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*maîtriser le risque
pour un développement durable*

Workshop CHIMERE

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SURROGATE MODELLING WITH CHIMERE: ACT AND ACT-FRANCE

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Summary

- Metamodeling
- Air control toolbox (ACT): Concept and Methodology
- ACT and ACT France
- How ACT-Fr can be used to describe pollution episodes:
 1. Winter episode
 2. Spring episode
- ACT France : future actions

Metamodeling

Context

Necessity of flexible and simple tool to help policy decision makers to face air quality issues.

Understanding which kind of air pollution episodes, we must face to.

Inform and form general public on pollution and its sources.



Chemistry-transport models (CTM) are designed to account for the complexity of chemical processes. They should be the best tools but design the scenarios and give answers take time.

Use of metamodeling to simplify the CTM but keeping the necessary degree of complexity to provide sufficiently accurate answers.

Air control toolbox (ACT): Concept

ACT is a metamodel of the CHIMERE CTM (<https://www.lmd.polytechnique.fr/chimere/>), designed to rapidly estimate air-quality responses to emission changes.

It can be demonstrated that under specific conditions the variation of the daily pollutant concentration can be described as a polynomial equation of the variation in emissions of the 6 principal sectors: i) Agriculture (K – AgriOther and L - Livestock), ii) Industry (A - Public Power, B – Industry, D - Fugitive), iii) Residential heating (C - Other Stationary Combustion), iv) Road traffic (F - Road Transport, v) Shipping (G - Shipping), vi) Others (E - Solvents, H - Aviation, I - Offroad, J - Waste and M - Other).

$$C_{ref} - C_{agr,ind,res,tra,shp,oth} = F(agr, ind, res, tra, shp, oth)$$

Where :

agr, ind, res, tra, shp, oth

are the sectoral emissions percentage reduction with respect to the emissions in reference simulation.

Pollutants considered: PM₁₀, PM_{2.5}, NO₂ and O₃

[Colette et al., 2022]

ACT : Methodology

$$\begin{aligned}
 C_{ref} - C_{agr,ind,res,tra,shp,oth} &= \alpha_{agr} agr + \beta_{agr} agr^2 + \alpha_{ind} ind + \beta_{ind} ind^2 + \alpha_{res} res + \alpha_{tra} tra \\
 &+ \beta_{tra} tra^2 + \alpha_{shp} shp + \beta_{shp} shp^2 + \alpha_{oth} oth + \beta_{oth} oth^2 + \gamma_{agr,ind} agr \cdot ind \\
 &+ \gamma_{tra,agr} tra \cdot agr + \gamma_{tra,ind} tra \cdot ind + \delta agr \cdot ind \cdot res \cdot tra \cdot shp \cdot oth
 \end{aligned}$$

$\alpha_{agr}, \beta_{agr}, \alpha_{ind}, \beta_{ind}, \alpha_{res}, \alpha_{tra}, \beta_{tra}, \alpha_{shp}, \beta_{shp}, \alpha_{oth}, \beta_{oth}, \gamma_{agr,ind}, \gamma_{tra,agr}, \gamma_{tra,ind}, \delta$

They are 15 parameters of the polynomial function that are fixed using **CHIMERE reference simulation** and a **set of 15 perturbed emissions simulations**.

In that case the problem comes down to solving a linear system of 15 equations point by point of the CHIMERE run grid. It is also imposed the condition that no emission reductions imply no concentration variation.

ACT et ACT France

ACT

- European CHIMERE simulations as a resolution of $0.1^\circ \times 0.2^\circ$
- Chimere V2020-Fast version used (Couvidat et al., 2025)
- <https://policy.atmosphere.copernicus.eu/>

ACT - France

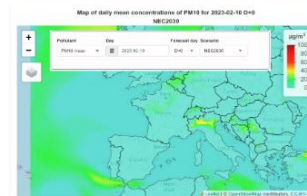
- Based on the same multivariate polynomial framework as ACT.
- Trained with daily CHIMERE simulations over France at 4–5 km resolution, D0–D2 forecast horizon.
- Calibration performed for each grid cell using perturbed-emission scenario simulations.
- Corresponding European CHIMERE simulations employed for training ACT used as boundary conditions.

