

# NUMERICAL ASSESSMENT OF THE APPLICABILITY OF GAUSSIAN MODELS FOR THE PREDICTION OF NEAR-FIELD DISPERSION NEAR URBAN ENVIRONMENTS

*Erwan Rondeaux<sup>1</sup>, Irène Korsakissok<sup>1</sup>, Olivier Connan<sup>2</sup> and Guillevic Lamaison<sup>3</sup>*

<sup>1</sup>IRSN/PSE-SANTE/SESUC/BMCA

<sup>2</sup>IRSN/PSE-ENV/STAAR/LERTA

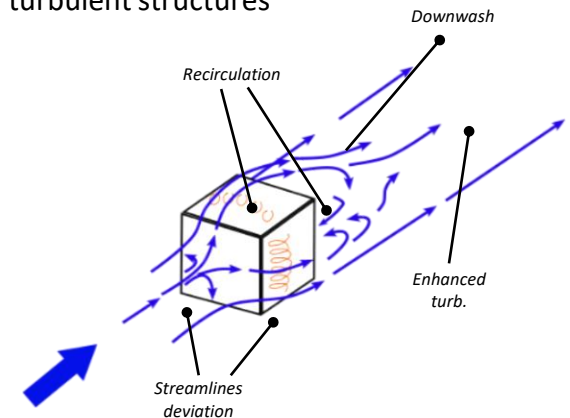
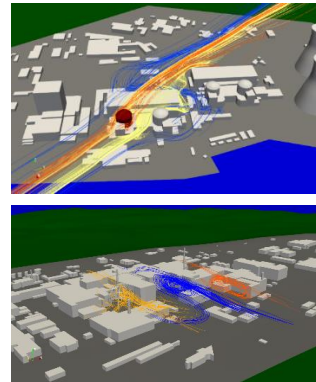
<sup>3</sup>Ecole Centrale Lyon/LMFA

# Dispersion modelling for emergency response

## In the event of accidental release of radionuclides in the atmosphere

- IRSN uses **dispersion modelling tools** to anticipate radiological consequences ...
- ... to advise decision makers on **countermeasures to protect the population and environment** (Evacuation, Sheltering, Stable iodine prophylaxis, Food restrictions)

## Most nuclear site can be assimilated to peri-urban areas, where the **presence of buildings and obstacles may impact the dispersion of pollutants**, through complex interaction mechanisms with turbulent structures



# Dispersion modeling tools

**Simplified models**

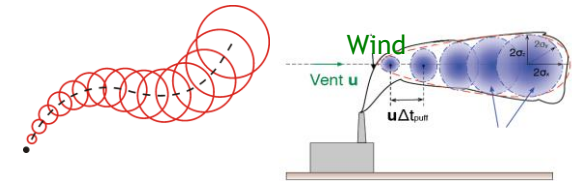
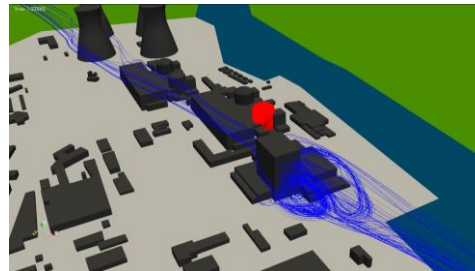
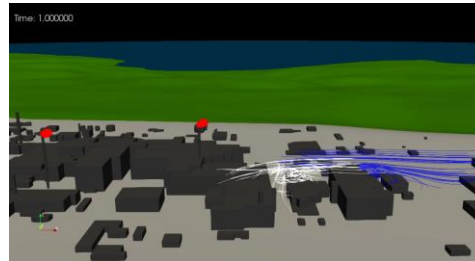
*CFD-based models*

Complexity/Precision

**Complex models**

*IRSN Operationnal model (pX)*

- Resolution of Navier-stokes equations
- Explicit modeling of buildings and terrain effects, account for the intricate wind flow around buildings (recirculation, blocking effects, etc)
- Time and computational ressources demanding, incompatibility with emergency constraints



- Gaussian model : simplified discretization of the plume in puffs
- Empirical Gaussian laws to describe the distribution of concentration in a puff
- No explicit modeling of buildings and terrains effects



