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

by Alexander Mahura

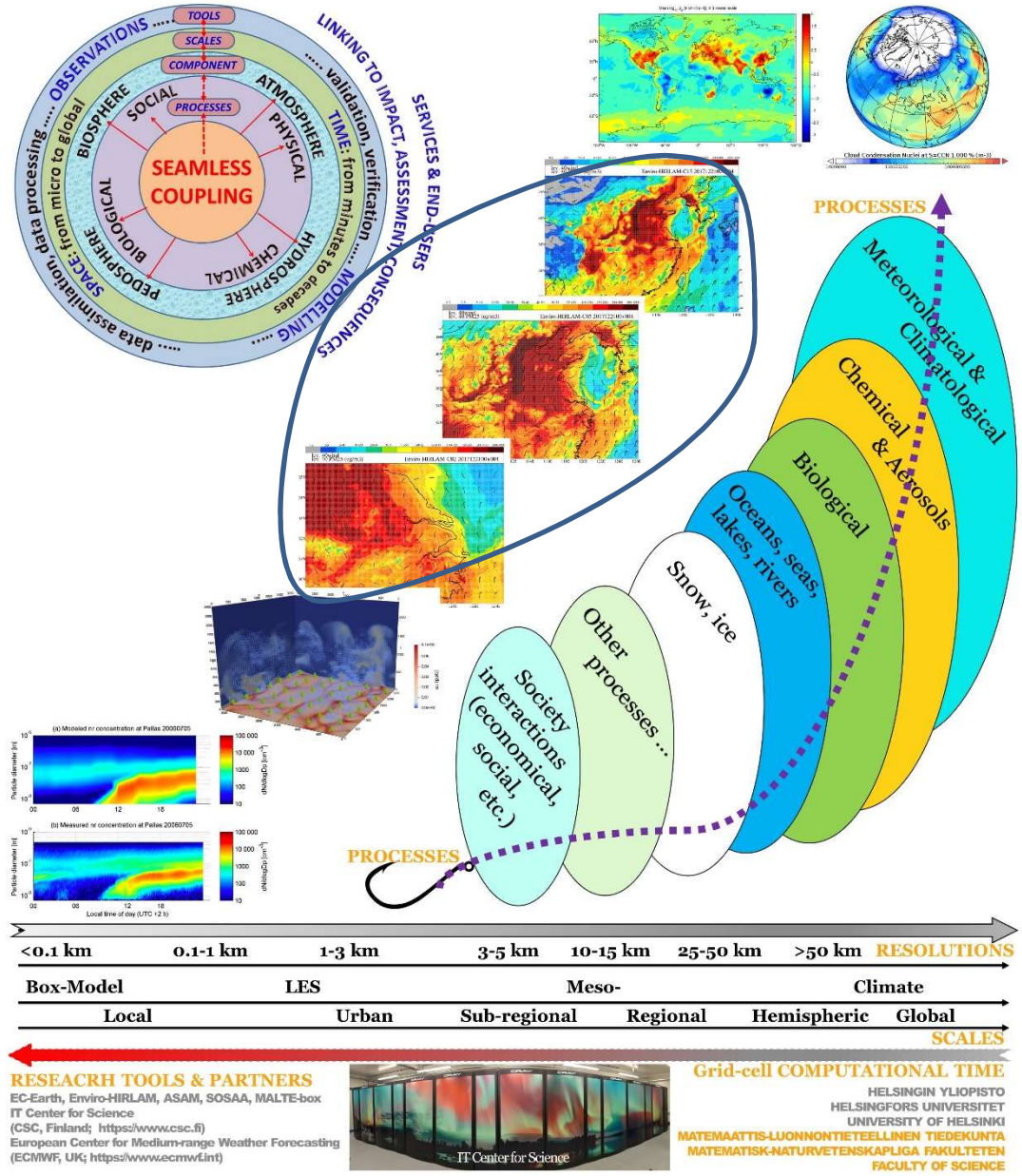
Institute for Atmospheric and Earth System Research (INAR) / Physics
Faculty of Science, University of Helsinki (UHEL), Finland

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

INEP-KSC-RAS & UHEL-INAR virtual-meeting & discussions
12 November 2020
Helsinki, Finland / Apatity, Russia

Multi-Scale & -Processes Modelling at INAR

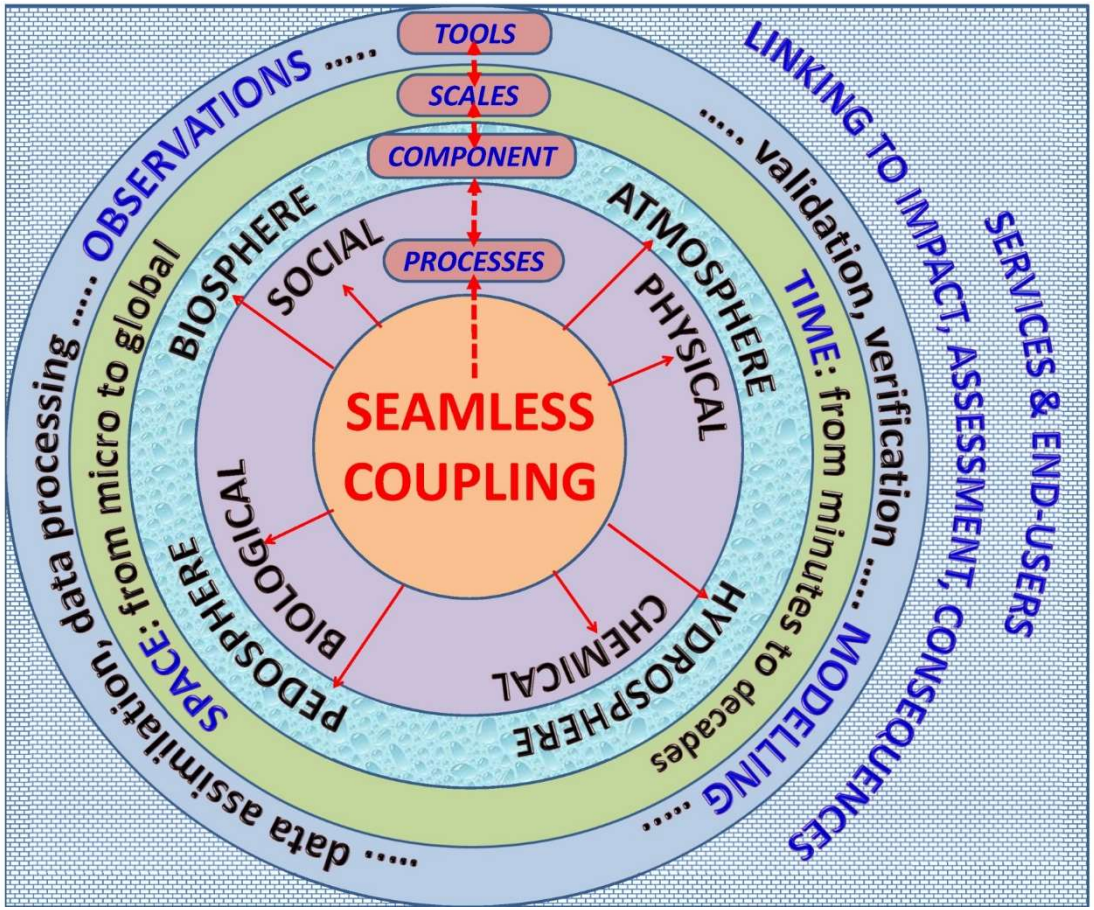
Pan-Eurasian Experiment PEEX



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

PEEX Modelling Platform (PEEX-MP)

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

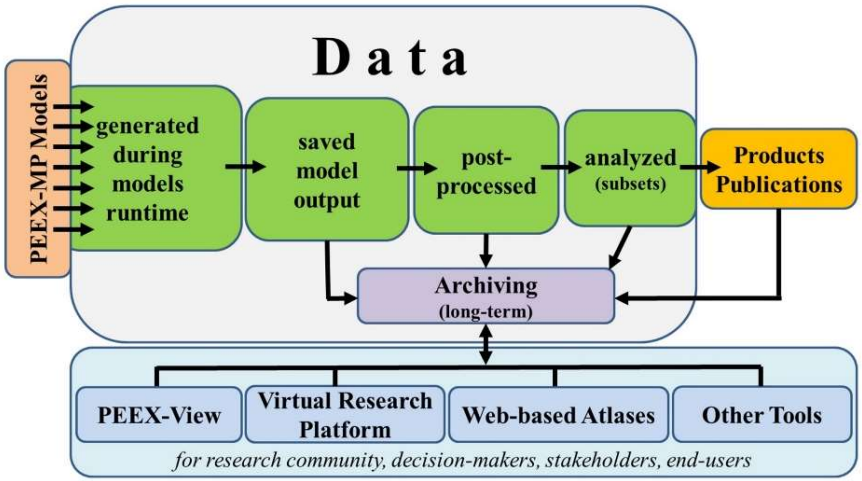
vi) **User-oriented** integrated systems and **impact based forecasts and services**.

