



Seamless / online integrated regional/subregional/urban scales and -process modelling

*Enviro-HIRLAM Research, Development, Application and
Science Education*

*by Alexander Mahura et al.
&
In collaboration with many colleagues*

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

*INAR-UHEL & IMMSP-NAS Online Workshop
6 June 2024*

Multi-Scales & -Processes Modelling at INAR

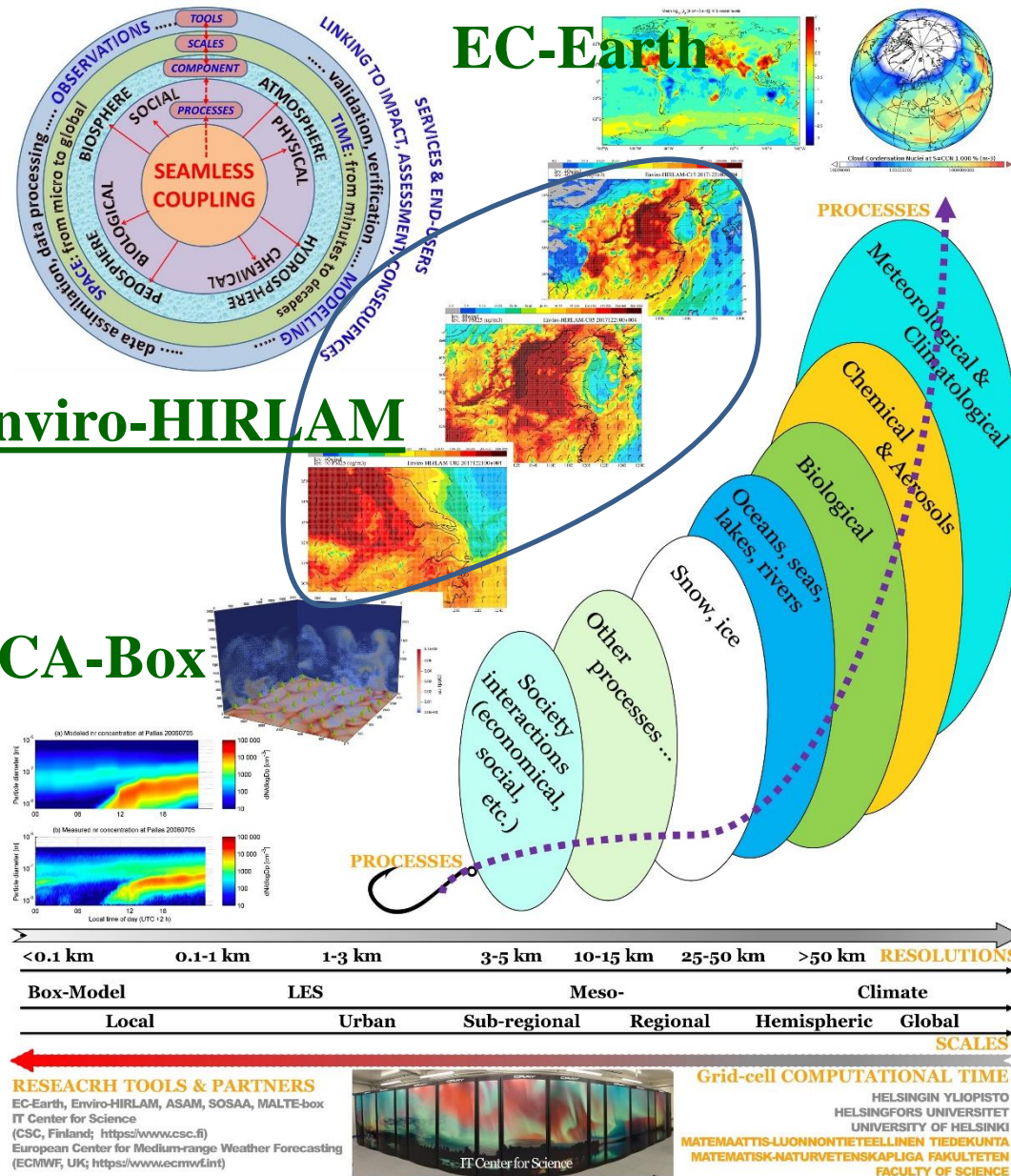
EC-Earth

Enviro-HIRLAM

ARCA-Box



Enviro-HIRLAM:
Environment –
High Resolution
Limited Area Model



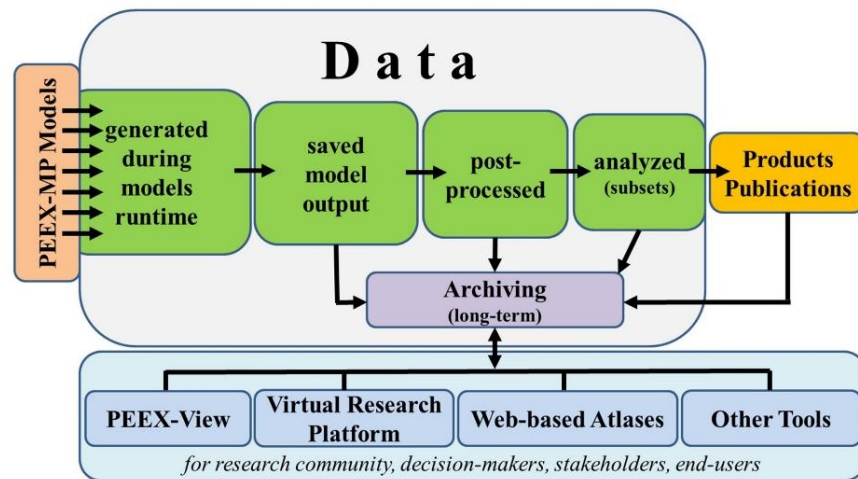
Poster of the Modelling Group at the INAR kick-off-meeting (Helsinki, Finland)

PEEX-MP Models as Research Tools



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

- PEE-Modelling-Platform (PEEX-MP) Overview
- Modelling Tools & Demonstration
- PEE-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		UCLAES-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			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



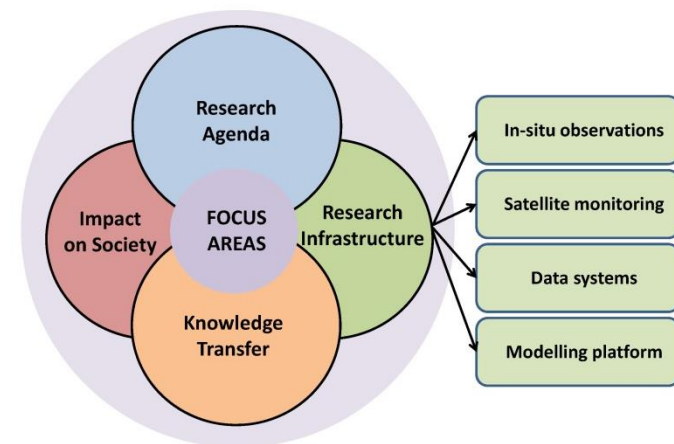
Pan-Eurasian Experiment
PEEX

INAR
INSTITUTE FOR ATMOSPHERIC AND
EARTH SYSTEM RESEARCH



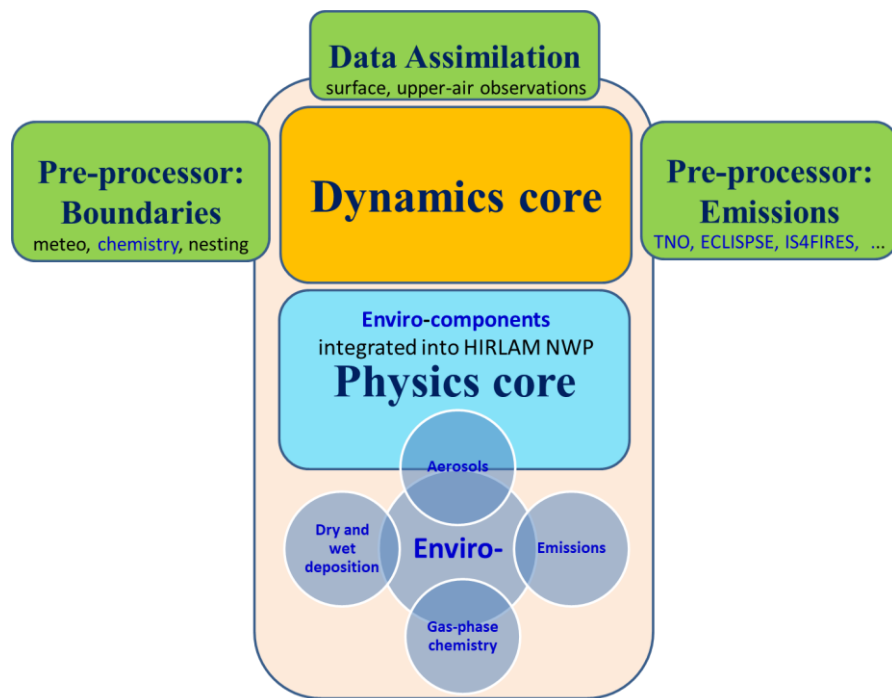
Enviro-HIRLAM/ HARMONIE (EnviroHH)

