ASNR Autorité de sûreté nucléaire et de radioprotection

NERIS

SEPT. 2025

Numerical assessment of Gaussian models for atmospheric dispersion near urban environments in emergency situations

Erwan Rondeaux, Songzhi Yang, Irène Korsakissok, Olivier Connan, Philippe Laguionie, Fabien Duval

Potential emergency situations in peri-urban environments

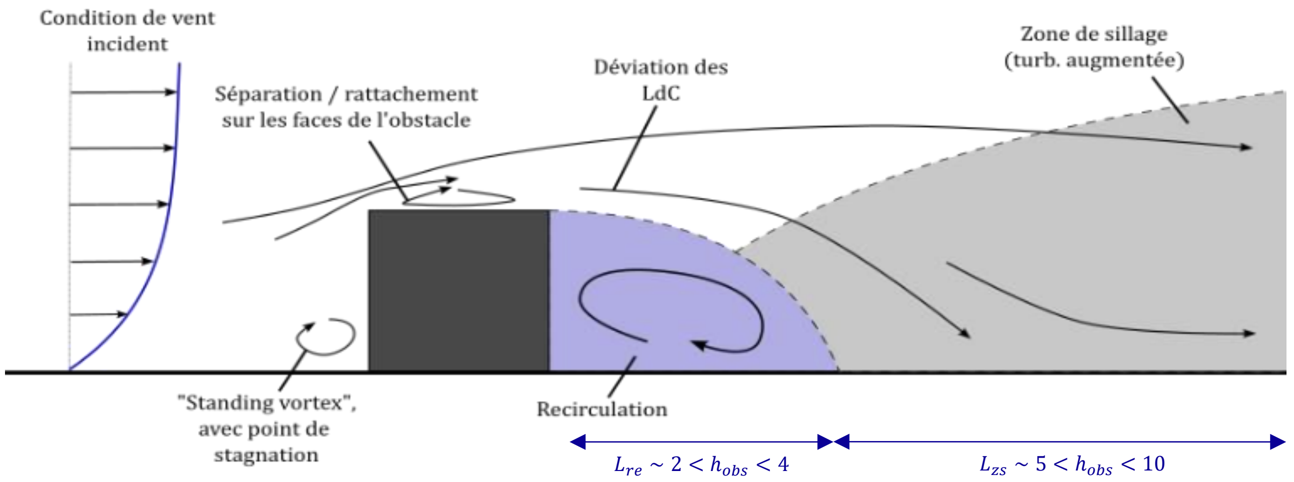
Location of the cyclotron in Beuvry, France. From Laguionie et al. (2022)

- When it comes to radioactive risks in urban-like or peri-urban environments, various potential scenarios come to mind:
  - Hazardous releases due to malicious events;
  - Emissions from industries such as cyclotrons;
  - Release due to the implantation of NNRs/SMRs;
  - Accidents linked to the transport of radioactive materials;
  - …

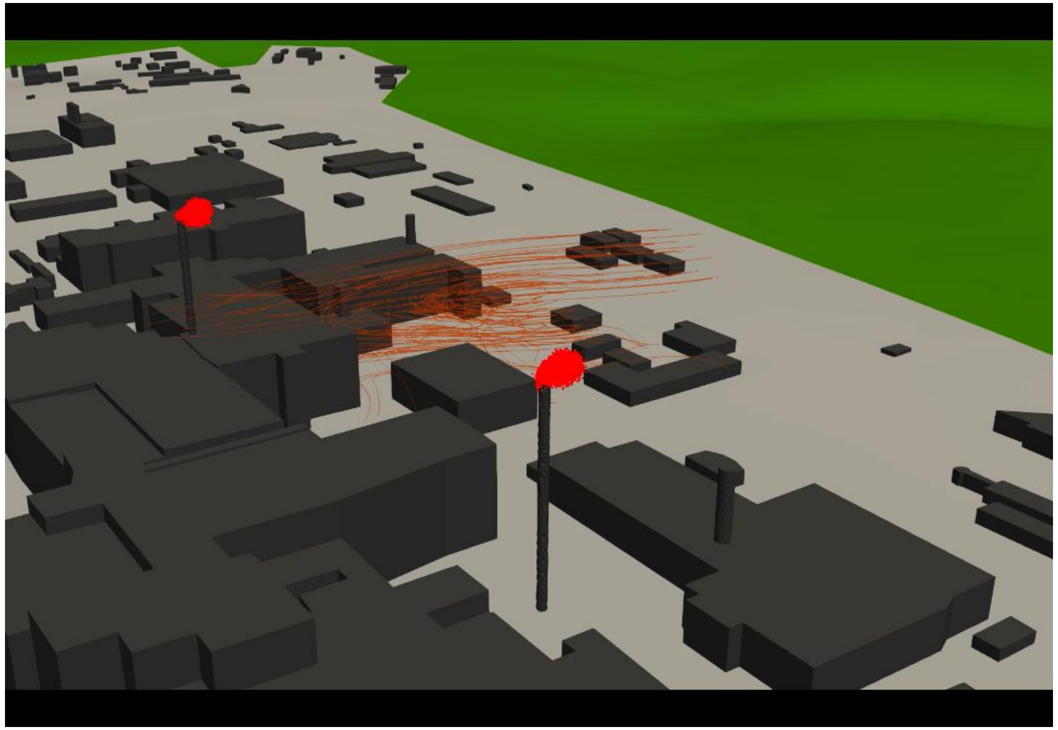
Exemple of fire in an industrial complex in Florida (2023), from Matveev et al (2024)

Radioactive package loaded on a truck, Le transport de matières radioactives (2021)

DISPERSION IN BUILT AREAS



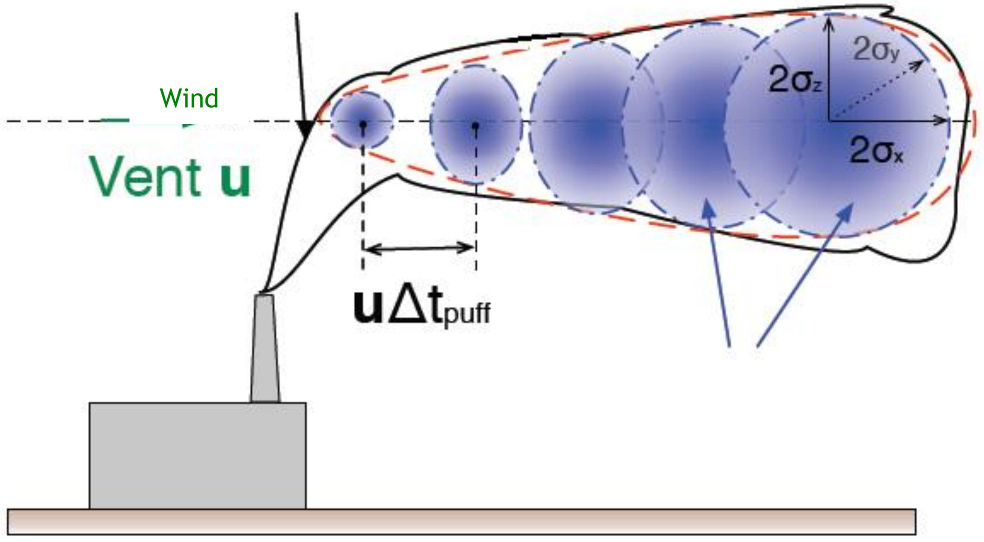
- **Effects on flow and dispersion:**
  - Turbulent structures and recirculation regions
  - Lower wind speed and higher turbulence
  - Increase of turbulence in the wake, and by extension higher dispersion of the plume
  - Dependency to buildings density and disposition, emissions caracteristics



