Lessons learned on atmospheric radon modelling by statistical model-to-data comparison on gamma dose rate peaks

Air concentration on the column
07 Feb 2020, 00:00
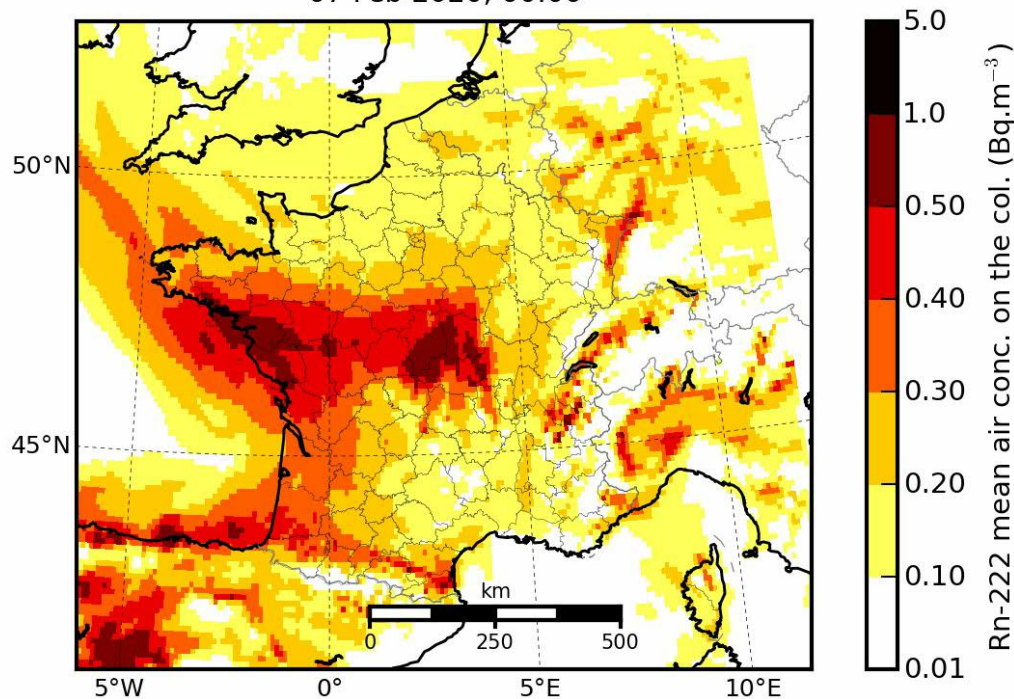
EGU 2020
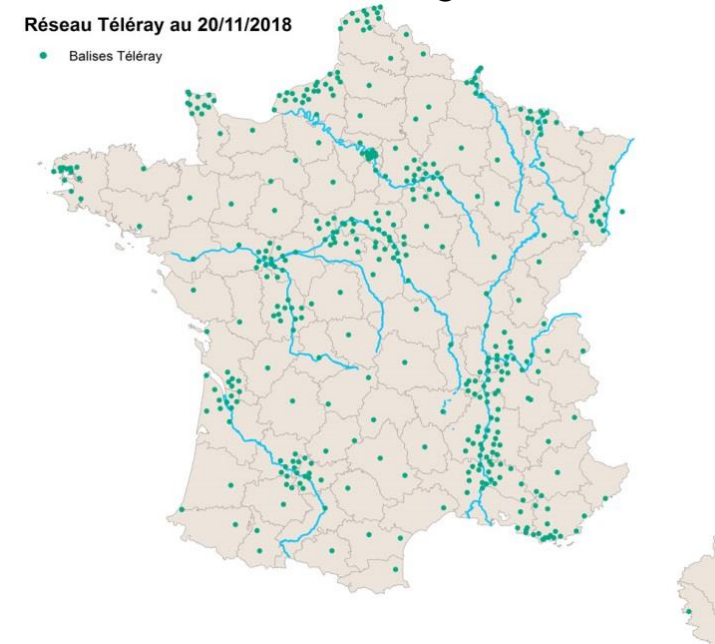D685 | EGU2020-14940
May, 8th 2020

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Denis QUÉLO
Thierry DOURSOUT
Claire GRÉAU
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IRSN
INSTITUT
DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

Faire avancer la sûreté nucléaire

In the event of an incident or accident involving radioactive materials, IRSN provides guidance to public authorities on the technical, public health and medical measures to be taken to protect the population and the environment.

The monitoring network Téléray in France: 432 gamma dose rate monitoring stations recording data each ten minutes all year round.

Several times a year, alarms of this emergency monitoring network are triggered due to gamma dose rate peaks occurring during rainfall events because radon progenies concentrate in rain drops and fall down to ground (Barbosa et al., 2017, Bossew et al., 2017)

Although these peaks do not present any risks to the population or environment, it is necessary to discriminate whether it comes from the natural radioactivity or if an accidental release of radioactive materials occurred.

A daily forecast of the gamma dose rate is operated since May 2019 (Quérel et al, 2019).

Gamma dose rate monitoring network Téléray

Réseau Téléray au 20/11/2018
• Balises Téléray

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Each month

- Gamma dose rate peaks > **50 nSv/h** : from 0 to 15 events

- Gamma dose rate peaks > **10 nSv/h** : more than 1000 events

➡ Database to validate and to improve:

- Radon exhalation map
- Atmospheric transport modelling
- Monitoring station representativeness

