in space (FMS)

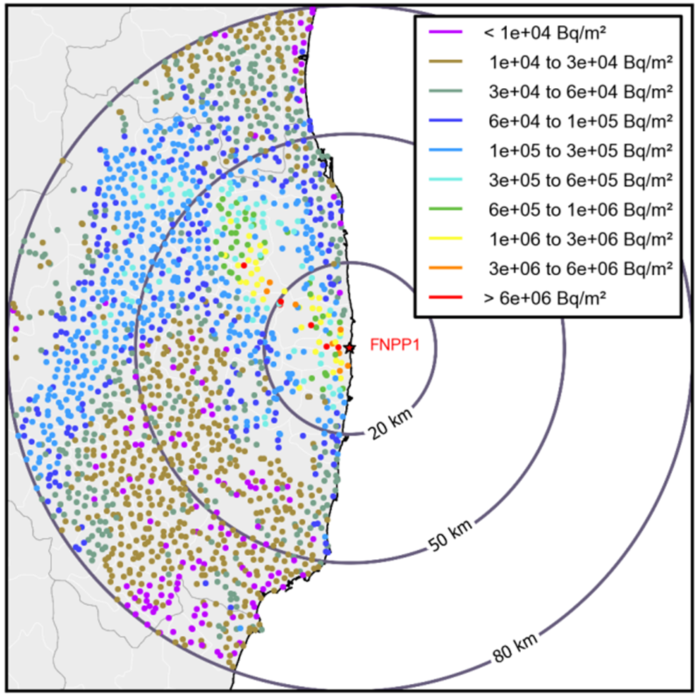


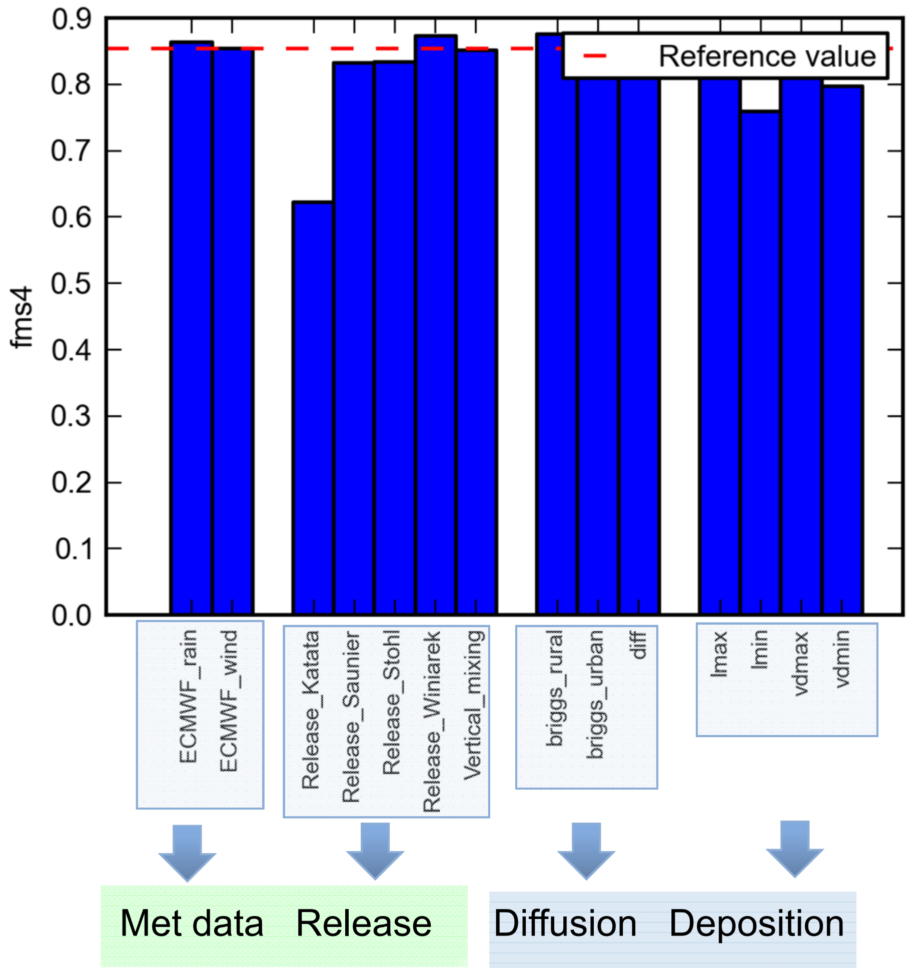
$$FMS = \frac{A_P \cap A_O}{A_P \cup A_O}$$