Available applications

- **Source Allocation:** source apportionment for ~40 French cities
- **Chemical Regime:** pollutant response to emission reductions (0–100%) in two sectors simultaneously
- **Emission Scenario Design:** air quality impacts of user-defined emission reduction scenarios

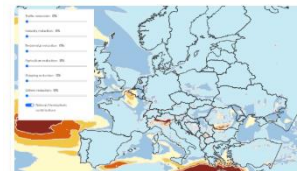
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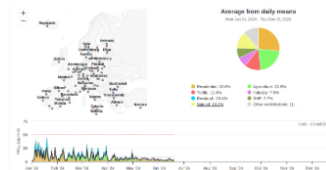
Policy scenarios

Investigate **how the air quality will improve in 2030** through implementation of the [Clean Air Programme Directive \(EU\)](#) on the reduction of national emissions of certain atmospheric pollutants.



Sector apportionment

Inspect the potential impact of different measures affecting **sector emissions** at **targeted cities**, make **custom scenarios** and inspect **chemical regimes** with the [Air Control Toolbox](#).



Sector apportionment

Annual and seasonal summary of the **sector apportionment** of the $PM_{10/2.5}$, O_3 and NO_2 at targeted cities with the CHIMERE model.

Use of ACT in analysing pollution episodes

1. Winter PM₁₀ episode (14–21 January 2025): over an eight-day period, residential heating was the main source.
2. A spring episode (4–5 March 2025): residential heating at the end of the cold season, combined with agricultural emissions.
3. A summer ozone episode (19–22 June 2025): with the arrival of hot weather, road transport was the main source of precursors, followed by the maritime sector in coastal cities.

[Messina, P. and Meleux, F., (2026). *Annual report on the analyses of the pollution episodes which occurred over the last year 2025 using ACT-fr*, CAMS NCP, Deliverable D72FR.1.1.4-2025, CAMS National Collaboration Programme | Copernicus]



Use of ACT in analysing pollution episodes

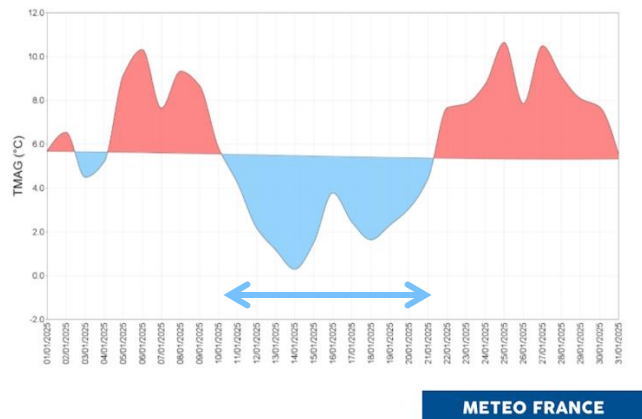
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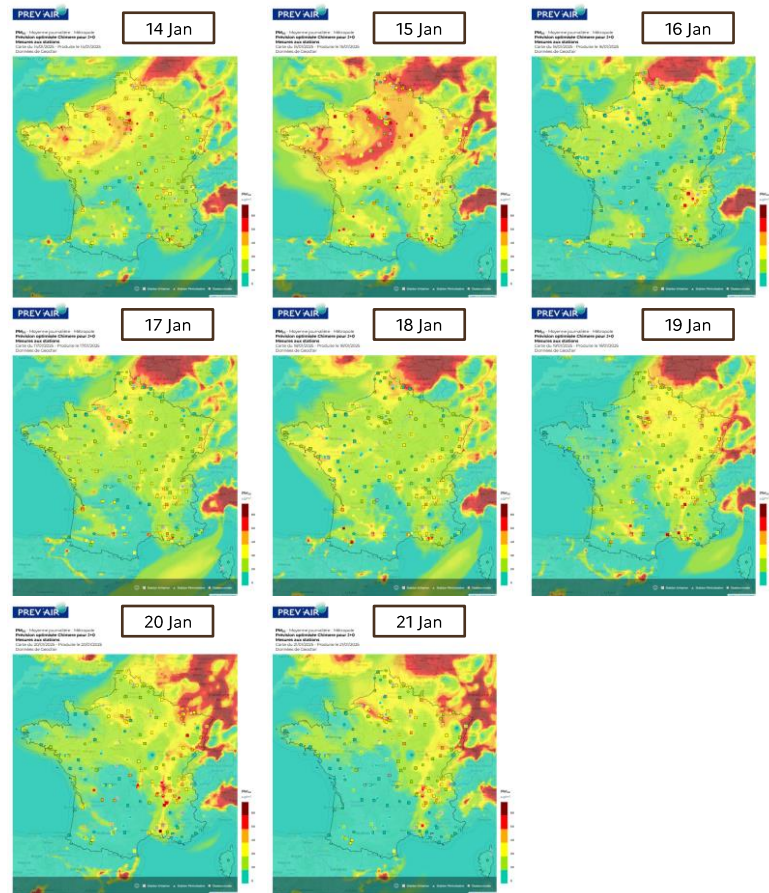


