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FMI / Air Quality modelling

”from global to micro scales”

Ari Karppinen

04/2024

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

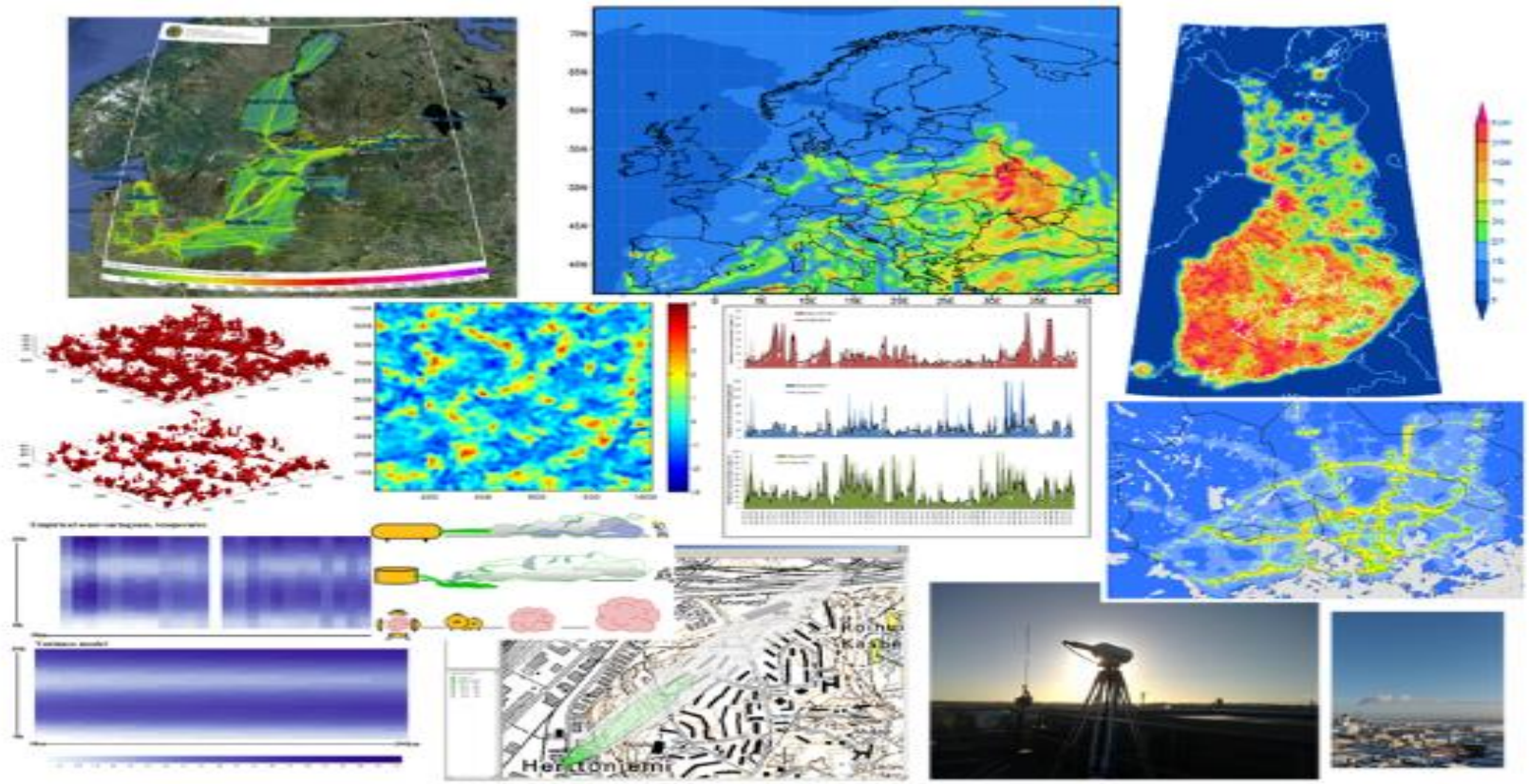
Contents

General

1. Microscale/flow modelling :LES/PALM
2. Shipping : STEAM
3. Urban AQ Foreccast/datafusion :EnFuser
4. SILAM

Atmospheric Dispersion Modelling

31 researchers



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Ari Karppinen

Mia Aarnio
Nina Atanasova (*Microbiology*)
Mikko Auvinen
Yalda Fatahi
Tiia Grönholm
Mikko Heikkilä
***Antti Hellsten (PALM/LES)**
Risto Hänninen
Daulet Izbassarov
Jukka-Pekka Jalkanen (Shipping)
Lasse Johansson (EnFuser)
Matti Jokinen
Leena Kangas
Mari Kauhaniemi
Rostislav Kouznetsov
Elisa Majamäki
Androniki Maragkidou
Juha Nikmo
Julia Palamarchuk
Tero Partanen
Anton Rusanen
Kari Riikonen
Rahul Subburaj
Anders Stangel
Pilvi Siljamo
Mikhail Sofiev (SILAM)
Svyatoslav Tyuryakov
Andreas Uppstu
Jukka-Pekka Keskinen
Evgenij Kadantsev
(17-6-7)

EU-coordinations:
EMERGE (J-P Jalkanen,Tiia , Niki & al.)
SYLVA(M Sofiev, SILAM team)

Emphasis on specific research areas

- Regional air quality modeling (SILAM)
- Bioaerosols (SILAM, EU/SYLVA, bioinformatics)
- Operative Air quality forecasts (SILAM, EnFuser)
- Computational fluid dynamics (PALM)
  - Outdoor/indoor AQ & meteorology (LESCAPE, CAR-LES, EU/xxxx)
- Accidents involving hazardous materials (ESCAPE)
- Local air quality modeling (CAR,UDM)
- Environmental information fusion service (EnFuser)
- Maritime emissions (STEAM, EU/EMERGE)
- *Urban boundary layer network (supporting data)*

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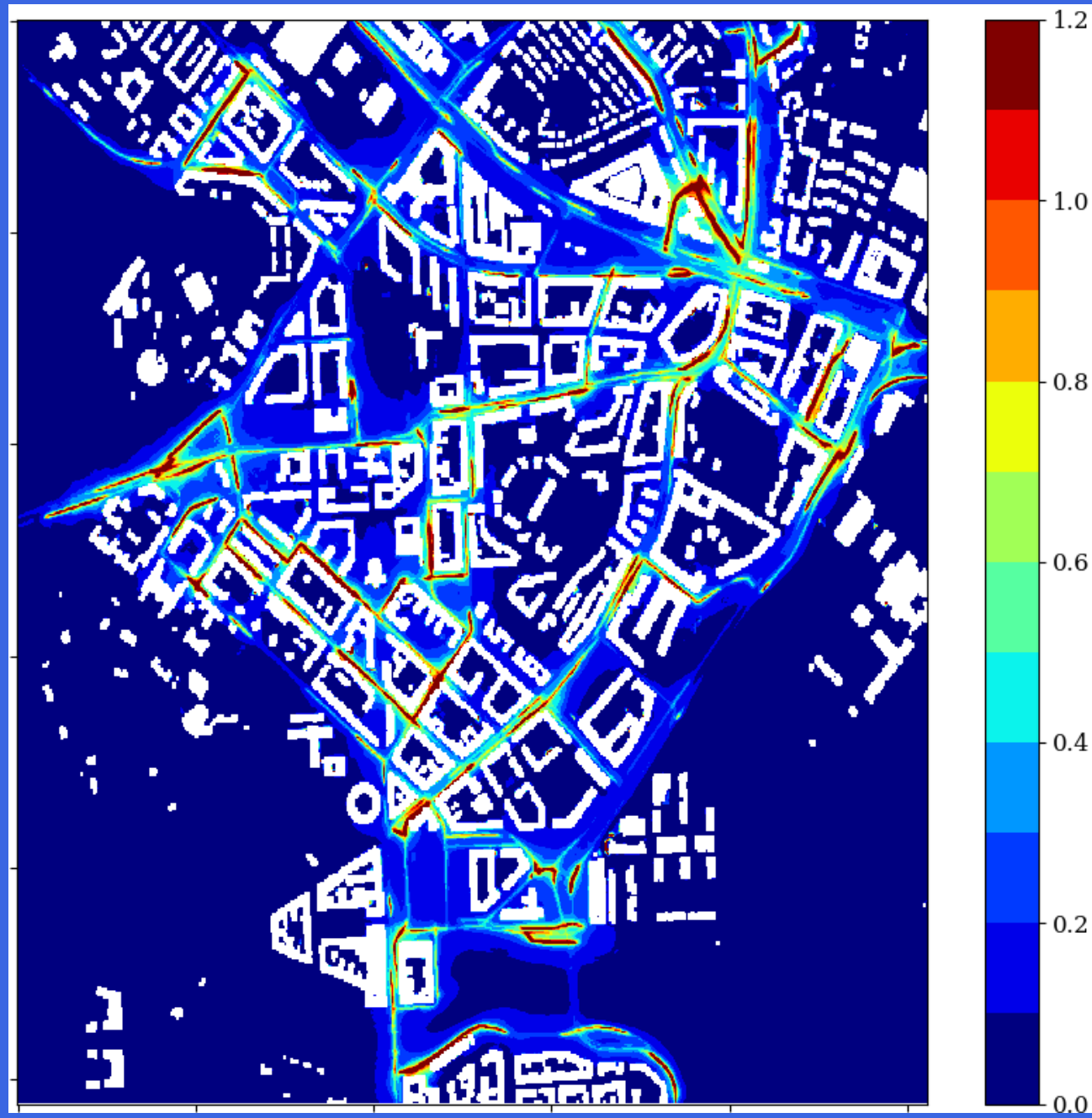
Overview of LES/PALM work



