Enviro-HIRLAM in Research Training

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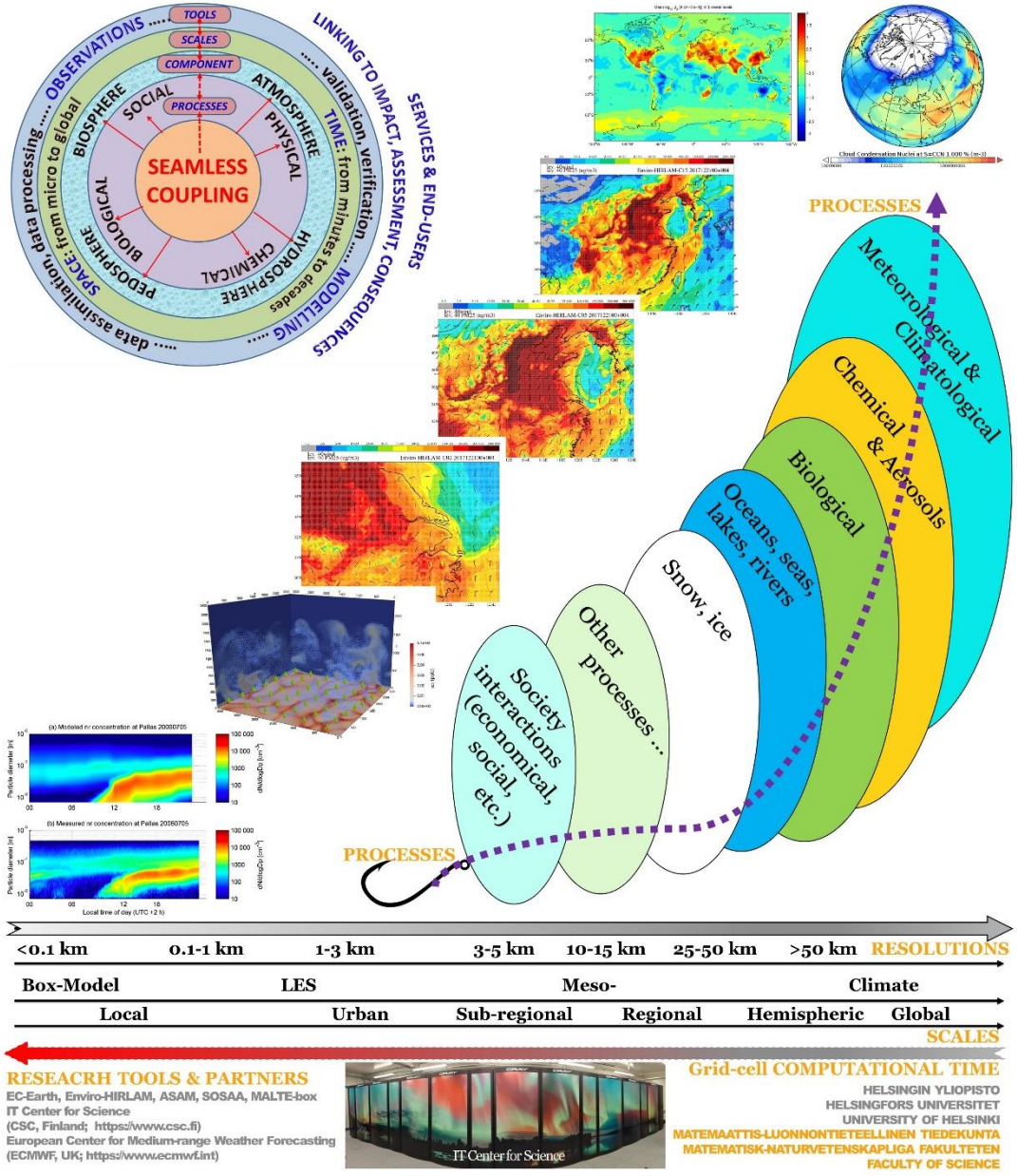
2 - University of Copenhagen, Niels Bohr Institute (UCPH-NBI)
3 - World Meteorological Organization (WMO)
4 - Saint-Peterburg State University (SPBU)
5 - Ukrainian Hydrometeorological Institute (UHMI)

(!) In linkage with multiple research projects and collaboration with many colleagues (!)

Online Young Scientist School MEGAPOLIS-2021
15 Nov – 3 Dec 2021

Small-Scale Research Projects (SSRP)



- **Based on Approaches for Multi-Scale and – Processes Modelling**
- **Research projects are designed by teachers of SSRPs with following selected models:**
  EC-Earth
  Enviro-HIRLAM
  ARCA-Box/ MALTE-Box
- **More than 30 models are being a part of the PEEX-Modelling-Platform**

https://www.atm.helsinki.fi/peex/index.php/portfolio-items/modelling-platform

From the poster at the INAR kick-off-meeting (Helsinki, Finland), Jan 2018

HIRLAM/ALADIN Consortium Institutions
linking with **ECMWF**

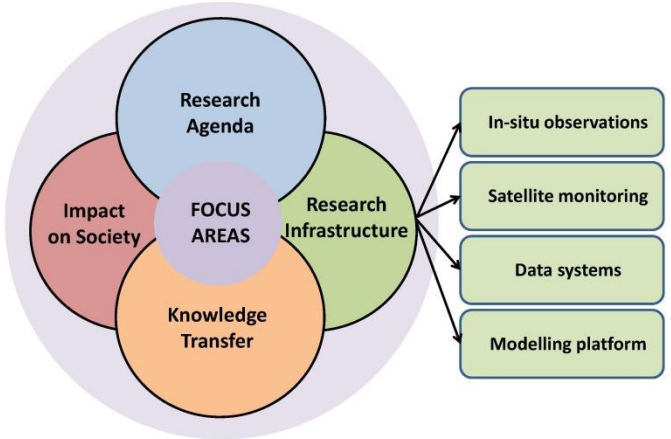
International Collaboration with
Universities and Research Institutions

Pan-Eurasian Experiment PEEX

INAR

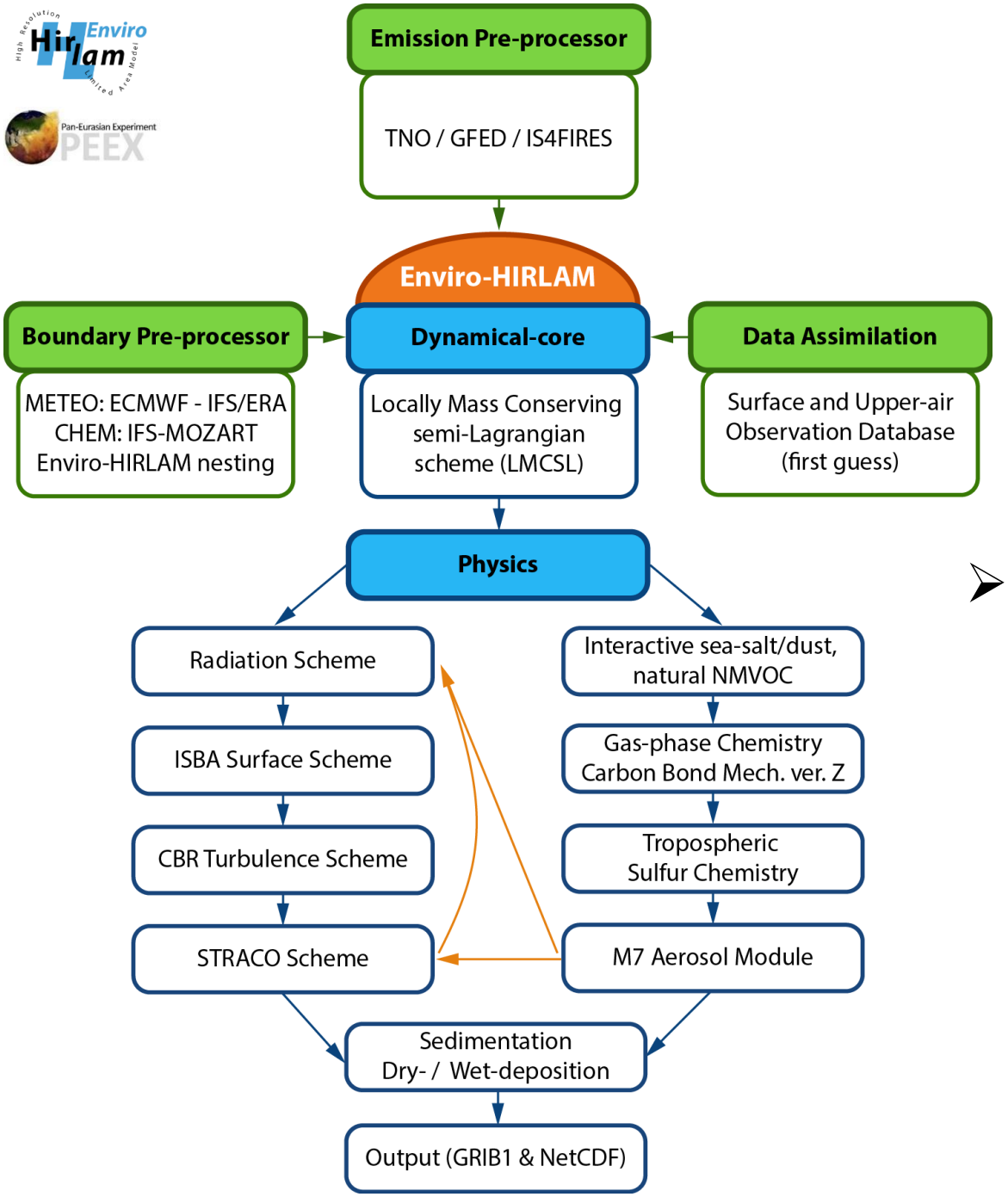
Enviro-HIRLAM/ HARMONIE (EnviroHH)

(Collaboration, Research and Development, Science Education, Dissemination, New Products and Applications)



Enviro-HIRLAM is linked to the PEEX-Modelling Platform

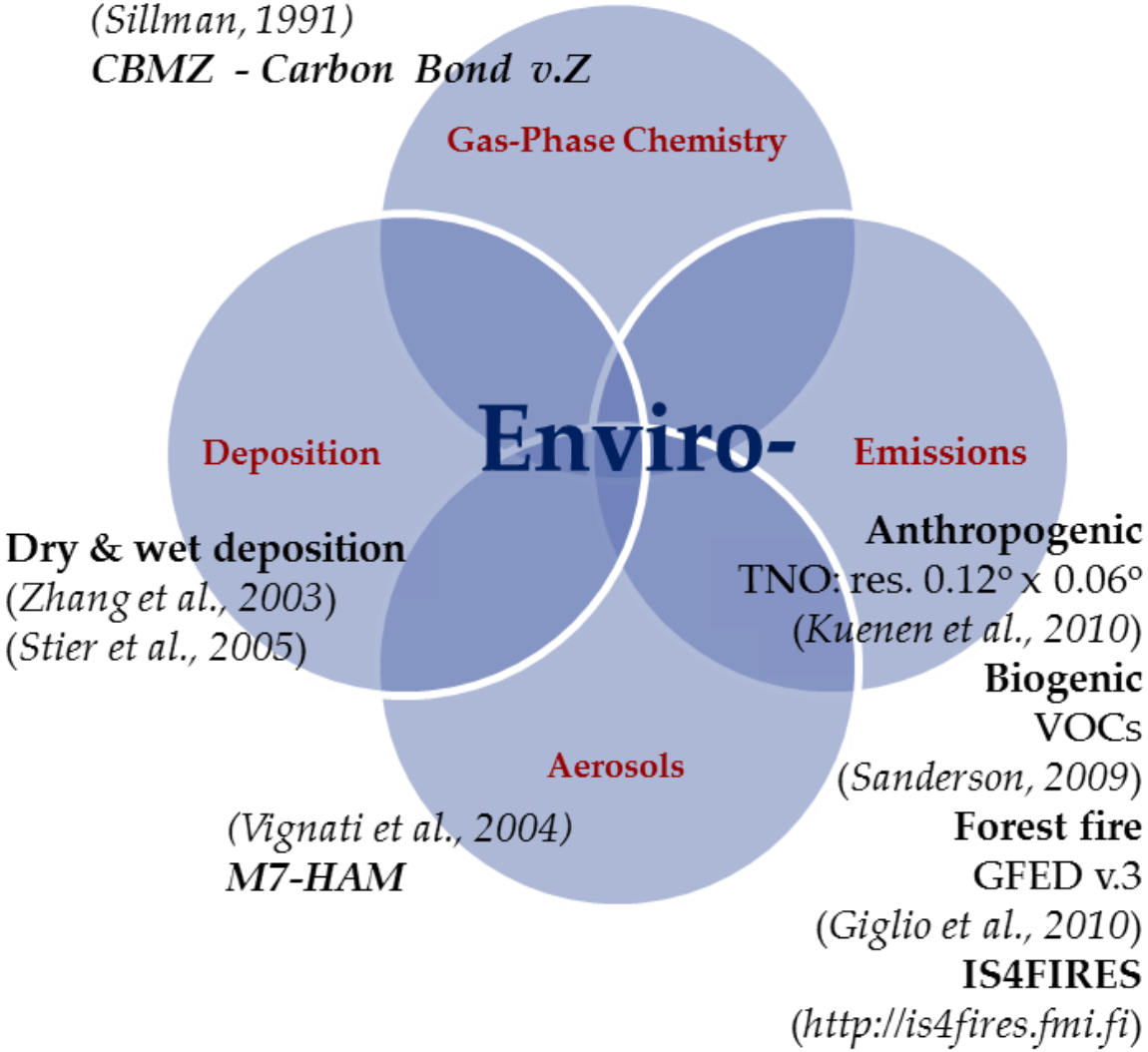
Enviro-HIRLAM (Environment – HIgh Resolution Limited Area Model)