Dispersion from two 100m high stacks, Orano La Hague

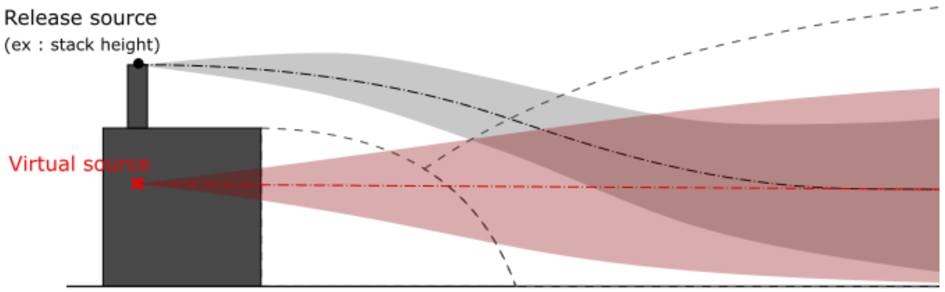
EMERGENCY SHORT TO MEDIUM RANGE ATM. DISPERSION MODEL PX

pX is a **Gaussian puff model**, adapted to modeling the emission of radioactive pollutants



- Activity distribution in a puff is considered gaussian and parametrized by « standard deviation laws » depending on the atmospheric stability and distance/time since emission
- **The impact of obstacles on the dispersion is not explicitly accounted for**

- **Compensation strategies for unresolved physics:**
  - Dilution models
  - Virtual source approaches
  - Splitting/multi-sources



  - Introduce new parameters to tune for (source height and standard deviation law)
  - Source of uncertainties and discussion with nuclear power plant operators

INTEREST OF CFD-BASED APPROACHES

Gaussian models

Plume | Puffs

- No explicit modeling of obstacles and buildings
- Compensation strategies (virtual source, dilution, splitting)

Cost/expertise ⟷ **Complexity/precision**

Tables/empirical methods

CFD based methods

Database | LPDMs | Eulerian

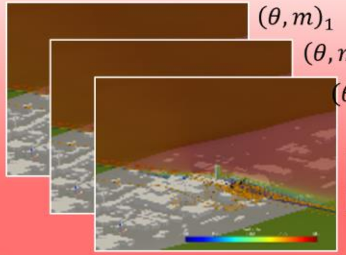
- Decoupling between the resolution of the flow state and dispersion

- Precise resolution of the flow field
- Explicit modeling of obstacles and buildings impact
- Computationaly expensive, high level of expertise required

Safety Lagrangian Atmospheric Model

SLAM, AN OPERATIONNAL CFD-BASED APPROACH

« Offline » database constitution



Database of 3D flow and turbulence fields for various meteorological conditions

Input data

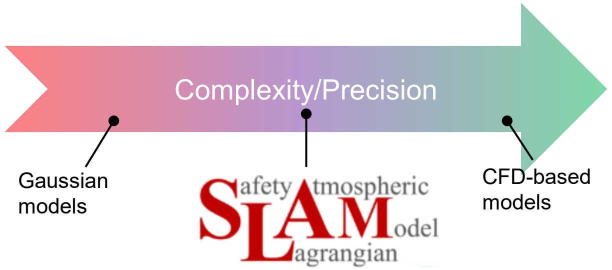
New meteo parameters $(\theta, m)_{new}$

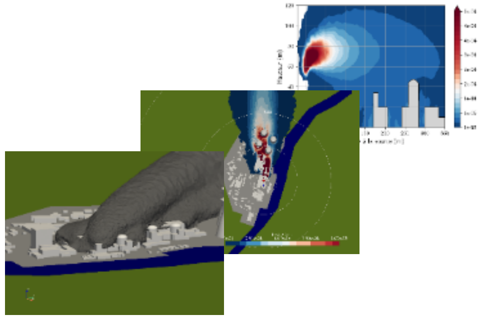
« Online » CFD-based dispersion model

- Selection and interpolation from the database
- Interpolated flow and turbulence 3D field
- Lagrangian dispersion of particules on the interpolation flow field

Results

Pollutant(s) concentration field(s)





ÉCOLE CENTRALE LYON

LMFA

Validation case

CNPE
Bugey – wind tunnel

Litterature field campaigns
Prairie Grass, Kincaid, Indianapolis…

IRSN field campaign
AREVA La Hague

ASNR field campaigns He
DISPAC / DIVA / DAIMO…

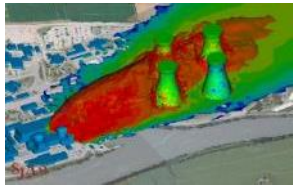
Fukushima γ λ

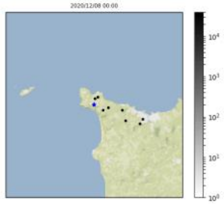
ERS Écarpière (Rn)

DIFLU (He)

DISKRYNOC (^{85}Kr)

GIROSCOPE WP3





Near-field (< 1km) → Local scale (1-10 km) → Intermediate scale (10-100 km)

SLAM
PANACHE, CALIF3S, CODE_SATURNE

pX

VALIDATION CASE 1 : DIFLU

DIspersion du **FL**uor 18 en milieu **U**rbain

- Fluorine 18 is widely used in the hospital applications. There exists potential releases to the atmosphere during the production in the cyclotrons. The radioactive fluorine 18 may affect the habitants living near the **cyclotron** (<500m). To characterize its dispersion in the urban environment, IRSN has initiated the DIFLU (Dispersion du Fluor 18 en Milieu Urbain) project in 2019.
- **Measurments :** Helium is used as the tracer, 2 campaigns were launched in October (15/10-17/10) and December (10/12-12/12), 2019.

