Importance of spatially representative emission inventories in regional air quality modeling

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Outline

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  - AQ models need spatially representative emission inventories
  - Spatial representation in emission inventories – different approaches
  - Challenges in spatial representation of emissions
- Examples of challenging emission source sectors for spatial representation and solutions
  - Residential wood combustion
  - Machinery and other challenges in urban emission inventories
- Conclusions and further work

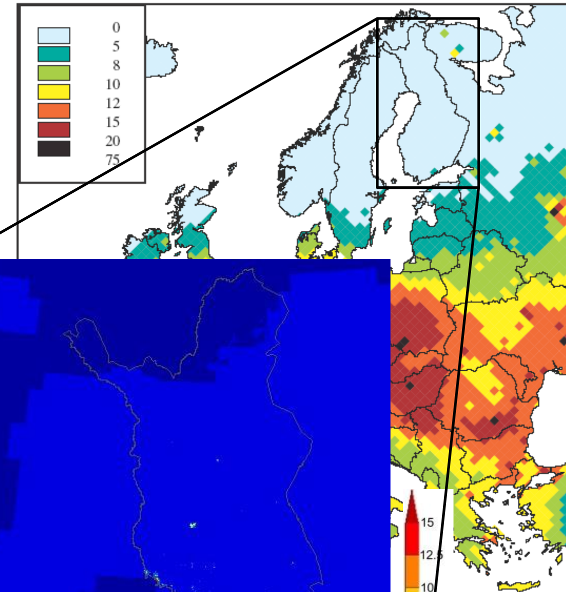
Introduction

Air quality models need spatially representative emission data

AQ models at different scales have different needs as emission fields

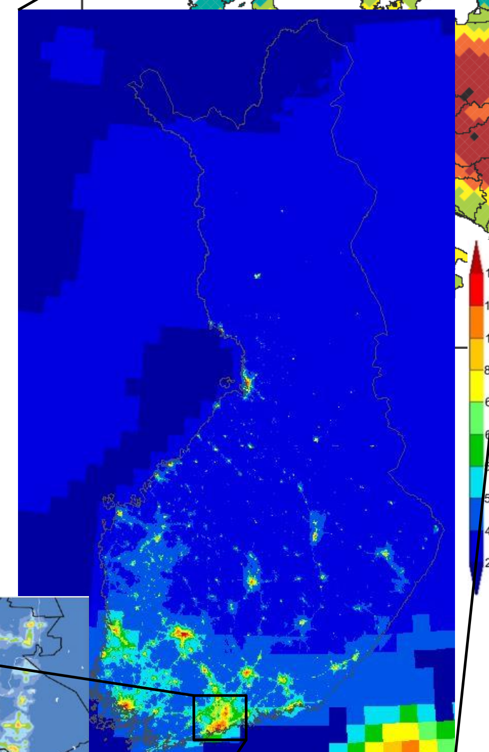
Global-to-regional
- Modeling domain globe or continent
- Effects of long-range transport of emissions
- Emission grid resolution typically 10 – 100 km

E.g. GAINS model of IIASA



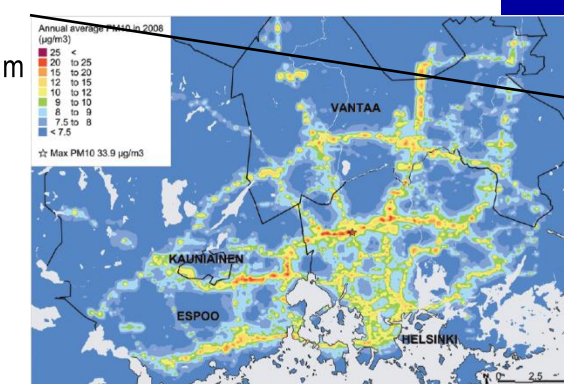
Regional-to-local
- Modeling domain country or urban agglomerate
- Effects of both long-range transport and local emission sources
- Emission grid resolution typically 250 m – 5 km

E.g. FRES model of SYKE



Local and finer
- Modeling domain city to street canyon
- Mainly effects of local emission sources
- Emission grid resolution typically 10 m – 100 m

E.g. CAR-FMI of FMI



source: Aarnio et al. 2016

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Introduction

Spatial representation in emission inventories

Different approach for different emission source types

Point sources

- Limited number of big individual emitters
- Emissions and location of the plants and/or stacks often known
- E.g. industrial and power plants
- “Bottom-up” approach, i.e. emission information gathered or calculated from each plant individually