A_P = number of predicted values above threshold

A_O = number of observed values above threshold

Threshold = 10^4 Bq/m^2
(94% of observations)





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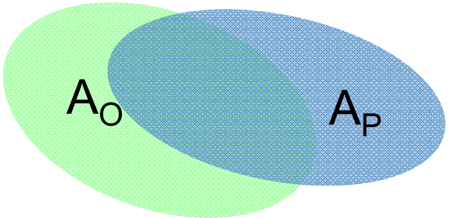
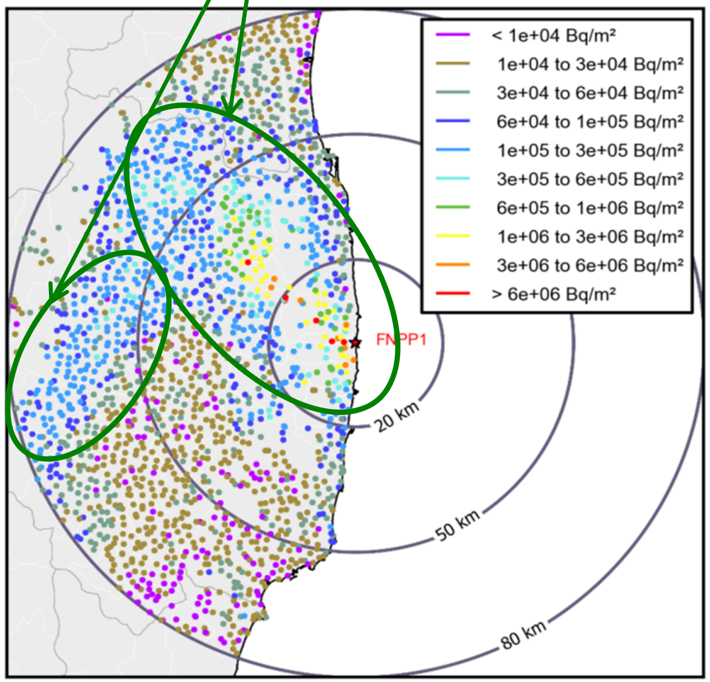


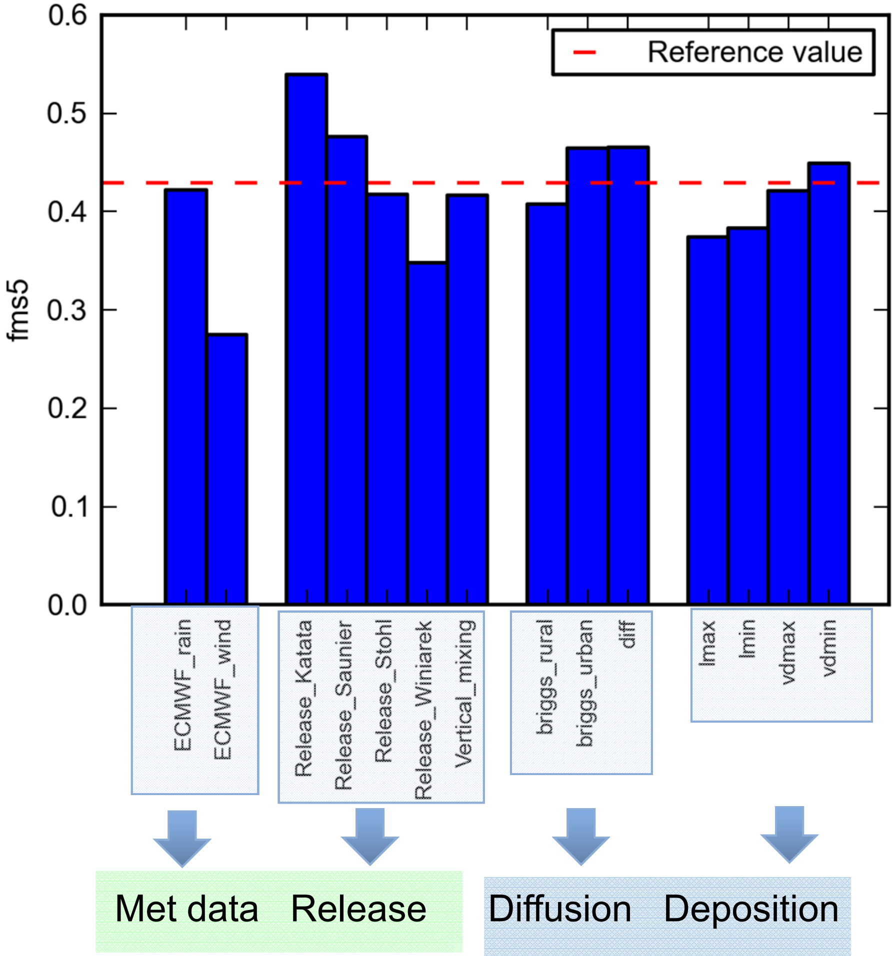
$$FMS = \frac{A_P \cap A_O}{A_P \cup A_O}$$