LES/PALM: research areas

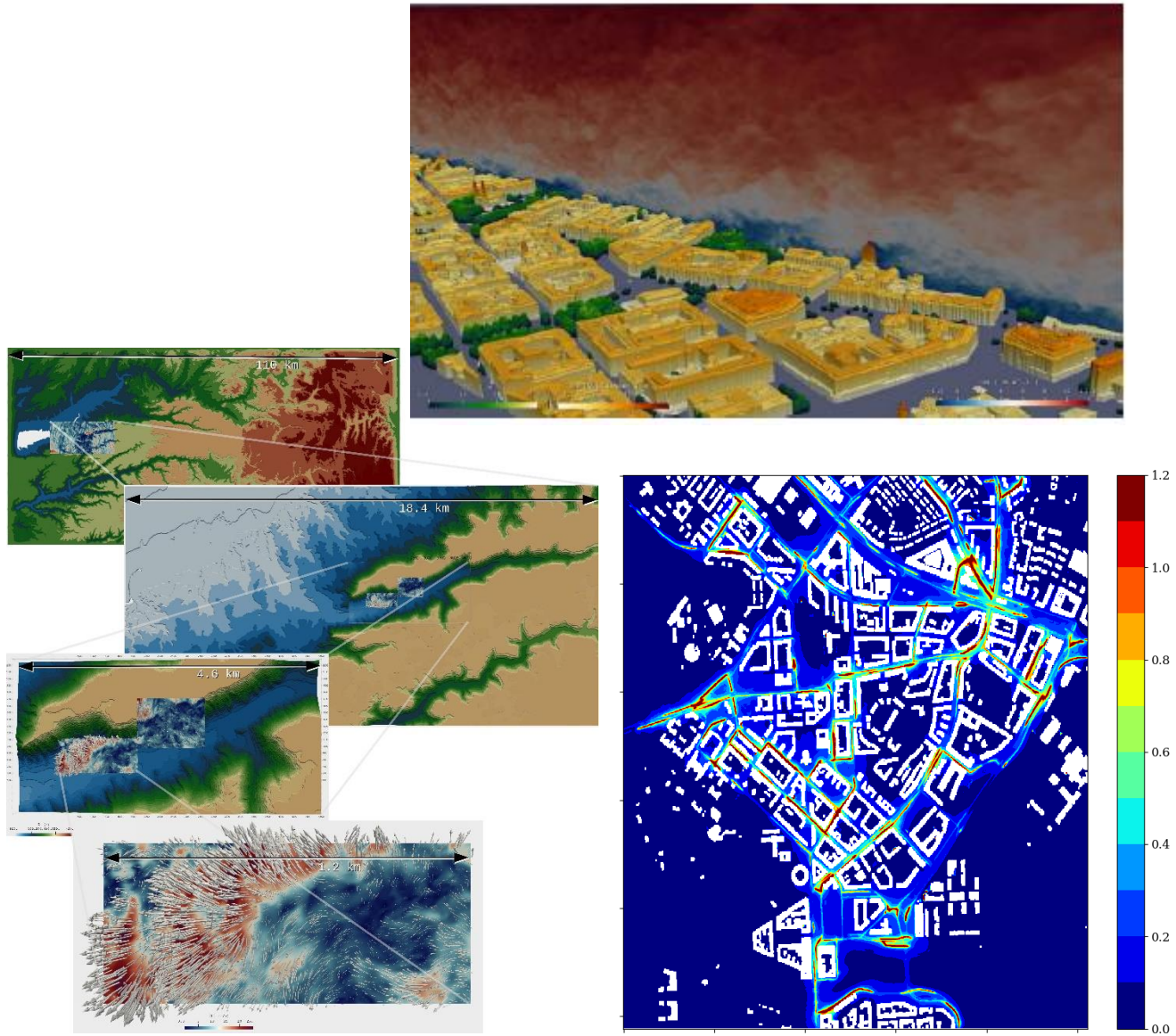
Various kinds of high-resolution Large-Eddy Simulation (LES) studies on Atmospheric Boundary Layer (ABL) flow and turbulence over numerous types of complex environments

Indoor dispersion studies

Study of flows inside human lugns (New!)

Small-scale ABL studies

- Various studies on wind conditions and pollutant dispersion in complex environments
- Downscaling of large-scale model data with the aid of high-resolution LES
- Several EU-funded projects around safety and resilience against wind hazards in changing climate
- Research Council of Finland funded study on GHG fluxes and transport mechanisms in heterogeneous forest environment



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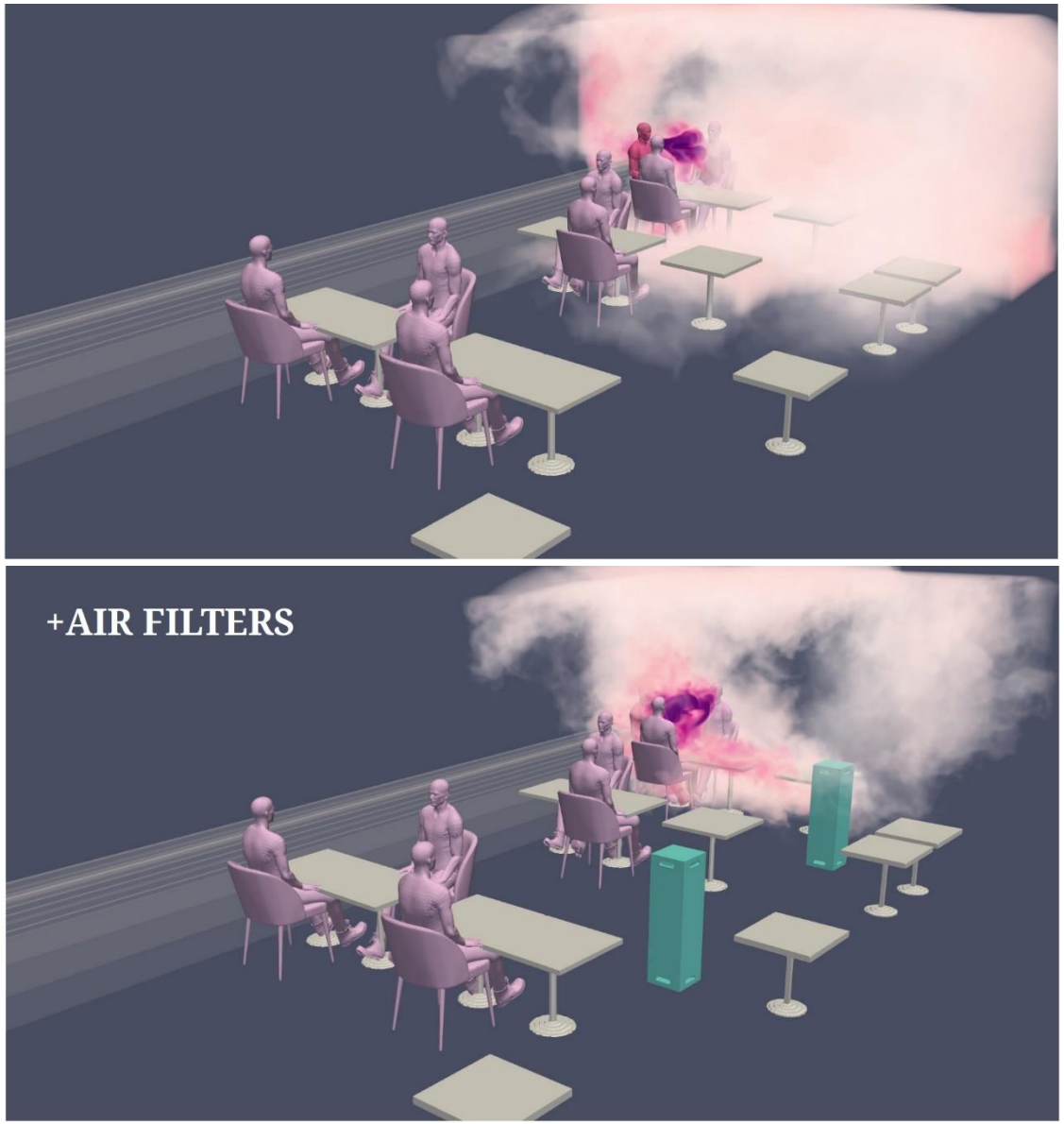
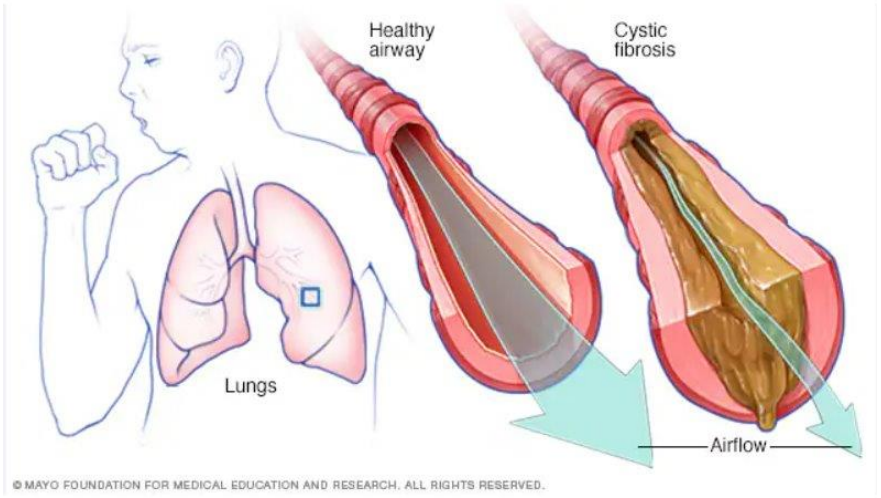
Indoor dispersion studies

- We started studying indoor air flows and dispersion of pathogen laden aerosol in March 2020
- We were **among the first ones** to show evidence of aerosol transmission of SARS-CoV-2
- Very high-resolution LES
- **Extension of infection-probability** analysis
- Several new findings
- Ongoing: underground **mine** study



Study of flows inside human lung (New!)

