METHOD TO COMPUTE ANNUAL AVERAGE USING CFD MODELS

JURADO Xavier, REIMINGER Nicolas, VAZQUEZ José,
BLOND Nadège, WEMMERT Cédric.

Xavier Jurado 19 October 2022

TABLE OF MATTER

3D CFD : A FINE MODELISATION FOR LOCAL POLLUTION SOURCE ESTIMATION

Complex equations

$$\frac{\partial \rho}{\partial t} + \nabla.(\rho u) = 0 \qquad \rho\left(\frac{\partial u}{\partial t} + u.\nabla u\right) = -\nabla p + \nabla.\left(2\mu_{eff} D(u)\right) - \nabla\left(\frac{2}{3}\mu_{eff}(\nabla.u)\right) + \rho g$$

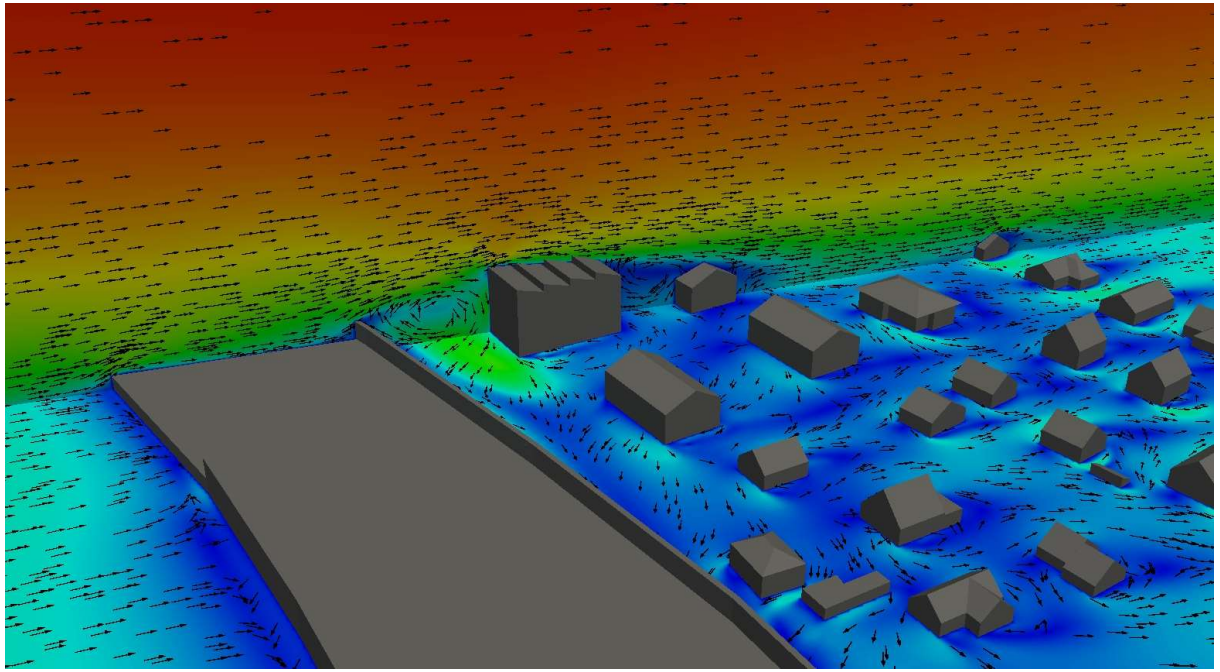
$$\frac{\partial \rho e}{\partial t} + \nabla.(\rho u e) + \frac{\partial \rho K}{\partial t} + \nabla.(\rho u K) + \nabla.(up) = \nabla.\left(\alpha_{eff}\nabla e\right) + \rho g.u$$

... Model able to take into account complex phenomenon :

- Buildings
- Turbulence
- Speed variations
- Recirculation
- Transient effects
- ...

