# *Online integrated meteorology-chemistry-aerosols regional/subregional/urban scale modelling*

## *by Alexander Mahura*

Institute for Atmospheric and Earth System Research (INAR) / Physics
Faculty of Science, University of Helsinki (UHEL), Finland

&
*In linkage with multiple research projects and collaboration with many colleagues*

*SPBU & UHEL virtual-meeting & discussions*
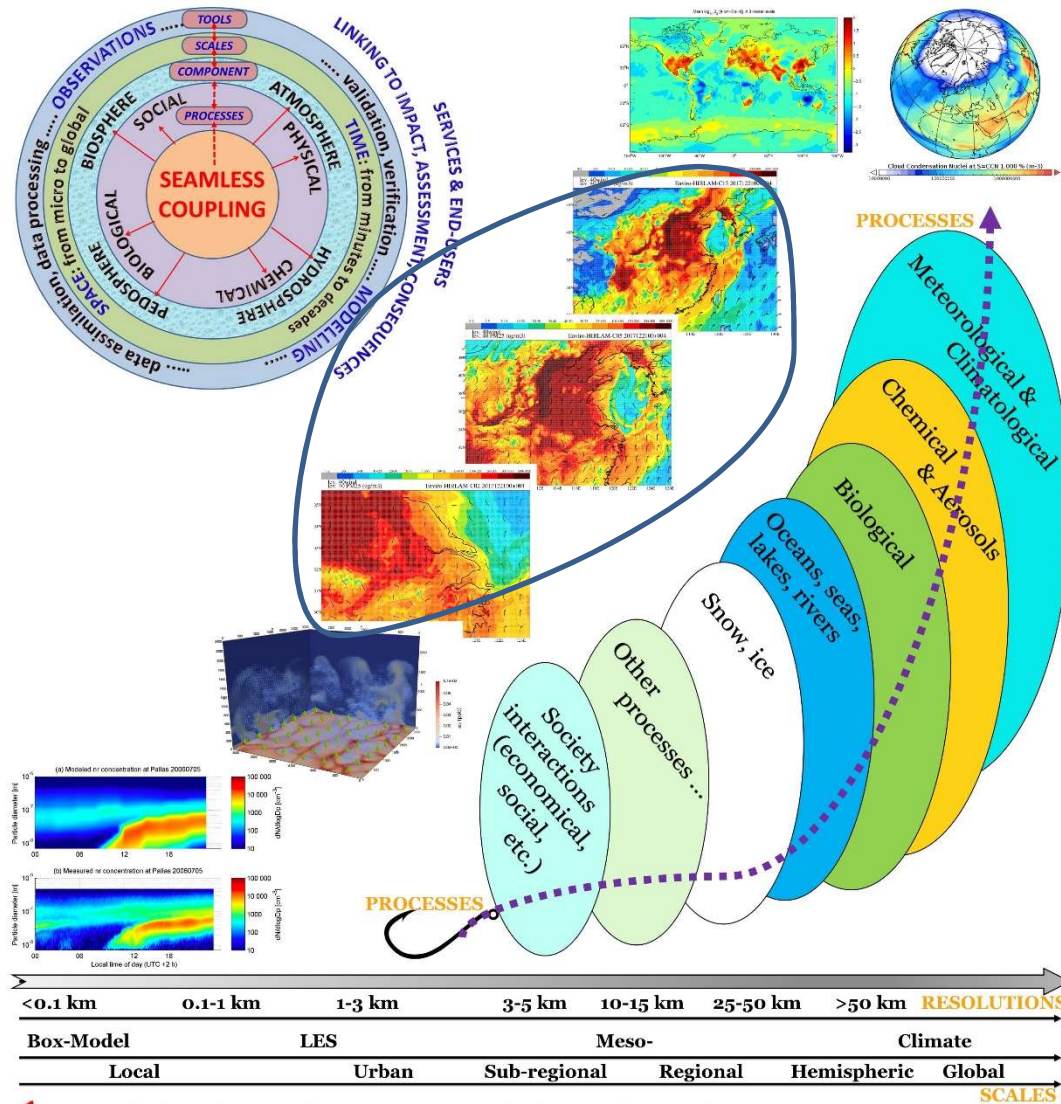*24 April 2020*
*Helsinki, Finland / St. Petersburg, Russia*

# Multi-Scale & -Processes Modelling at INAR



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

**Seamless approach considers several dimensions of the coupling**
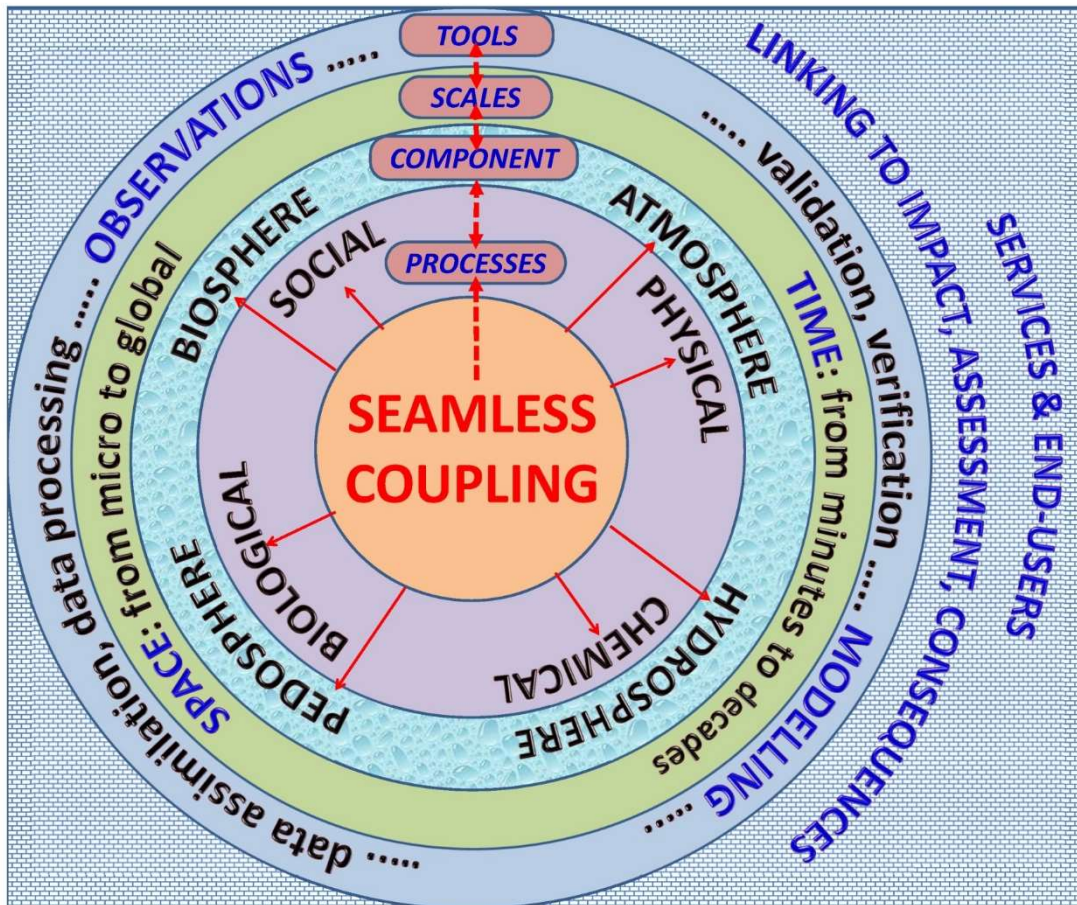
i) **Time scales** (from minutes and nowcasting till decades and climate time-scale);

ii) **Spatial scales** (from street till global scales with downscaling and upscaling methods);

iii) **Processes**: physical, chemical, biological, and social;

iv) **Earth system components**: atmosphere, hydrosphere, pedosphere, ecosystems/ biosphere;

v) Different types of **observations** and **modelling tools**: data processing and data assimilation, validation and verification of modelling results; and

vi) **User-oriented** integrated systems and **impact based forecasts and services**.

=> **New generation of seamless models integrated with observations**
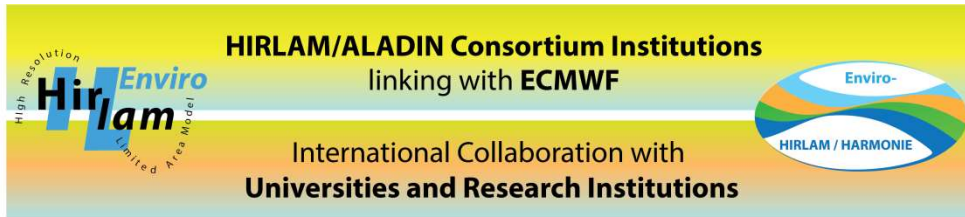
# PEEX-MP Models as Research Tools



Pan-Eurasian Experiment PEEX

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

- **PEEX-Modelling-Platform (PEEX-MP) Overview**
- **Modelling Tools & Demonstration**
- **PEEX-MP Meetings & Sessions**
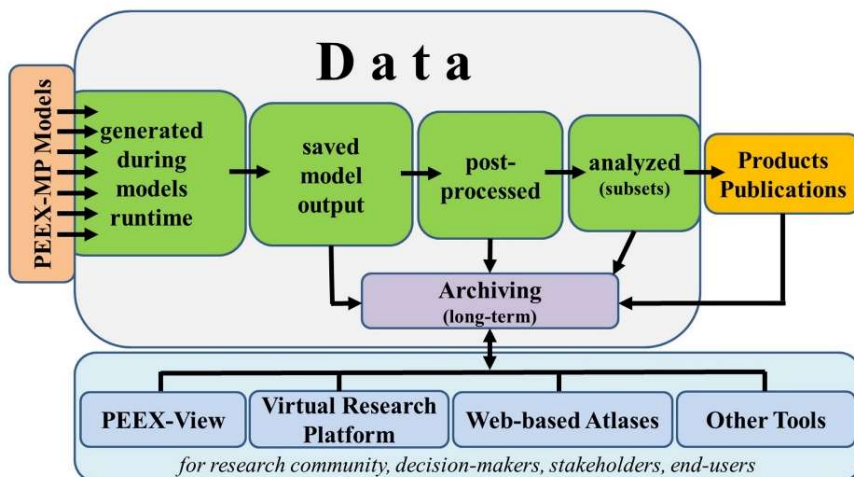


| ATMOSPHERE | HYDROSPHERE | PEDOSPHERE | BIOSPHERE | | PHYSICAL | CHEMICAL | BIOLOGICAL | PEEX-MP Models |
|---|---|---|---|---|---|---|---|---|
| XXX | | | | | XXX | XXX | | HadGEM2-ES |
| XXX | XXX | XXX | | | XXX | XXX | | Enviro-HIRLAM |
| XXX | XXX | | XXX | | XXX | XXX | XXX | SILAM |
| XXX | XXX | | | | XXX | XXX | | FLEXPART |
| XXX | | | | | XXX | XXX | | DERMA |
| XXX | XXX | | XXX | | XXX | XXX | XXX | SOSAA |
| | XXX | | | | XXX | | | HYCOM-CICE |
| XXX | | | XXX | | XXX | XXX | XXX | CH4MOD |
| | XXX | | | | XXX | | | SWAN |
| XXX | | | XXX | | XXX | XXX | XXX | Argo-C |
| XXX | XXX | | | | XXX | | | GLOBO/BOLAM/MOLOCH |
| XXX | | XXX | XXX | | XXX | | XXX | AVIM2 |
| XXX | XXX | XXX | XXX | | XXX | XXX | XXX | EC-Earth |
| XXX | | | | | XXX | XXX | | UCLALES-SALSA |
| XXX | | | | | XXX | XXX | | CTDAS |
| XXX | | | XXX | | XXX | XXX | XXX | SIM-BIM |
| XXX | | | | | XXX | XXX | | TOMCAT-GLOMAP |
| XXX | | | | | XXX | XXX | | CAM-Chem |
| XXX | XXX | | | | XXX | XXX | | MPI-ESM |
| XXX | XXX | XXX | XXX | | XXX | XXX | XXX | CESM |
| XXX | XXX | | | | XXX | | | PALM |
| XXX | | | | | XXX | | | LESNIC |
| XXX | | | XXX | | XXX | XXX | XXX | EmpBVOC |
| | XXX | | | | XXX | | | HBM |
| XXX | | | | | XXX | XXX | | WRF-Chem |
| XXX | | | | | XXX | XXX | | DNDC-HONO |
| XXX | | | | | XXX | XXX | | GEOS-Chem |
| XXX | XXX | XXX | XXX | | XXX | XXX | XXX | CNMM-DNDC |
| XXX | XXX | | XXX | | XXX | | | SUEWS |
| XXX | | | | | XXX | XXX | | ATMES |
| XXX | | | | | XXX | | | MMAD&IT |
| XXX | | | | | XXX | XXX | | IMDAF |
| XXX | | | | | XXX | XXX | | EurCTM |