=> New generation of seamless models integrated with observations

PEEX-MP Models as Research Tools

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

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



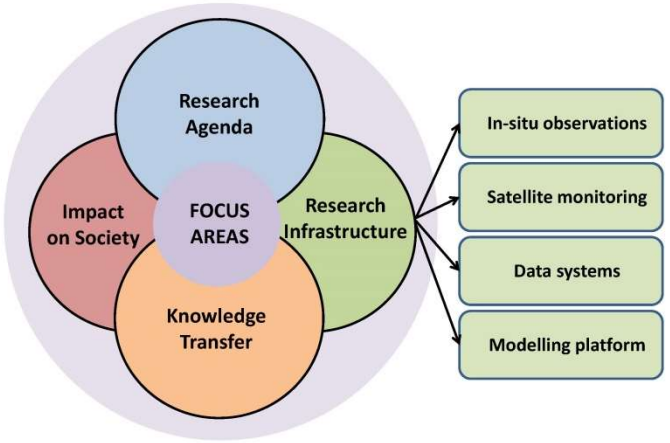
ATMOSPHERE	HYDROSPHERE	PEDOSPHERE	BIOSPHERE	PHYSICAL	CHEMICAL	BIOLOGICAL	PEEX-MP Models
XXX				XXX	XXX		HadGEM2-ES
XXX	XXX	XXX		XXX	XXX		Enviro-HIRLAM
XXX	XXX		XXX	XXX	XXX	XXX	SILAM
XXX	XXX			XXX	XXX		FLEXPART
XXX				XXX	XXX		DERMA
XXX	XXX		XXX	XXX	XXX	XXX	SOSAA
	XXX			XXX			HYCOM-CICE
XXX			XXX	XXX	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

INAR

Enviro-HIRLAM/ HARMONIE (EnviroHH)

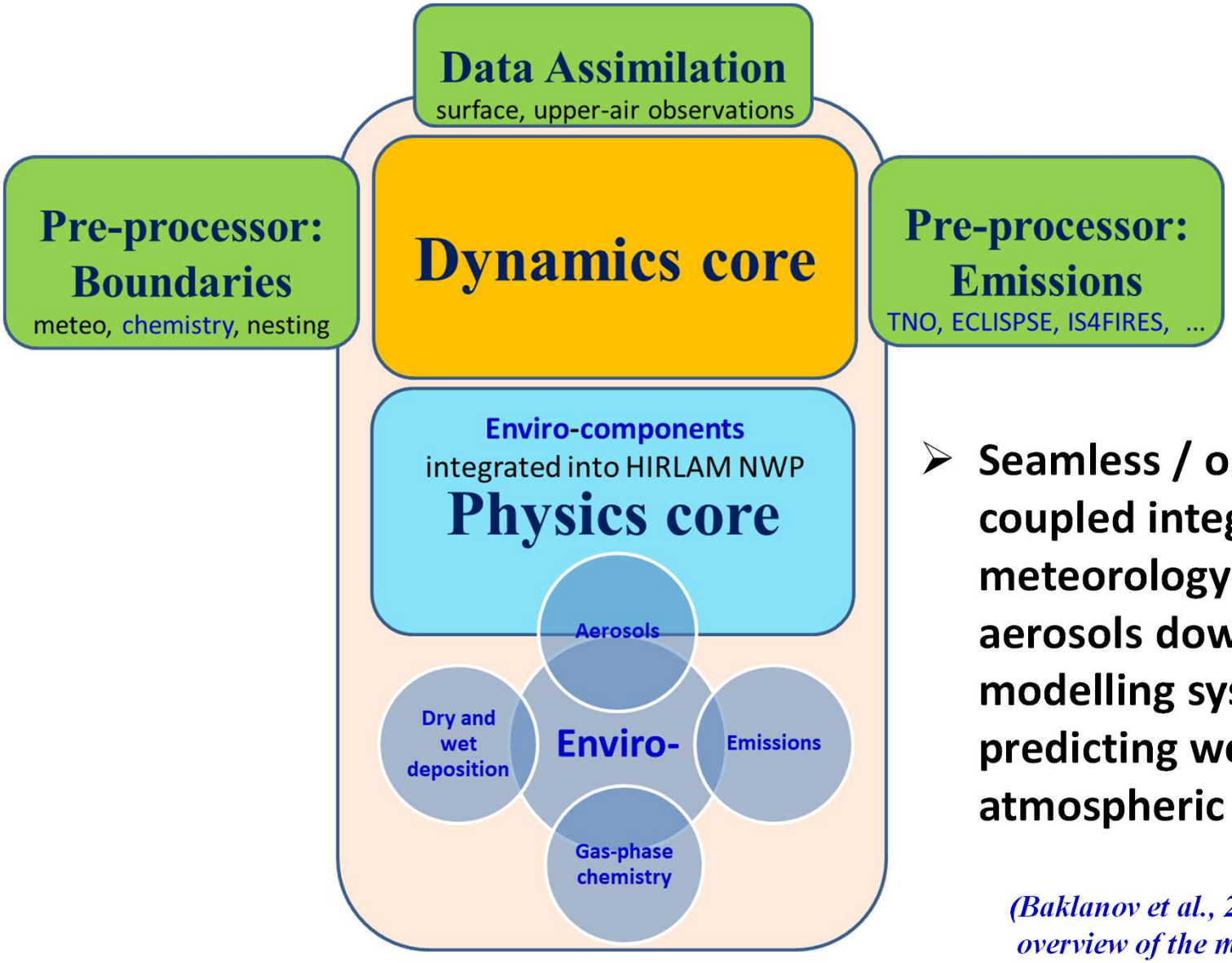
(Collaboration, Research and Development, Science Education, Dissemination, New Products and Applications)

Pan-Eurasian Experiment PEEX



Enviro-HIRLAM linkage to the PEEX-Modelling Platform

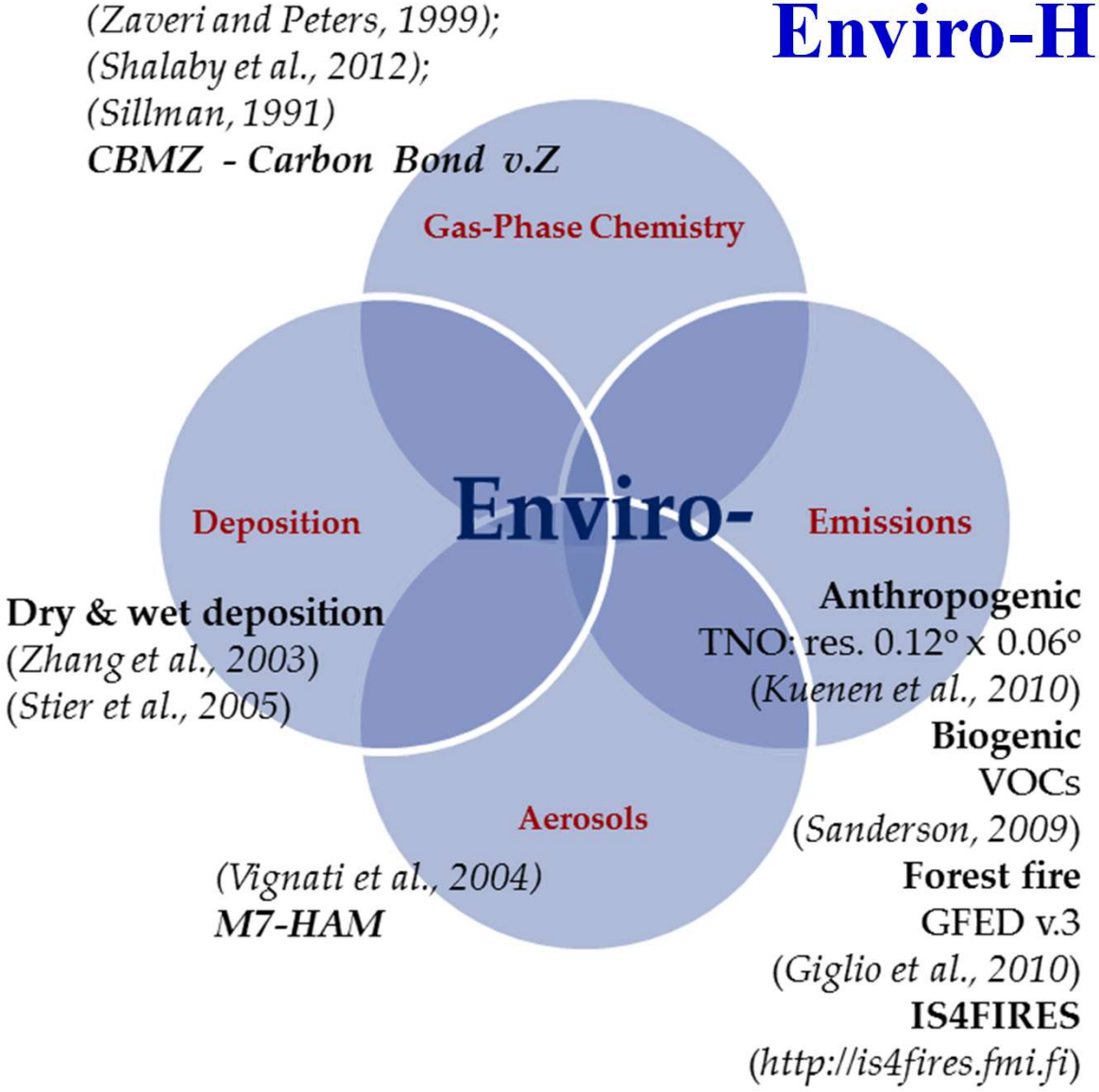
Enviro-HIRLAM (Environment – HIgh Resolution Limited Area Model)