Richards and Hoxey (1993)

Richards and Norris (2011)



How can annual exposure be determined with modelling ?

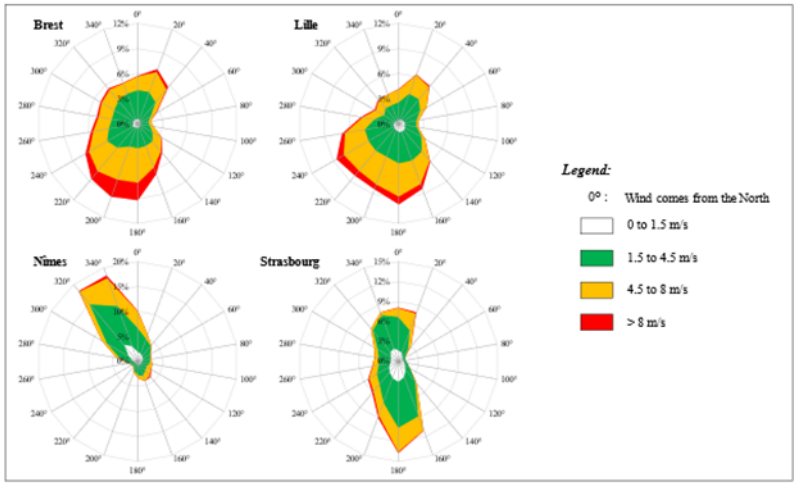
Forward way : Simulate every meteorological conditions hour by hour on the whole year and then averaging the concentration to get the annual exposure.

~~UNREALISTIC~~

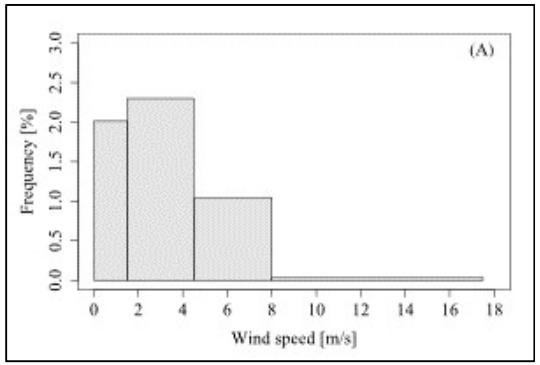
Why ?

An area of interest of a few hectares can require several hours of computation for one wind direction and one wind speed.

Solution : Statical approach based on wind frequencies on intensity and direction



Wind direction frequencies



Wind intensity frequencies of a wind direction

Reiminger et al (2020)

INTERPOLATING WIND INTENSITY FREQUENCIES

Weibull function

$$f(v) = \frac{k}{\lambda}\left(\frac{v}{\lambda}\right)^{k-1} e^{-(v/\lambda)^k}$$

Sigmoid function

$$f(v) = \alpha.\left(-1 + \frac{1}{1+\beta_1.e^{-\gamma_1.v}} + \frac{1}{1+\beta_2.e^{\gamma_2.v}}\right)$$

Conditions :