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



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

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

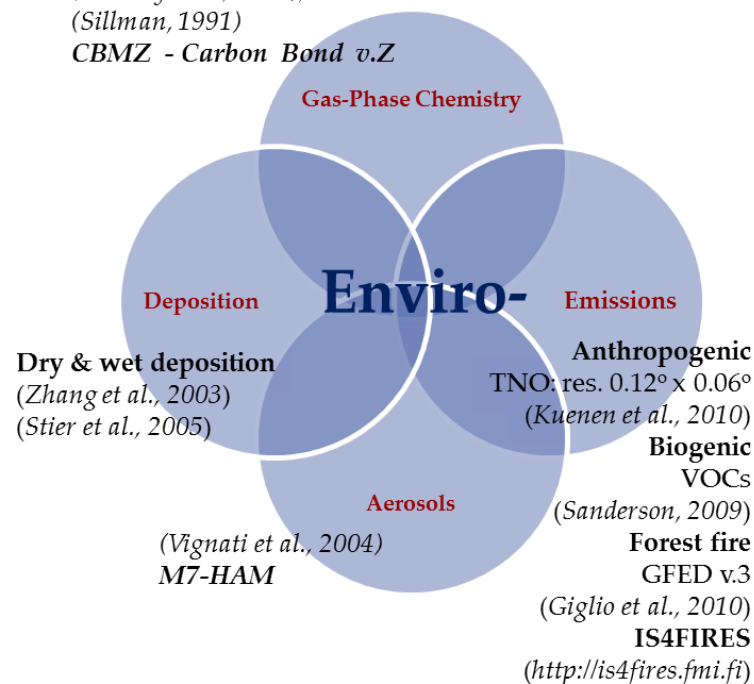


(Zaveri and Peters, 1999);

(Shalaby et al., 2012);

(Sillman, 1991)

CBMZ - Carbon Bond v.Z



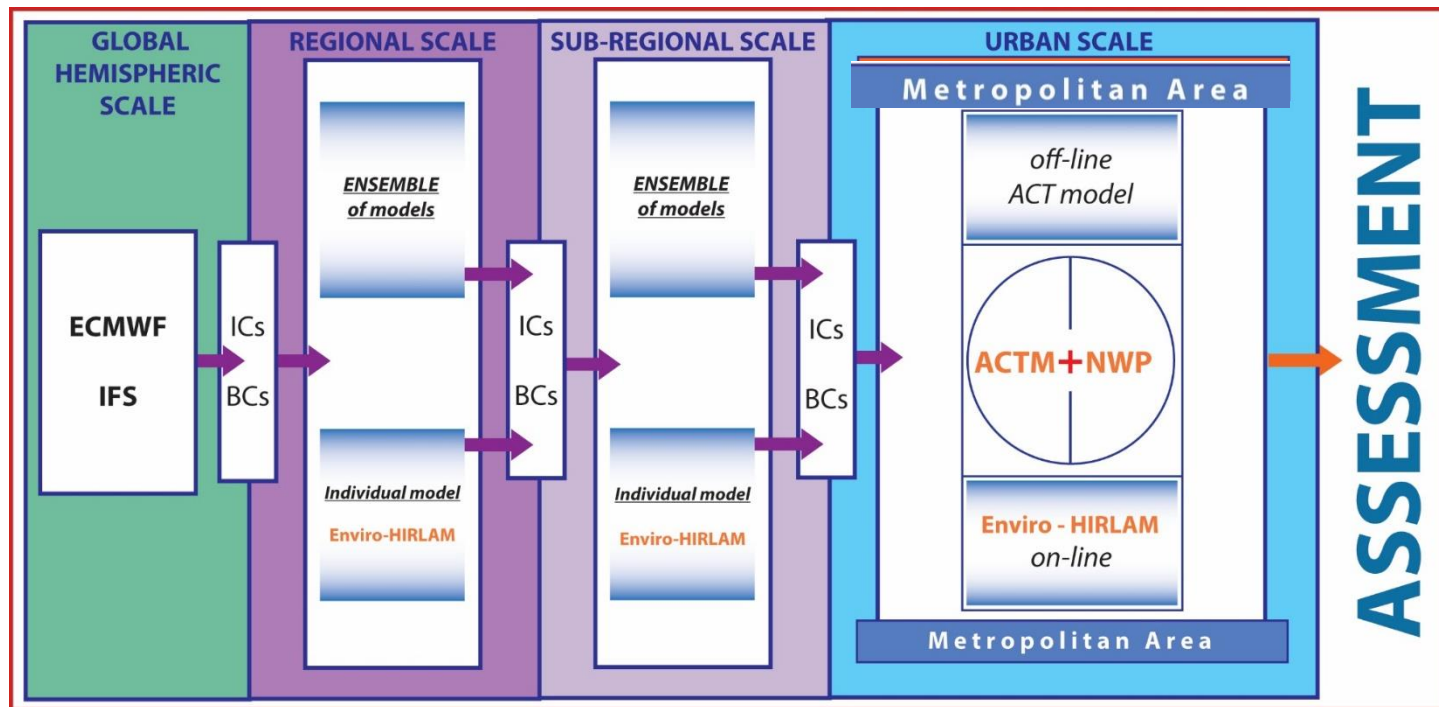
- Seamless / online coupled integrated meteorology-chemistry-aerosols downscaling modelling system for predicting weather and atmospheric composition

Enviro-HIRLAM research and development team
contributions from many colleagues through collaboration Finland, Denmark, Russia, Ukraine, Kazakhstan, Baltic States, Spain, Turkey, etc.)

(Baklanov et al., 2017; GMD) - last overview of the modelling system

(Mahura et al., 2024; BEData) – PEEX-MP overview; in Big Earth Data; <https://doi.org/10.1080/20964471.2024.2325019>

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



...- 2017 – 2018 – 2019 – 2020 – 2021 – 2022 – 2023 – 2024 – ...

DMI, DK: CRAY-XT5 (hirdev) -> CRAY-XC30/XC40 (hirdev/disperse)

*ECMWF, UK/INT: CRAY-XC30/40 -> (ecgate + cca) -> **migration in 2023+**, IT/INT*

*UHEL, FI: CRAY-XC30/40 (taito/sisu) -> Atos BullSequana X400/XH2000 (puhti/mahti -> **lumi**, 2024+)*

Atmospheric pressure, air/soil/water & mx-min temperatures, wind characteristics, specific/ relative humidity, precipitation, cloudiness, fluxes (latent, sensible, etc.), boundary layer height, etc.

& more detailed list (i.e. modelled parameters) is at:

HIRLAM/HARMONIE website <http://hirlam.org> &
<http://apps.ecmwf.int/codes/grib/param-db>

Available Modelled Atmospheric Composition

PM2.5, PM10, sulphates, black and organic carbon, dimethyl sulphide, sea salt, dust, etc. + ozone, nitrogen dioxide and oxide, carbon monoxide, ammonia, sulfur dioxide, etc.

Deposition (wet, dry, total), concentrations of chemical species, number & mass concentration (for coarse, Aitken and accumulation modes/ soluble-insoluble) for aerosol components

& more detailed list (i.e. modelled parameters) is at:

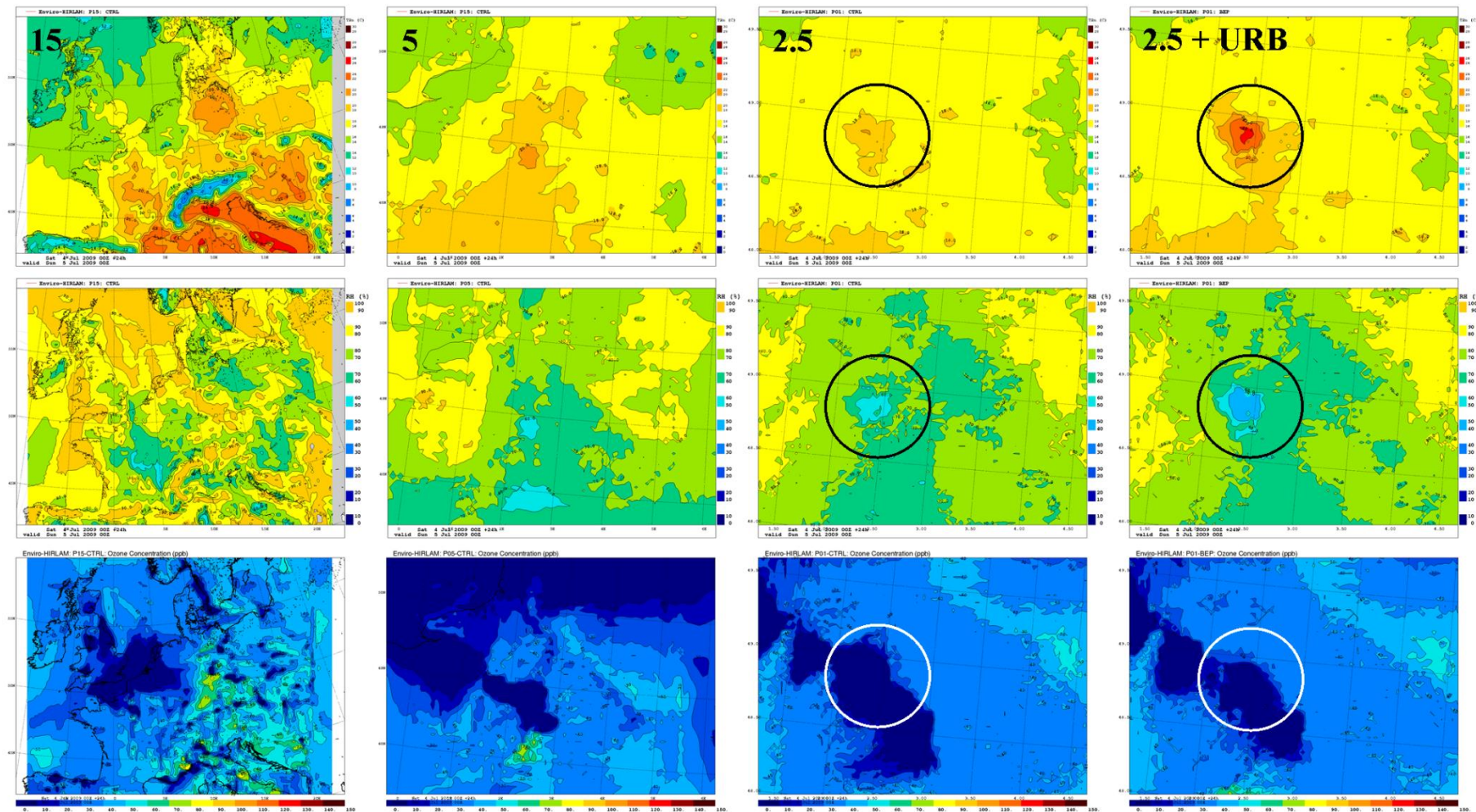
Enviro-HIRLAM Chem Branch at <http://hirlam.org>



Paris Metropolitan Area France

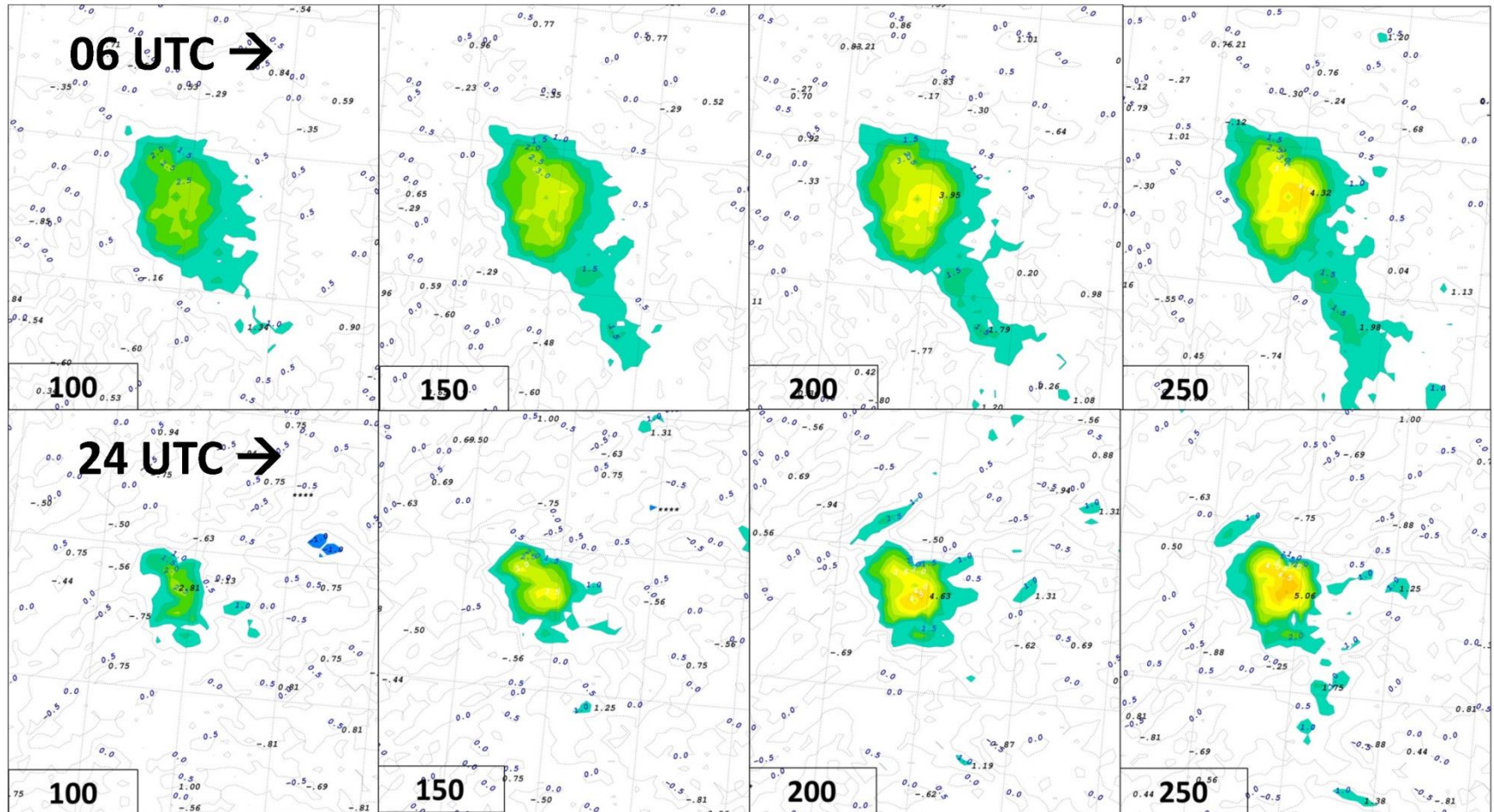


Downscaling for Paris Metropolitan Area (meteorology & chemistry)



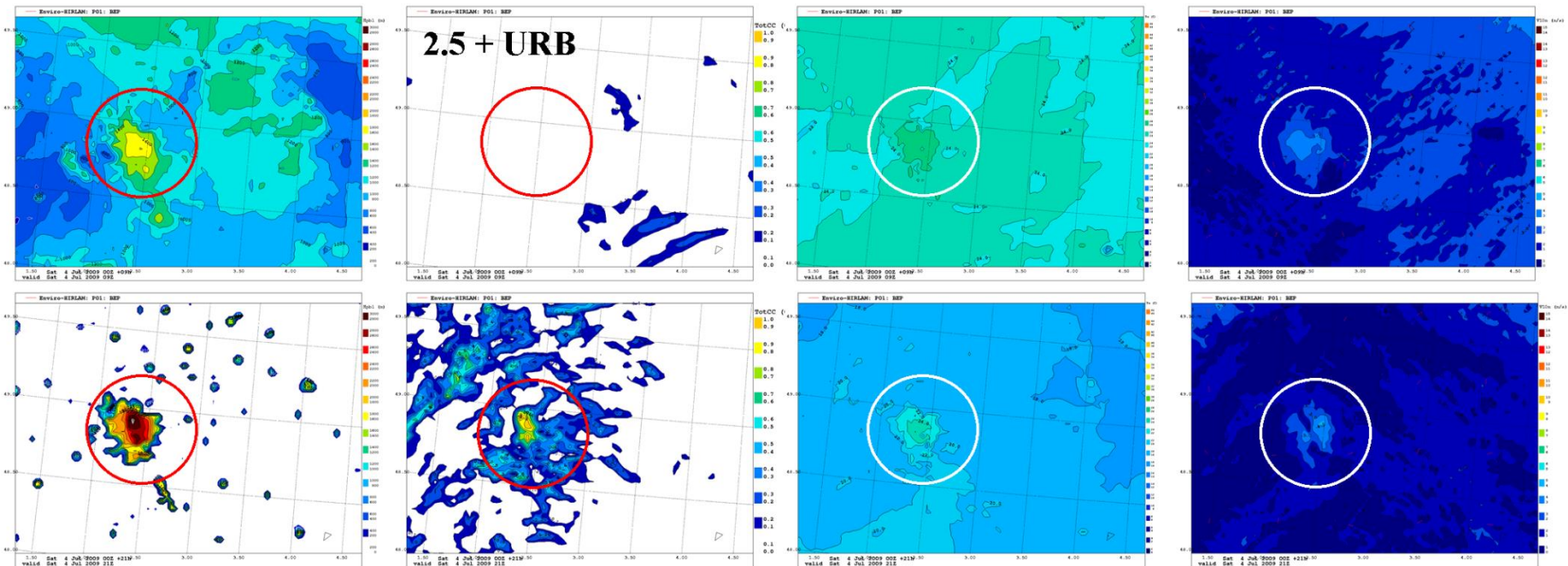
Enviro-HIRLAM downscaling (from left to right: CTRL 15—5—2.5 km & 2.5+URB) meteorological (top—air temperature, middle—humidity) and chemical (bottom—ozone) fields on 4 Jul 2009, 00+24 UTC.

