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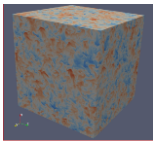
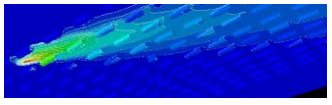
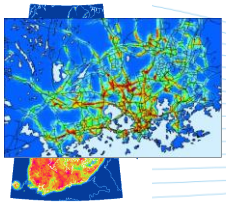
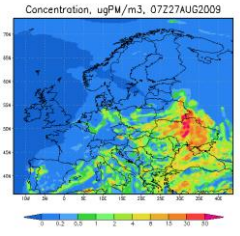
Dispersion Modelling

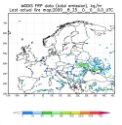


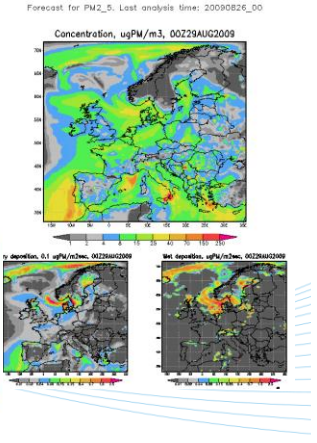
Research manager,
Dr. Tech, Docent
Ari Karppinen
9/2015











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Contents

- Introduction:
  - goals
  - “Fit for purpose”
  - model classification
- Practical examples/snapshots
  - Regional/global scales
  - “country”-scale modeling
  - Urban scale modelling
  - Fusion
  - Emission (ships) modeling
- Challenges

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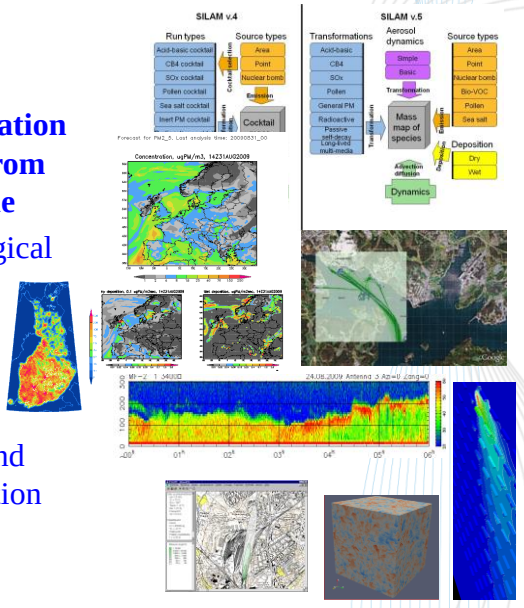
AQMg : the aims

1. **Development and evaluation of air quality models : from microscale to global scale**
2. Integration of meteorological models (including climat dispersion models
3. Efficient use of all availa measurement informatio
4. Application of models, and dissemination of information



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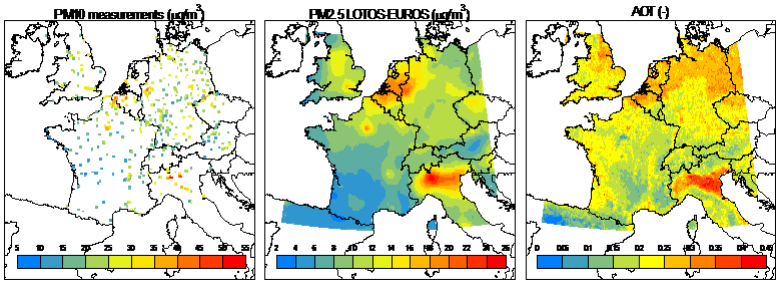
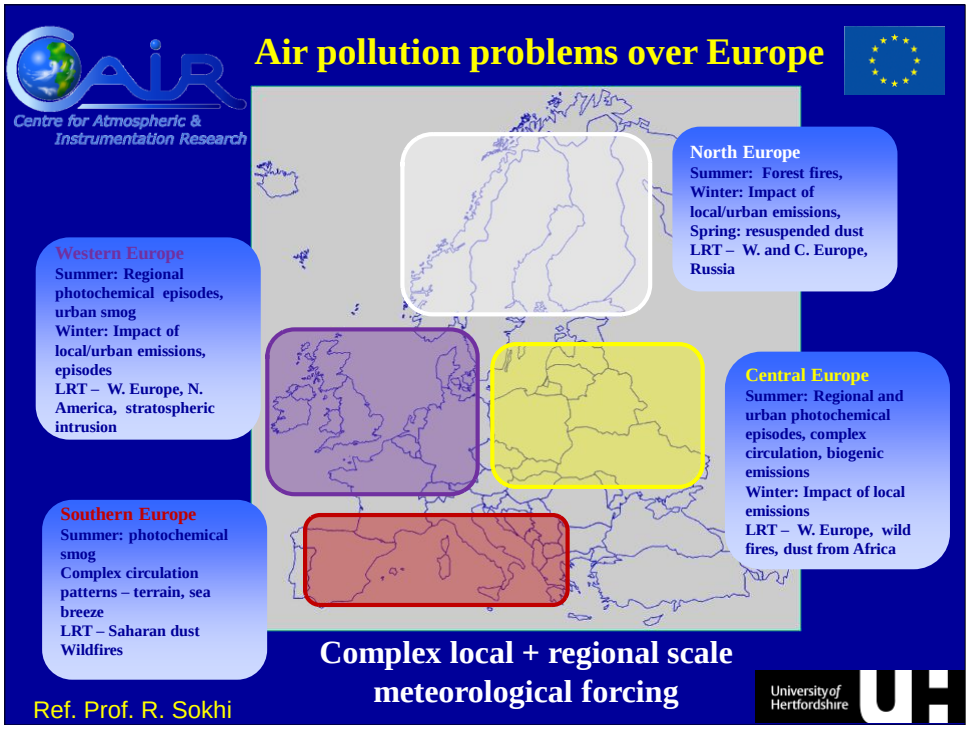
Integrated use of models