Area sources

- Large number of small emitters
- Not possible/practical to describe as point sources
- “Top-down” approach, i.e. calculation of sector emissions using activity and emission factor information from a wide area and large number of emission sources (e.g. residential house heating of a country)
- Location of emissions is defined using weighting surrogates, i.e. spatial proxies that represent spatial distribution of emissions (e.g. residential housing register)

Line sources

- E.g. traffic
- Can be described also as area sources at fine grid resolution

Often combination

- E.g. traffic and residential heating emissions calculated as country totals and then allocated to desired grid resolution (top-down) and industrial and power plants as individual sources (bottom-up)

Introduction

Challenges in spatial representation of area emissions

Some emission source types representation easy, some more challenging

- Critical to find spatial proxy that represents the emission source sector adequately
- Traffic emissions are typically well represented
    - Road network and traffic count information often available as detailed GIS data
    - Additional useful data include e.g. speed limit information
    - Traffic models can provide further useful information for spatial emission allocation, e.g. congestions, accelerations etc.
- More challenging emission sources for gridding: residential combustion and machinery
    - Lack of residential housing register with information about combustion devices (e.g. wood stoves, heating boilers)
    - Individual households use their residential stoves variably -> need for local questionnaires
    - Machinery emissions take place mainly outside road network – What would be representative spatial proxies for different vehicle types?
- Often residential combustion and much of the machinery emissions are gridded using population density data as a proxy
- However, **population density is a good proxy for emission gridding only in a very few cases!**

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Example 1: Residential wood combustion

Comparison of different spatial gridding proxies

- A detailed gridding method used in the Finnish Regional Emissions Scenario (FRES) model was compared with two other common gridding proxies
  - Population density
  - Land use (detached housing area)

- PM2.5 emissions from residential wood combustion were gridded using the three different spatial proxies

- Emission dispersion was modelled and population exposure calculated in the three cases

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Example 1: Residential wood combustion

Comparison of different spatial gridding proxies

- Emission gridding method used in the FRES model for residential wood combustion:

Gridding proxy	Source	Resolution
Number of detached houses	National building and dwelling register	Building
Average wood use (depending on residential area type and Primary heating method)	Urban structure monitoring system National building and dwelling register Wood use surveys	250 m x 250 m
Heating degree day	Finnish Meteorological Institute	Municipality

Primary heating method	Helsinki metropolitan area	City, pop. > 20 000	Population centre, pop. < 20 000	Countryside / scattered settlement
District heating	1.0	1.4	1.7	3.2
Electricity, geothermal heat etc.	1.7	2.5	3.1	5.5
Oil, gas	1.6	2.4	2.9	5.3
Wood oven	4.2	4.2	5.2	9.4
Wood central	9.3	9.3	16.1	18.0

source: Paunu et al. 2013

Dispersion modelling used in FRES for residential wood combustion primary PM2.5:

- Source-receptor matrices at 1 x 1 km resolution based on Gaussian UDM-FMI

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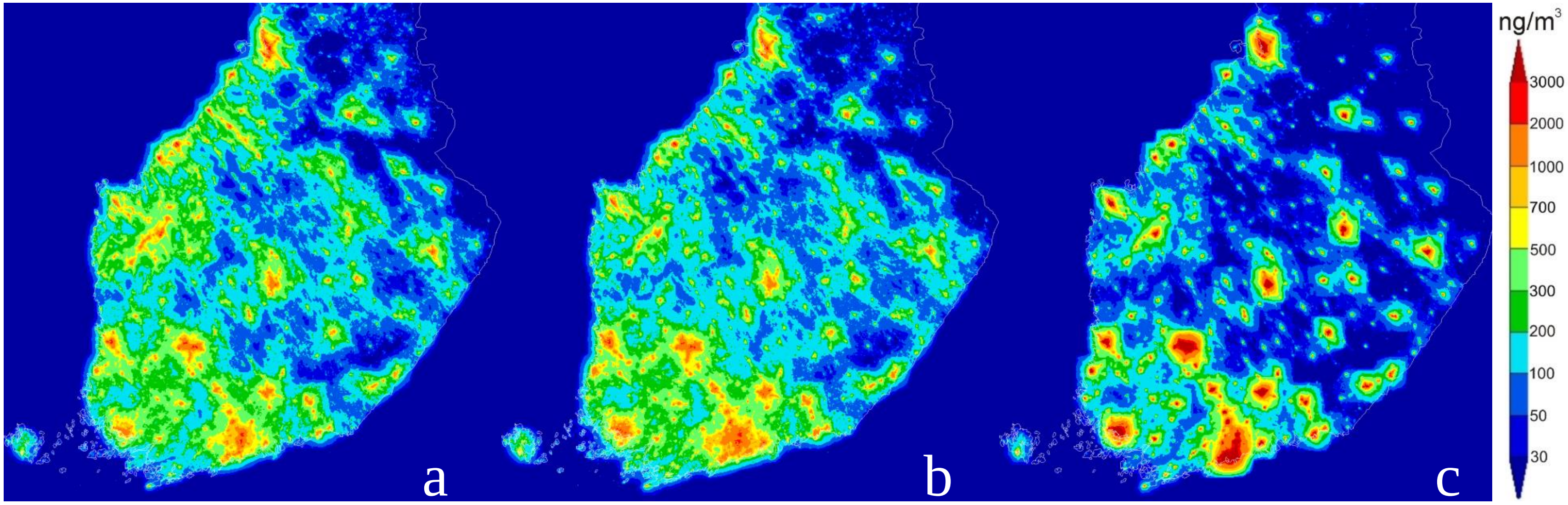
Example 1: Residential wood combustion