## Range of validity of dispersion modeling tools

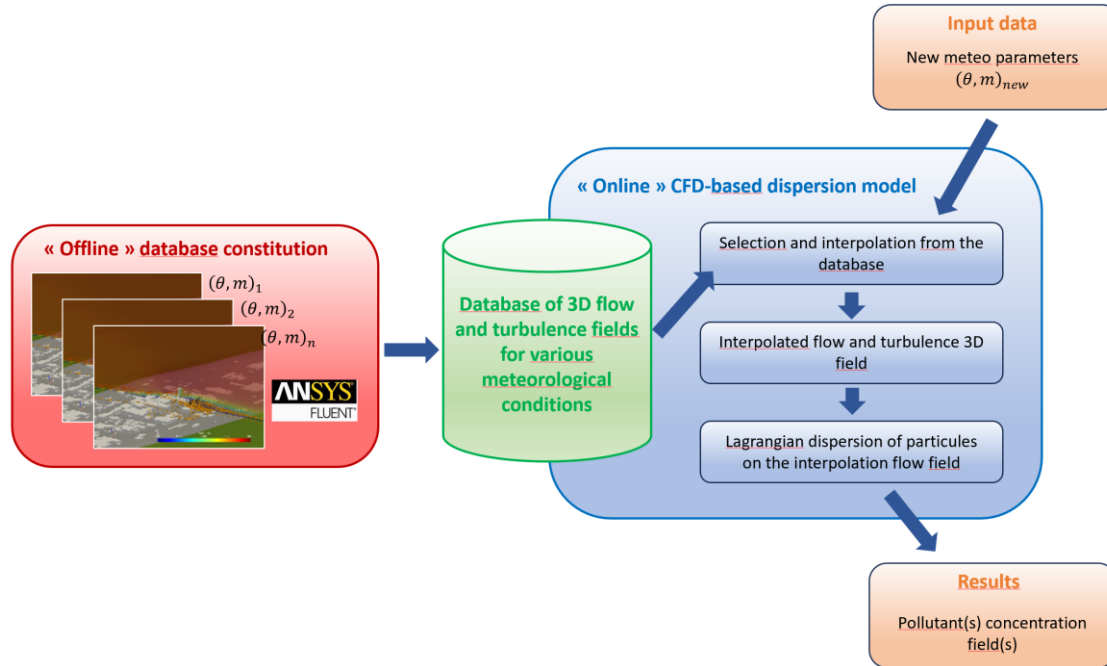


Uncertainty on the transition distance from which the Gaussian approach becomes acceptable.

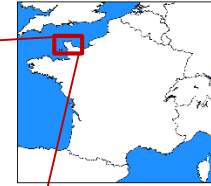
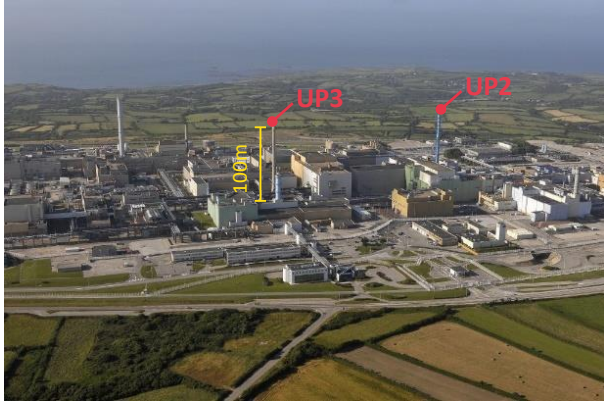
### Objectives of the work:

- explore the applicability of simplified approaches compared to more complex approaches against a **real case measurement campaign** at intermediate distances (few kms)
- evaluate the added value of CFD-based tools against simplified models in the **context of emergency response**
- study the **sensibility of pX to some of its parameters and meteorological forcing**, ... to eventually adapt good practices

# SLAM, a CFD-based approach compatible with emergency constraints



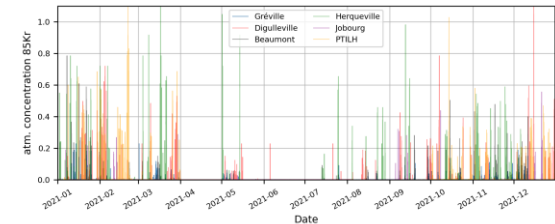
# Case study – Orano La Hague RP



| Station      | Distance/UP2 (m) | Direction/UP2 (°) |
|--------------|------------------|-------------------|
| Jobourg      | 2200             | 126               |
| Herqueville  | 800              | 6                 |
| Digulleville | 2600             | 2,6               |
| PTILH        | 2000             | 193               |
| Beaumont     | 2600             | 292               |
| Gréville     | 5200             | 272               |

## DISKRYNOC project :

- Krypton-85 is a good tracer of dispersion (neglectable deposition)
- Continuous measurements of <sup>85</sup>Kr concentration between November 2020 and December 2022 performed by Orano and IRSN (800 – 5.2km) ( $\Delta t = 10min$ )
- Release rate at UP2 and UP3 ( $\Delta t = 10min$ )
- Access to complete meteorological measurements ( $\Delta t = 10min$ )

