Helsinki research between AQ-meteorology & observations-models

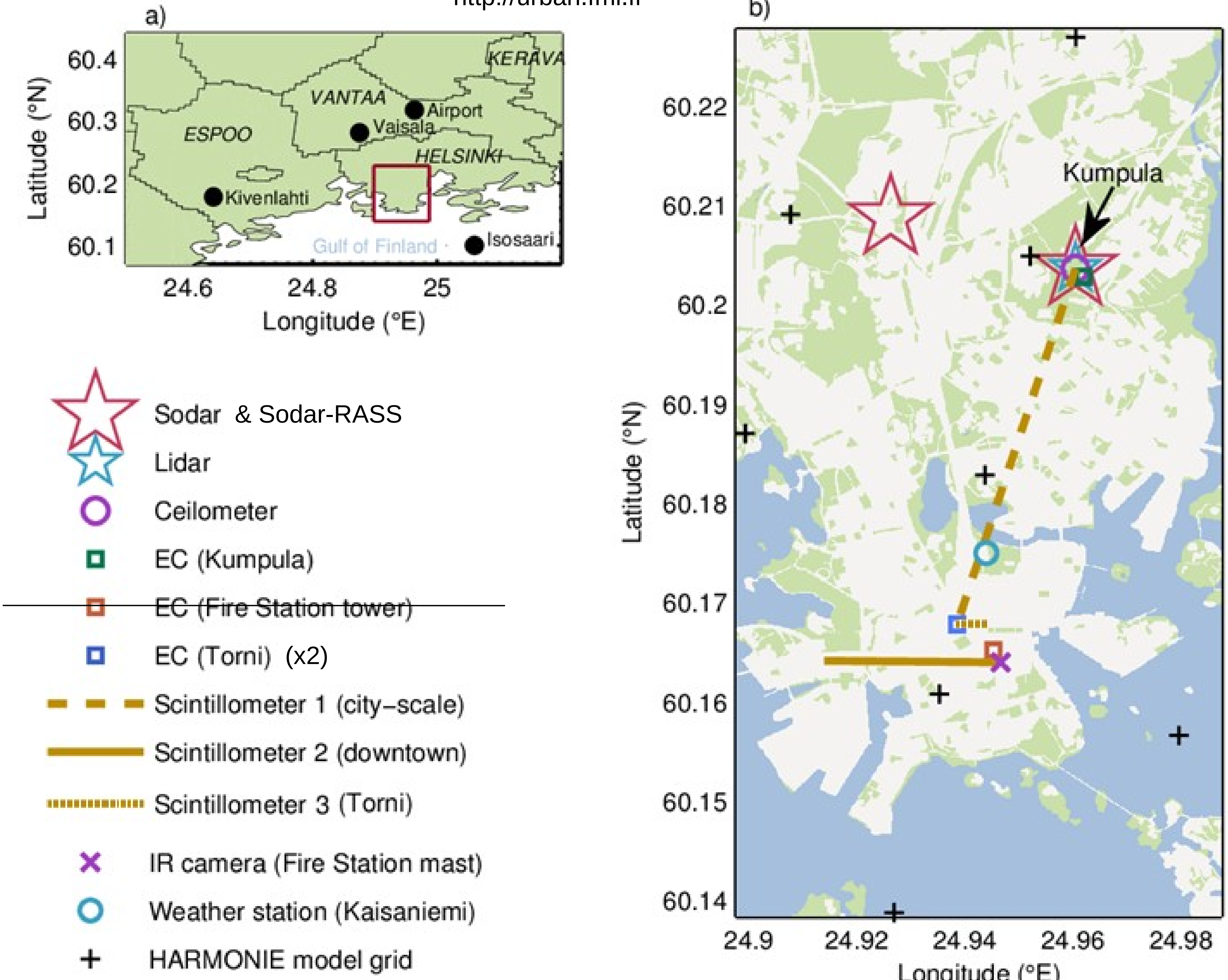
FMI (Aura, Dynamicum) 12.01.2015

10:00 Curtis Wood
10:20 Hilkka Timonen
10:40 Leena Järvi
11:00 Ari Karppinen
11:20 Mari Kauhaniemi
11:40 Katja Loven
11:50 Hanna Hannuniemi

13:15 Carl Fortelius
13:35 Antti Hellsten
13:55 Jukka-Pekka Jalkanen
14:15 Ville Vakkari

14:35 Final discussions

http://urban.fmi.fi



Example measurements

- Profile of temperature
- Profile of wind speed and direction
- Profile of turbulence
- Profile of 'aerosols' (lidar/ceilometer)
- Fluxes (heat, moisture, momentum)
  – point or average
- Atmospheric stability
- Surface temperatures of buildings downtown

Most are available since year 2010 onwards

Scope

- Met / ABL / urban climate

  > Modelling

  > Helsinki Observations

- Air Quality / Composition / Chemistry

  > Modelling

  > Helsinki Observations

Each 4 parts alone ok:

but combined use more powerful/interesting

Approaches

- Exploratory look at Mannerheimintie data - support from Helsinki UrBAN (and ?SILAM) where needed. What would be NEW here?
  > Differences between Kumpula and Mann?

  > Diurnal cycle (traffic vs ABL)
- Can we update FMI's AQ models (FMI-CAR, MPP, UDM, etc)?
- Is there something we can focus on that steakholders would need? (e.g. HSY)

Nessling proposal was...

Improving air-quality models for city planning, based on better descriptions of urban meteorology

Aim: to substantially improve the skill of operational air-quality models with state-of-the-art observations of the urban atmosphere

Some common words included: Helsinki UrBAN, ABL, AMS, ASCM, Kumpula, Mannerheimintie

Nessling project starts 1. Feb

2015: (i) Helsinki UrBAN analysis and (ii) construct modules for use in AQ models (e.g. CAR-FMI, SILAM, etc)

(e.g., examine profiles of wind and temperature; atmospheric structure from scintillometers).

2016: Compare the measured air-quality data at the two supersites, and additional AMS measurement sites, with the predictions of the air-quality models.

2017: Perform an integrated assessment of both measured and modelled results,

especially concerning aerosol data, and draw concrete conclusions on the importance of the relevant source categories in Helsinki (including especially small-scale combustion and shipping)

and provide recommendations to HSY for traffic and urban planning

- New rule: grant applied by grantee (and no transfer of grant between people)
- Post-doc funding is only <u>2 years</u>
- Deadline for application is Mid-September 2015 (useful to have something submitted by then?!)
- Decisions public in November!

FINNISH METEOROLOGICAL INSTITUTE

Fine particulate matter measurements in Helsinki - from emissions to ambient air

Hilkka Timonen, Minna Aurela, Kimmo Teinilä, Sanna Saarikoski, Risto Hillamo

Spring 2015

These slides were removed!

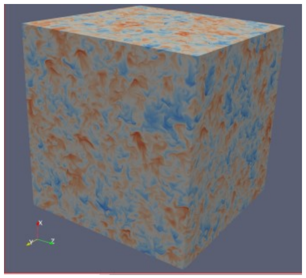
Rough content was about...

- AMS, ACSM, PAM, PMF, ME-2
- PM, NOx, COx, SOx, organics, HCs, BC, O3, NH4
- Secondary versus primary sources
- Local versus long-range
- Downtown versus residential
- Downtown and supersites

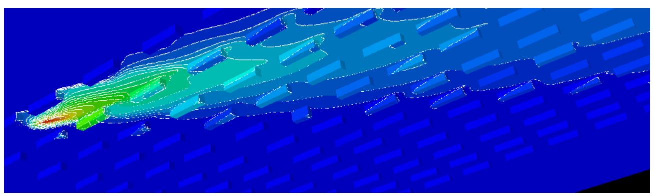
Factors influencing PM concentration in Helsinki

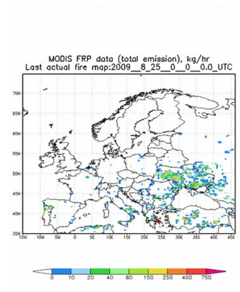
- Local sources e.g. Traffic
- Long-range transport
- Boundary layer height
- Meteorology e.g. Wind
- SOA formation (UV, oxidants, gases..)
- ?

Dispersion Models



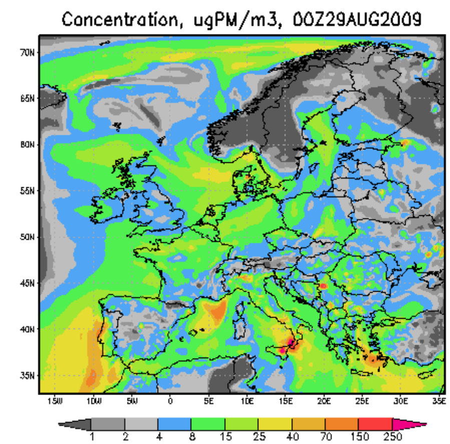
Ari Karppinen
011/2015

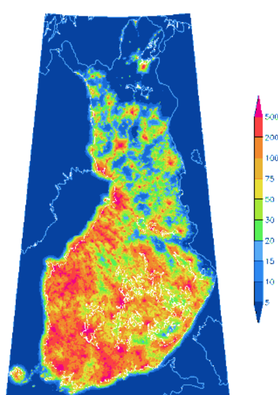


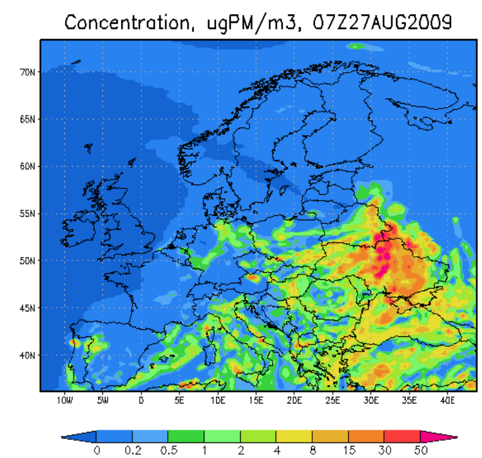


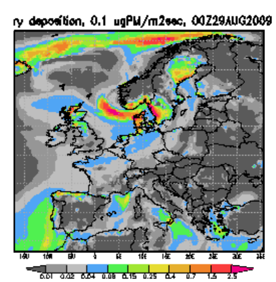
Forecast for pm2_5 from forest fires.
Last actual fire map: 2009 8 25 0 0 0.0 UTC

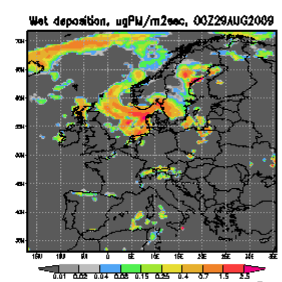
Forecast for PM2_5. Last analysis time: 20090826_00









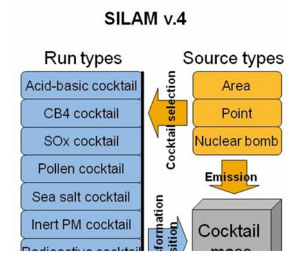


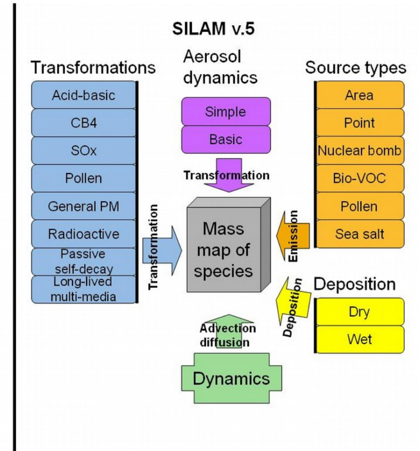
Contents

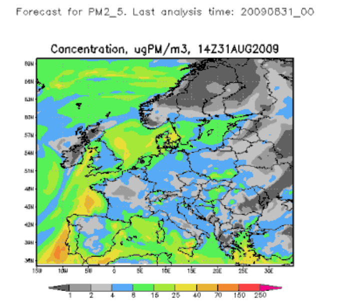
- **Introduction:**
  - goals
  - “Fit for purpose”
  - model classification
- **Practical examples/snapshots**
  - Regional/global scales
  - “country”-scale modeling
  - Urban scale models
  - Fusion
  - Emission (ships) modes
- **Challenges**

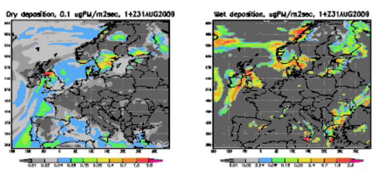
AQMg : the aims

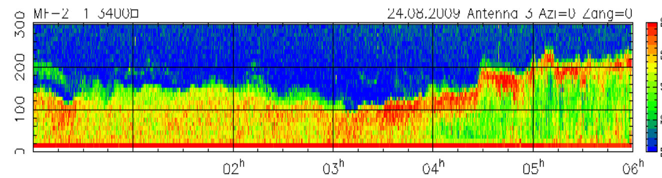
1. **Development and evaluation of air quality models : from microscale to global scale**
2. Integration of meteorological models (including climate) and dispersion models
3. Efficient use of all available measurement information
4. Application of models, and dissemination of information

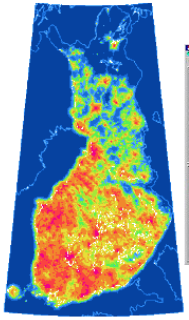


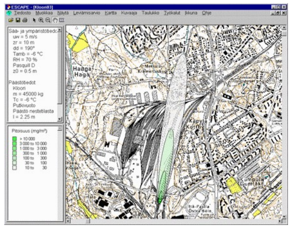


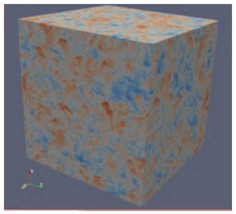


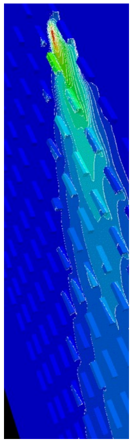




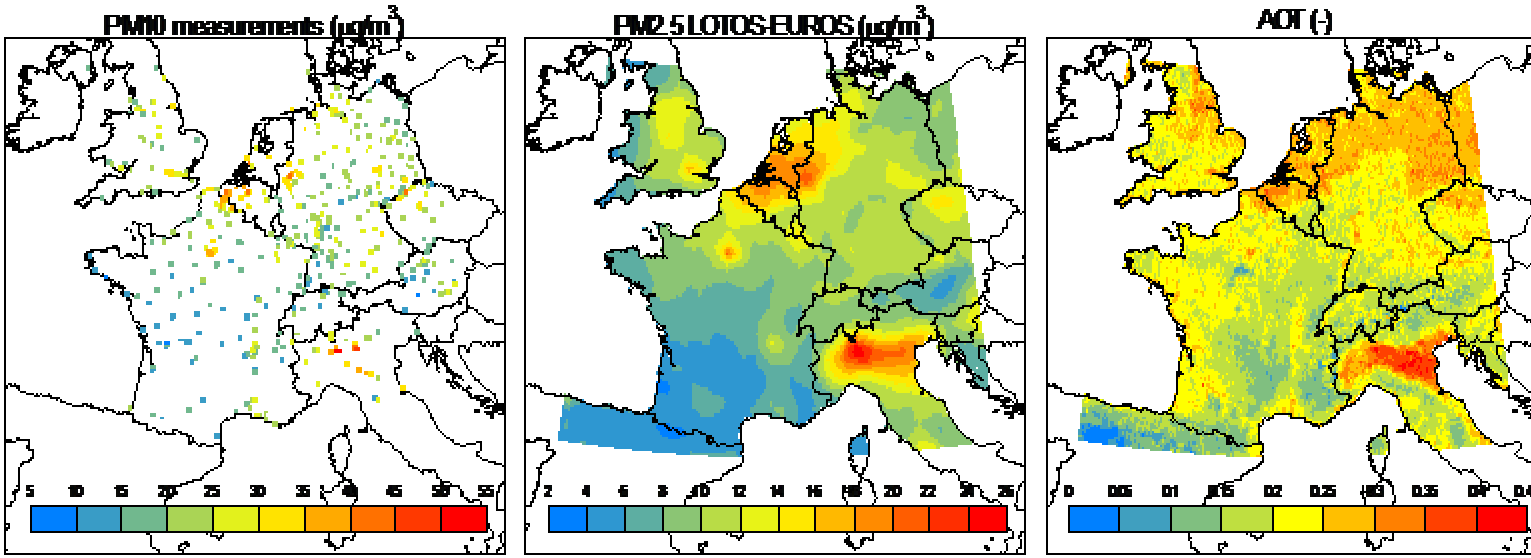




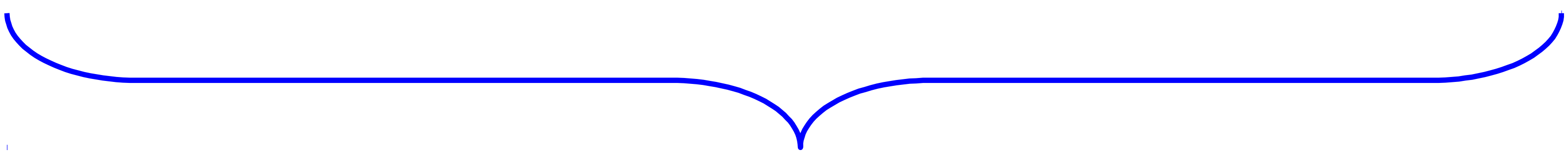




Integrated use of models and data



Monitoring Models Satellite



Goal: operational system taking into account all sources of information -> Fusion/assimilation..

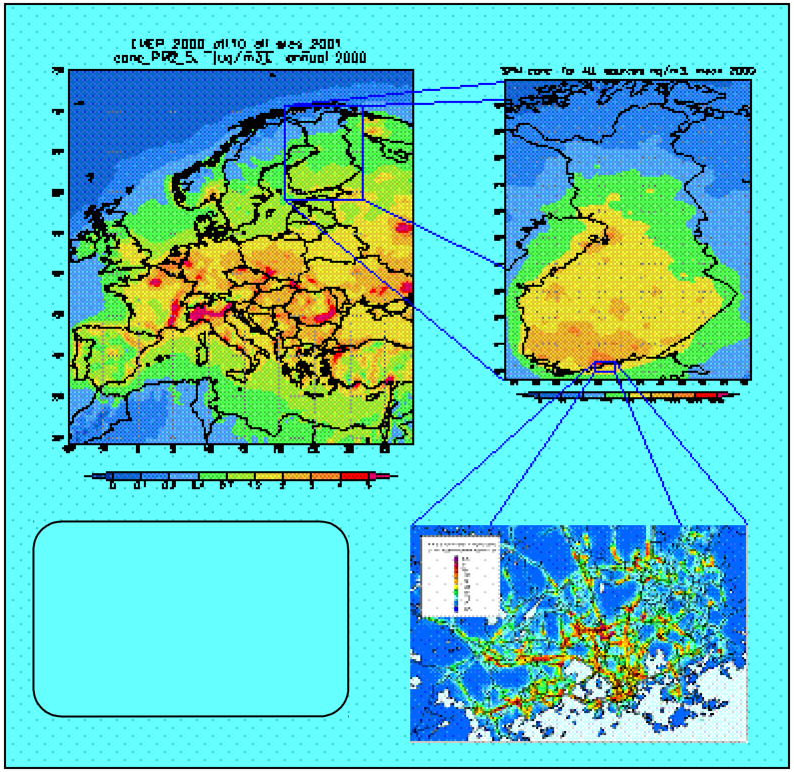
Model selection (fit for purpose)

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



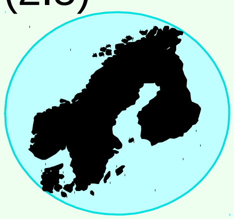
Modelling system - FMI

Weather prediction models

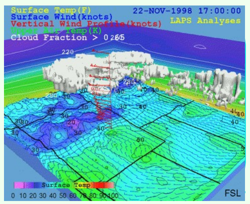
ECMWF (~16)

HIRLAM RCR (7.5)

HARMONIE (2.5)



WRF, *LAPS*



Dispersion models - long-range, regional

SILAM
LRT,
meso/global-scale,
radioactivity, pollen

HILATAR
LRT, meso-scale

Aerosol process models:

SALSA(UH,UKU,FMI)
SILAM-APMs

Dispersion and effects models – urban, local

CAR-FMI, roadside

UDM-FMI, urban

OSPM (NERI), street canyon

BUOYANT, fires

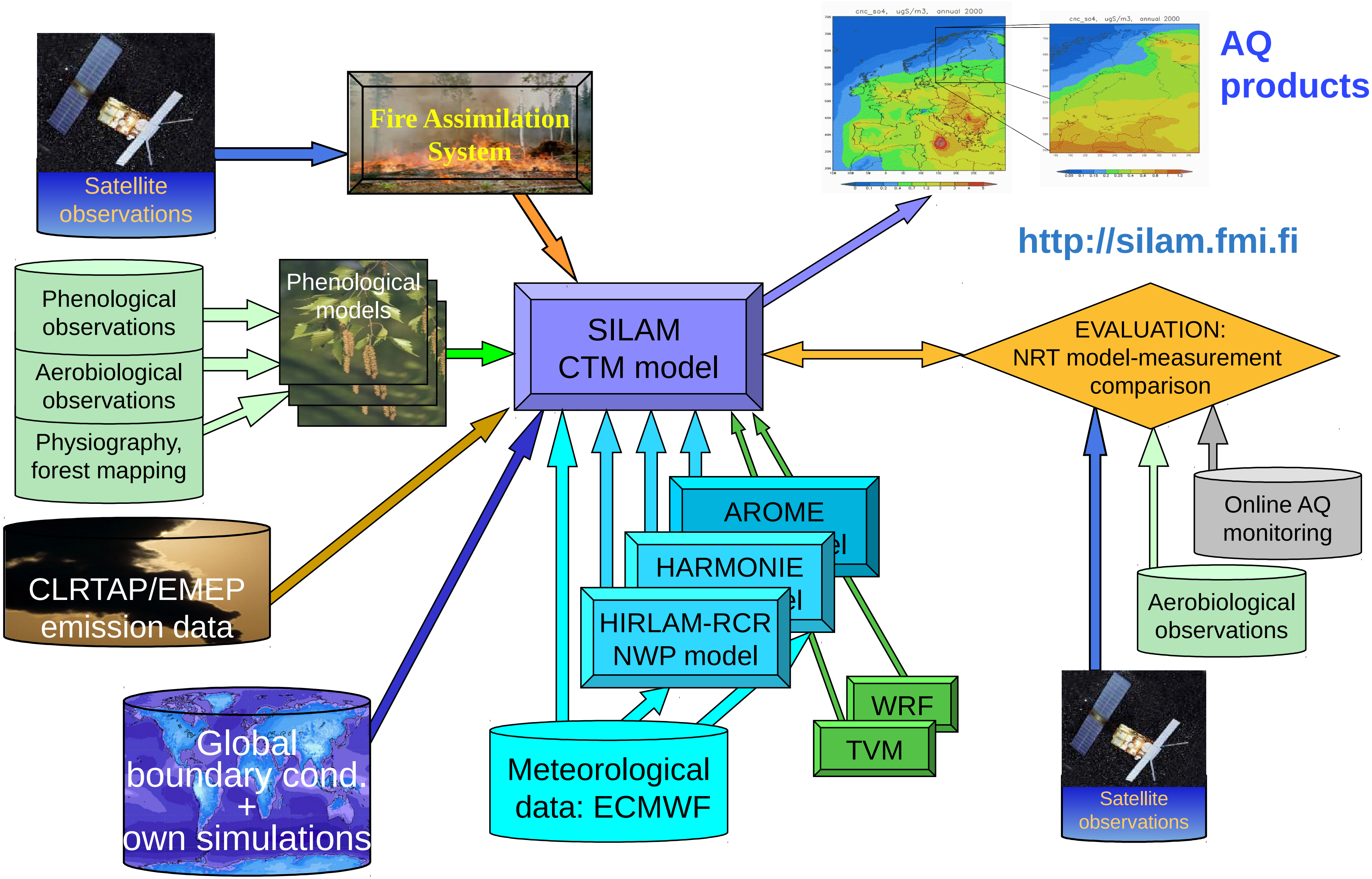
ESCAPE, chemical accidents

PALM,
FLUENT(CFD),
DNS-code development

EXPAND (FMI, YTV) population exposure

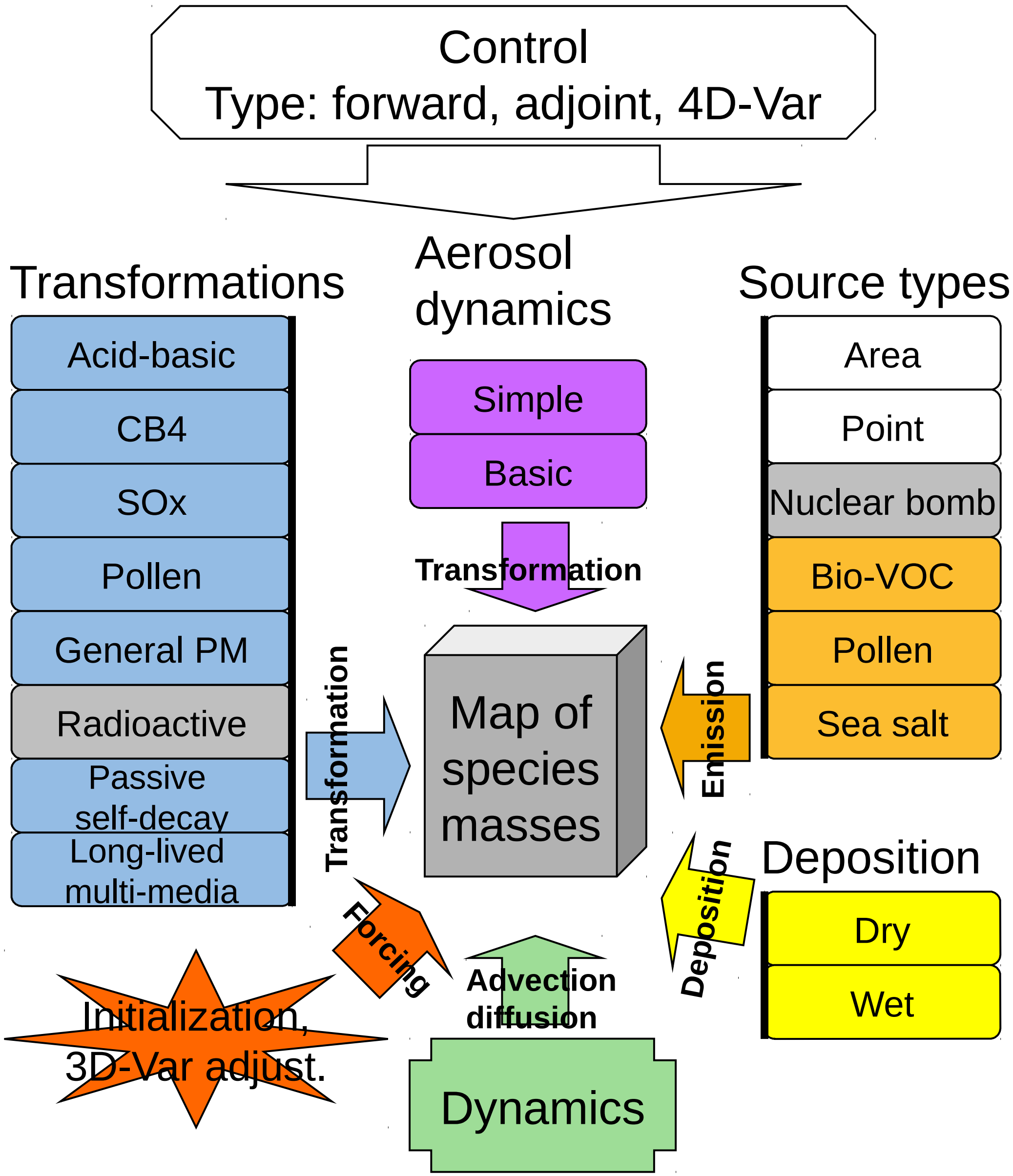
MPP-FMI, Meteorological pre-processing model

SILAM now


Satellite observations
Fire Assimilation System
cnc_so4, ugS/m3, annual 2000
cnc_so4, ugS/m3, annual 2000
AQ products
http://silam.fmi.fi
Phenological observations
Aerobiological observations
Physiography, forest mapping
Phenological models
SILAM CTM model
EVALUATION: NRT model-measurement comparison
Online AQ monitoring
Aerobiological observations
CLRTAP/EMEP emission data
AROME
HARMONIE
HIRLAM-RCR NWP model
WRF
TVM
Global boundary cond. + own simulations
Meteorological data: ECMWF
Satellite observations

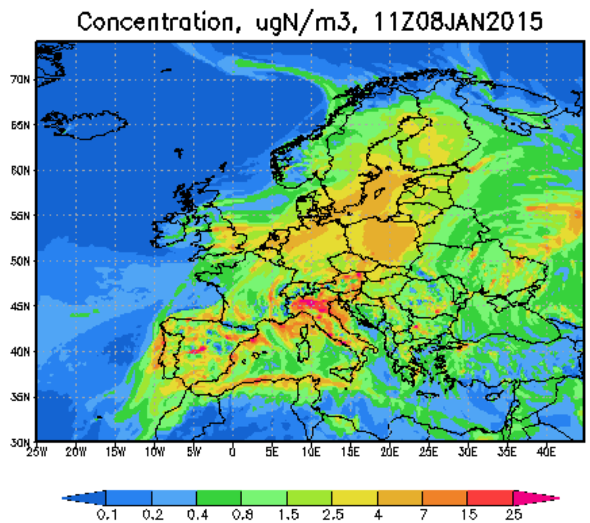
SILAM v.5: modules and capabilities

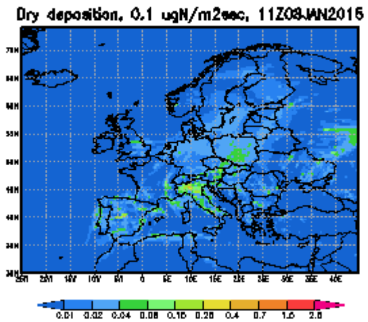
- **Modules**
  - 8 chemical and physical transformation modules (6 open for operational use),
  - 6 source terms (all open),
  - 2 aerosol dynamics (one open)
  - 3D- and 4D- Var
- **Domains: from global to beta-meso scale (~1km resolution)**
- **Meteo input:**
  - ECMWF
  - HIRLAM, AROME, HIRHAM, ECHAM, and any other who can write GRIB-1 or GRIB-2
  - WRF

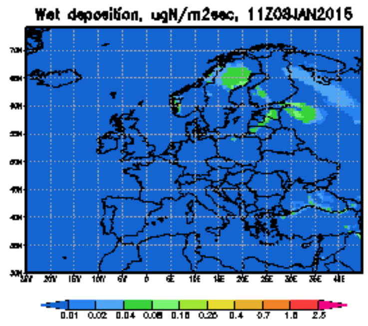


European AQ forecast (SO2, NO, NO2, CO, O3, PM10, PM2.5)

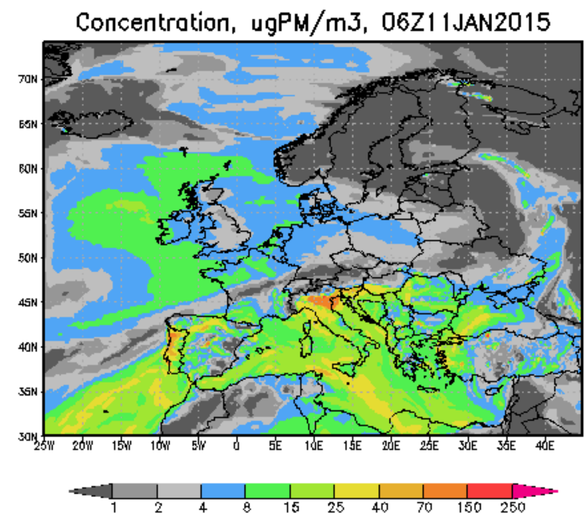
Forecast for NO2_gas. Last analysis time: 20150108_00

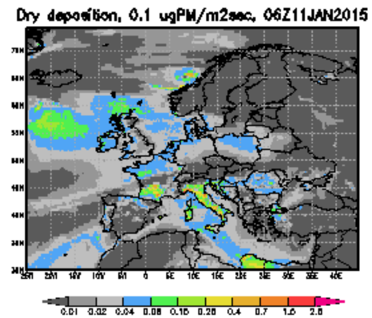


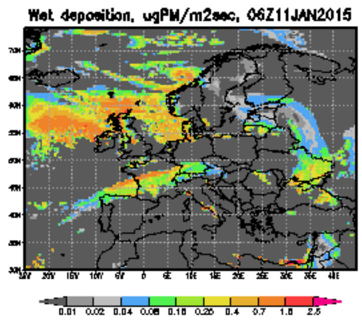




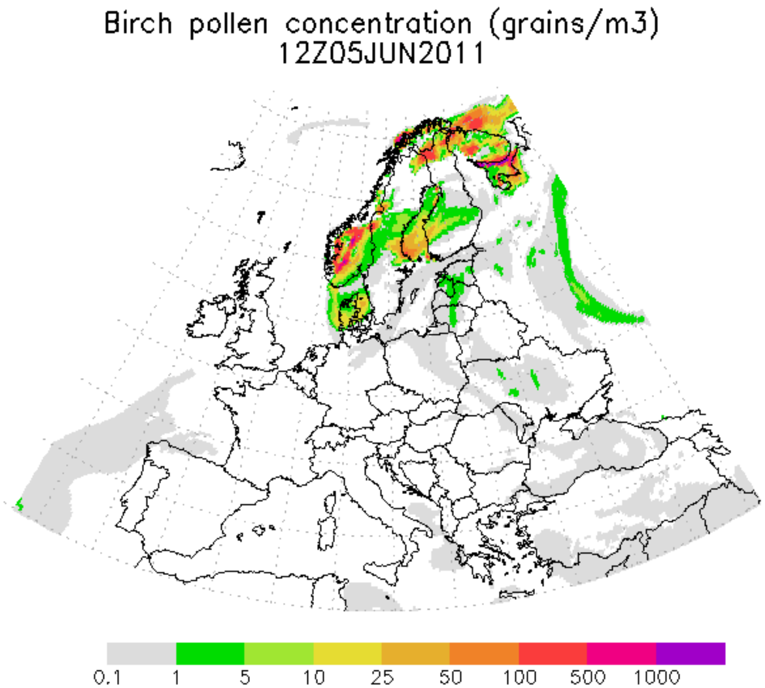
Forecast for PM2_5. Last analysis time: 20150109_00