Gamma dose rate observed and modelled
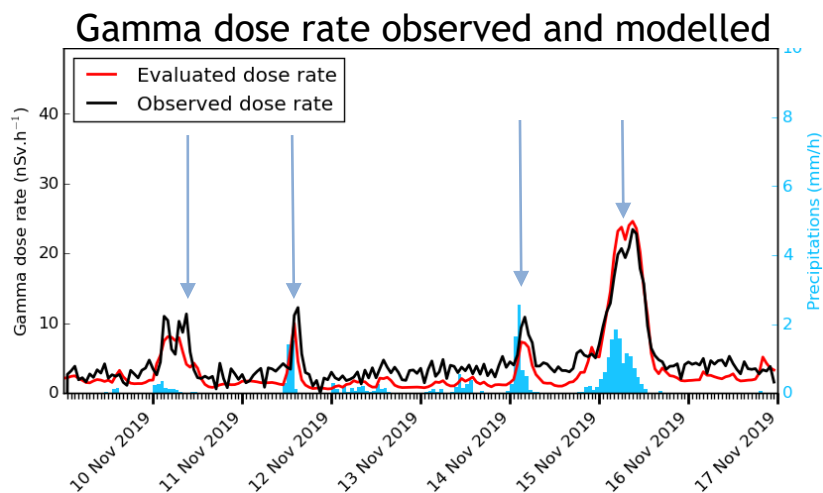
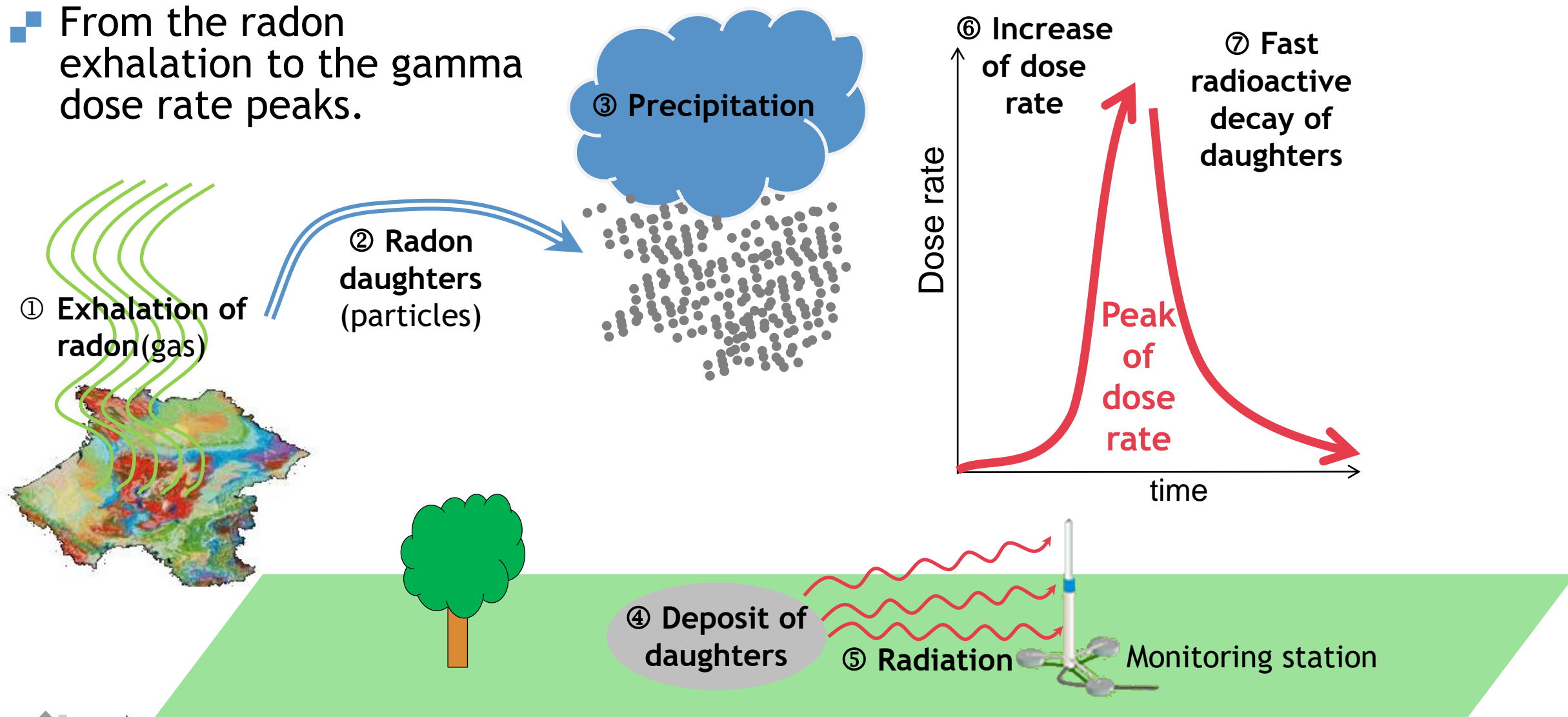Four peaks greater than 10 nSv/h on this example

Which lessons can be learned from the gamma dose rate peaks ?

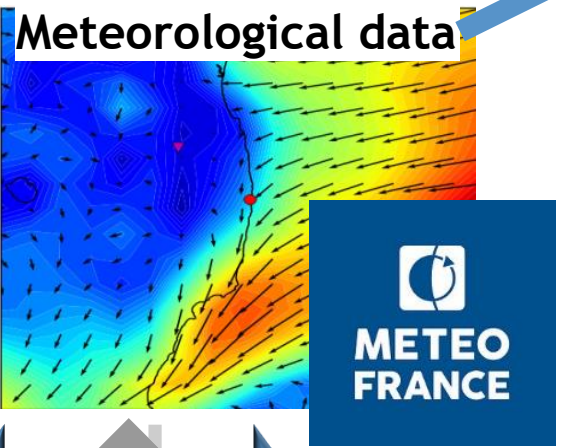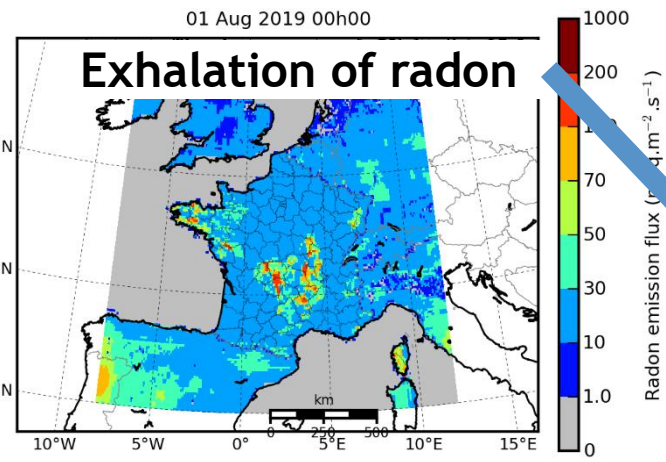➡**Focus on the radon exhalation map.**

Atmospheric transport of radon

- From the radon exhalation to the gamma dose rate peaks.

③ **Precipitation**

② **Radon daughters** (particles)

① **Exhalation of radon**(gas)

⑥ **Increase of dose rate**

⑦ **Fast radioactive decay of daughters**

Dose rate

Peak of dose rate

time

④ **Deposit of daughters**

⑤ **Radiation**

Monitoring station

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Atmospheric transport of radon Modelling

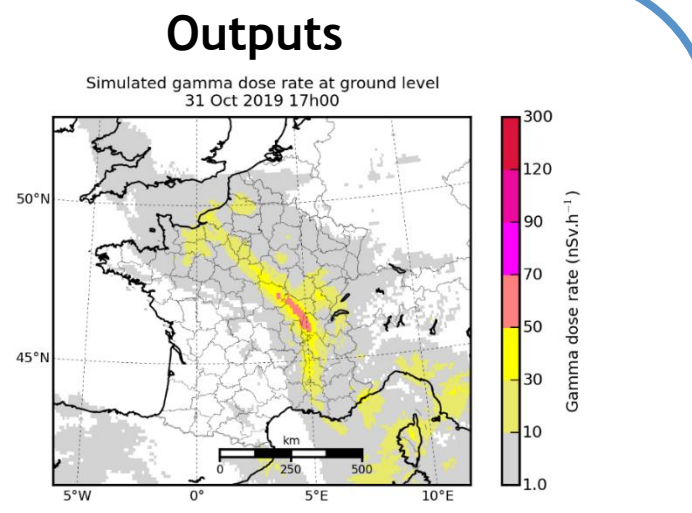**Exhalation of radon**

01 Aug 2019 00h00

Physical properties (decay chain, phys. form, …)