- Healthy lung:
  - mucus coating the airways
- Unhealthy lung:
  - air flow blocked due to several reasons
- A natural surfactant deficiency:
  - rupture of the mucus layer
  - harmful to the epithelial cells



- A multi-year computational study project on multi-phase non-Newtonian flow problems in human airways
- Research Fellowship granted for Daulet Izbassarov 2023 by Research Council of Finland

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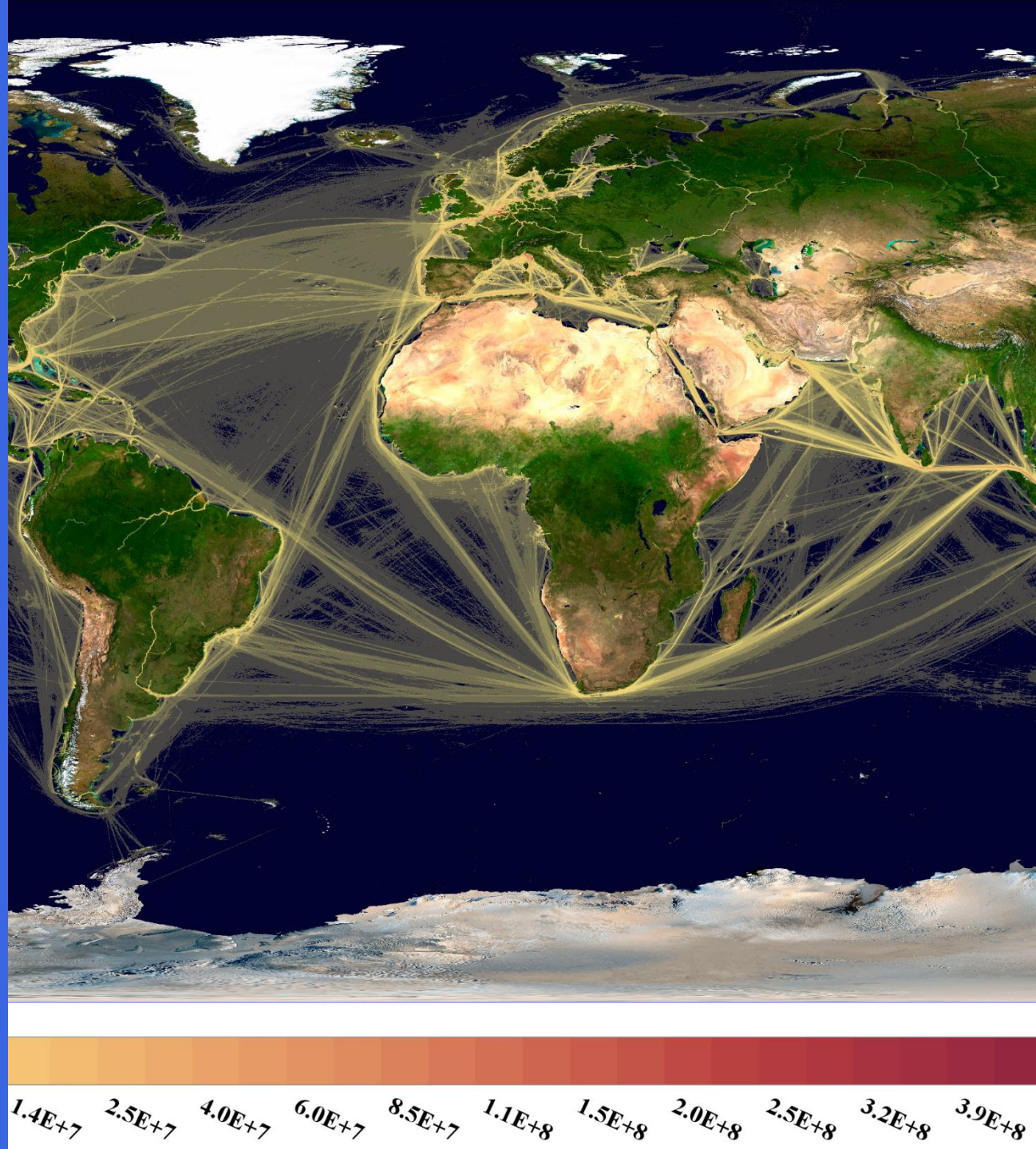
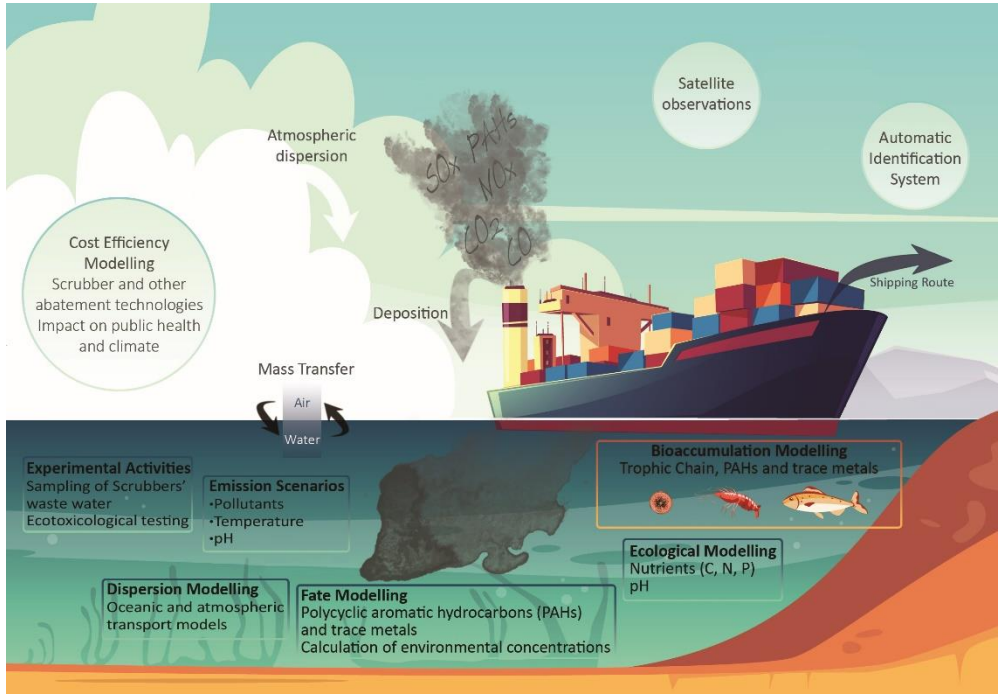
Overview of ship emissions work



Shipping team status

- 5+1 persons available for ship emissions work
  - 3 postdocs
  - 2+1 PhDs in preparation
- Coordination responsibility
  - H2020/EMERGE (Ends 5/2024) – Env impacts of SOx scrubbers
  - ShipNOEm (annual emission reporting for HELCOM, 2007-)
- Publications
  - 42 peer reviewed papers during last 3 years
  - +11 large reports (HELCOM, OSPAR, IMO submissions)
  - High impact papers
    - Sofiev et al, Nature Communications, 2018
    - Manshausen et al, Nature, 2023
    - Lunde Hermansson et al, Nature Sustainability, 2024
    - Aim: One high impact paper each year, +10 peer reviewed papers/year
- Current projects: 4 (2 Horizon, 1 Copernicus, 1 national)
- Proposals pending: 5 (2 Horizon, 1 ESA, 1 STN, 2 national)
- Proposals in preparation: 4 (1 Horizon, 1 German, 1 Arctic Council, 1 Dutch)



Air and water quality aspects of shipping (EMERGE project)

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Highlights

- Global modelling of ship emissions to air, water, noise, **we are the only group who can do this currently**
- STRONG policy support role
  - Environmental impact assessments for new Emission Control Areas
    - Baltic Sea, North Sea, Mediterranean Sea → IMO
    - Global 2020 sulfur cap, climate vs human health
  - Supporting the work of HELCOM, OSPAR(NE atl), REMPEC(Medit), ICES
- Annual reporting of air emissions, discharges, underwater noise
  - HELCOM (air, water, noise)
  - Copernicus/CAMS (air emissions)
- Close cooperation with Traficom, Ministry
  - FMI part of Finnish delegation to International Maritime Organization (IMO)
    - Marine Env. Protection Committee, Pollution Prevention & Response, ISWG for GHGs
  - FMI part of 3rd IMO GHG report workgroup, reviewer for 4th IMO GHG study
- Cooperation & data exchange agreements signed with European Maritime Safety Agency
  - European Maritime Transport Environmental Report (1 & 2)
  - Copernicus Atmospheres -> WP tailored for EMSA purposes
  - Research linkages concerning shipping ETS

Future targets

- We **currently cover almost all environmental topics handled at IMO MEPC**
  - Air pollution, GHGs, water pollution, underwater noise
  - Make ourselves irreplaceable to Traficom, MinTC, EU and become the first stop shop for shipping research globally
    - When EU member states consider changing env regulation for shipping, they call us first
- Developing shipping research towards policy needs
  - Research outputs with a clear stakeholder need → EMSA, EPAs, DGs, int. orgs
  - Expanding emission reporting to water discharges through Copernicus Marine
    - FMI high level support required
  - **Science**: Combination of emission modeling + remote sensing
  - **Science**: Underwater noise capability, linking with relevant industry, regulatory bodies
  - **Science**: Work towards more comprehensive impact assessments avoiding partial optimization
    - avoid efforts which clean one part but pollute others (scrubbers, antifouling paints)
    - New marine fuels, new env problems: Ammonia, LNG, Methanol
  - **Science**: Physical disturbance of coastline/seabed, collisions with marine mammals