Monitoring Models Satellite

Goal: operational system taking into account all sources of information



http://aqicn.org/map/china/

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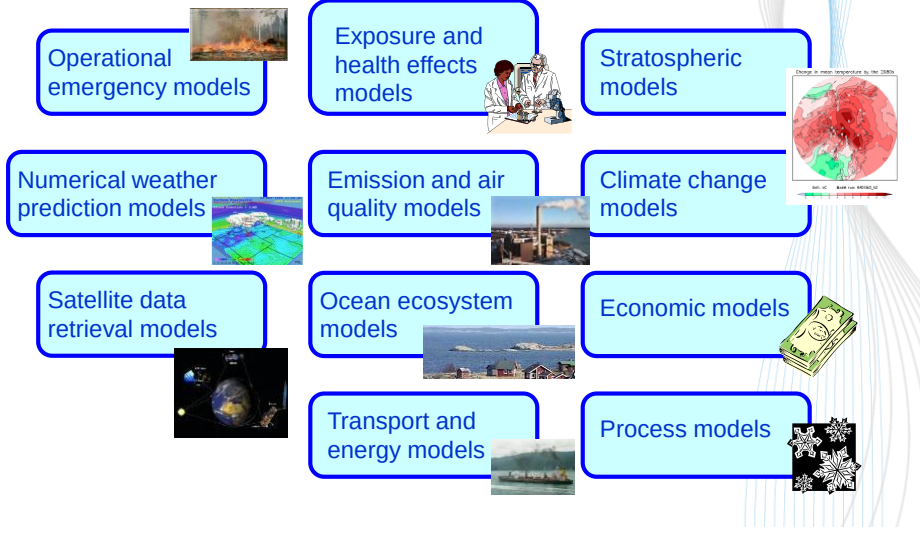
Some potential combinations of models



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Model classification

$$C = \frac{Q_l}{2\sqrt{2\pi}\,\sigma_z\, u \sin\theta}\left[\exp\left(-\frac{(z-H)^2}{2\sigma_z^2}\right) + \exp\left(-\frac{(z+H)^2}{2\sigma_z^2}\right)\right]\left[\operatorname{erf}\left(\frac{\sin\theta\,(p-y)-}{\sqrt{2}\,\sigma_y}\right) + \operatorname{erf}\left(\frac{\sin\theta\,(p+y)+x\cos\theta}{\sqrt{2}\,\sigma_y}\right)\right],$$

where C is the concentration, Q_l is the source per unit length, u is the average wind speed, θ is between the wind direction and the road, x, y the coordinates, H is the effective source height half-length of the line source, erf is the error func σ_z and σ_y are the vertical and lateral dispersi meters, respectively. The solution (1) allows for direction with respect to the road.

- Gaussian models
  - Point, line, area, volume
  - **Static** conditions
- Lagrangian models
  - Tracking the movement on thousands of particles representing air pollution
- Eulerian (4D-grid) models
  - Chemistry, aerosol processes, large scales..
- *box models; receptor models, statistical models ..*

$$L\varphi = E, \qquad L = \frac{\partial}{\partial t} + \frac{\partial}{\partial x_i}(u_i) - \frac{\partial}{\partial x_i}\mu_{ii}\frac{\partial}{\partial}$$ (1)

with boundary conditions:

$$\varphi(t=0) = 0$$

$$\mu_{i3}\left.\frac{\partial\varphi}{\partial x_3}\right|_{x_3=h_1} = v_d\,\varphi(h_1); \qquad \left.\frac{\partial\varphi}{\partial x_3}\right|_{x_3=H} = ($$ (2)

$$\left.\frac{\partial\varphi}{\partial x_i}\right|_{(x_1,x_2)\in\partial\Omega} = 0, \quad i = 1,2$$

Here L is a differential operator, x_i, $i=1..3$ denote the three spatial axes, u_i are t is the turbulent diffusion coefficient in air (we shall use this first-order closu represents all sink processes, φ is the unknown concentration of the pollutant heights h_2 and H are the lower and upper boundaries of the air transport domai

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Model selection (fit for purpose)

European scale => urban and local scales

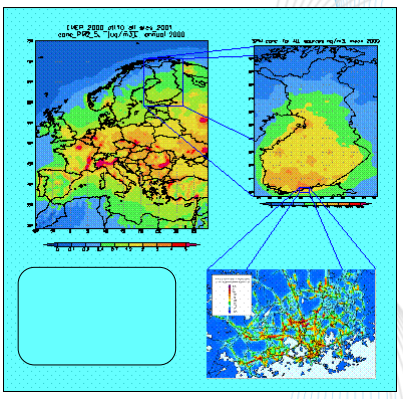
•For regional scales Eulerian models the natural option

- connection with NWP's
- chemistry & aerosol processes

• for urban /local scales models capable of dealing with sharp local concentration gradients needed

+ spatial resolution

- temporal resolution and chemistry/aerosol process descriptions



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Specific challenges of PM modelling

- Modelling the <u>emissions</u>
  - suspension, biogenic emissions, fires, sea-salt…
- Modelling the chemistry & <u>aerosol processes</u>
  - Especially important for regional scale studies
- Modelling the <u>physical properties</u> of aerosols
  - Shape, density, size distribution , composition..