Winter episode

Northern half of the country: **Hauts-de-France**, **Île-de-France**, **Normandie**, **Bretagne**, and **Centre-Val de Loire**. Subsequently, other regions were progressively affected, such as **Nouvelle-Aquitaine**, **Occitanie**, and **Auvergne-Rhône-Alpes**. During the final days, regions most strongly impacted were **Bourgogne-Franche-Comté**, together with **Grand Est** and **Auvergne-Rhône-Alpes**.



The episode was characterized by **cold anticyclonic conditions**, marked by temperatures below the seasonal average from **11 to 21 January**.

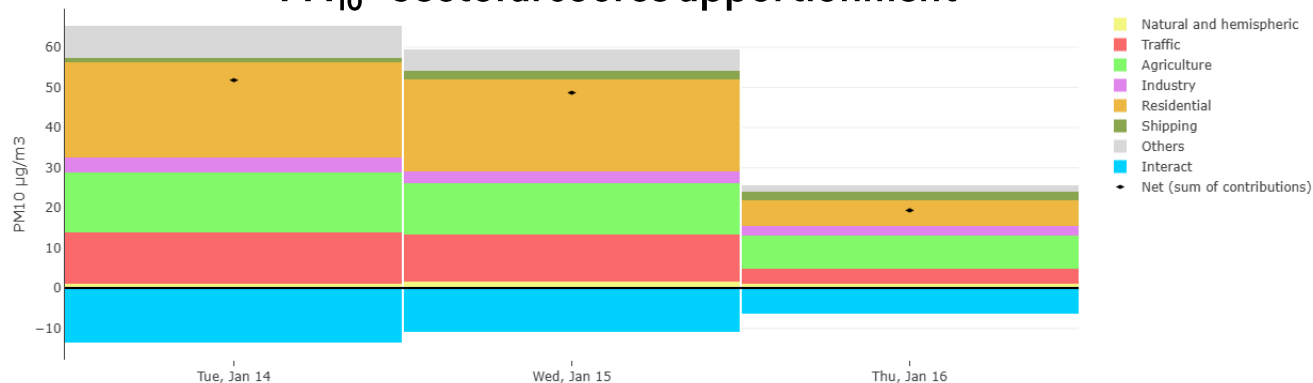


Focus on Rennes

Residential sector (mainly heating) is predominant and exceeds that of traffic.