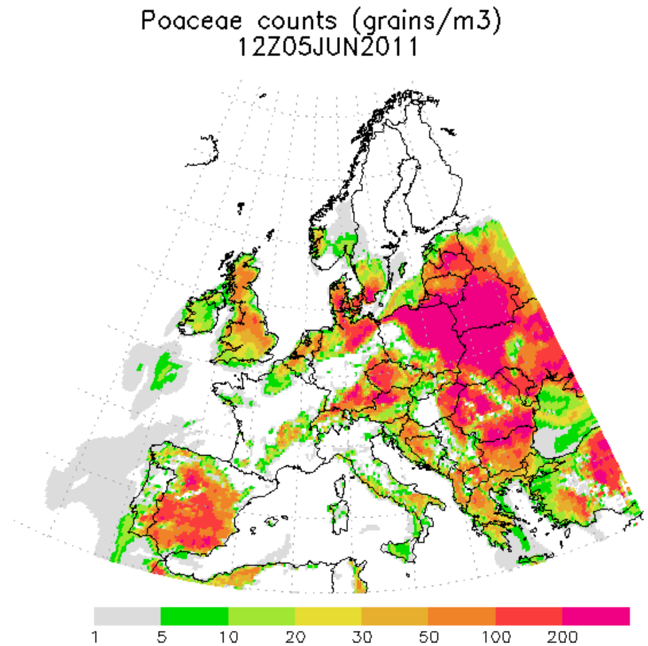


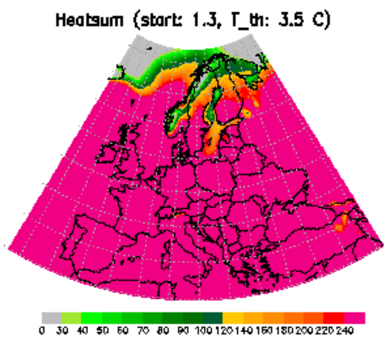


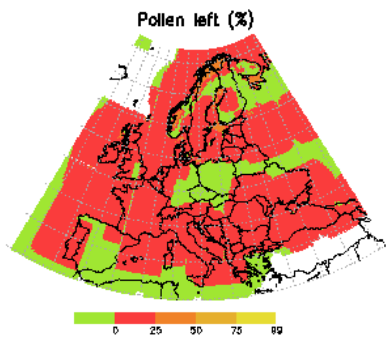


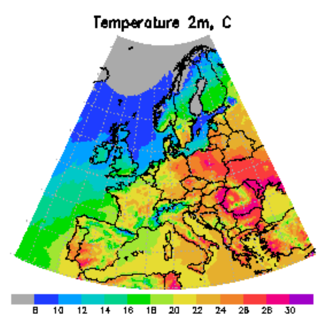
POLLEN FORECAST (Birch, grass, *olive*)

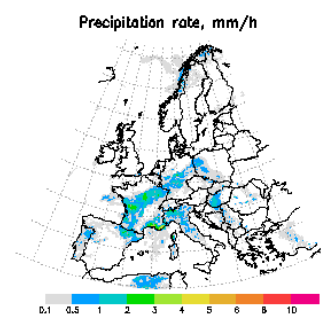








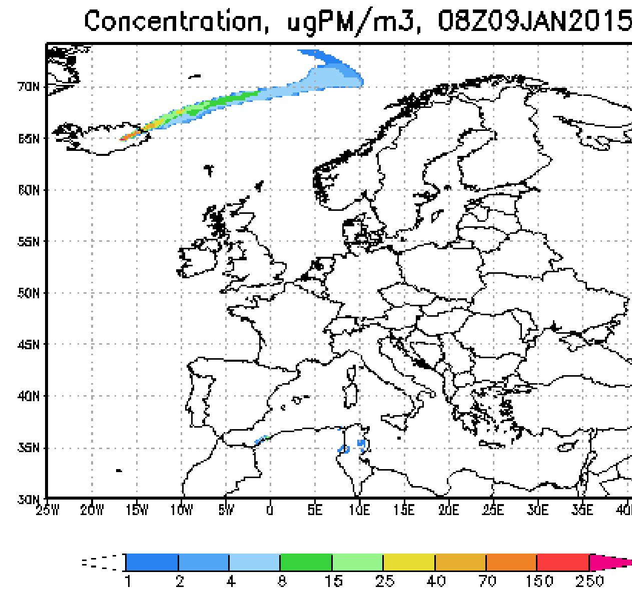


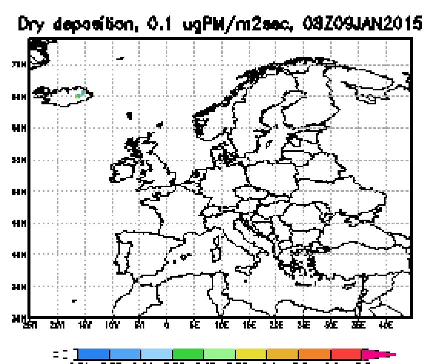


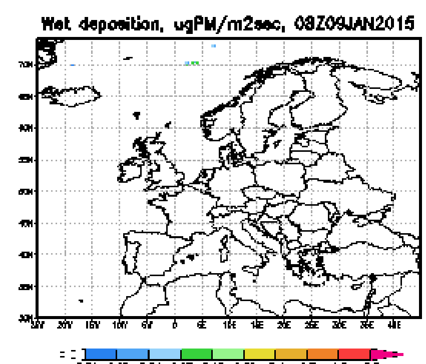
http://silam.fmi.fi/

Forest fires,
volcanoes,
etc…

Forecast for PM_2_5__TA. Last analysis time: 20150109_00







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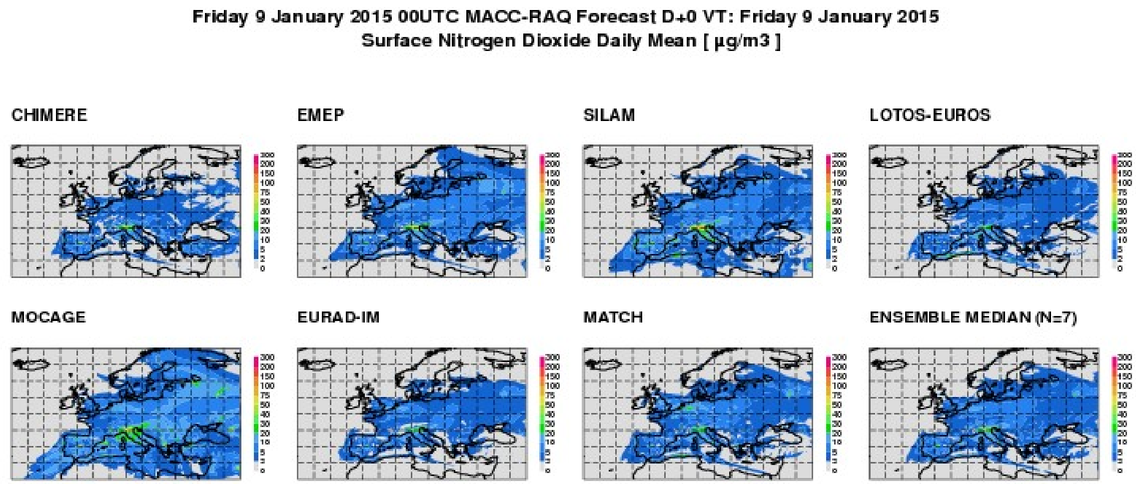
macc Monitoring atmospheric composition & climate

MACC3 - Monitoring Atmospheric Composition and Climate: European air quality forecasting ensemble, (https://www.gmes-atmosphere.eu/)

+ 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,



Example forecasts using models , and ensemble forecast

Local/Urban scale models

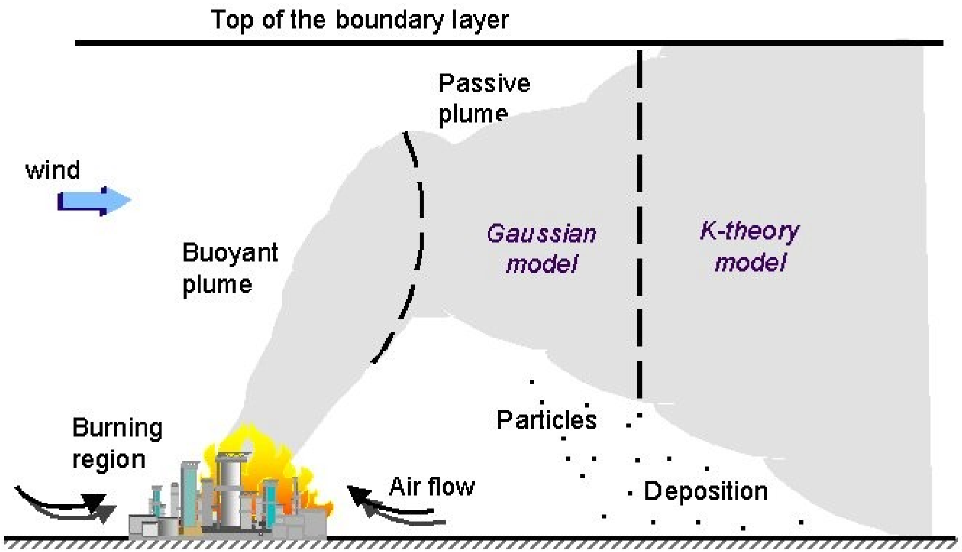
UDM-FMI/ CAR-FMI

GAUSSIAN plume models (for point,line and area sources)

- **"Simple" tools mainly for long-term (~1 year) statistical analyses**
- **CAR-FMI evaluated also for very short term (up to 1 hour) calculations**
- **models are deterministic :**
  - **Input: real emissions, real meteorology**
- **models are never dynamic and are not capable of handling complex terrain and obstacles!**

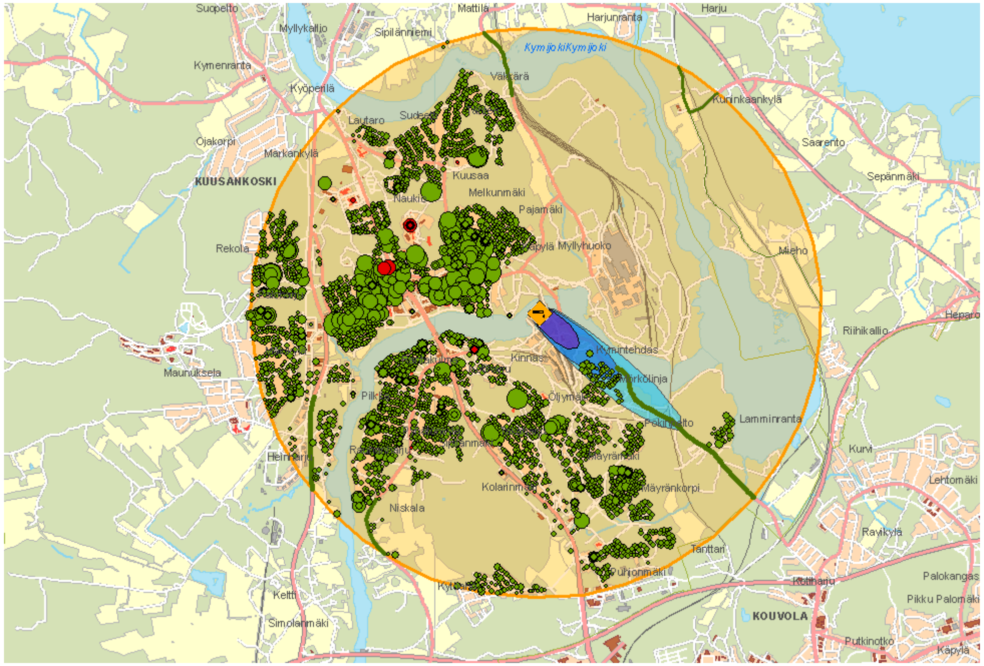
BUO-FMI –

Dispersion from Strongly Buoyant Sources – Finnish Meteorological Institute

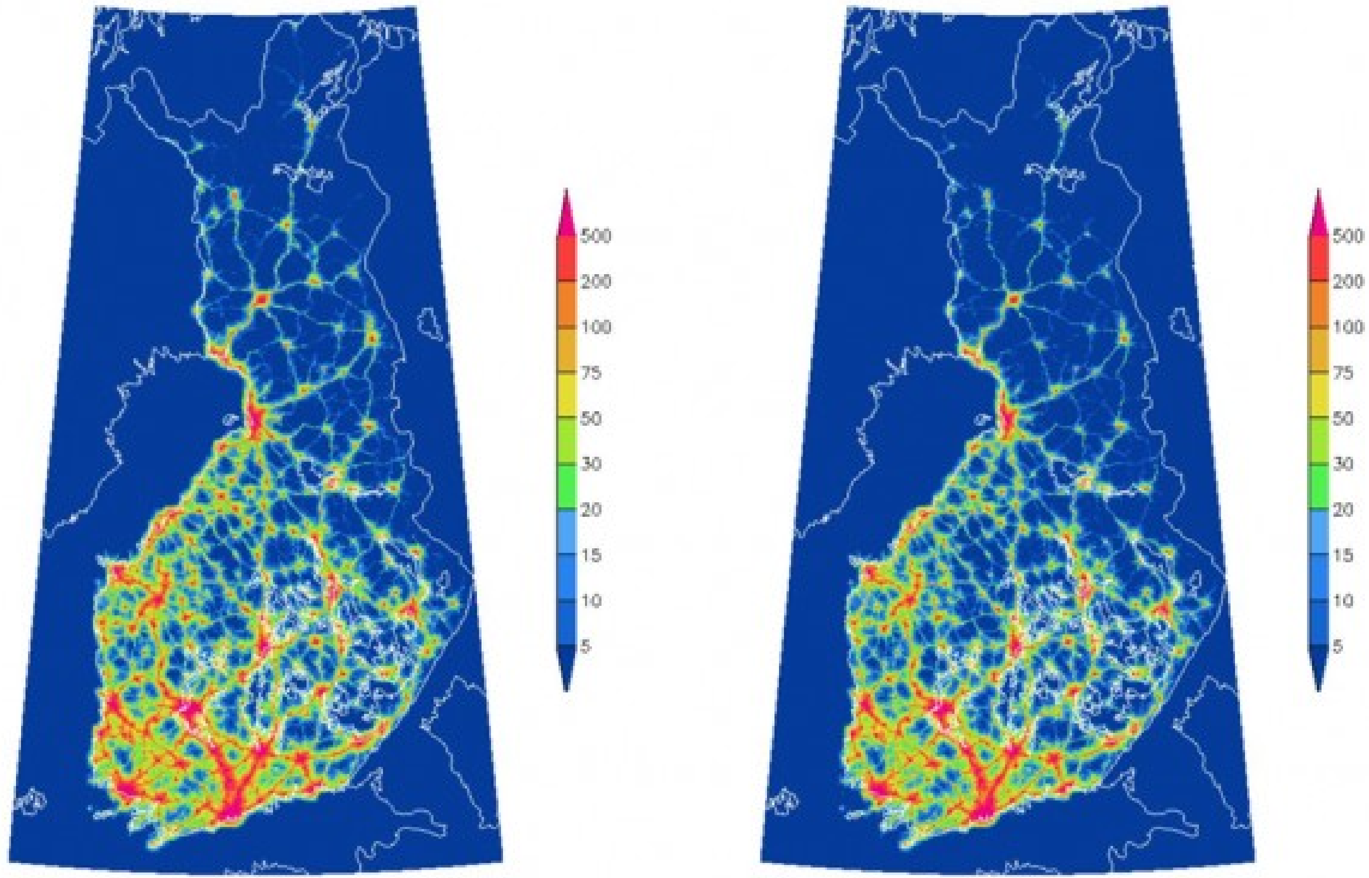


ESCAPE –

Expert System for Consequence Analysis using a PErsonal computer



Spatial distribution of annual mean concentration of $PM_{2.5}$ due to nearby direct and suspended emissions of traffic in 2000 (ng/m^3). (UDM-FMI)



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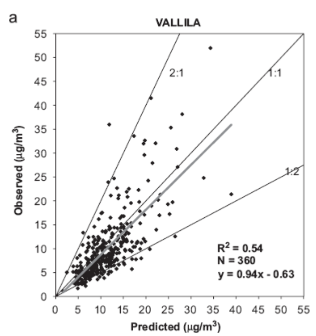
ytv

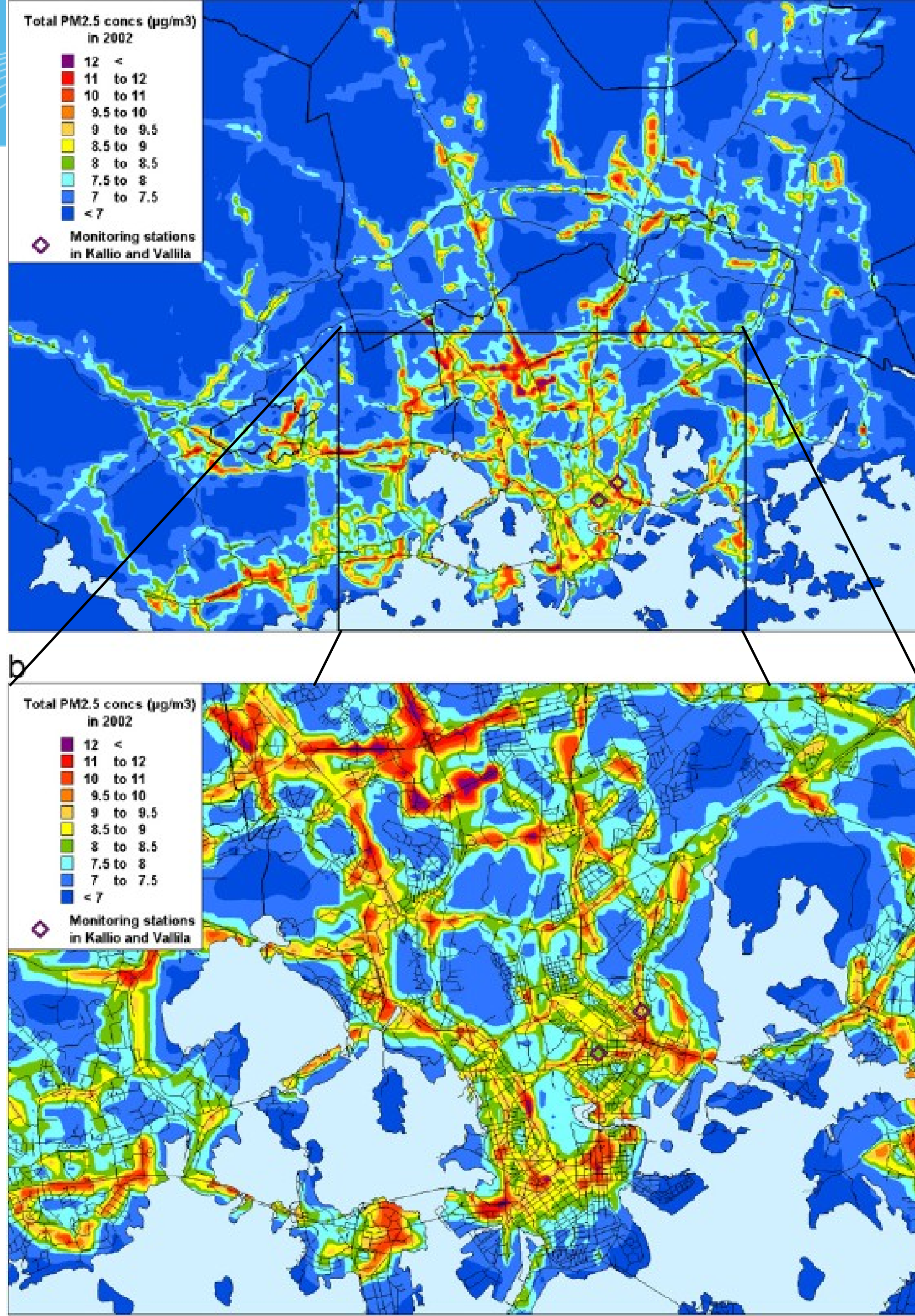
Predicted spatial distribution of the yearly means of PM2.5 concentrations (mg / m³) (upper figure) in the Helsinki Metropolitan Area, and (lower figure) in the centres of the cities of Helsinki and Espoo, in 2002.

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

◊ = the locations of the urban monitoring stations

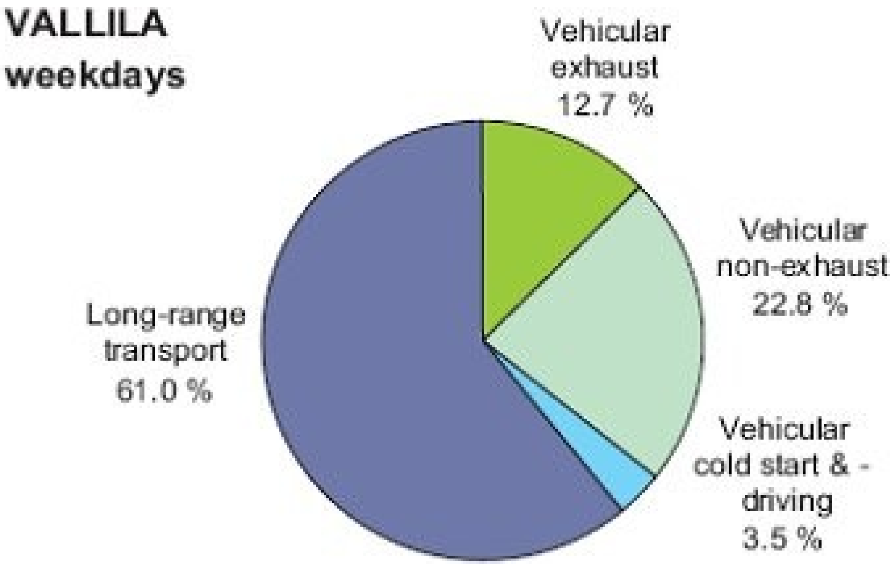
Scatter plot of measured and predicted daily averaged concentrations at the station of Vallila.



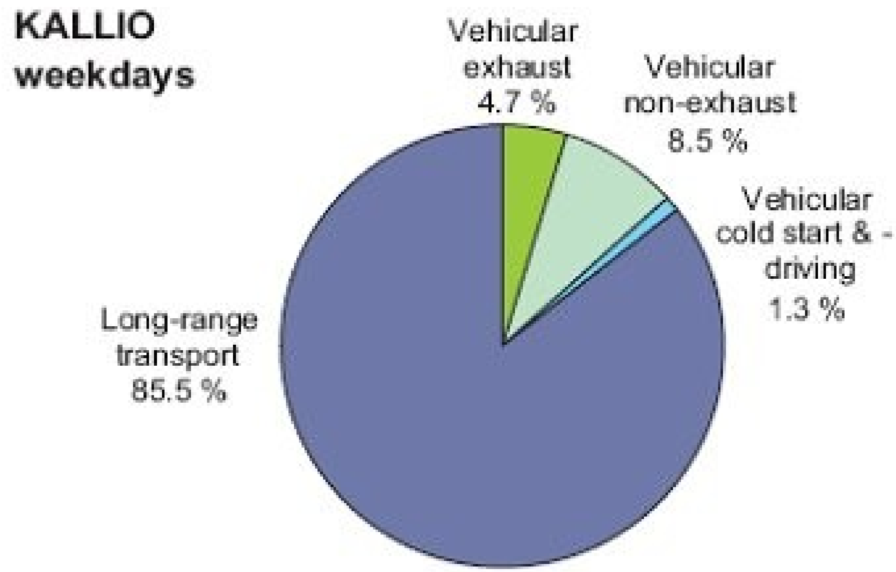


Ref. Kauhaniemi et al., 2008. Atmos. Environ. Vol 42/19 pp 4517-4529.

Urban traffic



Urban background



The predicted relative contributions of various emission source categories to the annual average $PM_{2.5}$ concentrations at two stations in Helsinki during weekdays in 2002. Domestic combustion was not included in the computations.

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

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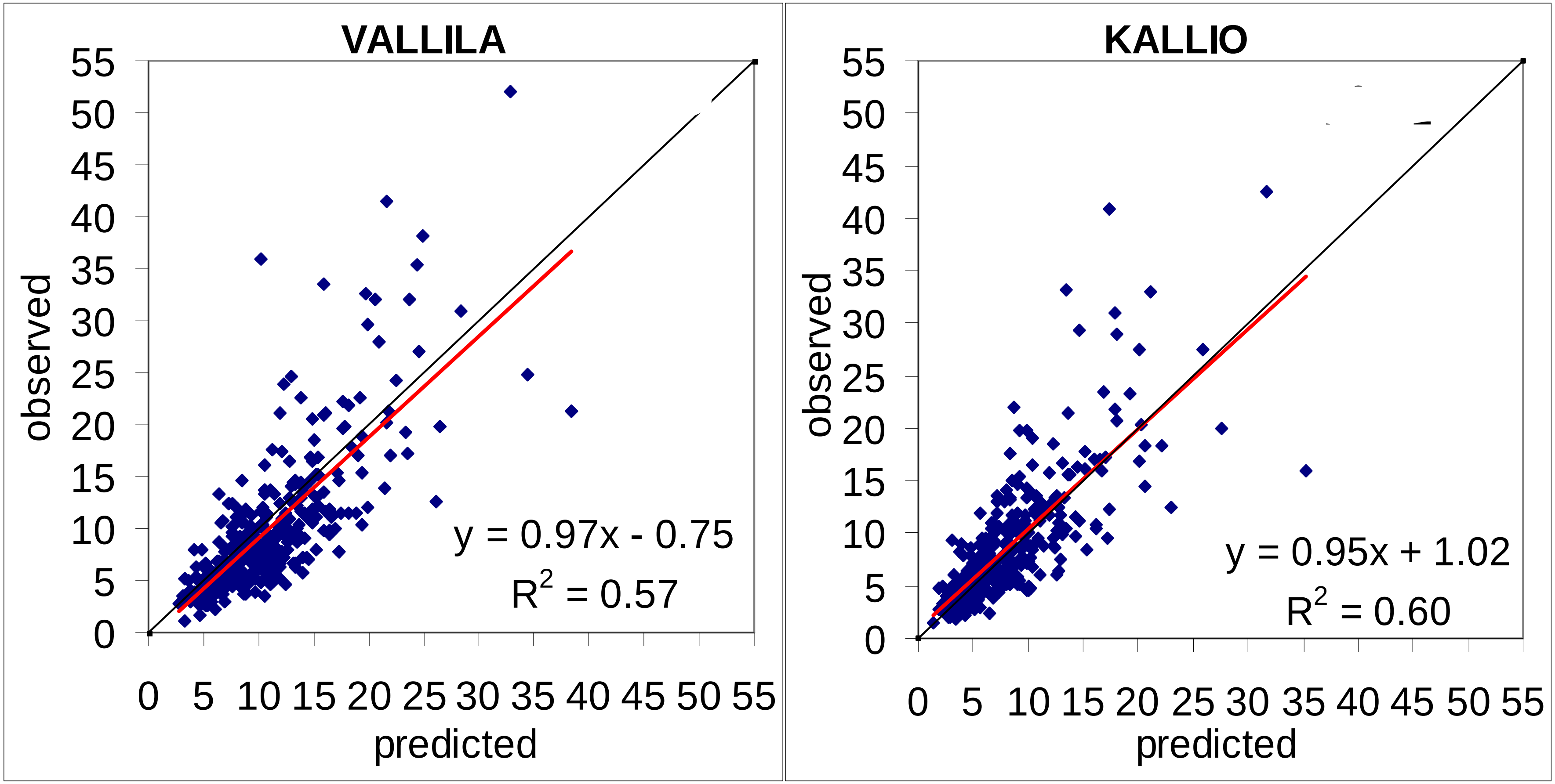
Predicted vs. observed daily mean
$PM_{2.5}$ concentrations at two stations – scatter plot, Correlation Coefficient squared (R^2) and Index of Agreement (IA)



VALLILA: R^2 = 0.57, IA = 0.84

KALLIO: R^2 = 0.60, IA = 0.86

Improvements ?

- **Urban AQ modeling is a challenge: one main uncertainties is the urban meteorology - >NEW research grade measurement network in Helsinki:**
- **http://urban.fmi.fi**

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

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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PESCaDO

- A web portal prototype, EU/FP7 project 2010-2013.
- aims to provide understandable and accurate responses environmental, personalized queries

- **A large amount of relevant raw data (measurements, forecasts) is searched and extracted**

- **Competing and complementary data needs to be fused**

Fusion of environmental information – the main principle

- Each datapiece describing conditions in (r_i, t_i) is regarded as an estimator $\theta(\mathbf{r}_i, t_i) = c(\mathbf{r}, t) + \varepsilon$ where $c(\mathbf{r}, t)$ is the pollutant concentration/ weather condition in the user defined time and place
- The overall aim is to form an ensemble value $\theta_F(\mathbf{r}, t)$ from n independent non-biased statistical estimators $\theta(\mathbf{r}_i, t_i)$ given by (Potemski, Galmarini 2011)

$$\theta_F(\mathbf{r}, t) = \sum_{i=1}^{n} w_i \theta_i(\mathbf{r}_i, t_i) \qquad w_i = \frac{VAR(\theta_i(\mathbf{r}_i, t_i))^{-1}}{\sum_{i=1}^{n} VAR(\theta_i(\mathbf{r}_i, t_i))^{-1}}$$

- Simply put, evaluate the expected $VAR(\theta(\mathbf{r}_i, t_i))$ and weight each datapoint with normalized $\frac{1}{VAR(\theta(\mathbf{r}_i, t_i))}$

In theory, the fused estimator $\theta_F(r, t)$ should have the lowest Squared Error, while beating all the individual estimators

- Each datapiece describing conditions in is regarded as an estimator where is the pollutant concentration/ weather condition in the user defined time and place
- The overall aim is to form an ensemble value from independent, non-biased statistical estimators given by (Potemski, Galmarini 2011)
- Simply put, evaluate the expected and weight each datapoint with normalized
- In theory, the fused estimator should have the lowest Squared Error, while beating all the individual estimators

Variance – sensor historical performance

Information flows through PESCaDO

Fusion of Information

Measurements are stored as evaluation material

Model forecasts are stored to be evaluated

Performance is being evaluated **continuously**

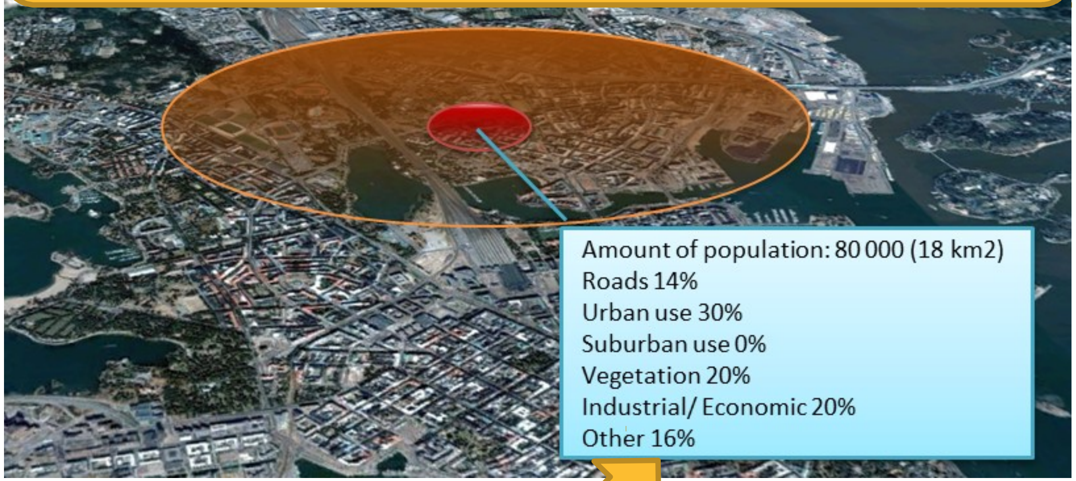
Historic performance database

The use of stored evaluation material is used for updating a large set of fusion parameters, including the **variance calculation** and **bias removal**

Fusion of environmental information - bias

- Datapoint can be a bad estimator because it might describe conditions in a different **environment**
- **The variance model will not help! A measurement just 500m away can be strongly biased if urban**

Environment is expressed in selected land-use frequencies and population count!

