# The SHERPA approach

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Palmanova, Aprile 2017

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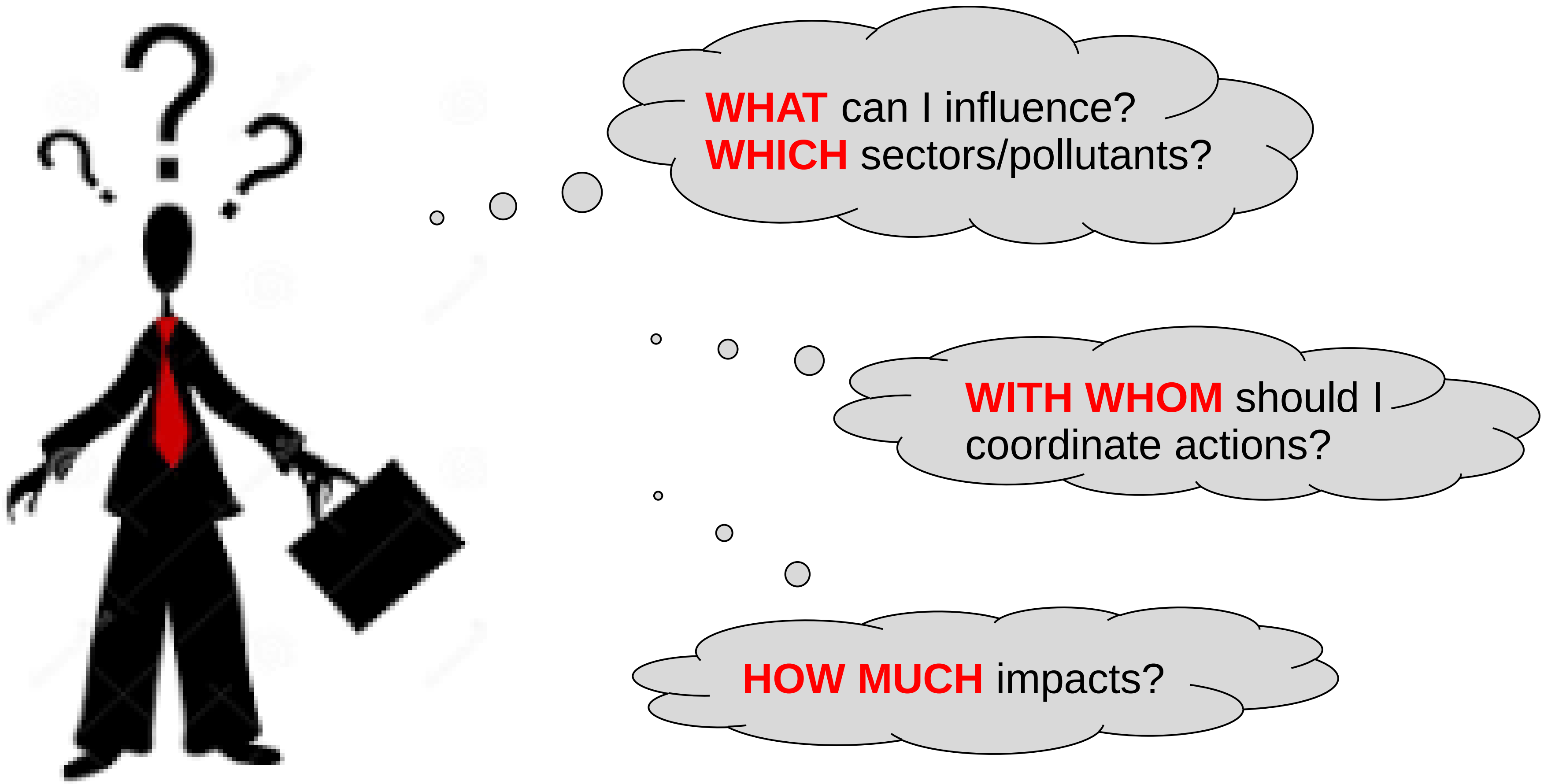
# Motivations

**S**creening for **H**igh **E**mission **R**eduction **P**otentials on **A**ir quality

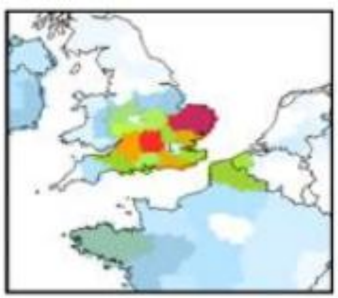


# Tasks


**Source allocation**

*Computes the relative contribution of the various emission sectors/precursors originating inside a region to the amount of pollution in the area*

**WHAT** can I influence?
**WHICH** sectors/pollutants?



**Governance**

*Identifies the principal source areas of the pollution at a location*

**WITH WHOM** should I coordinate actions?

**HOW MUCH** impacts?

**Impacts**

*Tests the impact of an emission reduction scenario in a region*

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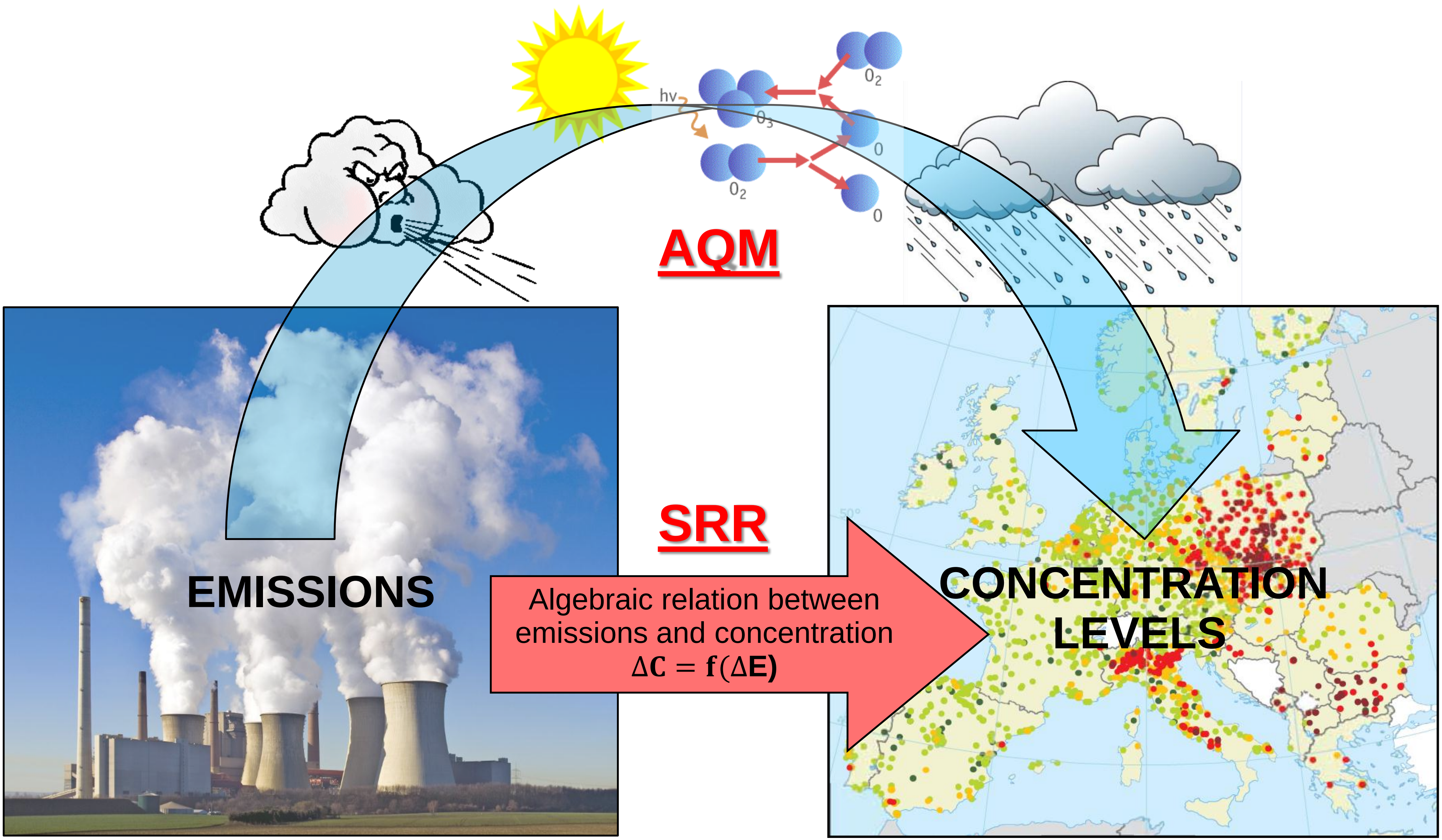
# Source Receptor Relationships (SRR)

The goal of the SRR is to mimic an AQM to calculate as quickly as possible the effect of emission reductions on concentration levels



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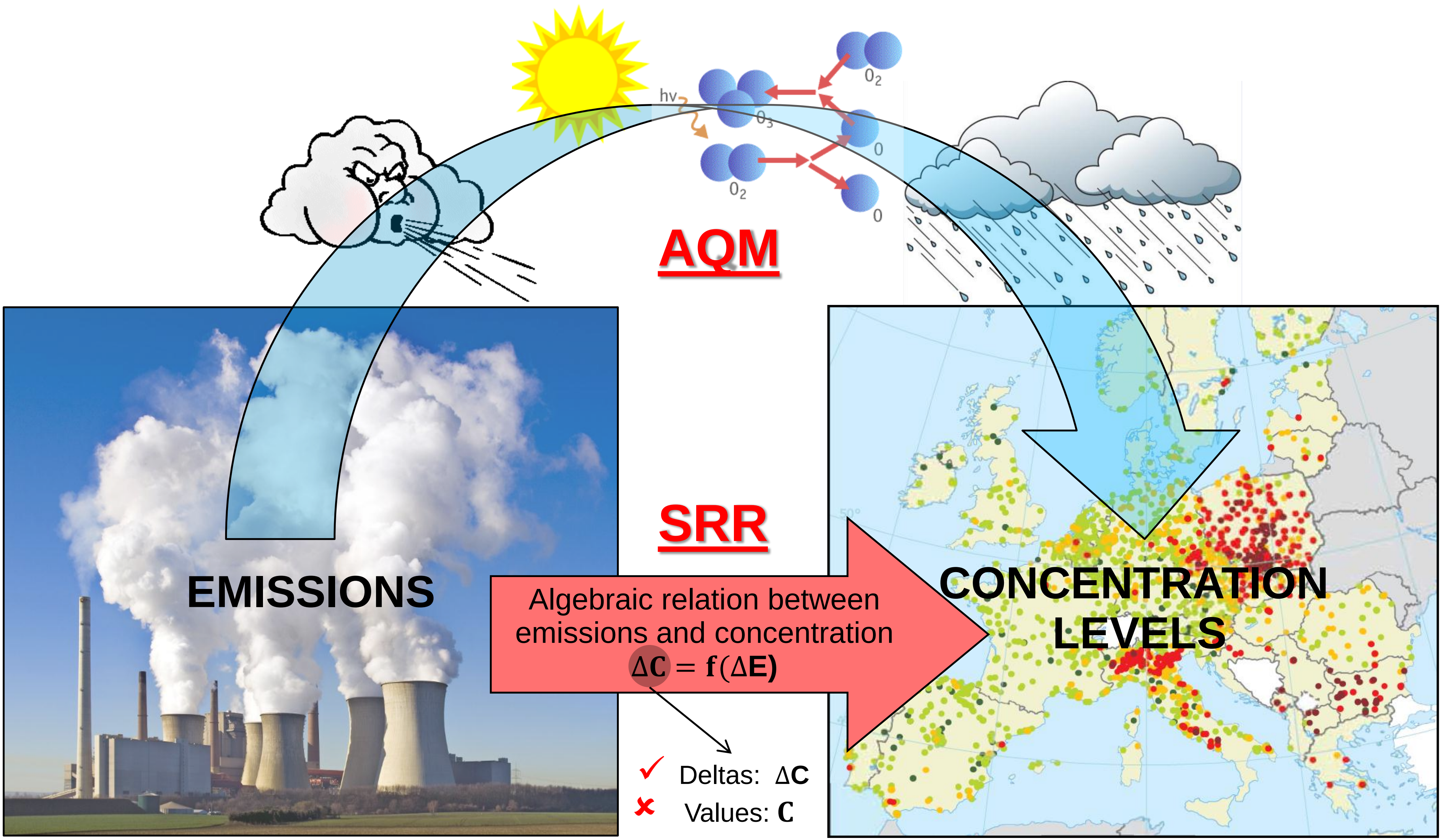