Challenges

- Policy support tasks often require three things;
  - 1) high quality, peer-reviewed research,
  - 2) delivered yesterday,
  - 3) for free
  - Funding emphasis seems to be on industrial cooperation in the future, less funding available for env impact studies despite the recognized need for this work
  - Identification of silent signals, what kind of knowledge gaps need filling in the next 10 years
    - Preparing a suitable funding call, if none currently exists
    - Form the consortium and succeed in attracting the funding
    - Do the research work, publish the results
    - Timely delivery of results to policymakers
    - Time required to process regulatory change at IMO, EU, national levels

~15 years from identification of a knowledge gap to regulatory change

- Active dialogue with policy stakeholders required
  - IMO, HELCOM, OSPAR, ICES, EUSBSR, project meetings
    - Limited time for actual research work + writing papers
    - Practically no time for official evaluations of upcoming legislation
      - Gov admin definition of “ample time” is couple of weeks, will disrupt work scheduling
  - Challenge for time management & welfare, risk of burnout

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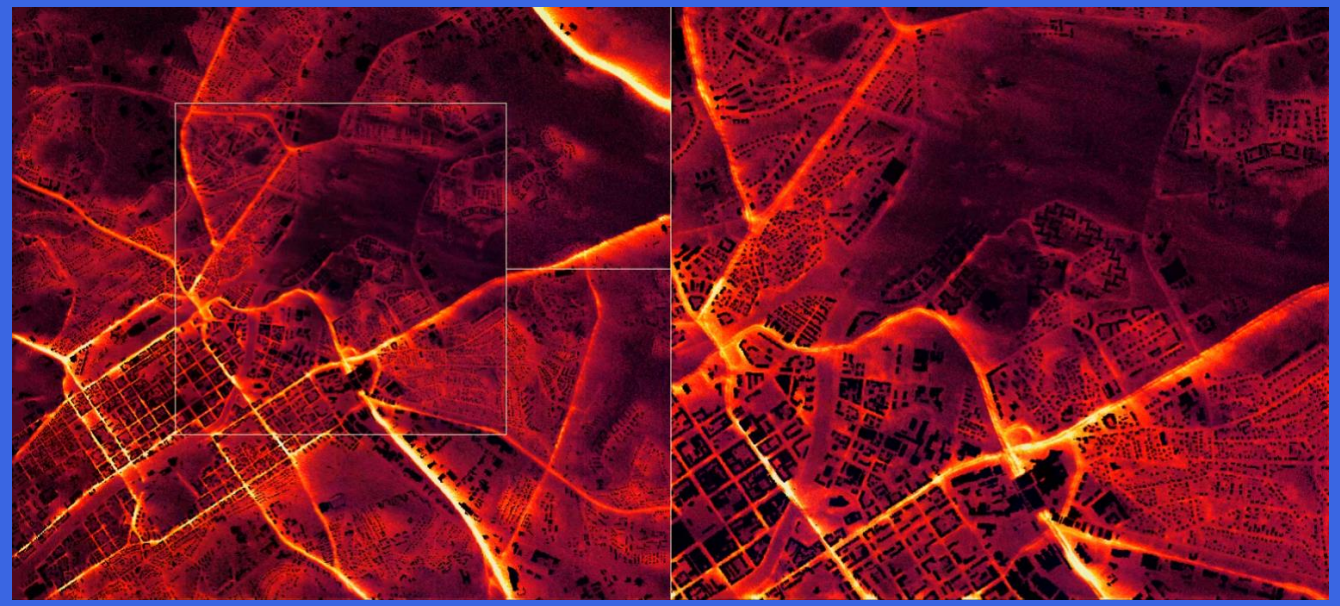
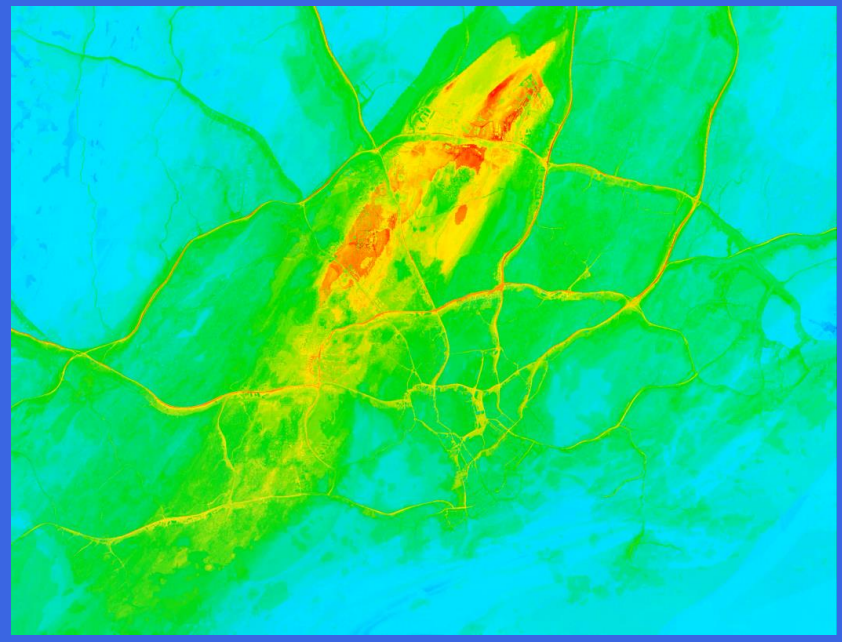
Highlights for recent ENFUSER work 2024



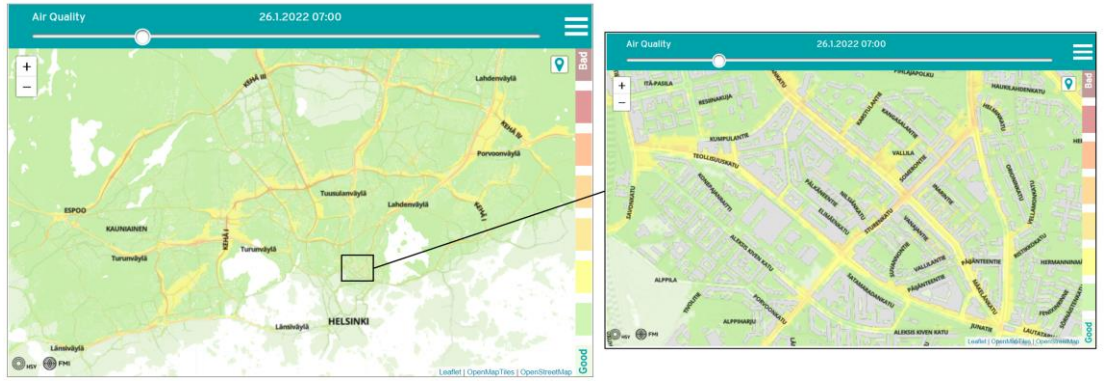


Enfuser: Operational AQ modelling service

- **Since 2018 we have provided timely high resolution AQ predictions for Helsinki region**
  - Other modelling areas previously: Nanjing, Delhi, Zagreb
  - High visibilty via **public transport displays**
  - Data assimilation of recent measurements
    - AQ sensors are used as well

Recently added species:

- black carbon (BC)
- Lung-deposited surface area (LDSA)
- Particle number concentration (PNC)



Example of air quality index visualizations provided for the general public based on ENFUSER model data. The service can be accessed from: https://www.hsy.fi/en/air-quality-and-climate/air-quality-now/air-quality-map/. Visited: Jan 26th, 2022.

Collaboration

Other groups at FMI

Nowcasting and Intelligent Traffic Weather Research	Road weather, rain nowcast (Inputs for Enfuser, project proposals)
Aerosol composition group	Several ongoing projects (AQ measurement data is key input for Enfuser)
Air Quality Expert Services group	Commercial AQ services and modelling solutions abroad (pending, **need more of this!**)

Within Air Quality Modelling group

SILAM team	Regional-scale AQ provided by SILAM is one of the most important input for Enfuser
PALM-team	Development of PALM-Enfuser (RESPONSE-project)
STEAM-team	Shipping emission inventories are used in Enfuser. Actually, in near-real-time.

External

HSY	Many past and ongoing projects. The main user of Enfuser data. Officially, **Helsinki region only**, we could do all Finnish cities.
University of Helsinki	Many past and ongoing research projects.
Vaisala	Commercialization of Enfuser (since 2019)
Aristotle University of Thessaloniki (AUTH)	Collaboration on machine learning related approaches on AQ modelling

FMI-Vaisala collaboration on AQ (since 2019)

FMI provides

- Scientific expertise on dispersion modelling and air quality
- Enfuser model (data fusion/utilizing sensors)

Vaisala provides

- Better software development tools and expertise on software development
- Scalability (large coverage for services)
- Improved measurement infrastructure for modelling areas (sensors)
- Integrated commercial solutions
  - Modelling + measurement infrastructure working together

Conventional network

Supplementary
dense sensor network

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RESPONSE project – PALM-Enfuser

Development of a more realistic disperion model, based on LES-precomputations

3D wind fields (Turku central area, PALM model)