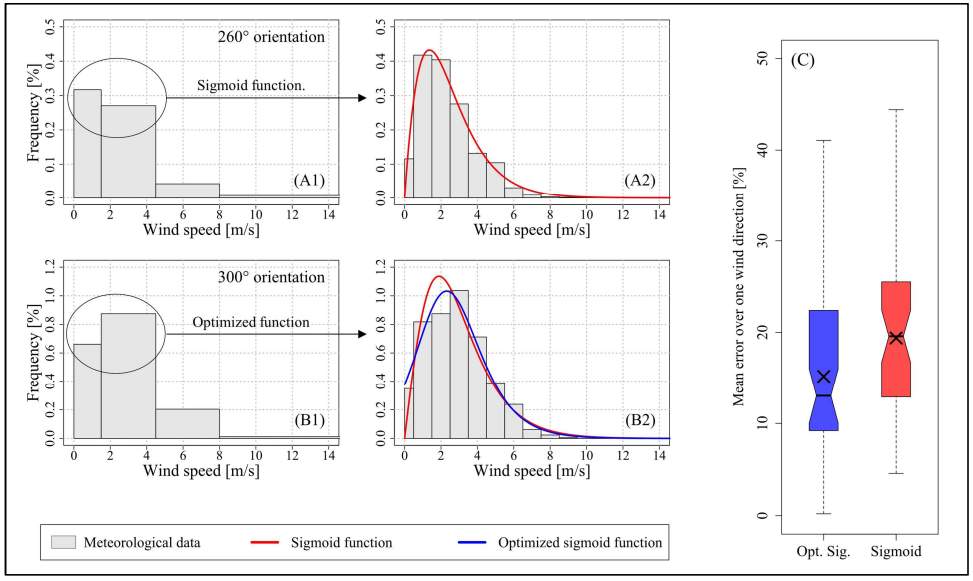
$$\int_a^b f(v)\,.dv = FVR_{[a;b[}$$

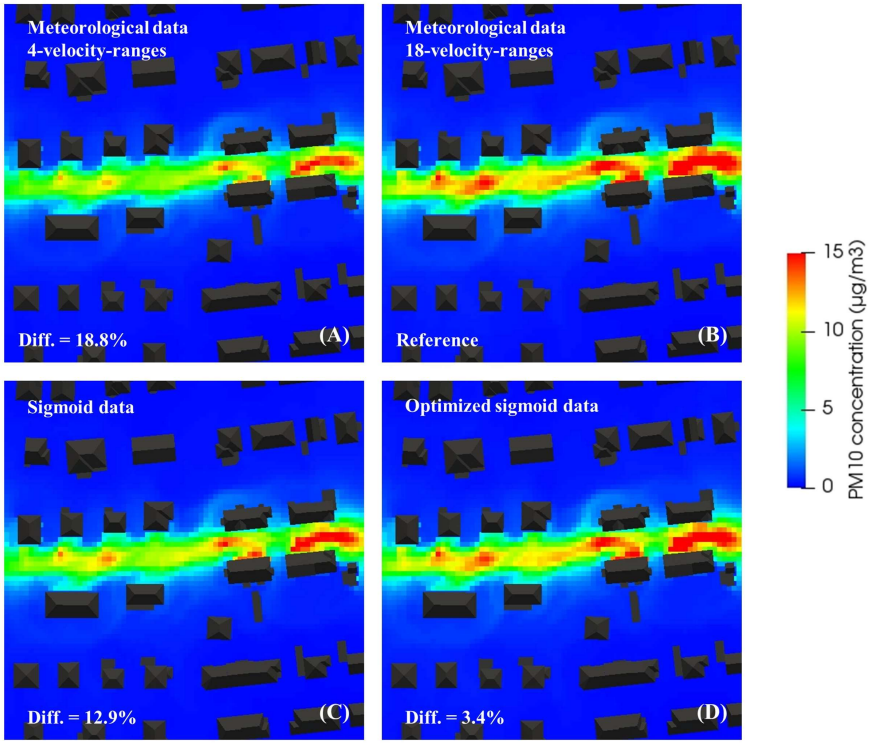
$$f(0) = 0$$

or

$$f(0) = FVR_{[0;\alpha[}\frac{FVR_{[0,\alpha[}}{FVR_{[\alpha,\beta[}}$$

▼ Sigmoid allow a different approach for some type of wind profile



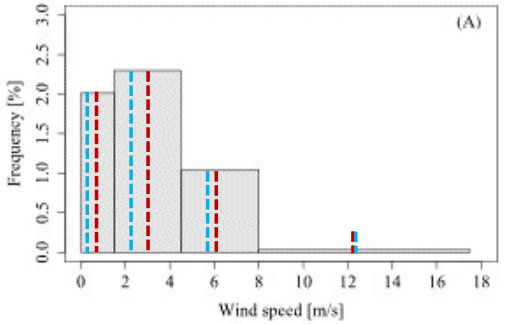


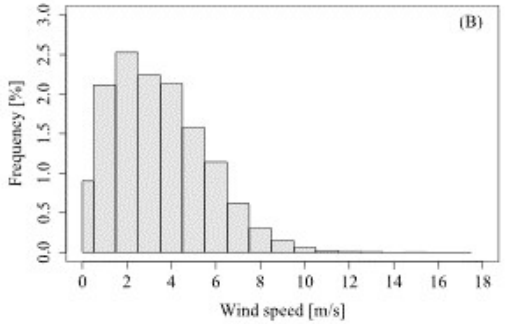
Reiminger et al (2020)

ASSESSING MEAN ANNUAL CONCENTRATION

$$\overline{C} = \frac{\sum_{i=1}^{n} \overline{C}_d . f_d}{\sum_{i=1}^{n} f_d} \qquad C_u = U_{ref} . \frac{C_{ref}}{u}$$

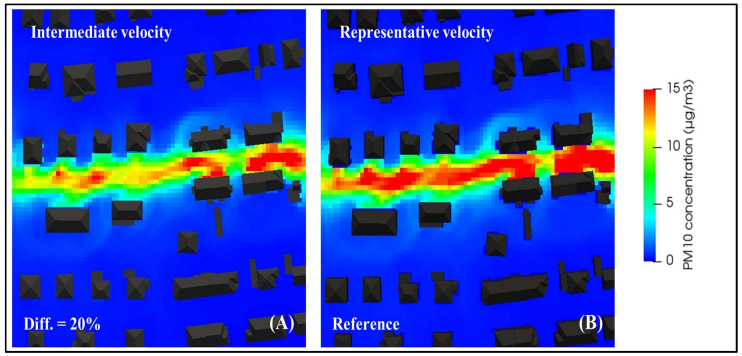