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

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

Components of Enviro-HIRLAM



Components of the Enviro-HIRLAM modelling system

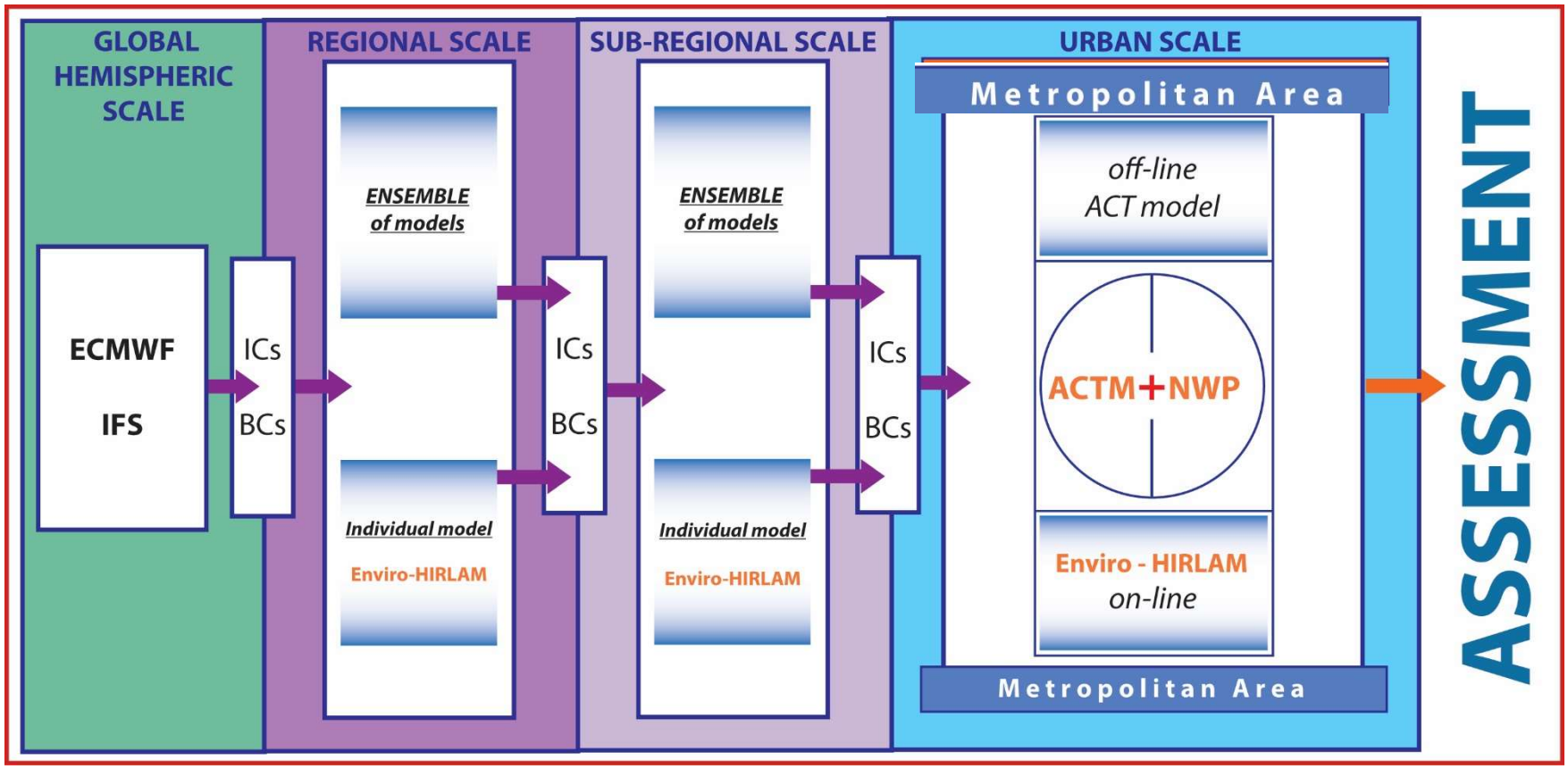
Enviro-HIRLAM research and development team

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



Urban Districts in Metropolitan Areas: Classification & Characteristics

Residential (RD)

City Center/High Buildings District (CC/HBD)

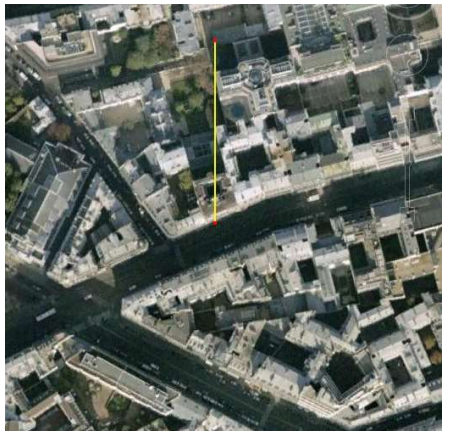
Industrial Commercial (ICD)

GIS - Extraction of districts related characteristics (statistics):

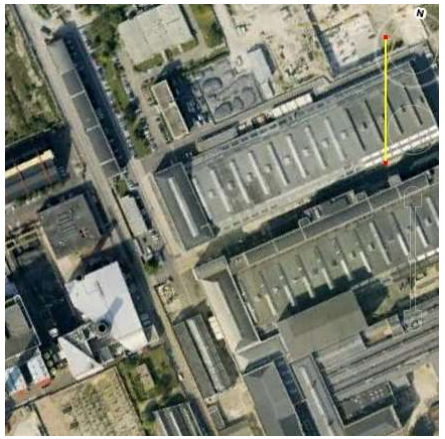
- ***Morphology parameters*** **(avg. height, volume, perimeter, compactness, space between buildings)**
- ***Cover modes*** **(surface density (SD) of buildings, of vegetation, hydrography, roads, N buildings)**
- ***Aerodynamic parameters*** **(roughness length, displacement height, frontal and lateral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

City Center

High Buildings District

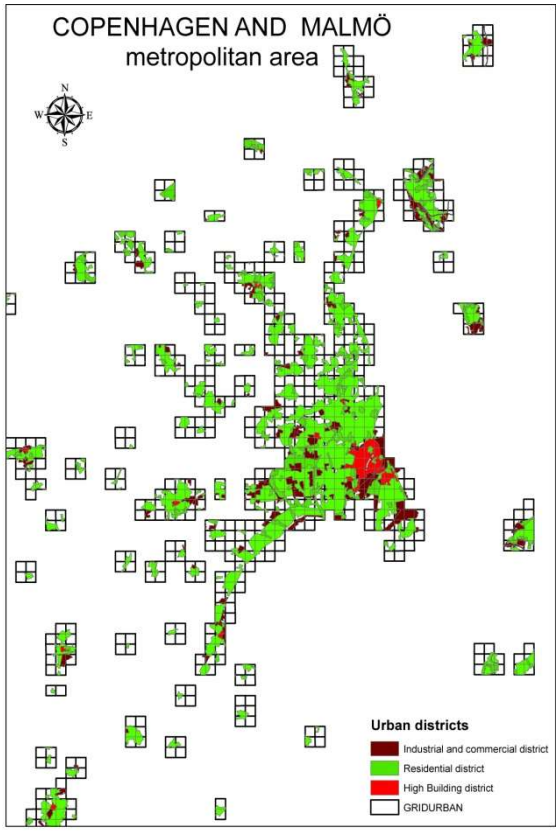


Residential District

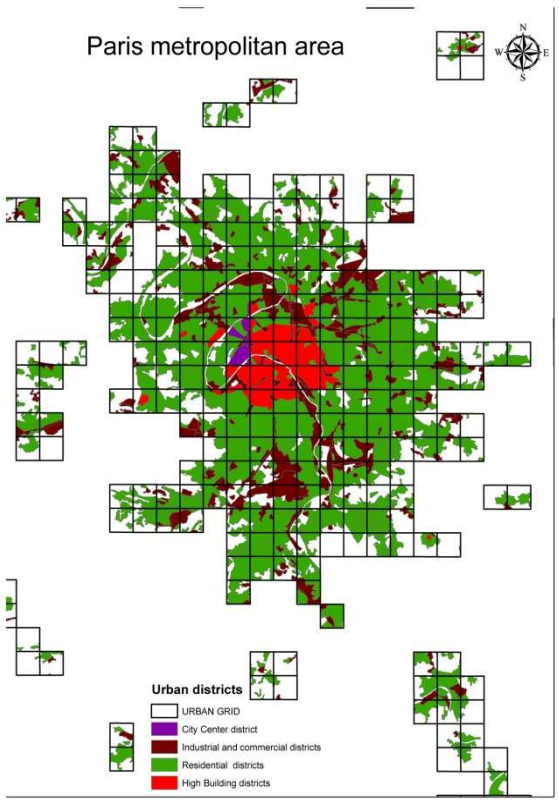


Industrial Commercial District

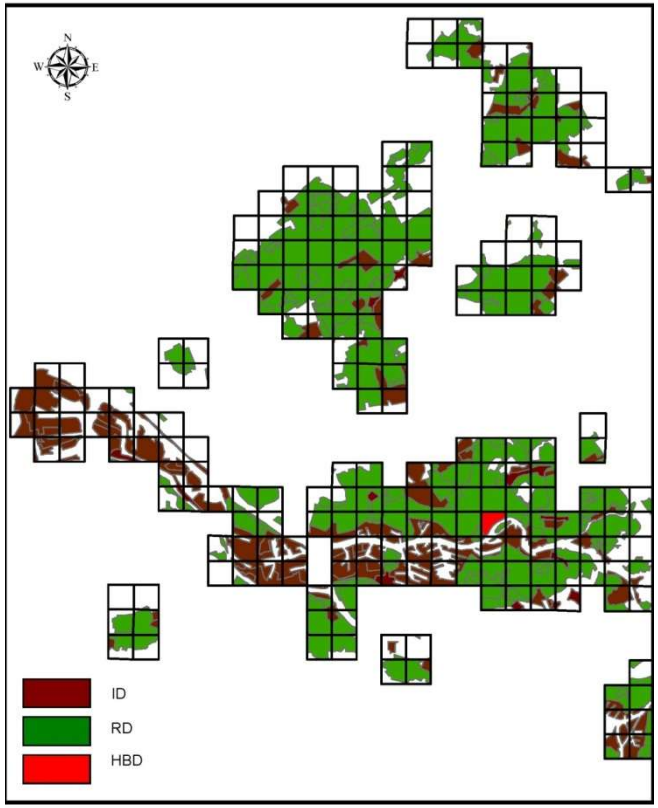
Urban Districts in Metropolitan Areas: Classification & Characteristics



Copenhagen (Denmark)