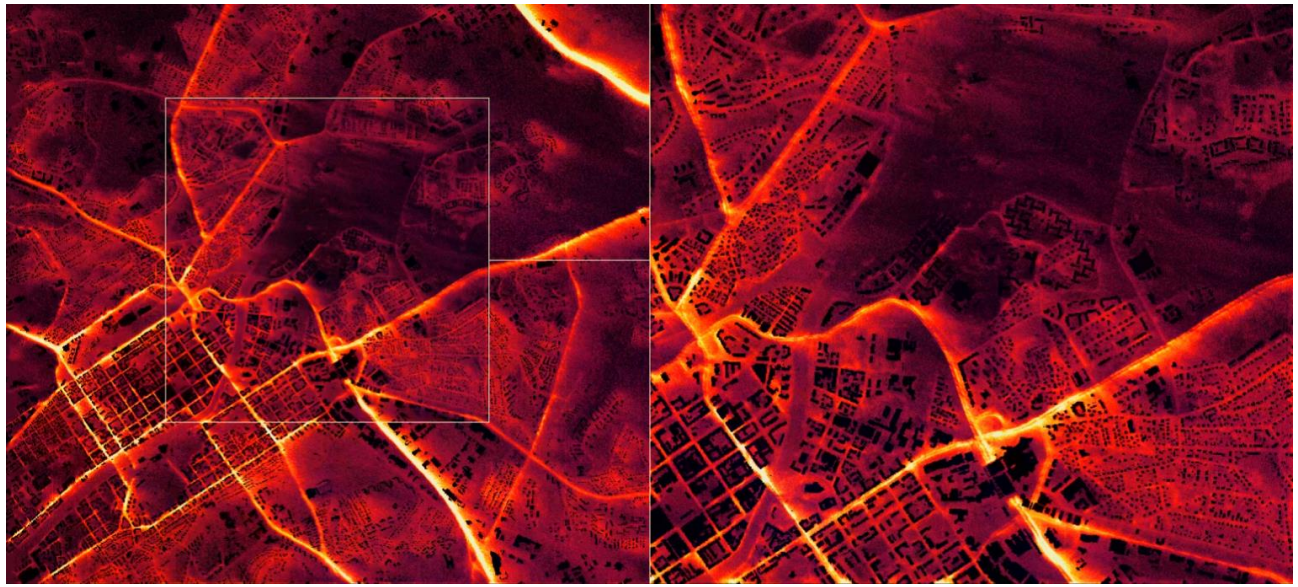
Down to 4 x 4 x 2m resolution

Computationally intensive, yet we managed to provide **operational AQ modeling** for Turku

Left: 8x8m outer grid concentration field

Right: inner grid 4x4m.

Enfuser without LES-coupling is used to obtain concentrations at the boundary of outer nest.



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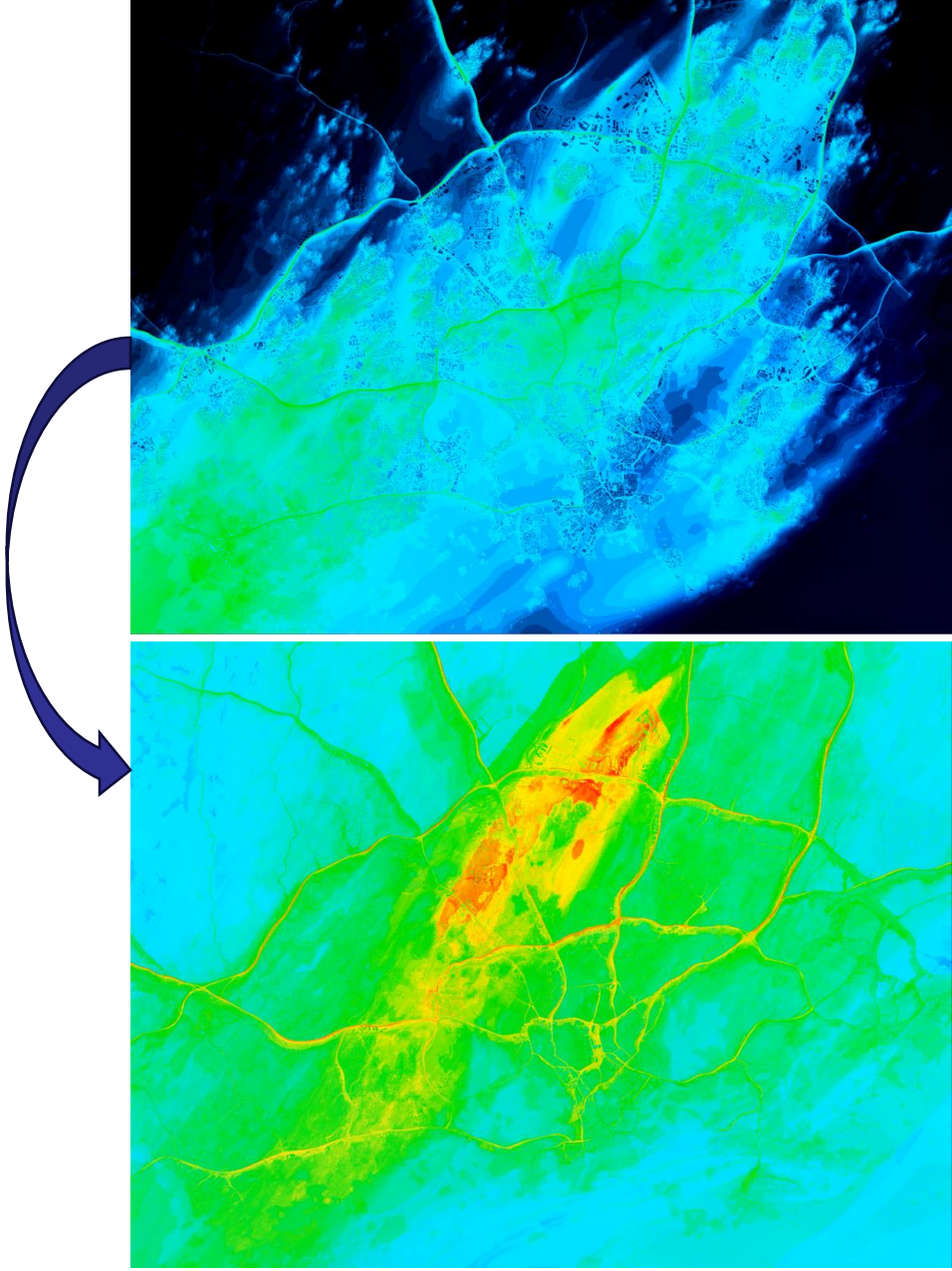
Urban Air Quality 2.0 -project

- **Partners: Helsinki University and HSY**
- we have been recently developing:
  - **Machine learning assisted urban scale forecasting**
    - Basic concept: A machine learning model is trained with ”vanilla” Enfuser data (with meteorological- and regional scale AQ data, SILAM) against AQ measurement data
      - Continuous re-training with the most recent data occurs in the background
  - **Objective:** increase the forecasting accuracy **substantially** for the targeted urban area
- This work continues in (GIANT/BF)



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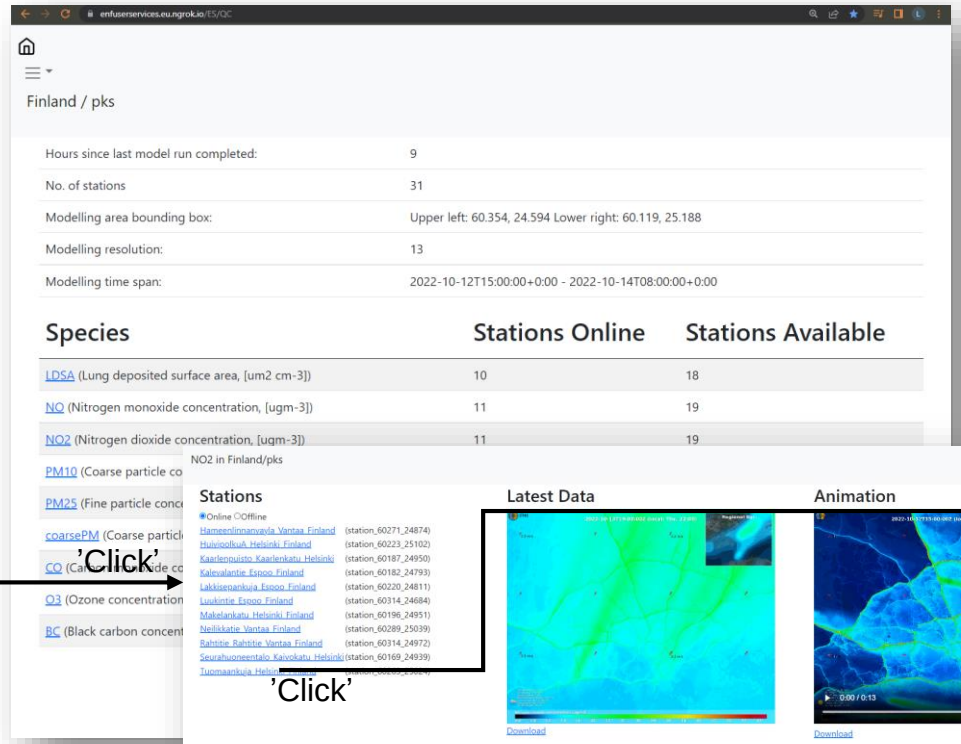
Upper figure: **Enfuser PNC** (2023-04-21T15:00)
Lower figure: **Machine learning assisted** (ML) version of the original.
Seemingly, the ML-model has adjusted backround and increased the contribution of aviation.