- **Seamless / online coupled integrated meteorology-chemistry-aerosols downscaling modelling system for predicting weather and atmospheric composition**

(Baklanov et al., 2017; GMD) - last overview of the modelling system
Mahura et al. (2021+) – in preparation

Components of Enviro-HIRLAM



Components of the Enviro-HIRLAM modelling system

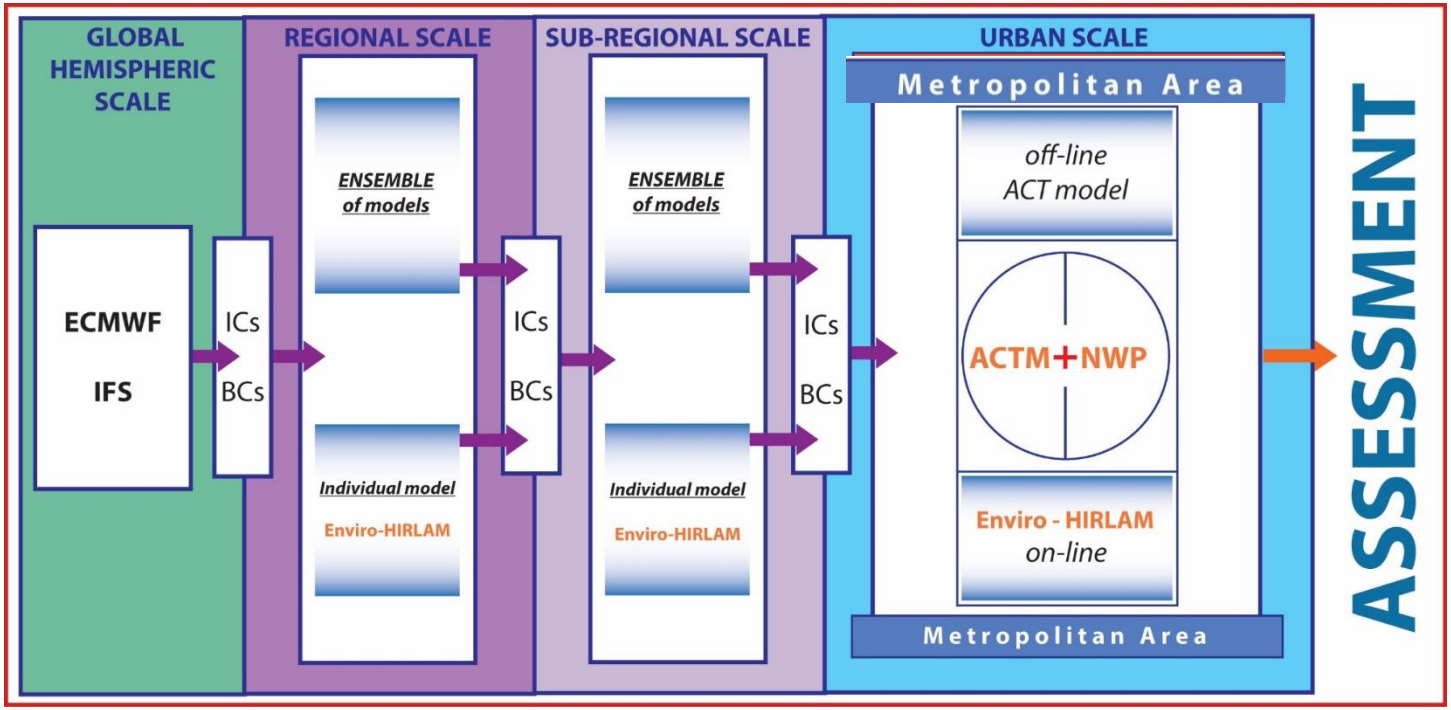
Enviro-HIRLAM research and development team

Baklanov et al., 2002-…
Mahura et al., 2004-…
Nuterman et al., 2007-…
Nerobelov et al., 2016-…
Savenets et al., 2017-…

& many other colleagues through collaboration (Denmark, Russia, Ukraine, Kazakhstan, Baltic States, Spain, Turkey, etc.)

Note: emission datasets used depend on research projects:
MEGAPOLI, TRANSPHORM, PEGASOS, MarcoPolo, EnsCLIM, CarboNord, RI-URBANS, …

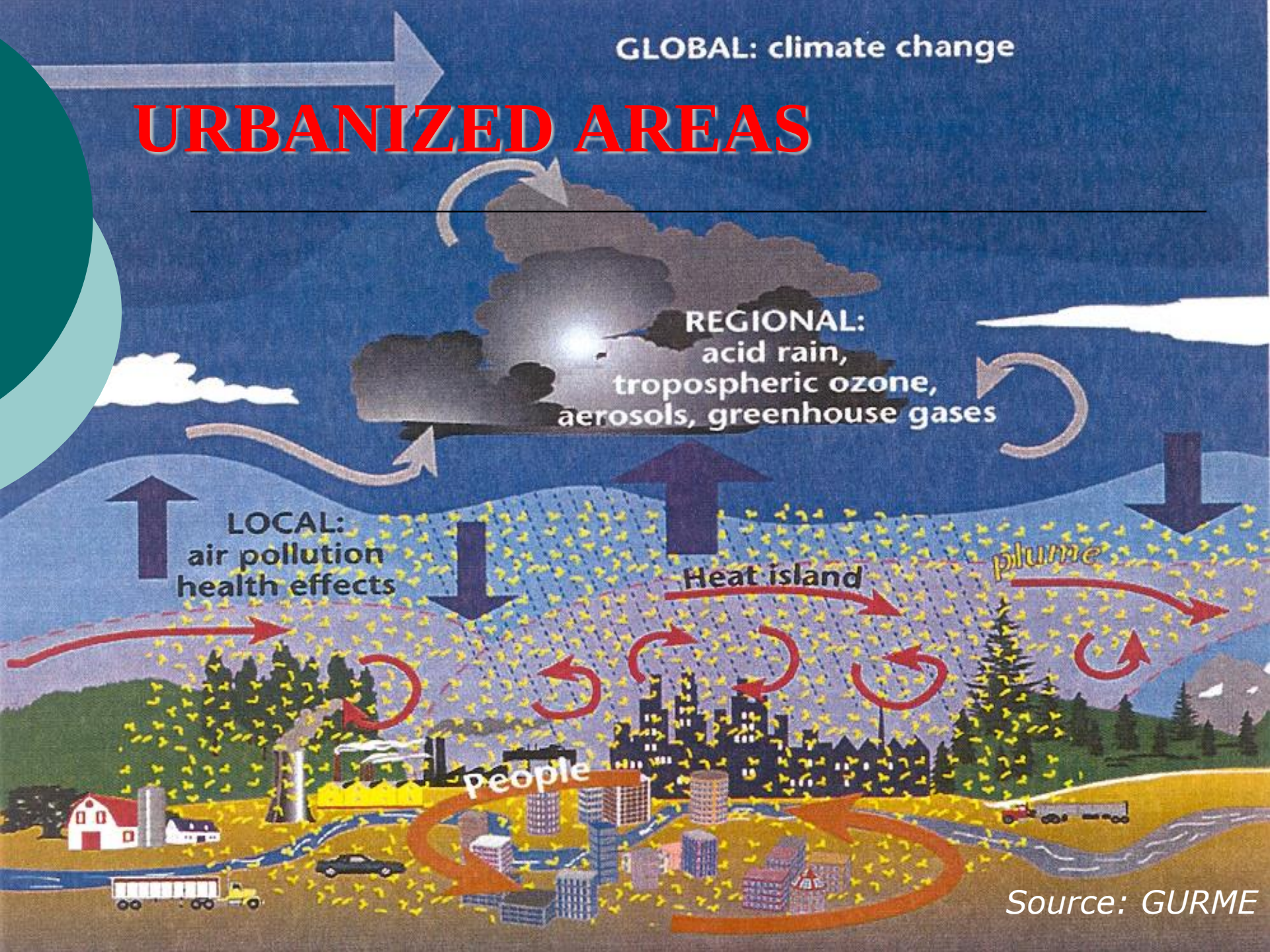
Downscaling for Enviro-HIRLAM Regional-Subregional-Urban/City/Local scales



…- 2017 – 2018 – 2019 – 2020 – 2021 -…

DMI, DK: *CRAY-XT5 (hirdev) -> CRAY-XC30/XC40 (hirdev/disperse)*
ECMWF, UK/INT*: CRAY-XC30/40 -> (ecgate + cca)*
UHEL, FI: *CRAY-XC30/40 (taito/sisu) -> Atos BullSequana X400/XH2000 (puhti/mahti)*

URBANIZED AREAS



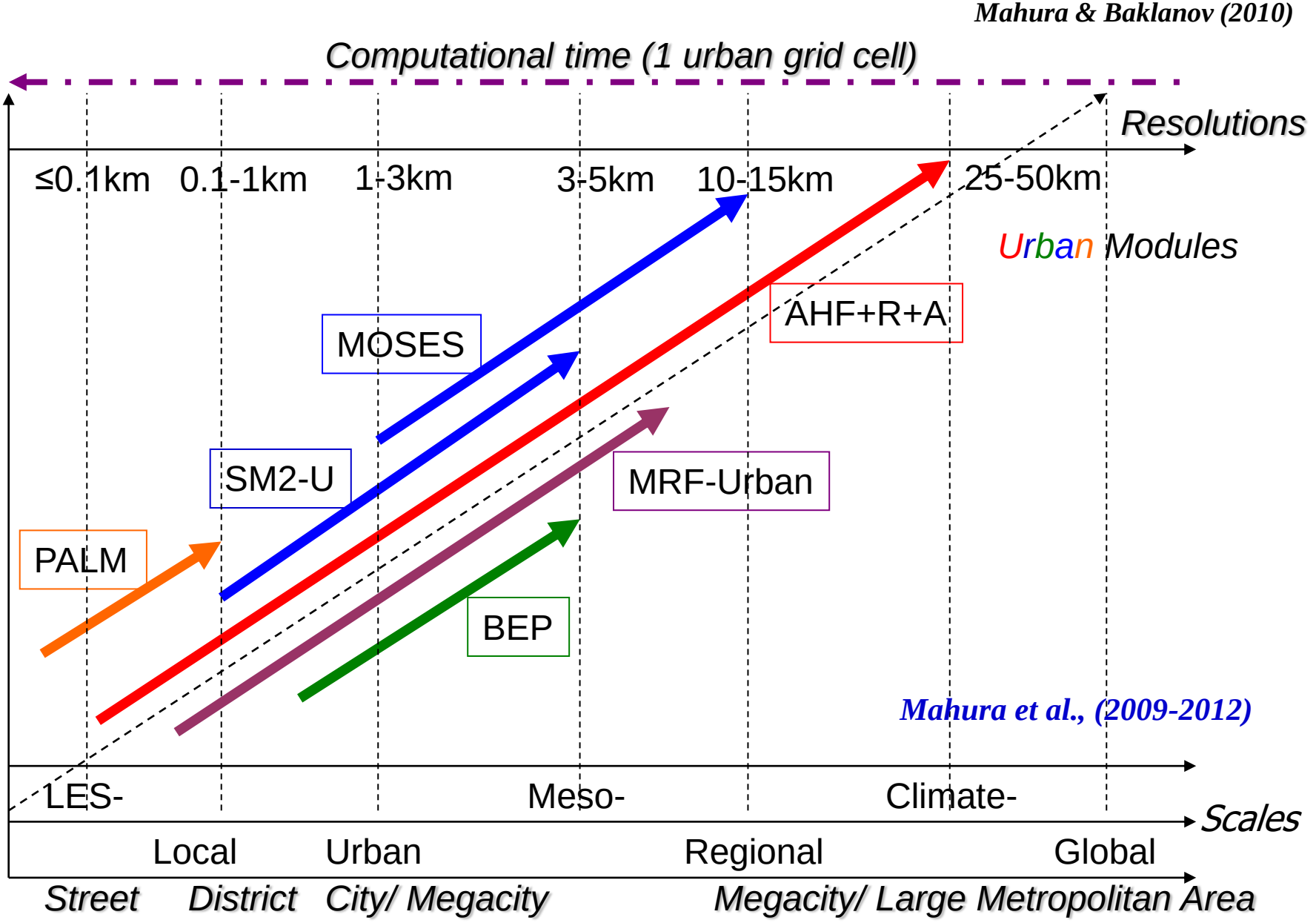
Source: GURME

Features of Urban Areas

- **Local-scale inhomogeneties, sharp changes of roughness and heat fluxes;**
- **Wind velocity reduce effect due to buildings;**
- **Redistribution of eddies due to buildings, from large to small;**
- **Trapping of radiation in street canyons;**
- **Effect of urban soil structure, diffusivities heat and water vapor;**
- **Anthropogenic heat fluxes, urban heat island;**
- **Internal urban boundary layers, urban mixing height,**
- **Effects of pollutants (aerosols) emissions, transformation and transport on urban meteorology and climate;**
- **Land use drastic changes due to urbanization;**
- **Urban effects on clouds, precipitation and thunderstorms.**

These urban features influence formation of airflow, its turbulence regime, microclimate, and accordingly modify transport, dispersion, and deposition of atmospheric pollutants in urban areas.