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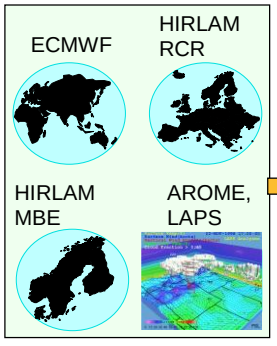
Modelling system - FMI

Weather prediction models

Dispersion models - long-range, regional

Dispersion and effects models – urban, local



SILAM LRT, meso-scale, radioactivity , pollen

HILATAR LRT, meso-scale

Aerosol process models:
UHMA (U Helsinki, FMI)
MONO32 (U Helsinki, Stadia)
SALSA(UH,UKU,FMI)
SILAM-APMs

CAR-FMI, roadside

UDM-FMI, urban

OSPM (NERI), street canyon

BUOYANT, fires

ESCAPE, chemical accidents

FINFLO,FLUENT(CFD), PALM, DNS-code development

EXPAND (FMI, YTV) population exposure

MPP-FMI, Meteorological pre-processing model

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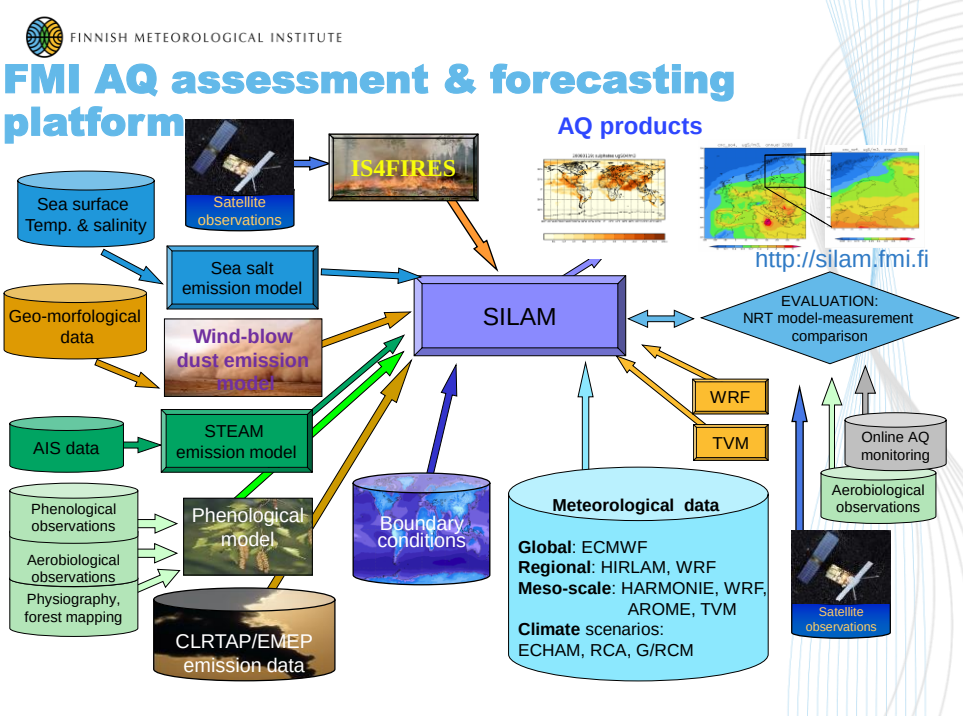
FMI AQ assessment & forecasting platform



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SILAM application types & scales

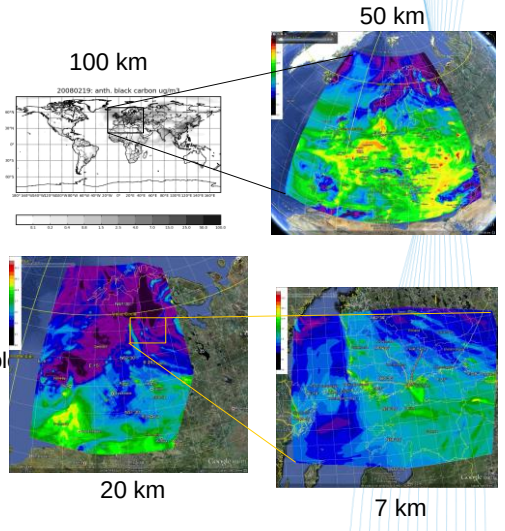
Short-term forecasting and re-analy
- atmospheric chemical composition
- allergenic air pollution
- plumes of wild-land fires

Emergency preparedness
- nuclear
- volcanic

Source apportionment studies
- anthropogenic sources
- natural sources: allergenic pollen, vol

Risk assessment
- chemical
- nuclear

Climate change forcing and impact



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SILAM v.5.5

Atmospheric dispersion simulation

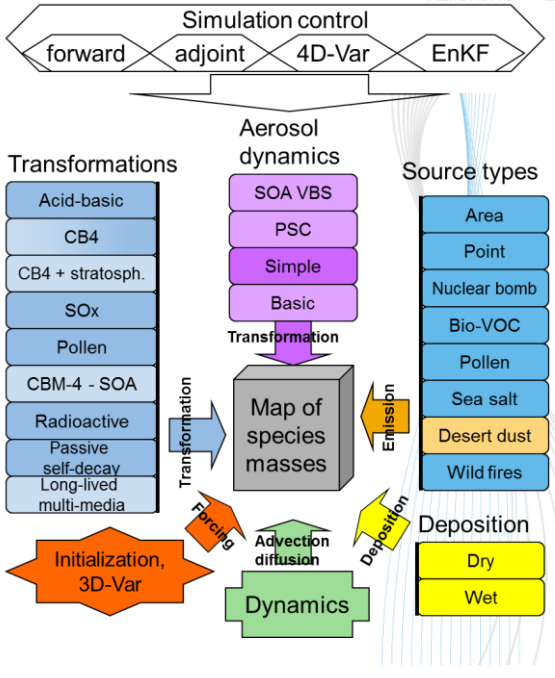
1) Forward problem: to estimate concentrations

$$L = \frac{\partial}{\partial t} + \frac{\partial}{\partial x_i}(u_i) - \frac{\partial}{\partial x_i}\mu_{ij}\frac{\partial}{\partial x_j} + \sigma; \quad L\varphi = f;\ M = (p, \varphi)$$

2) Adjoint problem: source apportionment

$$L^* = -\frac{\partial}{\partial t} - \frac{\partial}{\partial x_i}(u_i) - \frac{\partial}{\partial x_i}\mu_{ij}\frac{\partial}{\partial x_j} + \sigma; \quad L^*\varphi^* = p;\ M = (f, \varphi^*)$$