Objectives :

- Direct comparison pX – SLAM (– CALIF3S)
- Evaluate SLAM sensitivity to meteorological conditions


atmosphere MDPI

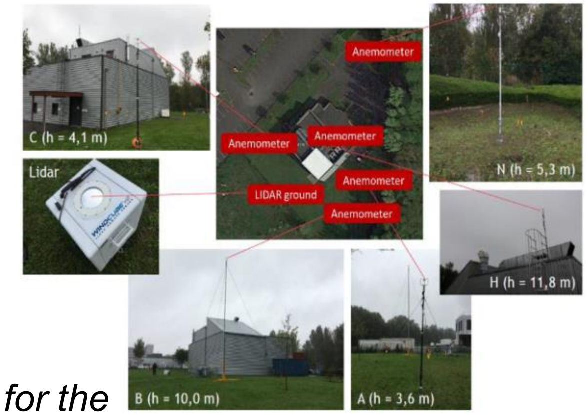
Article

Investigation of a Gaussian Plume in the Vicinity of an Urban Cyclotron Using Helium as a Tracer Gas

Philippe Laguionie [1,*], Olivier Connan [1], Thinh Lai Tien [2], Sophie Vecchiola [3], Johann Chardeur [1], Olivier Cazimajou [1], Luc Solier [1], Perrine Charvolin-Volta [4], Liying Chen [5], Irène Korsakissok [6], Malo Le Guellec [5], Lionel Soulhac [4], Amita Tripathi [5] and Denis Maro [1]

Site de Beuvry, France

Dispersion of smoke



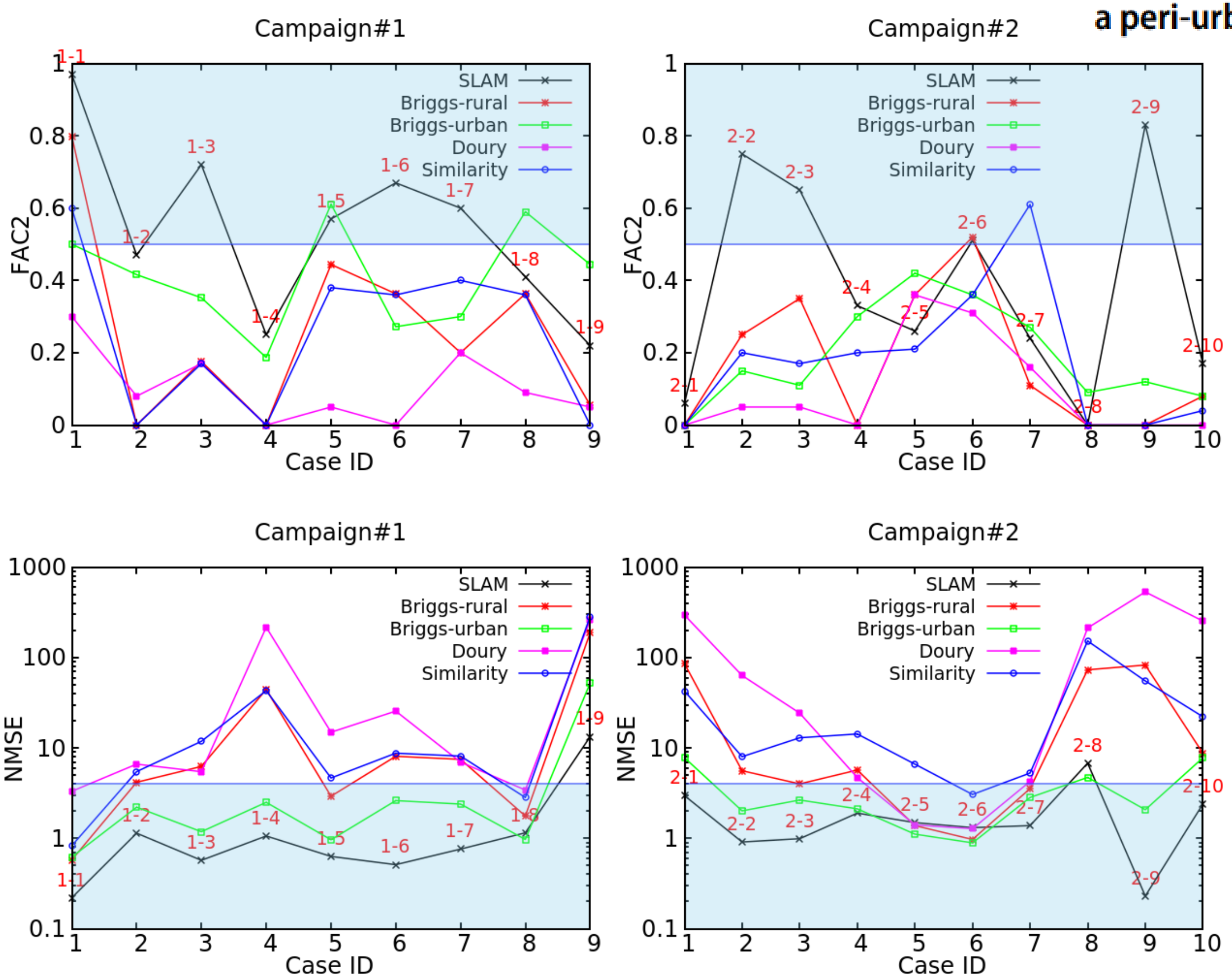
Different test points for the meteorological conditions

Air Quality, Atmosphere & Health
https://doi.org/10.1007/s11869-025-01799-0

RESULTS

Near-field atmospheric dispersion simulation and global sensitivity analysis: comparisons to a full-scale atmospheric tracer experiment in a peri-urban area

Songzhi Yang[1] · Irène Korsakissok[1] · Erwan Rondeaux[1] · Perrine Charvolin-Volta[2]



Acceptable models (FAC2>0.5):

- SLAM (46% cases)
- Briggs-urban (16% cases)

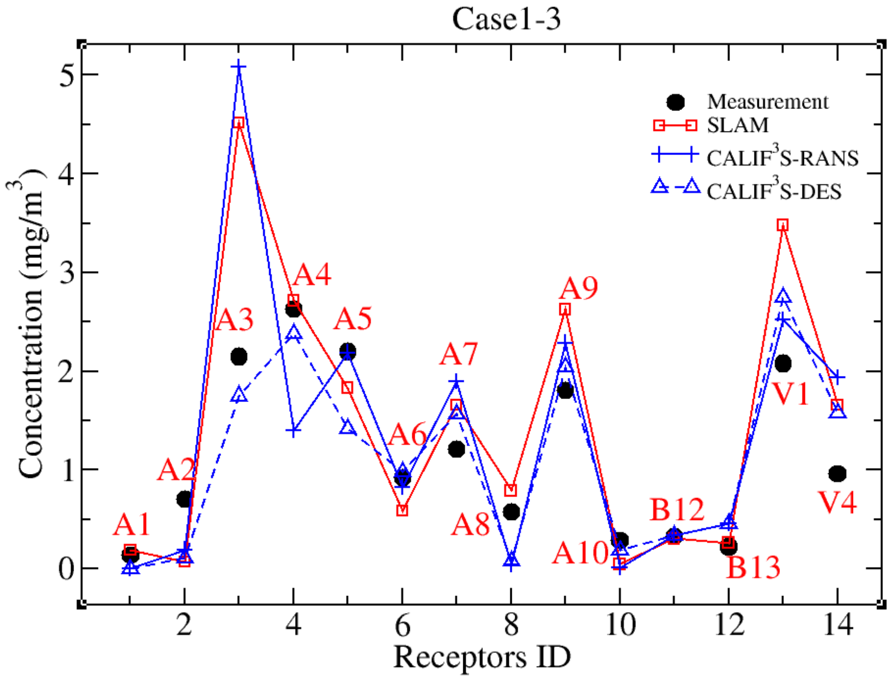
Statistical evaluation of model performances (pX vs SLAM):