$$\overline{C}_d = \frac{\sum_{r=1}^{n} C_{d,r} . f_{d,r}}{\sum_{r=1}^{n} f_{d,r}} + C_{bg}$$





$$v_r = \frac{v_{min} + v_{max}}{2}$$

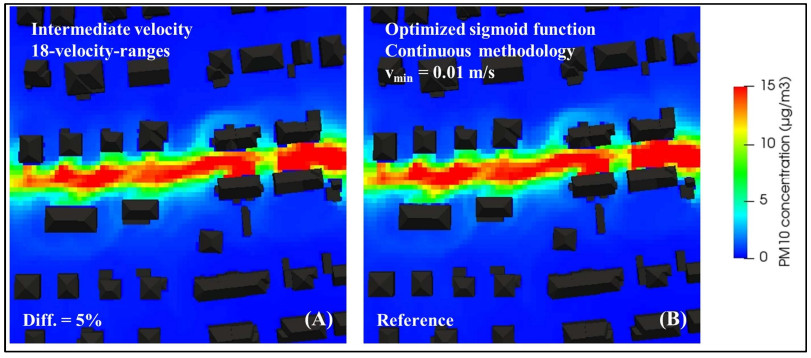
$$v_r = \sqrt{\frac{2}{\frac{1}{{v_{max}}^2} + \frac{1}{{v_{min}}^2}}}$$



$$f(v) = \alpha . \left(-1 + \frac{1}{1 + \beta_1 . e^{-\gamma_1 . v}} + \frac{1}{1 + \beta_2 . e^{\gamma_2 . v}} \right)$$

$$\overline{C_d} = C_{max} . \frac{\int_0^{v_{min}} f(v) . dv}{\int_0^{+\infty} f(v) . dv} + \frac{\int_{v_{min}}^{+\infty} c(v) . f(v) . dv}{\int_0^{+\infty} f(v) . dv} + C_{bg}$$