Atmospheric transport modelling
(ldX, part of C3X, Groëll et al., 2014)

Dose rate modelling
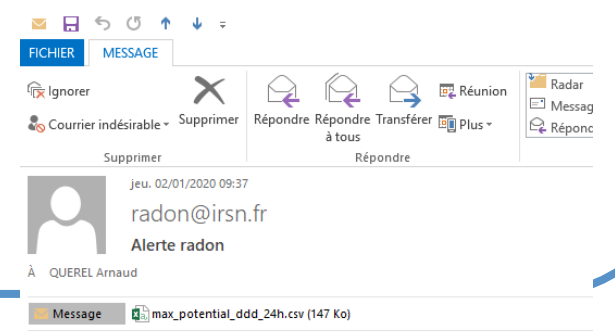
Meteorological data

METEO FRANCE

Observations

Réseau Téléray au 20/11/2018

Outputs

Maps

Simulated gamma dose rate at ground level
31 Oct 2019 17h00

Time series

Evaluated dose rate
Observed dose rate

Mails

jeu. 02/01/2020 09:37
radon@irsn.fr
Alerte radon
À   QUEREL Arnaud
Message   max_potential_ddd_24h.csv (147 Ko)

Attention, le potentiel radon prévu est supérieure à 60 nSv/h.
Le potentiel maximum est prévu à la station MORNANT_69_AGG_CP

Model/measure comparisons

■ Peaks could be **well modelled**

Seringes

Melun

■ Could be **false positive**
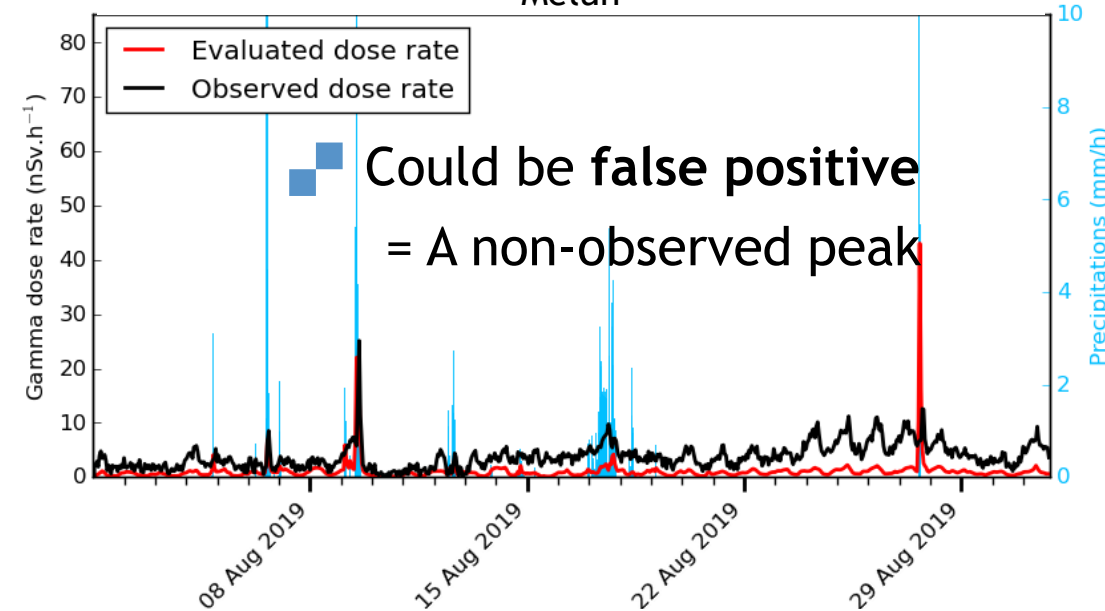
= A non-observed peak

Bastia

■ Could be **false negative**

= A non-modelled peak

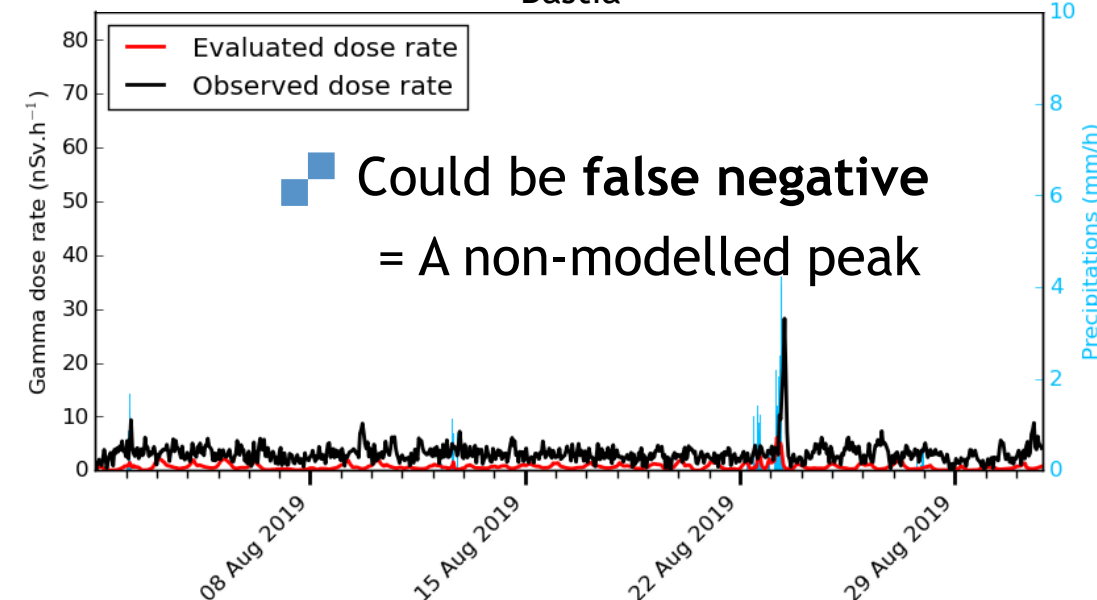**The numbers of peaks well and poorly modelled are used to estimate the quality of the simulation, including the exhalation map.**

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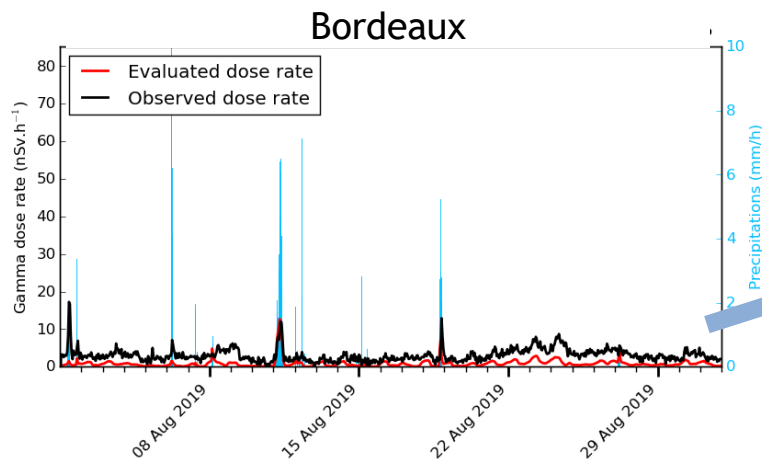
© IRSN   **IRSN**

Summer particularity

■ In summer, underestimation of the exhalation flux in the already "active" areas.