Hierarchy of Approaches



MODELS' URBANIZATION

Urbanization Modules Applied

Mahura et al. (2004-2017) in FUMAPEX, HIRLAM, COST728, MEGAPOLI, MACC, TRANSPHORM, MarcoPolo

NWP Model

NWP Initialization
(urban domain/ resolution / land-cover)

Model Run

Land Surface Scheme
ISBA
Interactions
Soil-
Biosphere
Atmosphere

Model Output

ISBA Tiles:
low veg., forest, ice, snow, water, bare soil/ urban

Urban Modules Initialization:

AHF+R+A: *Urban - fraction, flux, roughness, albedo*
BEP: *Urban - fraction, districts, characteristics*
SM2-U: *Urban – fraction, surfaces, classes, characteristics*

Urban Modules:

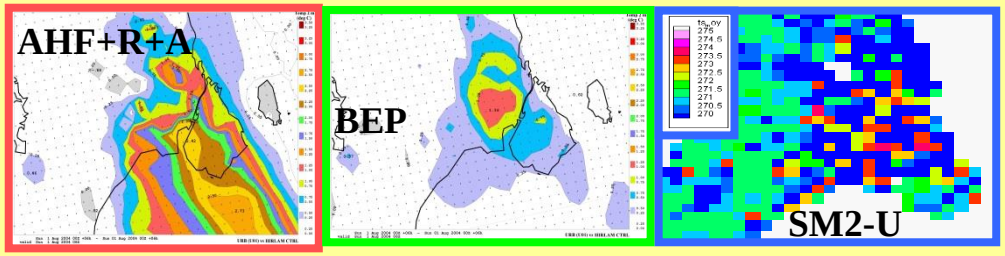
AHF+R+A

BEP

SM2-U

IF Urban Frac > 0
Pass MeteoParams

Re-calculated meteoparams and fluxes



AHF+R+A

Mahura et al. (2005-2007) in FUMAPEX, HIRLAM, COST728

NWP Model

NWP Initialization
(urban domain/ resolution / land-cover)

Model Run

Land Surface Scheme
ISBA
Interactions Soil-Biosphere Atmosphere

Model Output

Initialization:

AHF+R+A:
Urban fraction, anthropogenic heat flux, urban roughness (1-2 m), albedo (winter – snow covered vs. other seasons)

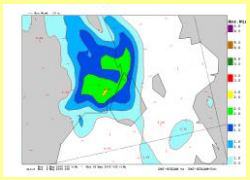
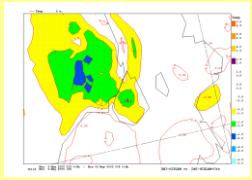
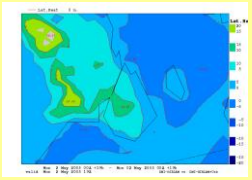
Modify Roughness (1-2 m)

Modify Albedo (0.2-0.8)

Modify AHF (10-200 W/m^2)

IF Urban Frac > 0
Pass MeteoParams

Re-calculated meteoparams and fluxes

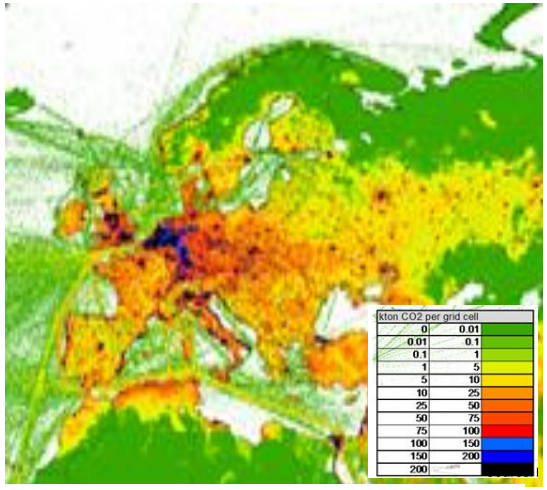




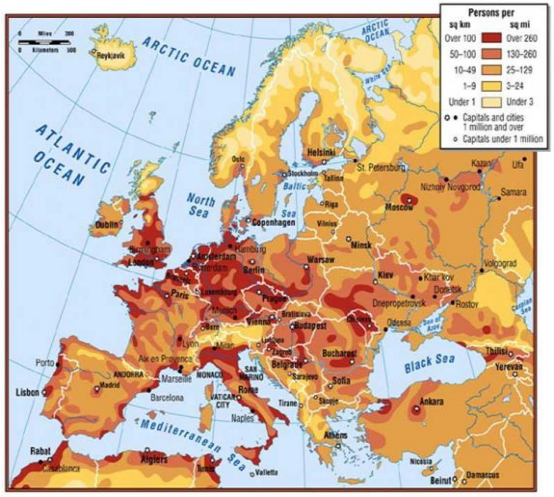
***Difference plots*: wind speed at 10 m, air temperature at 2 m, latent heat flux**

Anthropogenic Heat Flux in Urban Areas (AHF)

can be estimated based on assumption of dependency/ proportionality to other urban characteristics

- **Population density maps with a high resolution in urban areas;**
- **Satellite images of the night lightness over urban areas (but difficulties to use for industrial and developing countries, should be corrected);**
- **Land-use classification as a percentage of urban classes (central part, urban, sub-urban, industrial, etc.);**
- **Emission inventory for specific pollutants typical for urban areas (e.g., due to traffic emission, etc.);**
- **Monitoring or simulation of concentration fields for specific air pollutants typical for urban areas.**



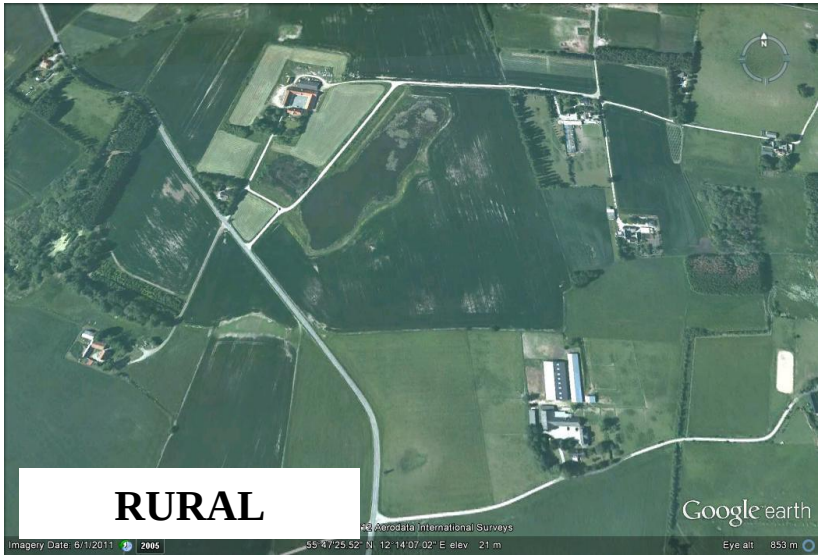


http://edgar.jrc.ec.ec.europa.eu

http://spworldstudiescp.wordpress.com

Roughness in Urban Areas (R)

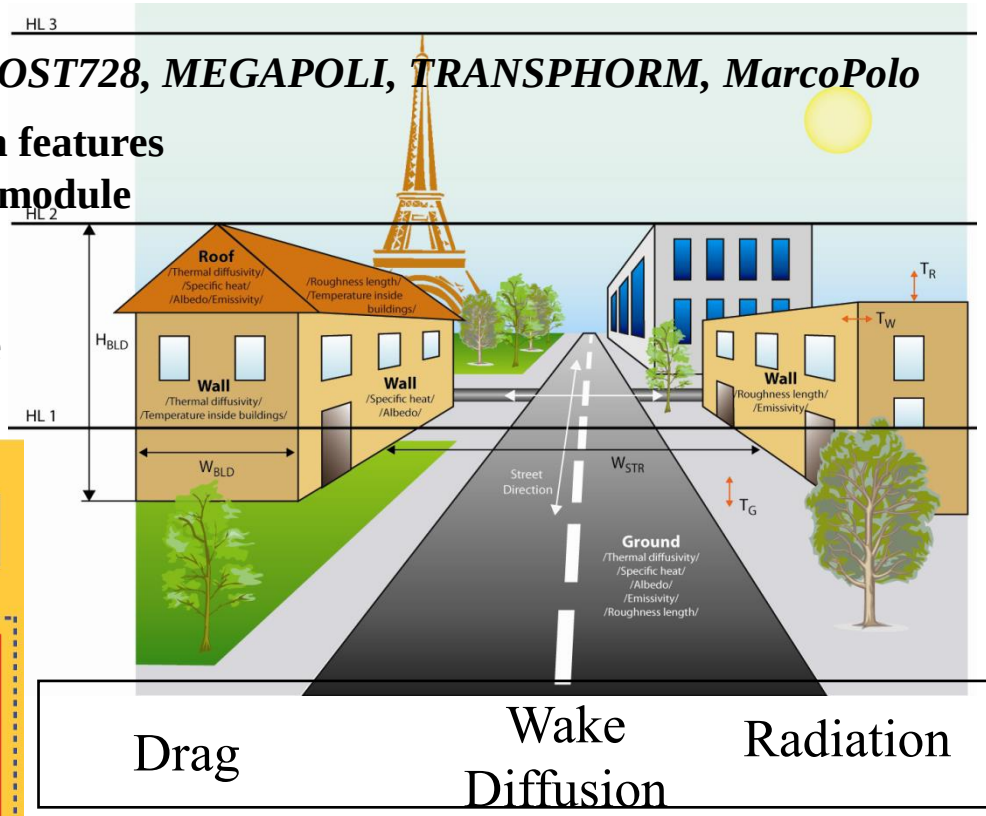
can be estimated based on assumption of dependency to urban environment characteristics (buildings/houses, infrastructure, industry, etc.)



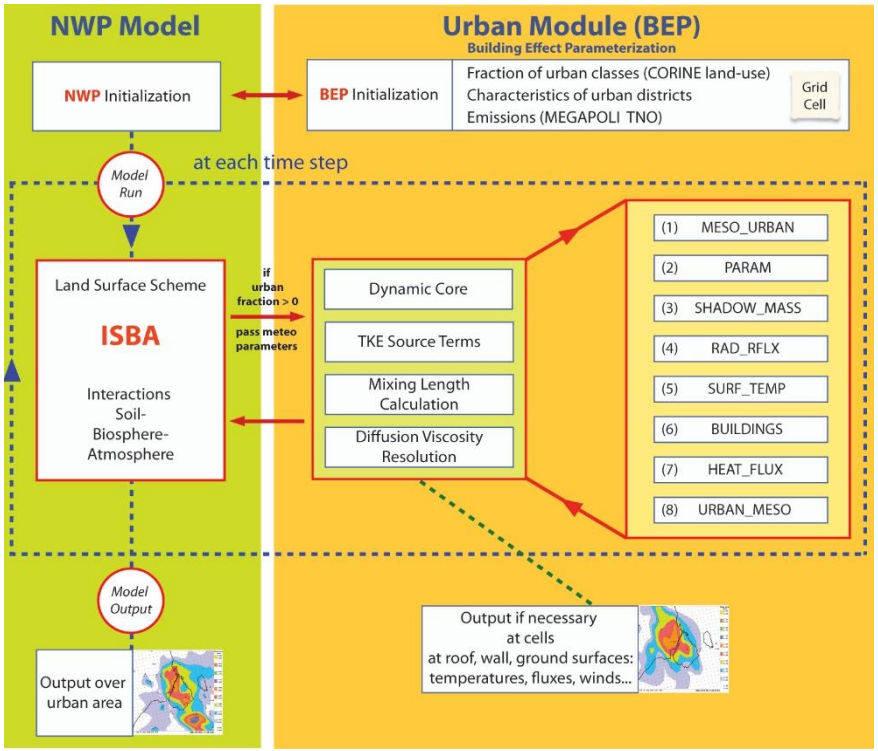
Urban/ City Scale Modelling (with BEP)