Threshold value because 1/v diverge when v->0



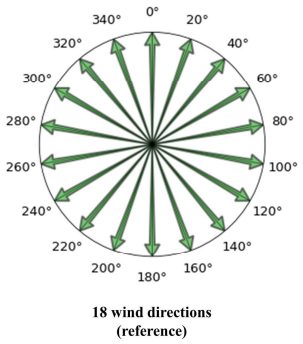
Jurado et al (2021)

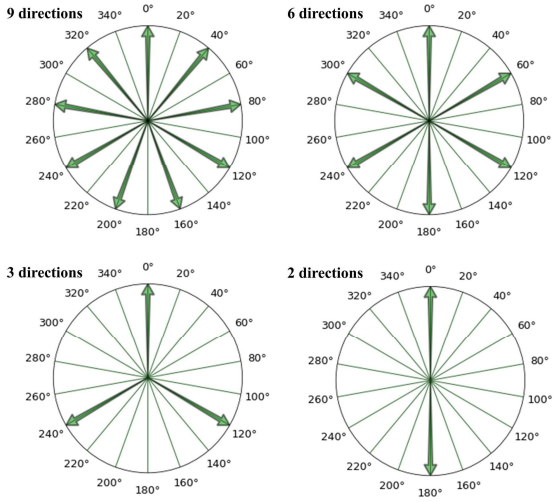
In practice, how many directions are needed ?

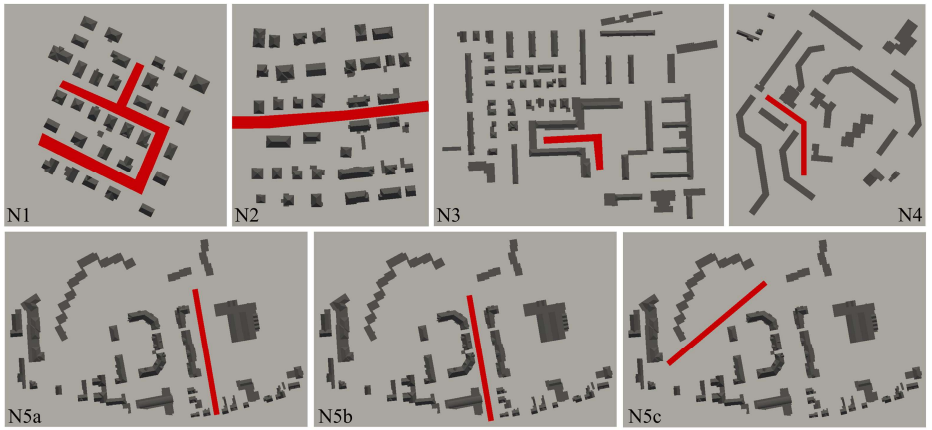
$$\overline{C} = \frac{\sum_{i=1}^{n} \overline{C}_d \cdot f_d}{\sum_{i=1}^{n} f_d}$$

Issue : To compute the average annual concentration of an area it is necessary to make the summation of the different wind directions weighted by their frequencies.

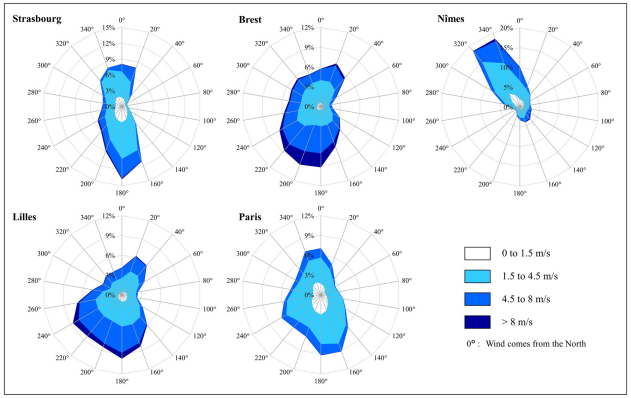
How many directions needs to be computed ? Each direction is a supplementary cost