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

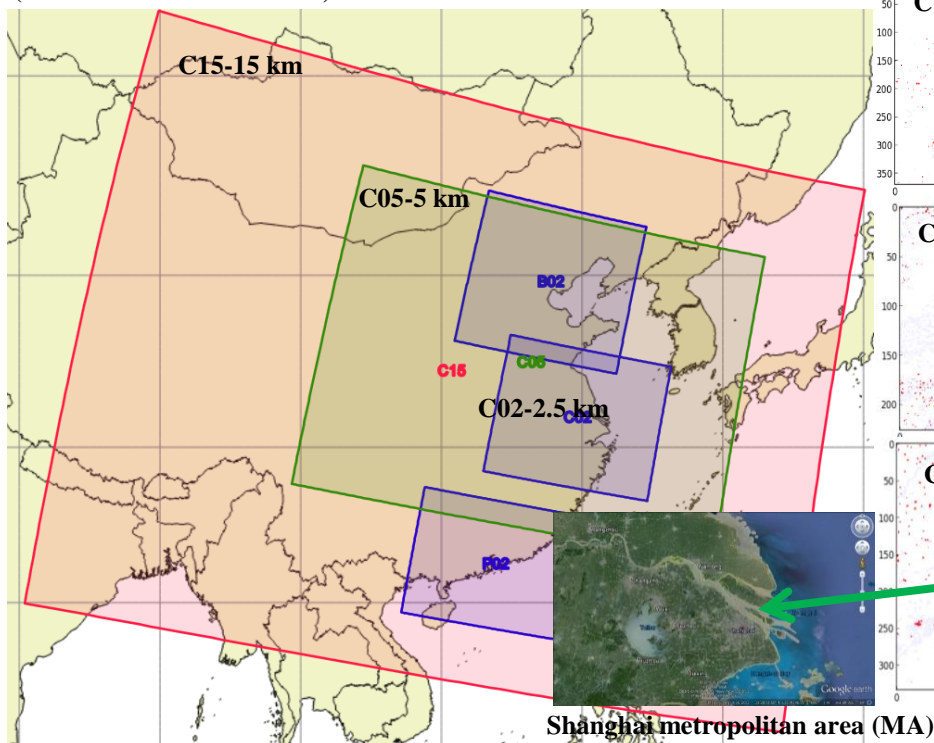
Paris Metropolitan Area: Temporal Variability of Meteo.Parameters



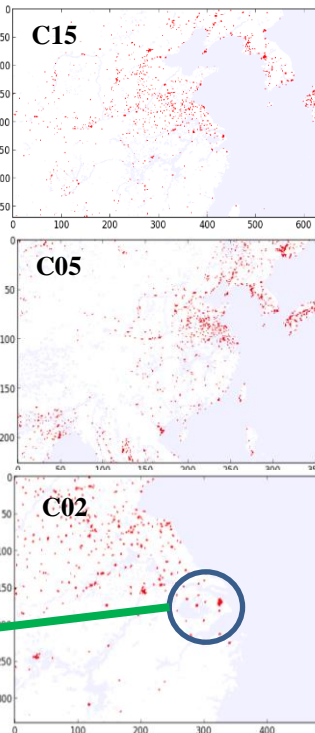
Variability of (from left-to-right) boundary layer height, total cloud cover, surface temperature, wind speed on 4 Jul 2009 at (top) 09 UTC and (bottom) 21 UTC based on Enviro-HIRLAM model run at 2.5 km resolution with URB=BEP+AHF included.

EU MarcoPolo Project

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



Urban areas in domains



CPU time spent for 1 run:

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

Surface level disc use for 1 run:

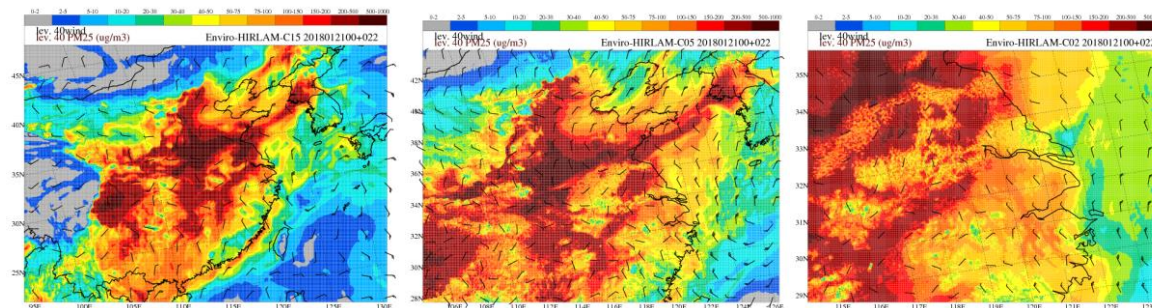
C15: 533M
C05: 1,5G
C02: 947M

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)



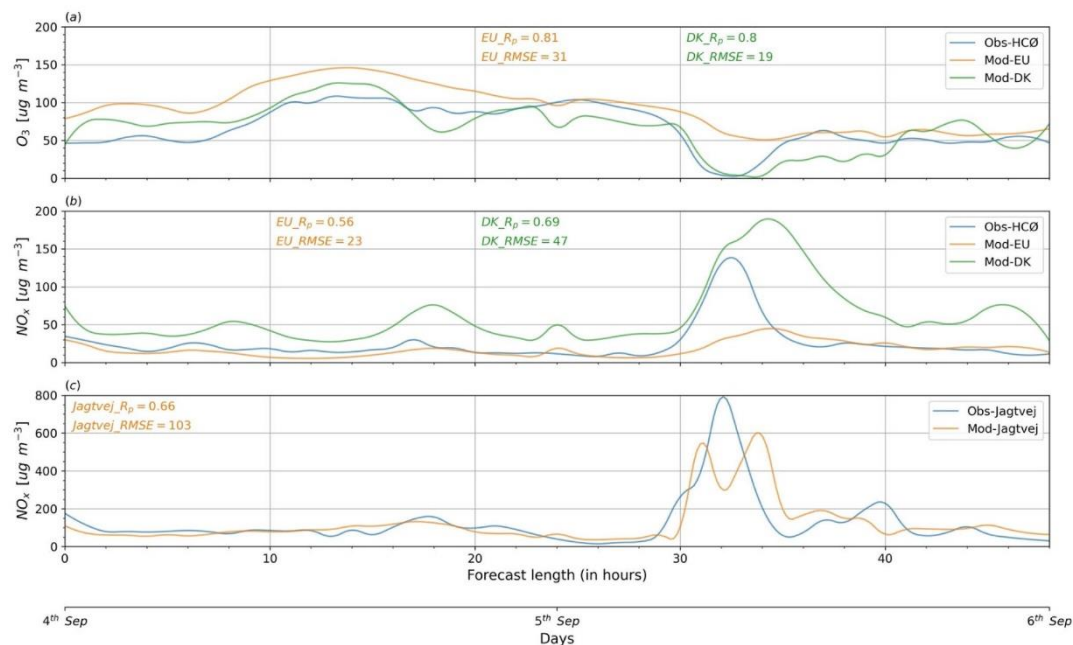
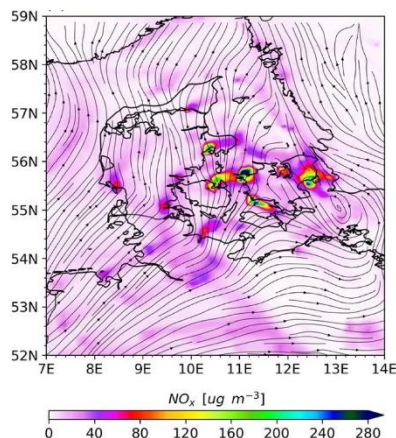
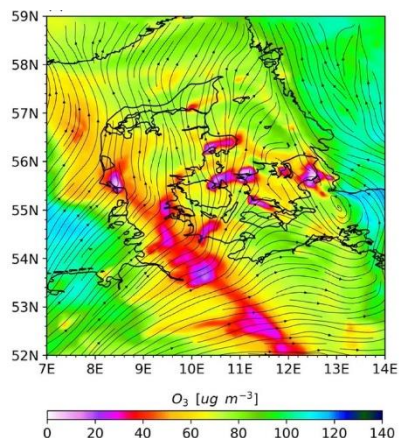
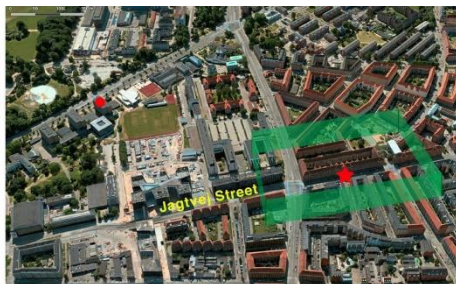
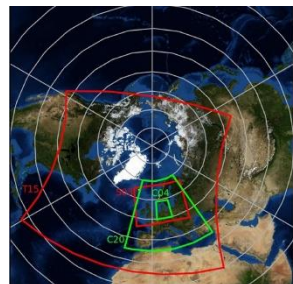
Enviro-HIRLAM operational PM2.5 concentration forecasts for China in a downscaling chain
(left-right: regional, sub-regional, urban - Shanghai metropolitan area) for 21 Jan 2018, 22 UTC