# AQM - SRR

## AQM ( Integrated Assessment Modeling frame )

- ✓ High accuracy
- ✓ High temporal resolution
- ✓ High spatial resolution

- ✗ Long calculation time (hours for 1yr simulations)
- ✗ Interactivity not allowed

## SRR (SHERPA,GAINS,AERIS,RIAT+)

- ✓ **Speed** (minutes for 1yr simulations)
- ✓ Robustness
- ✓ User friendly
- ✓ Interactivity

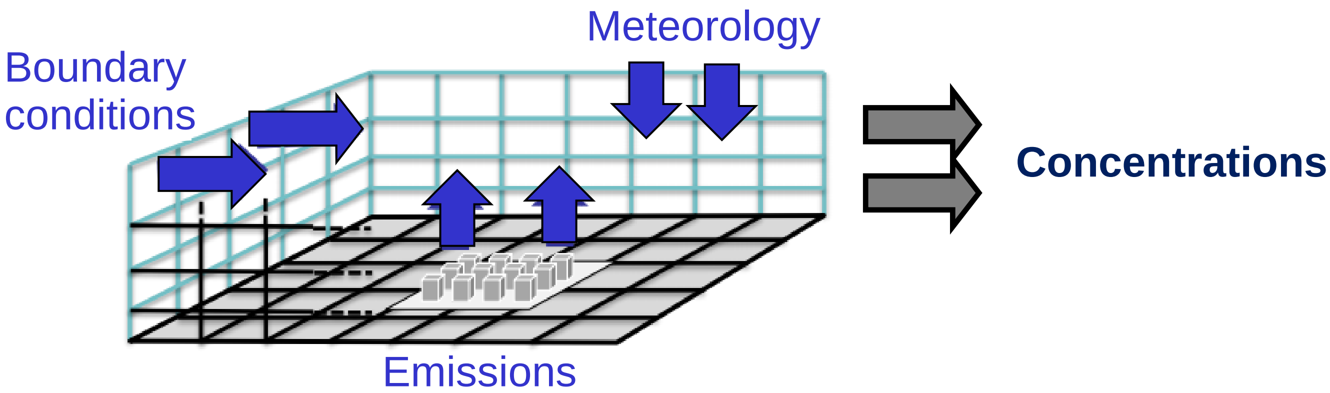
SRR ensures a **good compromise among speed and accuracy**: relative bias (compared to the AQM) less than 10%

# SRR Methodology

## 0) Base case

- Meteorology
- Emissions

## 1) Full Air Quality Model simulations



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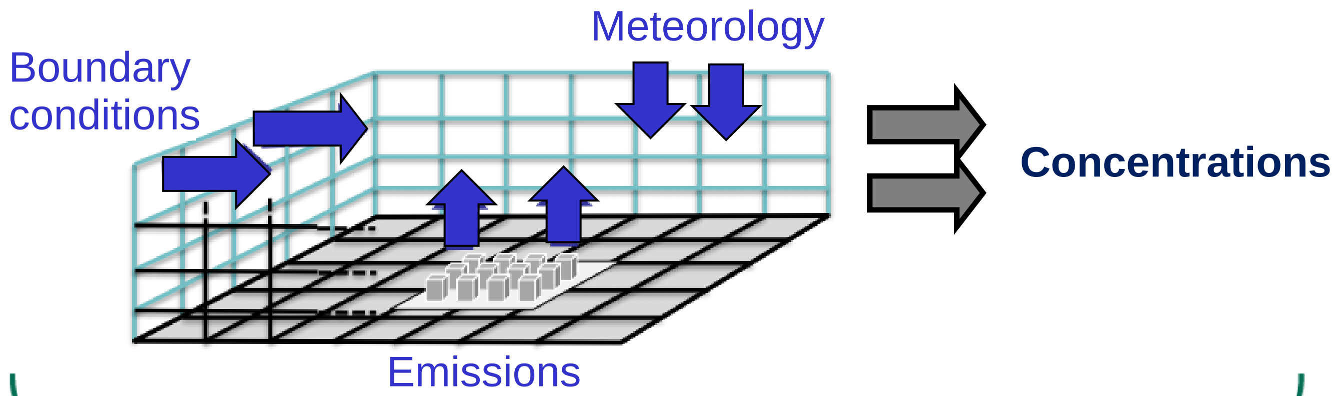


## 2) Training phase

Algebraic relation between gridded emission and concentration deltas

$$\Delta C_j = f_j(\Delta E_1, \ldots, \Delta E_i, \ldots, \Delta E_n)$$

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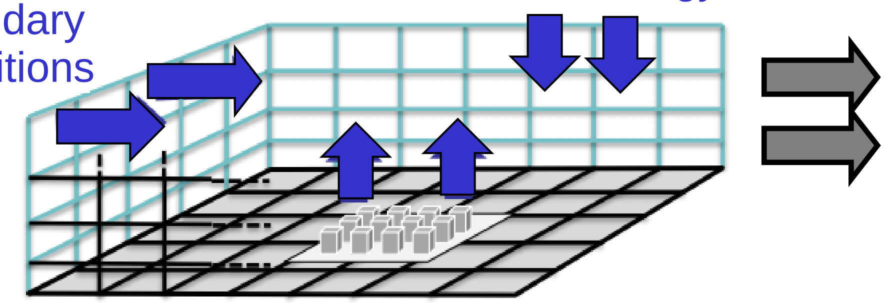
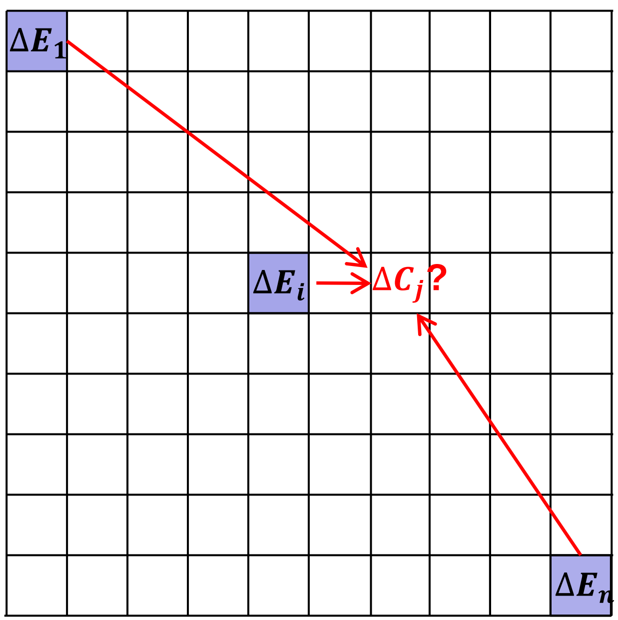



## 2) Training phase

Emission reductions

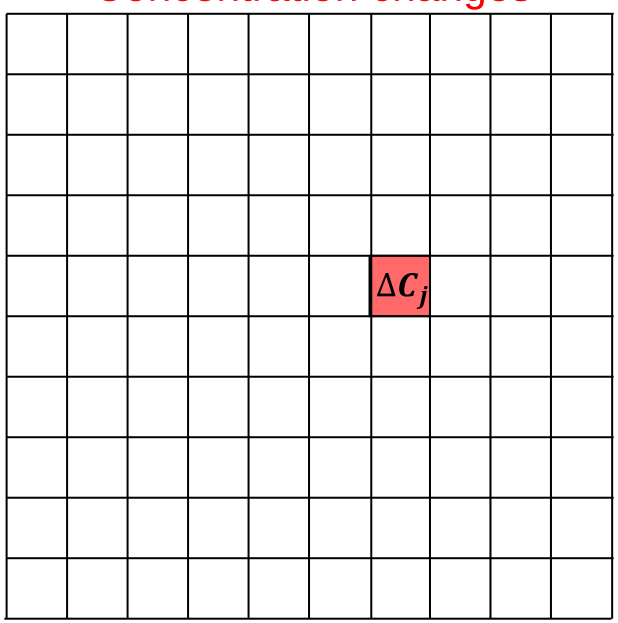



## 3) Source Receptor relationship simulations

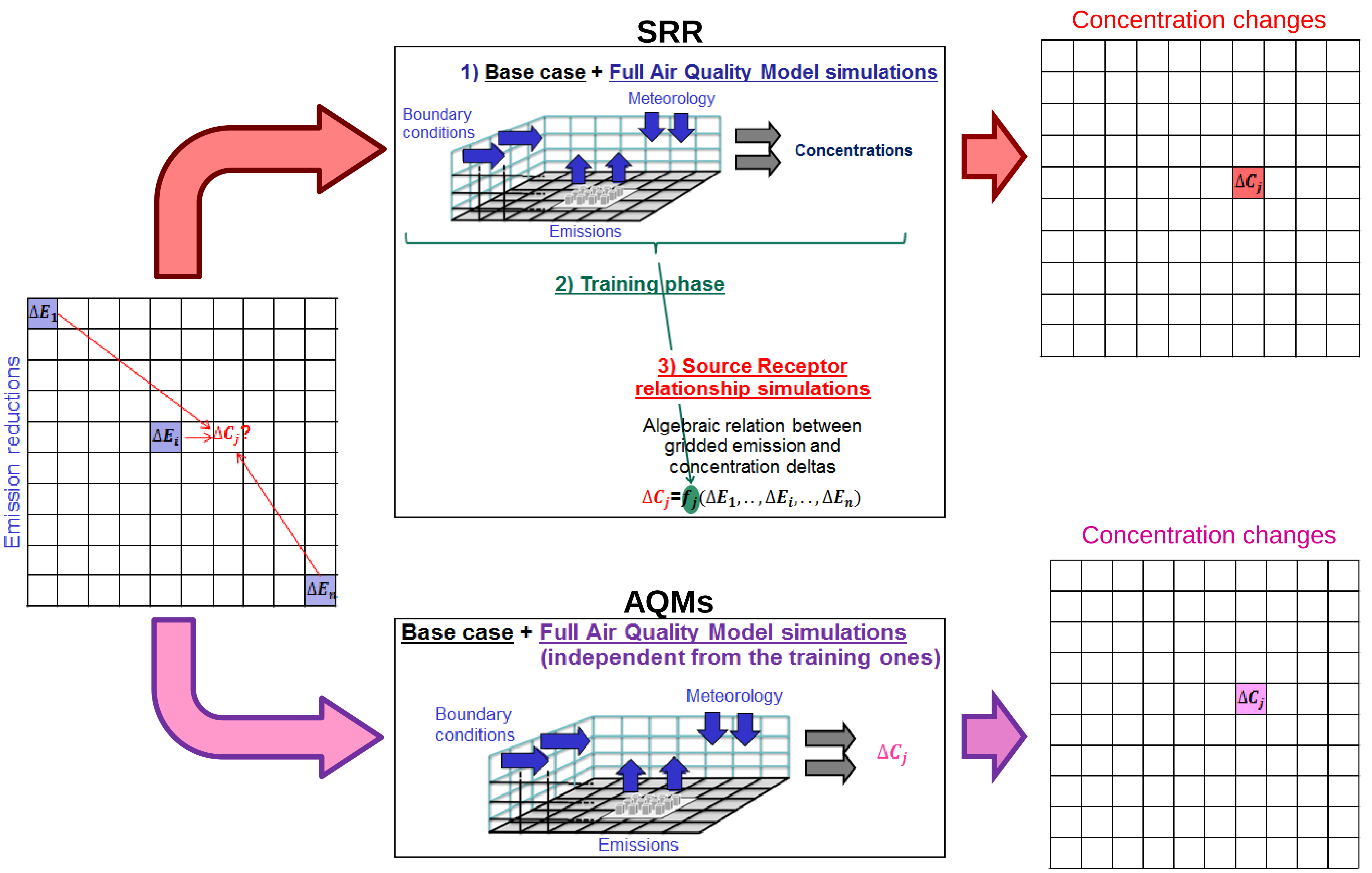
Algebraic relation between gridded emission and concentration deltas