Enfuser portal & database

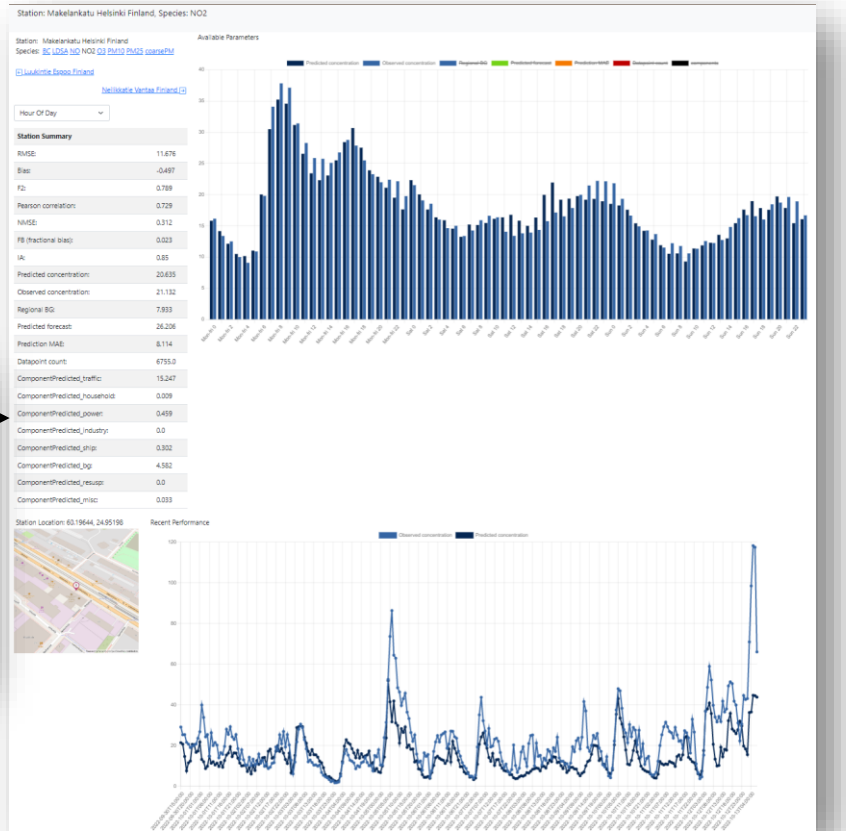
- **A long-term development target:** a portal coupled with a database to provide an access point to current and historic AQ data (all Enfuser modelling areas)

In E3/BF project, we **manually** provided AQ concentration data for kindergardens (for HUS health experts)
In the future, we want 3rd parties to be able to **get** this kind of information **easily** from our portal.



’Click’

’Click’



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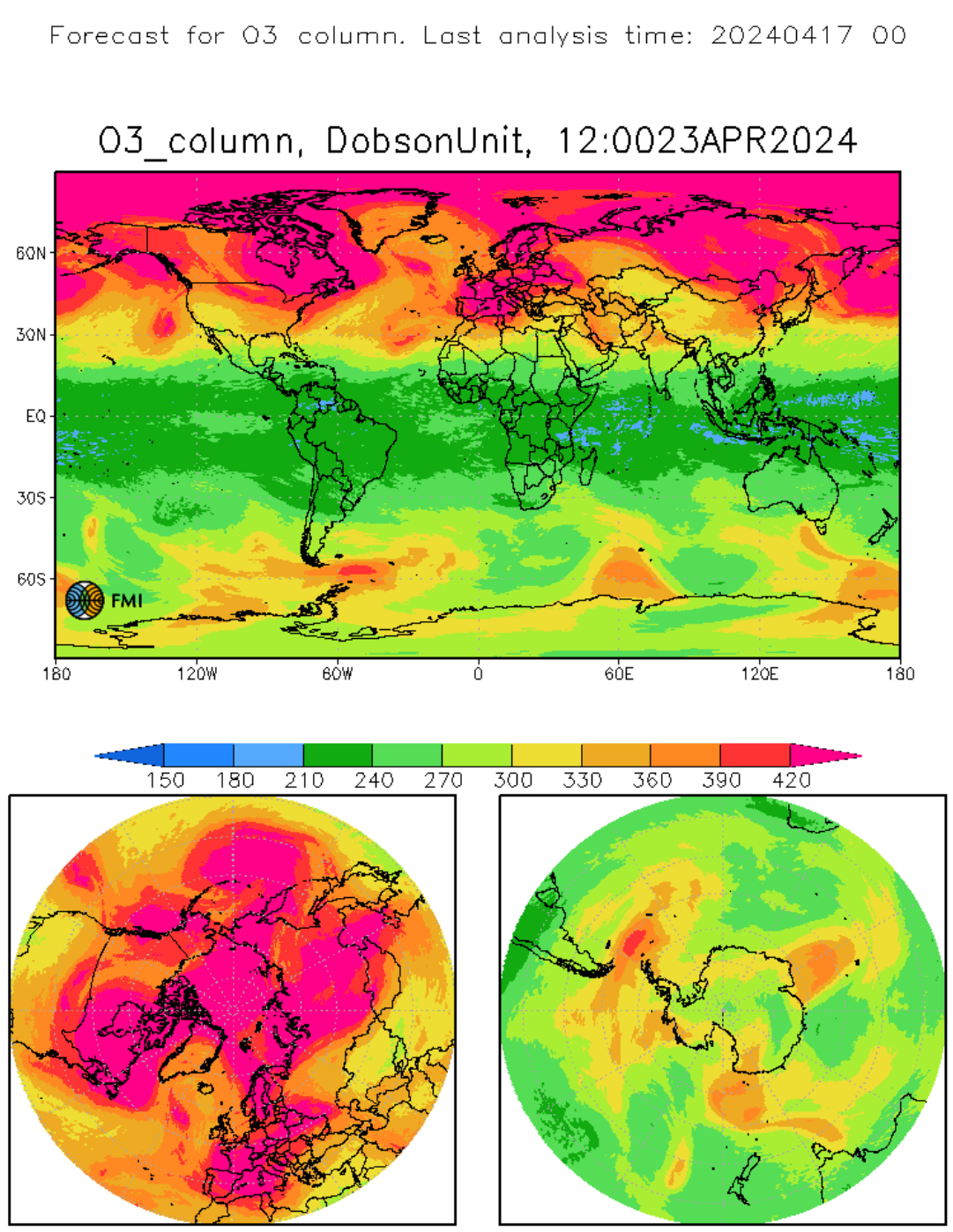
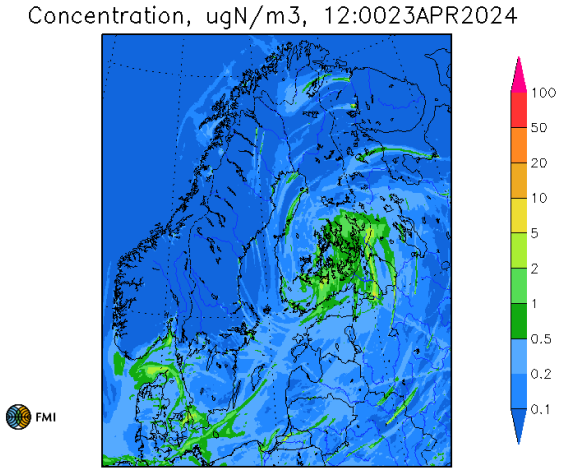
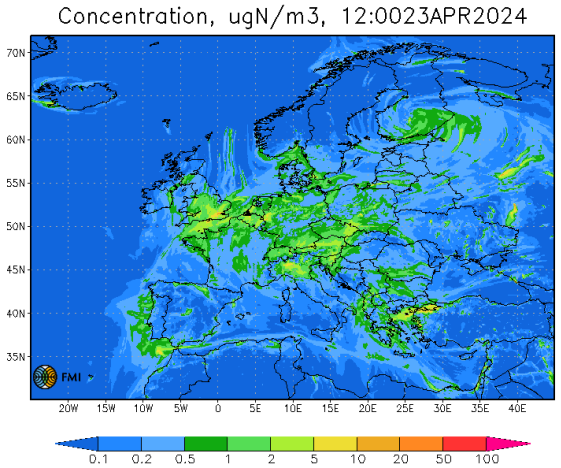
Higlights for SILAM team



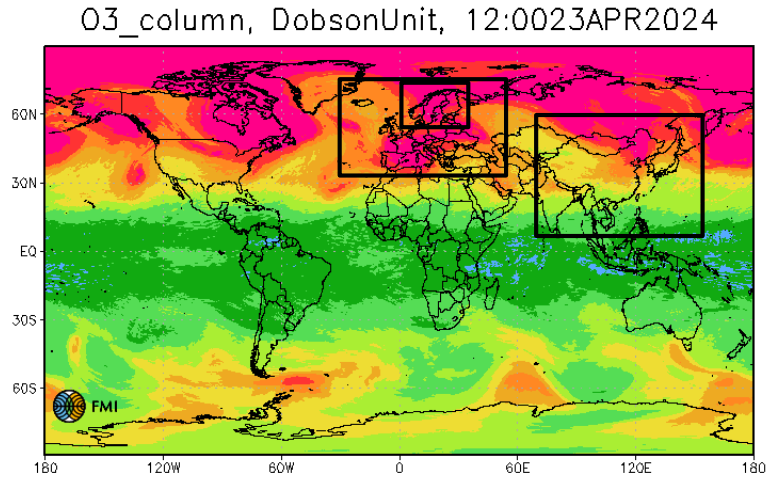
Operational AC/AQ-modelling at FMI



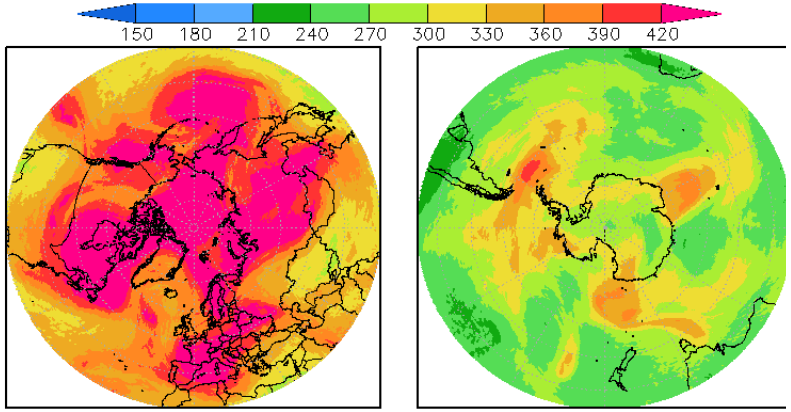


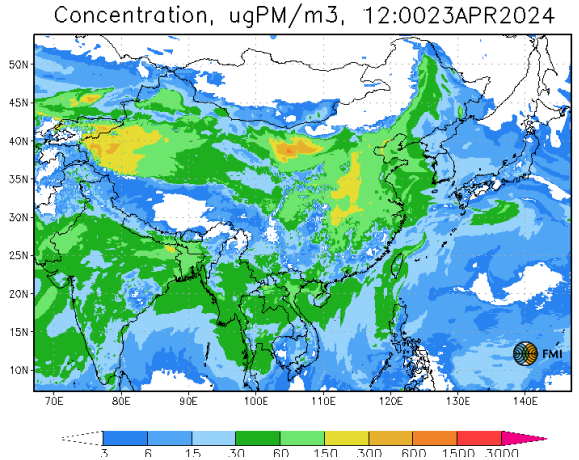
Global: **20km**, SILAM v.5.8
troposphere+ stratosphere