<http://www.marcopolo-panda.eu/products/regional-air-quality-forecasts/enviro-hirham>



Downscaling Chain Testing

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



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

By Nuterman, Mahura, Baklanov, Amstrup, Zakey

MS: acp-2020-1308 (2021)



Nordic TRAKT Project



Pan-Eurasian Experiment
PEEX

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EARTH SYSTEM RESEARCH



TRAnsferable Knowledge & Technologies for high-resolution environmental impact assessment & management

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

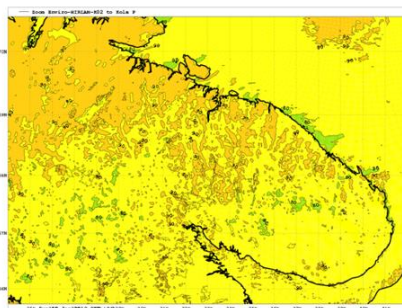
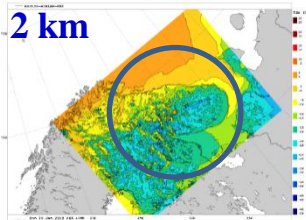
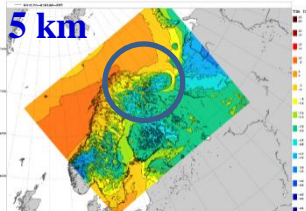
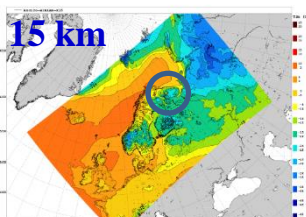
**Regional-
subregional-
urban
scale
domains**



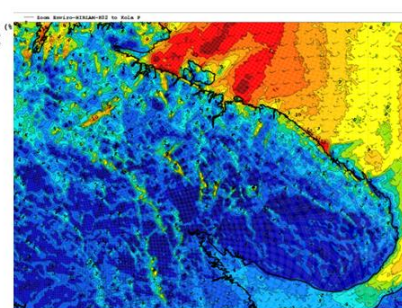
**Seamless /
online
integrated**

**meteorolog-
-chemistry-
aerosols
modelling**

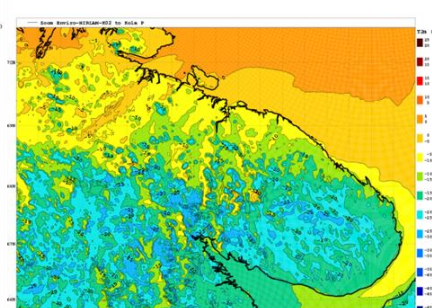
**at multi-
scales**



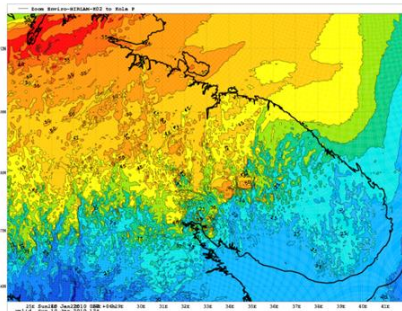
Meteorology:
Relative Humidity (RH2m)



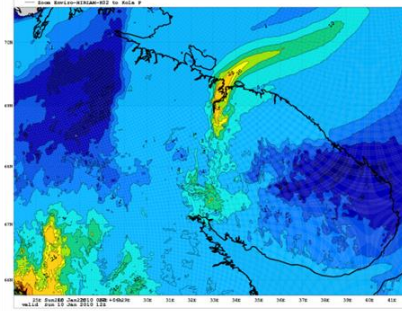
Wind Speed at 10m (U10m)



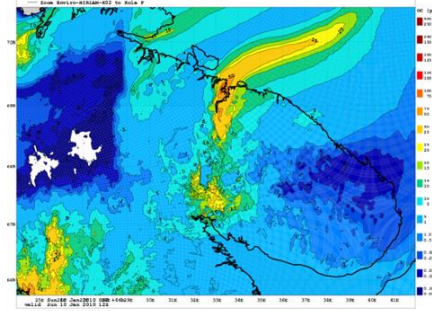
Air temperature at 2m (T2m)



Atmospheric Composition:
Ozone (O₃)



Black Carbon (BC)



Organic Carbon (OC)

Enhanced integrated approach to knowledgeable high-resolution environmental quality assessment
by Esau, Bobylev, Donchenko, Gnatiuk, Lappalainen, Konstantinov, Kulmala, Mahura, Makkonen, Manvelovac, Miles, Petäjä, Poutanen, Fedorov, Varentsov, Wolf, Zilitinkevich, Baklanovh
MS: ENVSCI 2877 (2021)



Enviro-HIRLAM:

Research, Development & Application

in recent on-going projects

Enviro-PEEX(Plus) on ECMWF project



The authors are thankful to the CSC – IT Center for Science, Finland (CSC; www.csc.fi/csc) for technical support and advice & visits to acknowledge grants for generous computational resources.

The CSC & CSCHE@ supercomputing facilities (Ahti Salonen and J. CRISTOFARI) were used as part of the CSCHE@Envi-PeSOS projects.

The CSCHE@ boundary conditions, meteorological and air quality observational datasets were used for application, validation and verification of the models.

The authors would like to thank Dr. Eero Mäkelä from CSCHE@-PESSO@ for providing the AQS data.

*Generated by Enviro-HIRLAM model output
can be used for various assessment studies*

Integrated Modelling and Analysis of Influence of Land Cover Changes on Regional Weather Conditions/ Patterns

with Larysa Pysarenko (with UHMI, UA)

Aim: to investigate influence of land-cover changes (current vs. scenarios) and its consequences on meteorology for cases of extreme meteorological situations (heatwave, heavy rains and snowfall) & air quality/ atmospheric composition.

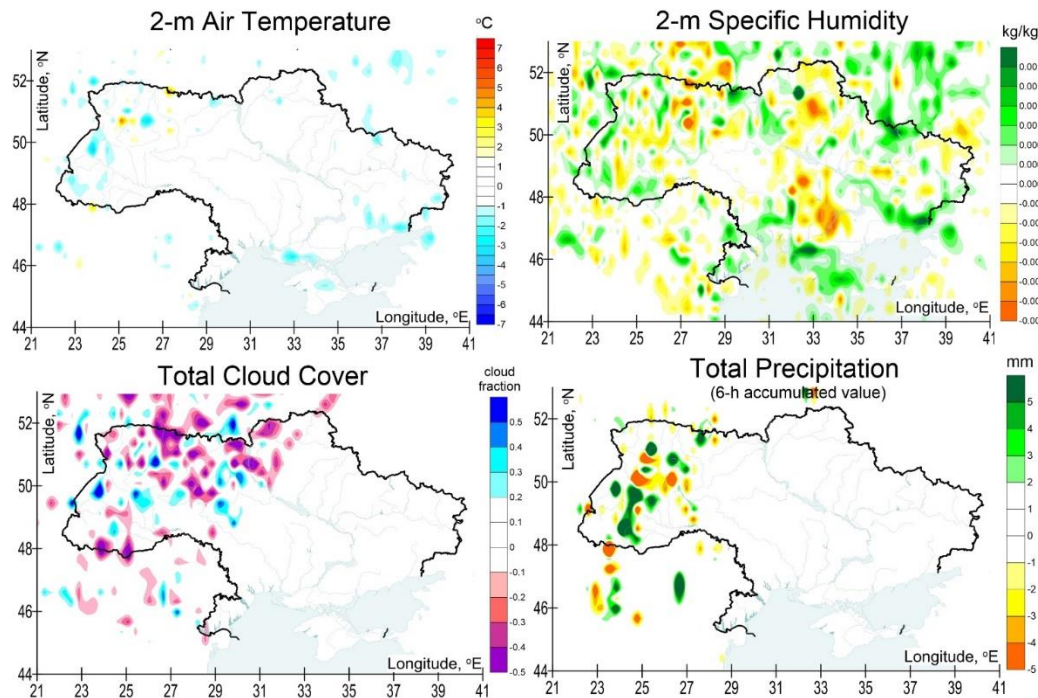
Pysarenko et al. (articles in preparation)

Methods:

(1) **Seamless** multi-scale (15-5-2-1.5 km res.) Enviro-HIRLAM modelling; (2) **Study period:** Jul-Aug 2010; Mar-Apr 2013; (3) **Scenarios:** **deforestation** total (TOT_DEF) & half (HALF_DEF); **afforestation** total (TOT_AFF) & half (HALF_AFF); (4) **Model runs:** REF + DAE, IDAE, DAI+IDAE aerosol effects included.