$$\Delta C_j = f_j(\Delta E_1, \ldots, \Delta E_i, \ldots, \Delta E_n)$$

Concentration changes



# SRR Validation



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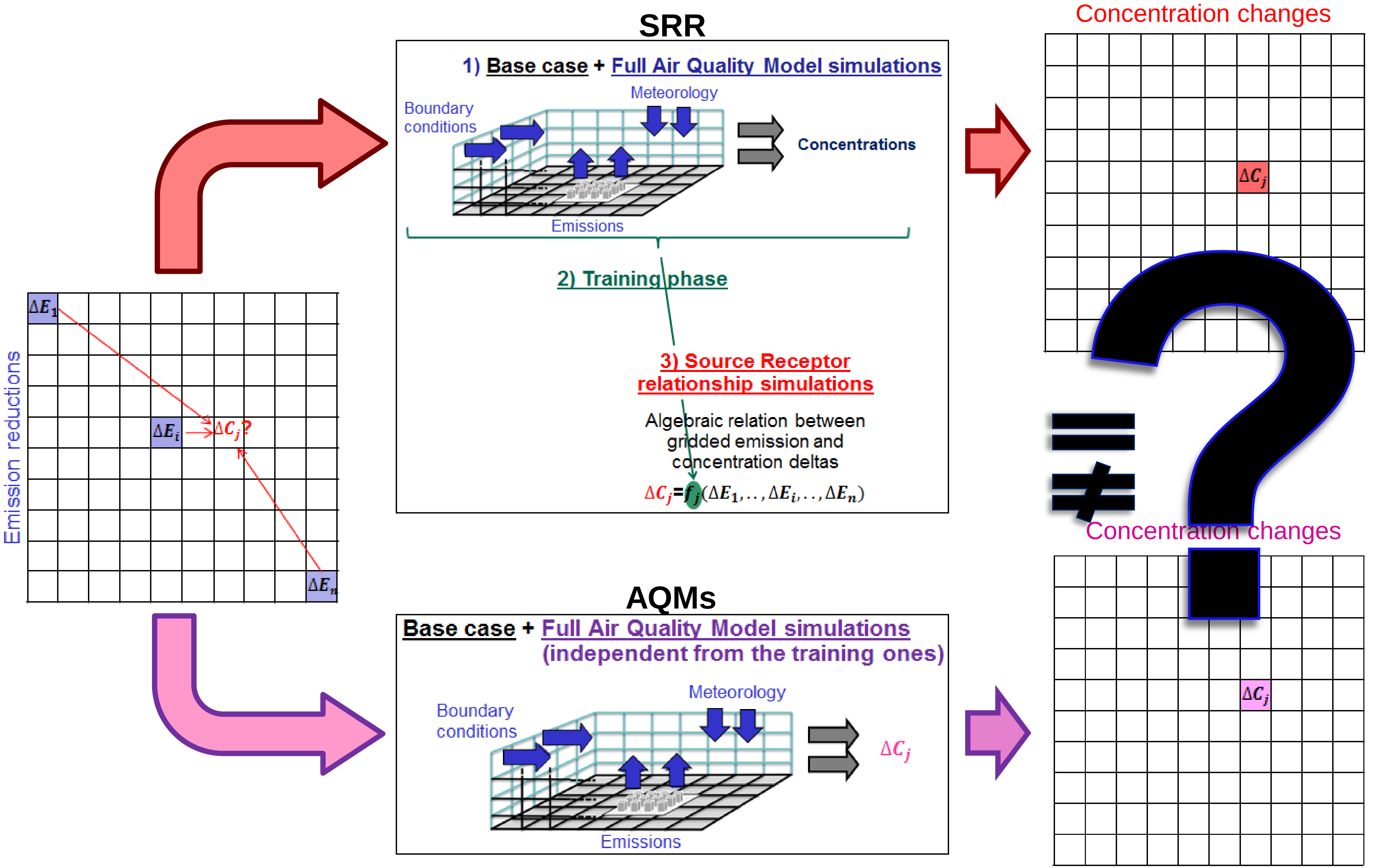
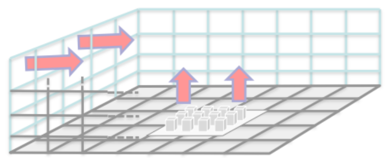


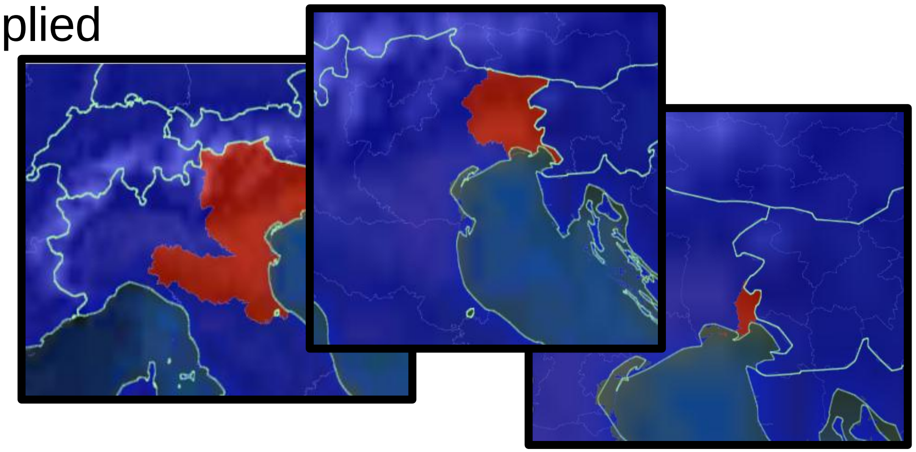
# SRR characteristics

- ✓ **Speed**
- ✓ **Spatial flexibility**
- ✓ **Light set-up**
- ✓ **Robustness**
- ✓ **Accuracy**

# SRR characteristics

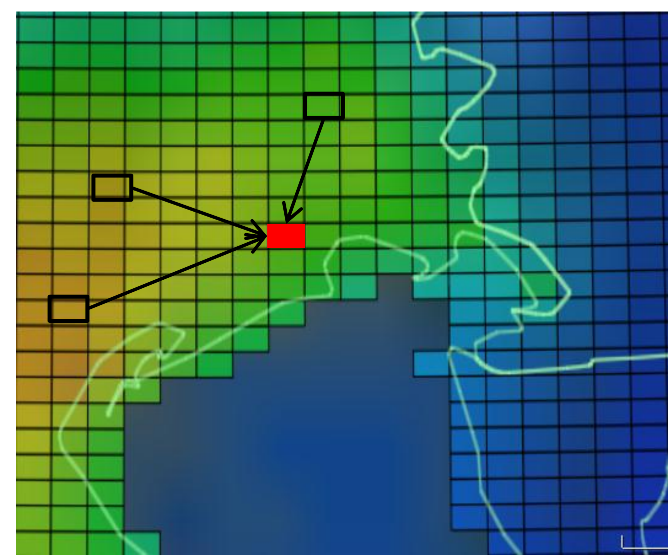
- ✓ Speed
- ✓ **Spatial flexibility** → Freedom in defining the resolution of the areas where emission reductions will be applied
- ✓ Light set-up → Limited number of AQM simulations required for training
- ✓ Robustness
- ✓ Accuracy → Good comparability between SRR and AQM results (dependence on training AQMs)





Source-aggregations (fixed or sliding)

Cell-to-cell relationships



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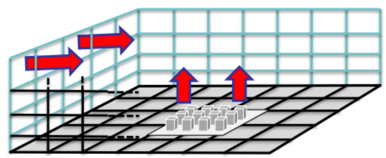

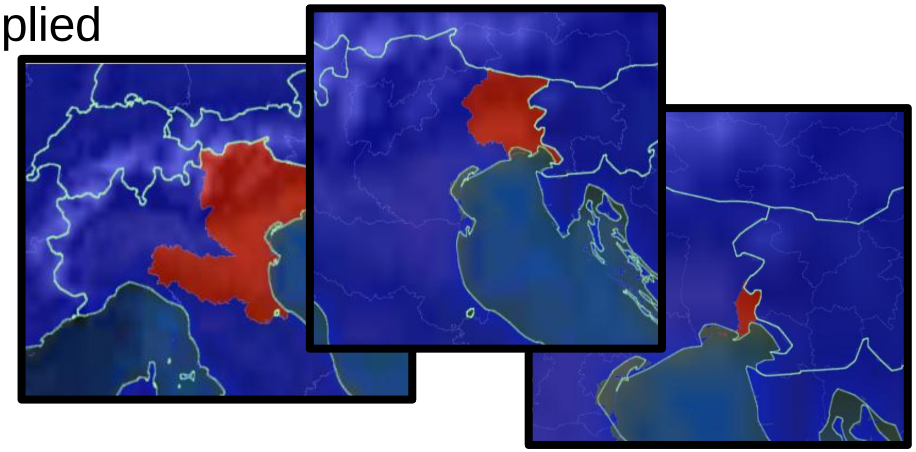

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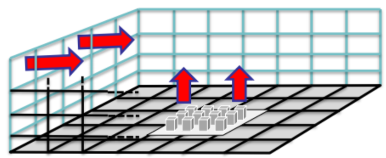

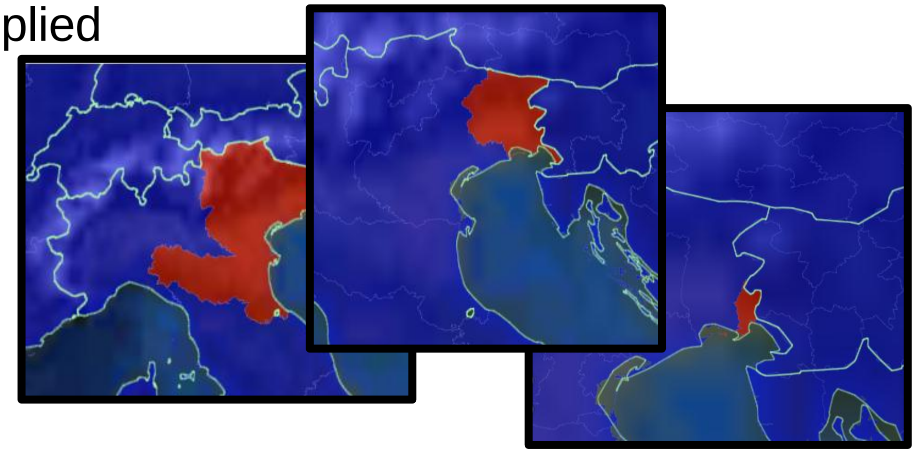

| SRR: | Description: | SPEED | SPATIAL FLEXIBILITY | LIGHT SET-UP | ROBUSTNESS |
|---|---|---|---|---|---|
| **GAINS** | S-aggregation in terms of countries<br>Assumes linearity | **T** | **F** | **T** | **T** |
| **AERIS** | S-aggregation in specific sectors | **T** | **F** | **T** | **T** |
| **RIAT+** | S-aggregation in four large quadrants<br>Neural network | **T** | **T** | **F** | **T** |
| **Multi-ring** | sliding S-aggregation (rings)<br>Assumes linearity | **T** | **T** | **T** | **F** |
| **Bell-shape (SHERPA)** | Cell-to-cell relationship distance weighted<br>Assumes linearity | **T** | **T** | **T** | **T** |

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# SHERPA characteristics

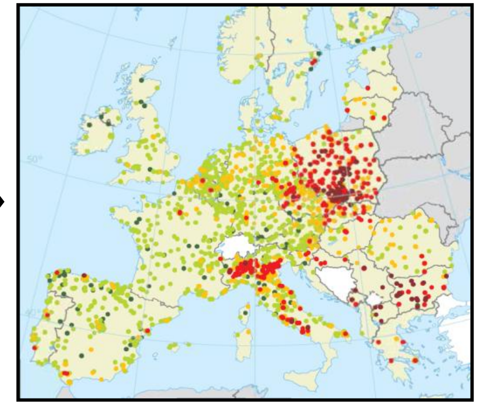
- ✓ **Speed** — **< 5 min**
- ✓ **Spatial flexibility** — **High (cell-to-cell)**
- ✓ **Light set-up** — **~ 10 AQMs**
- ✓ **Robustness**
- ✓ **Accuracy** — **< 5-10%**