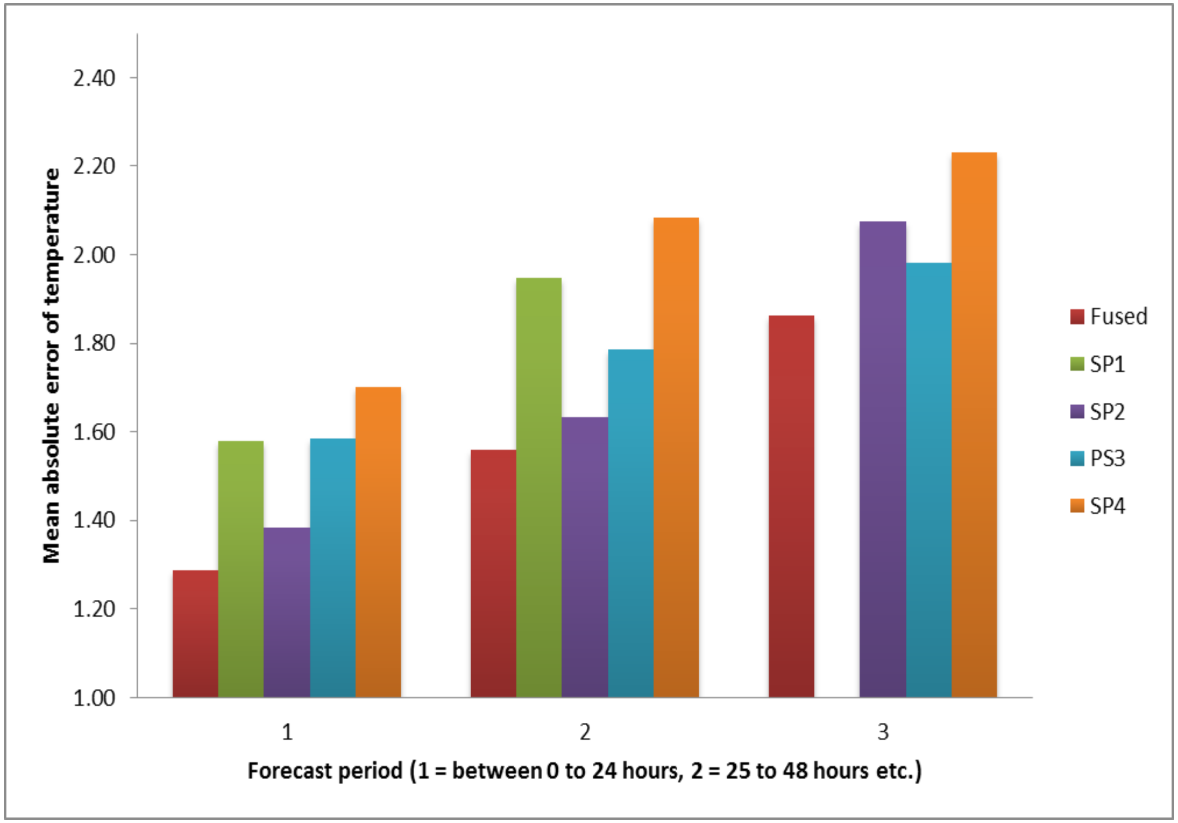


Fortunately, this bias can be evaluated by using an adaptation of Land-Use Regression (LUR)

- Datapoints are augmented with an **Environment**
- The expected value **within the Environment** can be estimated
- The requirement to ensemble **non-biased estimators** will be satisfied!

Results – temperature forecast fusion

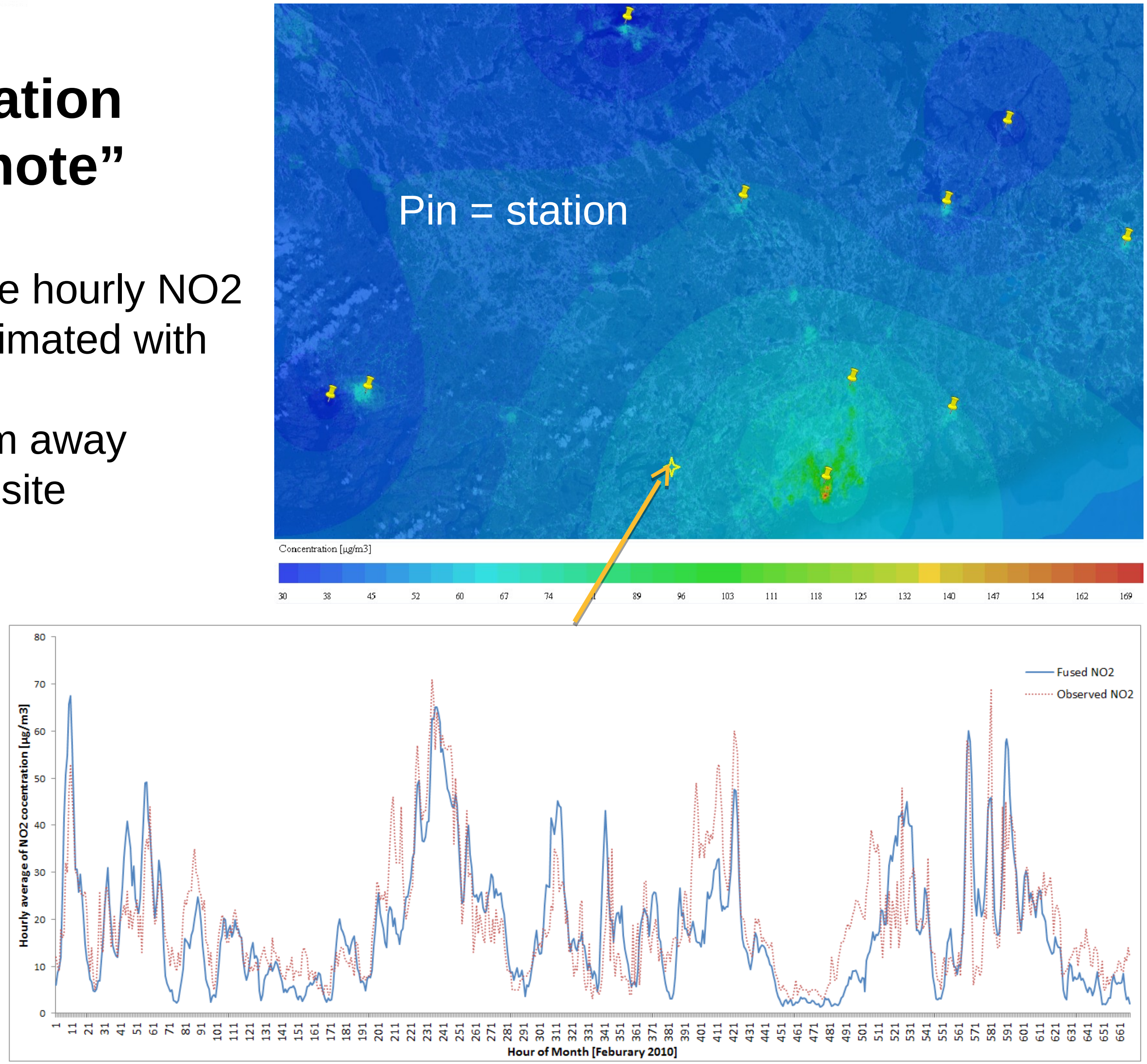
- Four service providers offering temperature forecast for the next 1 to 48 hours
- Service provider's historic performance had been evaluated
- For one month, August 2012, in 40 locations the forecasts and fused forecasts were compared against observed temperature
- => The fused temperature forecast **had the smallest mean absolute error** in all three forecast periods



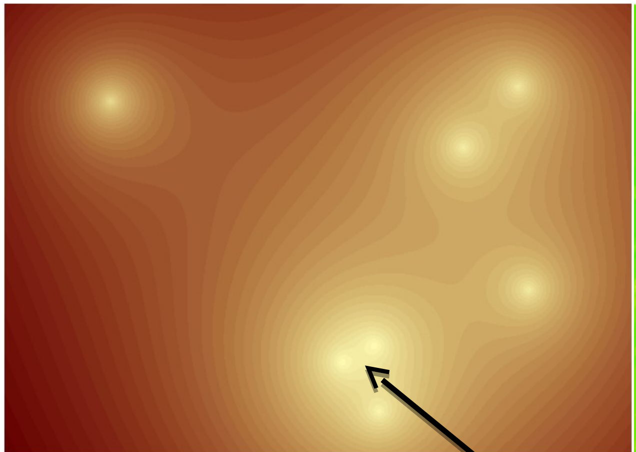
Results – Estimation of NO2 in a ”remote” town

For February 2011, the hourly NO2 concentration was estimated with fusion

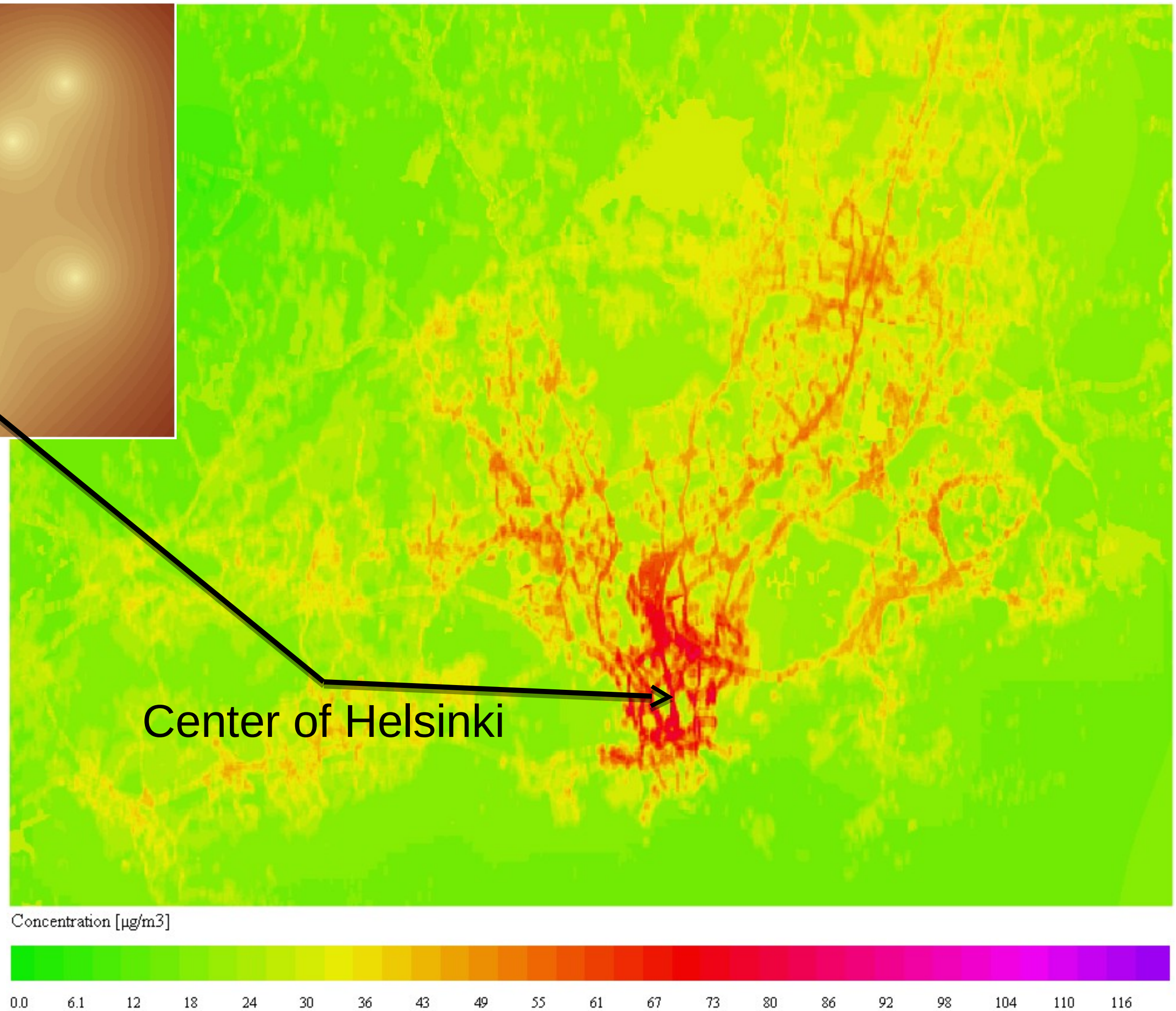
- Closest station 50 km away
- Comparison with on-site measurements



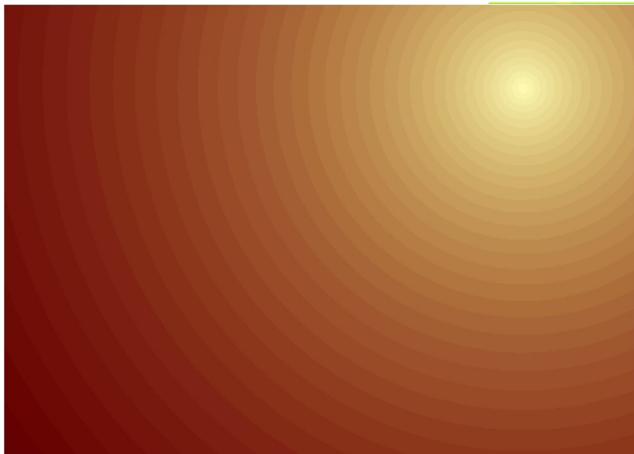
NO2 at 2011-04-06T07:00 - All seven stations



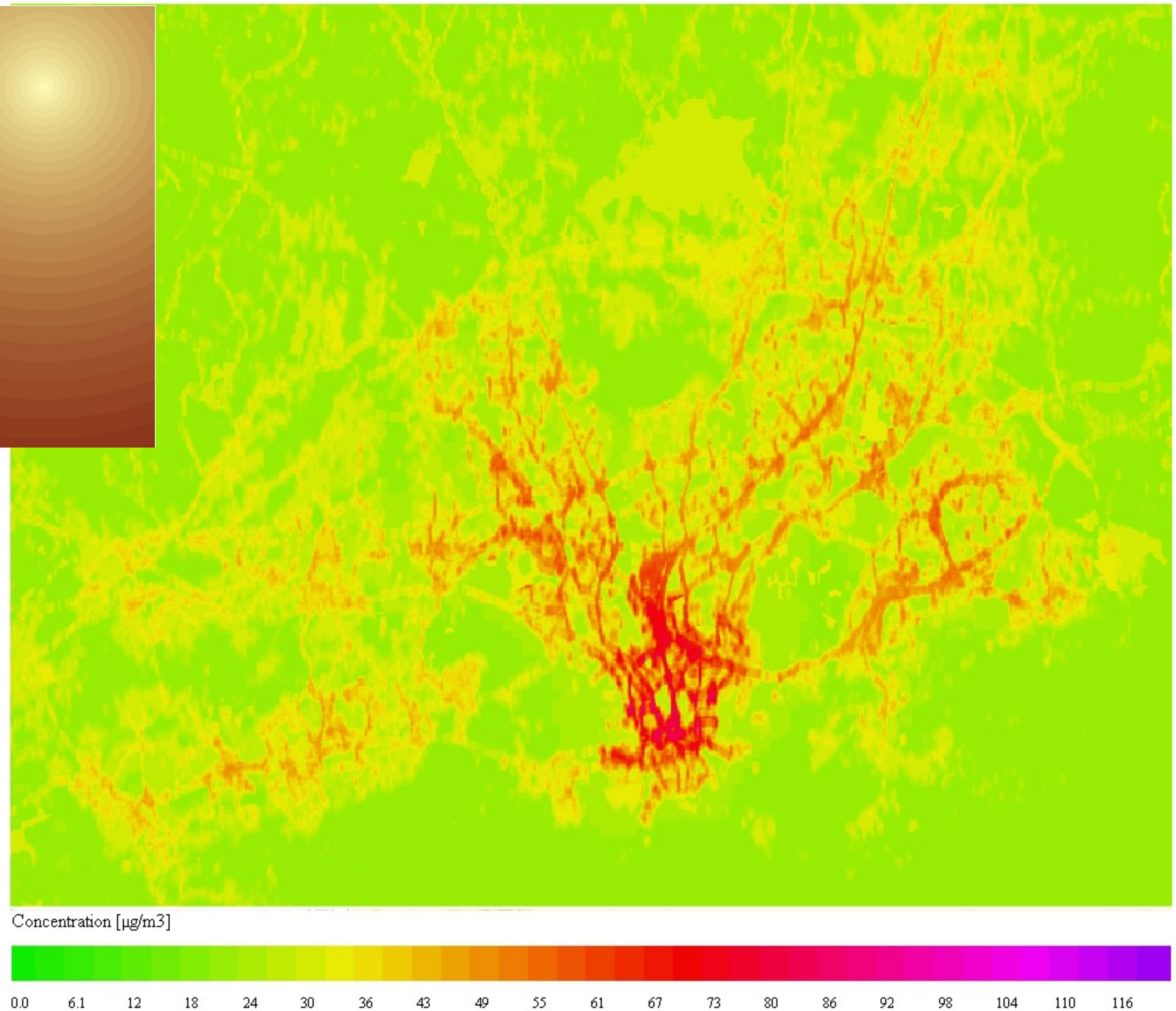
Expected standard deviation (darker = greater)



NO2 at 2011-04-06T07:00 – one station



Expected standard deviation (darker = greater)



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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Input data of the Ship Traffic Emission Assessment Model (STEAM)

- **AIS:**
  - Position, speed, registry number of a ship
  - Over 210 million position reports in 2007
- **Lloyds register:**
  - Technical data
- **Shipowners, other sources:**
  - Emission certificate
  - Abatement techniques
  - Fuel type, consumption
  - Additional technical data
- **FMI WAve Model (WAM)**
  - Wave data
  - Ice cover (planned)
  - Sea currents (planned)

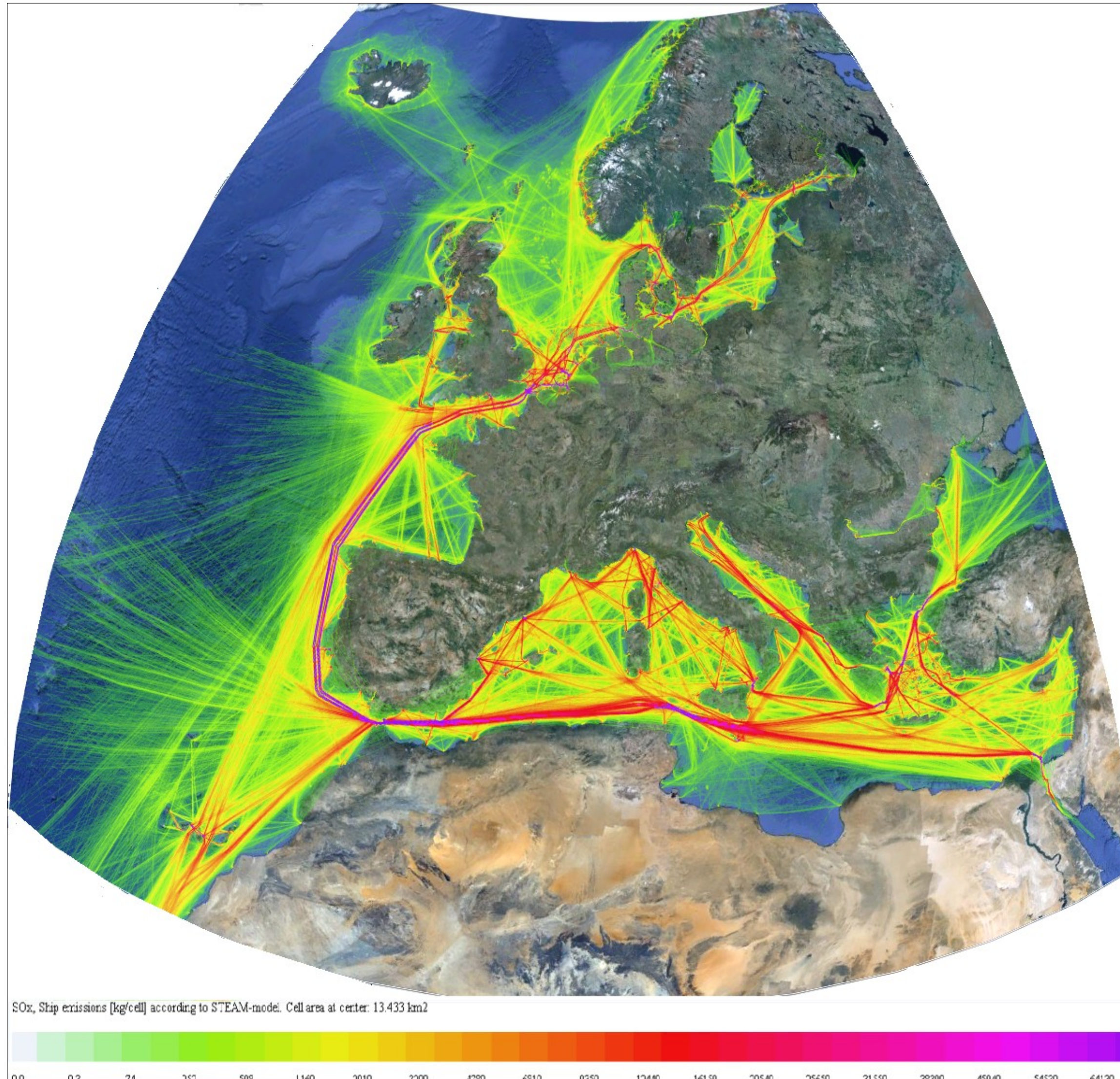
Extension of an assessment model of ship traffic exhaust emissions for particulate matter and carbon monoxide"
J.-P. Jalkanen, et al.
Atmos. Chem. Phys., 12, 2641-2659, 2012

A modelling system for the exhaust emissions of marine traffic and its application in the Baltic Sea area
J.-P. **Jalkanen**, , et al.
Atmos. Chem. Phys., 9, 9209-9223, 2009

The latest on shipping emissions

- **New fuel type (HFO,MGO) deduction logic as a function of region, date and engine specs**
- **Reduction scenarios**
  - Monetary considerations
  - Slow-steaming
  - Imposed and Upcoming regulations in Emisson Control Area (ECA)

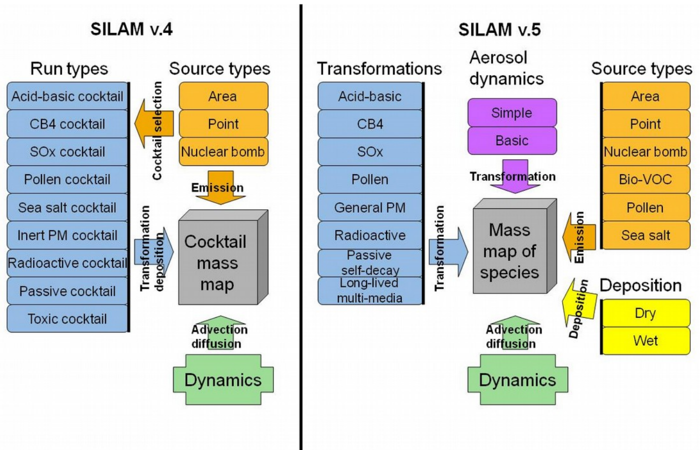
- **IMO 2013 : update for GLOBAL ship emissions: FMI in the winning consortia**

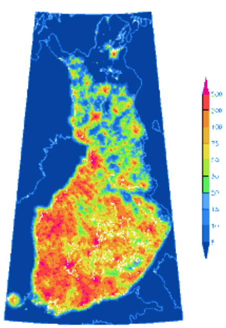


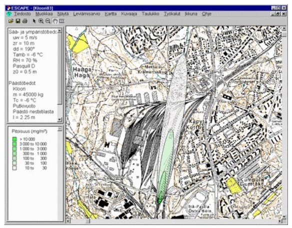
Challenges in model development:

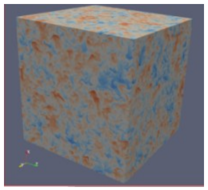
1. **Regional scale modelling system**
   - **Aerosol procecess, full chemistry, data assimilation**
   - ship emissions : global (/European) coverage
2. **Combined** utilisation of meteorological models and dispersion models (including co-operation with met-model development)
   - **Down to** resolution ~1 km with Eulerian models
   - Obstacle resolving models (CFD, LES, DNS)
   - **Nowcasting & Short-time** forecasting
   - **Operative integrated** systems (met-AQ, measurements –models)
3. **Health effects** of especially (fine/ultrafine) particulate matter
   - **Evaluation** of current systems with chemically specifiated PM-data
   - Further development of exposure models (local->regional scale)

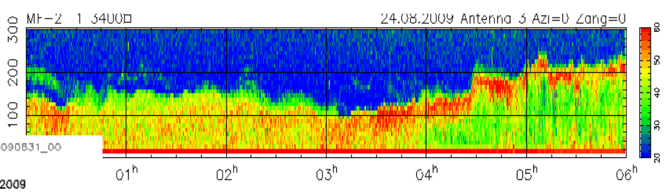
http://en.ilmatieteenlaitos.fi/atmospheric-dispersion-modelling-group

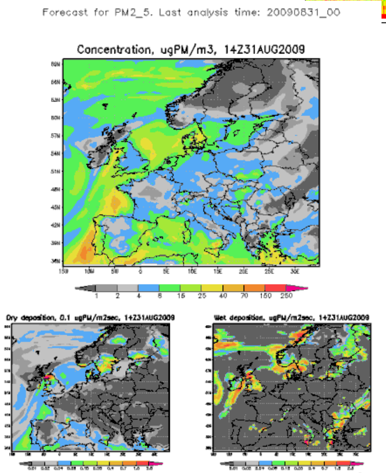


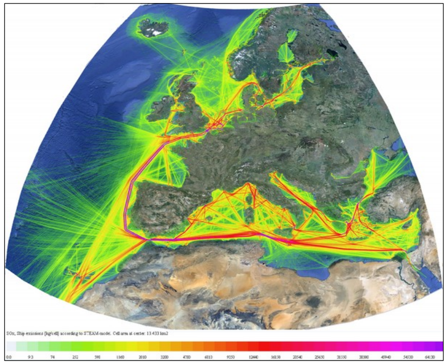


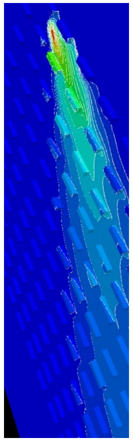


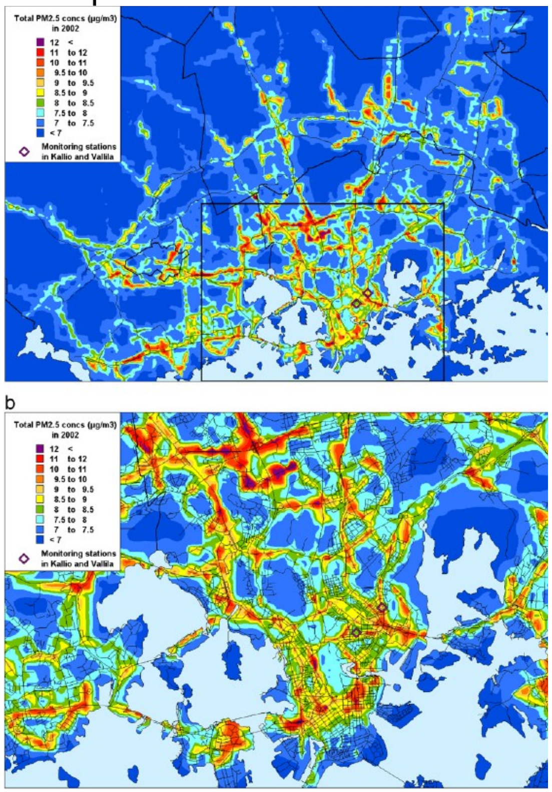












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An operational urban scale air quality forecast system

Mari Kauhaniemi
Ari Karppinen
Jari Härkönen
Juha Nikmo
Julius Vira
Marje Prank
Lasse Johansson
Jaakko Kukkonen

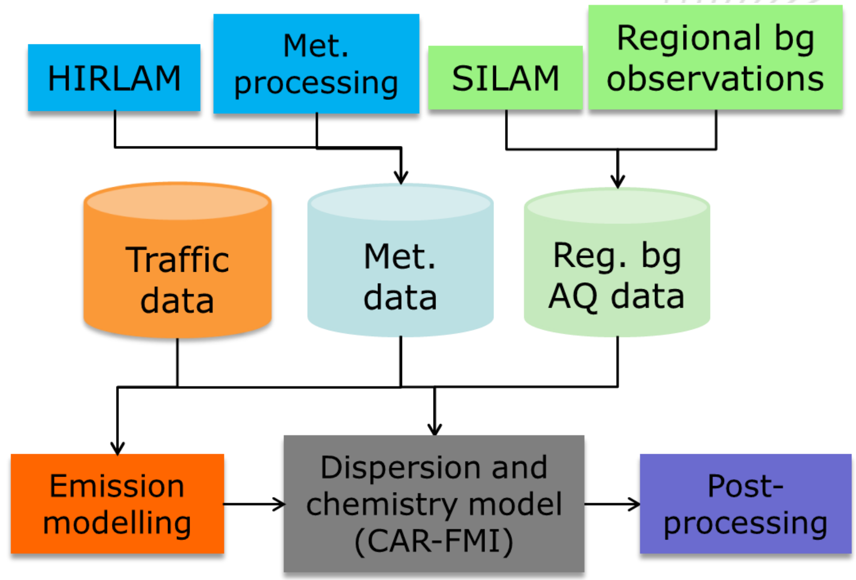
Workshop: Helsinki AQ-met, obs-models, Dynamicum 12.1.2015

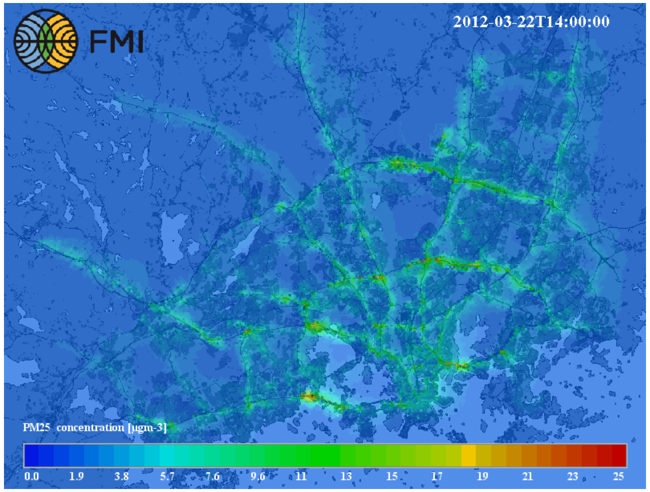
Background

- Aim
  - Information and planning tool for authorities
  - Information and warnings for public about high air pollution
- Requirements
  - Series of models from emission modelling and meteorological forecasting to dispersion of pollutants
  - Data retrieval and processing tools
  - Operational forecasting
  - Web interface for results

Urban air quality forecast system at FMI

- Includes
  - Meteorological and air quality data retrieval
  - Models for emission, chemistry, and dispersion (FORE, CAR-FMI)
- Limitations
  - Considers only road traffic emissions
- Output
  - 44 hour forecast four times a day (02, 08, 14, and 20 local time)
  - NO2, NO, CO, O3, PM2.5, and PM10
  - Domain is the Helsinki metropolitan area (40 km x 30 km; grid size 50-500 m)





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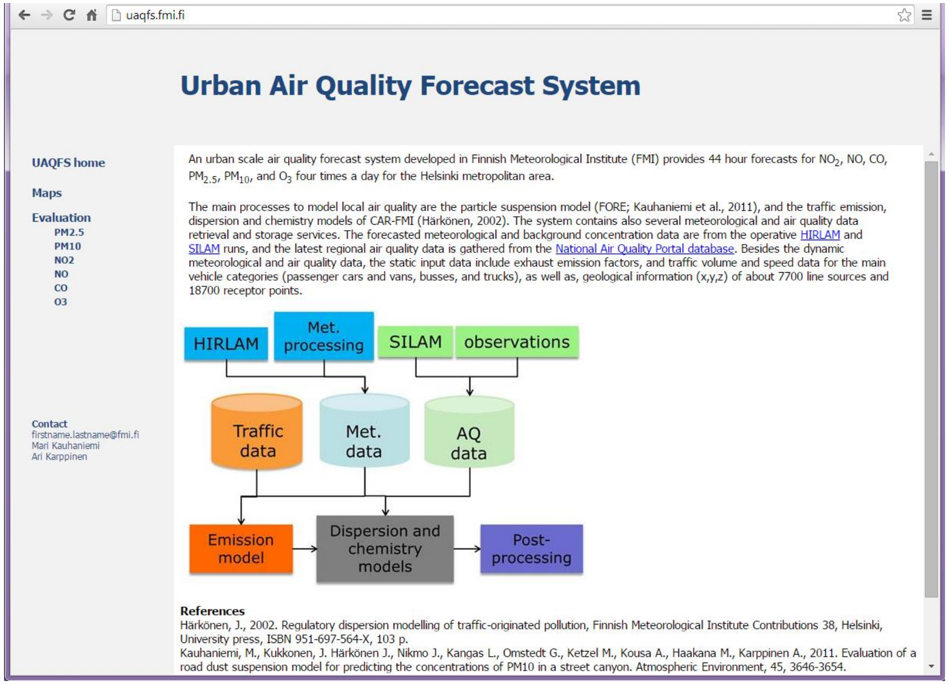
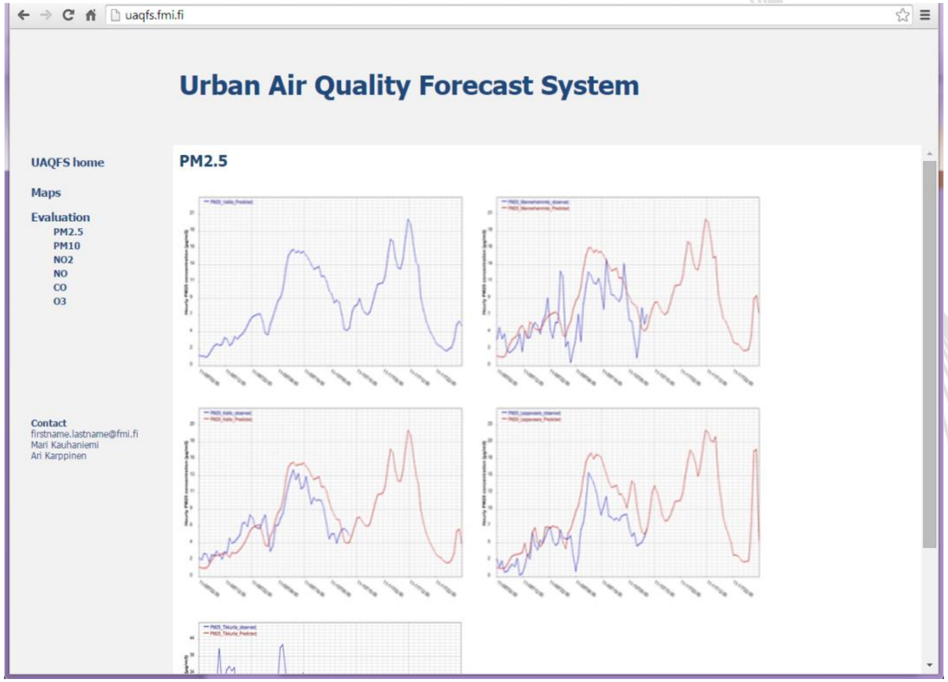
Urban air quality forecast system at FMI

- Real-time results shown on website uaqfs.fmi.fi



Description of the system.