Modules
- 9 chemical and physical transformation modules (7 open for operational use),
- 8 source terms (all open),
- 4 aerosol dynamics (1 open)
- 3D-,4D- Var, EnKF



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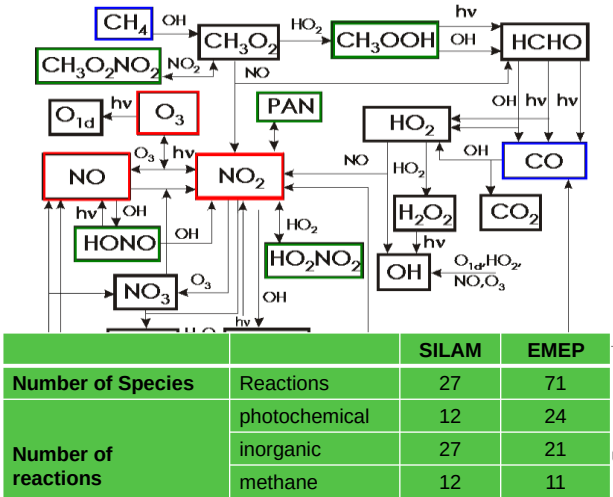
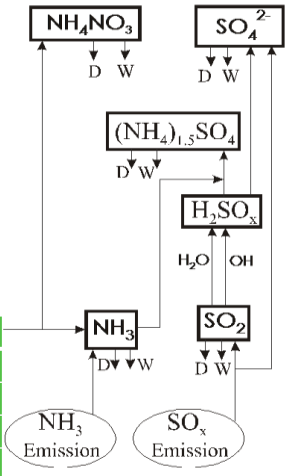
SILAM acid-basic chemistry





		SILAM	EMEP
Number of Species	Reactions	27	71
Number of reactions	photochemical	12	24
	inorganic	27	21
	methane	12	11
	ethane	2	15

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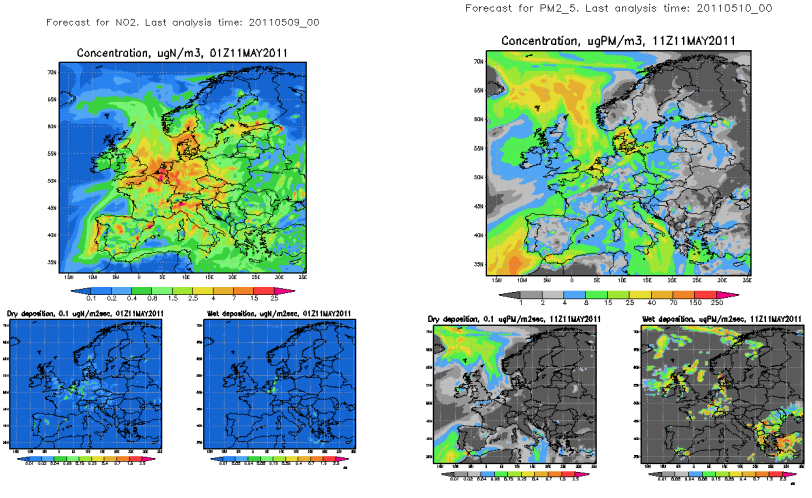
European AQ forecast (SO2, NO, NO2, CO, O3, PM10, PM2.5, *Rn*)



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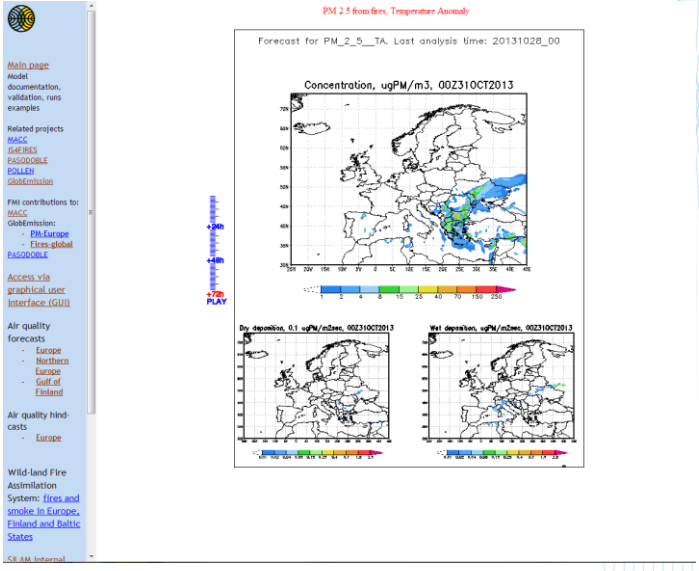
Forest fires, volcanoes, etc…

http://silam.fmi.fi/



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macc Monitoring atmospheric composition & climate

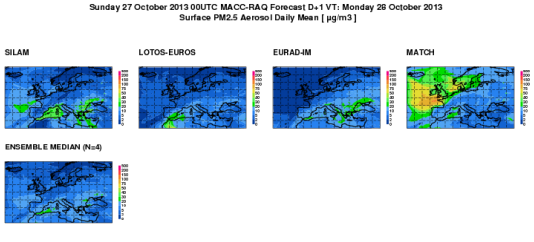
MACC3 - Monitoring Atmospheric Composition and Climate: European air quality forecasting ensemble, (http://macc-raq-op.meteo.fr/?op=get)

+ Clearly largest forecasting ensemble up to date, for main gaseous and PM pollutants

+ A concerted effort with a better overall reliability and versalitility

- Can still be improved: mass closure of PM, non-antropogenic PM

- Structure and treatments of models are variable (e.g. data assimilation, evaluation)



Example forecasts using 4 (7) models , and ensemble forecast

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From global and regional to local scales.