- SLAM outperforms pX in general, even though BU gives reasonable results for campaign 1
- Lower performance for campaign #2, which could be due to the state/modeling of the vegetation (porous medium) + sensor closer to the buildings + meteorological conditions

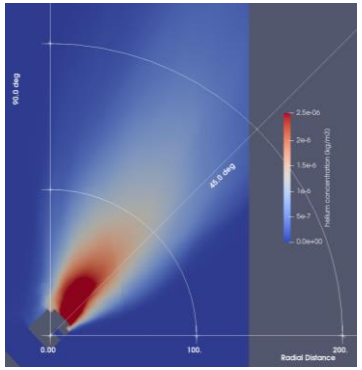
Songzhi Yang, Fabien Duval, and irene Korsakissok

RESULTS

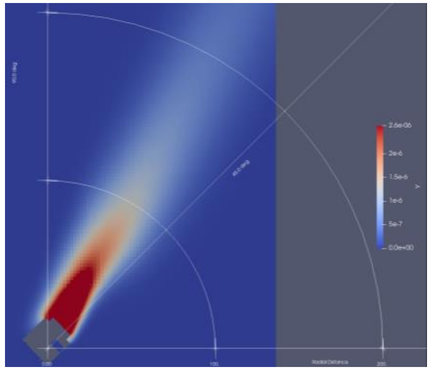
- **Validation of SLAM against direct CFD**
  - RANS and DES with CALIF3S (cases 1-3, 2-4)
  - DES produces a higher averaged dispersion of the plume in the wake of the building
  - While DES gave the best statistical as well as visual results, SLAM gave at least comparable results to direct RANS computations = validation of the database approach



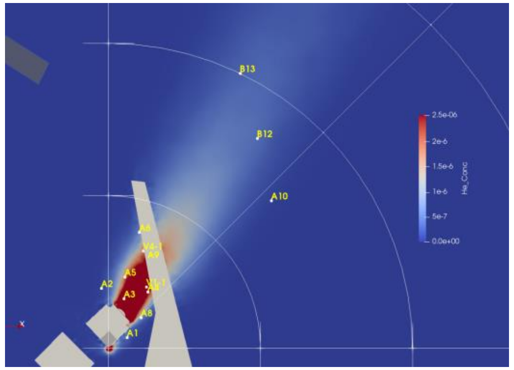
Case 1-3 – neutral conditions



DES



RANS



SLAM

Ground concentration fields

VALIDATION CASE 2 : DISKRYNOC

Combining short-range dispersion simulations with fine-scale meteorological ensembles: probabilistic indicators and evaluation during a ^{85}Kr field campaign

Atmospheric Chemistry and Physics

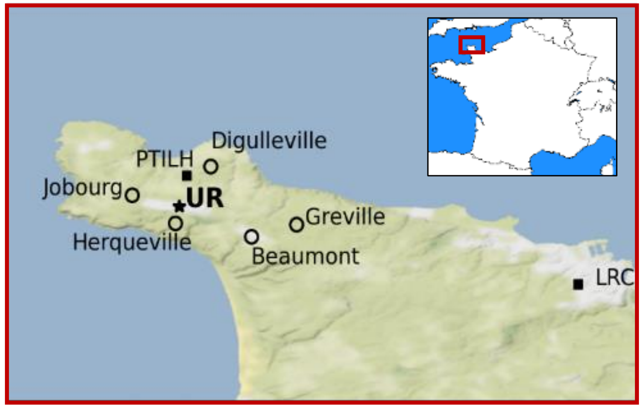
Youness El-Ouartassy[1,2], Irène Korsakissok[2], Matthieu Plu[1], Olivier Connan[3], Laurent Descamps[1], and Laure Raynaud[1]

DISpersion du **KRY**pton 85 dans le **NO**rd-**C**otentin

- The Orano La Hague plant is the largest European reprocessing facilities of used nuclear fuel, that intermittently emits ^{85}Kr from two 100m-high stacks.
- As a noble gas, ^{85}Kr is a good tracer of dispersion (neglectable deposition), and the DISKRYNOC project aimed at creating a database for the validation of dispersion models over long periods of time.

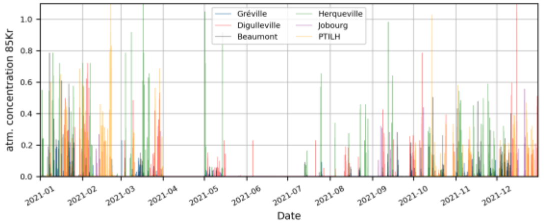
Measurment stations

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



RP location, North-Cotentin, France

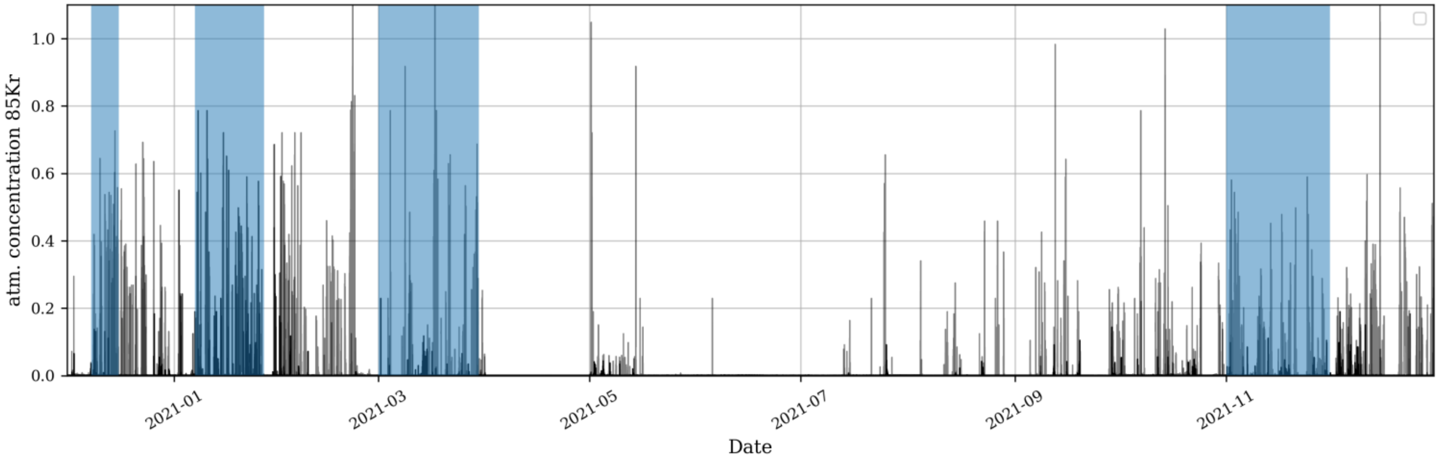
- **Full-available data** (as Δt=10min. time series)**:**
  - ^{85}Kr release rate at stacks UP2 and UP3
  - Complete meteorological measurments at the PTILH station
  - Continuous measurements of ^{85}Kr air concentration (Nov. 2020 to Dec 2022) in ranges (800−5.2km)