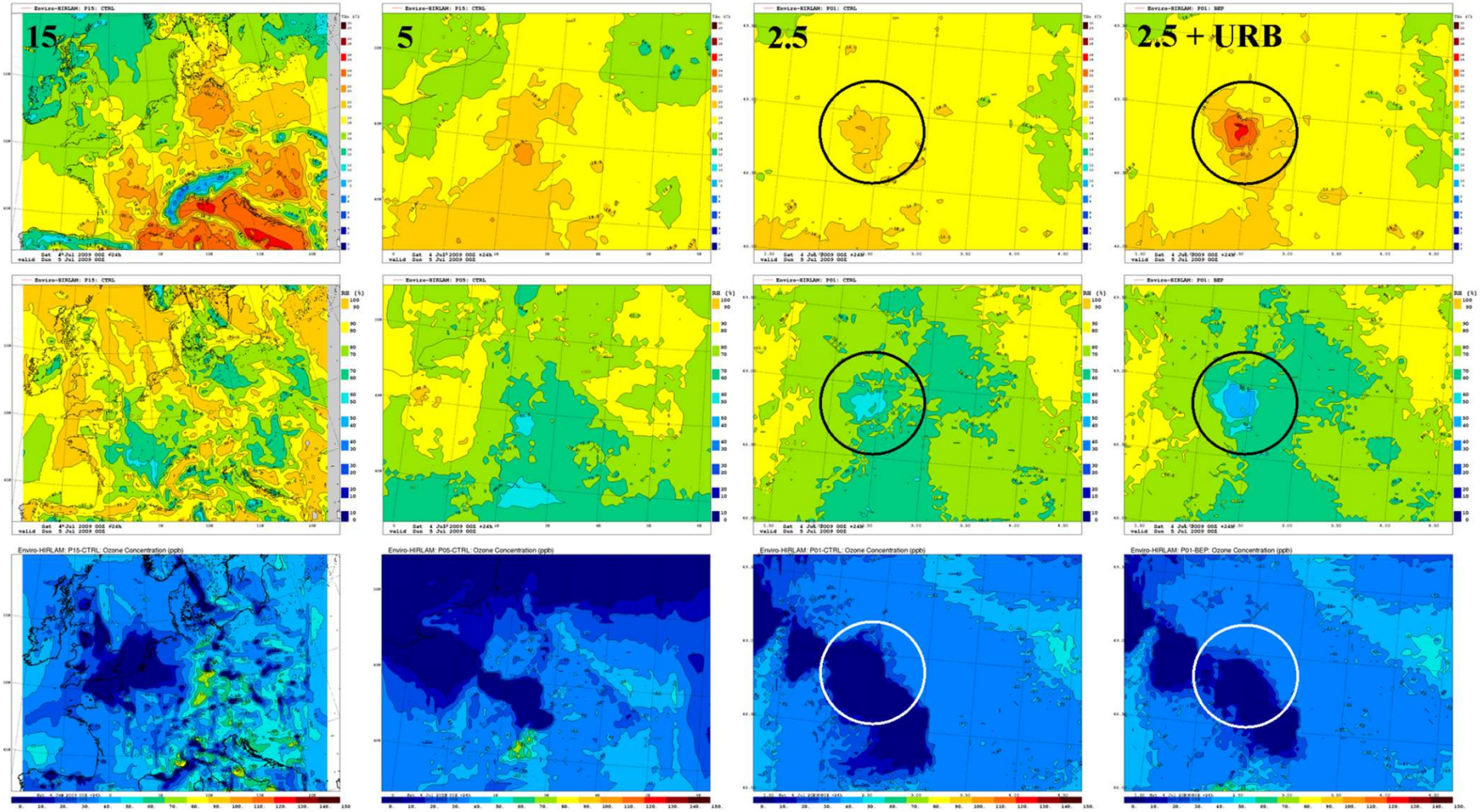


Paris (France) Metropolitan Areas



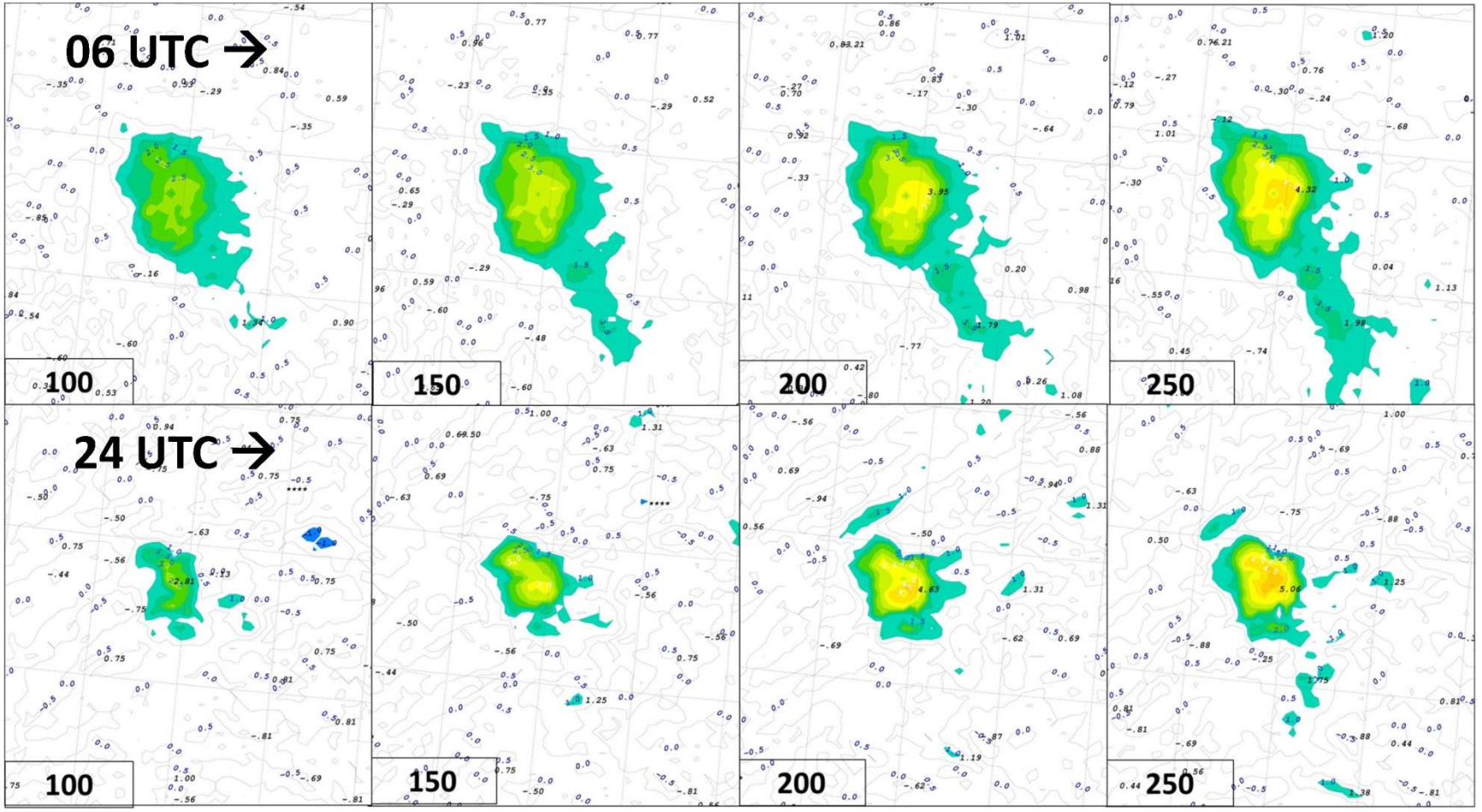
Rotterdam (The Netherlands)

Downscaling for Paris Metropolitan Area (meteorology & chemistry)



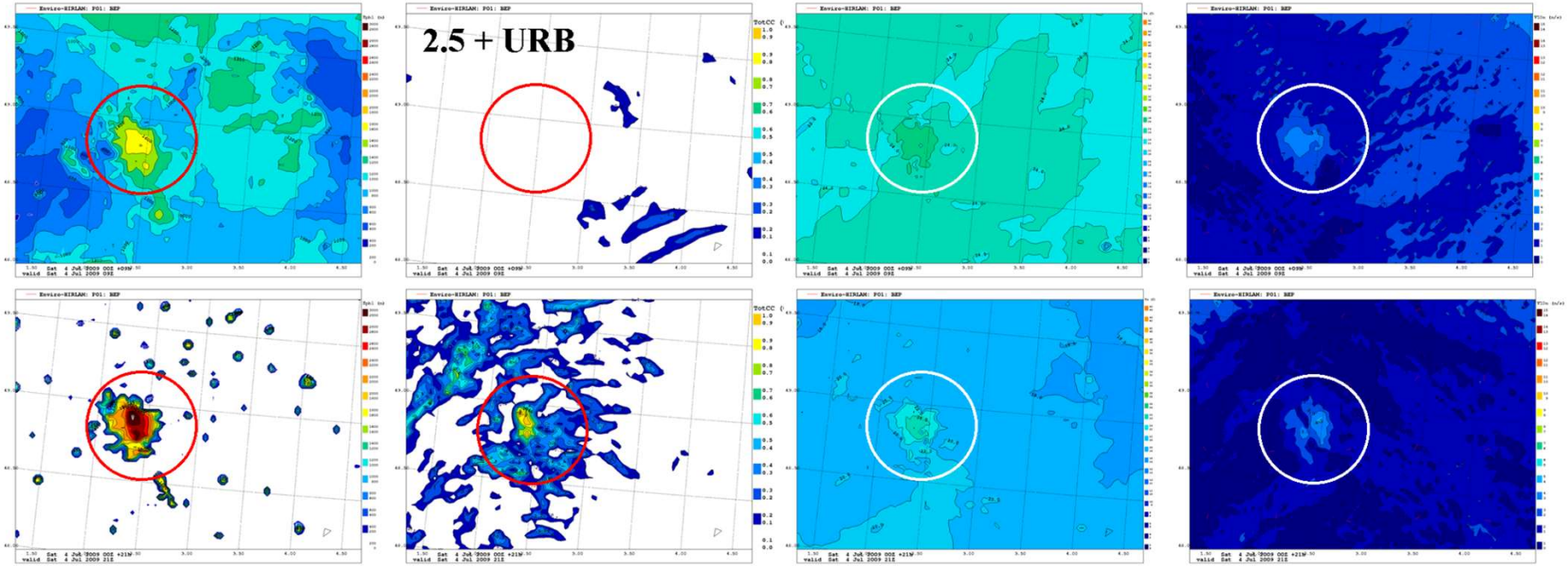
Enviro-HIRLAM downscaling (from left to right: CTRL 15—5—2.5 km & 2.5+URB) meteorological (top—air temperature, middle—humidity) and chemical (bottom—ozone) fields on 4 Jul 2009, 00+24 UTC.