# BUT

- ✘ Strong dependence on training model — **INERIS: CHIMERE (EU 7km x7 km res) + ECMWF 2010 + EMISSIONS 2009**
- ✘ Non linearities neglected
- ✘ Directionality ignored — **bias in windy areas**
- ✘ Geographical complexities not accounted — **bias in mountain areas**

# SHERPA assumptions

SRR
$$C = f(E)$$



**Main assumptions**:

- **Delta**-SRR better reproduce AQMs results in respect of absolute-values-SRR

$$\Delta C = f(\Delta E)$$

- For long term indicators (**yearly average**) the delta-SRR can be approximated accurately with a **linear function**

$$\Delta C_j = \sum_{p}^{P} \sum_{i}^{N} a^{p}{}_{ij} \; \Delta E_j{}^{p}$$

*p* = precursors
*i* = source cells
*j* = receptor cells

# Linear approaches

$$\Delta C_j = \sum_{p}^{P} \sum_{i}^{N} \boldsymbol{a^p}_{\boldsymbol{ij}} \; \Delta E_i{}^p \longrightarrow \quad \text{d.o.f.} = N \times P \; \textbf{!!!}$$

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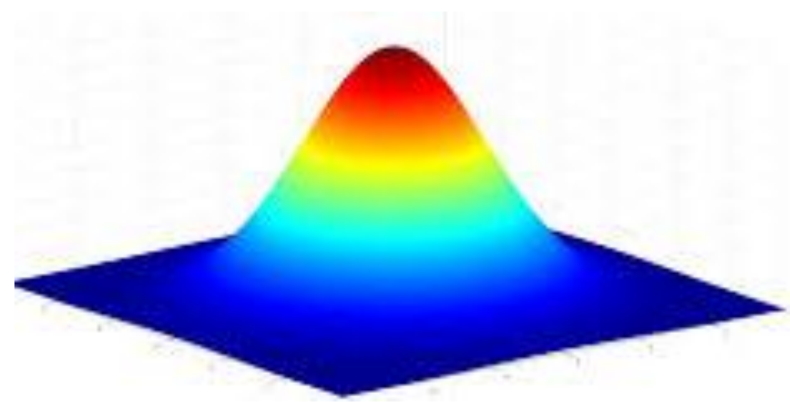
## Multi-ring approach

- SOURCE AGGREGATION
- RECEPTOR WINDOWS

## Bell-shape approach

- CELL-TO-CELL RELATIONSHIP **DISTANCE WEIGHTED**
- ~ RECEPTOR WINDOWS



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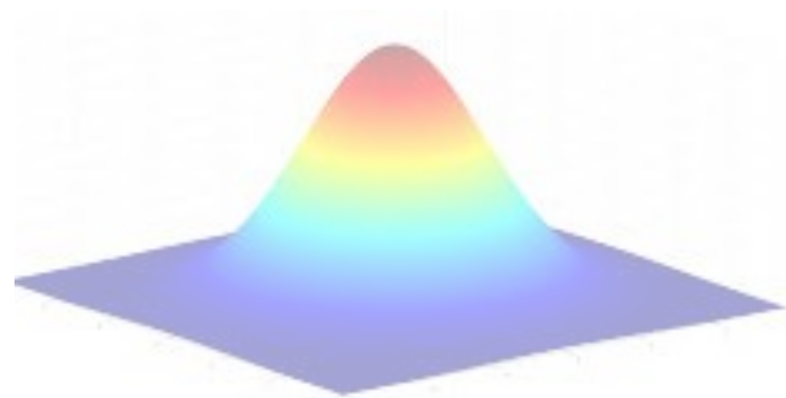
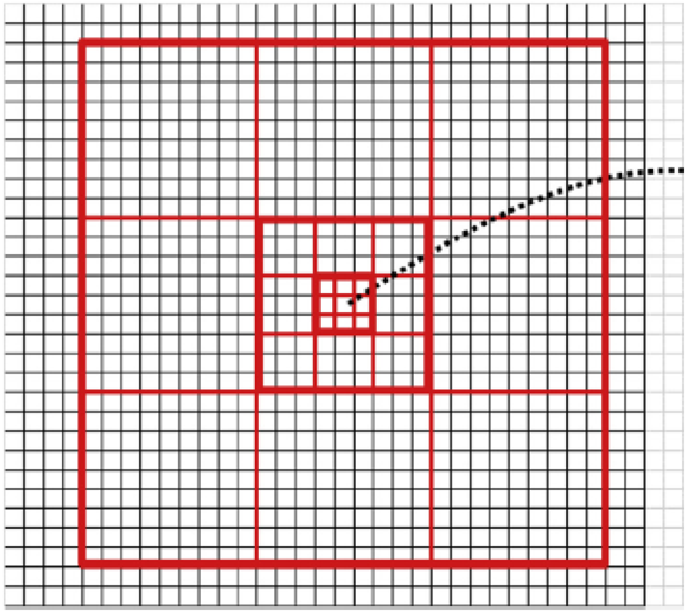


# Multi-ring approach

## SOURCE AGGREGATION

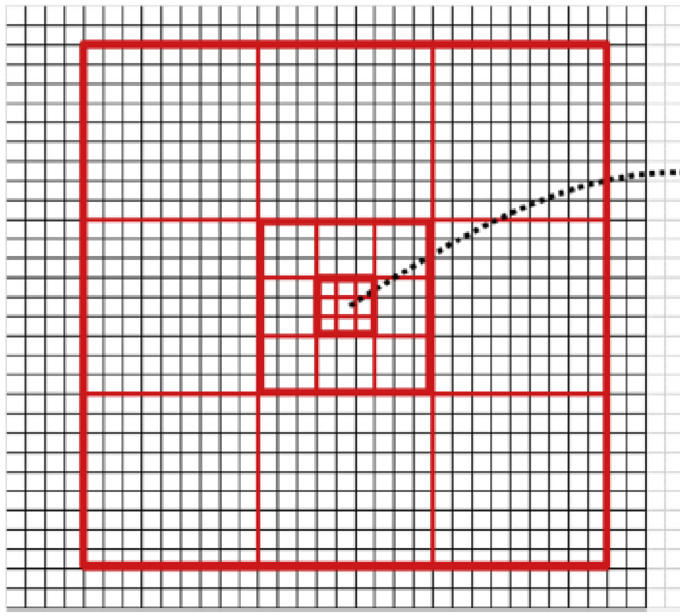


$$\Delta C_j = \sum_{p}^{P} \sum_{k}^{N_A} \boldsymbol{a^p}_{\boldsymbol{kj}} \; \Delta E_{k,j}{}^{p} \longrightarrow \quad \text{d.o.f.} = \boldsymbol{N_A} \times P$$

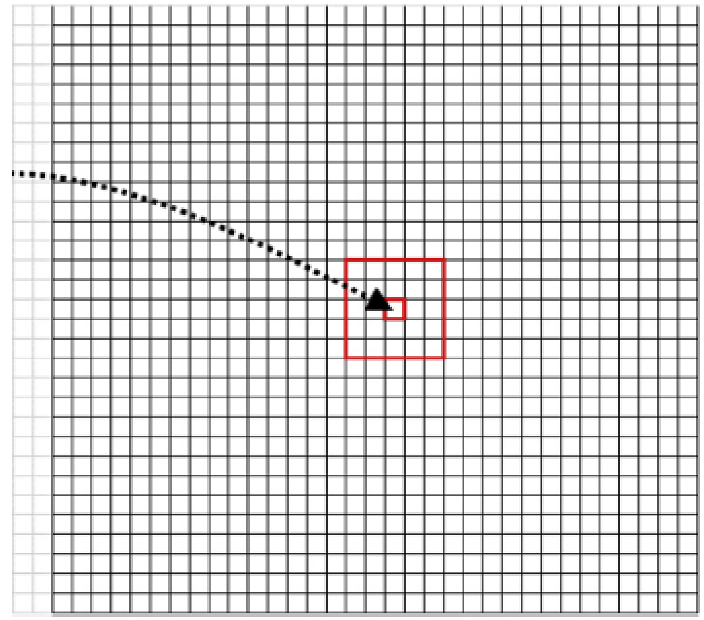
*p* = precursors
*k* = source aggregations
*j* = receptor cells

# Multi-ring approach

## SOURCE AGGREGATION



## RECEPTOR WINDOWS



$$\Delta C_j^{SC(1)} = \sum_{p}^{P} \sum_{k}^{N_A} a^{p}{}_{kj} \; \Delta E_{k,j}^{SC(1)\,p}$$

$$\parallel$$

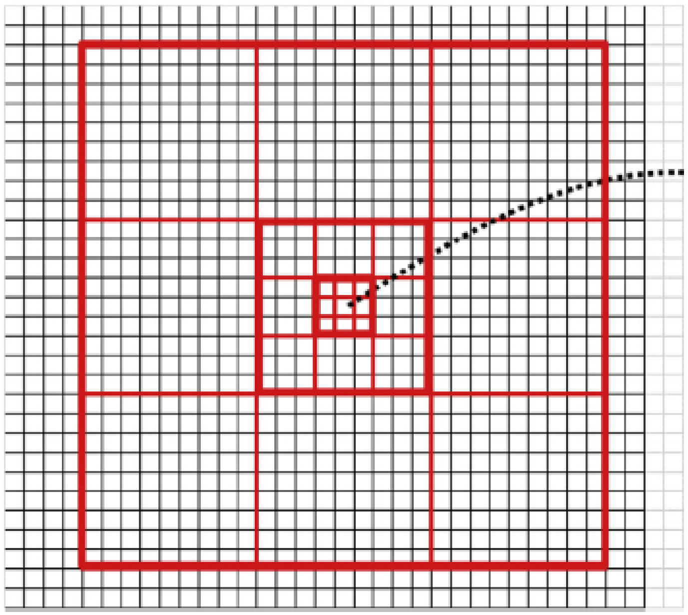
$$\Delta C_{j+1}^{SC(1)} = \sum_{p}^{P} \sum_{k}^{N_A} a^{p}{}_{kj} \; \Delta E_{k,j+1}^{SC(1)\,p}$$

d.o.f. = ( $N_A$ x P ) – ( $N_W$ x $N_{SC}$ ) ←

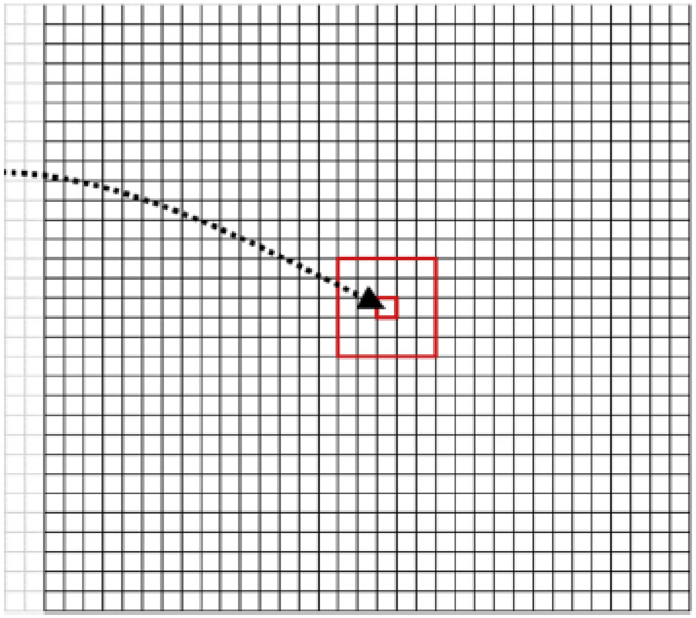
*p* = precursors
*k* = source aggregations
*j* = receptor cells
SC = scenario

# Multi-ring approach

**SOURCE AGGREGATION**



**RECEPTOR WINDOWS**



d.o.f. = $( N_A \times P ) - ( N_W \times N_{SC} )$

**BUT**

- ✘ Lack of robustness (small windows)
- ✘ Low accuracy (large windows)

# Linear approaches

$$\Delta C_j = \sum_{p}^{P} \sum_{i}^{N} a^p{}_{ij} \; \Delta E_i{}^p \longrightarrow \text{d.o.f.} = \text{N x P} \;\textbf{!!!}$$