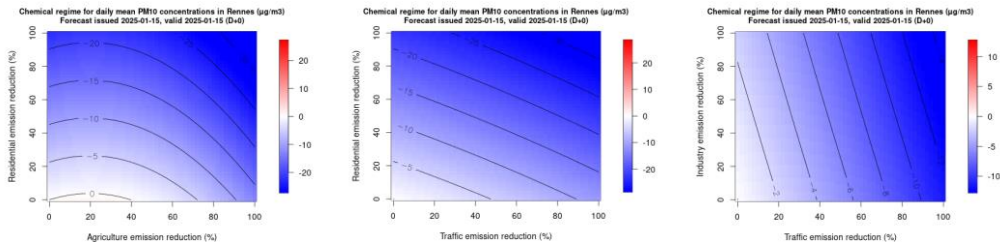
Reduction of the residential sector leads to a more effective decrease in PM_{10} concentrations compared to reductions in the agricultural and traffic sectors

PM_{10} - Sectoral source apportionment

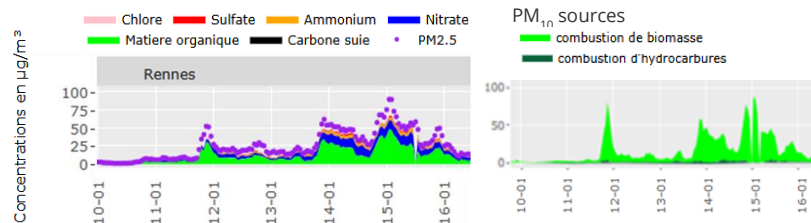


During this episode, a large fraction of PM_{10} was composed of organic matter associated with **biomass combustion** → **residential sector**

PM_{10} – 15 January 2025

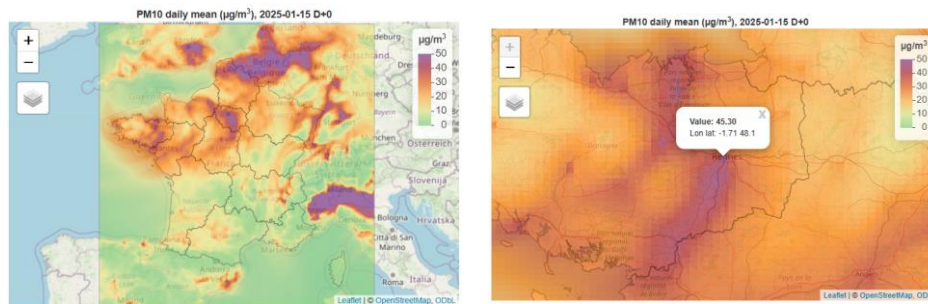


CARA - National Observatory for the Chemical Composition and Sources of Fine Particles in Urban Areas (<https://www.lcsqa.org/fr/le-dispositif-cara>)