Mahura et al. (2005-2017) in HIRLAM, COST728, MEGAPOLI, TRANSPHORM, MarcoPolo

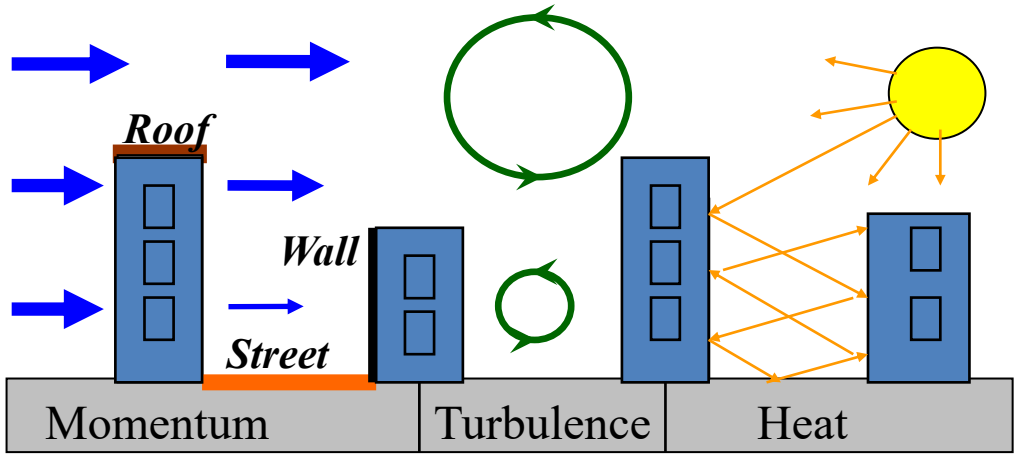
Schematic representation of urban features and numerical grid in the urban module



General scheme of BEP module for the HIRLAM model urbanization with a structure of the subroutine concept



(Martilli et al., 2002)



LAND COVER and LAND USE

Land Cover and Land Use

Land cover -

defined as observed physical cover, as seen from the ground or through remote sensing, including natural or planted vegetation and human constructions (buildings, roads, etc.) which cover the earth's surface. Water, ice, bare rock or sand surfaces count as land cover.

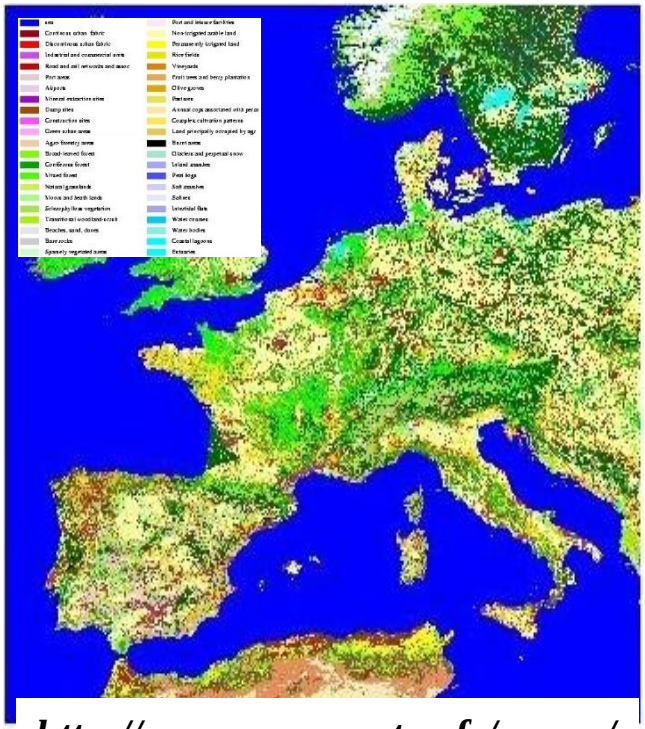
Land Use –

defined as a series of activities undertaken to produce one or more goods or services. A given land use may take place on one or several pieces of land, and several land uses may occur on the same piece of land.

Land-Cover Data

observed physical cover, as seen from the ground or through remote sensing (water, ice, bare rock, sand, natural/planted vegetation and human constructions)

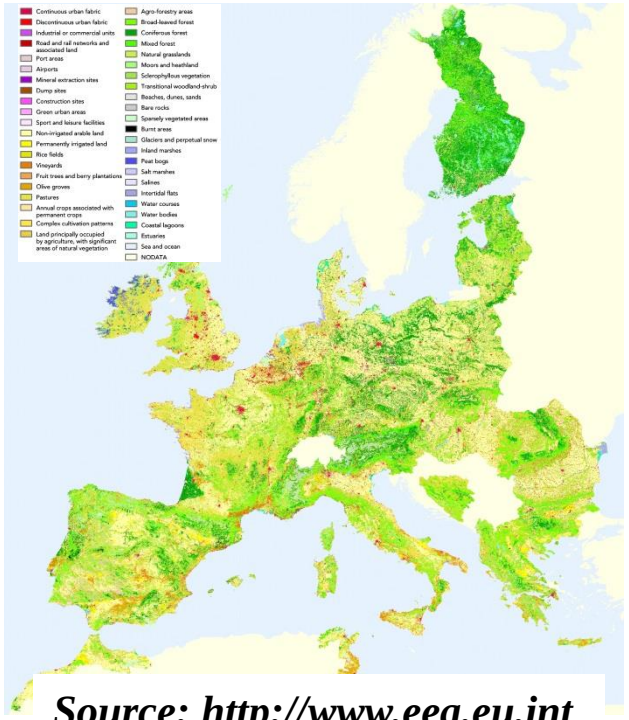
Need for meteorological modelling



http://www.cnrm.meteo.fr/gmme/PROJETS/ECOCLIMAP

ECOCLIMAP-I, II :
1 km resolution,
200+ & 500+ classes

- **Simulate exchanges between surface and atmosphere (momentum, heat, water, chemical species, etc.);**
- **Take into account the climate variability from one region to another;**
- **Separate the surface schemes from the atmospheric model - allows to use the same surface code for several atmospheric models (runs) - easy switch between surface schemes and options;**
- **All surface fields necessary to land surface schemes**



Source: http://www.eea.eu.int

CORINE :
250 & 100 m resolution

+ USGS, PELCOM, etc. datasets

Urban Districts in Metropolitan Areas: Classification & Characteristics

Residential (RD)

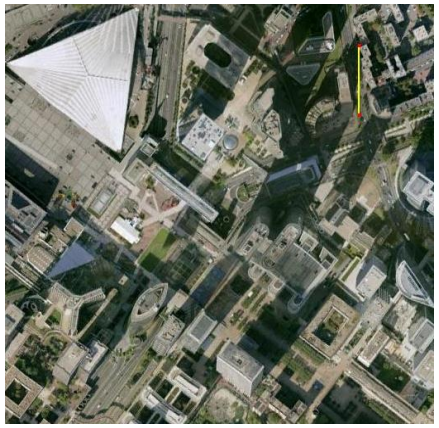
City Center/High Buildings District (CC/HBD)

Industrial Commercial (ICD)

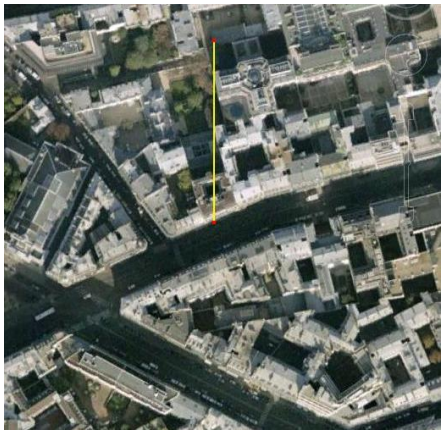
GIS - Extraction of districts related characteristics (statistics):

- *Morphology parameters* (avg. height, volume, perimeter, compactness, space between buildings)
- *Cover modes* (surface density (SD) of buildings, of vegetation, hydrography, roads, N buildings)
- *Aerodynamic parameters* (roughness length, displacement height, frontal and lateral SD)

City Center



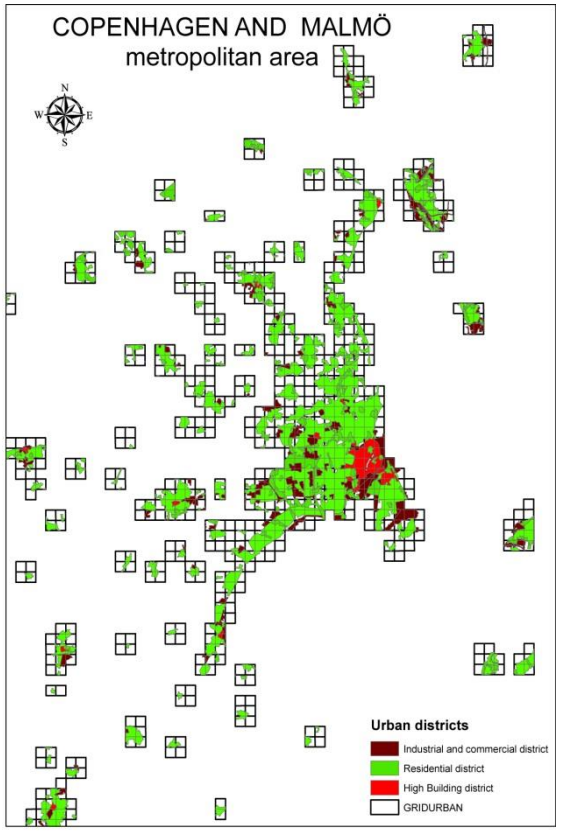
High Buildings District

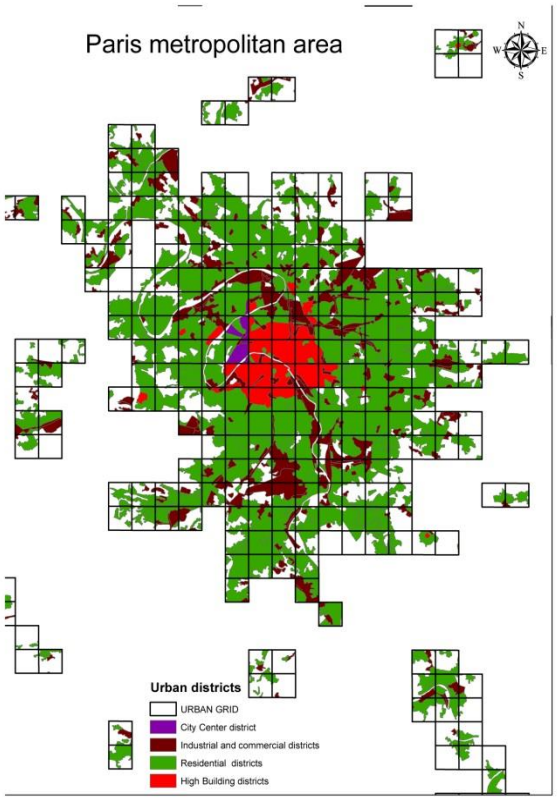


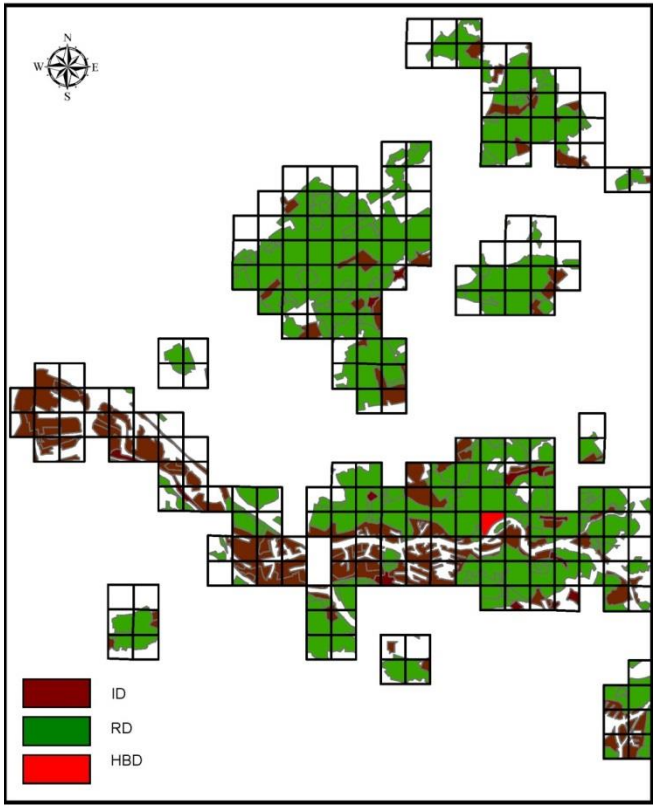
Residential District

Industrial Commercial District

Urban Districts in Metropolitan Areas: Classification & Characteristics





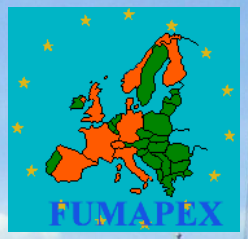


Copenhagen (Denmark)