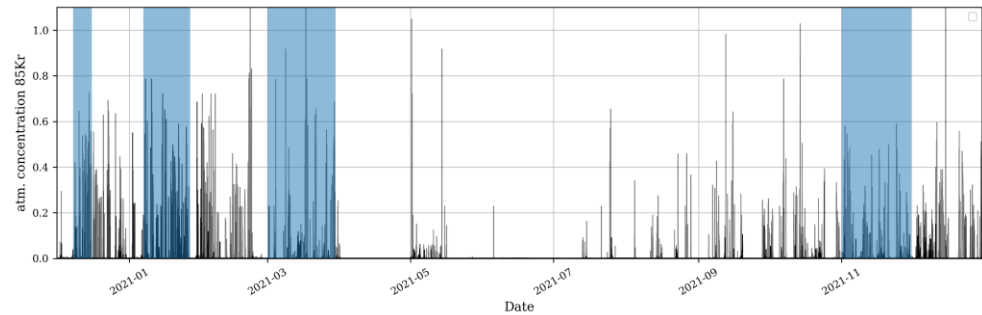


# Study setup

## Selection of simulation intervals

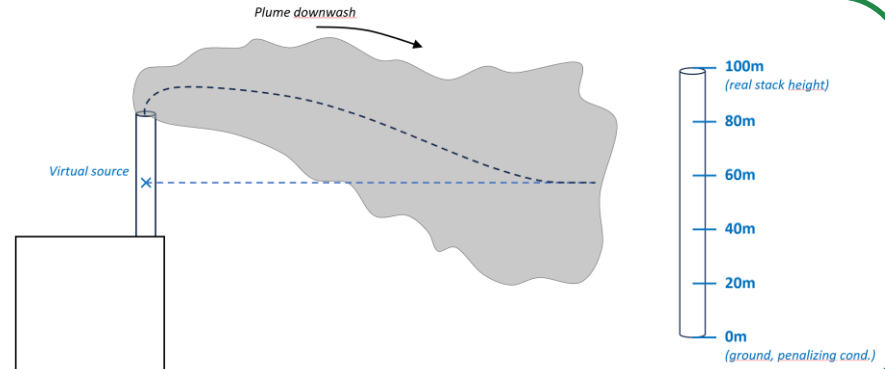
- 4 sub-periods where there are both significant releases as well as a significant density of concentration measurements
  - 8-15 Dec 2020
  - 7-26 Jan 2021
  - 1-29 March 2021
  - 1-30 Nov 2021

■ Total of about 3 months simulated!



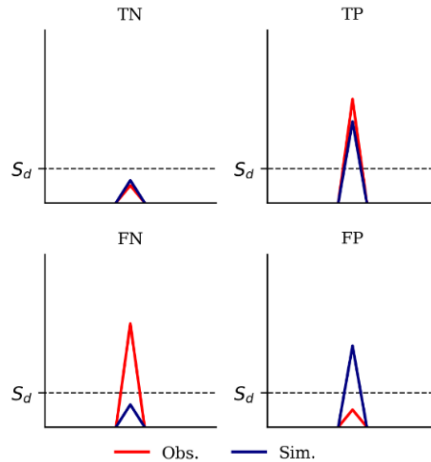
## Simulations setup

|                              | pX   | SLAM                               |
|------------------------------|--|------------------------------------|
| <b>Inputs</b>                | 10min meteorological and release rate time series            |                                    |
| <b>Source representation</b> | Single point source located at the barycentre of UP2 and UP3 | 2 cylindrical sources, UP2 and UP3 |
| <b>Source height</b>         | 0-100m (20m increments)                                      | Real stack height (100m)           |
| <b>Gaussian law</b>          | Doury, Pasquill, Briggs (Urban & Rural)                      | ---                                |



# Results processing

- Results are gathered in the form of 10 min times series of concentration at the different stations and further processed to compute the 1hour integrated concentration in sliding windows (proportional to the hourly received dose)
- We are interested in evaluating the ability of models to simulate all the observed peaks → because, in emergency context, missing a radiation event could have an impact on the population health and environment



Contingency table for successes and failures

**TP** : True Positive  
**FP** : False Positive  
**FN** : False Negative  
**TN** : True Negative

Failures and successes are aggregated by statistical indicators :

$$Hit\ Rate\ (HR) = \frac{TP}{TP+FN} \quad precision = \frac{TP}{TP+FP}$$

$$F1 = 2 \times \left( \frac{HR \times prec}{HR + prec} \right)$$

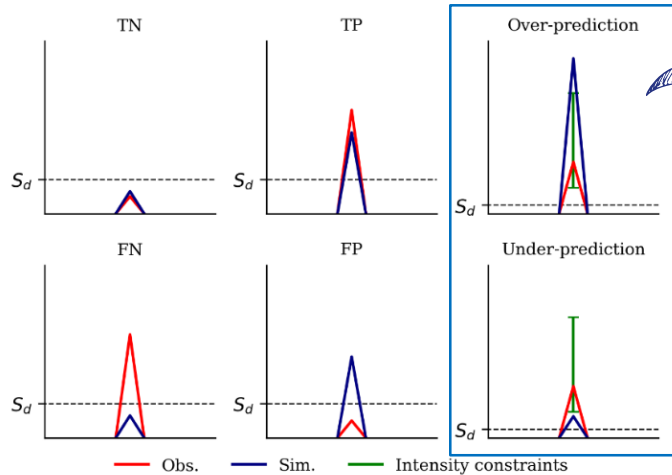


# Results processing

- Results are gathered in the form of 10 min times series of concentration at the different stations and further processed to compute the 1 hour integrated concentration in sliding windows (proportional to the hourly received dose)
- We are interested in evaluating the ability of models to simulate all the observed peaks → because, in emergency context, missing a radiation event could have an impact on the population health and environment