A false negative peak every day, due to the night-time radon accumulation in stable atmosphere.
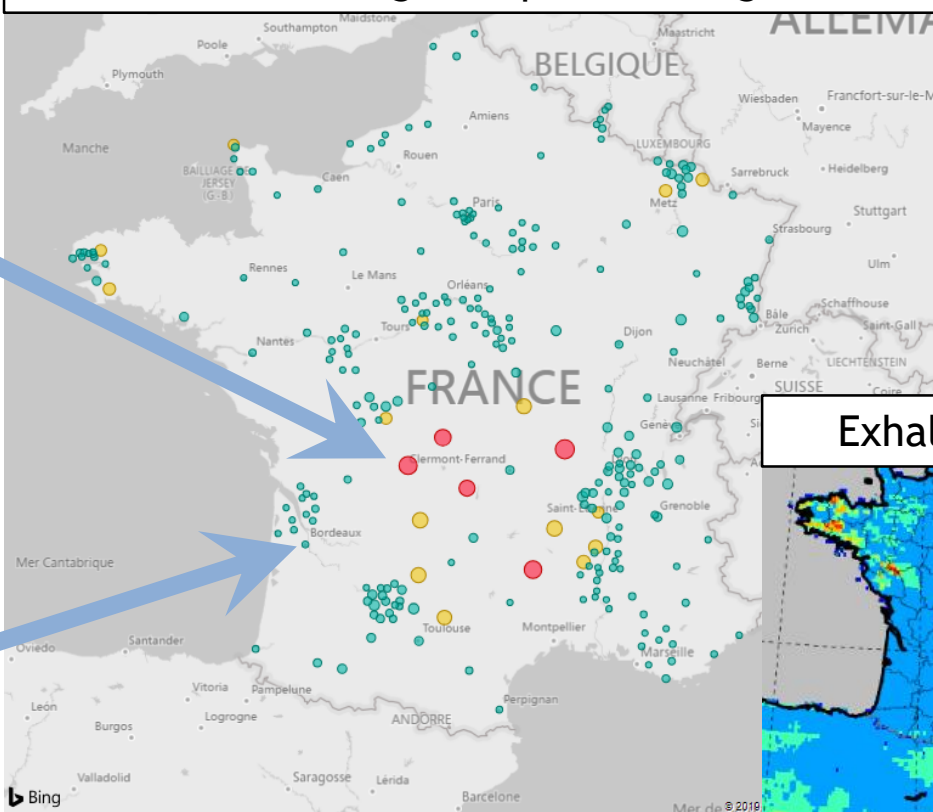

Limoges
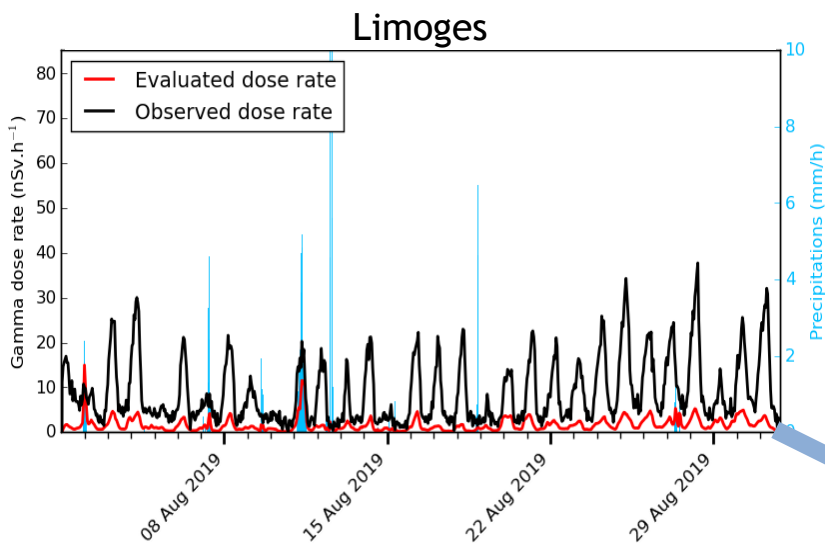
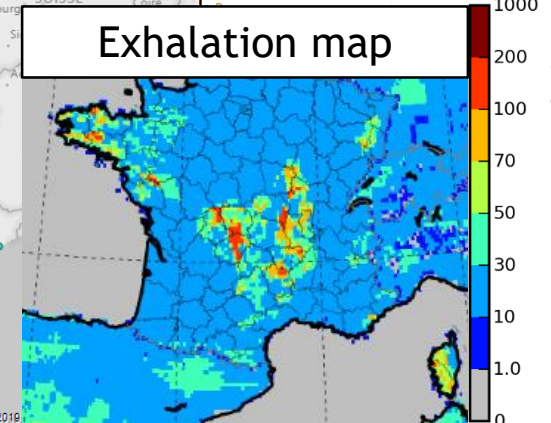No false negative in weak exhalation area

Bordeaux

The summer-time number of false negative peaks is correlated to location with the highest radon exhalation flux.