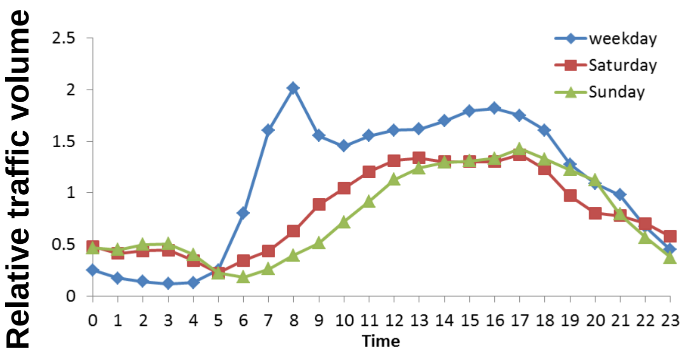
Example of model evaluation.

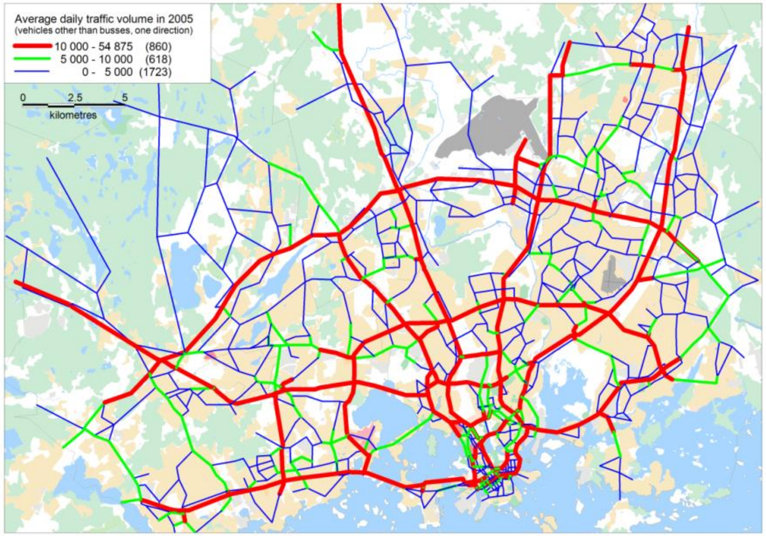
Dispersion and chemistry model (CAR-FMI)

- Contaminants in the Air from a Road (Härkönen, 2002)
- Traffic-originated pollution from an open road network
- Includes
  - Gaussian plume dispersion
  - Dry deposition of particles
  - Discrete parcel method for NO-O3-NO2 chemistry
  - Traffic-induced turbulence
- Evaluated e.g. by
  - NO2: Levitin et al., 2005, Kukkonen et al., 2001, Kousa et al., 2001, Karppinen et al., 2000
  - PM2.5: Kauhaniemi et al., 2008, Tiitta et al., 2002
  - PM2.5 and NO2: Sokhi et al., 2008

Traffic emission modelling

- Exhaust emission factors for NOx, CO, PM2.5
  - National estimates
- Non-exhaust emission factors for PM10
  - Road dust emission model (FORE)
- Traffic data (EMME-2 model)
  - Traffic volume
  - Travel speed (for exhausts)





Road dust emission model (FORE)

- Forecasting Of Road dust Emissions (Kauhaniemi et al., 2011)
- Based on PM emission model of SMHI (Omstedt et al., 2005)
- Considers
  - Moisture content of the road surface.
  - Particles from the wear of pavement due to tyres and traction sand.
- Not included
  - Emissions from brake, tyre, and clutch.
  - Dependencies of emissions on vehicle speed or fleet composition.
  - Influence of salting, dust binding, ploughing, and cleaning.
- Output
  - The emission factor of road wear and traction sand for all traffic in µg/veh/m.

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Meteorological and regional background AQ data

- Meteorological forecasts from HIRLAM
  - High resolution limited area model
  - 54 h forecast
  - four times a day (at 00, 06, 12, 18 UTC)

- Background air quality forecasts from SILAM
  - System for integrated modelling of atmospheric composition
  - 72 h forecast
  - one time a day (at 02 UTC)

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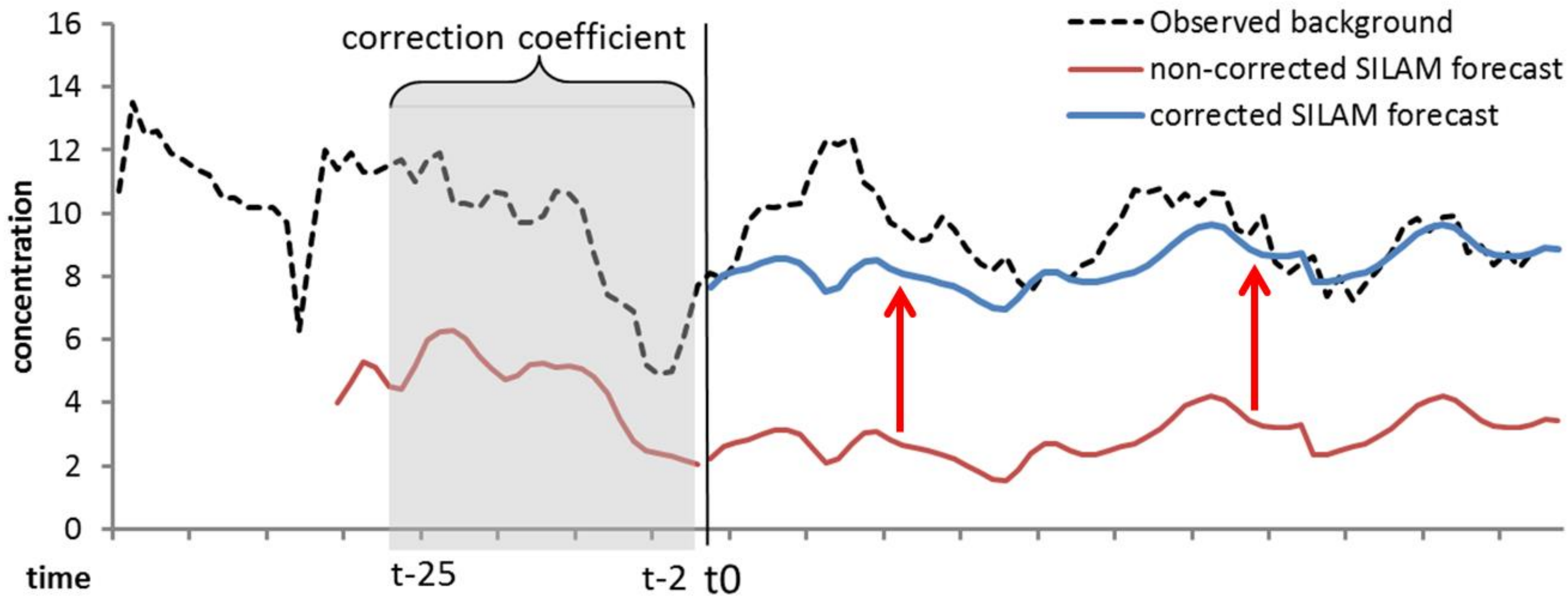
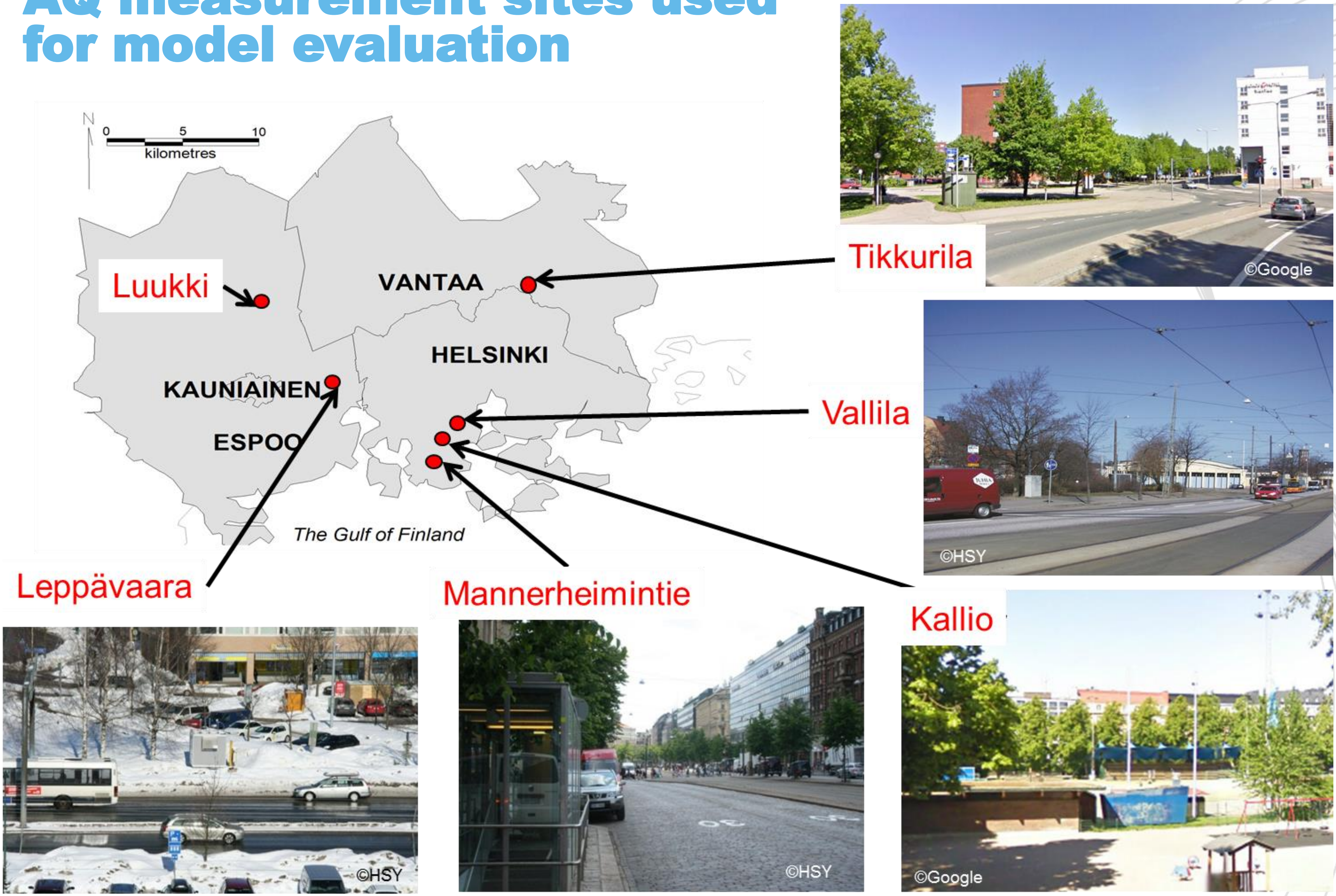
Correction of predicted background air quality

- The level of forecasted background concentrations is corrected with regional background air quality observations.

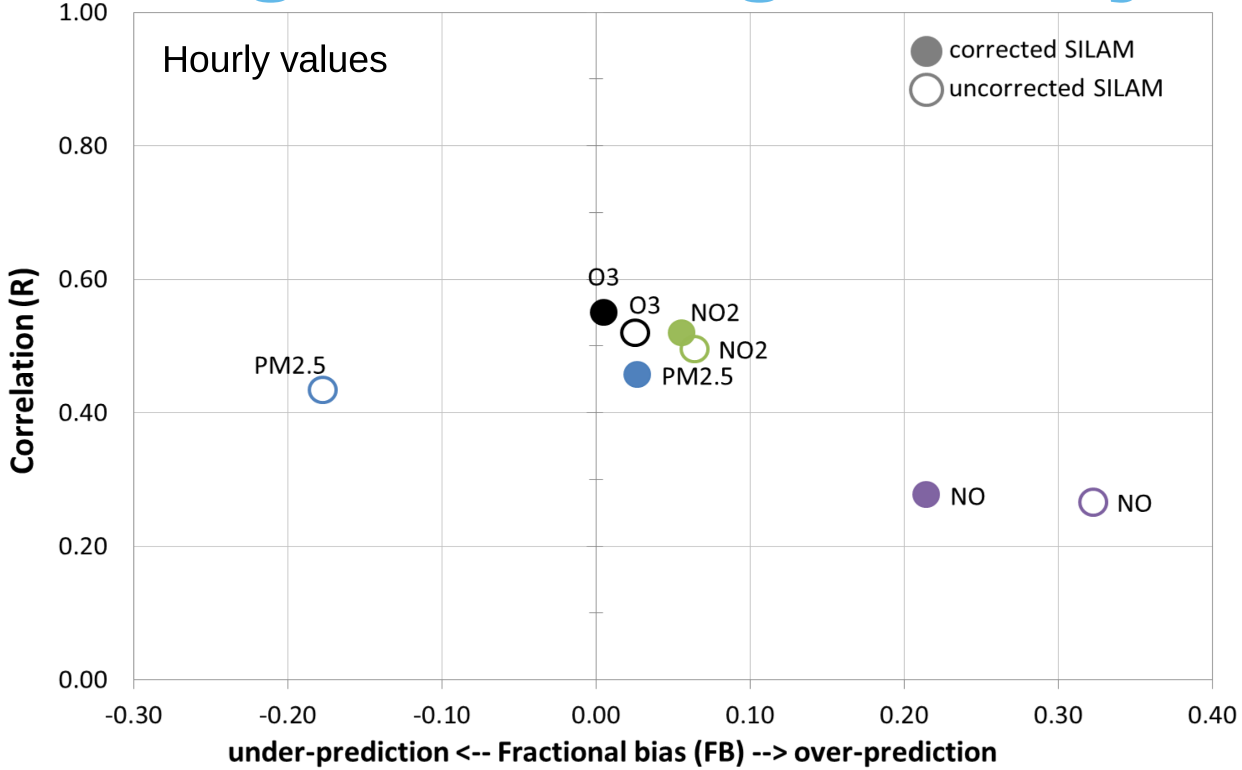


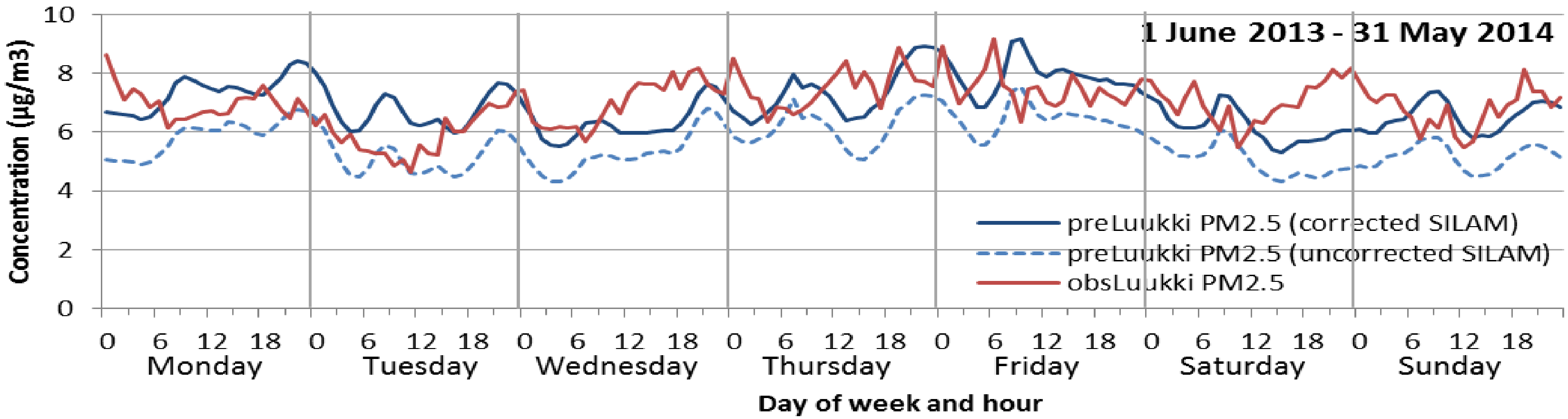
AQF start time t0 = 02, 08, 14, and 20 local time

AQ measurement sites used for model evaluation

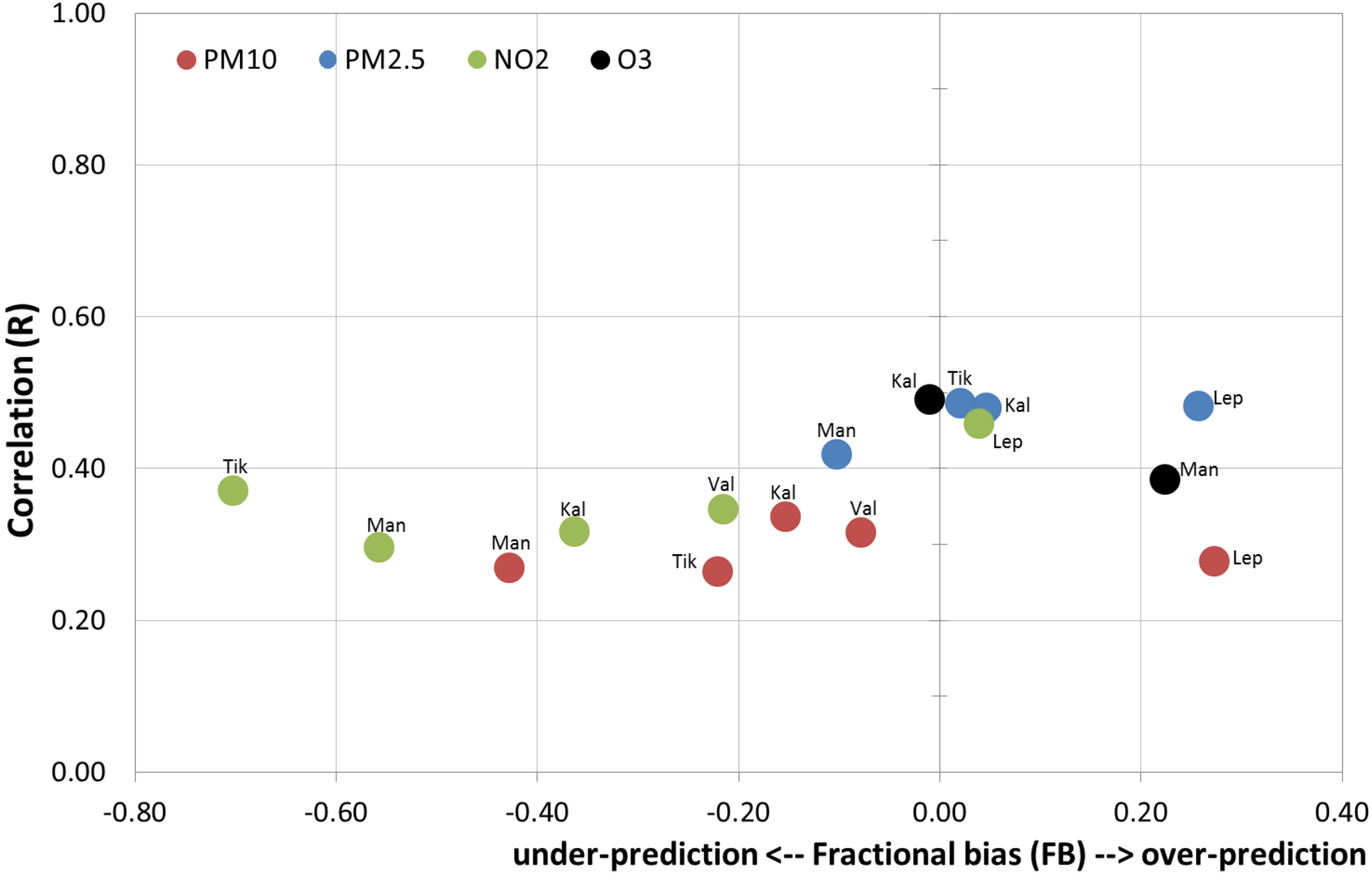


Results: Regional background by SILAM





Results: Hourly values summary



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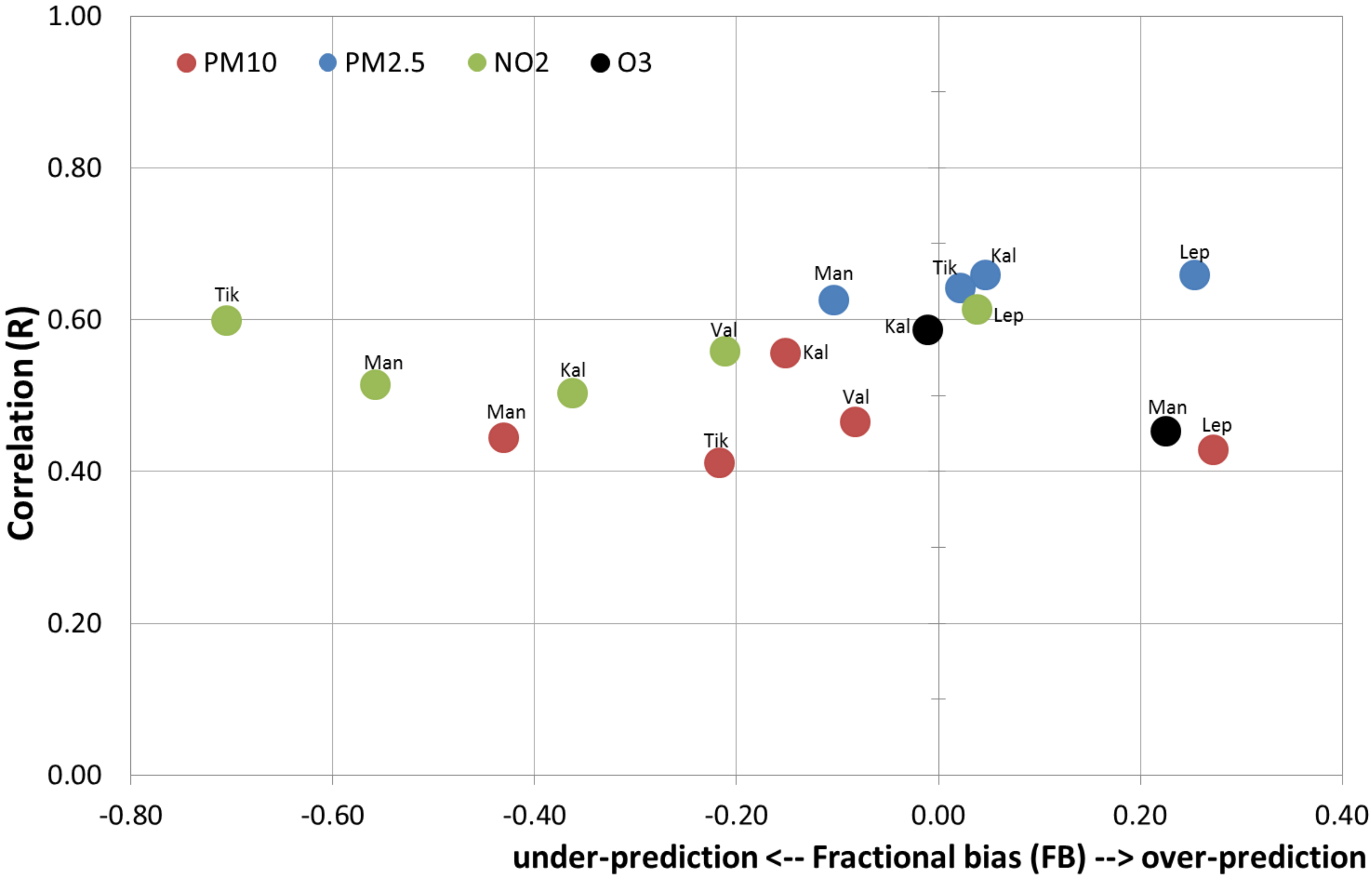
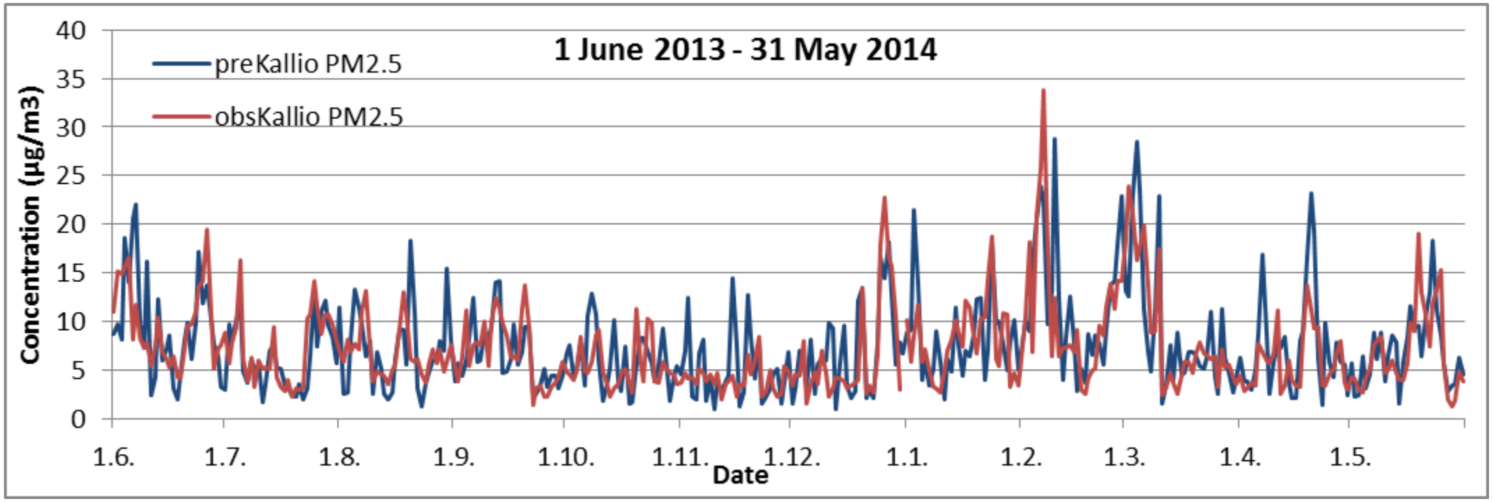
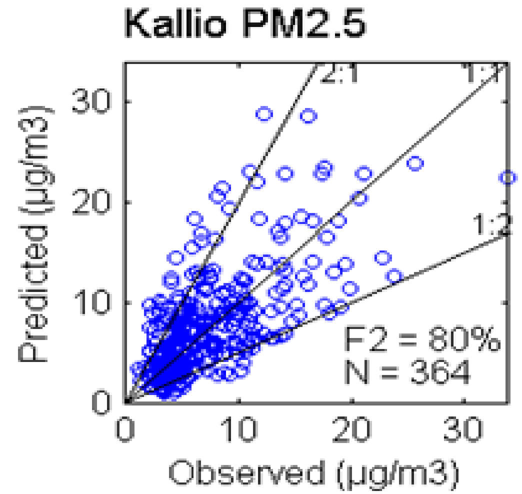
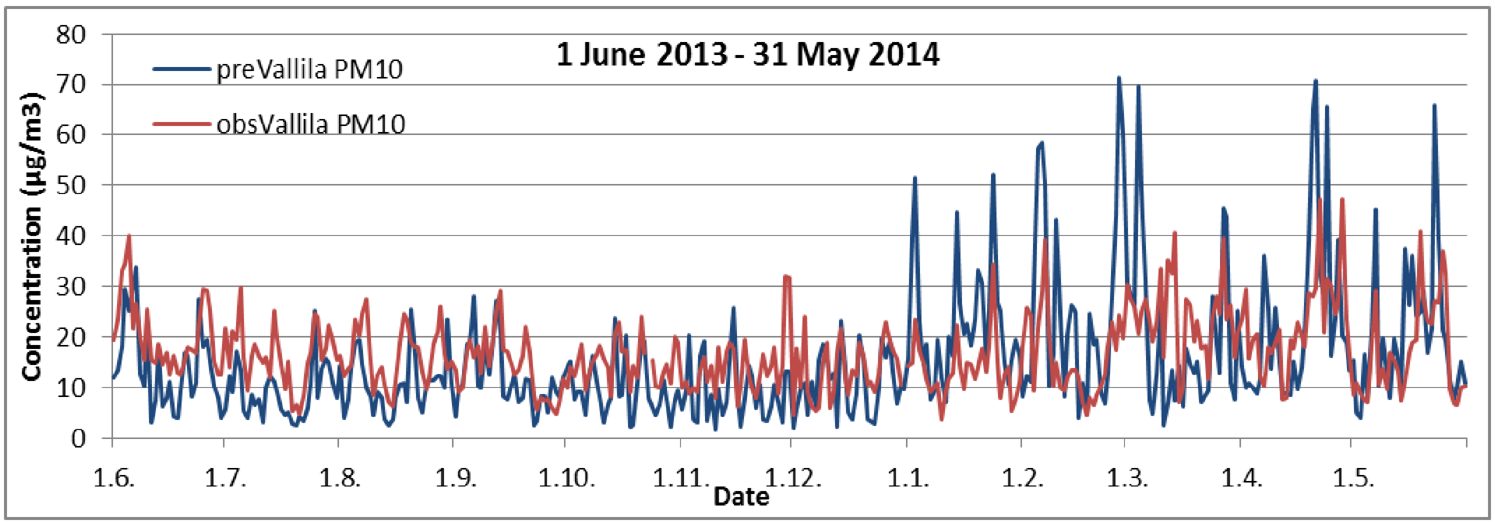
Results: Daily values summary

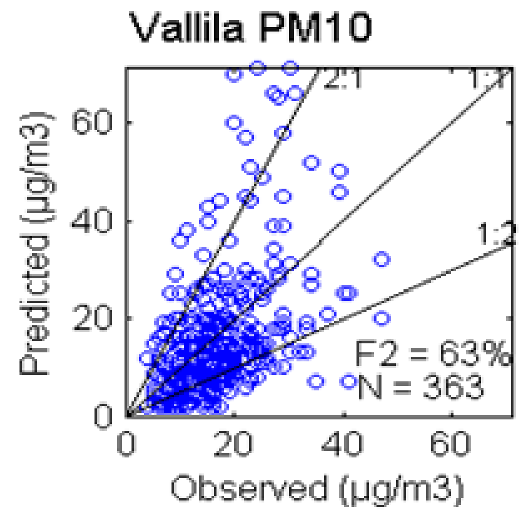


Results: Daily averaged PM2.5 and PM10

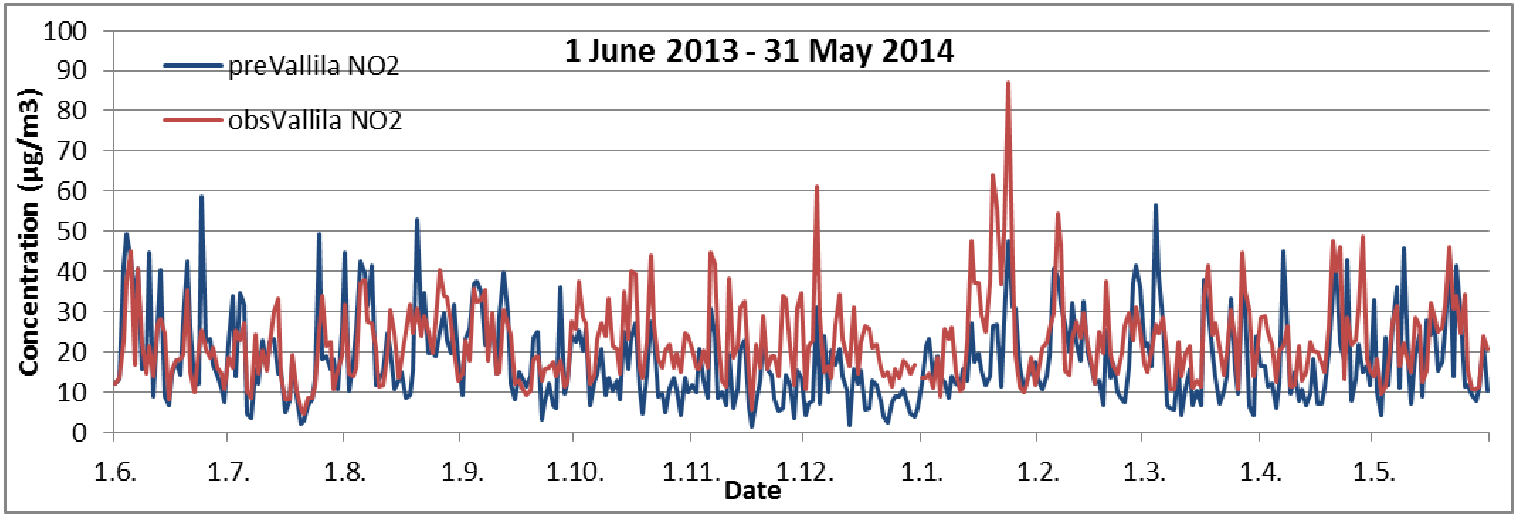


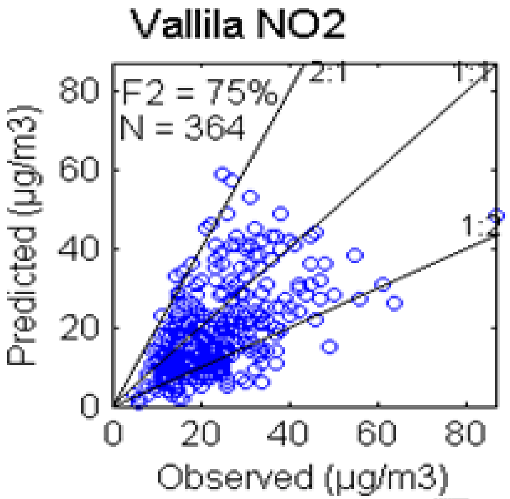


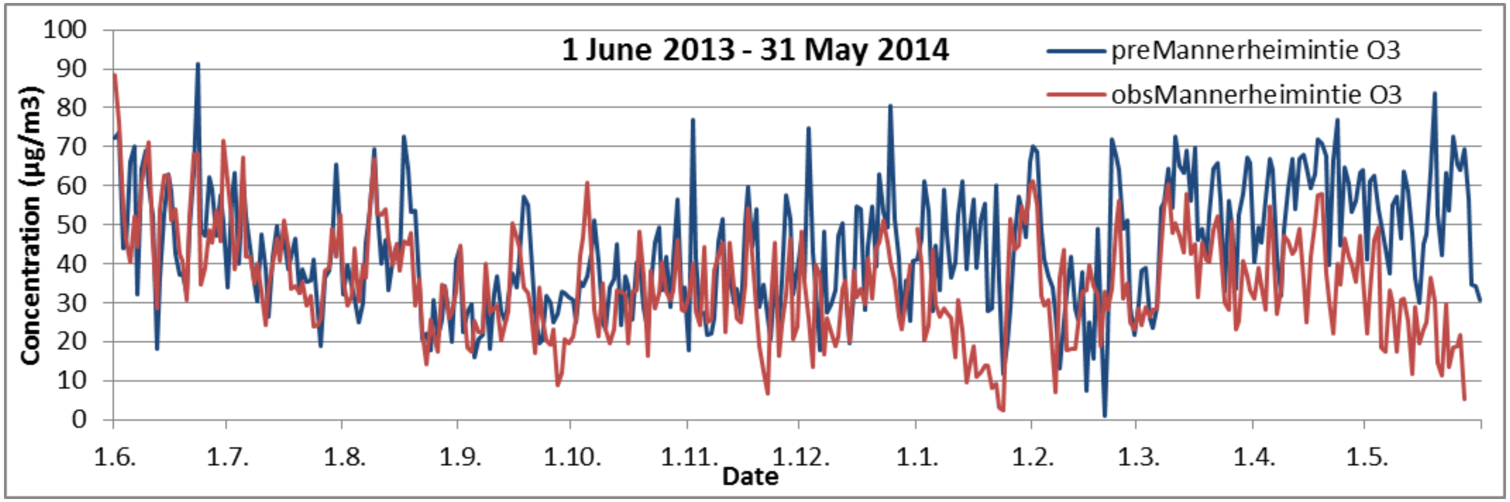


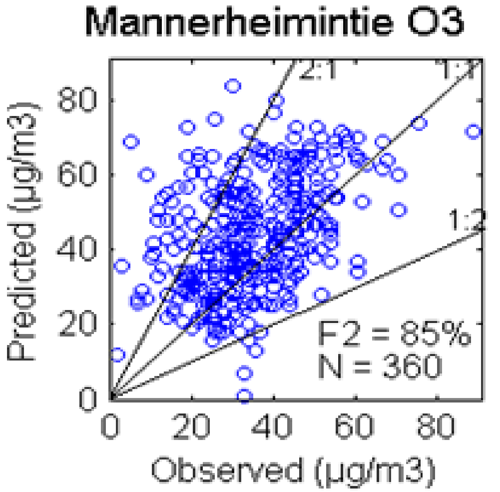


Results: Daily averaged NO2 and O3









Conclusions

- Accuracy of AQ forecasting system regarding daily values for t+24 forecast data:
  - PM2.5: fairly good
  - PM10, NO2 and O3: moderate
- PM2.5 usually somewhat over-predicted and NO2 and PM10 under-predicted.
- Correlation regarding daily values is better than for hourly values.