## Contingency table for successes and failures

- TP** : True Positive
- FP** : False Positive
- FN** : False Negative
- TN** : True Negative



Intensity constraints to account for risks of over- or under-estimation of ground consequences

- $TP$  if  $0,5 < \frac{I_{sim}}{I_{obs}} < 10$

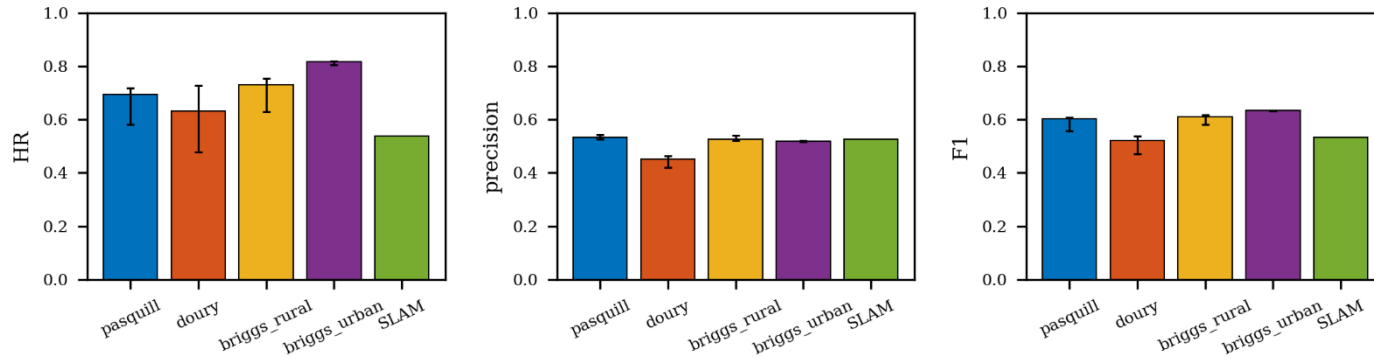
Failures and successes are aggregated by statistical indicators :

$$Hit\ Rate\ (HR) = \frac{TP}{TP+FN} \quad precision = \frac{TP}{TP+FP}$$

$$F1 = 2 \times \left( \frac{HR \times prec}{HR + prec} \right)$$

## Unconstrained statistical performances

### [ ABILITY (MEDIAN) OF THE MODELS TO DETECT PEAKS



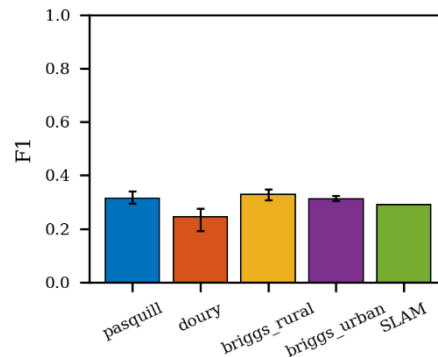
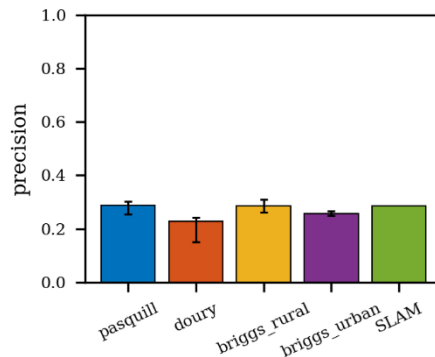
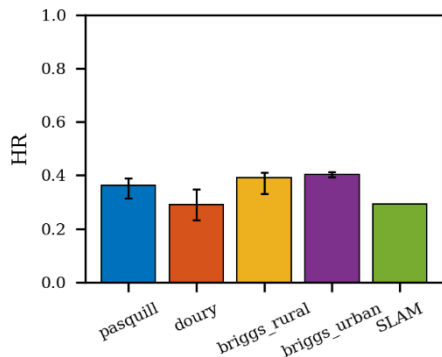
| Model             | HR Best estimate (%) | Associated source height (m) |
|-------------------|----------------------|------------------------------|
| pX + Pasquill     | 76                   | 0                            |
| pX + Briggs Rural | 82                   | 0                            |
| pX + Briggs Urban | <b>88</b>            | 0                            |
| pX + Doury        | 74                   | 0                            |
| SLAM              | 58                   | --                           |