Paris (France) Metropolitan Areas

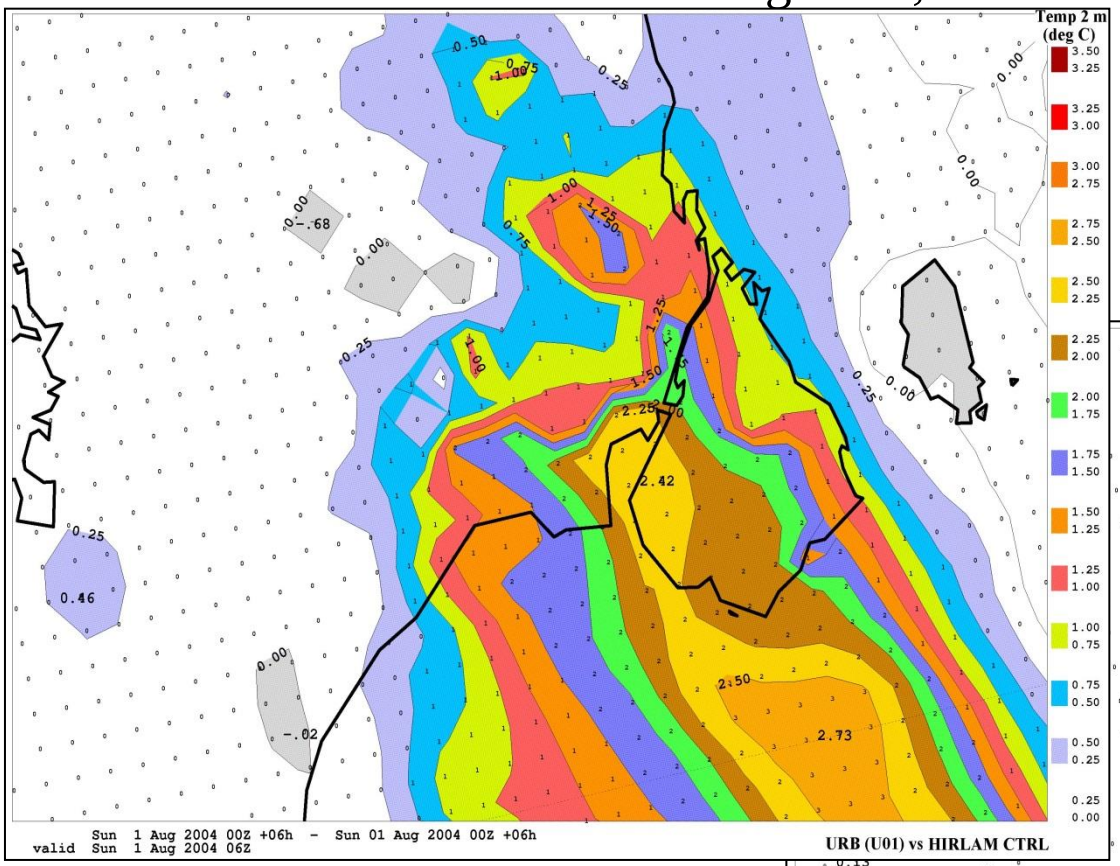
Rotterdam (The Netherlands)

Copenhagen Metropolitan Area
Denmark



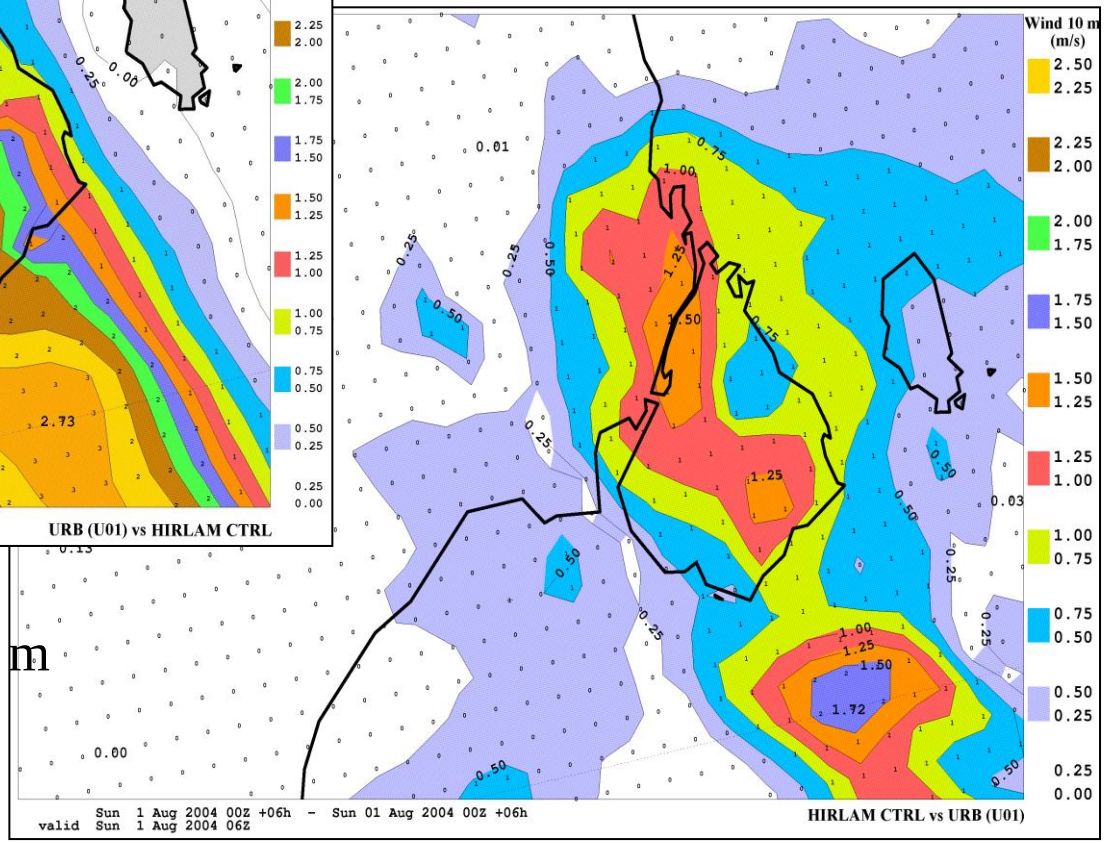
AHF+R: Copenhagen Urban Effects Modelling

Difference between runs: 01 Aug 2004, 06 UTC



(control vs. urbanized run)
Difference field for temperature at 2 m

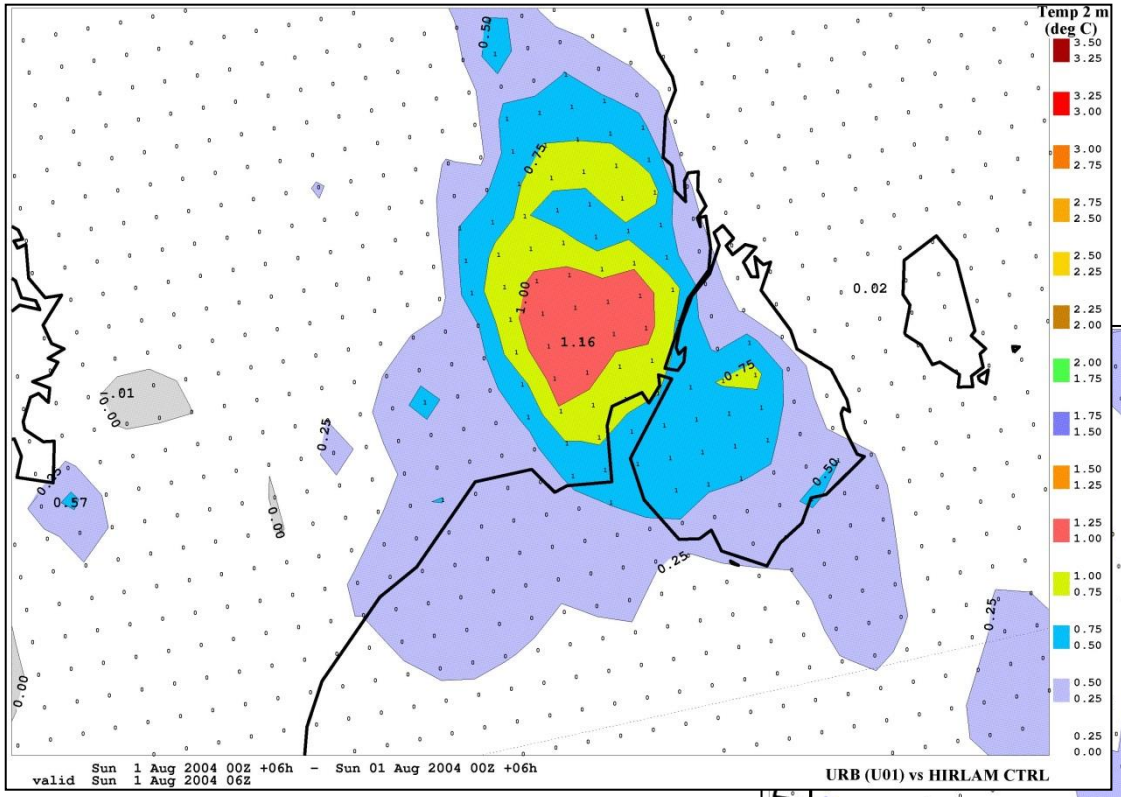
(control vs. urbanized run)
Difference field for wind at 10 m



Mahura et al. (2005-6)