Comparison of different spatial gridding proxies

Results:



PM$_{2.5}$ concentration maps (ng/m^3) calculated with emission gridding based on:

source: Paunu et al. 2013

(a) FRES model — Population exposure (population weighted concentration **0.97** µg m^{-3})

(b) Land use (detached house areas) — Population exposure (population weighted concentration **1.03** µg m^{-3})

(c) Population density — Population exposure (population weighted concentration **3.55** µg m^{-3})

The choice of emission gridding proxy matters in population exposure -> health assessment:

- Using population density as a proxy 3.7 * overestimates population exposure
- Using detached housing area very close to our best estimate FRES (**BUT**, less wood use per house and denser housing structure in urban areas cancel each other out)

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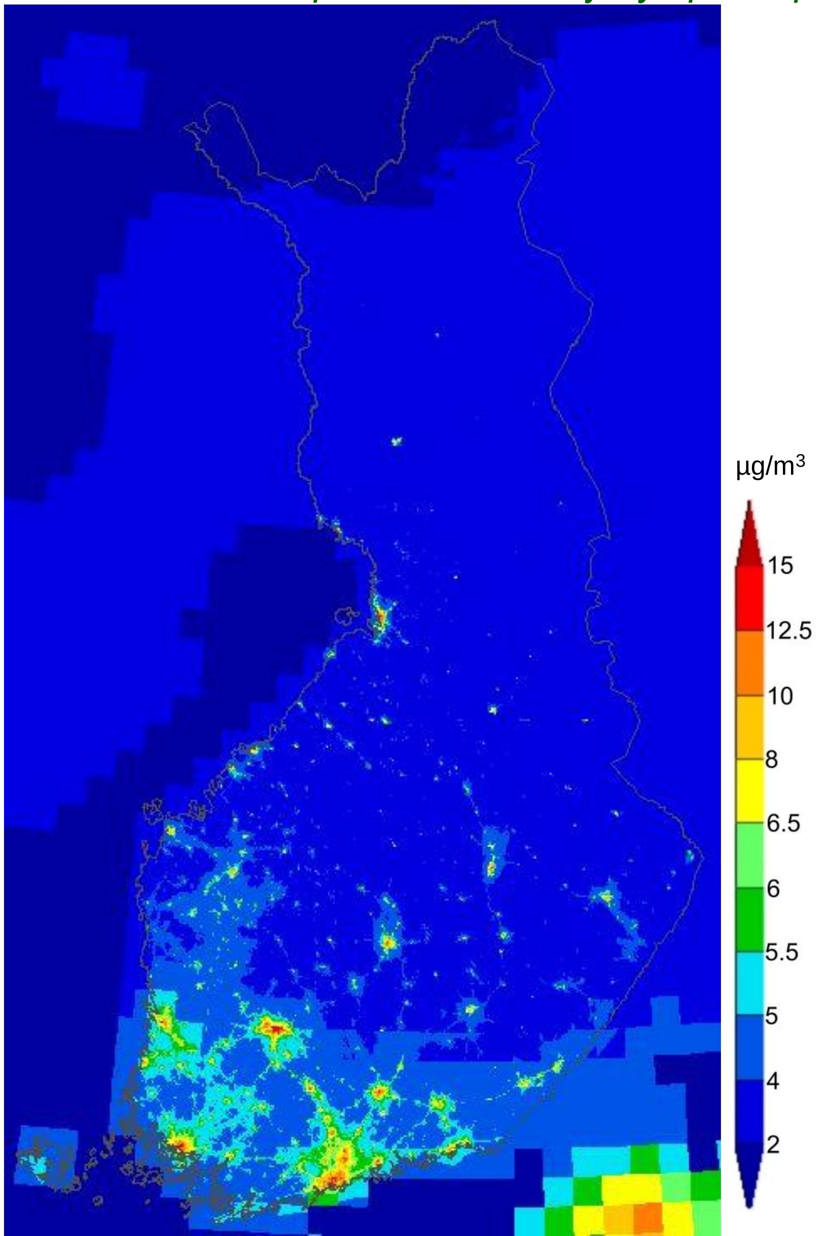
Example 2: Helsinki Area emission inventory