Examples and future plans

FUSION

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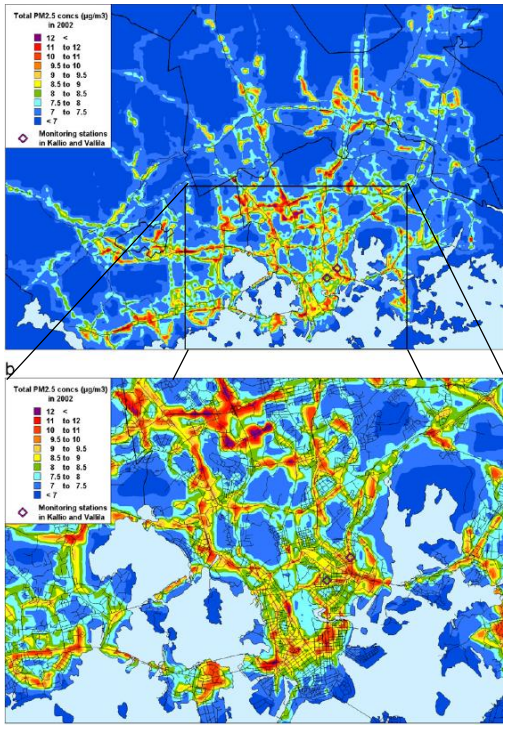
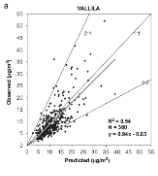
Predicted spatial distribution of the yearly means of $PM_{2.5}$ concentrations (mg / m^3) (upper figure) in the Helsinki Metropolitan Area, and (lower figure) in the centres of the cities of Helsinki and Espoo, in 2002.

The size of the depicted area in upper figure is 35 km times 25 km.

◊ = the locations of the urban monitoring stations



Scatter plot of measured and predicted daily averaged concentrations at the station of Vallila.



Ref. Kauhaniemi et al., 2008. Atmos. Environ. Vol 42/19 pp 4517-4529.

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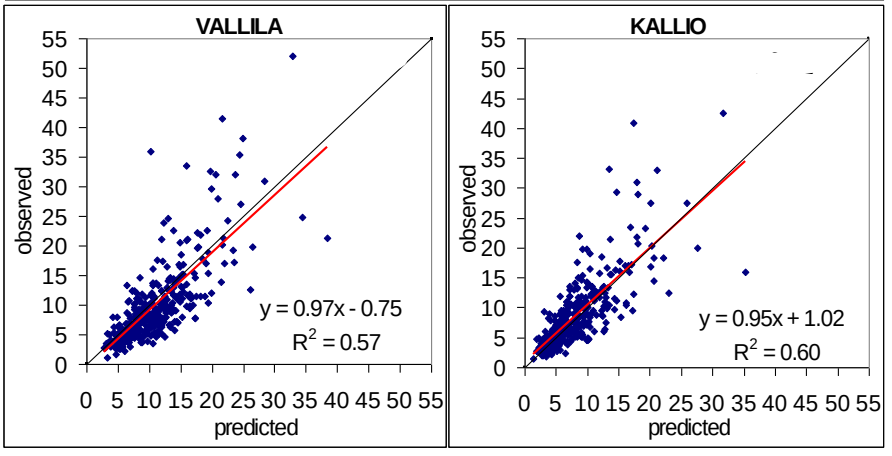
ytv

Predicted vs. observed daily mean
$PM_{2.5}$ concentrations at two stations – scatter plot, Correlation Coefficient squared (R^2) and Index of Agreement (IA)



VALLILA: R^2 = 0.57, IA = 0.84

KALLIO: R^2 = 0.60, IA = 0.86

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Future:

Fusion of meteorological and air quality information

Idea: to combine ALL available information (models, measurements, land use, traffic, population data..)

to achieve the ”optimal” view of the state of environment

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Huge potential

- The methodology would bridge the gap between modeling and the measurements especially in difficult environments like megacities

- Basic requirements :
  - dense measurement network : good coverage of all relevant environments
  - Supporting information available: land use, traffic, population density

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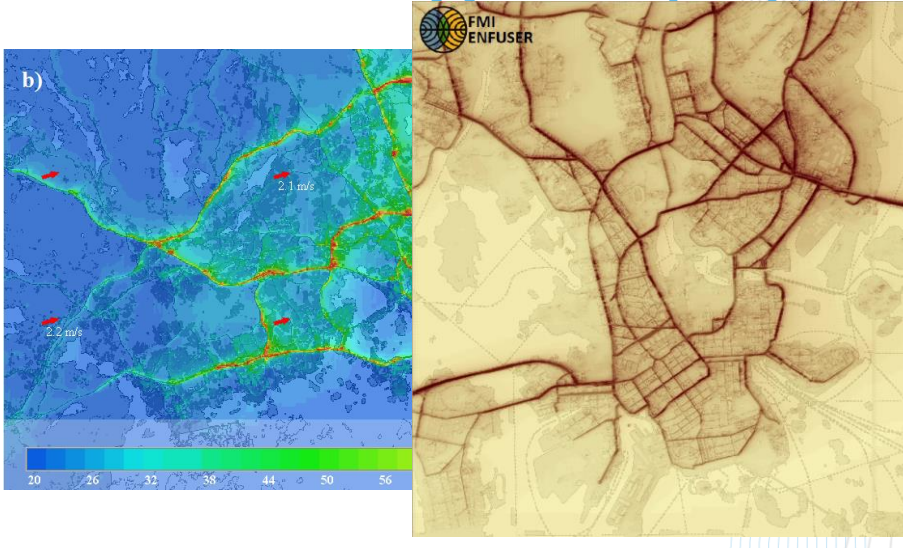
FMI-ENFUSER approach (1/3)



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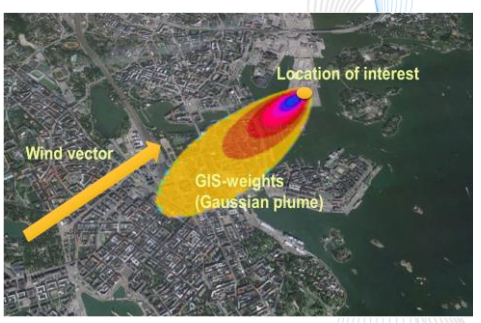
Dynamic land use regression

- Combines **land-use regression** (LUR) and **dispersion modelling** into a novel approach named as ”**dynamic land-use regression**”



LUR: Calibration methodolody without knowledge of local emission sources

Dispersion modelling: Meteorology, wind profiles, 3D (height-differences!)