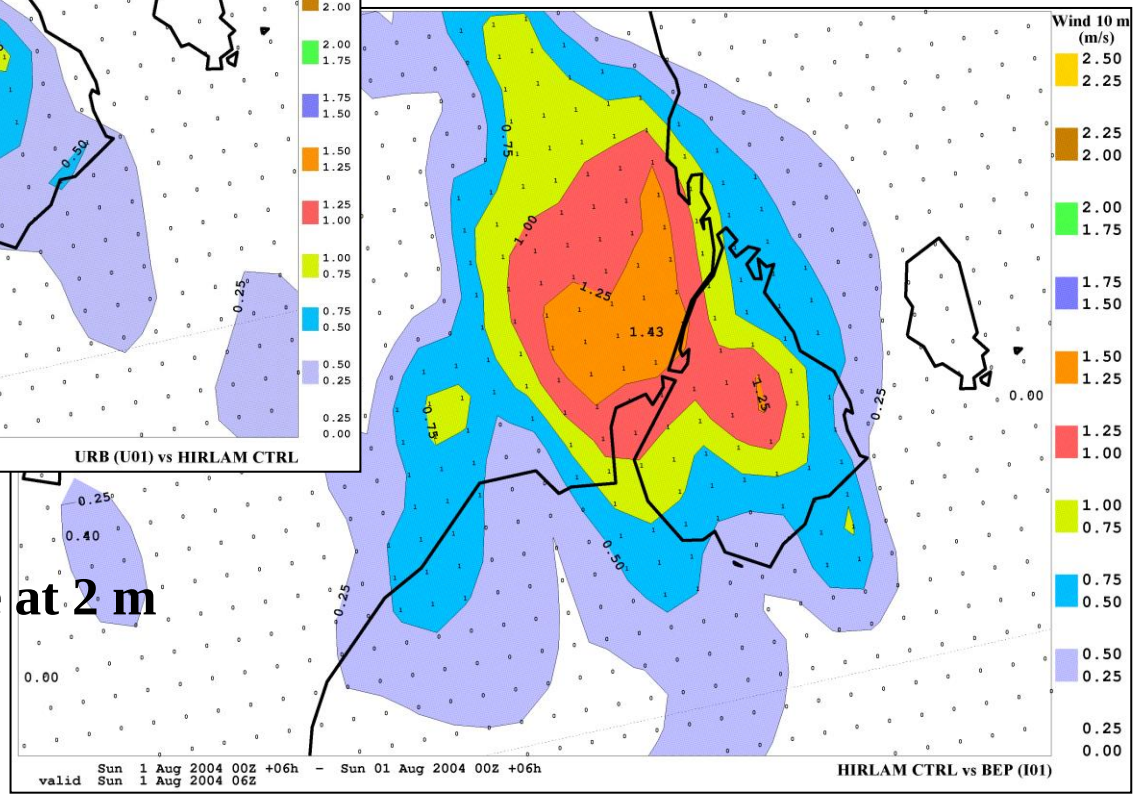
BEP: Copenhagen Urban Effects Modelling

Difference between runs: 01 Aug 2004, 06 UTC



(control vs. urbanized run)
Difference field for temperature at 2 m

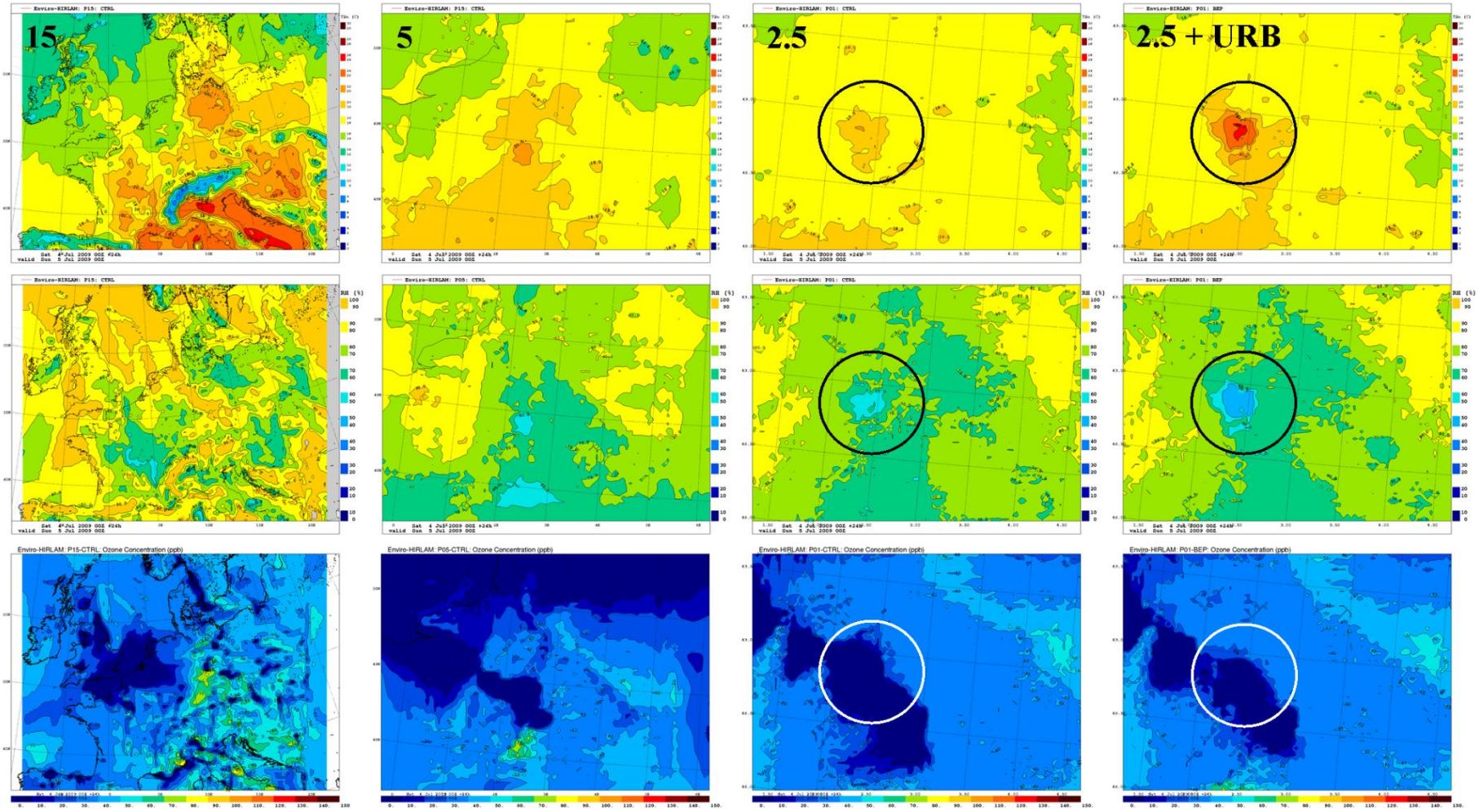
(control vs. urbanized run)
Difference field for wind at 10 m



Mahura et al. (2005-6)

Paris Metropolitan Area
France

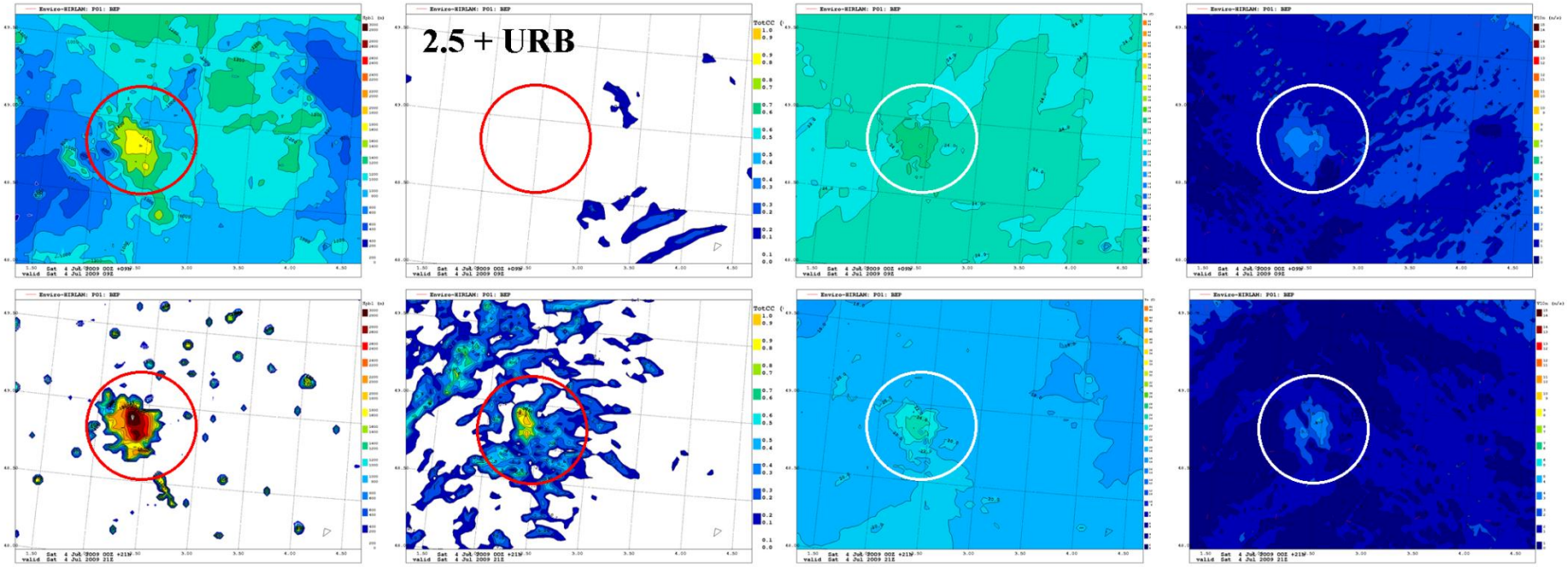
Research: Downscaling for Paris Metropolitan Area (meteorology & chemistry)



Enviro-HIRLAM downscaling (from left to right: CTRL 15—5—2.5 km & 2.5+URB) meteorological (top—air temperature, middle—humidity) and chemical (bottom—ozone) fields on 4 Jul 2009, 00+24 UTC.

Mahura et al. (2009-12)

Paris Metropolitan Area: Temporal Variability of Meteo.Parameters



Variability of (from left-to-right) boundary layer height, total cloud cover, surface temperature, wind speed on 4 Jul 2009 at (top) 09 UTC and (bottom) 21 UTC based on Enviro-HIRLAM model run at 2.5 km resolution with URB=BEP+AHF included.

Mahura et al. (2009-12)

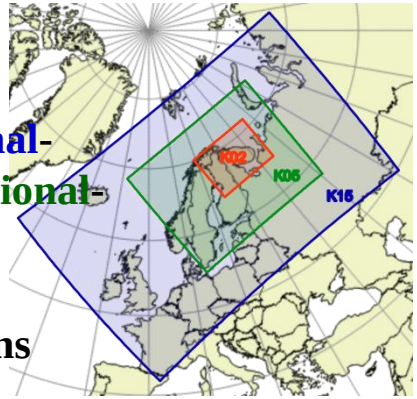
TRAKT-2018

Kola Peninsula

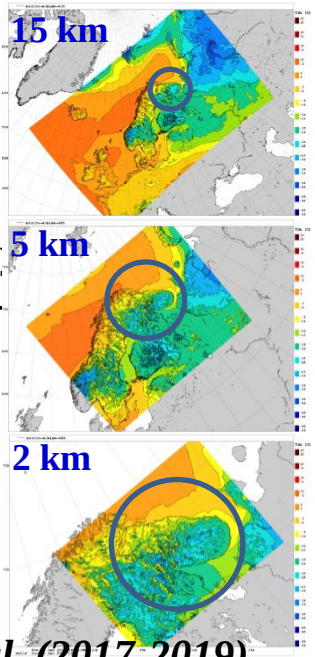
Seamless/ On-line Integrated Modelling

TRAKT - TRAnsferable Knowledge & Technologies for high-resolution environmental impact assessment & management (www.atm.helsinki.fi/peex/index.php/trakt-2018)

Regional-subregional-urban scale domains

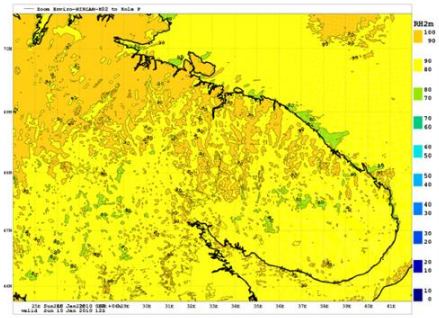


Seamless / online integrated meteorolog-chemistry-aerosols modelling at multi-scales

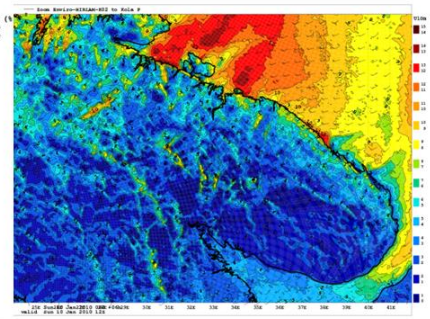


Mahura et al. (2017-2019)

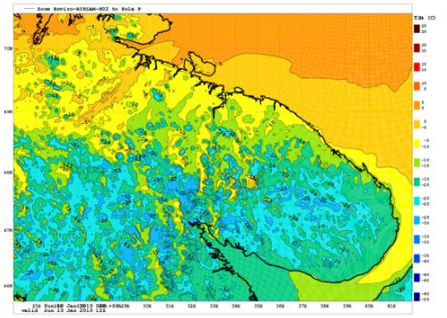
High resolution modelling (at 2 km) for meteorology and atmospheric composition



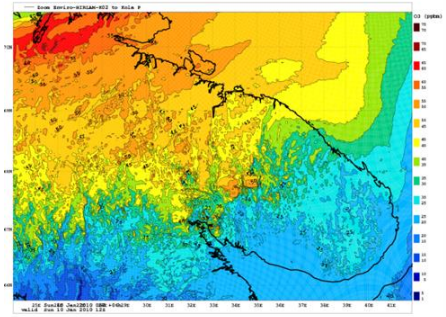
Meteorology:
Relative Humidity (RH2m)



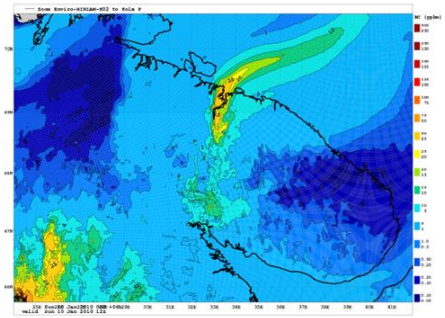
Wind Speed at 10m (U10m)



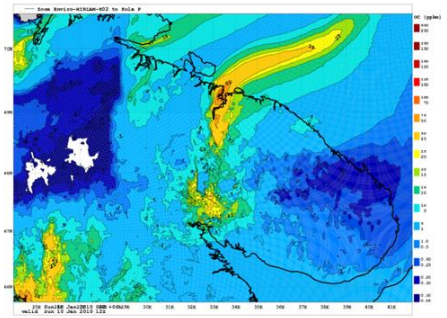
Air temperature at 2m (T2m)



Atmospheric Composition:
Ozone (O_3)



Black Carbon (BC)