2-5 days with 1hr step,
SILAM v.5.x
http://silam.fmi.fi



Asia: 14km,
troposphere
SILAM v.5.5





Northern Europe:
2.5km, troposphere

Europe: SILAM v.5.9
10km, troposphere
boundaries: C-IFS
hindcast: 3D-Var

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European AQ forecast scores

CAMS2_40:

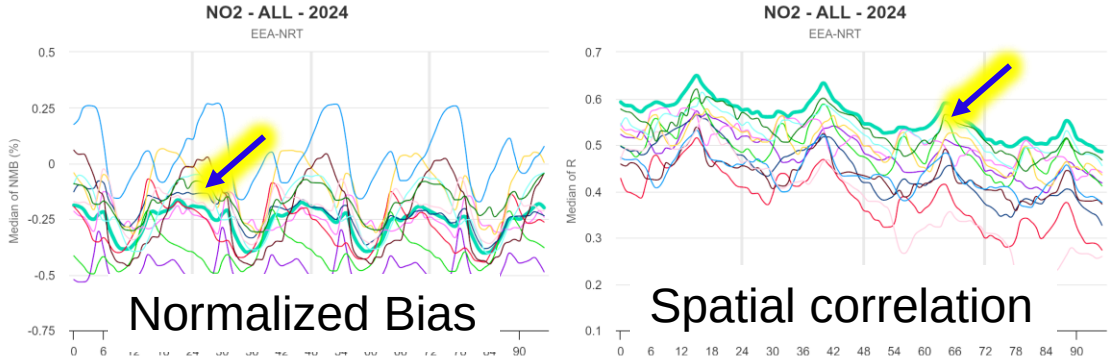
- 11 European models
- Daily production
- 5 days forecast
- Evaluated with EEA stations by CAMS2_83

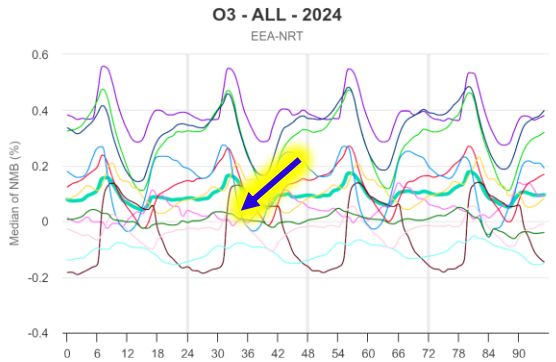
Evaluation 2024:

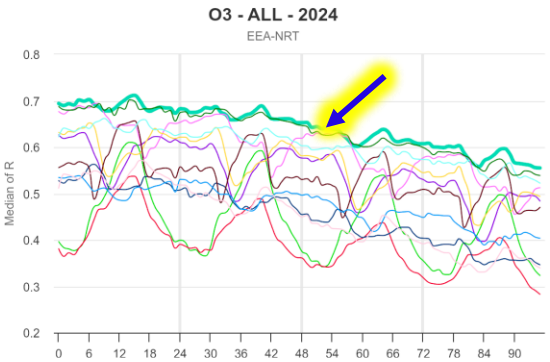
SILAM best or in most,

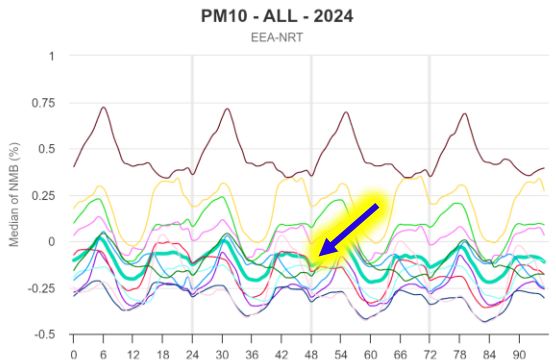
top3 in all scores

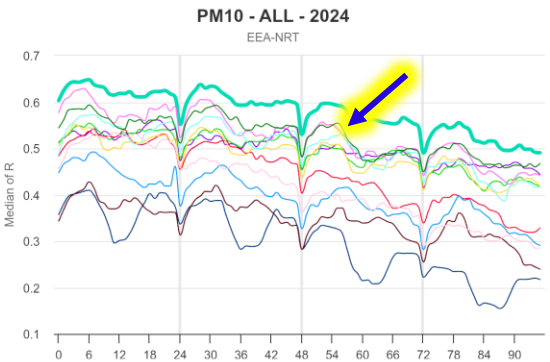
https://regional-evaluation.atmosphere.copernicus.eu

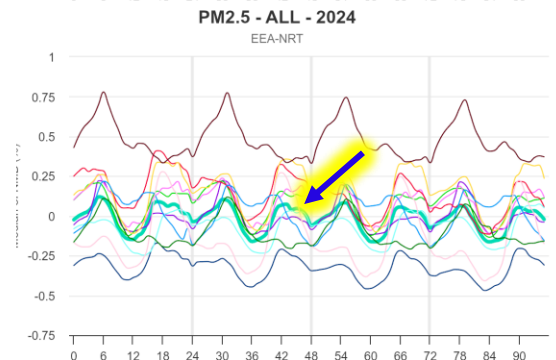


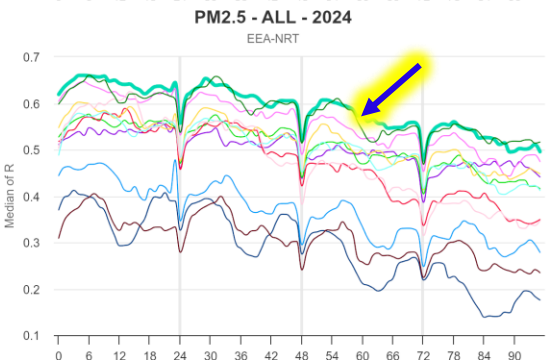








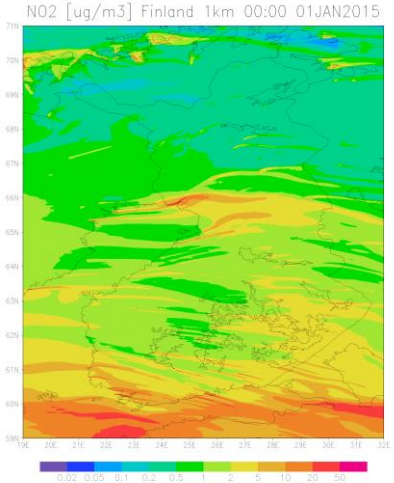




ENSEMBLE
GEMAQ
MONARCH
EMEP
CHIMERE
LOTOS
SILAM
EURAD
DEHM
MATCH
MINNI
MOCAGE

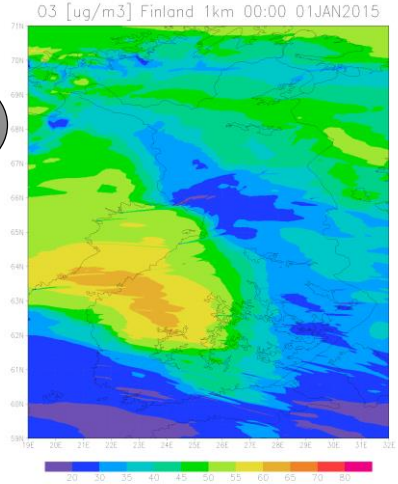
ILMATIETEEI
METEOROLO
FINNISH MET

Hourly concentrations over Finland resolution 1 km
1 – 3 Jan 2015



NO2

O3

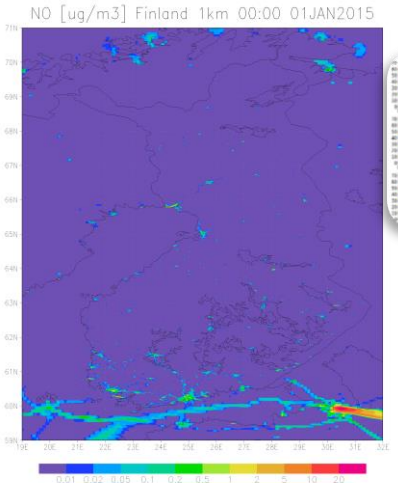


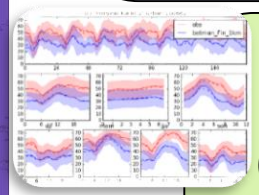
Emissions:

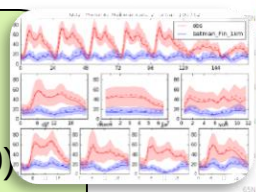
- SYKE over Finland (250 m)
- STEAM (1 h, 1 km), ship emission
- IS4FIRES fire PM emission
- GFAS fire gaseous emission
- TNO CAMS over rest territory

Meteo:

- ECMWF operational (~15km, 3hr)