**D a t a**

PEEX-MP Models → generated during models runtime → saved model output → post-processed → analyzed (subsets) → Products Publications

Archiving (long-term)

PEEX-View | Virtual Research Platform | Web-based Atlases | Other Tools

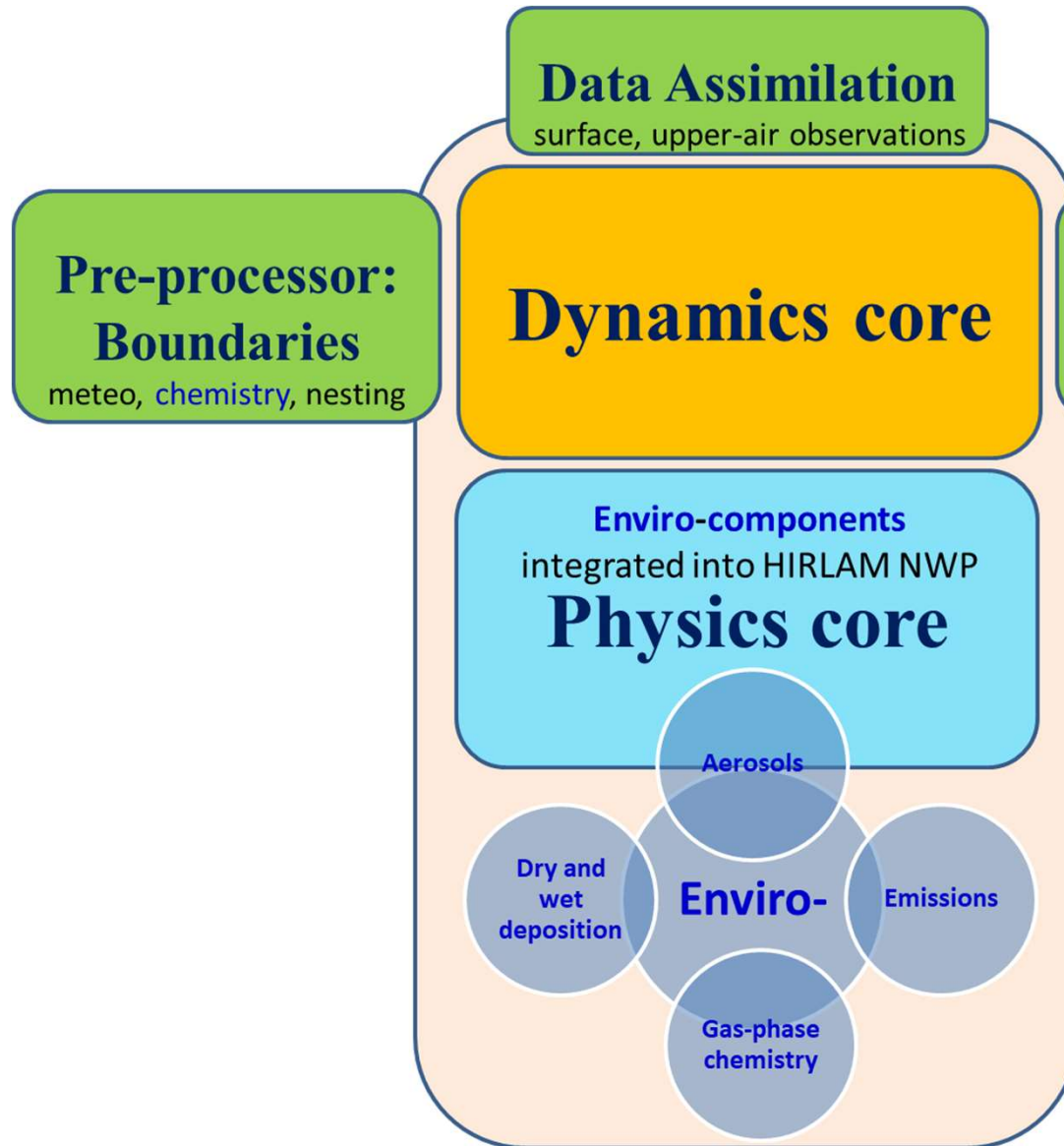*for research community, decision-makers, stakeholders, end-users*

# Enviro-HIRLAM/ HARMONIE (EnviroHH)

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

### RESEARCH AND DEVELOPMENT

Strategy for on-line integrated modelling
Coupling of chemical and aerosol schemes
Convection and cloud microphysics
Dynamical core
Land-surface scheme and urbanization
Aerosol chemistry and microphysics
Radiation schemes, direct effects of gases and aerosols
Aerosol cloud indirect effects
Boundary layer and turbulence closure schemes
Data assimilation of chemical species
Validation (case studies and long-term evaluation)

### DISSEMINATION

HIRLAM Chemistry Branch
https://hirlam.org/trac/wiki/HirlamChemicalBranch/Introduction
Peer-reviewed publications
Presentations on conferences, seminars, workshops etc.

### SCIENCE EDUCATION

Advising and consulting young researches
Networking NordForsk, TEMPUS, EU & national projects
Young Scientist Summer Schools (YSSS) on seamless integrated modelling for various applications
Research training weeks

### NEW PRODUCTS AND APPLICATIONS

**PAN EURASIAN EXPERIMENT (PEEX)** – TOWARDS A NEW MULTINATIONAL, MULTIDISCIPLINE CLIMATE, AIR QUALITY AND ENVIRONMENT RESEARCH EFFORT IN ARCTIC AND BOREAL PAN-EURASIA REGIONS

Research Agenda
Impact on Society
FOCUS AREAS
Research Infrastructure
Knowledge Transfer

In-situ observations
Satellite monitoring
Data systems
Modelling platform

**Enviro-HIRLAM linkage to the PEEX-Modelling Platform**

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



- Data Assimilation
  surface, upper-air observations
- Pre-processor: Boundaries
  meteo, chemistry, nesting
- Dynamics core
- Pre-processor: Emissions
  TNO, ECLISPSE, IS4FIRES, …
- Enviro-components integrated into HIRLAM NWP Physics core
  - Aerosols
  - Dry and wet deposition
  - Enviro-
  - Emissions
  - Gas-phase chemistry

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

*(Baklanov et al., 2017) most recent overview of the modelling system*

# Components of Enviro-HIRLAM

(Zaveri and Peters, 1999);
(Shalaby et al., 2012);
(Sillman, 1991)
**CBMZ** - Carbon Bond v.Z

**Gas-Phase Chemistry**

**Deposition**

**Emissions**

**Enviro-**

**Dry & wet deposition**
(Zhang et al., 2003)
(Stier et al., 2005)

**Anthropogenic**
TNO: res. 0.12° x 0.06°
(Kuenen et al., 2010)
**Biogenic**
VOCs
(Sanderson, 2009)
**Forest fire**
GFED v.3
(Giglio et al., 2010)
**IS4FIRES**
(http://is4fires.fmi.fi)

**Aerosols**

(Vignati et al., 2004)
**M7-HAM**

**Components of the Enviro-HIRLAM modelling system**
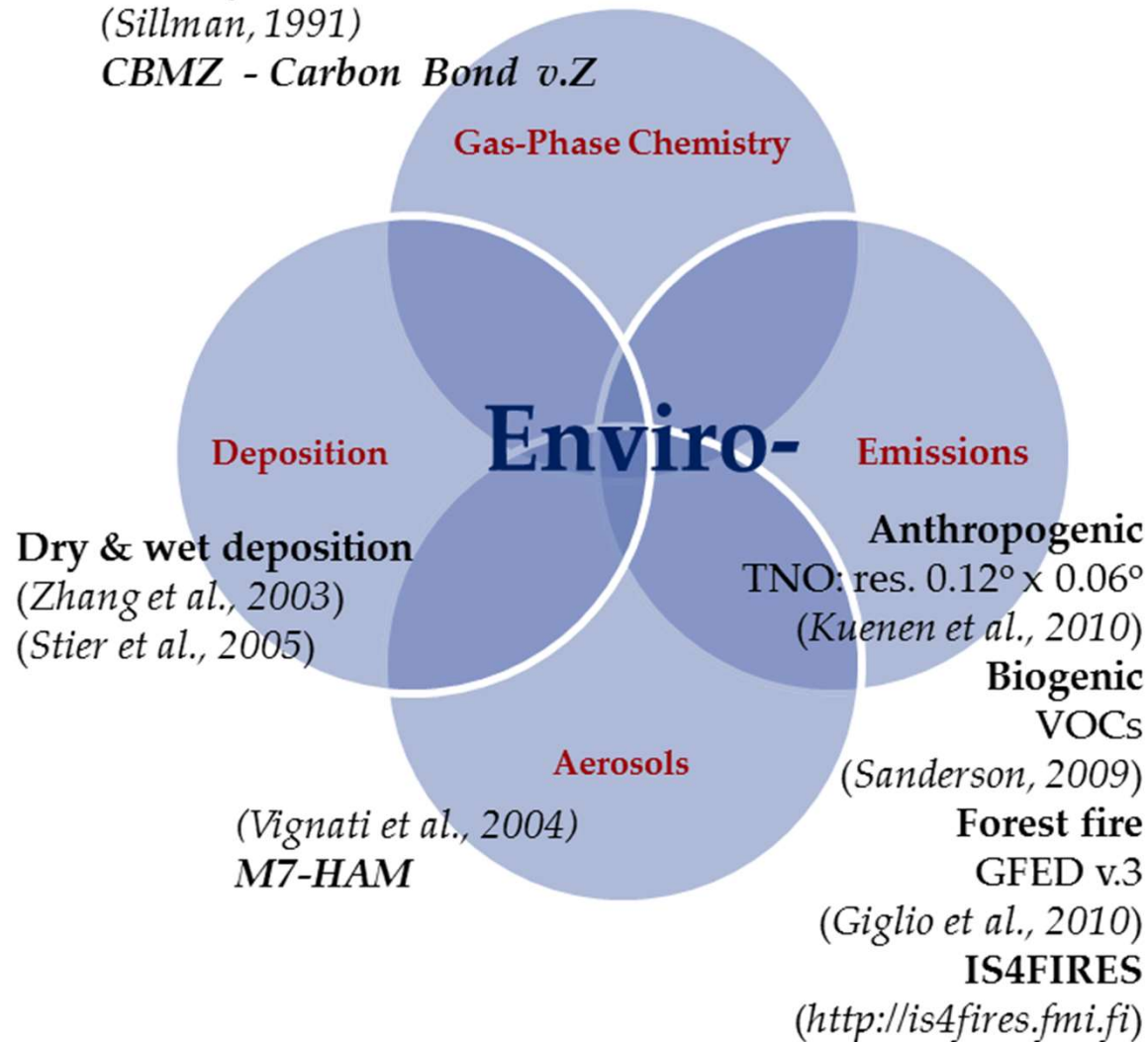
**Enviro-HIRLAM research and development team**

*Baklanov et al., 2002-…;*
*Korsholm et al., 2006-2010;*
*Mahura et al., 2004-…;*
*Nuterman et al., 2007-…;*

*& 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, etc.