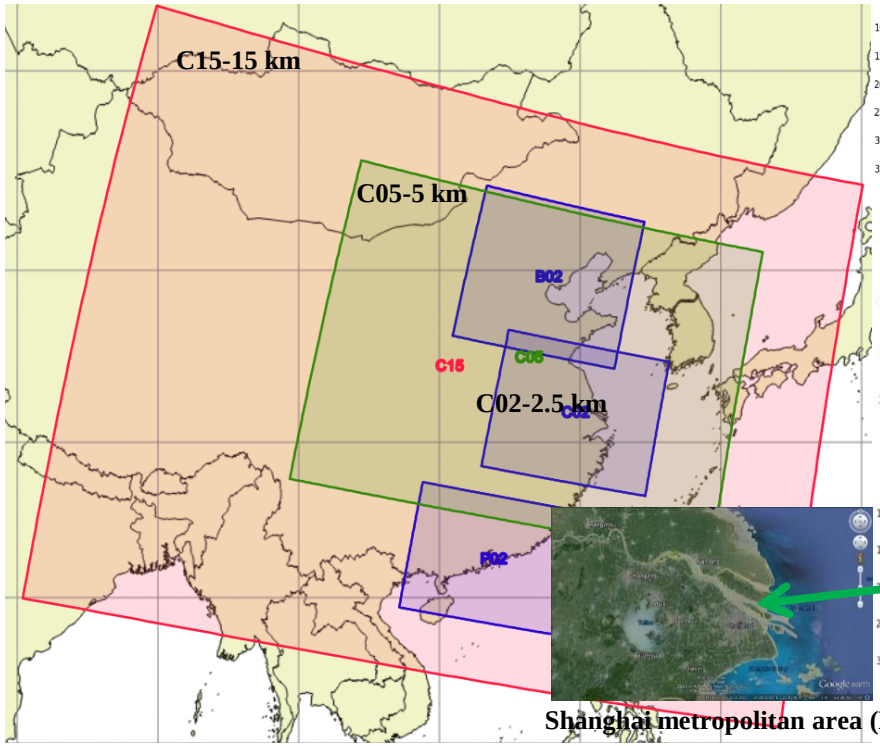


Organic Carbon (OC)

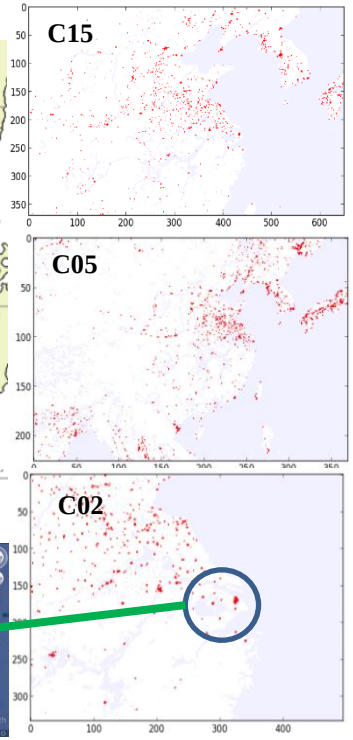
Shanghai Metropolitan Area
China

Downscaling for Shanghai (meteo & aerosols)

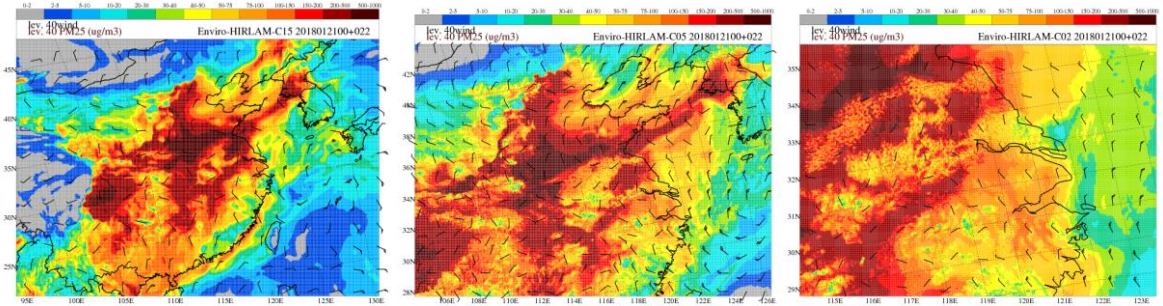
Enviro-HIRLAM model downscaling domains
(15 – 5 – 2.5 km resolutions)



Urban areas in domains



Shanghai metropolitan area (MA)



Enviro-HILRAM operational PM2.5 concentration forecasts for China in a downscaling chain (left-right: regional, sub-regional, urban - Shanghai metropolitan area) for 21 Jan 2018, 22 UTC
http://www.marcopolo-panda.eu/products/regional-air-quality-forecasts/enviro-hirlam

CPU time spent for 1 run:

C15: 1h2min
C05: 3h3min
C02: 3h6min

Surface level disc use for 1 run:

C15: 533M
C05: 1,5G
C02: 947M

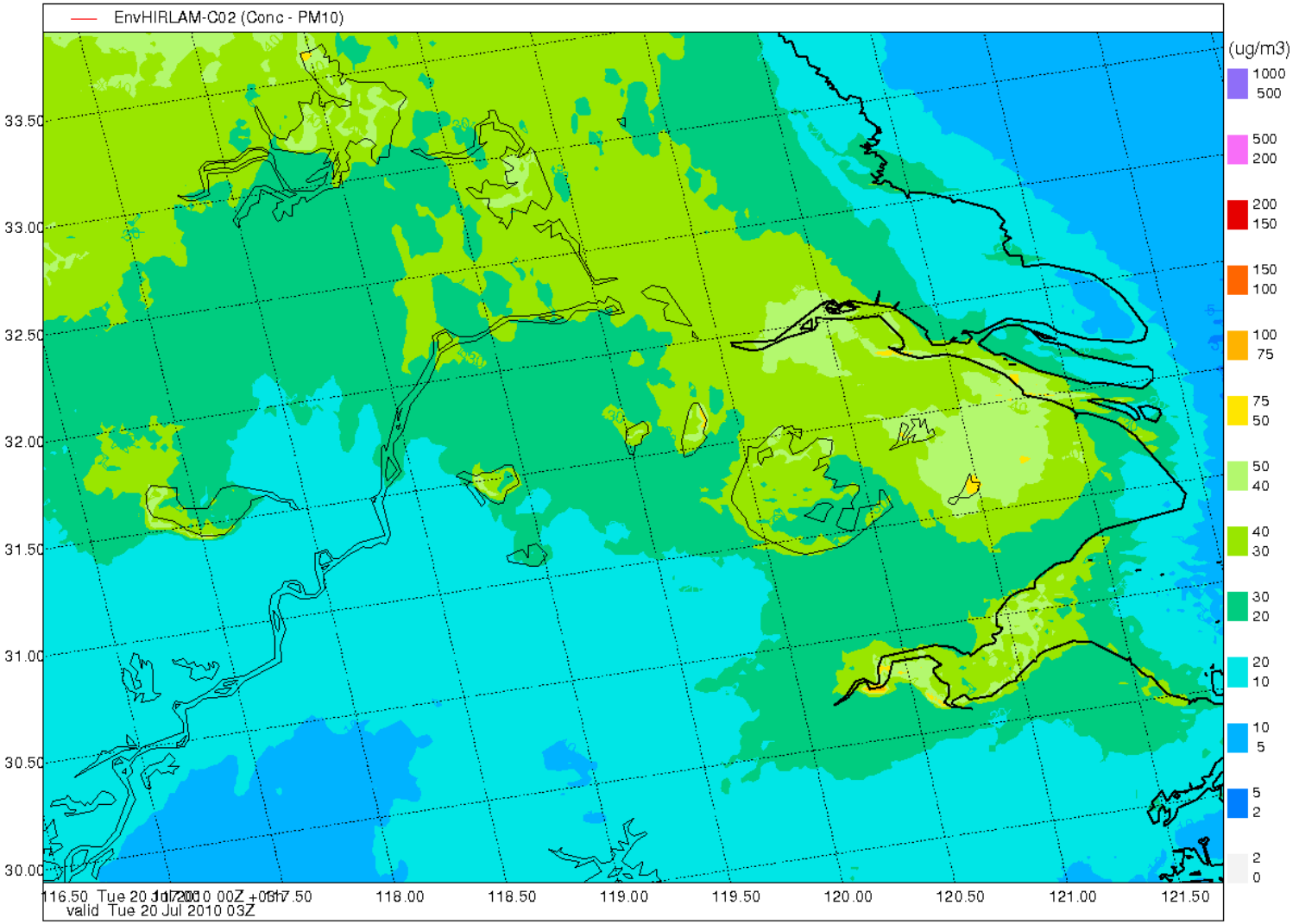
Model level disc use for 1 run:

C15: 12G
C05: 33G
C02: 23G

The Silk Road agenda of the Pan-Eurasian Experiment (PEEX) Program
by Lappalainen, Kulmala, Kujansuu, Petäjä, Mahura, de Leeuw, Zilitinkevich, Juustila, Kerminen, Bornstein, Zhang, Yong, Yubao, Dong, Jie, Guo
MS: BED (2018)

2.5km: Urban Scale - Shanghai: PM10

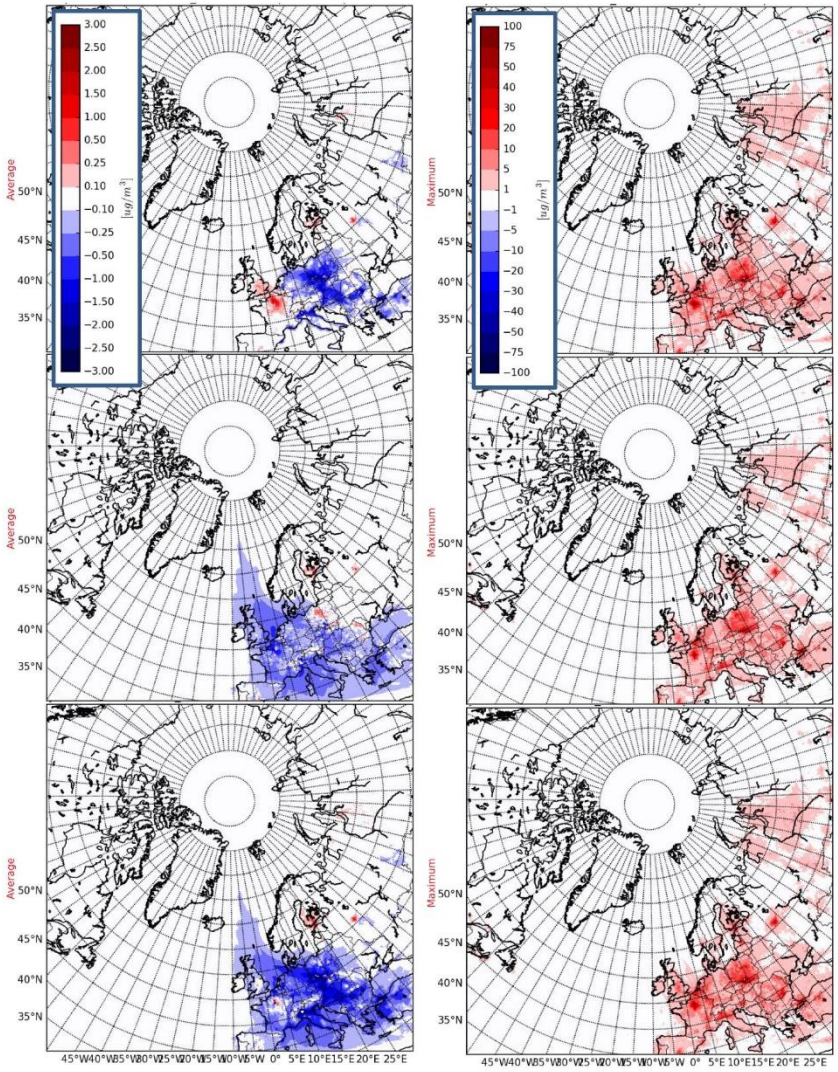
Diurnal cycle: 20 Jul 2010



Mahura et al., 2014-2017

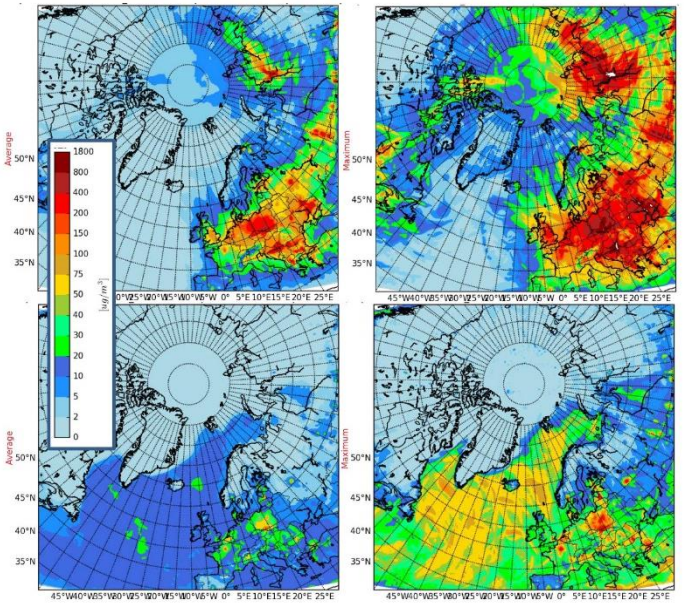
Examples of Enviro-HIRLAM Applications

Aerosols Effects - Northern Hemisphere



◄ Difference fields between CTRL&DAE (top), CTRL&IDAE (middle), CTRL&DAE+IDEA (bottom) runs with the Enviro-HIRLAM model for monthly (January) averaged (left) and maximum (right) concentration of **black carbon**, BC (in μg/m^3).