Paris Metropolitan Area: T2m / AHF



Diurnal cycle variability of the difference fields (Enviro-HIRLAM-P01: urban vs. control runs) for air temperature at 2m with changing anthropogenic heat fluxes (100, 150, 200, and 250 W/m2) on 4 Jul 2009 at 06 and 24 UTCs

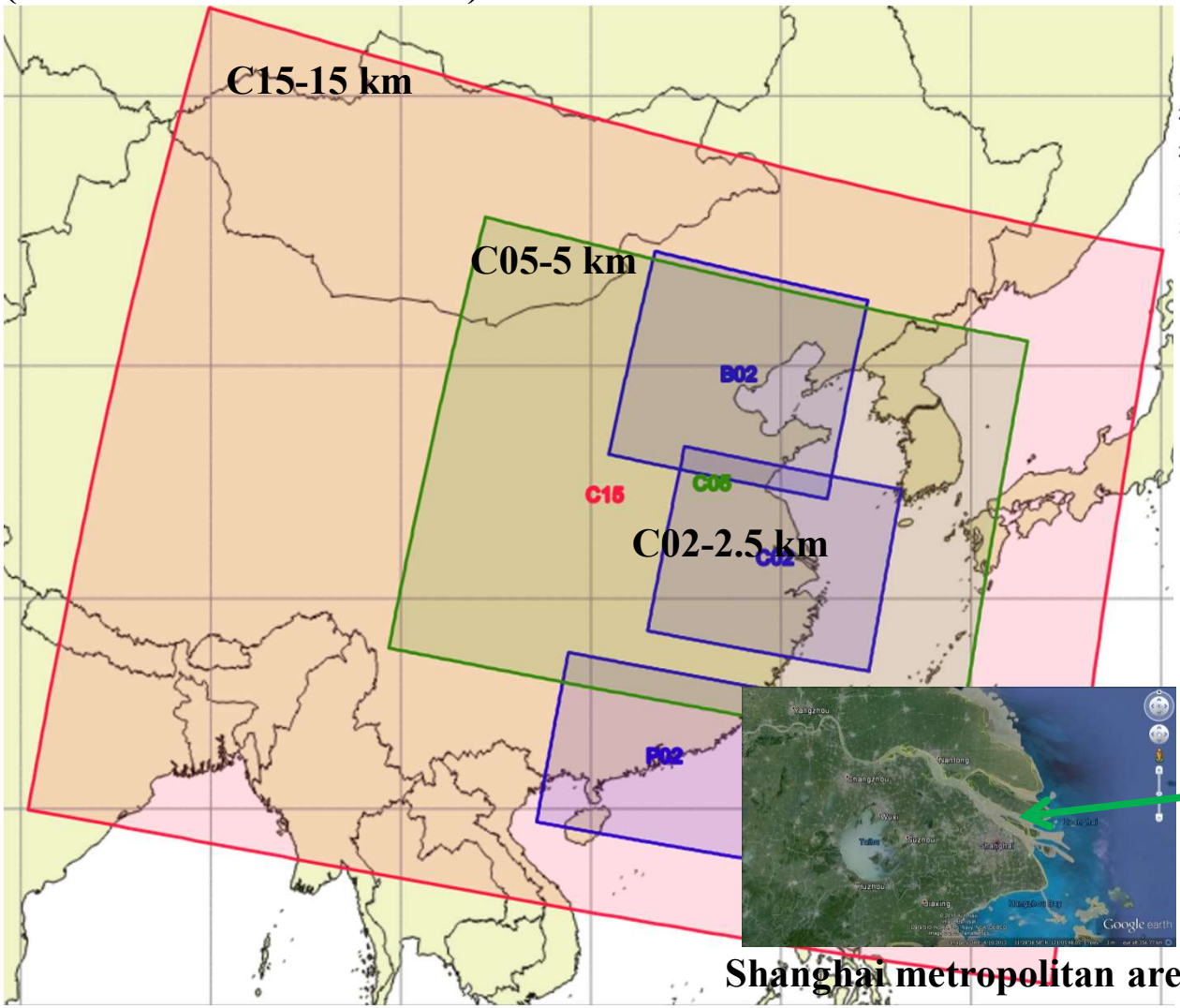
Paris Metropolitan Area: Temporal Variability of Meteo.Parameters



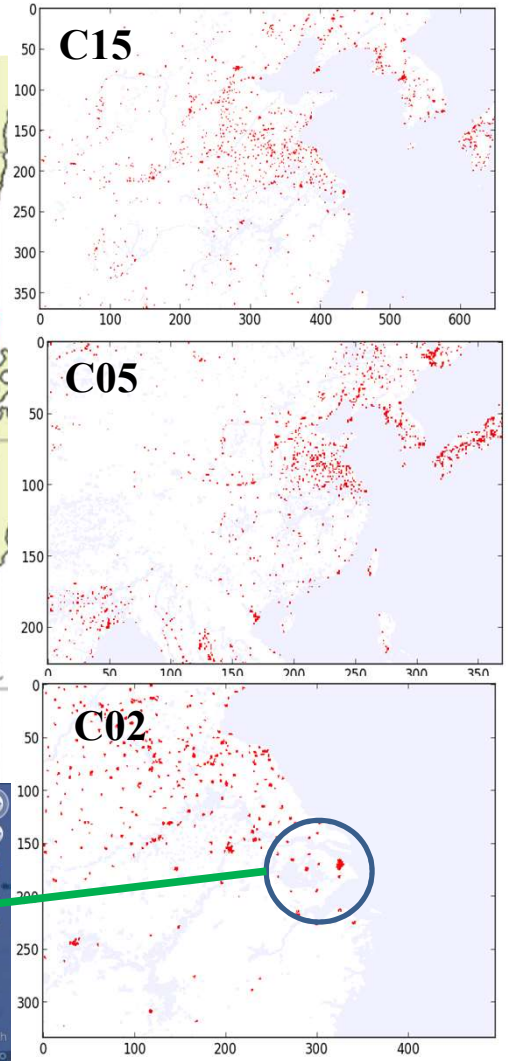
Variability of (from left-to-right) boundary layer height, total cloud cover, surface temperature, wind speed on 4 Jul 2009 at (top) 09 UTC and (bottom) 21 UTC based on Enviro-HIRLAM model run at 2.5 km resolution with URB=BEP+AHF included.