North view of the Orano La Hague RP

STUDY SETUP

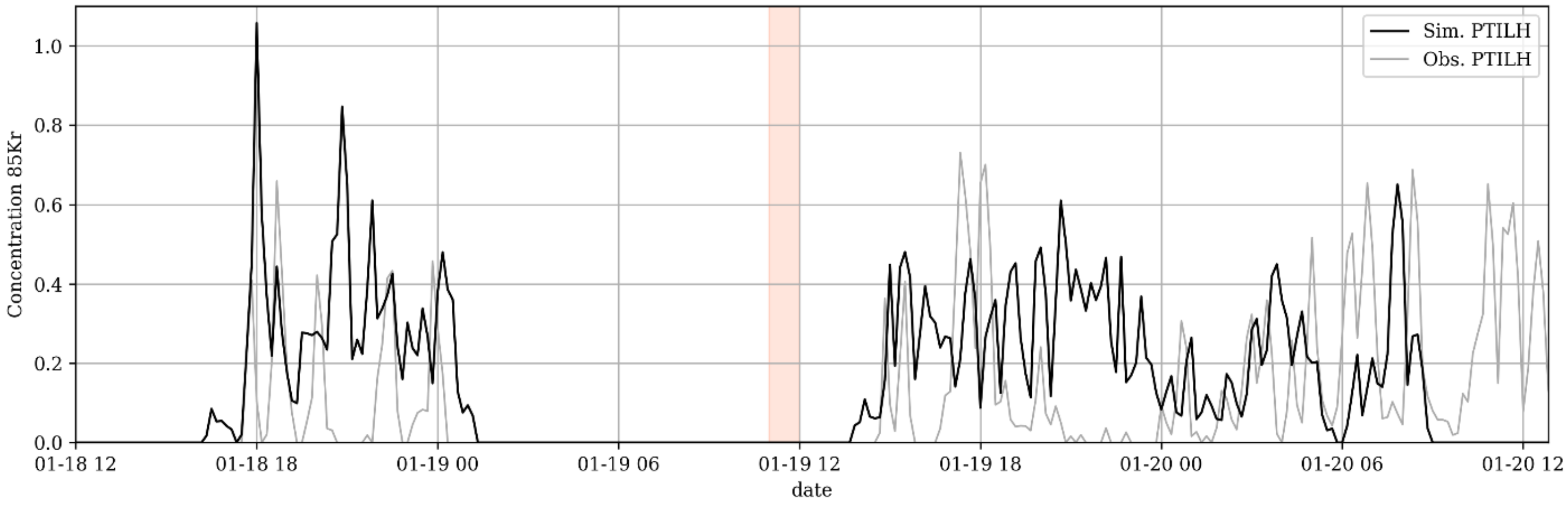
- **Selection of time intervals**
  - 4 sub-periods where there are both significant releases as well as a significant density of concentration measurements
    - 8-15 Dec 2020, 7-26 Jan 2021, 1-29 March 2021, 1-30 Nov 2021
    - Total of about 3 months simulated!