- pX best estimates detect 74% up to 88% of peaks, against 58% of peaks for SLAM
- High variability of pX performances depending on its parameterization
- pX best estimates systematically obtained with a source at ground

$$TP \text{ if } 0,5 < \frac{I_{sim}}{I_{obs}} < 10$$

## Constrained statistical performances

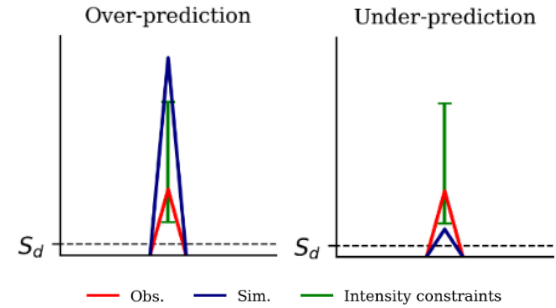
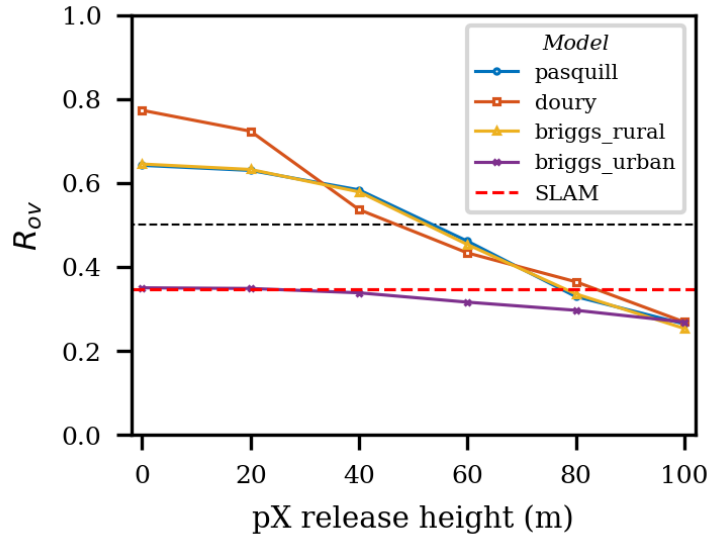
### [ ABILITY OF MODELS TO PREDICT ADEQUATE PEAK INTENSITIES



| Model             | HR Best estimate (%) | Associated source height (m) |
|-------------------|----------------------|------------------------------|
| pX + Pasquill     | 39                   | 60                           |
| pX + Briggs Rural | <b>41</b>            | 60                           |
| pX + Briggs Urban | <b>41</b>            | --                           |
| pX + Doury        | 35                   | 40                           |
| SLAM              | 29                   | --                           |

- A significant proportion of initially well simulated peaks do not respect intensity tolerances!
- pX best estimates are obtained with a source at approximately half the real stack height.

# Impact of the source height parameter



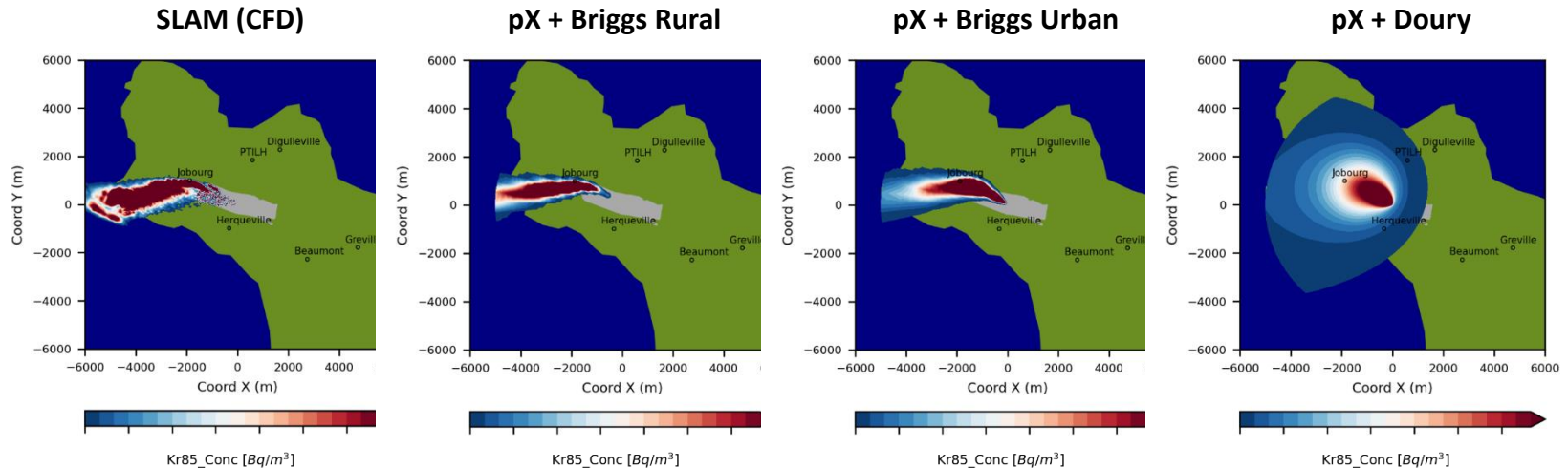
$$R_{ov} = \frac{n_{opv}}{n_{opv} + n_{upv}}$$