Downscaling for Enviro-HIRLAM: Modelling Domains vs. Metropolitan Areas

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



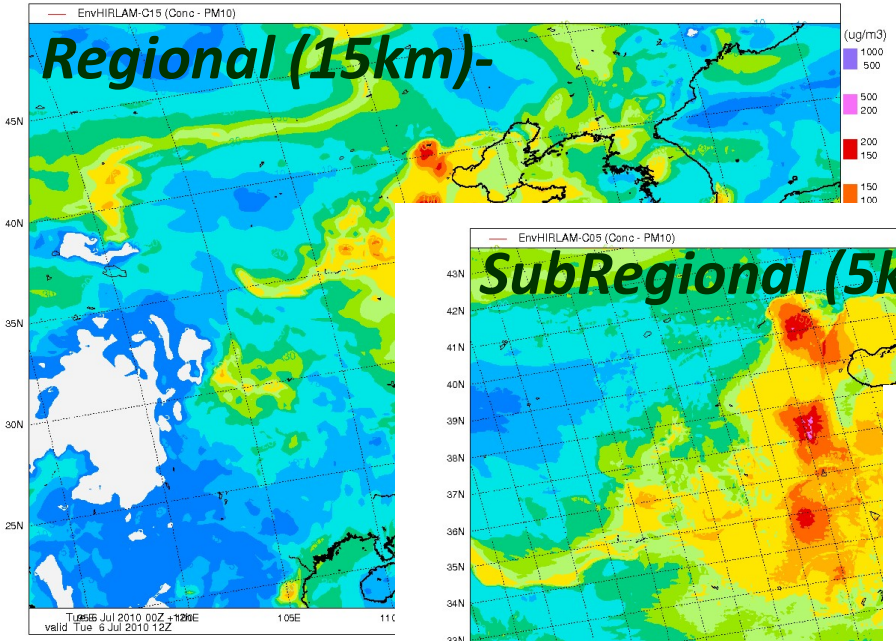
Urban areas in domains

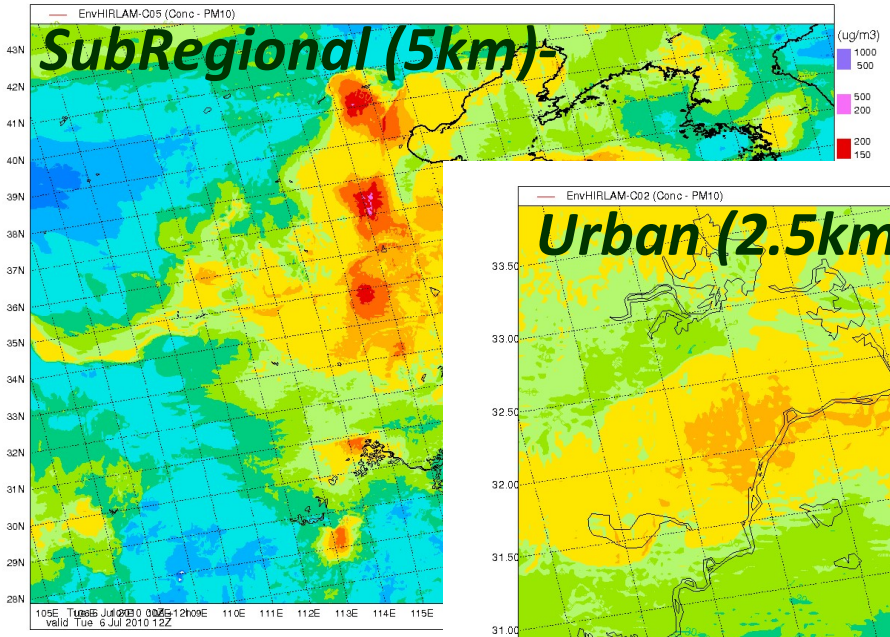


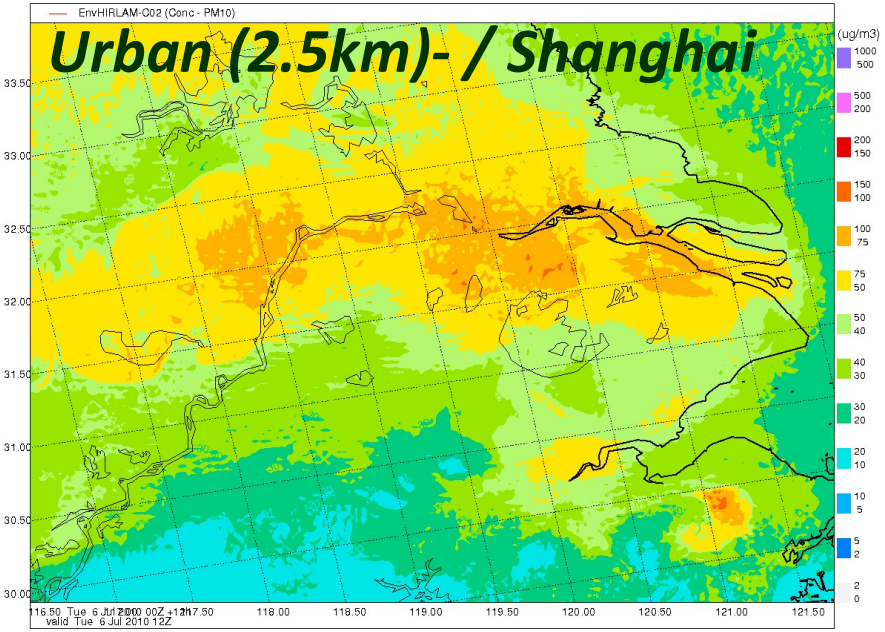
Shanghai metropolitan area (MA)

Enviro-HIRLAM Downscaling: Aerosols

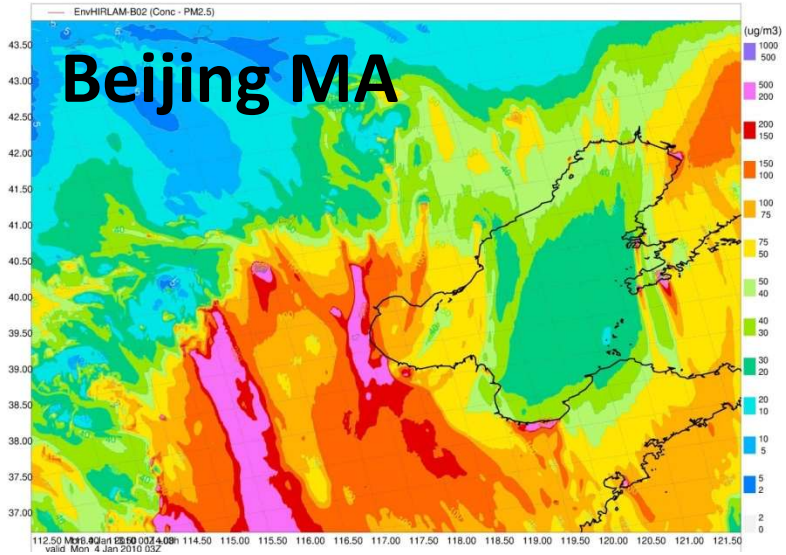
PM10 (ug/m3)

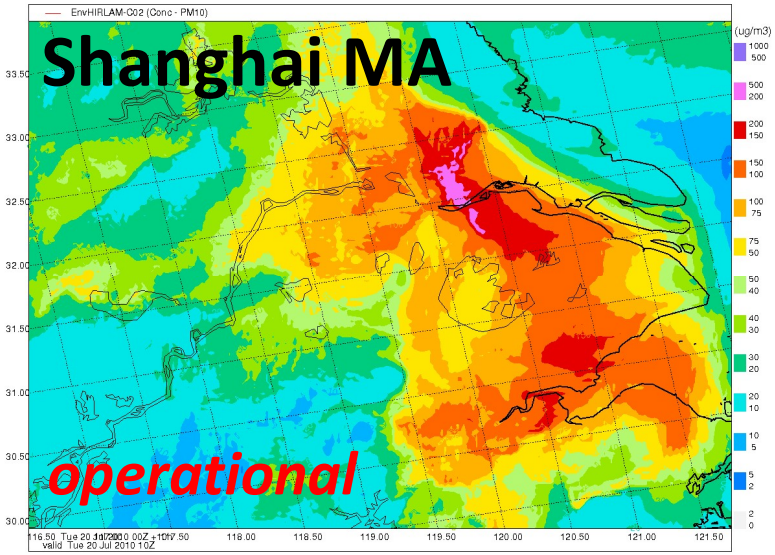


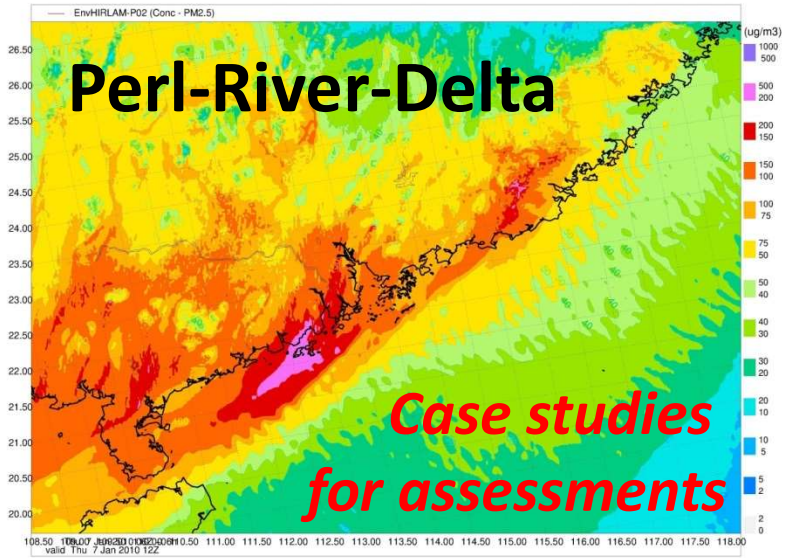




Downscaling to Metropolitan Areas (MA)





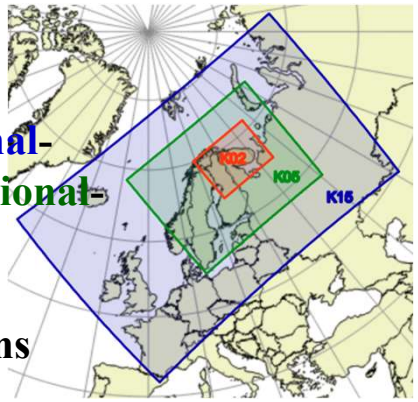


http://www.marcopolo-panda.eu/products/regional-air-quality-forecasts/enviro-hirlam

Seamless/ On-line Integrated Modelling

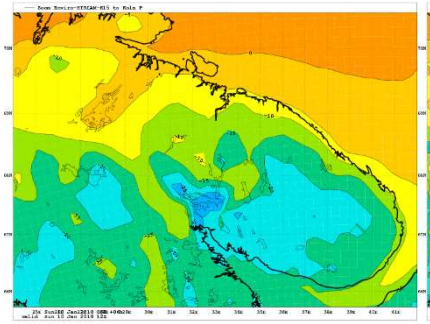
TRAKT - TRAnsferable Knowledge & Technologies for high-resolution environmental impact assessment & management (www.atm.helsinki.fi/peex/index.php/trakt-2018)

Regional-
subregional-
urban
scale
domains

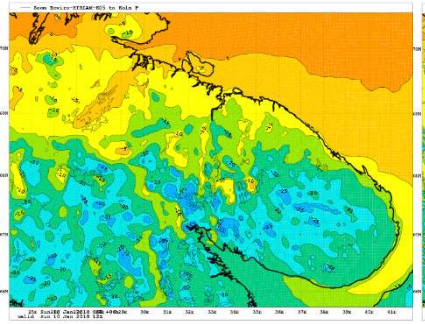


Enviro-HIRLAM Downscaling (with zooming)

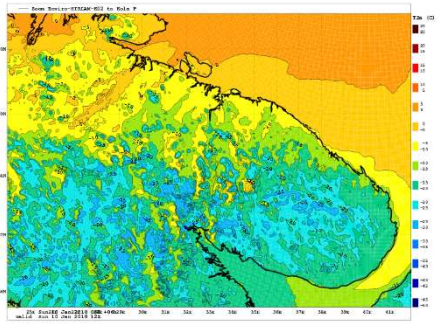
over the Kola Peninsula area)



15 km

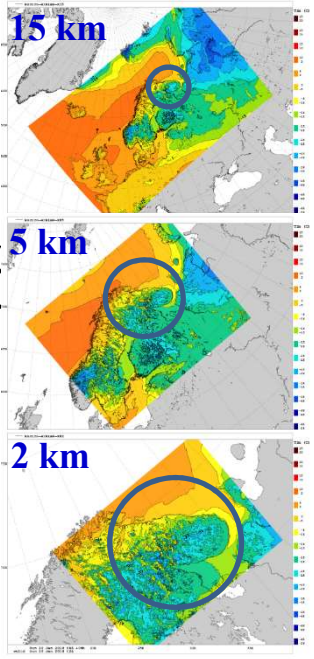


5 km

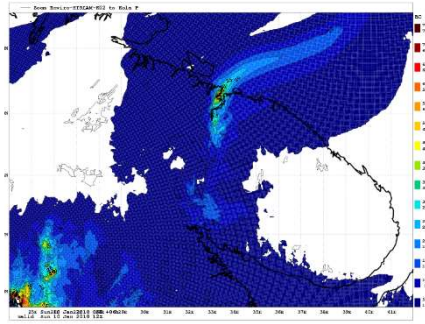


2 km

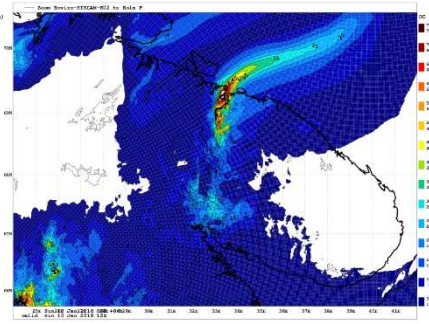
Seamless / online integrated meteorolog-chemistry-aerosols modelling at multi-scales