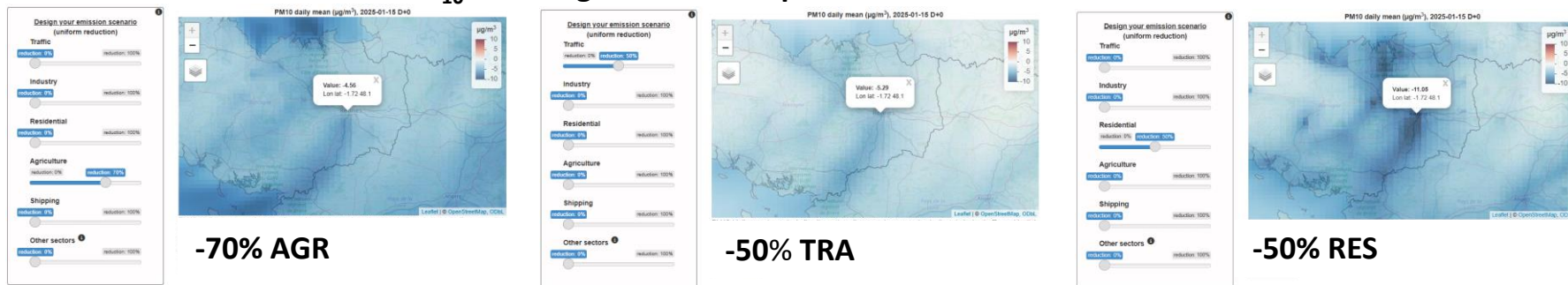
Focus on Rennes

PM₁₀ concentration on 15 January



70% reduction in the **agriculture** leads to a **decrease** of about **4.6 µg/m³** out of a total concentration of **45.3 µg/m³**, corresponding to **-10%**. A **50% reduction** in the **traffic** results in a **decrease** of **5.3 µg/m³** corresponding to **-11.5%**. A **50% reduction** in the **residential** sector leads to a **decrease** of **11 µg/m³** corresponding to **-24.3%**.

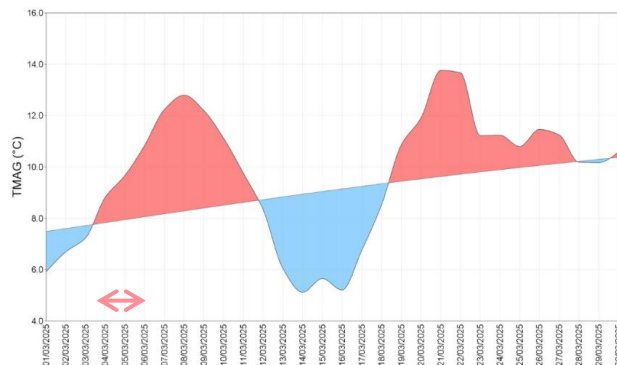
PM₁₀ resulting from sector-specific emission reductions



Spring episode

Northern half of metropolitan France: **Hauts-de-France**, **Normandy**, and **Île-de-France**, on the second day to areas in the **Grand Est** and **Centre-Val de Loire** regions.

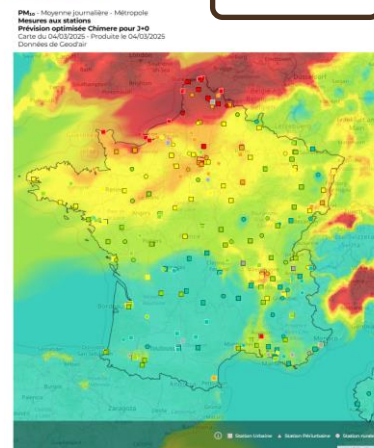
This episode can be classified as a spring-type event, in which the influence of **residential emissions** is still present, while the contribution from the **agricultural sector** becomes increasingly significant.



(© Météo-France, source: Mars 2025 | Météo-France)