# Enviro-HIRLAM Downscaling for Regional-Subregional-Urban/City/Local scales
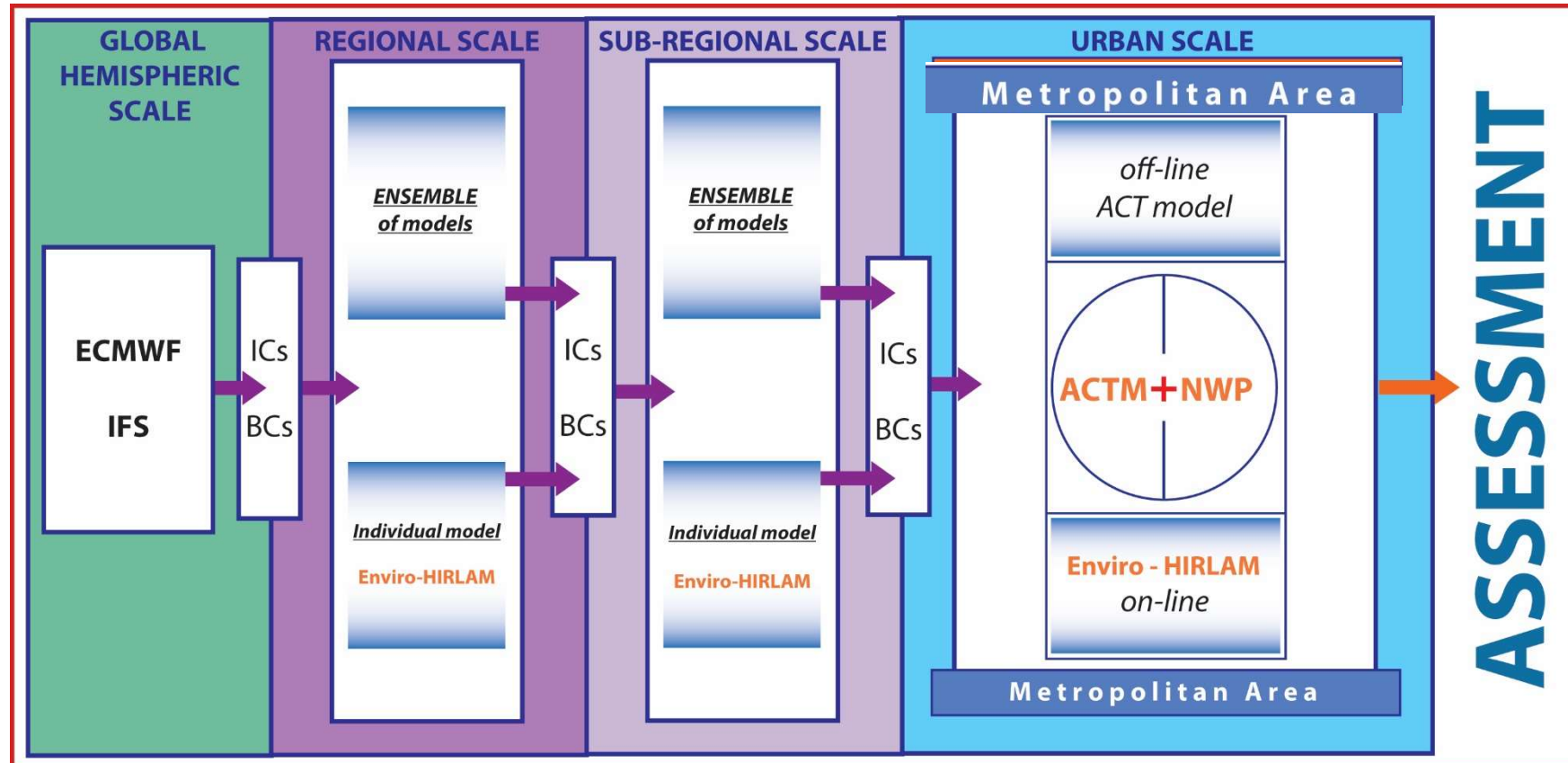
# Hierarchy of Urbanization Approaches

**(Mahura & Baklanov, 2011)**



*Computational time (1 urban grid cell)*

Resolutions

≤0.1km  0.1-1km  1-3km  3-5km  10-15km  25-50km

*Urban* Modules

AHF+R+A

MOSES

SM2-U

MRF-Urban

PALM

BEP

LES-    Meso-    Climate-

Scales

Local    Urban    Regional    Global

*Street    District    City/ Megacity    Megacity/ Large Metropolitan Area*
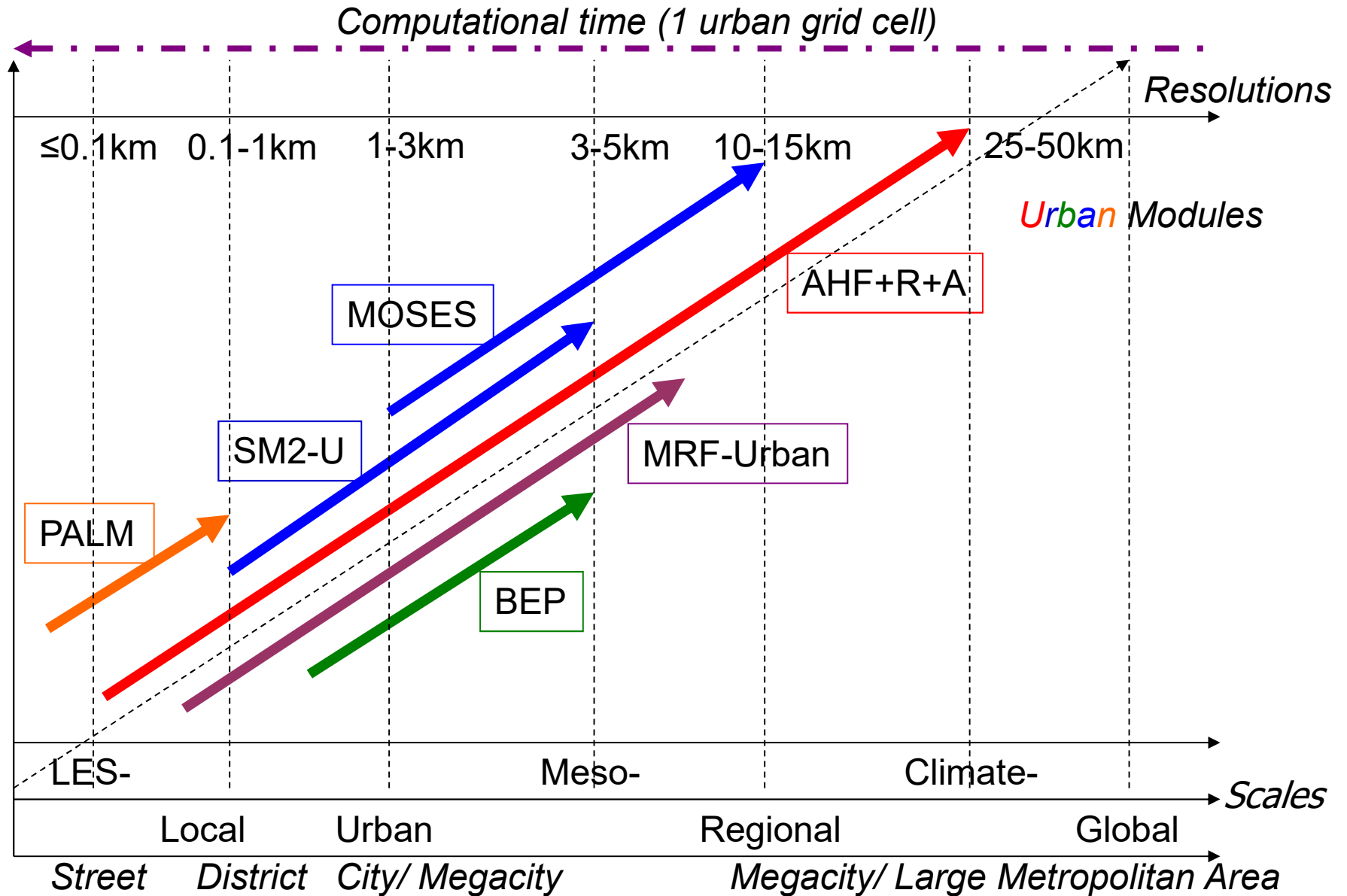
# Urban Districts in Metropolitan Areas: Classification & Characteristics

**Residential (RD)**

**City Center/High Buildings District (CC/HBD)**
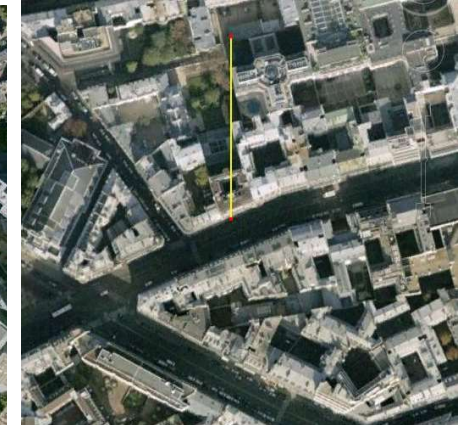


**Industrial Commercial (ICD)**



*GIS - Extraction of districts related characteristics (statistics):*

**City Center**

**High Buildings District**



**Residential District**

**Industrial Commercial District**

- *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)