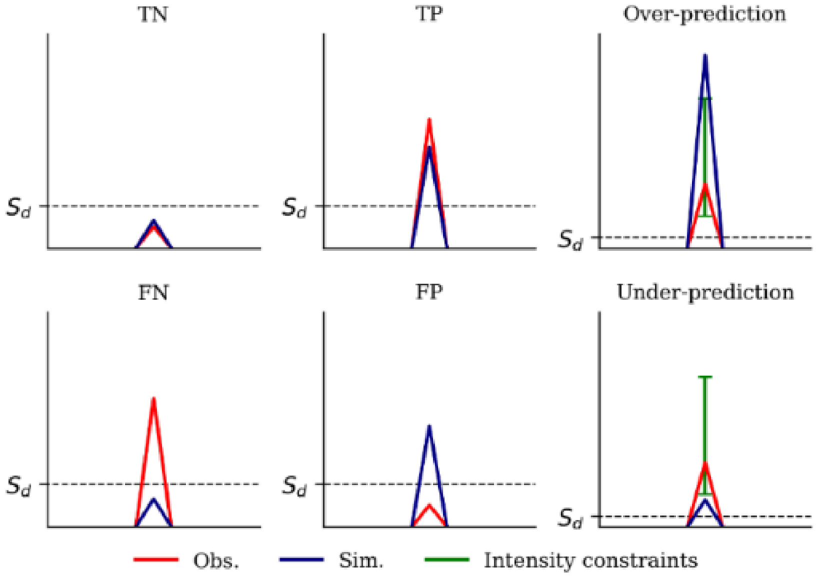
Simulations setup

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

RESULTS PROCESSING



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



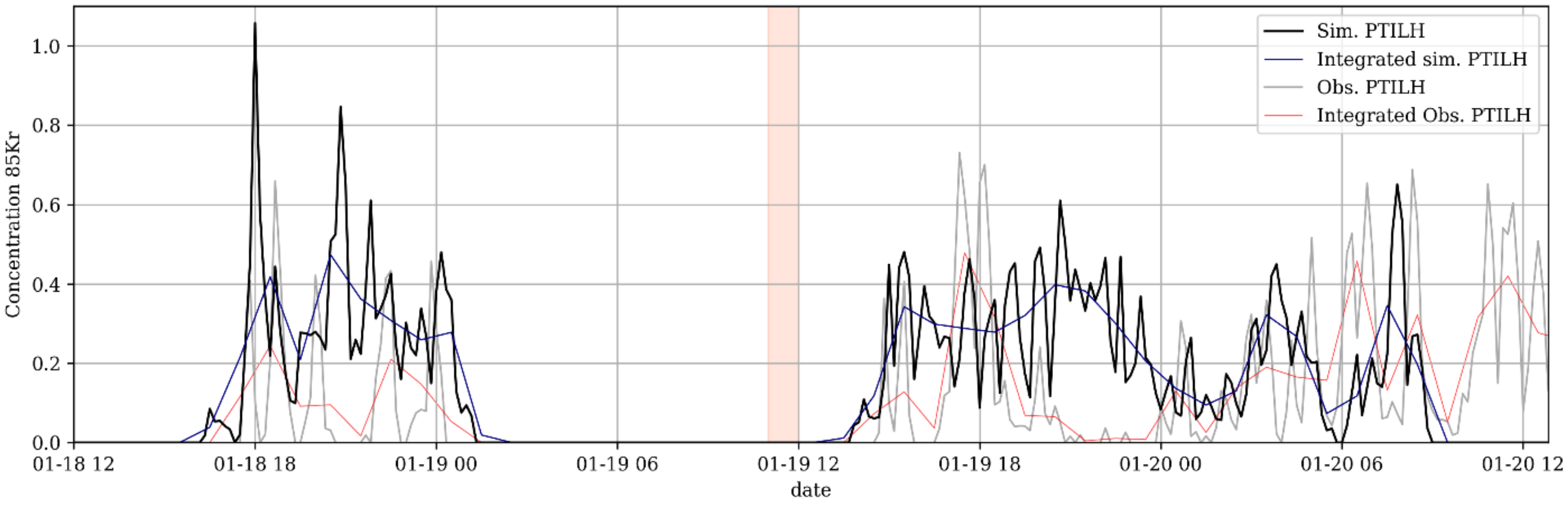
- Constraints on peak detection to account for constraints met during emergency situations
  - Time : hourly average
  - Intensity : risks of over- or under-estimation of ground consequences:

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

- Failures and successes are aggregated by statistical indicators :

$$HR = \frac{TP}{TP+FN} \qquad precision = \frac{TP}{TP+FP} \qquad F1 = 2 \times \left(\frac{HR \times prec}{HR+prec}\right)$$

RESULTS PROCESSING



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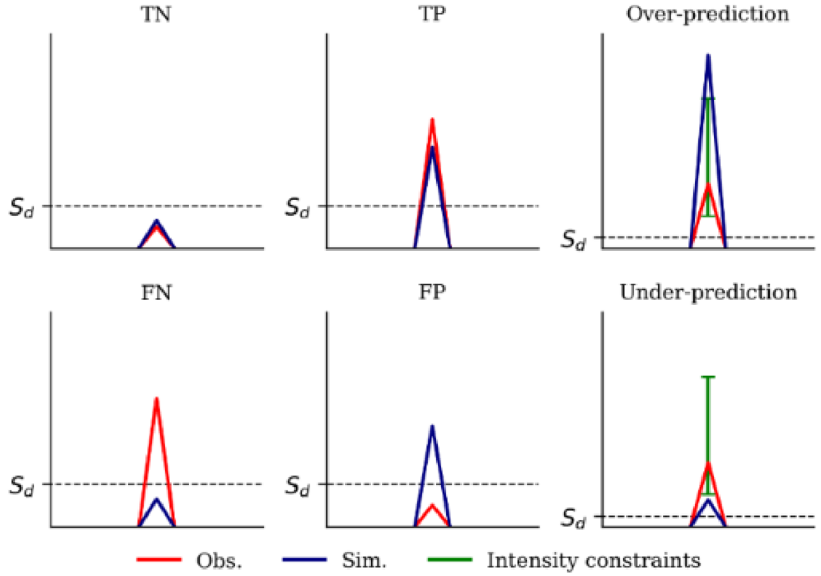

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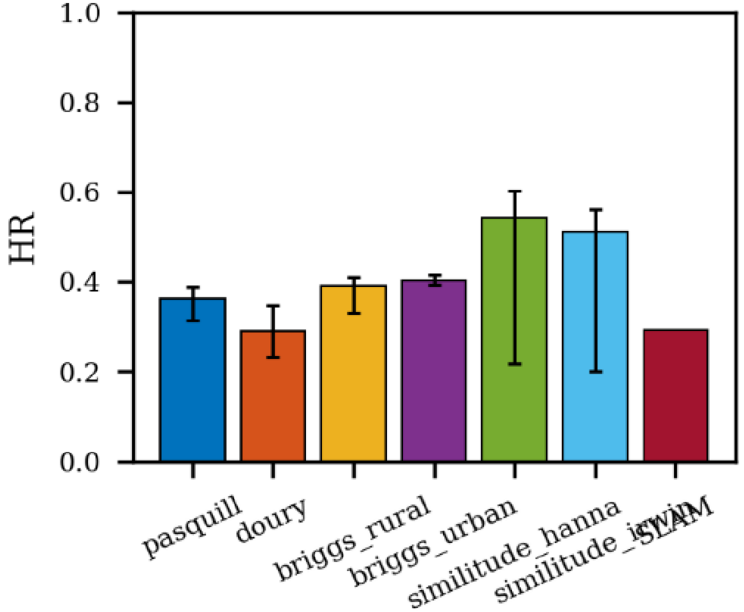
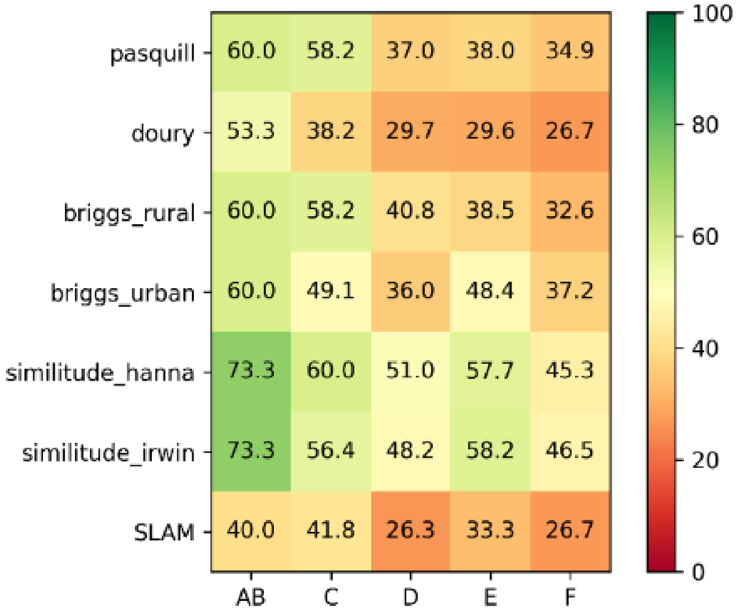
RESULTS

Erwan Rondeaux[1,2], Irène Korsakissok[2], Olivier Connan[3] and Guillevic lamaison[4]