Number of false negative peaks in August 2019

Nom de la station	False negative d10
ROANNE_42_AGG_CP	26
LIMOGES_87_AGG_CP	24
MENDE_48_AGG_CP	23
GUERET_23_AGG_CP	21
USSEL_19_AGG_CP	20
BRIVE_19_AGG_CP	19
LE PUY-EN-VELAY_43_AGG_CP	19
CAHORS_46_AGG_CP	18
MOULINS_03_AGG_CP	18
GAILLAC_81_AGG_CP	17
LES OLLIERES-SUR-EYRIEUX_07_AGG_CP	16
AJACCIO_2A_AGG_CP	15
AUBENAS_07_AGG_CP	15
BOUZONVILLE_57_AGG_CP	14
JARNY_54_AGG_CP	13
QUIMPER_29_AGG_CP	13
MONTMORILLON_86_AGG_C	12

Exhalation map

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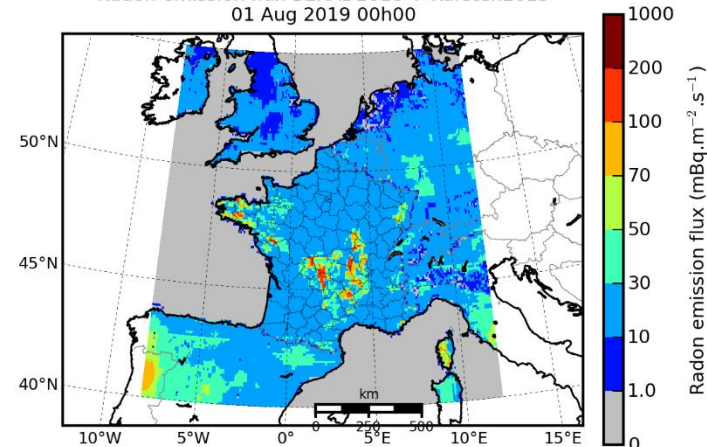
© IRSN   IRSN

Large impact of the exhalation flux map

Example of August 2019 simulation. *False* is the sum of false positive and false negative peaks.
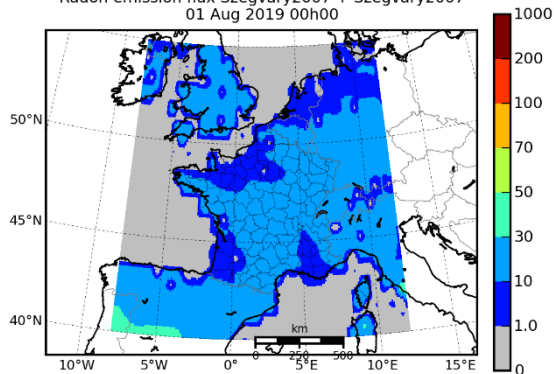
Reference exhalation map : IRSN over France (internal report + Ielsch et al.), Karsten 2015 over the rest of Europe

Radon emission flux BERAD2018 + Karsten2015
01 Aug 2019 00h00

Szegvary (2007) exhalation map

Radon emission flux Szegvary2007 + Szegvary2007
01 Aug 2019 00h00

Small number of well simulated peaks (312) despite only 1637 false

Ref emission x0.33, an attempt to reduce the false number

Radon emission flux BERAD2018 + Karsten2015
01 Aug 2019 00h00
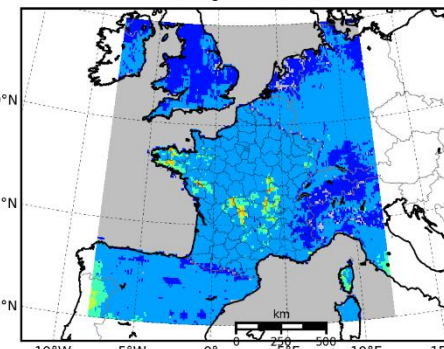
Small number of well simulated peaks (374) despite only 1663 false

Uniform (50 mBq.m^{-2}.s^{-1}) exhalation map

Radon emission flux uniform + uniform
01 Aug 2019 00h00
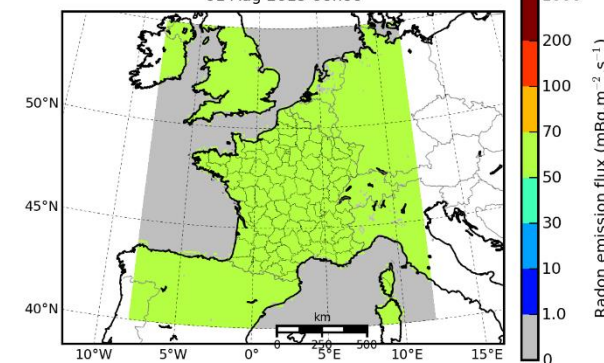
Large number of false (2811) despite 807 well simulated peaks

■ Best compromise : medium number of well simulated peaks (638) and medium number of false (1882)

The best exhalation map is a compromise between the well and poorly modelled gamma dose rate peaks.

Conclusion

- The radon exhalation map can have a strong influence on the forecast of the gamma dose rate peaks.

- Gamma dose rate peaks modelling is a valuable tool to analyse exhalation map on a continental scale.

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... Outlook

- Only 40 % of the gamma dose peaks are forecast within a factor 2. Must be improved. Remain a challenge for the community:

  - Geology (radon emission)

  - Meteorology (precipitation accuracy)

  - Atmospheric physics (wet deposition)

- How to improve the radon exhalation map ?

  - Function of meteorological data (atmospheric pressure, soil humidity, ...)

  - Complete the radon emitter inventory (eg, to add punctual sources)

  - Benefit of using more detailed exhalation model (eg, T2RN - Saâdi et al., 2014)

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■ Quérel, A., Roustan, Y., Quélo, D., Benoit, J.-P., 2015. Hints to discriminate the choice of wet deposition models applied to an accidental radioactive release. Int. J. Environment and Pollution 58, 268–279. https://doi.org/10.1504/IJEP.2015.077457

■ Saâdi, Z., Gay, D., Guillevic, J., Améon, R., 2014. EOS7Rn—A new TOUGH2 module for simulating radon emanation and transport in the subsurface. Computers & Geosciences 65, 72–83. https://doi.org/10.1016/j.cageo.2013.09.003

■ Szegvary, T., 2007. European 222Rn flux map for atmospheric tracer applications. University of Basel, Basel.

Appendix

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Appendix A

- The observed dose rate of the « radon peaks » is mainly due to the Bi-214 disintegration

Radium-226, ½ life of **1602 years**

Radon-222, ½ life of **3,8 days**

Short life elements

Bismuth-214, ½ life **20 min, strong gamma emitter**

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Appendix B

Atmospheric transport model ldX

Exhalation of Rn-222 →

Plume transport   Plume diffusion

Dry deposition

Radioactive decay

Wet deposition
In-cloud scavenging
Below-cloud scavenging
Cloud diagnosis

Decay chain

For each radionuclides at each time step :

■ Air concentration (3D)

■ Deposit (2D)

Met data →

■ Eulerian model

■ Long range transport model of the operational response platform C3X

■ Operated on several cases : Chernobyl, Fukushima, CTBTO, …

Eslinger, Paul W., Ted W. Bowyer, Pascal Achim, Tianfeng Chai, Benoit Deconninck, Katie Freeman, Sylvia Generoso, et al. 2016. « International Challenge to Predict the Impact of Radioxenon Releases from Medical Isotope Production on a Comprehensive Nuclear Test Ban Treaty Sampling Station ». *Journal of Environmental Radioactivity* 157 (juin): 41-51. https://doi.org/10.1016/j.jenvrad.2016.03.001.