- **Fusion algorithm:** adaptation to sensor measurements & modelled data
  - Assimilation of these 3 techiniques into one
    – **on-going process since 2011**

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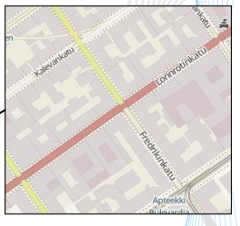
OpenStreetMap & street canyons

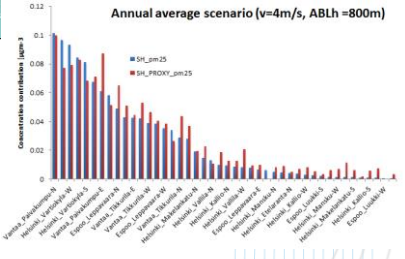
OpenSreetMap (OSM) is an open access map service provider that offers high resolution maps world wide.

Together with **Population density mapping**, this yields a good mapping of **vehicular traffic.**

Alongside with OSM, other information sources can be used (CORINE, satellite images)



Street canyons and buildings can be analyzed from the



Even households (buildings) that act as sources for PM2.5 can be detected from OSM

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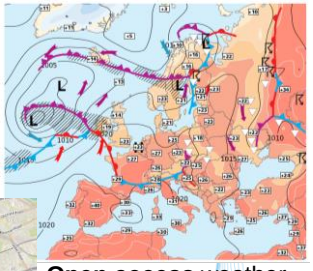
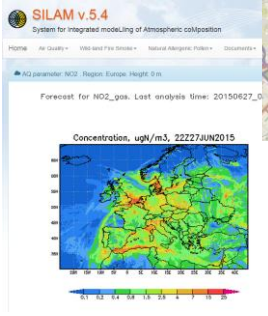
Available data source for MobileAirQual



Open access weather

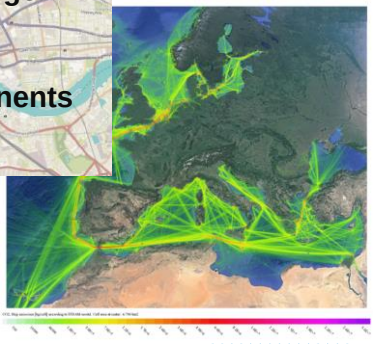
OpenStreetMap – the backbone of our LUR-approach is **freely availabe**

FMI-SILAM: regional air quality in Europe – implemented in our approach (**free**)



All we need is sensor data for a cutting edge real-time system.

(At least the components for one are all here)



FMI-STEAM: Shipping emissions in Europe (up to 25 x 25m x 6min resolution), **implemented**

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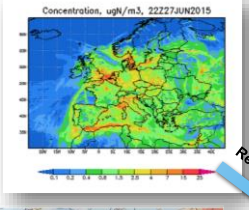
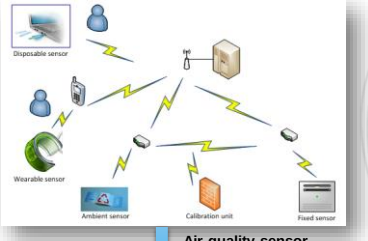


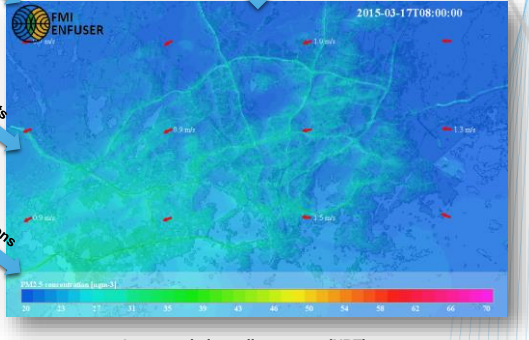
Regional AQ forecasts

Weather forecasts

Shipping emissions



Air quality sensor network



Integrated air quality system (NRT)

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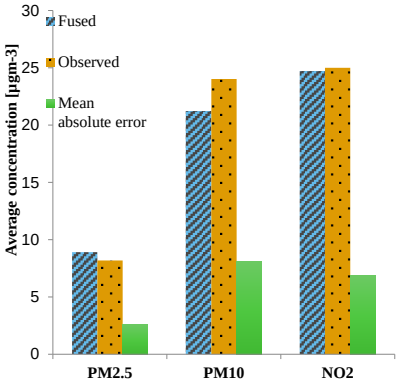
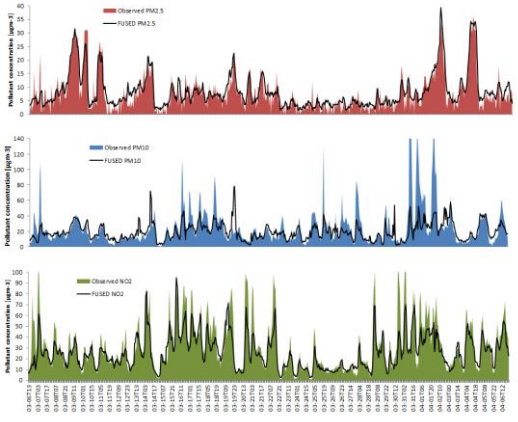
In Finland it Works (1/2)

- Estimation of hourly PM2.5, PM10, NO2 at selected urban measurement site (Leppävaara, one of the sites used in the study)





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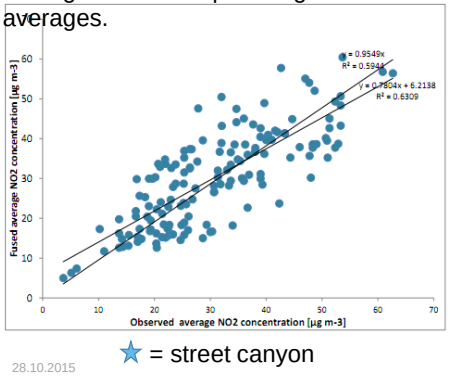
In Finland it Works (2/2)

ENFUSER was calibrated with 2011 data from another region. Then, ENFUSER predicted hourly concentration of NO2 in 38 locations near Helsinki in 2010. Predicted seasonal averages were compared against measured averages.