HARMO22



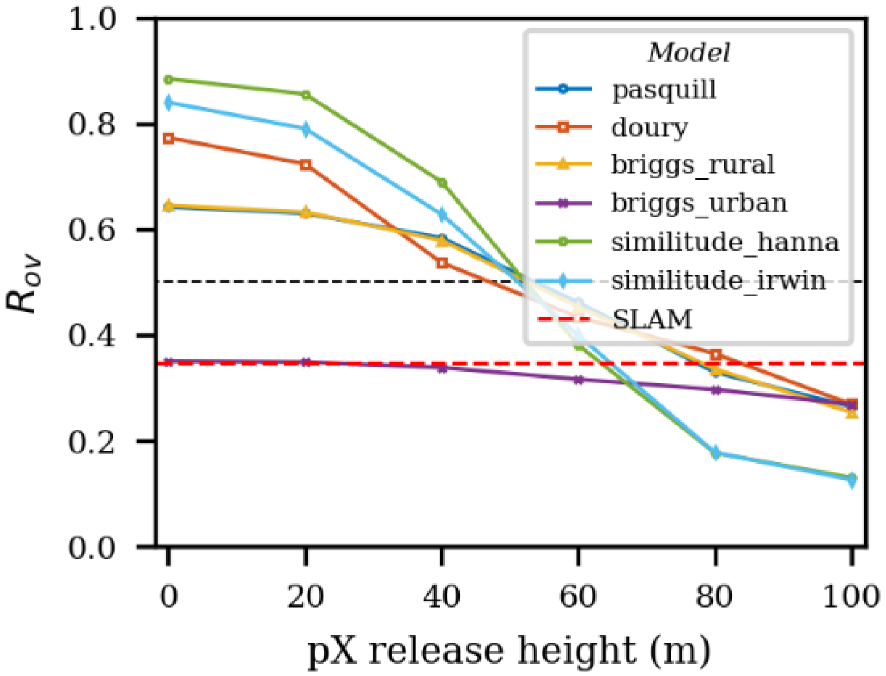
Median statistical perf. unconstrained (left) vs constrained (right). Error bars show the impact of the source height (pX).

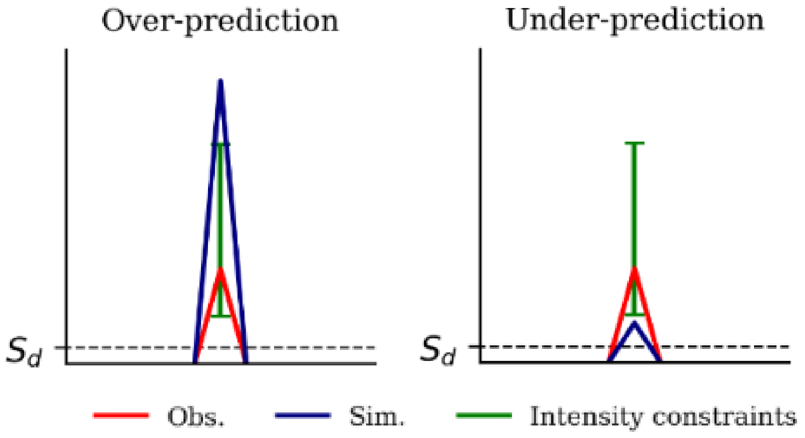


Constrained statistical perf. vs atm. stability. pX simulations with $h_{rel} = 60m$.

- pX tend to outperform SLAM at intermediate distances …
- … BUT shows a high dependency to its parametrization (both h_{rel} and the standard deviation law)
- Both models show decreased performances instable conditions

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 consequences

CONCLUSIONS & PERSPECTIVES

- **On the assessment of gaussian models and CFD-based approaches for near-field and intermediate distances atmospheric dispersion:**
  - Interest of CFD-based approach in the close vicinity of discharge sources, but no real added value at intermediate distances
  - Simplified approaches such as pX can lead to great statistical performances for intermediate distances … but are highly sensible to their parametrization
  - Typical transition distance unclear ?
  - Both models show decreased performances in stable conditions

- **On the sensibility of gaussian models to its parametrization and atm. Stability**
  - Standard deviation laws based on a continuous representation of atmospheric stability give better performances … but require meteorological inputs generally not available during emergency situations
  - The source height is a valid parameter to mitigate the risk of under- or over-estimationg ground consequences, ++ a source at ground is a penalizing choice to limit the risk of under-estimation at all cost

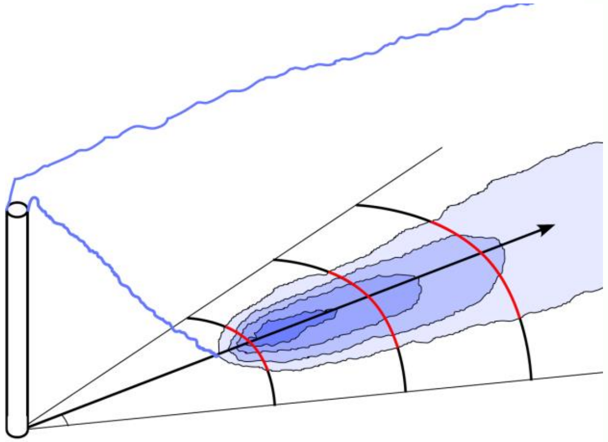
- **Perspectives**
  - Consolidate the comparison Gaussian – SLAM in the very near field in densely built-up areas (ongoing measurment campaign at Orano La Hague + GIROSCOPE)
  - Infer knowledge on the transition distance from which a Gaussian approach becomes acceptable

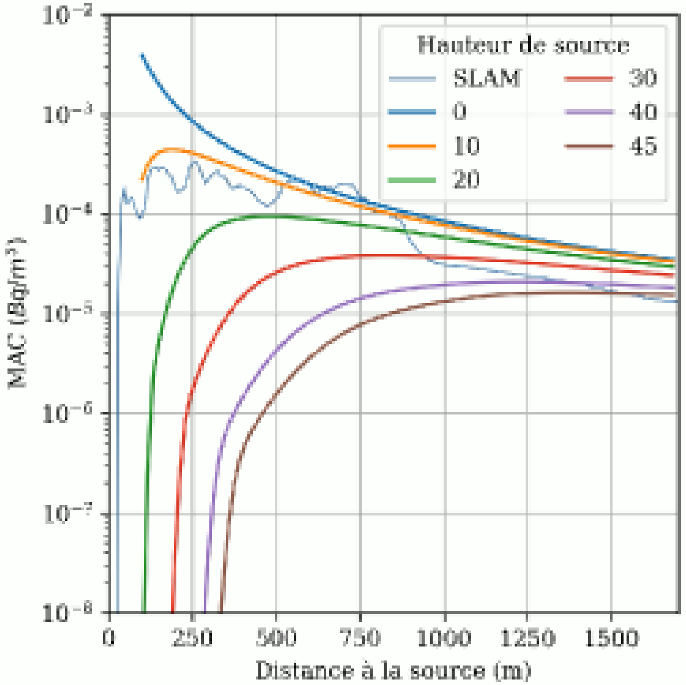
PERSPECTIVES - CFD-BASED MODELS AS REFERENCE FOR THE OPERATIONAL PARAMETRISATION OF PX