Improved inventory by spatial proxy development - machinery



- The FRES model emission inventory is a combined top-down calculation for area sources at 250 m resolution and bottom-up approach for ~400 point sources
- Dispersion modelling in FRES consists of three different source-receptor matrices (SRMs):
  - Finnish near-ground emissions based on Gaussian UDM-FMI at 1 km resolution
  - Finnish high-stack emissions based on Lagrangian SILAM at 10 km resolution
  - Long-range transport and secondary PM based on EMEP SRMs at ~28 km resolution

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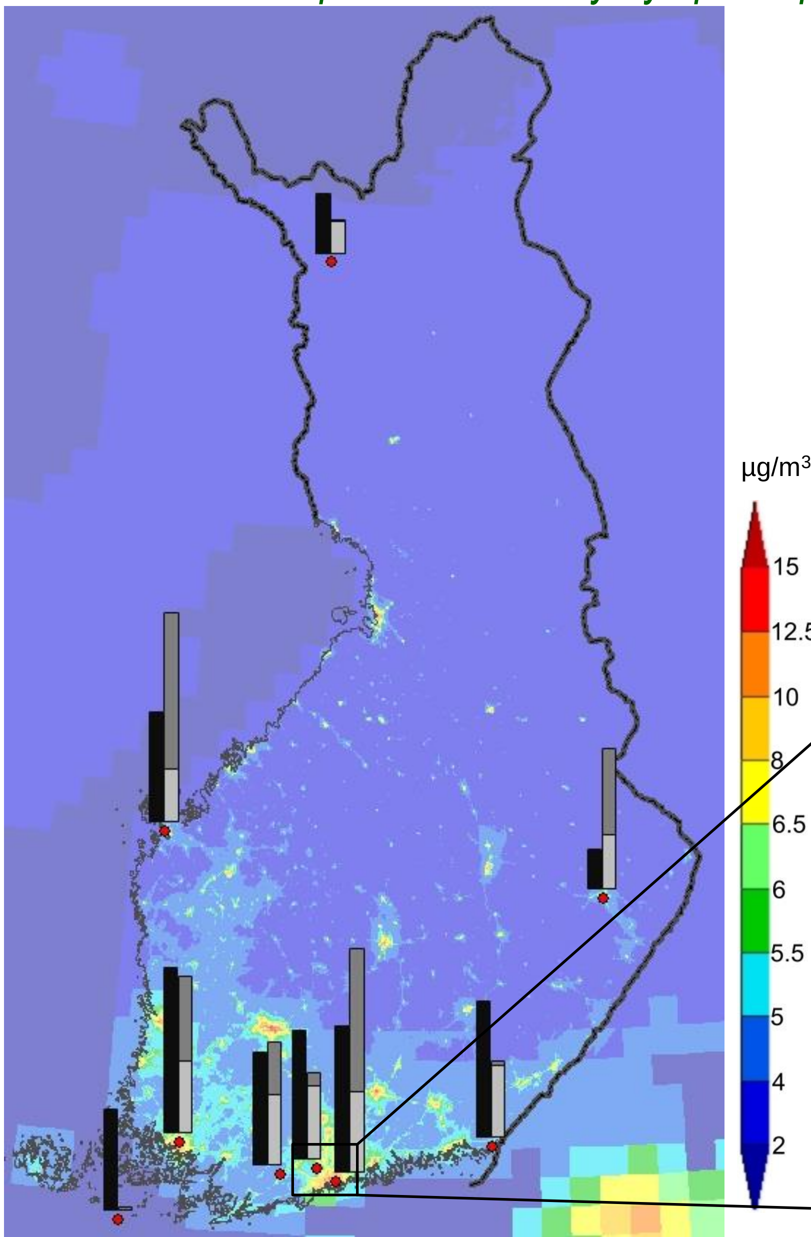
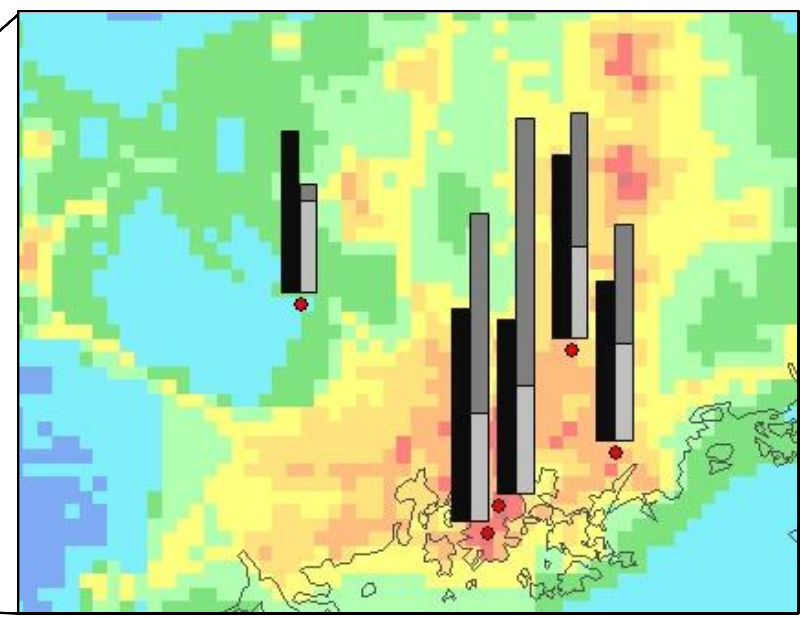
Example 2: Helsinki Area emission inventory