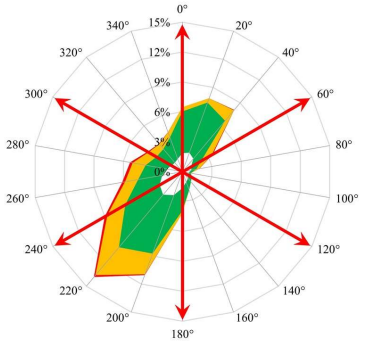
For 5 building layouts 18 wind directions were computed and the annual average determined for 5 different type of wind roses



Jurado et al (2021)

TWO STRATEGIES : PREDOMINANT WIND DIRECTION AGAINST HOMOGENEOUS DISCRETIZATION

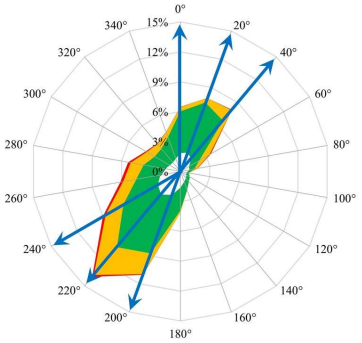
Strategy 1 : Homogeneous discretization



Advantage :

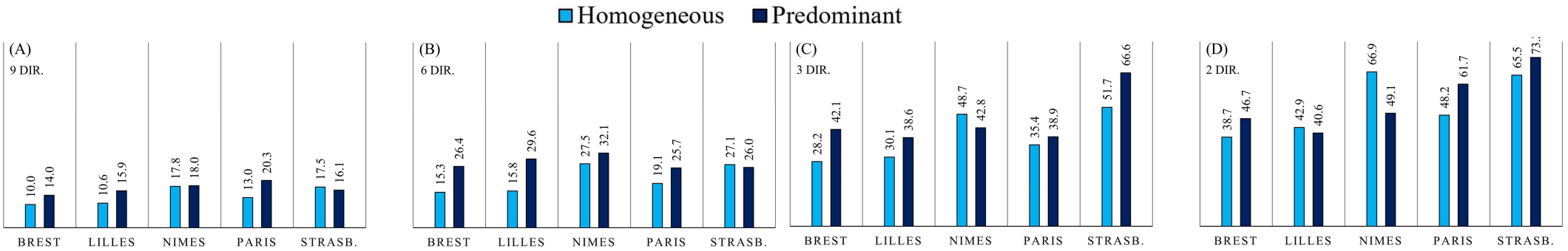
Every direction will not be too far from a computed wind direction and thus not too badly taken into account

Strategy 2 : Predominant wind direction frequency



Advantage :

The wind direction that impact the concentration the most are the best taken into account