Challenges and further work

- Forecasting urban meteorology
  - Stability, precipitation, …
- Forecasting of regional background concentrations
- Emission and traffic data up-to-date as possible
- PM10 modelling
  - Road dust emission model

- Other
  - Street canyons,… other emission sources e.g. small scale combustion?

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Thank you!

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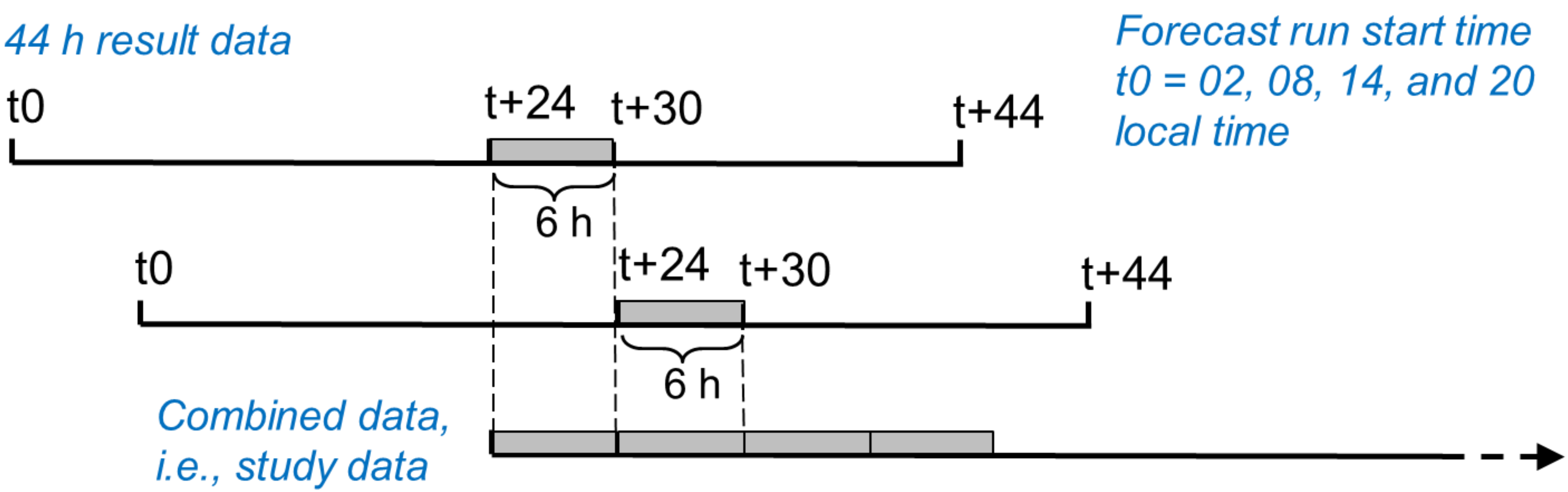
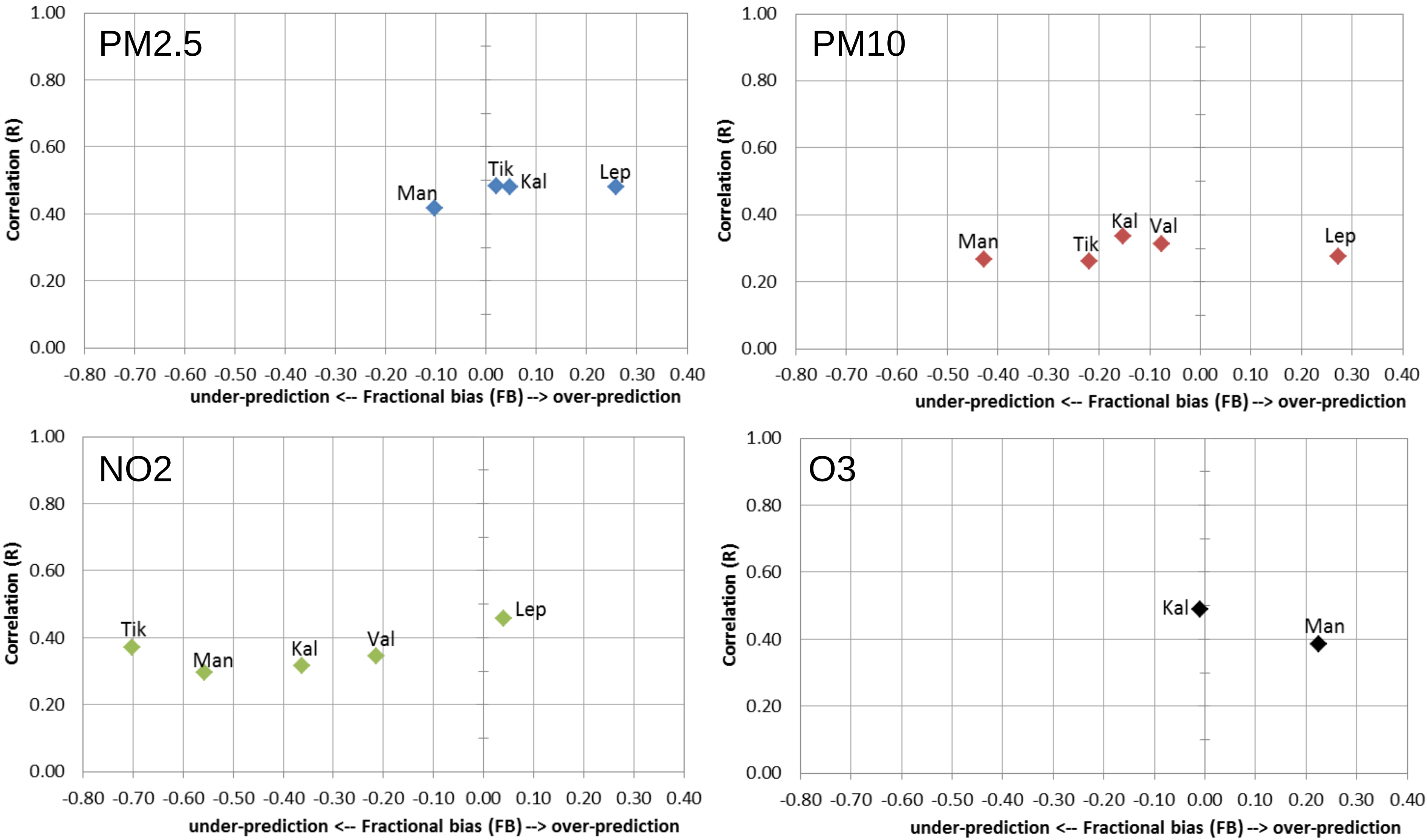
System performance study

- 24 h forecast of PM2.5, PM10, NO2, O3 concentrations
- Values t+24 … t+30 picked from each result file and combined together for one time series.
- Time period: 1 June 2013 to 31 May 2014

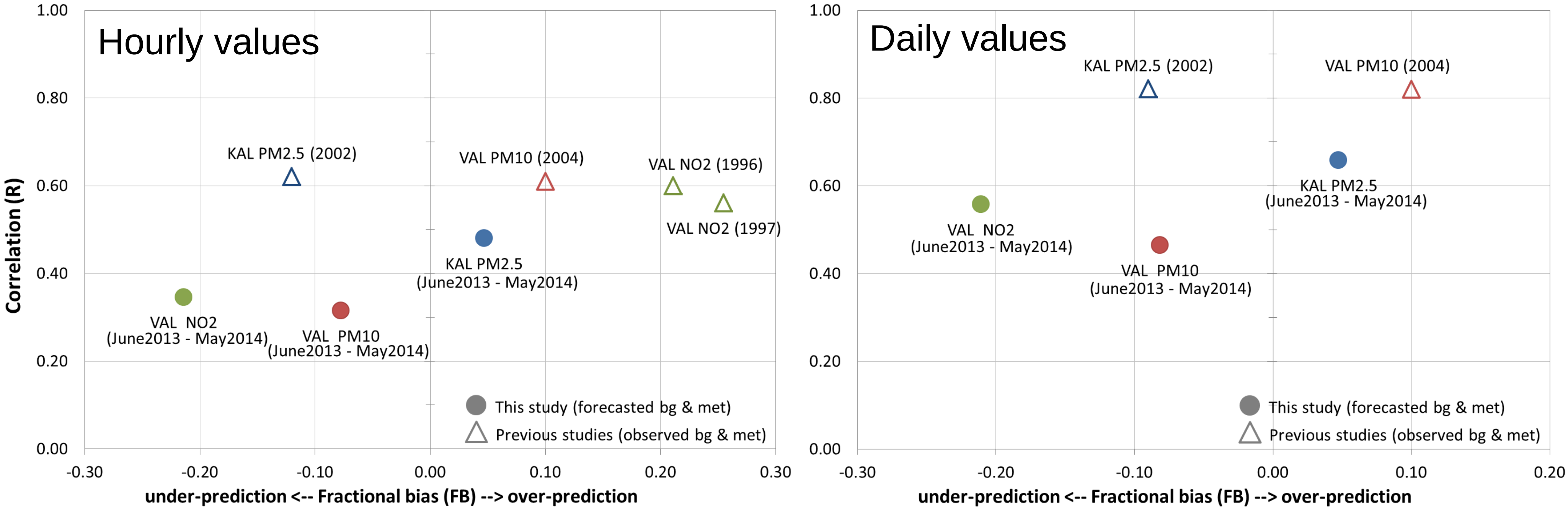


Results: Hourly values



Comparison with previous studies with observed bg and met data

NOTE! Not directly comparable with this study.



- **VALLILA NO2 (1996, 1997):** Evaluation of modelling system with observed met. (MPP-FMI) and regional background data, emi. from stationary sources included (Kousa et al., 2001)
- **KALLIO PM2.5 (2002):** Modelling system with observed met. (MPP-FMI) and regional background data, non exh. emi. included by coefficient (Kauhaniemi et al., 2008)
- **VALLILA PM10 (2004):** Modelling system with observed met. (MPP-FMI) and regional background data, road dust emi. Included

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Overview of recent dispersion-modelling projects in Helsinki area

12.1.2015 Katja Lovén
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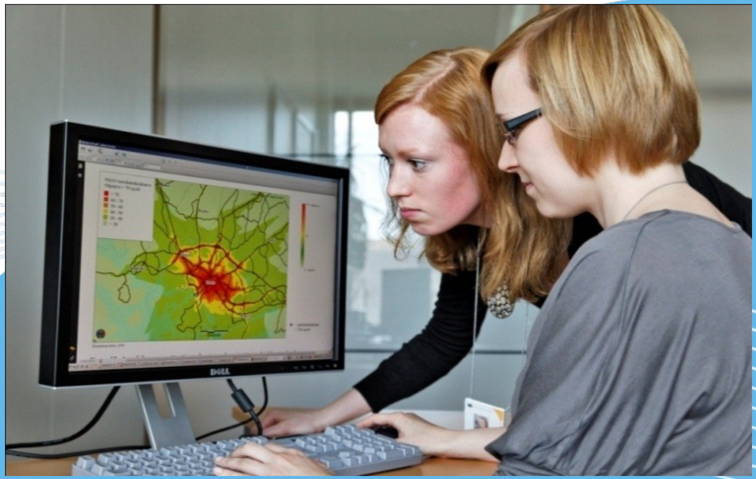

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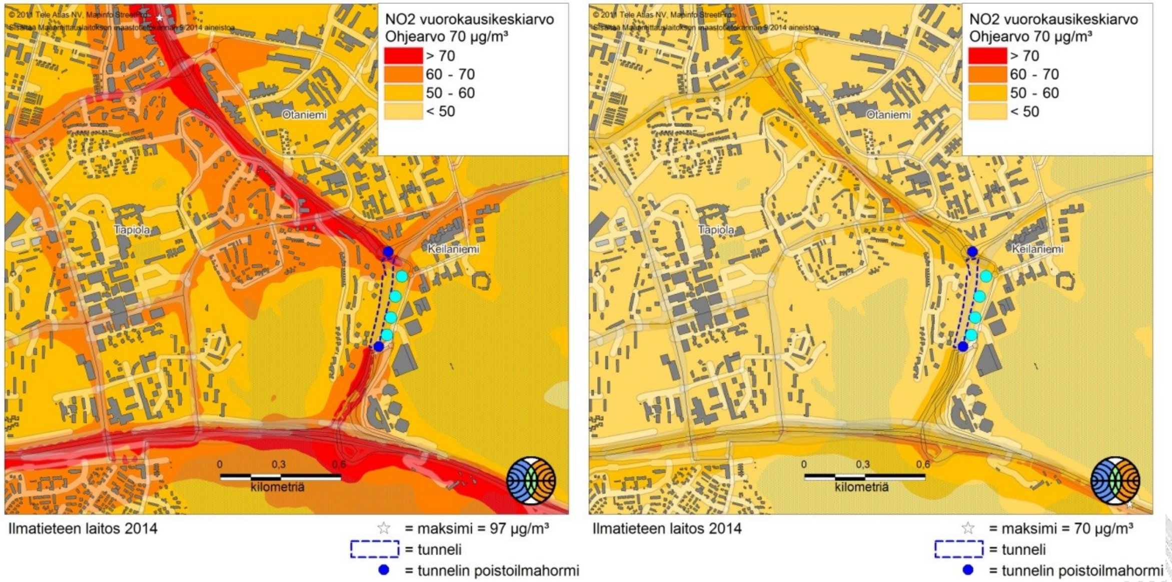
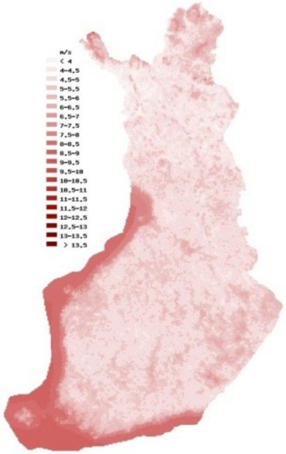
Air Quality Expert Services

Air Quality Assessments
- Dispersion modeling
- monitoring

Wind Energy Consulting
- Wind analysis
- Wind measurements

Consulting and training
- International projects
- Capacity building





Research projects

Our Customers

- Industry
  - Energy industry
  - Mining industry
  - Construction industry
  - Metal industry
  - Food industry

- Engineering offices
  - Pöyry, Sito, Ramboll etc..

- Cities, municipalities
- Ports

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TRIPLA-Center in Pasila

Disperison modeling calculations for the new TRIPLA center to find out:

- Does the design for the planned TRIPLA-center meet the air quality criteria?
- To support for the ventilation design, where to locate the clean air inlets

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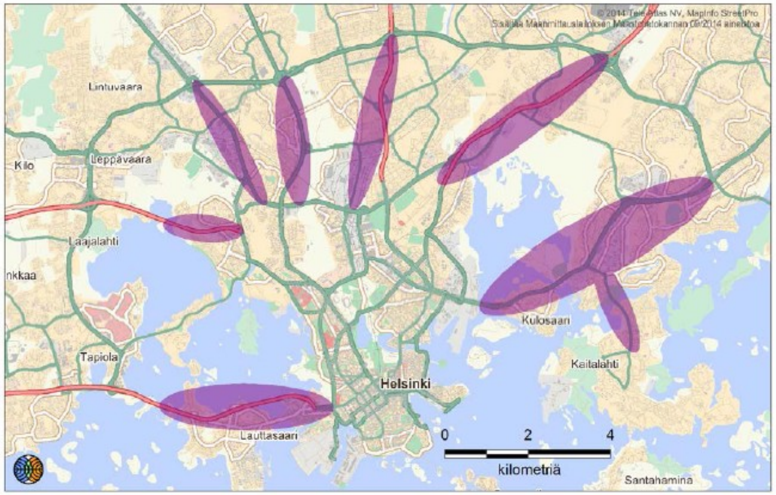
Helsinki city planning Office – the new master plan for Helsinki

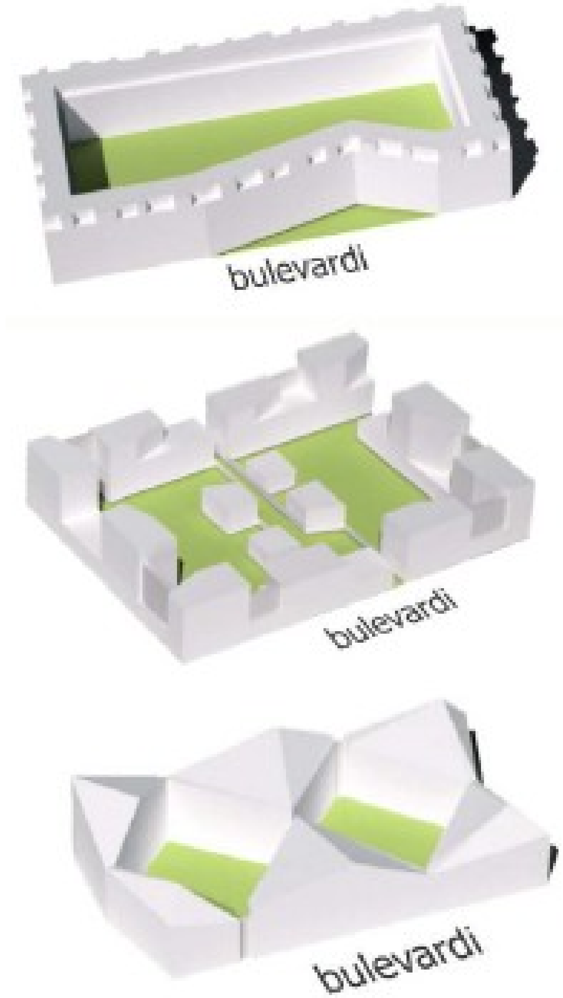


- The transformation of the Highways entering the city center to the bulevards that form street canyons
- Formulating the Criteria how these bulevards would meet the air quality standards
- Currently, limit value (NO_2) exceed only in street canyon environments in Helsinki
- The recommendations for the city planning

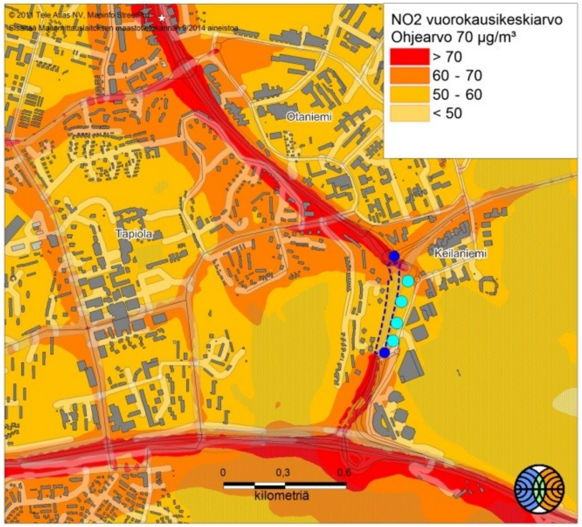
	Mittauspaikka	NO_2 vuosi-keskiarvo ($\mu g/m^3$)	Mittaus-vuosi	KVL (ajoneu-voa/vrk)	KVL raskas (%)	Nopeus-rajoitus (km/h)	Suhde	Mene-telmä
1	Unioninkatu	36	2007	12 800	7	40	1,4	S
2	Lönnrotinkatu	33	2009	10 600	2	40	1,1	P
3	Malminrinne 1	36	2011	22 400	4	30	1,1	P
4	Runeberginkatu 10	30	2011	7 200	12	40	0,8	P
5	Runeberginkatu	39	2004	23 100	**	40	1,0	S
		36	2008	24 800	**	40	1,0	P
		38	2009	23 500	6	40	1,0	P
		41	2010	17 500	7	40	1,0	P
		36	2011	18 900	6	40	1,0	P
		36	2012	18 900	7	40	1,0	P
		34	2013	18 900	7	40	1,0	P
6	Kaisaniemenkatu 16	42	2010	17 500	20	40	1,0	P
7	Vilhonkatu	48	2011	7 200	19	40	0,9	P
8	Hämeentie 7	43	2009	16 500	23	40	0,9	P
		43	2009	16 500	23	40	0,9	S
		49	2010	16 500	23	40	0,9	P
		45	2011	17 000	26	40	0,9	P
		44	2012	17 900	23	40	0,9	P
		45	2013	17 900	23	40	0,9	P
9	Hämeentie 21	41	2005	19 500	**	50	1,0	P
10	Sturenkatu 38	37	2011	18 600	6	40	0,6	P
11	Mäkelänkatu 50 A	48	2010	(28 300)*	10	50	0,5	P
		45	2012	(28 300)*	10	50	0,5	P
		43	2013	28 300	10	50	0,5	P
12	Mäkelänkatu 52	50	2011	(28 300)*	10	50	0,4	S
13	Mannerheimintie 47 B	44	2010	24 400	10	50	0,7	P
14	Töölöntulli	52	2009	(32 100)*	10	50	0,7	P
		53	2010	(32 100)*	10	50	0,7	S
		54	2010	(32 100)*	10	50	0,7	P
		49	2011	(32 100)*	10	50	0,7	P
		49	2012	(32 100)*	10	50	0,7	P
		49	2013	32 100	10	50	0,7	P
15	Mannerheimintie 132	41	2011	38 200	13	50	0,5	P
16	Mannerheimintie 85	29	2011	38 200	13	50	0,6	P

* Mäkelänkadun ja Töölöntullin liikennemäärien laskennassa epävarmuutta vuosina 2009–2012
** Tieto ei saatavilla (YTV, 2005), (YTV, 2008) tai (YTV, 2009)

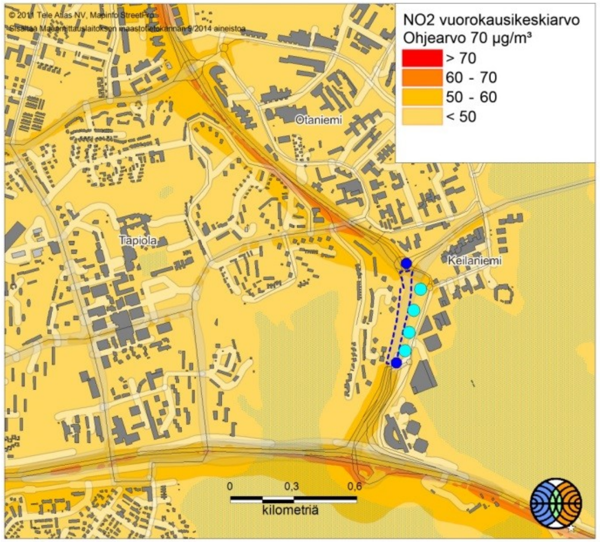
The impact of the Block structure??



Traffic tunnel to Keilaniemi



Ilmatieteen laitos 2014 **Euro 3** ☆ = maksimi = 97 µg/m³ = tunneli



Ilmatieteen laitos 2014 **Euro 5** ☆ = maksimi = 70 µg/m³ = tunneli ● = tunnelin poistoilmahormi

- Tunnels generally improve the air quality but the areas around the tunnels end might be critical
- Additional Stacks (part of the emissions are released to the air through stacks) might improve the AQ situation around the tunnel ends
- Validation of the modeling results?
- How effective is the ventilation through the stacks?

CLEEN Healthy Urban Living SHOK project in preparation

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CASE STUDY

Östersundom Solar Energy potential assessment

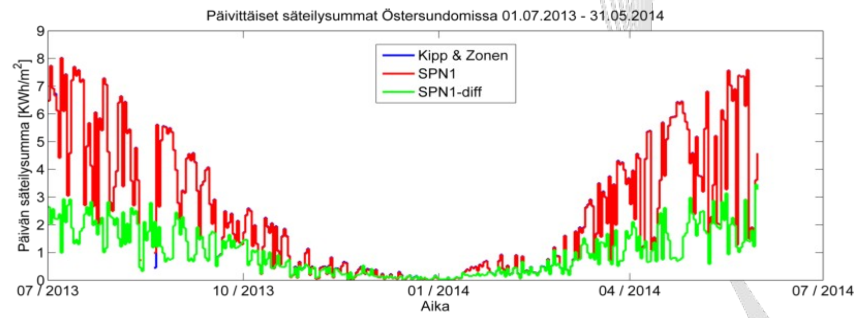
Anders Lindfors
Aku Riihelä
Antti Aarva
Jenni Latikka

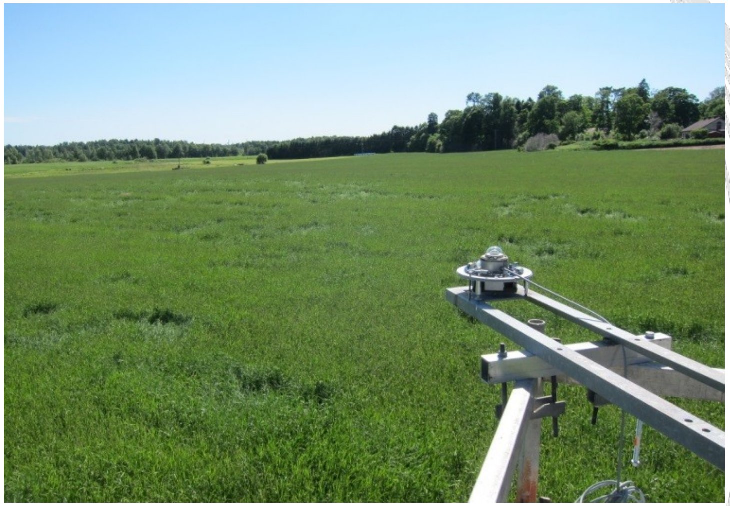
Solar energy potential at Östersundom, Helsinki

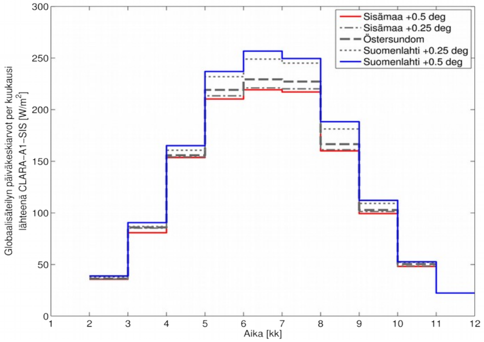
- Research for Östersundom energy plan and land use planning

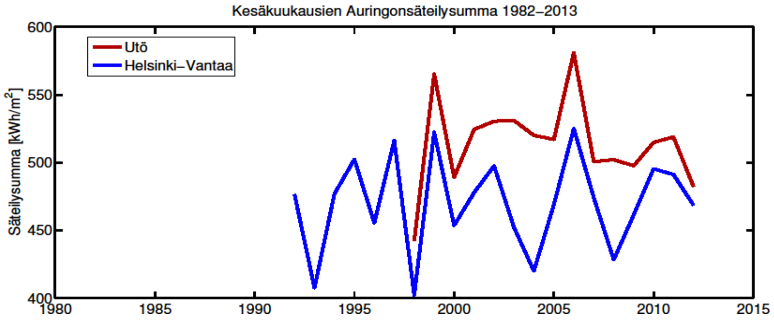
- Measurements 06/2013-06/2014

- Objects
    - radiation at Östersundom vs south coast
    - influence of costal zone
    - usability of satellite information









Need for further research

- Effect of snow
- Spectral of ration, influence to energy production–measurements?
- Reliable forecast length for solar radiation?
- influence of aerosols

Radiation atlas

- need for additional measurements
- influence of climate change?
- most potential areas to utilize the solar energy in Finland?