A_P = number of predicted values above threshold

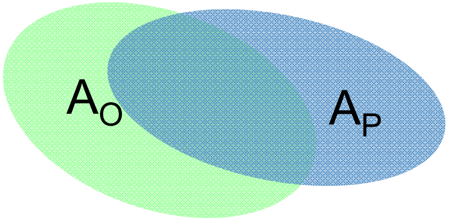
A_O = number of observed values above threshold

Threshold = 10^5 Bq/m^2
(30% of observations)





Spatial coverage for a given threshold: figure of merit in space (FMS)

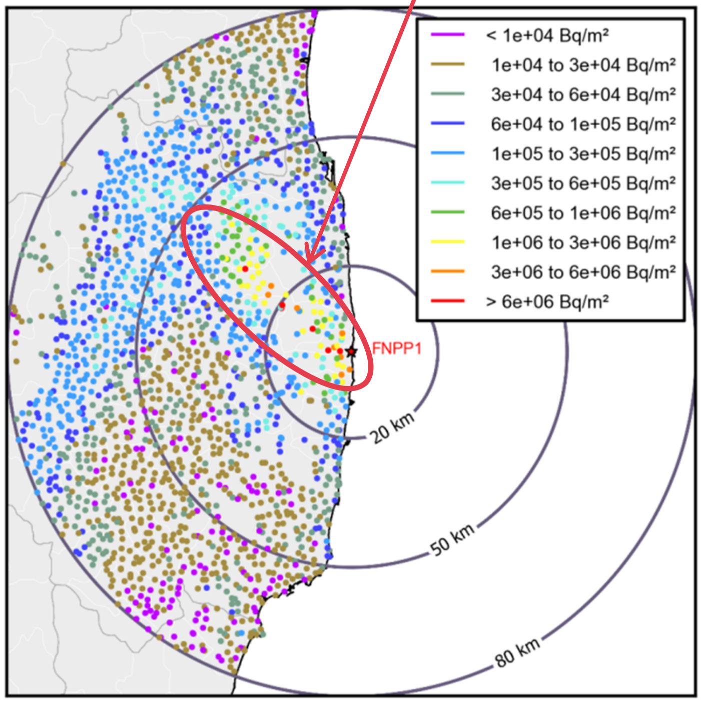


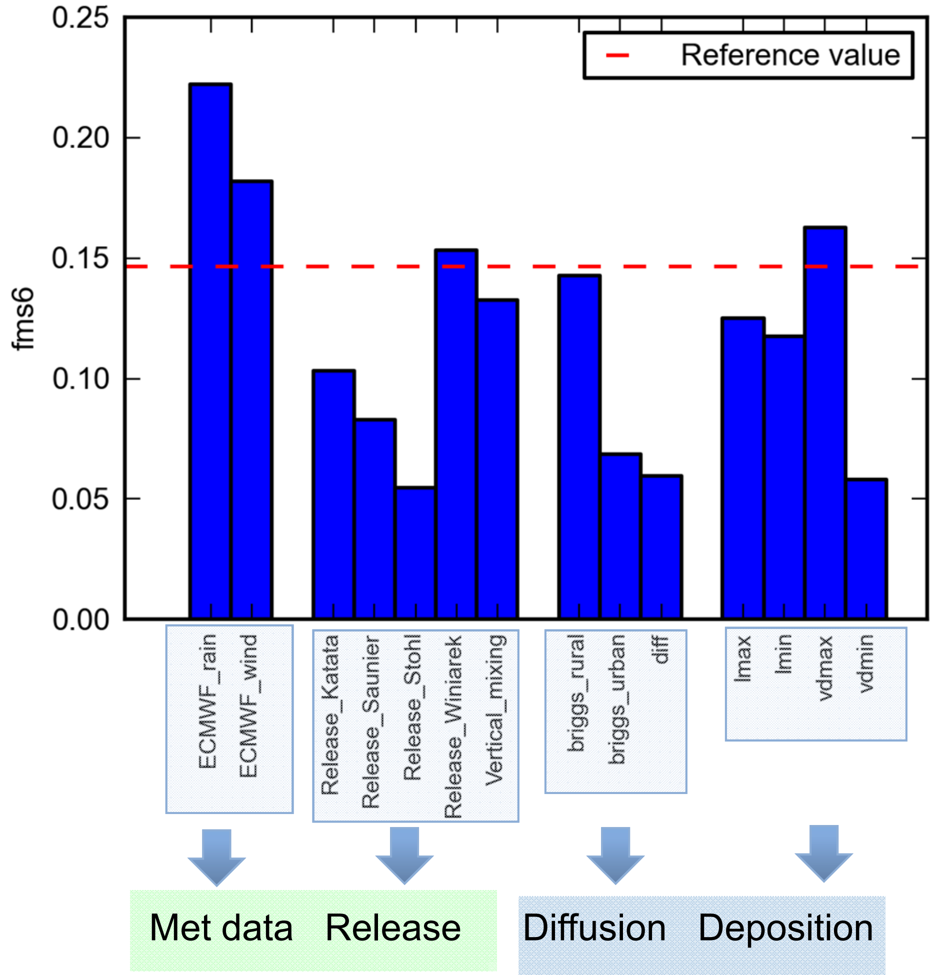
$$FMS = \frac{A_P \cap A_O}{A_P \cup A_O}$$

A_P = number of predicted values above threshold

A_O = number of observed values above threshold

Threshold = 10^6 Bq/m^2
(2.6% of observations)





Some answers...

What are the most sensitive parameters ?

- For deposition : release++, deposition parameters+, vertical diffusion (for dry deposition), wind direction (for figure of merit in space)
- For gamma dose rate: peaks are ***very*** sensitive to dispersion parameters, meteorology and release height (details in Korsakissok et al (2013), atmospheric environment)

What are the most sensitive results ?

- Deposition dry deposition is more sensitive than wet deposition
- Spatial coverage high values > 10^6Bq/m^2 very sensitive
- Gamma dose rate peak values are very sensitive, arrival times very insensitive