Improved inventory by spatial proxy development - machinery



Starting point:

- FRES tended to underestimate rural concentrations. Reason possibly exclusion of natural sources and sea traffic emissions.
- FRES tended to **overestimate urban concentrations**, one reason being **too much emissions allocated to urban areas** (unrealistic spatial gridding proxies)
- We analyzed Helsinki Metropolitan Area and improved the spatial proxies



Example 2: Helsinki Area emission inventory

Improved inventory by spatial proxy development - machinery

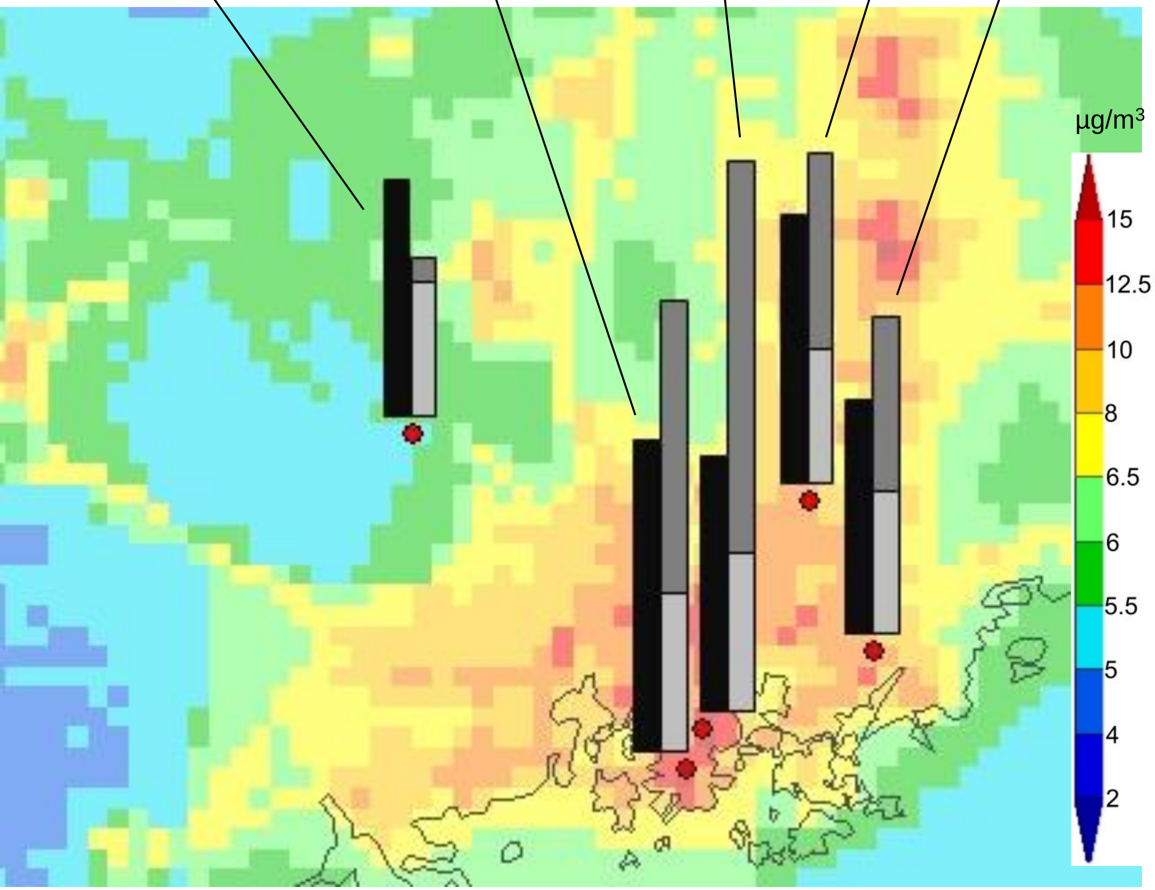
Tikkurila: Semi-urban traffic station
9.4 µg/m³; FRES: **+23%**