Interest of the source height parameter to mitigate the risk of under- or over-estimation of ground concentrations

# Comparison of ground consequences maps

[ STABLE CONDITIONS ON THE 15 JAN 2021 AT 17H00



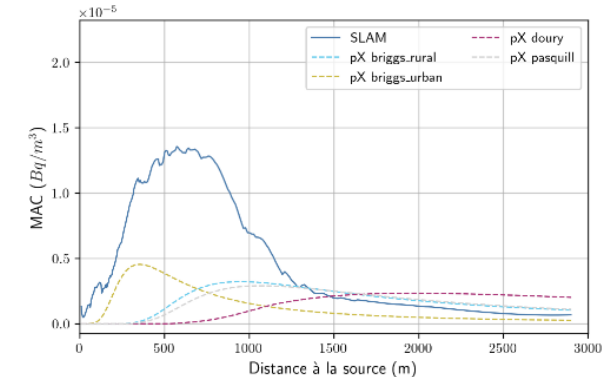
- « Staggering » of the concentration map with SLAM on site, due to interactions between the emitted plume and buildings on site that are not captured with by the Gaussian model
- In stable conditions, despite a comparable Hit Rate to other laws, the law of Doury will lead to numerous False Positive

# Conclusions

- Simplified approaches such as pX can lead to great statistical performances for the distances under consideration ...
- ... but need an adapted parameterization
  - Best performances are obtained with the laws of Briggs Rural and Pasquill, while the law of Doury leads to the worst results (especially in stable conditions)
  - A source at half the real stack height mitigate the risk of over or under-estimation of ground concentration levels
  - A source at ground maximize the probability to detect peaks and is still a reasonable choice in emergency situations
- While SLAM doesn't seem to add a real added value at those distances, it presents interest in the close vicinity of discharge sources, where the wind flow will be strongly impacted by the presence of buildings

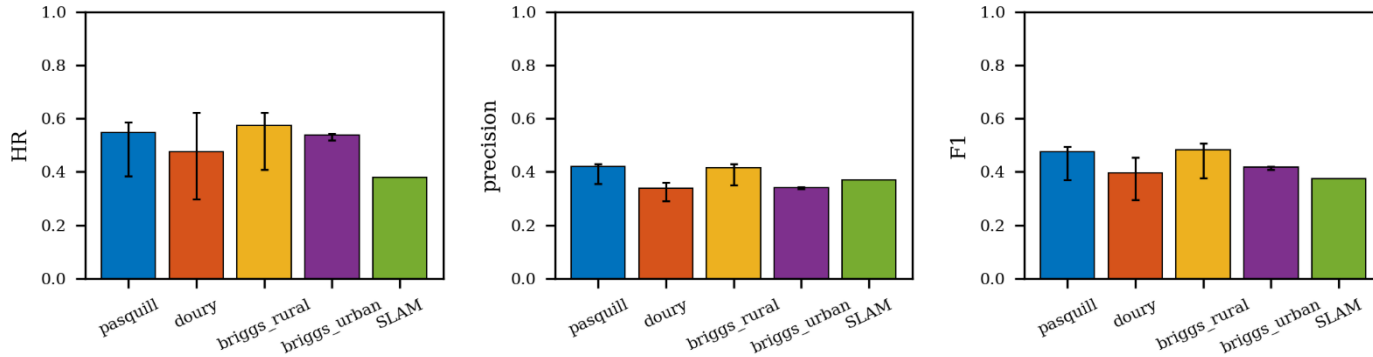
## ... and perspectives

- Consolidate the comparison Gaussian – SLAM in the very near field (topic of a future field campaign from IRSN and Orano) ... to infer knowledge on the transition distance at which the Gaussian approx. becomes acceptable



Comparison of Maximum Arcwise Concentrations for a unitary release in neutral conditions