*p* = precursors
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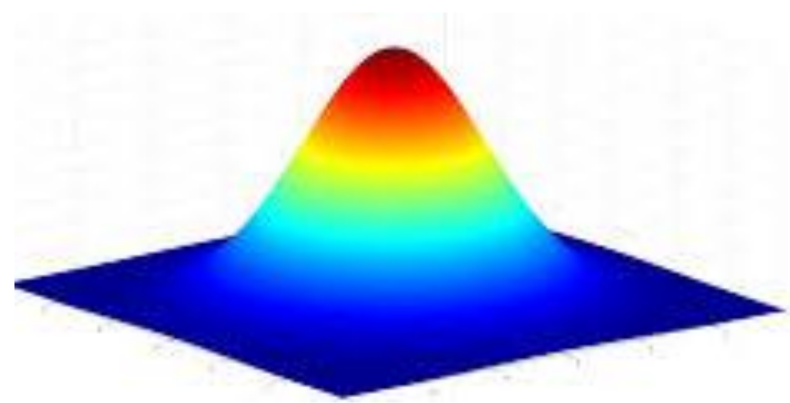
## *Multi-ring approach*

- SOURCE AGGREGATION
- RECEPTOR WINDOWS

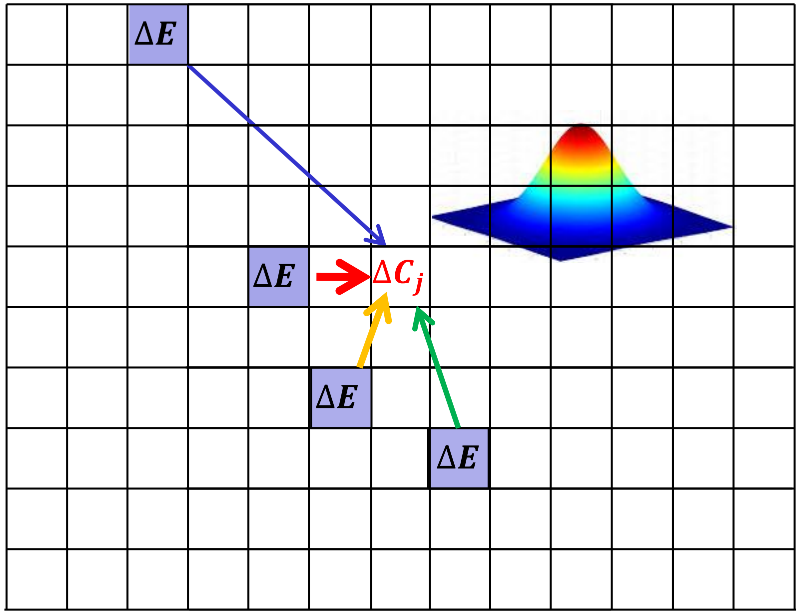
## *Bell-shape approach*

- CELL-TO-CELL RELATIONSHIP **DISTANCE WEIGHTED**
- ~ RECEPTOR WINDOWS



# Bell-shape approach

CELL-TO-CELL RELATIONSHIP
**DISTANCE WEIGHTED**




$$a^{p}{}_{ij} = \propto^{p}{}_{j} \; (1 + d_{ij})^{-\omega^{p}{}_{j}}$$

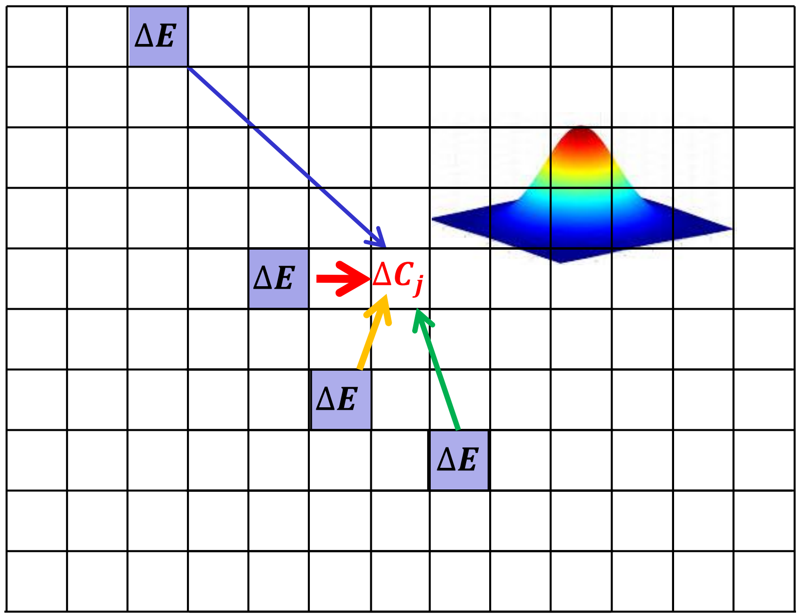
$$\Downarrow$$

$$\Delta C_j = \sum_{p}^{P} \propto^{p}{}_{j} \sum_{i}^{N} (1 + d_{ij})^{-\omega^{p}{}_{j}} \, \Delta E_i{}^{p}$$

→ d.o.f. = 2 x P

# Bell-shape approach

## CELL-TO-CELL RELATIONSHIP
## DISTANCE WEIGHTED

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$\longrightarrow$ d.o.f. = 2 x P

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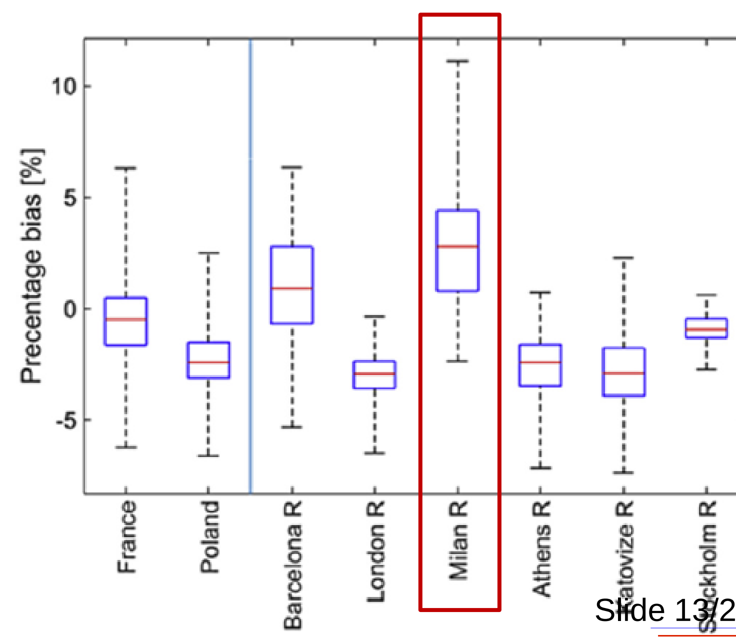
- ✘ Directionality ignored — **bias in windy areas**
- ✘ Geographical complexities not accounted — **bias in mountain areas**



# Bell-shape approach

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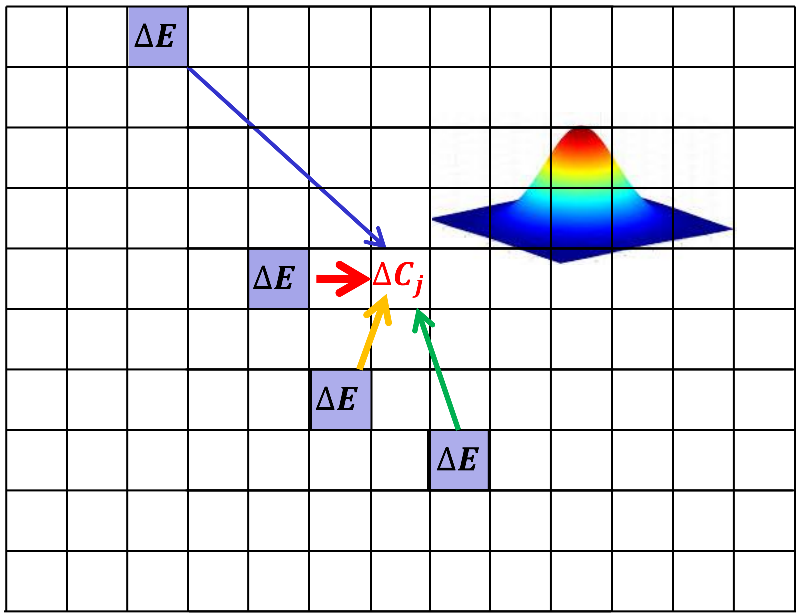


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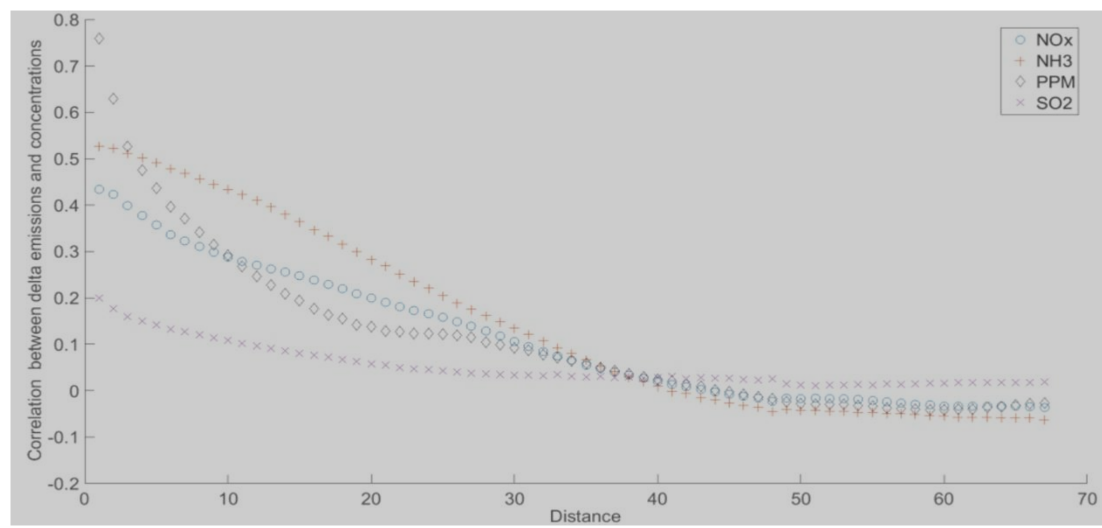
⟶ d.o.f. = 2 x P

- $\omega$ ↓ Low spatial variability

  ↑ High precursor dependence

- $\alpha$ ↑ High spatial variability

  ↑ High precursor dependence



# SHERPA Algorithm

$$\Delta C_j = \sum_{p}^{P} \propto^{p}{}_{j} \sum_{i}^{N} (1 + d_{ij})^{-\omega^{p}{}_{j}} \Delta E_i{}^{p}$$

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$$\Downarrow$$

**STEP 1**

Precursors treated independentely

$$\Delta C_j{}^{p} = \propto^{p}{}_{j} \sum_{i}^{N} (1 + d_{ij})^{-\omega^{p}{}_{j}} \Delta E_i{}^{p} \qquad \forall p$$

$$\Downarrow$$

Unique R-Window
( or wind speed based, thershold 0.5 m/s)

$$\Delta C_j{}^{p} = \propto^{p} \sum_{i}^{N} (1 + d_{ij})^{-\omega^{p}} \Delta E_i{}^{p} \qquad \forall p \; \forall j$$

⟶ d.o.f. = 2

$$\Downarrow$$

Least square estimation
between emission and concentration changes

$$\boldsymbol{\omega^{p}} \, , \boldsymbol{\alpha^{p}} \qquad \forall j$$

# SHERPA Algorithm

$$\Delta C_j = \sum_{p}^{P} \propto^p{}_j \sum_{i}^{N} (1 + d_{ij})^{-\omega^p{}_j} \Delta E_i{}^p$$

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Least square estimation
between emission and concentration changes

$$\omega^p \, , \alpha^p \qquad \forall j$$

$$\Downarrow$$

## STEP 2

Emission weighted average delta calculation

$$\Delta \bar{E}_j{}^p = \sum_i^N (1 + d_{ij})^{-\omega^p} \Delta E_i{}^p \quad \forall p$$

$$\Downarrow$$

All training scenario at the same time
(all precursors reduced contemporarily)

$$\Delta C_j = \sum_p^P \propto^p{}_j \Delta \bar{E}_j{}^p$$

$$\Downarrow$$

Multi linear regression
between emission weighted average and concentration deltas

$$\alpha^p{}_j$$

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# Software specifications and hardware requirements

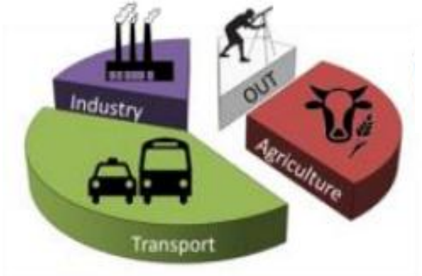
SHERPA (graphical user interfaces - GUIs - and operation processes) is developed on J2SE platform (java 2 standard edition). SHERPA data pre- and post- processing is managed by FORTRAN executables. The core computation module uses PYTHON executable. SHERPA GIS interface is implemented using NASA World Wind. SHERPA is entirely open-source.