# Urban Districts in Metropolitan Areas: Classification & Characteristics
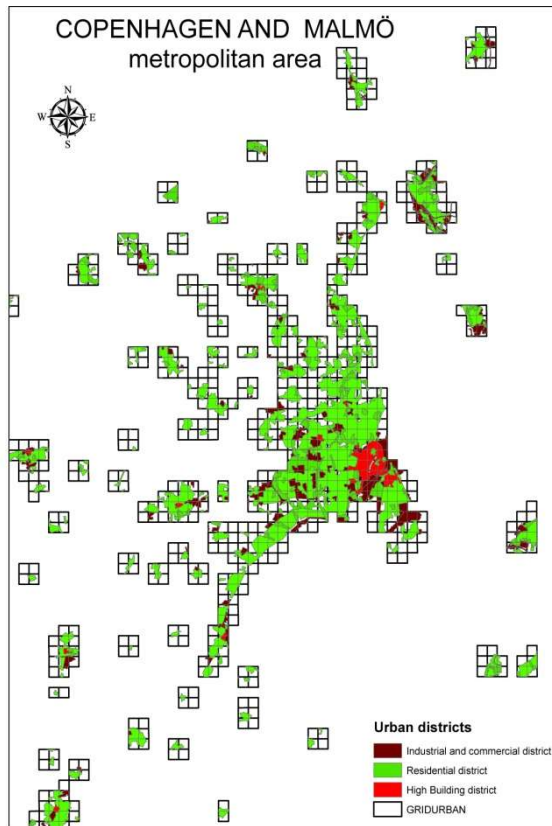


Copenhagen (Denmark)
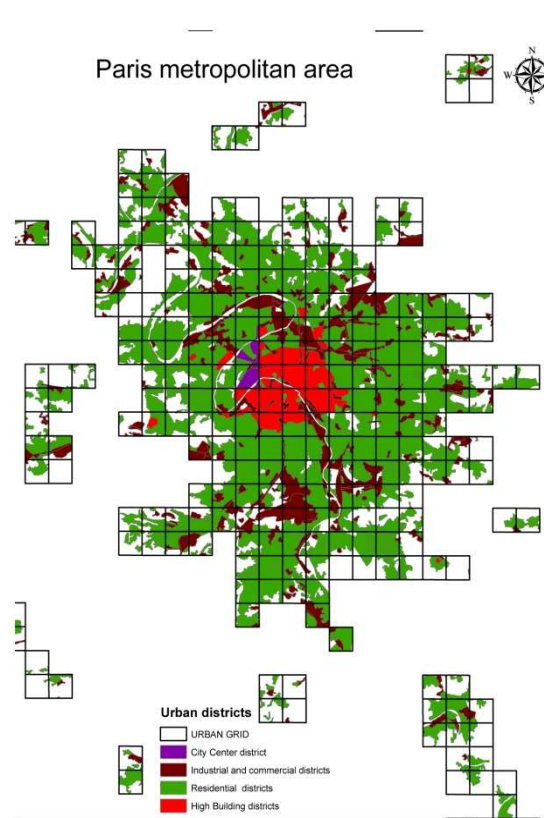
Paris (France)
Metropolitan Areas
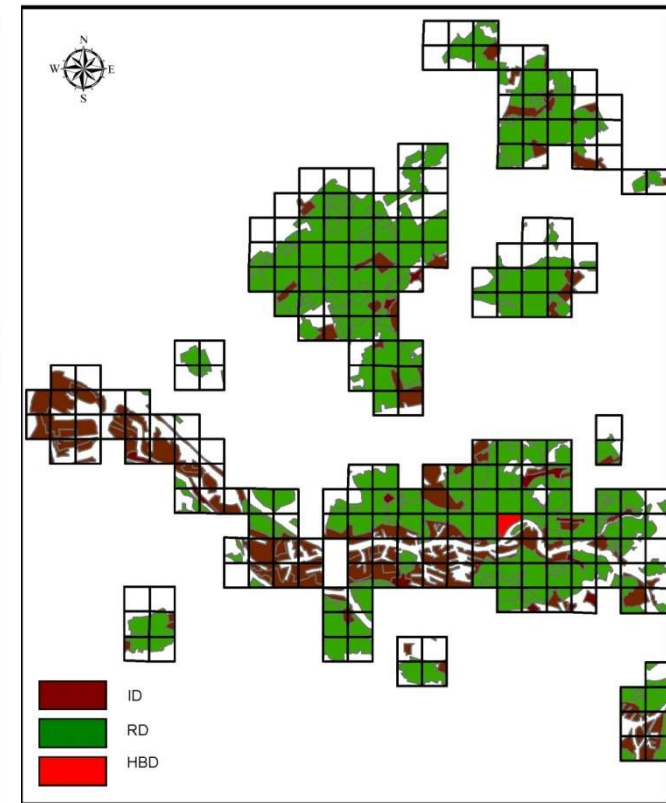
Rotterdam (The Netherlands)

# Downscaling for Paris Metropolitan Area (meteorology & chemistry)
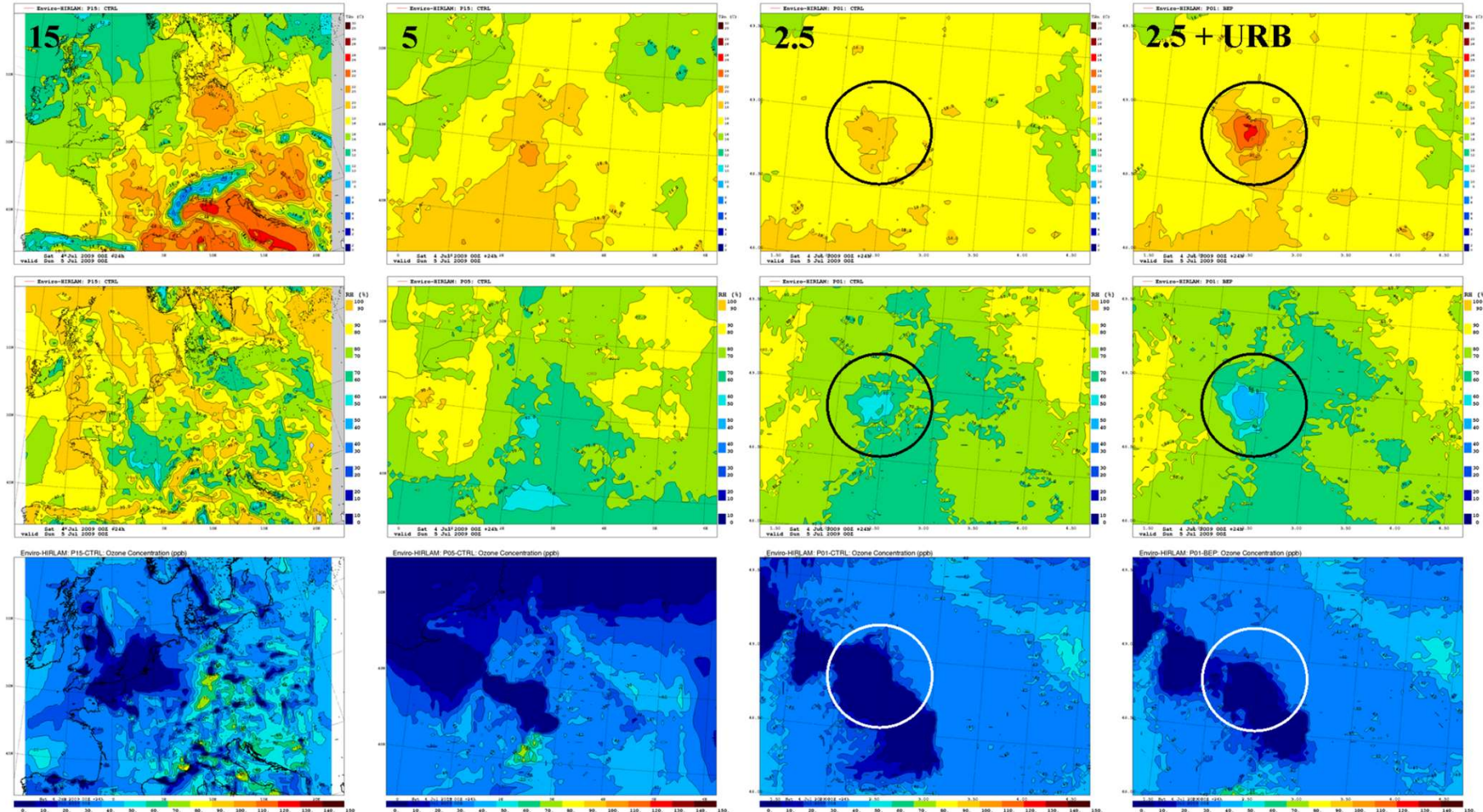


**Enviro-HIRLAM downscaling (from left to right: CTRL 15—5—2.5 km & 2.5+URB) meteorological (top—air temperature, middle—humidity) and chemical (bottom—ozone) fields on 4 Jul 2009, 00+24 UTC.**