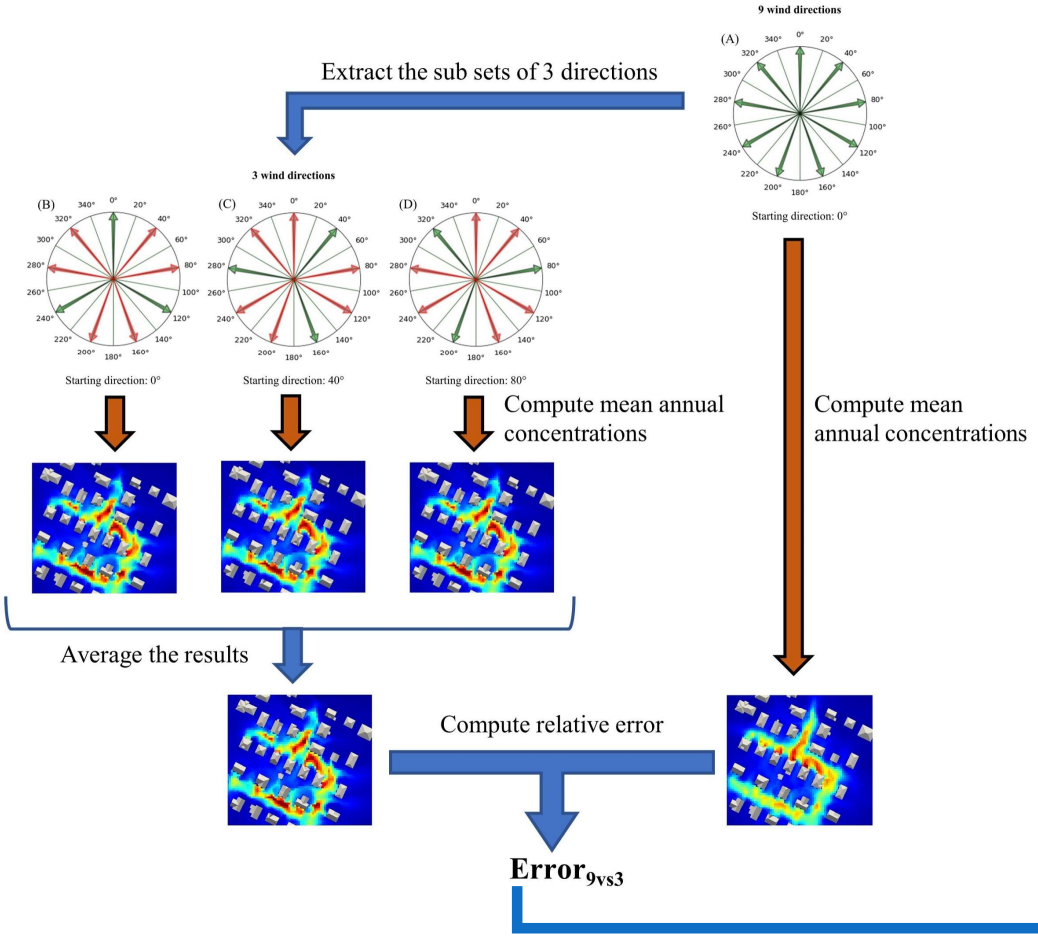


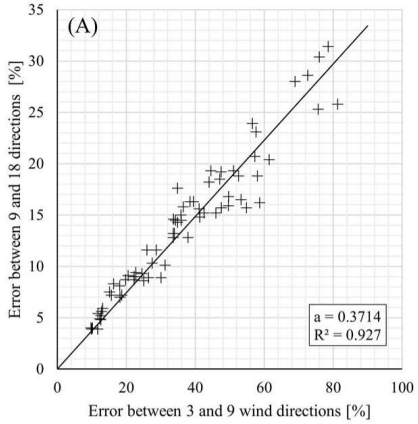
1 **Homogenous is better in ¾ of the cases**

2 **High variance in the error, no general trend**

Jurado et al (2021)

DETERMINE THE ERROR THAT IS MADE COMPARED TO 18 DIRECTIONS





Estimated Error$_{18vs9}$

Satisfying Error ?