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Kajino, Mizuo, Tsuyoshi Thomas Sekiyama, Anne Mathieu, Irène Korsakissok, Raphaël Périllat, Denis Quélo, Arnaud Quérel, et al. 2018. « Lessons Learned from Atmospheric Modeling Studies after the Fukushima Nuclear Accident: Ensemble Simulations, Data Assimilation, Elemental Process Modeling, and Inverse Modeling ». *Geochemical Journal* 52 (2): 85-101. https://doi.org/10.2343/geochemj.2.0503.

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Mathieu, Anne, Irène Korsakissok, Denis Quélo, Jérôme Groëll, Marilyne Tombette, Damien Didier, Emmanuel Quentric, Olivier Saunier, Jean-Pierre Benoit, et Olivier Isnard. 2012. « Fukushima Daiichi: Atmospheric Dispersion and Deposition of Radionuclides from the Fukushima Daiichi Nuclear Power Plant Accident ». *Elements* 8 (3): 195-200. https://doi.org/10.2113/gselements.8.3.195.

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Quérel, Arnaud, Yelva Roustan, Denis Quélo, et Jean-Pierre Benoit. 2015. « Hints to Discriminate the Choice of Wet Deposition Models Applied to an Accidental Radioactive Release. » *International Journal of Environment and Pollution* 58 (4): 268-79. https://doi.org/10.1504/IJEP.2015.077457.

Sato, Yousuke, Masayuki Takigawa, Tsuyoshi Thomas Sekiyama, Mizuo Kajino, Hiroaki Terada, Haruyasu Nagai, Hiroaki Kondo, et al. 2018. « Model Intercomparison of Atmospheric 137 Cs from the Fukushima Daiichi Nuclear Power Plant Accident: Simulations Based on Identical Input Data ». *Journal of Geophysical Research: Atmospheres*, octobre. https://doi.org/10.1029/2018JD029144.

Saunier, Olivier, Anne Mathieu, Damien Didier, Marilyne Tombette, Denis Quélo, Victor Winiarek, et Marc Bocquet. 2013. « An inverse modelling method to assess the source term of the Fukushima Nuclear Power Plant accident using gamma dose rate observations ». *Atmospheric Chemistry and Physics* 13: 11403-21. https://doi.org/10.5194/acp-13-11403-2013.
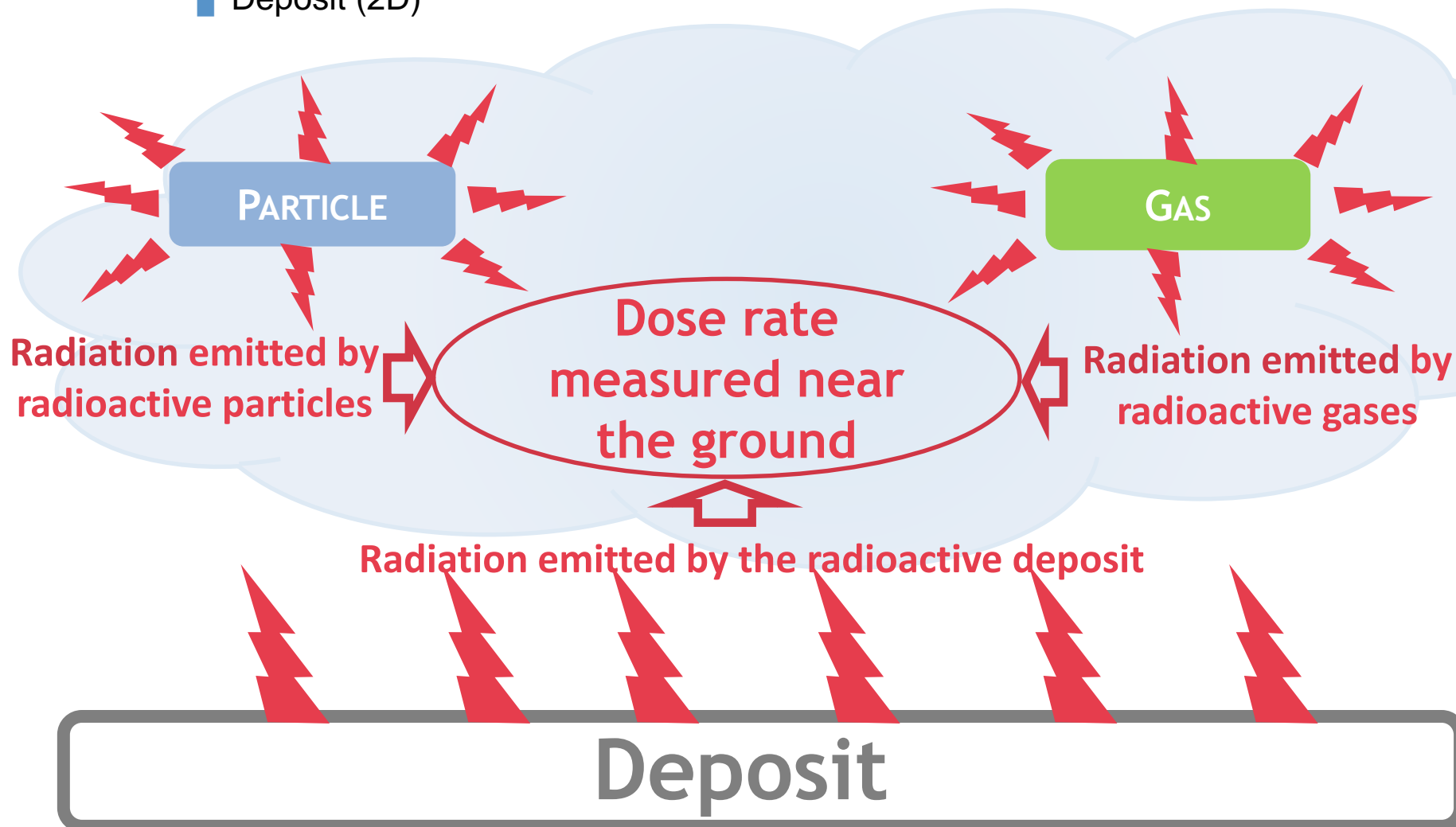
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Appendix C

For each radionuclide at each time step :