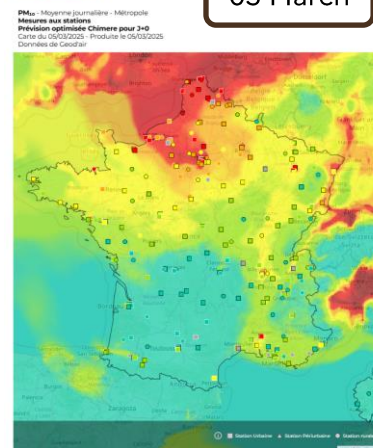
PREV-AIR

04 March



PREV-AIR

05 March



https://www.prevoir.org/prevoir-plus/historical_data

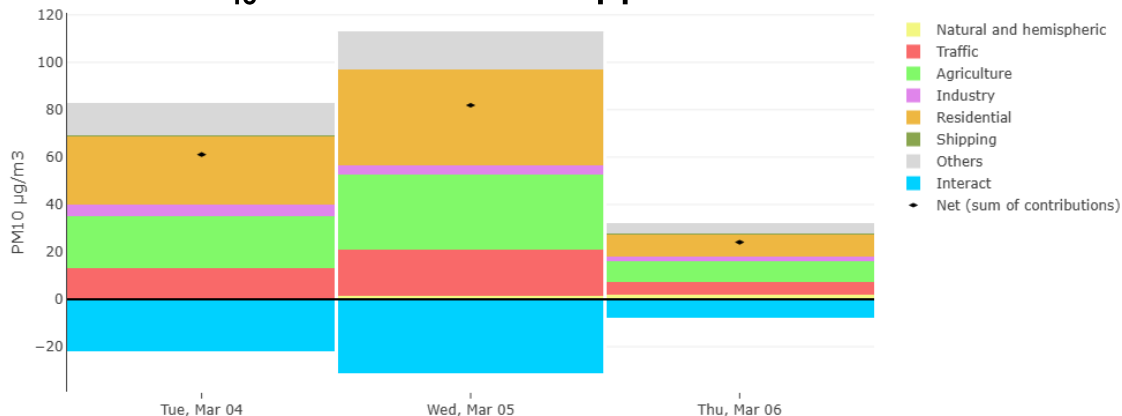
From a meteorological perspective, these days were characterized by **anticyclonic conditions** over the **northern part** of the **country**, with a marked amplitude between nighttime and daytime temperatures, accompanied by **slightly above-average temperatures** on 4–5 March and a **precipitation deficit** and **limited cloud cover** in northern France.

Focus on Paris

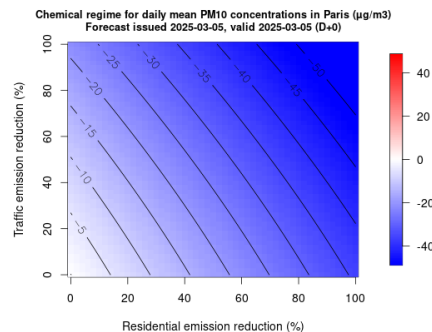
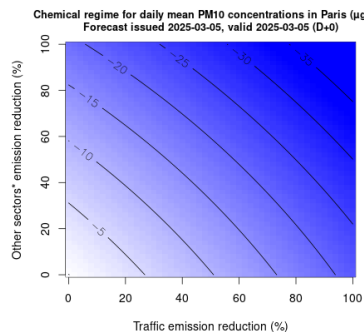
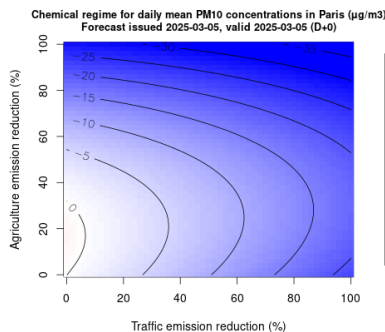
Dominant contributing sector is the **residential sector**, followed by **agriculture**, traffic, and the "other" sector, while the industrial sector contributes only slightly.

Residential sector is the most impactful sector on which to act in order to achieve the **largest reductions** in **PM₁₀** concentrations

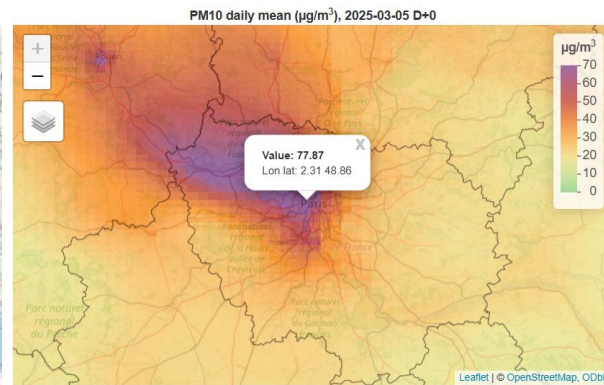
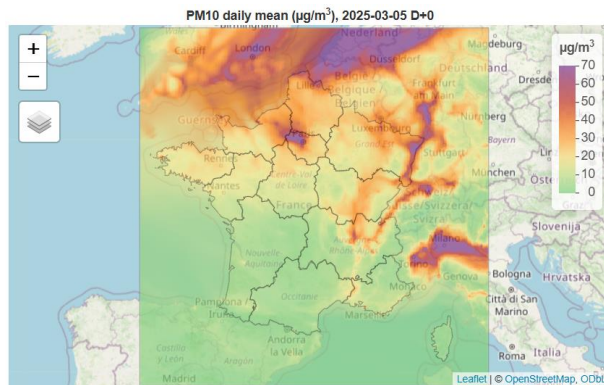
PM₁₀ - Sectoral source apportionment