SHERPA is developed for Windows operating systems.
The minimum hardware requirements are:

- CPU, no request, the current standard (3 - 3.50GHz) will guarantee an acceptable computation time
- RAM: minimum 2GB
- Disk storage: minimum 2GB (each simulation will require additional disk space)

- Database (input) and output ⟶ netCDF, txt

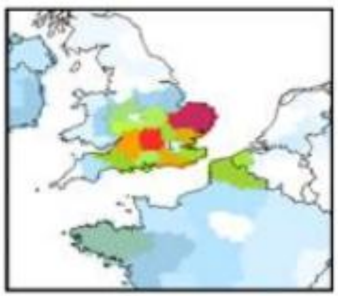
# Tasks




**Source allocation**

*Computes the relative contribution of the various emission sectors/precursors originating inside a region to the amount of pollution in the area*

**WHAT** can I influence?
**WHICH** sectors/pollutants?



**Governance**

*Identifies the principal source areas of the pollution at a location*

**WITH WHOM** should I coordinate actions?

**Impacts**

**HOW MUCH** impacts?

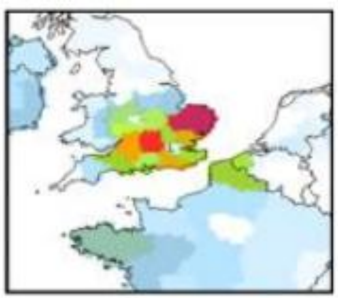
*Tests the impact of an emission reduction scenario in a region*

# Modules


Source allocation

**Module**: SOURCE APPORTIONMENT

**WHAT** can I influence?
**WHICH** sectors/pollutants?



**Module**: GOVERNANCE CONTROL AREA

Governance

**WITH WHOM** should I coordinate actions?

**HOW MUCH** impacts?

Impacts

**Module**: SCENARIO ASSESSMENT

# Module SOURCE APPORTIONMENT

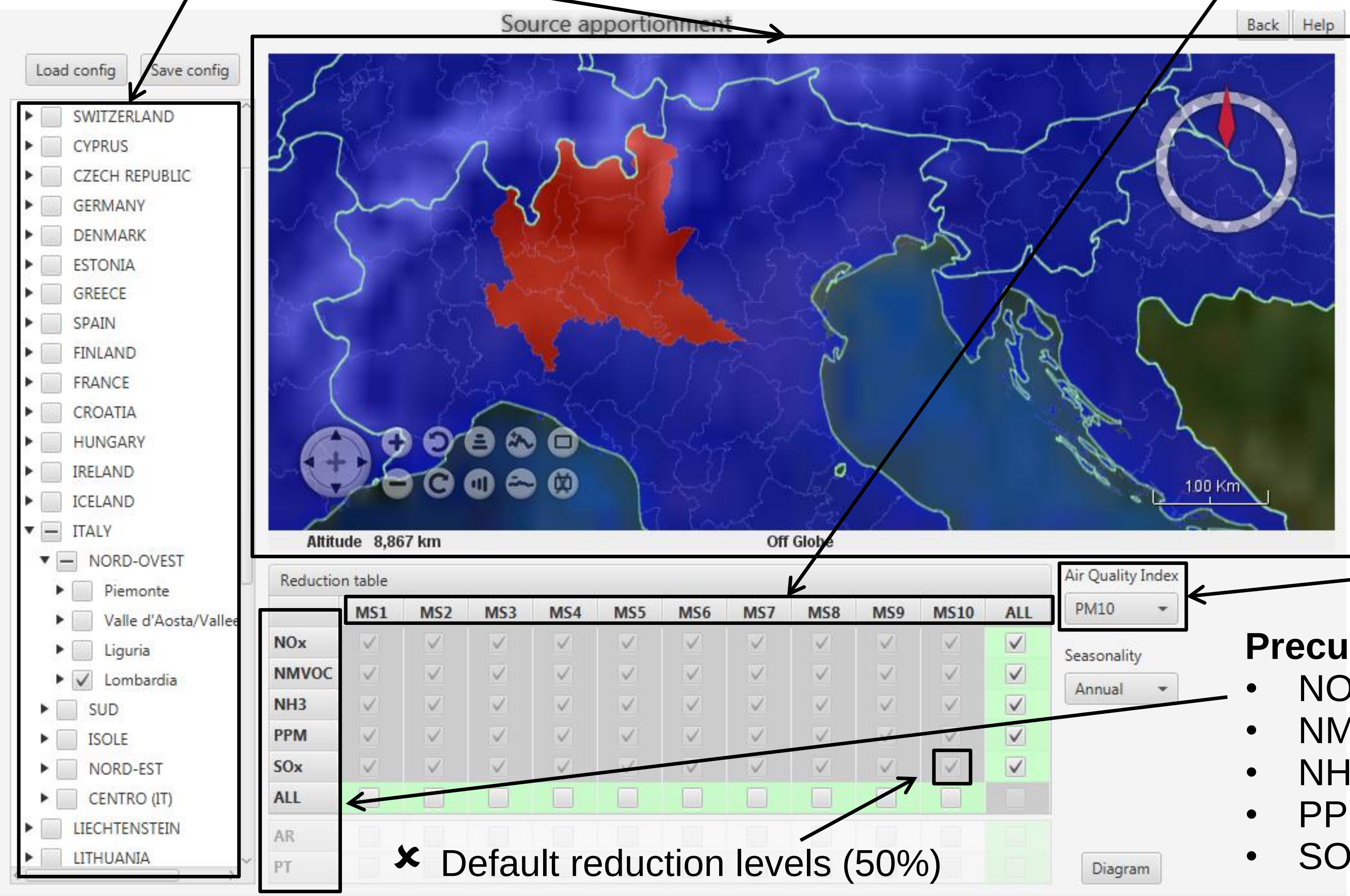
## INPUT

**NUTS:**

- NUTS0: country areas (e.g. Italy)
- NUTS1: major socio-economic regions (e.g. Nord-Est )
- NUTS2: basic regions for the application of regional policies (e.g. FVG)
- NUTS3: small regions for specific diagnoses (e.g. Udine)

**SNAP Macrosectors:**

- MS1: combustion in energy industries
- MS2: residential combustion
- MS3: combustion in manufacturing industry
- MS4: production processes
- MS5: fuels extraction and distribution
- MS6: solvent use
- MS7: road transport
- MS8:other transports
- MS9: Waste treatment
- MS10: Agricolture




✘ Default reduction levels (50%)

**AQ Indexes:**

- NO2
- PM10
- PM2.5
- (O3)

**Precursors:**

- NOx
- NMVOC
- NH3
- PPM
- SOx

**WHICH** pollutants?

# Module SOURCE APPORTIONMENT

## OUTPUT

Absolute or relative potential
(in respect of the base case)

Cells contribution

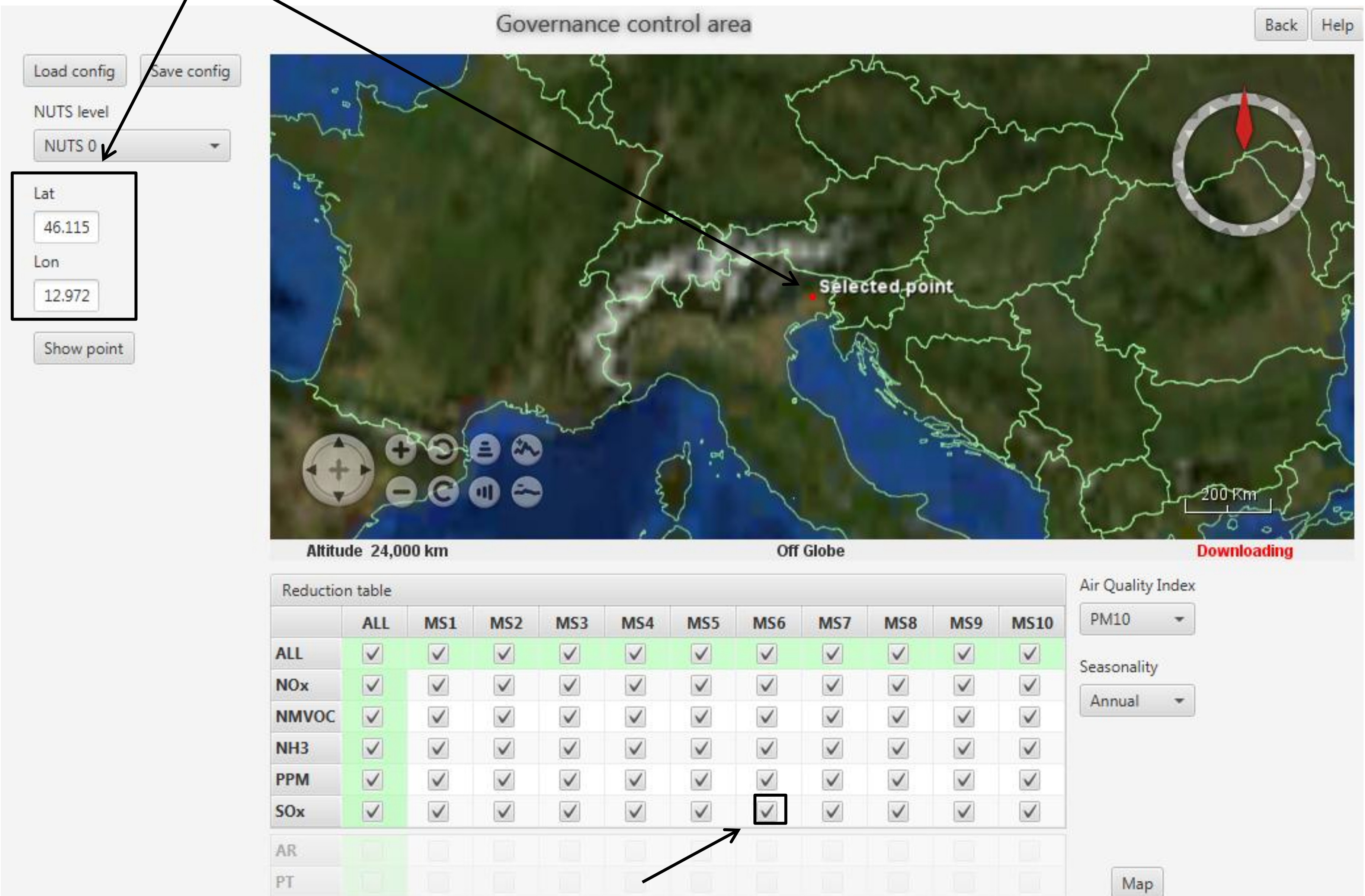
WHAT can I influence?


WHICH sectors?