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Meteorological data in local scale dispersion models (UDM, CAR, ODO)

Hanna Hannuniemi

AQ Workshop 12.1.2015

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Meteorological pre-processor (MPP)

- Measurements from FMI observation stations
    - Surface parameters (temperature, wind speed and direction, amount of rain, cloudiness, pressure, global radiation,…
    - Profile data: soundings from Jokioinen and Sodankylä
    - Metadata from station surroundings (roughness, wind measurement height)

- Produces hourly time series of 34 meteorological parameters

- Usually 3 years time series in dispersion modelling projects

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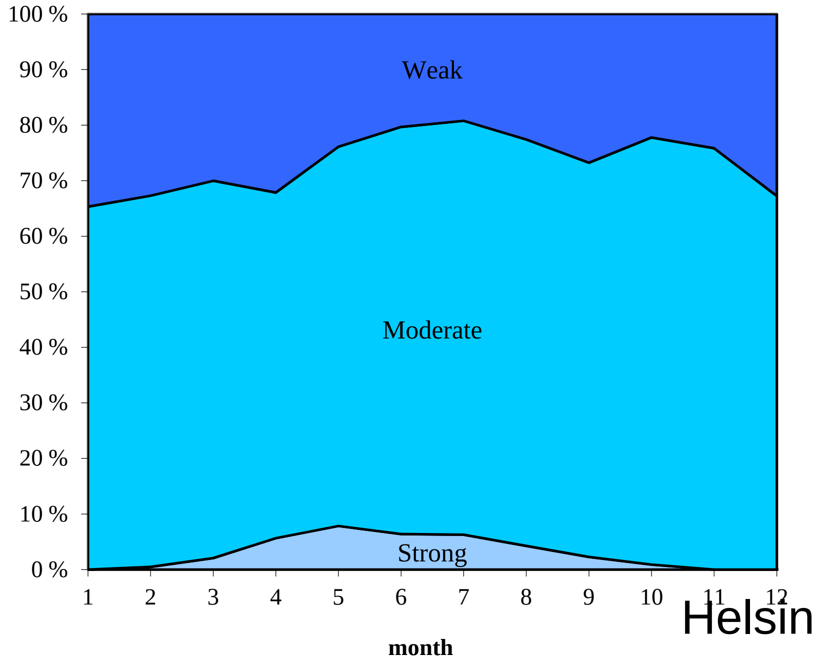
Table 1: MPP output parameters

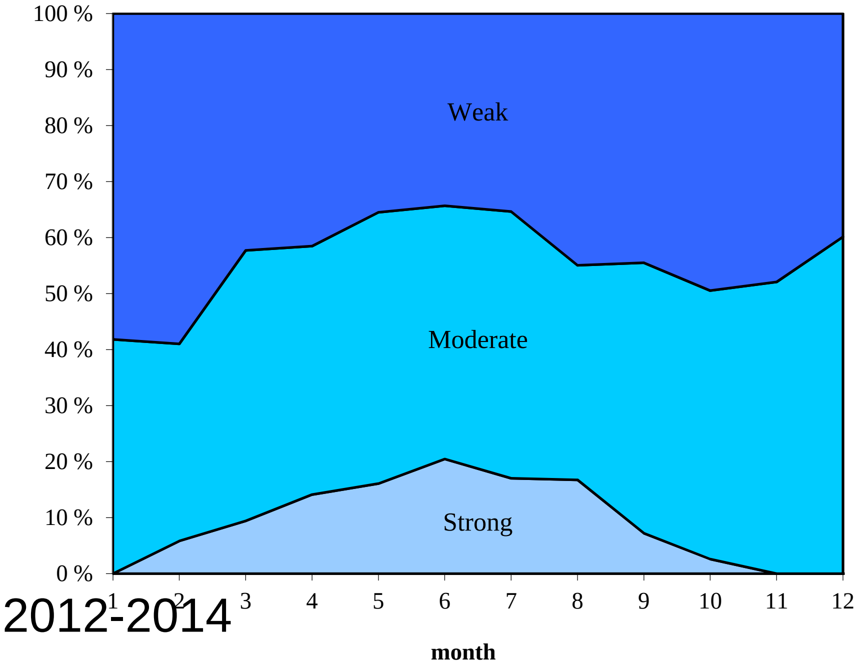
1	Record number
2	LPNN number of the station
3	Year of the date
4	Month of the date
5	Day of the date
6	Hour of the date. Supposed to be multiplied by 100.
7	Sea level pressure
8	Temperature at 2 meters
9	Relative humidity
10	State of the ground (0…9)
11	Total cloudiness (0...1)
12	Dew point temperature
13	Wet bulb temperature
14	Amount of rain
15	Visibility
16	Present weather, synop code 0…99
17	Weather of previous hour (0…9)
18	Weather of previous 3 hours (0…9)
19	Amount of low clouds (0…1)
20	Type of low clouds (0…10)
21	Height of low clouds
22	Type of middle clouds (0…10)
23	Type of high clouds (0…10)
24	Direction of flow (aritmetic degrees)
25	Windspeed at 10 meters
26	Hourly amount of sunshine (relative)
27	Albedo (0…1)
28	Solar elevation
29	Solar radiation
30	Moisture parameter
31	Inverse of Monin-Obukhov length
32	Temperature scale
33	Friction velocity
34	Turbulent heat flux
35	Net radiation
36	Latent heat flux
37	Mixing height
38	Height of wind shear layer
39	Convective velocity scale
40	Potential temperature gradient

- Ongoing development project in ASP to make use of MPP easier
  - → user interface to select stations and input parameters
  - → automated data retrieving from database including handling of missing parameters
  - → script converts data in right format for MPP programs and runs all programs
  - → produces input files for dispersion models
  - → http://dev.kop.fmi.fi/mpp/cmd_helper.php

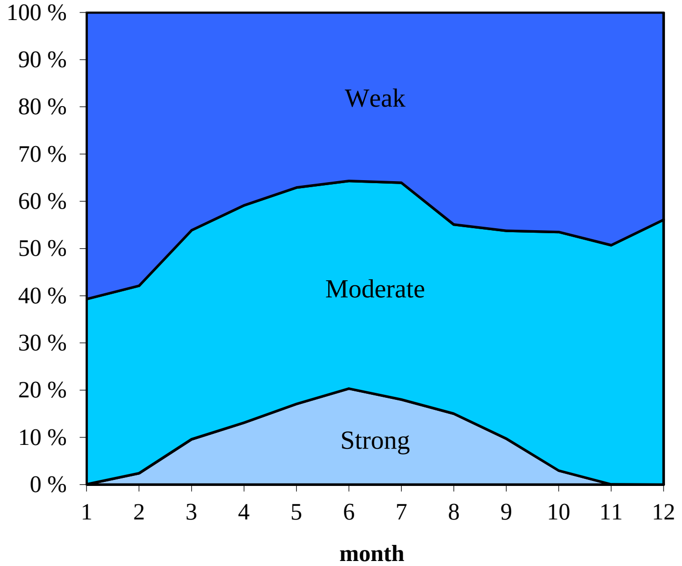
Helsinki 2008-2010



Helsinki 2011-2013



Helsinki 2012-2014



MPP´s distribution of 1/L

Future plans

- test HIRLAM model data from Helsinki area (year 2012 data available) at local dispersion models
  - →compare resulting concentration levels between MPP metseries and model metseries

The FMI urban weather forecasting system

A dream, January 9, 2015

C. Fortelius[1]

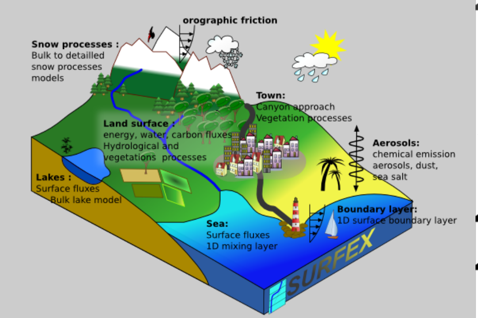
[1]Meteorological Research
Finnish Meteorological Institute

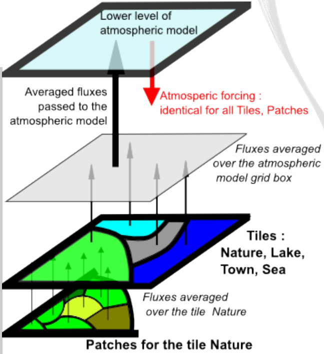
Contents

Uses of urban forecasting

- Conditions of roads and pavements
- Heating demand, cooling demand
- Urban flooding
- Freezing and thawing of soil
- Local energy production: Solar, wind
- Urban planning, (e.g. building density, green roofs) and local interpretation climate scenarios

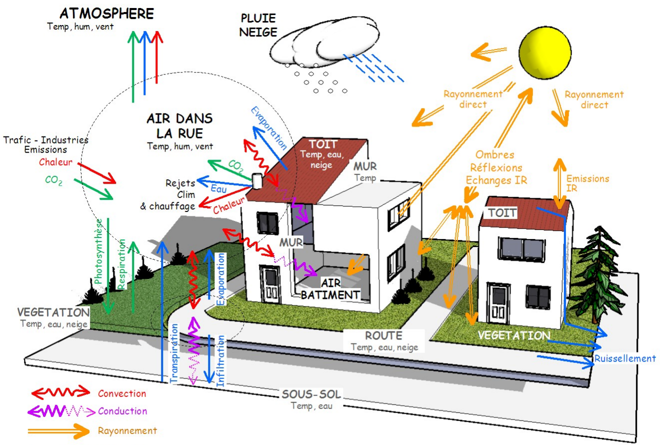
Air-surface interactions in NWP and climate models



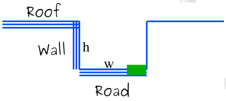


SURFEX tiling and coupling with an atmospheric model

The urban system

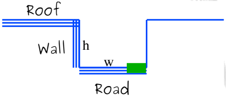


The Town Energy Balance model TEB



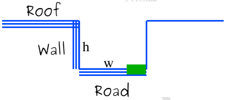
- **Conceptual model:** array of "canyons"
  - Horizontal scale upwards of a city block
  - All buildings have the same height and width located along identical roads without intersections.
  - All canyon orientations exists with the same probability. Orientation effects for roads and walls are averaged over 360° (or over several sectors).

The Town Energy Balance model TEB



- Conceptual model: array of "canyons"
- **Realization**
  - The urban area is represented by three surfaces representing **roofs, walls and roads**, all having separate energy budgets accounting for radiation, turbulent fluxes of sensible and latent heat, and conduction into the materials
  - Snow may exist on roofs and roads
  - Vegetation can be present in the roads
  - Key parameters depend on canyon shape and construction materials.

Radiation



- Sky view factor of roads and walls:
  $\Psi_r = \left[(h/w)^2 + 1\right]^{1/2} - h/w$
  $\Psi_w = \frac{1}{2}\{h/w + 1 - \left[(h/w)^2 + 1\right]^{1/2}\}/(h/w)$
- Shadow effects of direct short wave radiation, integration over azimuth angle
- Infinite number or reflections of scattered short wave radiation
- Trapping of long wave radiation accounting for one re-emission

Turbulent exchange

Controlled by aerodynamic resistances depending on roughness, wind speed, and stability

$$H_R = C_p \rho_a (\hat{T}_R - \hat{T}_a)/RES_R$$

$$LE_R = L \rho_a [q_s(\hat{T}_R, ps) - \hat{q}_a]/RES_R$$

$$H_r = C_p \rho_a (T_r - T_can)/RES_r$$

$$LE_r = L \rho_a [q_s(T_r, ps) - q_{can}]/RES_r$$

$$H_w = C_p \rho_a (T_w - T_{can})/RES_w$$

$$H_{top} = C_p \rho_a (T_{can} - \hat{T}_a)/RES_{top}$$

$$LE_{top} = L \rho_a (q_{can} - q_a)/RES_{top}$$

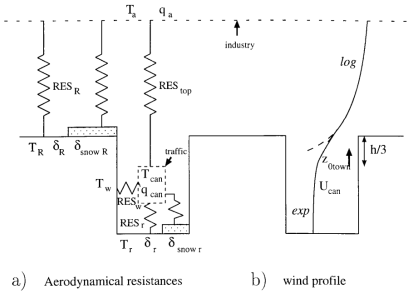


Figure 3. Scheme options for: (a) aerodynamic resistances; (b) wind profile within and above the canyon.

Town vegetation

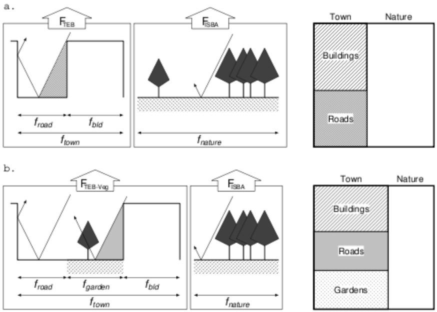


Fig. 1. Comparison of tiling approaches applied in TEB-ISBA (top) and TEB-Veg (bottom) to compute surface fluxes for a SURFEX's grid point containing pervious and impervious covers.

Anthropogenic heating and moistening

- Traffic: Prescribed, released into the canyon
- Industry: Prescribed, released into the atmosphere above
- Building space: Modelled, released through roofs and walls

Air in the canyon

- Option 1:
  Temperature, humidity and wind in the canyon can be solved diagnostically, assuming fluxes to be in balance
- Option 2:
  Prognostic temperature, humidity and wind profiles in the canyon controlled by a turbulence closure model

Buildings

- Heat conduction through walls and roofs
- Prognostic internal temperature
- Energy used for heating, simple
- Building Energy Model (Optional):
  - · Air conditioning, comprehensive
  - · Ventilation and infiltration
  - · Solar radiation through windows
  - · Vegetated roofs
  - · etc

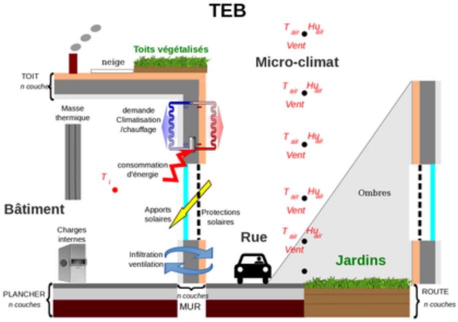


Schéma conceptuel de TEB

Urban Forecasting System

Input

a: WEATHER

- NWP-model, or
- Climate model, or
- Observations

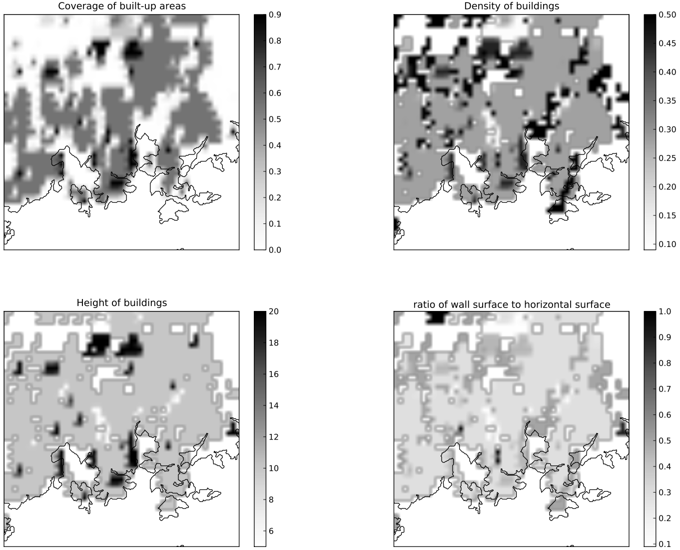
b: TOWN PROPERTIES

- automatically from ECOCLIMAP data base, or
- specified by user

Output

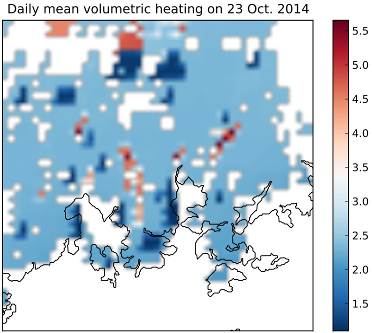
- Temperature of air and in structures
- Water and snow on surfaces, generation of runoff
- Energy balance of surfaces, including radiative fluxes
- Energy used for heating and cooling of building space
- etc

Helsinki area in ECOCLIMAP

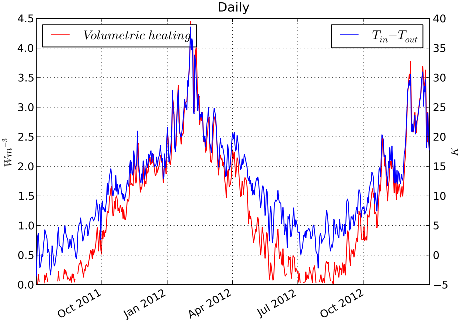


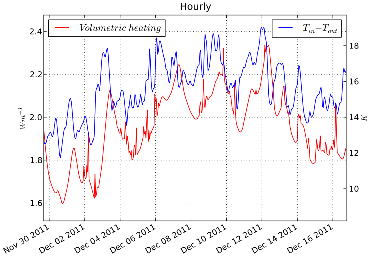
Heating of building space

Average heating of building space in, Wm^{-3}, required to maintain a specified minimum inside temperature against heat losses through walls and roofs, on 23rd October 2014, a cool and windy atumn day. Variations are caused mainly by differences in exposure of the buidlings to the weather, related to variations in buidling density, building height, etc.



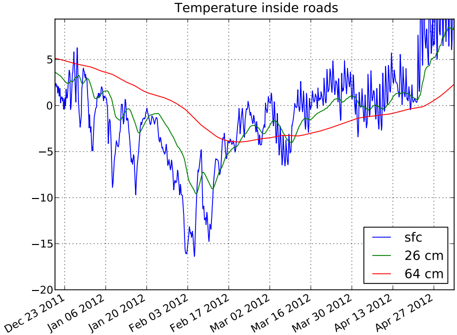
Heating of building space





Heating of building space (Wm^{-3}) and temperature difference $T_{in} - T_{out}$ in central Helsinki calculated in TEB forced by observations at Hotel Torni. On scales of several days or more, heating (left) correlates strongly with the temperature difference, especially in the cold season. On shorter time scales other factors, including the thermal inertia of the building materials, become important (right), underpinning the importance of using a dynamical model in calculating the heating.

Road temperature



Temperature below the road surfaces in central Helsinki, calculated in TEB forced by observations at Hotel Torni. Variations at the surface propagating into the road substrate are progressively damped and lagged in time.

For Further Reading I

V. Masson et al.
The SURFEXv7.2 land and ocean surface platform for coupled or offline simulation of earth surface variables and fluxes.
Geosci. Model Dev. 6, 563-582, 2013

B. Bueno et al
Development and evaluation of a building energy model integrated in the TEB schem.
Geosci. Model Dev. 5, 433-448, 2012

V. Masson
A physically based scheme for the urban energy budget in atmospheric models.
Bound. Layer Meteor. 94, 357–397, 2000

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Some ongoing and planned work to further develop the PALM model for urban LES for Helsinki

Antti Hellsten
Finnish Meteorological Institute

Outline

- What is Large Eddy Simulation (LES)
- What is PALM?
- Urban LES – the state of the art
- Some of the ongoing and planned work:
  - Current Helsinki simulation
  - Domain nesting

What is LES?

- Large Eddy Simulation (LES) is numerically solving the Navier-Stokes equations and e.g. pollutant transport equations for a given turbulent-flow problem.
- LES is applied nowadays to a wide range of problems e.g. from engineering to astrophysics.
- LES is pioneered by the meteorologists in the late -60's and early -70's (Smagorinsky, Deardorff, …).
- LES is well suited for sub meso-scale ABL studies.
- The computational domain may range from the order of 1 km scale to 100 km scale depending on the ABL height and other things.
- LES is heavy computing thus large-scale parallel computing is typically needed.

What is LES?

- The principal challenge is similar to that of NWP: the vast range of scales of important phenomena.
- In ABL turbulence the scales may range from, say, centimetres to kilometres or tens of kilometres and even the smallest scales are important because they contribute the dissipation of TKE.
- In LES the largest phenomena are solved explicitly as a function of space and time typically down to the order of a few metres or a few tens of metres depending again on the ABL height.
- The effects of the smaller scales are parameterized.

What is PALM?

- Parallel large eddy simulation model.
- Developed at Leibniz Universität Hannover, Institute of Meteorology and Climatology (IMUK).
- Development is led by Prof. Siegfried Raasch.
- Originally designed for ABL studies.
- Originally designed for massively parallel computing especially on distributed memory systems (such as Voima and Sisu).
- Suitable for *urban* ABL problems (buildings can be modelled).
- Freely available open-source software with a number of users.

Urban LES – the state of the art

- One of the big challenges is again the wide range of scales: turbulent events in the street canyons must be captured simultaneously with the largest ABL-scale events.
- This implies that a minimum range of captured scales is typically from metres to kilometres → the grid spacing must be about 1 m and the domain size must be several kilometres.
- Often the domain size should be even larger than what is possible with the present-day computing capacity.
- Helsinki is a typical example because it is a very heterogeneous urban environment. More homogeneous urban areas can sometimes be a little easier.

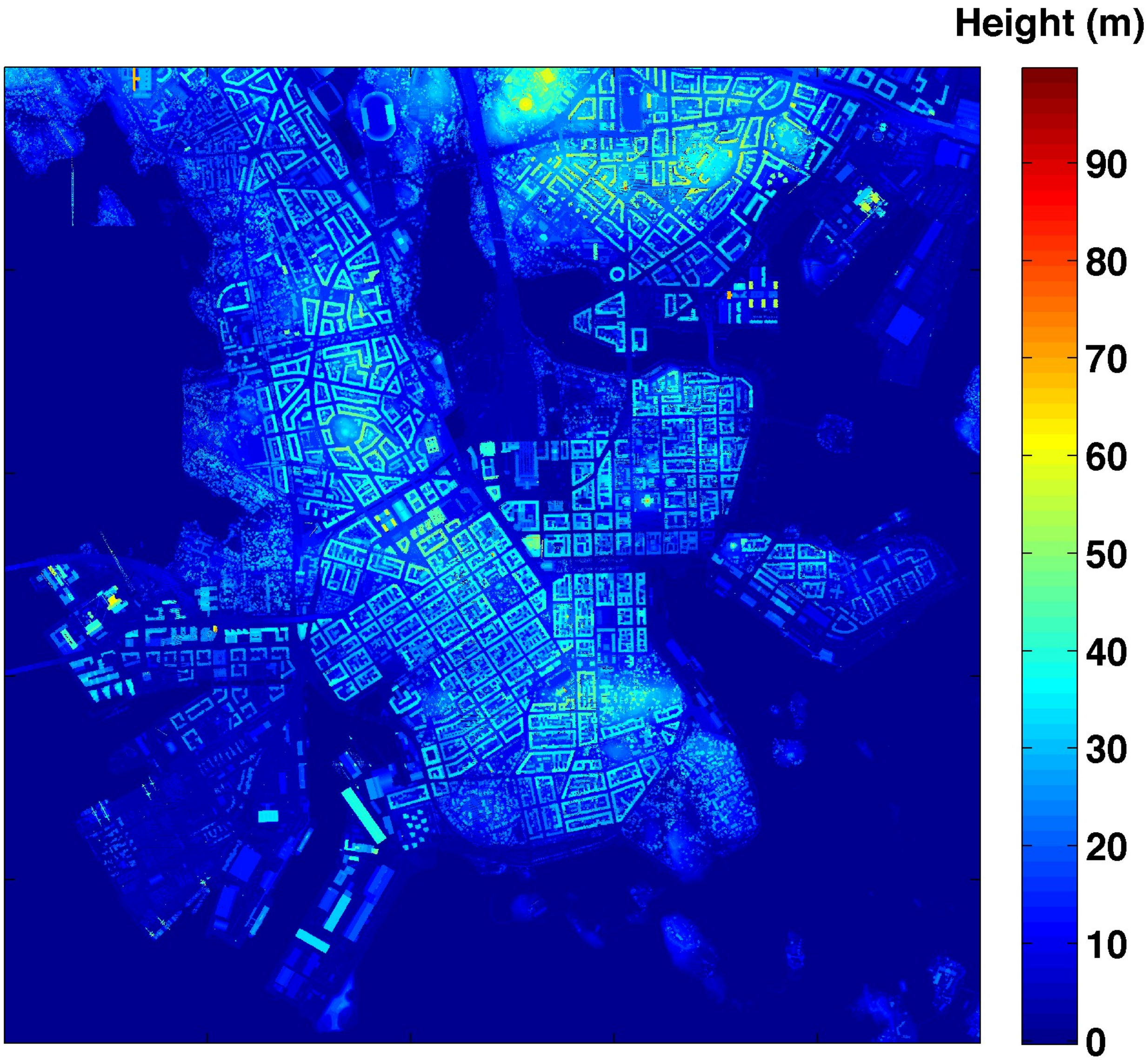
Urban LES – the state of the art

- The key requirement is that the whole vertical extent of the ABL must be accommodated in the computing domain.
- Urban LES studies that fulfil the requirements to capture the minimum range of scales has been done only quite recently.
- Earlier many studies were made for neighbourhood-scale urban areas ignoring the larger scale ABL phenomena.
- Such modelling is quite unphysical!

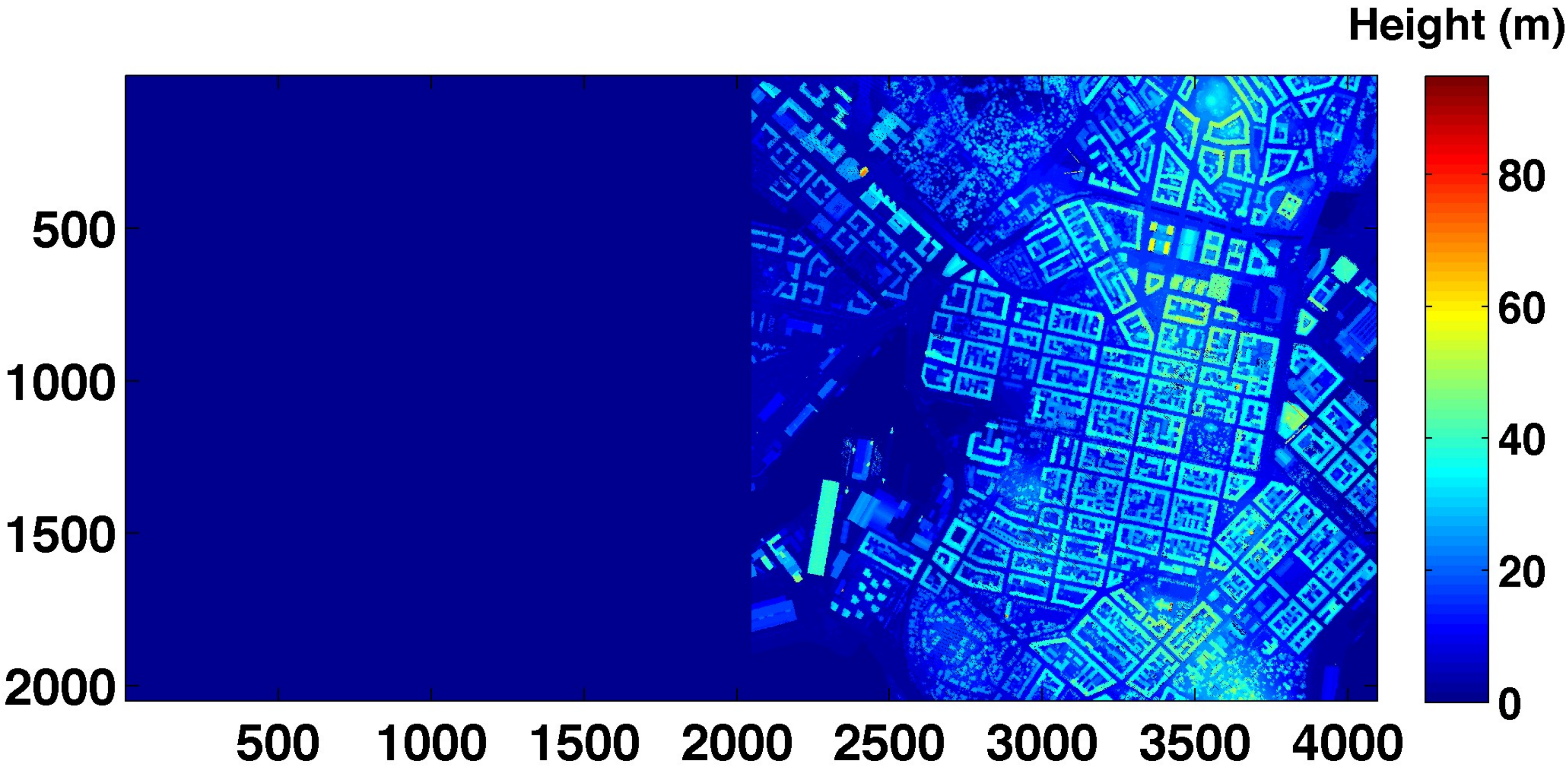
Example

- Example of a simulated plume from a ground level point source in a complicated urban environment.

Ongoing Helsinki modelling



Ongoing Helsinki modelling



Domain nesting

- Now, we want to push the limits by further enlarging the domain size, especially for the needs of Helsinki studies.
- This will be implemented by a domain-nesting technigue not yet existing in the PALM model.
- The principal area of interest will be covered by the innermost relatively small domain with a high resolution.
- The innermost domain is nested to a larger domain with a lower (half) resolution.
- A chain of 3-4 different-size nested domains is planned and the outermost domain is planned to be forced by HARMONIE data when necessary.

Domain nesting

- The nesting will be based on two-way coupling.
- Data is moved from an outer domain to the nested-in domain boundaries.
- Interpolations are required because of different grid spacings.
- The outer-domain solution overlapped by the nested-in domain is replaced by filtered and restricted data from the nested-in domain.
- Simultaneous run of different-domain simulations and the domain-domain communication will be implemented by using separated process groups and MPI-communicators for each domain.
- This is a highly challenging parallel programming effort.

Domain nesting

- This work will be done in close collaboration with the Hannover group.
- I will be working in Hannover from January 19th to March 31st.
- This work is part of the CityClim project (2014-2018) funded by the Academy of Finland.

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Health impact of shipping in the Helsinki metropolitan area

Jukka-Pekka Jalkanen

BSR InnoShip

TRANSPHORM
transport pollution health

SNOOP – Shipping-induced NOx and SOx emissions – Operational monitoring network

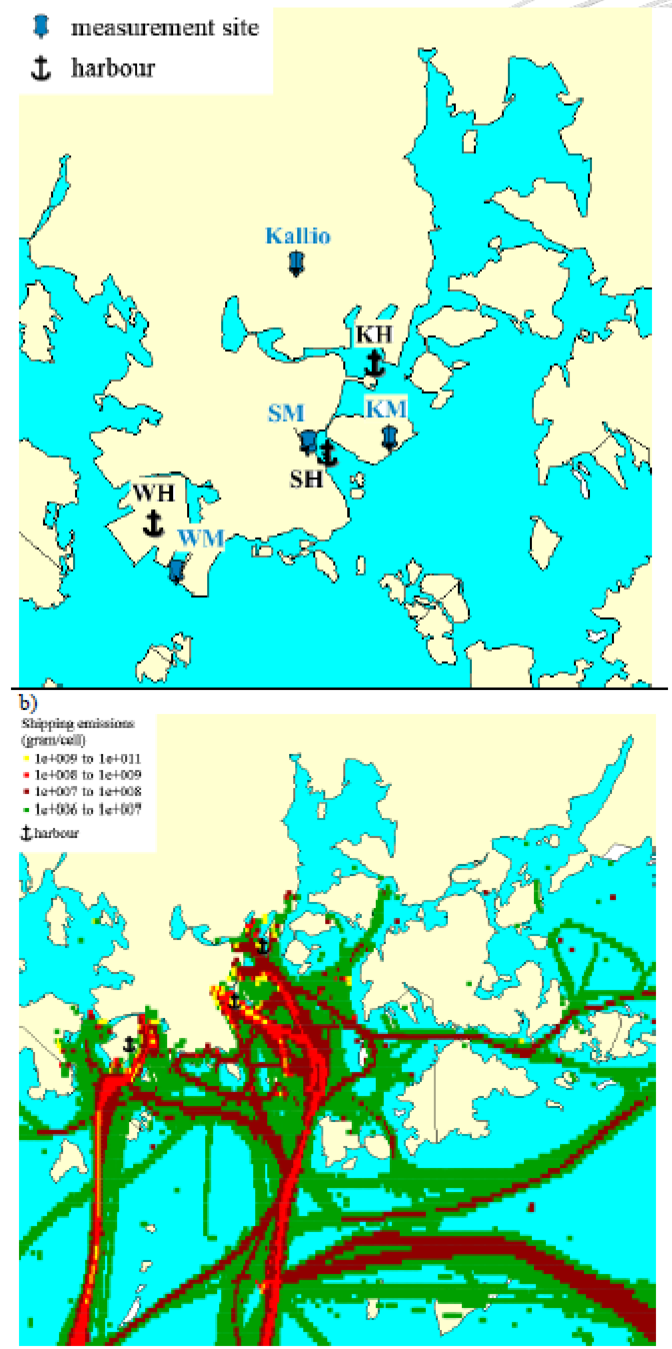
CENTRAL BALTIC
INTERREG IV A
PROGRAMME
2007–2013

EUROPEAN UNION
EUROPEAN REGIONAL DEVELOPMENT FUND
INVESTING IN YOUR FUTURE

Objectives

- Identify the shipping contribution to overall air quality in Helsinki metropolitan area (HMA)
    - Source apportionment
- How large is the human health impact?
- Chain of models from ship emissions to impacts
- Policy changes and their effectiveness?