- Air concentration (3D)
- Deposit (2D)
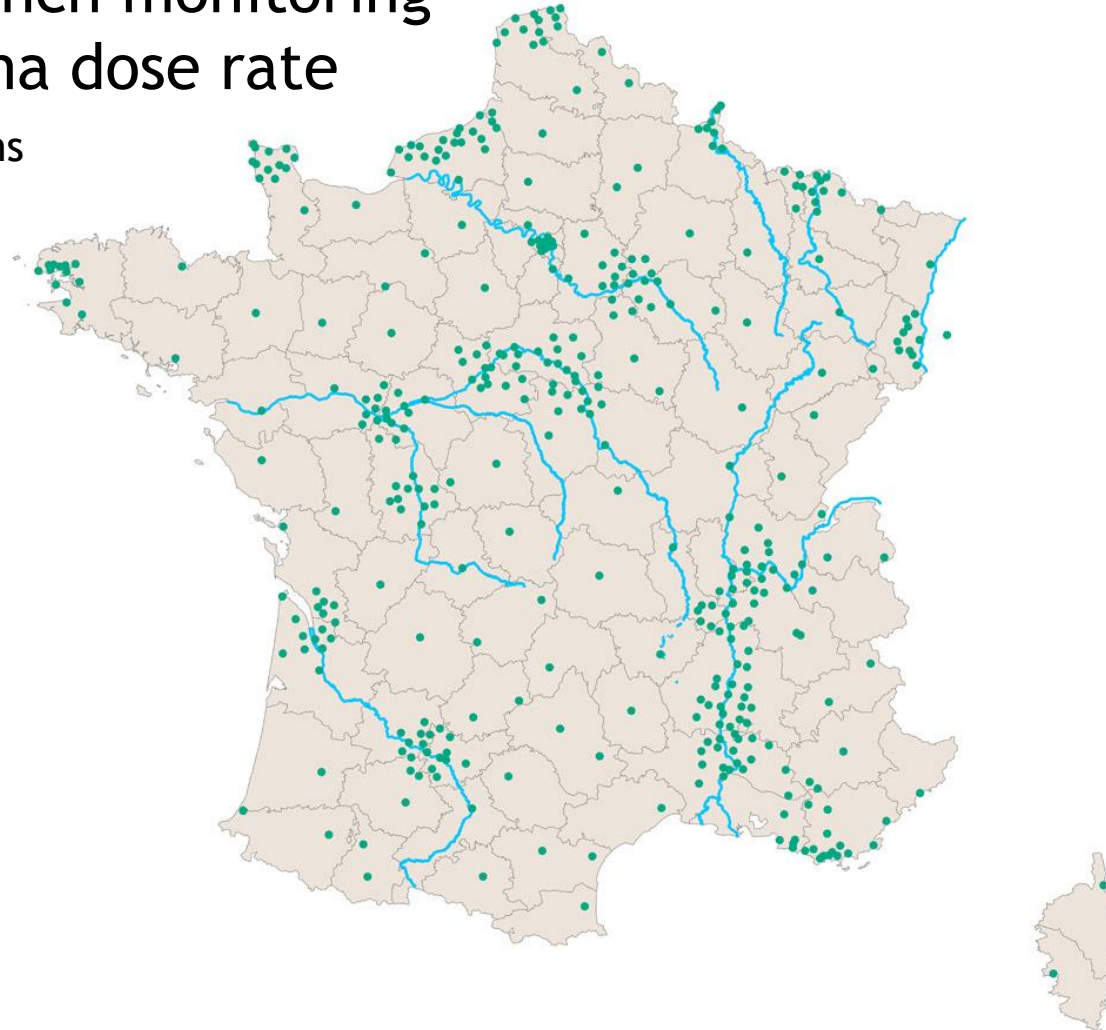
→ **Dose rate computation** →

For each time step :

- Dose rate at ground level (2D)

PARTICLE

GAS

Radiation emitted by radioactive particles

Dose rate measured near the ground

Radiation emitted by radioactive gases

Radiation emitted by the radioactive deposit

Deposit

Appendix D

Téléray : the French monitoring network of gamma dose rate

- 432 monitoring stations
- Frequency : 10 min

Aiguille –du-Midi

Clermont-Ferrand

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Appendix E

- Radar observations are used to improve the past events simulation

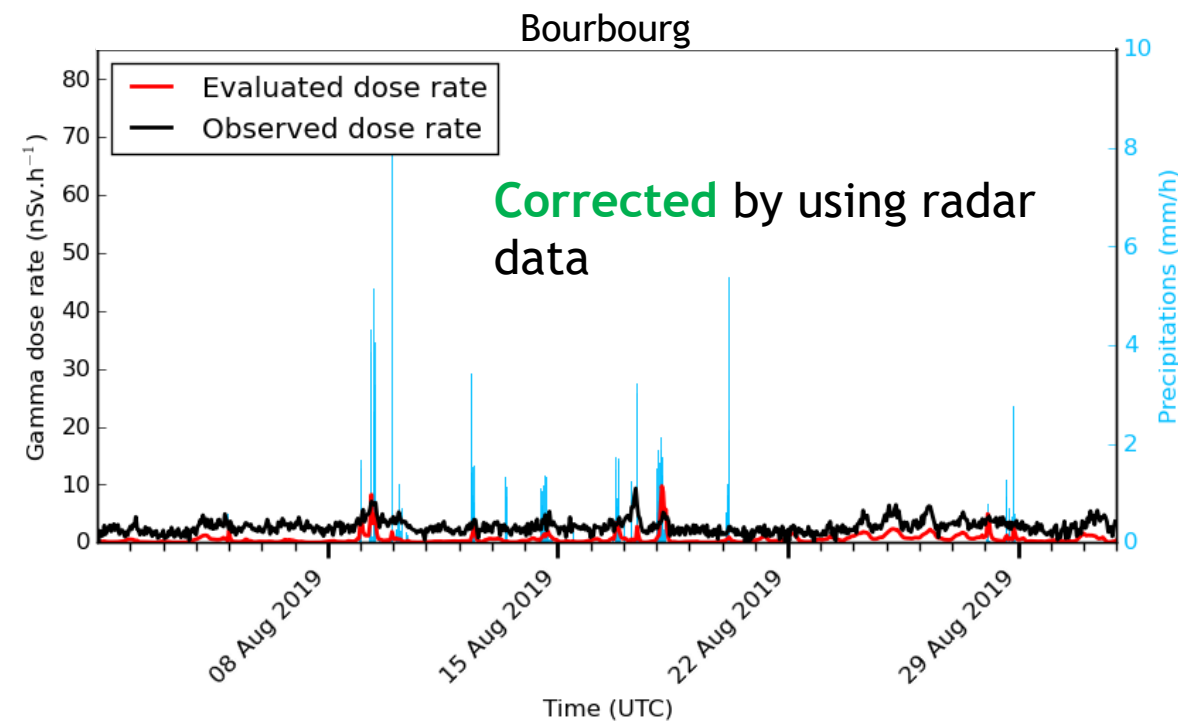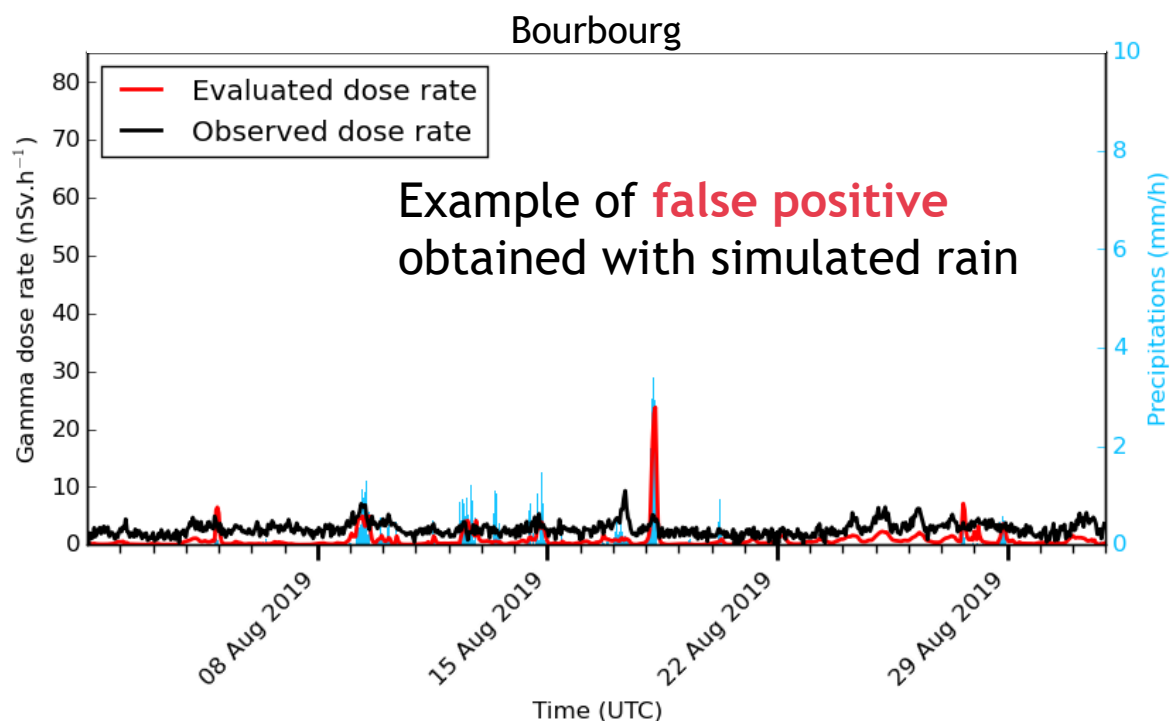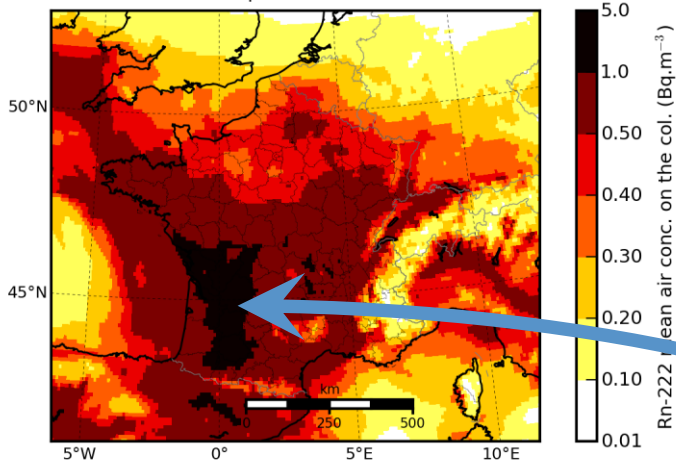| Rain data used for the august 2019 simulation	False positive and negative	Well-modelled peaks number
radar	1882	638
model	2603	269