CTRL – reference run
DAE – Direct Aerosol Effect
IDAE – Indirect Aerosol Effect



January (12 UTC) monthly averaged (left) and ▲ maximum (right) simulated concentration (in μg/m^3)
of **SO_2** (top) and **PM2.5** (bottom) based on the Enviro-HIRLAM control run simulations.

Focus on 12 months of 2010 | ICs/BCs ERA-5 meteo & CAMS gases+aerosols, DA obs, SST | Emis.Inv – biogenic, anthropogenic | Spin up 1 month – Dec 2009/ Run – CTRL vs Aerosol Effects included | 15km horiz.resol | focus on black and organic carbon concentration and deposition (dry vs. wet) variabilities

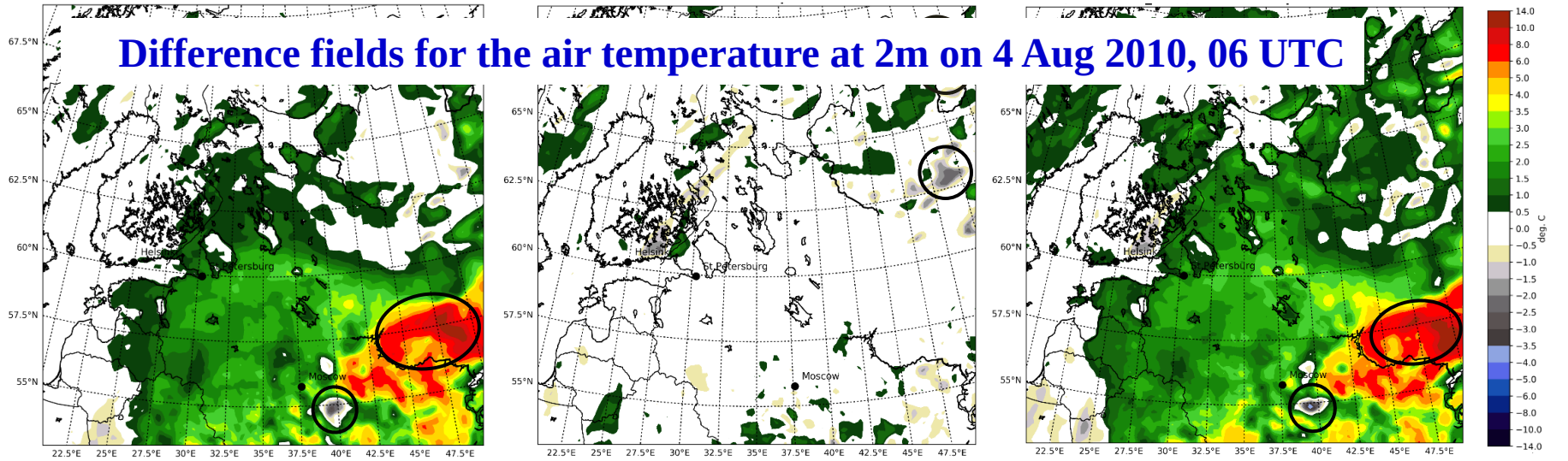
Aerosol feedbacks and interactions at regional scale in Arctic-boreal domain
by Mahura, Nuterman, Baklanov, Makkonen, Petaja, Zilitinkevich, Kulmala, + MS: in preparation, 2021+

Aerosol Effects - Regional Scale

Nerobelov, 2019

CTRL-DAE | **CTRL-IDAE** | **CTRL-DAE+IDAE**

Difference fields for the air temperature at 2m on 4 Aug 2010, 06 UTC

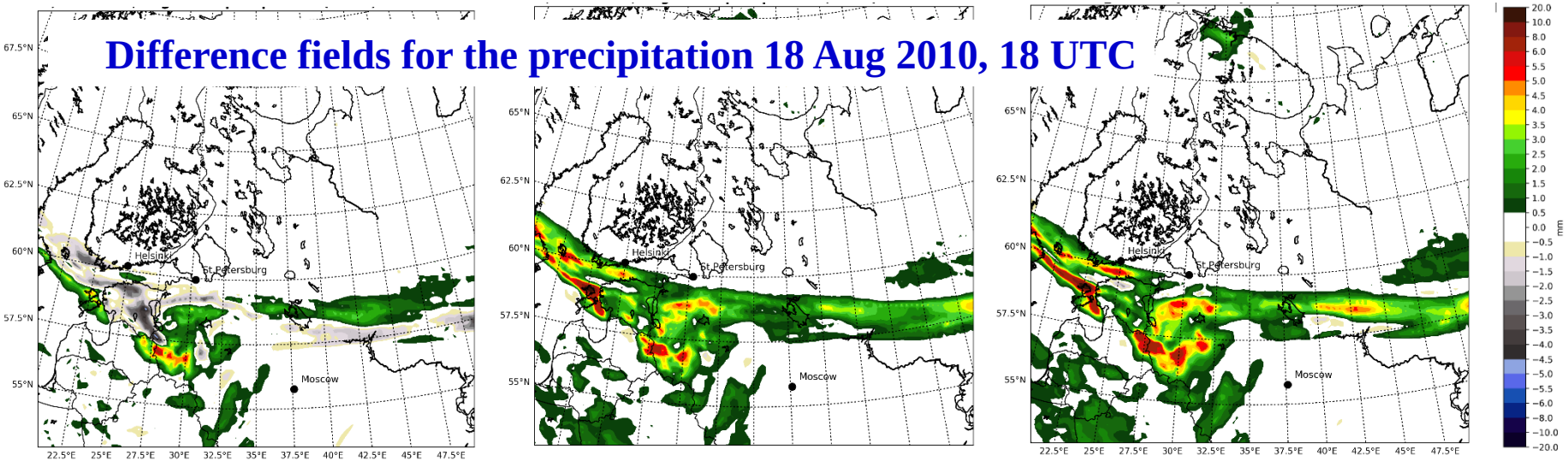


Direct effect ↓ 14, ↑ 3.5 °C

Indirect effect↓ 3, ↑2.5 °C

Combined effect ↓ 14, ↑ 4 °C

Difference fields for the precipitation 18 Aug 2010, 18 UTC



Direct effect↓ 8, ↑ 5 мм

Indirect effect ↓ 20, ↑ 1 мм

Combined effect ↓ 20, ↑ 1 мм

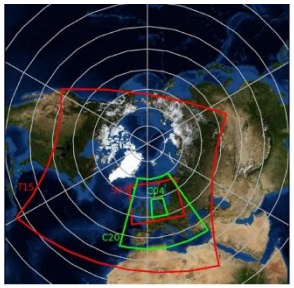
Downscaling to Local Scale

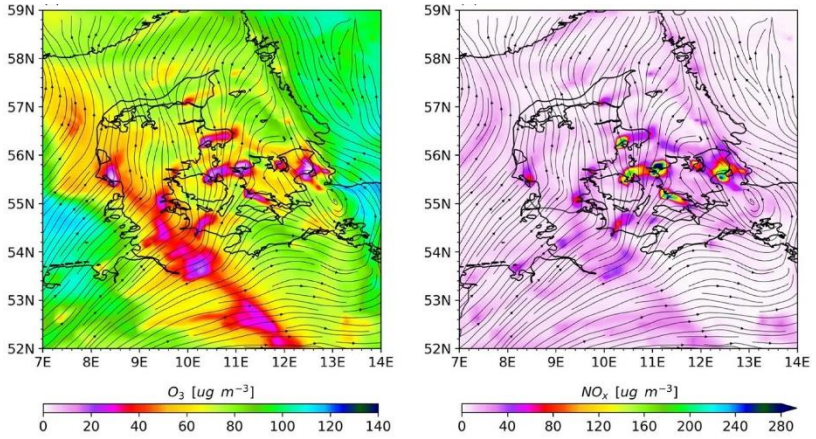
Downscaling system for modelling of atmospheric composition on regional, urban and street scales

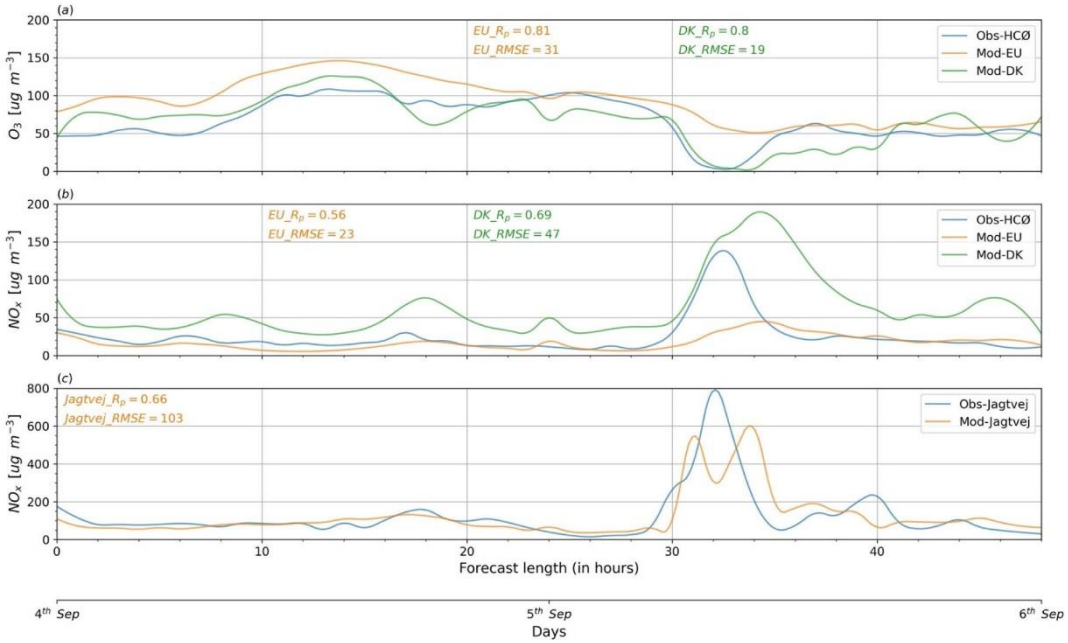
by Nuterman, Mahura, Baklanov, Amstrup, Zakey

MS: acp-2020-1308 (2021)

- To demo possibilities of operationalization through linking to CFD model (**M2UE**) with NWP + ACT models in a downscaling chain (case study for DK, Copenhagen's Jagtvej street)







ACKNOWLEDGEMENTS

- *Dr. Juha Lentho (UHEL- INAR & Center for Science Computing, CSC, Finland) – for CSC's HPC's hints and advises*
- *Dr. Carsten Maass (ECMWF, UK) - for providing support to ECMWF HPCs computing and storage resources, datasets and their usage*
- *Dr. Daniel Santos Munoz (UCM, Spain) - for providing and maintaining access to hirlam.org (Enviro-HIRLAM, HIRLAM, HARMONIE models repositories)*
- *Members of the current Enviro-PEEX(Plus) project team for active involvement into the PEEX-Modelling-Platform modelling activities and tasks (https://www.atm.helsinki.fi/peex/index.php/enviro-peex_plus)*
- *Center for Science Computing (CSC, Finland) and ECMWF (UK) - Computing Centers - technical staff for providing access, technical support and maintenance, computing and storage resources*

Enviro-HIRLAM: Science Education and Training

Science Education:
Small-Scale Research Projects (SSRPs)

See you soon on the next zoom-meeting

18 November 2021

Thursday

16 pm of Helsinki time

https://www.helsinki.fi/en/inar-institute-for-atmospheric-and-earth-system-research

Thank you! Спасибо!

https://www.atm.helsinki.fi/peex

Additional Slides

Research & Development through Collaboration with Partners

- **(2017-…) Enviro-HIRLAM on CSC –** "*Enviro-HIRLAM seamless modelling of meteorology-chemistry-aerosols interactions and feedbacks on multi-scales*"

- **(2018-2020) Enviro-PEEX on ECMWF** - "*PEEX-MP research and development for online coupled integrated meteorology-chemistry-aerosols feedbacks & interactions in weather, climate & atmospheric composition multi-scale modelling*" https://www.atm.helsinki.fi/peex/index.php/enviro-peex-2018-2020

- **(2021-2023) Enviro-PEEX(Plus) on ECMWF (Plus)** - "*Research and development for integrated meteorology – atmospheric composition multi-scales and – processes modelling for the PEEX domain for weather, air quality and climate applications*" https://www.atm.helsinki.fi/peex/index.php/enviro-peex_plus

- **(2020-2022) PEEX-MP-Europa3** – "*PEEX Modelling Platform research and development through HPC-Europa3 Transnational Access Programme*" (individual grants)
  https://www.atm.helsinki.fi/peex/index.php/peex-mp-europa3

✓ Project: *High-Resolution Integrated Urban Environmental Modeling*

✓ Project: *Online Integrated Atmospheric Modelling: the Python Way*

✓ Project: *Integrated Modelling for Assessment of Potential Pollution Regional Atmospheric Transport as Result of Accidental Wildfires*

✓ Project: *Integrated Modelling and Analysis of Influence of Land Cover Changes on Regional Weather Conditions/ Patterns*