➚ **A model can be good on deposition and not on gamma dose rate (or conversely)**
➚ **What do we want to reproduce best ?**

Next steps…

Inverse modeling on gamma dose rate measurements

- The inverse source term showed here was reconstructed with simulations and measurements at Japan scale: very promising results (Saunier et al, 2013)

Better meteorological data

- Still questions: is it the source term or the meteorological data that is at fault ? …
- Several configurations (source term, meteorology) could give acceptable results…

Better modeling

- Puff splitting, similarity theory, improving dry deposition/wet scavenging, land-use…
- Representativity of the observations ?

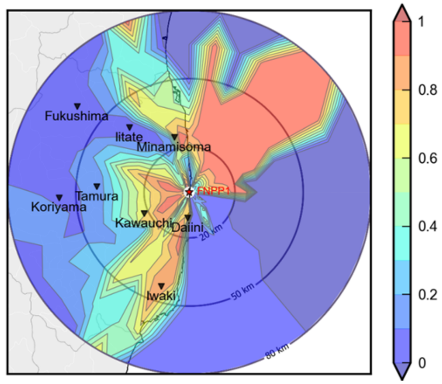
Uncertainties and ensemble simulations

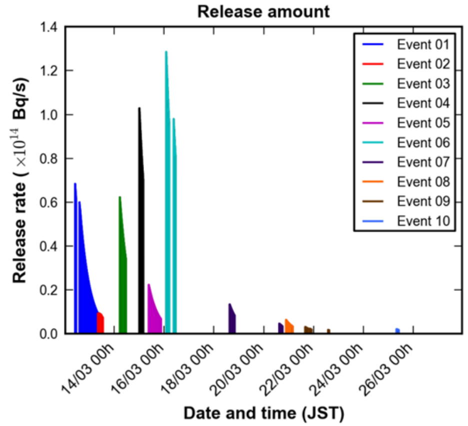
- Necessity to take into account uncertainties, on input data AND modeling parameters
- Ensemble simulations: to get an "envelope" response rather than a deterministic one

Thank you for your attention…

Questions ?

irene.korsakissok@irsn.fr





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