Vartiokylä: Residential area with detached houses
8.1 µg/m³; FRES: **+36%**

Kallio: Urban background station
8.9 µg/m³; FRES: **+115%**

Luukki: natural sources and a gravel road near the measurement station not captured by modelling
8.2 µg/m³; FRES: **-33%**

Mannerheimintie: Urban traffic station
10.9 µg/m³; FRES: **+44%**



Initial analysis: Helsinki Metropolitan Area (HMA)

- Main HMA emission sources in the previous calculation were traffic resuspension (32%) and traffic exhaust (15%), residential wood combustion (14%), machinery (12%) and barbeques (11%)
- We suspected emission **overestimations** for the following sectors for HMA
  - Maintenance and construction **machinery**: Country total emissions were gridded using population density as a proxy. However, part of the machinery are used for highway construction and maintenance, instead of urban activities.
  - Traffic **resuspension** emissions: Helsinki performs dust binding and street cleaning methods that were not incorporated in the previous calculation
  - **Barbeque**: The emission factors were based on U.S. measurements and probably highly overestimated. In addition, population as a gridding proxy increased the overestimation.

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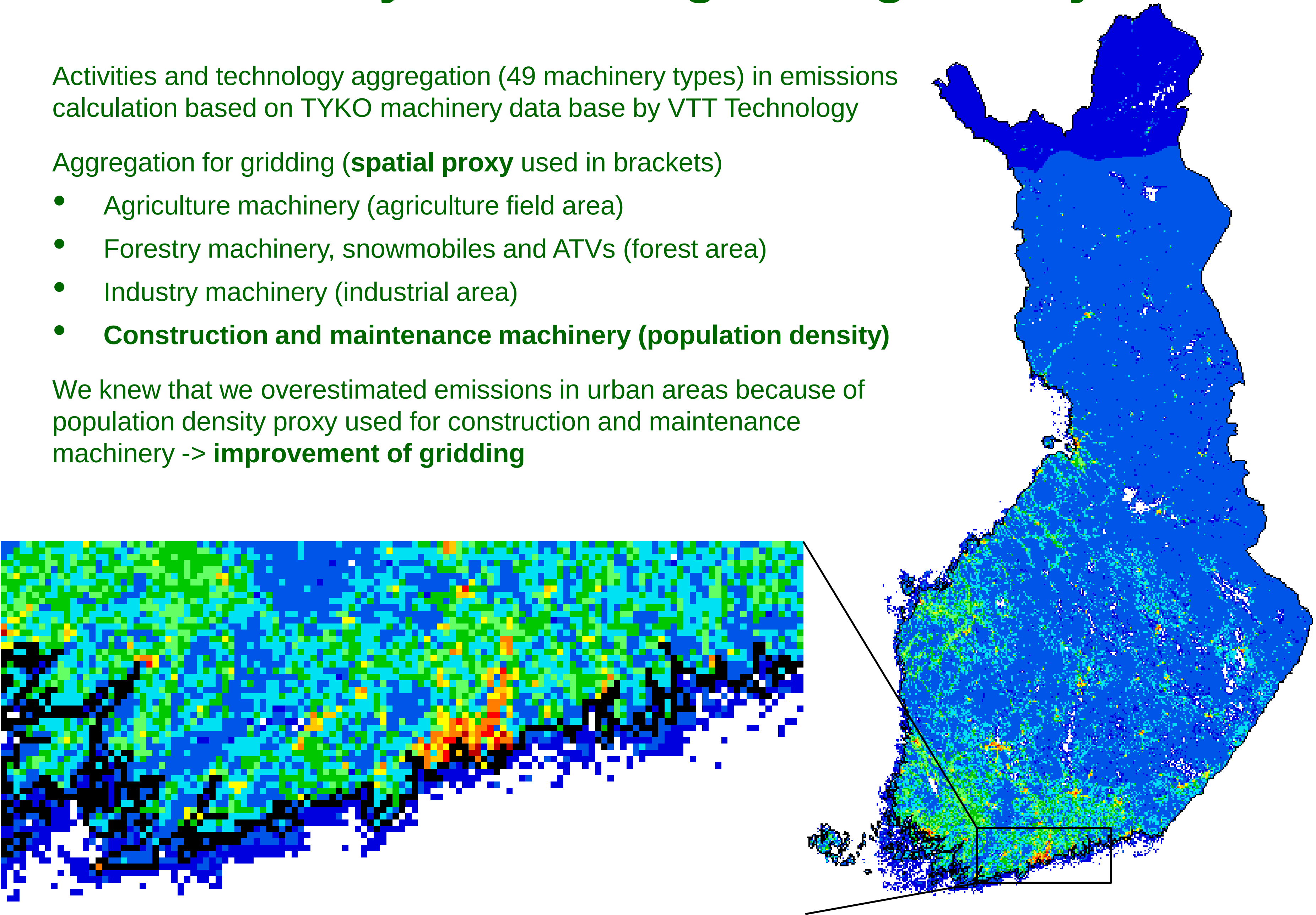
Machinery emission gridding, old system