Conclusions:

- (*) **Land cover** changes significantly impact **regional weather** patterns through changes in radiation, moisture, temperature and wind regimes.
- (*) **Land cover** changes can enhance the consequences of extreme meteorological conditions.
- (*) **Outcomes** — showed **consequences of deforestation** and give solid ground for decision-makers in **planning adaptation** measures to **climate change** & developing possible **recommendations** for national **forestry** service.



Impact of total deforestation on selected meteorological parameters
on 1 August 2010 (12UTC)
(for differences between runs: TOT_DEF – REF)

Integrated Modelling for Assessment of Potential Pollution Regional Atmospheric Transport as Result of Accidental Wildfires

with Mykhailo Savenets (with UHMI, UA)

Aim: to analyse regional influence of wildfires occurred in the Chernobyl exclusion zone & to identify affected territories in case of active wildfires near, within radioactive polluted hotspots, and in a close proximity to the nuclear power plant.

Savenets et al. (Atmosphere, 2024); <https://doi.org/10.3390/atmos15050550>

Methods:

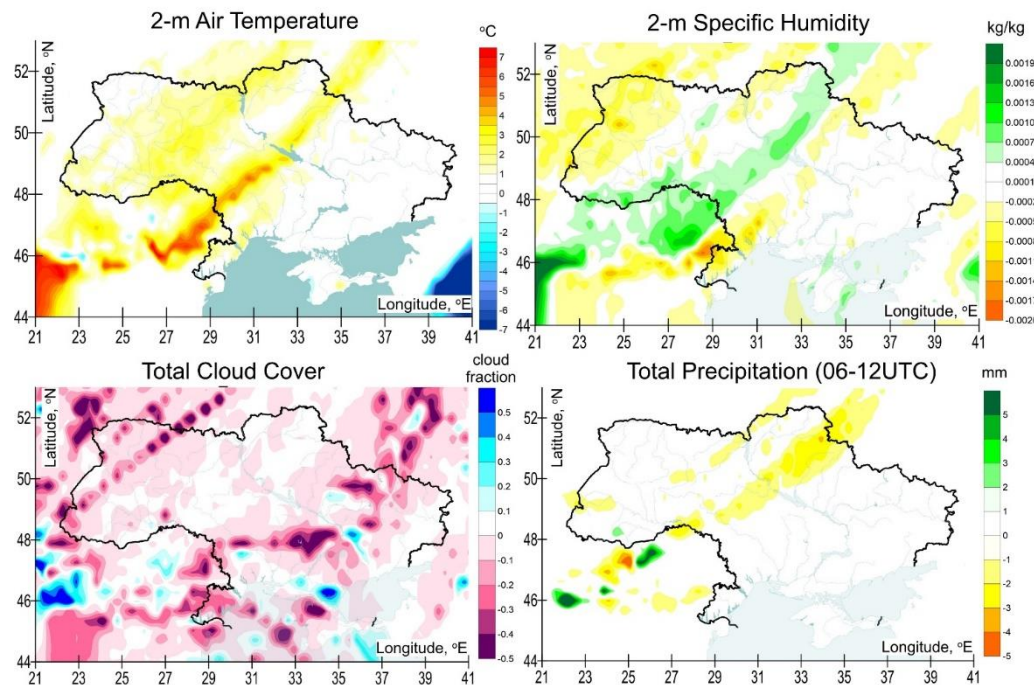
(1) **Seamless** multi-scale (15-5-2-1.5 km res.) Enviro-HIRLAM modelling; (2) **Study period:** 2-30 Apr 2020; (3) **Model runs:** REF + DAE, IDEA, DAI+IDAE aerosol effects included; (4) **Sensitivity tests:** time steps 300-240-180 sec (15 km), 150-120-90, 90-60-30 (2 & 1.5)

Conclusions:

(*) **Numerous feedbacks revealed** in the atmosphere enhanced by aerosol compounds (emitted from wildfires).

(*) **Aerosol effects** show spatial **non-homogeneity**, **dependence** on meteorological conditions, and **ratio** of species.

(*) **Outcomes** – crucial for **improving weather prediction** considering aerosols' influence & valuable for **impact assessment** on health and ecosystems in decision-making.



Difference between runs (DAE+IDAE – REF) selected meteorological parameters on 14 April 2020 (12UTC)

Evaluating Arctic Sea-Spray Emissions with Seamless Modelling

with Roman Nuterman (with UCPH, DK)

Aim: to evaluate 7 parameterizations of sea-spray emissions for selected months in winter/summer (with largest/lowest coverage by sea-ice) and in spring/autumn (as transitional periods in melting/building-up sea-ice in Arctic seas).

Methods:

- (1) **Seamless** (15 km res.) Enviro-HIRLAM modelling;
- (2) **Study period:** Feb, May, Aug, and Oct 2010;
- (3) **Model runs:** REF + DAE, IDAE aerosol effects included;
- (4) **Observations:** sea-salt, EBAS database

Work in Progress:

- | | |
|------------------------------------|---------------------------------|
| P1 Martensson et al. (2003) | P5 Zakey et al. (2008) |
| P2 Monahan et al. (1986) | P6 Clarke et al. (2006) |
| P3 Guelle et al. (2001) | P7 Vignati et al. (2001) |
| P4 Gong (2003) | |

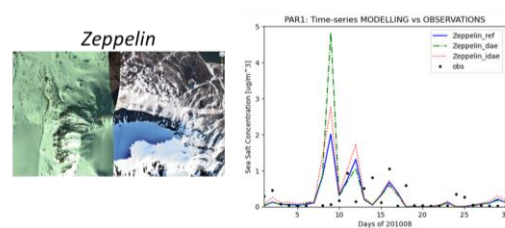
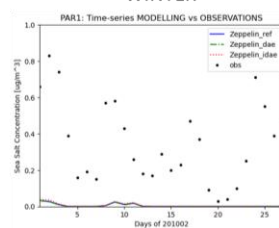
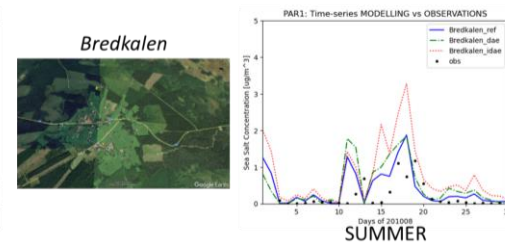
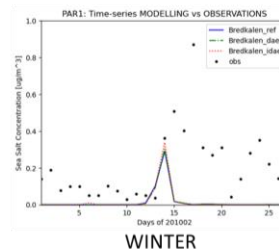
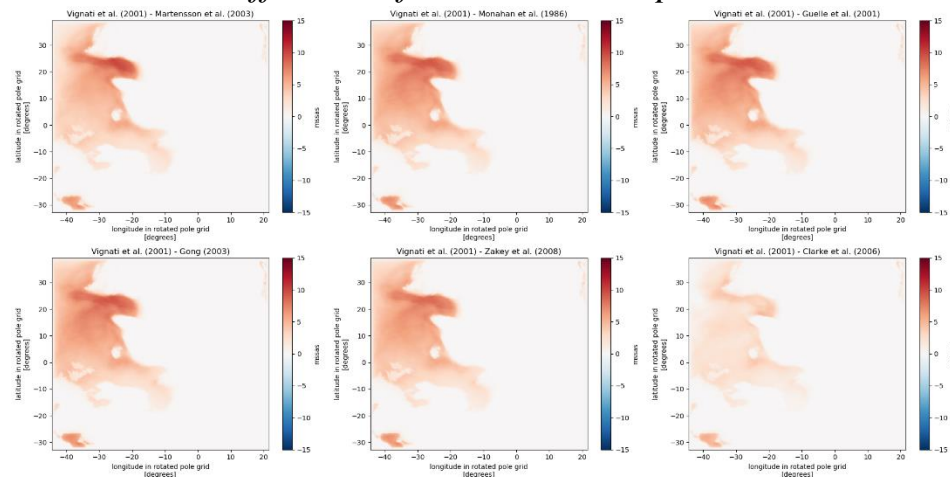
Mahura et al. (article in preparation)



Observation sites & Model domain

Observations vs. Modelling

Feb 2010: Difference of means between parameterisations



High-Resolution Integrated Urban Environmental Modeling

with Igor Esau (with UiT/NERSC, NO)

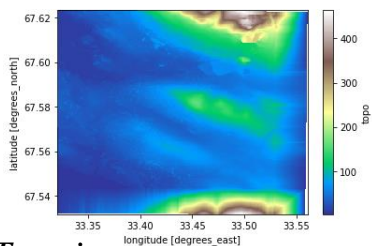
Aim: to integrate turbulence-resolving urban large-eddy simulation, LES (meter-scale; PALM) and meteorological (km-scale; Enviro-HIRLAM) simulations into a seamless modeling chain & to study urban climate and air quality with high-resolution (from km to m) numerical modeling and urban observational data fusion.