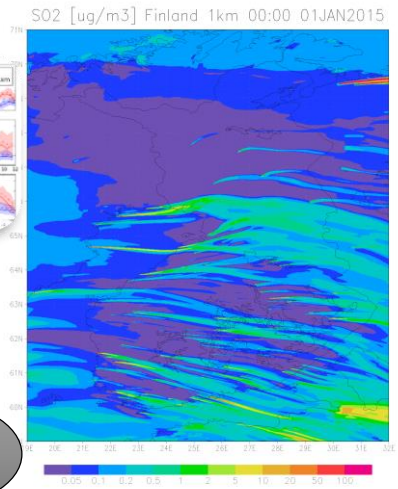
Results verified over ~100 AQ stations in Finland
(CO, SO2, NO2, O3, PM2.5, PM10)

General conclusion:

(1) SILAM quite well reproduces daily evolution and seasonality for all species; (2) street-level NOx still unresolved by 1km resolution

NO

SO2

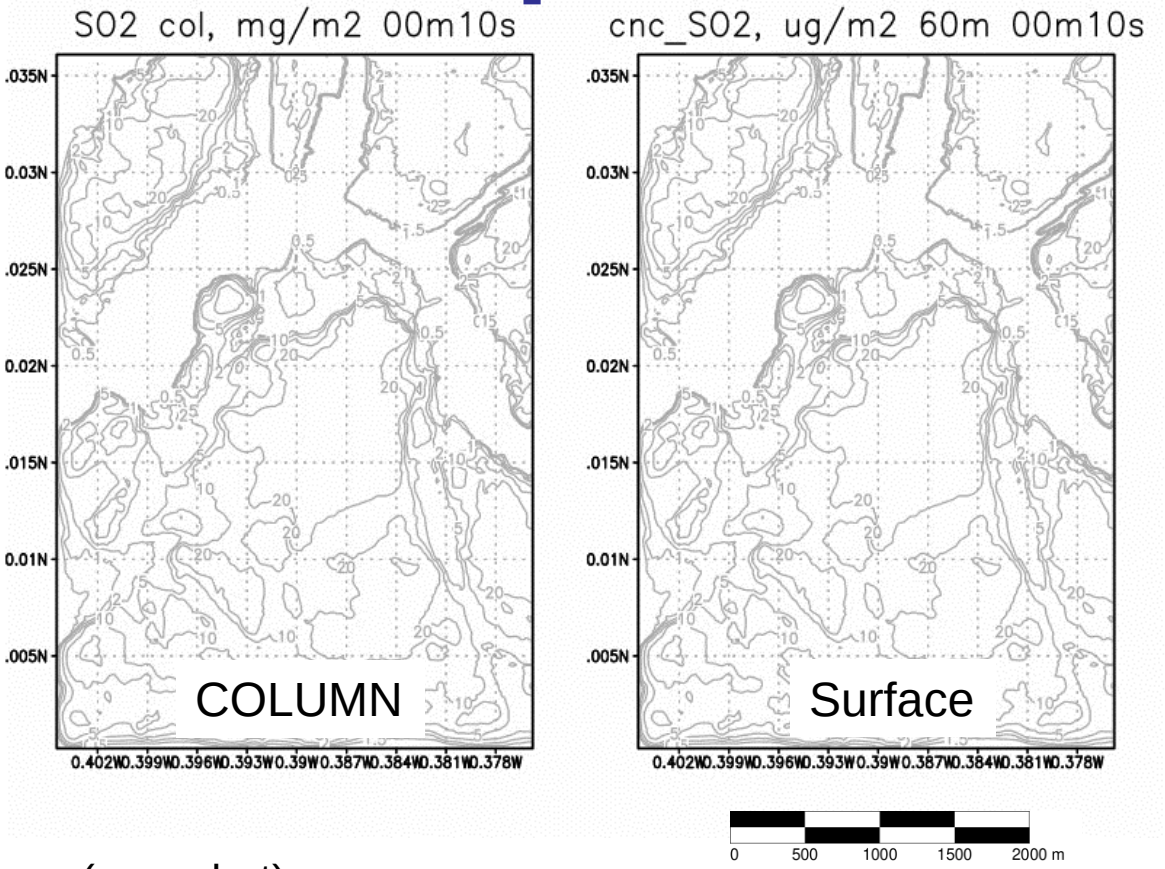


Co-founded by IHKU, BATMAN projects

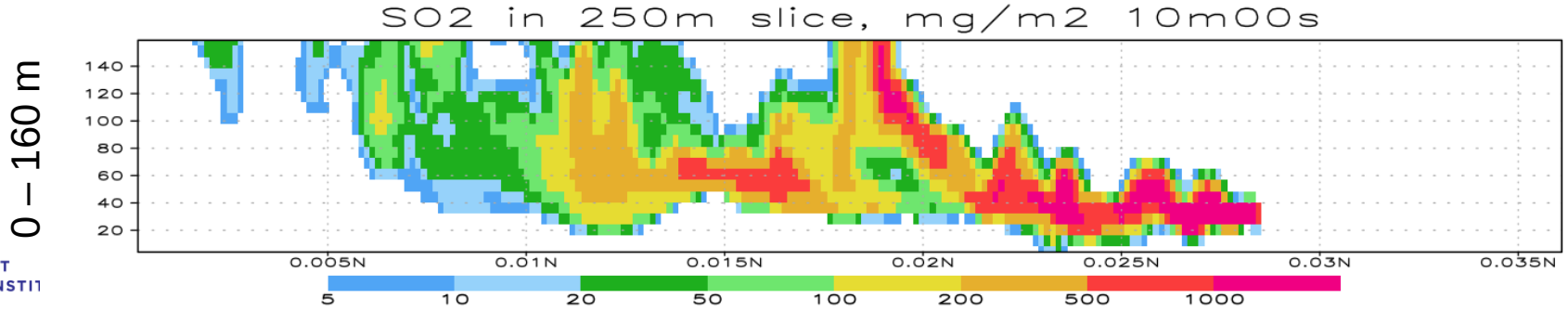
Deca-meter resolution: Ship in Turku

PALM LES:
202x252x64 of
16mx16mx8m cells
3.2 x 4 km
Turku harbor
Neutral stratification

SILAM:
- MS Viking Glory (STEAM)
- SO2 tracer
- Interpolated locations/rates

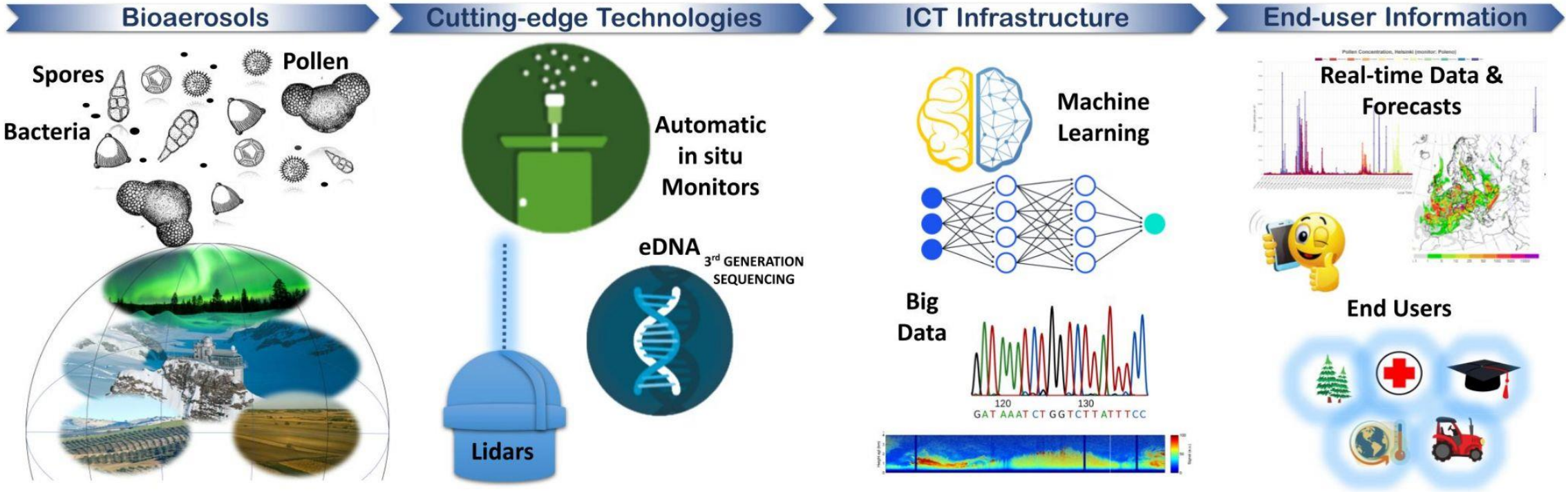


Vertical slice of the plume (snapshot)



Gaps in the bottom – masked cells (hills)

EU SYLVA: new-generation tools in aerobiology



Projects (28), publications (2023: 16)

- EU Horizon Europe: 12
  - AURORA
  - CAMEO
  - CAMAERA
  - CATALYSE
  - EMERGE
  - EO4EU
  - EXHAUSTION
  - FirEUrisk
  - RESPONSE
  - RiskAdapt
  - RI-URBANS
  - SYLVA
- Finnish Research Council: 5
  - All-Impress
  - HeatCost
  - IBA-ILMA
  - SPORELIFE
  - VFSP-WASE
- Copernicus / DE: 3
  - CAMS2_40
  - CAMS2_83
  - DestinationEarth-330
- Other: 8
  - ACCC (flagship)
  - Autopollen (EUMETNET)
  - ADOPT (COST)
  - BioAirMet (METAS)
  - Regional applications (4 countries)

- High-impact: 5
  - The Lancet
  - Nature Scientific Reports
  - Nature Physics
  - Allergy (2 papers)
- Environmental journals: 7
  - STOTEN
  - Atmospheric Environment (2 papers)
  - Ecological Indicators
  - BLM
  - ACP
  - Fire
- Health impact: 4
  - Clinical and translational allergy
  - eBioMedicine
  - Meteorological applications
  - Journal of Investigational Allergology and Clinical Immunology

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