Observed 2010				Fused 2010			
Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall
53.3	51.3	42.0	48.3	50.6	42.6	41.6	37.7
53.3	50.7	46.0	44.3	48.3	40.1	37.9	35.2
33.7	22.5	17.0	26.0	29.4	17.6	15.3	17.0
39.7	38.0	39.7	31.3	48.9	36.7	36.2	32.0
36.0	35.3	33.7	31.3	45.0	34.4	33.4	30.2
32.0	26.3	25.3	23.0	50.5	37.4	36.9	32.6
25.3	19.7	18.3	17.3	35.2	29.9	25.3	25.6
51.3	39.0	35.7	39.0	45.0	31.1	30.1	30.0
42.7	32.0	28.7	31.7	57.8	38.9	39.6	36.7
62.7	52.3	49.0	51.0	56.4	37.7	38.6	35.2
53.7	43.3	39.0	41.0	60.4	41.4	42.6	39.7
47.0	44.7	37.7	40.0	55.1	44.9	43.6	39.6
52.3	40.3	34.3	36.7	49.3	40.9	38.5	35.9
48.7	53.3	43.3	48.3	52.0	43.2	41.3	38.6
34.7	26.7	21.0	26.3	44.1	37.3	32.9	32.8
34.7	26.3	20.7	25.3	47.5	32.5	33.7	31.5
27.7	19.0	13.7	16.7	34.2	23.0	19.7	20.5
33.7	23.3	16.7	22.5	36.6	27.9	21.8	22.9
27.3	17.3	11.0	17.0	27.5	17.3	11.7	14.1
36.0	22.7	13.7	21.3	29.4	18.3	12.6	15.3
48.0	36.7	25.3	30.3	30.2	22.7	15.8	16.7
39.3	29.3	20.3	30.0	28.5	18.4	13.7	16.5
30.7	21.7	14.3	22.0	26.5	18.4	12.8	15.1
33.3	22.3	15.3	22.7	28.2	17.4	13.1	15.8
33.0	19.3	13.7	19.3	32.1	19.4	16.2	17.2
42.3	34.0	24.7	28.7	23.7	18.2	14.5	15.0
25.7	25.3	17.7	23.3	23.5	18.9	14.8	15.9
39.0	30.7	21.1	24.7	40.4	26.6	24.0	23.1
15.4	6.1	3.7	5.1	15.8	7.4	5.0	6.3
30.6	21.4	14.2	20.3	28.1	21.1	14.8	16.2
27.8	21.9	23.8	19.0	47.6	34.8	33.5	29.9
32.1	22.0	16.8	20.1	43.2	33.7	29.8	30.3
47.7	41.6	40.4	36.2	54.0	42.0	40.2	38.5
60.8	52.9	50.9	47.8	56.8	38.7	39.5	35.7
34.9	25.2	20.4	22.9	34.8	28.7	22.2	24.6
23.8	18.7	18.7	10.2	28.7	20.4	12.6	17.3
36.9	26.1	19.2	24.8	30.9	20.5	16.8	18.3
38.1	31.8	25.2	26.8	37.6	28.5	23.8	24.7

★ = street canyon

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Will it work in China, other places?

- **Availability of population density mappings?**
- **Sufficient calibration material for the ENFUSER model available?**
  - Full annual time series in several locations needed.
    - Then again we are placing a large number of sensors to provide such data.
- **Contribution of local industrial sources of emissions?**
  - Manual mapping if nothing else available?
- **Other sources of local emissions that cannot be analysed based on the available GIS-datasets?**

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Testbed setup

- **Main objective: Fuse PM2.5 measurements in Langfang**

1. **Describe the environment in the surronding region as accurately as possible**
   - Source and the nature of GIS data unknown
2. **Gain access to AQ measurements in the surrounding region**
   - Pegasor + other unknown sources of information
   - For calibration and operational use
     - Decent calibration: 20+ stations, full annual time series
3. **Gain access to weather data**
   - For calibration and operational use
   - Forecasts?

Optimal calibration: weather data for the same period as AQ measurements

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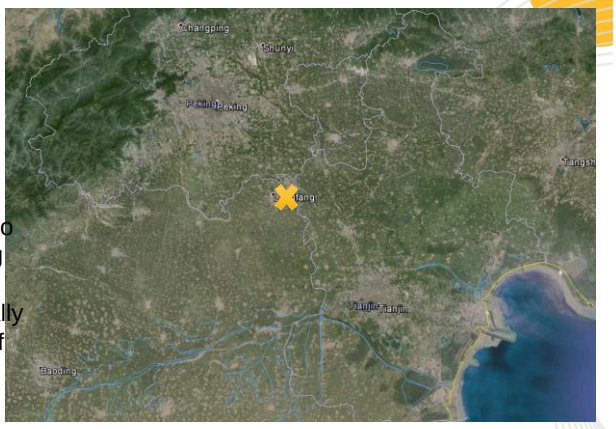
Testbed region



To obtain realistic behaviour in the model it is not enough to concentrate only on Langfang.

The surrounding area is equally important for the calibration of the model.