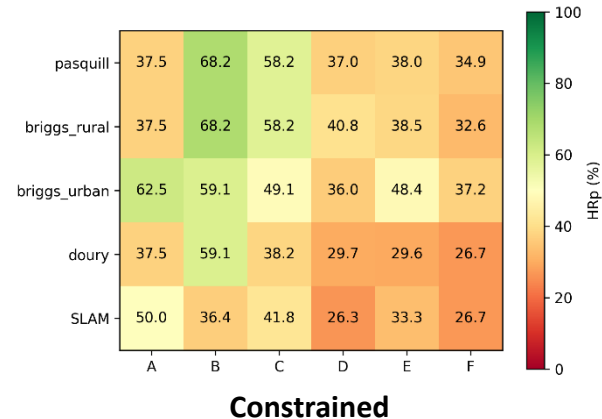
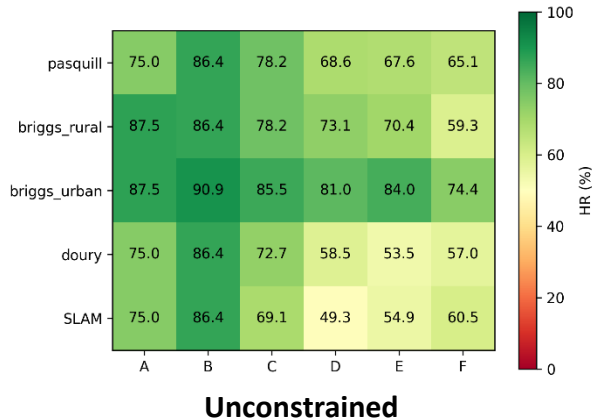
## Partially constrained statistical performances



| Model             | HR Best estimate (%) | Associated source height (m) |
|-------------------|----------------------|------------------------------|
| pX + Pasquill     | 59                   | 0                            |
| pX + Briggs Rural | <b>62</b>            | 0                            |
| pX + Briggs Urban | 54                   | 0-20                         |
| pX + Doury        | 62                   | 0                            |
| SLAM              | 38                   | --                           |

# Impact of meteorological conditions on model performances

## [ PERFORMANCE OF MODELS AS A FUNCTION OF ATM. STABILITY

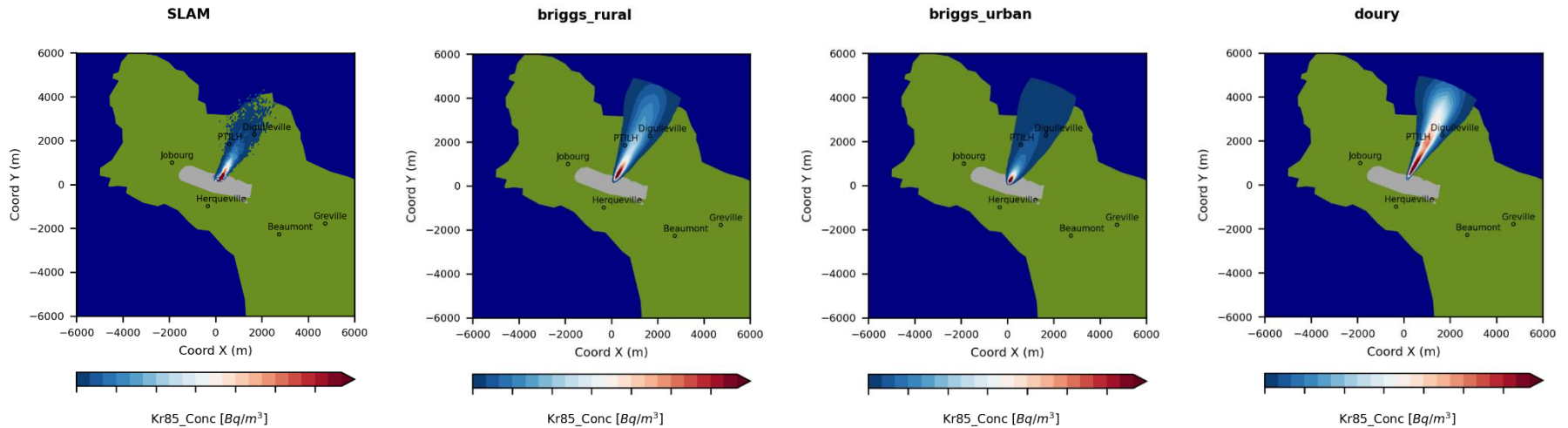


Tendency to decrease performances for stable atmospheric conditions for all models!