# Paris Metropolitan Area:
# Temporal Variability of Meteo.Parameters
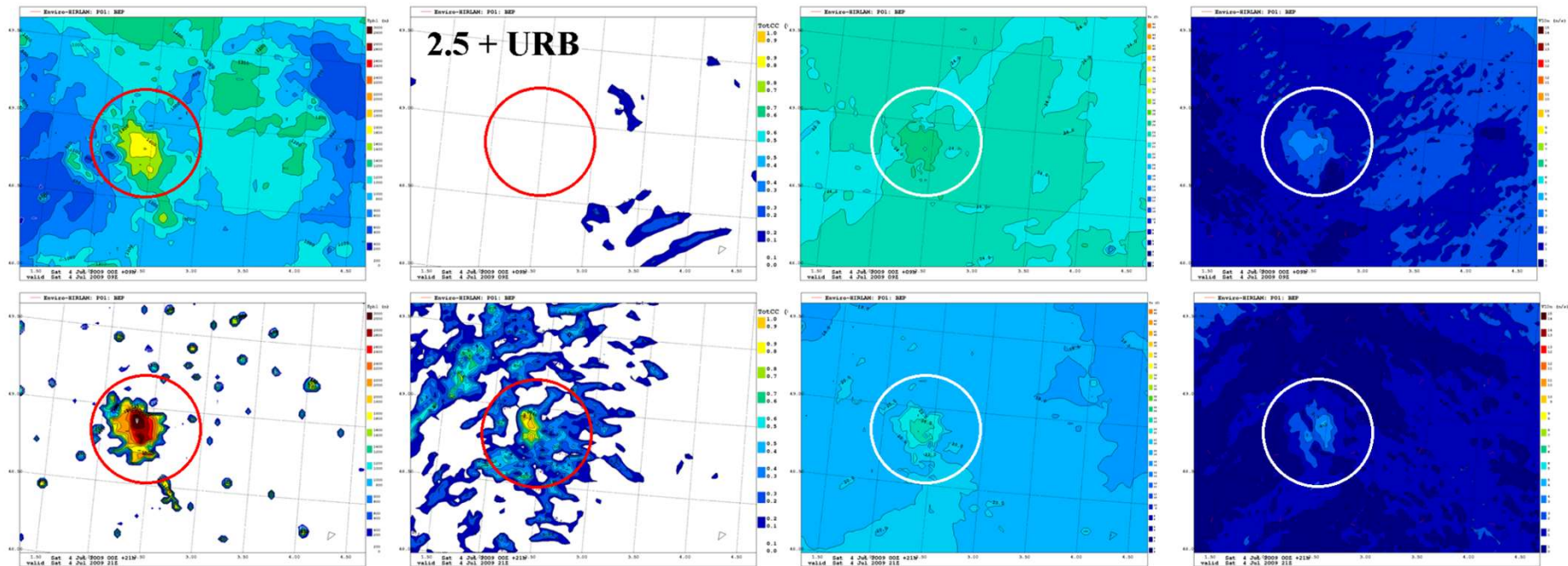


Variability of (from left-to-right) boundary layer height, total cloud cover, surface temperature, wind speed on 4 Jul 2009 at (top) 09 UTC and (bottom) 21 UTC based on Enviro-HIRLAM model run at 2.5 km resolution with URB=BEP+AHF included.
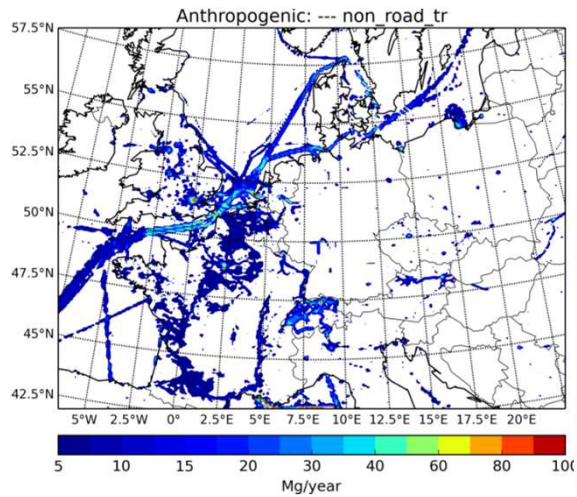
# Enviro-HIRLAM: Rotterdam
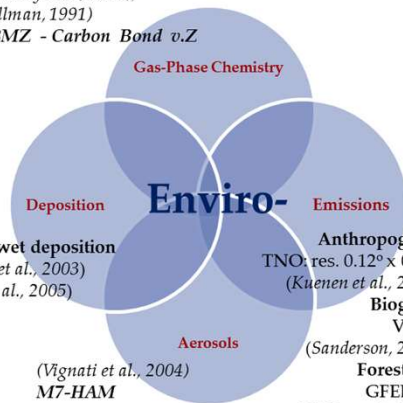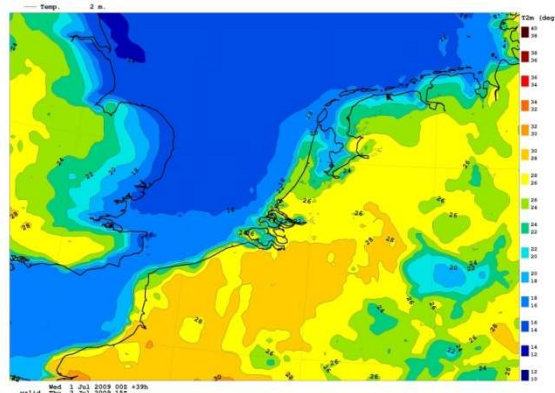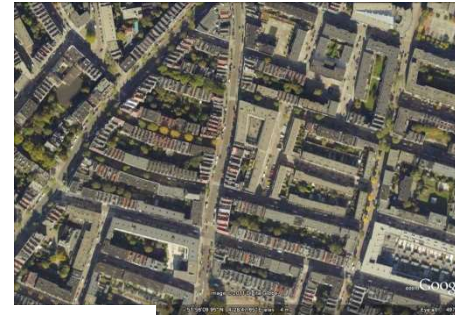


**Regional-Scale run (Enviro-HIRLAM-R15 – 15 km)**

| R15 (NWP+Enviro) | 154 x 148 grids, 40 vert.l., 240 sec, rotated coord.; BCs - ECMWF |

**Meso-Scale run (Enviro-HIRLAM-R05 – 5 km)**

| R05 (NWP+Enviro) | 172 x 142 grids, 40 vert.l., 120 sec, rotated coord., BCs – R15 |

**Urban-Scale run (Enviro-HIRLAM-R02 – 1.5 km)**

| R02 (NWP+Enviro ± BEP) | 172 x 158 grids, 40 vert.l., 60 sec, rotated coord., BCs – R05 |

(Zaveri and Peters, 1999);
(Shalaby et al., 2012);
(Sillman, 1991)
**CBMZ - Carbon Bond v.Z**

**Gas-Phase Chemistry**

**Enviro-**

**Deposition**

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(http://is4fires.fmi.fi)

(Vignati et al., 2004)
**M7-HAM**
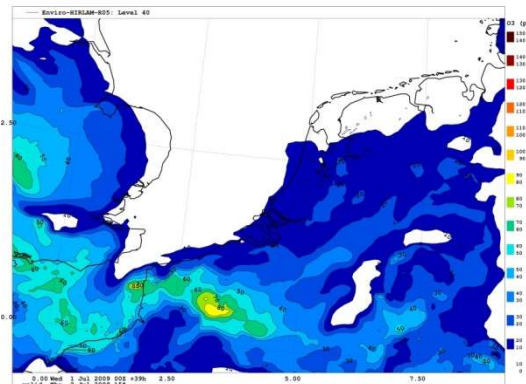
# Downscaling for Enviro-HIRLAM: Modelling Domains vs. Metropolitan Areas

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

**Urban areas in domains**



C15-15 km

C05-5 km

C02-2.5 km

Shanghai metropolitan area (MA)
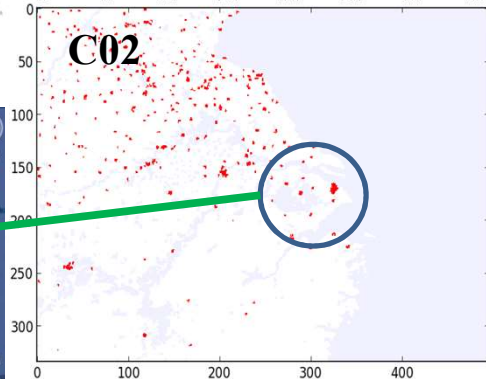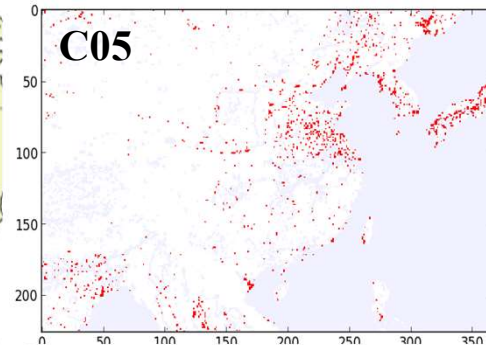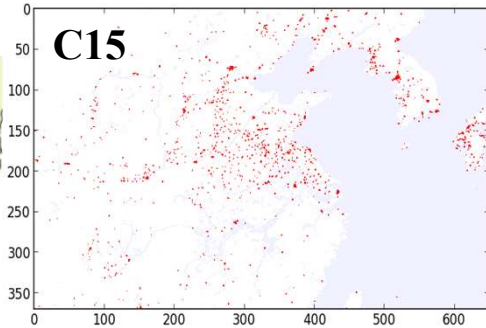
# Enviro-HIRLAM Downscaling: Aerosols

## PM10 (ug/m3)
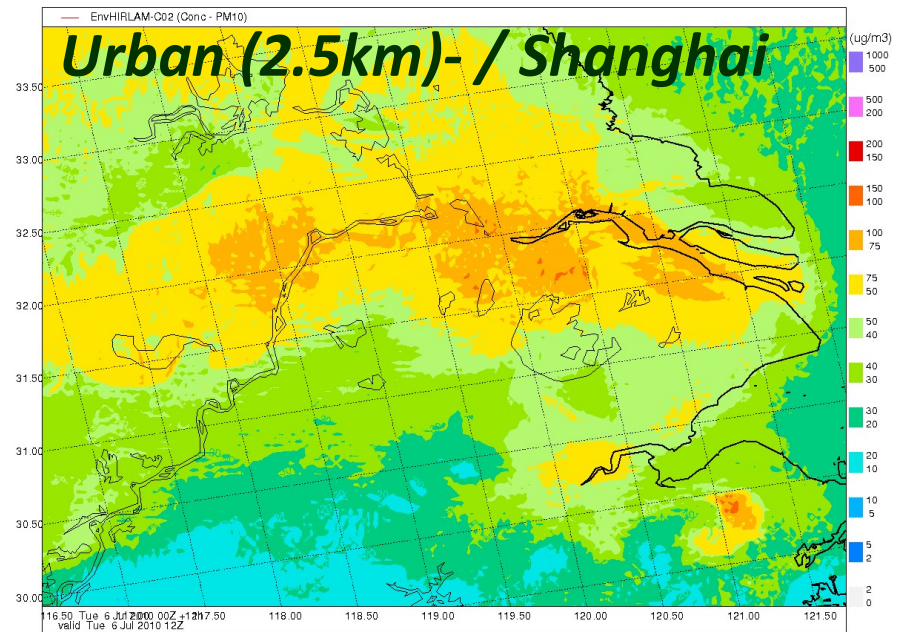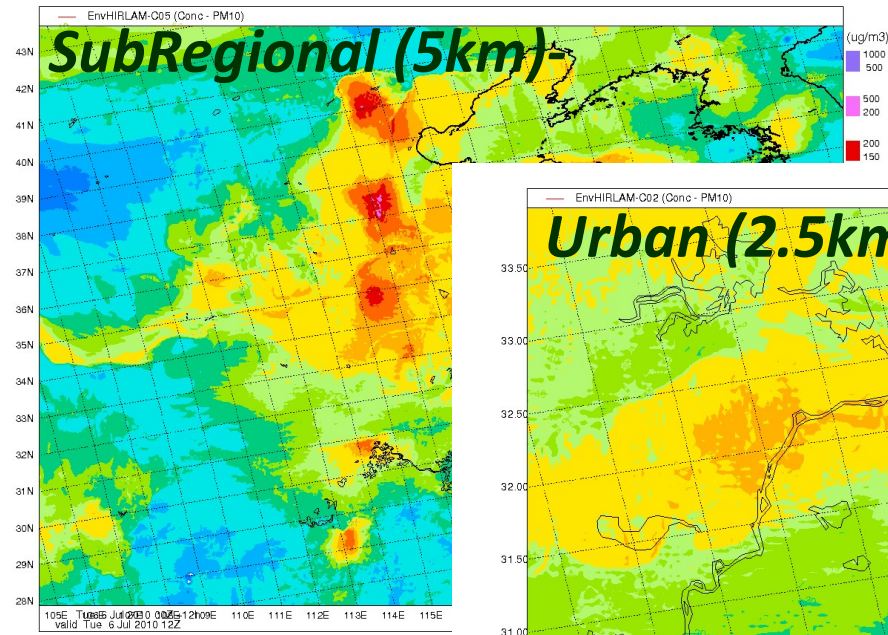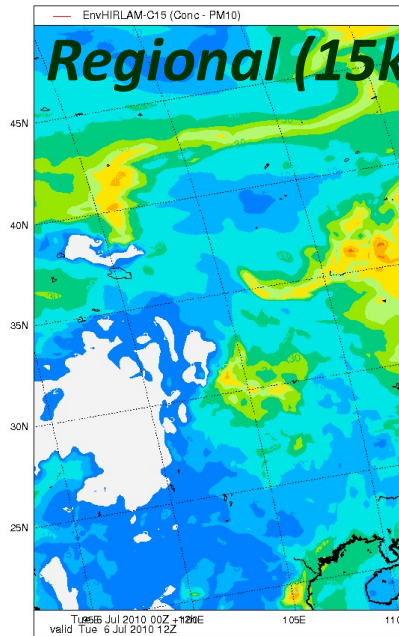
# Downscaling to Metropolitan Areas (MA)