No

Compute more directions

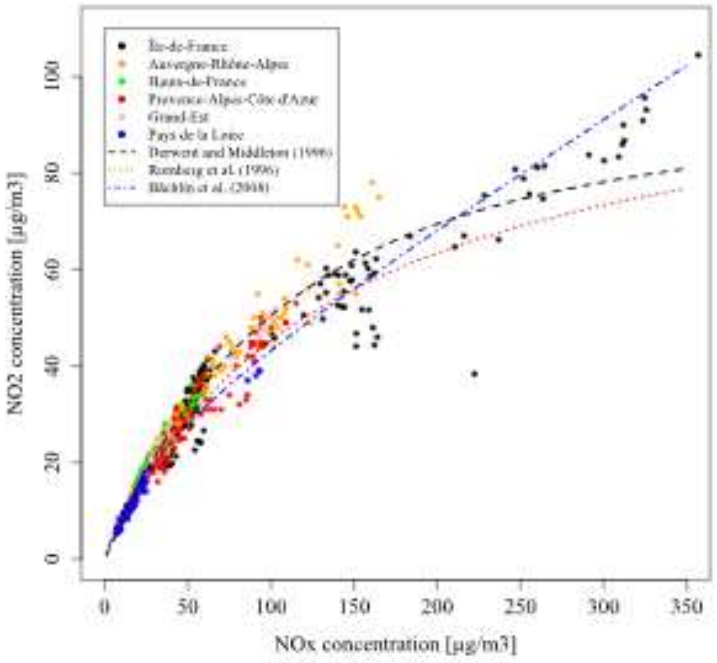
Yes

Use the results of 9 directions as mean annual concentration

Jurado et al (2020)

RELATIONSHIP BEETWEN NO_2/NO_X AND $PM_{10}/PM_{2.5}$

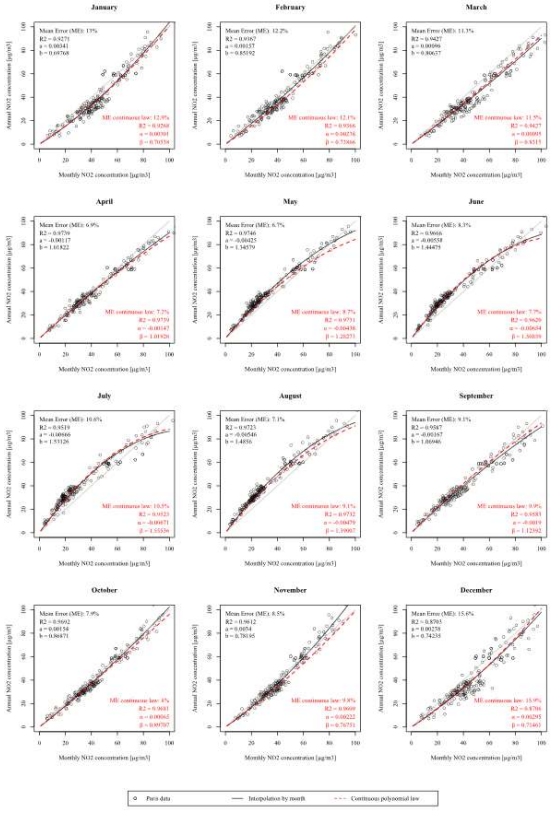
NO_2/NO_X



3 relationship from the literature :

- Derwent and Middleton (1996)
- Romberg et al (1996)
- Bachlin et al (2008)

Mean error on France dataset : 8%



Good correlation between monthly and annual concentration for each month with a mean error below 10% with a quadratic relationship

Improvement of 38% using the quadratic law results (16%) than the direct month concentration as annual concentration (28%)

REFERENCE

Reiminger, N., Jurado, X., Vazquez, J., Wemmert, C., Dufresne, M., Blond,N., and Wertel, J. Methodologies to assess mean annual air pollution concentrationcombining numerical results and wind roses.Sustainable Cities and Society 59(Aug.18 2020), 10222

→ **Article on the interpolation of wind data and the statistical approach to compute mean annual concentration**

Jurado, X., Reiminger, N., Vazquez, J., and Wemmert, C. On the minimal wind directions required to assess mean annual air pollution concentration based on CFD results.Sustainable Cities and Society 71(Aug. 2021), 10292

→ **Article on the discretization of the wind roses and the method to determine the error from it**

Jurado, X., Reiminger, N., Vazquez, J., Wemmert, C., Dufresne, M., Blond,N., and Wertel, J. Assessment of mean annual NO2 concentration based on a partialdataset.Atmospheric Environment 221(Jan. 2020), 117087

→ **Article on NOx/NO2 data sensors over France and annual average from monthly measurements**