- Results described in two papers
    - Soares et al, ”Refinement of a model for evaluating the population exposure in an urban area”, Geosci. Model Dev., 7, 1855–1872, 2014
    - Jonson et al, ”Model calculations of the effects of present and future emissions of air pollutants from shipping in the Baltic Sea and the North Sea”, Atmos. Chem. Phys. Discuss., 14, 21943-21974, 2014



List of models used, input

- **Road traffic:** EMME/2 interactive transportation planning package, CAR-FMI
  - Road suspension emissions for PM2.5
  - Brake, tire, and clutch wear are not included in the model
- **Ships:** Ship Traffic Emissions Assessment Model (STEAM)
  - 2009: 1.5% S in fuel
- **Stationary sources**: UDM-FMI model (Urban Dispersion Model)
- **Wood combustion**: Insufficient data of spatial distribution of these emissions
  - 157 tons of PM emitted
- **Background concentrations:** LOTOS-EUROS model (TRANSPHORM project)

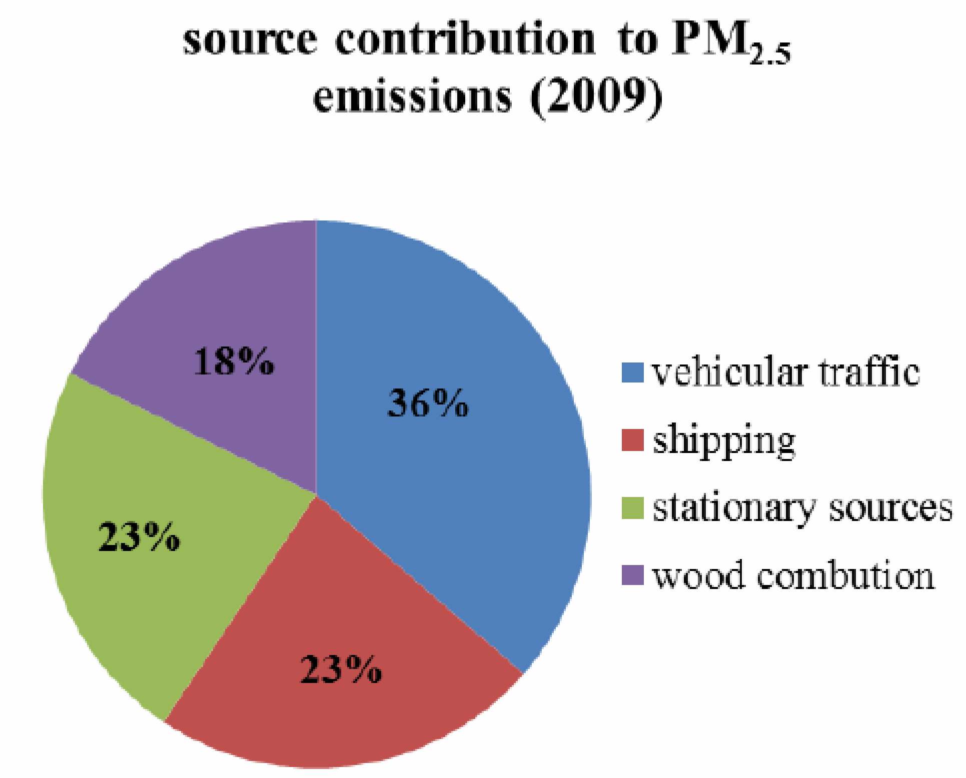
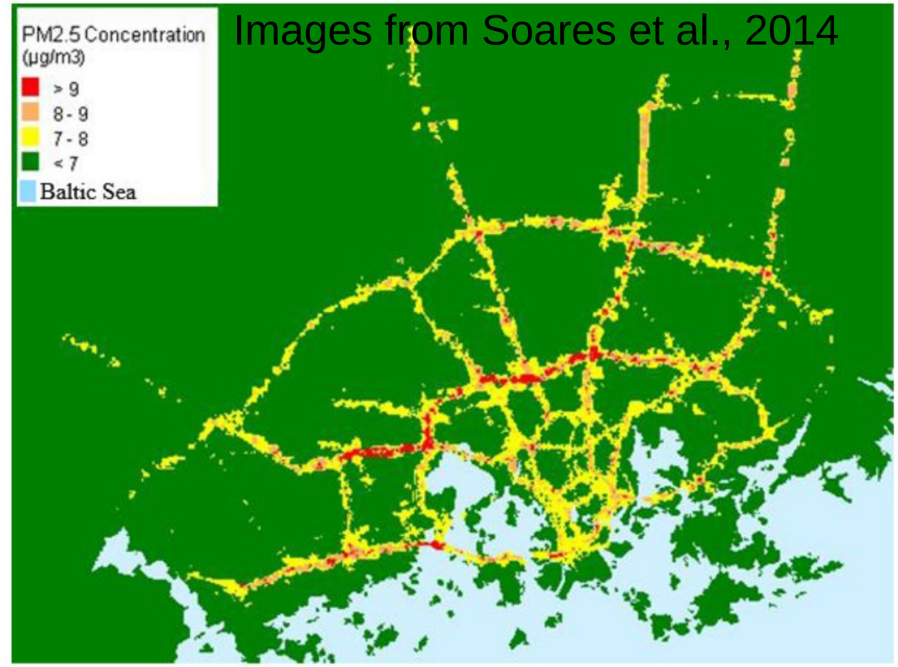


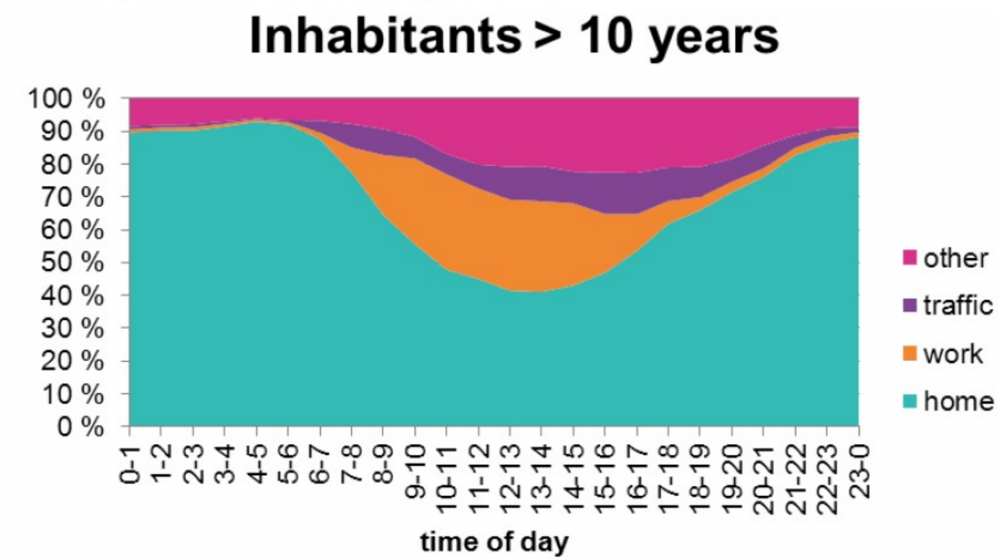
Image from Soares et al., 2014

EXposure model for Particulate matter And Nitrogen oxiDes (EXPAND)

- Location of the population **AND**
  - Human activity data
    - Children (<10 years) stay at home all the time
    - Age distribution of people living in a particular building
    - Total number of people working at a particular workplace
- **Microrenvironment** (In/Outside)
  - Building age
    - Infiltration factor*; How much of ambient pollutants enter the indoor air*
  - Home, Workplace, Traffic, and Other
    - Other: shops, restaurants, cafes,pubs, cinemas, libraries and theatres
- 1.31 passengers in each car



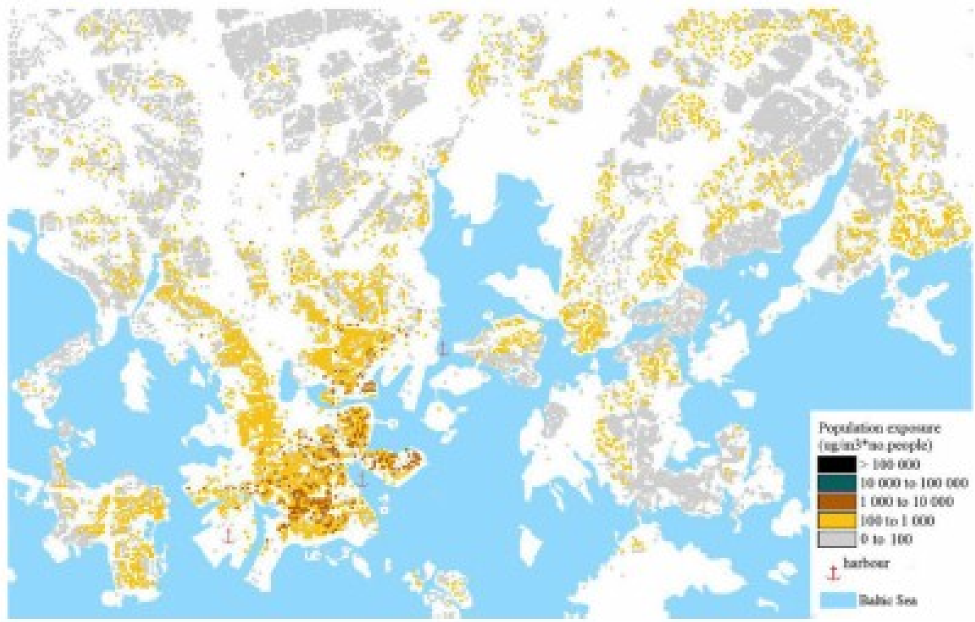
Images from Soares et al., 2014



Exposure, all

Exposure, cars

c)



(Vuosaari harbor area just outside the map)

Exposure, ships

Image from Soares et al., 2014

Significance of sources

- Approximately 60% of the total exposure occurred at home, 17% at work, 4% in traffic and 19% in other microenvironments.
- On average, for 2008, PM2.5 concentrations are due to:
    - LRT: 86%, vehicular traffic: 11% and shipping: 3%
    - Shipping contribution can be > 20% in the vicinity of the harbors
        - Distance < 1 km

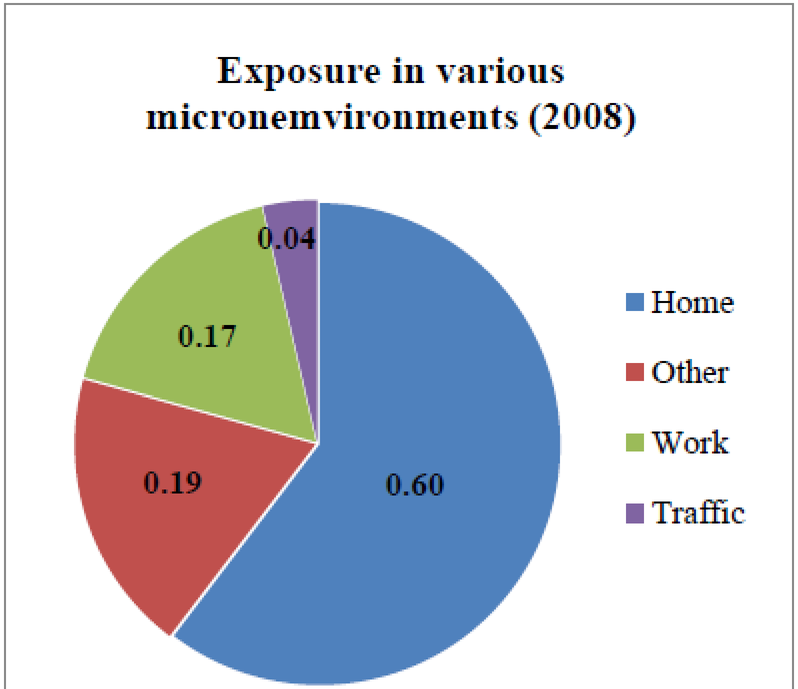
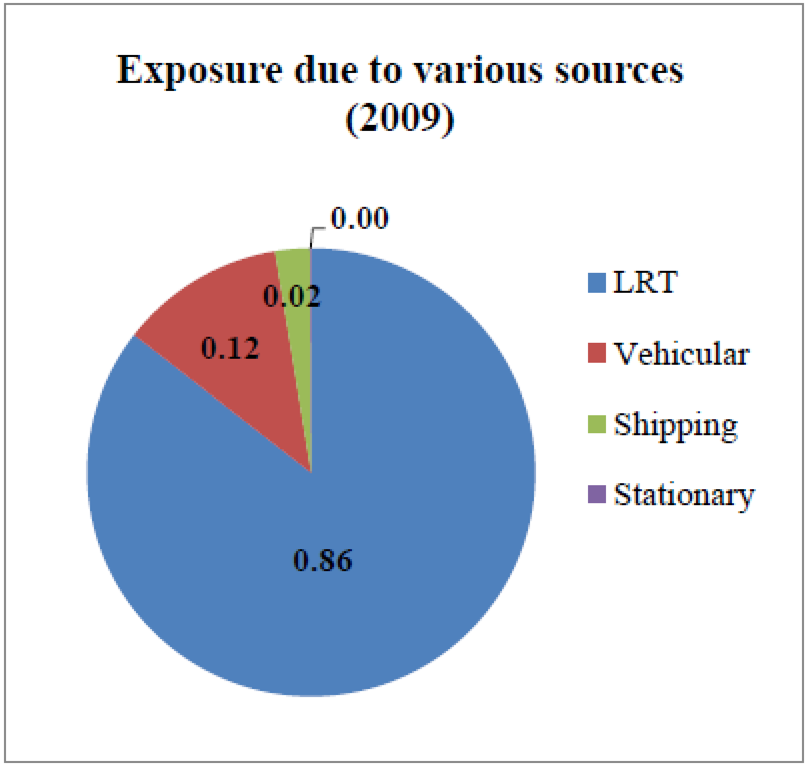
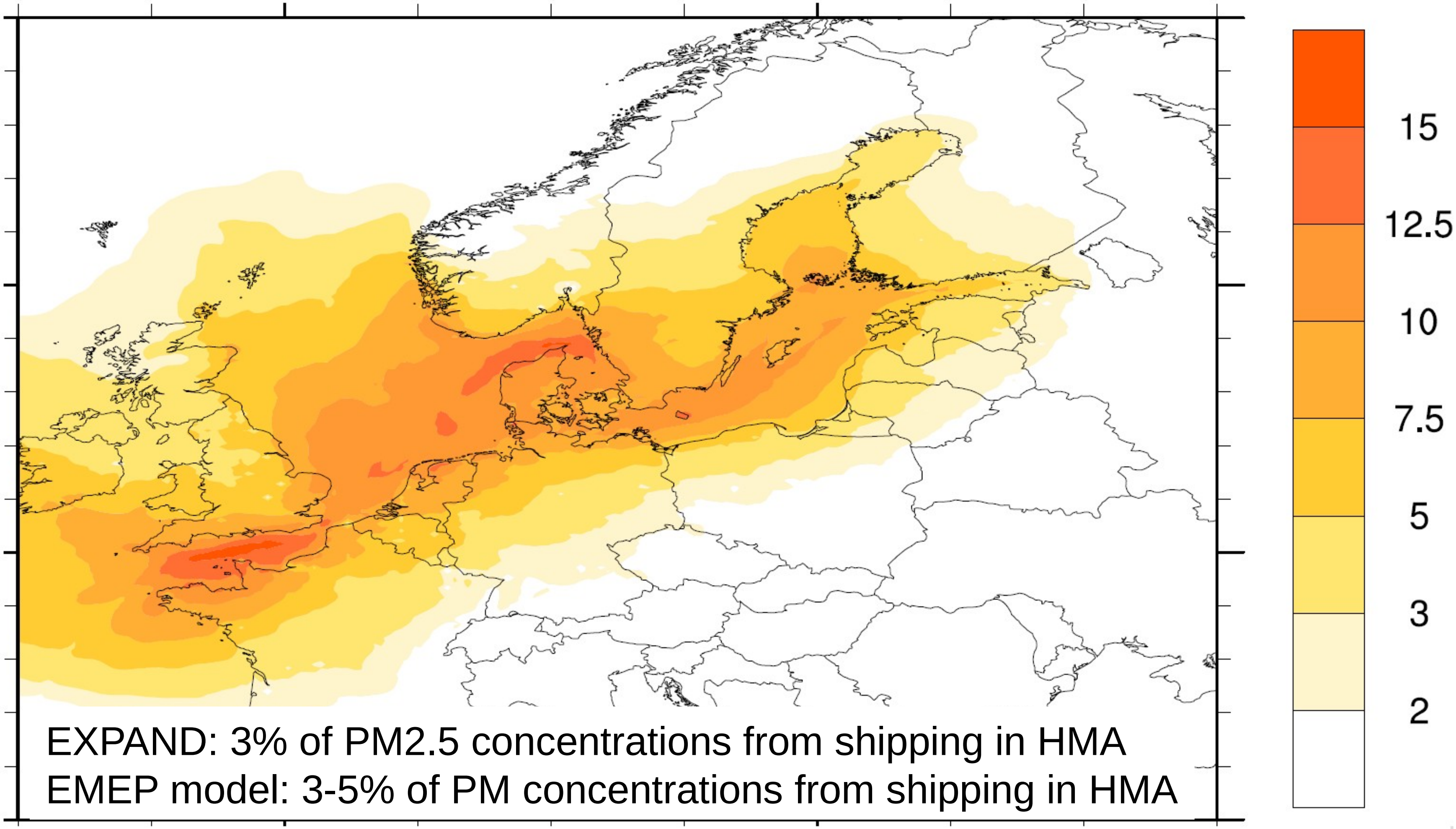


Image from Soares et al., 2014

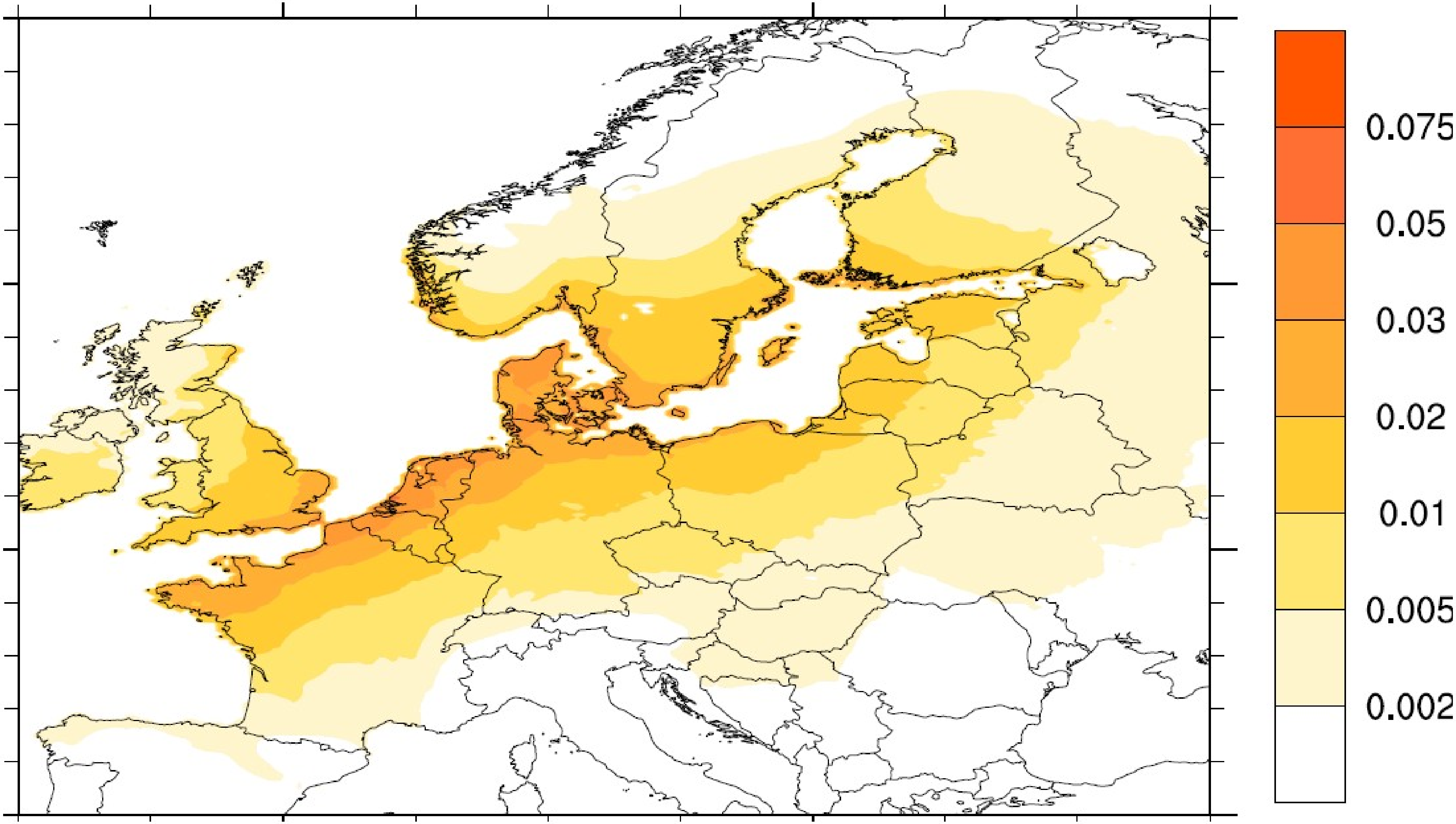


PM as a tracer? No secondary aerosols?



b) PM2.5 from shipping in percent (in 2009)

Jonson et al, ACPD 14 (2014) 21943-21974



a) YOLL per person from shipping (in 2009)

HMA: 1.1 million people, 0.01-0.02 YOLLs/person, over 50 years period, life expectancy 80 years

Note: Jonson et al do not include people <30 years of age (+35%) and neglect morbidity (+30%)

Conclusions

- During 2009, shipping was responsible for 2-5% of human exposure to PM in HMA
  - Confirmed both with EXPAND and EMEP models, with and without secondary aerosols
  - ~86% of airborne PM is from long-range sources
- HMA exposure study is unique in the level of detail
- One important emission source missing: small scale wood combustion, about 18% of primary emissions of PM in HMA
- In 2010, new requirement for ships: Must use low sulphur fuel while in EU harbor area
  - PM contribution from ships will have decreased significantly starting from 2010

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Table 2. Comparison between measured and predicted annual average $PM_{2.5}$ concentrations ($\mu g\, m^{-3}$) at the measurement sites in the vicinity of harbours, and at an urban background site in Helsinki. All modelled values are for 2009. SD = standard deviation based on the hourly values.

Name of the measurement site	Classification of the measurement site	Annual mean ± SD, modelled	Year of measurements	Annual mean ± SD, measured
Eteläranta	In the vicinity of a harbour	8.7 ± 3.3	2010	9.8 ± 9.9
Katajanokka	In the vicinity of a harbour	8.0 ± 2.9	2009	7.7 ± 6.0
Western harbour	In the vicinity of a harbour	8.2 ± 3.2	2008	8.7 ± 8.7
Kallio	Urban background	8.2 ± 3.0	2009	8.4 ± 5.7

Table from Soares et al., 2014

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Overview of Doppler lidars with respect to air quality

Ville Vakkari, Anne Hirsikko,
Ewan J. O'Connor, Curtis R. Wood

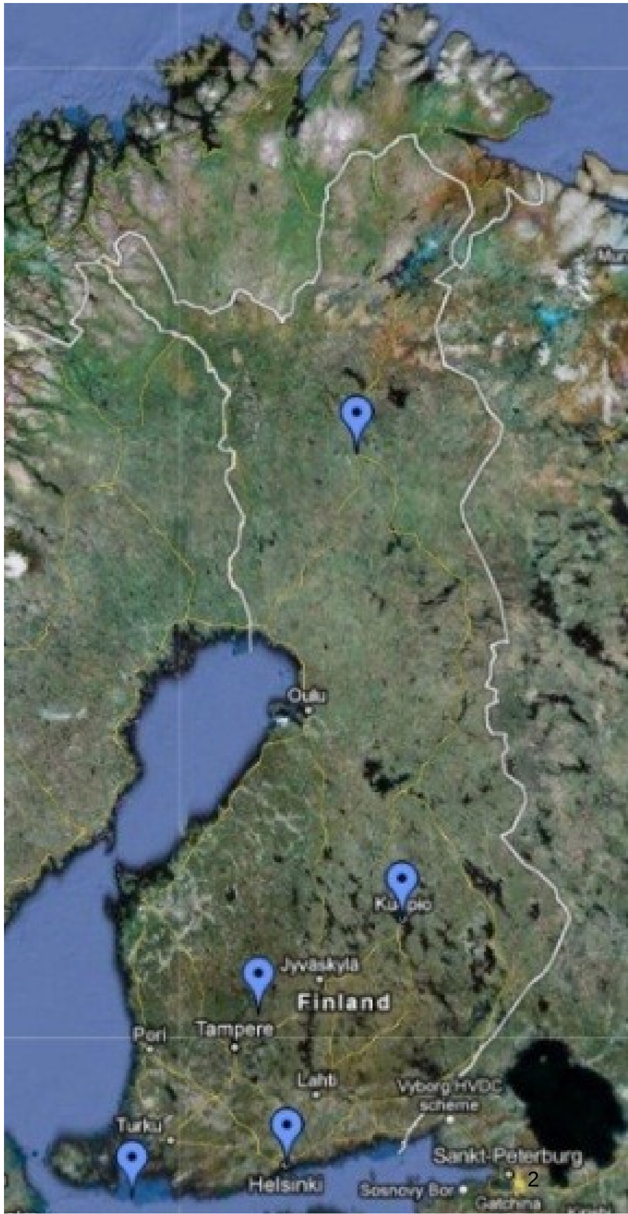
Finnish Meteorological Institute

5-Lidar network in Finland

- Continuous operation in five locations
  - Utö
  - Helsinki
  - Hyytiälä
  - Kuopio
  - Sodankylä
- Urban, coastal, rural and arctic environments
- Scan strategy varies
- One (spare) for campaigns

Hirsikko et al., AMT, 2014,

www.atmos-meas-tech.net/7/1351/2014/



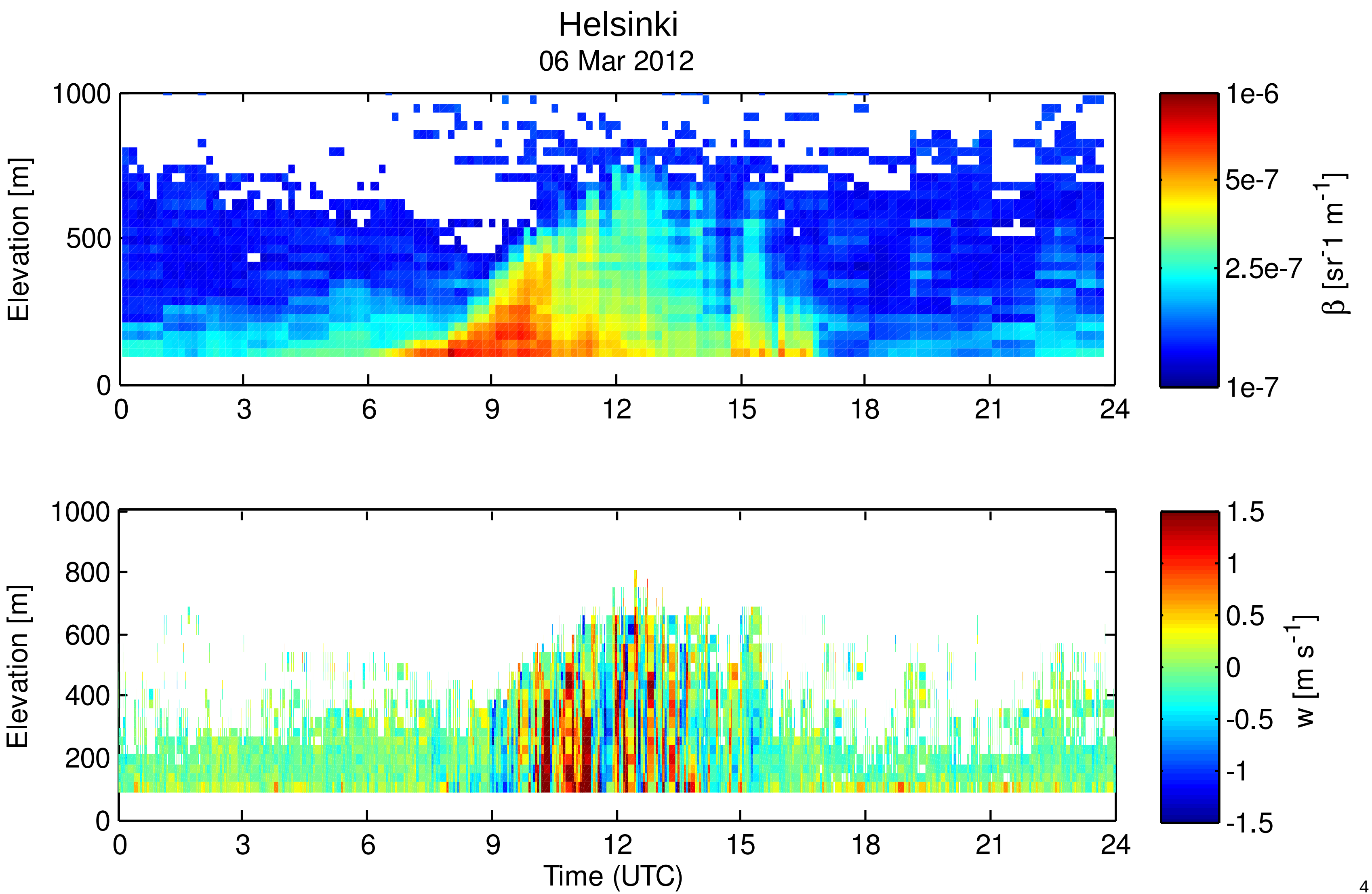
Halo scanning Doppler lidar

- Lidar = light detection and ranging
  - Send out a laser pulse, wait and see what comes back:
  - Time = distance
  - Backscatter intensity ~ cross-sectional area (aerosol, cloud)
  - Depolarisation ratio: spherical (liquid droplet) or not (ice, ash)

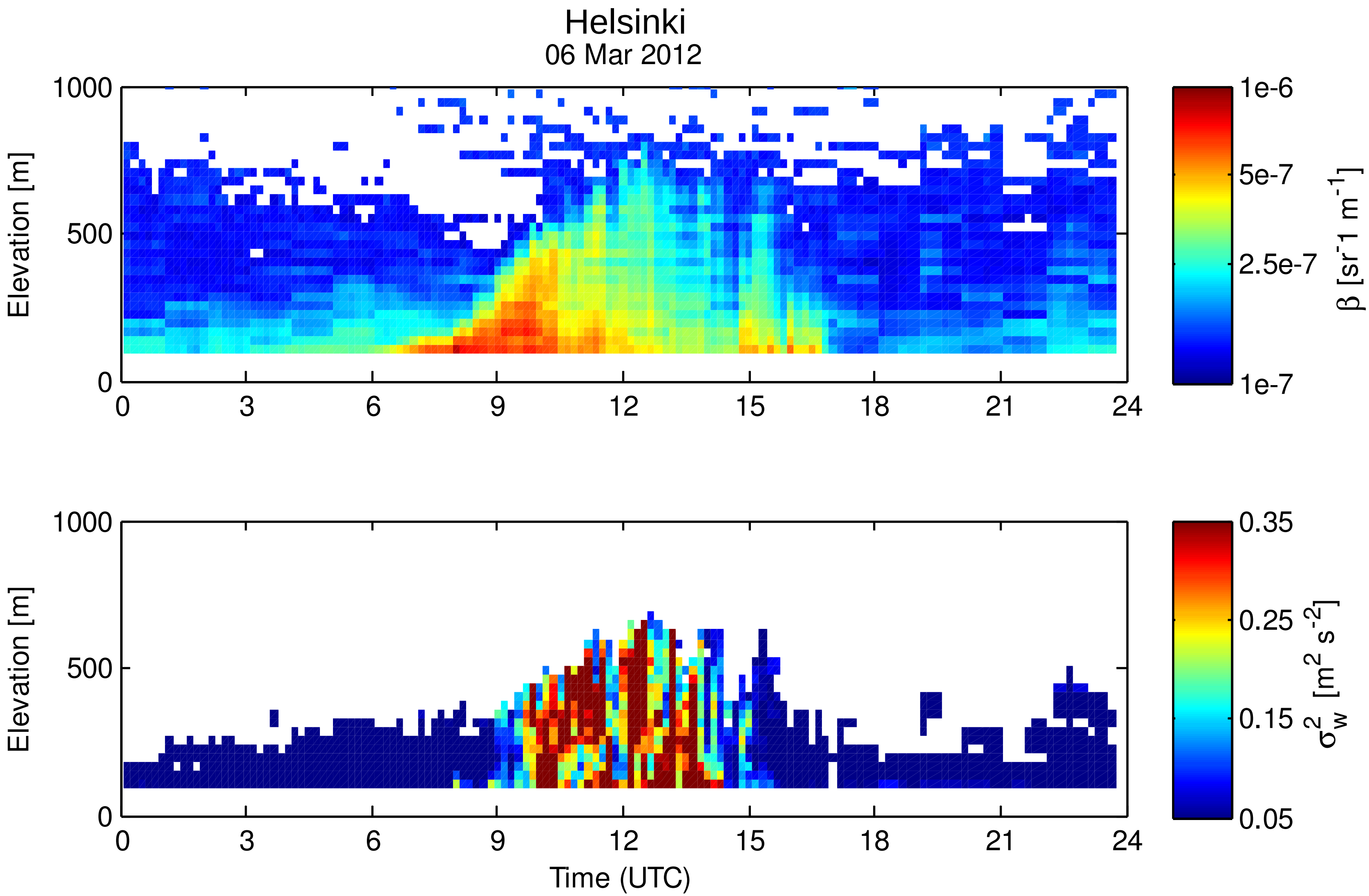
- Doppler shift = wavelength changes if reflecting object moves
  - Radial (wind) velocity

- Eye-safe 1.5 µm laser (low-energy ~0.1mJ)
- Range 90 – 9600 m, resolution 30 m
  - Full hemispheric scanning
- Continuous operation for months