Esau et al. (article in preparation)

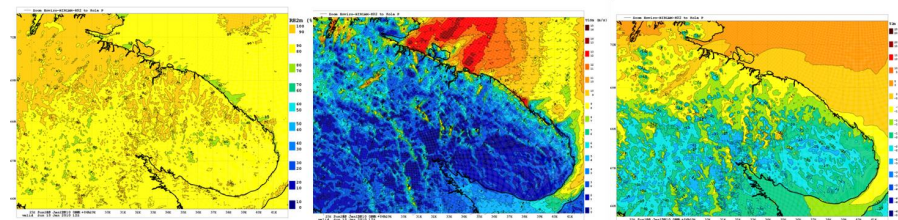
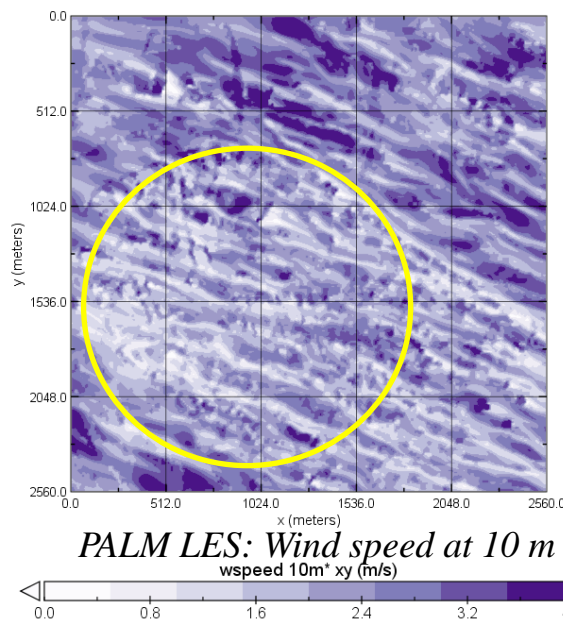
Methods:

- (1) **Seamless** multi-scale (15-5-2 km res.) Enviro-HIRLAM modelling;
- (2) **Study period:** 1 Dec 2017 – 31 Jan 2018;
- (3) **Model runs:** REF + DAE, IDEA aerosol effects included;
- (4) **LES PALM modelling:** modelling for Apatity urban area.

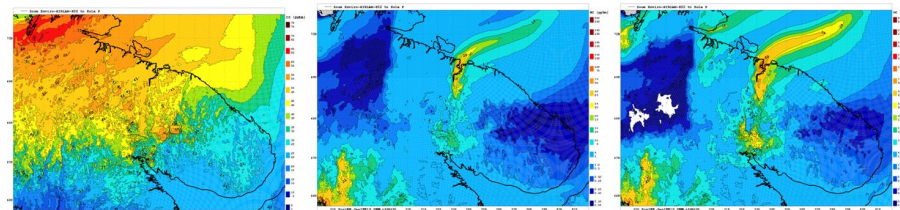
Work in Progress:



Terrain
(over Apatity urban area)
PALM: Friction velocity

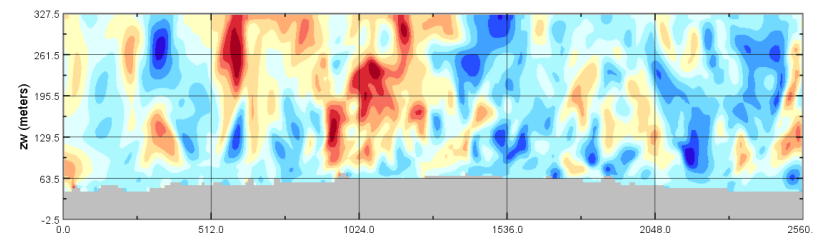


Meteorology:
Relative Humidity (RH2m) Wind Speed at 10m (U10m) Air temperature at 2m (T2m)



Atmospheric Composition:
Ozone (O₃) Black Carbon (BC) Organic Carbon (OC)

Enviro-HIRLAM: Downscaling (at 15, 5, 2 km resolutions)



PALM LES: Vertical wind velocity

Effects of Spring Air Pollution and Weather on Covid-19 Infection in Finland

with Behzad Heibati (with UoOulu, FI)

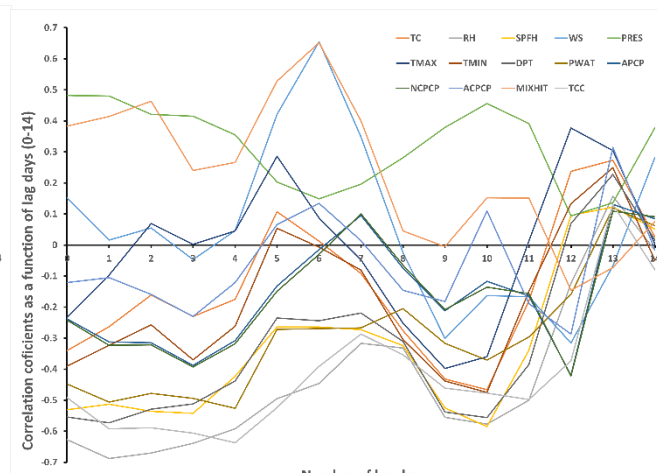
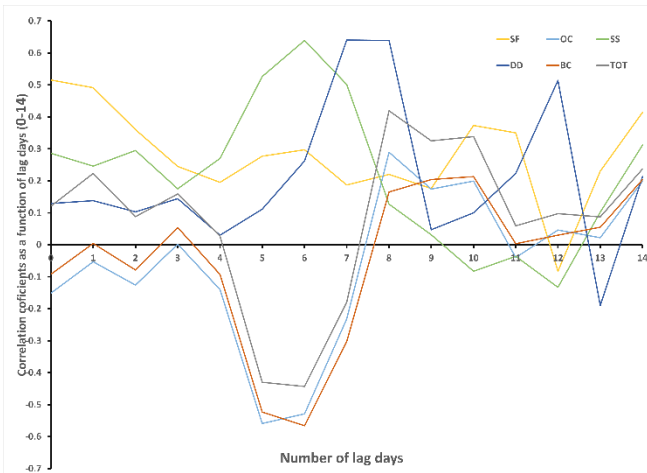
Aim: to assess effects of meteorological (temperature, humidity and momentum regimes in the boundary layer) and air pollution (aerosol components) factors on covid19 cases in 20 hospital districts of Finland during spring 2020.

Methods:

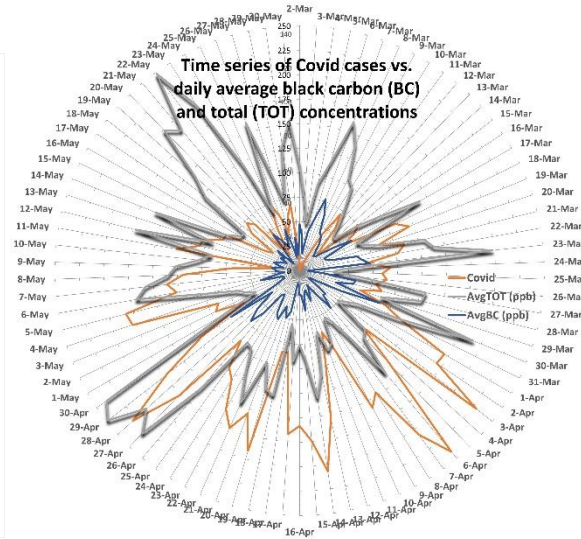
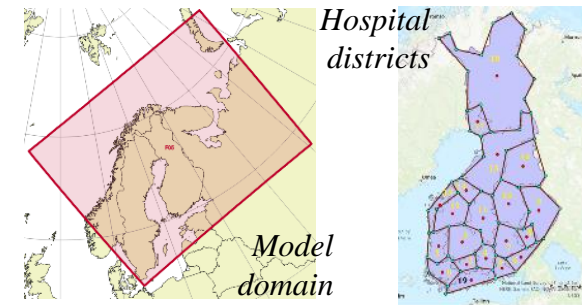
(1) **Seamless** subregional scale Enviro-HIRLAM modelling; (2) **Study period:** 1 March – 31 May 2020 with covid19 lockdowns; (3) **Model runs:** DAE+IDAE aerosol effects included; (4) **Covid19 data:** time-series of daily cases in 20 hospital districts of Finland in March-June 2020.