Activities and technology aggregation (49 machinery types) in emissions calculation based on TYKO machinery data base by VTT Technology

Aggregation for gridding (**spatial proxy** used in brackets)

- Agriculture machinery (agriculture field area)
- Forestry machinery, snowmobiles and ATVs (forest area)
- Industry machinery (industrial area)
- **Construction and maintenance machinery (population density)**

We knew that we overestimated emissions in urban areas because of population density proxy used for construction and maintenance machinery -> **improvement of gridding**



Machinery emission gridding, new system

Main technology categories and planned proxy types to be used

Machinery type	Proxy type	Activity in 2015
		TJ/a
Cranes	Building, industry	532
Forklift trucks, industrial tractors	Industry	2890
Road graders	Roads	469
Wheel loaders, dumper trucks	Roads, mines	5093
Excavators	Building, road, industry	5990
Agricultural tractors	Agriculture	6463
Other maintenance machinery	Building, street	1434
Combine harvester	Agriculture	697
Felling machine	Forestry	2314
Forest tractors	Forestry	1156
Lawnmowers	Residential, greeneries	1172
Snow mobiles, ATVs	Forestry	2083
Diesel generators	Roads	1373
Diesel compressors	Building, streets	496
Chain saws	Forestry	358

Proxies to be used

- Agriculture machinery: agriculture field areas
- Forestry machinery, snowmobiles and ATVs: forest area excl. national parks etc.
- Industry machinery: industrial areas
- Construction machinery: population density
- Road construction and maintenance: roads weighted with activity
- Street construction and maintenance: streets weighted with activity
- Mining machinery: mine areas
- Residential maintenance machinery: detached house areas
- Greenery maintenance machinery: greenery areas

NEW GRIDDING FOR CONSTRUCTION AND MAINTENANCE MACHINERY

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Example 2: Helsinki Area emission inventory