- While CFD-based models present interest in the close vicinity of discharge sources, **computational constraints limits their operational use** (generation and maintenance of flow fields database, computational costs, …)

- **CFD models enable systematic comparison for various meteorological conditions and can be used as a reference for multi-parameter sensitivity analyzes and operational parametrization of gaussian models**

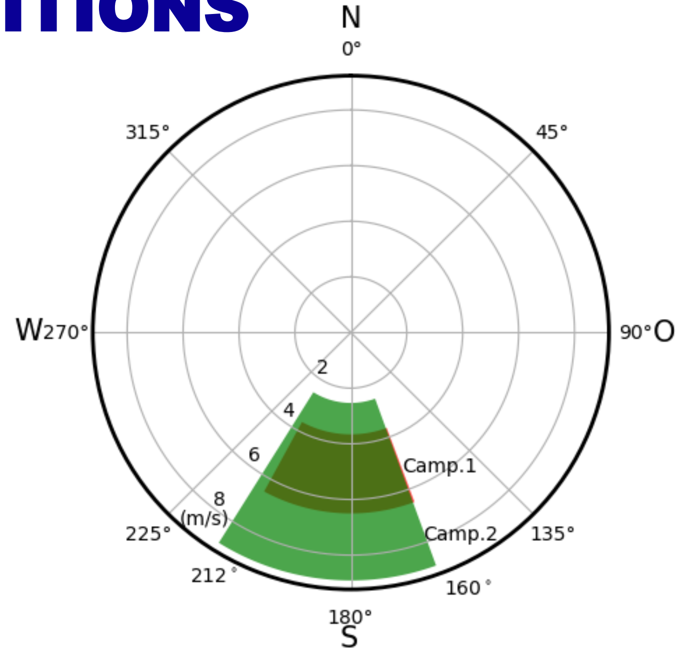
- **Operational constraints for emergency situations:**
  - **Protection of civilian populations**: mission to protect populations outside the site (first homes)
  - **Precautionary principle:** minimize the risk of underestimating the consequences (penalizing predictions) and, secondarily, the risk of overestimating (reasonably penalizing aspect)
  - **Simplicity:** A single parameterization, or a small number with clearly defined application cases





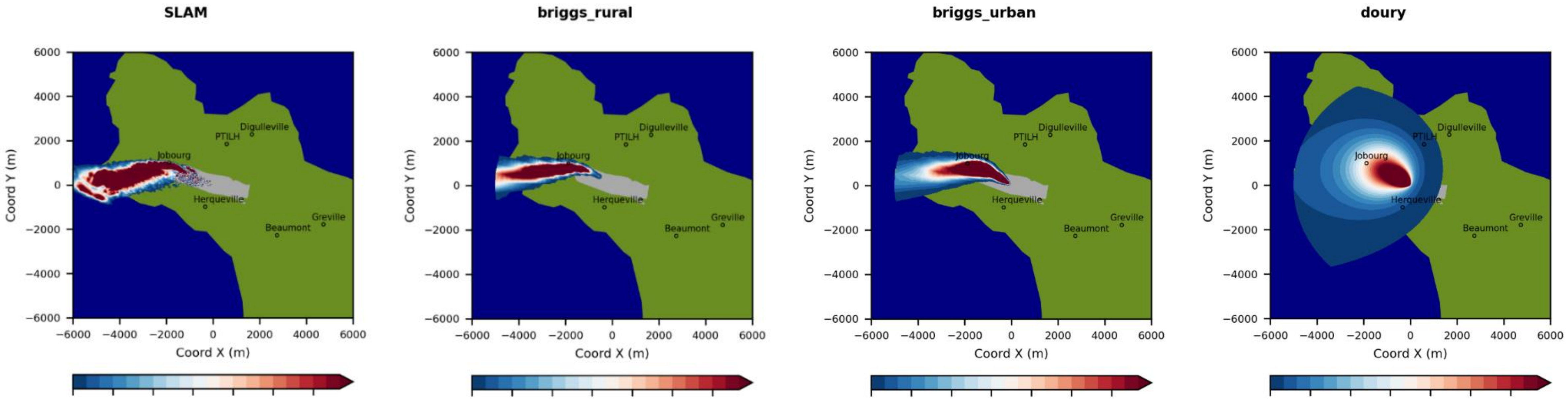
DIFLU : EXPERIMENTS METEROLOGICAL CONDITIONS

Cases #ID	Date (D/M)	Wind speed@40 m (m/s)	Wind direction (°)	Temperature (°C)	Cloud class (octa)	Stability class (Pasquill)	Helium discharge rate (g/s)
1-1	15/10	3.66	184	16	8	C	1.49
1-2	15/10	3.85	198	15.7	7	C	2.35
1-3	15/10	4.82	208	15.3	8	C	2.68
1-4	16/10	5.43	159	12.9	8	D	2.38
1-5	16/10	6.50	191	15.5	8	D	2.38
1-6	16/10	6.18	193	15.6	8	D	5.29
1-7	17/10	3.83	188	11.4	8	C	5.49
1-8	17/10	3.64	189	12.5	8	C	5.36
1-9	17/10	5.06	199	16.7	7	C	2.53
2-1	10/12	6.02	173	5.9	8	D	2.38
2-2	10/12	7.55	172	7	7	D	2.38
2-3	10/12	7.69	174	7.8	7	D	2.38
2-4	11/12	2.53	212	8	8	B	2.38
2-5	11/12	3.26	191	8	8	B	2.38
2-6	11/12	3.54	203	9	7	C	5.06
2-7	11/12	4.07	186	9	7	C	5.06
2-8	12/12	3.77	166	4	8	B	2.38
2-9	12/12	5.46	168	4.7	8	D	2.38
2-10	12/12	8.91	160	6	8	D	2.38



- Wind direction (#1,2): 160°-212°
- Wind speed (#1): 3.64-6.50 m/s
- Wind speed (#2): 2.53-8.91 m/s
- All the meteorological conditions are the mean values in the measured time span (10~15 mins).
- 2-4, 2-5, 2-8 are in unstable atmospheric conditions

GROUND CONCENTRATION MAPS (DISKRYNOC)



- **Exemple of ground concentration maps for a stable condition with low winds on the 15 Jan. 2021 at 17h00**
- « Staggering » of the concentration map with SLAM on site, partly 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 (Herqueville, PTILH)