Beijing MA

Shanghai MA

*operational*

Perl-River-Delta

*Case studies for assessments*

http://www.marcopolo-panda.eu/products/regional-air-quality-forecasts/enviro-hirlam
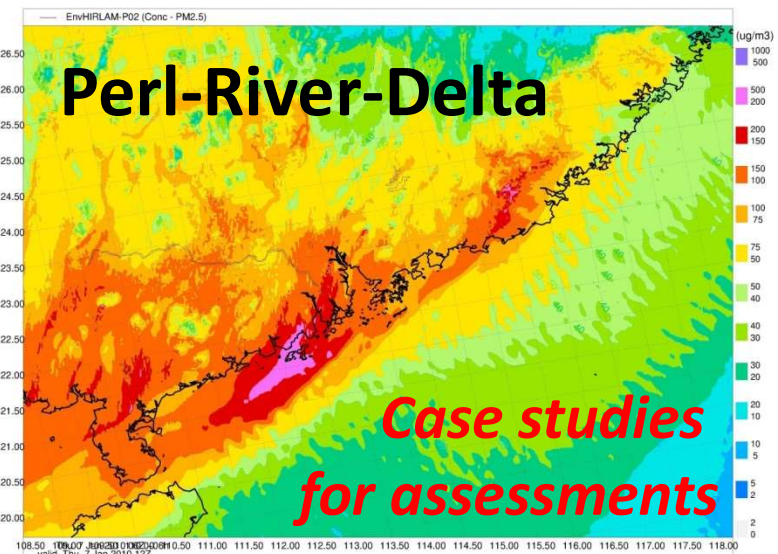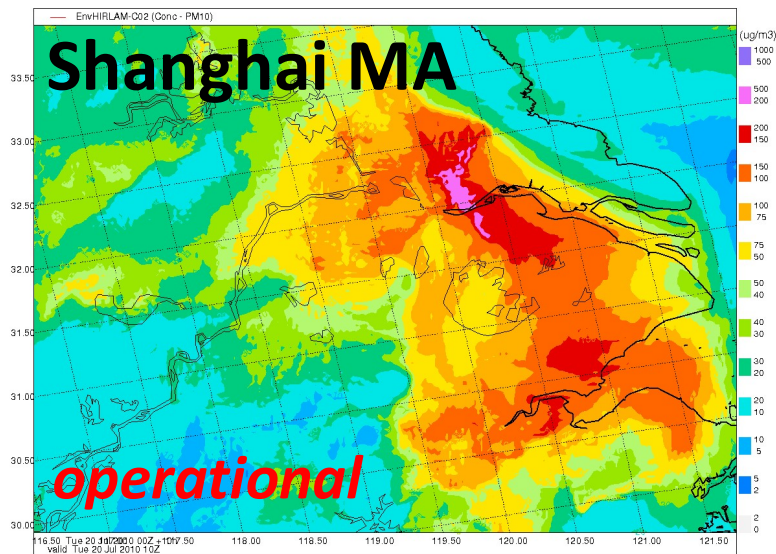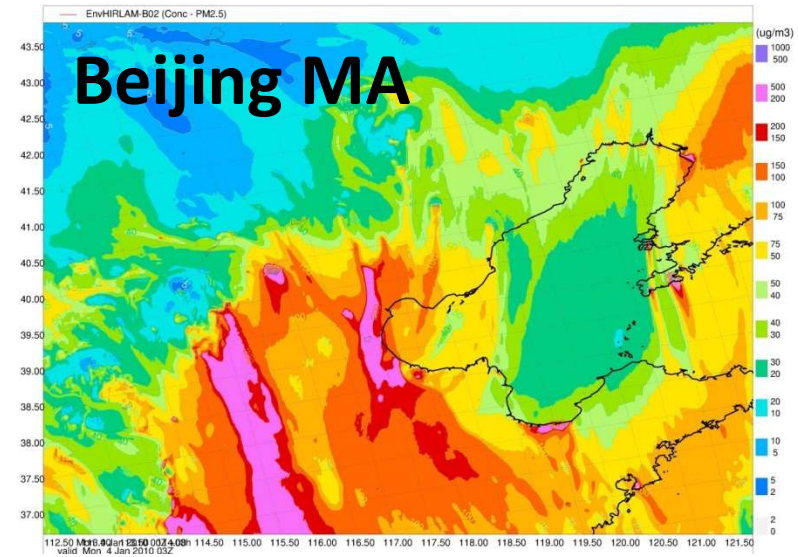
# 2.5km: Shanghai MA: PM10

**Diurnal cycle: 20 Jul 2010**
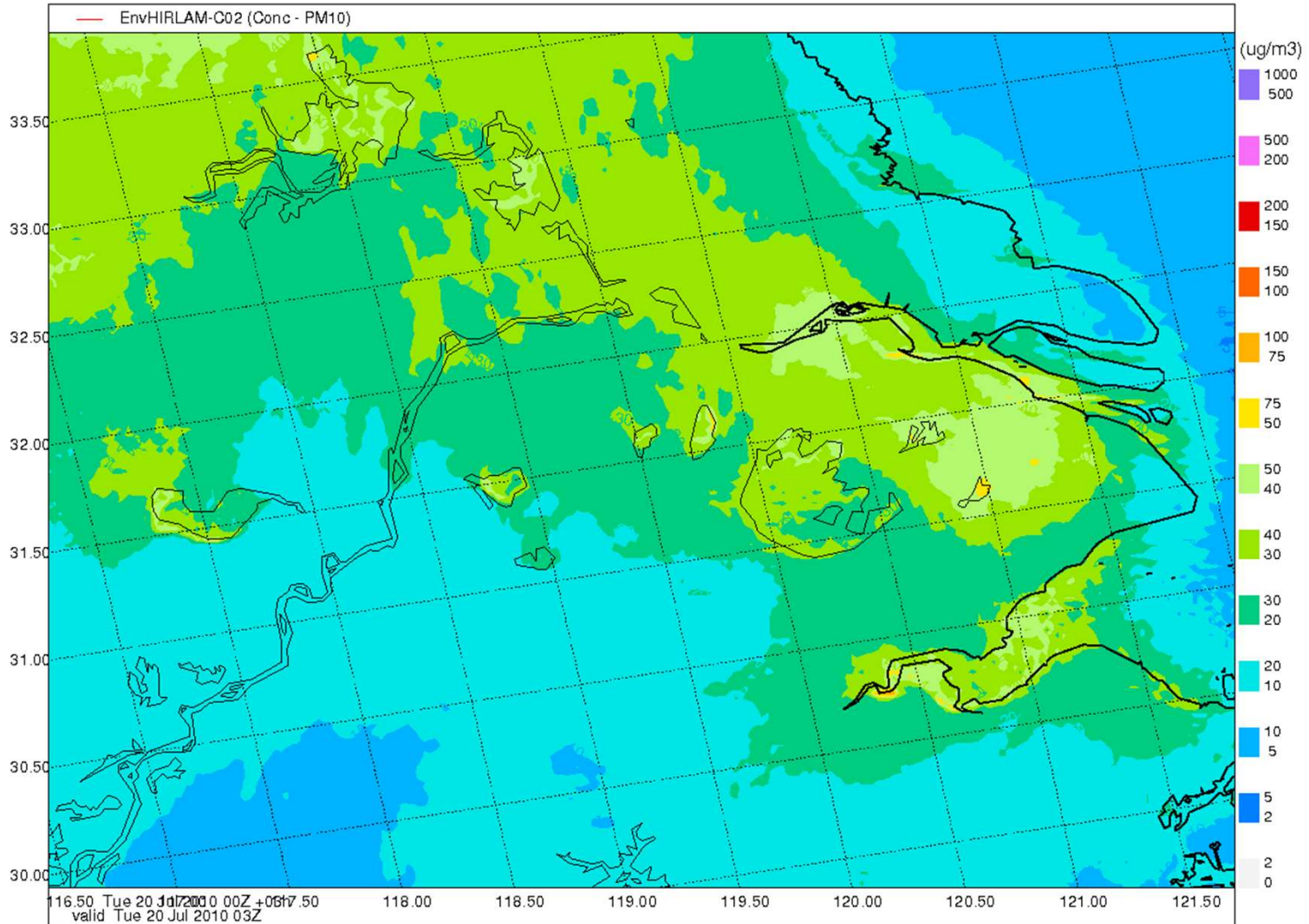
# Seamless/ On-line Integrated Modelling

**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**
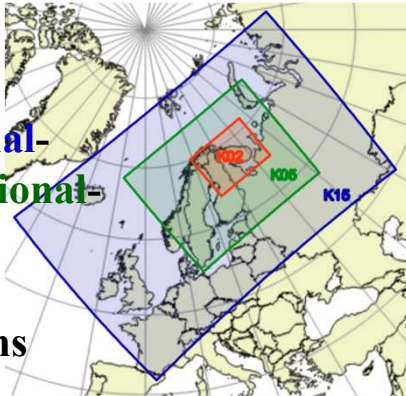
**Enviro-HIRLAM Downscaling (with zooming) over the Kola Peninsula area)**

15 km          5 km          2 km

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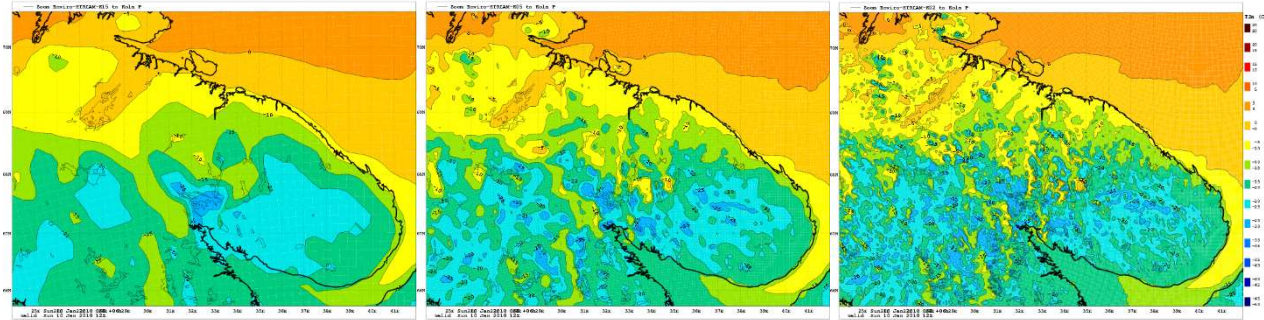
15 km