Work in Progress:

Example of correlation coefficients (for March 2020, with 0-14 lag days) for aerosol components & meteorological parameters for the Helsinki Hospital District (Finland)



Heibati et al. (article in preparation)



Enviro-HIRLAM meteorology for FLEXPART atmospheric trajectory calculations

with Benjamin Foreback & Petri Clusius

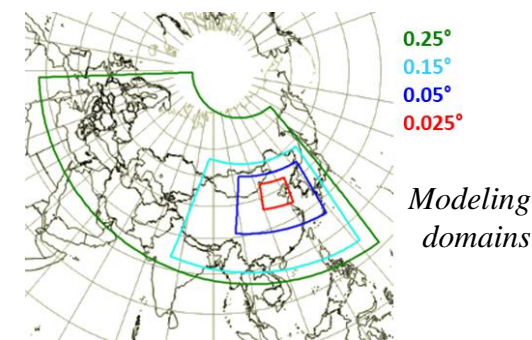
Aim: to integrate (develop method) the Enviro-HIRLAM modelled meteorology as input for FLEXPART's calculations of trajectories and dispersion of particles & to evaluate impact of aerosol effects on meteorology and trajectories.

Foreback et al. (Big Earth Data, 2024); <https://doi.org/10.1080/20964471.2024.2316320>

Methods:

- (1) **Seamless downscaling** (25-15-5-2+ km resol.) Enviro-HIRLAM **modelling**;
- (2) **Study period:** 1 Oct - 23 Nov 2018; (3) **Model runs:** REF, DAE, IDAE, DAE+IDAE aerosol effects included; (4) **FLEXPART:** atmospheric backward trajectory calculations for elevated pollution episode in Beijing, China.

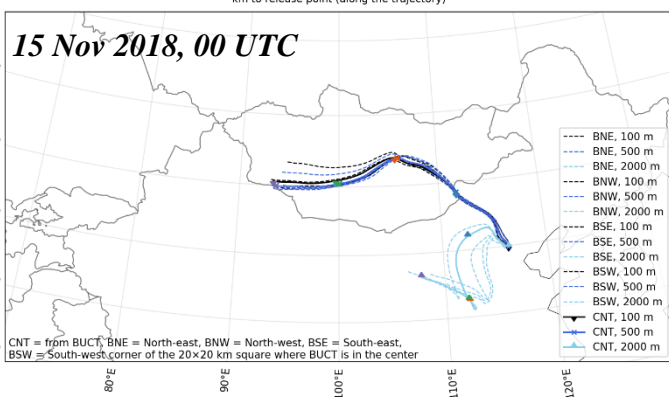
Work in Progress:



Atmospheric backward trajectories (96 hrs or 4 days) calculated by FLEX PART model

Meteorology from ERA-5

15 Nov 2018, 00 UTC



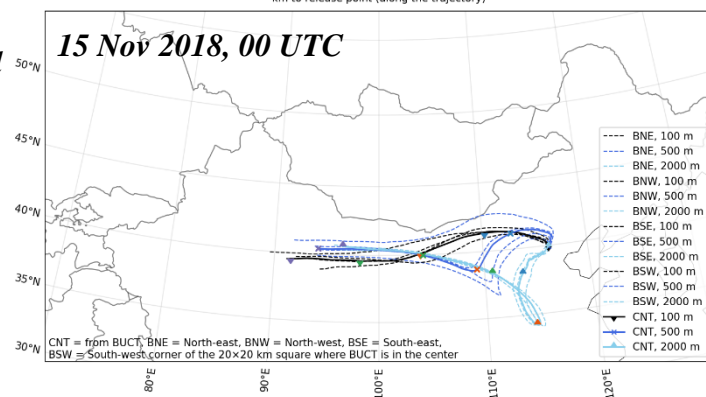
based on ERA-5 (0.25° resol.) and
Enviro-HIRLAM (reference run at
0.25° resol.)

meteorological input
arriving at heights of 100, 500 and
2000 m at 5 locations
(i.e., BUCT, Beijing & the corners
of a 20×20 km box with BUCT in
the centre).

Note, top panel shows altitude
(ASL) and mean orography along
the trajectories.

Meteorology from Enviro-HIRLAM

15 Nov 2018, 00 UTC





PEEX-MP-at-CSC (2024-2025)



PEEX Modelling Platform research and development through CSC HPC research projects

<https://www.atm.helsinki.fi/peex/index.php/portfolio-items/mp-at-csc>

In progress

(1) INTURBEM-DI:

“INTEgrated URBan Environmental Modeling: from Development to Implementation”

Prof. Igor Esau, The Arctic University of Norway (UiT), Tromsø, Norway



(2) ACM–EWAI:

“Effects of Aerosol-Cloud-Meteor. interactions on Extreme Weather events under Anthropogenic Impact”

Dr. Mykhailo Savenets, Ukrainian Hydrometeorological Institute (UHMI), Kyiv, Ukraine



(3) ACM–LCC:

“Influence of Aerosol-Cloud-Meteorology interactions on extreme weather events under Land use/land Cover Changes”

Dr. Larysa Pysarenko, Ukrainian Hydrometeorological Institute (UHMI), Kyiv, Ukraine



(4) ISA–URB:

“Integrated Systems and Analysis of URBan mobility for climate-neutral and sustainable cities in Europe”

Dr. Maher Sahyoun, Niels Bohr Institute (NBI), University of Copenhagen (UCPH), Copenhagen, Denmark





in On-going Projects

H2020 CRiceS (coord. R. Makkonen & J. Thomas) - *Climate relevant interactions and feedbacks: the key role of sea ice and snow in the polar and global climate system*

- To analyze effects of aerosols and their interactions with clouds & radiation; influence of sea ice and sea-spray aerosols on cloudiness and precipitation, sea ice and clouds albedo effects and feedbacks; (ii) Downscaling modelling: regional - over the Arctic domain, subregional - Nordic and Russian Arctic, and urban - Fennoscandia and Kola region with adjacent seas at urban scales; (iii) Modelling results verification with Arctic datasets and up-scaling to EC-Earth climate scales



Horizon Europe FOCI (coord. T. Halenka & R. Sokhi) - *Non-CO2 Forcers and their Climate, Weather, Air Quality and Health Impacts*

- Regional and urban multiscale climate impact: multi-scale modelling approach for Paris metropolitan area for episode in near and far future representative years to study the impact and co-benefits of future air quality and health at regional -urban scale.

H2020 RI-URBANS (coord. X. Querol & T. Petaja) - *Research Infrastructures Services Reinforcing Air Quality Monitoring Capacities in European Urban and Industrial Areas*



- Urban scale modelling of atmospheric composition and meteorology for the St.Petersburg metropolitan area with focus on elevated pollution episodes; study effects of aerosols on urban meteorology, pollution, health



Horizon Europe CERTAINTY (coord. J. Thomas & H. Kokkola) - *Cloud-aERosol inTeractions & their impActs IN The earth sYstem*

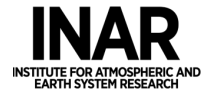
- Studying two-way interactions between aerosols and clouds (indirect aerosol effects) - UHMI

Recent Proposals with Application of Enviro-HIRLAM + UA Partners:

(*) **IN EVALUATION** - Subm. 2 May 2024 – TFK PEEX-FUESReN (FI Ministry funding) with 3 UA Univs (coord. Hanna Lappalainen, UHEL) – student/teacher's mobilities & TLRIs & intensive training course, Hyytiala, FI

(*) **IN PREPARATION** - To be subm. in Oct 2024 – COST Action for PEEX Collaboration (EU COST funding) with 20+ Partners (coord. Hanna Lappalainen, Markku Kulmala, UHEL) – (i) PEEX-Modeling-Platform; (ii) Enviro-HIRLAM in different studies; (iii) short-term scientific missions; (iv) YSSchool on observations, modelling, and assessment

Concluding Remarks - 1



- **Multi-scale modelling approach** with Enviro-HIRLAM online integrated meteorology – atmospheric composition modelling system – demonstrated on examples with generated meteorology – atmospheric composition output
- **Results of modelling** are applicable in principle for evaluation of risks, vulnerability, and consequences due to atmospheric; impact assessments on population and environment; supporting decision-makers, adjustment of legislation at regional-city levels; planning measures, mitigation scenarios, etc.

Concluding Remarks - 2

- **Continue research and development (R&D)** and improvement of seamless/online integrated approach with
 - (i) consideration of socio-economical aspects/ processes (also linking to PEEX Impact on Society) and physio-geographical specifics of regions in focus,
 - (ii) application of new IT technologies and digitalization approach for developing web-based services for public needs; and
 - (iii) combination of expertise and knowledge from collaborating partners and stakeholders.
- **Involvement of younger generation** of researchers (using Enviro-HIRLAM in their studies) & continue science education
- **Contributing** to revising/ improving existing parameterizations/ schemes/ etc. (**model's physics and dynamic cores**)
- **Exploring opportunities, after AQ-2024** (appl. Enviro-HIRLAM) – with CUNI (Czech Republic), UH (UK), ARIANET (Italy), MPI-Chemistry (Germany), AUTH (Greece), Dalian Univ of Technology & Fudan Univ (China)

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Thank you!



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

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- *Dr. Daniel Santos Munoz (UCM, Spain) - for providing and maintaining access to hirlam.org (Enviro-HIRLAM, HIRLAM, HARMONIE models repositories)*
- *Center for Science Computing (CSC, Finland) and ECMWF (UK, IT) - Computing Centers - technical staff for providing access, technical support and maintenance, computing and storage resources*