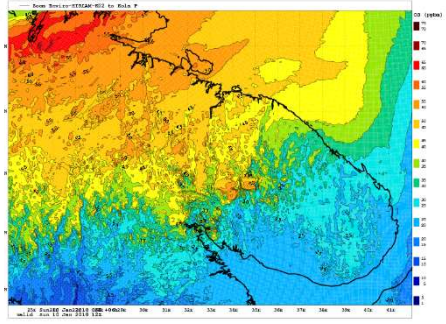
Meteorology: Air temperature at 2m (T2m)



Black carbon (BC)



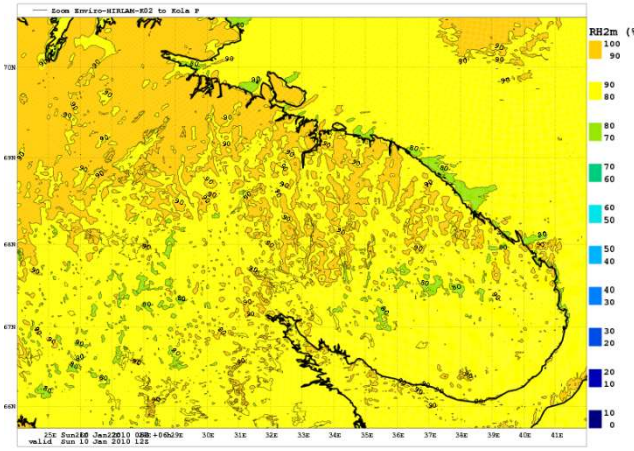
Organic Carbon (OC)

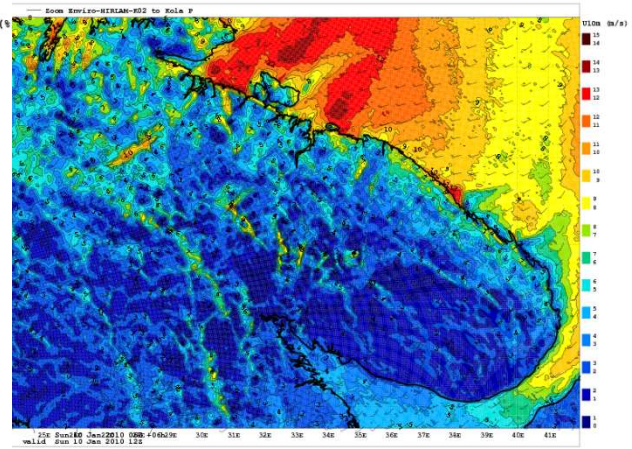


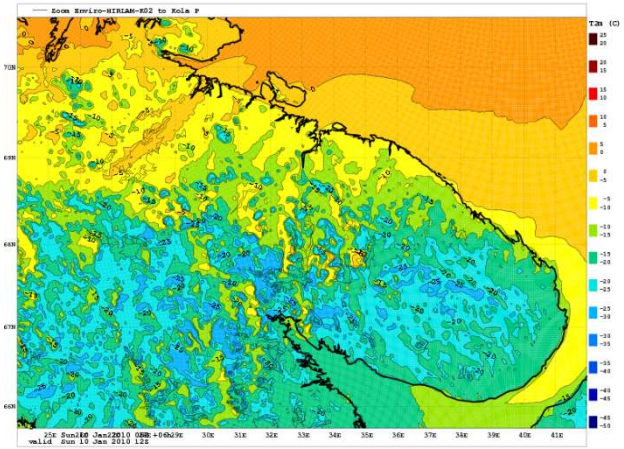
Ozone (O_3)

Atmospheric composition: at 2 km horizontal resolution

High resolution (at 2 km) for meteorology







Meteorology:

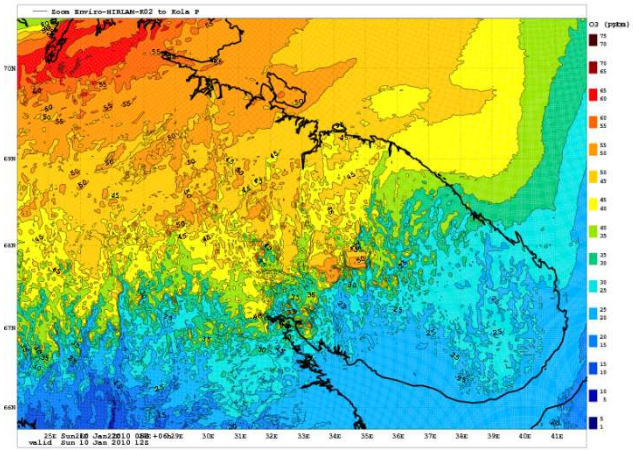
Relative Humidity (RH2m),

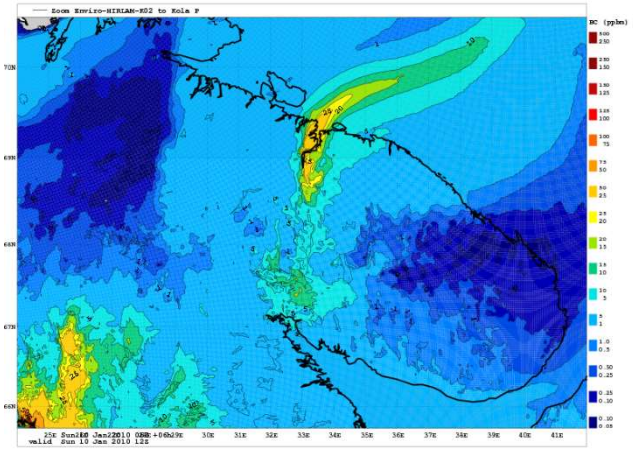
Wind Speed at 10m (U10m) ,

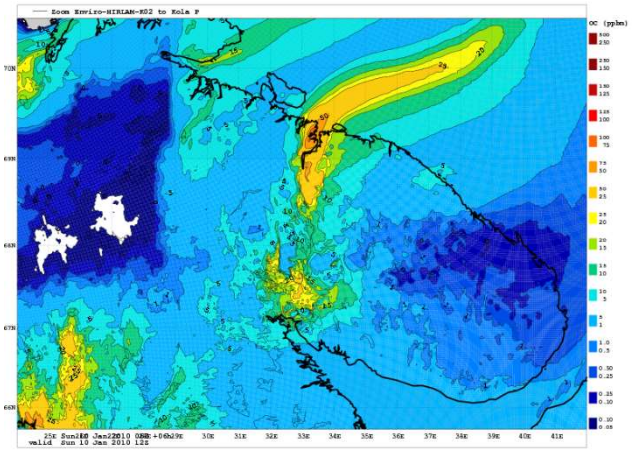
Air temperature at 2m (T2m)

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:

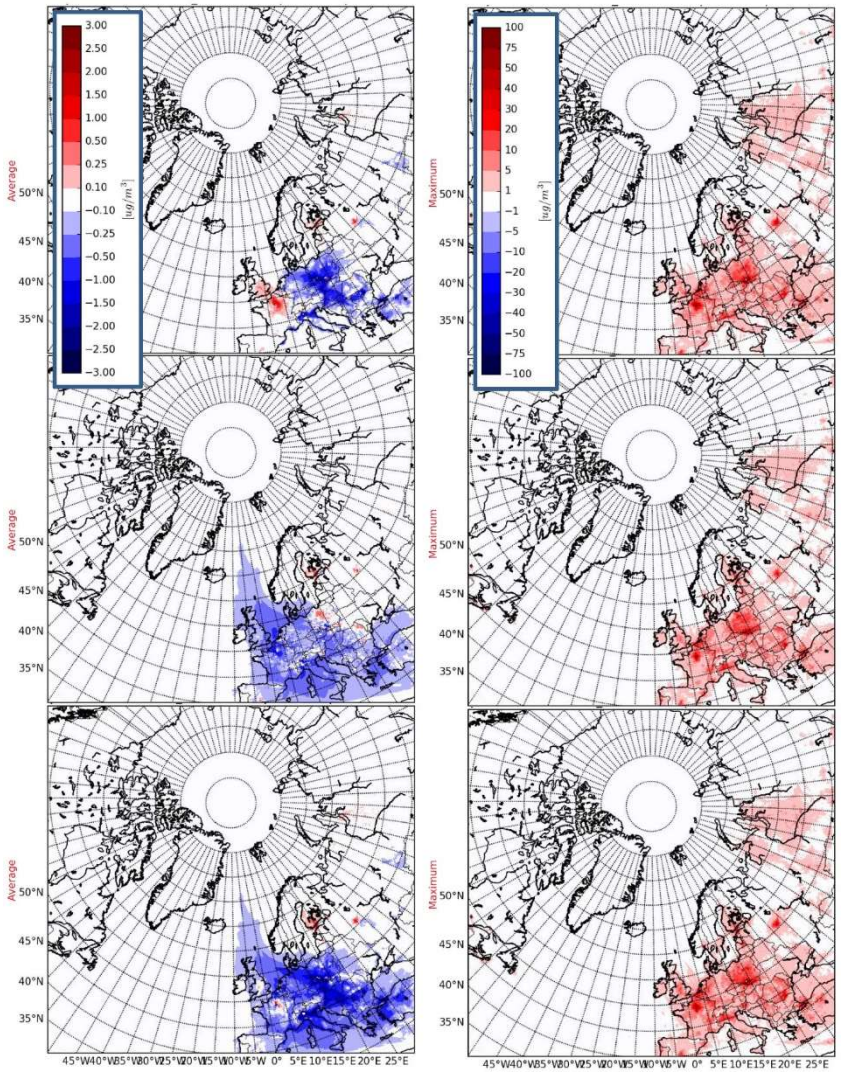
Ozone (O_3)

Black Carbon (BC),

Organic Carbon (OC),

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

Influence of Direct & Indirect Aerosols Effects

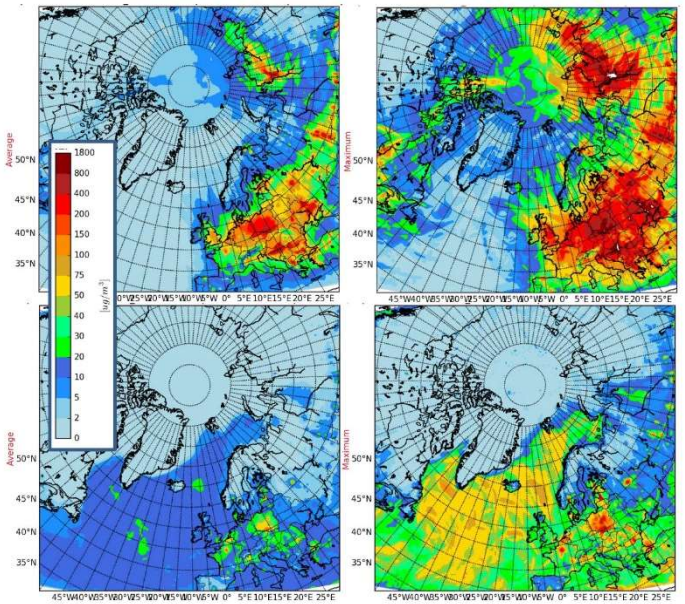


◄ Difference fields between CTRL&DAE (top), CTRL&IDAE (middle), CTRL&DAE+IDEA (bottom) runs with the Enviro-HIRLAM model for monthly (January) averaged (left) and maximum (right) concentration of **black carbon**, BC (in μg/m^3).