5 km

2 km

**Meteorology: Air temperature at 2m (T2m)**
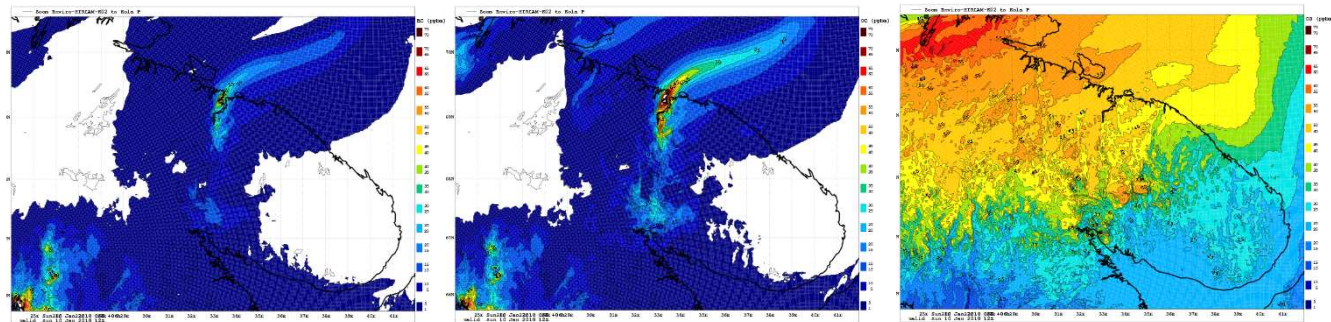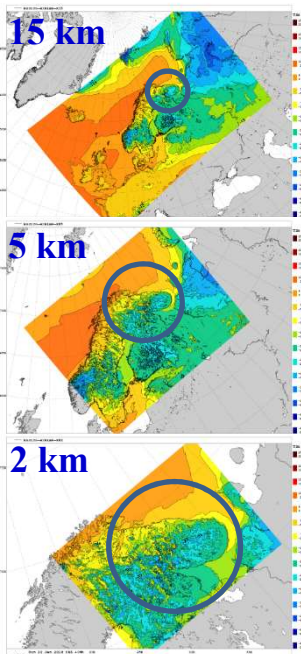
Black carbon (BC)          Organic Carbon (OC)          Ozone (O$_3$)

**Atmospheric composition: at 2 km horizontal resolution**

# High resolution (at 2 km) for meteorology
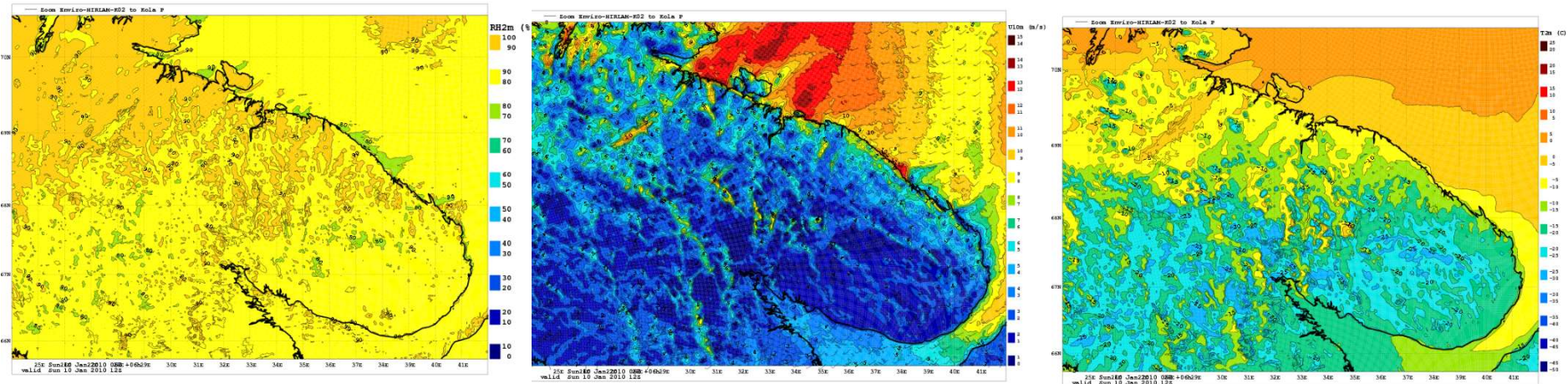


**Meteorology:**

Relative Humidity (RH2m),

Wind Speed at 10m (U10m) ,

Air temperature at 2m (T2m)

An example of the Enviro-HIRLAM model high resolution output over the Kola Peninsula area

# High resolution (at 2 km) for atmospheric composition
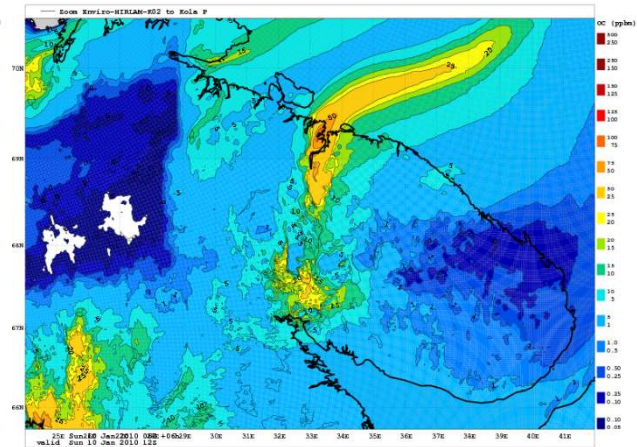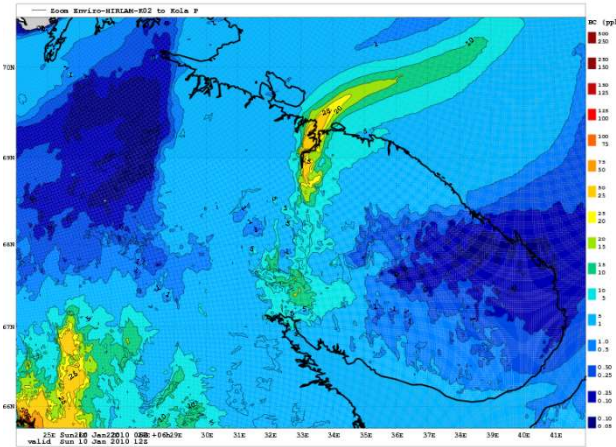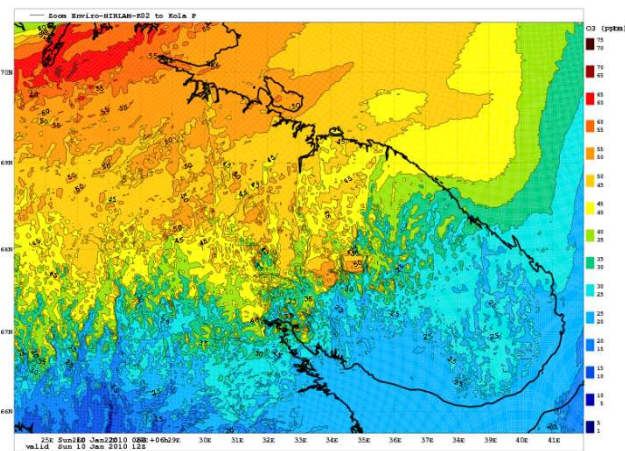


**Atmospheric Composition:**

Ozone (O$_3$)

Black Carbon (BC),

Organic Carbon (OC),

An example of the Enviro-HIRLAM model high resolution output over the Kola Peninsula area

# Web-Atlas for Transboundary Pollution & Loadings for Population
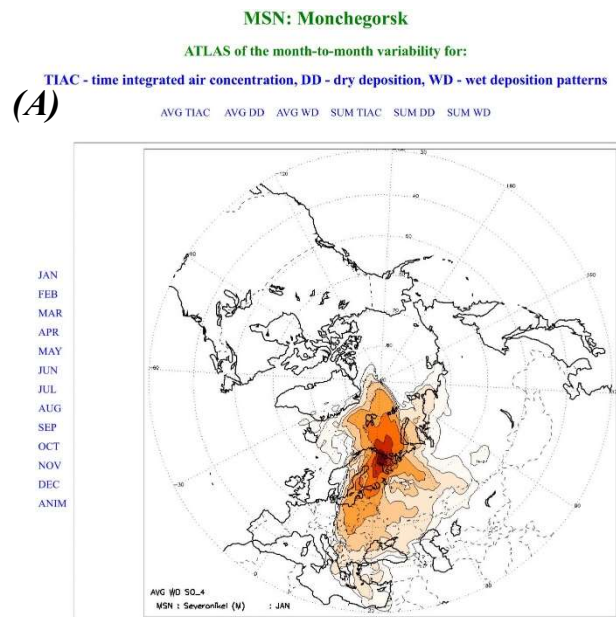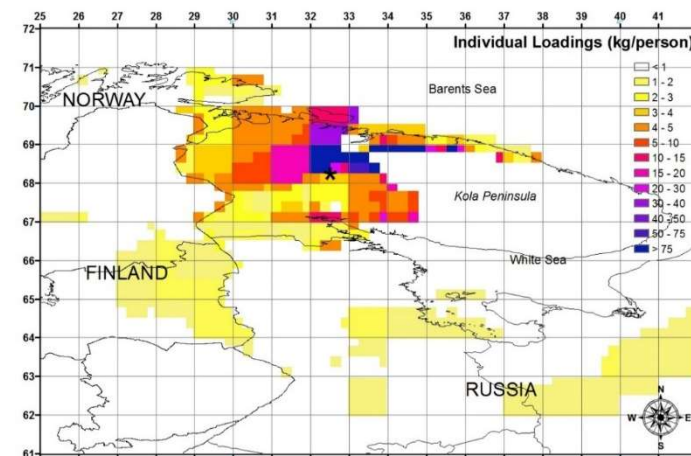
(A) **Month-to-month variability** of average (AVG) and summary (SUM) **time integrated air concentration** (TIAC), **dry** (DD) and **wet** (WD) **deposition patterns of sulphates** from smelters of the Mochegorsk Enterprize (Kola Peninsula, Mirmansk region, Russia);

&

(B) **Individual yearly loadings** for population (in kg/person) from deposited sulfates resulted from the Severonickel smelters continuous emissions (mild scenario, appx 32 thou. tonnes of $SO_2$).

# Web-based Atlas

*http://www.atm.helsinki.fi/peex/webatlas/WEBATLAS.html*



**Example of a month-to-month variability** of summary (SUM) **time integrated air concentration** (TIAC), **dry** (DD) and **wet** (WD) **deposition patterns of sulphates** from smelters of the Mochegorsk Enterprize (Kola Peninsula, Mirmansk region, Russia)

# Web-based Atlas

*http://www.atm.helsinki.fi/peex/webatlas/WEBATLAS.html*



**Example of a month-to-month variability** of summary (SUM) **time integrated air concentration** (TIAC), **dry** (DD) and **wet** (WD) **deposition patterns of sulphates** from smelters of the Norilsk Nickel Enterprize (Krasnoyask Krai, Russia)