The selected testbed region also includes **Beijing, Tianjin, Tangshan, Baoding** and several other cities.

For all of these other cities the environment has been mapped with the same detail as in Langfang.

=> When calibrated and operational **ENFUSER should work all across the selected region.**

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Open source Land-use

Finland/Europe

Forests, plains, parks, lakes, sea, roads (5), residential, industrial, buildings

Langfang/China

Lakes, sea, roads (5)

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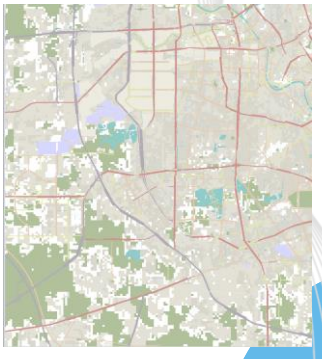
Enhancing Open source Land-use with satellite images

- **New approach: analyse rudimentary land use from satellite images => Fill in the gaps in OSM mappping**
  - Vegetation, Urban, Suburban
- **Simple image processing technique**
  - Deduction based on
    - Dominant color
    - Brigtness
    - Saturation
- **Approach seems to work well in Hebei province when the ”eye altitude” of satellite is approx. 100km**
  - 100 x 100m resolution acheived
  - Better resolution would require more sophisticated image processing and possibly shape/polygon detection



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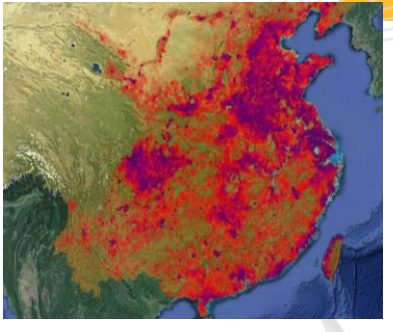
Population density mapping (1/3)

- **Important for ENFUSER**
  - Can be used to proxy traffic volumes (One of the subtasks considered in the calibration of the model)
  - Population => burning & heating
  - Desired resolution: 250 x 250m



- **Best ”dataset” found for this purpose was an image describing the population in a 5 x 5km resolution**
  - This was converted into Googe Earth layer file (kmz) and fitted to the area => coordinates for the data
  - Gives only **indicative** information on the population

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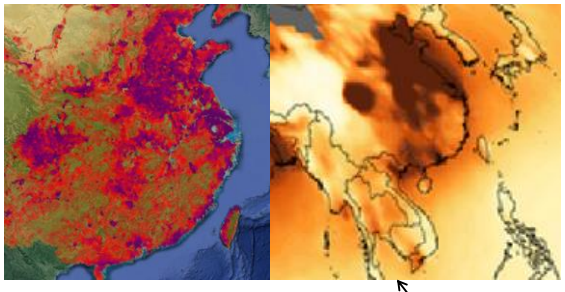
Population density mapping (2/3)



Average aerosol optical depth, indicating the relative amount of particles that absorb sunlight. Based on satellite remote sensing during 2007-2011.

Modis Terra (NASA), aerosol optical depth at 550nm 2007-01 to 2011-12 average.Data source:http://daac.gsfc.nasa.gov/giovanni

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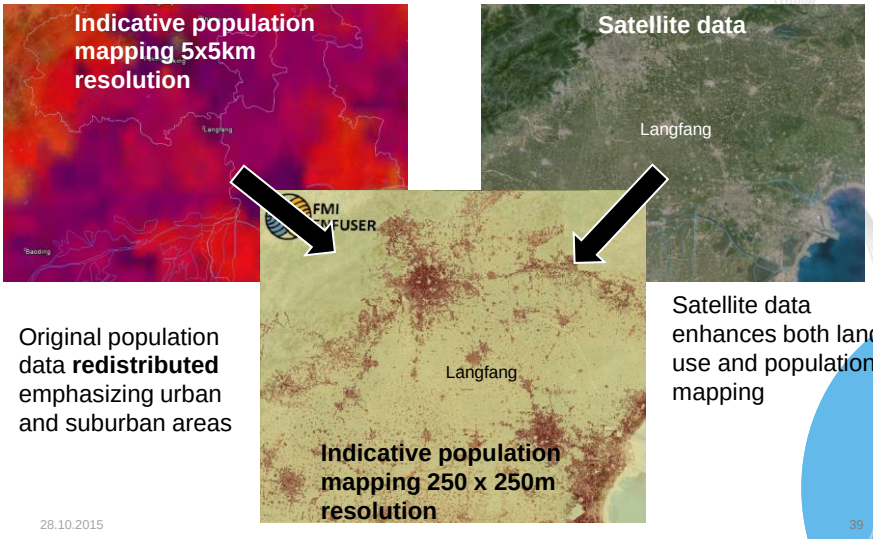
Population density mapping (3/3)



Original population data **redistributed** emphasizing urban and suburban areas

Satellite data enhances both land-use and population mapping

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OpenStreetMap & street canyons(1/2)

OpenSreetMap (OSM) is an open access map service provider that offers high resolution maps world wide.

FMI-ENFUSER uses OSM-maps with 5 x 5m resolution, covering all main cities in Finland

Street canyons and buildings can be analyzed from the image.

This is how FMI-ENFUSER ”sees” the crossing of Lönrotinkatu and Fredrikinkatu after image processing. The vicinity of buildings can be taken into account when the concentration is being estimated in urban areas.

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Conclusions: Fusion

- A general method for fusion environmental information :
  - Tailored for the PESCaDO prototype
  - Fuses complementary and competing data, while accounts for the differences in environment and time
  - Evalution suggests that the system works succesfully
    - Possibilty to detect costly yet unnecessary stations
- Future work
  - Expansion of ’Environment’
    - Topography, better road classification
  - Meteorology
    - The static environment cannot explain all variability, e.g. ozone (O3)
    - Orchestration: fusion of met. data and then use the met. data for pollutant fusion!

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Thank You for Your attention !