CTRL – reference run

DAE – Direct Aerosol Effect

IDAE – Indirect Aerosol Effect

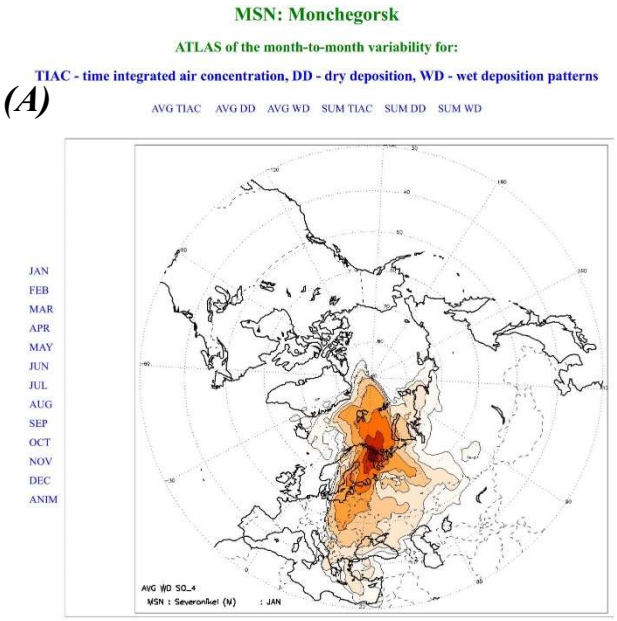


January (12 UTC) monthly averaged (left) and ▲ maximum (right) simulated concentration (in μg/m^3) of **SO_2** (top) and **PM2.5** (bottom) based on the Enviro-HIRLAM control run simulations.

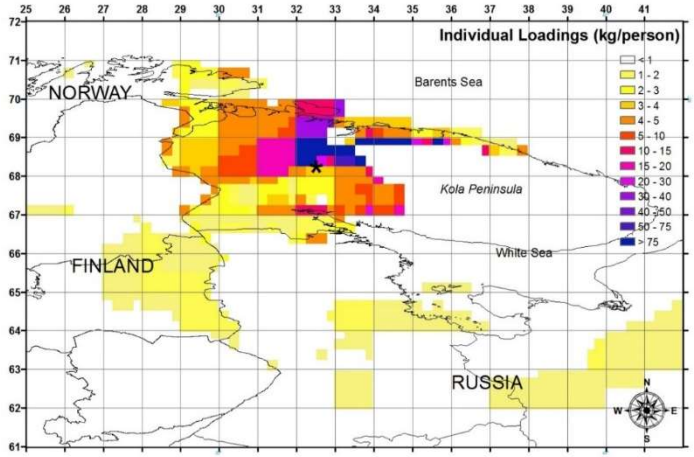
Web-Atlas for Transboundary Pollution & Loadings for Population

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

(A)



(B)



(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).

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

and others. *Respectfully, Dmitrii Gabyshev, UTMN and Alexander Mahura, UHEL-INAR.*

Planned 2020 research trainings as PEEX-AC intensive courses & YSSSs vs. COVID-19 shifted into 2021

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)

	Day 1 - 20 Apr Monday	Day 2 – 21 Apr Tuesday	Day 3 - 22 Apr Wednesday	Day 4 – 23 Apr Thursday	Day 5 – 24 Apr Friday	Day 6 – 25 Apr Saturday
08:30 – 09:15	Registration, welcome & useful info	L4. Multi-model ensembles of climate change simulations (Jouni Räisänen, UH)	L8. Physiographical data for multi-scale modelling (Alexander Mahura & Risto Makkonen, UH)	L12. Atmospheric gas-phase chemistry (Sergey Smyshlayev, RSHU)	L16. Aerosol - cloud - radiation interactions (Tuukka Petäjä, Risto Makkonen, Alexander Mahura, UH)	Exercises
09:20 – 10:05	L1. Introduction to PEEX program (Markku Kulmala, Hanna Lappalainen, UH; **with focus on** science education component)	L5. Numerical schemes (Maxim Motsakov, RSHU)	L9. Process-based modelling for meteorology-chemistry-aerosol System (Michael Boy, UH)	L13. Atmospheric liquid-phase chemistry (Sergey Smyshlayev, RSHU)	L17. Chemical (& meteorological) data assimilation (Polina Blakitnaya, RSHU & Michel Boy, UH)	Students oral presentations
10:05 – 10:25	*Coffee/ Tea Br.*	*Coffee/ Tea Br.*	*Coffee/ Tea Br.*	*Coffee/ Tea Br.*	*Coffee/ Tea Br.*	*Coffee/ Tea Br.*
10:25 – 11:10	L2. Numerical weather prediction and specific challenges (Sergey Smyshlayev, RSHU)	L6. Atmospheric chemical transport modelling & emissions (Sergey Smyshlayev, RSHU)	L10. Atmospheric boundary layer and dispersion processes (Sergey Zilitinkevich, UH)	L14. Aerosol particles properties (Tuukka Petäjä, UH)	L18. Evaluation of models and verification (Part 1 - meteorology) (Sergey Smyshlayev, RSHU & Risto Makkonen, Alexander Mahura, UH)	Students oral presentations
11:15 – 12:00	L3. Earth system modelling and and specific challenges (Risto Makkonen, UH)	L7. Seamless/ online integrated modelling (Alexander Mahura, UH)	L11. Atmospheric boundary layer and removal processes (Sergey Zilitinkevich, UH)	L15. Aerosol chemistry and microphysics (Tuukka Petäjä, UH)	L19. Evaluation of models and verification (Part 2 – atmospheric composition) (Sergey Smyshlayev, RSHU & Risto Makkonen, Alexander Mahura, UH)	Students oral presentations
12:00 – 13:30	*Lunch*	*Lunch*	*Lunch*	*Lunch*	*Lunch*	*Lunch*
13:30 – 14:15	Exercises	Exercises	Exercises	Exercises	Exercises	Awarding diplomas ceremony & Official closure of the Intensive Course Free Time / CitySightseeing
14:20 – 15:05	Exercises	Exercises	Exercises	Exercises	Exercises	
15:10 – 15:55	Exercises	Exercises	Exercises	Exercises	Exercises	
15:55 – 16:15	*Coffee/ Tea Br.*	*Coffee/ Tea Br.*	*Coffee/ Tea Br.*	*Coffee/ Tea Br.*	*Coffee/ Tea Br.*	
16:20 – 17:05	Exercises	Exercises	Exercises	Exercises	Exercises	
17:10 – 17:55	Exercises	Exercises	Exercises	Exercises	Exercises	
18:00 – 18:45	Exercises	Exercises	Exercises	Exercises	Exercises	
19:00 –	*Ice Breaking Party*	*St.Petersburg city Excursion*	*Official Dinner*	*RSHU Excursion (after lunch)*	Free Time / CitySightseeing	

COVID19 /shifted/ --- 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 /shifted/ --- 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

		Practical exercises: as Small-Scale Research Projects (SSRP) on seamless/ online integrated meteorology-chemistry-aerosols multi-scale and – multi-processes Enviro-HIRLAM, EC-Earth, MALTE-Box modelling for environmental applications (4-5 students per project) led by teachers (whom designed and realized the exercise – Michael Boy, Alexander Mahura, Risto Makkonen, Univ Helsinki) from 1st day till official oral presentation/ defence of SSRP outcomes)
		Socializing events: for participants - 1) Ice-Breaking Party, 2) Official Dinner, 3) Excursion to the City of St.Petersburg, 4) Excursion to RSHU University (will be organized after the lunch (for appx. 1-2 h period) and then exercises will be continued), and 5) Free Time / City Sightseeing
		Lectures covering aspects of: Fundamentals of atmospheric processes and modelling, surface and atmospheric boundary layer processes, atmospheric chemical transport modelling, aerosol physics and chemistry and modelling, evaluation and application
		Finals: Oral presentations & defence of SSRP – with awarding diplomas (3 ETCS) ceremony for students successfully presented and defended their projects, and official closure of the intensive training

Collaboration with Russian Partners

- **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"

  (2018-2020); www.atm.helsinki.fi/peex/index.php/enviro

- **Enviro-PEEX(Plus) on ECMWF** - "Research and development for integrated meteorology – atmospheric composition multi-scales and – processes modelling for the PEEX domain for weather, air quality and climate applications"

  (2021-2023)

  with RSHU, SRCES, SPBU, MSU, KSC, ICMMG, and others

- **PEEX-MP-Europa3** – "PEEX Modelling Platform research and development through HPC-Europa3 Transnational Access Programme" (individual grants)

  (2020-2022)

  - ✓ 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*

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

Thank you! Спасибо!

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