# Influence of
# Direct & Indirect Aerosols Effects
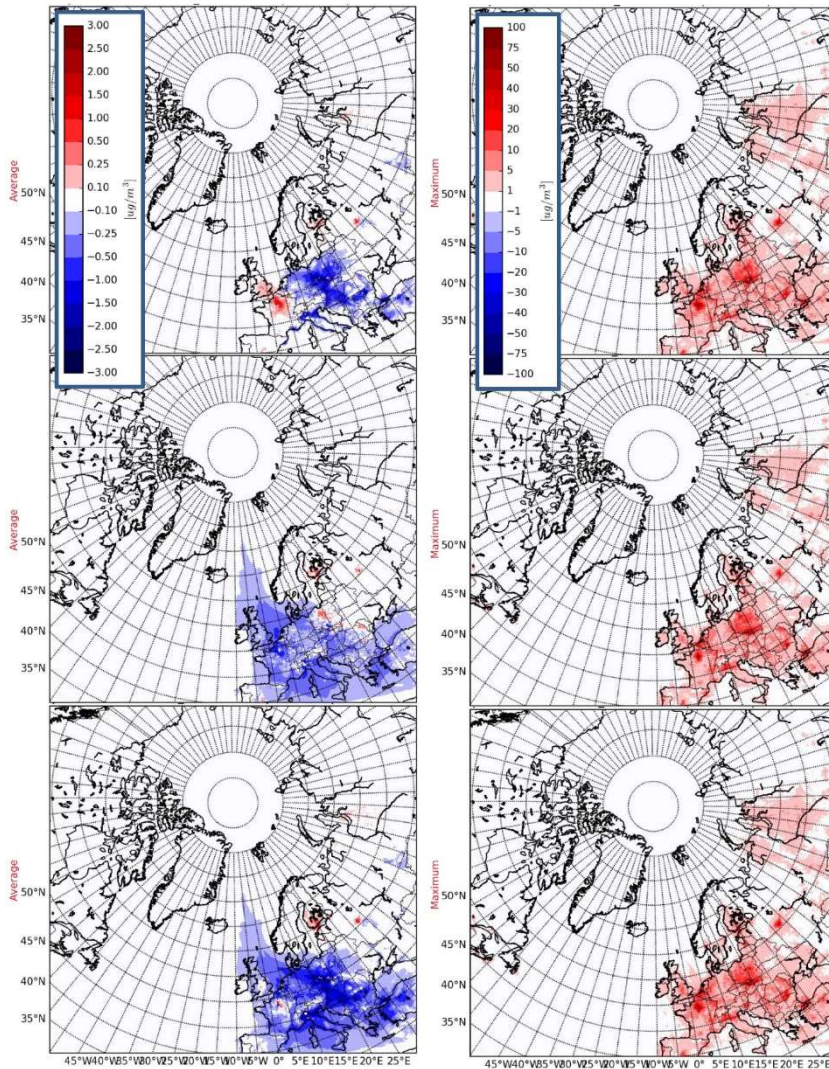


◄ Difference fields between CTRL&DAE (top), CTRL&IDAE (middle), CTRL&DAE+IDEA (bottom) runs with the Enviro-HIRLAM model for monthly (January) averaged (left) and maximum (right) concentration of **black carbon**, BC (in µg/m³).

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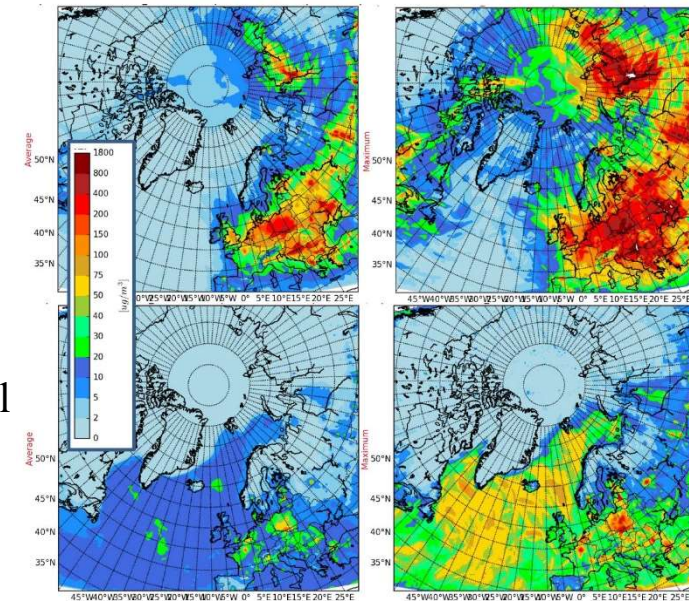


January (12 UTC) monthly averaged (left) and ▲ maximum (right) simulated concentration (in µg/m³) of **SO₂** (top) and **PM2.5** (bottom) based on the Enviro-HIRLAM control run simulations.

# Collaboration with PEEX Russian Partners

## Pan-Eurasian Experiment PEEX

## Enviro-PEEX on ECMWF project



*"PEEX-MP research and development for online coupled integrated meteorology-chemistry-aerosols feedbacks & interactions in weather, climate & atmospheric composition multi-scale modelling"*

*(2018-2020)*

www.atm.helsinki.fi/peex/index.php/enviro

**+ MSU, RSHU, ICMMG , NIERSC**

**Objectives:**
- to analyze importance of meteorology-chemistry-aerosols interactions & feedbacks;
- to provide a way for development of efficient techniques for on-line coupling of NWP and ACT via process-oriented parameterizations and feedback algorithms.

*& new HPC proposal for ECMWF is in preparation in May-Jun 2020*

# Enviro-HIRLAM:
# science education and training

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

**International Collaboration with Universities and Research Institutions**

PAN EURASIAN EXPERIMENT (PEEX)
- TOWARDS A NEW MULTINATIONAL, MULTIDISCIPLINE CLIMATE, AIR QUALITY AND ENVIRONMENT RESEARCH EFFORT IN ARCTIC AND BOREAL PAN EURASIA REGIONS

**RESEARCH AND DEVELOPMENT**

Strategy for on-line integrated modelling
Coupling of chemical and aerosol schemes
Convection and cloud microphysics
Dynamical core
Land-surface scheme and urbanization
Aerosol chemistry and microphysics
Radiation schemes, direct effects of gases and aerosols
Aerosol cloud indirect effects
Boundary layer and turbulence closure schemes
Data assimilation of chemical species
Validation (case studies and long-term evaluation)

**DISSEMINATION**

HIRLAM Chemistry Branch
https://hirlam.org/trac/wiki/HirlamChemicalBranch/Introduction
Peer-reviewed publications
Presentations on conferences,
seminars, workshops etc.

**SCIENCE EDUCATION**

Advising and consulting young researches
Networking NordForsk, TEMPUS,
EU & national projects
Young Scientist Summer Schools
(YSSS) on seamless integrated
modelling for various
applications
Research training weeks

**NEW PRODUCTS AND APPLICATIONS**

**Enviro-HIRLAM/ HARMONIE (EnviroHH)**
*(Collaboration, Research & Development, Science Education, Dissemination, New Products & Applications)*

# Science Education: Small-Scale Research Projects (SSRPs)

1) **Student workbooks on SSRPs**
2) **Supplementary materials**
3) **Introduction Into Exercises**
   **(lecture by teacher)**

# The recent Enviro-HIRLAM research trainings:

## Enviro-HIRLAM Research Training Week: Jun 2019 (UTMN, Tyumen, Russia)

https://www.atm.helsinki.fi/peex/index.php/education/16-courses/188-june-2019-research-training-course-seamless-online-integrated-meteorology-chemistry-aerosols-multi-scale-and-processes-modelling



During 24-29 June 2019, the Academy of Finland ClimEco project ("*Mechanisms, pathways and patchiness of the Arctic ecosystem responses and adaptation to changing climate*"; www.atm.helsinki.fi/peex/index.php/climeco) research training course on "*Seamless / Online Integrated Meteorology-Chemistry-Aerosols Multi-Scale and –Processes Modelling*" took place in the city of Tyumen (Russia) situated on banks of the beautiful Tura River. The event was organized jointly by the University of Helsinki (UHEL), the Institute for Atmospheric and Earth System Research (INAR), the Finnish Meteorological Institute (FMI), and the University of Tyumen (UTMN); and arranged in premises of the Institute of the Earth Sciences. The training was organized in order to strengthen the collaboration between Finnish and Russian key investigators and corresponding institutes in the frameworks of the ClimEco project and PEEX (Pan-Eurasian EXperiment; www.atm.helsinki.fi/peex) programme; to make a detailed design enabling a longer-term, a top-level research activities in PEEX; and to build direct links and to establish student training and short-term exchange between the institutes. One of the PEEX-Modelling-Platform (PEEX-MP; www.atm.helsinki.fi/peex/index.php/modelling-tools-demonstration) models, the Enviro-HIRLAM (*Environment - HIgh Resolution Limited Area Model*) modelling system was demonstrated and used.

The training included: lecturing with respect to theoretical and practical aspects of the Enviro-HIRLAM modelling system (with focus on research and development). The *theoretical aspects* included: weather modelling in European community; advantages/ shortcomings of on-line vs. off-line approaches; model structure, downscaling, components, schematics; specific features of urban areas and modules/ parameterizations for urbanization; land-cover and land-use

UHEL - Markku Kulmala, Sergej Zitlinkevich, Jaana Back, Tuukka Petäjä, Hanna Lappalainen, Stephany Mazon, Svyatoslav Tyuryakov, and Borisova, and others.                                         Respectfully, Dmitrii Gabyshev, UTMN and Alexander Mahura, UHEL-INAR.
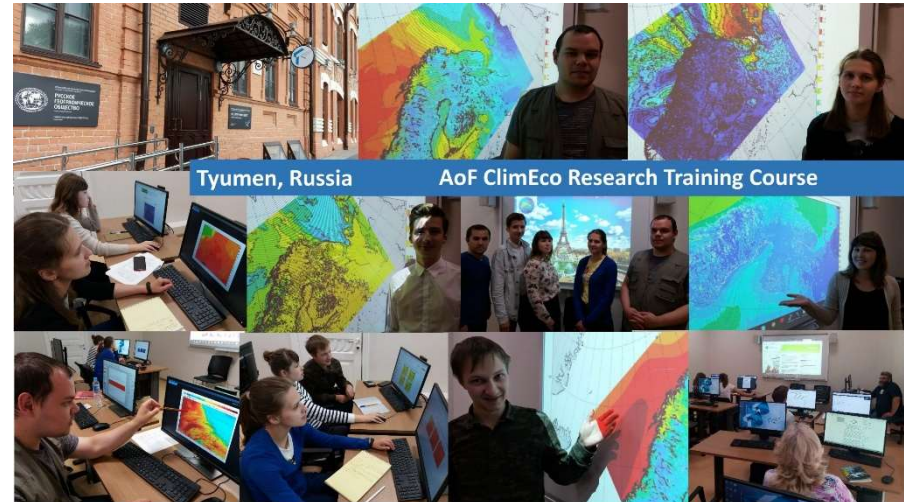
# Planned 2020 research trainings as PEEX-AC intensive courses & YSSSs vs. COVID-19

## PEEX-Academic Challenge – FIRST+ Intensive Course

**"Multi-Scales and -Processes Modelling and Assessment for Environmental Applications"**
Location/ Host: Russian State Hydrometeorological University (RSHU, St.Petersburg, Russia)
Timeline: 20-25 April 2020
(arrivals: Sunday, 19 Apr 2020 & Course starts from Monday, 20 Apr until Saturday, 25 Apr & departures: Sat/Sun, 25-26 Apr)



**COVID19 /cancelled/ --- PEEX-AC research training intensive course (host - RSHU, St.Petersburg, Russia, 20-25 April 2020)**

https://www.atm.helsinki.fi/peex/index.php/education/16-courses/184-april-2020-peex-ac-research-training-intensive-course

**COVID19 /cancelled/ --- AoF ClimEco & RSF MegaCity Young Scientist Summer School (host - MSU, Moscow, Russia, 27 Jul – 7 Aug 2020)**

https://www.atm.helsinki.fi/peex/index.php/education/16-courses/185-jul-aug-2020-young-scientist-summer-school-on-multi-scales-and-processes-integrated-modelling-observations-and-assessment-for-environmental-applications

# Thank you!