# Module GOVERNANCE CONTROL AREA

## INPUT

Selected point




✘ Default reduction levels (50%)

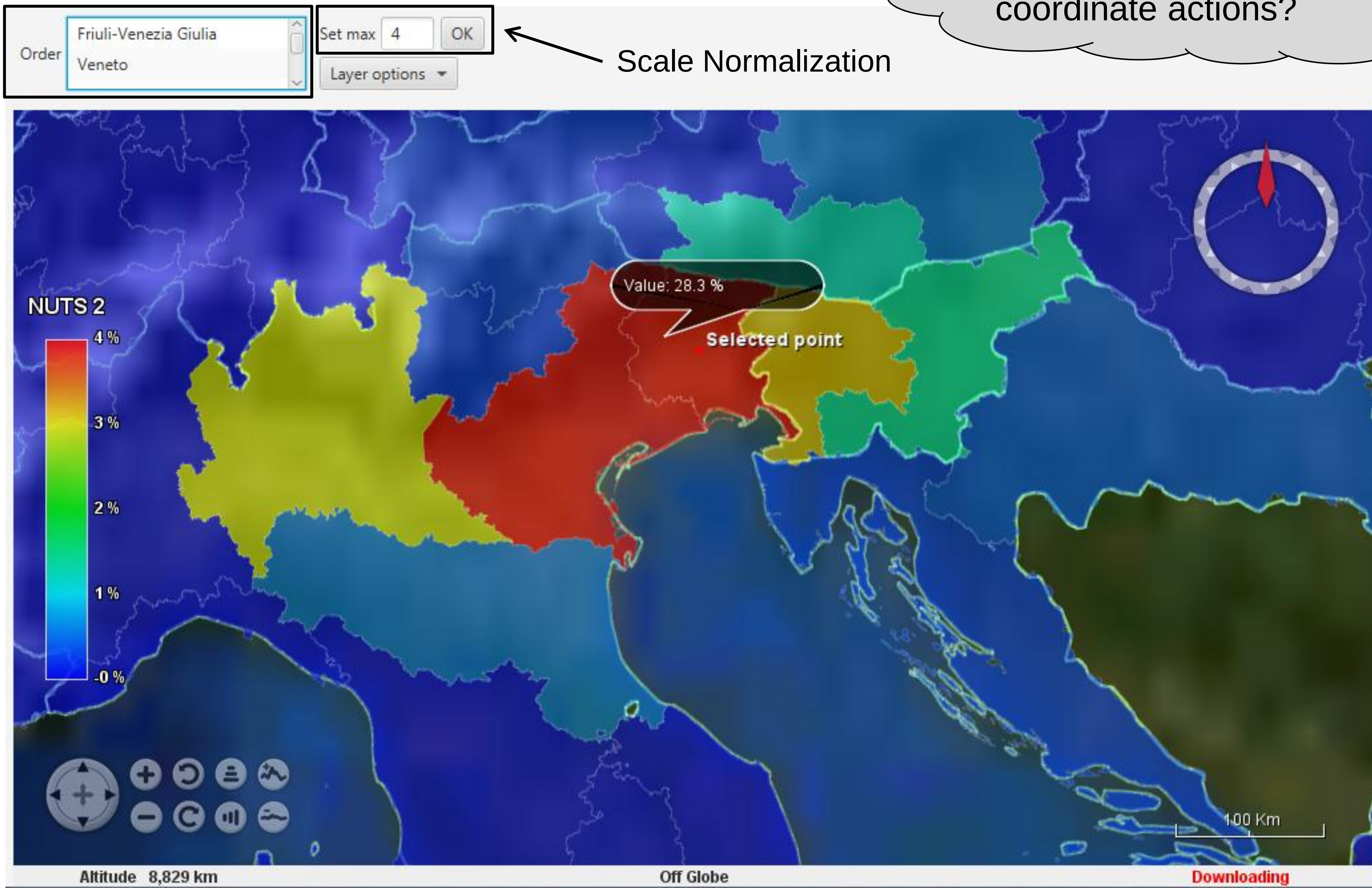
# Module GOVERNANCE CONTROL AREA

**OUTPUT**

WITH WHOM should I coordinate actions?

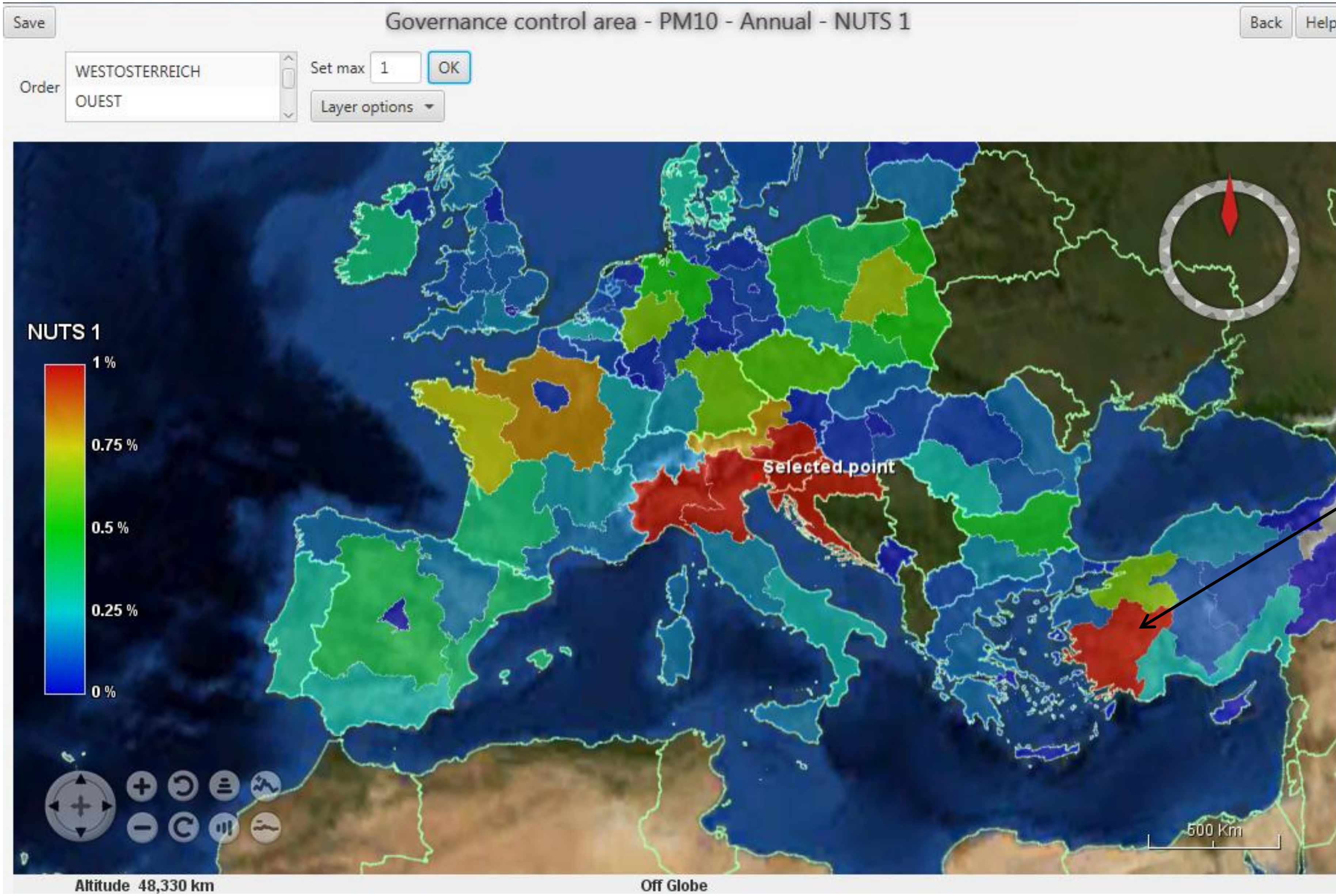
✗ Significance threshold ~1%

Scale Normalization



# Module GOVERNANCE CONTROL AREA

## OUTPUT (under significance threshold ( 1%)

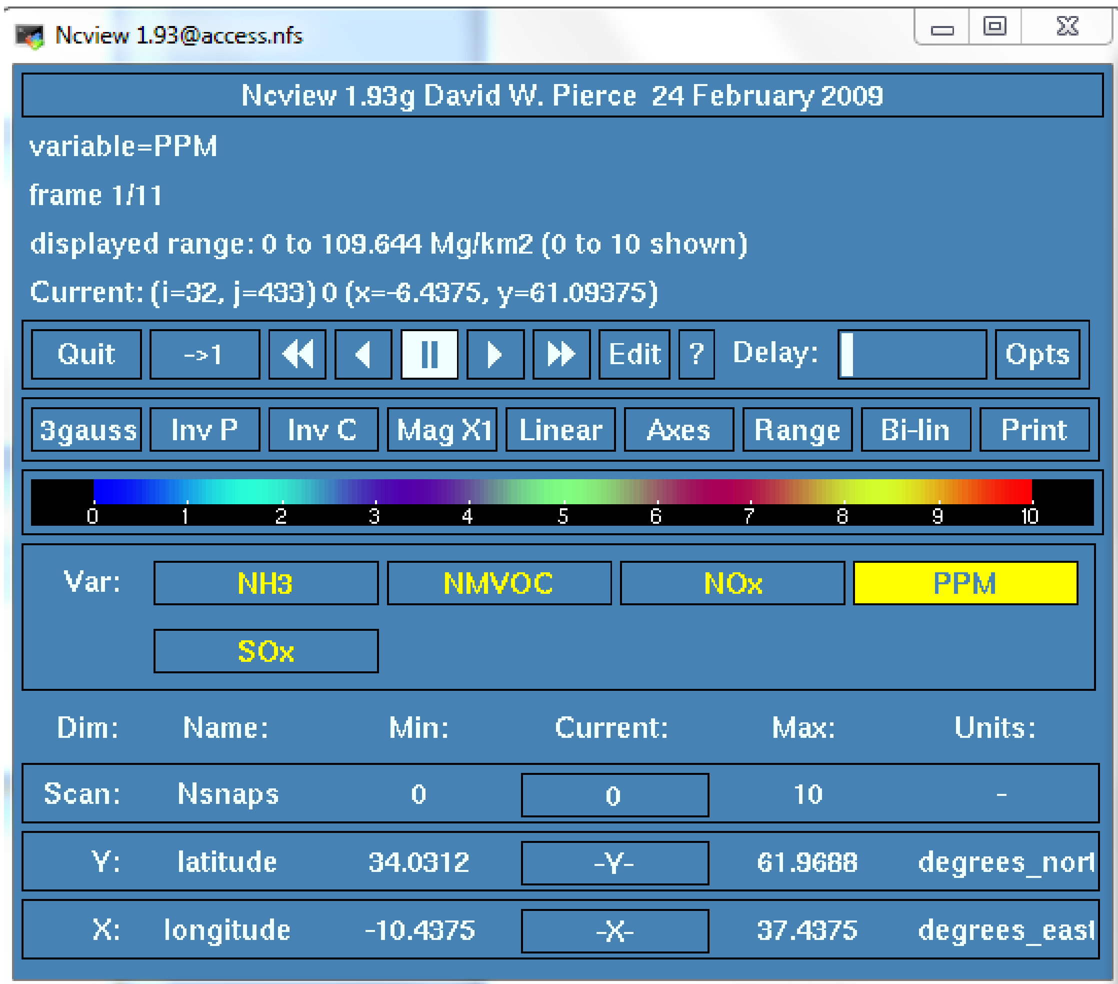


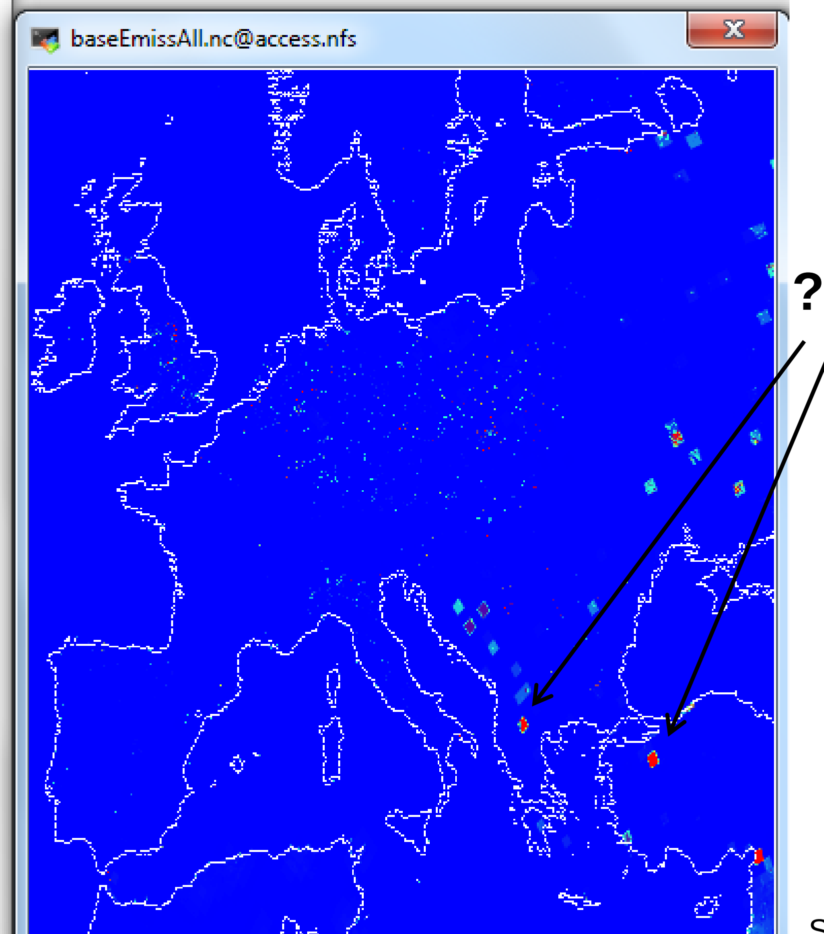

???!!!