Bourbourg

Example of **false positive** obtained with simulated rain

Bourbourg

Corrected by using radar data

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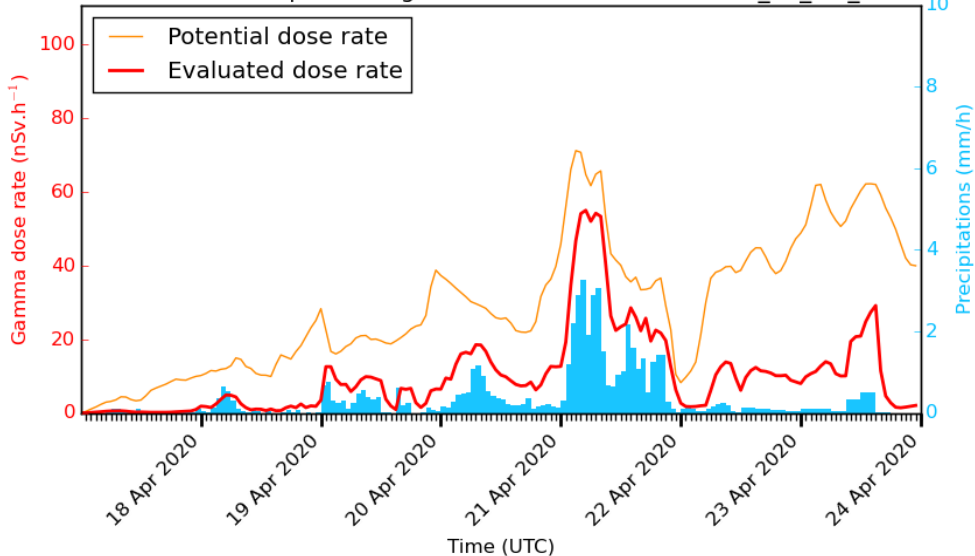
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Appendix F
Golfech 21ˢᵗ April 2020

Air concentration on the column
21 Apr 2020, 09:00

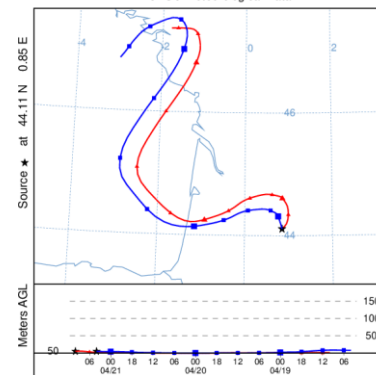■ The monitoring network of gamma dose rate trigged the alarm.

Air mass <1000 m are locals

NOAA HYSPLIT MODEL
Backward trajectories ending at 1000 UTC 21 Apr 20
GFSG Meteorological Data

75 % of the gamma dose rate

Air mass >1000 m are distant

NOAA HYSPLIT MODEL
Backward trajectories ending at 1000 UTC 21 Apr 20
GFSG Meteorological Data

25 % of the gamma dose rate

■ Strong radon concentration + rainfall in the south-west of France

Simulated and potential gamma dose rate at GOLFECH_82_SIT_CP
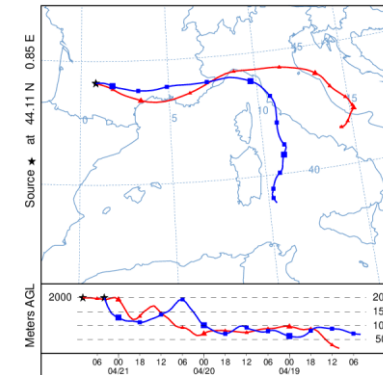
■ A gamma dose rate peak can be a combination of local **and** distant radon origin.