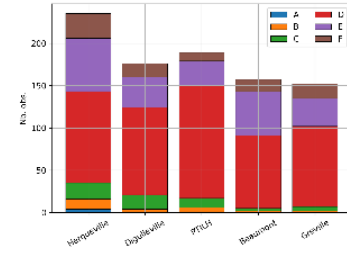
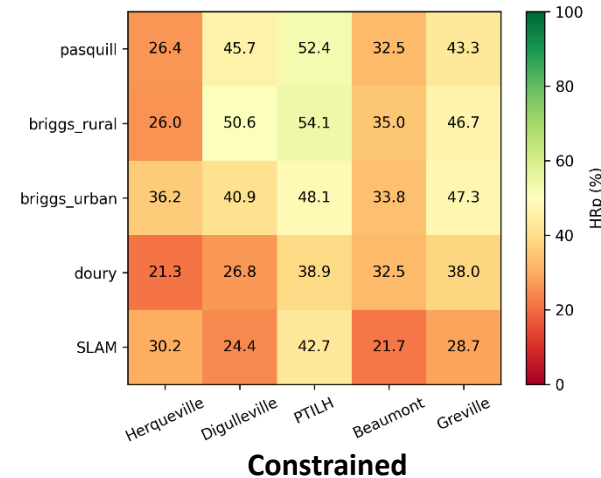
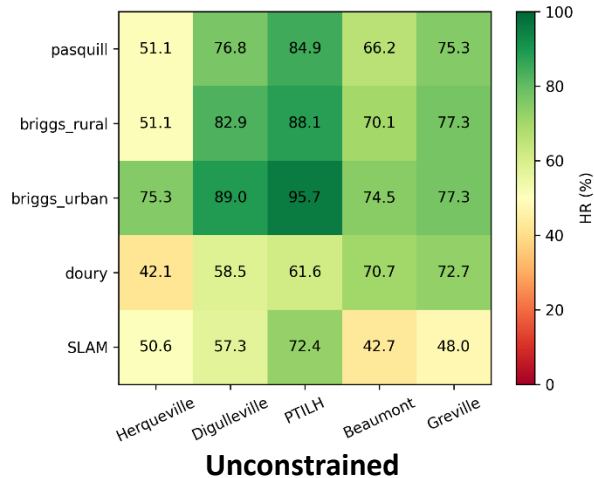
# Comparison of ground consequences maps

## [ NEUTRAL CONDITIONS ON THE 10 DEC 2020 AT 12H40



- « Scattering » of the concentration map with SLAM at a few km partly due to the decrease in particles density
  - Possibility to improve but with consequences on computation time!

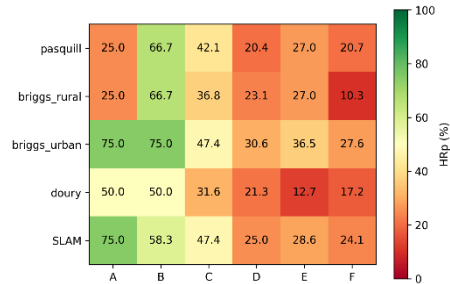
# Statistics per station



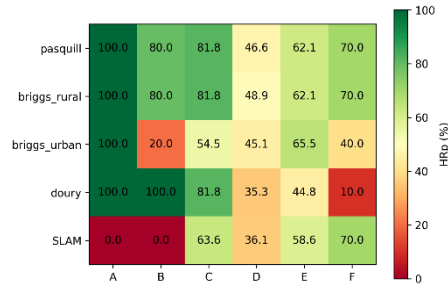
The worst performances are found at Herqueville and Beaumont, where the ratio of stable conditions is the highest

# Impact of meteo

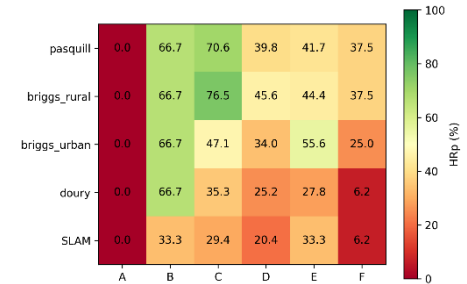
## [ PERFORMANCE OF MODELS AS A FUNCTION OF ATM. STABILITY



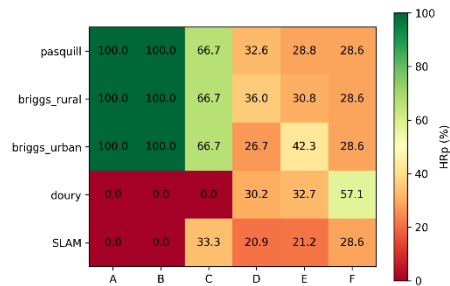
Herqueville



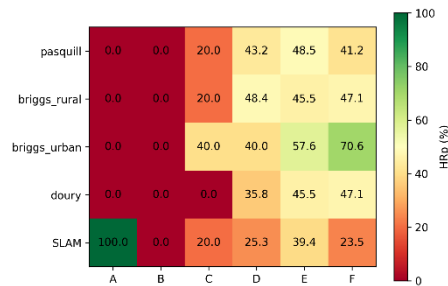
PTILH



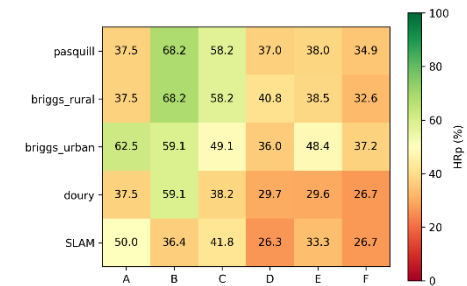
Digulleville



Beaumont



Gréville



Global