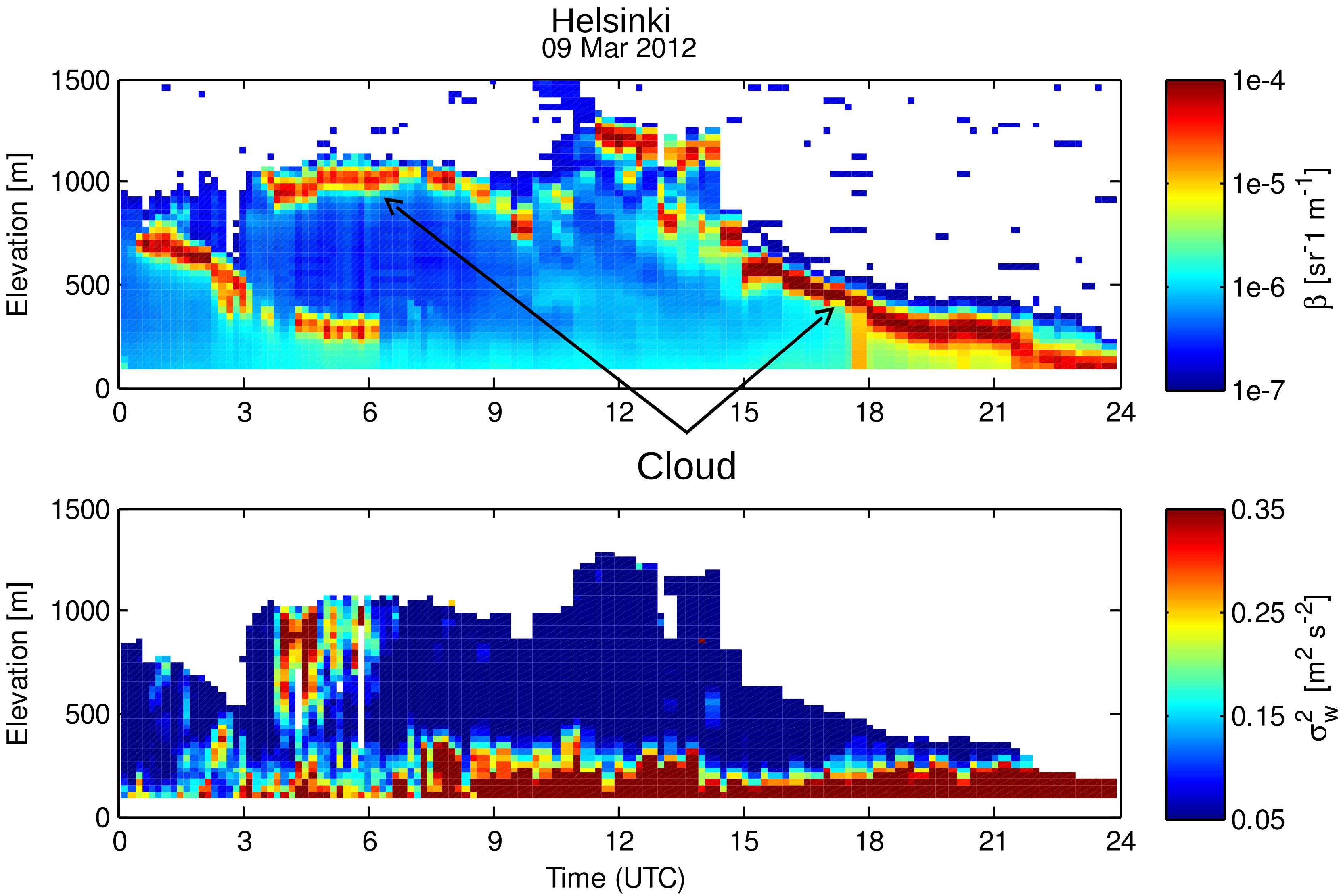
Backscatter and vertical wind profiles



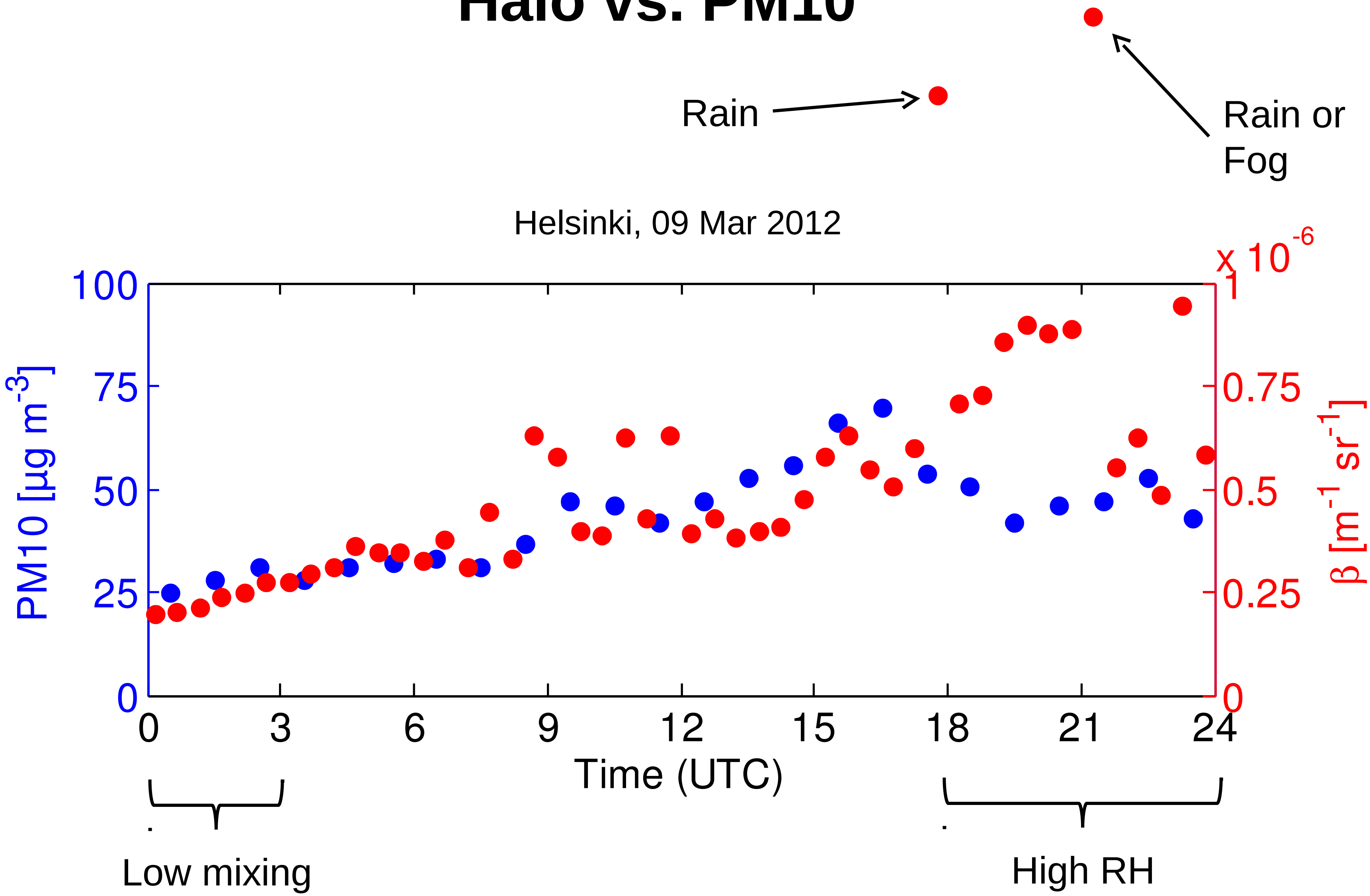
Daytime mixing layer top at 500 – 700 m



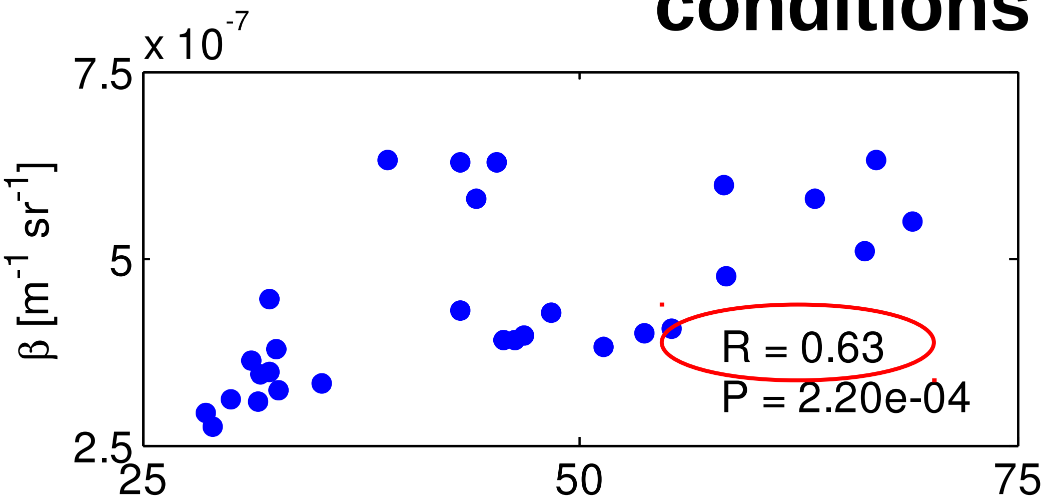
Shallow mixing layer also during night



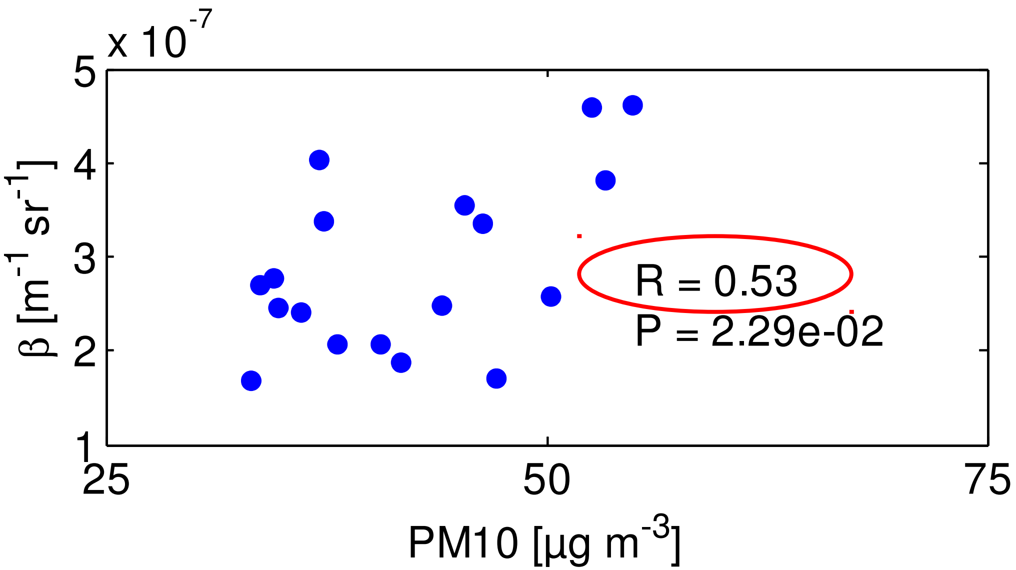
Halo vs. PM10


Rain
Rain or
Fog
Helsinki, 09 Mar 2012
x 10^-6
PM10 [µg m^-3]
β [m^-1 sr^-1]
0
25
50
75
100
0
0.25
0.5
0.75
1
0
3
6
9
12
15
18
21
24
Time (UTC)
Low mixing
High RH

Some correlation in low RH, well mixed conditions

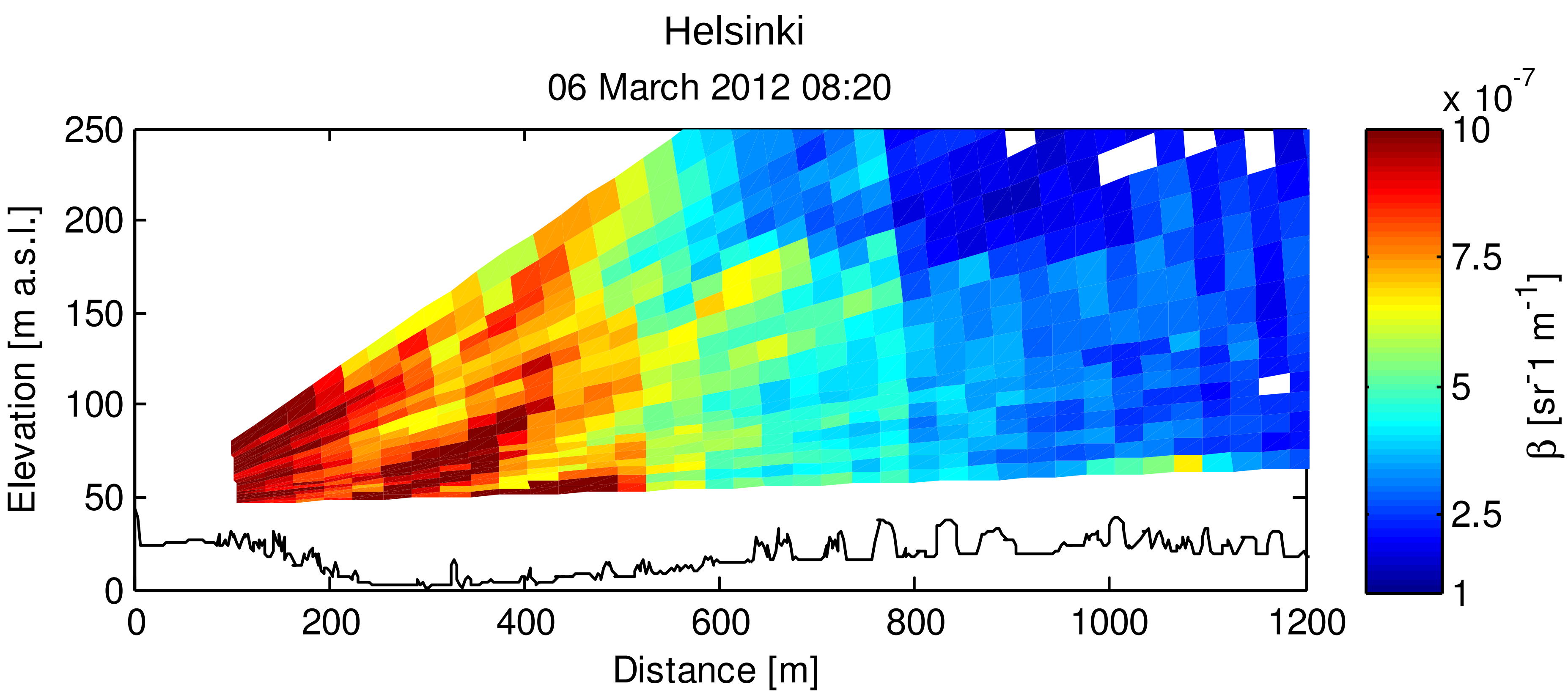


Helsinki
09 March 2012
- Mixing layer top 200 m
- Day and night

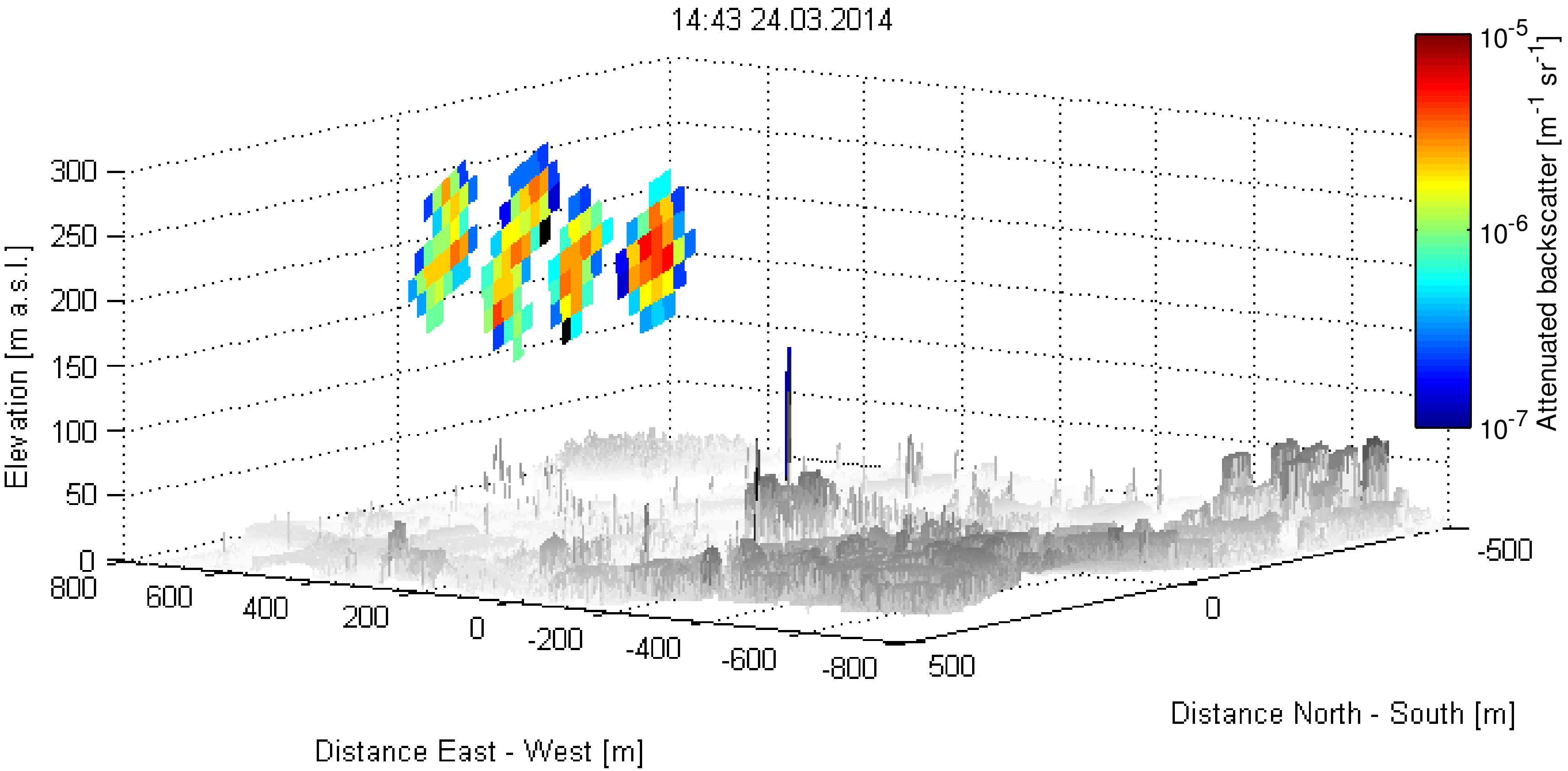


Helsinki
06 March 2012
- Mixing layer top 700 m
- Only daytime

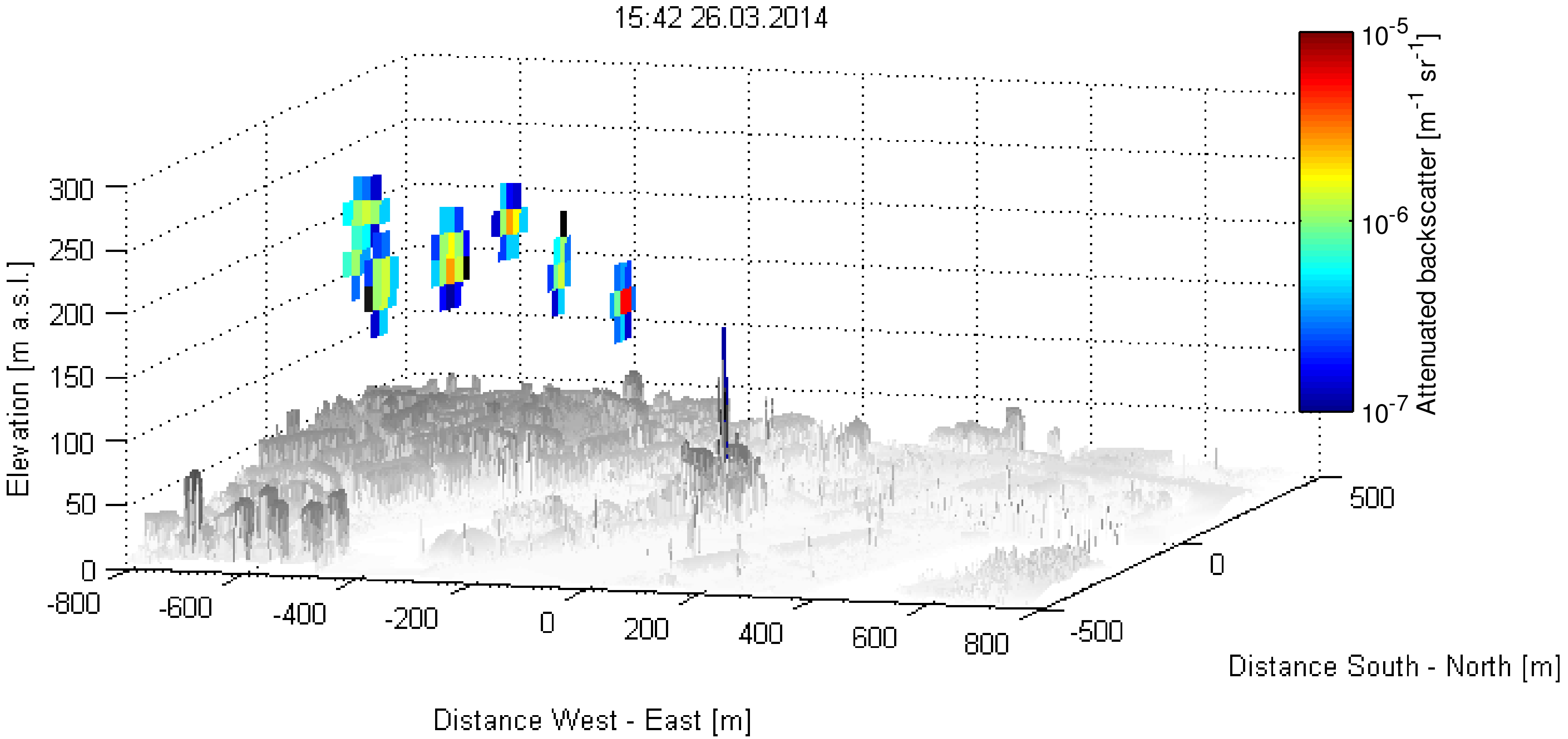
Backscatter profile south from Dynamicum roof



Tracking Hanasaari plume

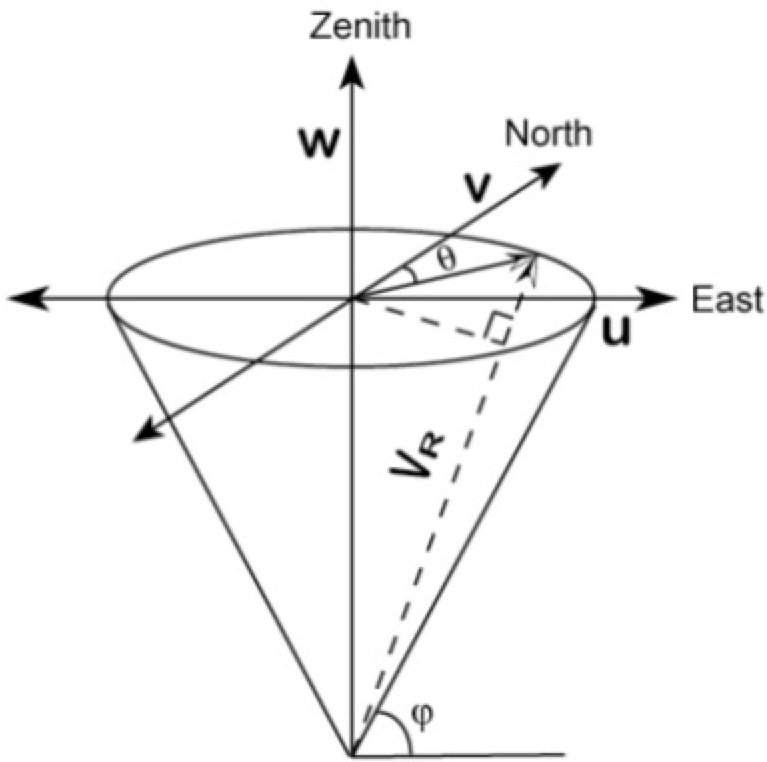


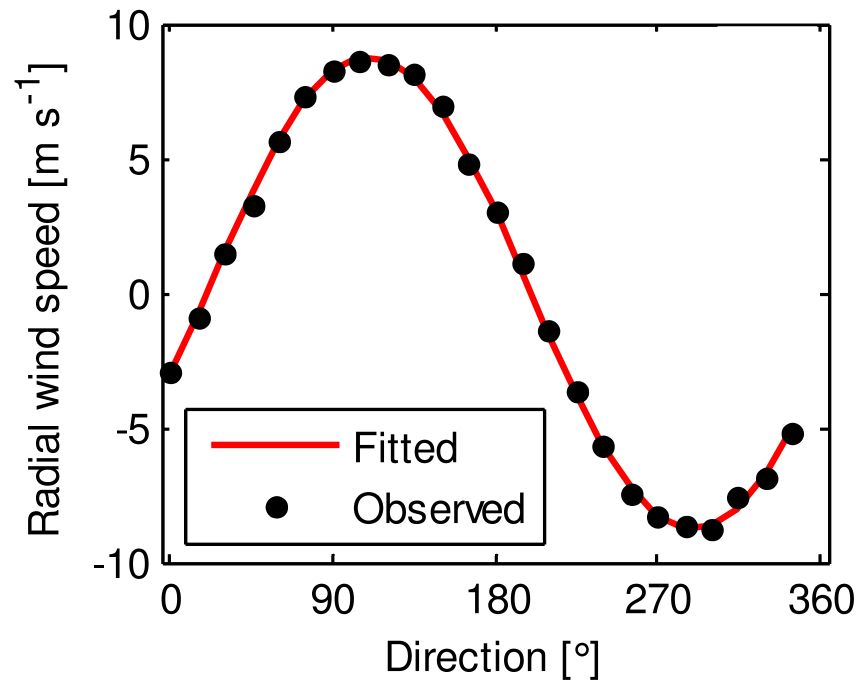
Tracking Hanasaari plume



Horizontal winds with conical scanning

- Requires at least three independent radial velocity measurements
- Typically 24 samples (every 15°) / wind profile at 30° elevation angle
- Wind speed and direction from a sinusoidal fit

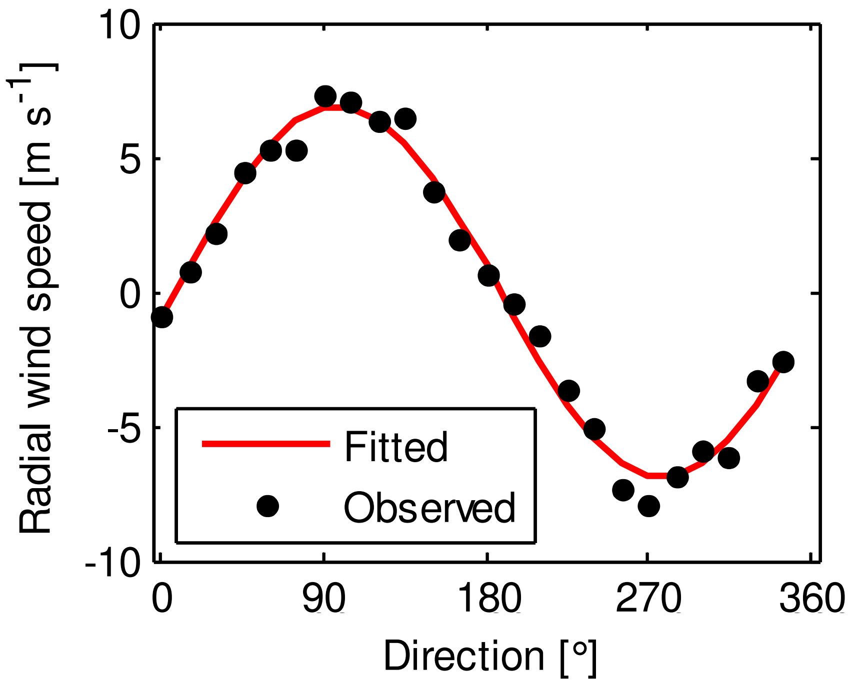




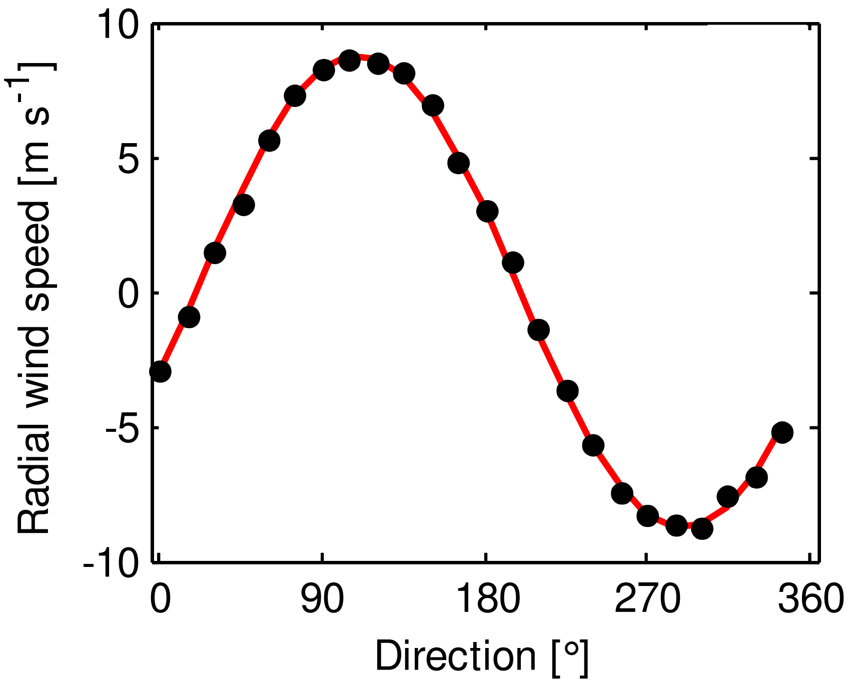
Turbulence estimated from the residuals

Inhomogeneity of wind field used to calculate

1. Confidence bounds for wind speed and direction
2. A proxy for turbulent mixing



Turbulent

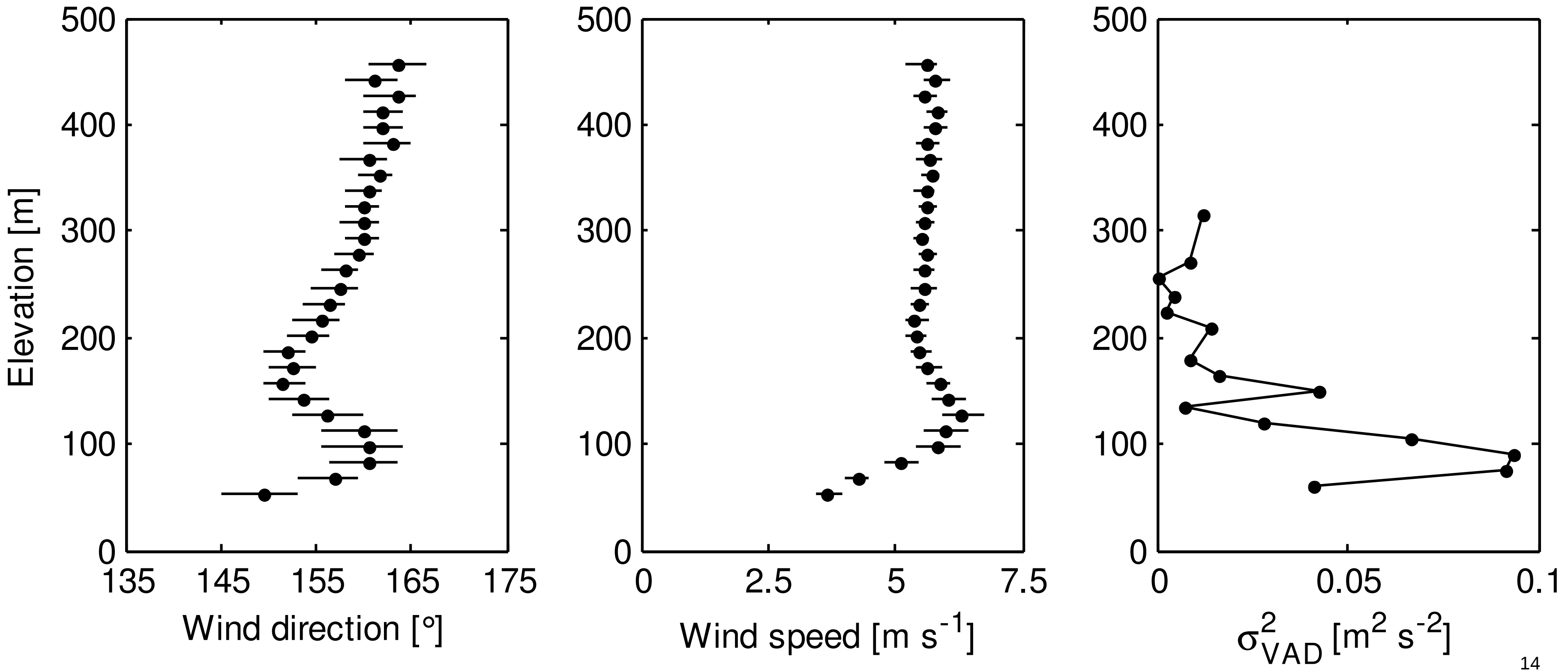


Quiescent

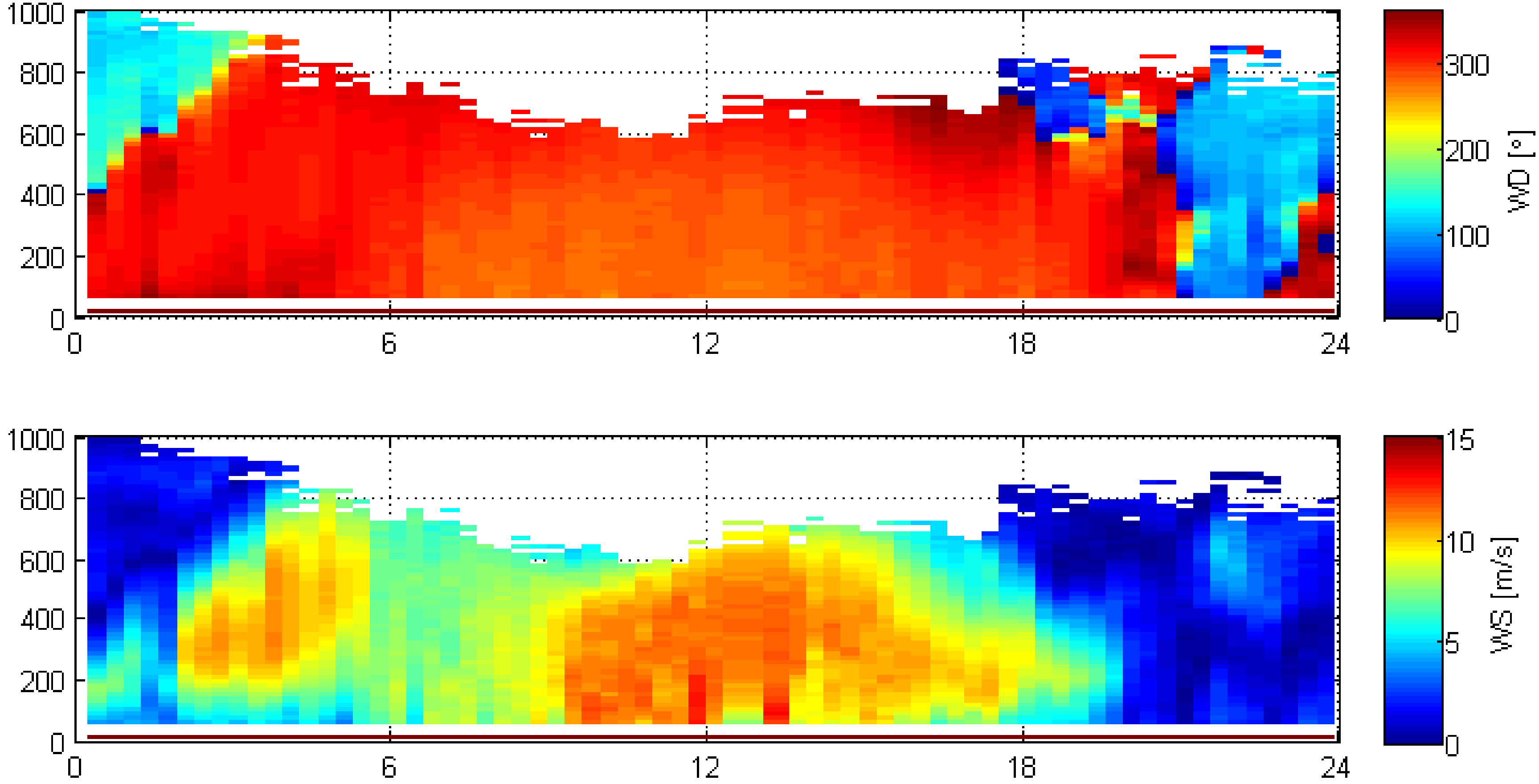
Vertical profiles of wind speed, direction and mixing

- Night-time turbulent mixing by a low level jet
  - Observed on 70% of nights in August 2014 at Hyytiälä

Hyytiälä 3 August 2014 at 04:00 UTC



Wind profile at Limassol, Cyprus, 24.8.2013



Conclusion – scanning Doppler lidars

- **Field-capable instrumentation (operated in –30°C to +35°C)**
  - Five lidar network in Finland, one for campaigns
- **Mixing layer height from 100 m up**
  - Using the low-level scanning to get below 100 m
  - Combining wind variance and aerosol backscatter
- **PM10 mapping, plume tracking**
  - Possible in low RH, well mixed conditions
  - Helsinki is most of the time too clean
- **Wind profile and 3D wind field**
  - With custom scans from 10 m up
  - Flow around buildings and islands
- **Optimization:**
  - Signal strength vs. time resolution
  - Vertical profile vs. scanning

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