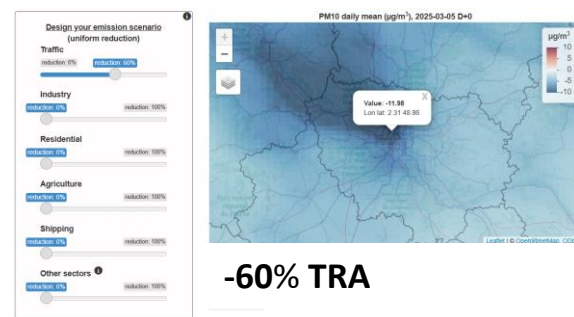
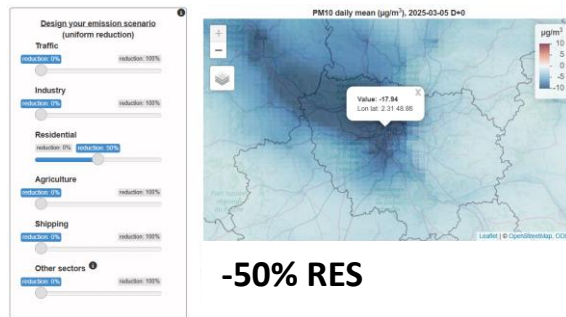
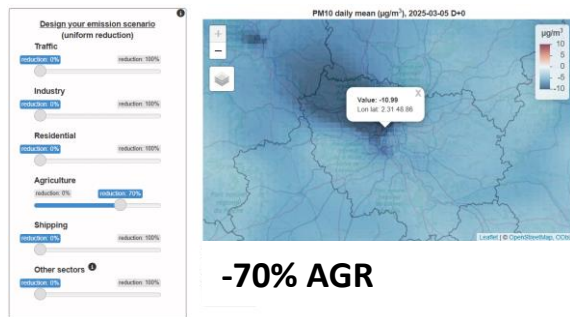
PM₁₀ – 05 March 2025



Focus on Paris



A **70% reduction** in the **agriculture** results in a **decrease of 11 $\mu\text{g}/\text{m}^3$** , corresponding to **-14.1%** relative to the **reference concentration** being equal to **77.9 $\mu\text{g}/\text{m}^3$** . The **residential sector** proves to be more effective: a **50% reduction** leads to a **decrease of 17.9 $\mu\text{g}/\text{m}^3$** corresponding to **-23.0%**. This is followed by the traffic sector, where a **60% reduction** results in a **decrease of 12 $\mu\text{g}/\text{m}^3$** corresponding to **-15.4%**.



ACT Fr : concluding remarks and future actions

1. ACT-Fr tool proved to be a valuable resource for understanding the main emission sources contributing to the formation of atmospheric pollutants.
2. For the winter episode, the residential sector is by far the dominant contributor, and its reduction can effectively lower PM₁₀ concentrations.
3. For the spring episode, the agricultural sector provides the largest contribution, but a reduction of at least more than 50% would be required to achieve a significant decrease in PM₁₀ concentrations. Residential sector is the most impactful sector to achieve the largest reductions in PM₁₀ concentrations.
4. Update the Chimere model version used for training ACT or ACT-Fr may improve results.
5. Improving the layout of the graphs.
6. Make the graphs production faster.
7. Expand the list of cities.

Thank you for your attention!