# Module GOVERNANCE CONTROL AREA

## OUTPUT (under significance threshold ( 1%)

Emissions database (INPUT)

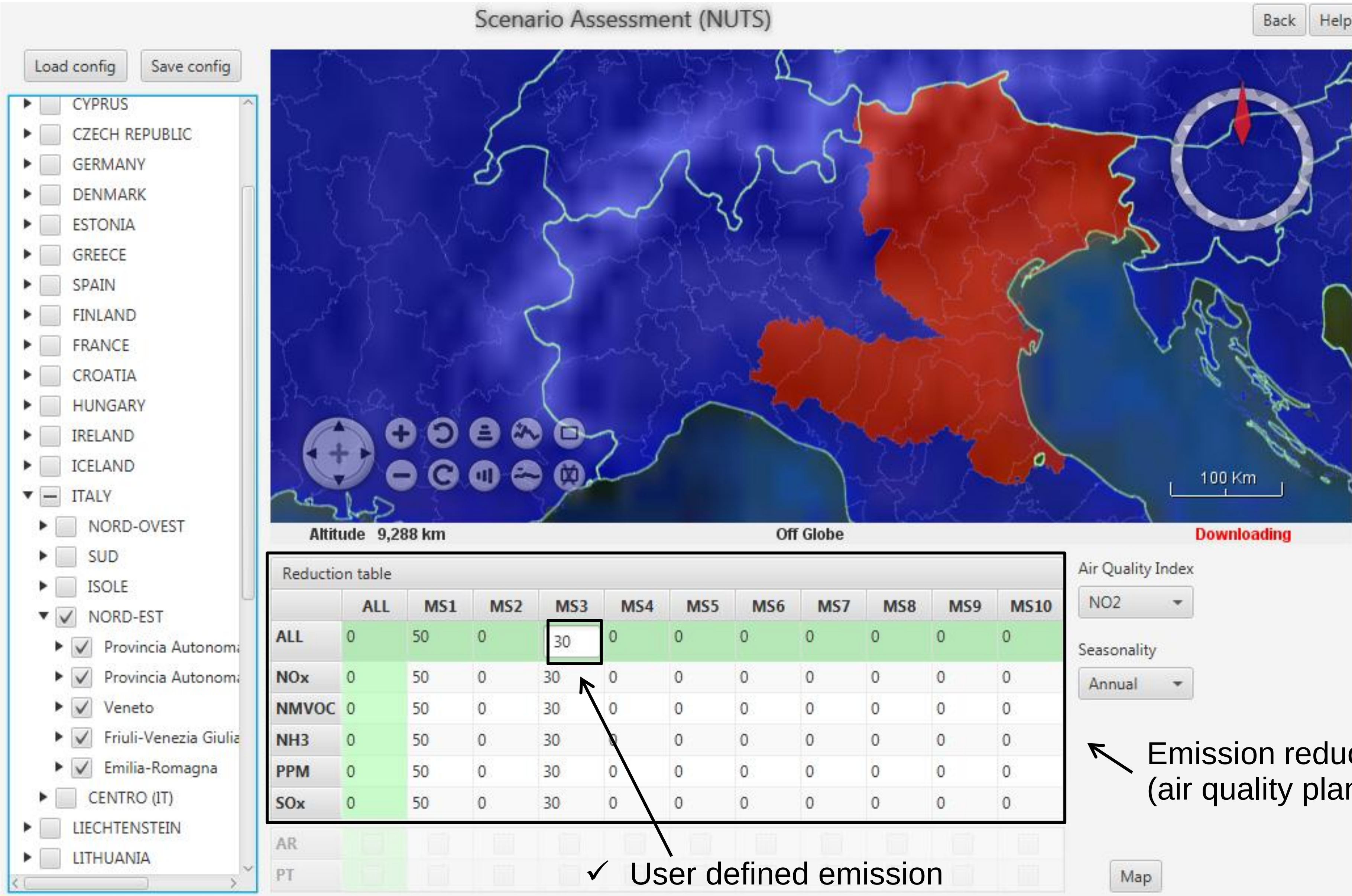



???!!!

# Module SCENARIO ASSESSMENT

## INPUT




| | ALL | MS1 | MS2 | MS3 | MS4 | MS5 | MS6 | MS7 | MS8 | MS9 | MS10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ALL | 0 | 50 | 0 | 30 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NOx | 0 | 50 | 0 | 30 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NMVOC | 0 | 50 | 0 | 30 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NH3 | 0 | 50 | 0 | 30 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| PPM | 0 | 50 | 0 | 30 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SOx | 0 | 50 | 0 | 30 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| AR | | | | | | | | | | | |
| PT | | | | | | | | | | | |

Emission reduction scenario (air quality plan)

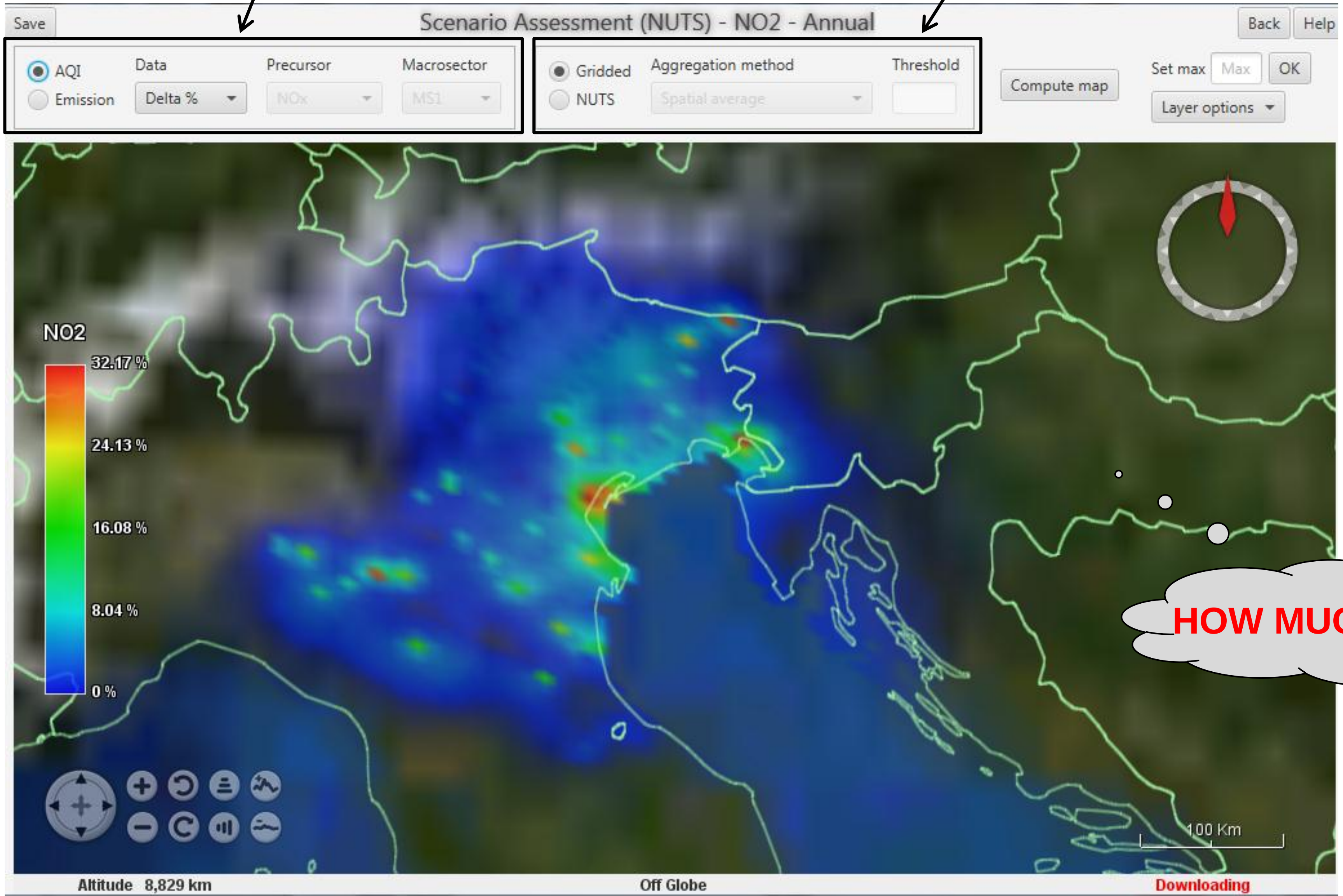
✓ User defined emission reductions percentages

# Module SCENARIO ASSESSMENT

## OUTPUT

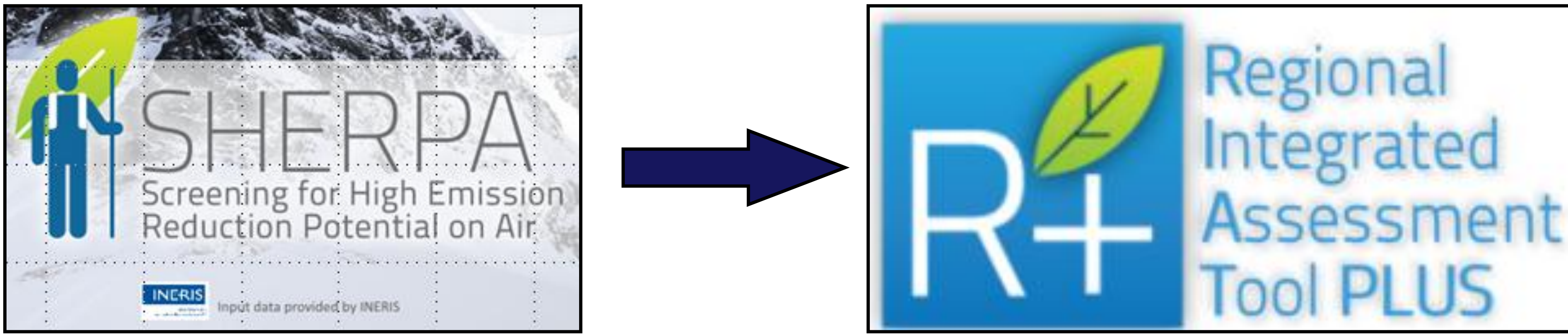
Concentrations or emissions (precursor, macrosector) maps

SPATIAL RESOLUTION:
gridded or aggregated in nuts
(spatial average, population
weighted, average over threshold)




HOW MUCH impacts?

# Module FIRST GUESS RIAT+




(cost/effectiveness analysis)

The system will automatically create all the required input files for the RIAT+ tool:

- Domain file;
- Mapping file;
- Emission inventory files;
- GAINS measures database;
- Source-Receptor functions.

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# Conclusions

✓ SHERPA represents a challenging **user-friendly** tool for the assessment of regional air quality plans

✓ Bell-shape methodology provides a good compromise between **accuracy** and **speed**, **spatial flexibility** and **light set-up**

✗ But it shows **biases in windy and mountainous areas**:

**Is the SHERPA tool suited for analysis in our area?**

# Index

# References


- **Adding spatial flexibility to source-receptor relationships for air quality modeling,** *E. Pisoni et al*., Environmental Modelling & Software 90 (2017) 68e77
- **On the design and assessment of regional air quality plans: The SHERPA approach,** *P. Thunis et al*., Journal of Environmental Management 183 (2016) 952e958
- **SHERPA User Guide**, Version 1.5, *April 2016*
- **SHERPA: a screening tool to support air quality plans,** (slide) *P. Thunis et al*.