Improved inventory by spatial proxy development - machinery

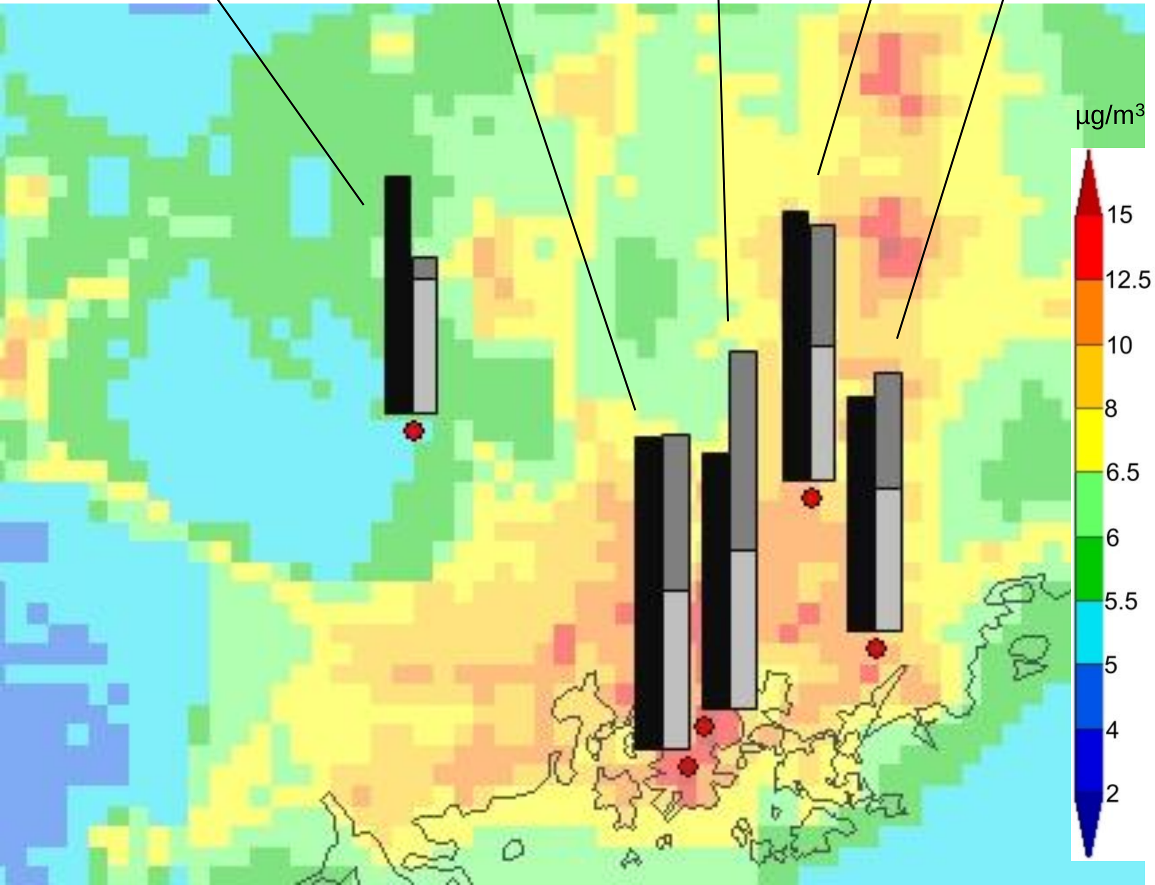
Tikkurila: Semi-urban traffic station
9.4 µg/m³; FRES: -5%

Vartiokylä: Residential area with detached houses
8.1 µg/m³; FRES: +10%

Kallio: Urban background station
8.9 µg/m³; FRES: +40%

Luukki: natural sources and a gravel road near the measurement station not captured by modelling
8.2 µg/m³; FRES: -35%

Mannerheimintie: Urban traffic station
10.9 µg/m³; FRES: +1%



Spatial proxy and em.f. adjustments resulted in:

- Considerable changes in emissions:
  - Maintenance and construction **machinery**: 34% decrease in HMA emissions due to the new refined spatial proxies
  - Traffic **resuspension**: 50% decrease in HMA emissions based on comparison with recent emission measurements
  - **Barbeque**: 77% decrease in emission factor based on more representative measurements (McDonald et al. 2003) and additional 65% decrease in HMA emissions due to more representative spatial proxy (detached house area)
- Better match against measurements
- Highlights the importance of
  - **Spatially correct emission data**
  - **Locally representative emission factors** in AQ modeling

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Conclusions and further work

- Emission inventories are crucial part of AQ modelling
- AQ modelers should know their emission inventories
  - How representative are the emission fields for different sectors?
  - What sectors are uncertain?
  - What sectors are missing?
- Uncertainties in emission inventories are affected by activities and emission factors, but also considerably by the quality of spatial emission allocation, i.e. gridding
- Challenging source sectors for good-quality emission gridding include residential combustion and machinery
- Inaccurate spatial representation of emissions might result in many-fold error in health impact assessment for some sectors (e.g. using population density as a proxy for residential combustion)

- In the future, the refined spatial representation of machinery emissions will be further developed and implemented and the methods and experiences disseminated among other country experts in the Nordic project "Understanding the link between air pollution and distribution of related health impacts and welfare in the Nordic countries (NordicWelfAir)" projects.au.dk/nordicwelfair/

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Thank you for your attention

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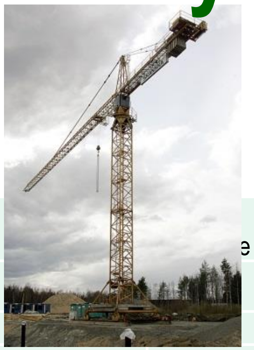
Machinery emission gridding, new system



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Critical questions on proxies

What are the shares of different proxy types?

- Cranes
- Wheel loaders
- Excavators
- Other maintenance machinery
- Diesel compressors

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